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BRITISH TELECOMMUNICATIONS ENGINEERING

Focus on

Synchronous Digital Hierarchy

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GUEST EDITORIAL by David Leakey

In the modern telecommunications world, network operators are faced with problems of ever-increasing complexity not only in terms of the number of operators, service providers and regulatory arrangements but also the technological possibilities that are being created. One possible result to this latter issue would be the application of ever-increasing variety with the attendant problem of ever-increasing complexity. A more realistic alternative is to rationalise requirements and limit the range of alternative options to some sensible level. This process is the essential element employed in determining network architecture which must itself take into account the minimisation of the overall cost whilst retaining the level of flexibility required to meet all reasonable service requirements.

To support this process, there is a need to gain agreement in international fora so that economies of scale may be achieved and international interconnection simplified. This is the essential drive behind the international standards activity which exists both on a worldwide and regional basis and explains the need for an appropriate degree of involvement.

The negotiation of the synchronous digital hierarchy (SDH) standards is a good example of how the process can work to the benefit of customers, operators and manufacturers alike. BT, in alliance with other organisations both in the UK and elsewhere, was able to drive the standards activity in several stages towards a worldwide agreement thus opening the market and providing a unique opportunity in the transmission world to unify network structure. Over the next decade the removal of complex internetworking arrangements followed by closer operational links between these networks are expected to underpin the improvement in facilities that customers will demand.

However, the agreements reached on SDH, though important technologically, are in many ways overshadowed by the opportunities that they create. The hope must be that they set a precedent which will have a positive influence on the pattern for standards making in the future.

The first five articles in this issue of the *Journal* address some of these issues in greater detail.

DAVID LEAKEY
Group Technical Advisor
BT Development and Procurement

The New CCITT Synchronous Digital Hierarchy: Introduction and Overview

K. R. HARRISON†

A great deal has already been written about the new CCITT synchronous digital hierarchy, much of which is in terms of history rather than network deployment[1,2]. This article is the first of five [3,4,5,6] which concentrate mainly on the future networking issues. For completeness, however, a short historical introduction is given.*

INTRODUCTION

In late-1986, the United States of America first reported on the work that it was undertaking on synchronous optical networks (SONET). At that time it was not intended that this would be a subject for international standardisation and was provided only to help the CCITT in its studies. Soon after that time, however, the UK and Japan took a strong interest in the technique and this marked the commencement of one of the most rapid and complex standardisation processes in the history of the CCITT. The net result was a change of direction in the USA which enabled the emerging synchronous digital hierarchy (SDH) to be made equally suitable for 1·5 Mbit/s-based and 2 Mbit/s-based countries. Finally in Seoul, Korea, in February 1988, agreement was reached on a new series of Recommendations, G.707[7], G.708[8] and G.709[9], which detail the hierarchy. This agreement was ratified by the CCITT plenary assembly in Melbourne in November 1988.

Since that time, Europe has examined its position more carefully and has eliminated one of the two alternative multiplexing paths of the SDH. This decision resulted in a considerable simplification of Recommendations G.707, G.708 and G.709 being agreed such that inter-operability and the emergence of worldwide equipment design can now be achieved.

PLESIOCHRONOUS DIGITAL HIERARCHY

CCITT Plesiochronous Hierarchy Rates

The CCITT plesiochronous digital hierarchy (PDH) is not one hierarchy but three[10] (see Table 1).

As can be seen from Table 1, little commonality exists between these rates, and an agreement was reached by the CCITT in 1987 on an inter-working arrangement[11], as follows:

2 Mbit/s, 6 Mbit/s, 45 Mbit/s, 140 Mbit/s.

While this facilitates the interchange of information between two countries with differing standards, it is far from an ideal solution, especially as it requires special equipment at the international gateways.

The Multiplex Mountain

The PDH is constructed on a stage-by-stage basis. To illustrate the point, for the 2 Mbit/s hierarchy:

(*a*) thirty-two 64 kbit/s time-slots are synchronously multiplexed by byte interleaving into a 2 Mbit/s stream, thirty of them being used for traffic and one each for framing and signalling[12];

(*b*) four 2 Mbit/s streams are multiplexed by bit interleaving into an 8 Mbit/s stream with the addition of framing and justification[13];

(*c*) four 8 Mbit/s streams are multiplexed by bit interleaving into a 34 Mbit/s stream with the addition of framing and justification[14]; and

(*d*) four 34 Mbit/s streams are multiplexed by bit interleaving into a 140 Mbit/s stream with the addition of framing and justification[14].

TABLE 1
CCITT Plesiochronous Digital Hierarchy

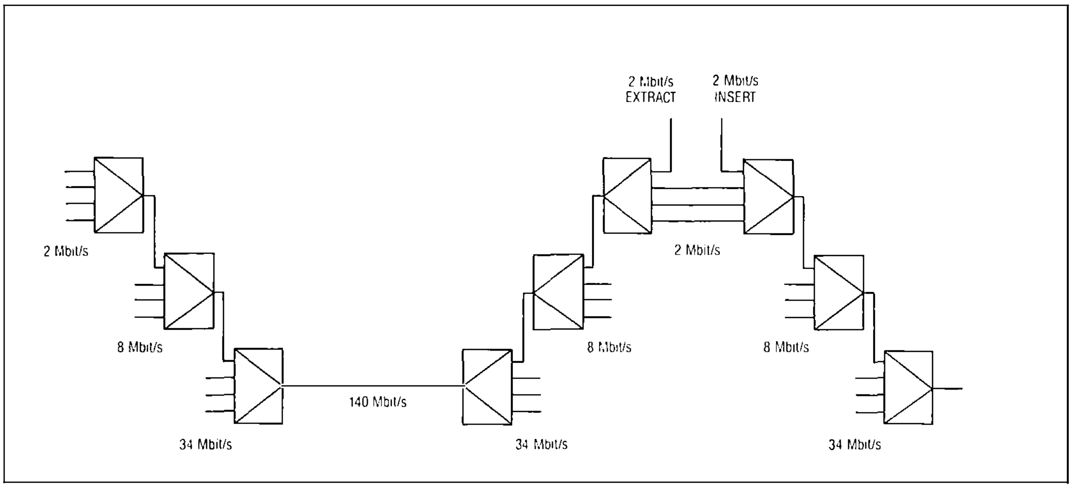
	USA (note 1)	Japan (note 1)	Europe (note 1) (+ Australia, etc.)
Primary Rate	1544 kbit/s	1544 kbit/s	2048 kbit/s
Secondary Rate	6312 kbit/s	6312 kbit/s (note 3)	8448 kbit/s
Tertiary Rate	44 736 kbit/s	32 064 kbit/s	34 368 kbit/s
Quaternary Rate	139 264 kbit/s (note 2)	97 728 kbit/s	139 264 kbit/s

Notes: 1 Bit rates above the quaternary rate (for example, 400, 565 Mbit/s) are not formally part of the CCITT PDH agreement but are nevertheless commonly used as transport bit rates.
2 Agreed but rarely used.
3 Japan uses an 8 Mbit/s interface to its switching equipment.

† BT Worldwide Networks

* CCITT—International Telephone and Telegraph Consultative Committee

Figure 1
The multiplex mountain



As a result of this complex arrangement, using multiple framing and justification stages, it is not trivial to identify a 2 Mbit/s (or a 64 kbit/s) tributary in the 140 Mbit/s bit stream.

Thus, each time it is necessary for a 2 Mbit/s tributary to be inserted into, or extracted from, a 140 Mbit/s stream, a complete range of multiplexing equipment must be provided as in Figure 1.

Transmission System Compatibility

Present optical and radio systems are commissioned on the basis of longitudinal compatibility; that is, matched equipment must be used at each end of the transmission system. This arises from line codes, modulation methods, supervisory systems etc., all of which are proprietary. Hence it is not possible to approach the ideal purchasing arrangement in which PDH equipment from different manufacturers may be mixed at will.

With the existence of more than one network operator within a particular territory, this means that information interchange at the system level can take place only at one of the CCITT-specified electrical interfaces[15] and never at an optical or air interface unless further agreements are reached.

Management Capability

The PDH offers little in the way of management facilities to the network operator. In principle it would have been possible to use some of the framing bits to provide for such capabilities, but this has not been agreed internationally. The situation has become even more difficult particularly with the provision of full-capacity unstructured signals (that is, 2048 and 8448 kbit/s) to the customer which makes it impossible to monitor the quality of a circuit with in-service measurement techniques. Indeed, many network operators have already decided not to provide unstructured bit streams to their customers.

Of course, although performance management is a major issue, it is by no means the only facility necessary for the management of networks.

SYNCHRONOUS DIGITAL HIERARCHY

Need for SDH Equipment

The SDH offers a considerably better solution to networking than that provided by the PDH. As part of the design criteria it encompasses:

- *One Global Hierarchy* With the recent simplification of CCITT Recommendations G.707, G.708 and G.709, there will truly be one synchronous hierarchy. Hence the need for the PDH interworking arrangements will disappear in time.
- *Byte Visibility at all Bit Rates* The existence of byte visibility at all bit rates implies simple multiplexing. Thus it is a relatively simple matter to extract one tributary and re-insert another. The removal of the multiplex mountain brings with it reduced equipment accommodation, power requirements and costs, improved reliability and performance and the basis for cross-connection.
- *Mid-Span Meet* The term *mid-span meet* was coined in North America to denote a fully specified interface between two operators such that equipment from different manufacturers can interwork satisfactorily. This has the advantage that special agreements are no longer necessary for compatibility reasons and operators are completely free to make commercial decisions regarding equipment sourcing. Radio and specially engineered (extra-long span) optical systems will remain a possible exception to this position for the time being.
- *Full Management Capability* A management capability is provided which covers all the functions necessary for an operator to plan, organise, command and control the network features at its disposal. This at once enables remote configuration, performance assessment and many other key features which will improve the

network response to the customer. Further details are provided in a companion article[6].

In addition to the above:

- The SDH encourages the use of optical technology for equipment interfaces. In turn, considerable cost savings and performance improvements may be realised through the substitution of numbers of electrical interfaces with one optical interface. The interconnection of switching and transmission equipment is one such example.
- The SDH enables the purchase of equipment on the world market by virtue of the existence of a single world standard.
- The SDH raises the possibility of an early international network capability at a variety of bit rates, together with appropriate management facilities.

SDH DEPLOYMENT

Early Synchronous Equipment Experience

Three or four years ago, synchronous networking advantages and, in particular, the reduced equipment accommodation and costs together with the management facilities were seen as being key factors in the development of the outer core network. Hence research work was sponsored which resulted in a frame structure in which sixty-eight 2 Mbit/s time-slots were synchronously multiplexed into 140 Mbit/s, and a product known as the *SMUX*. During this work, the SDH recommendations became available and BT, with its commitment to equipment based on international standards, decided to abandon this (now BT-unique) activity in favour of SDH networking. Although SDH offered many more advantages, small quantities of the SMUX were purchased in order to gain early experience of synchronous networking.

SDH Equipment Roll-out

Given that the SMUX was designed to operate on fibre rings and that District plans had been formulated to take this into account, it was natural that the first SDH deployment would be in add-drop rings for the outer-core network, expected in the latter part of 1991. Present plans are that this will be followed by 622 Mbit/s point-to-point systems.

It is intended that the deployment of SDH equipment will be phased in order to maximise the benefits and minimise the risks:

(*a*) add-drop multiplex rings for the outer core (155 Mbit/s first);
(*b*) long-haul high-bit-rate systems (622 Mbit/s and 2·5 Gbit/s);
(*c*) cross-connects with local control; and
(*d*) cross-connects with national control.

It is worth noting that each phase will stand on its own merits and that the deployment virtually follows the order of technology difficulty.

IMPORTANCE OF INTERNATIONAL STANDARDS AGREEMENTS

Modern telecommunications equipment places an increasing reliance on software. SDH is no exception in this respect and provides for a wide range of facilities to be offered, especially in network management terms. Thus the design of such equipment has become much more labour intensive and hence requires considerable investment to bring it to the market-place, so much so that manufacturers are pooling their resources.

This pooling has been made possible as a result of the international standards agreements. Without such agreements, manufacturers would not consider it wise to invest such large sums, either speculatively or for one network operator; hence many of the management facilities just would not be available.

Therefore network operators and manufacturers alike, around the world, have chosen to commit considerable resources to standardisation, mainly to protect their interests. The initial results appeared in Recommendations G.707, G.708 and G.709; equipment management and optical interface recommendations appeared soon after, and further recommendations will be coming to fruition shortly, thus completing the work.

CONCLUSIONS

An outline of the background and rationale behind the considerable interest in SDH networking has been given. The four articles that follow address specific key aspects in greater detail:

- SDH multiplexing concepts and methods;
- defining network architecture for SDH;
- equipment for SDH networks; and
- managing SDH network flexibility.

These articles should provide the reader with an understanding of the concepts behind the SDH. Future issues of the *Journal* are expected to provide information on deployment aspects and, taken together, these give an overview of the impact on the business and the customer alike.

ACKNOWLEDGEMENT

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Biography

Keith Harrison is responsible for architecture and standards within BT Worldwide Networks. He studied Electrical Engineering at Imperial College, London, where he obtained his first degree. After a brief spell with the Marconi Company, where he was working in the field of television, he joined Post Office Telecommunications in 1968. He subsequently obtained his Masters degree in Telecommunications at Essex University. His career in BT has spanned voiceband data transmission, frequency-division multiplexing equipment, standards for speech transmission and digital transmission and the systems engineering aspects of optical and radio systems. His international responsibilities have included chairmanship of the committee that delivered the world's first unique speech coding standard (32 kbit/s ADPCM) and the rapporteurship for error performance in CCITT SGXVIII. He is a Member of the IEE.

SDH Multiplexing Concepts and Methods

T. C. WRIGHT†

Transport networks, in providing bearer capacity needed to support telecommunications services, have always been the subject of international standardisation. The standards for second-generation transport networks are based on an interface signal, the structure of which is optimised for automatic digital cross-connection and capacity management. This article describes the underlying concepts and requirements which determined the format of the interface signal of the synchronous digital hierarchy. The signal is layered in nature, each layer being adapted into its supporting layer. The article describes the interface in terms of its layers and adaptation processes.

INTRODUCTION

At the heart of the synchronous digital hierarchy (SDH) is an internationally standardised signal format, a structured signal which supports traffic payloads and a host of operational features. The structure is organised to meet a wide range of requirements from the flexibility of payload types to easing switching payloads in equipment. Of course, the frame structure on its own does not give an SDH-based network with all the advanced operational and management features sought. It is of fundamental importance, though, since it determines the very fabric of the transmission network of the 1990s and beyond—the items of hardware that are deployed to transmit and switch payloads through the network. For this reason, it has been the subject of intense debate in international standards bodies in an attempt to devise a frame structure which optimally meets everyone's needs.

This article examines firstly the underlying concepts behind SDH and then identifies the specific requirements, many of which stem from the need to interwork with existing plesiochronous digital hierarchy (PDH) -based transmission networks. The resulting frame structure is then described.

CONCEPTS

Synchronous Frames and Byte Organisation

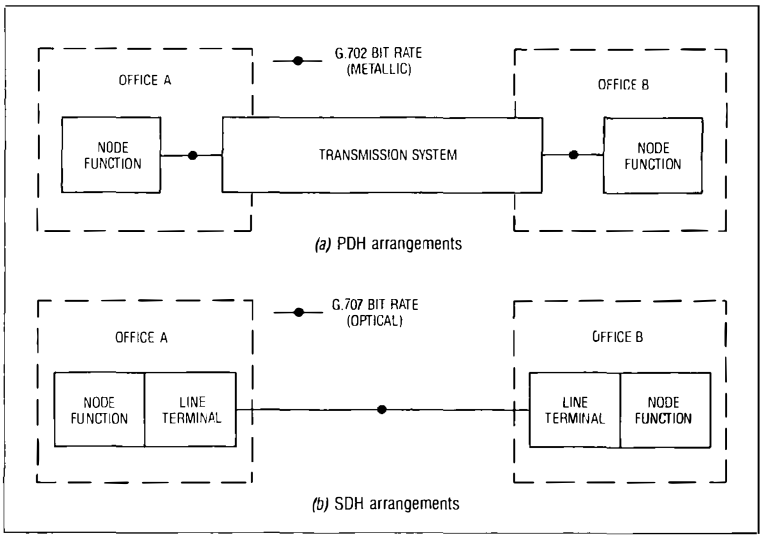
The two key features of existing primary-rate frame structures (at both 1544 kbit/s and 2048 kbit/s) are their synchronous nature and their 8-bit byte organisation in a 125 µs frame. The synchronous nature, characterised by the fixed location of the bytes of a given tributary in the frame, has resulted in cost-effective digital switching, and the 8-bit byte and 125 µs repetition makes possible global interworking at 64 and $n \times$ 64 kbit/s. Neither of these features was retained in the first generation of digital transport standards (the PDH) thus making direct switching or cross-connection of the constituent signals, including 64 kbit/s signals, from one high-bit-rate stream to another a very cumbersome prospect. The SDH, by definition, embodies synchronous features allowing payloads to be directly switched from one high-bit-rate stream to another. In addition, being byte-organised with 125 µs frame repetition, this direct switching can extend right down to the 64 kbit/s level.

Functional Integration and Optical Interfacing

For several years, it has been obvious to the telecommunications industry worldwide that the fixed network would steadily migrate to the predominant use of optical fibre as the transmission medium. The construction of a transport network, though, requires the interconnection of equipment, such as multiplexers and switches, from different vendors and thus open standards are required for the traffic interfaces.

In the PDH network, these open standards are based on metallic interfaces (Recommendation G.703[1]) suitable only for intra-office applications with reaches in the order of 100 m depending on

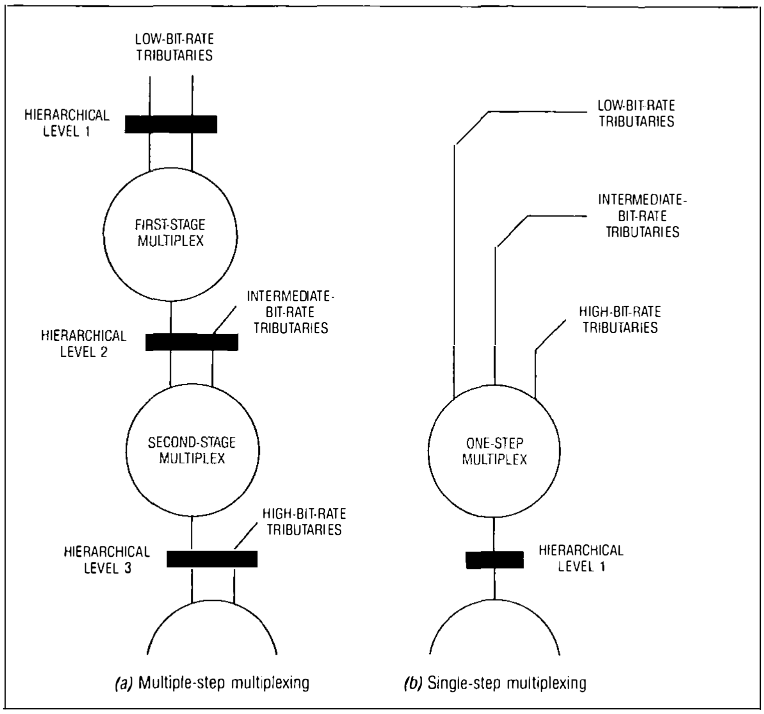
Figure 1
Functional integration of line terminal



† BT Worldwide Networks

bit rate and cable type. The interfaces for inter-office applications have all been proprietary. This does not matter much for multi-Gbit/s very long-haul multi-repeater systems which stretch technology since the transmission systems themselves embody significant functionality and the penalty of managing them as a stand-alone network element can be justified. However, for the less demanding inter-office applications, which represent the vast majority of cases, the functionality of the line system is minimal (essentially only electro-optical conversion) and the cost of managing them as a stand-alone network element cannot readily be justified.

Figure 2 Alternative multiplexing arrangements



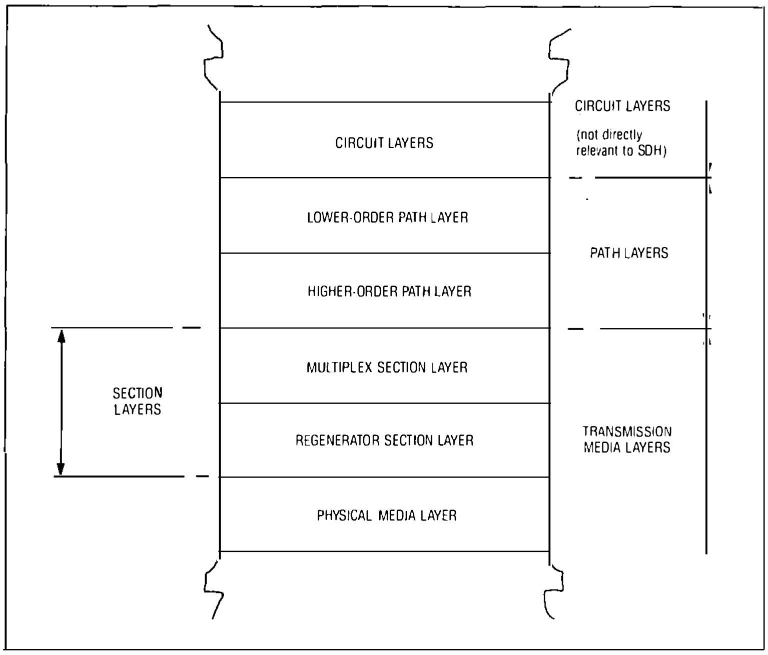


Figure 3—SDH functional transport layers

Thus, for the new generation SDH-based transport networks, standardised inter-office optical interfaces have been defined so that the line terminal functionality can be integrated into the multiplexers and switches (see Figure 1). This open optical interface standard has paved the way for high-functionality equipment with a significant reduction in the number of traffic interfaces thereby bringing major space, power and reliability savings. Of course, the inter-office interface can also be used in intra-office applications with the prospect of significant reduction of metallic traffic interfaces in telecommunications centres.

Global Interworking at the Transport Level

In addition to obscuring byte visibility, the PDH multiplexing arrangements fall into three distinct and incompatible groups based on local preferences in Europe, Japan and North America[2]. Global interworking at the transport level, and the potential for widespread networking of services which require high bit rates, has been severely constrained as a result. Recognising the desire for global networking, the SDH is based on an internationally supported framework of base standards with the minimal of regional differences thereby removing the necessity for onerous interworking functions at the transport level.

Number of Multiplexing Stages

The number of stages in any multiplexing hierarchy is a balance. On the one hand, simple access to individual tributaries within high-bit-rate aggregates requires, ideally, just one stage. This has to be balanced against the need to simplify transport network switching (for example, for facility management purposes, and for protection), which requires the grouping of tributaries into bundles that can be handled (that is, switched) as a bundle; this requires additional multiplexing stages. The multiplexing arrangement must also accommodate tributaries of different sizes. This can be achieved either by having a multiplexing hierarchy where the levels in the hierarchy match the bit rates of the tributaries or by adopting a multiplexing stage which can mix together tributaries of different sizes. These alternatives are illustrated in Figure 2. By using both techniques, the SDH can support a wide range of tributary sizes with just two multiplexing stages.

Direct Support of Circuit Layer Signals

Figure 3 shows the functional transport layers embodied in the interface signal. The SDH itself is confined to the path and transmission media layers and not directly with the circuit layers. The circuit layers are generally considered to be the bearers for telecommunications services to users and are not, therefore, of direct concern to the SDH transport network. However, one of the early requirements of SDH expressed in the standards bodies was the support of all the bit rates of the PDH given in Recommendation G.702[3]. This requirement stemmed from a time when SDH was being considered as simply an extension of PDH networks. As a consequence, the SDH standard describes the method of transparent support (that is, independent of the signal content) of most of the G.702 bit rates; the remainder could also be described if there is considered to be a real network need. More recently, the concept of direct support of the circuit layers which support telecommunications services has received wider consensus. This means that, rather than always supporting the G.702 bit rate irrespective of the circuit layers within the G.702 bit rate, the circuit layers themselves are directly supported. This direct visibility simplifies circuit layer switching since it cuts out the PDH network layers which are essentially redundant.

SPECIFIC REQUIREMENTS

Many of the specific requirements on SDH stem from the need to interwork with PDH-based networks. This section examines these and other requirements which have determined the details of the SDH.

Interfaces with PDH Transport Networks

The interfaces between PDH- and SDH-based networks use G.703 metallic interfaces with emphasis on the following cases:

1544 kbit/s Two cases are covered in the SDH standards in accordance with the concept of direct support of circuit layer signals. The first is a method of support which gives visibility to the 64 kbit/s tributaries. The second is transparent support, for example, in the case of primary-rate leased lines.

2048 kbit/s Again, the same two cases as above are covered.

44 736 kbit/s This is an important bit rate, particularly in North America, and the SDH standard allows for its transparent support. In addition, most high-bit-rate PDH transmission systems in North America transparently support multiples of 44 736 kbit/s and have traffic interfaces at 44 736 kbit/s. Initial deployments of SDH-based transmission systems will also have to support this rate.

139 264 kbit/s Many high-bit-rate PDH transmission systems in Europe and North America transparently support 139 264 kbit/s and multiples thereof with traffic interfaces at 139 264 kbit/s. As with 44 736 kbit/s, initial deployments of SDH-based transmission systems will also have to support this rate.

The PDH bit rate of 34 368 kbit/s is also worth a special mention since it has been the subject of intense debate in the standards bodies. Although the SDH standard describes a method whereby this rate can be supported transparently, there are limited instances where 34 368 kbit/s is a circuit layer signal directly supporting telecommunication services. In most cases (and in accordance with the notion of direct support of circuit layer signals), the signals supported in 34 368 kbit/s will be 'extracted' and directly supported in SDH-based path layers thus removing redundant PDH network layers.

Support of New Services

Within the International Telegraph and Telephone Consultative Committee (CCITT), the focus is strongly on developing standards for a future integrated services digital network capable of supporting all services including broadband services. The wide range of bit rates required by the different services, the desire to minimise the types of circuit layer switches and the increase in services demanding transient changes in bit rate (including variable-rate video coding and bursty data services), have put the emphasis on asynchronous transfer mode (ATM) in which services are supported in fixed-length packets (or cells) which are switched and bundled together (that is, multiplexed) according to information in the packet header[4]. As a transport network, the SDH is capable of transporting transparently ATM cells between terminal equipments and ATM-based switches and between switches. Fixed-bit-rate broadcast-quality television packetised into ATM cells requires at present a transport capacity of about 150 Mbit/s. This bit rate determined the lowest interface bit rate of the SDH.

Hierarchy of Digital Interfaces

To meet a range of network applications and the trend towards higher transmission bit rates, the SDH has a range of interface rates. Moreover, the interface rates form a modular family which is extendible to match the anticipated further technology advances in electro-optics to bit rates in excess of 10 Gbit/s.

Transport Across Clock Boundaries

Most operators have a reference clock with a long-term accuracy better than 10^{-11} from which they distribute timing to their switch nodes. Even with this accuracy, the difference between two such clocks can lead to slips in a signal bit stream which is transmitted with the accuracy of one clock and then retimed downstream with the accuracy of the other clock. There are basically two ways of dealing with this situation: one is to avoid retiming by using the transmit clock to time the final downstream receive terminal, the other is to introduce slips in a controlled manner with the objective of minimising the disturbance to the service as is done in present-generation 64 kbit/s circuit switches. The former technique is usually associated with the justification process used in transport networks although, in essence, it is also used in packet switching. Since transport networks have traditionally avoided resorting to the introduction of controlled slips, the SDH uses a novel form of justification (based on pointers, described later) which allows a signal which is timed from one source to be cross-connected or multiplexed with other signals at a node timed from a different source and so on.

Protection

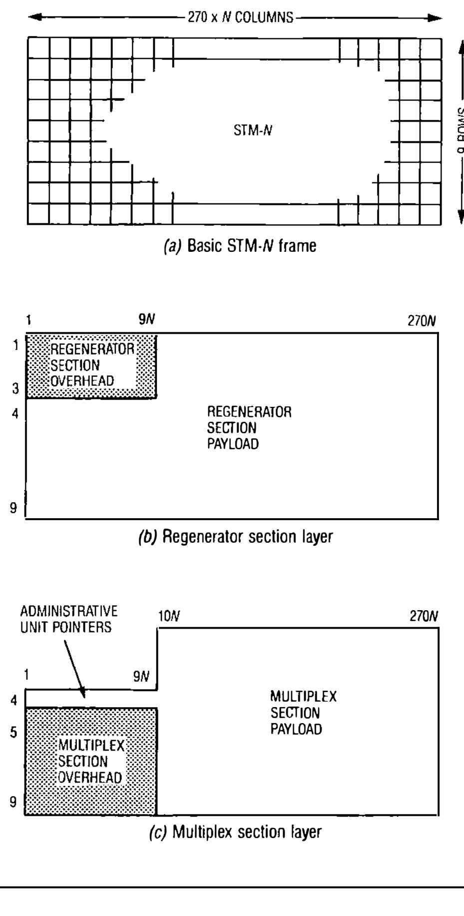
Many operators have deployed automatic protection switching arrangements to restore service in the event of a transmission failure. These switching arrangements are not generally an integral part of PDH-based networks and have usually been deployed as separate switching elements. Typically they are implemented using space switching at a given level of the PDH either at the individual transmission system level on a $N + 1$ (N workers and one stand-by) basis or at a network level which establishes an alternative routing for the failed path. The SDH frame format, in addition to permitting easy cross-connection of payloads (a feature which can be used to set up an alternative routing for a failed path), also offers simple $N + 1$ switching at the line level.

INTERFACE SIGNAL

General

The frame structure is described below in terms of the layered nature of the interface, as shown in Figure 3, starting with the physical media layer and including the way each layer is adapted into its supporting layer. It is believed that this is the clearest way of describing the interface and one which separates the various aspects and promotes better understanding of the concepts. For reasons of brevity, much of the detail, and in particular the numerology, is omitted. The reader is referred to Recommendations G.707[5], G.708[6] and G.709[7] for the complete detailed standard.

Figure 4
STM-*N* section layers



Layered Nature

The lowest layer, the physical media layer, is characterised by wavelength, pulse shape and other parameters of an optical signal. Next there is the section layer which ensures the integrity of the signal between nodes in the SDH network. It is sub-divided into two parts: the regenerator section layer, which is concerned with the transmission between line terminal and regenerators and between regenerators themselves; and the multiplex section layer (a somewhat misleading term), which is concerned with the transmission between line terminal equipments. Above that comes the SDH path layers, which are concerned with the integrity of the paths from end-to-end. These too are divided into two parts: the higher-order paths, which can support either circuit layer signals or lower-order paths; and lower-order paths, which support circuit layer signals. Then come the circuit layers (that is, the services which SDH transport networks support), the detail of which is not an issue for SDH. These layers should not be confused with the hierarchical *levels* (or bit rates) of the SDH; at each level of the SDH, the signal structure still has the same layered nature.

Rectangular Representation of the Frame

The frame structure is an arrangement of 8-bit bytes which repeats every 125 μs. For practical reasons, considering the large number of bytes in a frame, the frame is illustrated as a rectangular array of bytes which are transmitted from top left to bottom right like words on a page. Each byte represents 64 kbit/s. The rectangular representation is useful in another way in that it better illustrates the time relationship between bytes belonging to a particular tributary. The lowest level of the SDH, known as *synchronous transport module level 1* (STM-1) is represented by a rectangular arrangement of 270 columns by 9 rows of bytes yielding a gross bit rate of 155 520 kbit/s. The frame structures of higher levels in the hierarchy, generically known as *STM-N*, are represented by a rectangular arrangement of $N \times 270$ columns by 9 rows with gross bit rates of $N \times 155\ 520$ kbit/s. Values of N of 1, 4 and 16 have been standardised by the CCITT and the European Telecommunications Standards Institute (ETSI)[8]; additionally, 8 and 12 have been standardised by the American National Standards Institute (ANSI)[9].

Figure 4 gives an outline of the frame structure for an STM-*N* signal and illustrates the regenerator and multiplex section layers which are described in more detail below.

Regenerator Section Layer

At the lowest layer of interest to the SDH (the regenerator section layer), the frame is made up of a payload and a regenerator section overhead. This overhead contains the information needed to transfer the payload from one equipment to the next in the SDH network and includes frame alignment, order wire, block error detection, and a 192 kbit/s data communications channel for network management purposes. The overhead is terminated by all elements in an SDH-based network.

Multiplex Section Layer

Description

The multiplex section layer is supported in the payload of the regenerator section layer. Again it comprises payload and, in this case, a multiplex section overhead. This overhead includes a block error detector, a channel for controlling automatic $N+1$ protection switching of the multiplexer section layer and a 576 kbit/s data communications channel. The overhead is terminated by all elements in a SDH-based network except regenerators.

Adaptation

The adaptation of the multiplex section layer into the payload of the regenerator section layer is trivial since they are synchronous and phase aligned with one another such that they occupy the same columns in the frame.

Higher-Order Path Layer

Description

Higher-order path layers are supported in the payload of the multiplex section layer. They comprise payload and path overhead. The path overhead includes such functions as path name, path status, path content, block error detection and far-end block error status. The overhead is terminated only at the locations where the path is assembled and disassembled. The payloads of the paths are called *containers* (Cs), and, as discussed later, can support either high-bit-rate circuit layer signals or multiple lower-order path layers. The combination of payload and path overhead is called a *virtual container* (VC). The VC is a key entity in SDH in that it is the unit which is routed through SDH-based networks in a transparent manner from the path originating location to the path terminating location to deliver the content of its payload. At intermediate locations, which can include higher-order path layer cross-connects, the VC is transported transparently. There are two sizes of higher-order VCs, one at about 50 Mbit/s and the other at about 150 Mbit/s, and they are given suffix numbers which equate to the corresponding approximate level in the PDH: VC-3 and VC-4 respectively. These can be multiplexed together into the payload of the multiplex section layer, although for simplicity of management, some regions of interest will only use one size. The VC-4 will be used in Europe while both the VC-3 and VC-4 will be used in North America. This difference is not as significant as it may sound since the numerology of the frame organisation is such that the VC-4 is formed by concatenating the payloads of three VC-3s. Higher-order VC concatenation is also used to support circuit layer signals in excess of 150 Mbit/s.

Adaptation

The adaptation of higher-order VCs into the payload of the multiplex section layer involves two functions: the addition of a pointer to each VC (to form what is known as an *administrative unit* (AU)) and the multiplexing of the AUs (essentially by byte interleaving).

AU pointers allow higher-order VCs to float in phase and, to a small degree, in frequency with respect to each other and to the payload of the multiplex section layer. This floating is required to cross-connect or multiplex VCs:

(*a*) which originate from separate locations with different timing references without introducing slips;
(*b*) without first phase aligning the VCs and thereby minimising buffering (and hence delay); and
(*c*) which have been subject to network wander without the need for full wander buffering (and hence delay).

Each AU pointer is in two parts both of which occupy a few bytes in a fixed position in the payload of the multiplex section layer. The first is essentially a binary number corresponding to the distance in bytes between the position in the frame of the pointer and the position of the first byte of the VC. The second part either contains data from the VC or dummy data. This allows the phase of the VC to gradually drift with respect to the payload of the multiplex section layer (due, for example, to a frequency offset) without incurring a data slip. If the frequency of the VC is slightly less than that of the frame of the section layers, then the alignment of the VC in the payload of the multiplex section layer gradually slips back in time and the pointer value is incremented by one accompanied by some dummy data in the bytes following the pointer; in other words, positive justification. On the other hand, if the frequency is greater than the payload of the multiplex section layer, the alignment of the VC must be periodically advanced in time and the pointer value decremented by one accompanied by valid VC data bytes in the second part of the pointer (that is, negative justification). In practice, pointer adjustments are not expected to occur very often and the second part of the pointer will therefore contain dummy data for the most part.

Lower-Order Path Layer

Description

Lower-order path layers are supported in the payload of the higher-order path layer. They too are VCs comprising payload and path overhead which can be routed through SDH-based networks in a transparent manner from the path originating location to the path terminating location. At intermediate locations, which can include lower-order path layer cross-connects, the VC is transported transparently. Table 1 lists the different sizes of lower-order VCs.

TABLE 1
Lower-Order VCs

	Container Capacity	Comment
VC-11	1·7 Mbit/s	Used to support 1544 kbit/s either transparently or in a manner with 64 kbit/s byte visibility
VC-12	2·3 Mbit/s	Used to support 2048 kbit/s either transparently or in a manner with 64 kbit/s byte visibility
VC-2	6·8 Mbit/s	VC-2s can be concatenated (to provide payloads of $n \times 6{\cdot}8$ Mbit/s) which are then given the identity VC-2-nc
VC-3	50 Mbit/s	The terms *lower-order* and *higher-order* are relative and thus the VC-3 is classified as lower-order only in regions using the higher-order VC-4 (for example, Europe).

Adaptation

The adaptation of lower-order VCs into the containers of higher-order VCs involves two functions: the addition of a pointer to each VC (to form what is called a *tributary unit* (TU)) and the multiplexing of the TUs (in a manner which allows different sizes of lower-order VCs to be accommodated in the higher-order VC).

The requirements and principles of operation of the TU pointers are the same as for the AU pointers described above except that all the functions have moved up one layer. In other words, TU pointers allow lower-order VCs to float with respect to each other and to the container of the higher-order VC. TU pointers are located in fixed positions in the container of the higher-order VC.

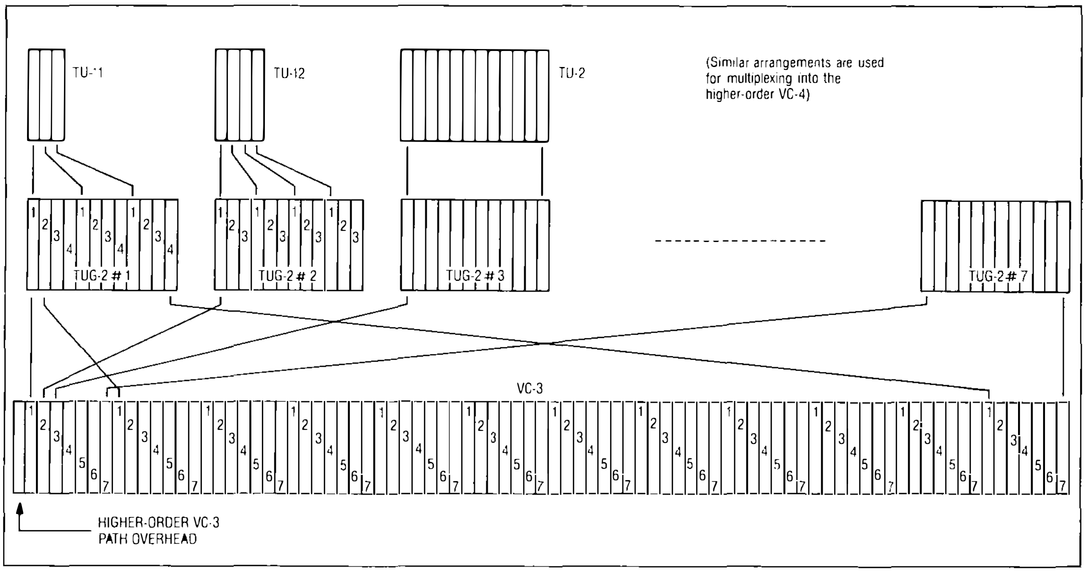
Multiplexing of TUs can be described by taking, as an example, the multiplexing of TU-11s, TU-12s and TU-2s. The bytes of each TU occupy respectively 3, 4 and 12 columns of the 9-row structure. To minimise buffering delay, the columns of a given TU are spaced out evenly across the payload of the higher-order VC. Thus there is some constraint on the way these VCs can be mixed. This is achieved by grouping together TUs of the same size into 12-column groups known as *tributary unit groups level 2* (TUG-2) and then interleaving the columns of each TUG-2. This is illustrated in Figure 5. It was this method of mixing that essentially determined that the structure should have 9 rows; the TU-11 requires a minimum of 26 bytes per 125 µs and the TU-12 requires a minimum of 34 bytes. A 9-row structure was optimum in this respect in that each TU could occupy an integer number of columns with minimum redundant stuff bytes.

To illustrate accurately the SDH frame with the offset VCs would result in a confusing diagram, and, therefore, a common representation is to show the offset VCs as displaced rectangles in the manner of Figure 6. Of course, in a real frame, all the bytes of the VCs reside within the basic STM-N frame with the bytes of a given VC generally crossing a 125 µs STM-N frame boundary.

Circuit Layers

Although the detail of the circuit layer is not a matter for SDH, provision of appropriate adaptation by SDH path layers requires certain aspects of the circuit layers to be known. The adaptation in this case is generally referred to as *mapping* (not multiplexing) since the circuit layer signal is

Figure 5 Multiplexing TUs into higher-order VC-3



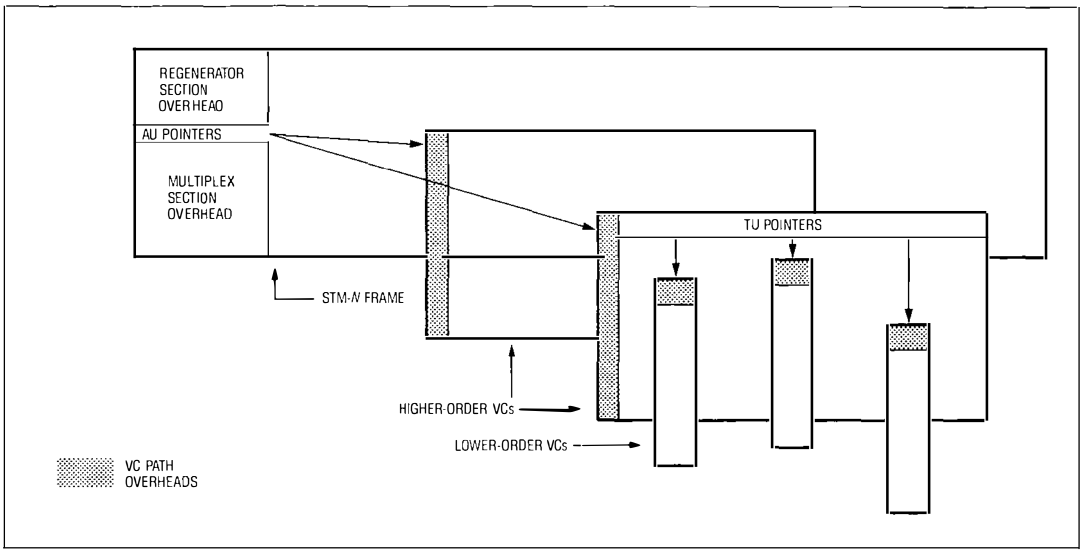


Figure 6
Representation of phase offset of VCs in STM-*N* frame

'poured into' the container together with fixed stuff bits (if needed) and justification (if the circuit layer signal is not synchronous with the container). Mappings have been standardised for many circuit layers including those listed in Table 2, with more envisaged as the need arises particularly for local area network interconnects and metropolitan area network (MAN) services.

Multiplex Structure

The diagram of Figure 7 has proved useful in showing how the various SDH multiplexing entities are related and how a particular signal is routed through the structure. When the CCITT agreed the SDH multiplexing structure in November 1988, there was a considerable number of optional routes which a given signal could take through the structure, options which represented local and regional preferences. It was clear that this would lead to the same signal being supported in different ways with a lack of

TABLE 2
Circuit Layer Mappings

Circuit Layer	VC Used
64 kbit/s	Mapped into VC-11 or VC-12 in a multiplexed format. Justification cannot be used and therefore the 64 kbit/s signals must be synchronous with the container
1 544 kbit/s	Mapped into VC-11
2 048 kbit/s	Mapped into VC-12
6 312 kbit/s	Mapped into VC-2. Likely to be a rarely used mapping
34 368 kbit/s	Mapped into VC-3
44 736 kbit/s	Mapped into VC-3
139 264 kbit/s	Mapped into VC-4
ATM cells	Generic mappings into all VC sizes. Also embraces IEEE 802.6 MAN standard.

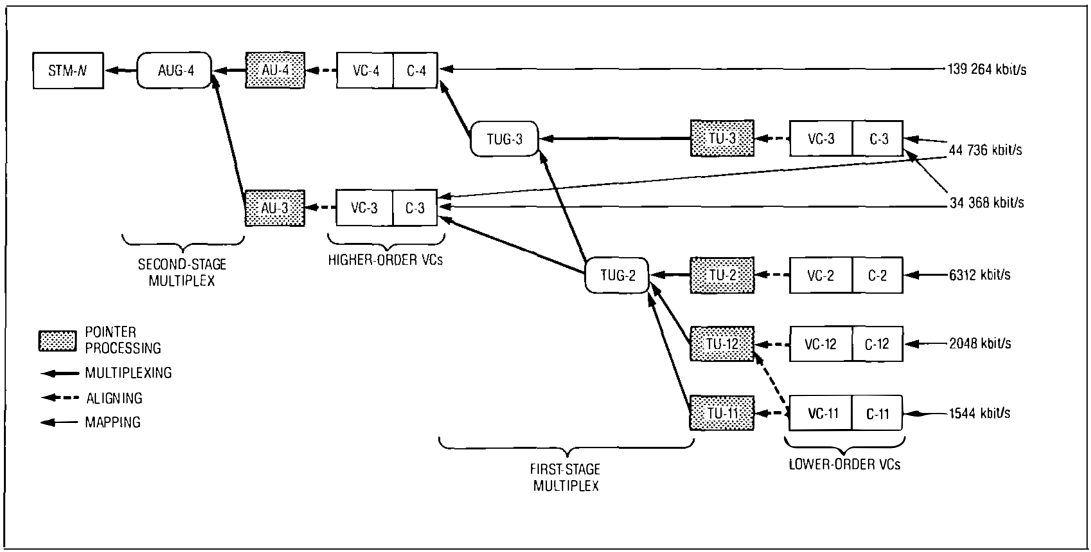


Figure 7
SDH multiplex structure

commonality of VCs between the regions and the consequent need for special gateway interworking functions. In May 1990, agreement was reached in the CCITT to eliminate all but two of the options thus leading to a common set of VC sizes and much less onerous interworking functions. Of the optional routes that remain, the ANSI standard falls into one camp and the ETSI standard falls into the other camp as follows:

Higher-Order VC Size In the ANSI standard, the higher-order VC-3 is used to support lower-order VCs; the VC-4 is used only to support high-bit-rate circuit layer signals. In the ETSI standard, the higher-order VC-4 (rather than the VC-3) is used to support lower-order VCs.

Support of VC-11 In the ANSI standard, the TU-11 pointer adapts the VC-11 into the higher-order VC while, in the ETSI standard, fixed stuff bytes are added to the VC-11 and the TU-12 pointer is used. The latter arrangement is claimed to offer some hardware and management advantages in regions where the VC-11 is seldom used.

FINAL WORDS

From some fundamental concepts of multiplexing and taking into account some specific network requirements, particularly the ease of transition from PDH-based transport networks, this article has described how the SDH frame is organised. The layered nature of the SDH has been exploited in order to simplify description and to promote better understanding of the concepts of SDH and SDH-based transport networks.

ACKNOWLEDGEMENTS

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Biography

Tim Wright presently leads a team addressing network architecture and standards strategy within Network Strategy Department of Worldwide Networks. He previously headed a group responsible for transmission network standards and was active in CCITT and ETSI in the development of the SDH standards. His international responsibilities include rapporteurship for SDH network aspects in CCITT SG XVIII and chairmanship of ETSI/STC TM3. He studied electrical engineering at Imperial College, London, from where he joined the then Post Office in 1972. During his career in BT, he has worked mainly in areas of transmission network development.

Defining Network Architecture for SDH

A. B. D. REID†

The international standardisation of the synchronous digital hierarchy has caused a significant rethink in the way network architecture is defined. A set of concepts has been developed in the CCITT which allow all the features of networks based on SDH to be described, modelled, designed, dimensioned, and managed. These fundamental concepts, while originally developed for SDH, are applicable to any telecommunications network, in particular those designed to provide broadband services.*

INTRODUCTION

The international work on the definition of the synchronous digital hierarchy (SDH) in the ANSI‡ and CCITT is based on several key principles which were developed in the standards bodies prior to the definition of the standards themselves. Some of these principles are technological; for example, the use of optical fibre and the latest integrated circuit technologies. However, most of the principles are architectural. These were based on experience gained by network operators in operating the existing plesiochronous digital hierarchy (PDH) and included the goal of a single world standard[1], the provision of generous management capacity for performance monitoring at every bit rate, and a strict adherence to the layering principles described below. The priority of the standards bodies was the generation of standards for the SDH interfaces and equipment, and these have been largely completed. However, the CCITT has more recently returned to some of the key architectural principles and has formalised them. This work has resulted in several new concepts which are currently in a draft CCITT Recommendation[2] due to be completed and approved by 1992.

NETWORK ARCHITECTURE

Architecture is a widely used term. Most notably, architecture is applied to buildings, although telecommunications operators have used the term for telecommunications networks. It is possible to draw out a common understanding of architecture which can be applied to both buildings and networks and that is that architecture is the subject concerned with a set of descriptive tools and their use in a design process.

There are two important aspects to architecture, whether it is the architecture of buildings or networks. Firstly, the descriptive tools may be used to evaluate and test different designs without constructing them. Secondly, the descriptive tools may be used to describe a design so that those who construct it and maintain the construction afterwards correctly understand the architect's intent in the design. Both of these aspects of architecture are essential to the design of BT's network so that it is fully optimised for the right balance of cost and functionality.

NETWORK ARCHITECTURE ISSUES RAISED BY SDH

In the past, network architecture has applied predominantely to the public switched telephone network (PSTN). When BT undertook its modernisation programme, a network architecture was developed based on System X and AXE10 exchanges, PDH higher-order multiplexing and line systems based on a variety of technologies including optical fibre, microwave radio, satellite, pair cable, and coaxial cable (new coaxial line systems have not been installed for several years). This network architecture is shown in Figure 1.

SDH presupposed the use of technology that allows the economic manufacture of digital cross-connects (DXC) that can cross-connect bit rates from 2 Mbit/s up to 2·5 Gbit/s. The DXC replaces multiplexers and digital distribution frames (DDFs) and is very much smaller in physical size. This means that the DXC, when compared to the multiplexers and DDFs, will be more reliable, require less maintenance, use less power and accommodation, and will cost significantly less. The DXC can be remotely managed, which means that it can facilitate rapid circuit provision without any of the existing circuit provision work in stations, again significantly improving quality and reducing costs. The remote management also means that the DXC can be used as part of a network restoration scheme to further improve network availability.

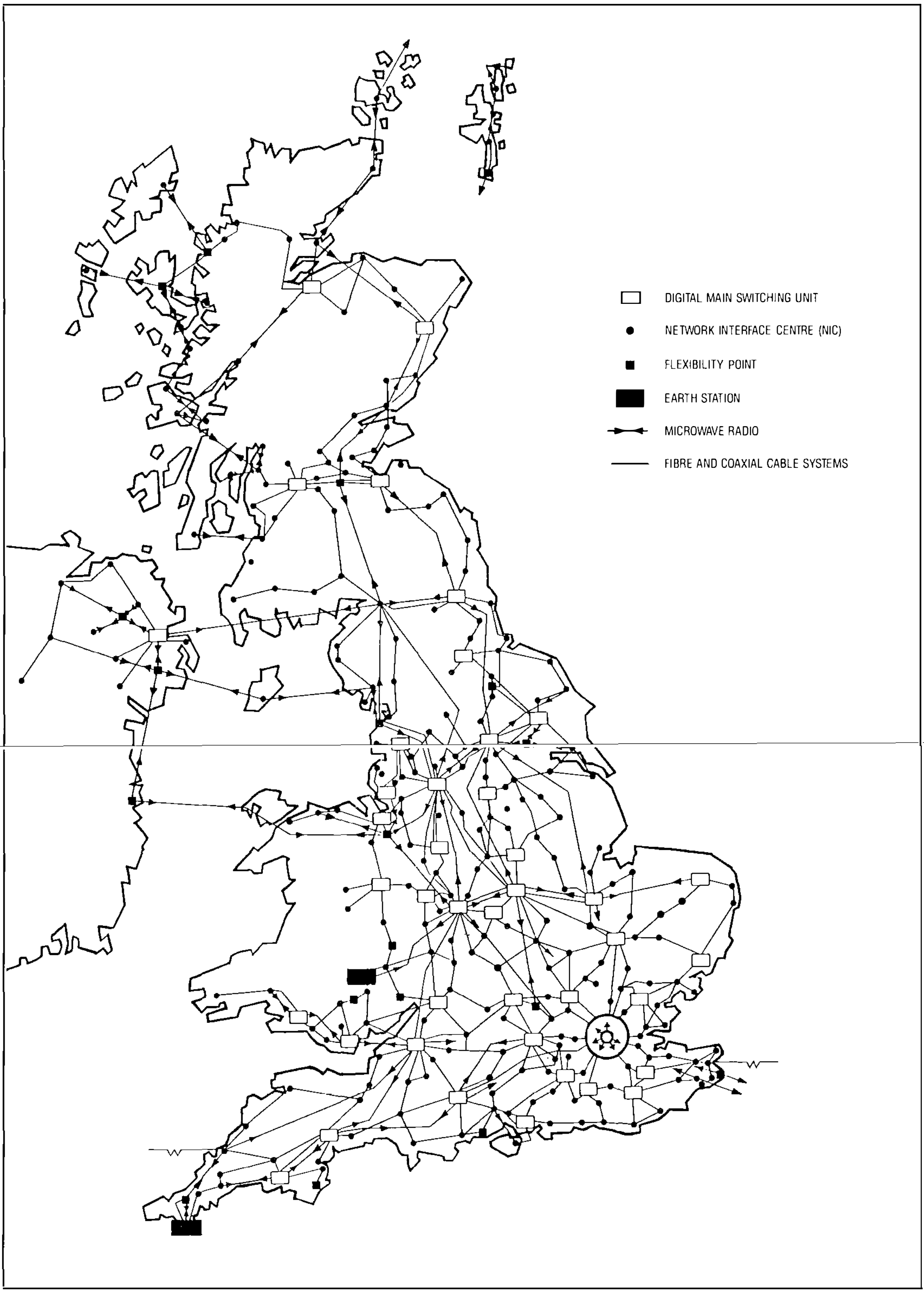
All network operators, including BT, are beginning to find that the PSTN is not the dominant network service it was in the past. New services based on information technology, for example, LAN interconnect, high-speed inter-processor links, video services of various types, remote

† BT Worldwide Networks

* CCITT—International Telephone and Telegraph Consultative Committee

‡ ANSI—American National Standards Institute

Figure 1
BT digital trunk network



CAD/CAM, etc, now account for a significant proportion of line system capacity, and this is certain to increase. The SDH is designed to provide a general transport network infrastructure that can support new networks specifically for these new services such as switched multi-megabit data service (SMDS)[3] and broadband ISDN (B-ISDN)[4], as well as supporting some of the services directly.

None of these features of SDH could be adequately described by the network architecture indicated in Figure 1 and so the descriptive tools of a new network architecture were required. The CCITT has called this *transport network architecture*. While transport network architecture was originally developed for SDH, it is generic in nature and can be applied to any telecommunication network from Telecom Gold to possible future networks based on optical wavelength-division multiplexing (WDM) and wavelength routing. It takes into account existing architectural frameworks including that shown in Figure 1 and the ISO seven-layer stack. Transport network architecture is set to become the basic framework for the development of broadband services including B-ISDN.

TRANSPORT NETWORK ARCHITECTURE

It is often the case when describing any new set of concepts that a certain amount of redefinition of terms is necessary. Some terms may have been used loosely in the past and a more precise definition is necessary. This has been the case with transport network architecture and much of the time in the CCITT has been taken up with the definition of these terms: the current draft of the Recommendation contains 44 definitions. Considerable effort has been made to avoid confusion with existing usage of these terms and, while the definitions themselves are now considered to be stable, it is possible that some of the terms associated with the definitions may change to further increase clarity. The terms used in this article are those currently used by the CCITT.

This article gives a brief presentation of transport network architecture and introduces the important concepts and terms. Some of the definitions may appear arbitrary, but this is due to the brevity of the presentation rather than any lack of rigour in the transport network architecture.

Layer Network, Access Points, and Trails

In the past, the term *network* has been used loosely to cover several concepts including all that shown in Figure 1. The term *network* is now used in a very general way to include all the things that a network operator must put in place in order to provide telecommunications services including equipment, software systems, and human processes. The *transport network* is defined to be the collection of logical functions in the network which convey user information between distant locations (the network may itself be a user). Transport network architecture, therefore, is concerned with the definition and use of descriptive tools for the transport network.

The key feature of the transport network is its ability to set up communication between any *access points* at distant locations when so requested. Not all access points, however, will be of the same type and successful communications will only take place between access points of the same type—an X.25 access point cannot communicate with a 140 Mbit/s access point. A *layer network* is the logical entity which can connect together access points of the same type.

The type of the access points, and hence the layer network, is defined by the *characteristic information*. Characteristic information has a defined format which will contain both user information and a certain amount of standard overhead which can normally be used for management functions like performance monitoring. Examples of this overhead are frame alignment words in PDH (for example, time-slot (TS) 0 of the 2 Mbit/s frame) and path overhead in SDH (for example, the V5 byte of the VC-12). The format of the characteristic information is generated at the access point in one direction of transmission and is interpreted at the access point in the other direction of transmission.

The layer network can set up communication between access points and this specific communication is called a *trail*. These concepts are illustrated in Figure 2.

Partitioning

In order to set up trails in an economic way, a layer network will normally consist of a number of nodes (exchanges, DXCs, or indeed DDFs) that are linked together in a defined topology. Normally the layer network will be global, as all possible access points are included, which will make the overall topology of the layer network

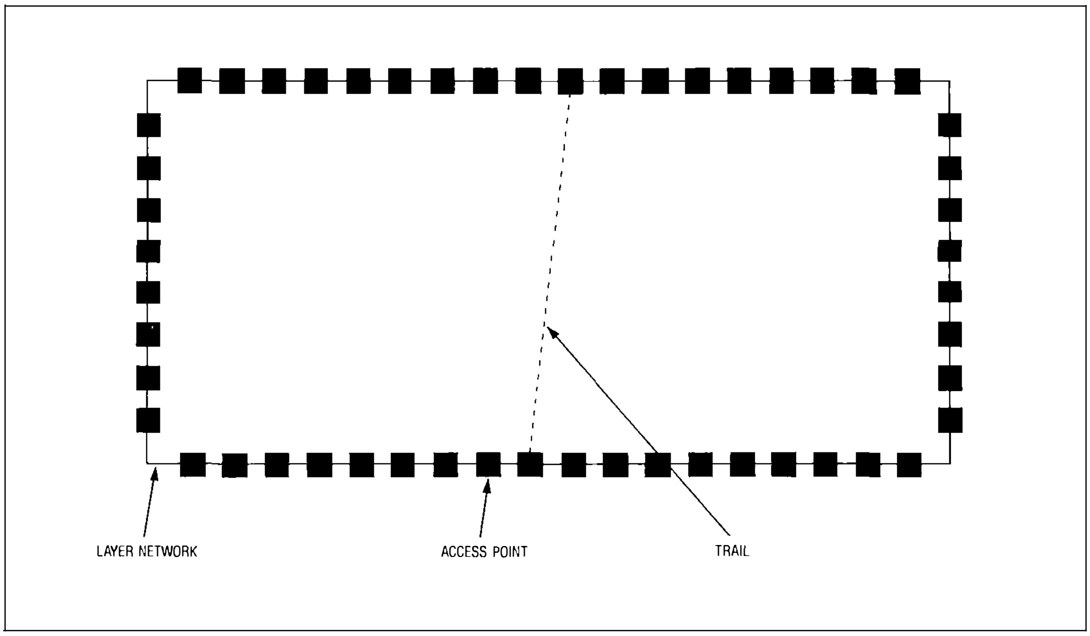
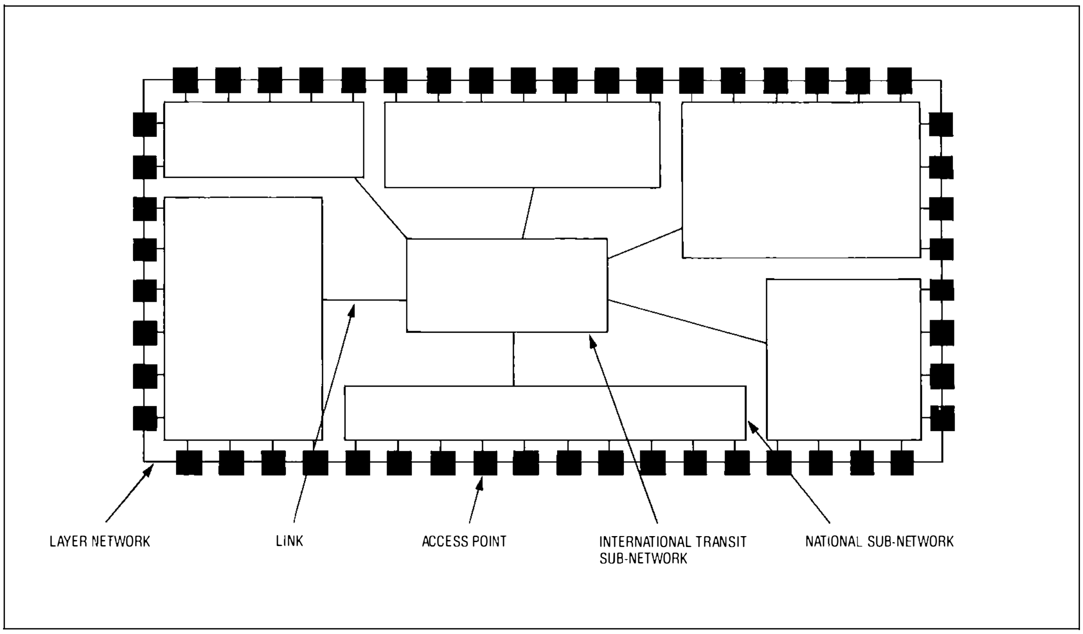


Figure 2
A layer network

Figure 3
Partitioning of a layer network



virtually impossible to describe. It is necessary to *partition* the layer network into manageable parts.

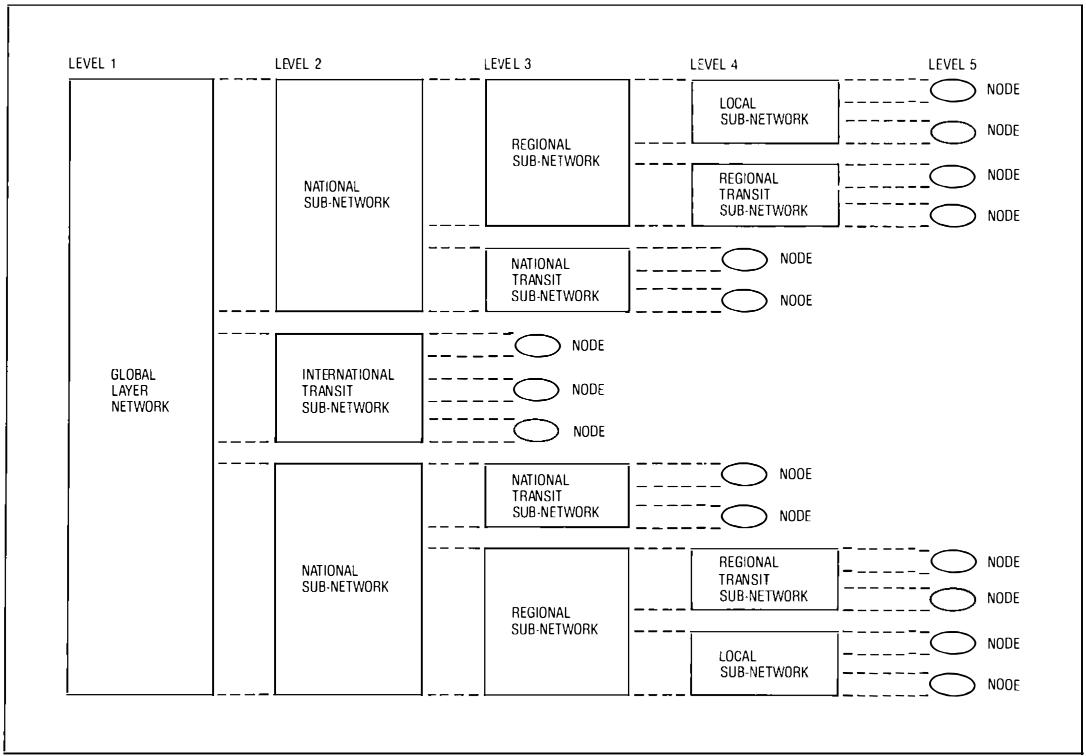
A first level of partitioning might be to divide the layer network into an international transit *sub-network* and national sub-networks. The result is a number of sub-networks with *links* between them in a defined topology as shown in Figure 3.

The international transit sub-network could then be further partitioned into the sub-networks provided by the international transit operators. Each national sub-network could be further partitioned into a trunk transit sub-network and regional sub-networks. Partitioning can continue and the end result of partitioning will be to end up with the fundamental nodes and links of the layer network with the nodes equating to sub-networks.

The importance of the partitioning concept is that it allows a part of a layer network to be considered as a single entity by the rest of the layer network and the internal structure of the sub-network is hidden. This is significant both for reducing the complexity of the management and control of the layer network, and allowing individual network operators the freedom to change and optimise their sub-network without affecting the rest of the layer network.

The partitioning process will produce a tree structure of transit sub-networks and so it is possible to define levels in the tree structure as illustrated in Figure 4. These levels are significant for several applications of the partitioning concept; for example, capacity consolidation, trail

Figure 4
Partitioning of a layer network



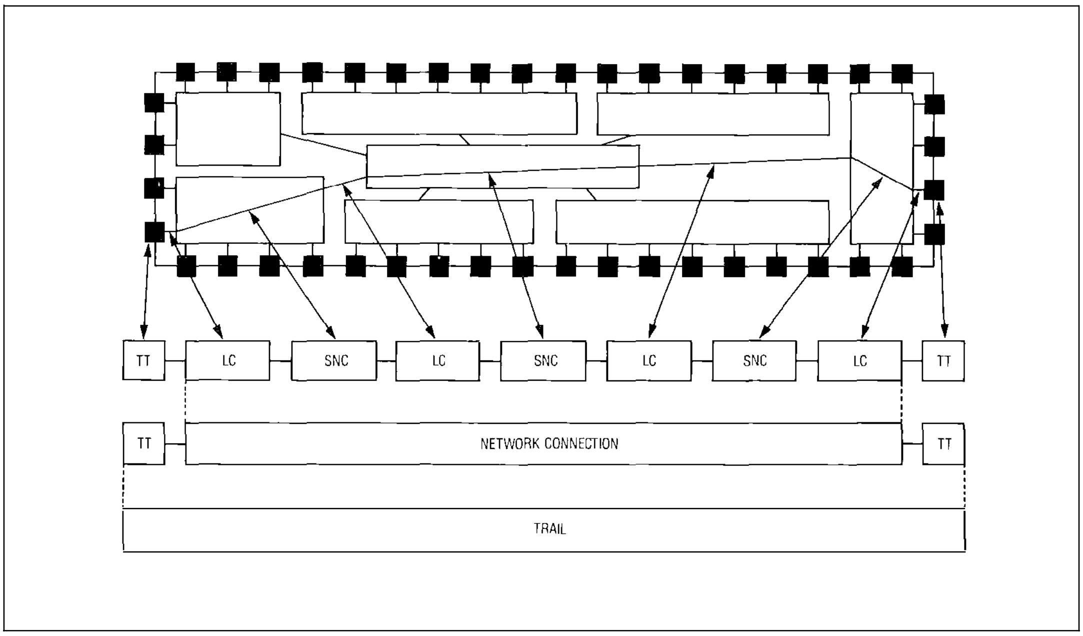


Figure 5
Partitioning of a trail

TT: Trail termination
LC: Link connection
SNC: Sub-network connection

set-up and restoration, etc. Each partitioning step can be described by a simple relationship:

sub-network =
decomposed sub-networks + links + topology.

While the partitioning concept has not been formalised in the past, extensive use has been made of it in switched networks, especially for numbering and routing. The fields of the PSTN numbering scheme are defined by the levels of the partitioning tree and the step-by-step routing makes full use of the hiding feature of partitioning.

So far, this description allows for the partitioning of the topology of the layer network. It is equally possible to partition the trails formed across the layer network. A trail is made from a *trail termination* function at each end, which generates and terminates the overhead, together with a *network connection* as illustrated in Figure 5. The network connection can be partitioned into *link connections* and *sub-network connections*. The link connection is formed across a link while the sub-network connection is formed across a sub-network. The sub-network connection can be further partitioned into sub-network connections and link connections in the same way as the sub-network and described by the following relationship:

sub-network connection =
decomposed sub-network connections +
link connections.

Layering

The other key concept of transport network architecture is *layering*. A layer network is made up from sub-networks and links. The links are fixed and generally cannot be partitioned. Since they are not partitioned, the most economic way of providing the links is by bundling a number of link connections together and transporting them on a trail of a higher capacity. For example, thirty 64 kbit/s connections are bundled together and carried on a 2 Mbit/s trail. The bundling function is called *adaptation* and normally will involve multiplexing. This is illustrated in Figure 6.

The concept of layering gives a view of one layer network serving another, or of one layer network being a client of another—a *client/server association* is formed between the two layer networks. This association provides a formal description of the way layer networks interact and allows layer networks to be designed for each other, but in independence of each other. Figure 1 might suggest that the 140 Mbit/s layer network has only a point-to-point topology; however, a correct use of the client/server association allows an independent topology to be developed.

While the topology of any layer network can be independent, the architectural components are the same. This means that the same management and control features can be used for every layer network to give significant simplifications.

The CCITT has divided layer network into three classes:

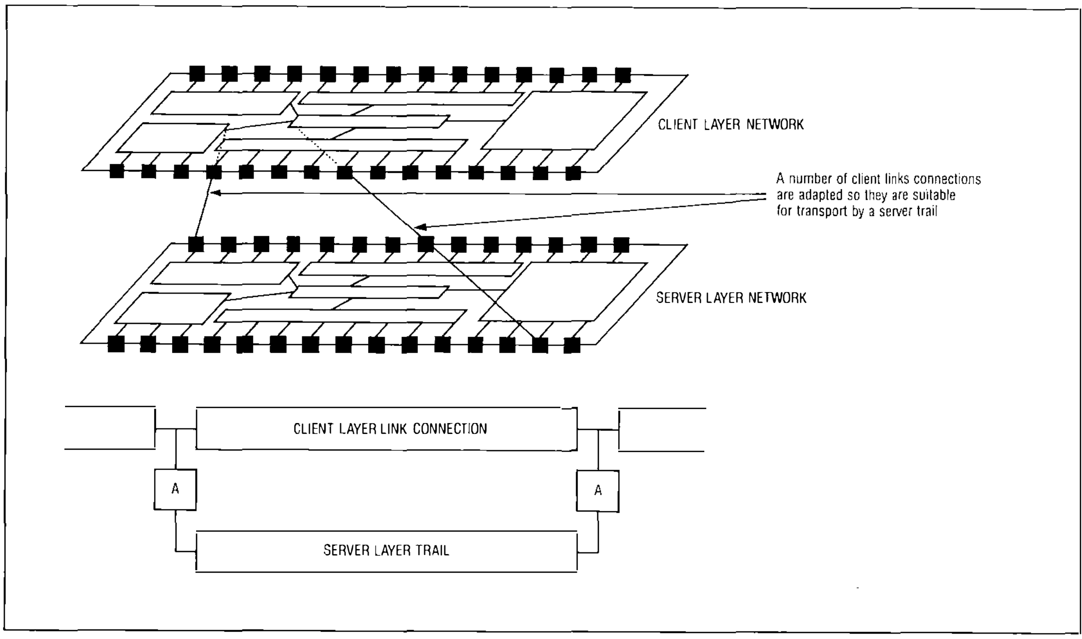
(*a*) *circuit layer networks*, which are oriented towards public switched services like the PSTN, ISDN, SMDS, B-ISDN/virtual channel, X.25, etc;

(*b*) *path layer networks*, which are oriented towards the provision of the links in the circuit layer networks like the 2 Mbit/s, 8 Mbit/s, 34 Mbit/s, 140 Mbit/s, VC-12, VC-2, VC-3, VC-4[5], B-ISDN/virtual path; and

(*c*) *transmission media layer networks* which are oriented towards point-to-point transport across line systems.

Trails in each of the types of layer network are called *circuits*, *paths*, and *sections*, respectively.

Figure 6
Layering and the client/server association



While this classification is not absolute and is not essential to transport network architecture, it has proved very useful in identifying the purpose of layer networks and resolving confusion between different groups of people working on the different layer networks.

Note: It is possible to relate the layer network to the Open Systems Interconnection (OSI) seven-layer stack. The OSI use of the term *layer*, however, is significantly different to that used in the layer network. The transport of client layer links is the application of the layer network—OSI layer 7. The trail is the OSI transport layer—OSI layer 4. The network connection is the OSI network layer—OSI layer 3. The link connection is the OSI link layer—OSI layer 2—and is an application of another layer network.

APPLICATIONS OF TRANSPORT NETWORK ARCHITECTURE

Designing and Sizing Network Topology

It may be noted that the existing notion of network architecture has centred on the PSTN and hence the 64 kbit/s layer network. Traditionally, it has been the only layer network that has had a well-developed topology and the transport layers have been viewed primarily as point-to-point links between exchanges.

This has meant that the existing PDH transport network has been built up on a route-by-route basis. When digital capacity was required between two centres, especially for exchange modernisation, line systems of the appropriate size have been planned and installed. Sometimes there has been capacity available on some part of the route from existing line systems, and so line systems have been required for only parts of the route with a through connection at 8 Mbit/s or 34 Mbit/s. This has meant that the layer networks at 2 Mbit/s, 8 Mbit/s, 34 Mbit/s, and 140 Mbit/s each lack a good structure as they have not been designed as individual networks. Applying the transport network architecture, it is possible to interpret each bit rate of the PDH as its own layer network, with its own topology which could be sized and optimised separately.

With the SDH, this optimisation of each layer network is very important as each layer network is used by a number of client layer networks. Each client layer network will have differing requirements of the server layer network and so the server layer network should be optimised to suit all requirements. For example, the VC-12 layer network is used by both the PSTN (64 kbit/s) layer network and the MegaStream layer network. The differing requirements from each can be added together to form a general VC-12 transport requirement which can then be used as the basis for developing an optimised topology for the VC-12 layer network. The VC-4 layer network will have VC-12, VC-2, VC-3, broadcast TV, and broadband ISDN as client layer networks. Again, the requirements from all of these layer networks can be added together and an optimised topology developed.

An essential feature of SDH networking allowed by the application of layering to SDH is that each layer network can have an independent topology. The topology of the VC-12 network can be independent from both the PSTN and the VC-4 network as illustrated in Figure 7.

Developing and Defining Routing Algorithms

As layer networks are normally global, and the topology can be complex, the development of algorithms which can work out the routing for a trail is an important aspect of the overall design of the layer network. Several factors need to be taken into account in the development of routing algorithms:

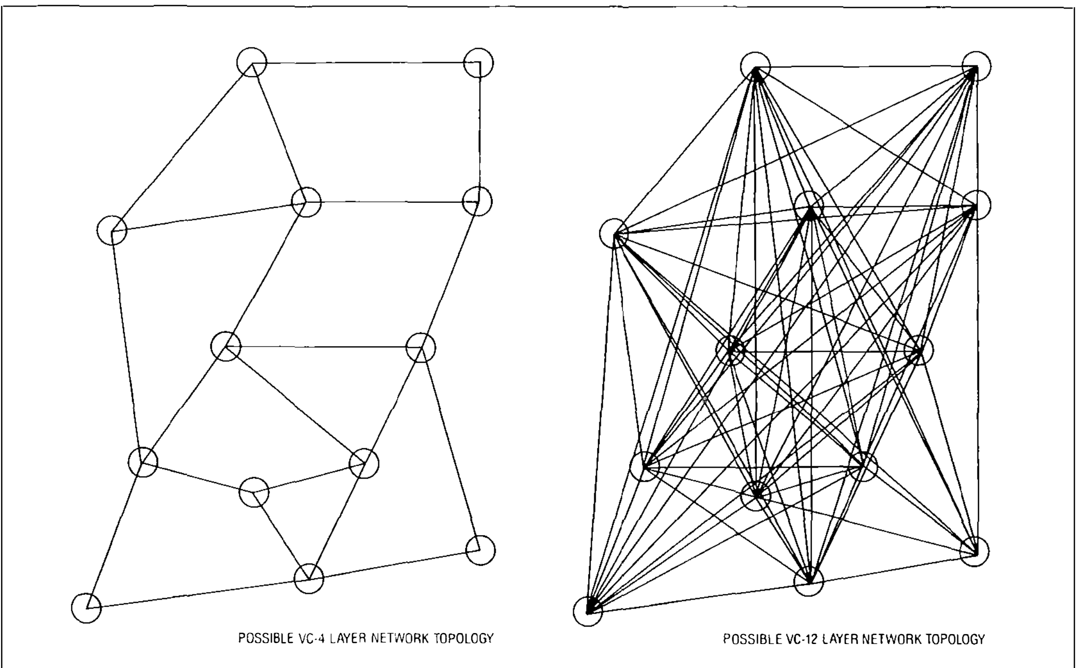


Figure 7
Independence of topology in different layer networks

- efficient utilisation of the network topology;
- network operators will not necessarily allow another network operator to control routing through its network;
- network failure and network congestion may make certain preferred routings impossible; and
- different network operators may wish to use different routing algorithms.

The partitioning concept allows the routing algorithm to be broken down into a number of stages. Routing across a sub-network can be the sole responsibility of that sub-network. As one network operator's part of the layer network can be regarded as a sub-network, the network operator can chose a routing algorithm that suits its network topology. However, routing between different network operators' sub-networks must be agreed on a multilateral basis. This applies particularly to the international transit sub-network illustrated in Figure 4.

The ability to define this international transit sub-network as a collection of sub-networks each belonging to an international transit network operator linked together in a defined topology allows suitable algorithms to be defined. Currently, international signalling systems, which are based on the partitioning concept, define and use such algorithms for the PSTN and ISDN. European network operators have agreed that international routing algorithms for SDH payloads should be developed for Europe and it is fully expected that these will be extended to all countries.

Deriving Network Performance Parameters

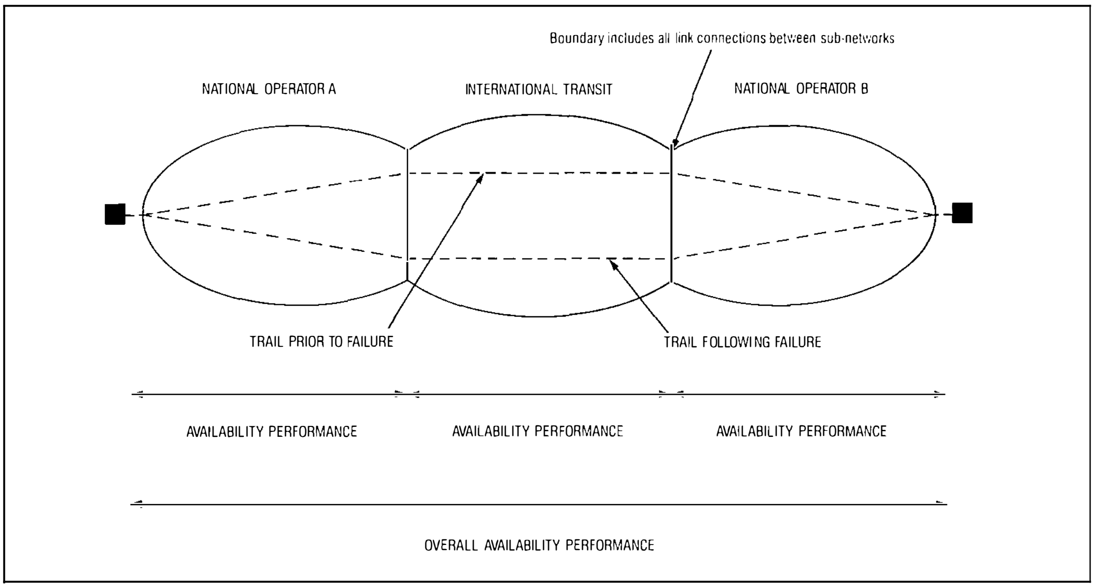
Some network performance parameters depend on the topology of the network. These include accessibility and availability. They are difficult to define and the CCITT has still not yet agreed an adequate definition of availability. A significant factor in the definition is the way the topological aspects of the parameter are taken into account and how the topology is divided across an inter-operator boundary.

This is illustrated in Figure 8, where a trail is formed from connections across several network operators' domains. SDH control will make possible the restoration of the trail as a whole rather than by the restoration of individual connections, and so the availability of the trail cannot be simply related to the availability of each connection. An application of the partitioning concept allows a network operator's domain to be adequately defined, thus allowing a definition of accessibility and availability to be related to the boundaries between network operators' domains and to include all the points on the boundary that might be used for a restoration.

Simulating Network Availability

Several factors have made network simulation for the purposes of assessing availability performance a difficult process. Firstly, it has been very difficult to relate the effects of restoration at higher bit rates with restoration at lower bit rates. For example, BT currently uses a 140 Mbit/s restoration scheme, called the *automatically-switched digital service protection network* (ASDSPN)[6], which will restore capacity following line system failures. The PSTN exchanges also take action when a failure is detected on the 2 Mbit/s switch port. The PSTN customer can also take action to restore the call after the failure by clearing down and dialling again. The interaction between these restoration mechanisms after a single failure in the network has been difficult to model.

Figure 8
The use of partitioning to define availability performance



The application of both the layering and partitioning concepts allows a complete model of the network to be constructed in which the interactions are properly formalised and are variables of the model. Simulations of the network can then be analysed and a restoration strategy developed which gives the best availability at the lowest network cost.

This work is especially relevant to SDH as most of the layer networks will be capable of offering restoration: 1+1 or 1-for-*N* protection at the multiplex section layer, network protection at the VC-4 layer, network protection at the VC-12, VC-2, and VC-3 layers, as well as the example given above where the PSTN user can clear down and redial.

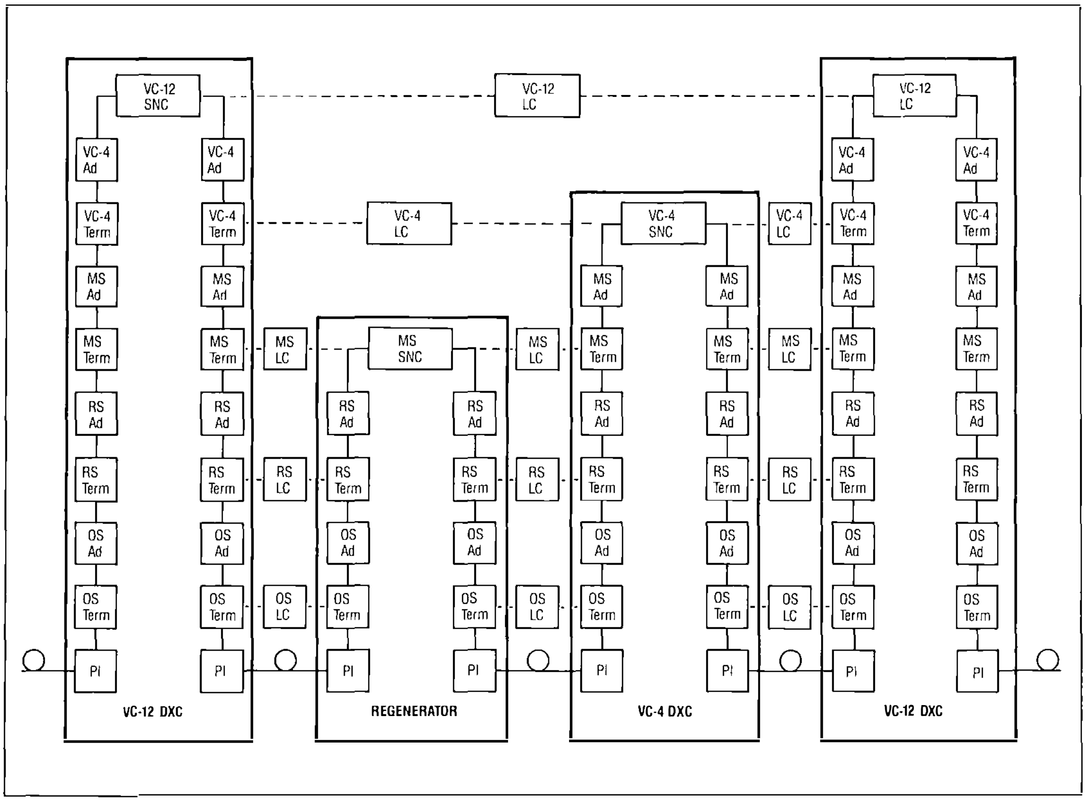
Deriving the Equipment Functional Reference Blocks

One of the first applications of the transport network architecture was in the development of the CCITT SDH equipment Recommendations, G.781, G.782, G.783, G.784[7].

If transport network architecture is used to develop a network design, the functional components required, and therefore the functionality required in the equipment, will be automatically identified. This functionality then forms the basis of the specification of the equipment required to implement the design as illustrated in Figure 9. The emphasis on the functionality is important with SDH equipment as the technology makes

Figure 9
Equipment functional blocks

Ad: Adaptation
DXC: Digital cross-connect
LC: Link connection
MS: Multiplex section
OS: Optical section
PI: Physical interface
RS: Regenerator section
SNC: Sub-network connection
Term: Termination



possible high levels of functional integration in one equipment. The CCITT and ETSI have recognised this and developed the equipment recommendations so that the functionality is specified in addition to the external interfaces. Network operators can therefore build a transport network with many features that are tailored precisely to the network operator's requirements but without large numbers of items of equipment. The small number of items of equipment means that the network will be inherently more reliable with good availability and low maintenance cost.

Deriving the Management Information Model

Remote management of equipment has long been a goal of network operators; however, this has necessitated a management interface on equipment[8]. In order to reduce the cost of this interface, both network operators and manufacturers have sought to agree an international standard for this interface. One of the most difficult aspects of developing this interface has been identifying the generic functionality requiring management. The transport network architecture provides the descriptive tools, since it describes not only the functional components requiring management, but also all the relationships between the functional components—an essential part of management. Within the CCITT and ETSI, the transport network architecture has been developed in close cooperation with the management interface.

A VISION OF THE TRANSPORT NETWORK IN THE YEAR 2000

The development of layer networks will play an essential role in the evolution of the transport network over the next 10 years. With growing customer demands for higher and higher bandwidths and increased competition at all levels of telecommunications, the ability to provide the right amount of capacity for a customer at the lowest possible network cost is vital to BT as, indeed, it is to any other network operator. It seems likely that this will necessitate the development of a number of layer networks, each of which is optimised for the transport of particular clients:

Circuit Layers:

- 64 kbit/s layer network for ISDN services and some 64 kbit/s layer network management and control links (signalling links).
- B-ISDN/virtual channel layer network for the variable bit rate and integrated broadband services.

Path Layers:

- VC-12 layer network for transport of 64 kbit/s links and existing MegaStream links.
- VC-2 layer network for the transport of broadcast TV links, and B-ISDN/virtual path links.
- VC-3 layer network for the transport of links between local area networks (LANs) and existing North American T3 links.
- B-ISDN/virtual path layer network for B-ISDN/virtual channel links and management and control links.
- VC-4 layer network for the transport of VC-12 links, VC-2 links, VC-3 links, B-ISDN/virtual path links, and high-definition TV links.

Transmission Media Layers:

- Multiplex section layer network for the transport of VC-4 links and management and control links.
- Regenerator section layer network for the transport of multiplex section links and management and control links (particularly relating to regenerators).
- Possible optical section layer network based on wavelength-division multiplexing (WDM) and wavelength routing to carry regenerator section links.

Management and Control Layers:

- A single management and control network conformant to Cooperative Network Architecture-Management (CNA-M) and ISO standards for all layer networks with three main groups of client applications:

(*a*) basic sub-network connection control which sets up and restores trails;
(*b*) customer and service management, for example, billing, virtual private networks (VPNs), mobility, guaranteed diversity, etc; and
(*c*) planning and maintenance support, for example, event and performance management with repair scheduling, inventory control, planning tools to predict requirements for new equipment in the network.

These interrelated layer networks are illustrated in Figure 10. It is seen that the management and control network is an integral part of the transport network architecture and controls all layer networks. This is possible because all layer networks are based on the same architectural principles.

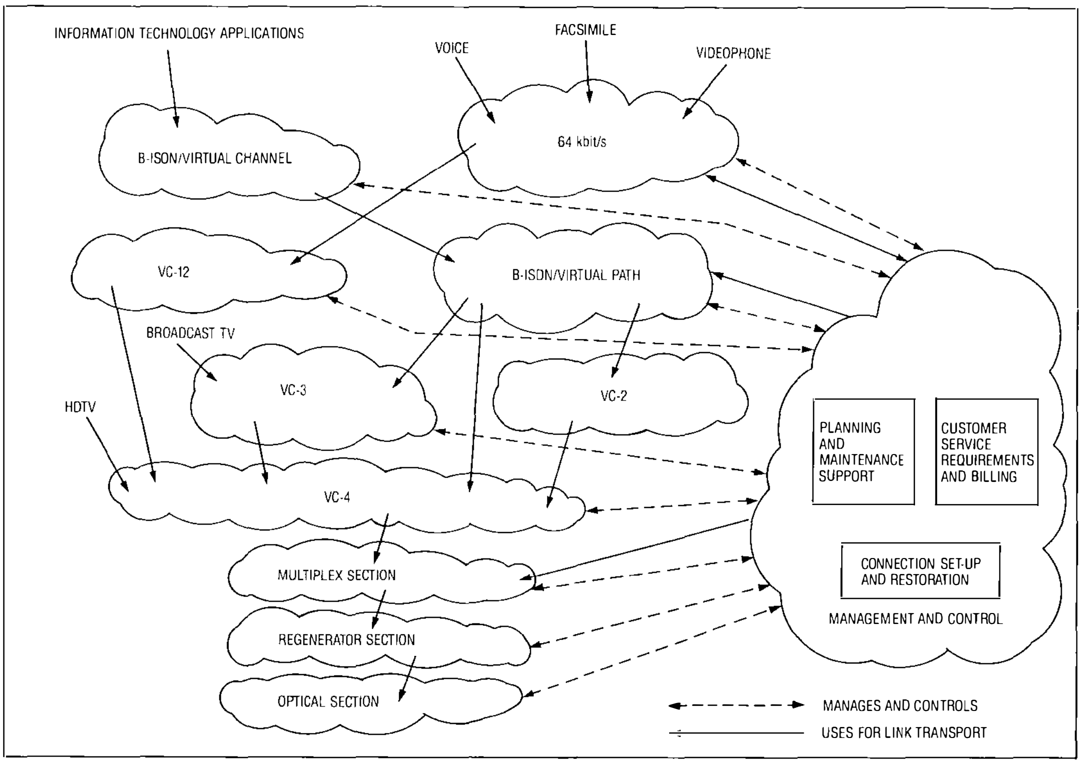
CONCLUDING REMARKS

The transport network architecture described in this article is generic to telecommunications and was first derived to describe adequately some of the features of SDH. It will, however, form a complete set of descriptive tools for broadband networks and will be essential to network operators worldwide if the ever-increasing complexity of telecommunications networks is to be managed both by efficient software systems and a finite human resource.

Acknowledgements

The author would like to thank his colleagues in Worldwide Networks for their help in the production and refining of this article.

Figure 10
A view of layer networks in the year 2000



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Biography

Andy Reid joined BT in 1982 after gaining a B.Sc. in Engineering from Dundee University. His early years were spent in BT's then international division, BTI, initially working on the integration of new equipment into the international network. In particular, he spent much time working on transmultiplexer equipment. He then worked in BTI's marketing department as product manager for International KiloStream, BTI's digital private circuit product. He moved to BT's national division where he joined a group representing both BT and the UK at the CCITT, ANSI, and ETSI, where he had particular responsibility for architectural, management, and synchronisation aspects of SDH. He now heads a team in the Network Strategy department responsible for developing future plans for transmission in the core network.

Equipment for SDH Networks

W. R. BALCER†

Equipment for synchronous digital hierarchy (SDH) networks is being standardised and developed. This article describes the methods used for standardising SDH equipment and provides an overview of the main types of equipment which are likely to be deployed.

INTRODUCTION

With the establishment of international standards on multiplexing concepts and methods, attention has focussed on the standardisation of equipment to be deployed in synchronous digital hierarchy (SDH) networks. The nature of SDH concepts and synchronous networking leads to a view of transmission equipment which is markedly different to the traditional one of standalone 'boxes' which can be connected together to form a network. This article examines the impact of the SDH on equipment functions and how they are standardised. It considers, in simplified terms, the types of equipment envisaged to be deployed in an SDH network, and the time-scales for introduction into the network.

EQUIPMENT STANDARDS AND SPECIFICATION METHOD

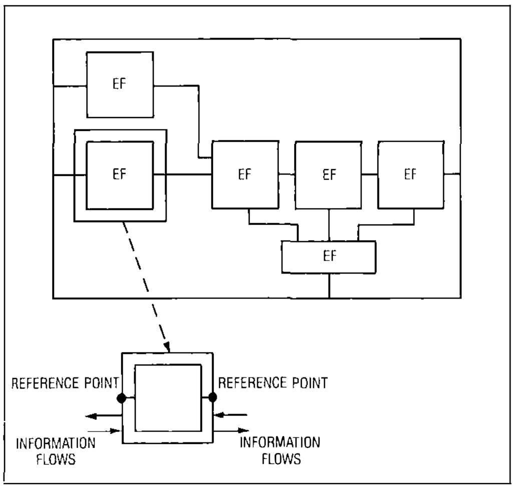
In the current plesiochronous digital hierarchy (PDH) network, the network functions which need to be realised in equipment terms are clearly implied by the structure of the PDH. Thus the PDH network is built up of well-established units such as 2–8 Mbit/s muldexes, 8–34 Mbit/s muldexes, 140 Mbit/s digital line systems, and so on, which can be connected together inside a station by using interfaces standardised in CCITT Recommendation G.703[1]. The basic units can be integrated to reduce equipment volumes and costs by combining functions; for example, two stages of multiplexing (say 2–8 and 8–34 Mbit/s), normally realised by two units, can be amalgamated to form a 2–34 Mbit/s muldex. Each equipment is specified as a 'box' whose interfaces and functions are fully defined. For an SDH network, the basic functions required are essentially the same as that for the PDH, namely multiplexing, cross-connection and line transmission; however, the manner of specifying equipment has to reconcile three conflicting requirements:

(*a*) The SDH offers high levels of functional integration; for example, no longer does the line termination function have to reside as a unit separate from, say, a multiplexer. Both can be integrated in the same equipment unit. In general, various functional capabilities may be packaged together in a single equipment.

(*b*) The SDH offers great flexibility in terms of which functions can be grouped together in a single equipment.

(*c*) The physical implementation of an equipment must be independent of its function. In other words, there must be freedom in how a particular function or group of functions are realised in terms of hardware and software.

The method adopted, aimed at reconciling these conflicting requirements, is based on a *functional reference model* for equipment. This means decomposing the function of an equipment into a set of elemental functions and describing each of them in rigorous detail in terms of its internal processes and the primitive information flows at the reference points at the input and output points of the element. This principle is illustrated in Figure 1; the overall equipment function is described in a generalised way so as to allow variations achievable by flexible composition of the elements. Equipment variants can then be specified by defining the requisite arrangement of elemental building blocks. Further steps in this approach are to group together a number of elemental functions to form a *compound function*, which then forms a larger building block, and to group a number of compound functions to form useful network functions which would constitute a single item of equipment. A useful analogy is



EF: Elemental function

Figure 1 Generalised equipment function diagram

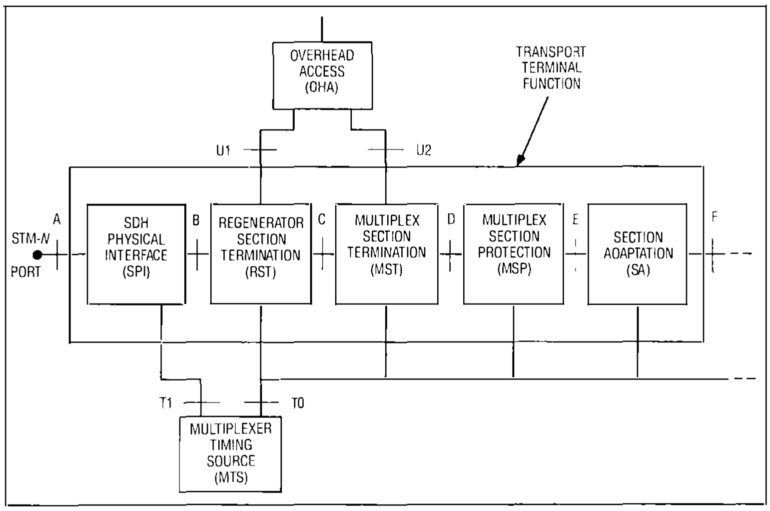
† BT Worldwide Networks

that of selecting integrated circuits from a catalogue to develop a circuit function; each one is fully defined and the functionality of a number of basic functions may be packaged together in one 'chip' to give a compound function.

Functional Reference Model

This approach can be appreciated by considering the functional reference model of an SDH multiplexer; Figure 2 shows a small part of this model. The SDH physical interface (SPI) function converts between an STM-*N* signal appearing at the transmission interface and its binary equivalent signal; in the case of optical transmission, it would essentially comprise an optical/electrical converter. The regenerator section termination (RST) function terminates the regenerator section overhead (RSOH) and adapts between the regenerator section layer and the multiplexer section layer. The multiplexer section termination (MST) function terminates the multiplexer section overhead (MSOH). The multiplexer section protection (MSP) function controls the automatic line protection process and the section adaptation (SA) function provides phase/frequency adaptation of the virtual container (VC-3 or VC-4) to the STM-*N* frame. The multiplexer timing source (MTS) derives timing information from the incoming transport signal and distributes timing to a number of other functional blocks. The overhead access (OHA) function provides an interface between some of the management data in the section overhead and the outside world.

Figure 2
Part of functional reference model of an SDH multiplexer



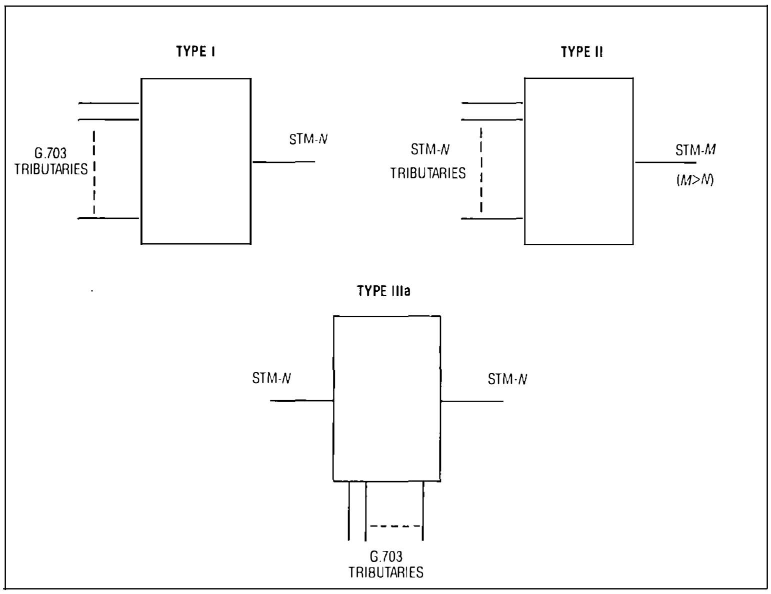


Figure 3—Types of SDH multiplexer

The functional blocks are specified in terms of all the processes carried out inside them and the signal flows over the reference points (A, B, C, T1, etc.) between them. In general, the reference points are not interfaces, and have no interface specifications associated with them (though the SPI function in this example does have a specified interface on the line side). The set of functions SPI, RST, MST, MSP and SA are such that they naturally stand together to form a useful compound function termed a *transport terminal function* (TTF). This is useful in the sense that the TTF is always required at the transport interface of SDH equipment and can be referred to as a single entity instead of referring to the elemental functions individually.

A particular advantage of this method is that once an elemental function has been specified, its specification can be reused when it is introduced in the specification of another type of equipment. Another advantage of this method is its capability to deal with the complexities of fault conditions and consequent actions. With PDH equipment, the simplicity of functions results in a straightforward definition of the actions that have to be carried out in equipment when faults occur. For example, a loss of frame alignment condition on an 8 Mbit/s input to a 8–2 Mbit/s demultiplexer should result in an *alarm indication* signal (AIS) on each 2 Mbit/s tributary output. With SDH equipment, such a definition for the equipment as a whole is made very cumbersome by the fact that signals feeding into the equipment may embody signals relating to different network layers and each of these constituent signals may be subject to independent fault conditions. The functional reference model approach simplifies and systematises this aspect of specification by resolving the treatment of fault conditions to each of the functional blocks individually.

CCITT Recommendations

This approach has been used to generate CCITT Recommendations on SDH multiplexers (Recommendations G.781[2], G.782[3] and G.783[4]) and optical line systems (Recommendation G.958[5]). In the case of multiplexers, a number of different types have been defined by describing each type as a configuration of the available elemental functions. Figure 3 illustrates three of the various types specified. Type I is a simple terminal multiplexer which multiplexes a number of G.703 tributaries into an STM-*N* signal; Type II takes a number of STM-N signals and multiplexes the constituent higher-order VCs (VC-3 or VC-4) into an STM-M aggregate signal; Type IIIa constitutes an add-drop multiplexer with STM-N aggregate ports and G.703 interfaces for the add/drop tributaries. The set of different types of multiplexer recorded in G.782 is not an exhaustive set, and other types consisting of other configurations may be established in the future if deemed useful.

Recommendations are being developed for SDH cross-connects and these will exploit the elemental function specifications established in the multiplexer Recommendations. These are planned to be completed in 1992.

As mentioned in a companion article[6], in accordance with the *mid-span meet* concept, a major driver is the potential for equipment at the two ends of a transmission link to be provided by two different suppliers, and this imposes the need for a standard transmission line interface for equipment. Recognising that optical systems will form the major means of signal transport, the CCITT has recommended a set of optical interface parameters to be used for SDH equipment transmission interfaces; these are given in Recommendation G.957[7]. Additionally, for intra-station use, a metallic interface has been standardised in Recommendation G.703 for the STM-1 signal. This interface is, in basic respects, the same as the established 140 Mbit/s coded mark inversion (CMI) interface, but scaled down in the time domain, inversely pro-rata with bit rate.

MANAGEMENT FUNCTIONALITY

In terms of signal transport functionality, SDH equipment is broadly equivalent to its PDH predecessor. However, in the area of management capability, SDH equipment is significantly in advance of its PDH counterpart. The generous provision of overhead bandwidth in VCs enables SDH equipment to be monitored, configured and controlled to a very high degree, thus rendering it eminently suitable for building a managed transmission network. In particular, parity checks are included in each layer of the network for performance monitoring, and the data communications channel in the section overhead gives ample bandwidth for the transmission of management messages between network nodes. Thus a substantial part of the overall functionality of SDH equipment is invested in the management of the equipment. The management aspects are described in more detail in another article[8].

EQUIPMENT BEING DEVELOPED

Equipment suppliers worldwide have embarked on the design and development of equipment for SDH networks. While the SDH standards support a wide variety of possible equipment realisations, network design considerations lead to certain basic function packages. Many variations on these are possible, and the following gives only examples of the kinds of equipment which are becoming, or might become, available:

Terminal Multiplexer

A terminal multiplexer, illustrated in Figure 4(*a*), is equivalent to the Type I multiplexer described above. In its basic form, it multiplexes sixty-three 2048 kbit/s tributaries into an STM-1 (155 Mbit/s) aggregate signal. The figure of 63 is a direct result of the multiplexing structure[6]. Such multiplexers will find wide usage at the boundary between the PDH and the SDH network for affording primary-rate signals access to the SDH network. In the case of optical transport, the STM-1 signal is available at a standard optical interface; thus the line terminal function, traditionally packaged separately from the multiplexer, is integrated into the equipment. As an option, it is possible to include a second aggregate signal port which, together with the addition of multiplexer section protection functionality, provides line protection; that is, a loss of signal on the working line results in fast autonomous switching to the protection line.

Higher-Order Multiplexer

A higher-order multiplexer is equivalent to the Type II multiplexer described above. In the form illustrated in Figure 4(*b*), it terminates the section overhead from 16 STM-1 signals, derives the constituent higher-order VC payloads and multiplexes them into an STM-16 aggregate signal which contains a newly formed section overhead.

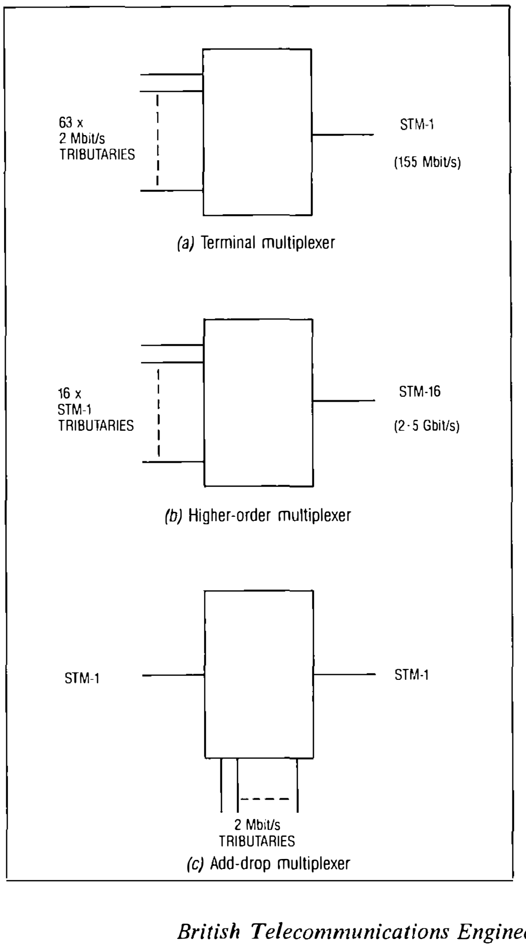


Figure 4
Examples of SDH multiplexers

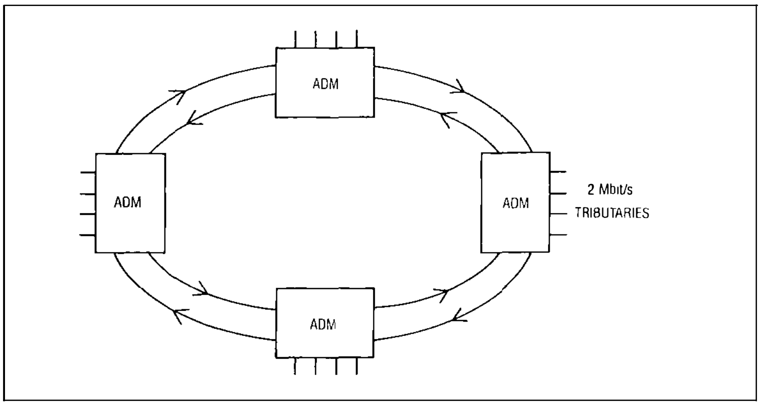
It is important to understand that there is no such thing as 'STM-1 multiplexing' or, in general, 'STM-*N* multiplexing', since it is only the payloads of the STM-*N* signals which are multiplexed. In general, the higher-order VC could be a VC-3 or VC-4; for Europe, the relevant European Telecommunications Standard (ETS)[9] specifies that it shall be the VC-4.

Many variations on this theme are possible. For example, the tributary and aggregate ports may consist of four STM-1s and an STM-4 respectively, or four STM-4s and an STM-16 respectively. One application is to gather together signals from within a station for transmission over high-bit-rate systems.

Add-Drop Multiplexer

An add-drop multiplexer equates to the Type IIIa multiplexer described above. The particular example depicted in Figure 4(*c*) has STM-1 aggregate ports and a number of primary-rate tributary ports on the add-drop side. Other variants could employ higher-rate aggregate ports, say STM-4 or STM-16, and could include add-drop tributaries at the STM-1 level. Such equipment is likely to be used in sub-networks whose topology is that of a 'ring' as illustrated in Figure 5. This type of arrangement gives high availability by virtue of the capability for sending traffic in two directions around the ring and thereby offering protection through route diversity. One application is the transport of primary-rate signals between remote concentrator units (RCUs) and their host processor.

Figure 5
Add-drop multiplexers in a ring configuration



ADM: Add-drop multiplexer

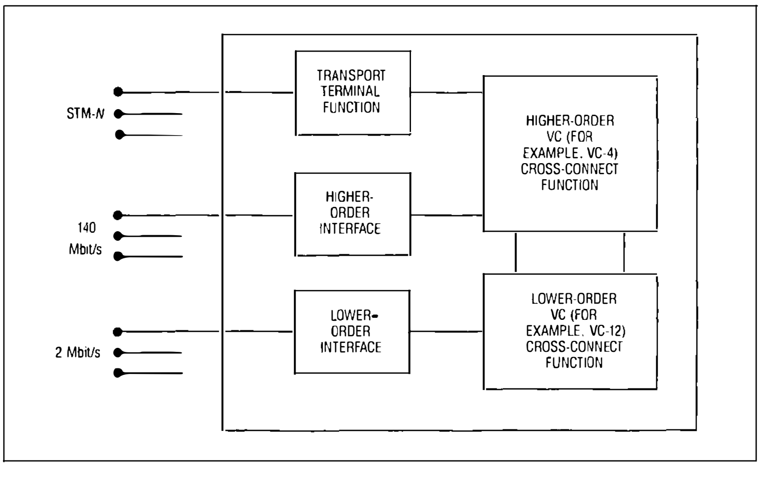


Figure 6—Higher and lower-order cross-connect

Cross-Connect Equipment

Cross-connect equipment will form a major element of SDH networks by providing a number of key functions. The intrinsically chief function of routing signals will be carried out at the higher- and lower-order path layers, for example, VC-4 and VC-12 paths respectively, as illustrated in Figure 6.

In general, cross-connects will carry out path management processes in the higher- and lower-order path layers; they will groom traffic between layers and consolidate traffic within a layer. For example, VC-12 connections may be groomed by allocating them to particular VC-4 paths according to their destination, the type of service they are carrying, or according to the level of protection required; the higher-order paths can then be managed accordingly. It is also possible to groom higher-order paths into STM-*N* sections on the same basis. The consolidation function is exemplified by the process of improving the *fill factor* of a VC-4 path by combining VC-12 connections from partially filled VC-4 paths into a smaller number of VC-4 paths.

The multiplex-section protection capability is an autonomous function implemented at the section layer. Cross-connect equipment can provide a similar protection facility at the VC-4 path layer, albeit at a slower speed, by re-routing VC-4s around a faulty section. Similarly, path-layer protection can also be provided at lower-order path layers; for example, for VC-12 paths.

Another application of cross-connects is the provision of test access facilities. For example, a spare STM-1 port on the cross-connect can be connected to a network test facility. Tests may range from a simple check of valid overhead to the application of special test sequences to the payload signals.

Interface ports may be provided at any of the STM-*N* levels, and the number of ports provided could vary over a large range. In addition to SDH signal ports, a number of PDH signal ports, for example at 140 Mbit/s, could be provided to give a direct interface with the PDH network. In this case, the cross-connect would carry out the process of demultiplexing the constituent PDH tributaries and mapping them into the appropriate VCs (for example, 2 Mbit/s into VC-12), thereby adapting the service rate signals to the SDH network. Alternatively, or additionally, 140 Mbit/s treated as a wideband signal could be adapted to the VC-4 by a compound function termed *higher-order interface* (HI) shown in Figure 6. A similar function, the *lower-order interface* (LI) is specified for adapting 2 Mbit/s signals into VC-12.

The term applied in BT for SDH-based cross-connect equipment is *higher-order automatic* *cross-connect equipment* (HACE), thus distinguishing it from the *automatic cross-connect equipment* (ACE) already deployed by BT in the PDH network for cross-connecting 64 kbit/s circuits synchronously multiplexed in 2 Mbit/s transport frames.

Synchronous Optical Line Systems

In the context of the PDH network, an optical line system is considered as two line terminating equipments (LTEs) connected by fibre with possibly one or more regenerators in between; the input and output points are specified as standard interfaces according to Recommendation G.703. In the SDH case, as mentioned above, the LTE functionality can be subsumed in equipment input/output ports, and thus the point where a multiplexer, say, ends and the line system begins cannot be defined in the same simple way. In practice, an SDH optical line system is taken to comprise two multiplexers connected by fibre and (optionally) regenerators, with the multiplexers satisfying the task of taking a number of STM-*N* tributaries and multiplexing the payloads to form an STM-*M* ($M>N$) stream, as described above for the higher-order multiplexer and depicted in Figure 4(*b*). In terms of the CCITT standard contained in Recommendation G.958[5], synchronous line systems are defined as the means used to transport an STM-*M* stream between reference points C (as shown in Figure 2) of two consecutive synchronous multiplexers or cross-connects. The main aim of this Recommendation and the associated Recommendation G.957[7] is to achieve the possibility of transverse compatibility on elementary cable sections; that is, mixing different manufacturers' equipment within a single optical section.

AVAILABILITY TIME-SCALES

Vigorous development activity by many equipment suppliers has resulted in early availability of basic SDH multiplexers. The general trend among network operators is to install the early products to build assessment networks which can be used to provide early experience of SDH networking. BT's plans include the setting up of trial networks in 1991/92. The introduction of SDH equipment into the network will commence with terminal and add-drop multiplexers and optical line systems in 1992. The introduction of cross-connect equipment will form a later deployment phase.

ACKNOWLEDGEMENT

The author wishes to thank his colleagues for their assistance in producing this article.

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Biography

Richard Balcer joined Post Office Telecommunications in 1972 after graduating from Imperial College with a degree in Electrical Engineering. He worked on the maintenance of microwave radio systems and in 1978 joined the Transmission Laboratory where he designed and developed specialised items of test and measurement equipment. In 1982 he moved to the development of primary multiplex equipment and in 1985 joined the Digital Transmission Network Standards Group, where he was engaged on SDH equipment standards and took on the role of Rapporteur in the CCITT for the international standardisation of SDH multiplexers. He now leads a team in Engineering Support and Launch engaged on network protection systems, and SDH management and network aspects.

Managing SDH Network Flexibility

R. M. GALLAGHER†

The growing range and sophistication of telecommunications services offered to customers is demanding high levels of flexibility within the transmission network. The synchronous digital hierarchy (SDH) provides opportunities for achieving such flexibility at an acceptable cost. Managing such flexibility effectively is crucial to achieving service requirements and maximising operational efficiency. To this end, methodologies and architectures for controlling the proposed flexibility in the network are being considered. These take into account the overall network strategic management structures currently being developed within BT, as well as emerging international standards for network management.

INTRODUCTION

Modern telecommunication transmission networks need to be highly flexible in order to meet the growing demands of customer services and to provide improved network operational efficiency. A significant step towards attaining such flexibility lies in network management—remotely controlling the facilities and functions of key network elements, such as multiplexers and digital cross-connects. Such control needs to be fast, coordinated and well managed if the dynamic needs of the customer are to be met and the performance and throughput of the network optimised.

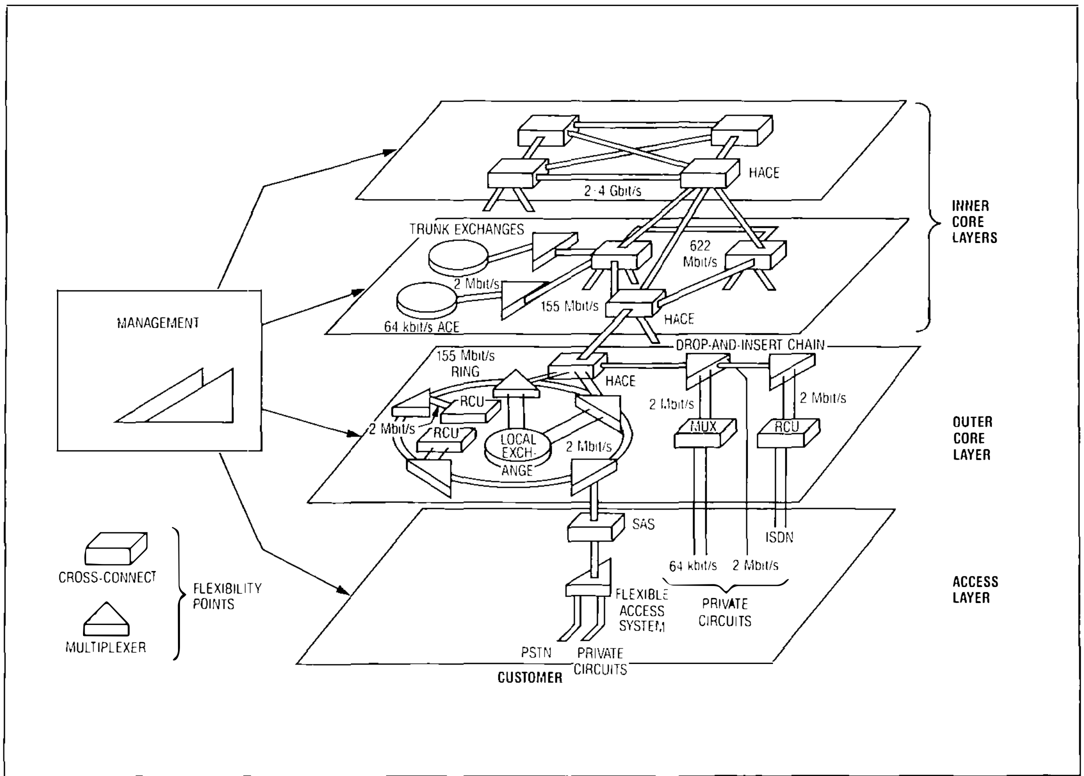
Traditionally, efficient remote control of network elements has been difficult to achieve in terms of cost-effective technology and the limitations imposed by the plesiochronous nature of the transmission network. There have been, however, some notable advances within BT in recent years with the advent of flexible access systems in the local loop part of the network and automatic cross-connect equipment (ACE), which provide flexibility for KiloStream services over the network. The new synchronous digital hierarchy (SDH) now being planned into transmission networks around the globe provides new opportunities for realising cost-effective managed flexibility as an integral part of a totally managed transmission network.

† BT Worldwide Networks

THE NEED FOR MANAGED FLEXIBILITY

Remotely controlled cross-connect and multiplex equipment affords a rapid means of configuring traffic capacity routings through the network in an efficient and coordinated manner. Figure 1 shows an envisaged network topology with cross-

Figure 1
Transmission network topology



HACE: Higher-order automatic cross-connect equipment
SAS: Service access switch
ACE: Automatic cross-connect equipment
RCU: Remote concentrator unit

connect and multiplexer flexibility points. The reason for configuring capacity remotely in the network varies according to the position in the topology.

(*a*) The remotely configured equipment within the access layer will provide opportunities for adding, ceasing or rearranging circuits to a customer on demand (service provision function). It also provides the network operator with the opportunity to groom certain customer services on to particular capacity blocks (for example, 2 Mbit/s) to aid segregation later in the network. If the customer has more than one feeder into the network, it is possible to provide alternative paths for specific priority services and for these to be switched in the event of failure.

(*b*) Further flexibility within the access and outer core layers of the network will provide other opportunities for grooming specific services into dedicated blocks of capacity for routing into the inner core network. It may also provide the capability for cross-connecting individual circuits between bearer ports and so, in conjunction with other nodes in the network, enables a specific circuit routing to be set up as part of the service provisioning function.

(*c*) Flexibility within the inner core network nodes would have similar functions to the above examples, but in general may be grooming and consolidating traffic at higher levels of capacity. Cross-connection here will also be employed to provide network protection capability in the event of link or node failures.

LIMITATIONS OF THE EXISTING NETWORK

The lack of a single worldwide standard has made interworking more difficult, both at the transmission level and for network management within, and between, countries.

The control of the existing digital network is hindered by the lack of a standard agreement on channels, protocols and message sets used within the digital signal.

THE IMPACT OF SDH

The SDH frame structure has been optimised not only for transmission but also for switching and providing management capability.

The ingredients on the network management side of the SDH standard can be related to the following benefits:

(*a*) a built-in performance monitoring capability that simplifies the control and management of the equipment in an SDH network;

(*b*) a worldwide market-place for SDH equipment, thus bringing further cost benefits with multi-vendor interworking; and

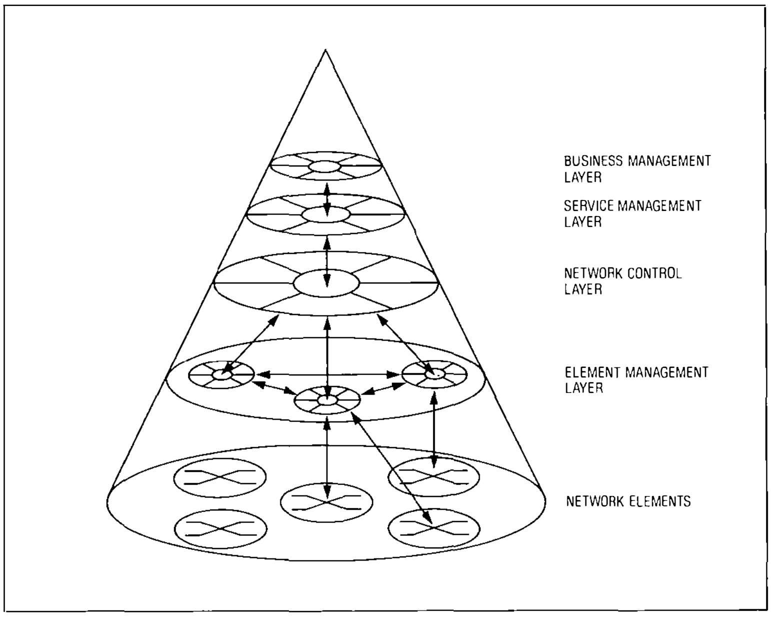
(*c*) the possibility of customer control of some network features.

These benefits would permit the realisation of economic software-controlled equipment, which leads to the concept of a totally controlled and managed network. To help realise these benefits, open management interfaces are currently being defined in the CCITT and ETSI standards bodies for the management systems to network element interfaces, and for the embedded management channels within the SDH frame structure for use between network elements.

MANAGEMENT PHILOSOPHY

The work on defining a management structure for networks has resulted in BT deriving a Cooperative Network Architecture-Management (CNA-M) structure. This management structure is based on OSI standards and has resulted in a 5-layer management structure shown in Figure 2. This consists of network elements, element management, network control, service management, and business management.

Figure 2 Network management hierarchy



This management structure spans the functions necessary for the administration to plan, organise, command and control the network features at its disposal and will provide the infrastructure for managing the flexibility within the managed SDH transmission network.

- The *network elements* are all the components that make up the network and include such items as multiplexers, cross-connect equipment, line systems, etc.
- The *element management* layer provides a uniform management view of the disparate element types to the network layer above. This layer also provides the first level of sieving and filtering of alarms and performance information.
- The *network control* layer provides the functionality to bind the individual elements, via their element managers, into a managed network.
- The *service management* layer manages the information passed over the network and is less concerned with the physical nature of the network

and more with the logical service functions offered by the physical network. It also interacts strongly with the customer interface.

- *Business management* is concerned with managing the complete undertaking, in accordance with the business objectives and customer requirements.

Within BT, the strategy for interfacing between the different layers has been to standardise on a defined set of protocol stacks.

Each of the control and management layers may be regarded as being made up from seven functional blocks, although all blocks may not be present in all layers. The functions (see Figure 3) consist of event management, configuration management, resource management, performance management, planning and design management, financial management, access and security management and the network database.

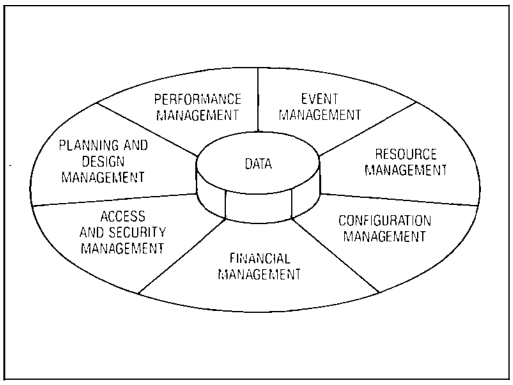


Figure 3
Seven functional blocks

- *Event management* deals with activities that occur in the network, such as alarms, and all management processes needed to deal with those events, such as testing and control of maintenance staff.
- *Configuration management* deals with how the network element resources are configured into a complete network and includes protection routing, new provisions, etc.
- *Resource management* is concerned with the physical and logical construction of the network, build status, test equipment, location of equipment, etc.
- *Performance management* functions deal with loading patterns, response-time analysis, utilisation factors and ensuring the network is tuned for optimum performance.
- *Planning and design management* are the functions used to plan the network, extensions or alterations to existing networks, fallback strategies and optimum routings and loadings.
- *Financial management* deals with cost of maintenance, asset depreciation, invoices and billing, etc.
- *Access and security management* is concerned with who is allowed to do what, where and when within the network. It does not necessarily provide the security functions but manages their implementation.

CONTROL ARCHITECTURE

In order to manage the flexibility of a complex network, it is important firstly to define the facilities and functions that need to be controlled within the network. From here, these facilities and functions then need to be apportioned to the individual layers of the CNA-M model described above. In view of the differing range of management requirements for the cross-connect and multiplexer equipment, and in the interest of reducing the complexity of the control system, it is considered preferable to separate the element management functions for each type of network element.

To aid this process, the network is described in an *information model*. This technique allows the network to be broken down into functions. These functions can in turn be defined as a set of managed objects that need to be administered across the open interfaces between the layers. For example, the managed objects at the network layer would describe the logical path across the network, whereas the managed objects at the network element layer would describe only the physical interconnections within the network element.

When mapping this functional model on to the hardware and software units, due account must be taken of the time-critical functions. In fact, the functions with real-time or defined-time constraints have the biggest influence on the apportionment of the functions to the individual processor units. One of the key time-critical facilities currently under study within BT, as part of the control architecture, is the network protection requirement.

PROTECTION

For the SDH network, two basic types of protection can be employed:

(*a*) restoration at the multiplexer section layer of the STM-*N* line rate, and
(*b*) restoration at the higher- or lower-order virtual container path layer across the network.

The first type is well suited for fast (sub-second) restoration between line terminal equipment and protects against fibre, regenerator and laser failures and hence gives the greatest benefits for very-long-haul fibre routes with many regenerators. This is generally implemented as a 1-for-*N* autonomous scheme with the value of *N* between 1 and 8.

The second type provides protection across the network between the virtual container termination points and would protect against intermediate node failures as well as those described in the first type. However, this requires a greater number of virtual container switching paths. The management system is inherently more complex, and hence would not be able to restore service as quickly. The possible exception to this is the use of autonomous 1-for-1 virtual container restoration, either within multiplexer rings or even across the network.

When designing and planning a managed network, it is important that all the parameters, such as network capacity utilisation, failure rates, management system complexity, cost, etc, are all carefully balanced in order to provide the required service restoration speed.

CONTROL CHANNELS

An important aspect of the control architecture is the use of the defined embedded data communication channel within the overheads of the STM-*N* frame. This high-capacity data channel (768 kbit/s) allows virtual data circuits from the element manager to be extended to a number of cross-connects or multiplexers from a single physical network management connection. Hence, this data channel will provide the communications infrastructure for managing and controlling the SDH network.

The international and regional standards bodies have been addressing the types of protocol stacks, information model and object definitions that could be used across this data channel. BT is engaged in these studies as the use of this data channel is seen as a fundamental part of a structured managed SDH transmission network.

CONCLUSION

The synchronous digital hierarchy transmission structure, together with modern technological developments, is offering opportunities for improved levels of flexibility within BT's transmission network. By incorporating a management methodology consistent with BT's strategic plan for network architecture, coordination of the flexibility function with other network operations is maximised and operational efficiency is ensured to meet the growing telecommunications needs of customers.

ACKNOWLEDGEMENT

The author wishes to thank his colleagues for their assistance in producing this article.

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Biography

Roger Gallagher is the programme manager for transmission network surveillance in Operational Policy and Systems in Worldwide Networks. He started as a Youth-in-Training in 1965 in the London Centre Area and progressed through the ranks on a variety of duties. During his career, he obtained a B.Sc. degree in Electrical and Electronic Engineering. He has been involved in a number of projects in the transmission area, including remote testing for private circuits (RATES), automatic digital cross-connect equipment for the fibre access systems, automatic switched digital service protection system (ASDSPN), and, previous to his current position, he was responsible for network protection systems and SDH management and network aspects.

Meridian Norstar Keysystem

B. C. SEARLE†

This article provides a technical appreciation of the Meridian Norstar digital keysystem. It discusses the design goals that were set for its development and describes the resulting software and hardware architectures. The Norstar Compact keysystem, the first of the Norstar product family to be made available in the UK, is described, together with the digital telephone extensions and system features. The article goes on to discuss the advanced manufacturing techniques used in the production of the system.*

INTRODUCTION

The Meridian Norstar digital keysystem is destined to provide the primary small and medium PBX/keysystem platform for the BT portfolio through the 1990s. Norstar is manufactured by Northern Telecom (NT), a large Canadian-based multinational supplier of telecommunications equipment, and BT will be the exclusive distributor of the product for the UK.

DESIGN CHALLENGES

NT's partly owned subsidiary Bell Northern Research (BNR) was commissioned to design a radical new keysystem product that would achieve the following design goals:

- embody absolute simplicity for end-users, installers, and distributors;
- meet very aggressive cost targets, providing the benefits of digital technology in small line sizes at an equivalent cost of traditional analogue systems; and
- deliver an enabling architecture that would provide flexibility in call processing, support terminal-based features, and allow the future integration of personal computers and PC applications within the telephone system.

Simplicity

The first of the design objectives—absolute simplicity—was the most fundamental of the design drivers. Research indicated that, above all else, users wanted a keysystem that was easy to operate. From the findings, it was concluded that users were dissatisfied with existing keysystems because they were complex and difficult to use. In fact, many of the features that users found most desirable in a keysystem were, ironically, the ones least frequently used because of their complexity. Simplicity of use was achieved by means of careful extension feature design and by the provision of visual displays on all extension telephones.

Designers also ensured simplicity of installation and commissioning. The central control unit (CCU) is simply mounted on the wall, and the exchange lines and extension telephones are connected to it by using a purpose-designed connection box. At this point, the system is fully functional at its default settings. A system can then be tailored to meet particular customer configuration requirements. The end-user can also conduct system-tailoring from one of the Norstar telephones, simply by following menu-driven programming steps provided on the telephones' displays. Installation is further simplified by the use of polarity-insensitive single-pair extension wiring.

System administration has also been simplified by the fact that Norstar terminals have been designed for easy location changes, which is an important feature for small businesses, where accommodation for growth and change is critical.

Simplicity was also incorporated into the design of end-user documentation. The extensive use of displays and system prompts on Norstar enabled customer and installation documentation to be kept to a minimum.

Cost-Effectiveness

The second fundamental design challenge was to develop a cost-effective architecture capable of delivering a fully featured digital product in small line sizes, at a cost that was competitive with traditional analogue systems.

The goal of cost-effectiveness was a severe design constraint that represented perhaps the most difficult design challenge. It was met through the extensive use of custom-designed silicon circuits, and through system architectural modularity.

The custom-designed large-scale integrated circuits used in Norstar, in addition to achieving the system cost targets, were the fundamental vehicle for setting a new bench-mark in keysystem functionality. In all, nine BNR-designed custom chips are used.

The initial Norstar *Compact* product is for businesses with requirements for up to 16 extension telephones and six exchange lines. Getting the cost right at the low end was a fundamental

† BT Worldwide Networks

* Meridian and Norstar are trademarks of Northern Telecom

decision that guaranteed the market entry of Norstar. This unique design strategy meant that, once the small Compact system was developed, the same architectural building blocks and extension telephones could then be used to produce a larger *Modular* system.

Enabling Architecture

The third key design challenge was the requirement for an enabling architecture that would facilitate flexibility in call-processing design, terminal-based features, and the future integration of personal computers (PCs). This capability is not normally possible with conventional designs.

This capability was achieved by combining a broadcast architecture with functional messaging to facilitate communication between intelligent terminals.

Norstar's architecture behaves as if each terminal has its own processing power, generating and sending its own high-level messages to every other terminal on the system. In physical terms however, the processing power of the terminals can be located centrally, keeping terminal costs down without compromising system functionality.

The hardware design uses serial digital interfaces that carry 32 simultaneous voice and signalling channels. This technique means that the system can be expanded using high-speed serial links between system modules instead of the traditional backplane and shelf configuration method that has characterised conventional key-system designs.

Bidirectional 2B+D digital communication between the centre and Norstar extensions is carried over a standard non-polarised copper twisted pair up to a distance of 800 m, using burst-mode, time-compression multiplexing (TCM) transmission. Each TCM path carries two 64 kbit/s B-channels and one 16 kbit/s D-channel. The B-channels carry digitally encoded speech or data. The D-channel carries system control and signalling messages.

DISTRIBUTED PROCESSING SOFTWARE ARCHITECTURE

The extensive use of custom silicon and a modular architecture has resulted in a unique distributed processing software design for Norstar.

In traditional keysystems, a single centrally-located program dictates the call-processing operations for all extension telephones. The CCU monitors all user prompts and signals on incoming lines, and then determines what action must be taken, such as activating audible and visual indicators on the extensions and making the appropriate connection between the extensions, The CCU then drives the hardware to perform these actions.

In order to achieve the required level of functionality and flexibility, every extension and every line on Norstar behaves as an independent device, controlled by a program of its own, with the separate programs communicating with each other by means of high-level functional messages.

For most Norstar extensions and lines, the control programs are similar and require minimal computing power. Because it would not have been cost-effective to provide each extension with an individual computer, all of these control programs share the processor in the CCU. For more complex terminals, or those attached to a personal computer, the terminal can provide, and run, its own program.

A major advantage of this distributed design is that details of a particular terminal do not affect the operation of the CCU or other terminals. Such factors as the number of keys, the type of display, and even the use of a computer screen and keyboard in place of conventional controls are handled by the control program for the terminal concerned.

In a conventional design, the extension user dialling a number accesses a common data table, in order to identify which extensions have that user number. Norstar avoids using a common table because it would have forced all calls to be mediated by a central unit. Instead, every Norstar extension is responsible for recognising its own user number, or as many different user numbers as it has appearances. When a call is originated, the desired user number is broadcast by the CCU in message format to all other extensions on the system, and those interested are able to respond.

As soon as a user answers the call at one of the responding extensions, the calling and responding extensions confirm the operation by exchanging messages.

Calls going to an outside line are handled in much the same way. Like the extensions, lines have individual programs, and each line has a Norstar user number. To make an outside call, the user presses a LINE key. The calling extension then broadcasts the line user number, and the appropriate line program responds. The user can then dial the digits of the outside telephone number. The digits are passed to the line program, which in turn transmits them to the public network.

Conversely, when an incoming call arrives, the line program acts as a caller within the Norstar system and broadcasts its user number; the appropriate extensions can then respond.

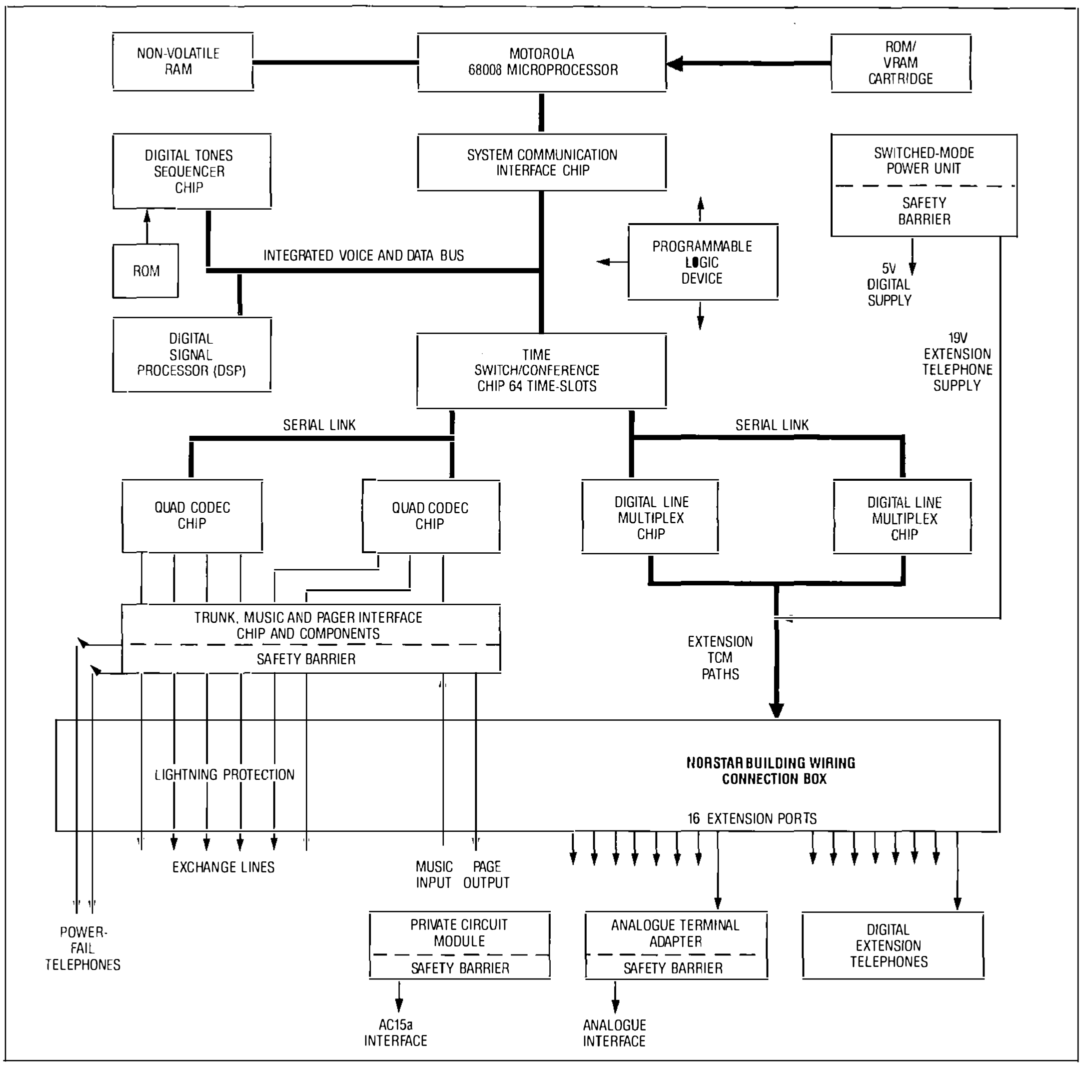
Adopting a software architecture of this nature required, however, a significant investment in design effort and results in a considerably greater call processing program size (in excess of 1 Mbyte) than a more conventional approach.

The program was written in a structured high-level language and rigorous verification routines and tests were developed as an integral part of the development programme.

INTEGRATED DIGITAL HARDWARE ARCHITECTURE

The Norstar common integrated voice and data (IVD) bus enables efficient distributed switching

Figure 1
Norstar Compact
6+16 block diagram



and communication with the processor and tone generator to be provided (see Figure 1). The IVD bus also acts as a system access point for capacity expansion and functionality development. Located in the CCU, the 10-bit-wide parallel bus allows for 640 time-slots to appear in each sample time of 125 microseconds.

Each custom time switch chip attached to this bus handles 64 B-channels. Every sample time, the time switch chip collects one sample from each of these channels and places the samples in 64 evenly spaced time-slots on the common bus. Samples from the 64 channels of the first time switch chip, for example, would occupy 64 different time-slots on the bus; for example, time-slots 1, 11, 21, and so on. Similarly, the 64 channels of the second time switch chip would occupy time-slots 2, 12, 22, etc.

Depending on the system size, up to nine time switch chips can be attached to the bus, using interleaved time-slots. The remaining time-slots (0, 10, 20, and so on) are reserved for control information sent from the system communications interface chip to the time switch chips. This arrangement allows a maximum of 576 (9×64) B-channels to be written to the bus.

In the outgoing direction, each time switch chip can connect any of the 576 B-channel time-slots to any of its 64 B-channels. Thus, any of 576 inputs can be connected to any of 576 outputs. Connections are normally set up in matched pairs to provide non-blocking two-way connectivity. Thus every Norstar extension telephone has full non-blocking access to two B-channels.

In the CCU, the digital line multiplexer chip combines eight incoming extension TCM paths. Two digital line multiplexer devices combine to fill a standard serial interface, which has a capacity of 32 B-channels and 16 D-channels in each direction.

Quad codec chips in the CCU provide analogue-to-digital and digital-to-analogue conversions, and set up the two-way connections between Norstar extensions and analogue outside lines.

The time switch chip also supports multi-party conferencing by providing each of the parties with a combination of signals from the others.

The Norstar Compact 6+16 Keysystem

The Norstar Compact is the first of the Norstar product family to be made available in the UK.

The technical definition of the product for the UK market was the result of close collaboration between NT and BT, which resulted in the generic North American product requiring significant adaptation to meet UK and European approval and market requirements. Compact is a wall-mounted 6+16 feature-rich digital keysystem offering a range of three fully digital extension telephones and an analogue extension adapter. Figure 1 is a block diagram of the Norstar Compact 6+16.

The CCU, Figure 2, is a high-reliability sealed unit and requires no on-site maintenance. Internally the CCU contains two circuit assemblies these being a power unit and a main control board.

The power unit is a robust high-efficiency switched-mode double-insulated design and is custom built for Norstar. It provides a high level of immunity to mains interference and is silent in operation.

The main circuit board is an excellent example of high-density surface-mount design. The design of the board permits the extensive use of automated manufacture and robot assembly methods, which result in a product of consistently high quality and reliability. The design has been optimised for low electromagnetic radiation and susceptibility in order to comply fully with future stringent European legislation.

Compact uses a Motorola 68008 processor, which features an internal 32 bit architecture while using an external 8 bit data bus. This permits efficient use of the powerful 68000 generic software instruction set but permits lower-cost 8 bit memory peripheral components to be used. The design of the CCU allows room for future software functionality expansion as up to 4 Mbyte of data may be directly addressed.

Custom silicon chips perform most of the main system functions: tone generation by DSP, tone sequencing for cadences and dual-tone multi-frequency dialling, processor bus and control interfacing, non-blocking time switch and conference function, analogue-to-digital and digital-to-analogue codecs, digital extension interface multiplexers and general utility logic functions.

The system software is stored in masked programmed read-only memory (ROM) by means of a sealed cartridge that plugs into the top of the CCU case. The cartridge also carries additional random-access memory (RAM) for use by the CCU. Future software enhancements can easily be installed as the cartridge is robust in design and easily replacable. Customer-specific data is stored in the CCU and remains intact for a number of days if the mains power is removed.

The Norstar Compact connection box, shown in Figure 2, houses the termination insulation-displacement connectors for the extension telephones, power fail telephones and lightning protection components. In addition, the external interfaces for music and paging are provided together with sockets for the link cables to the CCU.

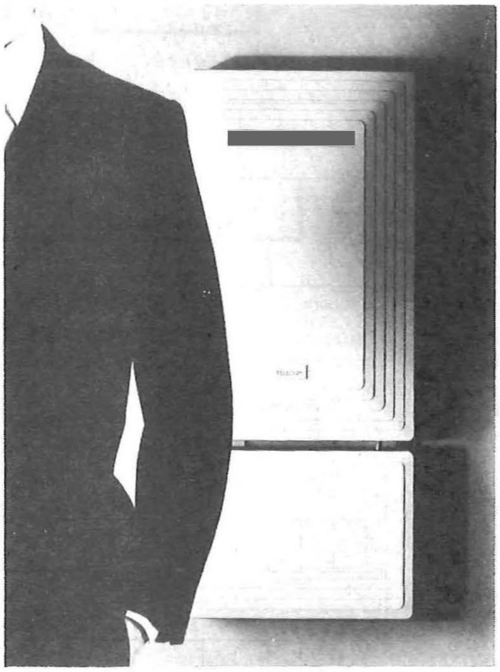


Figure 2
Norstar central control unit and connection box

Norstar Compact is BABT approved to British Standard BS 6450 Part 2 and supports loop-disconnect and MF4 signalling, loop-calling unguarded clear exchange lines or host PBX ports.

NORSTAR DIGITAL EXTENSION TELEPHONES

The use of custom silicon chips has enabled Norstar economically to provide digital functionality directly to the customer's desktop. The telephone chip integrates the following major functional blocks:

(*a*) the digital-to-analogue and analogue-to-digital codec,
(*b*) the microprocessor interface,
(*c*) the hands-free control circuits,
(*d*) the audio handset and speaker circuits, and
(*e*) the line interface circuits.

Integrating these functions was not an easy task to achieve. However, Norstar has benefited greatly from this work by virtue of its excellent hands-free performance, together with a simplified and stable manufacturing process and improved overall reliability performance. All telephones feature good-quality loudspeakers, and so desirable features such as paging and background music are universally available if required.

The maximum extension length is 300 m or, by using a small optional mains power unit, may be extended to 800 m.

The Norstar Compact system offers a choice of the following three digital extension telephone types together with an optional busy-lamp field module. All telephones feature a reversible base that allows wall mounting together with a choice of three colours: grey, beige and black. The 7310 telephone incorporates a two-line liquid-crystal

Figure 3—Norstar 7310 telephone

Figure 4—Norstar 7208 telephone

Figure 5—Norstar 7100 telephone

display (LCD) with associated soft keys, full loud-speaking telephone (LST), 12 autodial keys, 10 programmable buttons and a headset option (see Figure 3). The 7310 is the recommended terminal for programming the system. The telephone also provides a superior user interface for using present and future system features.

The 7208 telephone, shown in Figure 4, incorporates a single-line LCD, full LST, eight programmable buttons and a headset option. The 7208 may also be used for system programming.

The 7100 telephone (Figure 5) incorporates a single-line LCD, hands-free dialling and speaker, and one programmable button. The 7100 is not suitable for system programming.

The 7310 telephone optional busy-lamp field (BLF) unit incorporates a 24-segment LCD. It is fitted by simply replacing the standard telephone base with the BLF and by plugging a small ribbon cable connector into the base of the telephone.

The optional analogue terminal adapter (ATA) converts the Norstar digital extension port into a standard analogue (BS6317) extension port. The unit is supplied with a small plug-top external power unit. This allows a wide range of analogue devices such as answering machines, modems, fax machines or analogue telephones to be connected to the Norstar system. The ATA port is fully barriered, and so it may be connected without restriction to appropriate external line plant.

NORSTAR SYSTEM AND EXTENSION FEATURES

Norstar Compact offers a wide range of system and extension features. The selection listed in Table 1 reflects the range of functionality offered by Norstar.

TABLE 1
Norstar Features

Autodial keys	Background music
Call duration timer	Call forward
Call park	Call pick-up
Conference (3 party)	Contrast adjust
Dialling modes	Do not disturb
Feature key programme	Group listening
Hold	Host exchange (recall)
Hotline	Key enquiry
Last number redial	Line pool
Long tones	Messages
Names	Night service
Page	Priority call
Programmed release	Restriction password
Ring again	Ring type options
Ring volume	Run/stop
Saved number redial	Selective call forward
Service modes	Show time
Speed dial-personal (24)	System speed dial
Telephone administration lock	Transfer/announcement
Transfer/direct	Trunk answer
Voice call/deny	

NORSTAR DATA ENTRY

Norstar is programmed on site by using one of its own 7310 or 7208 terminals. The LCD displays are used together with an overlay card to label the required keys. The installer, having received details of the customer's requirements, enters the programming mode via a password and manipulates the following primary parameters:

line modes,
line destination access,
call handling, and
miscellaneous functions.

The customer appoints a selected person to be the system administrator, who enters programming mode in a similar way to the installer but via a different password and may access the following secondary parameters:

system speed dial entry,
names,
time/date,
restriction barring,
override data,
permissions, day/night service, and
administration passwords.

MANUFACTURE OF NORSTAR

Successful product development demands design excellence and manufacturing expertise. Rigourous design-for-manufacture criteria were applied throughout the development of Norstar to maximise the benefit of a modern automated production plant. The following five key areas were identified to guide the design and manufacturing planning processes for Norstar.

(*a*) Although the Norstar system had to be fully featured, the number and type of components used in its design had to be kept to a minimum to ensure that circuit assemblies could be manufactured with precision in a highly automated production environment.

(*b*) The layout of the printed circuit boards for the digital telephones and CCU must maximise the use of surface-mount components in order to benefit fully from the use of fully automated component-placement manufacturing systems.

(*c*) Advanced automated testing had to be developed and integrated into the production process to ensure that Norstar would meet stringent quality and reliability requirements.

(*d*) The manufacturing cycle time had to be reduced to less than 48 hours without compromising product quality. This is of great benefit to BT as a distributor as it permits minimising inventory (stores holding) which is of major strategic competitive advantage.

(*e*) Northern Telecom designed a manufacturing plant that flexibly could provide Norstar to worldwide distributors in a wide variety of national variants, colours and random-volume orders, without increasing the cost of the product to the distributor.

The Northern Telecom Canadian factory in Calgary, Alberta, consumes about 3 million components daily. Most of the parts inventory passes through the plant in 5 days. The plant is a world-class example of modern *Kan Ban* methodology and *just-in-time* high-quality manufacturing practice.

FUTURE DEVELOPMENTS

The Norstar Compact 6+16 system was launched in January 1991. An AC15a private circuit module and a V.24 call logging port adapter will be made available during 1991. The larger 128-port Norstar Modular system together with two further terminal options are scheduled for UK availability during late-1991. A variety of additional system enhancements and terminal developments are set to follow these initial product releases.

The advanced silicon building blocks, together with the flexible software broadcast architecture, functional messaging and user interface, provide a solid technology platform for the future. The digital architecture of Norstar and the internal 2B+D connectivity make the product ISDN-ready, a capability that can be further developed to complement the availability of appropriate national and international ISDN services.

ACKNOWLEDGEMENTS

The author would like to thank NT and BNR for access to material to assist in the preparation of this article He would also like to thank colleagues in the Norstar technical product management team for their help. Meridian and Norstar are trademarks of Northern Telecom.

Biography

At the time of writing, Barry Searle was Technical Product Manager for Meridian Norstar. He has recently moved to BT Worldwide Networks to work on the development of the BT Corporate VPN. Prior to his work with NT on Norstar, he was the programme manager for BT in-house ISPBX development. During the 1980s, he had responsibility for the technical development of, firstly, the Viceroy and Kinsman, and later the TSX50 ranges of private switching products produced by Mitel. In addition, he also managed the development of the GPT produced Octara 32X keysystem. His earlier career in BT was in the development of quality assurance systems and in the application of statistical sampling techniques. He is a Chartered Engineer, graduate and a Member of the Institution of Electrical Engineers.

A 29 GHz Radio System for Video Transmission

R. P. SCOTT†, and P. J. COOKE*

This article describes a 29 GHz radio system which has been developed for BT Visual and Broadcast Services, initially to alleviate difficulties in serving business customers. This has been achieved by providing short-range distribution of video signals from a 29 GHz transmitter to a number of receivers within a circular coverage area. The system has also been adapted to provide point-to-point video transmission. From the system's inception, manufacturing techniques and costs were taken into account to ensure that the radio equipment could be produced at low cost.

INTRODUCTION

A 29 GHz radio system has been developed as a means of extending video services, primarily transmitted by satellite, to customers' premises where it is difficult to install a satellite antenna or expensive to provide service by cable.

The initial application was to assist the implementation of *Racenet.* Racenet involves the distribution of racing information, consisting of video coverage and data, by satellite to bookmakers. Some difficulties and delays had been encountered with the installation of the satellite receiving antennas at bookmakers' premises. This was mostly due to lack of suitable mounting positions and delays in obtaining planning permission. The 29 GHz radio system was designed to overcome these problems by providing short-range distribution of the SIS (Satellite Information Services) video signal to a number of Racenet customers. The 29 GHz transmitter is installed close to where a satellite receiving antenna can be sited; for example, at a local telephone exchange or other suitable tall building. For each customer, a 29 GHz receiver is installed on a nearby roof. This arrangement is shown in Figure 1.

† BT Development and Procurement
* BT Visual and Broadcast Services

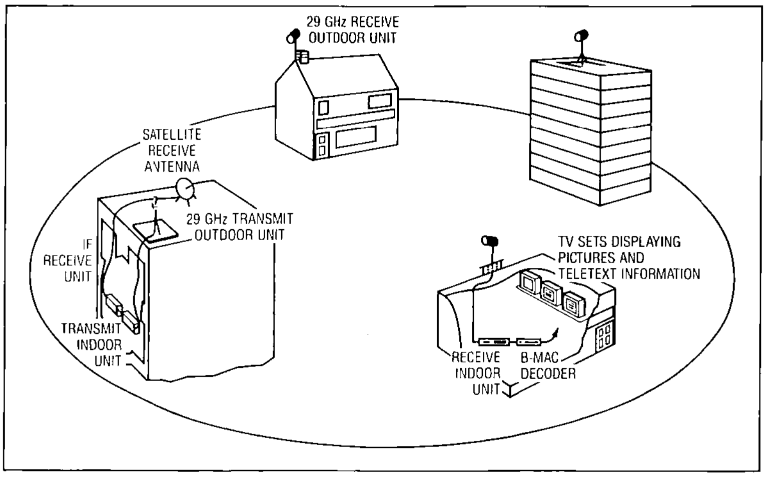


Figure 1
Racenet application

The 29 GHz system has been designed to provide compact, low-cost equipment, which is unobtrusive and easily installed. For the initial application, the system has a range of up to 1·8 km. However, the equipment has subsequently been adapted for point-to-point closed circuit TV applications, providing ranges up to 15 km. Ranges for point-to-multipoint applications have been extended up to 8·5 km. It should be noted, however, that ranges in particular applications depend upon the climate, the terrain and the availability required. A prototype duplex version of the system has also been shown to transmit video or 2 Mbit/s digital signals satisfactorily.

SYSTEM DESIGN

The initial requirement for the system was to provide transmission from a satellite receiver site to a number of Racenet customers over distances of up to about 1·5 km. The equipment and installation were required to be of lower cost than linking customers to a satellite receiver using cable.

The system required radio-frequency spectrum in a band available to BT. The 29 GHz band was chosen since lower-frequency bands are already extensively utilised. There were good prospects of providing compact equipment for this short-range application even with the increased rainfall attenuation at this higher frequency. Equipment had previously been developed by BT Laboratories at 29 GHz for a video conferencing trial[1] and hence some designs and techniques were already established.

Frequency modulation was chosen so as to achieve an adequate video signal-to-noise ratio at the low receiver carrier-to-noise ratios which result from the relatively low transmit power economically available at 29 GHz. Choosing the same modulation format as that of the direct broadcasting satellite (DBS) also permits the use of the intermediate-frequency (IF) receiver/demodulator units already developed and in volume production.

The Racenet application required the distribution of one video channel, but initially provision was made for a total of six (RF) channels to allow the distribution of the SIS video channel in a number of adjacent areas using different RF channels. It also provides for a small number of video channels to be distributed within a given area or transmitted over a point-to-point link. Further channels will be possible in this band. A channel spacing of 38·36 MHz has been adopted, which is compatible with DBS channel plans based on a raster of 19·18 MHz. This spacing is consistent with the present frequency stability limitations of low-cost oscillators at 29 GHz.

Choice of Transmitter Configuration

The traditional method of upconversion after IF modulation was initially considered. At the time, available upconverters at this frequency were expensive and would only provide an output of about 1 mW; hence an RF amplifier would be required. Adequate high-power amplification to about 100 mW was not economic at 29 GHz. Consequently, upconversion was ruled out as an option.

The lowest cost and most straightforward configuration involved direct modulation of a Gunn oscillator. A Gunn oscillator tuned by a varactor diode is capable of providing a sufficiently linear tuning range to permit peak-to-peak deviations up to about 25 MHz. Temperature stabilisation of the Gunn oscillator, as well as providing the required frequency stability, maintains the modulation over the chosen linear portion of the oscillator's tuning range.

Transmit Antenna

Since a number of randomly distributed receivers needed to be covered from a single transmit site, some initial consideration was given to the use of an omni-directional antenna. Not only was the antenna structure likely to be quite large and expensive, but it is often difficult to find an unobstructed site on the top of a tall building owing to the presence of other antennas (typically VHF/UHF).

An alternative solution is to use a sector-coverage antenna which can be located on the side or corner of a building and so avoid obstructions. A wide-beamwidth rectangular waveguide horn[2] provides a simple inexpensive antenna and can be used to engineer a system having an approximately circular coverage area with the transmitter sited on its circumference. The vertical beamwidth of the horn is much less than the wide azimuth beamwidth but sufficient to give vertical coverage from close to the transmitter to the maximum range for most transmitter heights. This small antenna also has the advantage that it can be mounted close to the outdoor RF equipment, thus minimising feeder loss.

Receiver Configuration

The receiver configuration is conventional, consisting of an outdoor antenna and downconverter unit, and an indoor IF receiver, as for DBS reception. To achieve the best performance and minimise cost, the antenna and the downconverter are integrated into a single unit. An IF within the standard satellite receiver IF band of 950 to 1750 MHz was adopted, so that readily available DBS receiver/demodulator indoor units could be used. The downconverter is powered from the indoor unit via the interconnecting coaxial cable.

To provide an adequate system range, with economically available transmit powers and receiver mixer noise figures, an antenna gain in the region of 30 dB was required. This has been achieved by using a 200 mm version of an offset reflector antenna developed for a 19 GHz multipoint system[3].

Video Channel Requirements

The design of the original system was based on the transmission requirements of pre-emphasised B-MAC formatted video signals. The B-MAC signals require a baseband bandwidth of 8·25 MHz and have an amplitude of 1 V peak-to-peak. As for the satellite path, a deviation of 18 MHz peak-to-peak has been adopted.

For CCTV applications, this bandwidth also allows the transmission of video signals in PAL format, which requires 5·5 MHz bandwidth.

System Configuration

The system configuration consists of indoor and outdoor units for both the transmitter and the receiver. The overall system configuration is shown in Figure 2. The transmitter has an outdoor

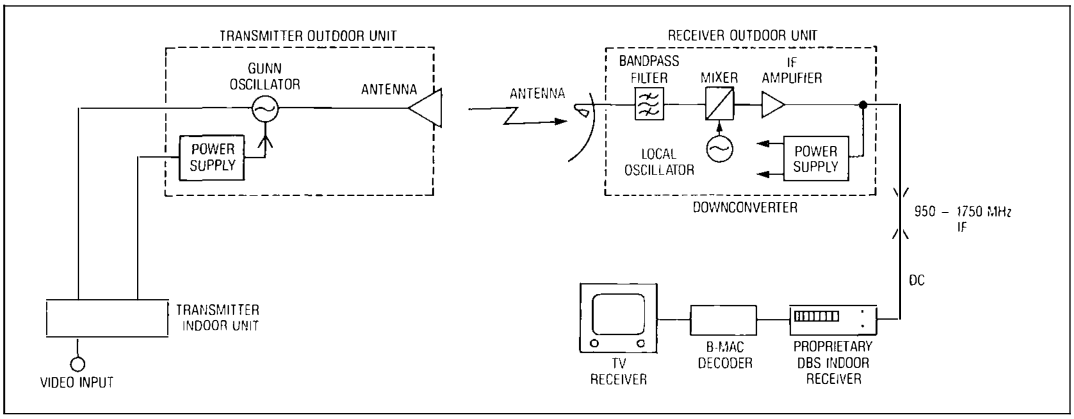


Figure 2
System configuration (B-MAC)

unit comprising a 29 GHz Gunn oscillator feeding the antenna. The oscillator is directly modulated by the video signal connected by cable from the indoor unit. Each receiver installation has a single unobtrusive antenna/downconverter usually mounted on the roof. The outdoor unit is cabled to an indoor unit of the type identical to those used for DBS reception.

The same system design approach was subsequently used for a demonstration of multichannel TV distribution[4] at Saxmundham.

System Parameters

The parameters of the system are given in Table 1.

TABLE 1
System Parameters

Transmit power per channel	80 mW minimum
Modulation	FM, typically 18 MHz peak-to-peak deviation
Video format	B-MAC, PAL-I and other formats requiring up to 8 MHz baseband bandwidth
Transmit antenna gain	15 dBi minimum (single waveguide horn), 11 dBi minimum (two waveguide horns, back to back)
Receiver noise figure	13 dB maximum
Receiver antenna gain	30 dBi maximum
Receiver bandwidth	30 MHz maximum
Threshold signal-to-noise ratio	12 dB for MAC and for PAL, giving a video signal-to-noise ratio of 42 dB

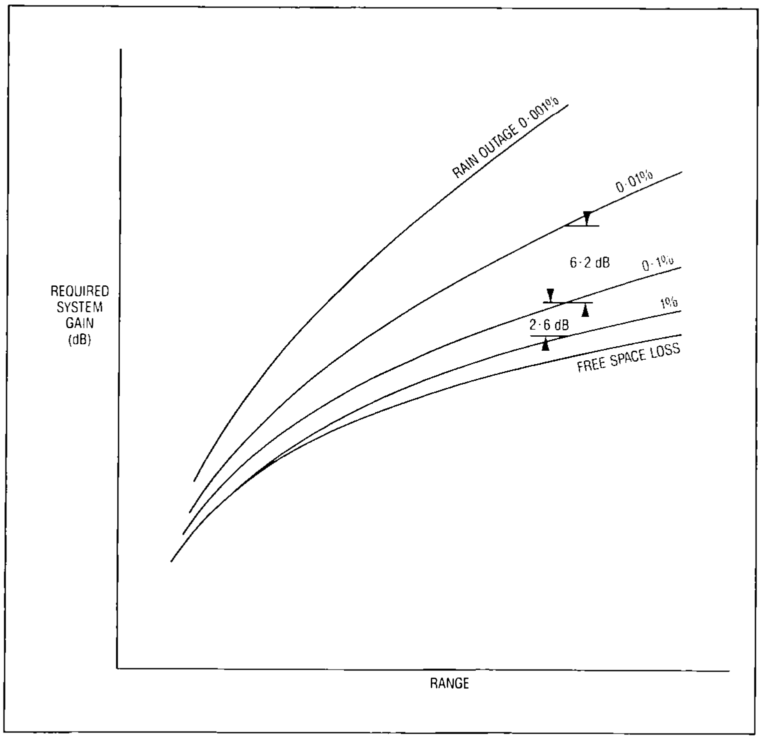


Figure 3—Required system gain

SYSTEM GAIN

The rainfall attenuation at 29 GHz is fairly high; consequently the range achievable with an economically viable system gain is relatively short when compared to lower-frequency systems. The rainfall attenuation that can be tolerated for the specified outage is only a few decibels per kilometre. The consequence of this is that, for the short-range distribution applications, the system is much more sensitive to reductions in system gain than lower-frequency systems. For example, as shown in Figure 3, a reduction in system gain of about 6 dB increases the outage from 0·01% to 0·1% and a further reduction of about 2·5 dB increases the outage to 1%. Hence it is necessary to specify firm minimum values for the parameters contributing to the system gain to prevent the system performance being eroded.

COVERAGE AREAS AND RANGES

The basic point-to-multipoint system has been designed to provide a circular azimuth coverage area with the transmitter located on the periphery. This was achieved by matching the gain variation of the transmit antenna to the variation of 'free space loss' and rainfall attenuation with distance, such that for a given outage the coverage area is circular. For example, for a rain outage of 0·01% of an average year (UK), the coverage area has a diameter of 1·8 km (Figure 4).

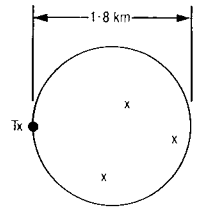


Figure 4—Coverage area: single horn transmit antenna (0·01% rain outage)

Recent increases in system gain together with the use of 1 m receiving antennas can result in ranges of 5 km for 0·01% outage with a single horn transmit antenna. If the permissible outage is increased to 0·1% for, say, the last stage of a distribution network, then the range increases to 8·5 km.

A two-horn transmit antenna is available which enables transmission in opposite directions from a central site. This is discussed in more detail in reference 5, together with details of the vertical coverage from the horn antennas.

LOW-COST MANUFACTURING TECHNOLOGY

From the system's inception, manufacturing costs were taken into account to ensure that the radio equipment could be produced economically. Only system configurations which would lead to low cost were considered; that is, those which could use low-cost components and manufacturing techniques. Parameters of the RF equipment which were known, through discussions with manufacturers, to be feasible within the cost targets of the equipment were specified.

Sections of the system were examined critically to establish if low-cost manufacturing techniques could be used. This particularly applied to the antennas, which have traditionally been purchased from specialist manufacturers. They have been of high cost, as a result of the design and manufacturing methods used. They often require detailed setting up and subsequent measurement of the antenna performance. (Detailed microwave measurements are expensive, particularly if they involve the use of an antenna test range.) The antennas were thus designed so that there would be no need to measure the performance of each unit, providing that it is manufactured and assembled to the defined tolerances. Production techniques used by other industries for manufacture in similar quantities to those required were examined. Where appropriate these have been adopted.

Transmit Antenna Horn

Prototypes of a wide-beamwidth horn, which has a large-aspect-ratio aperture, were produced by electroforming. Although electroforming is useful for small quantities, in volume the cost does not fall substantially. Although the tooling costs for die-casting are relatively high, unit costs can be very low. The horn and its waveguide flange were die-cast in one piece at a unit cost of just a few pounds.

Receive Antenna

The receiver uses an offset reflector antenna design similar to that developed previously for a 19 GHz system[3]. As for the earlier design, a forming process in aluminium is used for the reflector and die-casting for the feed horn. Subsequently, the feasibility of using a metallised plastic reflector has been demonstrated. Even in relatively low volumes it is likely that a plastic reflector could be produced for a small fraction of the cost of the aluminium version.

THE ROUTE TO PRODUCTION

Specification Preparation

The specification was produced taking account of factors likely to assist a manufacturer in producing the equipment at low cost. For instance, the required system gain includes a margin to allow for precipitation attenuation (predominantly due to rain), but at and towards the extremes of the ambient temperature range precipitation is unlikely to occur. Thus it is possible to reduce the specified system gain in the low and high regions of the ambient temperature range[6], as indicated in Figure 5. This relaxation will contribute to reducing costs by easing the thermal design problems for a manufacturer and, for example, allowing lower-cost designs of RF oscillator to be utilised.

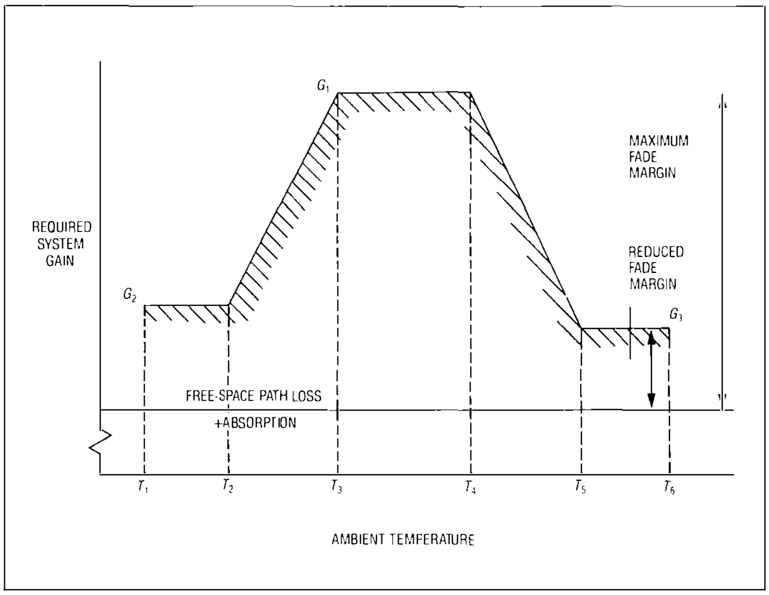


Figure 5
Required system gain mask

The preparation of the specification was supported by some experimental investigations to confirm the feasibility of the design. The specification was issued to a number of manufacturers and tenders invited. A development contract was subsequently placed with Philips Microwave, Hazel Grove.

In the equipment realisation, the manufacturer (Philips Microwave) used low-cost waveguide technology for much of the RF sections, helping to keep costs to a minimum[7]. For the projected quantities for this radio system, waveguide technology is the most appropriate. Also, the low-cost BT Laboratories 200 mm antenna design was adopted under licence.

Manufacture

The resulting manufactured units are shown in the following figures. Figure 6 shows one of the transmit outdoor units connected to a single-horn antenna, provided by BT Laboratories, and its associated indoor unit is shown in Figure 7. The receiver outdoor unit, which includes the BT Laboratories 200 mm antenna, and the receiver indoor unit are shown in Figures 8 and 9 respectively. Both outdoor units are designed to mount on to 50 mm diameter poles to facilitate rapid installation. The transmit indoor unit is designed to be 19 inch rack mounted; the receiver indoor unit is nominally free standing but can be rack mounted if desired.

POINT-TO-POINT CONFIGURATIONS

The system can be readily converted for point-to-point applications by replacing the transmit horn antenna with a higher-gain reflector antenna. As the 200 mm antenna is integral with the downconverter and mounting of the receiver outdoor unit, for shorter range applications it is convenient to use this unit unmodified.

Using a 355 mm transmit antenna[3], for instance, gives a range of about 5 km for 0·01% rain outage.

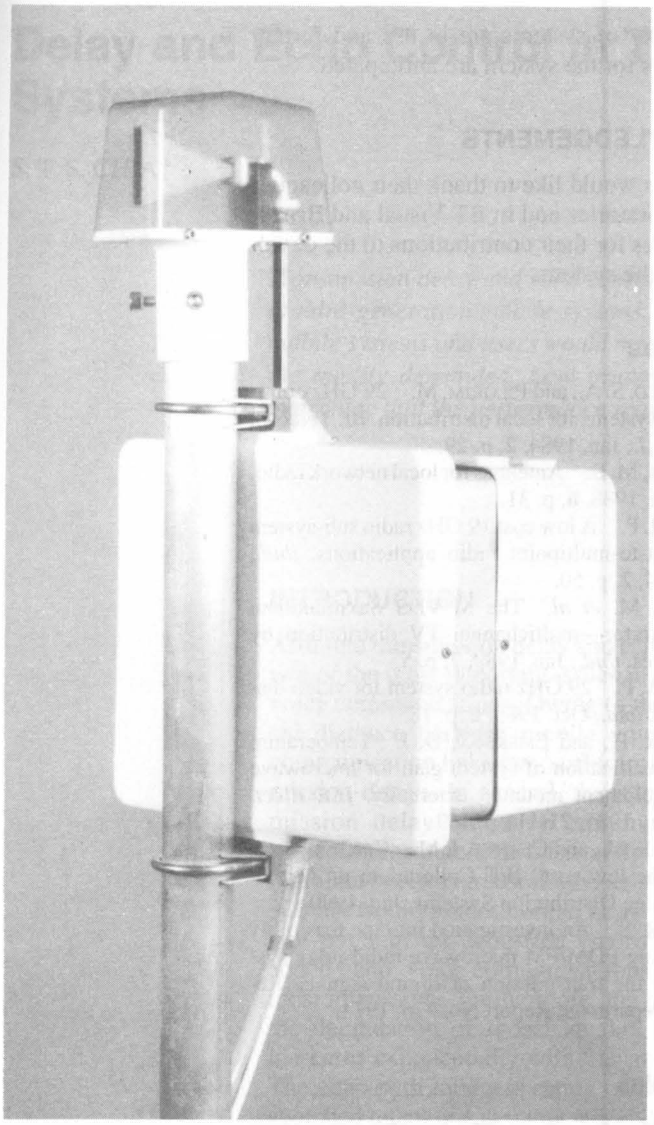


Figure 6—Transmit outdoor unit

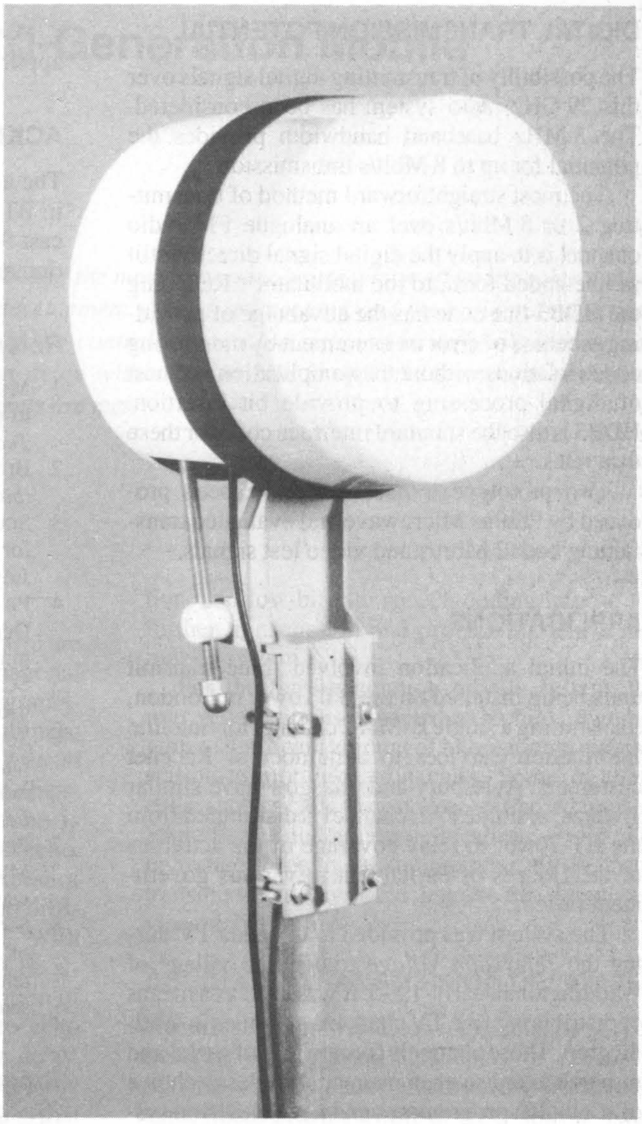


Figure 8—Receiver outdoor unit

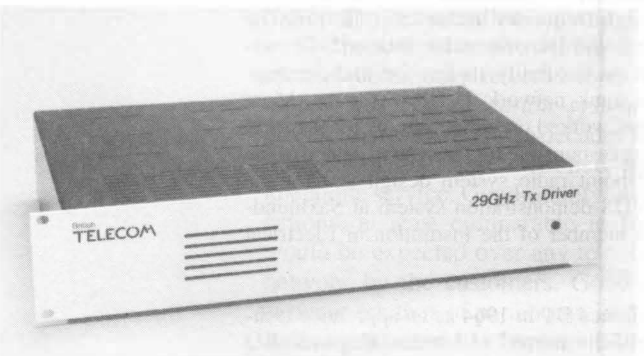


Figure 7—Transmit indoor unit

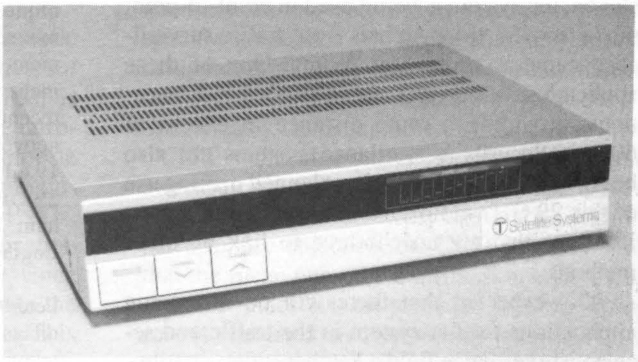


Figure 9—Receiver indoor unit

Longer-range applications can be provided by using, say, 1 m diameter antennas for both transmitter and receiver. A version of the receiver down-converter is then required which can attach to the back of a 1 m antenna. This arrangement could provide a range of about 15 km for 0·1% rain outage. For higher percentages, longer ranges are possible, but towards and above 20 km additional outage due to multipath fading is likely to occur.

VIDEO PERFORMANCE

The system provides high-quality colour video transmission of both B-MAC and PAL format signals providing a minimum video signal-to-noise ratio of 42 dB and a typical unfaded signal-to-noise ratio of 50 dB. The performance achieved is well within the published specification for BT CCTV services.

DIGITAL TRANSMISSION POTENTIAL

The possibility of transmitting digital signals over this 29 GHz radio system has been considered. The 8 MHz baseband bandwidth provides the potential for up to 8 Mbit/s transmission.

The most straightforward method of transmitting 2 or 8 Mbit/s over an analogue FM radio channel is to apply the digital signal directly, still in line-coded form, to the modulator[8]. Retaining the HDB3 line code has the advantage of providing a method of error measurement by monitoring code violations without the complication and cost of digital processing to provide bit insertion. HDB3 is also the standard interface code for these data rates.

Two prototype transceivers have been produced by Philips Microwave and evaluated transmitting both 2 Mbit/s and video test signals.

APPLICATIONS

The initial application involved three transmit units being installed on the BT Tower in London, transmitting a single B-MAC channel for Satellite Information Services to a number of Racenet customers. Aylesbury and Glasgow have similar systems. A single PAL channel is distributed from the BT Tower to relay coverage of the activities of the Houses of Parliament to various government offices.

The system was provided to Granada TV during the *Television Village* trial in the village of Waddington in early-1990. It was used as a means of distributing five TV channels to homes in Waddington. These channels formed part of a trial and research exercise on consumer attitudes to choice of television programmes and new television systems.

In London, Berkshire, Kent, Lancashire and Devon, the system is being used in point-to-point mode to relay video signals from traffic surveillance cameras to control rooms. One of these applications involves the use of five radio sections, providing a route distance in excess of 60 km. Security surveillance systems are also being installed, and are being planned making use of this 29 GHz radio system to reach cameras at locations that are uneconomic to link by other methods.

It is expected that there will be increasing applications for the system in the traffic and security surveillance fields. Further video distribution applications are also being examined for customers in Europe, for the distribution of cable TV channels.

CONCLUSIONS

A cost-effective 29 GHz microwave radio system which is providing both point-to-multipoint and point-to-point video transmission in the BT network has been rapidly developed.

The potential for digital transmission over the system has been demonstrated.

A number of systems are in use and further applications for the system are anticipated.

ACKNOWLEDGEMENTS

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Biographies

Dick Scott received a B.Sc.(Eng.) degree in Electrical Engineering from London University in 1965 and then joined BT, working on parameter measurement techniques for high-frequency transistors. In 1968 he moved to the Radio Division of the Research Department to work on feasibility studies for, and development of, the trunk network 11 GHz systems. More recently, he has worked on radio systems for the local network, being responsible for the system design of the 19 GHz multipoint radio system design and for the 29 GHz M^{3}VDS demonstration system at Saxmundham. He is a member of the Institution of Electrical Engineers.

Peter Cooke joined BT in 1964 as an apprentice technician. In 1968 he moved to London Regional HQ television provision and works group where his career in television began. In 1977 he moved to Telecommunications HQ to continue the provision and works for television circuits and networks nationally, such as the fourth television channel for the IBA and traffic surveillance schemes in Glasgow, Leeds and Bradford. More recently, he has been part of the system design team for Racenet and responsible for the use of 29 GHz radio for CCTV and other applications. In 1986 he received a B.A. degree from the Open University. He is currently Transmission Implementation Manager for Visual and Broadcast Services, and is responsible for the project management of development/provision of existing and new products and services.

Delay and Echo Control in Third-Generation Mobile Systems

S. T. S. CHIA†

Transmission delay and echo control are two of the most important issues which affect the voice quality of third-generation mobile systems. The development of the fixed network and the proliferation of both mobile systems and users would mean that echo-control devices alone may not be sufficient to cope with the quality demanded. Low transmission delay within the mobile network is, therefore, critical to guarantee that the performance requirements are met.

INTRODUCTION

Absolute transmission delay and echo control are two of the most important issues in international voice communications. Owing to the geographical distance between mobile voice terminals, communication links may suffer from long transmission delays. In general, the impact of transmission delay on voice communications is two-fold: absolute transmission delay and echo. Absolute one-way transmission delay in excess of 300 ms would render normal conversation difficult even in an echo-free environment. With added echo, voice communications could be almost impossible. Furthermore, the perception of the degradation of speech quality due to echo increases exponentially with transmission delay. The echo path loudness rating of today's public switched telephone network (PSTN) implies that one-way transmission delays in excess of 25 ms with echo would be a problem. Echo control is required in this situation.

By the time when the third-generation mobile system, commonly referred to as the *universal mobile telecommunication system* (UMTS), is launched, it would be two decades after the introduction of the first switched public mobile telephone service. Good-quality voice communications, at least comparable to today's PSTN, would be expected over any telecommunication network by the customers. Good-quality voice services are thus of paramount importance to the success and survival of new mobile systems. This is especially significant for the business and commercial sectors. With the proliferation of mobile systems internationally, transmission delay and echo present major problems to international mobile radio network designers. While short transmission delay is essential for good-quality voice communications, longer-than-optimum transmission delays may be required owing to the frame interleaving necessary for providing sufficient protection against error burst in fading mobile radio channels. Channel coding, equalisation, and low-bit-rate speech coding impose yet further transmission and processing delays in a mobile system.

For the third-generation mobile system, the user penetration is expected to be high, together with a significant amount of international mobile-station-to-mobile-station calls. Some of these calls, such as calls to customers on-board transatlantic flights and at remote locations, could only be routed through geostationary satellites. Long transmission delay could degrade the overall service quality immensely.

ABSOLUTE TRANSMISSION DELAY

Historically, it is well known that telephone connections with transmission delay in excess of 300 ms can be used only by very disciplined subscribers who are aware of the problems. Even with no echo, a delay in excess of 400 ms would render conversations very difficult, even under ideal conditions. The CCITT has taken steps to specify guidelines for acceptable transmission delay limits and echo control for telecommunication systems in a series of Recommendations [1–4]. Specifically, in Recommendation G.114[1], the CCITT states that '...As the propagation time increases, subscriber difficulties increase, and the rate of increase of difficulty rises'. As a network performance objective, the CCITT recommends that the mean one-way transmission delay is acceptable under 400 ms provided that 'increasing care is exercised on connections when the mean one-way propagation times exceeds 300 ms, and provided that echo-control devices, such as echo suppressors and echo cancellers, designed for long-delay circuits are used'. The Recommendation further states that transmission delay above 400 ms is unacceptable.

In the past, transmission delay was largely predictable within a national network. Nowadays, the National Code of Practice permits national resale of networks and private network connection to national networks. This may result in increased transmission delays in national networks. In general, the total transmission delay between

† BT Development and Procurement

the international switching centre and the subscriber farthest away from it in the national network can be estimated from the formulae given in CCITT Recommendation G.114 section 2.2.

SATELLITE LINKS

A significant contribution to the absolute transmission delay in international mobile-originated calls is the possibility of being routed via geostationary (synchronous orbit) satellites. International calls, especially outside Europe, would be statistically routed through geostationary satellites for decades to come. Currently, a common policy among major international telecommunication network operators is to provide echo-control devices on all satellite circuits, regardless of destination, as well as all intercontinental circuits. Echo control is, however, not provided on terrestrial circuits within Europe. In addition, most major international network operators have taken steps to limit the number of satellite hops to one per connection. However, this is not always possible since some locations can be reached only via a distant-end domestic satellite system. According to a satellite teletraffic forecast there will be no less than 10% of the European teletraffic to be transmitted statistically via geostationary satellite by the year 2000[5]. When comparing the relative significance of transmission delay and echo, if the one-way transmission delay is below 400 ms and remains relatively constant, echo is considered to be the more critical issue. However, customer surveys have indicated that, because of customer expectation, pure transmission delay is extremely disconcerting when it happens only occasionally to a specific destination. Customers have complained when using geostationary satellite circuits within Europe where they have normally used terrestrial routings.

The prerequisite of ubiquitous coverage and recent studies of the UMTS architecture have suggested that the UMTS, like the digital European cordless telecommunication (DECT) system, should be capable of attachment to any local exchange of the fixed network. Although the CCITT Signalling System No. 7 (SS7) would be used in future PSTNs, the extension of SS7 to all local exchanges and mobile terminals is practically impossible. Thus, unlike calls within the second-generation pan-European digital mobile radio system (otherwise known as the *groupe spéciale mobile* (GSM) system), not all mobile originated calls in the UMTS could be readily identifiable at international gateways. Some will be routed through land-lines instead. International calls, including mobile originated or destined calls, will continue to be statistically routed through geostationary satellites. Long transmission delays in excess of 300 ms would result in difficulty in conversations. Unfortunately, subjective perception of the degradation of speech increases exponentially with transmission delay and the quality of voice communication deteriorates rapidly beyond this threshold. The CCIR Interim Working Party 8/13 (now Technical Group 8/1) draft recommendation on the future public land mobile telecommunication system has categorically included the use of satellite[6]. The considerations of satellite links must therefore be included. It is unacceptable to ignore these calls by merely using the loose justification that they are relatively rare. In particular, from the customer's point of view, if a customer is consistently using international calls, his/her perception of the service quality would be deplorable unless the mobile system is designed to operate with geostationary satellites.

On the issue of using highly-elliptical orbit satellites as alternatives to geostationary satellites, the two most common highly elliptical orbits are the Molniya and the Tundra orbits. The Molniya orbit system consists of typically three satellites spaced 120° apart. Each satellite is active for 8 hours per day giving 24 hours continuous coverage. It has the disadvantage of passing through the Van Allen belt near the perigee. This increases the potential risk of damage to on-board equipment and is, therefore, unreliable. By contrast, the Tundra orbit requires typically two satellites each providing 12 hours continuous coverage. It has the disadvantage of long distance and hence long transmission delay. The apogee of a highly elliptical orbit satellite is of the order of 46 000 –53 000 km from the earth's surface. This range is dependent on the exact locations of the transmitter and the receiver on the earth. The typical maximum one-way transmission delay via a Tundra orbit satellite is about 350 ms (compare 260 ms for a geostationary satellite link) excluding the signal processing time on-board the satellite or the terrestrial ground station. Furthermore, the gradual change in transmission delay will render the tracking of the satellites and the control at the ground stations rather difficult. As more than one satellite will be used, the change-over of satellites may also be a potential problem.

ELECTRICAL AND ACOUSTIC ECHO

In switched mobile telephone systems, two sources of echo could arise. Imperfect impedance matching between 2-wire-to-4-wire terminations in a network could give rise to electrical echo. Acoustic coupling in the handset and in the acoustic environments of the end users could also contribute to significant echo. The former is well known and understood in years of PSTN developments. By contrast, the latter is a subject still under active research and discussion. In the following, this will be discussed further.

In an ordinary telephone system, the earpiece-to-microphone acoustic path (through the acoustic environment and via the handset) is usually sufficiently small to be ignored; modern handportable handsets are designed to be compact for the convenience of storage and carrying. Inevitably, compromise has to be made in the design which results in far less acoustic isolation between the earpiece and the microphone. When used in vehicles, hands-free operation is recommended for safety reasons. These render the acoustic coupling between the microphone and earpiece for both handportables and hands-free mobile telephone systems within vehicles an important issue. Furthermore, the echo path due to the acoustic environment can typically insert additional transmission delay of 10–20 ms. (Note that sound travels at approximately 331 m/s or 1 m in 3 ms under normal conditions.) This transmission delay is not constant and will be varying depending on the head movement and the physical environment of the customer. Since no normal mobile handset or hands-free operation is likely to be able to provide an echo attenuation of greater than 56 dB, echo is not negligible in mobile radio environments. Echo control will be needed for the radio paths to all mobile terminals if these paths involve more than 40 ms round trip transmission delay[7]. In a mixed network with 4-wire-to-2-wire terminations, acoustic and electrical echoes coupled with long transmission delay would result in intolerable voice quality. In general, for a round trip transmission delay greater than 25 ms, acoustic feedback will be perceived as echoes and not just as distorted sidetones.

Furthermore, the digitalisation of national networks is leading to reduced transmission loss and, therefore, a higher level of return echo. This may lead to subjective quality impairment, perhaps perceived by customers as high-level sidetones or even echoes depending on the actual transmission delay.

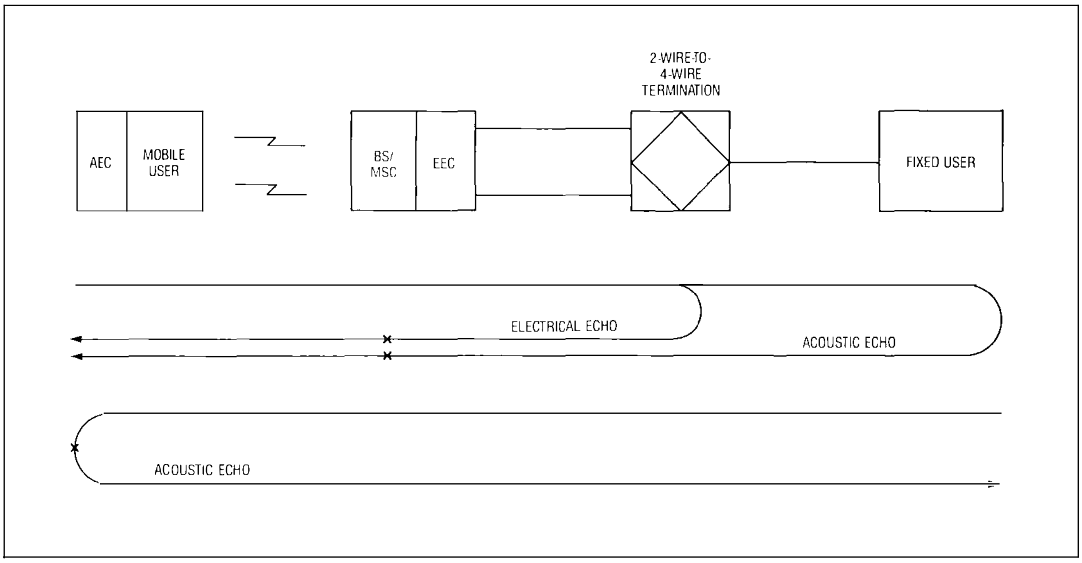
ECHO CONTROL

In the presence of transmission delay and echo, echo control could, in theory, be implemented to improve the performance. Unfortunately, echo-control devices are far from perfect and have severe limitations. Echo suppressors could introduce false switching in a noisy mobile radio environment, which could lead to speech clipping. They also introduce unacceptably high noise contrast. More sophisticated echo cancellers are inherently very expensive and have high power consumption. In the UMTS, acoustic echo with long and varying transmission delay due to multipath propagation of sound will occur within constantly changing user environments. Instantaneous re-adaptation of the register length by echo cancellers would be difficult. Echoes beyond the register length of the echo canceller and imperfect cancellation due to non-linear paths will give rise to additional noise in the communication link. Echo cancellers, although theoretically not leading to additional degradation when operating in tandem, have been shown to introduce additional distortion and interference in physical implementations.

In a mobile radio system, echo-control devices are best located at the sources of echoes. This will reduce the dynamic range and the transmission delay requirements of the echo-control device. The impairment due to additive noise and quantisation noise will also be minimised. In practice, it is usual to have two echo-control devices in a mobile radio communication link. Specifically, one echo-control device is located within the mobile handset for cancelling acoustic echoes. An additional echo-control device is also required to be located within the base station or the mobile switching centre in order to cancel both the far-end electrical and acoustic echoes originated from the fixed network (see Figure 1). However, it must be noted that the far-end electrical echo is normally far more dominant than its acoustic counterpart.

It must also be noted that the acoustic echo path in a mobile environment is non-stationary. In a practical system, there is a direct trade-off

Figure 1
The locations of echo control devices in a mobile network



X: Echo cancellation
AEC: Acoustic echo control
EEC: Electrical echo control
BS/MSC: Base station/mobile switching centre

between the speed of adaption, complexity, and resilience to noise. In a mobile environment, the cancellation must be resilient to near-end environmental noise and engine noise. As a result, the adaptive filter will be slow to track changes. Indeed the filter length is increased linearly with the effect of the near-end noise and the convergence rate[8,9]. In addition, loudspeakers are non-linear devices. Any non-linearity in the echo path can cause harmonics which are inherently uncancellable. These harmonics are disconcerting to users especially over a long echo path[8]. It has been shown that the implementation of a two-band echo canceller to combat a long echo path of 250 ms with a speech bandwidth of 7 kHz requires a total of 22 digital signal processing chips[9].

TRANSMISSION DELAY AND ECHO CONTROL IN THE GSM

The overall one-way transmission delay in the GSM system is significant. With 5 ms time-division multiple access (TDMA) frames, the largest contribution to the one-way transmission delay budget in the GSM full-rate speech channel is from the channel coding and the TDMA frame interleaving. This is approximately 37 ms, which is equivalent to about 50% of the overall transmission delay in the mobile network. In addition, the speech codec has an algorithmic delay of 20 ms due to the block-oriented linear predictive codec updating and an additional delay of 5 ms due to the actual processing. The rest of the transmission delay budget is to allow for a 16 kbit/s digital link between a mobile switching centre and its base station, analogue-to-digital and digital-to-analogue conversions, equalisation, channel encoding, and switching at various parts of the network. The overall one-way transmission delay budget thus amounts to the order of 90 ms.

At present, the GSM system with its associated long transmission delays on even the shortest of calls will require echo control nationally. When these mobile calls are routed internationally, an international gateway echo-control device may be connected in tandem with the GSM mobile echo-control device. The echo-control devices within the proposed GSM network were not specified and have yet to be tested for tandem and long transmission delay operation. Echo-control devices, at present, are not designed to work with non-linear processes, such as low-rate encoding, within their operating windows. With the roaming facilities that will be offered by some mobile services, the echo path of a connection may vary during the duration of a call. Current echo cancellers may not be able to converge on this new echo path without injecting a subjective impairment on the call.

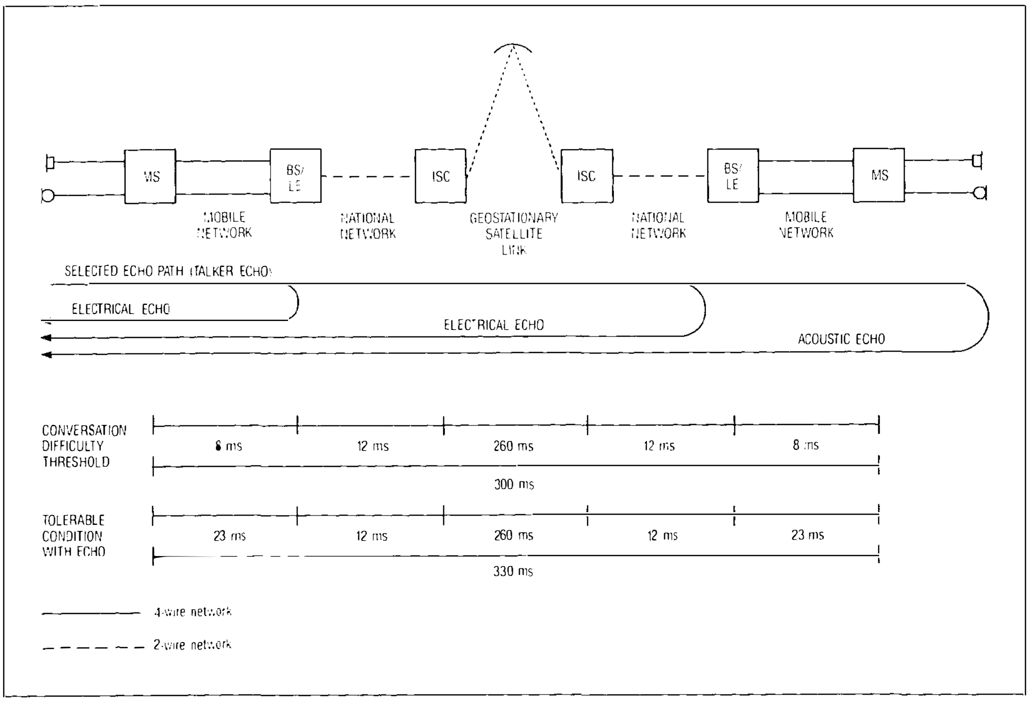
The transmission delay that is tolerable for the GSM system is not necessarily acceptable for the UMTS. The GSM system is predominantly a pan-European system aimed at business customers. With its limited customer profile, the number of mobile-station-to-mobile-station calls is expected to be low. As the GSM system is a self-contained system with access to the PSTN only via fixed interconnect points, the system is essentially a 4-wire system. Echo control is comparatively simple to achieve even though the performance has yet to be proven. By contrast, the UMTS is not restricted to European deployment and is aimed at both the mass public as well as the business sector. The system must be capable of operating in stand-alone mode or as an integral part of any PSTN worldwide; thus complete echo control is almost impossible. With a significantly higher user penetration, the frequency of mobile-station-to-mobile-station calls would also increase correspondingly. These fundamental differences between the GSM system and the UMTS result in a completely different perspective on the issue of transmission delay. From the customer's point of view, as the UMTS would launch almost a decade after the GSM system, it must offer good voice services that approach the PSTN quality before it has any chance of attracting the established users from existing mobile systems.

TRANSMISSION DELAY AND ECHO CONTROL IN THE UMTS

With a typical transmission delay of 260 ms for single-hop geostationary satellite links plus typical network transmission delays of 12 ms at either end of the satellite link, only a total of 16 ms of transmission delay can be distributed in a mobile communication link before reaching the 300 ms threshold (see Figure 2). Even if this limit is exceeded by 10% (that is, a threshold of 330 ms) for a mobile-station-to-mobile-station call, only 23 ms of transmission delay should be allowed in each path. This is far below the transmission delay permitted by the GSM system.

In a third-generation mobile system, longer than optimal transmission delay caused by frame interleaving and speech coding could be avoided by using diversity and frequency hopping. Currently, a large interleaving depth is thought to be necessary for randomising error bursts in order to facilitate error correction in a fading radio channel. However, successful error-burst randomisation not only depends on interleaving but also on the vehicle speed. For a stationary vehicle, frame interleaving would have no effect. To circumvent this shortcoming, slow frequency hopping could be introduced to provide at least some bursts with lower error ratios to enable error randomisation and correction. Theoretically, frequency hopping has exactly the same effect as interleaving in terms of randomising error bursts. Thus, to combat burst error, short frames (for example, 5 ms) with low interleaving depth (for example, two frames) coupled with increased frequency hop rate (for example, once per frame) could achieve equivalent error randomisation for the channel coder but with much lower transmission delay.

Figure 2
Delay and echo in the UMTS



MS: Mobile station
BS/LE: Base station/local exchange
ISC: International switching centre

In practice, owing to the higher transmission rate, the mobile station in the UMTS would potentially experience relatively shallow fast fading as compared to its lower transmission rate counterparts. Furthermore, spatial antenna micro-diversity could even further reduce the depth of fades. The benefit of frame interleaving is, therefore, expected to diminish significantly. It is probably desirable to have spatial micro-diversity at the base station in order to balance the link budget (that is, to supplement the lack of power in the uplink).

For the slow-varying component of the fading signal in a mobile radio channel (shadow fading), there is no gain by using interleaving or frequency hopping of any reasonable interleaving depth or hopping bandwidth, respectively. Techniques including macro-diversity coupled with adaptive power control could prove to be more effective.

Another source of delay is the processing delay of the speech codec. To reduce this delay, at least two strategies could be adopted: low delay predictive coding algorithms (for example, the low-delay codebook excited linear predictive codecs) or improved adaptive differential pulse-code modulation techniques. It was suggested that, for some of these codecs, all encoded bits would have similar error sensitivity. This is by no means a disadvantage. An optimum speech codec would have equal information in all bits and, therefore, equal error vulnerability in all bits. If some bits do not need error protection as much as others, it implies that they are potentially redundant. On a quality-for-quality basis, equal-priority-bit codecs are better. On the other hand, low-bit-rate codecs are not a prerequisite in the UMTS as microcellular techniques and multi-level modulations could effectively compensate for the reduced spectrum efficiency.

In fact, by improving the speech decoding and post-detection algorithms, the requirements for channel protection can be relaxed. Specifically, by exploiting the correlation properties between successive speech frames, bad frame indication coupled with speech extrapolation could go a long way in combating fading effects. Furthermore, methods such as zero-redundancy coding of line spectral pair coefficients could be introduced within the speech-decoding algorithms for inherent error detection and correction.

CONCLUSIONS

By the year 2000 (the time when the UMTS will be introduced), there will still be a significant amount of teletraffic to be routed via geostationary satellites. In Europe the amount will be in excess of 10%, and much higher beyond. The one-way transmission delays over satellite links are typically 260 ms for a geostationary satellite and 350 ms for a Tundra orbit satellite. Furthermore, the possibility of national resale of network resources will result in extra transmission delay in the fixed network. In mobile-radio environments, it is unlikely that echo-control devices alone will be able to cope with the increasing demand. Low transmission delay within the mobile network is, therefore, critical to ensure the quality of voice communications in the UMTS.

For mixed networks with 4-wire-to-2-wire terminations, electrical echo coupled with acoustic echo would present serious problems for echo control. Imperfect echo control would not only fail to cancel the echoes but also introduce additional noise and distortion in the link. Echo cancellers operating in tandem could potentially introduce degradation in physical implementations. Although a round-trip transmission delay in excess of 25 ms would require some echo control, it is still vital to maintain a low transmission delay to achieve good-quality voice communications. As the UMTS could potentially be used with any communication network worldwide, a high transmission delay requirement would be both unacceptable and undesirable.

Finally, until such time as additional, significant information confirms that long transmission delay in excess of 300 ms is acceptable, Recommendation G.114 should be adhered to. Also, in view of the considerations of the echo-induced impairment given in this article, it is suggested that low transmission delay of less than 30 ms is necessary to provide good-quality voice communication. It is important that when a good-quality system is being designed, the perception of the speech quality must not be designed so that it is just above the threshold of subjective impairment. Indeed, a substantial safety margin must be assumed in order to provide an acceptable confidence limit for customers.

ACKNOWLEDGEMENTS

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Biography

Stanley Chia received a B.Sc. degree in Engineering Electronics from the University of Warwick with a Plessey Prize in 1983 and a Ph.D. from the University of Southampton in 1988. When he joined the University of Southampton in 1983, he was appointed as a Research Assistant working in mobile communications and concurrently as a Computer System Manager. He was promoted to be a Research Fellow in 1987 continuing research into digital mobile radio at 900 MHz and 60 GHz, with particular emphasis on the characterisation of radio-wave propagation in microcellular environments. In 1988, he joined the Mobile Systems Division of BT Laboratories working on handover techniques and radio propagation for microcellular systems at 1·7 GHz. He is also actively involved in the study of interconnection strategies and signalling procedures for microcellular base station systems as well as the transmission quality for the future Universal Mobile Telecommunications System. Currently, he is the leader of the Cellular Coverage Core Area in the EC RACE Mobile Telecommunications Project, leading research studies in personal communications and microcellular systems. He has been three times awarded the IEE Younger Member Paper Premium, in 1986, 1988 and 1990. He is a registered Chartered Engineer and a member of both the IEE and the IEEE.

Heathrow Airport Optical-Fibre Network

P. ROBINS†, and J. LINESS*

Communications growth in the airport sector recently has prompted a concomitant expansion of the BT network. This article gives an overview of the use of monomode optical-fibre cables and the associated terminal equipment in the local access network at Heathrow Airport. The equipment used, and the networking techniques, complement the existing copper network but do not replace it.

INTRODUCTION

The specific demands of Heathrow airport's communication needs are dealt with by BT's *Heathrow Services*. This is targeted on BT's airport customers, which include airlines, aviation and airport authorities, HM customs, freight handlers, hotels, car hire and many others. The Heathrow Airport site and associated area forms a major business complex which is undergoing rapid expansion. The telecommunications needs of customers on the site are already extensive and growing at an unprecedented rate. Their requirements range from simple exchange line service and analogue private circuits to complex network configurations requiring high-capacity digital links and special individual networking arrangements.

Most customers are very conscious of rapid developments in technology and are becoming very demanding in their requests for the latest services, network security, flexibility of provision and quality of maintenance. Much of the business on the airport is vulnerable to competition, and there is a need to ensure that products and services meet customers' requirements precisely.

The aim of this article is to give an outline of the optical-fibre project at Heathrow airport. Traditionally, the access network has been served by copper cable, and although optical fibre is used extensively in the trunk and junction networks, it is unusual to feed customers directly with optical fibre for network services.

The existing network on the main Heathrow site is mainly centred on Skyport telephone exchange, which is within the airport curtilage. Service to customers for exchange lines, analogue private circuits and KiloStream circuits is mainly through a complex network of copper cables which has grown over many years. There are many interconnection points around the airport to provide flexibility. The cables are installed in numerous duct routes throughout the airport which are now seriously congested and there is little scope for major additions. MegaStream services are supported on a network of transverse-screen cables, and this has made the congestion problem more acute. It is also not suitable for the rapid provision and reconfiguration of service or the maintenance response that many customers demand for both private and public circuits.

To overcome these difficulties, extensive use is being made of monomode optical-fibre systems throughout the airport as a resource which can be equipped in an evolutionary way to respond to the customers' developing needs.

BACKGROUND

To ascertain whether optical fibre could be used to provide network services in the access network, Headquarters and Western London District installed a multimode optical-fibre ring around the airport in 1986. The multimode fibre used was a 120-fibre cable with subsidiary spurs using blown-fibre techniques. The equipment used was an American 6·3 Mbit/s line system incorporating 4×24 channel systems, which, although limited to simple exchange lines, has proved very reliable and is still in operation carrying 520 circuits. As a result of this exercise, the first circuit carried on an optical-fibre cable in the local access network went live at Heathrow Airport on 27 March 1986.

Experience gained from this installation was used by Headquarters to develop the flexible access system for the City of London District. In 1989, it was decided to install an overlay monomode optical-fibre network at Heathrow to complement the existing multimode network. Benefits to be gained over the use of copper cables were

- improved transmission quality,
- considerable savings on duct work costs,
- alternative routing possibilities, and
- the ability to offer services at rates above 2 Mbit/s to customers.

The new network was planned at the beginning of 1989, and Phase 1 was completed in the spring of 1990. Future additions will allow services to be carried to more customers.

NETWORK

Primary and Secondary Networks

Geographically, the network can be divided into four main concentration areas for network services, each of which is served via a complex

† BT Personal Communications
* BT Business Communications

tree-and-branch copper network. The copper network, although able to meet the demands of modern airport communications, did not lend itself to fast provision and maintenance. To overcome the limitations of the copper tree-and-branch network and to take maximum advantage of multiplexer technology, the multimode network was designed, in 1985, on a loop principle. The multimode loop circled the airport accessing the four main areas. The line systems utilised the clockwise and anticlockwise fibres for main and protect circuits with automatic switching.

Building on the success of the multimode loop, a primary monomode loop (see Figure 1) was installed during 1988/89 by using 96-fibre cable with an attenuation of 0·5 dB/km at 1300 nm and 1550 nm. In addition, a 96-fibre monomode spine to Hounslow exchange provided alternative access. The primary network was installed in three distinct parts:

Part 1 A loop around Heathrow Airport encompassing the four main areas.
Part 2 A 96-fibre spine to Hounslow interconnected to the Heathrow loop.
Part 3 A 96-fibre spine along the northern part of Heathrow connecting to the Heathrow loop.

Three secondary blown-fibre rings were interconnected into the primary network at three of the main concentration areas: Hatton Area, Cargo and Central Terminal Area. Interconnection with the primary loop took place at two distinctly separate points on the primary loop (see Figure 2). The secondary networks were cabled by using a combination of 96-fibre cable and blown-fibre tubing with blown-fibre bundle. The choice of using fibre cable or blown fibre depended on the geographical location of the site, the length of run and the density of fibre infill.

Optical-fibre cable was used in the primary network to provide a static high-density infrastructure configured to match fibre availability with future customer demands. Blown-fibre tubing was installed in the secondary loops and customer locations to provide a flexible network to meet demands at short notice. Blown-fibre bundle is installed into the tubing when required. There is a similarity between the traditional E-side and D-side copper network and the primary and secondary loops.

Interconnection of the primary loop at two separate points gave the network planner the possibility of producing an alternative route using clockwise and anticlockwise directional fibres on the primary loop; similarly, at the secondary cross-connection points and again on alternative routes using clockwise and anticlockwise fibres.

Network Application

Interconnection was achieved by arranging the fibre cables or blown-fibre tubes in a carriageway-type joint box with lockable covers designed to prevent unauthorised entry. Each cable was housed in a joint closure kit incorporating fibre layout trays to give total flexibility between all main loop cables and blown-fibre secondary loops (see Figures 3 and 4). The dotted line in

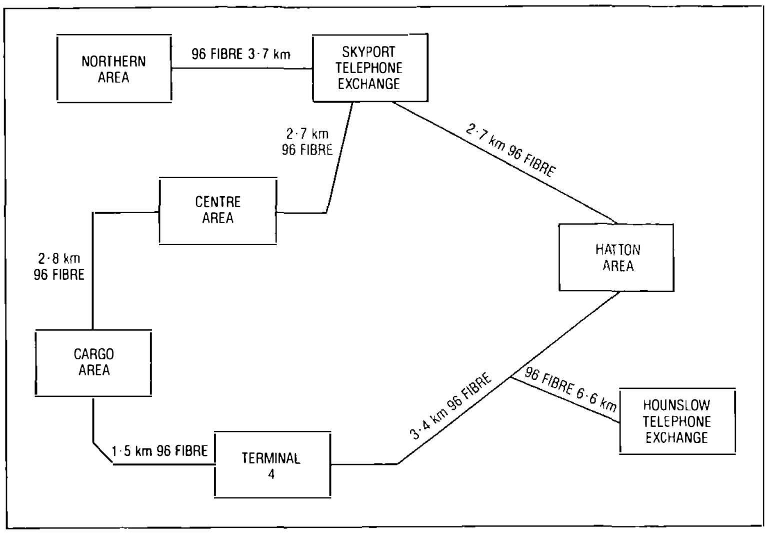


Figure 1—Heathrow primary optical-fibre network

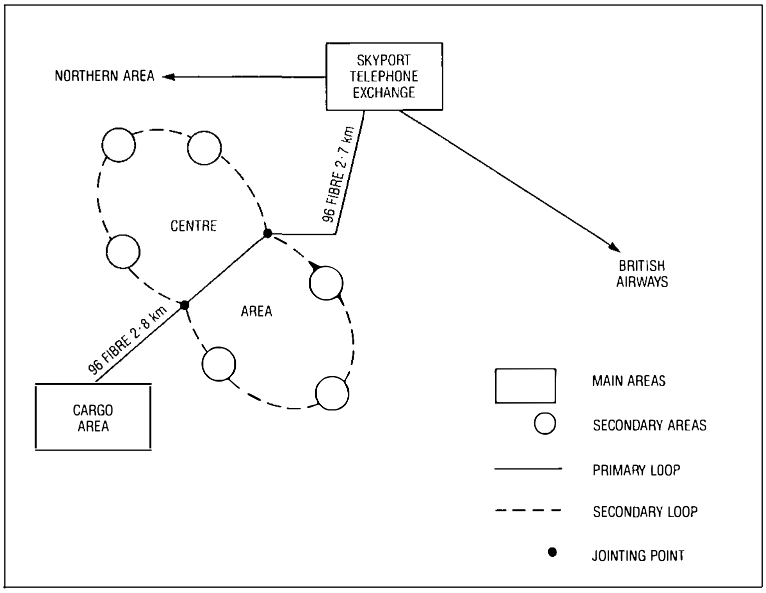


Figure 2 Secondary network, centre area

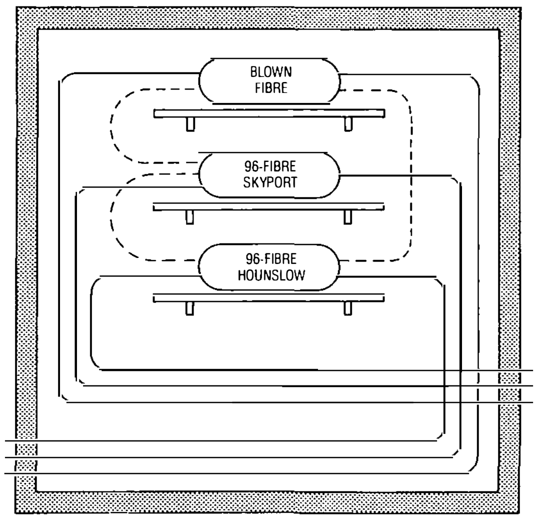


Figure 3 Primary-to-secondary cross-connection

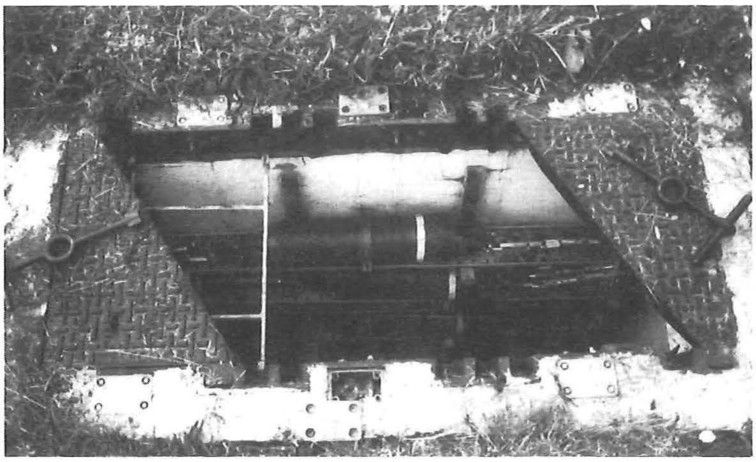
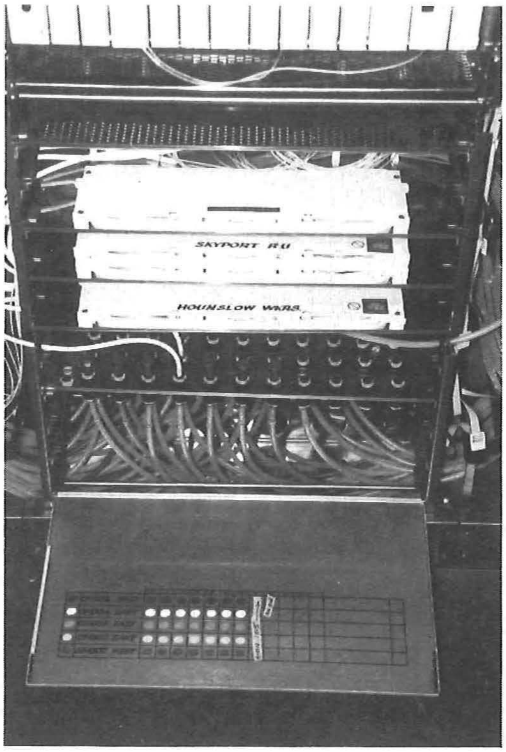


Figure 4—Carriageway joint box housing primary-to-secondary interconnection point

Figure 5
Building interconnection rack



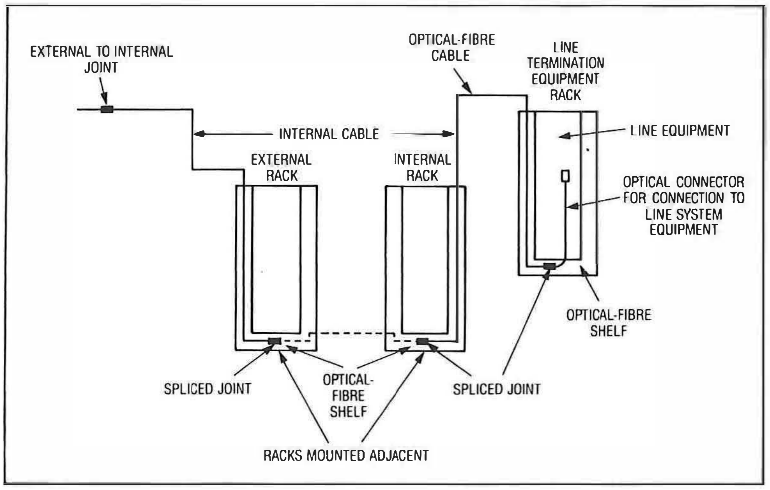


Figure 6—Arrangements for fibre and equipment rack flexibility

Figure 3 indicates that connection is possible between both serving telephone exchange sites, the secondary loop, or all three.

Interconnection within a building was achieved by using a standard optical-fibre tray, modified to terminate blown-fibre tubing and fixed within a standard TEP-1E rack (Figure 5).

Exchange Termination

The fibre connection to the exchange was made as simple as possible in all cases and existing work procedures retained where feasible. Figure 6 shows a typical external-to-internal layout using standard work practices.

Figure 7 shows the arrangement for presentation of copper cable pairs from the multiplexing equipment with the digital distribution frame (DDF) arrangement.

The copper pair presentation was effected in a similar manner to that of an ordinary copper analogue cable—given an alphabetical identity and terminated on the main distribution frame (MDF). This allowed the existing work procedures for circuit provision to be retained.

A 'mirror image' of the MDF was provided at the multiplex rack to provide the copper termination for the 30-channel multiplex equipment.

MegaStream and KiloStream Plus circuits were extracted at the 2 Mbit/s level from the DDF and presented ready for service in their own respective apparatus rack.

The dotted line in Figure 7 shows the eventual path for the connection of integrated digital access.

Customer Premises or Distribution Nodes

The customer premises or distribution nodes are almost an exact reverse of the exchange termination. The only exception being a DDF, in which case the 2 Mbit/s tributaries can be extracted directly from the backplane (see Figure 7).

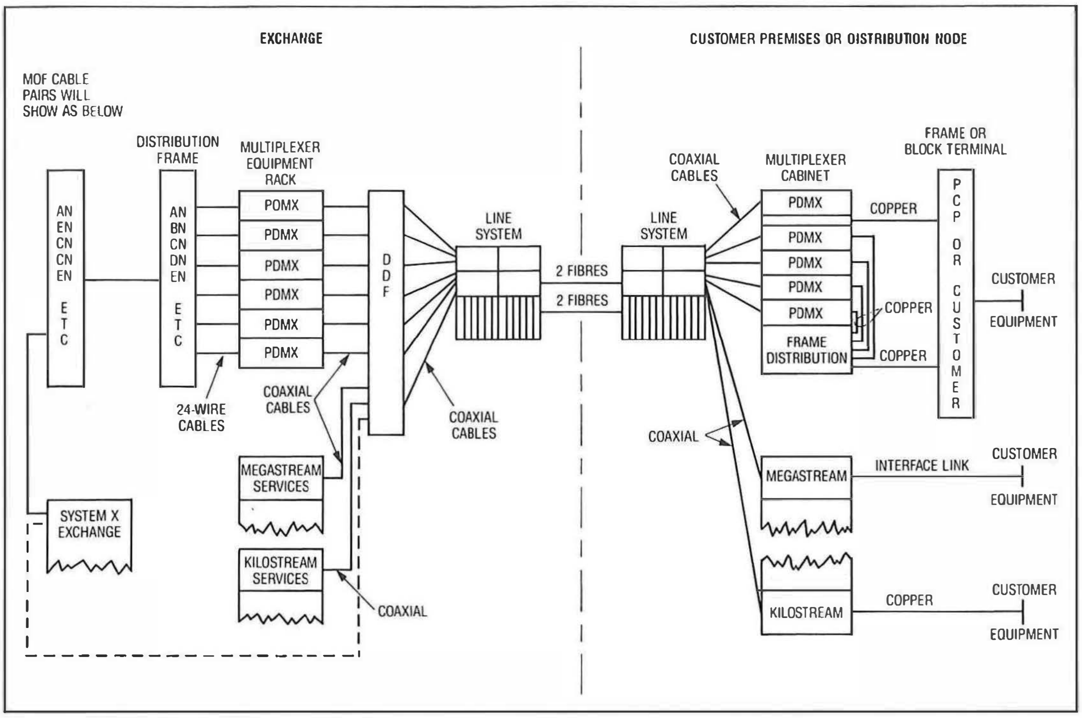
The copper interface is achieved by presenting the copper cable onto a suitable terminating box or primary cross-connection frame. The identity of this cable is by alphabetical letter with an appropriate exchange side (E-side) numerical range.

Other services are taken off the backplane of the line system in a similar way to those in the telephone exchange.

External Node

By using a standard cross-connection cabinet made slightly deeper to accommodate an optical-fibre shelf, the 96-fibre cable was organised on optical-fibre trays in the normal way. Some fibres were left at each external node and others sent further down the route, to be presented at subsequent nodes. The external node can accommodate both blown fibre and fibre cable.

In addition, a modular outdoor cross-connect system was installed to the side of the optical-



PDMX: Programmable digital multiplexer PCP: Primary cross-connection point

Figure 7
Optical-fibre network

fibre shelf to allow the termination of copper pairs for alarm purposes or a small copper distribution network (see Figures 8).

Work Procedures

Where possible, standard work procedures were retained to minimise the change to a fibre network:

(*a*) Circuit provision documentation is identical to provision on copper cables.
(*b*) Installation procedures are retained at exchange and customer end.
(*c*) Network provision uses fibre as the main carrier. New procedures were adopted to enable programming and commissioning of multiplexers to meet demand.
(*d*) Repeater station staff were trained in the maintenance of new equipment and existing fault reporting procedures were adopted.
(*e*) The national computerised routing and recording system was used for all fibre and associated equipment in conjunction with the normal exchange-side and distribution-side records.
(*f*) A diagram was produced to enable field staff to identify stores at a glance.

EQUIPMENT AND APPLICATION

To meet customer demands and maximise the potential of the fibre network, it is essential that its utilisation is planned and not allowed to grow in an ad hoc manner. The network addresses two main areas:

- areas of high-volume communication needs, and
- individual customers.

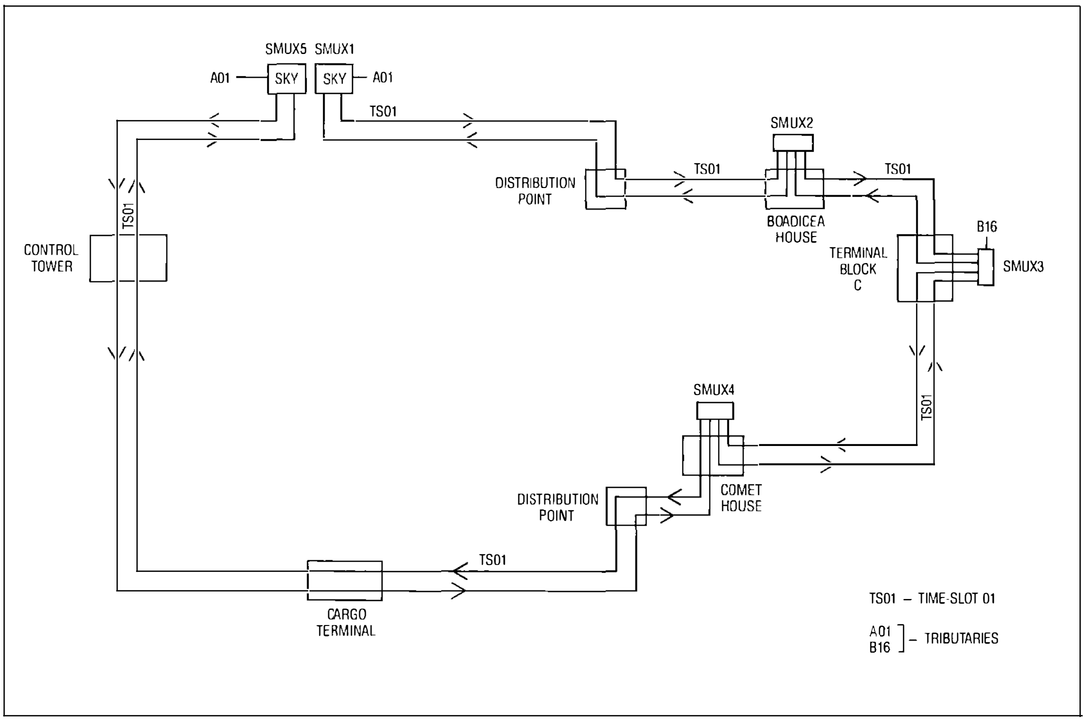
Figure 8
External cross-connection system

Areas of High-Volume Communication Needs

These areas have traditionally been served by an array of copper cables—main cables and link cables (PCP–PCP)—with the final connection being made to the customer with a traditional D-side network. To meet the continuing demand, a synchronous multiplexer (SMUX) has been configured in a horseshoe arrangement (Figure 9). This has provided high-capacity routes to supplement the E-side network and allows the flexibility of using either the D-side copper network or extending into the customer's premises at 2 Mbit/s.

The SMUX is a synchronous device running at 140 Mbit/s, incorporating both line system and multiplexer, which converts the 140 Mbit/s signal into 64 × 2 Mbit/s tributaries. It has a powerful

Figure 9
SMUX application



management system, and is compatible with the 140 Mbit/s and 2 Mbit/s multiplexing stages used in the trunk and junction network. The 64 × 2 Mbit/s time-slots available for traffic can be allocated to any tributary, and each node is housed in a standard 21 inch equipment rack or cabinet (TEP-1E). The SMUX supports the following features:

(*a*) dual power supplies, each served by separate fuses;
(*b*) dual optical cards, each fed from opposite sides of the fibre rings;
(*c*) single-step multiplexing, 140 Mbit/s direct to 2 Mbit/s;
(*d*) drop and insert at 2 Mbit/s;
(*e*) allocation of main and stand-by routes;
(*f*) automatic switching from main to stand-by in the event of failure;
(*g*) historical fault log, up to 1000 events can be recorded at each node;
(*h*) remote management, configuration and maintenance from the master node;
(*i*) entry to management system protected by password.

In Figure 9, SMUX1 is the master and is situated in the exchange, from which the system and each node can be managed by using the dedicated hand-held terminal (HHT) for both circuit provision and maintenance. Each intermediate node can drop and insert circuits at the 2 Mbit/s level and each link supports a maximum of 140 Mbit/s. The comprehensive management system allows for the interrogation of both system and node alarms and gives access to the historical fault logs.

The HHT is used to allocate time-slots to tributaries. From Figure 9, the following 2 Mbit/s circuit can be seen:

time-slot 01 allocated to tributary A01 at node 1
time-slot 01 allocated to tributary B16 at node 3

A back-up route has also been allocated:

time-slot 01 allocated to tributary B16 at node 3
time-slot 01 allocated to tributary A01 at node 5

A 2 Mbit/s path is shown to exist between A01 node 1 and B16 node 3 and in the event of a failure on this path, the SMUX automatically switches to the back-up route and a 2 Mbit/s path then exists between B16 node 3 and A01 node 5.

The networks are at present synchronised to their own internal clocks, and it is planned to derive timing from the KiloStream network at a later date.

As can be seen from the above, the SMUX is being used to deliver 2 Mbit/s circuits from the telephone exchange to a customer's premises. In order to present exchange lines or private circuits to a customer, the addition of 2 Mbit/s-to-64 kbit/s programmable digital multiplexers (PDMX) will provide 30 analogue channels. The customer- and exchange-located PDMX are managed from a master PDMX situated in the exchange by using a dedicated HHT which gives total control and flexibility. The PDMX supports the following features:

(*a*) remote management, configuration and maintenance from the master PDMX;
(*b*) tone processor;
(*c*) signalling processor;
(*d*) analogue private circuits, 2- or 4-wire presented from –6 dB to +6 dB; and
(*e*) exchange lines—direct dialling in, A-wire earth, loop disconnect, MF4.

In addition, exchange line services have been provided via a network access system (NAS). This equipment provides for 120 circuits, and incorporates a 4 × 30-channel multiplexer with automatic protection switching at 2 Mbit/s. Associated in the same cabinet are dual 2–8 Mbit/s multiplexers and 8 Mbit/s line systems which are served by fibres from different directions of the ring.

The NAS supports the following features:

(*a*) fully protected 2 Mbit/s paths;

(*b*) exchange lines—direct dialling in, subscribers private metering, loop disconnect, A-wire earth, external extension and MF4;

(*c*) power failure back-up at customer service modules; and

(*d*) comprehensive system alarm reporting.

Individual Customers

When a customer is not situated within a designated high-volume area of the airport, and is to be considered for direct connection by optical fibre, then either some or all of the following criteria need to be met:

(*a*) there is a positive benefit to BT by serving the customer by optical fibre,

(*b*) there is a positive benefit to the customer's communications needs/expectations, and

(*c*) the customer wishes to be served via optical fibre.

The equipment used for directly served customers is dependent on a forecast of the customer's communication requirements. The system normally used is 16 × 2 Mbit/s which incorporates dual line systems and automatic protection switching. The configuration is point-to-point and controlled for maintenance and provision by the same HHT used by the PDMX described above. The PDMX is again used to derive 30 × 64 kbit/s circuits from the 2 Mbit/s paths provided by the line system. By using this equipment, customers can be offered exchange lines, analogue private circuits and 2 Mbit/s services including MegaStream and KiloStream Plus.

Cargo Area

The cargo area situated on the south side of the airport has traditionally needed special attention to avoid transmission problems due to its distance from Skyport exchange. The optical fibre has enabled a better engineered service to be provided, and an NAS for PSTN services, PDMX for analogue private circuits and a remote KiloStream multiplexer have been installed.

Circuit Provision and Maintenance Procedures

The circuit provision and maintenance procedures for all of the scenarios described above have mirrored the existing copper procedures, and customers will see no change to the presentation of BT services.

As can be seen from Figure 7, the engineers' perception is a continuous copper cable labelled AN or BN, CN etc., allowing routing, fitting and maintenance staff to operate in exactly the same way as traditional copper cables. The copper breakout point from the multiplexer is presented to the engineers in the normal manner on the building distribution frame. This system has meant minimal training for engineers and has the added bonus that all line system and multiplexer maintenance is the responsibility of one existing transmission group.

FUTURE

The following paragraphs show that the network infrastructure facilitates its evolution and makes it highly adaptable:

(*a*) In addition to enhancing the existing facilities, the SMUX networks allow diversity in customer wide area networks and control of point-to-point circuits.

(*b*) Present procedures in the provision of private circuits services involves a high level of engineering intervention, most of which could be eliminated by installing a software-controlled matrix switch. Similar switches are at present used in the BT KiloStream network. The installation of such a switch would dramatically affect the exchange-end equipment and accommodation requirements by grooming 64 kbit/s circuits from incoming 2 Mbit/s paths onto outgoing 2 Mbit/s paths. This facility would also increase the efficiency of the junction network utilisation, give greater control and speed up provision and maintenance of circuits.

(*c*) In specific areas of the airport, there is the possibility of building an environmental manhole which would house an integrated line system and multiplexer designed to serve a number of small business needs. It is believed that the technology to develop this manhole is available today and that there may be a number of other applications for it within BT.

(*d*) The optimum design for a network such as the Heathrow optical-fibre network is a 'self-healing system' where all faults can be rectified without engineering intervention. It is believed that although the single point of failure can be reduced, this is not technically feasible at the moment. Therefore, it is necessary to know the cost of failure and ensure that the network is resilient and robust in order to provide the best service for customers. The network today achieves this, but as it grows, the need for a management centre will become more pressing in order to monitor and take corrective action where necessary.

(*e*) The network configuration utilising the SMUX has proved reliable in its horseshoe configuration and will be reconfigured to a closed ring to further enhance the network reliability. The SMUX has provided a sound foundation for the future migration to the synchronous digital hierarchy and passive optical networks.

(*f*) The travel and cargo businesses have traditionally demanded the latest communication facilities and short time-scales are common. The optical-fibre network allows BT to expand its services to meet these requirements. It enables BT to offer new services when the opportunity arises, and releases urgently needed E- and D-side copper cable pairs when a customer's existing services are transferred onto the fibre network.

Within the business community there is constant change, and the Heathrow optical-fibre network puts BT in a good position to keep pace with new developments.

CONCLUSION

In essence an optical-fibre network has been designed to meet customers' requirements and give Heathrow Services the following benefits:

(*a*) the network has ample capacity not only for today's needs but for those of the future,
(*b*) new work procedures have been kept to a minimum,
(*c*) there is more control and awareness of the access network,
(*d*) maximum savings on provision of new duct work have been made by using optical fibre as an alternative to copper,
(*e*) enhanced flexibility and resilience of the gateways to the trunk and junction networks,
(*f*) the Heathrow optical-fibre network provides a sound foundation to allow the introduction of new technologies and services as they are introduced,
(*g*) immediate maintenance attendance has been minimised by the introduction of automatic protection switching and remote software control, and
(*h*) the network and its application has been designed to meet specific customer needs, ensuring beneficial cost-effective solutions.

Biographies

Peter Robins joined the General Post Office (GPO) in 1955 as a Y2YC after which he served 2 years national service in the Royal Signals. On return to the GPO, he worked in the City of London on customer maintenance, at the Regional Training School, in London West Area on external planning and external works supervision. He also spent 4 years in the Middle East Gulf States on the external development of the telephone network. He currently works on external planning at Heathrow Airport.

Jim Liness joined the Post Office in 1971 as a Trainee Technician Apprentice. He has worked predominately in the field, in transmission, in both maintenance and works capacity, and more recently as a systems engineer for the airport sector. He is currently a project manager for Heathrow Services and has been elected as a member of the Association of Project Managers.

Distribution Networks in France

A. G. GRISEZ†

Distribution networks are a large part of the investments and assets of telecommunications companies. They increasingly contribute to the overall quality provided to customers. They must be flexible in adapting to new services, such as ISDN services, so that these new services can be offered on a nationwide basis. This article, after describing distribution networks in France, shows the main trends in the evolution of engineering standards and equipment in order to achieve the best compromise between different goals: an adequate pay-back period for investment, a high quality level provided to customers and sufficient flexibility in adapting to new services.

INTRODUCTION

Distribution networks represent an important part of the assets and investments of telecommunications companies.

The life of most of the equipment of which networks are composed is generally some tens of years.

These two characteristics mean that networks must be capable of being adapted, without major modification, to the rapid evolution of those services for which they provide the physical infrastructure (or at least, on the other hand, that such services must take account from the outset of the characteristics and the limitations of the existing distribution networks).

A notable example of this can be seen in the integrated services digital network (ISDN), called *Numéris* in France. From the start, France Télécom decided that this network would evolve from the general telephone network, and would not be an overlay network. This was in order that the wide range of facilities provided by the new ISDN services could be offered rapidly to all the 30 million telephone subscribers. This decision was made towards the end of 1990; that is, only three years after the first trials of ISDN in Brittany.

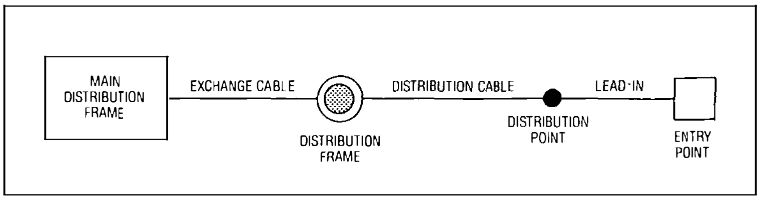
Of course, distribution networks, which were originally designed for the transmission of narrowband signals, cannot forever respond, in their current form, to the ever-increasing demands for faster information flows. Therefore, networks based on fibre-optics are being trialled in France to service business subscribers (these are not covered by this article, which is concerned only with the copper network). But for a number of decades to come, metallic networks will continue to satisfy most needs.

DISTRIBUTION NETWORK ARCHITECTURE

From the various possible solutions, the system which France has chosen to ensure service to telephone subscribers is a flexible system using sub-divided zones.

This system, the principle of which can be seen in Figure 1, allows the investment to be broken down and separates the primary network, which is comprised of the exchange cables, from the secondary network, which is comprised of the distribution cables; the uplift cycles are different for each of these two network components.

Figure 1
Structure of French distribution network



The following comments apply to Figure 1.

Primary Distribution

A specific geographic zone is served by one, and only one, sub-division. The size of a zone is limited to 600 subscribers' lines. This size is often reached in an urban area, and so it is necessary to divide up zones in those areas which are expanding rapidly. On the other hand, the rural areas are rather smaller, with an average of around 120 lines, and a lower limit of 40 lines. The practical reason for this limit is the lower density found in these zones, expressed as the number of lines per square kilometre, together with the need to adhere to the national transmission plan (9·5 dB available for the local loop in most cases between the main distribution frame and the entry point into the subscriber's premises).

The main distribution frame at the telephone exchange serves as the zone distribution frame for nearby subscribers. Around each exchange there is therefore a defined zone of direct distribution, similar to a sub-distribution zone, but without the need to apply the limit of 600 lines mentioned above.

† France Télécom

Techno-economic studies allow the definition of the boundaries of direct distribution zones in the same way of those for sub-distribution. They are generally very close to the exchange in urban areas, but can be some kilometres away in rural zones.

A very high utilisation rate can be achieved for exchange-side cables, even attaining 100%, but, for distribution cables, their modularity and the relatively small number of subscribers served by each force the utilisation rate down considerably. A utilisation rate of 70% in a zone distribution cable represents a situation where saturation is approached over the various distribution points.

Exchange cables, whose average length is 2·2 km, are almost all underground. They are hauled in duct in urban areas, or buried in the ground in rural areas. However, small exchange cables, generally less than 100 pairs, may be overhead but a special plan aims to normalise this situation.

Secondary Distribution

This uses similar cables as those used for exchange cables, but they are generally shorter (average length of 0·6 km), and are often overhead in rural zones. About 30% of the total distribution cable capacity in pair-kilometres is overhead.

France Télécom has no specific intentions, even in the long term, of burying all distribution cables, limiting this to the most heavily loaded or the most exposed ones.

The corresponding investment, which exceeds 50 billion francs (10 times the annual investment in the distribution networks), would have a pay-back period that would exceed the life of the buried cable.

Lead-in Cables and Distribution of Subscribers

This is the most sensitive part of the network, in spite of the short length of the lead-in cables (50 m on average). This is for a whole host of reasons peculiar to lead-ins; in particular:

- they are quite frequently overhead in rural zones or attached to facias in urban areas;
- both ends are terminated in connectors of different types, which are susceptible to corrosion; and
- they are made up of lighter and less-resistant cables than the multi-pair cables used for exchange or distribution cables.

It is therefore vital to improve the quality of lead-ins and of the associated connection techniques.

This can be done by means of improvements to the materials, and by seeking to reduce the length of lead-ins, by increasing the number of distribution points (and reducing their capacity from 14 down to 7 or even 3 or 4 pairs), or by using the technique of spur-joints, either underground or overhead, on the distribution cables.

Evolution of Engineering Standards

With the advent of the ISDN, the use of equipment such as line amplifiers, analogue pair-gain systems, etc, is becoming the exception. The current trend is towards a shortening of subscribers lines, which may not exceed, except in difficult circumstances, 5 to 6 km for exchange cable and 2 to 3 km in distribution cable, making 8 km in total.

Since 1988, the availability of digital concentrators enables the above objectives to be achieved for digital subscribers on the ISDN, just as for classical analogue subscribers, by creating new local zones around distant digital concentrators.

As a result, the area covered by local zones is constantly decreasing, heading towards 45 km^2 in provincial areas (and considerably less in Paris).

EQUIPMENT

Only the major trends are considered:

Cables

All types of cable are found in the French network, but for the past 20 years they have been plastic insulated with sheaths appropriately reinforced according to the environment in which they are to be used. The conductor diameters used are 0·4, 0·6, and 0·8 mm, not more than two changes of dimension being permitted on the same line.

The current trend is to use only pressurised cables, or, for cables of relatively low capacity, cables filled with petroleum jelly.

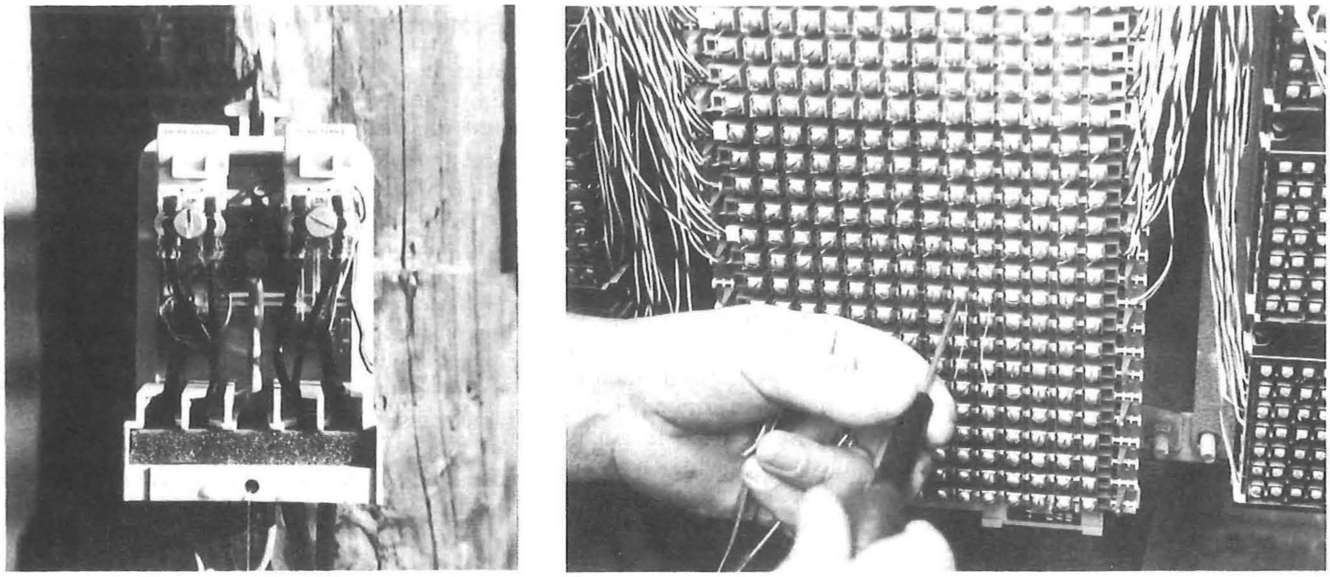
Another trend is to increase the number of pairs able to connect to 2 Mbit/s digital equipment to serve business subscribers. Specific cables in the distribution network can connect such equipment to all pairs.

Another characteristic of the cables used by France Télécom is that they are in multiples of 7 pairs, except for the very smallest ones. The cables in the French network are thus 4, 8, 14, 28, 56, 112, 224, 448, 896, 1792, and 2688 pairs. The debate over cables of base 7 and those of base 10 has concluded that there are no sufficient advantages to support a change to the base 10 cables, although French cable manufacturers mainly produce base 10 cables for export.

Jointing Techniques

This is an area where there is a great deal of research and development to be done in order to improve existing equipment.

The digitalisation of more and more far-reaching parts of the distribution network, with interfaces to TDM PABXs, the development of the ISDN, and the development of more demanding private digital data circuits necessitate jointing technology (cable heads, distribution points, entry points) that is fault-free. In particular, very short breaks, which go unnoticed by telephone subscribers, cannot be tolerated on data transmissions where continuous data flow is vital.



(*a*) 2-pair protected entry point

(*b*) 224-pair cable head

Figure 2—New equipment being introduced into the French distribution network

Figures 2(*a*) and 2(*b*) show techniques that are currently being introduced into the network.

Pressurisation Equipment

The current trend is towards true remote monitoring of the pressurised cable network, and being less satisfied with those imprecise indicators which show only a drop in insulation resistance in the cable.

This has necessitated the development of *addressable transducers*, which allow the identification of the defective section and speedier intervention to effect either a repair or a replacement.

QUALITY OF DISTRIBUTION NETWORKS

The quality is fundamental since it is broadly representative of the overall quality that clients perceive. The digitalisation of exchanges and of the associated transmission equipment means that one can now aspire to virtual perfection in quality for the 'higher level' of the general network which they constitute. It is therefore increasingly the distribution networks that will give a measure of the overall quality, in the environment where the requirements of the customers are growing with the diversity and sophistication of the services which they are offered.

Without neglecting this aspect, the policy of France Télécom during the 1970s and early-1980s largely revolved around the necessity to recover the country's backward position in the area of telecommunications equipment (4 million lines in 1970, 30 million now).

Since then, it has become progressively more necessary to aspire to a high level of quality in the network without needing to replace the huge investment in the local network.

Figure 4 shows the number of faults, including those originating in the distribution networks, reported by subscribers (as an annual percentage).

The question which arises is to know how far it is economically viable to go in the pursuit of quality. For the residential subscriber, having a problem once every 10 or 20 years is relatively unimportant as long as it is rapidly repaired. On the other hand, the position is more serious for business subscribers. France Télécom's response is based on economic criteria, except when the low level of quality in a given zone could adversely affect the image of the company.

In other words, with the above exception, investments must be able to be recovered within a

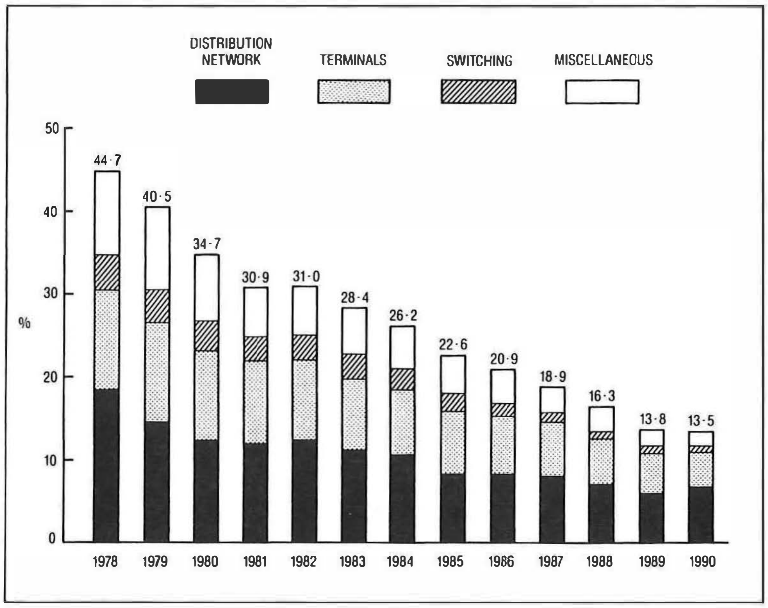


Figure 4
Percentage fault rate on the France Télécom network

Note: For example, in 1990, among 100 subscribers, 13·5 on average reported faults to France Télécom Customer Services. Among those 13·5 faults, nearly one half (6·6) originated in the distribution network reasonable time by cutting down operating expenditure.

France Télécom has therefore developed a whole range of tools which permits this objective to be met by increasing efforts in the area of preventative maintenance.

CONCLUSION

Although distribution networks are often considered as rather unimportant by those who only think of the most spectacular aspects of telecommunications technology, they contribute in large measure to the ability to develop those technologies.

They require heavy investment, which needs to be controlled, while constantly wrestling with the question of better value for money.

Their flexibility in adapting to new services for which they form the support infrastructure is an essential quality. They can and must evolve, since it is not economically viable to think of replacing them every time.

ACKNOWLEDGEMENT

The Managing Editor would like to thank Keith Morgan for his help in translating this article from French.

Biography

Alain Grisez graduated from Ecole Polytechnique and Ecole Nationale Superieure des Télécommunications, both in France. He has held various positions in France Télécom from the beginning of his career in 1962, except for several assignments abroad, including two years spent with the World Bank in Washington. He is currently head of a central organisation dealing with all aspects related to external plant in France.

Journal Awards for Volume 9

The Institution of British Telecommunications Engineers has again honoured authors from *British Telecommunications Engineering*. At the Institution's recent annual congress, Dr. Alan Rudge, IBTE President, presented prizes to authors of articles from Volume 9 (April 1990–January 1991).

The prize for best article this year went to Nigel Pope for his contribution 'The Cashless Services System' in the July 1990 issue. Nigel received a crystal bowl inscribed with the Institution's insignia and a cash award of £300.

His article describes the BT Chargecard service, the equipment used for the service, and how it was developed, and goes on to look at the future of telecrediting. The *Journal's* Board of Editors was impressed with the style and quality of the article. The Board considered that the article was well thought out and planned and its pleasant style allows ready understanding of this topical subject. The well-chosen illustrations are clear and well-balanced against the text to aid the reader. The Board congratulates Nigel on an excellent article which is a worthy winner for the prize for the year's best article.

This year, four runner-up prizes were awarded comprising glass paperweights for each author, together with cash awards of £100 for each of the four articles.

Mike Spooner, Jonathan Ash and Nick Furley received a runner-up prize for their article 'Network Support Systems Architecture and the Control of Systems Evolution' published in the April 1990 special issue on Information Networks.

With the evolution of many automated process management systems being introduced through the Network Administration Implementation Programme (NAIP), it is imperative that they are integrated in a cost-effective and efficient manner; particularly so when many use common data sources, and a variety of people need access to them. The article provides a logical structure to the solution, starting with a problem statement and followed by sections on an evolving international standards framework, examples of how BT requirements would map onto that framework and finally a control mechanism to monitor the successful implementation. The article made appropriate use of diagrams to explain what is a very theoretical subject in a way that people with little knowledge of computer or data communications structures could understand from a practical viewpoint.

The second runner-up prize was awarded to Peter Blake and Phil Lamb for their article 'The Network Field Unit—Its Role, Definition and Operation' published in the October 1990 special issue on Network Administration.

With the introduction of the so-called 'hands-off' network, we sometimes forget that engineering staff will still have to travel to the site of BT plant around the country for provision and maintenance purposes. The role of the network field unit (NFU) is to manage this activity in a cost-effective manner. The article is structured so that it provides anyone with little or no knowledge of network operations and management with a broad appreciation of the many complex issues involved in introducing NFUs. These range from the criteria for selecting NFU boundaries to the problems involved in deploying the skill base effectively. The article makes good use of diagrams, especially to highlight the close working relationship between the NFUs and network operations units, something which is crucial to the success of BT's NAIP.

The third runner-up prize went to Ian Dufour, John Marshall and Fred Welsby for their article 'ISDN for the 1990s' published in the January 1991 issue.

This article was selected for an award because it provides a very readable update on the roll-out of the ISDN in the UK. The subject is covered in a broad, practical manner, and clarifies many issues which may have long been unclear to readers not in close contact with the subject. The article is well constructed and brings in many facets of the ISDN roll-out in a logical fashion. These include the basic- and primary-rate services, international matters, the all-important question of which applications will be attractive to ISDN customers, and the requirement for compatible customer premises equipment to use them. The relevant standards are covered in overview, and listed for the reader who may wish to study them further. In summary, this article provides a useful ISDN update in a concise and very readable fashion.

Dr. Alan Rudge, IBTE President, presenting the prize for best article from Volume 9 to Nigel Pope

Finally, Ken Sutcliffe, Tony Hayes and Keith Newbegin were awarded a runner-up prize for their article 'The Modernisation of a Rural Network' published in the January 1991 issue.

This article, from the field, deals with the problems of network modernisation in a rural area, namely the Hexham cell in Northumberland. The article, based on a lecture given by the authors to the North-East Centre of the IBTE, was chosen to receive an award because it was a broad comprehensive article that covered all the issues involved in a good readable format.

The *Journal* Award Scheme was introduced in 1990 to encourage readers in furthering the role of the *Journal* and to give authors due recognition for an outstanding contribution. Prizes are awarded to the authors of articles which, in the opinion of the Board of Editors, demonstrate excellence in content and presentation and which enhance the quality and range of contributions published. Each year a prize is awarded for the best article published in a complete volume, together with a number of prizes for runners-up.

Martlesham Medal for Excellence in Cordless Telephony

This year, BT's Martlesham Medal has been awarded to Bob Swain, one of the company's senior engineering advisors, for his key role in the development and implementation of personal mobile cordless telephony services.

Cordless telephony services, including *Phonepoint*, can currently be used within 100 m of any base station to call any number in the world. In homes and offices, a small personal base unit allows the service to be used in the same way as an ordinary cordless telephone.

Cordless telephony services are seen as an increasingly convenient and cost-effective alternative to public payphones and cellphones. Research indicates that cordless telephony will account for up to 50% of telephone use worldwide by the turn of the century.

Mr. Swain, who works at BT's Laboratories, Martlesham Heath, is well known and highly respected internationally for his contribution to radio systems engineering, planning and standards. Over the past 10 years he has emerged as one of the world's leading authorities on cordless communications. The new-generation cordless telephone standard, CT2, is the latest of his developments to be put into practice.

In the early-1980s, he became interested in the evolving analogue cordless telephone market in the USA. He led a team working on the specification for the first generation of analogue cordless telephones in Britain, and the basic design of the digital CT2. He was involved in the development and implementation of the second-generation digital cordless products in 1985, and the common air interface standard in 1989—which in turn allowed the development of the telepoint service concept.

His current activities are in support of the Digital European Cordless Standard (DECT), aimed at business/wireless PBX use, and the RACE-Mobile programme which looks towards the future vision of a single universal mobile personal telecommunications system (UMTS).

Bob Swain joined the GPO's wireless experimental/development department at Dollis Hill in 1954, as an apprentice. After national service in the RAF, he returned to Dollis Hill in 1958 to work on analogue microwave radio-relay systems. In the mid-1960s, he was involved with satellite systems research, including Telstar, and worked at the Goonhilly Satellite Earth Station. A promotion in 1968 put him in charge of a group researching and developing digital microwave radio-relay systems, including performance-measuring systems and their international standardisation. Bob moved to BT Laboratories at Martlesham Heath in 1971 where he was promoted to the radio division as a section head working on radio-relay systems and cordless telephones. In 1991, he became a senior engineering advisor in BT Laboratories' radio division.

Bob Swain, winner of BT's Martlesham Medal

The Martlesham Medal recognises outstanding contributions to science or technology, with a particular relevance to telecommunications, made by BT staff both past and present. Entries are judged by international standards for value in enhancing national prestige and potential for increasing the prosperity of Britain, either by benefits to customers or significance to industry.

Editor's Note: An article by Bob Swain entitled 'Digital Cordless Communications—CT2' was published in the July 1990 issue of the *Journal*.

Notes and Comments

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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. Guidance notes for authors are available and these will be sent on request.

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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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