VOLUME 10 PART 1 APRIL 1991

# BRITISH TELECOMMUNICATIONS ENGINEERING


*Special Issue on the Access Network*

The Journal of The Institution of British Telecommunications Engineers

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# BRITISH TELECOMMUNICATIONS ENGINEERING

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VOL 10 PART 1 APRIL 1991

### SPECIAL ISSUE ON THE ACCESS NETWORK



ISSN 0262-401X

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*Special Issue on*
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## The Final Frontier

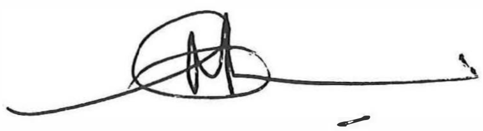
I am pleased to be able to introduce this special issue of the *Journal* focused on the Access Network, which has been referred to as the 'final frontier of every telecommunications network'.

The local loop, as it is traditionally known, is set to undergo important changes as the drive for improvement in service, quality and costs embraces the final link that serves every customer.

The challenge of exploiting the massive network of metallic cable and supporting civil engineering infrastructure, valued at many billions of pounds, is at the heart of BT's drive of Putting Customers First. The challenge is massive yet the potential benefits for both customer and company are enormous.

At the same time, the traditional metallic loop faces competition from new technological developments. Developments in digital radio and low-cost fibre technologies now offer real alternatives to copper. In recent years, BT has installed over 130 000 km of fibre in the local network, and radio offers increasing potential for rapid delivery of fixed as well as mobile services.

All of these changes mean that the Access Network will be the subject of much innovation and improvement during the 1990s.



CHRIS EARNSHAW
*Director, Policy, Planning and Performance,*
*BT Worldwide Networks*

# SPECIAL ISSUE ON THE ACCESS NETWORK

# Introduction

PAUL ALLEN

The first article in this special edition of *British Telecommunications Engineering* on the Access Network is a personal view of the local loop by John Young, who started his career in BT working in the access sector. In his article he discusses a number of issues which continue to be of concern to the people working in the sector. The large number of articles which follow, 14 in all, indicates the focus now being put onto the access network, and the increasing level of activity. The articles are laid out in as logical a manner as possible taking the reader successively through planning, infrastructure, technology and operational aspects, and ending with an international perspective.

## PLANNING THE ACCESS NETWORK

The article on page 8 considers the rapid and fundamental changes that the telecommunications environment is undergoing, with competition, new technologies, and ever-increasing customer expectations, and addresses the challenges that these pose in planning the access network of the future.

## ACCESS NETWORK INFRASTRUCTURE

The following two articles focus on the access network infrastructure. Firstly, the external network is described, together with the engineering aspects of the various elements of plant from which it is constructed. Likely future developments are covered for a network in which fibre will play an increasingly significant role.

Secondly, particular issues concerning the provision of BT's duct network are discussed, including practical aspects, a contractor's view of executing duct works, duct management and legal and regulatory matters.

## TECHNOLOGY

The optimal evolution of BT's access network will require a combination of copper, optical-fibre and radio technologies; developments in these fields are featured in the next four articles.

In the copper network, advances have been made in recent years in developing pair-gain systems to increase the information-carrying capacity of copper pairs. Developments are described which will enable the copper network to be exploited further, and reduce the need to deploy new copper in the access network. Consideration is given to the customer-service, marketing and engineering benefits that can be gained.

The opportunities for using radio systems in the access network are reviewed. BT experiences of using such systems are described. Consideration is given to the scope for using such systems particularly to meet customer needs and reduce costs within the rural network infrastructure.

Optical fibre will make a major impact on BT's access network in the 1990s. Successes that BT has already achieved in deploying fibre in the access network are described, the problems are discussed and a vision for the future access network is given. A second article particularly features the fibre trial to provide service to the home that is being conducted by BT at Bishop's Stortford in Hertfordshire. The aims of the trial are described together with the equipment and some of the results to date.

## OPERATIONAL ASPECTS

The emphasis in this special issue then shifts to operational issues. A major element in BT's total quality programme is the Local Network Resource Plan (LNRP), which is a group of related projects aimed at improving resource utilisation and engineering productivity in local access activity. The first article in this section describes how the changes which need to be made are being effected through the introduction of the LNRP.

Continuing the total quality theme, Alfie Kane's and David Young's article describes a quality improvement project aimed at developing an access network strategy that enables Manchester District to tackle problems being experienced in the access network.

The access network is one of BT's most valuable assets and an important factor in its proper management is the accuracy of the records concerning the utilisation of plant. The next article describes how the issues in this area are being addressed.

Computerised line test systems, in use throughout the BT public switched telephone network repair service, are essential to the effective maintenance of the access network. Their history, current capabilities and anticipated evolution are reviewed, together with their use for local network surveillance.

The final operational aspect to be featured is a review of local loop planning processes, including some of the current computer tools, records and working practices. Possible significant changes in the planning process are explained and their implications discussed.

## INTERNATIONAL PERSPECTIVE

Finally, in recognition that access is the key area of activity for telecommunications operators worldwide, two general articles on access from Japan and Germany have been included.

## BT REORGANISATION

This special edition has taken many months to prepare and during this period BT has undergone a major reorganisation through Project Sovereign. The old District-based organisation has been swept away by a customer-oriented organisation which has increased visibility of the access network. Inevitably, some of the articles in this *Journal* make reference to the old Districts, but it should be stressed that all the work described in the articles will continue in the new organisation. For the benefit of non-BT readers, and to refresh all our memories, the mapping of the old organisation onto the new is shown below.


## ACKNOWLEDGEMENTS

In conclusion, I would like to thank the many authors and mentors who have contributed to this special issue of the *Journal*.


| | | |
|---|---|---|
| CUSTOMERS AND MARKETS | | |
| BUSINESS COMMUNICATIONS | PERSONAL COMMUNICATIONS | SPECIAL BUSINESSES |
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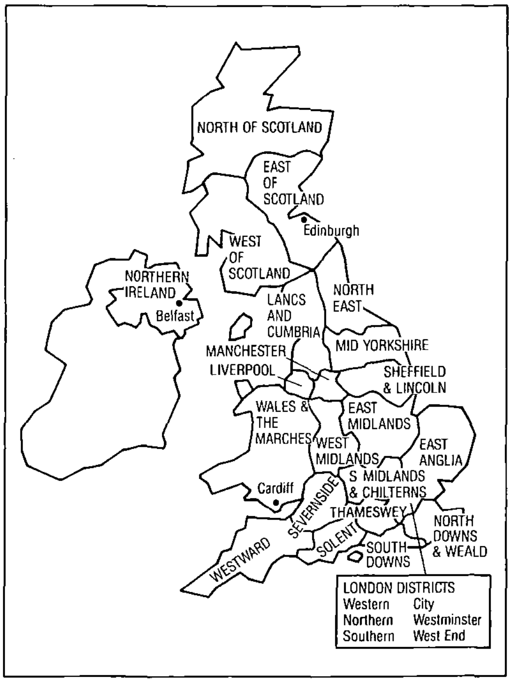
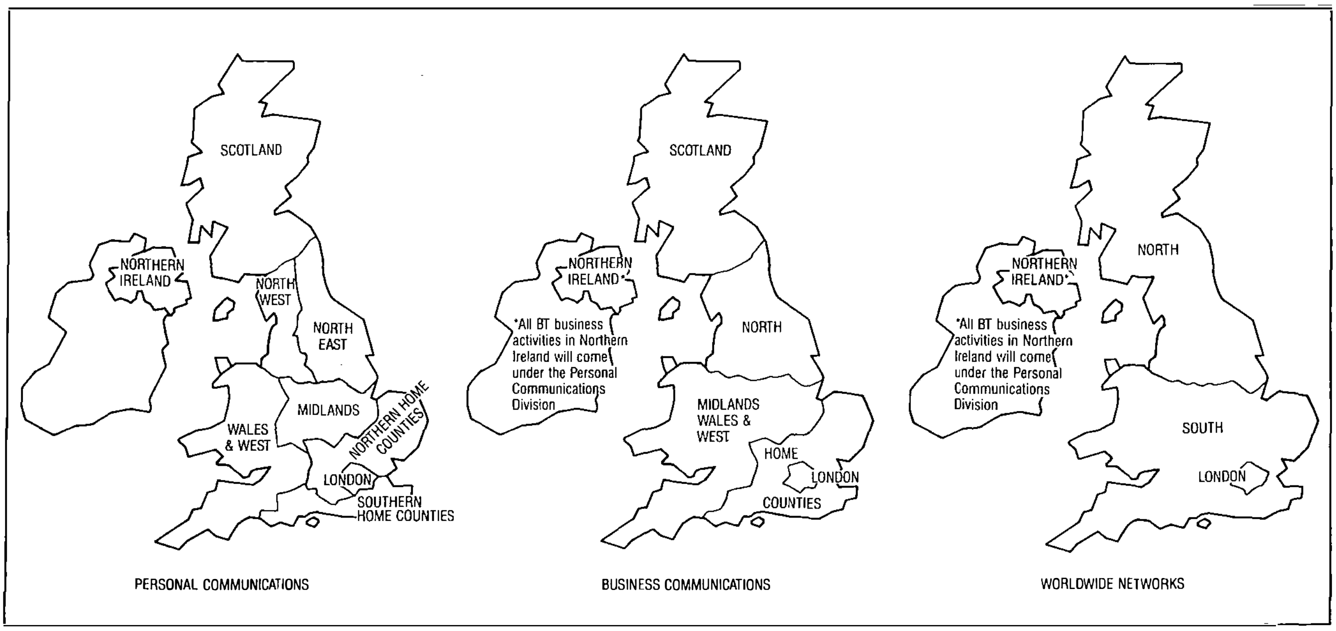
**New BT organisation**




**Old BTUK District-based organisation**




**Geographical organisation in the new BT**

# A Personal View of the Local Loop over 30 Years

J. W. YOUNG†

*This article reviews the history of the local loop over the past 30 years and gives some observations with the benefit of hindsight.*

## INTRODUCTION

Some 30 years ago, my first management appointment was to local lines planning, before moving on to other network activities. Recent years have again brought me into close involvement with the local loop and it is surprising how the pace of change has slackened over the past 30 years. There have been changes, of course, in technology, processes, procedures, systems, etc., but I am left with the feeling that developments have been slower in the local loop than in other parts of the network. This is illustrated by the following impediments to progress, which have remained largely unresolved over the years:

- availability and accuracy of forecasts,
- timing of S curve saturation,
- investment constraints,
- spare pair margins,
- pair diversions (reactive working),
- line plant waiters,
- accuracy of records,
- drawing office backlog of recording,
- dropwire reliability/suitability,
- distribution pole renewals,
- planning rules and procedures,
- methods of measuring planning achievement,
- cost reductions,
- cost controls, and
- productivity.

One welcome change is that shared service is now almost eliminated and there is the interesting aspect that the name has changed from *local lines* to *local loop* to *access*.

Looking back 30 years, perhaps the network was somewhat cumbersome, and it was certainly highly telephony orientated. The switch and transmission networks have undergone considerable modernisation, reducing costs and increasing functionality. To some extent the local loop can be viewed as frozen in time, as it has not shared in these continuous and dramatic changes. Perhaps there are some lessons to be learned with the benefits of hindsight?

## LOCAL LOOP HISTORY

Technology and process changes are closely linked. Changes in technology frequently demand process changes, but processes can develop independently from technology. Such changes have been few in the local loop, although works practices have evolved continuously.

### Works Practices

Little change occurred in external practices until the late-1950s. The tradition was lead-sheathed cables, with a paper and air insulant for copper conductors; the drop to customers was provided via open wire and insulators. These methods were labour- and stores-intensive, and the rate of system growth drove the need for productivity improvement. The late-1950s and early-1960s produced a step change in construction practice, led by the Engineering Manpower Groups 2 and 3. Polyethylene cable reduced the dependence upon craft skills, with revised joint closure methods, machine jointing and long-length cabling. The customer feed was simplified by the general use of dropwire. These solutions were not without their problems. Although they enabled the upsurge in demand to be met, there were considerable maintenance problems with dropwires, joint closures and directly buried cable. These techniques have been developing slowly ever since.

Refinement of works practices continued throughout the 1960s, led by experienced Headquarters engineers with considerable status, strongly supported by Regional teams composed of good, dedicated engineers, with practical field technicians to trial new ideas in Telephone Areas. The Midland Region team was particularly active with work on new housing estates, rodding and light cabling vehicles, pole erection units, pair identification and cabinet assembly design. This achieved much improvement in construction techniques, but copper technology remained.

Development continued in the early-1970s, but at a slower pace. A major change in 1972 was the introduction of aluminium conductor cables, as a replacement for copper. This change was driven by increases in copper prices and forecasts of continuing higher-than-normal copper prices. In the event, these predictions were unfounded and copper prices restored to traditional levels. Unfortunately, aluminium conductors had severe problems and even the change to an aluminium alloy failed to avoid a serious maintenance legacy. So copper technology again became the standard practice.

By the mid-1970s, the development teams had been mostly dissipated by the non replacement of

† BT Worldwide Networks South

leaving staff. This is illustrated by the continuous flow of local loop *Journal* articles up to 1976 and only occasional articles subsequently.

Thus the improvement in local loop works practices slowed as it was driven by only a small, but dedicated, Headquarters development team. The main activities related to jointing methods, sheath closures and dropwire.

### Technology

Over the years, attempts at new technology in the local loop, such as concentrators, loop extenders, pair gain, multiplexers, fibre, etc., have been in quantities insufficiently large to challenge the supremacy of copper.

### Process

There have been clearly identifiable process changes, such as works control and performance documentation, spare-pair records through SPRET, works programming through MACE and costing systems such as OPEX 5. However, the impact of changes in policy and other influences are less definitive. Thirty years ago, planners were charged with achieving the best economic solution for each individual scheme, but changes over the years have introduced constraints in the form of generalised rules which have not always fitted the wide range of local situations.

Local initiatives have frequently and continuously influenced local loop activities. This is illustrated by the Blackburn Telephone Area's initiative on underground faults[1]. In the early-1970s, Blackburn set about reducing underground faults and in 10 years reduced faults to one third of their previous level. This was achieved through positive driving by management, good workmanship standards, effective supervision and the systematic replacement of substandard plant. Mechanised blackspot analysis was a feature of this programme and spread to national use and the adoption of plant uplift programmes.

### Investment

Capital investment levels have always had a major impact on the local loop. In 1948, the Engineer-in-Chief, A. J. Gill[2] commented on the high proportion of capital invested in local loop and hence the need for developments to reduce costs. Investment levels are closely related to forecasts of future demand, because of the need to size cable and duct instalment periods. Telephony has lived since the early-1900s on the premise of imminent saturation of demand for telephones. Although this saturation has not occurred in the past 90 years, its expectation has had a major impact on capital investment levels. Understandably, spare capacity never has been viewed as a desirable asset, but conversely the costs of insufficient capacity has been mostly under-estimated.

In recent times, the most significant impact on investment arose from the application of H. J. C. Spencer's future value concept[3], which aimed to produce minimum delivered cost planning lines by balancing the economy of scale of pair provision with the inventory cost of unused pairs. The theory was sound, but the achievement of the desired result was again dependent upon the accuracy of the forecast. Interestingly, this concept is probably applicable to the new technologies of bearer and electronics (fibre and pair gain), but with a much lower dependency on forecast accuracy.

Most Regions limited their investment in the late-1970s and early-1980s by strict application of the future values concept. However, this was at a time of economic difficulties and eventually recession, conditions which tended to produce depressed forecasts. Thus the network had insufficient capacity to cope effectively with the longer-than-usual sustained growth of the 1980s. These problems were compounded by the organisational changes of 1984, which resulted in very limited Headquarters support on local loop and most Districts adopting short-term measures because, in general, the local loop was controlled by Customer Services Areas (CSAs). The prime responsibility of the CSAs was to deliver customer provision and repair; this resulted in exacerbation of the under-investment. Thus, to cope with pair shortages, much local loop activity became expedient or reactive. Reactive working resulted in fragmented planning and plant augmentation to meet individual customers' specific orders, within set normal quality target timescales. Reactive working used planning time ineffectively, greatly increased pair provision cost and increased network faults. Once reactive working became established, it grew rapidly and reduced normal planned plant augmentations, which further reduced capacity and increased costs.

The Chief Engineer, Keith Ward, set up the Local Lines Task Force (LLTF) in 1987 to investigate the condition of the local loop and make recommendations for the future. An early result was the appointment of Territory Loop Managers and District Local Loop Board Members, which increased the focus on loop activities. Subsequently a Headquarter team was set up to provide direction and support on the local loop. Capital investment was stimulated and capacity levels made modest advances.

The LLTF did much useful work and clearly identified many weaknesses in the local loop. Probably the most striking success of LLTF was to highlight the problems and the importance of the local loop, while demonstrating the high cost of an all-copper solution.

Currently, a new study is being undertaken on access network strategy.

## FORECASTS

Forecasts of future demand have always been crucial to trigger and determine the provisioning periods of duct and cable instalments. Basically, the requirement is to balance economically the cost savings resulting from increasing the length of the provisioning period (economy-of-scale savings) with the cost penalty of holding unused plant (stock holding). Over the years many authors have explored these relationships and produced theoretical analyses; for example, Macwhirter and Mason (1956)[4], Swain (1965)[5], Spencer (1977)[3]. However, all these analyses have been critically dependent upon the accuracy of forecasting future demand.

Unfortunately, forecasts have not been particularly accurate, even at national level. Two particular aspects have caused problems. Firstly, short-term fluctuation has had too much influence on the longer-term future. Frequently, each years' forecast line appeared to be tangential to the latest achievement. Thus short-term changes in demand, caused for example by the normal cyclical economic pattern, produced unrealistic variations in the slope of the forecast lines. Secondly, saturation of demand has been assumed at too early a date. In part, this may have resulted from not recognising that the traditional S curve is constructed from a family of S curves, each with a different starting point, saturation timing, and size.

Given the national difficulties, it was not surprising to find even more difficulties at plant level forecasting. It is now many years since formal tenancy forecasting was discontinued and, in general, no satisfactory method has been developed of integrating a plant-level forecast with the national forecast. Thus the accuracy of local forecasting is open to speculation.

Better segmentation of services has probably improved national forecasting, but the 1980s have produced new problems at local level. Business demand has increased rapidly, but the size of demand and location of growth has become more random—perhaps because of the increase in service industry activities, which have a higher volatility of telecommunications needs than manufacturing industries. The low penetration of new services continues to make forecasting these requirements difficult at local level.

## LOCAL LOOP IN A NETWORK CONTEXT

It has been mentioned already that the basic local loop technology of copper has remained virtually unchanged for many decades. Although some electronics are in use, the quantity is extremely small. In contrast the trunk and junction networks have experienced continuous change in technology. These networks also started from copper circuits, but were developed for multi-channel operation by the use of carrier and pulse-code modulation (PCM), before moving on to coaxial cable and fibre technology. Similarly, switching developed from step-by-step to digital through common control and semi-electronic. It may be possible to move directly from copper to fibre in the local loop, but it is open to debate as to whether this change would be easier with some intermediate stages, or whether opportunities to exploit copper fully have been missed.

Switch, transmission and loop developments have occurred largely independently, but with increasing switch and transmission coordination in the digital era. At some future date, the whole network, including the local loop, will be digital. Hence more consideration of interworking and integration of local loop with switch and transmission would be appropriate. As an example, telephone exchange locations were determined in bygone days to accommodate the signalling and transmission limitations of the copper loop; these restrictions will cease to apply in the future.

The switch and transmission networks are moving rapidly to implement network management. This is a feature which is desirable in the local loop, particularly as this section of the network accounts for most network faults. The new generation of line testing equipment, with enhanced network surveillance, should make some impact if used operationally as intended, but real hands-off operations will have to await loop penetration by electronics.

## A REVISED APPROACH

The local loop is a vital part of network service. However, copper technology is expensive in current and capital expenditure, is fault prone, inflexible and offers only a narrow bandwidth designed for telephony. Digitalisation of the trunk network and much of the junction network, coupled with switch modernisations, has produced excellent service. In consequence, the limit to quality of service seen by customers is frequently that of the local loop, because so much of the rest of the interconnecting network is near-transparent. Thus it is essential to address the known copper loop limitation and to note that future customer expectations on provision and repair times may be more demanding.

Not surprisingly the future is full of uncertainties and, as is usual with a developed commodity, the number and complexity of the uncertainties increase each year. Will residential connection saturate at about one per tenancy or will it develop similarly to cars and television sets? Will the integrated services digital network (ISDN) expand at the expected rate? Will Centrex and networked automatic call distribution (ACD) make demands for large numbers of circuits and what technology will be adopted? Will there be new product explosions, such as fax? How will Telepoint and personal communications networks develop? How will competition develop in the loop? In addition, all of these unknown quantities can, and no doubt will, be influenced by pricing and facilities.

Given the inaccuracy of plant level forecasts in past years in a simpler environment, there would seem to be no prospect of obtaining accurate plant level forecasts for the more complex future situation. This presents two options:

to accept the financial consequences of inaccurate forecasts (continue existing procedures) or to use a procedure which is less dependent on forecast accuracy.

Experience has shown that there are critical levels of spares which must be maintained, if new service is to be given on demand. Any new cable provision must maintain these critical spare pair levels, but there is a risk of over-forecasting and modular cable sizing leading to excessive spares. Of course, it would be possible to reduce spare pair levels, if it could be assumed for certain that saturation has been reached. However, it is difficult to be certain when saturation occurs and it may not apply to the actual location of new cable provision. Hence continuing the present procedures does not look to be an inviting prospect, particularly at this stage of local loop development.

The need is for a fresh approach to minimise the limitations of copper while using fully the vast investment in the copper asset. The loop as constructed is close to providing one pair per tenancy and has a large number of spare pairs, all using duct space and requiring much terminating capacity. Most unused plant is still attracting depreciation cost, but no revenue.

If technology can enable near instantaneous provision of plant when an order is received, then not only would it be possible to provide new plant without a spares burden, it would also be possible to use existing spares profitably without replacement.

Digital pair gain is a system which comes close to this ideal for small circuit demands. For larger customer needs, fibre electronics has similar characteristics, because advance provision of the fibre infrastructure is relatively cheap and the expensive electronics can be provided on demand. The use of fibre would also release existing copper pairs for reuse.

The significant point is that the choice is not a straight costing between copper pairs, fibre or electronics. The vital factor is being able eventually to run the network with a cost-effective capacity. The ideal is a network without spares, where every provided pair is earning revenue. The value of existing spare pairs, and the savings on not providing future spare pairs, is a very considerable sum of money and should be included in the financial evaluation of technology choice.

The implementation of such a dramatic change will need considerable management drive and engineering energy to achieve the many benefits. It has the advantage that digital pair gain and fibre electronics are complementary in addressing separate segments of the market and desirable for interworking with digital switching and transmission. It is useful also that pair-gain systems can be reused in new locations as they are displaced by the spread of fibre. Further advantages would be the possibility of introducing network management and making a start on an integrated approach to local loop and exchange network activities. In particular, flexibility in the local loop would gradually move to the exchange and be executed in software, enabling the eventual redundancy of street cross-connection points and perhaps reuse as housings for electronics. Because there is a wide range of costs in providing copper pairs, particularly between rural and urban locations, it is likely that a range of electronics solutions, including radio, will be necessary.

## CONCLUSIONS

The copper loop has served telecommunications well for over a century and will continue to be a principal part of the network for many more decades. This review of local loop history indicates that the development of copper works practices is near completion and gives some insight to the critical relationship between network capacity and forecasts of future needs. The resurgence of loop development work, resulting from the availability of new technology, has the potential to facilitate better management control of loop capital and depreciation costs. This new technology could enable a cheap infrastructure of copper and fibre, and allow the near instantaneous provision of demand by electronics. In addition, such technology would facilitate revenue-rich new services and pave the way for hands-off maintenance in the local loop. The benefits could be outstanding, and perhaps crucial, but will only be achieved by positive, determined and dedicated, management effort.

## ACKNOWLEDGEMENT

The advice and experience of Tony Ingram in producing this article is gratefully acknowledged.

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### Biography

John Young joined the Post Office in 1950 as a Youth-in-Training. He has spent the last 28 years engaged on network activities and was appointed Planning Controller Midland Region in 1980 and Territory Engineer, Central Territory, in 1984. He has a B.Sc. (Eng.) degree, is a Fellow of the Institution of Electrical Engineers and was awarded an IBTE Senior Silver Medal for his 1978 paper 'Time for Network Planning'.

# Planning the Access Network in a Changing Environment

P. A. ALLEN, and P. H. LISLE†

*The rapidly changing telecommunications environment is creating demands which are having an impact on the access network. This article discusses the issues that must be addressed in planning the future access network.*

## INTRODUCTION

On 8 November 1965, Mr. E. C. Swain, B.Sc.(Eng.), M.I.E.E., read a paper before the London Centre of the Institution of Post Office Electrical Engineers entitled 'Local Lines—Past, Present and Future'. The paper reviewed progress made in the implementation of a 'new system' for the provision of plant in the local line network described in a report by Mr. Harvey Smith and introduced by the Engineer-in-Chief in 1945. Figure 1 shows the network structure under review and it will not escape the reader's notice that this is, with some small variation, the structure used today to construct the copper access network. Mr. Swain concluded '... the recommendations of Mr. Harvey Smith's report have proved to be satisfactory for the development of the telephone service in the UK during the post war years... a firm foundation laid for the further expansion of the system to meet the challenge of the forecast rapid expansion in the next 20 years.'

† BT Worldwide Networks

And so it has proved. The access network has grown at a steady rate over a long period, the large majority of circuits, both switched and private circuits, being carried over dedicated copper pairs. The deployment of a copper access network based on that 1945 structure has been the backbone of telephone service provision to BT's customers for 45 years. Conceptually the planning task has been straightforward: to ensure that enough plant is available to meet the forecast level of demand at any particular location.

## NETWORK PLANNING

The network structure was designed to enable steady growth in take-up of service at each location to be matched by periodic augmentation. Different rules were applied to main and direct cables (termed *M-side* and *EO* cables) and

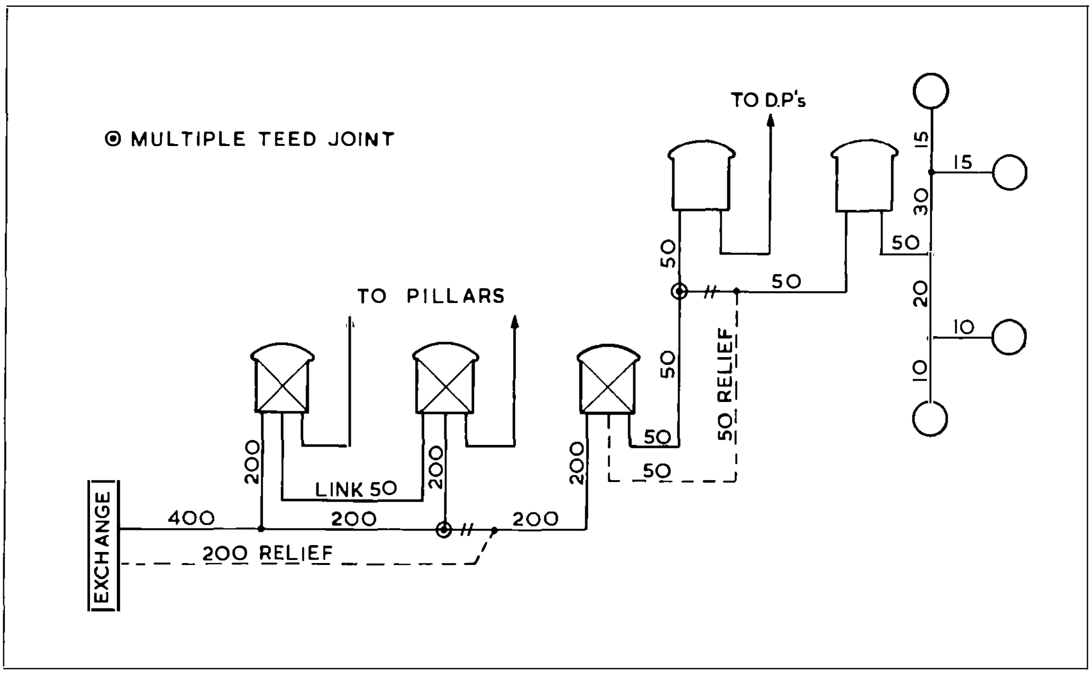



**Figure 1**
**Local line network as proposed by Mr. Harvey Smith**

distribution (*D-side*) cables. M-side cables were installed to meet typically 3 to 7 years growth, resulting in a supportable rate of augmentation and reasonably sized jobs. D-side cables were installed to meet 20 years growth or, more recently, for the maximum foreseeable demand at each distribution point (DP).

The result of these planning practices has been to leave BT with a copper access network that contains around 25% spare capacity in the M-side network and 35% spare in the D-side. Despite this level of spare capacity there are still occasions where, owing to unforeseen pockets of demand, there is insufficient capacity available to meet a customer order. Under these circumstances costly reactive work is required to install a new cable quickly or to divert capacity from one DP or primary cross-connection point (PCP) to another.

## ENVIRONMENTAL CHANGE

Although improved forecasting and planning practices can undoubtedly increase the probability of having capacity available to meet demand, the environment in which these practices must operate is rapidly becoming more demanding and more volatile. Environmental change is taking place at an unprecedented rate in telecommunications and in areas that impact the access network in particular.

In 1965, Mr. Swain wrote that customer needs '... can only be met by the provision of individual cable pairs from the subscribers' premises to the exchange, because no other more economical method is at present available.' He could not have foreseen the development of optical-fibre systems, or that radio systems would become so widely available. Nor could he have foreseen the advent of competition in telecommunications. If either one of these factors was absent, Mr. Harvey Smith's network structure might continue to be used for the next 45 years. Taken together, new technology and competition present a potent threat to the fixed copper access network which requires a re-think of present planning policies.

## CUSTOMER EXPECTATIONS

A primary requirement for any supplier is to meet the requirements of its customers on demand. Customer expectations vary according to the product. The prospective purchaser of a Patek-Phillipe watch expects to wait up to 5 years for its delivery, but a customer shopping for baked beans expects them to be on the shelf. If they are not, he/she goes somewhere else. In the market for telecommunications, the analogy is much closer to the baked beans than to the expensive watch.

Right across the market, from the major business sector through to low-calling-rate residential customers, expectations of the quality and capability of services are rising. In the business sector, with growing dependence on communications, customers are looking for high levels of reliability and, in some cases, diverse routed paths from their premises into the network to avoid total loss of service. In the residential sector, customers expect guaranteed provision times for new service and there is a growing demand for high levels of reliability, albeit with the accent on fast repair rather than on lower fault occurrence.

In the business sector there is an increasing level of movement and change, with customers changing both their location and their requirement for service with increasing frequency. To a certain extent this is being offset by a slowing down of growth in the residential sector, but taken as a whole the level of activity associated with new or changed demand is likely to rise by over 50% in the next 5 years.

## SERVICE MIGRATION AND NEW SERVICES

The advent of sophisticated networking features in both public and private networks will cause a significant change in demand patterns over the next few years. The most obvious examples are the growth of ISDN PABXs, which drive the demand for digital private circuits and digital connections to BT's switched network. Migration of a 30-channel PBX between analogue connection and 2 Mbit/s digital connection creates a step-change impact on the access network, simultaneously requiring a new high bandwidth bearer (for example, fibre) for the 2 Mbit/s connection, and releasing 30 copper pairs for potential re-use in the locality.

New services are on the horizon which will impact heavily on the access network. Interconnect services for local area networks, already available over short distances, are likely to expand to nationwide coverage and experience rapid growth. These services typically require transmission rates in excess of 2 Mbit/s in the access network, and thus an optical-fibre link. Video-conferencing (typically at 384 kbit/s) is another service with growth potential which could significantly impact on the access network.

## COMPETITION

The fixed copper access network has two main disadvantages. Firstly, its fixed costs, the pre-investment required in duct and cable in a particular location before a single customer is connected, are high. Secondly, a stock of pairs must be held in anticipation of future demand. In the absence of competition there is always the expectation that this pre-investment will one day provide a return. The advent of competition demands a different view.

In the short term, competition will arise mainly from other fixed network operators, notably Mercury Communications Ltd. and cable television operators. Mercury is likely to make the most impact in dense city and urban areas where it is financially attractive to install a competing access network. Cable television operators can attack a wider customer base, with a switched-service capability added at low incremental cost to networks primarily designed for (and financed from) the residential entertainment market.

In the longer term, the growth in personal communications networks (PCNs) could trigger a migration of customers from today's fixed access network to a radio access network. In practice these radio networks are likely to require fixed links at some point between outlying radio transceivers and switching units, but large parts of the existing fixed network could be by-passed by radio technology.

Accurate forecasts of demand are essential to the planning of a pre-provided fixed network. The activities of these competitors undermine BT's ability to forecast the demand for its own access network and therefore undermine the principle of building many years worth of capacity into the copper access network.

Unfortunately, at the same time that the risk of building future capacity into the network is increasing, the level of activity associated with new or changed demand—which drives a large proportion of copper deployment activity—is also increasing. This suggests that new planning policies are required to avoid investment in capacity which might merely add to BT's depreciation load without earning revenue.

In the short term, this risk may be controlled to some extent by reducing the planning design periods for duct and cable. This requires frequent augmentation of both cable and duct networks, which is expensive, disruptive and leads to duct congestion. It may also lead to provision of service difficulties when demand increases following a period of economic recession. This approach is therefore not sustainable for a copper access network over a long period but will be effective in the transition to a network structure based on technology which favours reactive working.

## PLANNED OR REACTIVE WORK?

The alternative to pre-providing the copper access network is to work reactively, only installing plant when a demand for service arises. In order to meet provision of service targets, this method of working leads to large numbers of small development schemes with large overheads, and the economies of scale of a larger scheme are lost. In practice, reactive working can cost up to five times the cost of pre-provision. Even in a network where planned pre-provision is the norm, reactive working is required on those occasions when plant does not already exist to meet a demand for service. A balance must therefore be struck between the levels of pre-provision and reactive work in order to reduce the risks associated with pre-provision and minimise the high cost of reactive working.

## TECHNOLOGY

There is a clear need to control future investment in the copper access network but this cannot be achieved by using present technology. Ways must be found of exploiting the existing copper network.

For many years, analogue pair-gain systems, which use a carrier to provide service to a second customer over an existing copper pair, have been used to provide service reactively in situations where a pair could not be provided in time to meet provision-of-service requirements. Restrictions on the use of the systems available have meant that, to date, it has been policy to use pair gain as an expedient measure pending deployment of a copper pair (although around 100 000 systems are presently deployed). The advent of digital pair-gain systems based on 144 kbit/s ISDN technology, which uses an existing copper pair to serve two customers digitally, offers the opportunity to make a radical change in planning policy and a significant impact on access network structure. Firstly, digital access carrier systems (DACS) are free of almost all the restrictions of their analogue counterparts and can be deployed as a permanent part of the network. Secondly, once their reliability has been proven, they can be used instead of copper to augment the access network, particularly in cases where additional ductwork would be required. Although it will not happen overnight, the time might well come when no more copper is deployed at all, and the standard method of providing service becomes the installation of a DACS system using existing copper to serve two, or more customers.

Technology is not always so kind to the copper access network. Other technologies provide bandwidth and mobility capabilities that copper cannot provide and thus pose the risk of obsolescence of the existing copper network.

Nevertheless, recent work has shown that, by using sophisticated coding techniques, bit rates in the order of 800 kbit/s can be carried on copper, offering the possibility that a number of future services requiring increased bandwidth will be delivered over the copper access network.

The fact remains, though, that copper is not a future-proof technology. In the longer term, only optical fibre and radio have the bandwidth capability that can deliver an access network which will meet all future service requirements.

Radio is unique in that it offers mobility and thus flexibility. What local lines planner would not give his eye teeth for a cost-effective 'radio drop wire' which would enable provision of service on demand from a 'radio DP'? In reality, despite the wide availability of radio systems and some excellent development work, radio remains an expensive option in the access network. The key to the cost problem is volume: the key to the volume problem is deregulation. BT is not a licensed PCN operator and cannot therefore deploy radio systems in its access network to support a combination of mobile and fixed services. Without such shared use, the economics of radio provision become unfavourable compared with a fixed copper or fibre network. Nevertheless, work continues to find an inexpensive radio solution which can be deployed in volume and whose use will not contravene the terms of BT's Licence.

Optical-fibre systems are the obvious choice for BT's future network and are already in use in increasing numbers to serve large customers, either because it is economic to do so, or because their future requirements can best be met using fibre. At present, the main inhibitor to the widespread deployment of fibre is cost. The fixed costs of fibre systems are high, and the associated terminal equipment requires high fill rates in order to be economic.

That said, it is relatively easy to build fibre cable spines on the back of fibre system deployment to major business and MegaStream customers. Studies have shown that these spines pass up to 90% of small and medium business customers, laying out a fibre infrastructure for wider deployment as the cost of terminal equipment falls.

Recent developments in passive optical networks (PONs) offer the imminent possibility that fibre systems can be deployed economically not only to small and medium businesses, but also to residential customers requiring broadband (for example, entertainment) services. Relative to copper and present fibre systems, the fixed costs of PONs are much lower, allowing them to be deployed initially with much lower fill rates. Moreover, a single fibre can be used to serve a number of customers in contrast to existing systems which, like copper, require dedicated fibres for each customer site. As a result, by using PONs, demands for service can be met on demand, and the pre-investment costs minimised.

## FIBRE READY NETWORKS

Technology always delivers its promises—eventually. New developments do not always go according to plan and today's access network cannot be planned using tomorrow's technology.

In the meantime, it is vital that the infrastructure for building tomorrow's access network be built today to enable the timely deployment of fibre in the future. Fibre can be installed either as cable in ductwork or as bundles in blown fibre tubing. While the copper access network continues to grow over the next few years, the reservation of duct space for subsequent fibre cable installation on the M-side, and provision of blown fibre tubing on the D-side, possibly in a composite distribution cable, will ensure that the infrastructure required for fibre will be ready when it is needed.

## QUALITY OF SERVICE

In the face of environmental change, planning the access network must concentrate on reducing dependency on the accuracy of forecasts, reducing costs, and ensuring that the network meets future service requirements. At the same time, customer requirements for quality of service must be met.

BT's customers have a perception of the company that depends on two main contact areas: BT's response to demands for service, and its response to complaints, including fault reports.

BT has set some demanding targets for the clearance of customer reported faults: 5 hours for business and 9 hours for residential customers. However, studies have shown that it can take as little as 20 minutes, or as long as 20 days or more for a customer to report a fault after it has occurred. The incidence of customer reported faults can therefore be reduced in two ways.

Firstly, a fault can be cleared before the customer notices or reports it. A programme is under way to install network surveillance equipment which will routinely test every customers' line every day. Service affecting faults, or progressive deterioration in performance, can be detected and cleared before the customer becomes aware of the problem.

Alternatively, the actual number of faults occurring can be reduced. Fault report analysis, in the future using the new network surveillance equipment, is used to identify sections of the network where the fault rate is high. Work to improve the quality and reliability of those parts of the network can then be planned. Generally, there will be a clear economic case for such work, based on anticipated reductions in maintenance effort. Nevertheless, there will be cases where work is required simply to meet fault rate targets and to reduce customer complaints. While many customers will enjoy the benefits of new technology, most will continue to be served over copper and continuous investment must be planned in the renewal of fault-prone sections of the network.

## INTERNAL ENVIRONMENT

In the access sector, changes in the external environment are forcing changes in the internal environment, too. The recent BT reorganisation, Project Sovereign, is the most visible change, putting customers first and bringing their first point of contact with BT, the access network, into sharp focus.

Technological change is also forcing the pace. By default, much of BT's planning skills relate to the construction of a copper access network, with other technologies playing a minor role.

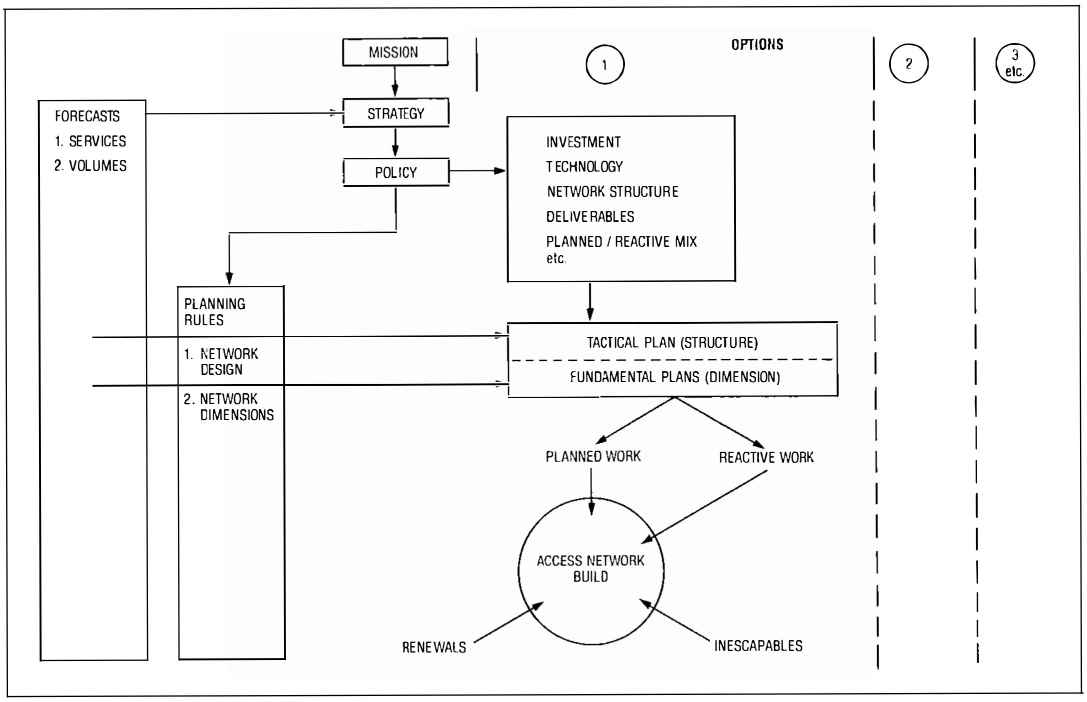



**Figure 2 Internal environment around access network build activity**

Figure 2 shows the environment that surrounds access network build activity.

From BT's enduring mission comes the development of appropriate strategies which will be influenced by customers' requirements for existing and new services, and by forecast volumes.

The development of policies across a wide range of key strategic enablers has in the past led to a set of planning rules constrained by the ability to use only copper as a means of delivering service. In future, planning rules will need to underpin a more flexible tactical plan which will have a number of options dependent on the policy mix and on forecasts.

Thus planners will need to build new skills not only in the planning of new technology, but also in the evaluation of the options available to meet both service on demand and, in the longer term, the requirements for new services and a coherent network platform. The need to develop tactical and fundamental plans, and to learn how to mix new technologies, represents a significant shift in access network planning and thinking.

## CONCLUSION

The challenges facing access network planners over the next few years are simultaneously enormous and exciting. They can only be met by moving away from the construction of a copper access network. How quickly, and how well this is done, depends on two things: firstly, on the development of a segmented market strategy for the provision of new and existing services which demand increased bandwidth, and secondly on the timely delivery of the appropriate technology. These enablers are a burden peculiar to BT: our competitors do not have and are unlikely to install the copper access network which has served BT well for many years, and which will continue to do so in many traditional areas. BT's competitors are using new technology to compete for the services which will generate the new revenues vital to the achievement of BT's long-term aims: BT must do the same. BT cannot afford, in 25 years time, to find that it has perpetuated Mr. Swain's version of the access network.

## Biographies

Paul Allen joined London Telecomunications Region in 1971 after a short career in electronics design. Initially, he worked on the construction of the sector switching centres and later moved into the building services field. In 1980, he joined Headquarters and in 1987 became Head of Power and Building Services. In October 1989, he formed the new Access Division in BTUK Network Planning and Works, where his task was to provide a focus for access planning and works activity and to improve management and control of capital investment. He continues this work as Head of the Access Planning Unit in Worldwide Networks. He is a Chartered Engineer and a Member of the Institution of Electrical Engineers.

Peter Lisle joined BT in 1973 on an undergraduate sponsorship, and, after graduation, joined the Systems Strategy Department to work on network synchronisation, quality of service and early ISDN developments. He then undertook a full-time M.Sc. in Computer Science, and returned to BT to specify and oversee the development of ISDN features on System X. In the mid-1980s, he moved to Network Strategy and has since been responsible at different times for advanced services, network management and his current work areas of access and core networks. He is a Chartered Engineer, a Member of the Institute of Electrical Engineers, and an Honorary Fellow of BT's Telecommunications Engineering Staff College.

# External Engineering

D. CRAMPSEY, and M. L. FASE†

*This article describes the external network, as a whole, and the engineering of some of the components from which it is constructed. It examines these elements in both an historic and functional setting, highlighting their interdependence and projecting their likely development in the next decade from copper-based technology into one in which fibre will play an increasingly significant role.*

## INTRODUCTION

BT's external network infrastructure is truly massive and includes some 4 million poles, 3·7 million holes (manholes and joint boxes), 80 000 cabinets, and more than 200 radio towers.

The disciplines required by the people responsible for the specification, evaluation and approval of the range of products and associated work practices, used in the company's external network, are extremely varied. They range over civil, mechanical, structural, electrical, electronic and optical engineering, and are all called upon to deliver the tools, plant, equipment and practices required to install and maintain the external network.

It is occasionally necessary, because of the unique nature of the external network, to develop BT-specific equipment. However, this process is undertaken only as a last resort when all other avenues, leading to the procurement of proprietary equipment, have been thoroughly explored.

Wherever possible, the services of industrial research facilities, or BT Laboratories, are enlisted to develop the required technology and systems.

Safety is, of course, a most vital part of any external engineering activity. Close liaison with BT Safety Unit and the National Communications Union is maintained to ensure that all external engineering products are safe to use.

## CABLE DESIGN

Today, BT customers are primarily served by underground cable. Gone are the days when they would have been connected to their exchange via an individual pair of overhead wires, which were visually intrusive. Generally, only the connection from telephone pole to the customer's premises is now overhead. The design of cables used by BT has undergone a quiet revolution in the last 35 years. The paper-insulated lead-sheathed-cable has been replaced by a polyethylene sheathed version with polyethylene also being the conductor insulant. Along the way, the conductor material has changed from copper to aluminium alloy and back to copper as the price advantage of the two metals reversed. The change from solid to cellular insulation has allowed a reduction in overall cable diameter and hence the development of very high density cable of up to 4800 pairs with 0·32 mm conductors. Cables of this type, called *Cable Polyethylene Unit Twin*, see Figure 1, are bunch stranded with air in the pair interstices, each unit being uniquely identified by its colour code-combination. The ingress of water molecules through the polyethylene sheath is inhibited by an aluminium moisture barrier laid longitudinally along the laid-up units. This type of cable is used in the main part of the access network between the exchange and the primary cross-connection point (PCP), with the number of pairs decreasing as the cable network fans out towards the customers' premises. Beyond the PCP, in the distribution part of the network, the cable is still constructed in units and sheathed and insulated with polyethylene, but now the number of pairs ranges from 100 down to two, and a petroleum jelly filling is used to inhibit the ingress of moisture. The conductor size ranges from 0·5 mm to 0·9 mm with the

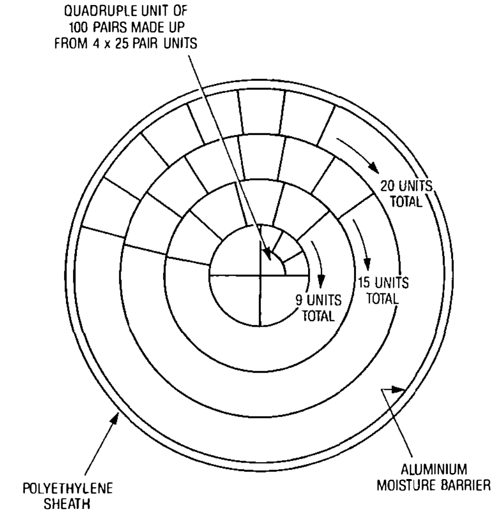



**Figure 1—Cable Polyethelene Unit Twin, 4800 pr/0·32 mm**

† BT Worldwide Networks

larger size providing the necessary network transmission characteristics for customers furthest away from the exchange.

For the 1990s, it is expected that cable design effort will be concentrated on providing fibre in the access network by both cable and blown-fibre methods.

## CONNECTION METHODS

Cable, of course, can be manufactured and installed only in finite lengths. However, the access network is characterised by relatively short lengths of reducing pair size cable as it threads its way to the customer. Therefore, methods are required to join conductors together. Historically, this would have been done by a skilled jointer stripping off the paper insulation, hand twisting the bared conductors around one another and insulating the 'joint' with a paper tube. The quality of the finished joint relied heavily on the skill of the jointer. As polyethylene superseded paper as conductor insulant, and aluminium replaced copper as the conductor material, the twisted joint was no longer a cost-effective method. Therefore, crimp connectors were designed with multiple tangs to 'bite' through unstripped insulant to give a number of points of contact from one wire through the connector to the other wire. However, it was found that over time these tangs relaxed and the original connection performance changed so that network conditions would not support the services available from modern exchanges. Hence a large amount of effort has been put into insulation displacement connector (IDC) technology. Here, the insulated wires are forced into a precisely formed and treated bifurcated tag in a grease-filled housing by the use a special tool. The shape (see Figure 2), material and treatment of the tag have been reached only after extensive research into the optimum amount of insulation and conductor displacement, to give ease of connection with minimum subsequent contact relief. The result is a user-friendly connection, with a much enhanced guarantee of contact performance over time. This type of connection is now replacing not only the previous cable jointing methods but also the screw terminal connection methods once employed in block terminals and PCP cabinets.

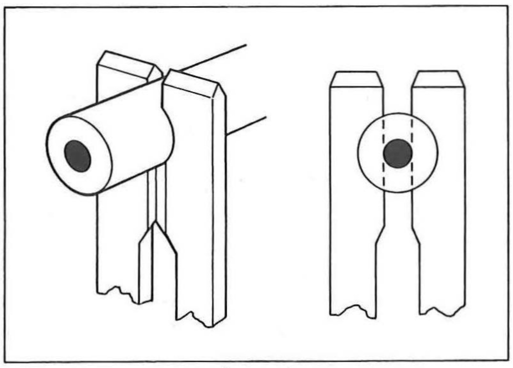


**Figure 2—IDC connector**

Hence this technology will become the norm over the next decade.

## SHEATH CLOSURES

Once metallic pairs have been joined, the gaps between adjacent cable sheath ends must be sealed or *closed*. Among other requirements, the sheath closure must:

(*a*) prevent the ingress of water,

(*b*) be capable of being bonded to the cable sheath material,

(*c*) withstand cable pressurisation forces, and

(*d*) permit re-entry and resealing in the distribution side of the access network.

When lead was the only cable sheath material, the choice of closure material and design was easy, but its execution was craft dependent and labour intensive. The lead plumbing of sleeves almost became an art form, particularly in the break-down joints in cable chambers. However, once polyethylene-sheathed cable was introduced, new closure methods were required. During the late-1950s and through the 1960s, the whole access network saw the introduction of expanding plug closures and epoxy putty plumbing, while the distribution network alone suffered the taped sheath closure. By the early 1970s, these were being replaced by the mechanically/resin-sealed re-enterable Sleeve 30 series of closures, see Figure 3, giving both

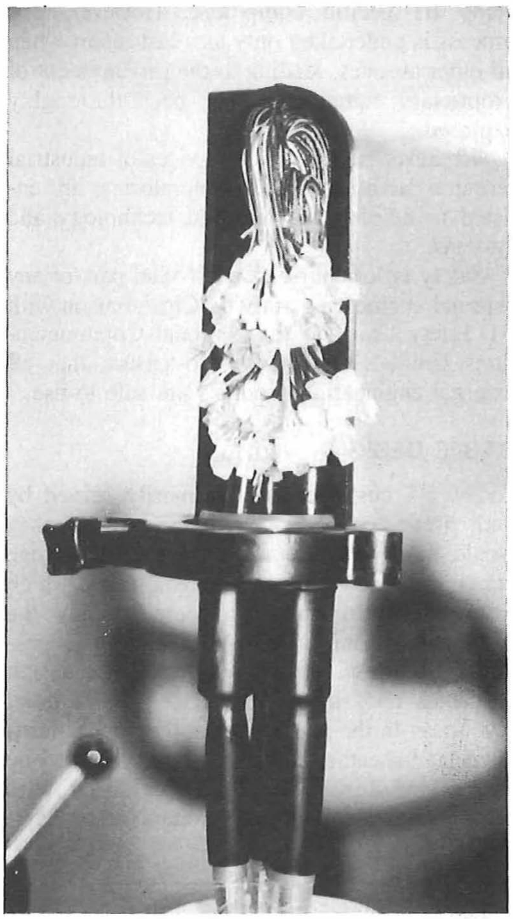


**Figure 3 Series 30 re-enterable sheath closure**

reliability and flexibility close to the customer. Since the mid-1970s, much use has been made of the injection welding technique, where molten polyethylene is forced into moulds sited between a preformed steel-reinforced polyethylene sleeve and the polyethylene cable sheath. This gives a continuous, homogeneous moisture-proof sheathing from cable end to cable end via the sleeve. However, the equipment required is bulky, expensive and the method labour intensive. Therefore, pressurised closures are now increasingly made with either heatshrink material pioneered in the non-pressurised distribution network, or the more expensive reusable mechanically-sealed re-enterable closures. With heatshrink closures, see Figure 4, a suitably shaped piece of cross-linked polyolefin is shrunk onto the joint under the controlled application of heat, while adhesive is activated to form a seal with the cable sheaths. Heatshrink closures have to be remade from a new kit each time the joint has to be opened. The reusable mechanical closure comprises a thermoplastic split cylinder, see Figure 5, that is bolted together, with mastic used for the cable entry and linear seals. The drawback with this type of closure is that a special tool kit has to be supplied to each jointer.

Over the next decade, it is believed that heatshrink technology and the reusable closure will, by careful choice of product, enable the access network to be constructed and maintained at the lowest whole-life cost.

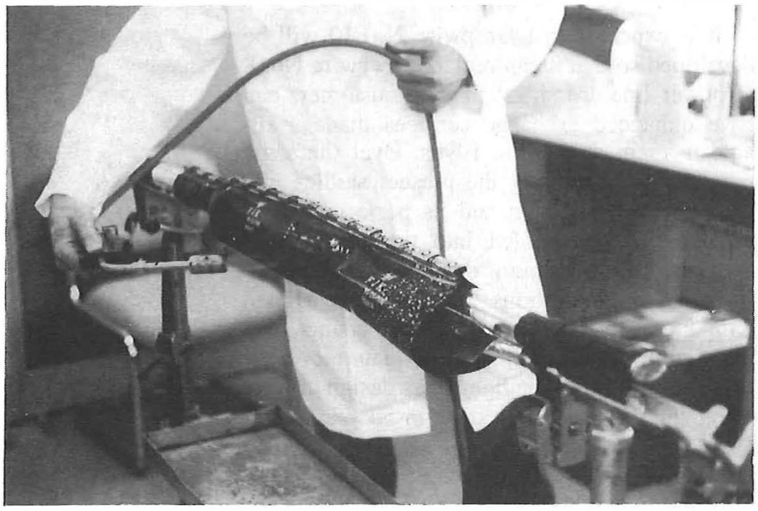


**Figure 4—Heatshrink sheath closure**

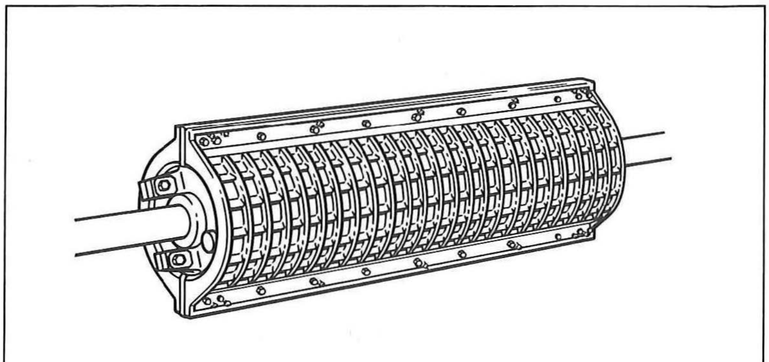


**Figure 5—Reusable mechanical closure**

## POLES

The wooden 'telegraph' pole has been a feature of the access network since its inception; it will remain so for as long as it provides the most cost-effective, safe and reliable means of providing the last link between the exchange and the customer. It could be reasonably said that it is a natural product that has been optimised by man, and specified by BT to ensure a product that will safely carry the loads imposed on it, by both climbing and the simultaneous action of wind and ice on the dropwires and cables it supports.

Both wood species and methods of preservation have changed over the years as different timbers have been deemed economically or structurally desirable. However, BT now specifies only *Pinus sylvestris*, either home grown (Scots pine) or imported (European redwood), or Southern Yellow Pine from the United States, treated for preservation with creosote by the empty-cell Rueping process. The specification of a naturally produced product is a very difficult task since few of the actions involved in its creation benefit from production control. The BRITE (Basic Research into Technology for Europe) Project, a European Community (EC) joint industry and user initiative in which BT is heavily involved, aims to arrive at a specification for a wooden pole that provides the user with the product the customer requires while committing the producer to a range of parameters that are understood and can be provided at reasonable cost.

Today, the requirement for overhead cable routes has largely disappeared. The need now is for the wooden pole to raise the last stage of the underground network to a position where the final 'drop' can be made to most customers. Hence BT uses a restricted range of medium- and light-class poles, most of which carry a distribution point (DP) block terminal and some a light aerial cable. It is at this DP that the underground cable that has been fed to the block terminal at the top of the pole is connected to the individual dropwires serving each customer. Figure 6 shows a wooden distribution pole. Where an overhead DP is required, but the climbing of a pole is considered additionally hazardous because of restricted ladder access or railings or other sharp features within 1 m of the pole base, hollow poles are available. These have a wiring technique that allows the customer to be connected via a dropwire without the technician having to leave the ground.

While the wooden pole is among the oldest technology in use in the access network, it is also featuring in the most recent innovations. Poles have already carried the WB900 pair gain systems. In addition, plans are being laid for poles to be fitted with the digital-access-over-

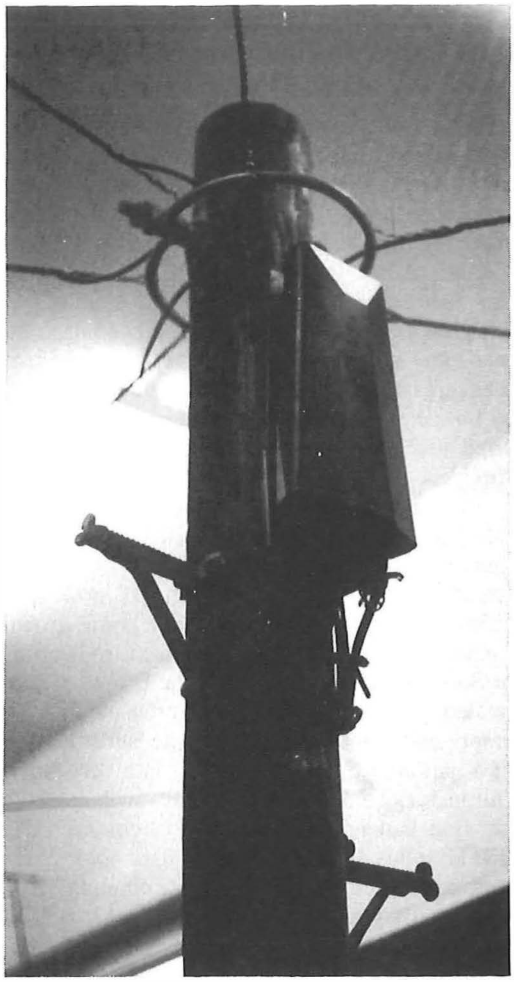


Figure 6—Wooden distribution pole

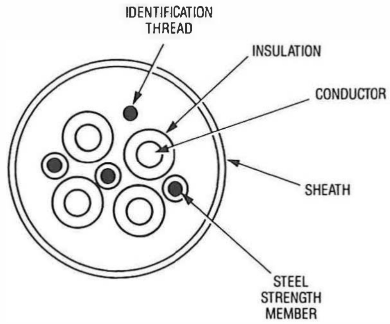
carrier system (DACS) to increase network capacity and for small pole-top radio systems to provide alternative service methods.

## DROPWIRE

As has already been indicated, the final connection to most of BT's customers is via the dropwire from the pole-top block terminal to the customer's premises. As late as 1962/63, this would have been via open copper wires from a ring-type pole head fitted with individual ceramic insulators. Although a single dropwire was available as early as 1932, the necessary insulation and braiding made its size intrusive.

As material technology advanced, the necessary strength could be obtained from smaller diameter wires. Therefore, an insulated pair could be manufactured that gave a suitable transmission path for ordinary telephony with acceptable visual impact. From 1955, a range of dropwire designs have been used, all containing two conductors and culminating in the present Dropwire No. 8, which uses solid cadmium copper wires insulated and sheathed in polyvinyl chloride (PVC). This remains in use today for crossing power lines up to 11 kV.

To give customer access to the range of facilities available from modern exchanges, it was necessary to improve the transmission characteristics beyond that provided by twin-construction dropwire, towards that provided in balanced pair-type underground cable. Hence Dropwire No. 10 was developed, with its two pairs of PVC-insulated tinned-copper wires and fine stranded steel strength members sheathed in medium-density polyethylene (see Figure 7). Thus the strength of steel was harnessed without suffering the problems of corrosion that occurred when the insulant and coating on steel-cored twin dropwire were damaged. Also, a pair-type construction is provided without loss of the visual acceptability of the twin-wire types of dropwire.




*Note*: Intra-cable spaces enlarged for clarity

**Figure 7**
**Dropwire 10**

It is expected that Dropwire No. 10 will be developed so that it can replace Dropwire No. 8 at power line crossings; thus all customers can have enhanced exchange services made available to them during the 1990s. Over the same period, the benefits of the present studies into dropwire cross-section and its performance as an aerofoil will be fed into the profiling of dropwire, for minimum 'dancing and twisting' in high wind conditions. Indeed, if the United Kingdom is to be subject to climatic change over the coming decade, all overhead plant may need to be reassessed in the light of its design criteria of having to withstand a once in 50 year event.

## DUCT NETWORK

The duct network is the system of underground pipes in varying configurations used to distribute most of the access network cables, the balance being carried overhead or buried directly in the ground. It is of course quite possible to operate a network with directly buried cable but the long-term needs of network development and the BT licence mitigate against this practice.

Thirty five years ago almost all duct being laid was of single-way or multi-way 2, 4, 6 or 9-bore earthenware construction with self-aligning (SA) spigots and sockets at either end. Single-way duct was made in 2 ft 3 in (686 mm) or 3 ft (914 mm) lengths. All 2-way duct was 2 ft 3 in long and all multi-way ducts 2 ft 6 in (762 mm) long. However, all the duct had a bore of 3·6 in (92 mm) diameter and was known generically as *self-aligning* duct. In 1967, the single-way Duct No. 15 replaced SA duct in part because of changes in manufacturing legislation and therefore methods. This duct also had a 92 mm bore and the length initially 914 mm as for SA duct was subsequently increased to 1·0 m.

Plastic duct had been available since the early-1960s. The Polyethylene Duct No. 100, of 19 mm bore and 2·5 mm wall thickness, had replaced galvanised wrought iron for short underground feeds to customers premises. Unplasticised polyvinyl chloride (UPVC) Duct No. 55 had been introduced for larger exchange lead-ins in place of pitch fibre and octagonal earthenware duct. This duct had an 89 mm internal diameter and a thin wall because of the then high price of UPVC. However, the thin wall gave rise to construction difficulties and, after various experimental ducts, the 3·8 mm wall UPVC Duct No. 54 was introduced in 1970. The 1973 oil crisis led to the introduction of the 90 mm bore Duct No. 54D with a wall thickness reduced by 14% to 3·25 mm and this remains the standard network duct today. By the early-1980s, further changes in the methods of manufacturing of earthenware duct encouraged work on the unsuccessful Duct No. 16 in an attempt to secure a second, basically independent duct supply route. Other plastic ducts are available, the main ones being:

(*a*) Duct No. 56, a 49 mm UPVC distribution duct for use on housing estates and other low-capacity requirements;

(*b*) Duct No. 57, a 102 mm UPVC for connection to the 102 mm steel Duct 70 used for bridge crossings and other heavy-duty purposes; and

(*c*) Duct No. 102, a 25 mm polyethylene duct for leading-in on housing estates and at kiosks.

With the more secure oil supply situation, earthenware duct has now been totally discarded in favour of UPVC and polyethylene.

Developments in the duct field for the 1990s are expected to centre on the introduction of *sub-duct*. This is a pre-roped, pre-lubricated 38 mm polyethylene pipe, see Figure 8, installed by standard cabling methods in full-size duct and joined to give a high-integrity cabling path of up to 2000 m length for the low-tension installation of delicate cables. It will have an impact on the access network when optical-fibre cable is introduced. In the distribution network, fibre to the home is likely to be provided through blown fibre tubing, see Figure 9, either made up into cable-like form or as the central core of a pair-type cable. In either case, it will be provided using standard cabling methods.

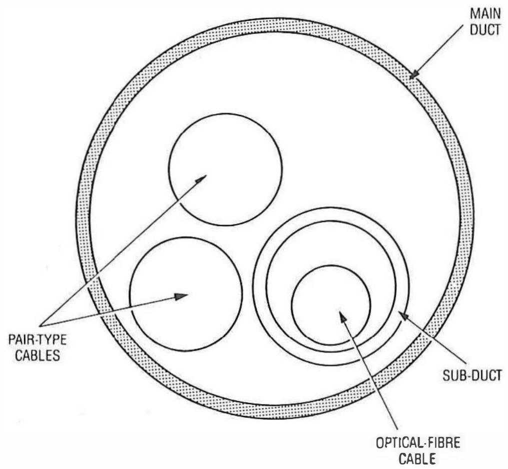



**Figure 8**
**Sub-duct installed in a main duct**

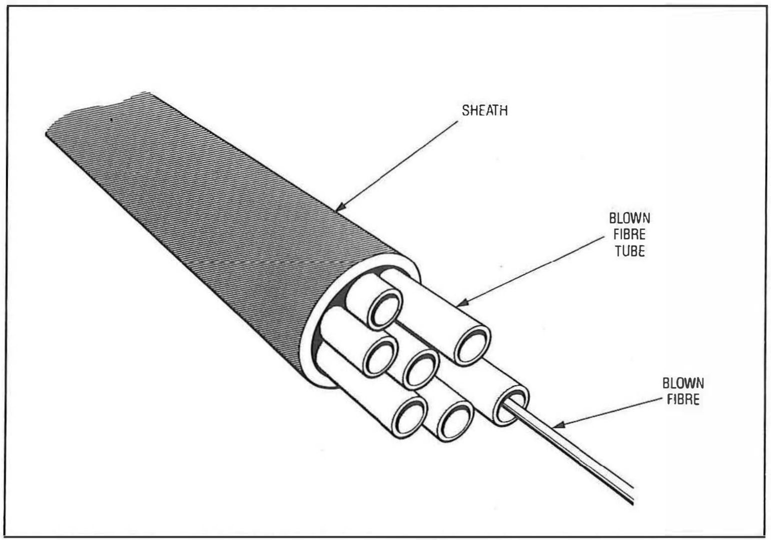



**Figure 9—Blown fibre tubing**

## WORK MECHANISATION

Up to now, this article has concentrated on the changes that have occurred in the lives of some of the many products used in the access network. However, it is only when installed that they perform a useful function. Given their nature, products such as cable and telephone poles require considerable effort, and therefore considerable resource, to install manually. Even individually light tasks such as jointing become onerous when performed in large quantity. If the labour cost of a task rises faster than the cost of mechanising it, it is prudent to invest in that mechanisation.

Prior to 1964, all telephone poles would have been installed manually. A hole would have been dug and, with the aid of sheerlegs, the pole erected, held vertical in both planes and the ground tamped by hand until the pole was firm. Any required ground anchors would also have been inserted manually. Typically, a five-man party would have installed two 9 m medium poles per day. In 1964–65, the first pole erection unit (PEU) was introduced; this was a self-contained vehicular machine that could carry the pole to site, auger the pole hole, insert the pole and provide the power to firm the pole into the ground. It could also install screw-type ground anchors. The fundamental concept of the machine remains the same today and, crewed by two people, is capable of installing up to four poles per day or recovering up to eight poles per day. Figure 10 shows a typical PEU.

Rodding has always been a labour-intensive part of cabling. The rods have to be pushed up the duct, between or over existing cable, and the operation stopped and restarted every 2 m as the next rod is attached. Therefore, during the 1960s, experiments were made to mechanise rodding. These led directly to the development of a vehicle that could be used for both rodding and cabling. The new vehicle, known as the *rodding and light cabling unit*, revolutionised cabling. It was a self-contained unit that could haul cable out to site, rod to install a rope and then install the cable. It employed two people instead of the previous four required just to install a cable. The unit was only surpassed in 1985 when the *light cabling and jointing unit* added the capacity to joint the cable.

In more recent times, attention has been paid to more efficient means of recovering underground cable. A self-contained cable recovery unit has been developed, see Figure 11, that reels recovered cable, either for scrap or for reuse, directly onto a cable drum, at cable speeds of up to 50 m/min. A typical crew for this machine is two, compared to the four required to extract cable at 12 m/min using a cable recovery trailer.

In the jointing field, the quest for improved efficiency in both the joint quality and quantity led to the development of the Machine Jointing No. 4. This initiative went hand in hand with that of the first crimp connectors in that the jointer set up the machine to make joints from a pre-loaded cassette of crimps. It has been demonstrated that up to 400 pairs/hour can be jointed using this machine. Besides the mechanised equipment described, many items are available for generating site electrical power, pumping out underground structures, excavating trenches and assisting with virtually all aspects of external work.

## SPECIFICATIONS

BT is a provider of telecommunications service and, with few exceptions, does not manufacture the products it uses. Certainly it does not produce external network products for access use. Therefore, Group Procurement Services purchases the items required from the large number of suppliers with which it deals.

To promote this activity, items to be purchased must first be described in terms that manufacturers understand. Traditionally, this would have been an engineering drawing or series of drawings, or even an actual item, deemed to have been a good example of that which was required, and labelled as a 'department's pattern'.

Increasingly these days, items are described in terms of functional specifications that describe all the attributes the item must have to perform its task in the network. These specifications lay down the test procedure and/or information which must be supplied to allow BT to judge whether the item is fit for its purpose. In this way, it is more likely that a potential supplier can match an existing product to the requirement. Also, BT gains the advantage of products from the world marketplace without incurring substantial development costs. Often the testing requirements are assembled as a result of investigative work carried out by BT Laboratories and BT's Quality and Reliability Centre.

This trend will extend through the 1990s as commercial pressures encourage the use of more 'fit for purpose' products from a marketplace directed to meet the global needs of telecommunications operators. In this context, specifications will need to be written in terms that will allow the tendering of contracts initially throughout the EC and then throughout the world.


**Figure 10 Modern pole erection unit**

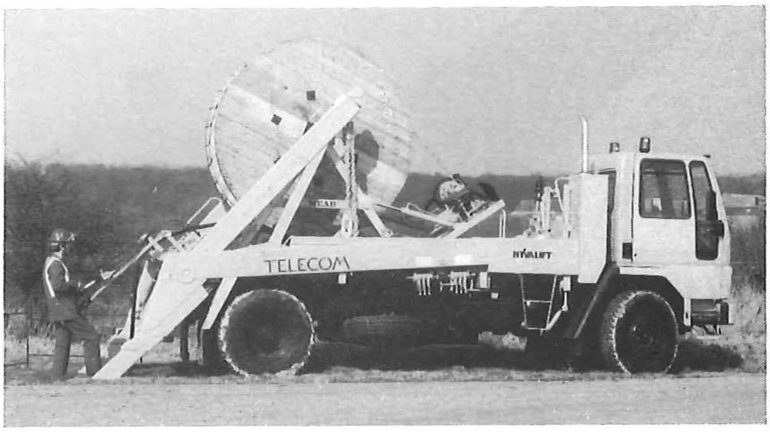



**Figure 11 Cable recovery unit**

## CONCLUSIONS

The range of external engineering activity within BT has been outlined and several specific elements described. It should be noted, however, that these elements are but examples of an exhaustive range of products and practices required to construct and maintain the external network.

The company's external network infrastructure has been built up over many decades and it should be understood that all modifications, or additions, to the network must interface with existing plant. Therefore, of necessity, enhancements are less likely to be as dramatic and revolutionary as those found in some other forms of engineering, enjoying fewer constraints.

Nevertheless, the challenge to improve the external network infrastructure is no less demanding, or exciting, than that experienced by others in their particular quest to improve the access network's performance and deliver the range of services required by BT's customers.

BT seeks to provide a fit-for-purpose infrastructure, pays close attention to whole life costs and practises a philosophy of continuous improvement.

### Biographies

David Crampsey began his career with the company in Carlisle. On transfer to London, he worked for several years on the development of digital transmission systems. In 1988, he became head of Local Broadband Networks and External Plant Division and in the following year also took responsibility for Power and Building Services. His current role, in the Access Planning and Systems Department is as head of the External Engineering Unit. He is a Chartered Engineer and Member of the Institution of Electrical Engineers.

Mike Fase joined the Postal Mechanisation Department of the General Post Office in 1968. After working on a variety of equipment, he transferred to Telecommunication Headquarters in 1972 on cable works. In 1974, Mike began full-time study at Middlesex Polytechnic, graduating in 1978 with first-class honours in Mechanical Engineering. He then joined External Plant Division, working on cable handling equipment, cable installation equipment, cabling practices, cable pressurisation and tools and mechanical aids. He is a Chartered Engineer and Member of the Institution of Mechanical Engineers.

# Digging up the Roads—Providing BT's Duct Network

D. J. ASHTON†, M. MUIR*, D. G. CLOW‡, and J. D. THOMAS**

*This article identifies the scale of provision of duct in the UK and sets out the issues which must be considered when augmenting the already vast infrastructure and asset to BT. Details of the practical aspects of providing that hole through the ground follow with an insight to materials and methods of installation. A contractor's view of executing duct works embraces relations with BT, labour, tools and practices. Duct management is considered and the essential subject of safety is necessarily addressed. Legal and regulatory issues bring the article to a conclusion with a message that challenges are there for tackling.*

## INTRODUCTION

Each year, BT installs some 25 million metres of duct to expand, improve and maintain its underground network. The investment in new duct represents about 35% of the total capital expenditure on external networks, some 78% of which is spent in the local access network. The 'trigger' for proposals to lay new duct, in most cases, is the need to augment the existing cable networks, whether they be trunk, junction or local cables. New duct is expensive, and where duct provision is envisaged, planners must examine all feasible alternatives to ensure that they produce the most cost-effective plans and make best use of the existing duct infrastructure.

Among the alternatives which may be considered are:

- cable consolidation (combining several small cables into one larger cable),
- recovery of out-of-use and abandoned cables,
- use of new technology (for example, optical-fibre cables, pair-gain devices etc.), and
- clearance of lightly used trunk and junction cables.

Full coordination between all duct users (local access planners, main and junction cable planners, local fibre and MegaStream planners, field works and maintenance, etc.) is also prerequisite to drawing up final plans when:

- laying new duct is proposed,
- new cables, sub-duct or blown fibre tubing are to be installed,
- cables are to be renewed or rearranged, and
- cables and/or ducts are to be diverted.

It is essential that all duct investment is targeted to ensure maximum benefit within the capital budget. To do this, duct requirements and costs must be assessed for 10 and 20 years growth, and a cost comparison to establish the most suitable and cost-effective method must always be made.

Duct management has been addressed by several quality improvement teams and several substatial savings identified. When, after consideration of alternatives and consultation with all users, there is clear need to lay new duct, several other issues need to be addressed, namely:

- the materials to be used,
- duct installation and contract works,
- duct management,
- the safety aspects of working in the underground network, and
- legal and regulatory constraints.

These issues are discussed in the following sections:

## MATERIALS

### Duct

The first underground ducts for telephone cables in the UK date from the late-nineteenth century, and, since then, various materials and constructions have been adopted[1,2]. Historically, the material most extensively employed has been glazed earthenware; other materials have included cast iron, concrete, pitch fibre, asbestos cement and wood. Originally, earthenware ducts were of the spigot-and-socket type and manufactured in single-way and multi-way designs up to a maximum of nine ways. In the late-1960s, these were superseded by a new type of single-way earthenware duct of uniform diameter and jointed by a plastic sleeve. This type of joint enabled multiple-way formations to be built up from the single-way duct and so multi-way units ceased to be manufactured. In 1963, a 90 mm bore unplasticised polyvinyl chloride (uPVC) duct was introduced. As a result of further development, plastic duct increasingly took over from earthenware for new work until 1982,

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** BT Worldwide Networks

when the decision was made to purchase only plastic duct for future needs. When PVC duct is used to build up multi-way formations up to 9-way, the ducts are laid in a rectangular formation with a soft soil back-fill. Formations of nine ways and over are encased in concrete.

Where duct space needs are limited, a 50 mm PVC duct is employed; for service feeds to customer premises, a 25 mm bore polyethylene duct is used. In special circumstances, such as in a bridge deck or other situations where the depth of cover is restricted, a 102 mm bore steel duct is used.

### Jointing Chambers

On duct tracks of not more than six ways, surface joint boxes are preferred and these are built in engineering bricks or concrete. The smaller boxes are often prefabricated and made from glass-reinforced plastic.

For duct tracks of more than six ways, surface joint boxes do not provide sufficient space, and manholes have to be provided. These are generally made from reinforced concrete although brick construction is also used. Access to a manhole is through a shaft from the surface. On major cable routes, manholes can be very large and sometimes multi-storeyed.

### Sub-Duct and Blown Fibre

The traditional duct network, especially in the access network, is often less than ideal for the installation of optical fibres. The small diameter of optical-fibre cables makes their installation sometimes hazardous in bores already partially occupied by other cables. Another factor is the requirement to defer installation until capacity is needed. The first of these problems can be dealt with by the use of sub-ducts and the second by blown fibre techniques. Both methods permit the use of long lengths of fibre without splices, a desirable feature to maximise fibre system performance.

Sub-ducts are small diameter ducts inserted into the bore of a conventional duct. There are several types available on the market but the version extensively used by BT is the single-tube type with a bore either of 26 mm or 33 mm. The bore is pre-lubricated and supplied complete with the cabling rope already installed in the bore. This type is best suited to pulling into occupied bores. Once installed, the optical-fibre cables can be pulled into the sub-duct with no risk of damage. The low-friction bore facilitates long-length cabling techniques.

Blown fibre is a novel method[3] developed by BT by which a bundle of very small diameter *micro-ducts* is pulled into the main duct bore and fibre units are then blown in as and when circuit demand requires.

Both techniques also facilitate straightforward recovery of defective or redundant cable systems.

Apart from the transmission performance benefits of long-length cabling, the fewer joints that are necessary eases problems of congestion in jointing chambers, so often a feature in the access network.

## DUCT INSTALLATION

Most duct is installed by the familiar open-cut trenching method. For preference, duct is laid under the footway or grass verges, as the reinstatement costs are much lower than for carriageway works. Disruption of traffic flow is also minimised and the location provides safer conditions for staff undertaking subsequent cabling or jointing operations. However, the congested underground environment in urban situations often means that the duct must be placed under the carriageway, although where there is a choice, trunk and junction cables are placed under the carriageway leaving local cables under the footpath because they are worked on more frequently.

When a large formation of ducts has to be provided in difficult locations, such as beneath a very busy road junction or where the track has to go extra deep to avoid other buried obstructions, a trenchless technique is often used. The duct is placed either in a hand-dug heading or in a steel or concrete tube installed by one of several techniques: pipe-jacking, auger boring, or mini-tunnelling. Once the space has been formed, the required number of standard 90 mm ducts is placed in the heading or tube and any unused space packed with concrete.

Single ducts can be installed economically by mole-ploughing in verges or across open ground provided the subsoil is not rocky or other buried apparatus is not present. Single bores can also be provided by using percussion moles[4]. This method is subject to similar constraints to mole-ploughing, and used where a fairly short length of duct track is needed. Typical applications for the use of percussion-moling would be for a road crossing of a customer feed under a driveway.

## DUCT CONTRACT WORKS

Virtually all duct laying is undertaken by contract. Most of this work is undertaken by companies who are members of the Federation of Telephone Duct Laying Contractors. The contractors are ever aware of the changing scene and recognise the need to modify and adjust their construction methods.

They, like in any other modern industry, live within a competitive environment, and the commitment to change in both labour and client relations is constantly under review.

Historically, Federation members have been operatives for many years in the BT duct-laying scene. In the days prior to privatisation, the volume of market available was considerably less than today and used to be cyclical, dependent on Government-controlled budgets. However, the industry was built on a hard core of labour able to meet the heavy and physical demands of excavating around underground plant laid by other utilities and which could adapt to the peculiarities of building underground boxes and manholes.

This specialist type of labour is still the core of the duct-laying industry and many old and reliable hands are still the mainstay of the more reputable and successful companies. In recent years, as the industry has grown and newer hands introduced, the training and quality required come very much from the long-term employees within the industry.

Long-term employees themselves have had to adapt to the modern world. They have seen their employment on a very casual basis move to full contract conditions, and moved into senior positions within meaningful companies. They have learnt to recognise the need for attention to other functions within the industry and adapt to health and safety and quality requirements, and pioneered the introduction of mechanisation in ever-improving equipment.

A major element of the contractors' task is the temporary and final reinstatement of the surfaces disturbed. The workforce has adapted once again to the many changes in specification and method required by each local authority. In recent years, the Model Agreement relating to back-filling requirements in the build-up to the final surface has been introduced by the Department of Transport.

The range of equipment used is considerable. A brief description of the equipment available is given in relation to each operation.

(*a*) *Cutting and Marking of Surfaces*

This would normally be carried out by using a pneumatic breaker driven off a compressor with the appropriate tarmac cutter attached. The more modern alternative is to 'saw' the surface with a diamond-tipped circular blade. This is particularly appropriate for concrete and high-quality surfacing.

(*b*) *Avoidance of Damage to Other Utilities' Services*

This operation requires consultation of other utilities' drawings and the use of an electronic cable locator which requires specialist operative training vital to safeguard the operatives and minimise damage to buried apparatus.

(*c*) *Excavation*

This is traditionally hand dug to minimise the risk of damage in 'heavily congested' underground areas. However, there are situations which are more suitable for machine excavation.

The original mechanical means of excavation is the well-known JCB and other backhoe excavators. These are particularly appropriate to country areas and excavation for large jointing chambers.

Variations to this theme are now available. Mini-excavators with rubber treads are available for excavation when crossing services are at a minimum in ordinary town footways. The rock wheel, a large-diameter wheel with tungsten-tipped teeth, actually saws the full trench width. This can be used in country carriageways or longer lengths where there are very minimal services in the area. An alternative to the rock wheel is the chain trencher which again 'saws out' the trench.

In roads with a heavy foundation or rock underneath, the addition of a large hydraulic hammer attached to a JCB is an effective tool.

**Cutting a road crossing**

**Excavating a trench using a mini-excavator**

**Compacting a back-filled trench**

(*d*) *Backfilling*

The apparently simple operation of back-filling is perhaps the most critical area in relation to quality. The quality of the back-fill material and the method employed to consolidate it are critical to minimising subsequent sinkage of the surface. A whole range of equipment is available for compaction, the *Wacker* being perhaps the most common tool, a power-driven compacting plate, some 200 mm across, which fits within the confines of a single-way duct trench.

The specifications for back-fill material have been developed by the Department of Transport after research, and the use of their specification is widely used by local authorities, particularly those who employ the Model Agreement specifications.

(*e*) *Reinstatement*

If required at an interim reinstatement stage, an appropriate mechanical roller will be used which vibrates and compacts at the same time. This will compact the tarmacadam to a flat and even surface.

The permanent reinstatement may or may not be carried out immediately after excavation. The surfaces do vary and each has its own particular method.

In footways, flagging work is carried out manually by trained operatives. The black top surfaces of bitumen and macadam and hot rolled asphalt are laid manually and consolidated by a roller heavy enough and appropriate to the specification required.

The future of the industry has a notable change on the immediate horizon, namely the implementation by the Government of the Horne Report, which has many wide implications for utilities in general. In the duct-laying industry, the impact is on the quality of reinstatement materials and workmanship used to back-fill trenching work.

## DUCT MANAGEMENT

As duct is a major capital asset, it is essential that effective use is made of the space provided. To achieve this, accurate records must be kept of the location of duct and the usage of the bores. Three sources contain the essential data:

(*a*) *Ordnance Survey Plant Record Map* This shows the topographical location of the exchanges, underground and overhead routes, jointing, flexibilities and distribution points, and other data.

(*b*) *Duct Plan* This shows all duct routes giving distances between jointing chambers, number of duct ways and types of jointing, flexibility and distribution points etc. These plans are in schematic form and need not be to scale.

(*c*) *Duct Space Record* This gives the formation, type and size of duct and occupancy of each bore by cables. The information is held on standard forms that tabulate essential details and show cross-sections of the duct route.

The combination of these three sources provides a comprehensive record of ducts and their utilisation. If the records have been well-maintained, then the principal unknown in the utilisation of duct will be the possibility of blocked bores. Blockages may result from the ingress of silt or tree roots, 'dropped' or misaligned joints and damage consequent upon other excavation works. Plastic ducts are much less prone to blockage than earthenware. Clearance of redundant cables from bores can sometimes be problematic and may be impossible in the case of large hessian-covered lead-sheathed cables.

Information on the location of duct tracks has to be made available to bona fide enquirers so that the risk of damage from their excavation works is minimised.

## SAFETY

Working in jointing chambers requires special precautions to be taken against gas and liquid pollutants. Gas precautions are of critical importance as the duct system is a vast interconnected and unsealed network into which any gases in the ground can seep[5]. The most common source of flammable gas is leakage from the public supply. The major constituent of this gas is methane. A less frequently encountered source of methane is generated by decaying vegetable material in landfill sites. Flammable gas is, however, not the only gas hazard as oxygen-deficient atmospheres can develop in jointing chambers. It is therefore essential that all staff working underground test for the presence of explosive gas in all jointing chambers and, except for shallow-depth joint boxes, test also for asphyxiating conditions.

As gas may be present in the external duct network, any duct entering a building must be carefully sealed. In the case of telephone exchanges that have many duct entries, additional precautions against gas ingress into cable chambers or trenches are necessary.

Another potential hazard is from liquid pollutants and rodent infestation. Care is needed when soiled jointing chambers are being cleaned, and staff working underground need to adopt some basic hygiene precautions.

## LEGAL AND REGULATORY CONSTRAINTS

Duct tracks are almost always constructed within the confines of the public highway, which comprises land over which a subject of the Crown may lawfully pass. The public right is solely that of passage, and if that land is to be used for any other purpose, then trespass is committed unless one has statutory authorisation. It follows that a utility wishing to place pipes or cables in the street must have been given a legal right to do so. The granting of such rights is counterbalanced by the imposition of statutory duties. In the case of telecommunications, these rights were given under the Telegraph Act 1863 and continued under the Telecommunications Act of 1984.

There has never been an easy relationship between the local authorities responsible for the maintenance of the highway and the utilities who have the right to place their apparatus in the highway. A multiplicity of Acts of Parliament from the seventeenth century onwards sought to regulate the relationships until the Public Utilities Street Works Act 1950 (PUSWA)[6] was enacted; this Act established uniform provisions for all utilities. PUSWA regulates the relationship between the street authorities and the utilities. It includes requirements for the notification and approval of works, the notices associated with such works, gives the highway authority the right to elect to do the final reinstatement and details the arrangements which prevail when utility apparatus has to be moved to allow road or bridge works to take place.

Although PUSWA brought uniformity into what had been a confusing situation, experience showed that it had some important deficiencies and its shortcomings became increasingly obvious with time. Since 1950, a dramatic increase in both the volume of vehicular traffic and the amount of utility provision and renewal activity has taken place. In the face of mounting problems, in 1983 the Minister for Roads and Traffic announced a review of PUSWA and appointed Professor Michael Horne to undertake the task with wide terms of reference. The Horne Report[7] was published in November 1985 and since then a large amount of effort has been expended in joint negotiation between the utilities, the highway authorities and the Government to establish new procedures appropriate to present-day conditions[8]. At the time of writing, the New Road and Street Works Bill is passing through the Parliamentary process and is expected to be enacted later in 1991. The Act will give the utilities the total responsibility for excavation and reinstatement, but the work will have to be done to well-defined quality standards using trained and certificated staff. A computer-based notification system will replace the multiplicity of paper notices which pass between utilities and highway authorities, and new arrangements for dealing with utilities' apparatus affected by highway or bridge works have been agreed. The new Act will have a very considerable impact on all work carried out by BT in the street.

In addition to the Telecommunications Act, PUSWA and its likely successor, constraints are placed upon BT's street works activity by the conditions of its operating licence granted by the Department of Trade and Industry (DTI). The licence for example expresses a preference for employing underground provision rather than overhead, and for underground cables in duct rather than directly buried in the ground; and specifies the depths of cover for duct and that duct is to be located in the verge or footway whenever practicable. The licence requires BT to operate in accordance with the requirements of PUSWA, to maintain plant records on Ordance Survey map bases, and to provide an information service for would-be excavators.

## CONCLUSION

This article gives an illustration of the complexity of identifying the need for, and then providing, that simple hole in the ground: the duct.

The duct network is one of BT's greatest assets and must be utilised efficiently and extended cost-effectively. It is expensive to alter and extend and therefore it must be planned with care. Yet with the vagaries of long-term forecasting, advances in technology and changes in utilisation of the duct network, it presents one of BT's greatest challenges to getting it right first time, everytime.

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## Biographies

David Ashton obtained an Honours Degree in Civil Engineering at the University of Leeds in 1958, and while employed as a site agent by Leonard Fairclough Ltd., now part of the AMEC Group, he became a member of the Institution of Civil Engineers. In 1964, he started his own company, ARM Construction Ltd., and from small beginnings has built the company to become BT's largest supplier in the underground duct-laying field. He is now Chairman and the major shareholder of the ARM Group Ltd, a £30M a year company with four subsidiary companies. In 1981 he was elected to the Council of the Federation of Telephone Duct Laying Contractors and in 1988 was elected Chairman of the Federation.

Malcolm Muir joined the then British Post Office as an adult entrant (Jointer Mate) in 1965 in Brighton Telephone Area. After 6 months he joined the external planning group, and was promoted to Level 1 manager in 1971. He has carried out a variety of duties at Area, Region, District and Territory levels, principally on local network functions. Until recently, he was a Level 3 manager in London and South East Territory Headquarters, and is now Network Support and Development Manager in Southern Home Counties, Personal Communications Division.

Don Clow retired from BT at the end of 1990 after 42 years service. His specialism was the civil engineering aspects of telecommunications, ranging from satellite earth station antennas to cable tunnels. Much of his activity in recent years has been with the National Joint Utilities Group and the Highway Authorities and Utilities Committee, especially in respect of the work in preparation for a new Street Works Act. He continues to have involvement in this area as a consultant. He also serves in a personal capacity as a member of the Government's Street Works Advisory Committee. He is a Fellow of the Institution of Mechanical Engineers and a Member of the Institution of Civil Engineers.

David Thomas joined the then General Post Office as a Youth-in-Training in York. After military service, he spent several years on customer installation work, mainly defence and small businesses. Success at the Assistant Executive Engineer limited promotion board took him to Power Branch in the Engineer-in-Chief's Office and later to North East Region. He set up the first network coordination centre in the North East and was responsible for radio and line transmission maintenance. He became Head of Training in North East Telecommunications Region in 1975 and chaired many promotion boards. Returning home in 1979, he became Head of Engineering Service in York Telephone Area followed by 5 years as Deputy General Manager in Middlesbrough Telephone Area. After an exciting year with BT Applied Technology, he became Territory Engineer in support to the Director of Operations, North of England. He was given the task of the initial roll-out of total quality management in BTUK North, and in 1988 he became Territory Engineer Local Networks. He is now Engineering Services Manager in BT Worldwide Networks, North East.

# Exploiting the Copper Network

P. H. LISLE†, and P. F. ADAMS*

*Significant advances have been made in recent years in developing pair-gain systems for the local access network to increase the information-carrying capacity of copper pairs. This article considers ongoing developments that further exploit the copper network, commencing with the new 2-channel Digital Access Carrier System No. 1 (DACS1) and looking ahead to higher channel capacity systems. The aim is to reduce the need for the deployment of new copper in the access network: ensuing benefits in the engineering, marketing and customer service fields are envisaged.*

## INTRODUCTION

In contrast to BT's core transmission and switching network, its access network has seen little real technology change since the early years of the telephone service. The vast majority of switched and private circuit services are still supported by dedicated copper pairs between the local exchange and the customer. The copper network itself has been the subject of continual improvement in installation and maintenance practices over the years, and this, together with its ubiquity, provides a sound platform for exploitation.

Over the past ten years, the focus of research and development activity worldwide has been on optical-fibre systems for the access network and, more recently, on radio systems for personal communication networks. Copper research and development has been left out of the limelight, but nevertheless significant advances have been made on systems to increase the information-carrying capacity of copper pairs, providing what are colloquially termed *pair-gain* capabilities.

It is now recognised that a combination of copper, fibre and radio technologies will be required to evolve BT's access network optimally over the next decade. A renewed interest in copper-based technology and its exploitation in the field has stimulated new strategic thinking, and is the basis of this article.

## COPPER-BASED TECHNOLOGY TODAY

The objective of most copper-based technical developments is the support of more than one channel per copper pair, with the channels being available to one or more customers. One of the earliest techniques was line-sharing, with a single pair usage-shared between two customers. This effective, but not exactly customer-friendly, option was discontinued by BT in the 1970s.

Other developments in the 1970s included line concentrator units (mechanical or reed switches for siting at cabinets or distribution points) and 2-channel analogue multiplexer (1 + 1 pair gain) systems, with a second analogue bothway speech channel supported on a copper pair by modulation on to a carrier frequency. Both options have seen fairly widespread use as expedients, or to serve locations where line plant augmentation would be costly. However, two factors have impeded deployment:

- significant weaknesses in design, quality, installation and maintenance procedures which have relegated them to expedient use only; and
- the conservative nature of access network planners, and lack of real drive from Headquarters for change.

Despite these factors, considerable use is being made of these systems, especially the 2-channel unit code-named *WB900* of which around 25 000 are installed each year.

## COPPER-BASED TECHNOLOGY DEVELOPMENTS

The main thrust in copper-based developments over the past ten years has been the implementation of low-cost digital transmission systems[1]. Initially, these resulted in equipment for digital private circuit access (KiloStream). Increasingly, interest has focussed on transceivers for supporting the 144 kbit/s digital transmission systems required for basic-rate access to the internationally defined integrated services digital network (ISDN). The key to this development has been the rapid advance of very large scale integrated (VLSI) circuit technology.

There has been a revolution in signal processing capability brought about by the concentration of enormous digital processing power on to VLSI circuits. By converting analogue signals

† BT Worldwide Networks
* BT Development and Procurement

into a series of digitally represented numbers in real time this processing power can be used to perform digital signal processing (DSP). DSP can give precise processing which can be replicated without performance variation, thus allowing mass production at low unit cost.

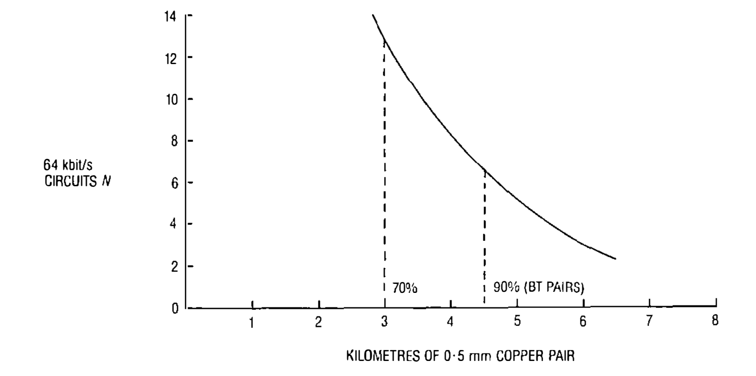
DSP was first applied to modems used to transmit digital data across the telephone network at data rates up to 19·2 kbit/s. To cope with the impairments such as distortion and echoes that a long-distance connection introduces, DSP algorithms to provide equalisation and echo cancellation have been developed. The shorter distance of copper local loops provides a more benign environment for digital transmission, but this is offset by the fact that applications demand higher data rates. Fortunately, as VLSI circuit technology has advanced, it has become possible to implement transceivers for digital transmission at 144 kbit/s on a single VLSI circuit. DSP could be applied to provide the modulation, demodulation and filtering for analogue pair gain, but digital transmission offers a number of advantages; for example,

- local access can be made largely independent of the services being carried, thus reducing equipment diversity and interworking problems;
- robust digital transmission prevents electrical interference degrading transmission quality and reduces speech attenuation on long copper pairs; and
- digital control and monitoring capabilities are inherent, thus allowing better maintenance facilities.

## Transmission Limitations

The main limitation on digital transmission over local network twisted pairs is crosstalk interference from pairs carrying similar digital signals[2]. This is most noticeable on longer loops where the greater attenuation of the digital signals makes the interference more significant. Theoretically, it is possible to send several megabits per second over many of BT's copper pairs. Practically, however, rather less is achievable. Figure 1 shows the number of 64 kbit/s channels that can be supported over 0·5 mm copper pair as a function of length. Relating this to the cumulative distribution of pair lengths in the local network, it is feasible to send 144 kbit/s over 98% of loops with an error rate of less than 1 in $10^7$. Similarly, rates of about 400 kbit/s and 800 kbit/s can be supported over 90% and 70% of loops. The reduction in reach is a consequence of the increased attenuation suffered by higher-rate signals and the increased crosstalk resulting from their higher frequency spectra. To achieve this coverage of the network requires careful design of transmission systems. In particular, it is necessary to use transmission techniques that keep signal energy at as low a frequency as possible to avoid excessive attenuation and crosstalk noise, both of which increase with frequency. The repeatable precision advantage of DSP helps to do this in a number of ways.

**Figure 1**
**Local network circuit capacity**




Multi-level baseband line codes can be used to reduce the signalling rate because the precision is available to provide the required accuracy in signal generation and decoding. Echo cancellation is feasible which permits signals in both directions of transmission to occupy the same low-frequency band. Precise equalisation is feasible especially to provide DC restoration. This means that there is no need to use redundancy to ensure a zero DC component in signals coupled to line by transformers, or ensure that signals avoid the highly distorting part of the copper pair frequency response at low frequencies.

A number of line codes have been used in commercially available transceivers for 144 kbit/s: biphase, alternate mark inversion (AMI), 4B3T, 3B2T and 2B1Q*. The first two require simpler DSP, but because of their high signalling rate and redundancy give inferior reach. AMI is used in the latest generation of KiloStream access equipment where, to support a single 64 kbit/s channel, the reach is acceptable. 4B3T was specified for the implementation of ISDN basic-rate access in Germany. 3B2T is used in the initial equipment being deployed by BT to provide ISDN 2 service. 2B1Q has been chosen as the ANSI standard for basic rate access in North America and looks set to become a de facto international standard. Both 3B2T and 2B1Q provide in excess of 98% coverage of BT's copper loops.

At higher transmission rates, similar line codes are being considered for relatively simple transceivers. However, the continuing progress in VLSI circuit technology and DSP techniques mean that more complex processing schemes are being researched involving multi-carrier modulation and multi-element detection. Such schemes offer improved reach and, therefore, network coverage.

* In an *n*B*m*X code, *n* is the number of bits that are mapped onto *m* X-level pulses. For example, 3B2T (T stands for ternary) means that the eight combinations of 3 bits are represented by eight of the nine combinations of two 3-level pulses.

### Signal Processing Functions

Figure 2 shows a block diagram of a typical transceiver. The main signal processing elements are the transmitter, the detector, the equaliser, the echo canceller and the timing recovery circuit. Analogue-to-digital and digital-to-analogue converters provide the interface between the analogue signals transmitted to and received from the pair and the DSP functions. A line driver generates the transmit signal which is coupled to the pair by a transformer.

The transmitter takes groups of *n* data bits and generates a series of pulses whose sizes are uniquely related to that group by the mapping of the *n*B*m*X code definition. The pulses are shaped to give desirable spectral content.

The detector has to interpret the incoming encoded pulses from the far-end transmitter in the presence of various sources of interference that cause the instantaneous value of any level to deviate from ideal. Too large a deviation can result in a detection error. Two large sources of interference are the local transmitter and previous pulses that have been dispersed in time by the electrical response characteristics of the copper pair. These are reduced to acceptable magnitude by the echo canceller and equaliser respectively.

Both the echo canceller and the equaliser are adjustable filters that are automatically adapted to reduce the error signal to a minimum. The echo canceller precisely models the form (echo) of the transmitted signal that appears at the input to the receiver, so that when the output of the echo canceller is subtracted from the received signal the echo is largely removed. The equaliser removes the dispersed energy of previous pulses in a similar manner.

The timing recovery circuit processes the incoming signal from the far-end transmitter to determine if there is any drift between the clock which drives the local transceiver and the clock which drives the far-end transceiver. If drift occurs, the timing recovery circuit adjusts the sampling phase of the analogue/digital interface to counteract it.

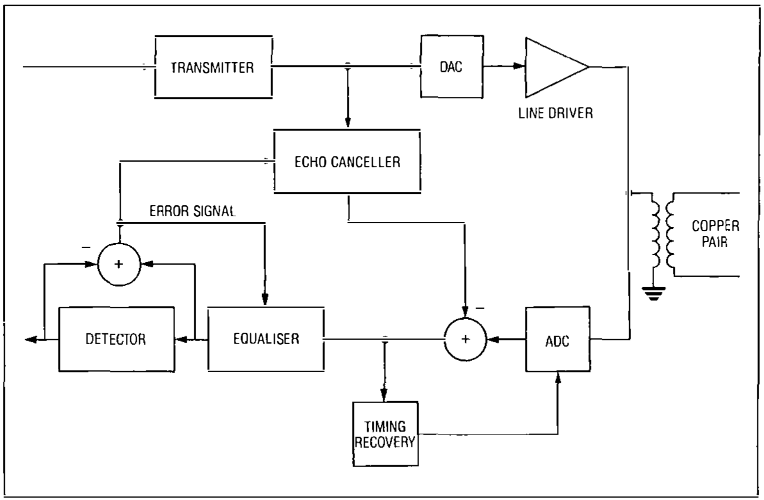
## COPPER-BASED PAIR-GAIN SYSTEMS IN THE FUTURE

### 2-Channel Systems

Not surprisingly, given that transceivers were specifically designed for it, the first 2-channel systems to emerge were basic-rate access ISDN systems. An example of these is used by BT in its recently launched ISDN 2 service. The two channels, each at 64 kbit/s, can support a range of services, including telephony, where the customer's terminals are designed to plug, either directly or via a terminal adaptor, into the S/T-bus, the internationally defined customer interface to the ISDN. ISDN access, while providing a form of pair gain to individual customers, is not intended to provide pair gain to support two independent customers, and for telephony requires a telephone with an ISDN interface, or an adaptor for an ordinary telephone. Pair gain for telephony requires a specially designed remote unit capable of supporting ordinary telephones (and other analogue terminals) to either a single customer or two independent customers.

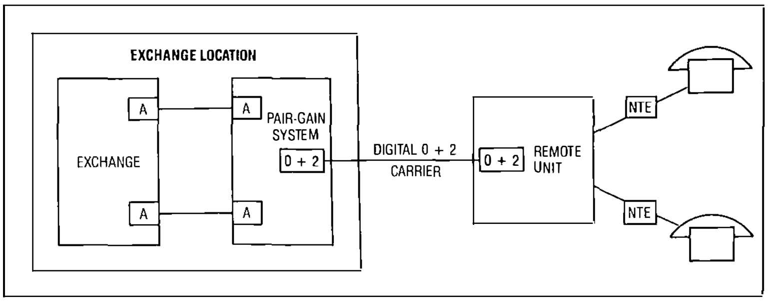
In 1990, a review was conducted to compare further development of the analogue WB900 2-channel unit, against the alternative of a 2-channel unit using digital transmission technology. The digital option was selected because of superior performance, maintenance capabilities, and future cost trends. An evaluation of various supply options for digital systems followed, and two suppliers are now providing BT with trial quantities, in advance of full-scale orders being placed in mid-1991.

The new system, code-named *DACS1* (Digital Access Carrier System No 1), will initially interface to the exchange via analogue interfaces (Figure 3). This interfacing arrangement is compatible with the full range of BT's exchanges. When working to a digital exchange, this interfacing arrangement means that a transmission path will undergo analogue-to-digital conversion in both the exchange and the carrier system: an unnecessary cost overhead and a source of transmission impairment. Subsequent digital interfacing arrangements are being investigated which would remove the back-to-back conversion. The



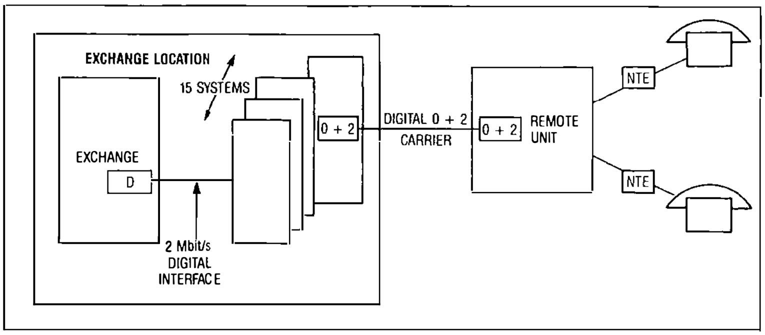
ADC: Analogue-to-digital converter DAC: Digital-to-analogue converter

**Figure 2**
**Typical transceiver block diagram**



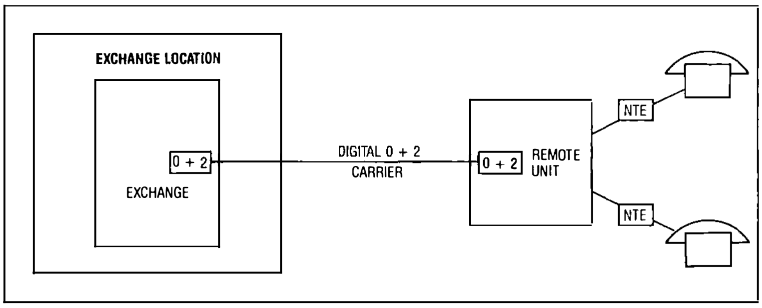
A: Analogue interface 0+2: Digital 0+2 interface
NTE: Network terminating equipment

**Figure 3**
**DACS1 with analogue exchange interfaces**



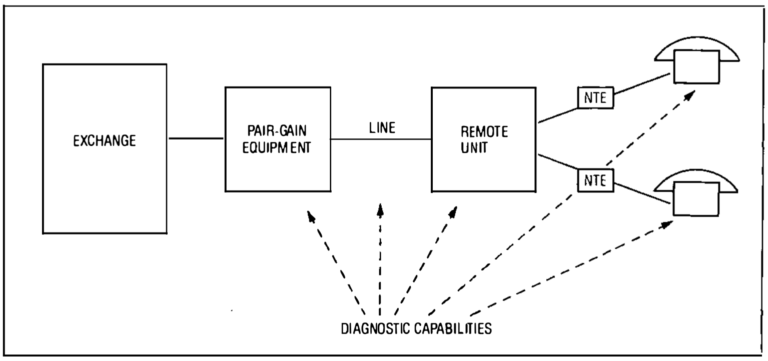

D: Digital 2 Mbit/s interface 0+2: Digital 0+2 interface
NTE: Network terminating equipment

**Figure 4—DACS1 with 2 Mbit/s digital exchange interface**



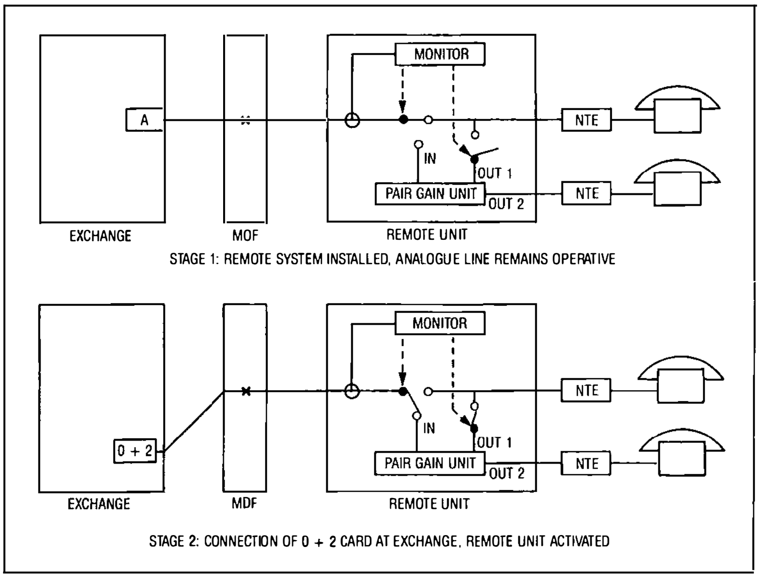

0+2: Digital 0+2 interface NTE: Network terminating equipment

**Figure 5—Direct support of DACS via exchange line card**




NTE: Network terminating equipment

**Figure 6—Diagnostic capabilities of DACS1**




NTE: Network terminating equipment

**Figure 7—Remote activation sequence for DACS1**

first option (Figure 4) employs a 2 Mbit/s digital interface and BT's proprietary DASS2 signalling system between the exchange and a 15-line block of carrier systems. This interface is already in use with fibre-based systems in the access network, and is a derivative of the interface BT provides for connection of ISDN PBXs (ISPBXs) to the network, via the ISDN 30 service. An alternative option (Figure 5) employs a line card supplied by the exchange manufacturer and resident in the line shelf of a standard exchange. There are clearly similarities between this line card and a card for basic-rate (144 kbit/s) ISDN service, and it may be possible to design a common card that can service either application by software configuration.

The DACS1 features are superior to the existing WB900 features in several important areas, and it is intended that widespread and permanent deployment could be undertaken with this unit as an alternative to new copper pairs. Obviously the extent of its use is critically dependent on the equipment cost, and thus volume/price commitments from industry will be a key factor in future plans. The features that allow widespread deployment to be contemplated are:

(*a*) Maintenance and diagnostic features. These include continuous monitoring of the line and equipment at both ends, diagnostic features that allow faults to be diagnosed, and a detection system to determine the presence or absence of a customer terminal (Figure 6).

(*b*) Line powering. In contrast to the WB900 which relies on either a local mains power source or a rechargeable battery in the remote unit, the DACS1 is fully line powered from the exchange. This improves the reliability of the unit and facilitates installation.

(*c*) Internal customer location (for 2-line customers) or external unit (for pole or footway box).

(*d*) Resilient transmission system—less prone to interference than the WB900.

(*e*) Supports all BT's switched analogue services.

(*f*) High levels (guaranteed by the supplier) of reliability, and long lifetime.

(*g*) Remote activation. Until triggered from the exchange end, the remote unit connects one of the two customer line interfaces on to the baseband copper pair. This enables installation of the remote unit to be carried out independently from the exchange jumpering, and the system converted from single-channel to 2-channel operation without disruption of service to the existing line (Figure 7).

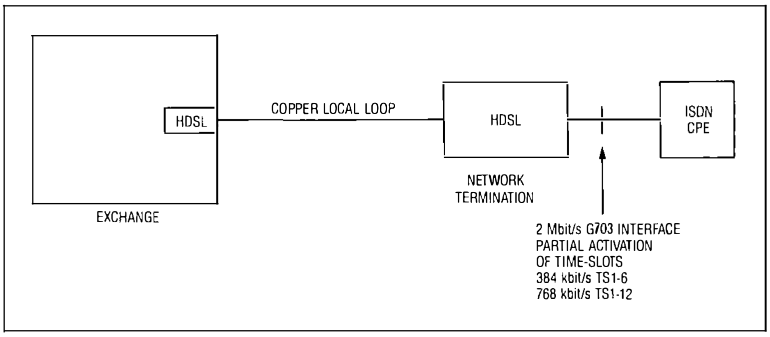
## Multi-Channel Systems

Multi-channel systems, carrying 4, 6 or 12 channels over one or two copper pairs are now under active research and development. There are a number of applications for such systems:

*Multiple-channel pair-gain systems* Four channel systems are potentially line powerable—a significant advantage for external location. Increased channel capacities (for example, 6 or 12) require local power, which will restrict use to internal locations (for example, flats or business premises).

*Service support for high bit-rates* An immediate application for a 6-channel unit is videoconferencing at 384 kbit/s. This rate can support reasonable quality video, and is already in use on BT's international videoconferencing service.

*Fractional-fill ISDN services* The existing rate jump between ISDN basic-rate (144 bit/s) and primary-rate (2 Mbit/s) services leaves an opportunity for an intermediate rate service employing copper-based multiple channel systems. The network interface to the customer would be 2 Mbit/s, but only a sub-set of the channels (for example, time-slots 1–12 for a 12-channel system) would be operational. This fractional-fill service would be suitable for a wide range of small PBXs and key systems. (Figure 8.)



HDSL: High-rate digital subscriber line

**Figure 8**
**Fractional-fill ISDN using copper pair local loop**

### Protected Pair-Gain Systems

So far this article has concentrated on how digital transmission can be used to provide pair gain to reduce costs and provide digital access for new service possibilities. A drawback of the copper pair network is that a fault on a pair results in loss or impairment of service to the customer, and so requires reactive maintenance to clear the fault as soon as possible. The passive nature of the copper pair makes identifying and locating faults a time consuming business. The introduction of digital transmission may possibly assist in the maintenance of copper pairs because the active equipment at the end of the loop can aid network surveillance, and provide evidence for fault location. However, the sharing of a single pair by more than one access line means that a fault will have a greater effect on customers.

This disadvantage could be offset by exploiting the fact that the potential increase in the number of channels that can be supported by most pairs is far greater than the likely increase in demand. This spare capacity could be used to provide service protection, thus making network faults largely 'invisible' to customers. If there were $P$ pair-gain systems each providing $N$ channels then $(P-L)N$ lines could be provided and there be no loss of service if L pairs were to go faulty. The additional hardware required to do this is small. The impact of such equipment could be considerable because it would greatly improve the quality of service in terms of availability and would allow scheduled rather than reactive maintenance. In addition, many faults would be detected automatically. The benefits of this approach need careful cost benefit study.

A further variation on service protection in pair-gain systems would be to combine pair gain with concentration. With the introduction of multi-channel systems deployable to the DP or customer's premises, the advantages of concentration diminish. Sufficient capacity can be added to the network to serve significant levels of increased demand without the need for concentration which brings with it system design and management overheads, and can result in inferior quality of service. However, one option for a pair-gain protection strategy which is under consideration is a 2-pair combined pair-gain/concentrator system which operates in straight multiplexing mode under normal operation, but 2:1 concentration mode if one copper pair between the unit and the exchange fails. Such a system could be developed either as a 4-line unit using 2-channel line systems, or an 8-line unit using 4-channel line systems, the latter being dependent on successful development of line-powerable systems.

## IMPACT OF NEW SYSTEMS ON COPPER NETWORK PLANNING

One of BT's strategic aims is to reduce the deployment of new copper pair cable in the access network[3]. The use of pair gain in established areas will contribute to this reduction, and will complement the deployment of fibre systems which in the early years are expected to be predominantly targeted at major customers and greenfield locations[4].

One of the most important features of pair-gain deployment in comparison with traditional copper cable is the ability to target real customer demand. Pair-gain systems can be installed when demand arises, whereas the lead-time on cable installation means that significant levels of spare capacity must be planned into the network. In the forthcoming decade, with increasing levels of customer moves and changes, and potential migration between BT and competitors, the demand-focussed investment in pair gain is more attractive than maintaining substantial levels of spare capacity in the cable network.

In the event that a customer migrates to a competitor, or changes the type of service required (for example, from analogue to ISDN), the pair-gain system can be recovered and re-used elsewhere. Such re-use of copper capacity is either impossible or costly.

Dependent on the cost of new pair-gain systems, several economic deployment targets are possible:

- Reactive use to avoid expensive expedient provision of copper. If additional copper capacity becomes available at a later date then the system could be recovered and retained for re-use.
- High-cost lines, where provision of additional copper capacity would be unusually expensive (long lines, no spare duct etc).
- Localities with low projected growth. The permanent use of pair-gain systems or small line concentrators would remove the need for providing additional copper capacity where little further growth is expected.
- Second lines. There is increasing evidence of growth in the number of residences with second lines. Pair-gain systems could become the primary method for provision of second lines.
- Fast track provision. The use of pair-gain systems or small line concentrators may also be appropriate where copper capacity is not immediately available, in order to meet provision of service targets.

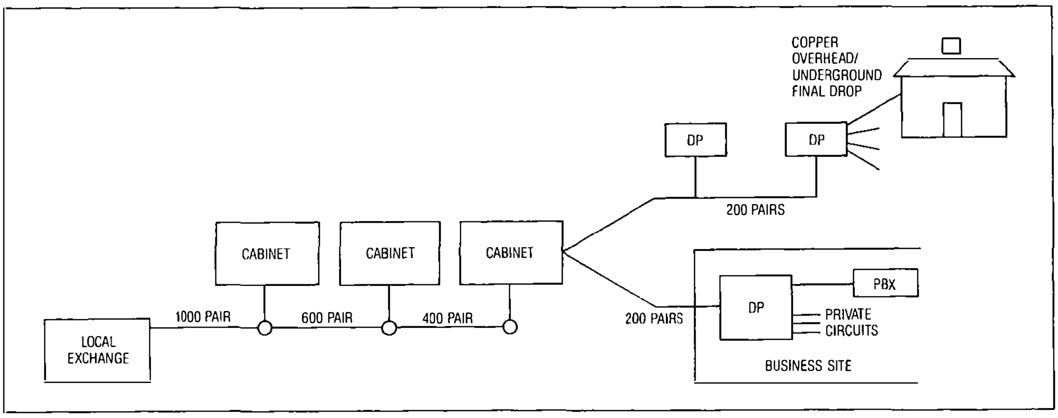
If widespread pair-gain deployment does take place, the underlying spare pair capacity of the cable network can be allowed to fall, further reducing the need to install new copper cables.

## EXPLOITATION OF COPPER IN A MIXED COPPER/FIBRE ENVIRONMENT

Fibre deployment to major customer sites is already underway, triggered by broadband requirements (for example, MegaStream) and providing the quality levels and service support required in the business sector. Many of these major sites are already served by copper, and the opportunity will arise for re-use of copper 'thrown spare' from the site, once fibred. The ability to re-use copper will substantially reduce the requirement for new copper cables, and should reduce expenditure on new duct. In many cases, such re-use will be a deciding factor in establishing favourable economic grounds for fibre installation.

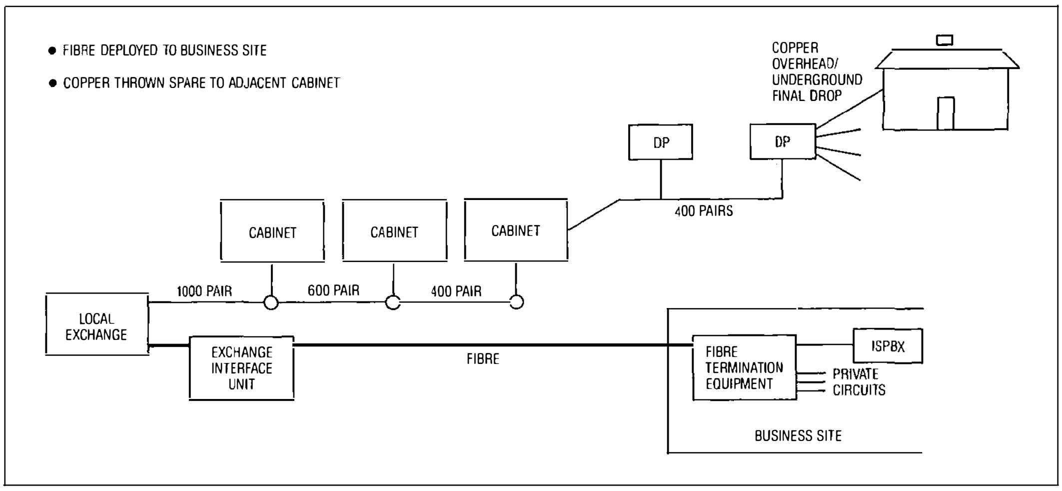
The process of employing copper 'thrown spare' is illustrated in Figures 9 and 10. Here, a major (200-line) customer site comprising a 100-line PSTN PBX and 100 mixed analogue/KiloStream private circuits has been converted from copper to fibre, with the customer

**Figure 9 Existing network prior to fibre deployment**

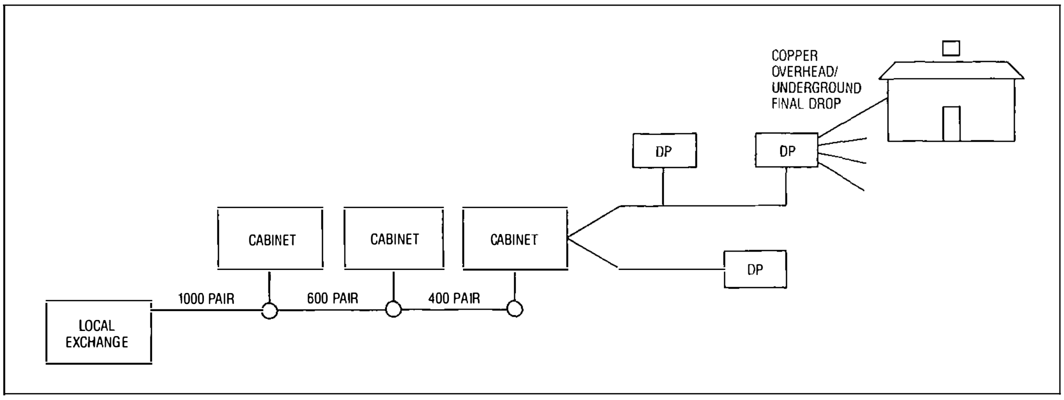



DP: Distribution point

**Figure 10 Capacity relief to outer cabinet by fibre to business site**

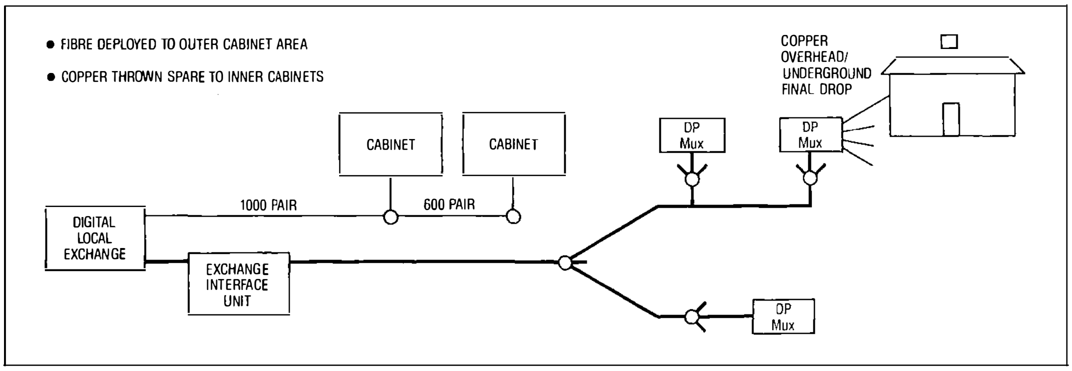



DP: Distribution point




DP: Distribution point

**Figure 11**
**Existing network prior to multiplexer deployment**




DP: Distribution point

**Figure 12**
**Capacity relief to inner cabinet areas via fibre deployment to outer cabinet area**

simultaneously changing from analogue PSTN delivery to ISDN 30. The 200-pair capacity has been returned to a nearby cabinet, thus providing sufficient capacity for nearby customers for the foreseeable future. With the use of pair-gain systems for smaller customers, further copper cable installation to the cabinet should never be required.

A derivation of this approach is illustrated in Figures 11 and 12. Here, the use of street-sited fibre equipment to replace an outlying cabinet enables the existing capacity in the cable from the exchange to be shared amongst the cabinets nearer the exchange. This capacity relief option makes maximum use of the embedded cable network, removes fault-prone long copper cable runs, and provides low-loss, high-quality transmission at the periphery of the access network, where it is often most needed.

## CUSTOMER BENEFITS OF NEW COPPER-BASED TECHNOLOGY

Hitherto, this article has concentrated on the engineering and cost benefits to BT in employing copper technology. However, there are significant benefits which customers will receive when served by the new systems.

The most obvious benefit will be extension of the digital network over the local access network, providing low-loss, noise-free transmission. This benefit will be particularly marked on longer lines where higher levels of loss and analogue crosstalk are experienced with traditional baseband analogue transmission.

A second benefit will be the active monitoring of lines and the diagnostic features available with an intelligent unit mounted in or near the customers' premises, giving rise to rapid fault logging and diagnostics. These features will allow BT to locate faults rapidly, without being dependent on customers to report faults. More sophisticated protected systems could dramatically reduce the levels of line failure experienced by customers.

Finally, the advent of a simple, flexible method of adding extra capacity to the installed copper pair network gives BT an opportunity, unique to itself in the UK, of promoting and supplying additional channels to many of its existing customers in short time-scales and at modest cost.

So here we have it—a technology that provides customer benefits, marketing opportunities, and engineering benefits. The challenge is now on to conclude the field tests of the new DACS1 systems and to put in place the processes and support for subsequent widespread use. Meanwhile the development of higher capacity systems continues apace. The success of these activities will confirm the major ongoing role for BT's existing copper cables as key components in a mixed copper, fibre, and radio-based evolution of the access network.

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## Biographies

Peter Lisle joined BT in 1973 on an undergraduate sponsorship, and, after graduation, joined the Systems Strategy Department to work on network synchronisation, quality of service and early ISDN developments. He then undertook a full-time M.Sc. in Computer Science, and returned to BT to specify and oversee the development of ISDN features on System X. In the mid-1980s, he moved to Network Strategy and has since been responsible at different times for advanced services, network management and his current work areas of access and core networks. He is a Chartered Engineer, a Member of the Institute of Electrical Engineers, and an Honorary Fellow of BT's Telecommunications Engineering Staff College.

Peter Adams obtained a B.Sc. in Electronic Engineering from Southampton University in 1970. He then joined BT Laboratories working initially on telecommunications applications of digital signal processing and later on the development of a VLSI circuit for digital filtering. From 1979–87, he headed a research and development group concerned with speech-band data modems and subsequently local loop transmission. Currently, he heads the Copper Access Systems Section, which is involved in research, development, measurement and testing activities for transmission over copper pair cables and local loop monitoring and fault location and diagnosis. He is a Chartered Engineer and a member of the IEE and the IEEE.

# Radio in the Access Network

J. BUTTLE†, and P. HUISH*

*This article reviews the range of options for the use of radio systems in the fixed access network. It outlines the experiences to date of the use of such systems within the BT network, and identifies the scope for their cost-effective use, particularly in serving customer needs and reducing costs within the rural network infrastructure.*

## INTRODUCTION

Amidst the publicity surrounding the use of mobile radio technologies in the access network, such as cellular and personal communication networks (PCNs), and their apparent threat to fixed access via copper or fibre, it would be easy to miss the quiet revolution taking place in the use of fixed radio systems to serve customers in the BT network. This revolution has occurred through the opportunity to exploit already existing radio technologies within the fixed access network, particularly in rural areas, to improve service and to meet new customer demand more flexibly, responsively, and cost effectively. The traditional monopoly view of the network as a homogeneous infrastructure, either in terms of geography or in terms of the customer base, is no longer valid in the competitive market-place. Equally, commercial investment decisions based on global average costs are flawed when the cost of providing and operating the access network can vary by an order of magnitude between a city centre and a remote rural location. Provision of customer service is not optional and network planners need a portfolio of complementary radio, optical fibre, and copper-based products in order to structure the network cost effectively to meet specific customer requirements, across a disparate geographical network infrastructure.

This article reviews the opportunities for, and benefits of, access radio and describes the collaborative work done to date to establish radio systems as legitimate and cost-effective solutions within the UK fixed network. It draws heavily on the various papers listed at the end and to which the reader is referred for further information.

## THE OPPORTUNITIES FOR ACCESS RADIO

The last five years have seen a dramatic modernisation of the UK core switching and transmission networks. The latter has mostly been achieved using copper and optical-fibre technology, albeit supplemented with the strategic deployment of long-haul radio systems, and most recently with the increased use of 19 GHz radio systems in the junction network. The modernisation has been accompanied by a radical restructuring of the network to exploit the technical capabilities and cost structure of the newer digital technologies.

The local access network, however, remains substantially unmodernised, dominated by analogue copper pairs, and structured around unavoidable signalling and transmission constraints in a traditional local loop environment. Nevertheless, it does represent a very significant proportion of the network assets and, despite its drawbacks, it adequately and cost effectively meets the majority of needs for straightforward telephony services at this time. The integrated services digital network (ISDN) and electronic pair-gain systems will enable this embedded asset to be further exploited, while optical fibre will be increasingly deployed direct to intensive users of telecommunications.

Network development has inevitably given early priority to urban and suburban areas and, until recently, has paid less attention to the growing needs of traditional rural areas for reliable and diverse telecommunications services. Increasingly, however, individuals are moving to rural areas and expecting the same standards of telecommunications service that they enjoy in an urban environment. The growth of 'information industries' which depend on 'tele-communications rather than road or rail communications provides opportunities for regenerating rural economies, and recent initiatives[1] aim to provide rural areas with telecommunications facilities at least equal to their urban counterparts.

Unfortunately, rural environments by definition tend to be sparsely populated and served by long, often overhead, local lines which are more fault prone. Severe winds, rain, heat, pole damage from vehicles, and falling trees all take their toll on overhead line plant, as does the over enthusiastic use of shot guns to a surprising

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degree! Network growth and its precise location is difficult to forecast in such areas, and pair provision can be extremely expensive, particularly where new duct and/or cable is required.

The application of mainstream technology which has been designed and dimensioned for urban applications does not provide cost-effective solutions. What is required is the visionary application and exploitation of new technology tailored to meet specific circumstances, and this is where radio has a key role to play.

Even at a relatively high cost per line, the flexibility, speed of provision, and reduced operating costs of radio systems can prove economically attractive in a rural environment. More generally, the ready availability of radio solutions in specific locations should reduce the need for the expensive capacity buffers and spare-pair margins that conventional planning methodology provides as an insurance policy against unknown or volatile demand.

Radio systems can also be used to provide temporary or expedient service and then moved on. Temporary radio links can be established, for instance, to off-load obsolete and exhausted cables while they are recovered and replaced within existing ducts, thereby avoiding the need for new and costly excavation and duct work.

Temporary or short-term service can also be provided for special events, county fairs, or agricultural shows—not mainstream businesses perhaps, but not optional either and nonetheless costly by conventional means.

Perhaps the biggest potential benefit of radio access in the rural environment is to bypass the local exchange altogether and meet demand direct from processor node sites. In the extreme this could replace completely the smaller rural exchanges.

**Figure 1**
**19 GHz radio at Polruan remote concentrator unit**

Even restricted to growth and new service facility provision on an overlay basis, the potential savings in junction cable and duct costs warrant serious consideration, albeit that current charging and routing structures, as well as existing operational support systems, pose some constraints.

In all these applications, the provision of the infrastructure necessary to be able to deploy radio quickly, such as pre-planning, equipment in store, and the construction of radio central stations, can be likened to the advance provision of cable. Unlike cable however, the commitment is smaller, the risks of putting it in the wrong place are dramatically reduced, and the amount of excess provision over forecast demand is much less.

It is therefore important to take a wider view of the specific economics underlying the rural infrastructure. An assumption of average costs is inappropriate to the extremes of the network, and underestimates the real scope for the cost-effective application of new technology in such specialist applications.

## THE RADIO SOLUTIONS

There is a range of systems and configurations for the application of radio within the access network including:

- point-to-point systems, typically at 19 GHz;
- point-to-point 'radio multiplexers';
- point-to-multipoint systems operating around 2 GHz; and
- 'one-per-customer' systems.

### Point-to-Point Systems

19 GHz point-to-point radio systems offering capacity of 2 or 8 Mbit/s are now used extensively for effective and economic provision of MegaStream services to individual customers and to cellular network operators. Despite some initial reluctance, their application in the junction network is also now rapidly increasing to provide route growth and diversity and to avoid expensive duct and cable schemes. The equipment is extremely reliable and relatively straightforward to install and operate. Several remote concentrator units (RCUs) (and before them UAXs) in Westward and other Districts are working very satisfactorily served only by radio—typically two systems with different polarisations on the same aerial. (Figure 1.)

Not all situations provide the requisite 'line of sight' over the distances involved, but where such systems are technically suitable these can save huge sums of money compared with conventional duct schemes.

### Point-to-Point Radio Multiplexer

A further application of point-to-point radio is in combination with a customer multiplexer mounted in street furniture to, in effect, provide relief at primary cross-connection (PCP) points within the local network. This can provide multiples of 30 speech circuits for the local network, parented directly onto the processor node. These 'radio' fed local lines can be used for overcoming cable blackspots, for accessing remote communities, or for temporary or expedient requirements. More significantly they could be used to provide service quickly to unexpected commercial or residential developments which often occur at the periphery of existing exchange areas where long local lines may cause service difficulties. The radio link can be provided by 19 GHz systems using small dishes for distances of up to 10 km or 2 GHz systems employing Yagi antennas for longer distances or marginal radio paths.

All the relevant system building blocks are already available but need packaging within suitable street furniture to provide an appropriate network product.

An early installation provided service at short notice for a new hotel on the Scilly Isles. It comprised a primary multiplex (PMUX) installation, suitably modified to provide ringing conditions, and fed by a standard 19 GHz radio system. This ad hoc installation saved an estimated £70 000 compared with the alternative of providing an additional submarine cable between the off islands. It is shortly to be replaced by a proprietary multipoint radio system providing more general relief to the island complex.

More recently, East Midlands District trialled a prototype system comprising a Fulcrum BTLA 30 MUX mounted in a proprietary street cabinet and fed by 19 GHz radio. Such an arrangement has capacity for four multiplexers serving up to 120 customers. Other manufacturers have expressed interest in the concept and it is hoped shortly to have a proprietary offering available.

#### Point-to-Multipoint Systems

The operation of a point to multipoint system is illustrated in Figure 2. The system comprises a central station and a number of geographically distributed customer outstations with line-of-sight paths to this central station. The central station is generally located at or near a telephone exchange. Usually, data or digitally encoded telephony signals are time-division multiplexed (TDM) and modulated at one microwave frequency, before transmission from a wide-beamwidth sector or omni-directional antenna. Customer outstations, which are commonly pole-mounted, serve one or multiple customers via overhead or buried cable. Telephony signals from the outstations back to the central station are encoded and formatted for short-burst transmission at a second microwave frequency by using a horn or Yagi antenna. Thus, the outstations, which derive their timing reference from the continuous transmissions on the down-link (central station to outstation), access the central station in a time-division multiple-access (TDMA) mode. Transmissions in both the up-link and down-link directions are generally up to 4 Mbit/s at the system aggregate rate. The trunks or time-slots in a time frame are generally available to all customers on a demand assignment basis under the control of a signalling control time-slot. Traffic is therefore concentrated and deconcentrated at both the central station and outstations. Depending on the terrain and climatic conditions, the microwave multipoint systems have a typical range of up to 30 km.

A small proprietary multipoint radio system has been trialled successfully by Westward District, initially at Plymouth, and currently at Camelford in the rural environment of Bodmin Moor. (Figure 3.) This particular system has 15 trunks which can support up to 94 customers on a demand assignment basis. Each outstation is designed to serve a small number (typically 1–6) of customers. It is currently serving eight paying customers (without copper pair back-up) and has proved to be extremely reliable without a single fault in the three years since it was installed on the Moor. It remained serviceable throughout the early-1990 gales which brought down much line plant, and has survived

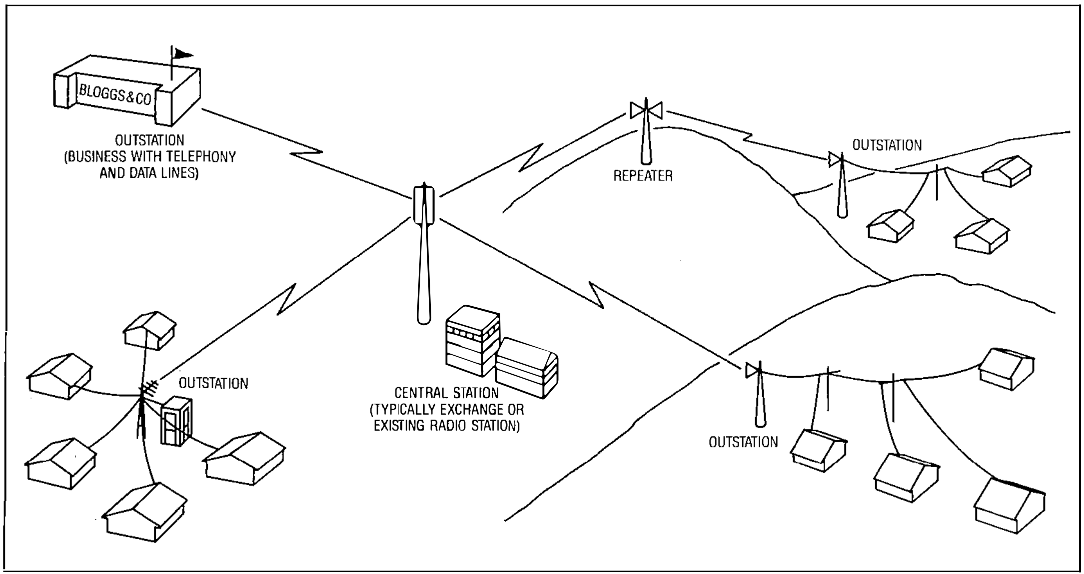


**Figure 2 Operation of point-to-multipoint system**

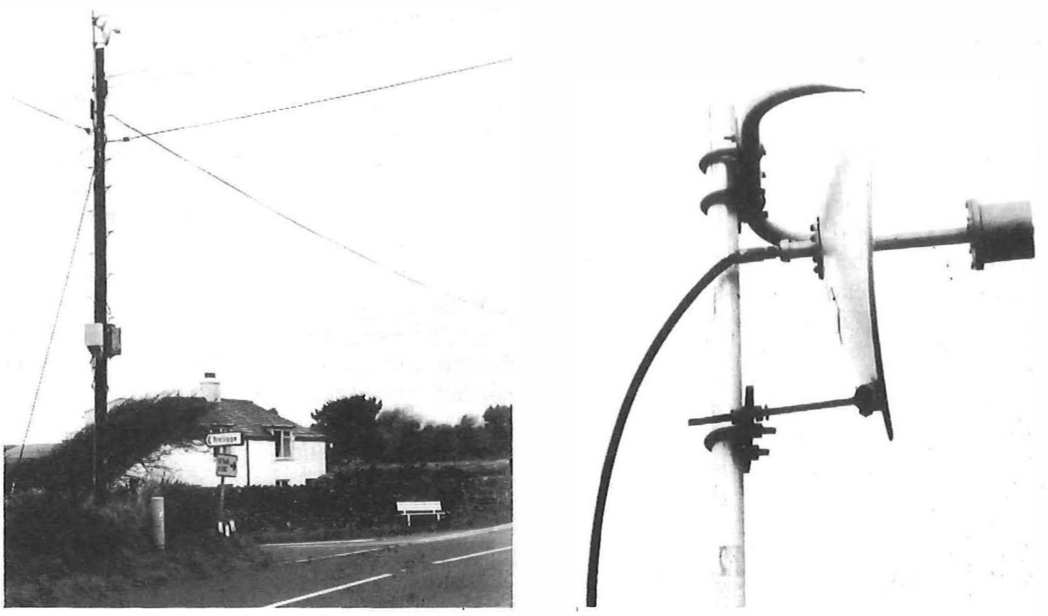

**Figure 3—Camelford multipoint system—pole-mounted outstation**

lightning storms which caused damage to other telecommunications plant in the vicinity.

A higher-capacity multipoint system with 60 trunks which can be shared by 500 or more customers has also been trialled recently in Lancs and Cumbria District. This trial tested customer perception of the service provided as well as technical and operational procedures. Although some echo was evident as a result of the TDM signal processing and frame delays, respondents were of the opinion that the service was at least as good as that previously provided over the long copper lines.

The two trials have been encouraging, and although small multipoint systems are unlikely to play a large role in terms of the numbers of customers connected, they have proved that this standard world technology has a niche role to play, as an effective tool within the local network planners' armoury. Initial studies showed that some 85% of Westward District terrain had line-of-sight access to existing radio masts and towers. Although the analysis was somewhat simplistic and did not take account of routing and charging constraints, it did lead to the concept of an overlay network which has shaped the current thinking on the practical application of radio within the District.

As a result, BT has recently signed a contract for the further supply of multipoint radio systems after commercial and technical evaluation of tender responses from world suppliers. These early systems have been cost-justified against specific local network schemes within the District, with the progressive development of an overlay capability being provided as a spin off.

## One-per-Customer Radio Systems

In contrast to multipoint systems, the one-per-customer radio system provides a fixed radio link all the way to the customer's premises avoiding the need for the last copper drop. Various systems of this sort working in the VHF band have been deployed in the network on a limited basis, mostly in specialised applications in Scotland.

Trials were carried out during 1989 and early-1990 using proprietary analogue equipment working at VHF. It was recognised that some uncertainty existed about the continued availability of the VHF band for a long-term solution. However, this did not impact on the main aim of the trials which was to gauge customers' reaction to the use of radio for providing telephone service and obtain preliminary information on the new practices and procedures that would be necessary to operate the systems in the field.

Three systems were set up in Lancs and Cumbria District, near Kendal, and a single system in Westward District, near Plymouth. All four systems were equipped with comprehensive monitoring facilities to measure performance and call patterns. The system in Westward survived the severe winter storms in January and February 1990, which damaged much of the rural network. The only attention required was a small realignment of the antenna resulting from the pole twisting in the ground due to the action of the wind!

Installation presented few problems, and antenna installation at the customer end followed domestic TV practice. No major faults directly attributable to the radio system were reported throughout the trials.

The overall conclusions from these trials were that there were no major barriers in the form of customer acceptability or working practices to the use of radio systems for the provision of basic telephony, but that further work was necessary to define and prove the feasibility of a lower-cost system that would operate in a frequency band allocated to fixed telephony service in the UK.

## ISSUES ARISING FROM THE TRIALS

### Delay and Echo

During the trials of the two multipoint systems, the signal processing delay introduced by them was measured. For the low-capacity system, the measured system delay was less than 1 ms, whereas that of the larger capacity system was 13·6 ms. Although the customers on the trial of the larger system grew accustomed to the effect of the delay, a majority nevertheless commented on the echo produced. In the UK, the vast majority of the end-to-end telephony connections in the national network have acceptable performance since the one-way delay is not permitted to exceed 23 ms. This UK planning target is sub-divided so that the delay allocation between a customer network termination point and the local exchange is 1 ms—considerably less than that measured on the larger system.

There are two possible solutions to the current dilemma: a relaxation of the delay limit for local access, or a redesign of current proprietary equipment. At present the use of standard worldwide technology is denied to UK operators.

### Pole-Mounted Equipment and Power Feed

Poles higher than 15 m require planning permission and may be required to achieve line-of-sight over difficult terrain. In some cases, small masts may be required. Planning permission can sometimes be difficult to obtain, especially in 'areas of outstanding natural beauty'. or where 'areas of special scientific interest' are concerned, although the environmental impact of a single pole or aerial is clearly less than that of a complete pole route carrying conventional aerial cable.

During the early multipoint trials, the radio equipment and the battery power supply units were both-mounted near the top of existing wooden poles. Installation and maintenance of equipment mounted in this fashion required the use of an elevating platform for ease of work and safety. Consideration of this and other factors, such as swaying poles in strong winds, and the safety aspects of feeding 240 V AC up the pole, all indicated that siting the equipment in a cabinet near the pole base would be the preferred option.

### Multipoint Network Administration

An important issue that needs consideration when providing and installing a multipoint system is to ensure that records and system administration procedures can integrate fully into the existing network and customer support activities. This is no small task with so many separate support databases in use. This is particularly important where radio customers form only a small fraction of the overall connection capacity in a given area. Repair centres need to have annotated records and procedures. Sales and marketing groups need to be aware of the existence of radio plant, particularly where it has a different facility set, and line test and maintenance diagnostic and repair procedures and responsibilities need to be clearly established. However, these issues are common to the roll-out of most examples of new technology (for example, optical fibre) in the access network and benefit can be obtained from the experience already gained with these systems.

### Network Interfaces

Interfacing radio systems with BT's network must be given careful consideration. The new local exchanges in the BT network now employ digital processing and a revised customer analogue interface. Constant-voltage (50 V) resistive loads have given way to constant-current ones with complex impedance matching. Similarly, the telephone instruments now provided for the UK market are complementary to the new exchange interface characteristics.

Correct matching at both the exchange and customer interfaces is therefore required to avoid problems with call loudness, sidetone and transmission inconsistencies.

Digital telephone exchanges offer 2 Mbit/s interfaces. Although there will be a continuing need for some time to interface to analogue exchanges, the opportunity to interface at the 2 Mbit/s level with an appropriate signalling system avoids analogue matching problems and the cost of unnecessary levels of channel translation. It also provides signalling capacity for network administration tasks such as alarm gathering, system configuration and remote line testing.

## CONCLUSIONS

This article has considered the needs and applications of three generic types of radio systems within BT's UK network. It has also outlined the results of various initiatives and trials that have been progressed jointly between BT research, network policy groups, and the field.

A major influence has been the availability of radio-frequency spectrum, particularly at a time when emphasis is being placed on increasing the availability of spectrum below 2 GHz to the mobile service. A particular consequence of this has been to preclude the many one-per-customer type of systems, currently available on the international market, from use in the UK. Due to the ubiquity of the existing means of service provision over copper, many current systems are also too expensive for use in the UK. Consequently it seems that if the needs of the single, isolated, rural customer are to be met at an economic cost, a microwave one-per-customer system must be developed. Since the market for one-per-customer systems will always be small, compared to other 'mainstream' services, it is essential that its development be allied to other, larger-scale systems.

For multipoint radio, the supply situation is more hopeful, although the need to meet the requirements of the UK network in terms of facilities, impedances, and transmission delay eliminate many promising systems currently on offer. Experience with multipoint radio is, however, very positive both in terms of customer satisfaction and feedback from BT people. This gives confidence for a modest further increase in the number of customers served by multipoint radio, and in time perhaps a national roll-out.

The use of point-to-point medium-capacity radio in conjunction with a multiplexer seems to have had the fewest problems in supply or in meeting requirements. This is not surprising since they comprise a combination of proven systems, each with a large market to fulfil in its own right. The market for medium-capacity radio systems within BT is large and any special requirements, such as remote line test and management, can be economically included. Similarly, customer multiplexers are likely to be used in increasingly large numbers and will meet UK network performance standards. The main challenge is to package these, with appropriate power equipment, in a way that is economic and environmentally rugged. It is this hybrid system that is most likely to be the first to meet all of BT's requirements.

These developments represent the crossing of a watershed in the application of radio for meeting the needs of a broad range of customers, but particularly those in the more rural and remote parts of the network.

Combinations of radio systems, multiplexers, copper lines and emerging passive optical-fibre networks offer a number of possibilities for replacing small local exchanges, junction and parts of the local access plant in an integrated manner that reflects the specific needs of the customers and network in the locality.

For a variety of reasons, fixed radio systems are unlikely ever to compete numerically with other technologies in the access network. They are, however, an invaluable tool to help meet the special requirements of those extremes of the network, particularly the rural network, suffering from high infrastructure costs and low telephone density. Provision of good-quality basic telephony services in these areas is not optional and the engineering challenge is to exploit technology in these areas to the mutual benefit of BT and its customers.

## References

The following papers have been freely referred to, and extracts included in this overview paper, for which thanks are extended to the relevant authors:


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## Biographies


John Buttle joined BT in 1967 as a student apprentice and graduated from Warwick University in 1971. John has been involved in long-term network planning and liaison on network development. He gained a Masters degree in business administration in 1976 and moved on to the newly formed Network Strategy Division. He was District Engineer, Westward District, from 1985–1991 and is currently Zone Planning Manager for Wales and West in Worldwide Networks South. John is a Fellow of the Institution of Electrical Engineers and a Member of the BIM. He is Chairman of the IBTE South Western Centre and Chairman elect of the Institution of Electrical Engineers South West Centre for 1991–92.

Peter Huish received his B.Eng. and Ph.D. degrees from the University of Sheffield in 1972 and 1980 respectively. He joined the BT Laboratories in 1972, and has worked on projects involving trunk waveguide communications, solid state microwave oscillators, microwave relay system design, and mobile radio propagation. He is currently head of the Terrestrial Radio Systems Section at BT Laboratories.

# Fibre in the Access Network

K. A. OAKLEY, R. GUYON†, and J. STERN*

*This article reports on possibly the greatest change in the 100 year history of the local line: the move from copper to fibre transport. It traces the successes that BT has already achieved along that path, discusses the problems and presents a vision for the future access network.*

## INTRODUCTION

As optical fibre is now used for virtually all growth in the core transmission network, expectation has been growing over the last few years that the 'last mile' of the local access network would be the next step.

The access network however is proving a tough challenge. Fibre has traditionally been economic in the core network because of its high capacity and long-range capability. The fact that all new circuit capacity is digital greatly assists core fibre economics. In the access network, distances are short, capacity needs are currently low (most customers have only one line) and, although the exchange end is increasingly digital, the customer end is an analogue telephone interface dating back to the last century. However, copper is increasingly expensive, has quality problems, has long lead times for service provision and cannot support future broadband services. All of these are problems that single-mode fibre can help solve.

There have been many false dawns for access fibre. There have already been major fibre successes such as London's City and Docklands fibre networks (CFN/DFN), new MegaStream provision is increasingly over fibre, and the fibre in the access network (FAN) programme to major customers will start later this year. The mass use of fibre however awaits new technology that will reduce equipment costs and increase the applicability of fibre to all customers not just a few major ones. Such technology is now in view with BT's Martlesham Heath laboratories very much in the forefront of a major international drive to get economic solutions available for *fibre into the loop* (FITL, a term widely used in North America).

Fibre will make a major impact on the access network in the 1990s, presenting a significant challenge to all those working in the access sector.

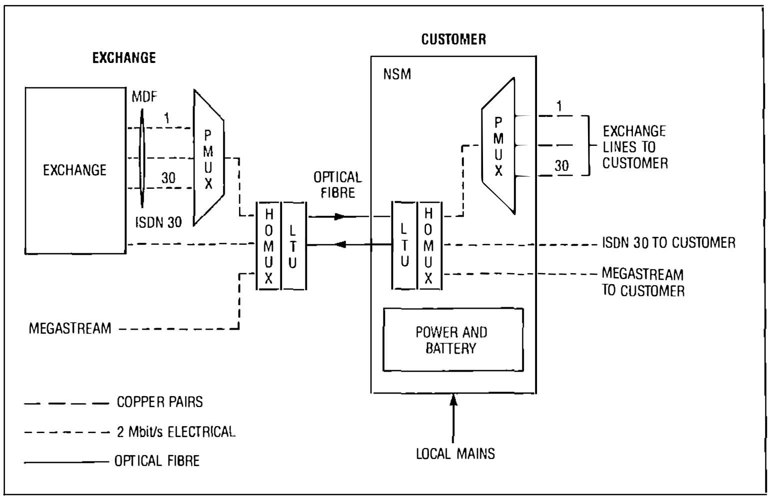
## BASIC SYSTEM DESIGN

A major difference between copper and fibre is that, while a telephone can be directly connected to a copper pair and power fed over it at the traditional 50 V, in a fibre system the pulses of light sent down the fibre need conversion to a copper pair to serve a conventional telephone. This requires a box of electronics at the customer's end and at the exchange. Power must be supplied locally at each end. However, while the capacity of a single copper pair is normally a single exchange line, or with future electronics up to perhaps 10 lines, that of a single fibre is initially hundreds of lines. With an upgrade, thousands of lines and TV channels can also be provided.

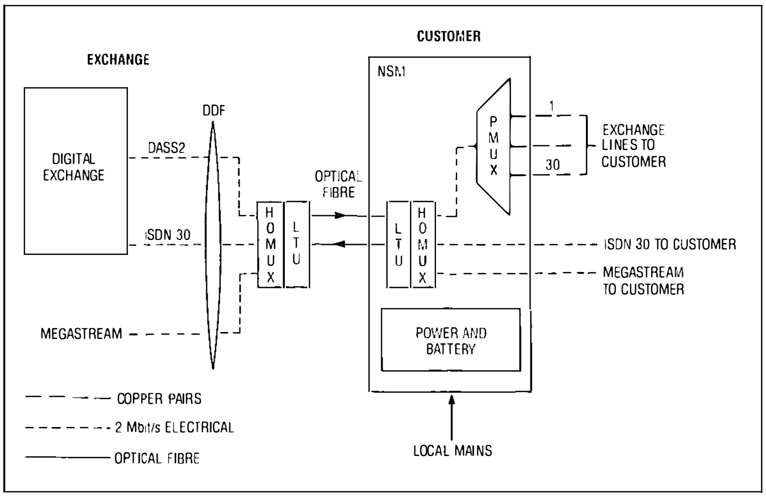
Figure 1 illustrates a typical early system, using equipment derived from junction network use. Copper pairs leaving an exchange are taken via the main distribution frame (MDF) to a primary MUX (PMUX) in the exchange. This converts the analogue signals on 30 pairs to thirty 64 kbit/s digital signals and multiplexes them up to a 2 Mbit/s signal. Four 2 Mbit/s signals are multiplexed together up to 8 Mbit/s in a higher-order MUX (HOMUX) and then passed to a line terminal unit (LTU). The LTU converts the 8 Mbit/s electrical signal to a series of light pulses on the fibre using a laser or for shorter distances a light-emitting diode (LED). Light is transmitted on one fibre and received from the distant end on another.

At the customer end, the network services module (NSM) containing an identical LTU and

**Figure 1**
**Typical early system using back-to-back multiplexers**




† BT Worldwide Networks
* BT Development and Procurement




DDF: Digital distribution frame

**Figure 2 Integrated PSTN using DASS2 interface**

HOMUX feeds 2 Mbit/s electrical signals to a PMUX. The PMUX has line cards which convert the 64 kbit/s digital signal to the familiar 50 V analogue telephony interface which can then be fed over a copper pair to the telephone. The NSM includes a local mains power supply with battery backup. By changing line cards, a variety of services such as analogue private circuits can be supported. The 2 Mbit/s bearers can be used directly to support MegaStream and ISDN 30 services.

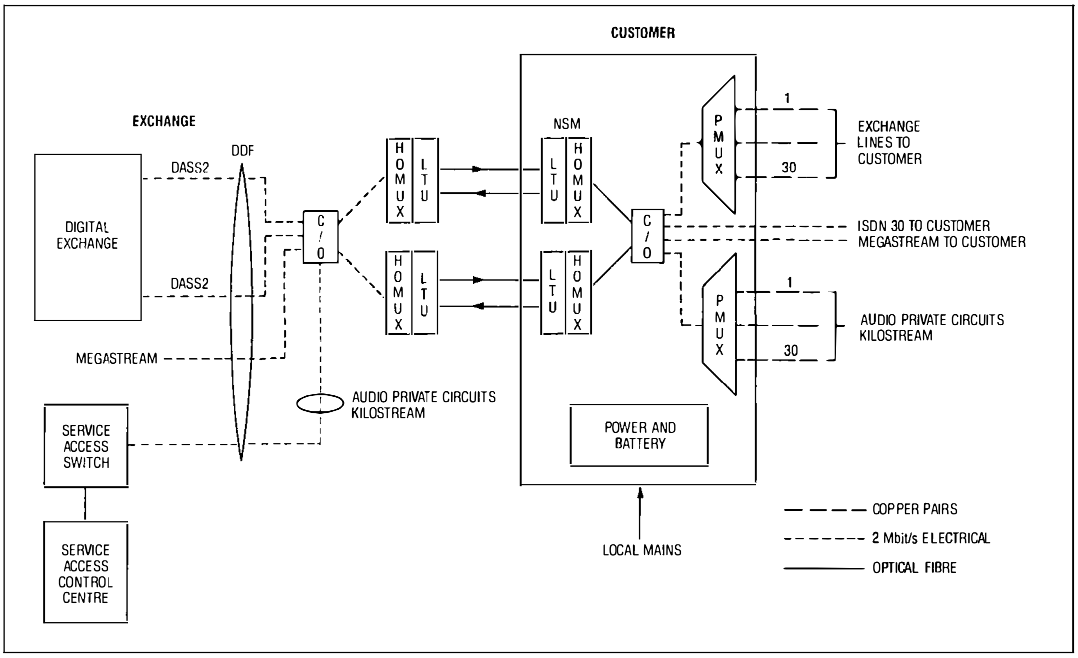
When the exchange is digital (System X or AXE10), considerable cost savings can be made. A digital exchange handles calls in the form of 64 kbit/s signals, converting them at the periphery of the exchange into analogue format using a line card. In the simple case of Figure 1 therefore, a line passes through three line cards between exchange and customer. As Figure 2 shows, only one line card is required if the exchange can output 30 lines in the form of a 2 Mbit/s electrical signal. A 2 Mbit/s interface using Digital Access Signalling System No. 2 (DASS2) common-channel signalling is now becoming available on BT's digital exchanges. It can support telephony, ISDN 2 and ISDN 30 services. The DASS2 interface is BT specified, thus allowing BT freedom to purchase transmission equipment from a variety of manufacturers independent of the exchange type. An open interface such as this is an ambition of many Telcos in Europe and the USA, but BT has one of the first to enter service.

## FLEXIBLE ACCESS SYSTEM

The flexible access system[1] (FAS) (Figure 3) represented an evolution of the basic system in Figure 2 above. To increase reliability the fibre system was duplicated using alternatively routed fibres where possible. The concept of a service access switch (SAS) was added to enable private circuits to be connected from one customer to another without expensive conversion back to analogue and connection via an MDF. A number of 2 Mbit/s bearers, each carrying up to 30 private circuits from a single customer, are fed into the SAS which then provides digital cross-connection between circuits at 64 kbit/s. Thus, instead of by the traditional MDF jumper wire, private circuits can be routed electronically via a computer system under the control of staff in the service access control centre (SACC).

During the late-1980s, BT planned an extensive programme to use the FAS system to serve major customers (typically over 50 exchange lines). Although the design owes its origins to trunk and junction equipment, considerable development was needed to reduce the cost to a point where it was economically attractive. To recover that research and development, manu-

**Figure 3 Flexible access system**




C/O: 1-for-1 protection switch

facturers required commitment to large volume purchases. BT began to have worries about the size of the capital investment programme needed and decided that it was not the right time to make a commitment to that approach when technology internationally was changing rapidly. The FAS concept does however live on in the form of the CFN/DFN and the FAN programme.

## CITY AND DOCKLANDS FIBRE NETWORKS

Stimulated by the advent of the Stock Exchange's 'Big Bang', the City Fibre Network and Docklands Fibre Network were created to meet the increasing demand for the provision and rearrangement of private circuits within the City and Docklands areas of London. The primary requirements of both system designs were

(*a*) that they support the full range of electrical interfaces traditionally supported by the DealerInterlink service over the copper access network, and

(*b*) that they were capable of accommodating the high level of churn endemic to the financial sector.

The traditional FAS architecture (Figure 3) described earlier was selected. Point-to-point optical line systems provide secure, duplicated access to the serving sites where access to the core network or one of the network's eight SASs is provided.

In all there are four serving sites with a potential capacity of over a quarter of a million private circuit ends and 60 000 public switched telephone network (PSTN) accesses.

The network has been introduced in phases with each award of contract having been made as a result of separate competitive tendering exercises. The initial two phases were entitled *City Fibre Network Phase 1 and 2* (CFN1 and CFN2), while the third and fourth phases were given the names *Docklands Fibre Network* (DFN) and *Canary Wharf*. Currently, analogue PSTN is only supported by DFN and Canary Wharf.

Today the network is providing more than 20 000 channel-ends to several hundred customer sites featuring services such as audio private circuits, MegaStream, ISDN 30, KiloStream and international 2 Mbit/s links.

As for the future, planning has now started on a scheme to enable the deployment of systems across other areas of London. This has been made possible following the start of the installation of a fibre infrastructure in the access network in London, initially focused on meeting future demand for 2 Mbit/s services. It will support both current and future fibre access technologies. The fibre access equipment will be deployed from customer sites to the serving exchange with the potential to link into existing CFN and DFN networks. The equipment will be deployed against criteria designed to maximise the benefits for both the access network and customers; thus these systems will be targeted on high 2 Mbit/s (ISDN 30/MegaStream) and private circuit users. The size and modularity of the current equipment means that it will be deployed in the larger sites, those with several 2 Mbit/s services in particular greenfield sites. As new technology becomes available the range of products and services will be extended.

## MEGASTREAM

The MegaStream service is currently provided using standard junction transmission equipment. Network terminating units are sited at each end of the serving section to provide the alarm and test functions required by the MegaStream maintenance duty at the XStream service centre (XSC). Additional equipment is provided to transport the alarms over either an auxiliary data channel or private circuit. The ISDN 30 service is delivered using the MegaStream equipment but it is specially configured to relay the alarm reports to the repair service centre (RSC) instead of the XSC.

Currently, 50% of all MegaStream growth is provided over fibre systems. The 4 $\times$ 2 Mbit/s system is, by far, the most popular delivery mechanism for fibre MegaStream. The number of sites demanding large numbers of MegaStream circuits is steadily increasing and this is resulting in more frequent deployment of 16 $\times$ 2 Mbit/s systems. The use of transverse-screen copper cable is now restricted to single MegaStream circuit customers, and fibre is used for most new sites. Thus fibre is accounting for a steadily increasing slice of the whole market.

Of late, the benefits of creating a generic 2 Mbit/s delivery mechanism with a single, fully specified alarm interface has become apparent. Work is currently under way to define the system architecture and the level of functionality required in the line system and NTU. The generic system will use the transmission network surveillance system (TNS) for the collection and processing of alarms and performance information for the 2 Mbit/s bearer and the service specific information. TNS will also provide control of the loop-back facility resident in the NTUs.

## INDIVIDUAL FIBRE SCHEMES (IFSs)

*Individual fibre schemes* (IFSs) comprise a variety of different transmission systems and primary multiplexers. By far the most common variant is the back-to-back (Figure 1) connection of PMUX, employing integrated optical transmission equipment, delivering PSTN and analogue private circuits. Most of these installations site the customer-end PMUXs in environmentally-friendly communications rooms but a 'street-hardened' version has been trialled in Manchester with great success.

IFSs are expedient systems designed to meet localised, unforeseen demand. Only when these schemes are considered economic or necessary for technical reasons are they approved. Because of their low penetration and 'special' status, IFSs survive operationally without the considerable backup organisation and procedural changes necessary to accommodate large-scale roll-out programmes such as FAN.

## FIBRE IN THE ACCESS NETWORK (FAN)

Fibre in the access network (FAN) is a programme of phased fibre equipment deployment into the access network. The current architecture for FAN is, basically, as shown in Figure 2, but with the additional capability of supporting a range of services through a variety of remotely sited primary multiplexers.

Primary multiplexers using DASS2 signalling are linked to the digital local exchange (DLE) by optical transmission systems to provide PSTN. Access to the DLE is at the primary rate and this removes the need for the analogue line cards at the exchange. Capacity at 2 Mbit/s is also provided over FAN enabling the delivery of MegaStream and ISDN 30. By employing the appropriate primary multiplexers in the network services module (NSM) and/or at the customer's site, analogue private circuits and KiloStream Plus can also be supported.

The procurement of the first tranche of FAN equipment has been based on a 'bottom up' approach to the economic modelling, potential customer sites having been identified through a strategic marketing approach.

Approval for a trial of the 'first tranche' FAN equipment has been obtained. The trial will take place in Severnside and London, beginning July 1991. Roll-out of FAN equipment is planned to start late-1991.

## TELEPHONY OVER A PASSIVE OPTICAL NETWORK

A key problem with the early systems above is that they are only economically suitable for large customers. Since smaller customers are still served via copper, both fibre and new copper cables have to be provided in parallel to a growth area with therefore little saving in cable or duct costs. If all sizes of customer, and all services, can be provided over fibre, there is a significant snowball effect on cost savings in cables and ducts.

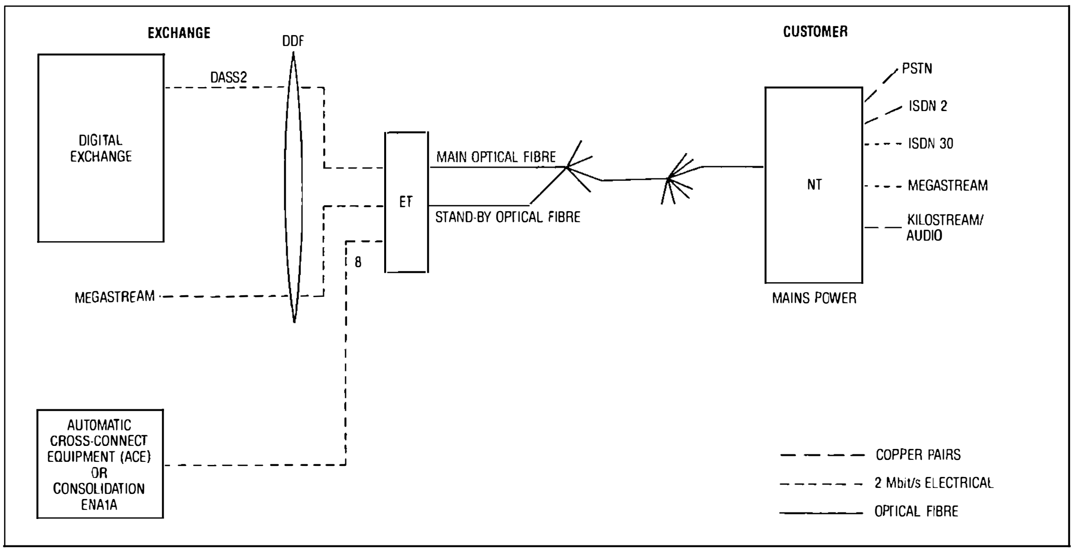
Another problem is that of high LTU and HOMUX costs, which, although acceptable when shared over the 100 lines of a major customer, become very expensive when the same fixed equipment cost is divided over only say 10 lines. Similarly, the use of four dedicated fibres from exchange to customer becomes expensive when that cost is shared over only 10 lines.

BT researchers at Martlesham Heath have produced what is now widely anticipated to be a solution to this problem in the next few years. BT's telephony over a passive optical network (TPON) system (Figure 4) features a single fibre from the exchange that is split at the cabinet into say four fibres and then each fibre is split again into say eight more fibres. The resulting 32 fibres can serve 32 individual customers. Such a fibre network is now referred to internationally as a *passive optical network* (PON). Network terminals (NTs) on the end of each fibre feature new-generation low-cost opto-electronics (lasers and receivers) and synchronous higher-order multiplexing to reduce dramatically the cost and size of the LTU/HOMUX function. The use of splitters to enable a single exchange-side fibre to serve several customers reduces both fibre and exchange LTU costs. Unlike earlier systems, TPON is likely to be a duplex system using the same fibre for both directions of transmission rather than two separate fibres. This issue is still under study.

The NT could take several forms:

*Business TPON* For business applications, it would be a small briefcase-sized wall-mounted

**Figure 4 Telephony over a passive optical network**



box providing 4–30 lines on the customer premises with power supplied by the customer. It could be fitted in the basement of a large building as with FAN or small units could be dispersed around the customer's premises to deliver services directly. In the latter case, a pencil-sized splitter in the customer's basement would collect and distribute signals from each of the units to a single D-side fibre.

*Street TPON* For residential customers, a similar multi-line unit fitted in an underground joint box at the distribution point (DP) would provide service to a number of customers over conventional copper drops. A range of power supply methods are being researched including power-feeding several DP-located units from a power supply cabinet or backfeeding power from one or more customers.

*House TPON* In this form, the NT is a small box about the size of a double power socket mounted on the customer's premises. It is locally powered from the customers mains. A splitter is used at the DP to serve say eight houses from a single D-side fibre. Today's high opto-electronics costs mean that street TPON is likely to be used initially because those costs are shared over a number of lines. House TPON will probably not be economic unless there is a market for broadband to help carry the extra cost.

### Time-Slot Routing Features

The TPON system accepts up to eight 2 Mbit/s streams from a digital exchange (using DASS2 signalling) or from special services such as the KiloStream network. They are converted into 240 64 kbit/s time-slots broadcast over the fibre PON to up to 32 NTs. Each NT is instructed which time-slots to select by a network management centre, via a discrete housekeeping data link over the fibre. The NT transmits back to the exchange terminal (ET) using time-division multiple access (TDMA). This technique features the sending of bursts of data from the NT which are timed so that the converging bursts passively interleave at the cabinet and DP splitters. Another inbuilt feature of the TDMA bit transport system (BTS) is that each of the time-slots can be freely allocated to any NT. Thus traffic for a particular service, say KiloStream, can be groomed from a number of NTs and consolidated into a single 2 Mbit/s stream from the ET into the automatic cross-connection equipment (ACE) network. This offers considerable benefits over earlier systems which incur high costs by taking traffic from only one customer and often under-utilised exchange or ACE ports.

### Maintenance Features

The TDMA approach involves measuring the time of flight of the light pulses and thus the ET–NT distance accurate to about 1 m in 20 km, as well as measuring the optical loss to ± 1 dB. As this process is automatically carried out on installation of each NT and several times per second subsequently, it provides a very useful acceptance test and subsequent early warning of service failure as well as a means of locating some faults. The housekeeping data link from each NT can also be used to pass various alarms and test loop-back commands and to control a simple test head which can test the copper drop.

In order to improve reliability, the ET and the exchange-side fibre to the cabinet splitter are duplicated (Figure 4). This is achieved by connecting a stand-by exchange-side fibre (routed over an alternative cable if feasible) from a spare splitter outlet back to a stand-by ET. In the event of ET failure, the 2 Mbit/s interfaces are switched automatically to the stand-by ET. Since the ET is shared by 240 lines, the cost implication is minimal. Each NT serves a maximum of 30 lines and is thus not normally duplicated. Larger customers are served by multiple NTs.

A key concern in the past has been to keep track of equipment; for example, where it is installed, the capacity available for particular services and occasionally tracking down a particular mark of card to facilitate its replacement because of a known defect. It is intended that the production TPON system will include a remote inventory system that will enable staff at the network management centre to discover instantly the type of cards fitted in a particular customer's NT and their serial numbers.

## BROADBAND OVER A PASSIVE OPTICAL NETWORK (BPON)

The TPON system operates at a wavelength (or colour of light) of 1310 nm. By adding other wavelengths, it is possible to add a wide range of new services in future simply by adding terminal equipment to specific customers without the need to lay more fibre cables[2] (Figure 5). These broadband services could be entertainment services such as cable television, although under current Government proposals BT will not be able to enter this market for up to 10 years,

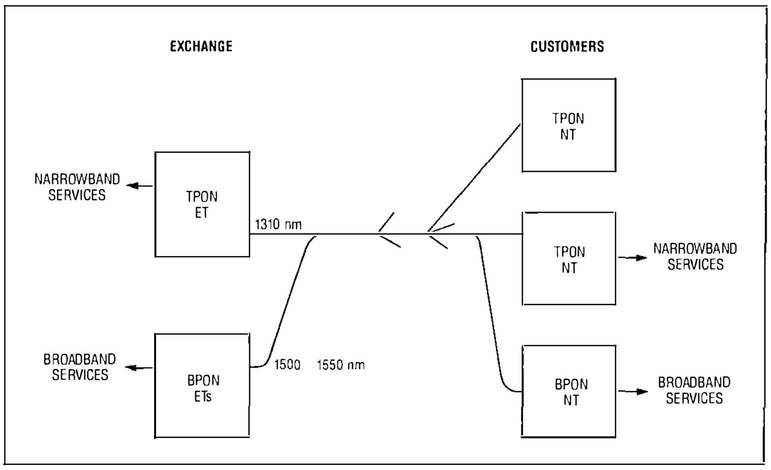



**Figure 5**
**Broadband over a passive optical network**

or they could be business services such as high-bit-rate data, video-conferencing or video telephony.

Several different modulation techniques have been demonstrated over a PON fibre architecture. One approach is to use a different electrical frequency (all on a single optical wavelength) to and from each subscriber. This frequency-division multiplexing (FDM) approach has the benefit that many different types of signal and bit rates can be used. One early system offers sixteen 2 Mbit/s paths, each 2 Mbit/s modulating a different frequency. Bit rates not meeting the CCITT standard, such as typical local area network (LAN) rates of 10 Mbit/s, can also be transported; this gives a convenient and cost-effective network alternative to specially laid cables from customer to customer.

Another modulation scheme uses TDMA at 150 Mbit/s, rather than 20 Mbit/s with TPON, to offer high-bit-rate asynchronous transfer mode (ATM) services to data customers. The APON system (ATM over a PON[3]) would allow customers who want to send a burst of data of anywhere between 0 and 150 Mbit/s to access instantly that amount of capacity from the network just for the period they require it, rather like packet switching.

More futuristic upgrades include the use of high-density wavelength-division multiplexing (WDM). Techniques are available now to use say 4–5 wavelengths in the 1300 nm and 1500 nm optical windows with a spacing of 20 nm between wavelengths.

Research has shown however that over 30 wavelengths could be added at 1 nm spacing using tuned laser transmitters and electronically tunable optical receivers[4]. Thus each customer on a 32-way split network could send and receive his/her own wavelength. Each wavelength could support up to say 2·4 Gbit/s although in practice a realistic application in the late-1990s is more likely to be a 150–600 Mbit/s broadband ISDN (BISDN) service.

Optical-loss consideration restricts the number of ways a fibre can be split: each 2-way split introduces 3·5 dB of loss. However, erbium fibre optical amplifiers now offer the prospect of a simple-to-use device which greatly increases potential split rates. One 'hero' experiment has already demonstrated the transmission of 384 high-quality digital TV channels by using 2·4 Gbit/s on each of 10 wavelengths from a single source to 39 million customers using just two amplifiers. The key significance of amplifier technology is that in the early days of a speculative new broadband service it allows the service to be offered to customers on many existing PONs for a low initial cost. Most costs are in the customer's NT and thus only incurred on demand.

Advanced optical technology thus offers the prospect of a wide variety of broadband services that can be economically added to an already installed PON network.

## INTERNATIONAL PERSPECTIVE

Internationally, BT is in the forefront of the fibre-in-the-loop revolution. It is believed that the 15 000 fibres terminated on Baynard House in the City of London are a world record for any single exchange. A number of countries use FAS-type technology in a small way, usually to very large customers. Some use fibres to street multiplexers with copper drops of 500 m–1 km to the customer. The US in particular has around 10 million lines fed over digital loop carrier systems, many served over fibre links between the exchange and the remote multiplexer site. However, because of the longer overall length of the local loop in the US, the remote multiplexer site (often up to 4000 lines and underground) still has a copper distribution network beyond it of up to 4 km in length. The US remote multiplexer site is therefore often where the local exchange is situated in the UK (and Europe).

World interest in using fibre in the access network is growing rapidly. BT has been actively promoting the passive optical network concept besides other telephone companies and leading international manufacturers in the interests of gaining rapid consensus on a common approach. Although systems may vary locally, commonality in certain key components such as splitters, lasers and optical receivers will lead to low costs for all Telcos. This approach has been very successful, with Telcos in the US, Europe, Japan, Australia and New Zealand now conducting research and development, producing specifications and setting up trials. The Deutsche Bundespost anticipates that the new access network being built as part of the overall national infrastructure programme in East Germany will be fibre rather than copper based from the outset.

## BISHOP'S STORTFORD TRIAL

A trial of business, street and house TPON is being conducted at Bishop's Stortford in East Anglia[5,6]. The trial is intended to demonstrate the technology and investigate a number of practical issues. It uses fibre to support both telephony and 16–18 channels of cable television, the latter using a simple FDM approach based on the use of standard off-the-shelf satellite-TV set-top boxes[7]. A special 2 year trial licence has been granted by the Government to allow BT to provide CATV over its main network. At the time of writing, two house TPON lines are in service at the specially built BT show house with actual residential customers expected to be connected by mid-1991.

The trial also features an alternative technology to TPON: broadband integrated distributed star (BIDS). In this approach, active electronics are used in the street in lieu of splitters to multiplex signals to and from several customers onto a single exchange-side fibre. This approach is not favoured in the long term because of its higher cost and the physical size of the cabinets used for the electronics.

## FORECASTING THE FUTURE

A major concern facing BT is that it is continuing to invest record sums in a copper access network to meet today's narrowband demand while the future may lay in providing broadband services which need fibre.

All telecommunications investments are driven by forecasts of future demand particularly in the access network where major new copper cables can take up to 18 months to plan, provide duct, and lay and joint cables. Forecasts have historically never been accurate, particularly at the cabinet or DP level where unforeseen local events often weigh more strongly than national trends. In the future, a number of factors will combine to make forecasts even more unreliable, notably:

(*a*) As the network reaches saturation (that is, virtually all households have a telephone), residential growth becomes mostly demand for second and third lines. Predicting just who will ask for such lines is very difficult.

(*b*) The effects of network competition.

(*c*) Migration of businesses to ISDN 2, which provides effectively two lines over a single copper pair.

(*d*) Migration of larger customers to ISDN 30 (2 Mbit/s), which requires fibre rather than its equivalent 30 exchange lines that would have been fed over 30 copper pairs.

BT's objective is to meet service on demand. In a copper environment with 18 month lead times, spare capacity must be available at the point of sale (the DP). The alternative is expedient pair provision or diversion on demand which generally is extremely costly. BT is therefore caught between expensive speculative initial investment in pair capacity or expensive expedient provision.

## FUTURE VISION

The solution may lie in the use of fibre and pair-gain over copper. Unlike copper, where most of the cost is in a fixed initial cable investment, fibre schemes have only around 20% of the eventual network cost in the fixed fibre cable and duct: 80% is in the terminal equipment. The aim must be to provide only just the right amount of terminal equipment to meet customers' immediate needs and to be able to increase or change it within a few hours or days on request from the customer.

Most service provision would therefore become a simple task of remote commissioning and testing a pre-provided line card from a customer service system (CSS) VDU many miles away or of dispatching staff to the customer to fit another line card or extension box on the wall. With careful design and organisation both could become simple, rapid tasks. Diverting cables, chasing spare pairs, with all its knock-on fault liabilities, would become a thing of the past.

The future network vision therefore is a network where exchange side growth by large copper cables has ceased and is replaced by a steadily growing thin veneer of fibre to cabinet locations and, hence, onto business customers and some greenfield residential situations. Exchange-side fundamental schemes that today speculatively place multiples of 100 pairs to exhausted cabinets (or cabinets passed by which exhaust in the next few years) might in future place two fibres in lieu of each 100 pairs at the cabinet location. In cabinet (and E/O) areas serving business growth, these fibres would be extended to business customers and their new growth taken up via fibre. In cabinet areas with primarily residential growth, the first option would be to extend fibre to existing businesses, converting them to fibre and using the pairs made spare to satisfy residential growth. Alternatively, street TPON or electronic pair-gain equipment[8] fed over existing copper pairs can be used.

Such a concept would aim

(*a*) to maximise the use of existing copper spare pair capacity,

(*b*) to limit speculative fixed investment,

(*c*) to focus growth progressively, particularly business, onto fibre systems, and

(*d*) to build up a fibre infrastructure for new broadband services.

Fibre will not replace copper in the next few years: the issue is to get the right balance between the two. The best of both technologies can be obtained by fully utilising the existing copper investment for the bulk of the embedded network, and deploying fibre for growth and areas where most change is likely, such as businesses.

### Fibre Ready

Full implementation of the vision above is 3–4 years away, but there are steps that can be taken now to ready the network for fibre. One approach is to build up the provision of fibre spine cables (up to 96 fibres) in the exchange side. These can be justified today for the provision of 2 Mbit/s, but a key aspect is to ensure that they are sensibly dimensioned for future needs rather than just the immediate demands of perhaps a single customer. Another approach is to ensure that copper distribution-side cables being provided now allow for future installation of fibre. One method being researched is the inclusion of a small plastic tube (say 5 mm diameter) in the centre of all new distribution-side cables of perhaps 20–100 pairs. This would facilitate the easy subsequent blowing in of a bundle of up to eight single-mode fibres[9]. The use of tubing rather than actually providing fibres from the outset reduces cost, minimises the need to immediately retrain and expensively re-equip today's copper jointing staff, and reduces extra on-site installation time to a minimum. It allows most costs and decisions on fibre layout, position of splices, splitters etc. to be deferred until needed.

### Challenges

Many challenges must be faced before the vision can be delivered:

(*a*) Equipment must be developed and manufactured that is low cost yet meets the exacting performance targets required in the access network.

(*b*) Field operations and maintenance techniques and equipment must be developed for fibre that transforms today's highly skilled task requiring expensive equipment into an everyday task for non-specialists for whom fibre will be only a part of the job. Low-cost fibre splicing, test aids, automatic fibre identification and remote test equipment are all under development.

(*c*) Network management computer systems and procedures need to be developed to facilitate the remote hands-off service provision maintenance and fault reporting features inherent in TPON. The order taking and fault reporting (151) functions provided by the CSS computer system need enhancing to accommodate fibre. A small-scale trial to investigate network management issues is currently underway in Manchester.

Management processes need developing and culture changes are needed to facilitate the move from the 'I must have capacity in hand' approach of today's copper pair to the 'just in time' approach of tomorrow's electronics.

## CONCLUSIONS

The deployment of fibre in the access network can help BT to address its problems with the copper network:

Currently, BT has a range of solutions for direct fibres to business customers and, in the longer term, PONs will supplement these for business and residential customers alike.

By focusing costs on equipment installed on a just-in-time basis rather than on long-lead-time speculative copper cable capacity, BT can reduce costs and match expenditure more accurately to demand.

That same just-in-time approach coupled with advanced network management and hands off service provision can allow BT to meet customers' rapid service provision needs.

The self-monitoring ability of electronic systems with the optional facility to duplicate parts of the network, together with a reduction in expedient work causing 'hands on' faults on the copper network should enable BT to improve its quality of service.

Finally, it has been shown that fibre has an almost infinite capacity for future new broadband services.

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### Biographies


Keith Oakley joined the then British Post Office as a Trainee Technician Apprentice in the London Telecommunications Region South West Area in 1967. He has spent most of his career in Headquarters posts dealing with various aspects of the access network inluding planning and works procedures, pair gain and local line amplifier equipment. For the past 5 years, he has led a section dealing with the introduction of fibre into the access network including the role of BTUK project manager for the TPON research and development project. Under Project Sovereign he has moved to access network strategy in Worldwide Networks and is currently working with Colin Shurrock on a major review of access strategy.

Ray Guyon joined the Post Office in 1974 as a Trainee Technician Apprentice in London's West Area specialising in Strowger exchange maintenance. In 1979, having obtained a Full Technological Certificate, he moved to the research laboratories at Alperton, where his work focused on the development of carrier-based transmission systems for the access network. Since 1984, he has been involved in the specification and implementation of fibre-based networks including CFN, FAS, FAN and TPON.

Jeff Stern joined BT Laboratories in 1966 and has since worked on a broad range of topics in the field of optical communications. During the period 1986–1989, he led and coordinated the feasibility phase of the TPON programme at BT Laboratories. Currently, he is Section Manager of Fibre Access Technology and has particular responsibilities for coordinating longer-term local access research and development programmes and for international liaison.

# The United Kingdom Trial of Fibre in the Loop

C. E. HOPPITT, and J. W. D. RAWSON†

*Deployment of a UK trial of fibre to the home is now well advanced. This article describes the aims of the trial, taking place in Bishop's Stortford, Hertfordshire, the equipment and some of the results to date.*

## INTRODUCTION

The application of optical technology to the local network has been a field of increasing interest and debate over the past few years[1]. It is usually assumed that optical networks will penetrate to small businesses and residential customers in order to provide a broadband bearer for services such as cable television and video telephony. Revenue from such new broadband services is a major motivation for installing optical fibre, but the uptake is uncertain and networks optimised for television distribution can be very expensive if initially providing mainly telephone service.

What is required is an entry strategy that enables optical technology to be installed in a way that is reasonably economic for telephony but readily allows a progressive upgrade to the less certain broadband services, thus obtaining the best of both worlds. The traditional approach to fibre provision is a direct copy of the copper network and based upon a big star; this approach has been successfully used in BT's FAS (flexible access system[2]), aimed at the large business user, where the high cost of optical components is shared across many 64 kbit/s circuits. Such cost sharing is not so effective for the smaller business and not possible for the single-line residential user. Several proposals have been made based upon the use of electronics at a node or nodes in the local access network at least to share costs over a portion of the link; this is particularly effective in the short and medium term but does not fully address the need to deliver fibre to the home in preparation for the provision of broadband services.

BT is currently engaged in a massive investment programme to upgrade copper cable and plant, such as fibre, between the exchange and customer in its drive to improve network availability and quality. Any measures which can bring forward new plant which has a measure of future-proofing, while being operationally compatible with the remainder of BT's network, must be seized. Back in 1988 there was no obvious solution to these problems, and no obvious choice of fibre architecture. It was clear that the only way to identify the right future strategy was to trial various systems; in particular, the more radical ideas from within BT on passive optical networks[3]. The decision to proceed with a trial also coincided with the publication of the Advisory Council on Science and Technology (ACOST) report to the UK cabinet office encouraging operators to stage trials of multi-service optical local networks.

Trials were being held elsewhere, in particular in North America, but a trial in the UK was deemed essential in view of the UK's different regulatory regime and network structure, even if the full information from other trials was available, which was not always the case. Also, none of the then existing or planned trials took into account passive optical networks.

## BACKGROUND TO THE TRIAL

### Objectives of the Trial

To obtain the information required, the following objectives were set for a trial:

- to demonstrate the technical feasibility of using optical fibres in the local loop for single-line telephony customers, and, in particular, to demonstrate that passive optical networks can be practical in the field;
- to allow comparison of active and passive architectures with regard to cost, technical performance and ease of operation;
- to give experience in the practical operational aspects of the optical local network, including installation, moving of customers, reliability, maintenance and network control;
- to provide experience to allow projection of procurement and operational costs with greater confidence than at present; and
- to give BT first-hand knowledge to allow full participation in the world debate on topologies, technologies and standards for optical local networks.

### Location

It was considered important that the trial should take place in an area which represented a mix of housing of different types and ages typical of the UK. Unlike most of the foreign trials it was

† BT Development and Procurement

not aimed at green-field sites and it was not aimed at wealthy multi-line households.

The trial area needed to meet the following requirements:

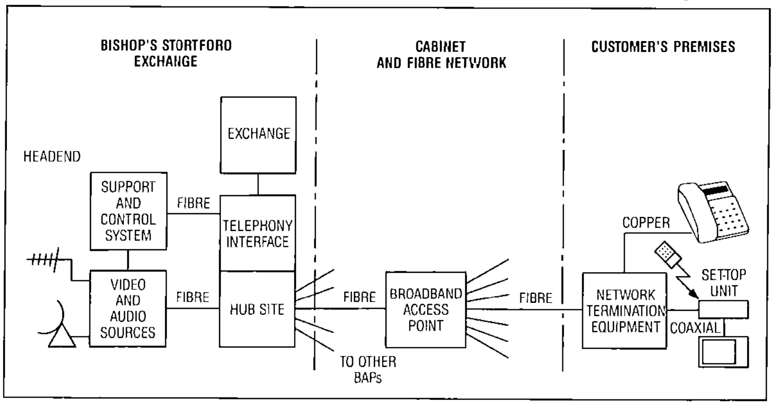
- A suitable mixture of different types of housing and methods of providing service; for example, via overhead and via underground for the final link to the customers' premises.
- Customers to be entirely serviced by a digital exchange and the exchange must be equipped with an advanced version of the DASS2 signalling system in time for the trials.
- Adequate accommodation and resources to be made available by the BT District.
- The trial site to be outside any existing or proposed cable TV franchise areas.
- The site needed to be easily accessible from BT Laboratories at Martlesham Heath and from London, BT Laboratories being responsible for the detailed integration and engineering of the trial and Network Systems Engineering and Technology Department, based in London, responsible for the planning, installation and maintenance of the systems.

After considering a number of sites, Bishop's Stortford was chosen. Bishop's Stortford is a small self-contained town of some 12 000 houses. It is about 50 km from London on the M11 motorway and on the London–Cambridge rail line. It is within 8 km of Stansted Airport, currently being expanded to become London's third international airport. The exchange is in the centre of the town directly adjacent to the railway station. It became fully digital using System X in March 1989. The good national and international links were important because of the great interest stimulated by the trial, both from within the UK and from abroad.

Several housing estates were identified as suitable, radiating outward from the telephone exchange in various directions. Within these estates there was the required mixture of modern and older property with the local feeds being overhead or directly buried underground. There is very little duct which extends all the way to the customers' premises.

If required, there were green-field housing estates existing on the edge of the town. There was also suitable space for the satellite antennas for the cable-TV headend on the exchange roof.

**Figure 1**
**BIDS architecture**




### Services

The trial will demonstrate the provision of a variety of telecommunication services over an integrated network. The basic service package is as follows:

*Telephony* One circuit will be provided to each customer.

*Broadcast TV* At least 16 broadcast channels will be provided (this is a commercial limit and not a technical limit).

*Stereo Audio* 12–16 high-quality stereo channels will be provided to a selection of customers.

*Videotex* Certain broadband customers will have access to a local information server and gateway access to Prestel-like text services without requiring adapters for their TV sets.

### Customers

The involvement of typical customers is an important feature of the trial, but customers in the selected location cannot be obliged to participate. Therefore, every care has been taken to ensure a positive response from customers. Participating customers will retain a copper line to the exchange as a stand-by and telephony service will be returned to the copper after removal of the trial equipment at the end of 1992.

The trial is not seen as a marketing exercise since the commercial conditions will be totally unrepresentative. However, the demand for, and acceptability of, the various services may provide useful information for future system definition. Consideration has been given to the design of the equipment that will be located on the customers' premises to ensure that, as far as possible, it is of an acceptable size and style, while allowing access for maintenance purposes, provision of a mains power supply and minimising disruption to interior decor.

In total, several hundred customers will be connected to the trial on the various systems described later in this article.

## NETWORKS

Two different optical networks are being trialled. Optical local systems are classed as either *active* or *passive* depending on whether there are any active electronics between the exchange and the customers' premises. Each offers a range of different advantages. While most worldwide interest has, until recently, been on active systems, there is now a growing interest in passive networks.

### Switched Star Networks

BT's active star network is known as *broadband integrated distributed star* (BIDS)[4] and is illustrated in Figure 1. The architecture is basically of star form (with a number of feeders radiating from the headend) and it has switching at the

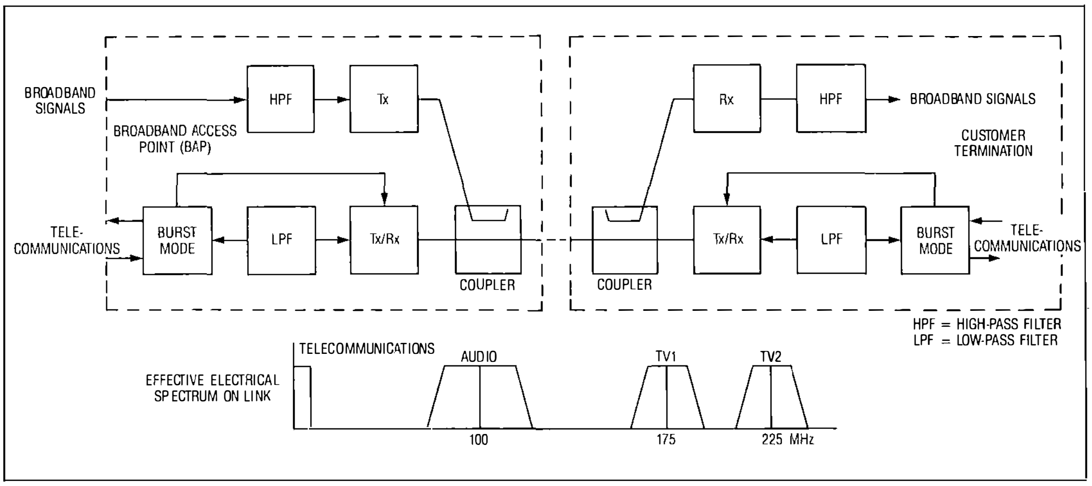



**Figure 2**
**BIDS optical secondary link**

broadband access point (BAP) so that each customer only receives the broadband channels that he/she requests. The BIDS network is based heavily on the BT design of switched star network (SSN) used for the Westminster Cable TV franchise area, but the design has been modified to allow the provision of telephony and to use single-mode fibre right up to the customer's premises. This type of system is best suited to situations where a full integrated service is to be introduced with high penetration of broadband service from the start.

Broadband signals from the headend are transmitted to the hub site (usually the local exchange) from whence they are broadcast to a number of BAPs. Each BAP is served by four fibres to carry video, telephony, stereo audio and control functions. For the trial a single BAP capable of serving more than 100 customers is used. The two video fibres carry a total of 18 TV channels using analogue frequency modulation and an additional fibre carries stereo audio. Telephony is carried from the exchange to the BAP using digital transmission on separate fibres.

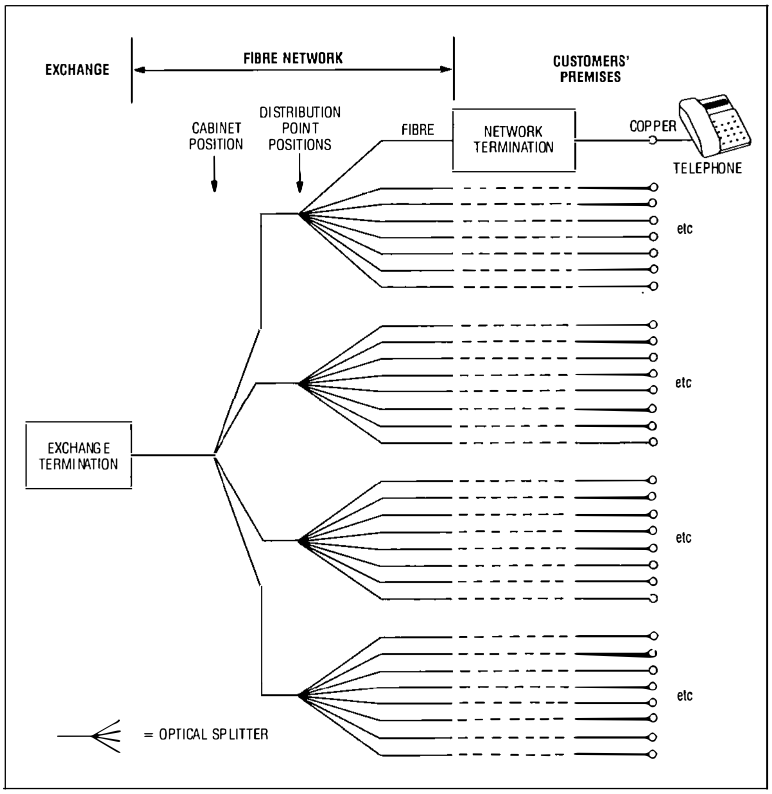
In the BAP, telephony for the individual customers is demultiplexed and the TV channels enter a switch of 48-channel capability. Each customer is provided with a fibre link from the BAP over which he/she receives telephony and two selected TV channels. The customer selects programmes for each channel by sending commands to the BAP from an infra-red keypad via the TV set-top unit. A subset of customers can also select a single stereo audio channel from a multiplex of 16 channels delivered to the home.

An essential requirement for BIDS is a potentially low-cost link from BAP to customer. The trial system uses burst-mode transmission with a single optical transceiver alternately acting as transmitter and receiver. This economises on fibre, fibre handling and opto-electronic devices. Figure 2 shows the optical secondary link complete with broadband transmitter, optical coupler and high-pass filter for the unidirectional cable TV signal. The figure also shows the electrical spectrum on the secondary link in which the lowest part is for telephony and control, while the selected TV transmissions are at 175 and 225 MHz in FM format. The narrowband and broadband signals are optically multiplexed by the coupler but electrically demultiplexed by the low- and high-pass electrical filters.

### Passive Optical Network

The basic configuration of *telephony over a passive optical network* (TPON) is shown in Figure 3. A single fibre is fed from the exchange and fanned out via passive optical splitters at the cabinet and distribution point (DP) positions to feed a number of individual customers. It is the optical splitter, which is inherently inexpensive, which gives TPON its potential cost advantages. A time-division multiplexed (TDM) signal is broadcast to all terminals from the exchange on

**Figure 3**
**TPON architecture**



a single optical wavelength. After detection by an optical receiver, the network terminating equipment accesses the multiplex and selects the channels intended for that destination. In the return direction, data from the network termination is inserted at a predetermined time in the TDM frame to arrive at the exchange within the correctly assigned time-slot; this technique is known as *time division multiple access* (TDMA). The time management of the system is implemented by a ranging protocol that periodically determines the path delay between the network termination and the exchange and updates a programmable digital delay element in the network termination.

An important feature of the network is the inclusion of an optical filter in the network termination equipment that passes only the TPON system wavelength. This enables other wavelengths to be added at a later date to provide new services without disturbing the existing receivers. In contrast to BIDS, TPON is better able to provide economic narrowband services at the outset, yet allowing future upgrade as the need arises.

TPON is a new concept and it is worthwhile to consider a specific example of the way in which a telephone can be connected (Figure 4) and, in particular, to consider the role of the *bit transport system* (BTS)[5].

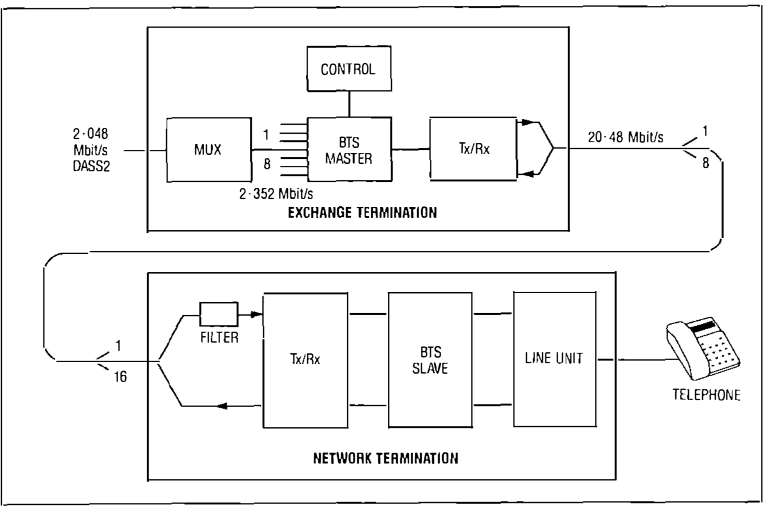



**Figure 4**
**TPON bit transport system**

Speech channels emerge from the exchange as part of a 2 Mbit/s PCM stream with DASS2 signalling. Within the TPON exchange termination, the statistically multiplexed signalling for the 30 speech channels in time-slot 16 of the DASS2 stream is converted to a form which can be delivered to individual network terminations. The signalling for each speech channel, formatted into 8 kbit/s channels, is used, for example, to control ringing and to provide loop detection. The 64 kbit/s speech channel and its associated 8 kbit/s signalling channel are then multiplexed with the other 29 channels to form a 2·16 Mbit/s (=30 × (64+8) kbit/s) signal which together with some spare bits forms the 2·352 Mbit/s interface to the BTS-Master hardware. The combination of speech signals and the associated signalling is referred to as the *traffic data*. The function of the BTS is to transport this traffic data transparently to the network termination and vice versa. Within the BTS-Master, the 2·352 Mbit/s stream is bit-interleaved with similar streams derived from seven other PCM/DASS2 streams, giving a total bit rate of 18·816 Mbit/s which, when control overheads are added, becomes 20·48 Mbit/s on the optical network.

The passive optical network intrinsically ensures that all of the 20·48 Mbit/s stream is received at all of the network terminations. Each particular network termination can be instructed by the BTS-Master to select its traffic starting anywhere in the multiplex and extract a given number of 8 kbit/s channels that were contiguous in the original 2·352 Mbit/s streams. In the case of a speech channel the network termination selects nine 8 kbit/s channels, 64 kbit/s for speech and 8 kbit/s for the associated signalling. The line unit then converts these to a form suitable for the connection of an ordinary analogue telephone.

In the reverse direction, a reciprocal process occurs, the 64+8 kbit/s traffic data derived from the telephone, plus certain control signals, are transmitted onto the optical network by bit-interleaving with other network terminations. The bits are actually passively interleaved by the optical network and at the exchange termination they appear as a continuous and perfectly interleaved stream. The ranging mechanism which ensures that this happens is controlled by the BTS-Master using the control signals in the 20·48 Mbit/s multiplex. The ranging control mechanism is capable of handling up to 128 network terminations, for example an 8-way split at the cabinet followed by a 16-way split at the DP.

Using an 8 kbit/s signalling channel to each network termination as described above makes optimum use of the BTS capabilities; however, for the trial it was more convenient to use 16 kbit/s for the signalling to simplify the interface to the line cards (the trial used existing equipment, such as line cards, wherever possible). The change makes use of the ability of the BTS to be configured in any multiple of 8 kbit/s and shows the flexibility of the design. A pragmatic approach was also taken with the optical network and only a 32-way split was used (4-way at the cabinet and 8-way at the DP).

A major benefit of the TPON approach is the ease with which it can be upgraded to carry new services. In simple terms, a TPON optical network can be upgraded to carry broadband services merely by the addition of an extra wavelength[6]; hence the inclusion in TPON of the optical filter in the network termination to prevent other wavelengths being received by the

TPON receiver. In practice (at least in the medium term), the optical power margins do not allow broadband signals to be received because of the high loss of the optical splitting network. Broadband signals are, therefore, injected into the network part-way down the split at the cabinet position, utilising spare ends on the optical couplers as shown in Figure 5; this still allows for an economic level of split to share optical-component costs. These issues are discussed in some detail in Reference 6. The Bishop's Stortford trial includes the addition of broadband to some of the house TPON customers; this configuration is called *broadband over a passive optical network* (BPON).

The Bishop's Stortford trial uses a sub-carrier multiplexed (SCM) system of 16 TV channels that are electrically multiplexed together using frequency modulation on carriers in the band 950 to 1700 MHz, which modulate a 1520 nm broadband laser. At the network termination, this is detected by a germanium avalanche photo-diode (APD) receiver and converted to an electrical multiplex which is directly compatible with standard satellite receiver set-top units. The conversion to baseband video and remodulation onto a UHF carrier is done within the set-top unit. Digital multiplexing is also being studied, but analogue multiplexing is seen as being less expensive and easier to engineer in the shorter term, benefitting from the cost declines of the world manufacture of set-top boxes.

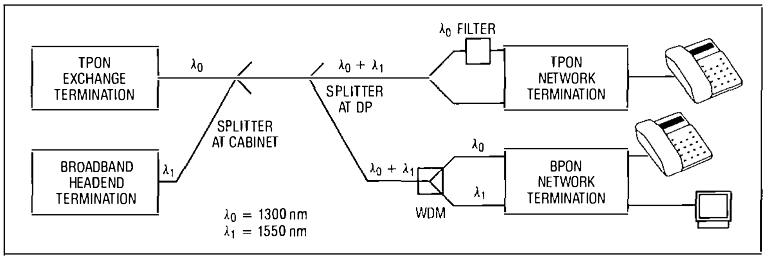



**Figure 5—An upgrade from TPON to BPON**

## TPON System Variants

The basic approach above can be extended to take into account the mix of customers currently connected to BT's network. In particular, small business customers wanting, for example, five lines, need not be served via five network terminations; instead a single optical transmitter/receiver can be used to serve a number of line-interface circuits. As well as being physically smaller, this configuration makes more cost-effective use of the optical components by sharing them across several circuits. For convenience in terminology this configuration is referred to as *business TPON* to distinguish it from the single-line termination, *house TPON*. Since all traffic data is available to all network terminations, a business TPON termination can access circuits from different 2·352 Mbit/s exchange termination ports; for example, one may carry telephony circuits while another could provide private circuits or ISDN. Not only can the BTS inherently provide this 'grooming' function it can also be used to ensure that each of the 2·352 Mbit/s inputs is fully loaded before calling into service another exchange port. This is referred to as *consolidation*. TPON's ability to groom and consolidate for the small business user increases its cost effectiveness to the operating company in comparison with dedicated, and perhaps part-utilised, standard 2 Mbit/s point-to-point fibre links for each type of service.

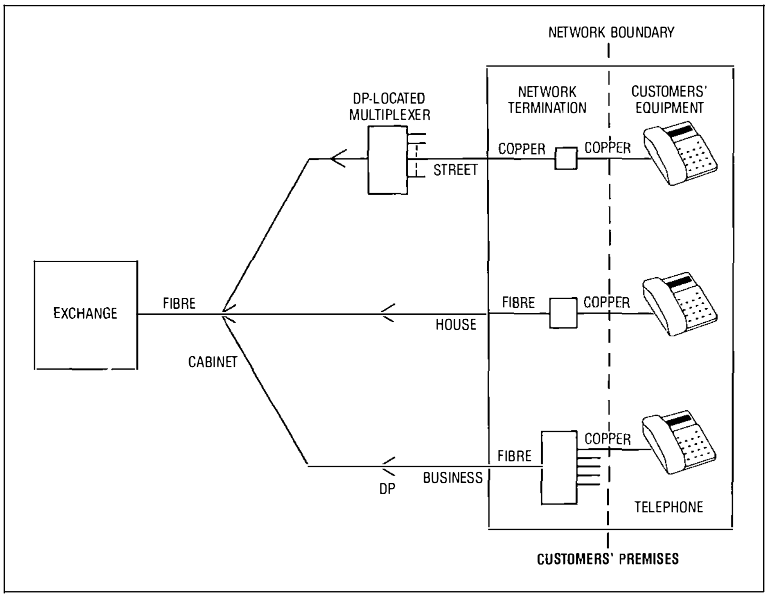



**Figure 6**
**Network termination options**

A further variant, referred to as *street TPON*, is shown in Figure 6. This is in many ways similar to business TPON in that it is a multiline unit, except it is situated in street furniture or in a footway box. The final link to the customers' premises retains the copper pairs. Because of the sharing of the fibre network and opto-electronics, street TPON is potentially more cost effective than conventional street multiplexers on point-to-point networks and can be used as an early means of deploying fibre in the local network. Later, as costs fall or broadband services are required, the multiplexer can be removed and fibre links taken directly to customers in the form of house TPON; no further changes are required to the optical network or exchange termination for the telephony provision. A major advantage of TPON is its ability for a single network to mix and match between single and multiline customers.

Recently, a whole new set of nomenclature has arisen in the international debate on fibre access. The new nomenclature takes the form of *fibre-to-the-home* (FTTH), *fibre-to-the-curb* (FTTC—this is based on the US spelling of kerb), and *fibre-to-the-office* (FTTO). House TPON and BIDS are thus an example of FTTH, business TPON an example of FTTO, and street TPON an example of FTTC. Also, the network termination is often referred to as the *optical network unit* (ONU). Currently BT, with its

Figure 7—A typical BIDS installation

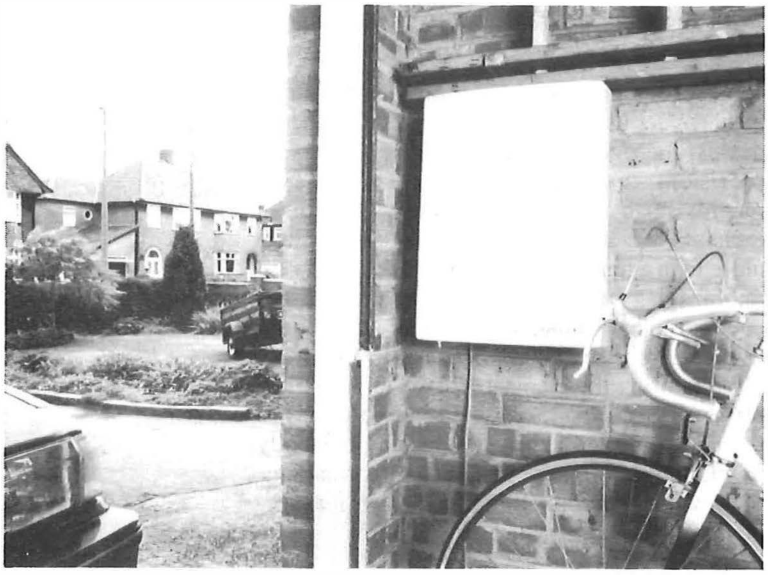


Figure 8—TPON network termination

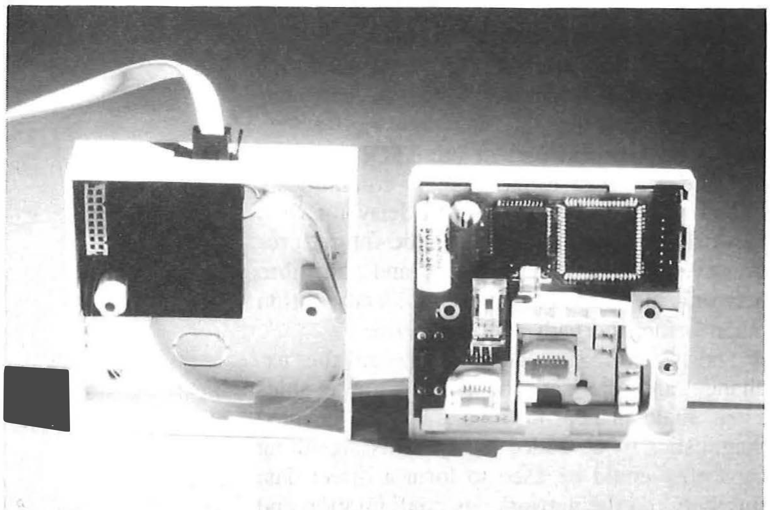


Figure 9—Mock up of future network termination

technical lead in passive optical networks, is also leading the way in the standardisation process for optical local access networks. The main focus of the debate is in the USA, where the major emphasis is on fibre-to-the-curb; the UK currently sees fibre-to-the-office for small and medium businesses as the priority. The different approach is partly due to the different regulatory regimes in the two countries.

The Bishop's Stortford trial includes both house TPON and street TPON. Trials to business customers in Bishop's Stortford may be connected using single-line house TPON units.

## FIBRE-TO-THE-HOME NETWORK TERMINATION

In simple terms the network termination allows an ordinary telephone and TV to be interfaced to the optical network. To do so it performs a range of functions:

- analogue telephony interface (including up to 40 mA line feed and 75 V AC ringing);
- interface to a standard TV (PAL) for BPON and BIDS via the set-top unit;
- interface to an infra-red controller for TV selection for BIDS via set-top unit (BPON TV selection is done solely within the set-top unit);
- optical interface;
- converts analogue telephone interface to 64 kbit/s plus signalling;
- controls the TPON laser power within 0·5 dB;
- controls the TPON laser pulse position ±5 ns;
- provides battery back-up in the event of mains fail;
- includes self-test features and problem reporting; and
- provides low-voltage power supplies derived from 240 V mains.

The network termination is a major challenge since the above functions have to be provided at minimum cost (the cost cannot be shared with other customers) and minimum size (it must be unobtrusive if it is to be acceptable to customers). In order to shorten timescales the network terminations used in the Bishop's Stortford field trial were based on existing multiplexer hardware and were fairly large as shown in Figures 7 and 8. This was acceptable since the main aim of the trial was to assess technical features and not market acceptability. Studies indicate that in the longer term the network termination could be reduced in size to a unit about 100 × 100 × 50 mm plus a separate power supply and battery housed in a plug-top unit similar to that used for calculators. A mock-up of such a unit is shown in Figure 9. This size reduction can be achieved by the use of custom-designed integrated circuits, sophisticated interconnection techniques and by careful attention to the optical components and fibre handling.

## NETWORK MANAGEMENT

Any development of the local network should pay particular attention to management and maintenance. Although this added functionality increases the initial capital cost it can reduce the whole-life costs of the system, especially if the system approaches the ideal 'hands-off' network which requires no manual intervention. The current copper network is far from being a hands-off network since manual access is involved at the exchange (on the main distribution frame (MDF)), at cabinets and at pillars, as well as at the customer's premises, to provide new circuits. Each time the MDF, cabinet or pillar is disturbed there is the possibility of disturbance to other customers' connections. Although the copper network can be modified to overcome some of these deficiencies, a broadband passive optical network inherently overcomes them, since new circuits can easily be provided just by adding extra equipment at the network termination.

The architecture for telecommunications network management can be defined, at an abstract level, in terms of a hierarchy of five layers as shown in Figure 10. Starting at the bottom layer, the network is partitioned into network elements which are treated as distinct network entities from a management point of view, but which cooperatively provide a service to the customer (for example, elements might be multiplexers, switches and transmission links).

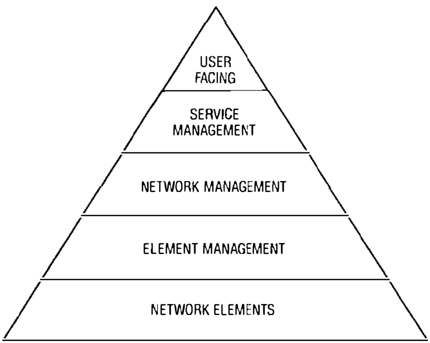



**Figure 10—General network management architecture**

The local network would, in practice, be made up of a number of managed element types and each element type has an associated element manager. This could be a separate processor linked to the element, or could be software embedded in the element.

The network management layer, in turn, controls the various element managers. This is the first layer where the management relationships amongst elements are coordinated to provide overall supervision. Workforce management facilities would be linked to this level to ensure that maintenance and repair activities are coordinated with network management.

Above the network level is the service management layer. This coordinates the networks to provide specific services. Above this are the user facing levels.

The design methodology for the Bishop's Stortford trial was keyed as far as possible to the above model. BT is in the process of specifying standards for the interfaces between the various layers, but these were not firm when design work for the trial started. The trial system, therefore, treads a pragmatic line between the ambition of the formal approach and making as much use of existing software as possible[7,8]. The main relevant existing software was that used to control the Westminster switched star network, and this formed the core of the network and service management layers.

The following paragraphs highlight the key issues which are directly pertinent to the trial architectures and to the associated element manager software.

Element manager software typically has the following functionality:

- Maintaining a complete record of all the elements under its control (for example, circuit card details, their configuration, and use for service provision). In a roll-out situation, such a set of records might cover all the systems within an exchange serving area and might therefore include more than a hundred optical networks.
- Managing remote access to the elements for configuration, testing, analysis, maintenance activities and, potentially, to control traffic.
- Monitoring the elements, performing limited processing of events, passing selected events to the network management level, and potentially providing performance and usage information.
- Providing concentration facilities for management messages and hence flow control.

The element manager must be able to communicate with the network management layer.

There is much about fibre architectures that simplifies maintenance, as follows:

- The network termination is in constant contact with the exchange termination and can report local faults (for example, self test, line card faults, low battery charge) before the customer detects any problem.
- It is an inherent part of the TPON concept that the exchange termination is continuously monitoring the laser power and delay for each network termination. Hence, in the future, progressive degradation of lasers and the fibre network can be spotted early and, ideally, action taken before the fault affects service.
- The signalling capability between the exchange and the network termination enables extra maintenance features such as detailed diagnostics to be added easily. This signalling capability could be used to form a direct data link between the network, its configuration and the field staff to avoid errors in network records and transferring works instructions.

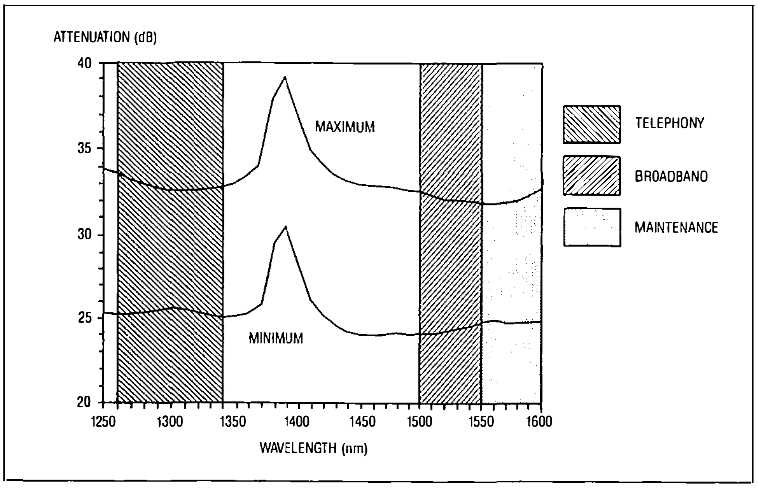



**Figure 11**
**Spectral allocation and attenuation characteristics for a 32-way split PON**

● Correlation of faults from several network terminations can help to pinpoint faults in the optical network. For example, if all the terminations from a particular DP have failed, it is likely that the fault lies between the cabinet and the DP.

These features, together with the optical plant maintenance aids described below, ensure that fibre networks have a good degree of maintainability. However, many of the proposals need to be verified in the field before all the problems are resolved. The Bishop's Stortford field trial will provide valuable data in this area.

## FIBRE NETWORK MAINTENANCE

Most faults occurring within the electronics or opto-electronics will be automatically detected by the hardware and an alarm flagged to the network management software. Appropriate repair action can be taken, usually by card replacement. This is also partially true of faults occurring in the optical network which will initially be signalled by the fault detectors within the electronic equipment, and flagged to the maintenance staff via the element manager and the network manager. Thereafter, the fault needs to be located and repaired. The localisation is a two-stage process; initially the hardware can provide some degree of localisation, secondly optical-fibre tools can be used.

### Optical Time Domain Reflectometer (OTDR)

Once a fault is known to be in a particular fibre network, special tools can be used to locate the fault[9]. In the particular case of passive optical networks, the network is shared by several customers and it would be impractical to turn it off to repair a fault affecting just one customer. The PON must, therefore, be maintained live. Live measurements on the network are facilitated by defining a wavelength plan for the PON in which windows within the usable spectrum are allocated to different services including maintenance:

(*a*) telephony 1260−1340 nm,
(*b*) broadband 1500−1550 nm, and
(*c*) maintenance 1550−1600 nm.

The wavelength allocation, together with typical attenuation characteristics for a 32-way split duplex PON, is shown in Figure 11.

The OTDR, operating at 1575 nm, enables reflections, distributed losses and point losses to be located and measured. However, its output can be difficult to interpret for PONs and its dynamic range and resolution can be a restriction. A particularly useful feature of the instrument is that all measurements can be taken from a single access point.

On a 32-way (2-stage 4-way flexibility point and then four 8-way distribution points) PON, with OTDR connected to the lead fibre via a wave-division multiplex (WDM) coupler, point losses up to the first 4-way splitter can be measured with a resolution of 0·2 dB or better. Beyond the 4-way splitter the resolution is reduced to 2 dB or worse. Reflections, which may cause crosstalk problems in a duplex system can be detected up to the network termination.

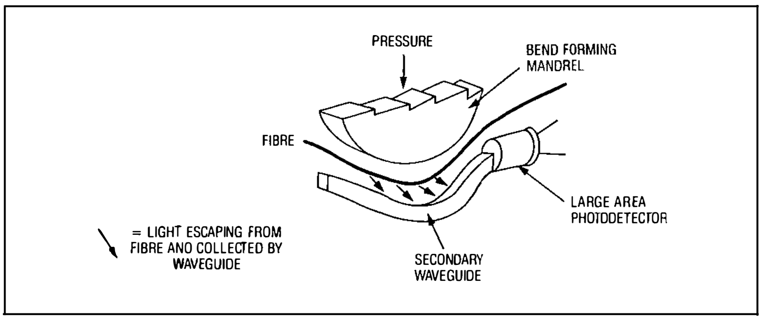
In future systems, it is planned to automate the collection of information to aid the maintenance technicians in their task. An OTDR could be linked to the TPON element manager or to the network manager via its own element manager.

### Fibre Tools

Conventional optical power meters can be used to take end-to-end measurements to an accuracy of better than 0·2 dB and spare connectorised taps have been provided on the network for attachment of such power meters (or OTDRs). However, end-on access is not always easily available, especially in duplex networks which are mainly fusion spliced to reduce crosstalk.

To avoid the need for end-on access, a clip-on power meter has been developed by James et al.[10]. This instrument, used in conjunction with a suitable light source, enables power measurements to be made through the side of the fibre without damaging it. This is done by putting a controlled bend in the fibre and measuring the level of light which 'escapes' the bend as shown in Figure 12. Figure 13 shows a photograph of the equipment used for the trial. The measurement can be made non-intrusively, with a gentle bend, to an accuracy of better than 0·5 dB, or intrusively, where a tight bend is made, with a

**Figure 12**
**Schematic of optical 'clip-on' testing**



similar accuracy but greater sensitivity. The intrusive version can be used during installation and commissioning. For characterisation and maintenance, the non-intrusive version is used with a maximum specified insertion loss of 2 dB which is included in the overall optical system budget. Under fault conditions, measurements at appropriate positions in the network can be compared to reference measurements taken during characterisation to locate the source of the fault. Figure 14 shows a photograph of the DP which was specially developed for Bishop's Stortford to allow access to the fibre. Each fibre splice, and its associated spare fibre, is allocated to a splice tray arranged like the pages of a book so that each can be accessed without disturbing the others.

### Training

A significant element of this trial has been the emphasis on testing the real applicability of the systems. In particular, the installers used are those that are normally employed on ordinary telephone installations. As a result, a high priority has been given to training field staff; where possible this has been done by the development teams themselves, thereby providing direct feedback to engineers on the real problems. It is a credit to the field staff that they have shown themselves both enthusiastic and very able to pick up new skills.

## TRIAL STATUS AND RESULTS

### Trial Status

Contracts were awarded last year to GPT for TPON system development, to FCL for street TPON development plus BIDS and BPON manufacturing, and to BICC for the fibre networks. A special licence has been granted to BT by the Government to allow BT to run the trial in Bishop's Stortford until the end of 1992.

The first public milestone was the completion of the main fibre network in April 1989. Since then the BIDS hardware and support software has been developed, tested, integrated, installed and commissioned by the local telephone District. At the time of writing (February 1991), twenty BIDS customers are connected; eventually this will rise towards 100. In parallel, the TPON systems have been developed, tested and are in the process of being integrated. Customers will be connected on the system in the first half of 1991, but already hardware demonstrations exist to the Optical-Fibre Centre in Bishop's Stortford and to sample customers.

The Optical-Fibre Centre is jointly run by the partners in the trial and consists of over 300 $m^2$ of exhibits and a conference room to which invited audiences can be shown the trial equipment and the future capabilities of fibre-to-the-home, fibre-to-the-office and fibre-to-the-curb systems.

**Figure 13—Clip-on tester**

**Figure 14 Optical distribution point**

### Results to Date

The aims of the trial were listed earlier in this article. As the trial proceeds, results will progressively be gathered but, already, certain of those aims have been achieved as described below.

The technical feasibility of fibre in the loop has been proven; in particular, the more radical passive optical network approach has been shown to work in a real environment. However, more work needs to be done to optimise the systems. The installation in Bishop's Stortford was the world's first practical application of the TPON system concept.

The fibre infrastructure was installed with very few problems; this is mainly because of the great similarity with existing work in the trunk and junction network. However, new techniques including tandem blowing were used. The clip-on meter has been found to be a valuable tool for installation and maintenance. Fibre overhead drops to customer's premises have also been shown to be feasible, but more work is needed to reduce the time taken for an installation.

Fibre has succesfully been taken to domestic customers. The difficulties of running fibre cables with restricted bend radii around the home was overcome by mounting equipment directly over the entry-point through the wall. While customers are also receiving cable TV services, the powering of the network termination from local mains power has not been a problem; however, this is an important issue for telephony-only service because customers are not accustomed to having to provide mains power for telephone service.

The current equipment design and installation practices have been shown to be practical for existing field staff to use given suitable training. However, installation times are still high and, as expected, the designs will need to be reworked before a mass roll-out can be considered. Even though current designs are not as simple to use as the next generation, the local field staff have shown themselves both capable and enthusiastic in using them.

A key point in the design of TPON was that at a later date it should be upgradeable to BPON without disruption to telephony service. This has been demonstrated to the extent that even equipment from different manufacturers has inter-worked satisfactorily; BPON manufactured by Fulcrum has been demonstrated working reliably over a network manufactured by BICC without affecting the TPON system manufactured by GPT. It is important that Telcos are able to procure systems which can be upgraded by equipment from other manufacturers. Only in this way can Telcos avoid being locked into one supplier.

As a result of the trial, the participating manufacturers are now much closer to being able to offer practical solutions for a larger roll-out. The next product will undoubtedly be a cost-effective multi-line business unit on a passive optical bearer. The next iteration of equipment design should now be suitable for that market.

Only if there is a world consensus on key aspects of the optical design will the economies of scale of opto-electronic production enable prices to fall sufficiently. The trial has provided a focus to encourage the world to consider the benefits of passive networks and the consensus is now that much closer.

The practical experience gained from planning, designing and implementing the trial has provided valuable experience for the procurement and management of the next generation of systems.

## CONCLUSION

The only way to achieve early cost-effective deployment of optical networks is through good operation and maintenance design. This cannot be accomplished without a network management system and maintenance tools which have been produced in concert with the system design. The trial that BT is holding at Bishop's Stortford is testing the basic facilities. More advanced systems are being produced and are under trial in the laboratories.

As more customers are connected to the trial, there will be an ongoing programme of monitoring all aspects of the trial from technical parameters (for example, loss variations) to operational parameters (time to repair). This will ensure that future systems are planned with the optimum technical and operational design to achieve the minimum whole life cost.


### Acknowledgements

This article summarises the work of many individuals (too numerous to mention individually) in several teams within BT's Access Networks Division.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## Biographies

Cliff Hoppitt is the manager of the Local Access Operations and Maintenance Section at BT Laboratories in Martlesham Heath, Suffolk. He is also the project manager for the Bishop's Stortford fibre trials. He graduated from Birmingham University with a first-class honours degree in Electrical and Electronic Engineering to take up a post in the then BPO to study the subjective effects of loss and echo on telephony transmission performance. During this time he studied for an M.Sc. in Applied Acoustics at Chelsea College, London. Subsequently he has worked on ISDN transmission research and development, as well as specification and contract management for the System X pilot ISDN service. He is a member of the the Institute of Acoustics and a member of the Institution of Electrical Engineers.

John Rawson is the Head of the Bishop's Stortford Fibre Trials Systems Engineering Group and is in the Access Operations and Maintenance Section at BT Laboratories at Martlesham Heath, Suffolk. He graduated from the University College of North Wales with an honours degree in Electronic Engineering Science to take up a post in the then Post Office Telecommunications Headquarters to study the economics for the introduction of digital transmission and switching to the telephony network. Subsequently he moved to BT Laboratories to work on novel local access signalling systems, System X message transmission and digital switching subsystems. More recently within the Access Networks Division, he has worked on the development of the switched star cable TV network and various studies on advanced local network architectures.

## APPENDIX 1

### Glossary of Terms and Abbreviations

**ACOST** Cabinet Office Advisory Council on Science and Technology
**APD** Avalanche photo diode
**BAP** Broadband access point
**BIDS** Broadband integrated distributed star
**BPON** Broadband over a passive optical network
**BTS** Bit transport system
**BTS-Master** Part of the BTS at the exchange termination
**BTS-Slave** Part of the BTS at the network termination
**Business TPON** TPON termination specifically adapted for multiline business customers
**Cu** Copper
**DASS2** Digital Access Signalling System No. 2
**DP** Distribution point
**FAS** Flexible access system
**FTTC** Fibre-to-the-curb
**FTTH** Fibre-to-the-home
**FTTO** Fibre-to-the-office
**GPT** GEC Plessey Telecommunications plc
**House TPON** TPON termination for single line residential customers
**ISDN** Integrated services digital network
**MDF** Main distribution frame of a telephone exchange
**NT** Network termination
**ONU** Optical network unit
**OTDR** Optical time domain reflectometer
**PAL** Phase Alternate Line (The standard UK TV modulation format)
**PON** Passive optical network
**SCM** Sub-carrier modulation
**SSN** Switched star network
**Street TPON** TPON termination specifically adapted for street sited multiplexers serving residential customers via a final copper drop
**TDM** Time division multiplex
**TDMA** Time-division multiple access
**TPON** Telephony over a passive optical network
**WDM** Wavelength-division multiplex

# Local Network Resource Plan—The Introduction of Total Quality in the Local Access Network

A. G. DUNN, and A. J. INGRAM†

*The Local Network Resource Plan illustrates the application of a range of relatively new management techniques to local network activities. These techniques are wholly consistent with BT's application of total quality and the early results confirmed the significant improvements in work throughput and productivity reported by other companies with advanced total quality programmes*[1].

## LOCAL NETWORK RESOURCE PLAN

The Local Network Resource Plan (LNRP) is a group of related projects aimed at improving resource utilisation and engineering productivity in local access network activities.

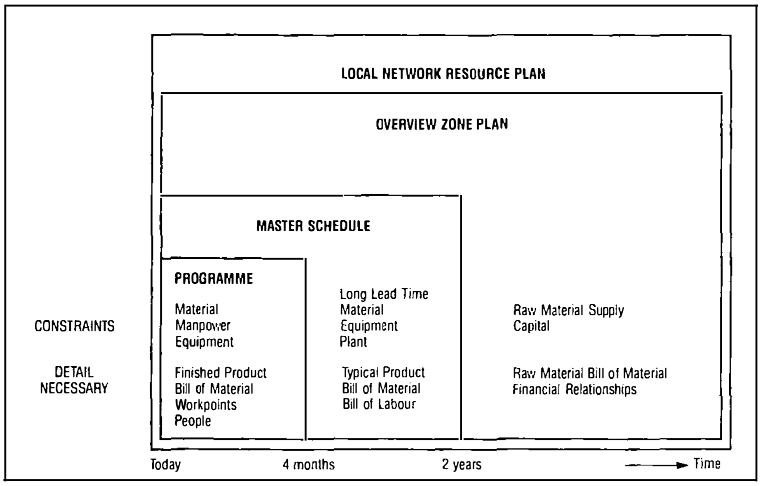
LNRP started from a belief that quantum improvements in resource utilisation and productivity could be achieved, not just by improving field efficiency, but by better management of the local network workforce.

The evidence stemmed from the Materials Management Programme (1984–1988), which improved the service level to local network units to more than 95%. As a result, improvements in stores deliveries led to a large number of jobs being fully planned and kitted which could not then be executed because of lack of local network resource. This led to an unacceptable increase in stock holding levels.

The scope for improvement in productivity was demonstrated by measurement of field effectiveness which showed that only 40% of field engineers' time was being spent fully effectively; 10% was fully effective but inefficient; 15% was spent on activities required by management but which did not contribute to getting local network plant in the ground, 10% was wasted, 20% was spent travelling and the remaining 5% was personal time.

† BT Personal Communications

**Figure 1**
**Phases of economic planning**




## LNRP OBJECTIVES

This article identifies the changes that needed to be made:

- improved resource planning,
- improved performance measurement,
- clarification of roles and responsibilities,
- improved communication,
- systems support, and
- change of culture;

and how these changes are being effected:

- learning model,
- soft systems approach to problem solving,
- project management,
- change of role for headquarters units,
- adoption of field resource utilisation studies,
- statistical process control, and
- continuous improvement.

## THE LOCAL NETWORK RESOURCE PLAN AND MASTER SCHEDULING

Much of the work in manufacturing industry and the construction of the local network is similar: both require the bringing together of people, materials and equipment in order to produce end-products. Manufacturing industry sells the end-products it makes, while BT uses its end-products (networks) in order to provide telecommunications services.

### Improved Resource Planning

Manufacturing industry developed resource planning techniques related to materials requirements planning (MRP) techniques which were introduced into BT through the Materials Management Programme. The task was to determine how best to apply these resource planning techniques—which involved the production of master schedules—within the local networks operations.

### The Local Network Resource Plan

The Local Network Resource Plan consists of three phases of economic planning (Figure 1):

(*a*) *Overview* The overview states simply and clearly how the network should look in five years time, and sets out the half dozen or so vital strategic steps the local network manager intends to take to ensure that his/her unit's activities support the corporate objectives over the following five years.

(*b*) *Master Schedule* A master schedule is an agreed resourced schedule of work. The schedule recognises both resource and process constraints, by bringing together the work to be done, the resources required and the resources available. It may be used to determine the optimum way of using the available resources to improve the quality of the network and the service to the customers. It may also be used to identify bottlenecks in the local network construction process.

In order to introduce master schedules, the data content and the process required to support the master schedule have to be determined. To produce satisfactory data, existing databases have to be cleansed and performance measurements have to be improved. New measures are required to assess the resource required to produce a given result (result/resource ratios), and new measurement techniques, such as statistical process control[2] are introduced to ensure these result/resource ratios have an appropriate level of detail. To determine the process, the soft systems methodology developed by Checkland[3] is used; this involves defining the purpose of the local networks unit and logically determining the minimum set of activities required to fulfil its purpose. Each of the activities in the minimum set is then broken down to a further level of detail and the minimum set reviewed. The focus of the exercise, as reflected in the LNRP process, is the role of resource planning.

(*c*) *Programme* From the master schedule come programmes of work for the planners and the construction staff. The planners add the finer detail required to execute the work in the field.

## THE LNRP PROCESS

The LNRP process is shown in Figure 2. It is a logically linked sub-set of the total set of activities that are required to provide, operate and maintain the local network in an efficient and cost-effective manner. This sub-set consists of the resource planning activities. The focus is the master schedule; the other activities in the process are required to build, maintain and give effect to the master schedule.

A master schedule is a set of numbers indicating what is to be made, when and where. It requires inputs: a forecast of the working circuits expected to be required for customers, business priorities and a higher-level overview of what the local network and local network activities should look like in 2–5 years time. The master schedule is used to determine the work that can be carried out with the available resources (skilled men, materials, vehicles, machinery, money); this involves project selection and budget setting. The output from the schedule is a set of programmes of work for planning and construction staff. The schedule also indicates the changes required in skill mix, materials mix, vehicle fleet and equipment requirements, from which training programmes and procurement schedules can be built.

### Progress Review

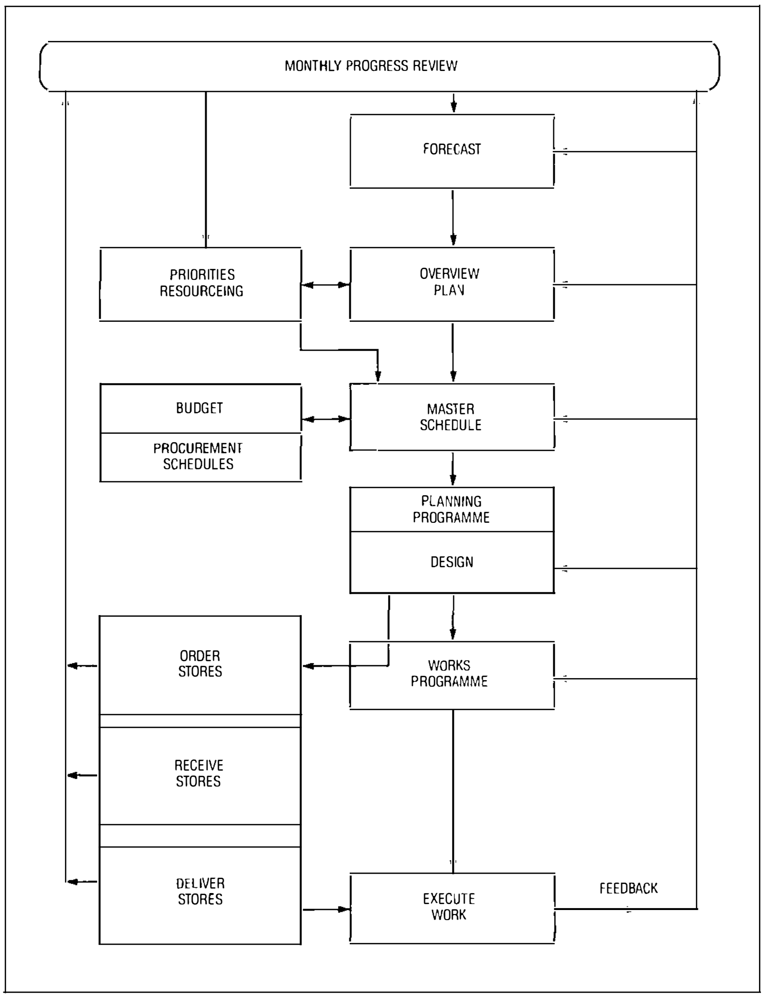
Feedback is required from the planning and construction staff on progress against the schedule and the resources used to deliver the work in the schedule.

The process also illustrates the relationship of the local network activities with those of other functions with whom service level agreements are required; for example, with Marketing for forecasts, Logistics for materials, Finance for budget, Personnel for training, Motor Transport for vehicles and vehicular equipment.

Finally, it is essential for all parties involved to meet regularly to:

(*a*) review progress,
(*b*) review forecast accuracy,
(*c*) review programme stability,
(*d*) review performance,
(*e*) ensure the schedule remains viable,
(*f*) identify problems, and
(*g*) agree action plans to eliminate the causes of problems.

**Figure 2**
**Local Network Resource Plan process**



## Improved Performance Measurement

When a master schedule is being produced, the resource required for a given result (result/resource ratio) needs to be known. For example, how many people and what skills are required, for how long, to pull in 1000 m of 200-pair cable? Identification of all of the resources needed to carry out the local network construction, operation and maintenance activities is required. Traditionally, only the construction manpower and materials have been assessed with any degree of rigour. It is therefore necessary to identify, for example, the result/resource ratios for local network planners. Unless all of the resources required are taken into account, bottlenecks build up within the process; this slows down the overall process and inhibits the optimal use of resources carrying out activities later in the process.

Traditionally, local network managers have used activity-based measures; for example, the number of hours worked on cabling, poling, jointing and the percentage of overtime. However, these measures ignore the results achieved such as the number of local network plant items constructed (for example, duct-bore km, cable-sheath km, number of poles erected, pairs jointed). In order to focus on unit costs, it is important to be able to measure the resource used in achieving the results not just the activity.

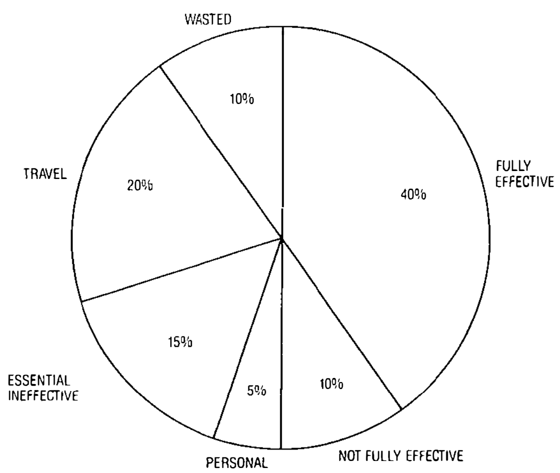
It is also possible to focus on the results achieved for the customer; that is, whether pairs were added in the right place in time for prompt delivery of customer service. Result/resource ratios continue to be improved as better definitions of results and resources are produced.

When a result/resource ratio is found to be more than 10% different from the figures being used by local network planners when estimating the resource required to carry out work, the discrepancy is investigated. If there is no evidence for an exceptional figure, the result/resource ratio used by the planner is adjusted to reflect the more recent achievement.

This crude Pareto-style analysis works well in identifying and capturing real performance improvements, but suffers from a number of defects; for example, the figure of 10% is subjective, the investigation is labour intensive and retrospective.

More recently, statistical process control (SPC) has been investigated as a technique for identifying when result/resource ratios have changed significantly. SPC is a technique for measuring and monitoring the performance of individual activities in the process, providing information about trends in the process and leading to the identification of statistically significant improvements in performance. These improvements are then reflected in the result/resource ratios used by the planners. SPC offers the benefits of a more rigorous, statistically objective, methodology, providing timely feedback not only to planners, but also to individual construction engineers on how well they are doing compared to the standard result/resource ratios.

**Figure 3**
**Analysis of local network engineers' time**




## Capacity Planning

The master schedule provides the basis for resource planning, but it can also be used for capacity planning; that is, capacity of the workforce to do work, rather than the volume and location of the network. Resource planning assumes there will be no change in the productivity of the resources used. Capacity is the product of resource and productivity; capacity planning allows the assessment of potential productivity improvements.

Traditionally, productivity improvements came from changes in technology which enabled engineers to work more efficiently. Productivity can also be improved by better direction of the workforce to the required activity and the activity content. Productivity has three components:

| | |
|---|---|
| Efficacy | Is the activity fit for purpose. |
| Effectiveness | Is the resource deployed full-time on the activity. |
| Efficiency | How quickly does the resource effect the activity. |

Resource utilisation studies (Figure 3) showed that the largest improvements in productivity would come not from improving efficiency (which would only have yielded some small percentage improvement on only 40% of the time), but by improving effectiveness (which could yield up to 100% of the 15% of ineffective time plus the 10% of wasted time). Further improvements could come from improving efficacy by reducing travelling time with a matching increase in fully effective time.

## Clarification of Roles and Responsibilities

The focus on results for which specific individuals or groups could be identified as responsible identified a number of inconsistencies between what some groups were doing and what they believed they were responsible for. This has provided a basis for improving the match between responsibility and accountability. For example, works controls spent much time expediting materials shortages by reassigning items issued for one job to another job. This solved an immediate problem but disrupted the works programme and produced data inaccuracy in the materials control system. By authorising materials management personnel as the only people allowed to reassign items between jobs, even after the items had been issued from the warehouse, visibility of the scale of the shortage problem was gained and the causes identified: a mixture of poor materials planning and poor local network planning, each making the other worse and masked by the activity of the works control.

### Improved Communication

The LNRP process highlighted the interdependence of the various functions involved in constructing the local network. The clarification of roles and responsibilities showed a need to understand better what each of the functions did. It became clear that improvements in the management of local network activities required the cooperation of groups additional to those within the local networks organisation and this required better communications with these groups. Key managers, including people from marketing, materials management, engineering and finance functions, now meet regularly to review progress, identify causes of problems and take away action plans to address these causes.

Ongoing activities are supported through service level agreements between the various functions. SPC provides up-to-date feedback to engineers on improvements they have initiated.

### Systems Support

To simplify the handling of the large volume of data involved in planning and construction operations, the monitoring and control of external works (MACE) system was introduced some years ago to enable the smooth running of the works programme.

To enhance the facilities provided by MACE, a software package was required to provide scheduling functionality. HORNET 5000 software was chosen as the most suitable, supported by DBase IV, which provides database and flexible reporting capability. The time-consuming compilation and analysis involved in good scheduling is quickly undertaken using HORNET/DBase IV. Particularly useful are the 'what if?' scenarios available for the annual budget dialogue.

## MANAGEMENT OF CHANGE

Previous major change programmes in BT produced benefits in trials, but did not generate the same enthusiasm or results when rolled out nationally. Analysis using the learning model (Figure 4), which is used to model buyer behaviour, indicated that people working on the trials were involved in the identification of the problem (be aware and understand), in the development (plan, experiment and evaluate) and implementation (educate, implement and review) of the solution.

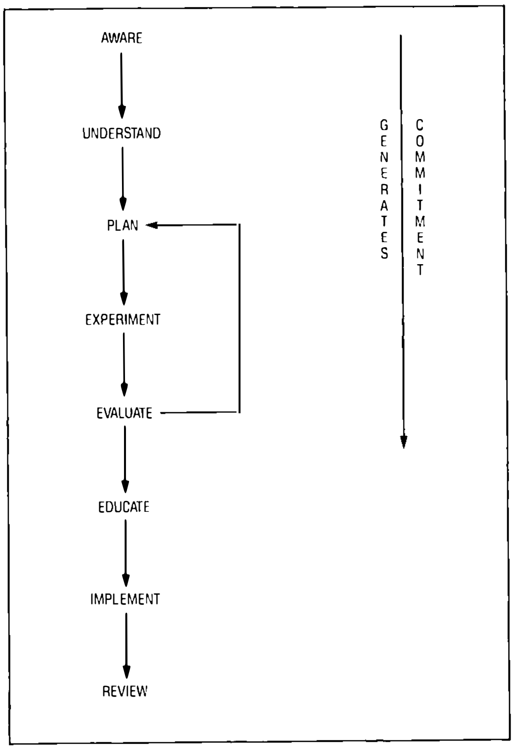



**Figure 4—A learning model**

However, once a solution had been found, it was often implemented (educate, implement and review) elsewhere without gaining the commitment of those involved; that is, people were trained to implement the solution and told to do so, little effort being expended to ensure that the problem was understood or that the solution was relevant to the people implementing it.

A major part of the implementation of LNRP is, therefore, effected through a series of tightly focused workshops, which create awareness of the current problems within the District and explore ways of improving their situation.

## CHANGE OF CULTURE

The focus on working together to solve problems is an essential ingredient in achieving results. LNRP locates headquarters support managers alongside field managers, enabling regular involvement and easy communication. The local network line management role in achieving results is thus stimulated.

The culture change is not restricted to District people. Headquarters people are required to change roles to become advisor, coach, team partner, helper and monitor of the effect of improvement initiatives.

Headquarters specifies *what* activities are to be performed and the *outcomes* from these activities, while District managers are responsibility for *how* activities are carried out, since *how* decisions are about cost and quality.

## HEADQUARTERS SUPPORT TEAM

Advice on pace, problem solving techniques and direction is provided by a small project management team. This team was formed by combining the interests of the Work Management Programme, the Local Lines Task Force and local network implementation managers, these last being drawn from Districts cement the relationship at the local level.

## SENIOR MANAGEMENT SUPPORT

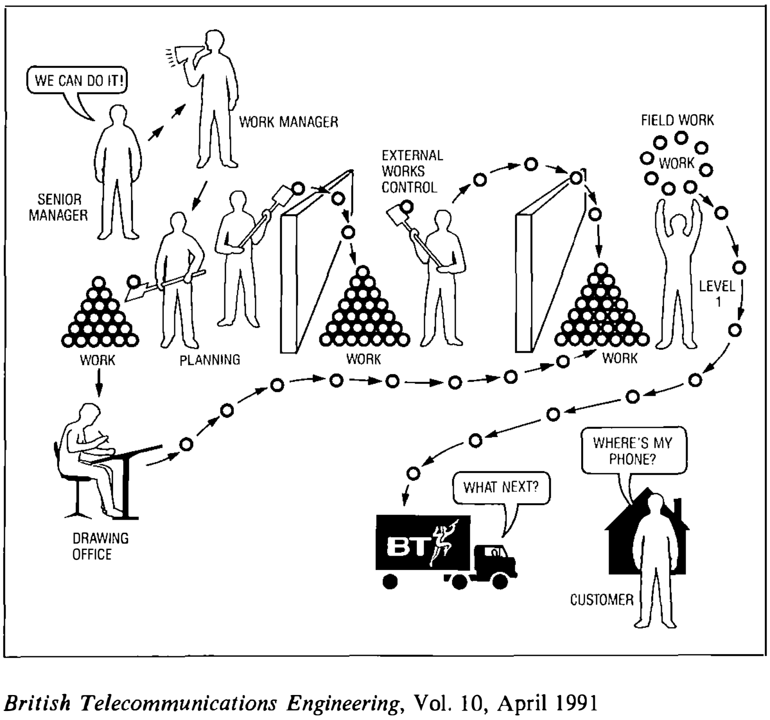
Senior management support is established at the outset by agreement to the implementation plan and shared resourcing of the effort required. Participation in the regular progress reviews gives visibility to the ongoing senior management support.

### Soft Systems Methodology

In developing the LNRP process, soft systems methodology[3,4] was used. Soft systems methodology is also used as part of the implementation process for LNRP. The approach is centred on a small number of key ideas:

- 'Problems' that arise in organisations do not have an existence independent of the people involved with them.
- People have different appreciations of situations because they see them in genuinely different ways.
- If 'problems' have no existence independent of the people involved with them, then the same must be true for 'solutions'.
- No problem exists in isolation; every problem interacts with other problems and is therefore part of a set of interrelated problems, called a *mess*[5].
- Improvements in complex messes are most likely to be brought about through the sharing of perceptions and through persuasion and debate.
- The analyst cannot be divorced or detached from the analysis. He/she is assumed to be part of the mess. Much soft systems analysis is thus close to what is known as *action research*, in that the analyst is attempting not only to understand the situation, but also to help change it for the better.

**Figure 5**
**A rich picture**




The soft systems approach is different from more traditional approaches to problem solving: it places an emphasis on appreciating and improving problem situations rather than on 'solving problems'. It also changes the role of analysts to team partners, helping by coaching, advising and supporting.

To create awareness of the current situations, local network managers and a few of their suppliers and/or customers gather data by drawing *rich pictures*. An example is shown in Figure 5.

A rich picture is a cartoon-type representation of the existing situation. It shows hard data such as the existing process and how the existing organisation maps onto the process, and soft data such as how people feel about the interaction of the process and the organisation, and how they feel about their suppliers and their customers.

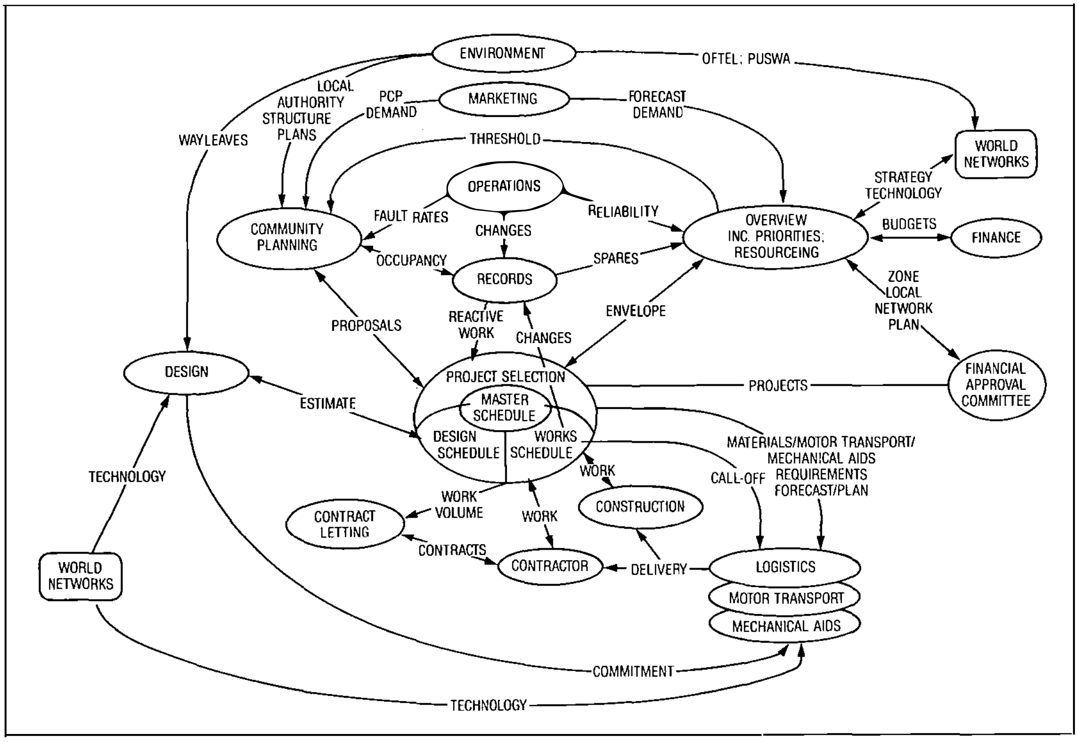
Figure 5 is taken from one of the District workshops which form part of the LNRP Implementation Programme. It illustrates the functional divisions that had grown up between the various players in the local network processes.

To create understanding of how the current situation could be improved, the LNRP vision is explained to the local network managers who assess the benefits for themselvcs of moving from the current to the future situation envisaged in the vision.

During the implementation of LNRP, local network managers had the opportunity to improve the original LNRP vision and process (Figure 2), and the latest version is shown in Figure 6. This later figure shows the same focus but has a much broader scope and is better because of the joint involvement.

For each of the activities in the LNRP process, the objectives and the outcomes of the activity are defined. A sub-process is recommended which allows the identification of the skills required to carry out the activity. Performance measures for the activity are also identified.

Local network managers can quickly identify the differences between their rich pictures and the LNRP process and determine what they want to do about the differences. This produces an action plan.




*Note*: Monitor and control all activities. Monitor includes performance measurement, service level agreements and measurement mechanisms. Control includes acceptable performance limits, decisions, escalation and change control procedures. Monitor and control effected daily, weekly and through monthly review meetings

**Figure 6**
**Local networks—a conceptual systems model**

### Project Management

Each District has its own project requirements definition, which spells out the implementation plan for the individual locality and management team. A project control board is responsible for agreeing and enabling the implementation plan. To organise and control the activities, a local project management team consisting of the main players reviews progress monthly and sets out the requirements for the next month.

The implementation is broken down into manageable chunks by use of a PERT derived chart. Targeted milestones for installing processes and achieving the associated results are key parts of LNRP implementation.

The use of the learning model in developing these plans has helped; the need to understand leads to an early identification of training (understanding) needs before embarking on the development of plans to make changes.

### Continuous Improvement

Training needs identified by the LNRP Implementation Programme are supported by the Training Division Consultancy Unit, Training Division management training and District total quality management implementation support managers. Training in interpersonal skills (soft skills) alongside technical skills (hard skills) leads to behaviour change and consistent behaviour change across the organisation produces culture change.

District-specific opportunities uncovered through the introduction of LNRP become District-owned quality improvement projects. The small central support team helps to ensure that Districts do not duplicate solutions to common problems.

By adopting and using techniques for dealing with complex problem situations, by introducing performance measurement concepts and by supporting more effective meetings, LNRP has changed the emphasis of training from educating in order to implement solutions to investigating ways to improve continuously.

District local network managers measure and analyse the way in which field staff spend their time at work in order to determine how much time is ineffective or wasted (often doing things which should have been done by someone else who hadn't, and were essential for the delivery of service to the customer). This enables local network managers to determine what they can do to improve productivity by helping their staff to spend more of their time being fully effective. This also focuses on the planning/works customer/supplier relationship to ensure that the design process is simple and produces estimates which are 'fit for purpose'.

The resource planning process provides a vehicle for ensuring that productivity gains from quality improvement projects are captured and held. It identifies bottlenecks, which allows management to apply improvements to these bottlenecks rather than to activities which are already adequately resourced.

## BENEFITS AND RESULTS

LNRP was launched in May 1990 as one of BT's 'vital few' total quality programmes, and national roll-out is due to finish in April 1992. Improvements in the stockturn of local network materials has increased from 4 to 6 during 1990/91, which represents a stock reduction so far of £20m.

Early District results show that fully effective time has increased from 40% to 55% in the first year and in the first pilot District from 40% to 64% in two years, which represents a potential increase in productivity of over 50%.

The culture change outlined for Headquarters has been adopted in the new Personal Communications Division of BT.


## ACKNOWLEDGEMENTS

The authors wish to acknowledge the help and support received from Linda Ward and Tim Legood during the early stages of LNRP, and latterly the cooperation of all local network managers without whom the benefits reported above would never have been achieved.

Figure 5 is reproduced by kind permission of the local network management, Liverpool District. Figure 6 is reproduced by kind permission of the local network management, Personal Communications Division, London.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### Biographies

Tony Dunn joined BT in 1974 from Oxford University with a degree in Chemistry. He worked on the development and production of optical fibres until 1980, when he was awarded a BT Major Scholarship to take an M.B.A. at Warwick University Business School. Returning to BT, he worked on area reorganisation with the Management Services Unit, before joining the Southend Area Board as Business Information Systems Manager. He was a founder member of the Customer Service Systems Task Force. He set up Wickford Computer Centre and with a small team developed and implemented the Cullinet materials system. Having initiated the Local Network Resource Plan Programme, he is now the Local Loop Support Manager for Personal Communications Division. He is a Member of the British Institute of Management and the British Inventory and Production Control Society.

Tony Ingram joined the Post Office Engineering Department as an apprentice in 1954. Long periods on external network and transmission, customer apparatus installation and maintenance as well as local network in Birmingham and Bristol followed. He was appointed Head of Planning and Works in the Plymouth Telephone Area in 1981. He was a member of the Local Lines Task Force from October 1987 to June 1988 and recently held local loop responsibility for the Central Territory Office. He is a project manager for the Local Network Resource Plan and is the Local Loop Support Manager South. He is an Incorporated Engineer and a Member of the British Institute of Management.

# Towards a Hassle-Free Access Network

A. KANE†, and D. J. YOUNG*

*This article describes a quality improvement project (QIP) which sought to establish an operational strategy which would enable Manchester District to begin the journey towards the realisation of a 'hassle free' access network—an objective which is an essential ingredient of every successful telephone company.*

## INTRODUCTION

Every successful telephone company (Telco) has clearly demonstrated that focussed and professional management of its access network is crucial to its business and commercial success.

On the other hand, Telcos with poorly managed access networks have invariably found it impossible to provide speedy and effective services to their customers while at the same time minimising operating costs.

This article describes a quality improvement project (QIP) which sought to establish an operational strategy which would enable Manchester District to begin the journey towards the realisation of a 'hassle-free' access network, an objective which could become a reality, not just a dream.

This project does not address the wider strategy issues in the access network such as roll-out of optical fibre, radio and long-term capital investment criteria. These issues are being considered as part of a national review.

## PUBLIC TELECOMMUNICATIONS NETWORK

Any public telecommunications network is essentially made up of five main elements (see Figure 1):

*Customer Premises Equipment* ranging from basic telephone instruments to sophisticated business call connect systems;

*Access Network* comprising, in the main, underground copper cables with some overhead distribution;

*Local Telephone Exchanges* comprising the equipment which enables all customers to make and receive calls;

*Transmission Links* connecting the local and main exchanges together into a total telephone network;

*Main Exchanges* comprising the equipment which enables trunk and international calls to be made.

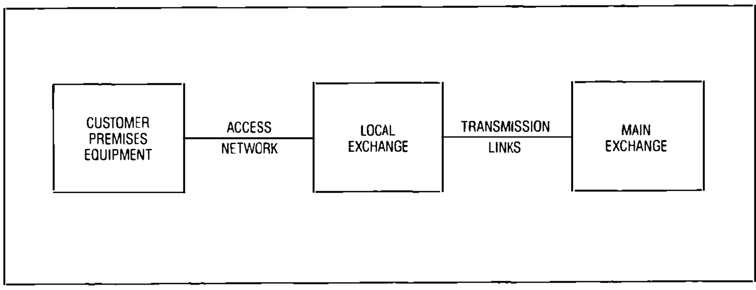


**Figure 1 Public telecommunications network**

## PRIORITIES FOR ACTION

The motivation and rationale for this project grew out of an audit, of all the District's activities, to identify and assess operational problem areas and the extent to which solutions were in place to resolve them.

In the case of the network, each element was examined against three main criteria:

- relative importance to the network;
- evidence of problems existing; and
- the extent to which solutions were already in place.

The results are as shown in Table 1. This analysis clearly showed that the priority area for early attention was the access network.

**Table 1**
**Operational Audit**

| Criteria | Network Element | | | | |
|---|---|---|---|---|---|
| | Customer Premises Equipment | Access | Local Exchange | Transmission Links | Main Exchange |
| Importance | High | High | High | High | High |
| Problems | High | High | Medium | Low | Low |
| Solutions in Hand | Partly | No | Yes | Yes | Yes |
| Priority for Action | Medium | High | Low | Low | Low |

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* BT Worldwide Networks

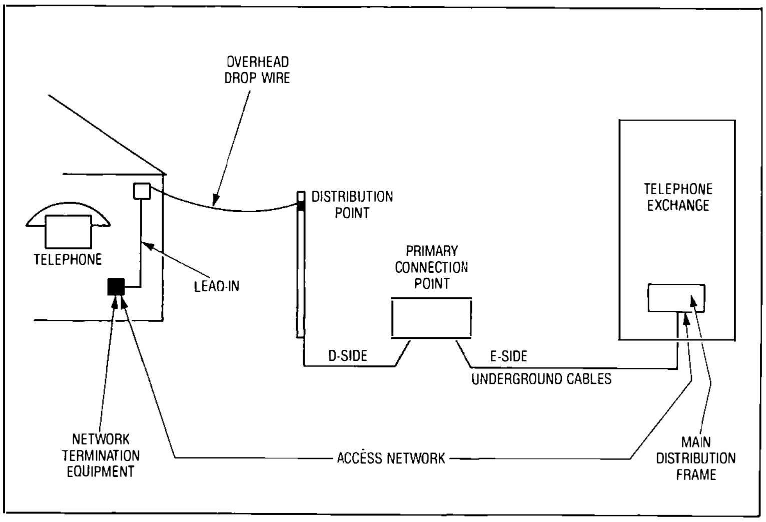



**Figure 2**
**Access network**

**TABLE 2**
**Manchester District Access Network Statistics**

| | |
|---|---|
| Exchange lines | 958 941 |
| Private circuits | 90 539 |
| D-side pairs | 1 426 812 |
| E-side pairs | 1 405 151 |
| Primary cross-connection points | 2 781 |
| Distribution points | 106 794 |
| Poles | 88 109 |

**TABLE 3**
**Manchester District—Financial Statistics**

| | |
|---|---|
| Access network asset base | £120M |
| Annual capital investment | £16·5M |
| Provision and installation | £5·6M |
| External network maintenance | £4·2M |
| Customers' apparatus and line maintenance | £2·5M |
| Maintenance controls | £3·3M |
| Total (access network) current account costs (per annum) | £15·6M |
| Estimated cost of poor quality (per annum) | £5M |

**TABLE 4**
**Manchester District—Failure Statistics**

| Activity | | Failures Per Annum | Failure Rate |
|---|---|---|---|
| Maintenance | Overhead | 58 528 | 0·064 faults/EC/pa |
| | Underground D-side | 36 353 | 0·039 faults/EC/pa |
| | Underground E-side | 22 041 | 0·024 faults/EC/pa |
| Installation | Routing pairs | 4000 | 10% |
| | Installers pairs | 6000 | 15% |
| Activities affected by record inaccuracies | | | 32% |

faults/EC/pa = faults/exchange connection/per annum

## ACCESS NETWORK STRUCTURE

By far the major portion of the existing access network components comprise 'copper' underground cables with some overhead distribution, as illustrated in Figure 2.

Underground exchange (E-side) cables are routed from the telephone exchange main distribution frame (MDF) to a primary cross-connection point (PCP). They are connected through to distribution (D-side) cables to serve individual customers via overhead or underground distribution points (DPs).

The total access network is made up of vast numbers of these components and an indication of the volume of each is shown in Table 2.

## ACCESS NETWORK FINANCIAL PROFILE

A good deal of money is spent on the access network, not only in providing additional plant and renewing old plant items but also in maintenance and installation activities, as can be seen from Table 3.

The cost of poor quality opportunity is enormous. Potential savings are at least as high as £5M per annum for Manchester District.

## ACCESS NETWORK—SIZING THE PROBLEM

From an operational viewpoint, it is possible to get a good understanding of the size of the problem by looking at a sample of existing available statistics, as summarised in Table 4.

These failures, which constitute 'the hassle factor', result in poor quality of service to customers, inconvenience to BT staff and are the prime cause of the high cost of poor quality on both installation and maintenance activities.

This cost of poor quality would be substantially reduced if the problems currently being experienced in the access network could be eliminated.

## QIP TERMS OF REFERENCE

Having identified a major problem area, with no positive evidence of an adequate solution for improvement in hand, it became clear that a first step along the road to recovery was the development of a comprehensive operational strategy for the access network.

Also it was recognised that, although optical fibre and radio alternatives were being developed, by far the majority of customers would be served by the copper network for many years to come. It was decided therefore that the project team would concentrate on the operational aspects of the copper network.

The traditional approach to this problem has been to try and 'buy' a solution through increased capital expenditure. However, two important and significant points were initially establised which ruled out this approach.

Firstly, it was seen that, relatively speaking, the District had not been starved of capital investment when compared with other Districts which had better access networks.

Secondly, it was difficult to identify and quantify the financial savings necessary to service the additional depreciation and interest charges which would result if capital expenditure was increased.

It was decided therefore that a quality improvement project (QIP) should be established with terms of reference to develop and implement a clear comprehensive strategy aimed at increasing E- and D-side pair provision; reducing failures experienced by installation staff; and significantly reducing fault rates, without any increase in capital expenditure.

As depicted in Figure 3, it was felt that if these three specific key objectives could be achieved, there would be a substantial bonus to be gained through reductions in current account costs and improvements in quality of service (QOS) to customers.

Having explained the background, the remainder of this article summaries how the project was tackled by the quality improvement team (QIT).

## QUALITY IMPROVEMENT TEAM

The District Quality Council owned the project as one of the Districts vital few QIPs.

The team which tackled this problem comprised the senior managers responsible for external planning, works and maintenance, and was led by the District Engineer. The team also included representatives from other divisions in the District whose work depended on the access network (for example, sales, installation, customer apparatus and line maintenance and frame management), and from HQ and the Northern Territory Field Office.

## TACKLING THE PROBLEM

The project route, which is depicted in Figure 4, was mapped out in line with the total quality management five-stage approach.

Given the scale and urgency of the problem, it was decided to develop a fast-track 'interim strategy', and this was quickly implemented as business as usual for external planning, works and maintenance activities.

This would be followed by the development of a more comprehensive long-term strategy which involved a full analysis of all aspects of access network activities.

In addition, it was decided to establish a small pilot exchange area to test, in a practical way, the ideas, practices and strategies developed.

## DEFINING THE PROBLEM

The problem was seen to be the absence of a clearly defined strategy for improvement. The requirement was to develop and document an effective strategy.

## COLLECTING THE DATA

Although much information (such as fault history) was readily available for analysis, it soon

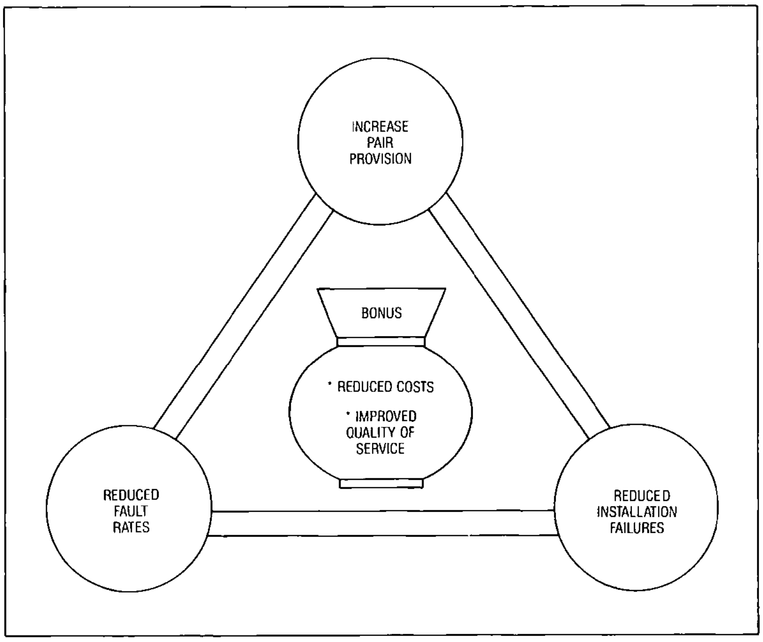



**Figure 3—Key objectives**

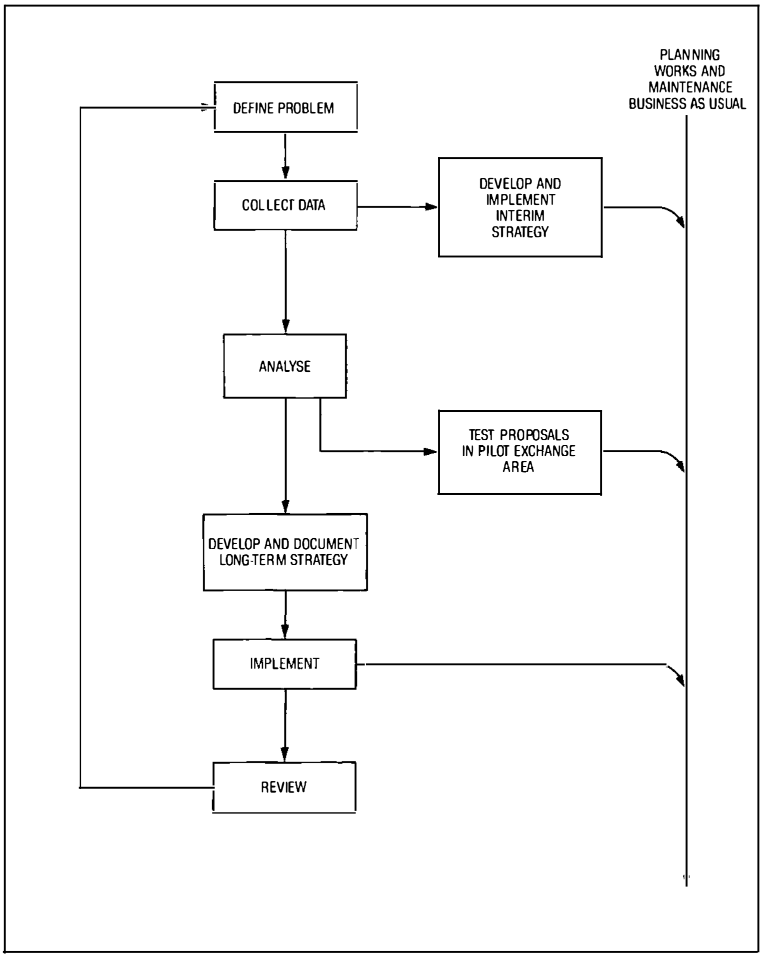



**Figure 4—Project route**

became apparent that, in order to get a clear understanding of the actual condition of the network, it would be necessary to undertake a number of physical surveys of existing plant items.

It was also recognised at this early stage that, in order for the resulting strategy to be accepted fully and implemented effectively, it would be essential to secure the personal commitment of all the managers concerned.

In an attempt to get them to own the problem and the solutions at an early stage, it was therefore decided that every manager, from District General Manager to first line supervisor, would participate in the data collection exercise.

Primary cross-connection points (PCPs) were the obvious choice for the first survey. PCPs are a major component of the access network and, with a total of 2700 in the District, it was possible to undertake a 100% survey.

## SURVEY RESULTS

The PCP survey results, given in Table 5, convinced everyone concerned that there were some real problems which needed to be addressed.

**TABLE 5**
**PCP Survey Results**

| | |
|---|---|
| No speaker pairs | 20% |
| Not ventilated | 14·5% |
| Faulty stays/hinges | 34% |
| Faulty duct seals | 81% |
| Not fully pre-connected | 81% |
| Faulty pressure alarms and gauges | 34·5% |

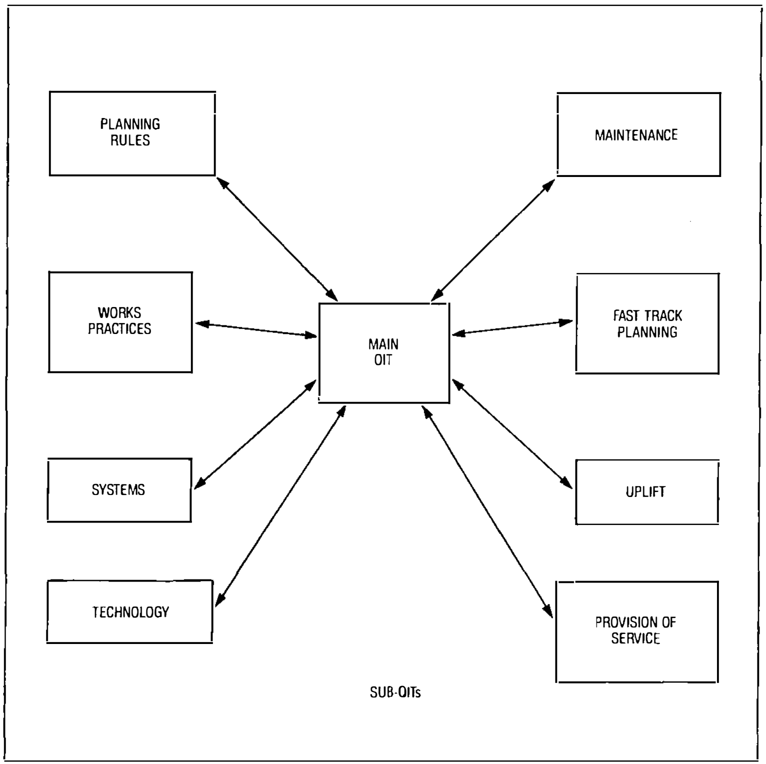



**Figure 5—Analysis QITs**

Initially, some managers were reluctant to be involved in the PCP survey. However, the findings of this survey, and the realisation that it would generate action plans necessary for real improvement, effectively converted all of them into eager surveyors, keen to be involved with unearthing the next problem area to be addressed.

Further surveys were then undertaken to assess the current state of poles, joint boxes, manholes, external block terminals, main distribution frame (MDF), cable chambers, business and residential network terminating units, line plant records, duct space records and network fault rates.

## INTERIM STRATEGY

At this stage, without any further detailed analysis work being undertaken, it became very clear that there were several obvious improvements which could be made. These were incorporated in an interim strategy document which was then rolled out at a three day external network conference held in May 1990. All of the external planning, works and maintenance managers attended for one whole day and left with specific action plans.

The conference was organised on the basis of a total quality management (TQM) workshop and designed to explain fully the results of the surveys and the link with the interim strategy.

In addition, all of the managers were given briefing packs which enabled them to cascade a common brief to all access network people and this began the process of involving everyone.

## ANALYSING THE RESULTS

With the interim strategy in place, it was then possible to begin the difficult task of analysing the vast amount of data which had been collected.

In order to involve more managers and staff in this process and move forward at a realistic pace, a number of sub-QITs were established to tackle specific problem areas as shown in Figure 5.

## DEVELOPING AND DOCUMENTING THE STRATEGY

The work of the main QIT and the output from the various sub-QITs, apart from 'systems', has been build into a comprehensive strategy, which is now fully supported by a series of local line instructions, document controlled to ISO 9000 standards.

The main thrust of the final strategy is as follows:

- *Planning* Employ saturation planning, best resource allocation, line plant gazetteer, fast-track planning and local lines records verification procedures.

● *Works* Employ best practices across the District with regard to cabling, jointing and overhead activities.
● *Maintenance* Employ best practices across the District with regard to joint closures, diagnostics, renewal and uplift activities.

The final strategy document covers all aspect of access network practices and procedures from fast- and slow-track planning to detailed works and maintenance instructions. Detailed guidance is also given on jointing methods, joint closure types, uplift practices and fault rate reduction initiatives.

The strategy extends beyond the District Engineer's responsibility, working practices, and procedures for sales, installation and customer apparatus maintenance divisions, for example, being updated through the involvement of their representatives on the main QIT.

## IMPLEMENTATION

The strategy has now been fully developed and the next long-haul stage is to implement this throughout the District and get the best practices into the blood stream of everyone who has anything to do with the access network.

A number of measures are being monitored and tracked to demonstrate the effectiveness of the strategy in improving the availability and reliability of the access network.

It is important that, as operational objectives are achieved, due attention is paid to ensuring that the benefits are carried through to improvements in customer service and reductions in current account operating costs.

If successful, the potential annual savings, illustrated in Figure 6, could exceed £5M each year for Manchester District alone.

## WHERE TO NOW?

*Implementation* The next step is to implement this strategy with as much determination and clarity as deployed during the development stage.

*Sharing* In addition, the information gained and conclusions reached will be passed to Personal Communications Division Zones and will be incorporated into the national review.

*Systems* An area which it has not been possible for the QIT to address is a review of the support and information systems employed in the management of the network.

The systems currently in use are virtually all standalone and were originally designed to meet a specific requirement. Very few refinements have been added and the systems are generally incapable of communicating with each other.

There is need for an urgent review and the development of fully integrated systems to ensure the most efficient and effective management of the network in the future and this is now being addressed at national level.

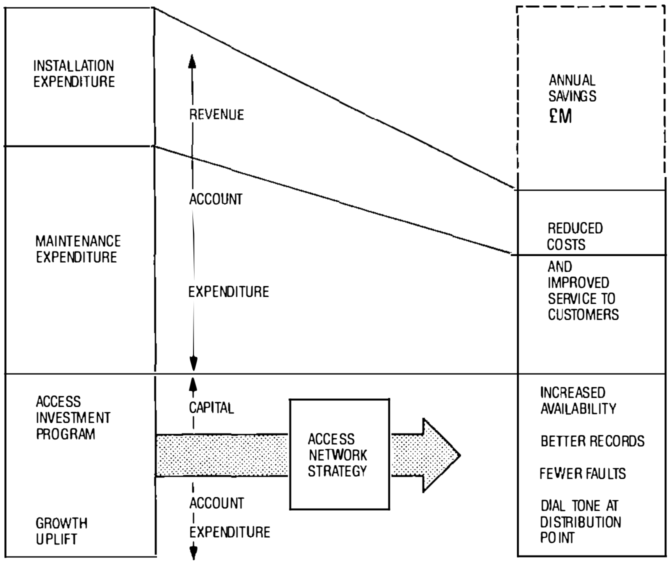



**Figure 6 Potential effects of access network strategy**

*Sovereign* Discussions are taking place to ensure that this important work continues in the Project Sovereign organisation.

## CONCLUSION

This QIP has achieved its objective by developing an access network strategy for Manchester District. It is now necessary to forge ahead with its implementation to ensure that the desired results are achieved.

The approach taken to gather the information and the involvement of a number of managers and staff in sub-QIPs, and all managers in access network strategy workshops, has brought about a significant change in culture.

The total quality management (TQM) approach adopted has given managers the means to evaluate and tackle problems with confidence, and they are already reaping benefits from some of the initiatives introduced.

Indeed, this process has transformed the access network team into a group of enabled and committed people who, by utilising TQM, have begun the journey towards a hassle-free access network.

### Biographies


Alfie Kane is Operations Director, Worldwide Networks North. He is a graduate of Queens University, Belfast, and has had extensive operational experience at all levels in BT. During the past few years, he has focussed particular attention on the task of establishing how best to create a hassle-free access network.

David Young joined BT as a Youth-in-Training in Birmingham Telephone Area in 1958 and has gained considerable operational experience in a variety of network and customer-facing appointments. He has been Manchester District's Customer Operations Manager and District Engineer (External) and is now Access Network Pilot Manager, Worldwide Networks.

# Keeping the Records Straight

P. H. SMITH†

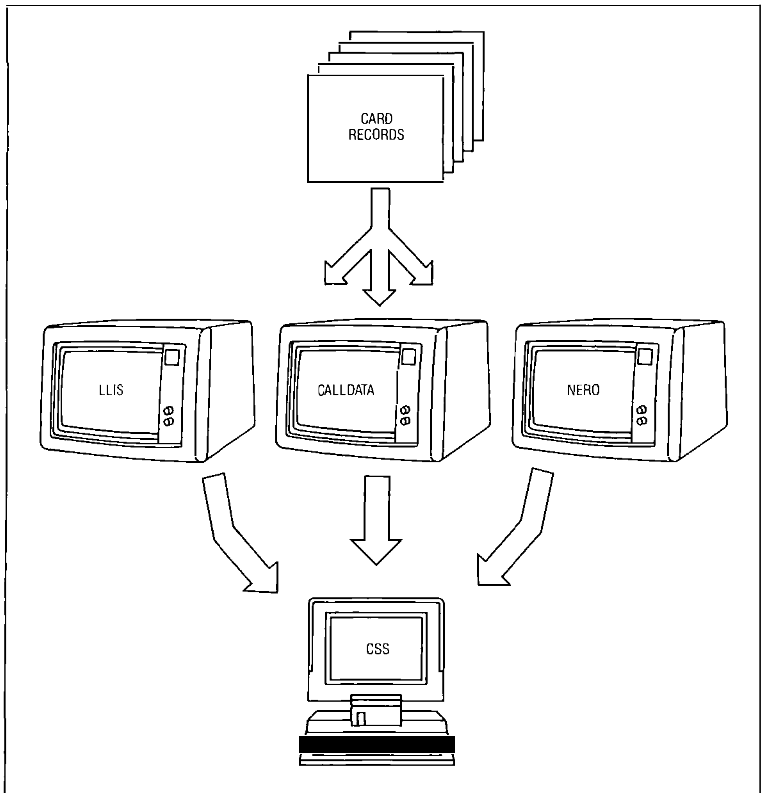
*This article describes the work done by BT to address the problem of inaccuracies in the records associated with the access network.*

## INTRODUCTION

It has taken BT many years to develop the copper access network and until recently card records have been the only record showing the utilisation of each pair in the local loop. The records keep information on each customer's line and the routing used to connect it to the local exchange, and they are also used to identify spare and faulty line plant. (Note that this is the 'logical' record, not the 'physical' record which shows the location of physical plant in the network and which is held on paper-based drawings.) The continuing high demand for services and the ever-increasing rate at which BT provides and ceases lines has led to a deterioration in the accuracy of the records. Given BT's commitment to improved service provision and restoration targets, it is more important than ever that its records are accurate.

† BT Personal Communications

**Figure 1**
**The transition from card records to CSS**




## BACKGROUND

The local loop access network provides lines to more than 22 million customers. These lines are routed via the main distribution frame (MDF) of the exchange through primary cross-connection points (PCPs), secondary cross-connection points (SCPs) and distribution points (DPs) to customers.

Prior to the introduction of computerised records, the information on these routings was kept on a card system in the routing office. Inconsistencies in the way the records were kept led to a gradual deterioration in their quality and accuracy.

### Customer Service Systems

Customer service systems (CSS) are a set of fully integrated computer systems that are installed in each of the Personal Communications (PC) Customer Service Zones. One of the subsystems, *local network records*, holds the local loop records. To make the transition from card records to CSS, it was decided to use interim computerised record systems as a cleansing device (Figure 1).

Three systems were eventually approved for the conversion:

(*a*) LLIS (local lines information system),
(*b*) CALLDATA (computerised administration of local line data), and
(*c*) NERO (networks records).

Each of these systems has its own housekeeping routines which are used to cleanse the database of any inconsistencies before downloading to CSS. Use of the housekeeping routines ensures consistency of the data, that routings are complete and without duplication, but the record may not necessarily be accurate and reflect the actual situation.

### Record Accuracy

A study carried out during 1985 into the accuracy of local loop records found that:

(*a*) The routings of a large number of circuits was incorrectly recorded.
(*b*) Some records of plant only one year old or less were already incorrect.

(*c*) A significant proportion of network changes due to installation and maintenance activities were not recorded.

(*d*) A significant number of DP records contained at least one routing error.

(*e*) A clear majority of the errors were between the PCP and the exchange.

Poor records quality carries a high cost to the business in terms of wasted effort, customer dissatisfaction, failed appointments and low morale among field people. Periodically, considerable effort has been expended in bringing the records up to a high level of accuracy but the inadequacy of the necessary records maintenance processes has allowed them to revert to their former state with the passage of time.

## TOTAL QUALITY MANAGEMENT

When total quality management (TQM) was introduced to the business, teams were set up in Districts to identify costs of poor quality. One common cost of failure was due to inaccurate records and the surveys carried out by teams confirmed the results of the 1985 study.

This cost of failure can be summarised as follows:

*Time wasted by people* Three groups of people depend on the local loop record: exchange, provision of service and repair people. Dealing with requests to provide or restore service to customers depends on a knowledge of the routings of the customers' lines and/or what pairs are available. If the pair identified to field people is in use, faulty or routed to another location, valuable time is wasted in finding and providing an alternative. In some cases, an alternative may not be available and appointments may fail or restoration of service be delayed.

*Time wasted by people responsible for routings* The job of a routing officer is to allocate available pairs to new orders and to provide information to repair people on the routing of existing customers. When an inaccurate routing is given out, the router wastes time looking for and allocating an alternative.

*Premature provision of line plant* If local loop records are allowed to become inaccurate, the identification of available pairs is made more difficult. In some cases, a PCP or DP may appear to be full on the record database while still having pairs available. This could result in the planning group providing a pair-gain device, diverting existing pairs or providing new line plant prematurely.

## CULLIS REPORT

Typical of the many projects undertaken to tackle this problem was one embarked upon by Thameswey District. It was recognised that there were several databases containing common information, and a computer program was developed to compare two databases and produce reports detailing the exceptions. Further investigation would then point to the inaccurate record which could be corrected on all databases holding that information. The program, which was called *CULLIS* (compare utility for local line information systems), was part of a package of initiatives aimed at cleansing and maintaining an accurate record database. Other parts of the package included functionalising the routing office, analysis of the routing failures and regular audit routines.

The BTUK Quality Council gave its support to the Thameswey project and recommended that it should be further developed and implemented nationally.

### Development

Early on it was recognised that the CULLIS software was only part of the solution. In addition to the database comparisons, it was essential to establish procedures which would maintain the accuracy of the records once cleansed. Additionally, two other initiatives needed to be coordinated with the project: the Frame Management Strategy Paper and the conversion of local lines onto the CSS database.

All Districts were suffering from the problems caused by inaccurate records, and to capture initiatives from other Districts a series of national workshops and seminars was held. The information gathered at these events was used to widen the input to the project.

### Best Practice

Through the national workshops, visits to Districts and District quality improvement teams, a manual was produced which contained the best practices identified at the time.

## RECORD CLEANSE PROCESS

The record cleanse process is outlined in Figure 2.

Before the record cleanse work commences, it is necessary to identify and implement processes and procedures which will keep the records accurate. These procedures are essential in order to eliminate the causes of failure and to maintain the accuracy of the records once cleansed.

The process relies upon the creation of an accurate MDF record as the starting point.

### Building the Frame Record

Exchange records are kept on the LLIS/FR (local lines information system frame record) database. This holds information about the cross-connections on the MDF and the customer's telephone number or private circuit designation. The exchange modernisation pro-

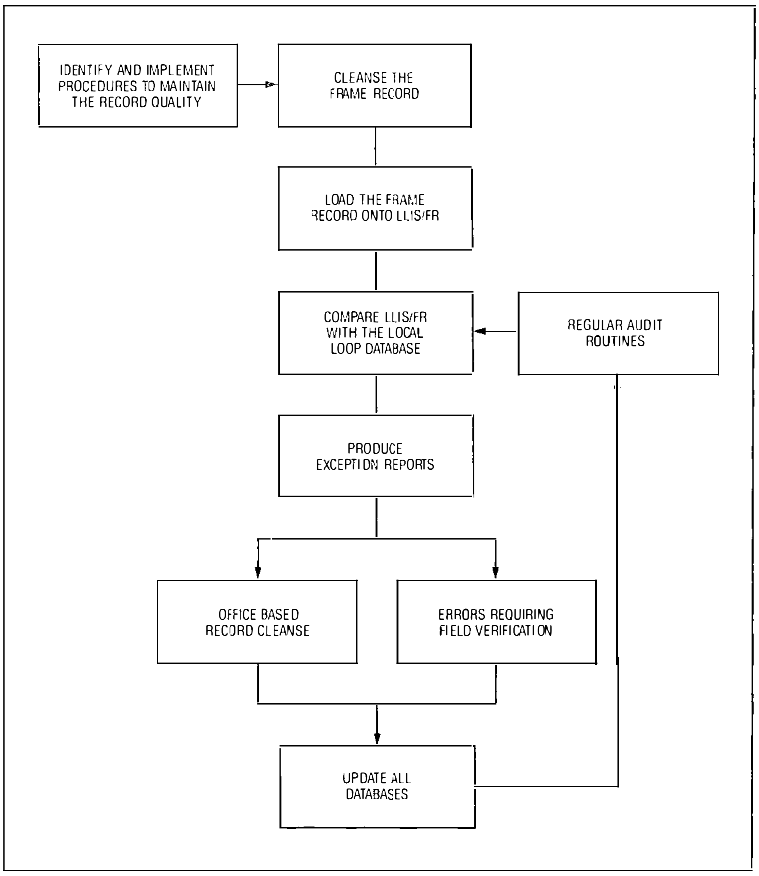



**Figure 2**
**The record cleanse process**

gramme has provided an excellent starting point for building the LLIS/FR record. The programme requires an accurate record of all public switched telephone network (PSTN) lines connected to the switch at the time of conversion and with some extra effort an accurate record of the private circuits can be added.

Where an exchange is not included in the programme or where an existing LLIS/FR record must be verified, several items of equipment can help. These testers build up a record electronically and can save time and effort. Best results are obtained at digital and electronic exchanges, although success has been achieved with the older exchanges.

## Correcting the Local Loop Record

The local loop record contains information about the customer's telephone number or private circuit identification and the routing used from the MDF through the PCP and SCP to the DP. The telephone number, or private circuit identification, and MDF termination are common to both the local loop record and the LLIS/FR record, so the next step is to compare the two databases and produce a report of all the discrepancies. These discrepancies will fall into two groups: those that can be cleared from the office and the remainder that will need investigation in the field. After investigation, the local loop database can be corrected and is then in step with the MDF record.

## Audits

Little benefit would be gained in carrying out a record cleanse programme if the records were again allowed to deteriorate with time. The final stage of the process is to implement an audit routine to ensure that the accuracy of all databases is maintained.

## Awareness

One reason for the continual decline in the accuracy of the records is the lack of awareness of the cost of poor quality. More demanding service provision and restoration targets have meant that there has been 'no time to update records' at the end of a job. It has always been 'someone else's problem' that the records are inaccurate. 'Someone else' has always been responsible for cleaning up the records.

The ongoing accuracy of the records relies on feedback from everyone who makes any changes or finds inaccuracies during the course of their work. They should all understand the consequences of not reporting such changes.

In order to publicise this message, a video was produced for use at team briefs. The main purpose of the video is to make people aware of the importance of the records and the cost of failing to keep them accurate.

## Record Quality

During and after the record clean-up process, it is essential to monitor the accuracy of the records. When the cleanse starts, it is necessary to prioritise the work and this requires a knowledge of the areas which are causing the most problems. When the records have been cleansed there is a need to monitor the quality so that early action can be taken if the records deteriorate.. One tool which has been developed to enable this to be done is the REQUEST (records quality estimation) software package.

## Central Records Office

Historically, the routing and records officer was responsible for all functions of the routing process on a particular group of exchanges. The officer would provide routings for new orders, give out routings when a faulty pair had to be changed, answer the telephone to give out information on the records, and update the records when pairs were provided or moved.

With the advent of CSS order handling, and the computerisation of the local loop record, it has become possible to make more efficient use of the router's time by redistributing the router's tasks. This concept has been realised as the *central records office*. Tasks are not carried out on a geographical or patch basis but each group is responsible for a particular function. That function could be allocating orders to new customers, answering telephone queries, maintaining the record database or database cleanse and integrity. Figure 3 shows some of the tasks which are carried out in the central records office. Peaks in one functional area can be covered by people from the other functional areas and a rotation of duties helps to prevent boredom and increase the skill level of the office. Also shown in the central records office is the postal address file (PAF) maintenance team. The PAF links engineering data and customer address details and its accuracy is vital to get the most out of CSS.

Several PC Customer Service Zones have already adopted the central records office concept and are achieving a faster throughput of work as a result.

## RESULTS

Record cleanse is still in its infancy and the early results have concentrated on the number of pairs which have been returned to the network for re-allocation. It has been found that, on average, 1 % of the working connections on an exchange can be recovered through record cleanse activities.

## FUTURE

Record cleanse procedures are continually being refined and updated. There cannot be a universal solution for the cleanse and maintenance of the local loop records to suit all situations. The process has to be tailored to meet the particular needs and situation of the customer.

The next step is a project which will:

- develop processes and procedures to eliminate the causes of failure and maintain the accuracy of the local loop records,
- implement these processes and procedures consistently across BT, and
- cleanse the records knowing that they will remain clean.

## CONCLUSION

The access network is one of BT's most valuable assets and the proper management of it has a definite impact on BT's profitability. Much valuable work has been done to cleanse the local loop records and it is important that these foundations are built upon. There are valuable benefits to both BT and its customers from a record cleanse programme but it needs continuous effort by all concerned to maintain the records in an accurate state.


## ACKNOWLEDGEMENTS

The author would like to acknowledge the work done by Districts on the record cleanse process and to thank them for their cooperation during the course of the project. In particular, he would like to thank Malcolm Coulson of Thameswey District where much of the early work was done.



### Biography

Peter Smith is the Records Quality Manager in the Business Process Group of Personal Communications London Division. He started his career in Bradford Telephone Area in 1963, where he spent his early years in the external planning group before working for the Hong Kong Telephone Company on a major electrification project. His career has concentrated on the local loop and has included spells on Major Works Control and the CSS National User Group Local Lines Cutover Team. He has also worked in the Middle East on various assignments for British Telconsult and lately worked on the records cleanse process for Field Engineering Support.

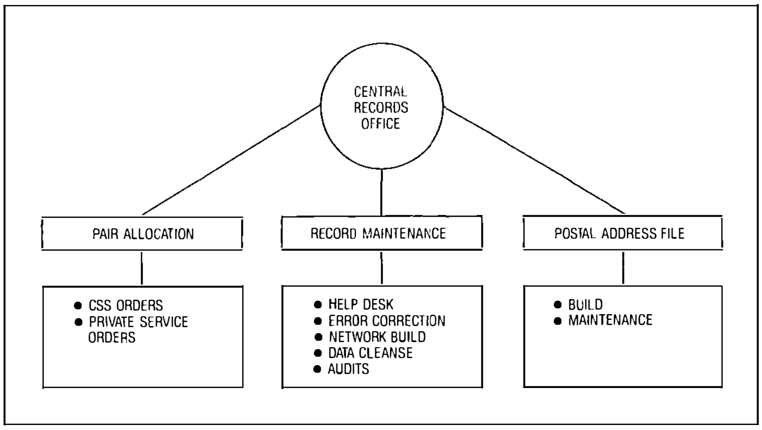




**Figure 3**
**The central records office**

# Automated Line Testing for the BT Repair Service

J. R. FALCONER†, C. P. HEMMINGS*, S. POTTS†, I. F. BLAKE†, and N. J. VANNER†

*Computerised line test systems are in use throughout the BT public switched telephone network repair service. This article reviews their history, current capability and anticipated evolution. It also covers their overnight use for local network surveillance.*

## INTRODUCTION

The BT repair service handles about 30 million customer contacts per year and employs in excess of 30 000 staff in public switched telephone network (PSTN) fault reception and clearance roles. This process is increasingly managed using customer service system (CSS) repair handling as it replaces the older repair service control (RSC) administration systems.

Modernisation of the repair service has progressed dramatically over the past two decades. In the early-1970s, most customers reported telephone faults to an operator, who relayed the details to an engineer at a test desk in the appropriate exchange building. Paper records were used for all customer, fault and routing details. Line testing from each test desk was restricted to about 16 km (10 miles) by the physical parameters of the test junctions. During the 1970s, many test desks were replaced by modular RSC equipment. These retained the moving coil meter of the old test desks, but introduced a call distribution and queuing facility enabling direct reception of customer fault reports.

In the late-1970s, trials were conducted on computerised remote line test (RLT) systems. The prime objectives were to overcome the geographic constraints of line testing and achieve benefits of scale with larger and better managed fault repair centres. Parallel developments were in hand with optical mark read (OMR) fault dockets and the computerisation of records and fault management processes.

After the success of these trials, the BT Board, in 1982, authorised a programme to modernise the repair service by the introduction of integrated workstations providing call reception, remote line testing and computerised records and fault handling. The technology to achieve this was not available at that time and further development was required.

To improve test coverage and to gain experience, early limited implementation of remote line test systems was targeted at problem areas where large exchanges were outside test junction limits.

The equipment used (known as *RLT2*) was provided by STC but was not at that stage capable of integration with the administration of repair service controls by computer (ARSCC) equipment being used for records and fault handling.

This phase, having proved the capability and benefits of remote testing, was followed by a major international tender for line test system (LTS) equipment to cover half the UK customer base (10 million lines).

Northern Telecom and Vanderhoff were selected to supply their LRS100T and CL680 systems respectively. During this period, Teradyne 4TEL systems were installed in two Districts, and early versions of Gateway H, designed by BT East of Scotland and manufactured by BT Fulcrum, were in service in Scotland. Subsequently, the Teradyne 4TEL system was selected for London. By 1989, the whole BT repair service was using computerised LTSs, with roughly equal coverage by each of the four systems.

### Outline of Generic Line Test System Architecture

The architecture of LTSs has not significantly changed from that described in an earlier article on 'Processor-Controlled Systems for the Testing of Customers Lines'[1].

As shown in Figure 1, LTSs comprise two main components:

- test system control processors, and
- remote test units or test heads.

The test system control processors interpret user commands, then select and control the appropriate remote test unit. They also process the parametric results passed back from the remote test units and determine the probable fault location to one of three possible locations: exchange, local network or customer apparatus. The test system control processors are usually centrally located adjacent to the RSC or at a computer centre.

Remote test heads are usually situated within the exchanges and have two main functions:

† BT Worldwide Networks
* BT Personal Communications Division

firstly, to control the exchange test access switches to connect the test unit to the customer's line; and secondly, to perform parametric tests on the line and pass the measurements back to the test system control processor. The parametric tests cover resistance and capacitance/impedance of the line, both as a loop circuit and each leg to earth. A check is also made for any extraneous voltages.

### *Test Access*

Test access is a feature provided by all exchange types which is used to connect the remote test head to the circuit to be tested (see Figure 2). The actual physical control of it varies between exchange types but the facilities offered are generally consistent. These are as follows:

- Split out: allows the remote test head to be connected to the customer's line with the exchange conditions removed.
- Split in: allows the remote test head to be connected to the customer's line circuit with the customer's line removed. This facility is only provided on digital exchanges (see below).
- Bridged: allows the remote test head to be connected (bridged) onto the customer's circuit, without the removal of the exchange conditions or the customer's line.

(*a*) *Split out* In this configuration, the exchange conditions are removed from the customer's circuit. A direct connection is made between the remote test head and the customer's line. This configuration is used by the test head to measure the electrical characteristics of the line and its distant termination. In conjunction with a speech path, it also allows interactive tests

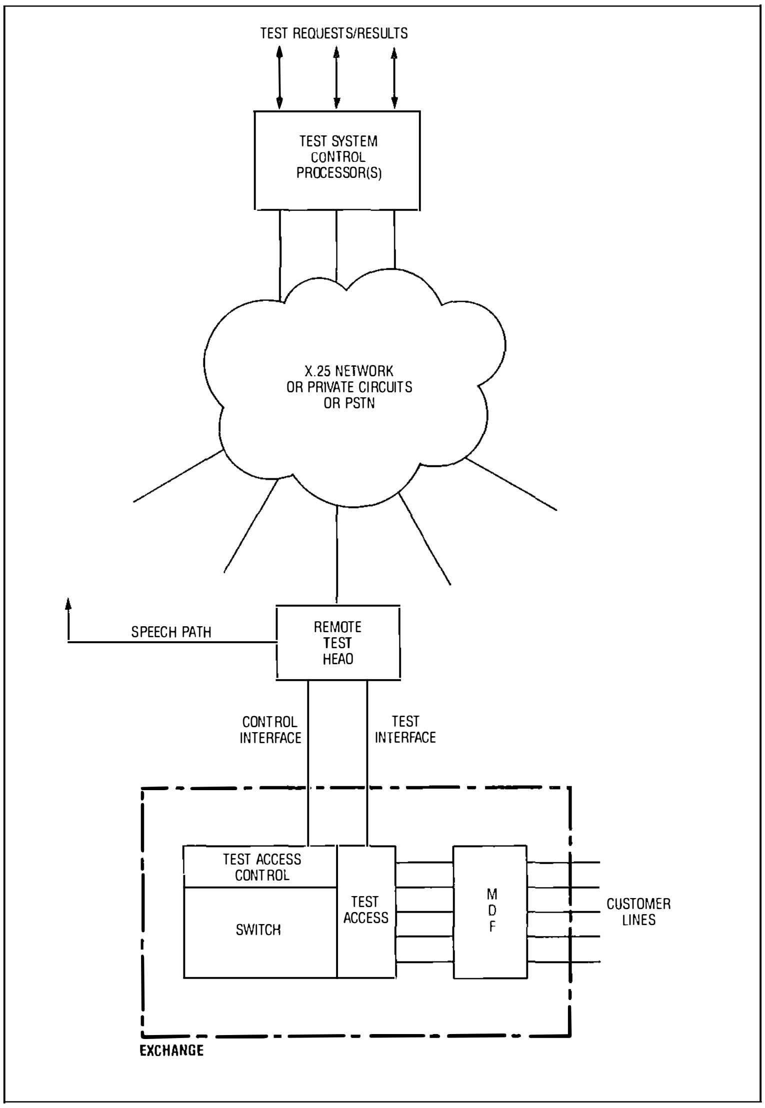



**Figure 1**
**Line test system: general architecture**

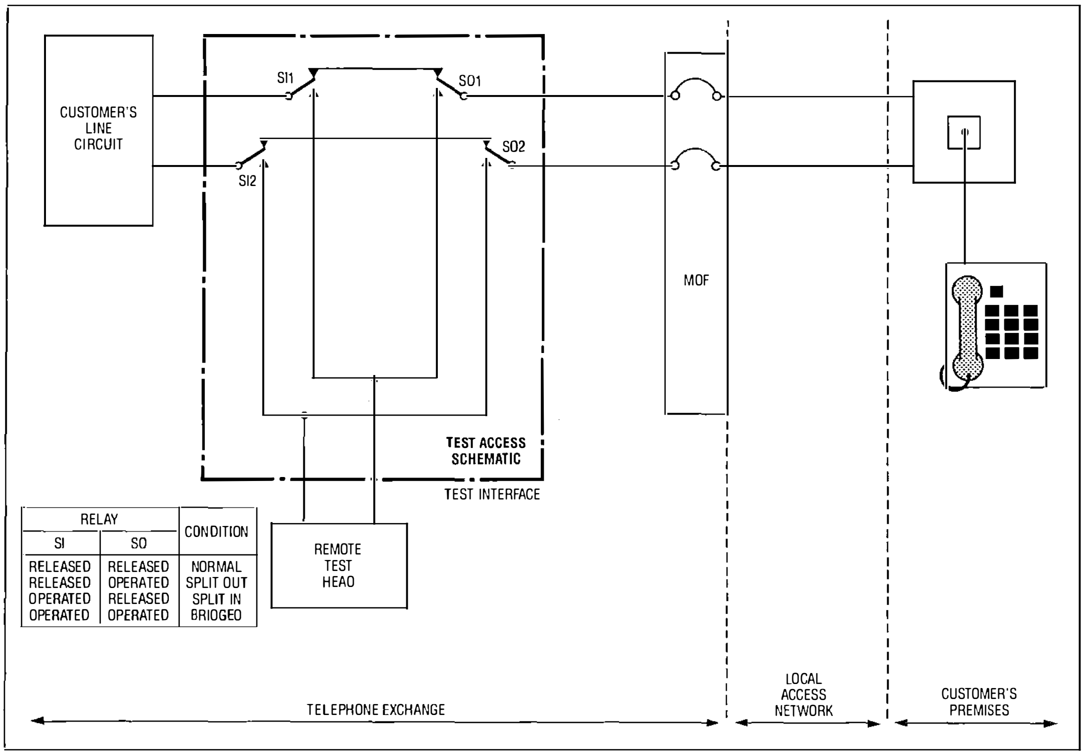



**Figure 2**
**Test access: schematic**

to be performed, with the co-operation of the customer (that is, key-pad test, ringing, etc), to determine if their telephone equipment is functioning correctly.

(*b*) *Split in* This configuration disconnects the customer's line and allows the test head to be connected directly to the customer's line circuit in the exchange. By simulating the customer's telephone/PBX, the test head can confirm correct operation of the customer's exchange termination. This configuration is only supported by digital exchanges. However, if analogue exchanges are instructed to *split in*, they go into the BRIDGED configuration.

(*c*) *Bridged* This configuration is used for analogue exchanges in place of the SPLIT IN configuration or when a fault condition prevents test access switching to the SPLIT OUT condition. The LTS interpretation of the results then allows for the presence of the exchange conditions on the line. In addition, this configuration is used by all exchange types, in conjunction with a speech path, to monitor customer's calls; for example, if they are having outgoing service difficulties.

When LTSs were first introduced, users were served by visual display terminals (VDTs) connected directly to the test system processors. Even with multi-processor configurations, users generally only had access to test customer lines within their own RSC area. The early method of integrating line test facilities with RSC computerised administration systems, now referred to as *screen level integration*, was by the use of multi-ported VDTs with customised firmware.

The first use of this system was trialled and implemented in Portsmouth during the early-1980s using Lynwood Beta VDTs connected to a Teradyne 4Tel LTS and an ARSCC fault repair administration system. This permitted a single entry of the customer number to both systems and testing to be conducted in background while entering the fault details into the ARSCC system. The screen display could be switched from ARSCC to LTS and back as required. Test results received by the VDT when displaying the ARSCC screen were superimposed on the bottom line of the screen display.

Screen-level integration provided a very useful form of linking test and fault administration systems for the repair service, but required constant support to maintain compatibility with new software releases on the host systems and frequent changing of EPROMs in the terminals.

The VDTs, although expensive, were a practical proposition for the limited numbers required in RSCs. The introduction of CSS repair handling (CSS RH) increased the potential number of users of each repair service administration system, hence the development of processor-level integration between the LTSs and the CSS large mainframe computers.

## CUSTOMER SERVICE SYSTEMS INTEGRATION OF LINE TEST SYSTEMS

By the end of 1984, it had been decided that LTSs should be integrated with the CSS mainframe-based development at processor-to-processor level to bring widespread availability of LTS facilities to CSS users via the standard CSS terminal network.

The specific aims were to:

- provide line testing facilities to repair service users in both front office and back office organisations via standard CSS terminals (front offices are the reception point for customer fault reports and other customer requests, back offices are more specialised and organise field activity to provide or restore customer service);
- provide line testing facilities tailored to other business users requirements via standard CSS terminals;
- closely integrate LTS facilities with user facilities provided by the CSS job and activity management, and repair handling subsystems;
- integrate the LTS facilities to produce virtually standard user procedures irrespective of LTS type whilst incorporating all the available features of each LTS type; and
- provide District-wide test access from any CSS terminal with transparent access irrespective of LTS type.

### Interface Messages Specifications

Interface messages specifications defining the CSS requests, LTS responses, request/response sequences, error handling, etc and incorporating LTS state machine models of operation have been developed for each of the LTSs. The production of these message specifications allowed the CSS and LTS developments to be conducted concurrently by defining the precise set of rules by which the systems interact. The processor–processor link uses X.25 protocol via a packet switched interface working over point-to-point full duplex data transmission facilities at 9·6 kbit/s.

### CSS Software Design

CSS interface software is separated into three entities:

(*a*) the software interacting with user driven transactions,

(*b*) the CSS database, and

(*c*) the software managing the LTS processes.

The user transactions are handled by the normal CSS production communications interface control system (CICS). The LTS systems interface is in a separate CICS on the same mainframe. The two CICS systems interact in a standard IBM environment (MRO). The LTS system interface module, which is itself part of the common interface system (CIS) managing all on-line interfaces with CSS, controls the LTS interfaces at the applications and session levels of operation via the network packet switch interface (NPSI) software in the front-end processor. The NPSI software manages the X.25 communications at Level 3 and below in the open systems interconnection (OSI) model.

Figure 3 shows a generalised system architecture which serves to illustrate the basic elements of the integration.

The first CSS–LTS integration of the Vanderhoff CL680 LTS was brought into service in Newport, South Wales in September 1988 with the other integrations following:

Teradyne 4Tel, South Downs, October 1989;
Northern Telecom/STC LRS100T, Lancs and Cumbria, June 1990,
Fulcrum Gateway H, East Anglia, December 1990.

Roll-out across the UK continues with full coverage expected by mid-1991.

### Testing of a Customer's Line from a CSS Front Office Terminal

The basic schematic of the interconnection between CSS, LTS and test access is shown in Figures 1 and 3. The CSS front office receptionist, on receipt of a customer reported fault, enters the customer's directory number into the CSS terminal. All the customer's details are then displayed on the receptionist's terminal; these include name and address plus a brief description of any previous fault. The receptionist records the reported symptoms by using the enter fault (EF) transaction, and the testing and dispatch phase is progressed automatically. CSS selects the appropriate LTS processor and forwards the directory number or equipment number. The information from CSS enables the test system processor to select a remote test unit which has access to that particular customer and to set up data and speech communication paths.

The remote test head instructs the test access controller to set the test access switches to the required customer. When this has been performed, the test access controller confirms its status to the test unit. At this stage, the test access is in the SPLIT OUT configuration with the remote test unit measurement head connected to the customer's circuit. The appropriate parametric tests are carried out by the measurement unit and the results stored. In some cases, some analysis is performed within the test unit; otherwise, all the parametric results are passed back to the LTS processor. The processor then runs these parametric results through a diagnostic algorithm which produces a number of statements. These statements can include the current status of test access (that is, SPLIT OUT, BRIDGED or SPLIT IN), whether the line is terminated (that is, a master jack or telephone has been detected) and a dispatch statement that details the most likely location of the fault. These statements and all the parametric results are passed back to CSS, where further analysis takes place prior to plain language statements being displayed on the receptionist's terminal.

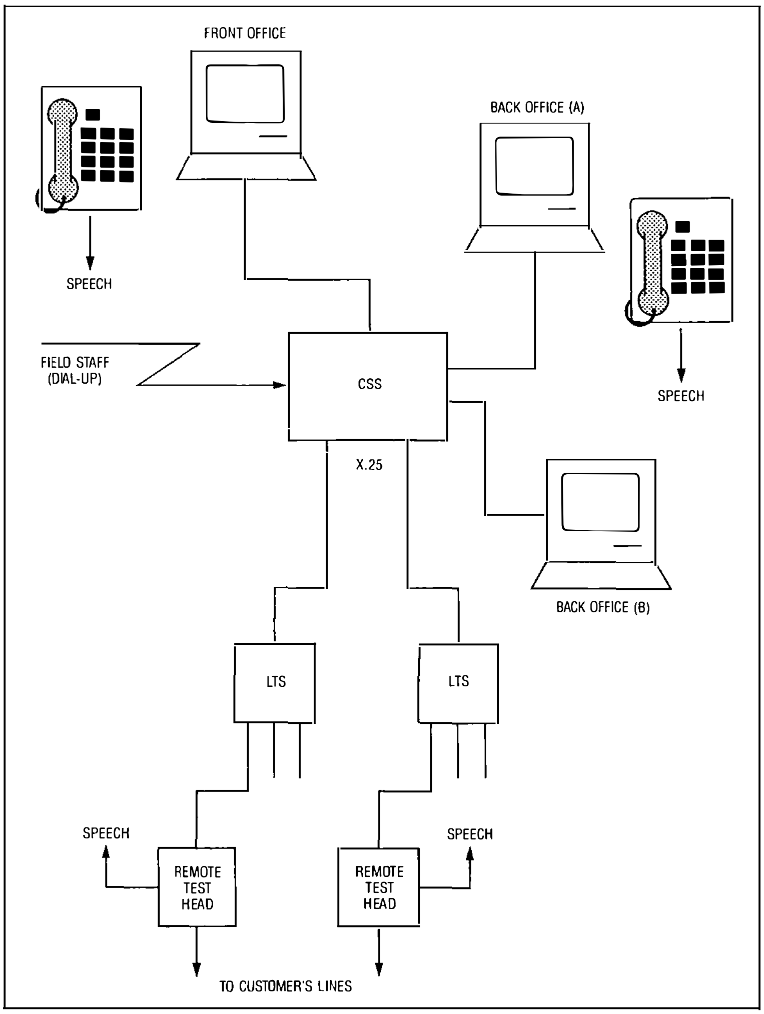



**Figure 3 CSS–LTS integration**

The EF transaction controls the testing carried out at this reception phase and can include line testing, exchange testing (draw and detect dial tone) and customer apparatus testing (dial and key-pad functionality).

A customer reporting a fault using his/her own line may be requested to hang up and wait to be rung back by the receptionist after a line test has been performed. The customer will be rung back utilising the speech path from the front office to the remote test head. Once this link has been established, any interactive testing that is required between the receptionist and the customer can be performed (for example, testing the key pad).

The receptionist can now inform the customer of the most likely location of the fault, make an appointment for the telephone engineer to call, if required, and release the fault report automatically into the appropriate work queue.

Once the testing has been completed, communication with the customer has been concluded and a fault report created, the EF transaction releases the link to the LTS processor. This in turn causes the remote test head and

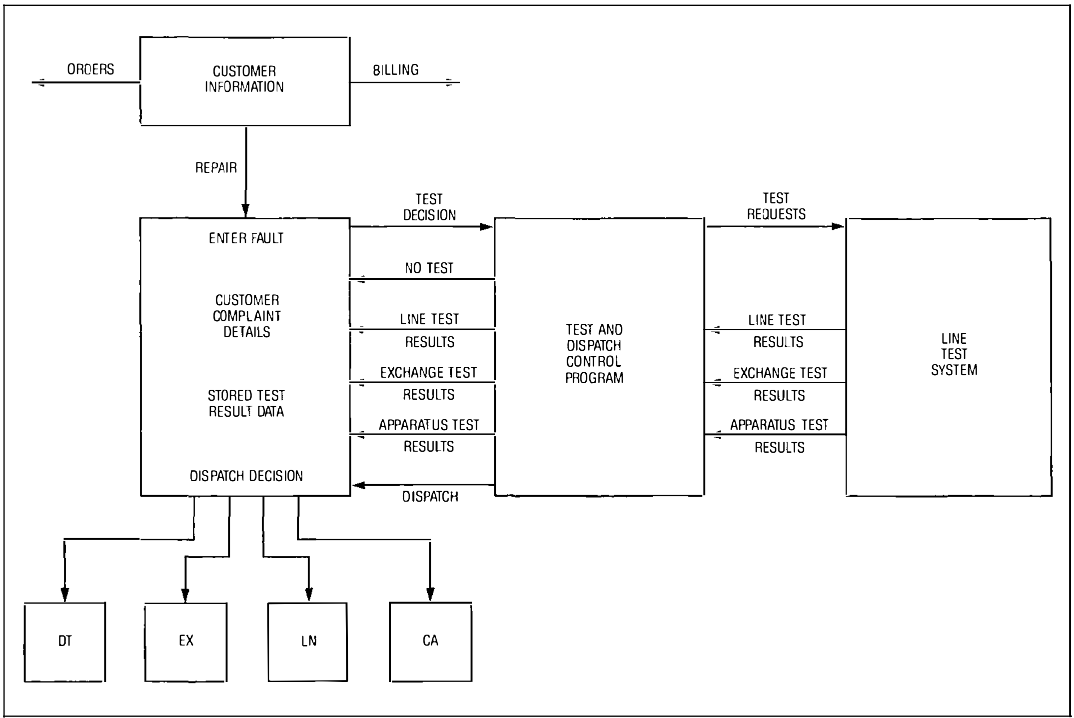



**Figure 4**
**CSS fault entry**

test access to be released. This completes the line testing cycle. The detailed test results are stored in the CSS database for use by back office and field staff during the fault clearance process.

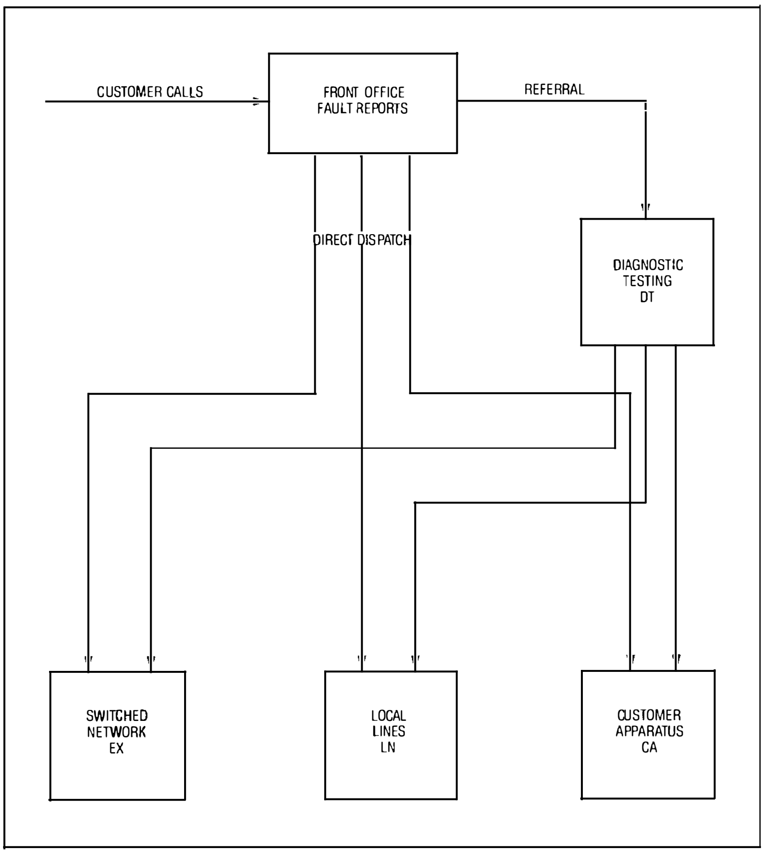
The testing carried out at the reception stage is determined by the CSS EF (enter fault) transaction from a knowledge base, created and maintained on the CSS database by local management (see Figure 4). Also on the database is information defining the status of the customer's service, for example, TEMPORARILY OUT OF SERVICE, SERVICE INTERCEPTION, or INCOMING CALLS ONLY. The combination of the coded customer's complaint (for example, no dial tone), the line test result, the exchange test result and the customer apparatus test result produces a dispatch decision which is converted by the EF transaction into a CSS job which is then controlled by the repair handling subsystem and automatically distributed.

The receptionist need have no knowledge of the repair organisation for the fault to be distributed to the appropriate work queue. The dispatch, and hence job categories, are:

CA: customer apparatus maintenance,
EX: exchange and the switched network maintenance,
LN: local network maintenance, and
DT: diagnostic testing required.

Initial correct fault dispatch from the front office speeds restoration of customer service and minimises work for others in the repair organisation. If the fault location can be determined whilst the receptionist is still in contact with the customer, an appointment can be agreed for an engineer to visit the customer's premises, if necessary, avoiding the risk, delay and frustration of a no-access visit. When an automatic direct dispatch is not appropriate, a referral (see Figure 5) can be made to an expert diagnostic tester who will make the necessary dispatch decision using the parametric results and taking into account such factors as prevailing weather conditions and recent history of faults in the locality.

**Figure 5**
**Key repair service processes**



The level of decision making performed in CSS is essentially to define the testing necessary to find the fault and the required dispatch of fault reports where no fault condition is detected by the LTS. At a more detailed decision making level, the LTS dispatch decision can be fine tuned. These facilities are LTS specific and are:

- For the Teradyne LTS, the ability to modify dispatch decisions received by CSS in CSS Table TD800.
- For the Northern Telecom LTS, there is a District configurable dispatch matrix in the LTS interface processor (micro-Vax).
- For the Fulcrum Gateway LTS, the ability to modify dispatch decisions received by CSS in CSS Tables GWADS and GWLOC, and to set test condition failure thresholds in the LTS interface processor (GIX) and in the remote test units.
- To date, the Vanderhoff LTS changes have been made within the LTS.

Work is continuing to optimise the set of decisions/test procedures on an LTS and specific locality basis. Progress is now being measured as described in a later section on LTS dispatch accuracy.

### CSS Back Office Facilities

A set of common CSS transactions incorporate and augment the features and facilities of the LTSs. These transactions take the CSS user transparently into the appropriate CSS transaction for the LTS type being accessed making LTS specific features available. Access for test is by telephone number or fault report number. Conversion to the appropriate test access number for multi-line installations is performed invisibly to the user by CSS applications software. Users can move freely between repair handling transactions and line test transactions by means of the active-key system without the need to re-input telephone or fault report numbers. During on-line test transactions, all test results obtained can be stored on the database. Results are stored:

- by telephone number for one week;
- by fault report number for as long as that fault report has a status other than historic (HIS) (the first and last set of results are stored for 6 months when the fault report status becomes HIS); and
- by telephone number for 6 months if stored as provision of new service via CSS transaction RAT (request auto-test).

### CSS User Speech Path

When using certain CSS transactions, the user needs to be able to speak and listen on the line under test. This allows users to monitor lines for customer conversations or to talk to the customer on the line being tested. A speech path needs to be established between the user and the LTS. The direction of call set up, the point in the LTS system architecture to which the call is connected and the type of signalling used are LTS specific.

In Figure 3, the user speech terminal is represented by a telephone, but this could be any speech network terminating device; typically an automatic call distribution (ACD) system in the front office. Also shown in Figure 3 is back office (A) representing a user with speech path access and, therefore, being able to access all the on-line and background transactions. Back office (B) represents a user without speech path access only able to carry out tests not requiring the speech facility. Typical uses include scheduling sequences of background tests and automatic camp-on testing of a line over a period of time.

### CSS Transaction Switching

Hitherto, CSS users have only had access to the database and facilities on their local mainframe computer, generally covering one District. The integration of LTSs with CSS has enabled District-wide test access from any CSS terminal.

With the development of networked CSS mainframes with transaction switching facilities, it will soon become possible to access any integrated LTS in the UK from any authorised CSS terminal and test any customer's line. This represents a major achievement when as recently as 1987 many RSCs only had test access over a radius of about 16 km.

## ASSESSING THE DISPATCH ACCURACY OF LINE TEST SYSTEMS

LTSs only have an impact on the handling of some categories of fault report:

- Total Fault Reports
  - No Test (eg broken telephone)
  - Test
    - Tests OK (TOK)
    - Customer Apparatus (CA)
    - Local Network (LN)
    - Exchange (EX)
    - Diagnostic Test (DT)

In assessing the value-add provided by any LTS in a given environment, the fault reports dealt with as no test and tests OK are generally ignored, being significant only if the system makes a lot of tests OK errors (an aspect requiring further investigation).

Until recently, the accuracy of LTSs has been assessed by considering simply the percentage of faults dispatched to the correct skill group first time, the correct skill group being judged by comparing the LTS dispatch statement with the Fault Report (A51) clear code. In calculating the percentages, there has not been consistency about the inclusion or exclusion of the fault reports dispatched to diagnostic test. Typically the calculation would be:

$$\text{accuracy} = \frac{CA + LN + EX}{\text{faults tested} - TOK}$$

where CA = faults correctly dispatched to customer apparatus,
LN = faults correctly dispatched to local network,
EX = faults correctly dispatched to exchange, and
TOK = tests OK faults which generally are either not dispatched or referred to a diagnostic tester.

This calculation makes no allowance for the differing value-add or failure costs associated with success or failure of dispatch to each dispatch category. The differences arise from the contrasting times and hence costs associated with clearing or localising different types of fault (see Table 1).

**TABLE 1**
**Typical Fault Handling Times**

| Initial Dispatch | Fault Cleared (mins) | Initial Dispatch Proved Incorrect (mins) |
|---|---|---|
| CA | 60 | 40 |
| LN | 180 | 90 |
| EX | 30 | 20 |
| DT | 3 (*Note 1*) | 12 (*Note 2*) |

*Note 1*: Typical time to carry out diagnostic test and despatch fault to work queue.

*Note 2*: Typical average time/DT fault to account for DT dispatched faults which are incorrect on first attempt. (Assumes DT accuracy of about 75%)

Given that a fault has occurred (a source of failure cost in its own right), the fault clearance time will inevitably be incurred by the skill group finally clearing the fault. The failure cost caused by inaccurate dispatch by the LTS can therefore be assessed by the formula:

average wasted minutes/tested fault

$$= \frac{40\ CA' + 90\ LN' + 20\ EX' + 15DT}{\text{fault reports tested} - TOK}$$

where CA′ = total faults incorrectly dispatched to customer apparatus by LTS,
LN′ = total faults incorrectly dispatched to local network by LTS,
EX′ = total faults incorrectly dispatched to exchange by LTS,
DT = total faults dispatched to diagnostic test by LTS (note, factor of 15 allows for DT fault cleared time plus DT incorrect dispatches),
TOK = total faults dispatched tests OK by LTS.

A computer programme called *TAROT* has been produced by Thameswey District to compare the A51 fault clearance code with the initial LTS dispatch statement where CSS repair handling is used with a processor-level integrated LTS. Using data gathered in this way, results ranging between 10 and 19 average wasted minutes per tested fault have been observed. Evidence is now being gathered to guide the fine tuning of systems to optimise dispatch accuracy.

In its present form, the dispatch accuracy formula produces results which are not totally independent of the fault mix (that is, proportions CA, LN, EX) and further consideration is being given to the need for a more sophisticated calculation of dispatch accuracy.

## LOCAL NETWORK SURVEILLANCE

Line test facilities have historically been used following receipt of a fault report from a customer to assist in the localisation and clearance of the fault. The availability of microprocessor controlled remote test units capable of accessing and testing all customers' lines presents the opportunity to carry out line testing during the night when the test traffic generated by repair service is low.

Local network surveillance (LNS) is a facility for testing customers' lines each night and identifying, by computer analysis, plant degradation and service affecting faults, thus providing a capability for detecting and repairing defects before they become service affecting. For some years, Fulcrum has provided a dedicated LNS test and analysis system called *SCOUR*, which was implemented in a number of Districts.

Teradyne, Fulcrum and Vanderhoff are now offering similar capability on their LTSs with analysis systems, LPAS, RAP and REVEAL respectively.

All of these systems work in a similar manner, being programmed with details of exchange number ranges, required insulation standard thresholds for good, suspect and faulty lines, and the start and stop times for the routine test programme. Line routing information is obtained from CSS or one of the interim systems still in use (for example, LLIS, CALLDATA and NERO).

BT has recently introduced a programme to expand the LNS capability from the current low level of implementation to full national coverage by March 1993. This capability will be essential to achieve the quality standards set by the business, including the 5 and 9 hour fault clearance times and the recent target set by the BT Management Board to reduce customer service failures by 90% over the next 5 years.

Implementation has commenced with several trial systems. Some parts of BT with Fulcrum SCOUR equipment are planning to upgrade and extend their systems to improve the coverage and test access capabilities to lines on System X exchanges. The availability of LNS facilities is only the start with the provision of the tool. The real challenge is the introduction of new processes and procedures to change the repair service from a reactive to a proactive role—a major challenge for local management. This change must take place before the benefits in quality of service and manpower savings are achieved.

### Bell Tinkle

One of the problems with implementing LNS is the sensitivity of telephones and other devices attached to the PSTN. There is at present no agreed national specification for test signals which can be applied to lines without causing interruption to approved attachments.

During the test cycle, a very small proportion of telephones will bleep or bells tinkle, and some alarm systems will respond to the removal of exchange conditions during testing. The test cycle varies between one and a half seconds up to nearly 20 seconds depending upon the test unit type and the line conditions, faulty lines generally result in a longer test time while precise measurements are made. This has not caused great problems in the past when most testing was carried out following a fault report from the customer. A few bell tinkles were generally taken as an encouraging sign that someone was working on the line.

Two approaches are being pursued to overcome these problems. Firstly, a bell-tinkle suppression device has been developed which can be plugged into a telephone socket in a similar way to a doubler which will eliminate the problem on all telephones connected on that line.

This device has been tested on many different telephone types and found to be effective on all three-wire types. British Standards Institution (BSI) approval for attachment to the network is being sought (the green spot) and volume production is now being planned.

The long-term solution involves representation to the BSI TCT2 committee and the agreement of industry to a new clause in the specifications for telephone and all PSTN attachments to detail the testing which can take place without causing the device to mis-operate. In the short term, many customers who complain about bell tinkle are only too pleased to accept this minor inconvenience once they realise its cause. In other cases, the line in question can be omitted from LNS routines. All new telephone models now sold or rented by BT have been tested to ensure that they do not produce bleeps or bell tinkle when tested by LNS.

## IMPACT OF NEW NETWORK TECHNOLOGY ON LINE TESTING

The current generation of LTSs and their interfaces were developed primarily to support simple PSTN services delivered to the customer via the existing access network, with the majority of customers served by a dedicated metallic pair. However, line testing must evolve in order to support a more widespread use of optical fibre and radio in the access network and the introduction of digital customer services such as ISDN 2 and ISDN 30. It is important for both quality of service and operational costs that line testing capabilities and accurate dispatch are maintained or improved as these changes take place.

### Test Access

The use of the test access by existing LTSs has already been described. However, the introduction of new services (for example, ISDN) and bearers (for example, radio, fibre or multiplex systems in place of dedicated metallic pairs) leads to new testing and test access requirements. New services and modern bearer systems often incorporate at least a degree of fault self-reporting and diagnosis; however, this rarely covers customer–exchange signalling or the final link from the bearer remote system terminal (for example, multiplexer) and the customer's telephone or equipment. This capability can only be achieved by either incorporating a simple test head into the remote system terminal or by providing test access at this point for use by LTSs. This latter method requires either a collocated LTS test head or a metallic pair back to the exchange-based test head. Both these options can prove prohibitively expensive.

The overall requirement is for transparent, integrated testing irrespective of service and bearer. The evolution of test access and management system (TAMS) based architectures (see below) plus the development of a CSS–operations and maintenance centre (OMC) link combined with appropriate in-built test capability are key elements in meeting these requirements.

### Impact of Switch Technology

The interface between the remote test head and the exchange consists of two separate interfaces (see Figure 1): the test interface and the control interface to test access. The test interface is the same for all exchange variants. All analogue exchange types require different control interfaces to set up the test access, as do currently both the main digital exchange types (that is, System X and AXE10). Work is in hand to develop the AXE10 exchange to use the BT Network Requirement BTNR 316 interface already used by System X.

### Impact of Access Network Technology

The technology in the access network can be categorised into four groups:

(*a*) metallic lines providing basic PSTN services,
(*b*) metallic lines providing digital services,

(*c*) fibre providing PSTN and digital services, and

(*d*) radio providing PSTN and digital services.

The testing of metallic lines providing PSTN has been well covered already.

### *Metallic Lines Providing Digital Services*

Where test access is not provided, the only testing that can be achieved is via the OMC. This testing will only determine the status of the link, no testing of the physical metallic path is generally possible. Until completion of the CSS–OMC interface currently being developed, faults will have to be double handled by CSS front and back offices. The economics of including test access in the provision of digital services over a metallic bearer are currently being considered.

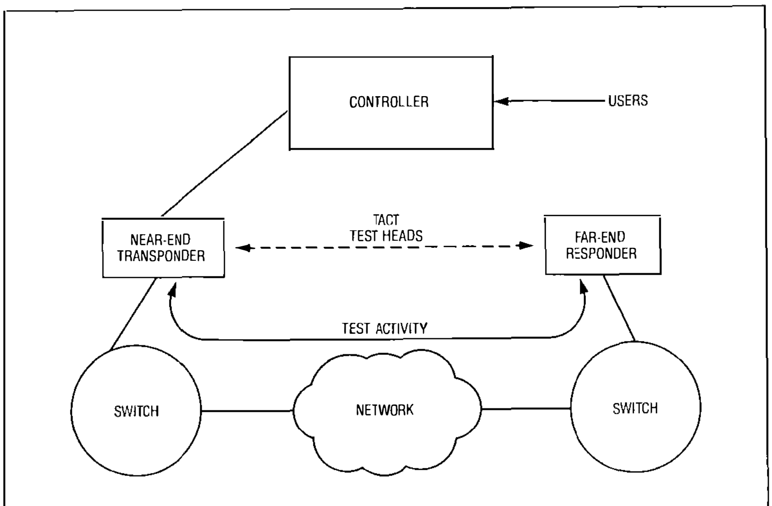
If test access is provided, tests can be performed both by the OMC and the RLT systems. This would improve the diagnostics on initial contact with the customer. When such a line is tested, the digital network terminating equipment exhibits conditions that are similar to a faulty line. A solution to this problem is currently being sought.

### *Fibre/Radio Providing PSTN and Digital Services*

The provision of service over fibre and radio system bearers exhibit similar testing problems, though their technologies are of course completely different. They are covered jointly in this section. From the testing viewpoint the provision of service can be split into three distinct parts: exchange, fibre/radio system/multiplexer (referred to as the *bearer*), and the metallic tail.

Fibre/radio systems generally have an inbuilt management system which monitors correct functioning. The status of the exchange and customer's line can be determined by the use of the OMC. If test access is available the metallic tail may be tested using the LTSs. Test access under this situation is not in the exchange but in the remote multiplexer. A physical metallic pair is required from the test head in the exchange to the test access in the remote multiplexer. This is often referred to as *metallic bypass* or *metallic backhaul*. If the multiplexer is large, then a dedicated test head may be provided at the remote site. A current research and development project is investigating the possibility of a low cost test head that could be incorporated within remote multiplexer designs.

**Figure 6**
**Transmission and connectivity tester architecture**




## OTHER SYSTEMS FOR LINE TESTING

### Network Quality Testing

Customers buy end-to-end telephone calls, so it is not sufficient merely to test the customer's local line and signalling capability. Quality assurance of telephone calls is achieved through network quality testing. There are two main facets to network quality testing: the ability of the network to connect calls, and the transmission performance of the path.

Measurement and analysis centre (MAC) equipment is the main tool in the present network for assessing the switching/connectivity capability but, as it has very limited capability for measuring transmission performance, it is complemented by a range of proprietary transmission testing tools generically called *automatic transmission test systems* (ATTS). These include systems such as 3M Clearline, Rotadata ANA, Teradyne Testnet 1000, Vanderhoff ATMS 2001 and Anglia Line Tester.

As with MAC, ATTS places test calls in the network and then, on a call-by-call basis, measures the bothway transmission quality of the path established between sender and responder. Transmission quality is highly subjective and to obtain an objective measurement, ATTS considers the gain, response and noise of the circuit. Some connectivity information is also available. The use of proprietary senders and responders limits the use of such equipment, and no interworking is currently possible between the various ATTS systems. Each system is effectively a closed user group and it is not possible to obtain consistent measurements across the network to give an accurate picture of the service being experienced by customers.

A feasibility study to produce a BT specified version of ATTS is well underway. Potential suppliers are already closely involved in this work. The system will be known as *transmission and connectivity tester* (TACT). The main objectives are to allow full interworking of equipment and to produce clear standards for end-to-end transmission performance of the network.

The main uses for TACT will be to manage the performance of the network and to assist transmission maintenance. Additionally there are requirements arising for the international parts of the network for quantification of echo and time clipping on international circuits.

The likely architecture of the system is outlined in Figure 6. As indicated in the diagram, TACT is expected to comprise a controller with a number of test heads remotely situated at exchanges in the network. It is expected that there will be two types of test heads:

*transponders* which communicate with the controller and then instigate testing activity via a network test connection, and

*responders* which have only a network test connection and respond to test activity generated by transponders.

Digital signal processing techniques (hardware configurable by software) are likely to be employed and it will be possible to remotely upgrade test heads by software download as in some of the existing LTSs.

The initial realisation of TACT test heads is likely to be standalone with direct connection to circuits at an exchange. It is however the long-term aim to engineer TACT onto the LTS equipment. There are many benefits of such an approach, both technical and operational. Such a configuration would allow TACT to share LTS engineering; for example, racking, power and exchange test access. The use of test access in preference to permanent wiring would provide greater flexibility allowing tests out to the customer and through the network to be coordinated; for example, in response to the customer's fault report. This is shown in Figure 7.

## Repair Service Users of Operations and Maintenance Centre Facilities

The OMC provides all the administration functions, where interaction with a modern exchange is required. OMC terminals are situated in various locations to allow appropriate maintenance, installation and provision staff to access them. Each user is only allowed access/use of the facilities that they require to perform their duties.

The basic facilities that are available from an OMC terminal for repair service users are as follows:

- Provide and remove administration-controlled call barring.
- Read customers' facilities. This facility allows the current state of the service markings of a customer line to be checked.
- Hold and trace activities. Provides the facility to hold a connected line or to trace the originator of the call to either the route circuit or an individual customer.
- Change customer facilities. Allows the user to change the calling condition of PBX line cards, change the device state for a directory number, change the disconnect/clear time, provide a howler tone to an AXE10 line, provide other user finished announcements and to provide/cease service interception (SVI).
- Automatic line test and status check. The line test facility, in the case of digital exchanges, uses the in-built exchange test facilities rather than the line test systems that have previously been discussed. Their functionality is similar to that of the line test systems; however, the overall test time is very slow, which is one of the reasons why they are not generally used by the repair service. The line status facility enables the status of the customer's line to be determined and monitored.
- Enhanced fault information. Facility to maintain an enhanced level of service care for specific customers and inform the repair service that a fault is interrupting customer service.
- Access transparent mode. This enables specialist staff to interact directly with the exchange in man–machine language (MML).
- Read equipment number. Enables the user to read the equipment number for a specified directory number.

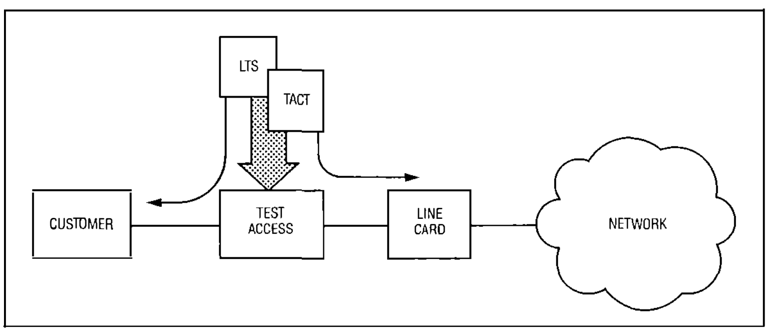
## Test Access and Management System

Test access and management system (TAMS) is a strategic system concept covering all testing of the network. It forms part of BT's strategic systems architecture the purpose of which is to guide the evolution of systems architecture to produce integrated, cost-effective support systems for future operations. TAMS is responsible for responding to all test requests to confirm and locate network faults, confirm satisfactory network operation or identify network degradation. In order to do this it will:

- maintain testing information (for example, test systems available, test access numbers etc),
- schedule tests (for example, prioritise demand and routine testing, co-ordinate tests requiring sequencing of several test systems), and
- receive and respond to test requests.

Some of the key interfaces between TAMS and other strategic systems are shown in Figure 8. Figure 9 illustrates the TAMS role using more familiar, present-day terms. Work, taking account of proposed international standards, is currently in hand to decide whether TAMS should be built as a standalone system. The alternative is for the functions to be embedded in the network and other support systems. Whatever the answer, it will take many years to evolve TAMS-based architectures for network testing. Meanwhile, every effort is being made to ensure that current developments do not prejudice the long-term aim.

**Figure 7**
**Relationship between TACT and LTS**



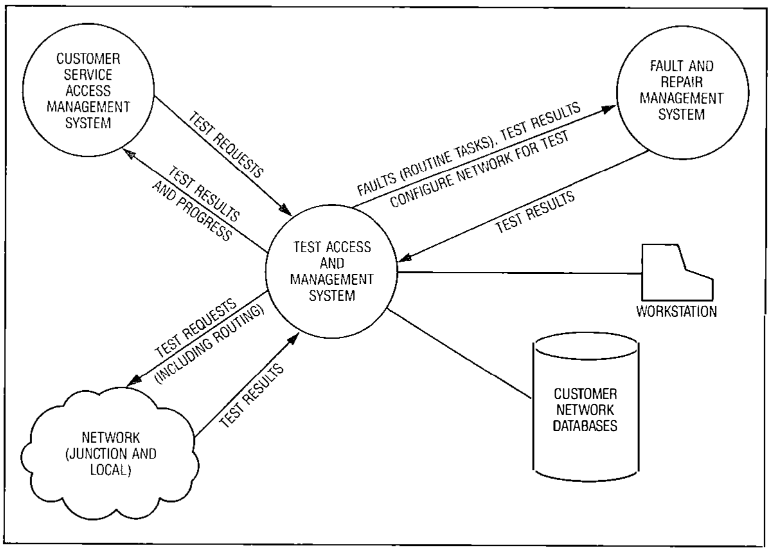
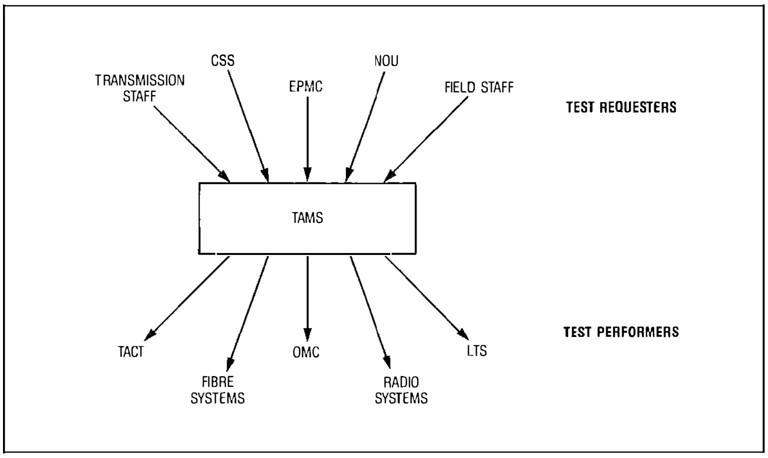



**Figure 8—Test access and management system: simplified architecture**




EPMC: External plant maintenance centre NOU: Network operations unit

**Figure 9—Test access and management system**

## CONCLUSIONS

An earlier issue of this *Journal*[2] was a special issue covering network administration for the 1990s. It highlighted the importance of effective and efficient network management in providing and maintaining world-class telecommunications to customers. The access network is generally the final link in the delivery of services and so must be managed and maintained to the same high standards as the rest of the network. The importance to the repair service of an on-line testing capability has been described along with the complexities of maintaining this capability as new technology is increasingly used in the network.

## ACKNOWLEDGEMENTS

This article has described technology which has evolved over many years and tribute is due to countless Headquarters, District and suppliers people both past and present who have contributed to the achievements described. We look forward to working with many of you on the next chapters.

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## Biographies

John Falconer started his career as a Post Office student gaining a degree in electronic engineering from Southampton University. He worked in Headquarters on network and switch planning before spending nine years in Wales and the Marches where as Customer Service Area Manager in Newport he implemented the pilot for CSS including repair handling and front office. In 1989, he returned to Headquarters where he now heads the unit in Worldwide Networks responsible for access network operational policy processes and support systems including LTSs.

Colin Hemmings worked in the Leicester Telephone Area on private circuit design, data transmission provision and the repair service until 1984 when he joined the CSS National User Group at the outset of the CSS project working on repair handling and the integration of LTSs.

Steve Potts started his career in the Circuit Laboratory in 1967 designing test equipment for 24- and 30-channel PCM. He worked in HQ on teletraffic theory, TXE4A design and development, System X, maintenance control subsystem and test network subsystem top level design, installation support and support to Districts on the Branch Systems General Licence when BT was liberalised. Since 1986, he has been involved with the management of the design and development of LTSs plus the control and management of research and development into new testing techniques and control mechanisms. He currently leads the team in Worldwide Networks responsible for this area of work.

Ian Blake started his career in the Guildford Telephone Area working in the exchange maintenance and customer repair service areas before moving to HQ where he was involved in the design and development of portable exchange test equipment. He then joined the tripartite TXK1 exchange enhancement study before moving into the line testing area with responsibility for the design and development of modular line test equipment for the repair service. He was responsible for the specification and implementation of the early RLT systems and now leads a team in Worldwide Networks responsible for the LNS and line testing implementation programme.

Nigel Vanner joined the Post Office in 1971 having gained a first class honours degree in electronic engineering at Southampton University. He worked on the initial design feasibility of System X and latterly on trunk systems proving. In 1986, he moved onto exchange maintenance policy and the wider aspects of managing an all-digital network as an entity. Since 1989, he has been responsible for the processes and systems for network performance management. He now heads up the unit in Worldwide Networks on Network Technical Audit.

# Practical Network Planning—A Day in the Life of a Local Line Planner

P. H. SHANKS†

*This article reviews the work of a local loop planner through the eyes of a Level 1 manager. The opportunity is taken to look at current computer tools, records and working practices. Explanation of how the various tools are used will give an understanding of the planning process. Towards the end of the article, possible significant changes to the planning process are explained and their implications reviewed.*

## INTRODUCTION

The day recorded in this article is an amalgam of the activities of two Level 1 managers responsible for external planning in Bristol Customer Service Area (CSA) within the Severnside District during a two-week period in late-1990.

## ARRIVAL

On the manager's arrival at the office at 7.45 hours, three of the six (TO and T2A) planners are already busy at work. While there is still peace and quiet and before the telephones start ringing, the first half to three quarters of an hour of the day are to be devoted to checking the electronic mail and looking at queues on the customer service system (CSS). The general clearing of the normal post will take place later in the day when the post has been delivered.

The first task is to look at each of the queues associated with the individual planner's load. Of particular importance is a check for potential waiters. This is a daily requirement to ensure that any reactive planning is quickly completed to avoid missing a customer completion date. Where there is a need for extra line plant, a decision will be required. The decision could take one of three forms:

(*a*) a small works estimate (which should be completed quickly) may be prepared for either a pair diversion or a minor relief scheme;

(*b*) a more comprehensive plan is required; or

(*c*) part of a planned scheme may be released for completion.

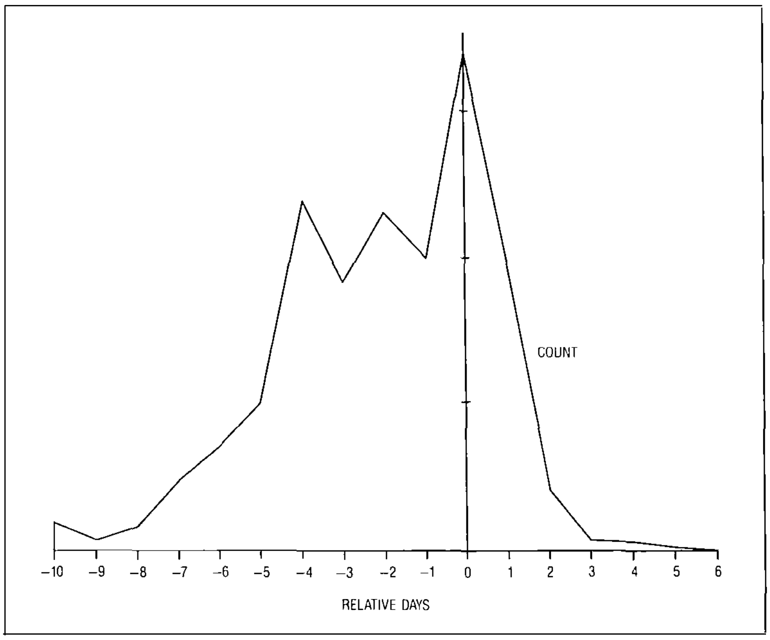
Since the beginning of the financial year, the last category thankfully is not appearing very often. The necessary relief plans prepared earlier in the year have either been completed or for a few are awaiting execution. Those awaiting execution are with either the contract duty or the direct labour works controls.

Once the queues have been checked, the workflow is addressed via CSS-MIS. The performance of the planning group is quickly evaluated. Of particular interest here are the commands which give graphical output:

| | |
|---|---|
| GBWF | Backlogged work by function |
| GDMD | Demand pattern |
| GECDN | EC (exchange connection) work in delay (by total) |
| GECDV | EC work in delay (by value) |
| GFLF | Future load by function |
| GFLFQ | Future load by function/queue |
| GFLQ | Future load by queue |
| GLBF | Line balance by function/queue |
| GLLOOP | Local loop backlog |
| GWLF | Work load backlog—function/queue |
| GWSF | Work scheduling by function |

Examples of the outputs from these commands are shown in Figures 1–4. Other commands are available to give tabular information. The next step before moving on to the main work of the day is to check the appointments schedule and to see if there are any urgent messages that need to be addressed. A message is waiting from a Sales/Marketing colleague that suggests a need to have discussions about a major customer at Avonmouth. A time for a meeting that afternoon

**Figure 1**
**Work scheduling—routing**




† BT Worldwide Networks South

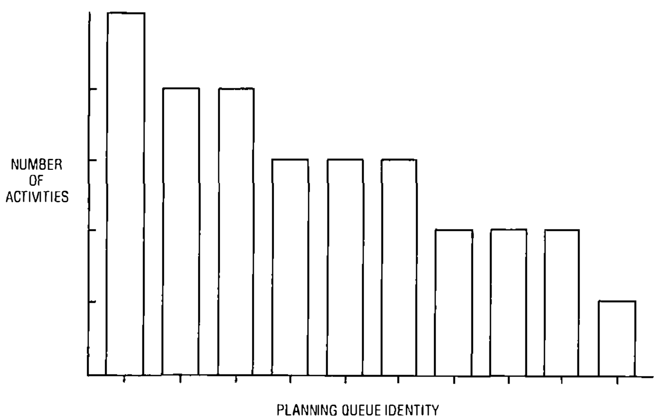



**Figure 2—Typical weekly workload by CSS function**

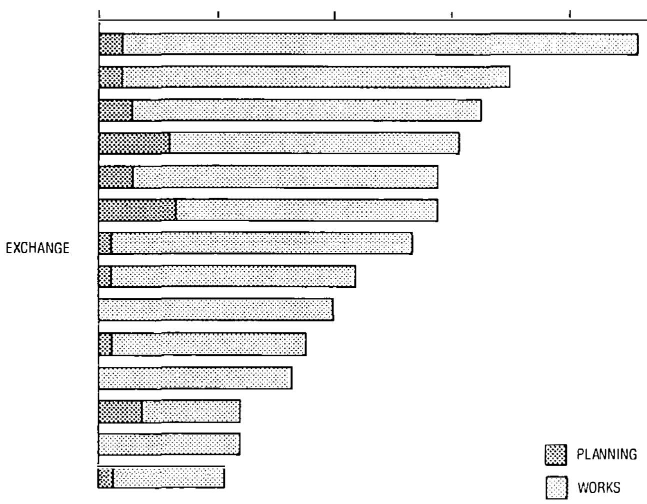



**Figure 3—Local loop backlog (typical week ending)**

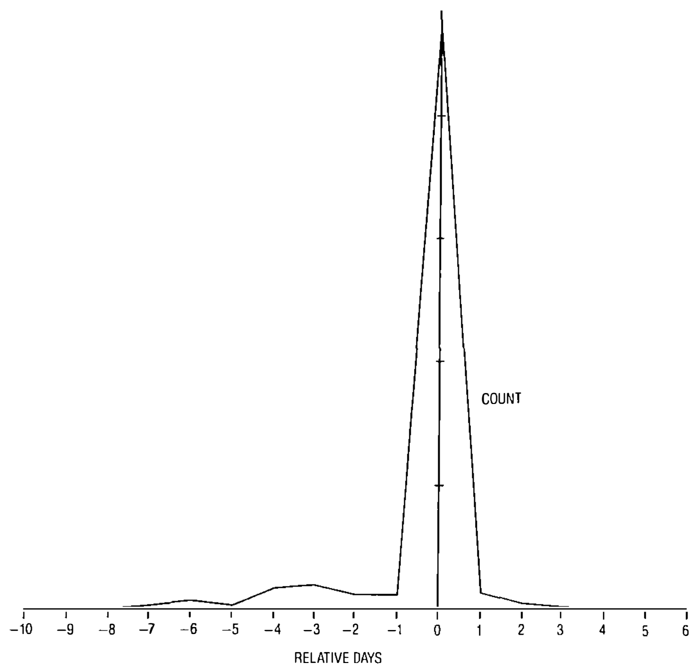



**Figure 4—Work scheduling—installation (typical week ending)**

is proposed and confirmed to the Network Account Manager (NAM) with the suggestion that perhaps a site visit would be beneficial.

## TEAM BRIEFING

The previous week there had been a team brief with the Level 2 manager. At that meeting there had been discussion firstly on the Core Brief made available by the District Public Relations Group. Then the productivity within the Planning Office had been examined and there had also been a quick analysis of the availability of spare pairs in the network. Of particular interest here is the change in emphasis from planning on the basis of percentage spare pairs to looking at years' growth in hand. The planner must determine the capacity in hand, to take cognisance of previous growth history and incorporate marketing information and any local knowledge, such as housing developments. Currently, the aim is to build into the relief of all principal cross-connection points (PCPs) sufficient spare pairs to allow for about 5 years growth. Fortunately, the historical record for Severnside District going back to 1982 is available on a computer database. It is therefore relatively simple either to print or to view graphs showing the take-up of pairs on each PCP. The database analysis package also highlights all those PCPs with low growth margins and gives an indication as to when they are likely to reach exhaustion. An important part of this data is the faulty pair record, which is used to decide on the viability of replacing particularly faulty plant at the time any additional plant is provided. This information will be needed in any discussion on future investment. The final part of the team brief had been an examination of people issues.

## PLANNING MEETING

Almost every day there is a need to discuss progress with one or more of the planners. The discussion tends to follow similar lines irrespective of the job, as follows:

- Is the job in accordance with the task set by the manager?
- Is the job being prepared correctly?
- What resources are available and how are they being used?
- How much will the job cost?
- What are the time-scales?

Most schemes are initiated to deal with either potential waiters, development plans produced by builders, repayment roadworks, or general relief to cover growth as determined from the database analysis. Some schemes are requested by the maintenance group and together with 'blackspot' (fault) information are designed to improve the quality of the network for our customers. The computer tool used locally for line plant records is CALLDATA, although in other parts of the country other systems are used such as Local Line Information System (LLIS), North East Records System (NERO) and more recently the package that will progressively replace these systems—CSS Local Network Records (LNR). CALLDATA is run at the local District information systems unit (DISU) and is available via the same terminal as CSS. By using CALLDATA the available spare pairs can be quickly identified. Examination of the records shows the utilisation of every pair including those used for private circuits. However, the system does not show fibre routings, and care needs to be taken when service requests come in to ascertain whether such a routing exists. Wherever possible a fibre routing is used.

Once the requirement has been identified, the various maps are gathered together. These are the Plant on (Ordnance Survey) Map, the duct plans, the straight line cable diagrams and, if required, thc A2558 duct space records (DSRs). Reference on occasion will be made to the A55 works supervisor diagrams of previous works. By looking at the plans and with a good knowledge of the local geography, the outline of a scheme can be worked out.

The details of the elements which make up the scheme are then entered into MACE (Monitoring and Control External Works) via ESPREP (EStimate PREParation). Every element of the job must be specified from types and sizes of cables to types of joints (and closures) and on to building works such as footway boxes, ducts and duct tracks. When all the data has been entered, the cost of the scheme is available from ESPREP. Usually about 3–5 iterations are required before a scheme is ready for discussion and a site visit may have been necessary.

When the general outline and budgetary costs have been settled, the scheme is then ready for conversion into a format suitable for approval by the District Financial Authorising Committee (DFAC). The DFAC reviews all schemes over £50k and authorises those costing between £100k and £750k. Schemes over £750k are remitted from the DFAC either for concurrence or authority in the Territorial Office. It is thus important before submitting any scheme for approval to ensure that the file contains a clear explanation of the purpose of the scheme; the costs, including timing and classes of work; the growth margins (years in hand); the expected take-up rate, etc.

## BUDGETARY PLANNING

After clearing the post and again checking the electronic mail, the final part of the morning revolves around the plans for the future. One Level 1 manager is responsible for monitoring and preparing budgets in conjunction with the Budgetary Control Officer (BCO) in the Finance Unit. He meets regularly with the Divisional Manager and the District Engineer and at those meetings needs to know what work is in hand, what is planned and what is awaiting completion/recording. This information usually needs to be broken down to give the likely expenditure per quarter in either the current or coming financial year. At the meeting there will be a quick run through of the planning groups' work in hand and the likely work to be completed in the coming quarter. This information will then be cross-checked against the master schedule, which records all work planned for the coming period (currently the master schedule only looks 3 months ahead but a 12-month schedule is being prepared).

## PLANNING BY COMPUTER

One of the Technical Officers in the group has been assisting in the development of a computer system that could dramatically change the method of planning. A review of this development will be used in the next team brief by each of the Level 1 groups in the Division prior to trial introduction into the Planning Office. The terminal-based system being developed has the major advantage of needing only a single terminal to access all of the required computer systems, ranging from CSS to CALLDATA and including the new computer planning system. The network connecting the terminals comprises 15 stations running Netware 386 and using the ORACLE relational database with AutoCAD as the user interface into the system. Other software links the terminals to CSS etc.

The process of preparing schemes via the new system is fundamentally the same. All of the maps, DSR diagrams and, in the longer term, the duct space records are captured and stored in digital format in a large database accessed via a file server. The graphic and database information stored for each exchange is about 70 Mbyte and the trial process will require storage of data for 17 exchanges. The information stored shows where the ducts run in relation to the Ordnance Survey base maps, these base maps having been either purchased from Ordnance Survey or the paper copy scanned. The interrogation of the various parts of the database, that is, the base maps, the straight-line cable diagrams and the plant on maps, is through an enquiry language, Generation 5's GEO/SQL. The original paper-based line-plant records are captured by contractors in AutoCAD's DWG format and then entered automatically into the database.

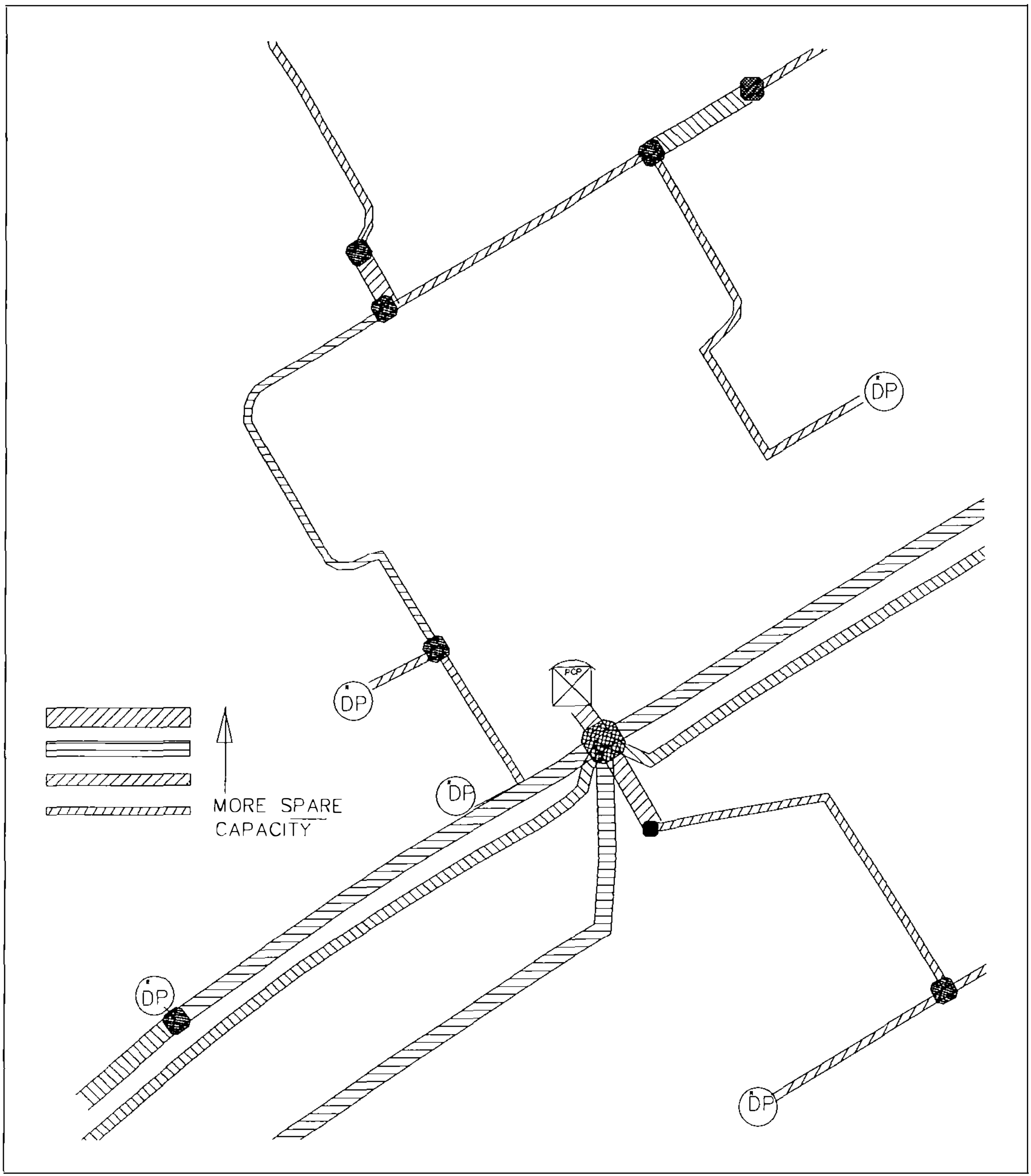
To access the system, the planner enters a request for, say, a distribution point (DP) where extra service is required and, via a customised tablet, calls up the relevant information. The request for the information to be displayed may be in either geographic format or schematic. The information displayed would be as much line plant as the planner requires, which might be for an area, say, 30 m on either side of the road centre. The major change at this stage is the ability to use *thematics*. Thematics is the interpretation of data on a theme. The results of a question asked of the system are not only given in graphical form, but by using AutoCAD's capabilities the lines associated with the different themes are shown in different colours and different line weights. The thematics approach should be extremely valuable to the planner as potential problems can be clearly identified before they arise. For example, where there is a shortage of spare pairs between exchange and cabinet or between cabinet and DPs, this can be shown thematically. If the duct space records were included, this could quickly show the duct routes available for new cables, again thematically. The 'pinch' spots would be particularly obvious. At present, however, the system derives that information from knowledge of cable sizes and the duct availability and is thus not completely accurate, but can be used as a guide. Where more information is required, reference is made to the A2558 DSR, either as a paper original or a scanned copy if available.

Figure 5 gives an example of an enquiry which has a thematic output. Figure 6 gives an example of an enquiry which gives an output ready for dispatch in reply to a PUSWA (Public Utilities Street Works Act) request.

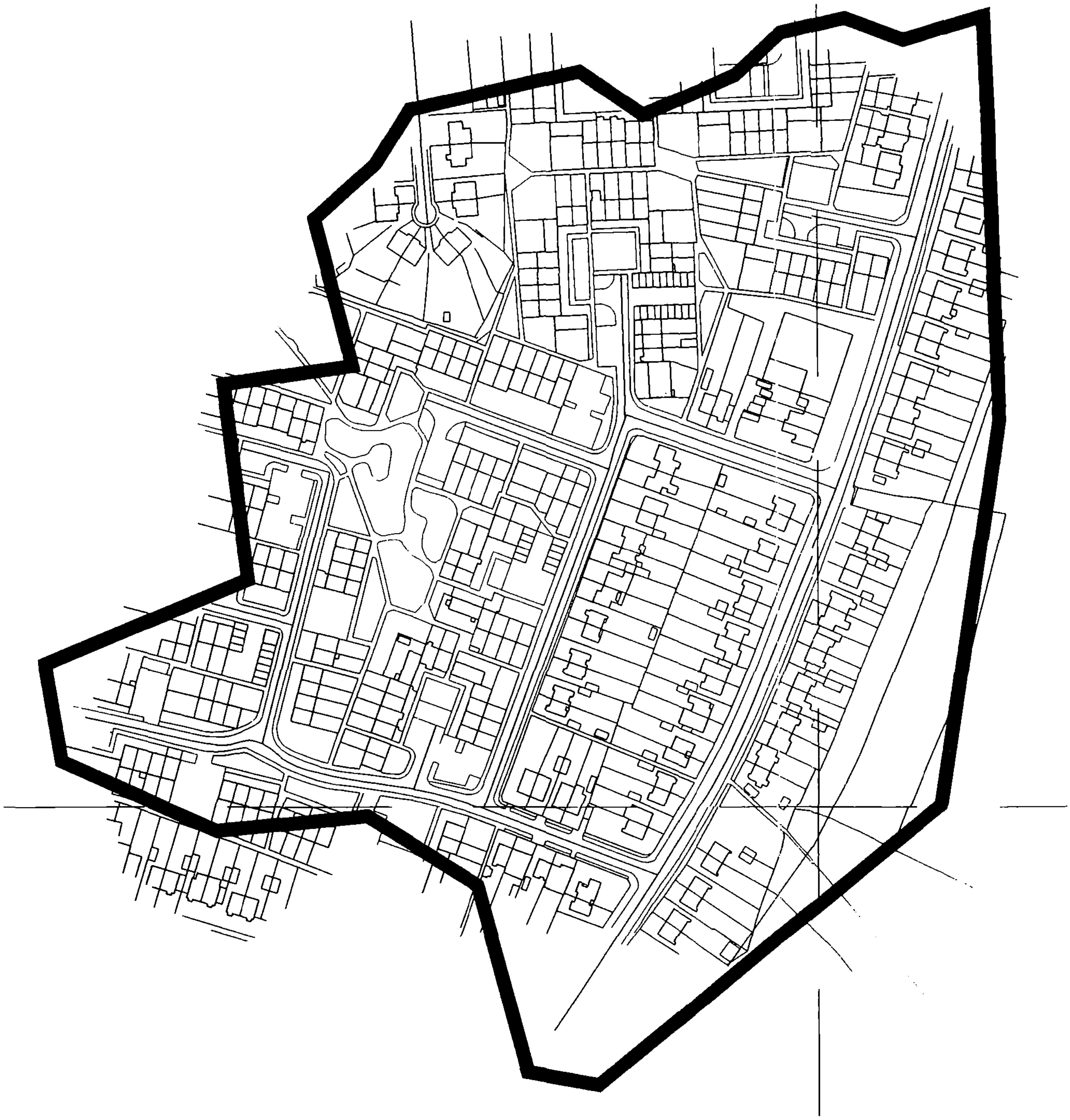
The facility of the new system to provide costings of stores and labour (split between duct and cabling) will give important savings in time. The planner can very quickly look at a series of alternatives and establish the costs for each of them. This ensures that the most viable, cost-effective scheme (allowing for perhaps deferred provision of parts of the scheme) can be chosen.

On completion of the scheme-plans on the computer, the file is saved, but is always available for other planners to see as a planned scheme. When the work has been executed, the Drawing Office will ensure that the database maps and records are updated. The system also

**Figure 5**
**Thematics**




*Note*: Two-dimensional representation. Line thickness denotes spare capacity: the thicker the line, the more capacity that is available



produces an output that can be used for manual entry into MACE. By using the computer system, outputs are also available to provide stores listings, the works instructions and paperwork for FAC submissions. One particular aspect being considered is the incorporation of photographs. If there is a possible difficulty at a site, then a photograph taken can be scanned and incorporated into the database. This can be made available to either the works group or contractor. The scanned photograph can be modified by using the equivalent of an electronic paint brush/pen to show the route to be taken for a cable and/or duct. Alternatively, in a congested manhole, for example, labels can be shown against various items of plant.

## CUSTOMER VISIT

Before travelling to Avonmouth, the customer's line plant file is collected and paper copies taken of the relevant site plans and recent orders. On site, the customer's telecommunications manager explains the potential job: the move of a switchboard from one building to another and the provision of new lines to a third building. Being a large site, the discussions are complicated by the ownership of the plant within the site. Resulting from the 1982 Telecommunications Act, the duct had been purchased by the customer, although some lack of clarity exists on the ownership of duct provided under contract since that date. In providing the shift which will be carried

**Figure 6**
**PUSWA information**

out as a repayment contract, the stores will be provided by BT and, depending upon the agreement with the customer, either installed by BT or by the customer's own sub-contractor, the latter being the normal case. For the latter, BT normally provides the Works Supervisor. The provision of cable will depend upon the particular cable runs: where they run within duct, BT normally installs and connects; where they run on gantries, they are installed by the customer via their own sub-contractor, the final connections being made by BT staff. Although the complete job is surveyed, only the shift will be charged via a repayments works order. The provision of any new plant will be at standard rates. Occasionally, the Sales/Marketing representative will, after consultation, produce a single quote for a complete job such as the one described.

During the visit, the projected routes are surveyed, thoroughly measured up and difficulties noted. At the end of the visit, the customer is advised that a preliminary estimate giving the projected cost will be prepared and dispatched within about a week. This cost will include an allowance for overheads. If the customer finds the estimate acceptable, he will confirm the order in writing and, via contracts duty in the finance division, a definitive contract will be produced.

## LOOKING TO THE FUTURE

With the day virtually over, time remains to look towards the changing role of the local line planner. First of all, with the introduction of the new organisation under Project Sovereign the new title for the job will be *Community Planner*. There will be a considerable change relating to fibre, pair-gain equipment, computerisation and more rigorous financial controls. To be able to manage in this environment, the Level 1 manager will have to adapt and take more of the role of a manager of a group of people rather than being a manager who also plans.

The fibre roll-out programme has varied throughout the country. In the vicinity of Bristol, over 15 000 fibre-kilometres have been laid and plans exist for the roll-out of fibre into other major conurbations, which will result in the provision of less copper. The introduction of street multiplexers will require only a short copper tail from the customers' premises to the multiplexer with transmission onward to the exchange being by fibre. Coupled with fibre going direct to customers' premises, there will be more involvement with the knowledge of the equipment at the termination and hence different planning techniques.

With the need to reduce the cost of provision in the local access network, consideration is being given by BT to digital pair-gain devices to provide additional pairs. Ranges of these devices (for example, 0+2 and 0+*N*) will enable extra pairs to be provided rapidly without heavily involving the planning office other than to record their provision. This will introduce further changes into the planning office.

Computer systems will also introduce many changes to the planner. The present computer systems are very unfriendly. The expectation will be over the coming years that these computers will 'talk' more and more to each other with a user-friendly human interface.

Over the last year, considerable emphasis has been placed on the preparation of sound financial cases for the provision of additional line plant. The cases presented to the DFAC must be comprehensible to the committee members who may not be familiar with external planning, but who do need to understand the requirements being set out. The case papers must also be suitable for the works staff and controls. Consideration must be given to the effect of competition in the local area, usually from cable TV companies but possibly also from Telepoint operators. Consideration will also need to be given to the use of either contract or direct labour in the execution of the work. In recent years, a large proportion of cable and duct provision has been provided by contract.

The final thought must be that the Level 1 planner will have a very different role, with the need to supervise and train a larger group of staff than at present. There will be the need to understand much more clearly the financial requirements and the ability to look forward and produce the fundamental work plans to anticipate customers' demands. Overall the changes appear positive and look set to make the job of the local line planner even more challenging.

## ACKNOWLEDGEMENTS

The author wishes to thank Steve Kimbrey and Martin Evans for their help in preparing the source information for this article, and Jan Skraba of SysCon for information about the computer-based line-plant planning system.

## Biography

Paul Shanks joined the Post Office Research Department in 1964. He then spent periods of time on secondment with the Technical Support Unit of the Ministry of Technology. On returning, he joined Development Department and was involved with data networks. He then spent two years in the Post Office Appointments Centre in CHQ before moving to Bristol in 1976 as Deputy Personnel Controller, South West Region. In 1978, he moved to Bristol Telephone Area as Deputy General Manager (Service). With the formation of Severnside District, he was appointed CSS Implementation Manager, and then Deputy District General Manager. Until the end of March 1991, he was District Engineering Manager with responsibility for all of the network, estates services and computing. He is now with Worldwide Networks UK Operations South.

# Deployment of Optical Fibre into Subscriber Networks in Japan

I. SAKAKIBARA†

*This article reviews NTT's strategy for deploying optical fibre in subscriber telecommunications networks in Japan to enable future advanced services to be provided.*

## INTRODUCTION

Telecommunications networks have become increasingly sophisticated in recent years to provide customers with enticing telephony and advanced integrated services digital network (ISDN) services. Optical-fibre technology is enabling many new service offerings that simply could not be provided over metallic cables. It is very important that fibre is extended into subscriber loops to provide a viable network platform for future advanced services.

NTT has conceived a strategy for gradually deploying a nationwide optical-fibre subscriber network based on an optical-fibre multiplex system called the *central-terminal/remote-terminal* (CT/RT) system. In January 1988, NTT installed the first CT/RT system to provide analogue telephone services. Meanwhile, the system has been further advanced to support ISDN and leased-line circuit services. NTT is now accelerating nationwide deployment of its optical-fibre subscriber network as an essential infrastructure for providing future advance services. This article surveys NTT's vision of a gradual evolution toward full deployment of fibre into subscriber networks.

## NTT'S PLANNED NETWORK MODERNISATION

In 1990, NTT celebrated the 100th anniversary of the Japanese telecommunications network. NTT's telephone service, which began with 197 subscribers in 1890, has now grown into a huge network embracing more than 50 million telephone circuits. In addition to plain old telephone services (POTS), a wide range of newer services is attracting increasing numbers of subscribers including facsimile, packet switching, and even more advanced services. For example, the facsimile network in Japan has some 370 000 circuits installed today, and this number continues to grow because of the popularity of facsimile as a business tool. The packet-switching (DDX-P) and circuit-switching (DDX-C) networks serve about 200 000 circuits between them. Finally, the videotex network now serves more than 90 000 subscribers by providing interactive still-picture information over the telephone network.

NTT began offering basic-rate interface ISDN services in April 1988, followed by primary-rate interface services in June 1989. ISDN packet services began in June 1990. Demand for ISDN services is growing rapidly, especially among large enterprises that are constructing their own nationwide data networks. ISDN services were available in 90% of the cities all across the country by March 1991.

NTT is now completing digitalisation of its networks. This digital backbone will support future enhanced services and modernised telecommunication facilities, as well as enhanced operations and management. As of December 1990, some 33% of network terminations had been digitalised. According to plan, all crossbar switches will be replaced by digital switches by March 1995, and all local switches will have been digitalised by 1997. The time frame for digitalisation of inter-city trunks is even shorter. By March 1993, almost all cities will be connected by digital circuits. Digitalisation will be completed by March 1996.

## BACKGROUND OF FIBRE DEPLOYMENT

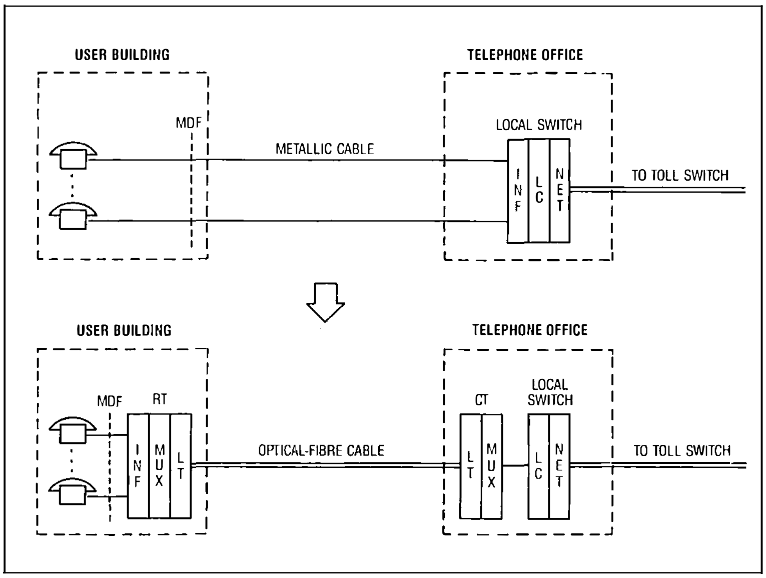
For a century now, NTT has been at work building a highly reliable, efficient and ubiquitous telecommunications network. Today, anyone requesting a telephone can have it installed within a few days. Meanwhile, ISDN primary-rate service and leased-line circuits with 1·5 Mbit/s or higher speed are coming to play an increasingly important role in providing services for business users. These business-oriented services cannot be provided over conventional subscriber networks, and thus require the high throughput capacity of optical fibre in subscriber access lines. Looking further out on the horizon, it is generally accepted that fibre-based high-capacity subscriber loops will be essential to provide diverse and acceptable services in the coming century. Considering the

† Network Systems Development Centre, Nippon Telegraph and Telephone Corporation (NTT)

tremendous investment in the existing network plant, migration to fibre cannot happen overnight. This prompted NTT to adopt fibre at an early stage, to strive gradually but steadily toward the final objective of an end-to-end fibre network.

This is not NTT's only motive for moving toward a sophisticated subscriber network. The telecommunications network in Japan was thrown open to so-called new common carriers—competitors to NTT—with enactment of the Telecommunications Business Law in April 1985. To stay ahead of these new competitors, who are deploying fibre networks of their own, NTT must introduce fibre into subscriber networks to offer more diversified and attractive services to customers.

Normal attrition and congestion of the outside plant are also important factors. Some plant has deteriorated and should be retired. Moreover, some underground facilities have already become congested with the huge amount of metallic cable. For these reasons, it is imperative that subscriber networks are upgraded and converted to fibre.




INF: Subscriber line interface LC: Digital line concentrator
NET: Digital switching network LT: Line terminal MUX: Multiplexer

**Figure 1—CT/RT system**

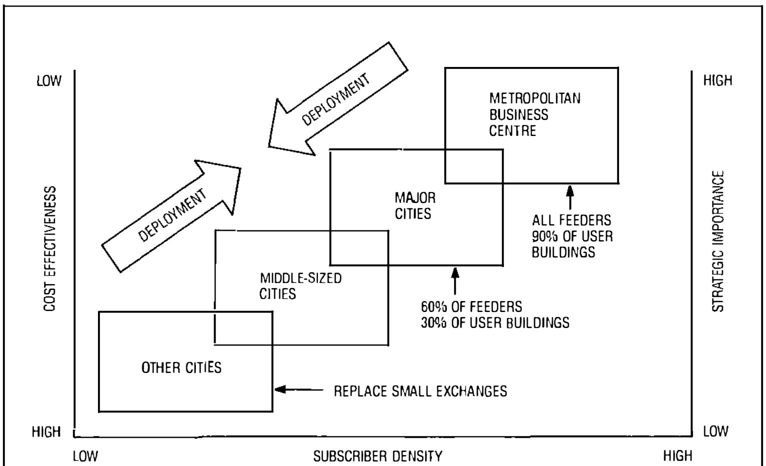



**Figure 2—CT/RT deployment concept**

## STRATEGY FOR DEPLOYMENT OF FIBRE INTO SUBSCRIBER NETWORKS

Deployment of optical fibre into subscriber networks will proceed in two phases. Considering the strategic importance of business development, fibre will first be deployed in core business areas where it can be extended to link customers' buildings. NTT's photonic CT/RT multiplex system is a key element in this plan. Besides POTS, it is designed to support the ISDN basic-rate interface and leased-line circuits. Ultimately, the system will be deployed to extend service to apartment floors and feeder sections of subscriber cables—generally called *fibre to the curb*. These fibre cables will serve as the core infrastructure for future expansion to connect residential customers.

The CT/RT system consists of a central terminal at a telephone office, a remote terminal located at a customer's building, and a span of fibre connecting the two, as shown in Figure 1. The system is already cost-effective for distances of 2 km or more for more than 100 subscribers, or for 1 km or more for more than 400 subscribers even if the cost reduction of underground facilities obtained by using thinner fibre cable than metallic cable is not counted in. System costs will continue to decline with volume production permitting broader application to the network.

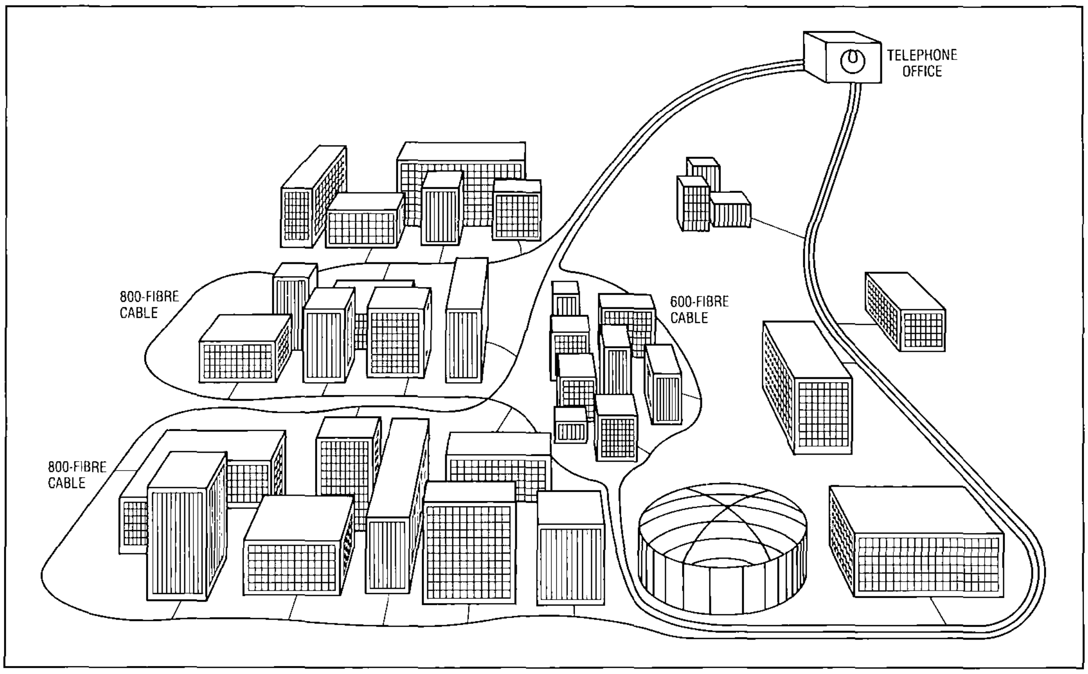
On the other hand, the CT/RT architecture is very effective for application to small local telephone offices (up to around 5000 lines); for example, its simple architecture is much more cost-effective than installing independent exchanges. The CT/RT system is expected to replace several thousand small crossbar exchanges in rural areas over the next 5 – 10 years. Thus CT/RT deployment is a first-phase development. The system will be installed preferentially in both urban and rural areas as shown in Figure 2.

In the second phase, broadband and/or high-speed services will be made available to individual residential customers over optical lines extended to the home. The optical-fibre subscriber network will gradually be extended by expanding the core infrastructure set up in phase 1. This way, when demand develops for high-speed digital service, it can easily be provided by extending fibre from a feeder point or pedestal to the customer. For residential customers satisfied with existing low-speed services, these will continue to be offered from a remote terminal over metallic pairs. NTT envisages a gradual process as fibre is deployed in subscriber loops on demand.

## HOW URBAN AND RURAL AREAS WILL BE SUPPORTED

CT/RT systems to support 20 000 subscriber lines were installed during 1990. It is planned to install CT/RT systems to accommodate up to several hundred thousand lines per year over the next few years.

A schematic CT/RT system installation showing how it will be applied to urban areas is shown in Figure 3. The site is Makuhari, a redevelopment area about 30 km east of Tokyo. The area, located on 430 hectares, is still being developed; eight buildings have been completed, more than 10 are under construction and around 15 are being planned. Two 800-fibre cables and a 600-fibre cable are laid through the area to provide those buildings with communications services. At present, CT/RT systems are serving eight buildings with 2500 subscribers. CTs are located at Makuhari central office and connected with the D70 digital exchange. RTs are placed at the main-distribution-frame (MDF) rooms and communication equipment rooms in the




Location: Makuhari in suburban Tokyo

**Figure 3 Optical-fibre subscriber loop application**

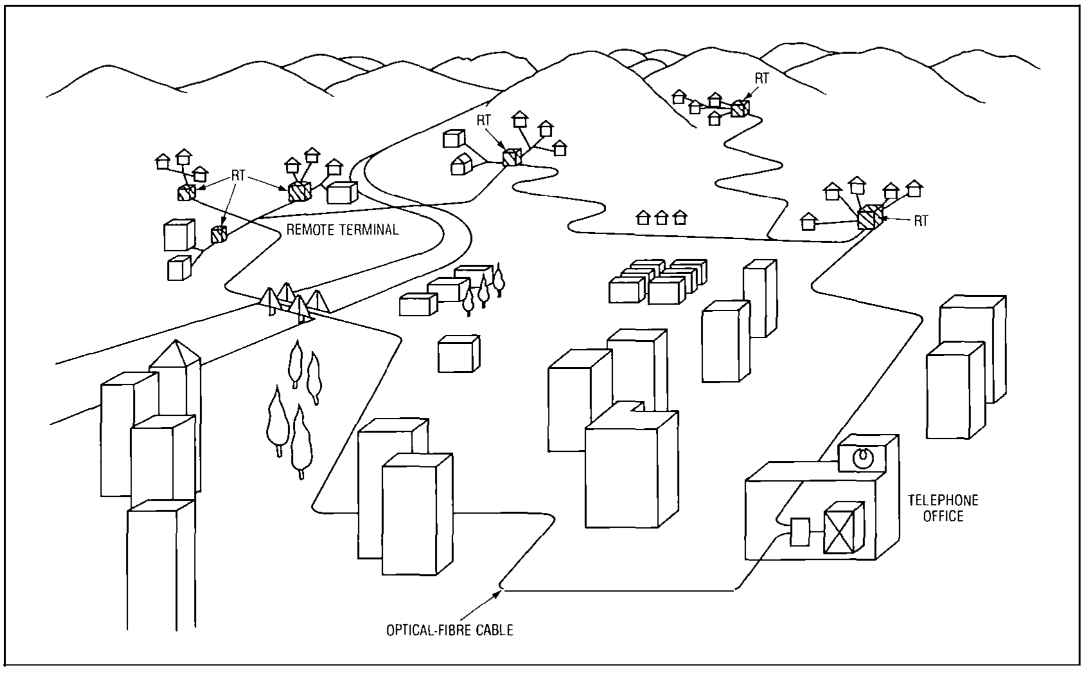



**Figure 4 Optical-fibre subscriber loops in rural areas**

buildings. The area is expected to support more than 30 000 subscribers by the year 2000.

Turning to rural areas, a digital exchange is installed at a telephone office in the demand centre of the rural area, and affiliated RTs placed at small exchange offices linked by fibre cables in a ring configuration. Figure 4 shows a typical rural layout.

NTT has a pilot plant project in progress in the Chiyoda district of Tokyo. This is the core business centre of Tokyo with 75 000 telephone lines, 1000 ISDN subscribers, and 24 000 leased-line circuits. It is projected that, within two years of the cut-over in 1992, half the subscribers in this area will be served by CT/RT systems through four 1000-fibre cables laid in a ring configuration.

## CONCLUSION

NTT's plans for constructing an enhanced and sophisticated network for the 21st century involves—indeed is based upon—full deployment of fibre into local subscriber loops. *Fibre to the office* deployment is an indispensable first step. The company's strategy is to extend fibre gradually on a cost-effective basis into subscriber networks. The CT/RT system is an indispensable element in implementing NTT's strategy and will play a key role in the gradual evolution towards *fibre to the home.*

### Biography

Ichiroh Sakakibara joined Nippon Telegraph and Telephone Public Corporation after obtaining an M.S. degree in Electrical Engineering at the University of Tokyo in 1971. He was senior staff engineer at the Engineering Bureau in 1984, senior manager at the Telephone Service Development Headquarters and senior manager at the Business Coordination Department Affiliated Companies Headquarters. He is currently general manager of the Fibre Optic Local Network Systems Project Group, Network Systems Development Centre. He has worked on the development of analogue ESS, digital switches and optical-fibre subscriber systems.

# Deutsche Bundespost Telekom Network: Current and Future Requirements for Copper and Optical-Fibre Cables

D. FREUDENSPRUNG, and H. MIDDEL†

*The first part of this article gives an overview of the copper and optical-fibre cable networks of the Deutsche Bundespost Telekom (DBPT). Details of cable construction, statistical values and the demand over the next few years are given. The second part describes the future trend for copper cables and the initiatives being taken by the DBPT for introducing optical-fibre cables and systems into the local loop. The status of several different pilot projects is reviewed. This article refers to the network in which was formerly the Federal Republic of Germany (West Germany).*

## INTRODUCTION

Until about 1980, the cable network of the Deutsche Bundespost Telekom (DBPT) consisted only of copper cables. In general, copper has continued to dominate the local loop (local access network) up to the present time, while in the junction and trunk networks optical-fibre cables have been introduced. DBPT has undertaken or is planning to undertake field trials of optical-fibre systems in the local loop. Before these activities are considered, however, some details of the existing network are given.

## PRESENT SITUATION

### Copper Cable Local Network

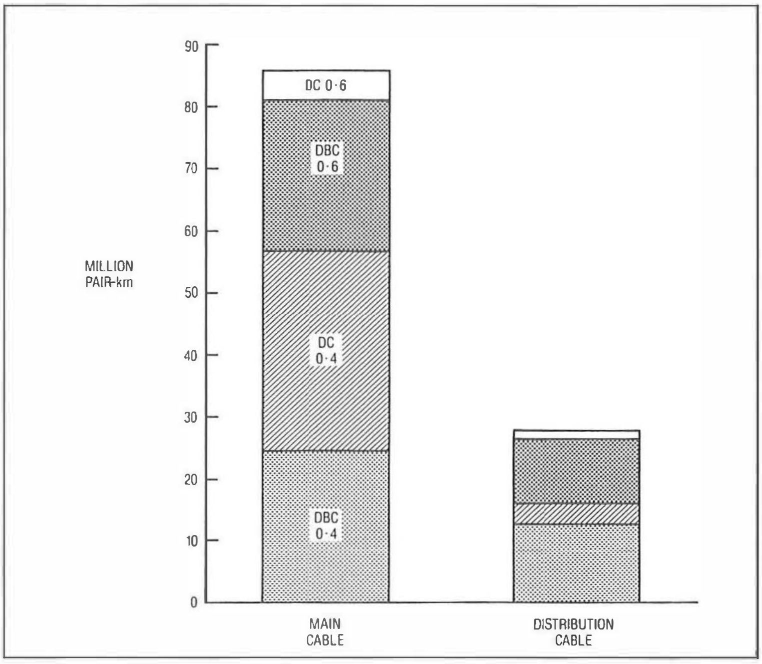
The backbone of the narrowband services is the telephone service, with about 30 million subscriber main stations in 3748 local networks and 6657 subscriber line areas. Other narrowband services such as Telex have less than a 3% share. The subscriber line network is therefore tailored to the telephone service. The subscriber line network is a star network consisting of symmetrical copper cables and pairs which are 0·4, 0·6, and 0·8 mm in diameter. The subscriber line area is divided into main and distribution cable areas. Main cables are provided section by section according to demand. Main cables are unfilled polyethylene-insulated cables with a laminated polyethylene sheath. Cables with 0·4 mm diameter pairs have a solid polyethylene insulation. Cables with 0·6 and 0·8 mm diameter pairs have a cellular polyethylene insulation. The same cable construction is used both for directly buried cables and for cables pulled into ducts.

The pulling of cables into ducts restricts maximum cable size to 2000 pairs of 0·4 mm diameter or to 1200 pairs of 0·6 mm. The smallest element is, as in the case of the formerly used paper-insulated cables, a quad. Main cables are pressurised with a maximum pressure of 0·5 bar. The air flow through the cable is monitored at the exchange for the purpose of fault identification.

Because the costs of laying a cable are high compared to cable costs, it is more economical, in the case of distribution cables, to choose, from the start, a cable size which will meet the final demand. The construction of distribution cables is similar to that of main cables, but they are filled and not pressurised.

Cables with pairs of 0·4 mm diameter have, like main cables, a solid polyethylene insulation, whereas cables with pairs of 0·6 and 0·8 mm diameter have a foam-skin polyethylene insulation. Figure 1 classifies the main and distribution cables according to their various conductor diameters, (0·4 mm, and greater than or equal to 0·6 mm), and to the different methods of cable laying (directly buried or in ducts). Overall, main and distribution cables contain a particularly large proportion (about 64%) of pairs which are 0·4 mm in diameter. In Figure 1, no distinction is made between cables with plastic-insulated

**Figure 1**
**Deutsche Bundespost Telekom (DBPT) local network: distribution of cable pairs by diameter and cable laying method**




DC: Cables in ducts DBC: Directly buried cables

† Fernmeldetechnisches Zentralamt, Deutsche Bundespost Telekom

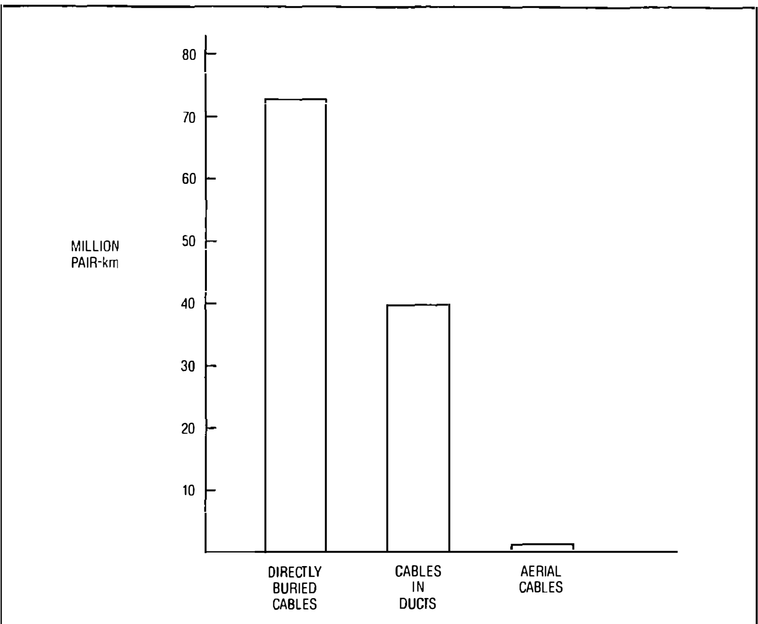



**Figure 2—DBPT local network: distribution of pairs by cable laying method**

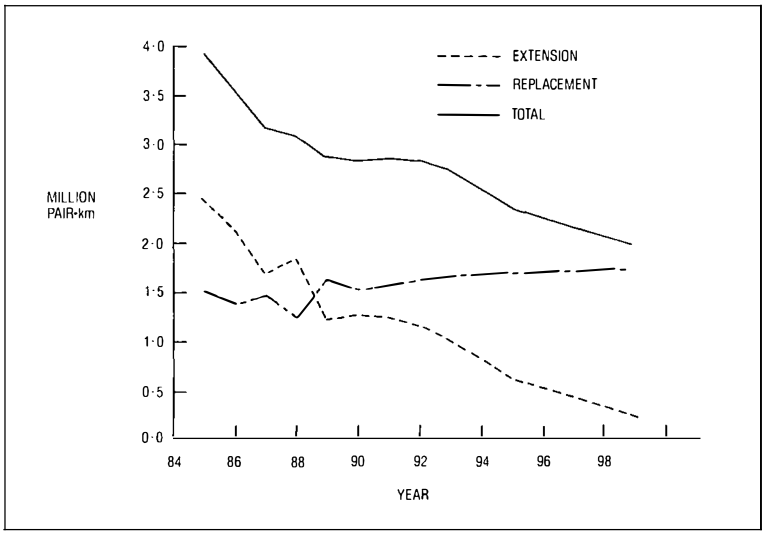



**Figure 3—DBPT material investment: main cable in local network**

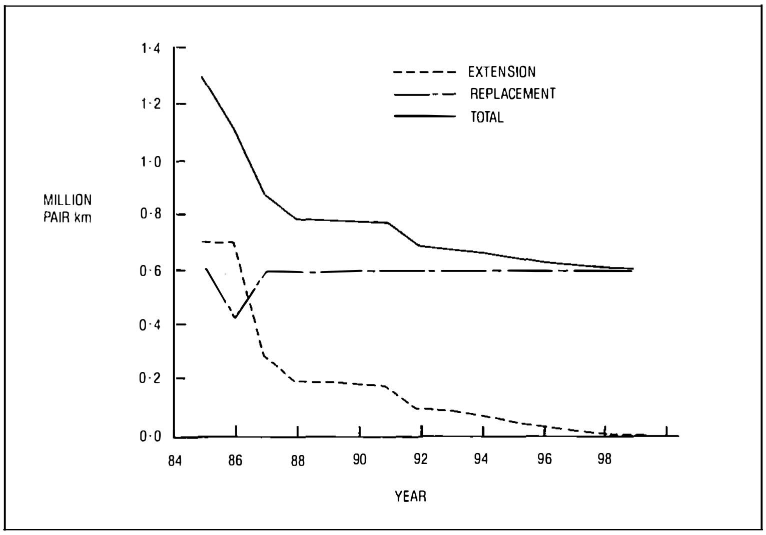



**Figure 4—DBPT material investment: distribution cables in local network**

pairs and a plastic sheath, and paper-insulated pairs with a lead sheath. The proportion of paper-insulated cables in the local loop is about 25%, but this share is decreasing year by year.

Aerial cables are of minor importance in the DBPT local loop. In principle, the aerial cables used have a maximum of 10 pairs. For many years, DBPT has employed self-supporting cables with glass yarn in the sheath. Several years ago, *figure 8 cables* were used, some of which are still in the network. The minor significance of aerial cables in the DBPT local loop is indicated in Figure 2. Based on the latest forecasts, the level of utilisation of main cables is 85%, and for distribution cables 94%. Requests for new telephone main stations can be fulfilled in almost every case. The increase in main stations in 1989 was about 1 million. Only about 0·03 million new subscribers have to wait more than 4 weeks because of lack of lines.

In spite of the large increase in the number of subscribers, material investment of copper cable in the local loop has been decreasing for many years. This trend is illustrated in Figures 3 and 4. Figure 3 shows the demand split between extension (new) and replacement main cables. Figure 4 indicates the corresponding values for distribution cables. The large proportion of replacement items should be noted. Overall material investment in extension and replacement main and distribution cables will decrease from the present figure of about 3·9 million pair-km to approximately 2·7 million pair-km within 10 years.

## Copper Cable Trunk Network

Up to 1980, DBPT used only copper cables with symmetrical and coaxial pairs for extending the trunk network. Since then, with the introduction of optical-fibre cables, the importance of copper cable in the trunk network has decreased. The supply of copper cable (9·5 million pair-km and 0·35 million coaxial pair-km) is stationary. Material investment for extension, which is very small, and for replacement is now below 0·5% of the supply and will decrease to less than 0·1%. Copper trunk cables are therefore no longer of economic importance.

## Cable TV Network

In the early-1980s, DBPT decided to install a large-scale coaxial broadband network for CATV across the whole country. This network uses coaxial cables with longitudinal welded outer conductors and transmits, in the frequency range up to 450 MHz, a maximum of 35 TV channels plus 30 FM and 16 digital stereophonic sound channels. A tree structure is used and all programmes are offered simultaneously at the network subscriber interfaces. In the CATV network, a distinction is made between four levels. A and B basic links contain active elements. C basic links are connected to repeater points of level A and B without, however, containing any active elements. The links to the D level are passive couplers. D basic links terminate at the subscriber interfaces. The CATV subscriber line areas should be as congruent as possible with telephone subscriber line areas.

The number of households ready for connection was about 14·5 million in the middle of 1990 and about 6·8 million homes were actually connected. This is equivalent to a provision rate of 55% (ratio of homes ready for connection to total number of accommodation units) and a broadband service of about 47% (ratio of connected accommodation units ready for connection).

With respect to the completion of the CATV network, it must be borne in mind that there are certain profitability constraints. The average investment per accommodation unit ought not to exceed DM 700. This strategy is shown in Figure 5. After a large increase up to 1990, the investment will decrease in the future.

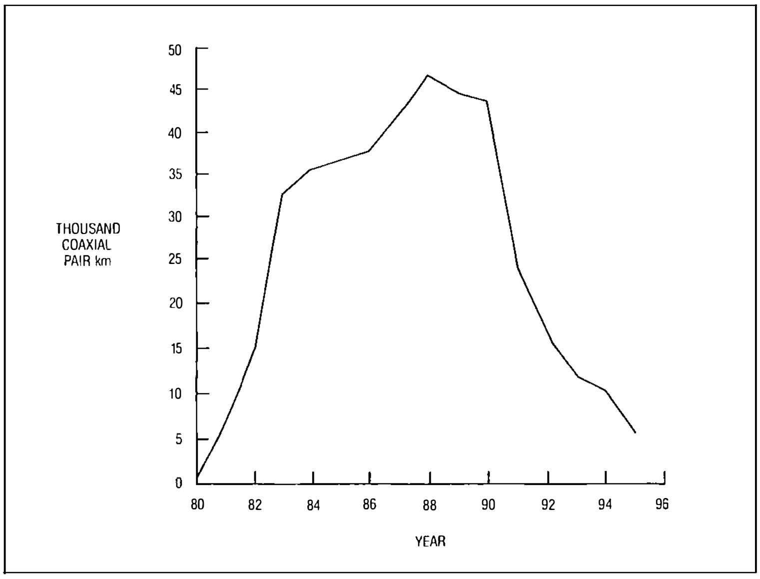



**Figure 5—DBPT material investment: CATV cables**

### Optical-Fibre Local Network

Up to now, the DBPT has not conceived a strategy for introducing optical-fibre cables into the local network for small and/or broadband services. In 1986/87, however, the DBPT started to lay optical-fibre cables in those parts of the 29 biggest local areas where demand—for example, centre of business—is expected. Optical-fibre cables have also been installed in the junction network. Figure 6 shows the growth of optical-fibre cables in the local network. The curve stops rising in 1990, the year when the planned network was completed. A total of about 250 000 fibre-km will be installed:

(*a*) 100 000 fibre-km of junction cables,

(*b*) 75 000 fibre-km of junction cables for the general digitalisation, and

(*c*) 75 000 fibre-km in the local loop for new services.

This prototype optical-fibre network will be used, in part, in the prototype digital broadband network, which offers the possibility of direct distance dialling. The network is being developed for 1500 subscribers.

### Optical-Fibre Trunk Network

Since about 1985, only optical-fibre cables have been installed in the trunk network. These are single-mode optical-fibre cables in bundle construction having a laminated polyethylene sheath. The 1300 nm wavelength region is used for transmission. Investment in optical-fibre cables in the trunk network will also decrease in the next few years because:

(*a*) large reserves were installed at the outset to allow for future services, and

(*b*) demand for future services has been lacking up to now.

Moreover, the repeater spacing in the network was chosen such that, while at present it is possible to transmit at 565 Mbit/s, later, as soon as systems are available, a rate of 2·4 Gbit/s will be achievable. This will quadruple the capacity of the existing network without a single additional cable having to be laid. Furthermore, the 1550 nm wavelength region is available for transmission. Figure 6 shows the decreasing demand for optical-fibre cables in the trunk network (trunk and regional).

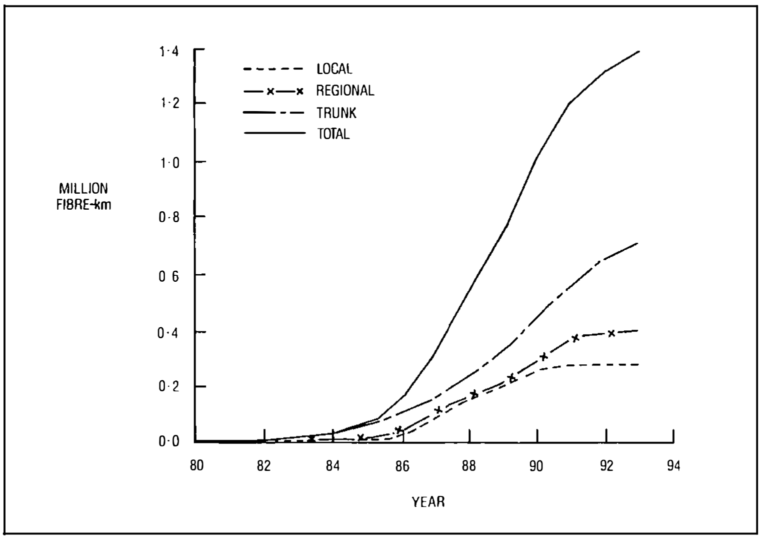



**Figure 6**
**DBPT material investment: optical fibres**

## DEVELOPMENTS

### Copper Cables/Network

With the introduction of plastic-insulated copper cables in the local network about 20 years ago, a transmission medium was introduced which is very sophisticated and has a long life.

Other fundamental changes are not expected. The introduction of the narrowband ISDN did not call for new copper cables since the existing network can be used for ISDN as well. Thus, the installed network with its existing cables fulfils both the requirements of analogue systems and narrowband ISDN.

Bearing in mind that ISDN can transmit two channels on one pair, the copper network still contains substantial reserve. As the changeover in the local loop to an optical-fibre network is awaited, investment is being minimised by the use of multiplex transmission systems. To sum up, the development of copper cables is, in principle, coming to an end. Efforts are, therefore, aimed solely at maintaining the quality of the network and at buying the required cables as cheaply as possible. This goal has been achieved in recent years by the precise specification of the technical terms of delivery of cable purchases to permit both European and worldwide tendering.

For completeness, it is necessary to mention one new cable type of minor importance. A new ISDN indoor cable has been developed for use instead of the commonly used PVC-insulated type with a PVC sheath. This new indoor cable has polyethylene-insulated pairs and a halogen-free sheath. Because of this, pair capacitance has been reduced from 70 nF/km to 35 nF/km, and the bus length between the network terminator and the telephone set has been increased from about 150 m to approximately 230 m. The development of copper trunk cables has been discontinued, now that they are being displaced by optical-fibre cables. In the case of CATV, the replacement of conventional cables, as discussed later, is awaited in the future.

## Optical-Fibre Cables/Networks

While the use of optical fibre in the trunk network has proved to be a success, its use in the local loop has been limited by economic constraints such as insufficient demand for broadband services and lack of economical solutions and techniques. DBPT is convinced that optical-fibre will in the long run be used in the local loop and is looking for a flexible stategy. Regardless of the development and introduction of broadband services, DBPT intends to install optical-fibre systems for supplying customers with conventional telecommunications services in order to achieve a significant cost reduction brought about by scale. The option of extending these systems to broadband services will remain open.

DBPT has therefore decided to undertake a number of pilot projects in the local loop to be code-named *OPAL* (*OP*tical *A*ccess *L*ine) to seek the optimum technical and economic solutions to the problem and has placed contracts with a number of firms to implement the trials.

### *Projects in City Areas*

*OPAL1* This is an optical-fibre system for 192 analogue telephone sets and 96 network user interfaces for CATV. The project was initiated in May 1990 in Cologne.

*OPAL2* This is an optical-fibre system for analogue and digital transmission. In the latter case it is intended especially for ISDN basic and 2 Mbit/s access and 2 Mbit/s fixed connections. The project is planned to commence in Frankfurt/Main in September 1991. An extension of OPAL2 to encompass broadband communications is envisaged.

### *Projects in Rural Areas*

A cost limit of 700DM per accommodation unit limits the scope of CATV penetration in rural areas. Nevertheless, these areas contain more than 50% of the population, so DBPT is looking for economical methods of connecting these communities to the CATV network. Optical-fibre systems obviously offer a possible solution.

*OPAL3* This system, now on order, will verify the economics of the OPAL1 CATV system in a rural community of about 4500 accommodation units.

*OPAL7* This project, still in its early stages, will examine the economical use of optical-fibre systems for conventional telecommunications services in the local loop, including the concept of a system for a CATV network in rural areas.

### *Other Pilot Projects*

Three further projects are being planned for commencement in late-1991 covering conventional telecommunications services, fixed connections and CATV.

*OPAL4* A system catering for a maximum of 400 main stations is envisaged for the Leipzig local area (formerly part of the German Democratic Republic (East Germany)).

*OPAL5* A 3 × 180=540 64 kbit/s channel system is being planned for installation in the Cologne 'Media Park'.

*OPAL6* A novel ribbon-type optical-fibre cable will be utilised in a pilot project of about 200 main stations due to be installed in the Nuremberg local area.

It is intended that these pilot projects to introduce optical-fibre systems into the local network will pave the way for the provision of telecommunications services at reasonable cost.

## Biographies

Dieter Freudensprung studied at the Technical University of Aachen, where he received the diploma of communications engineering in 1969 and then joined the DBPT. Since 1971, he has been employed at the Telecommunications Engineering Centre (FTZ) in Darmstadt. He was head of several sections in the Outside Plant Division and has been Head of the Cable System Section since 1985.

Horst Middel received his diploma in telecommunication engineering in 1966 before joining DBPT. Since 1974, he has been located in the Telecommunications Engineering Centre (FTZ) in Darmstadt. Prior to his present post he was engaged in cable techniques for copper and optical-fibre cables: he is now responsible for cable measurements.

# THE INSTITUTION OF BRITISH TELECOMMUNICATIONS ENGINEERS

(Founded as the Institution of Post Office Electrical Engineers in 1906)

General Secretary: Mr. J. H. Inchley, PP 113, The Angel Centre, 403 St. John Street, London EC1V 4PL; Telephone 071-239 1912. Membership and other queries should be addressed to the appropriate Local-Centre Secretary as listed on p. 222 of the October 1990 issue of the *Journal*.

## STUDENT MEMBERSHIP

At a meeting of Council, held at Worthing in November 1990, Council agreed to the introduction of a new class of Student Membership (see *IBTE Review* No. 2). Pending a complete redrafting of the Rules during the coming year, it is necessary to amend the existing Rules to cover this new category of membership. Thus a new Rule 5X has been formed, which is as follows:

5X *Student Members*
The following types of student are eligible to become Student Members. As such they shall be entitled to all rights and privileges of Members, but for the duration of their period of study shall only be charged a subscription equal to half that of full membership.

(*a*) Minor Award Holders—BT staff from a clerical or ETG background who are given special leave to pursue a mathematics, engineering or science degree.

(*b*) Bursary Students—people external to BT who, having achieved good A-levels in the required subjects, are sponsored by BT to attend an M.Eng. course at one of three Universities over a four year period.

(*c*) Other full-time students; that is, Bridging Course Students, Windsor Fellowship Students, Post Technical Students and Major Award holders.

## COMMUTED LIFE MEMBERSHIP

It was also necessary at that meeting to clarify the Rule relating to commuted life membership. Whilst this is not a change to the existing Rules, it interprets them more strictly, in that commuted life membership is restricted to those employees who have reached the age of 60, the normal age for retirement. Those employees leaving the business before age 60 who wish to continue to receive the *Journal* have two options:

(*a*) They sign an undertaking that they will not be engaging in 'responsible work connected with communications engineering', and are then eligible to the benefits of Corporate Membership at a special rate—set at the cost of the *Journal* plus 20% of the differential membership rate. These Members would also enjoy the other privileges of membership, including attendance at Centre meetings.

(*b*) Those who were unable to sign such an undertaking would be eligible for Corresponding Member status, as defined by the Rules, and would thus be charged the cost of an external subscription to the *Journal* plus 20% of the differential membership subscription. These Members, being non-Corporate Members, would not enjoy any other benefits.

Upon reaching age 60, Corporate Members only would be offered the option of commuting their payments.

## SUBSCRIPTION INCREASE

At its meeting in March 1991, held in Liverpool, Council considered in detail the finances of the Institution, and concluded that an increase in subscription was necessary to meet the increased cost of the *Journal*, and to increase and develop the range of services being offered to Members. The new subscription rate has been set at £12, or £1 per month. This increased sum will be deducted from salary with effect from June 1991.

## COUNCIL REPRESENTATION

Council also agreed to change the Rules relating to representation on Council. This was in response to the view that a two year term did not give sufficient opportunity for Council members to contribute. It also increases the size of Council to ensure adequate attendance at meetings and a wide cross-section of opinion when discussing IBTE issues. The revised Rules are as follows:

### Revised Rule 18

18 The President and Vice-Presidents shall be appointed by the Council. The Chairman and Vice-Chairmen of Council shall be nominated by the President.

Fourteen Members of Council shall be nominated by Local Centre Committees. Any person so nominated shall be a member of a Local Centre Committee, and will serve for a period not exceeding three years on the Council. For the purpose of nominating members of Council from within their ranks, Local Centres shall be grouped together as determined from time to time by Council, in order to ensure a fair, representative and workable distribution of Council membership.

It shall be the responsibility of the nominated Council Members to represent the views of their group of Centres at meetings of Council. To that end it is expected that the nominee should attend at least one committee meeting in each Centre within the grouping each year.

No more than five of the fourteen nominated members of Council shall retire each year, and, except with the express permission of the Chairman of Council, they shall not be eligible for immediate re-nomination by their Centres for the following session. The Chairman of Council may however exercise the right to co-opt retiring Members to Council for a period not exceeding three years.

The grouping of Centres and the allocation of Council members to Centres are described in Rule 18X.

The Honorary Treasurer shall be appointed by Council.

### Revised Rule 18X

The representation cycle shown in the following table ensures that every Centre has the opportunity to nominate a representative. Centres are established by the Institution to serve the needs of the membership. Therefore their geographical coverage is determined by the need to serve the population of IBTE Members, not by British Telecommunications organisational structure.

*The Secretary*

## Representational Cycle

| | 90/91 | 91/92 | 92/93 | 93/94 | 94/95 | 95/96 |
|---|---|---|---|---|---|---|
| London 1 | xxxxxx | xxxxxx | *xxxxx | xxxxxx | xxxxxx | *xxxxx |
| London 2 | xxxxxx | *xxxxx | xxxxxx | xxxxxx | *xxxxx | xxxxxx |
| Martlesham Heath | xxxxxx | xxxxxx | xxxxxx | *xxxxx | xxxxxx | xxxxxx |
| NORTH GROUP 1 | | | | | | |
| Aberdeen | | xxxxxx | xxxxxx | xxxxxx | * | |
| Edinburgh | xxxxxx | * | | | xxxxxx | xxxxxx |
| NORTH GROUP 2 | | | | | | |
| Glasgow | | xxxxxx | xxxxxx | xxxxxx | * | |
| Lancaster/Preston | xxxxxx | * | | | xxxxxx | xxxxxx |
| NORTH GROUP 3 | | | | | | |
| Newcastle | xxxxxx | xxxxxx | * | | | xxxxxx |
| Leeds/Sheffield | | | xxxxxx | xxxxxx | xxxxxx | * |
| NORTH GROUP 4 | | | | | | |
| Manchester | | xxxxxx | xxxxxx | * | | |
| Liverpool | | | | xxxxxx | xxxxxx | xxxxxx |
| Northern Ireland | xxxxxx | xxxxxx | *xxxxx | xxxxxx | xxxxxx | *xxxxx |
| CENTRAL GROUP 1 | | | | | | |
| W Midlands (North) | | | | | | |
| W Midlands (South) | xxxxxx | xxxxxx | xxxxxx | * | | |
| E Midlands | | | | xxxxxx | xxxxxx | xxxxxx |
| CENTRAL GROUP 2 | | | | | | |
| S Wales | xxxxxx | xxxxxx | xxxxxx | * | | |
| N Wales | | | | xxxxxx | xxxxxx | xxxxxx |
| SOUTH WEST GROUP | | | | | | |
| Westward | | xxxxxx | xxxxxx | xxxxxx | * | |
| Solent | | | | | xxxxxx | xxxxxx |
| SOUTH GROUP 1 | | | | | | |
| Severnside | xxxxxx | xxxxxx | * | | | xxxxxx |
| Thameswey | | | xxxxxx | xxxxxx | xxxxxx | * |
| SOUTH GROUP 2 | | | | | | |
| South Downs | xxxxxx | xxxxxx | * | | | xxxxxx |
| North Downs | | | xxxxxx | xxxxxx | xxxxxx | * |
| EAST GROUP | | | | | | |
| South Midlands | xxxxxx | * | | | xxxxxx | xxxxxx |
| East Anglia | | xxxxxx | xxxxxx | xxxxxx | * | |

* Replaced by new representative

# Notes and Comments

## INCREASE IN SUBSCRIPTION RATES

The price of the *Journal* to employees of BT and The Post Office will be increased to £4·80 per annum (£1·20 per copy) from July 1991.

## CONTRIBUTIONS TO THE JOURNAL

Contributions of articles to *British Telecommunications Engineering* are always welcome. Anyone who feels that he or she could contribute an article (either short or long) of technical, managerial or general interest to engineers in BT and The Post Office is invited to contact the Managing Editor at the address given below. The editors will always be pleased to give advice and try to arrange for help with the preparation of an article if needed.

### Guidance for Authors

Some guidance notes are available to authors to help them prepare *Journal* articles in a way that will assist in the uniformity of presentation, simplify the work of the *Journal*'s editors, printers and illustrators, and help ensure that authors' wishes are easily interpreted. Any author preparing an article is invited to write to the Editorial Office, at the address given below, to obtain a copy.

All contributions to the *Journal* should preferably be submitted on IBM-compatible disc. As a guide, there are about 750 words to a page, allowing for illustrations, and the average length of an article is about six pages, although shorter articles are welcome. Contributions should preferably be illustrated with photographs, diagrams or sketches. Each diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that is required. Photographs should be clear and sharply focused. Prints should preferably be glossy and should be unmounted, any notes or captions being written on a separate sheet of paper. Good colour slides can be accepted for black-and-white reproduction. Negatives are not required.

It is important that approval for publication is given at the appropriate level in the author's organisation, and authors should seek approval, through supervising officers if appropriate, before submitting articles.

## JOURNAL DISTRIBUTION—NOTIFICATION OF CHANGES OF ADDRESS

IBTE Members and *Journal* subscribers who change their home address should ensure that they notify the *Journal* office on the address-label slip provided with every copy of the *Journal*.

All enquires related to distribution of the *Journal* should be directed to The Administration Manager at the address given below.

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All correspondence and enquiries relating to editorial matters ('letters to the editor, submissions of articles, requests for authors' notes etc.) and distribution of the *Journal* should be sent to: *BTE Journal* Editorial Office/IBTE Administration Office, Post Point G012, 2–12 Gresham Street, London EC2V 7AG. (Telephone: 071–356 8050. Fax: 071–356 7942.)


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(Founded as the Institution of Post Office Electrical Engineers in 1906)

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FITCE is an organisation of national associations with similar objectives to IBTE and draws its members from the public telecommunications administrations of Belgium, Denmark, Eire, France, Greece, Italy, Luxemburg, the Netherlands, Portugal, Spain, the United Kingdom and Germany. FITCE sponsors multi-national study groups (Commissions) to enquire into and report on problems of general interest, and each year one of the member countries hosts a General Assembly/Congress at which a given technical theme is discussed.

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The Membership of FITCE is available to Members and Affiliated Members of IBTE who hold a University Science Degree and/or are Corporate Members of the Chartered Engineering Institutions and/or are Chartered Engineers.

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Assistant Secretary, IBTE/FITCE Group
Post Point 213, The Angel Centre, 403 St John Street, London EC1V 4PL

I wish to become a member of FITCE through the FITCE Group of IBTE and enclose a cheque for £10.00, made payable to IBTE, in payment of my subscription to 31 March 19____. My qualifications are as follows:

Degree ______________ University ____________________________________ Year Awarded ____*

I am a Corporate Member of ______________________________________________________________*

I am/am not* a Chartered Engineer (**Delete as appropriate*)

Date ____________ Signature ______________________________

NAME ________________________________________ DUTY CODE ______________________________

ADDRESS ________________________________________ TEL: ______________________________

________________________________________

________________________________________

________________________________________ POST CODE ______________

(BLOCK CAPITALS PLEASE)

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_________________________

Your application for membership of the FITCE Group has been accepted. Your name and address will be forwarded to the FITCE Secretariat. Please advise of any change of address in writing.

Date _________________ Signed ____________________________________Asst. Sec, IBTE/FITCE

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The Journal of The Institution of
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