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GUIDE PLANNING OF POWER UTILITY DIGITAL TELECOMMUNICATIONS NETWORKS

Working Group 02
of
Study Committee 35 (Communication and Telecontrol)

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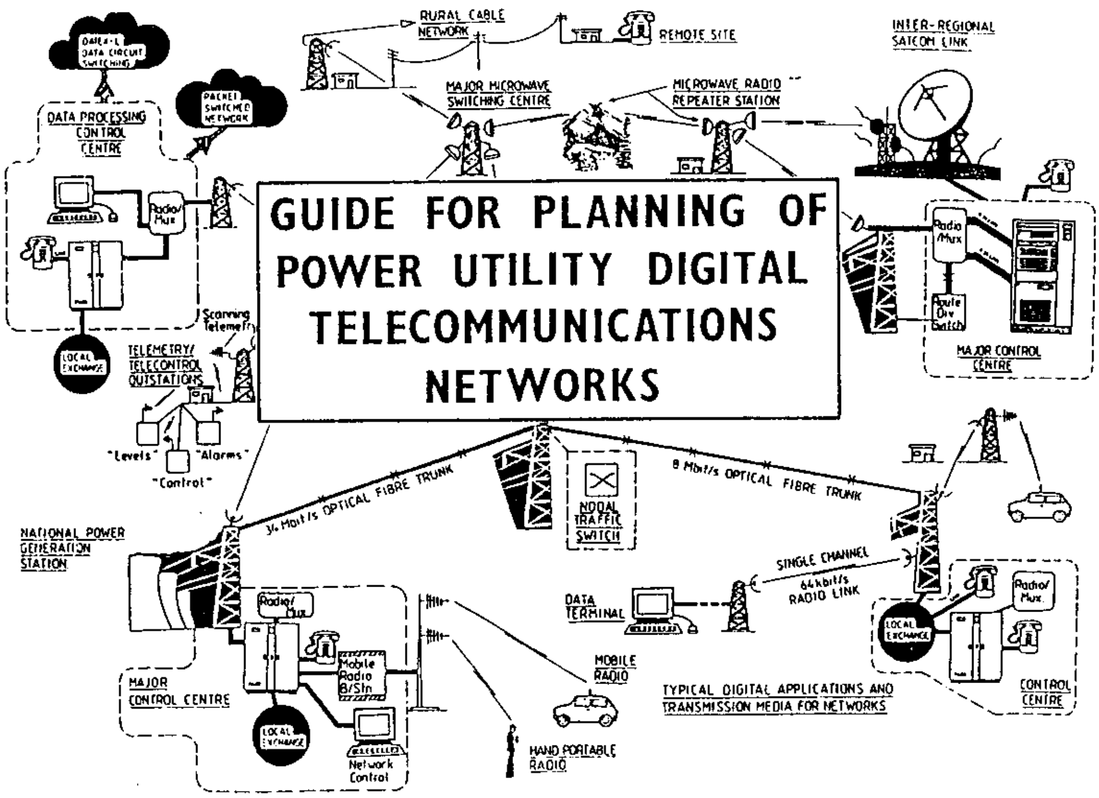
CIGRE

GUIDE FOR PLANNING OF POWER UTILITY DIGITAL TELECOMMUNICATIONS NETWORKS



STUDY COMMITTEE 35

WORKING GROUP 02

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"GUIDE FOR PLANNING OF POWER UTILITY DIGITAL TELECOMMUNICATIONS NETWORKS"

FOREWORD

In March 1987 CIGRE Study Committee 35 (SC35) formed Working Group 35.02 specifically to produce a Planning Guide to assist Power Utilities in setting up their own digital telecommunications networks.

Working Group 35.02 were charged with producing this Guide in draft form by December 1988, with final completion of the document by December 1989.

The main contributors to this Planning Guide from CIGRE Study Committee 35, Working Group 35.02 are as follows:-

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Other Working Groups within SC35 undertaking work which is complementary to Working Group 35.02 studies are herewith listed.

35.01 Control Centres

35.03 Digital Communication for Telecontrol

35.04 Optical Fibre Systems

35.05 -

35.06 Integration of Telecontrol with Station Control

Explanatory Notes

1. A Glossary of terms is contained in Appendix A which explains technical phrases and terms used in this Planning Guide.

2. References denoted by (1), (2) etc. are contained in Section 13.

SUMMARY

On new telecommunications projects, digital techniques have almost replaced analogue ones in the public telecommunications networks. This development will also be predominant in power utility networks due to the many advantages offered by digital networks. SC35 has noted this trend and a requirement for digital network planning information to assist power utilities, therefore they established a working group (WG35.02) to prepare a planning guide. This paper aims to present guidelines to power utilities intent on designing and planning their own digital telecommunications networks.

Section 1 of the planning guide contains a short introduction into the subject, pointing out development trends and some important differences between analogue and digital networks. The main advantages discussed include economical factors, improved transmission quality, flexibility and much higher data transmission capacity using digital networks. Section 2 presents a tutorial overview on basic aspects of digital networks.

Section 3 presents details on services used today by power utilities. It also includes considerations on how these services are implemented in the digital environment. The following Section 4 deals with network performance matters and attempts to define the most suitable performance parameters and objectives required for power utility digital networks.

Section 5 contains one of the main issues, namely the digital network design considerations. It explains basic network elements, switching systems, transmission network nodes and links. It also deals with some problems which are specific to power utility networks, such as protection of connections, synchronisation and various kinds of regulations. Section 6 closely considers the transmission network, alternatives for the links and nodes (such as multiplexers, branching and cross-connect systems). Some of this equipment is remotely controllable, thus allowing dynamic transmission availability.

The next Sections, 7 and 8, are devoted to switching systems and network management, respectively. Digital switching systems form the core of all demand-based (dialled) services, either on circuit or packet switched principles. Network management does, in the digital mode, offer totally new supervisory possibilities and challenges. In addition to switching systems the transmission network can be remotely controlled, and networks covering large areas may be managed from a network management centre. Section 9 considers the transition issues when converting from an analogue to a digital network. The transition will be gradual and the two differing technologies must be able to co-exist.

Section 10 discusses the effect of locating digital transmission equipment in severe electromagnetic environments within high voltage installations and states the precautions and tests required before finalising equipment layouts.

Section 11 briefly gives the conclusions reached by WG 35.02 on the main issues of this Planning Guide.

Sections 12 and 13 give general acknowledgements and references applicable to this Guide.

Examples of typical power utility digital networks, with calculations, are contained in the Appendices.

SECTION 1 INTRODUCTION

Digital techniques are now preferred to analogue ones, in particular on new systems, by both the public telecommunications operators and power utilities for both technical and economical reasons. The overall performance of digital telecommunications networks can be designed significantly better than that of analogue networks, and digital networks are more flexible for transmission of different types of signals. Digital networks are also much more efficient in the fast growing data transmission sector. Digital systems have benefits also when considering maintenance features because very few regular adjustments are needed and detailed equipment supervision is possible from a network management centre.

All the advantages of digital telecommunications apply also for the power utility telecommunications networks. Some of the advantages, such as flexibility for various kinds of signals are even more significant in power utility networks. This means that the same transmission links can be used alternatively for different kinds of signals without re-adjustments (e.g. voice, data or video). Due to these advantages digital systems are increasingly used in new installations in the power utility telecommunications networks, and digital systems will finally totally replace the analogue ones. Some power utilities have already digitalised significant parts of their networks, whilst others are planning the introduction of their first digital systems. However, all power utilities still need to make investments in their digital networks, and therefore efficient planning will be required for these changes while keeping the network operating normally during all the transition stages.

Planning of digital telecommunications networks is, however, quite a demanding task, particularly for personnel being involved only with analogue systems. The basic character of the systems, link quality criteria, facilities available etc. are different, and this affects the whole planning of digital systems. Furthermore, almost all available literature on digital networks concerns public networks where the needs, problems and best solutions often are significantly different from those of power utilities. This means that in many cases there is an urgent need for guidance on the planning of power utilities digital networks.

This Guide is intended to help the planners in their task of planning digital networks which are herewith defined to consist of 64 kbit/s and higher rate links and nodes. This guide goes through the most important points to be considered in the planning of digital networks, and evaluates various matters from a power utility point of view. This guide is also intended to give practical advice on preferable solutions for the power utility digital networks in various environments, e.g. considering existing networks, area covered, legal restrictions, final network capacity target etc.

Figure 1.1 shows in diagram form what a typical network could be.

The values of transmission rates shown on the trunk routes are typical values only and the transmission media could be either radio, optical fibre, copper wire, satellite link or any combination of the available transmission media. The diagram also illustrates the major elements and types of service that a utility could require or which would be advantageous to the design of an economical, flexible and efficient digital system. In many cases there may be alternative methods of achieving the users operational needs and these are covered in more detail in the appropriate sections of the guide, but the diagram also acts to illustrate how with careful design a digital network has almost unlimited possibilities for integrating a wide range of services once the restrictions and constraints of older analogue systems are removed.

The guide covers in general the major elements in design and choice of equipment for:-

- Multiplex
- Microwave Radio Relay Links
- Optical Fibre
- Mobile Radio
- Satellite Radio Links
- Switching Systems
- Data Systems
- Packet Switches
- PABX
- Telemetry/Telecontrol
- Network Management

The importance of the creation of various types of Control Centres for the management of the network is also covered in the Guide.

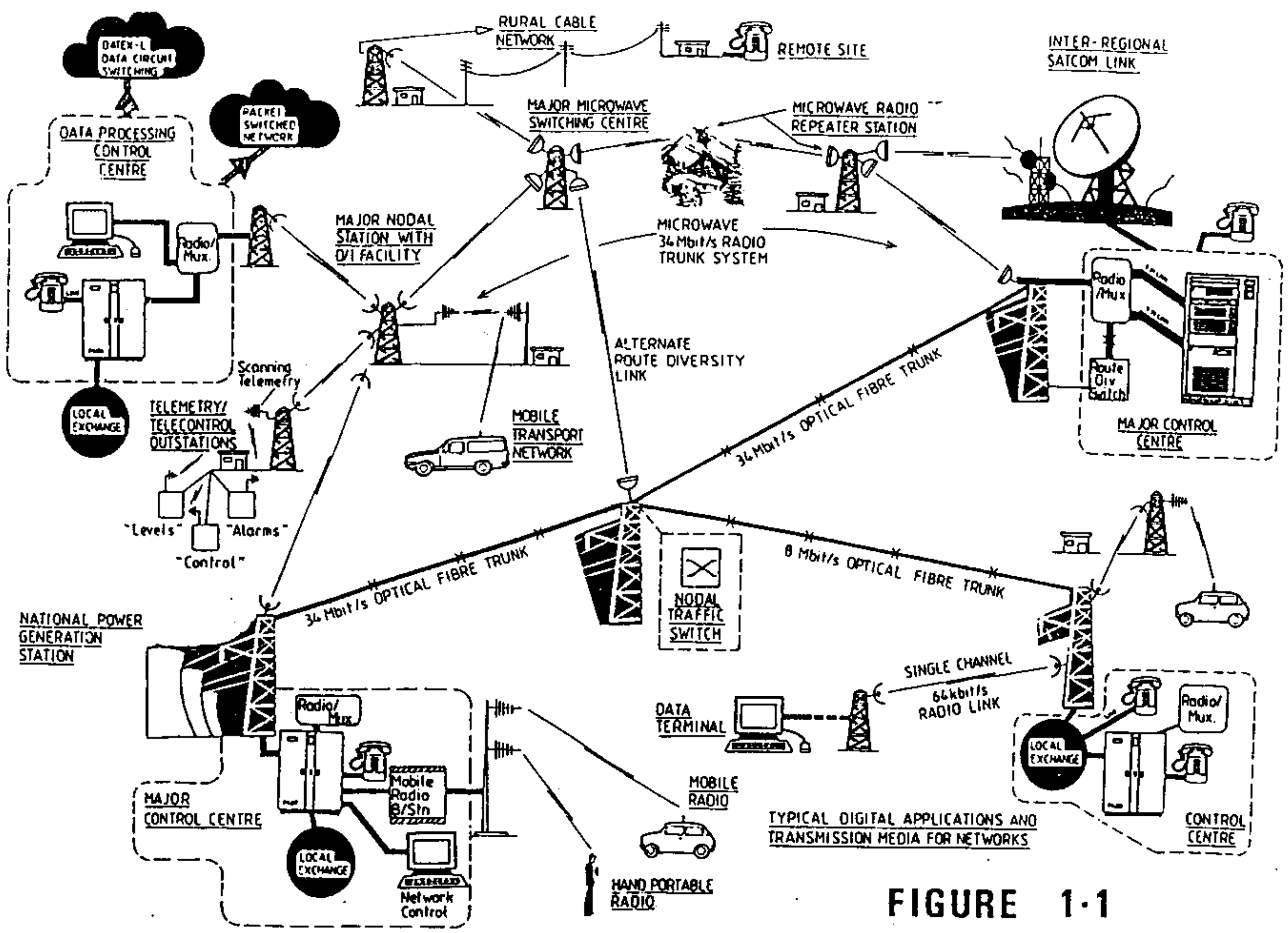


FIGURE 1·1

SECTION 2 GENERAL ASPECTS OF DIGITAL NETWORKS

2.1 Signals in Digital Telecommunications Networks

2.1.1 General

In analogue transmission the problem of transmitting several 4 kHz channels is resolved by stacking the channels on top of each other (FDM: Frequency Division Multiplexing), either corresponding to the CCITT hierarchy or direct to line. In digital transmission, the individual channels are sampled at defined time intervals then are selected in sequence on a time division basis (TDM Time Division Multiplexing).

Where analogue transmission is hierarchical, starting with a 4 kHz channel which can be stacked up to 12 channels, which can be stacked up to 60 channels, etc., digital transmission consists of a basic element of 64 kbit/s (a time slot) which can be stacked up to 24 channels (standard in USA, Canada and Japan) corresponding to 1544 kbit/s, or up to 30 channels (European standard used in the rest of the world) corresponding to 2048 kbit/s etc. for the first order of digitalisation (normally called primary multiplex).

These systems are covered by CCITT's recommendations but power utilities also use 10-channel systems each channel corresponding to 64 kbit/s. When even more channels are needed, the transmission takes place more rapidly. As an example the next level offers 120 time slots corresponding to a transmission speed of 8 Mbit/s, and the level after offers 480 time slots corresponding to a transmission speed of 34 Mbit/s, and so on.

The hierarchy of the two concepts are discussed in more detail in Section 5.

The hierarchy is shown in Fig. 2.1.

2 Mbit/s multiplexers of the first order can be synchronised to each other so that an overall synchronous network is created. The existing CCITT recommendations do not need mutual synchronisation for multiplexers of higher orders. The CCITT is, however, preparing recommendations for multiplexers of higher orders which can be synchronised.

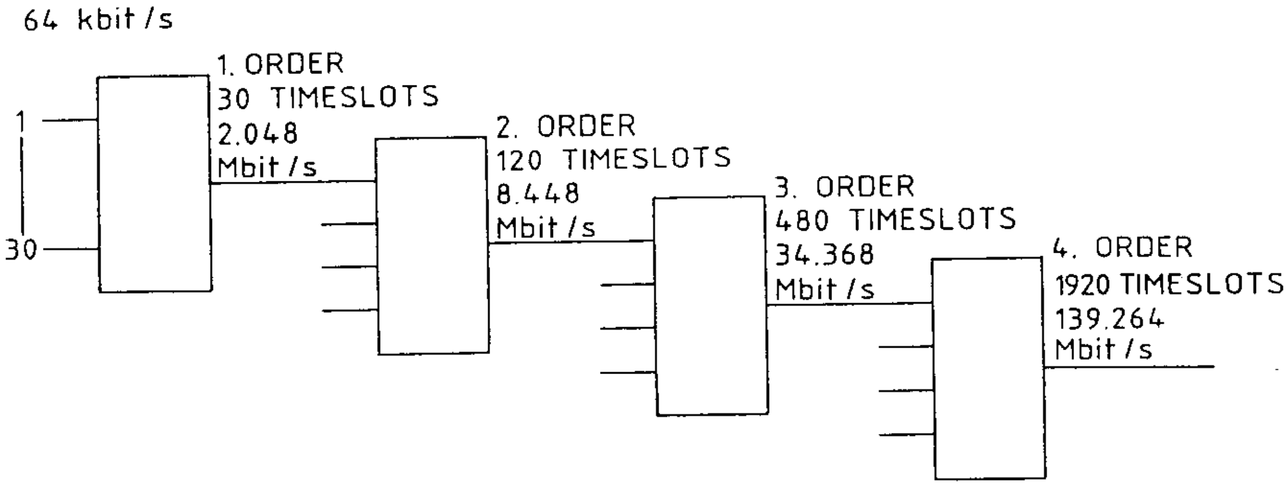


FIG 2.1
THE EUROPEAN MULTIPLEX HIERARCHY

2.1.2 Conversion of analogue signals (Refer also to Section 9).

The CCITT has laid down rules for PCM conversion of an analogue signal into a 64 kbit/s digital stream.

The encoding is made in accordance with the following rules:

a. The sampling frequency is to be 8000 samples per second.

b. The current value of an analogue signal is converted into a bit pattern consisting of 8 bits (8000 x 8 = 64 kbit/s).

c. Encoding is made by a non-linear quantizing method (A-curve in Europe and u-curve in the USA and Japan), the exact shape of the curves is represented in the encoding tables contained in (1). As an example of this, the A-curve is shown in Fig. 2.2.

d. The number of quantizing values is set forth in the encoding tables.

By fixing the sampling frequency at 8000 samples per second an upper limit to the frequency of about 4000 Hz is obtained, and by using 8 bits to represent the analogue signal 128 (127 u-curve) quantizing steps with positive sign and 128 (127 u-curve) with negative sign are available. The size of the quantizing intervals are chosen so that the quality of the recorded voice signals with low amplitude is particularly good.

In addition to transmission of the actual analogue signal there is a need in telephony for transmitting signalling (e.g. E and M signalling), see Section 7. Such signals are transmitted through a separate time slot, as described in Sub-Section 2.2.2. The use of 64 kbit/s for an analogue signal gives excellent voice quality, and interest in better utilisation of the channels without any essential impairment of the quality is achieved.

CCITT's Recommendation (2) contains the specifications for ADPCM (Adaptive Differential Pulse Code Modulation) where 32 kbit/s are used for speech. Contrary to PCM where the absolute amplitude value is quantified, in ADPCM only the difference from the latest sample is quantified. As this value is usually considerably smaller than the absolute value, 4 bits are sufficient for the quantity.

CCITT's Recommendation (3) states how 30 channels each encoded for 64 kbit/s can be converted to 60 channels each encoded for 32 kbit/s and vice versa, so that each 64 kbit/s time slot can be split up into 2 x 32 kbit/s slots which is more attractive to the power utilities because it provides better utilisation of the channels.

Work is going on into an even more efficient utilisation of the channels, for instance by developing more sophisticated codes to enable conversion of a voice channel to 16 kbit/s and a 7 kHz channel to 64 kbit/s.

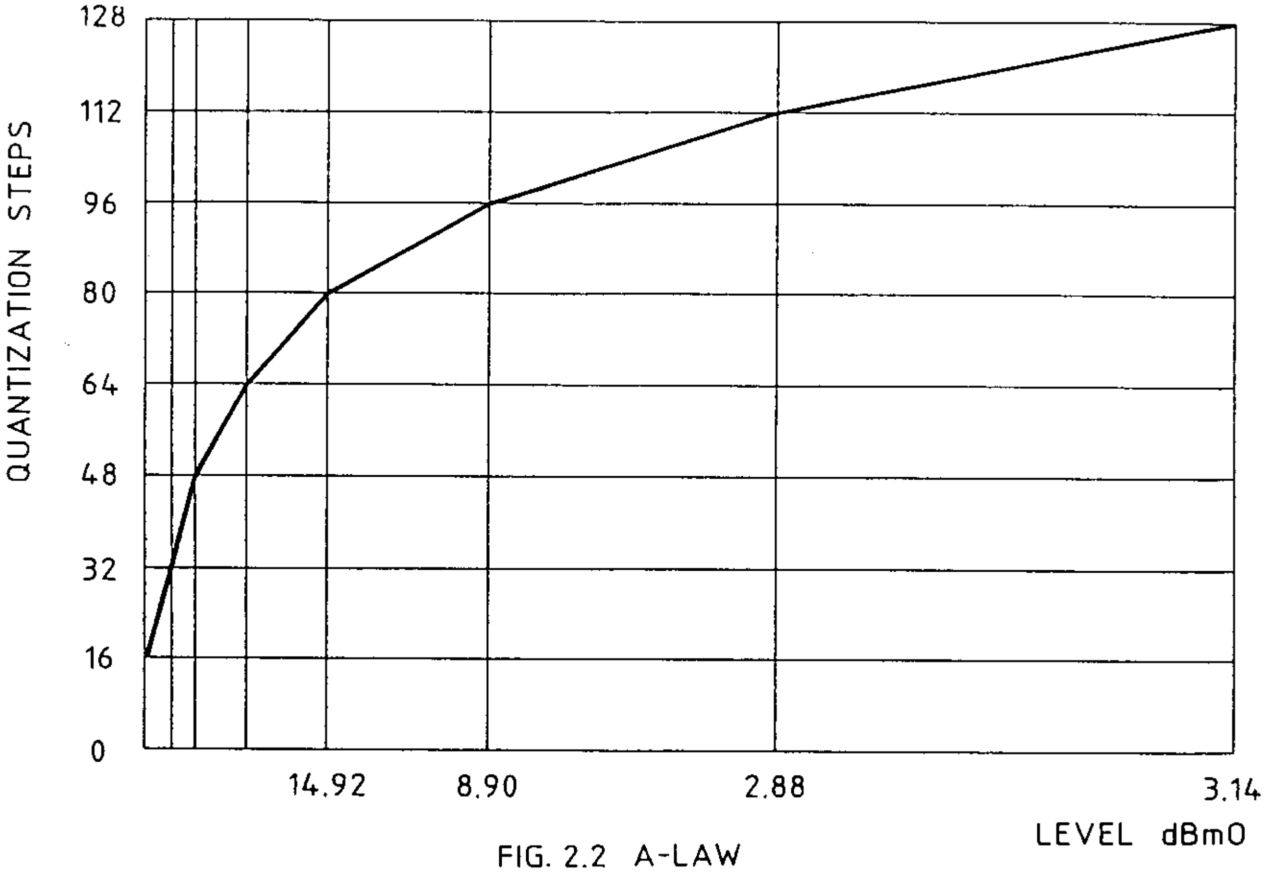


FIG. 2.2 A-LAW

Picture transmission, e.g. transmission of video signals, is another form of analogue transmission. Direct conversion of the video signal to a digital code requires a transmission speed of the order of 100 Mbit/s. More effective encoding approaches have therefore been adopted where for instance differences from the previous picture are transmitted instead of the full picture. Thereby a reduction of the required transmission speed down to approx. 34 Mbit/s is made possible, when broadcast quality is required. Video signals can also be transmitted at lower transmission speeds, down to 64 kbit/s, but this is suitable only for pictures which change very slowly, or where less perfect picture quality is acceptable.

2.1.3 Transmission of digital signals

The use of VF modem to convert digital signals to voice frequency signals has up until now been the preferred method most in use, and with a reasonably priced modem it is possible to get a transmission speed of 2400 bit/s in a 4 kHz channel. Higher speeds can be used, up to the technically possible maximum of 19.2 kbit/s.

With digital transmission, where the basic element is 64 kbit/s, you do not have to make that conversion. The digital signals can be guided direct to the transmission equipment.

The advantages of this are primarily:

- VF modem not required
- higher transmission speed possible; a transmission speed of n x 64 kbit/s can be achieved by combining several basic elements
- better utilisation of channel capacity, as the 64 kbit/s can be sub-divided into, say. 10 x 4.8 kbit/s.
- reduced costs.

2.2 Digital Telecommunication Networks

2.2.1 Transmission in digital networks

Unlike analogue FDM transmission, overmodulation in a channel will lead to distortion only in the relevant channel and will not affect any of the other channels. A free choice therefore exists when it comes to adjustment of the levels of the different channels. Overmodulation only means that all levels above the permissible ceiling are transferred in that bit pattern which corresponds to maximum level.

In digital transmission the same media can be used as in analogue transmission: quads, coaxial cables, radio and optical fibres. A next generation of PLC equipment may be expected to use digital transmission technique. The signalling rate provided will, amongst others, depend on the bandwidth available. One possible approach supports the idea to provide a transmission capacity of 64 kbit/s (basic CCITT bearer channel). This method makes use of a wide band modulation scheme (e.g. spread spectrum method). Another strategy is based on multi-level narrow band modulation, which in terms of channel bandwidth, is compatible with existing 4 or 8kHz analogue PLC systems. The signalling rate provided with this type of modulation is expected to be a fraction of 64 kbit/s (e.g. 19.2 or 32 kbit/s).

With quads the distance between repeaters in digital transmission is much shorter than in analogue transmission.

The price differences between digital and analogue radio systems are generally minimal, but the associated multiplexing equipment is considerably cheaper than carrier frequency equipment.

Optical fibres are extremely suited for digital transmission since the greater bandwidth of the optical fibres can be fully utilised. But power utilities rarely require the large number of channels which optical fibres offer, so this medium will (as yet) be a comparatively costly choice in terms of channel capacity used, unless this capacity is also used for the larger amount of administrative traffic. Another possibility is to share the capacity with e.g. the PTT.

2.2.2 Switching in digital networks

At the end of the 1960s the telephone companies started to digitalise its transmission network, and at the beginning of the 1980s went on with digitalisation of the exchanges so that 2 Mbit/s digital streams can now be transmitted direct between the exchanges. This has simplified the exchanges greatly because switching does not take place through circuits but as digital streams (computer controlled). This simplification of course means lower costs.

Utilities with their own PAX's used exclusively for operational purposes need fewer channels than the 30, 64 kbit/s channels offered by a 2 Mbit/s digital stream. The development of digital transmission and switching has led to a demand for more effective signalling than what is normally used. The CCITT (4) has put forward some recommendations on a CCS system (Common Channel Signalling) which in addition to faster connections offers new facilities which are not available in an analogue network, (see Section 7).

The CCITT has issued recommendations in the X series on both circuit switched and packet switched data transmission with principles also applicable to private data transmission networks. Circuit switched data utilises the same principle as the telephone network. This implies that a data link can be switched in the same way as a telephone call, and at the end of the call the connection is released and so is available to others (see Section 7).

Packet switched networks rest on another principle. The data is split into packets. These packets are provided with the address of the recipient(s) and transmitted through the network to them. As each small data packet is marked unambiguously with the address, several data transmissions can be carried by the same line which means that the individual transmission lines can be used by several users at the same time (see Section 7).

2.2.3 Main characteristics of digital networks

One advantage of digital transmission is the facility for regeneration of a signal.

In analogue transmission noise on the transmission path (poor S/N-ratio) will lead to distortion of the information carrying signal, and with connections in series the distortion from each sub-section will be accumulated.

In digital transmission the signal will also be distorted, but if the signal can be recognised in the repeater stations, the digital signal can be regenerated completely, and the degradation, if any, will not be accumulative. Errors appear as bit errors, usually expressed as BER (Bit Error Ratio), i.e. number of bit errors per number of bits transmitted.

Unlike analogue transmission where the quality of transmissions mostly is proportional to the S/N-ratio, digital transmission maintains acceptable quality up to a certain limit beyond which the link is unserviceable. This limit is of the order of BER $=10^{-3}$. In digital transmission filters are virtually omitted whereby delay and distortion are avoided.

In digital transmission a special time slot (No. 16) is allotted to signalling in the primary multiplex. In this time slot pulses can be transmitted at a speed 5-10 times higher than in analogue systems. This is valid for the 30 channel concept. In the 24 channel concept it is necessary to use one of the bits of the time slot for signalling.

2.3 New Service Possibilities In Digital Networks

2.3.1 Enhancement of existing services

Digitalisation of both transmission and switching with the 64 kbit/s time slot as basic element has offered a greater degree of flexibility where, as mentioned above, the 2 Mbit/s flow can be fed direct to the exchange and the individual 64 kbit/s time slots then routed in different directions to where it is needed.

With digitalisation greater speeds have also been made possible which enables transmission of facsimile group 4 signals and video signals as well as high speed data signals.

2.3.2 New services

CCITT (5) describes the attributes of ISDN, including the new possibilities offered by the ISDN concept, e.g. data transmission at 64, 384 and 1920 kbit/s; audio frequency transmission at 3.1, 7 or 15 kHz; video transmission at 64, 384 or 1920 kbit/s. ISDN is described in more detail in Section 3. The recommendation further specifies the different communication parameters - permanent or switched connections, point-to-point, multipoint or broadcast communication. These are examples covered by the existing recommendations, but new recommendations are being prepared by the CCITT so in future different combinations will occur.

The trend of public telecommunications is increasingly towards integration of the different services, such as voice, facsimile, data communication, video, etc., with well-defined interfacing for all of these services. It is therefore to be expected that private telecommunication systems will follow this trend.

2.4 Data Communication

The transfer of signals between two points within a data communications network is referred to as "data communication". There is no concern of the content or meaning of the signals conveyed between the two points.

"Data communications network" is a network where different devices (computers, telephones, terminals and other communication devices) are connected to share the communications resources (lines, multiplexers, controllers, switches, etc.) that are used to convey the data between any two devices attached to the network. On the boundary of the network, the network nodes to which the communicating devices are attached, are visible. The content or meaning of the data exchanged by the communicating devices, is irrelevant to the network. The services performed by the data communications network are generally known as "bearer services".

A number of interconnected computers is referred to as a "computer network". The computers considered in this network are all autonomous. A large computer managing its disc drives, magnetic tape drives, printers etc. is not a computer network. The services performed by a computer network are known as "tele-services" and includes the bearer services. Electronic mail, telex and file transfer are all examples of tele-services.

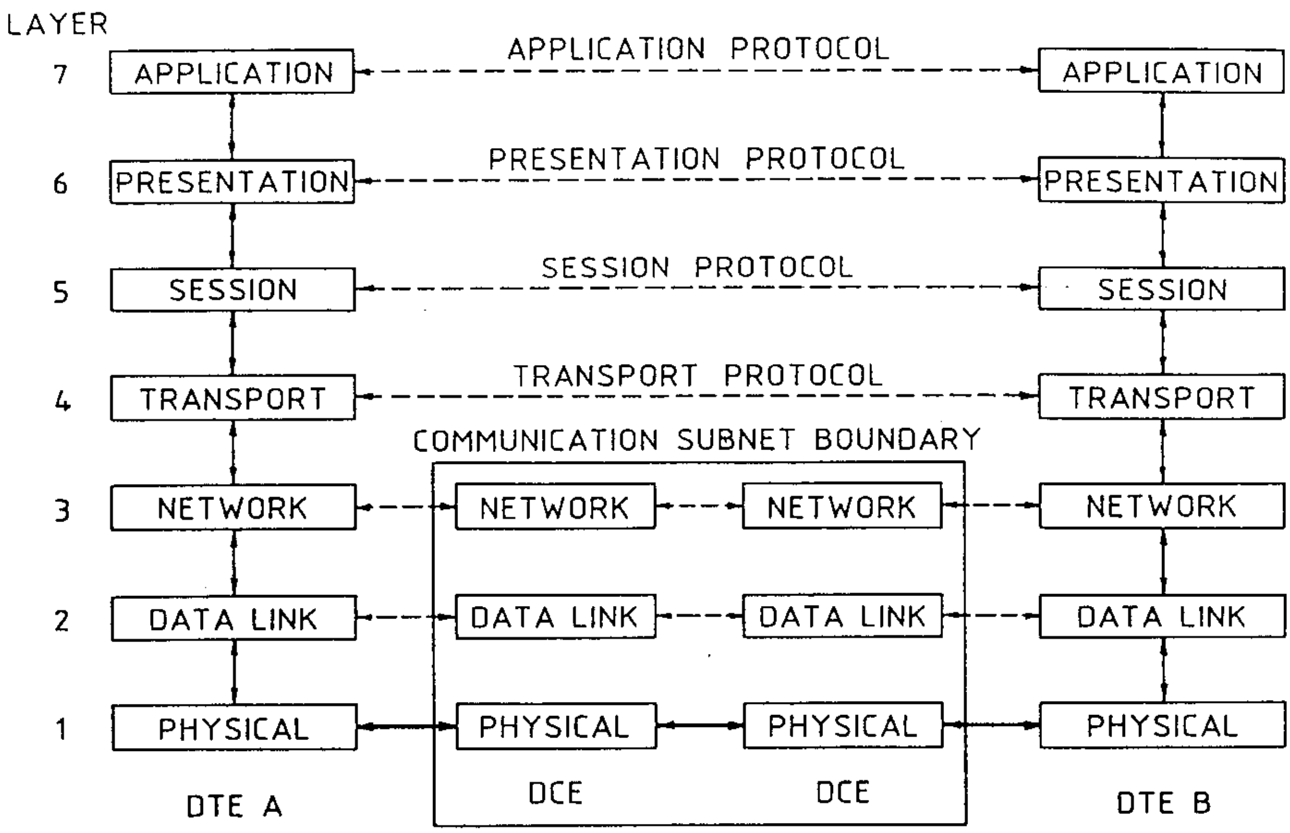


FIG 2.3 OSI NETWORK ARCHITECTURE

Early in the age of computer technology the need to interconnect computers of different makes became apparent. ISO responded to this need by deciding to create a new Sub-Committee (SC16) "Open Systems Interconnection". The objective of SC16 was to come up with standards required for "Open Systems Interconnection". The term "open" was to emphasise the fact that by conforming to those international standards, a system will be open to all other systems obeying the same standards throughout the world. The term "system" is used to denote a set of one or more computers and associated software, peripherals, terminals, human operators, physical processes, information transfer means, etc. that forms an autonomous whole capable of performing information processing and/or information transfer.

Fig. 2.3 shows the structure of the standard the ISO arrived at for "Open System Interconnection", the so-called "OSI" model. As it appears from the figure, the model consists of 7 layers, the three lower of which comprise "bearer services" while all 7 layers take care of "teleservices". It is a charactistic of the "OSI" model that each layer interacts solely with elements in the two adjoining layers. Although the ISO has not completed the standardisation of all the layers, a series of standards, particularly for the lower layers, is in existence already. Even though the need for standardisation is recognised internationally, and it is widely held that the OSI model is the standard for the future, there are nevertheless both advantages and drawbacks to it.

Benefits of OSI

OSI standards will give the system builder an independance from any one supplier of information processing equipment. This will enable system components to be chosen based on the criterion of meeting end-user requirements, rather than that of compatibility with existing equipment. The user is also freed from any restriction to a particular carrier network. The structuring of OSI standards enables the same application to run over any number of underlaying network technologies. Thus any standard network topology can be used for both local and wide area networking. When interconnection and interworking problems are minimised by the use of an agreed set of standards, the information processing resources will be shared across an organisation and between organisations rather than within individual user communities. Furthermore, expertise will be confined to one methodology rather than being effectively diluted by a number of different methodologies. The users choice is maximised by selecting a strategy based on standardised services and protocols and this strategy should be the Open Systems Interconnection.

Limitations of OSI

Any standard for communications has limitations, and this is no more true than in the case of OSI standards. With OSI standards the principal concern is with their relative immaturity compared with existing proprietary standards. Although implementations are starting to appear, most suppliers are not yet offering implementations standards at each of the full seven layers of the reference model. Another concern is that of performance. OSI protocols are perceived as being complex and, as a consequence, slow in performance terms. The ability of some systems to handle OSI protocols at high data rates has been called into question, but the data rates involved are those that are operated by proprietary protocols today. The performance issues should become less important as implementations of the standards become available in hardware rather than software.

SECTION 3 SERVICES REQUIRED BY POWER UTILITIES AND THEIR APPLICATION IN DIGITAL NETWORKS

3.1 Power Utilities Telecommunications Services

3.1.1 Critical telecommunication services

A power utilities telecommunication network must provide facilities for a range of services, some of which are essential for the safe and efficient operation of the power network. The critical services, upon which the power utilities operations depend are outlined below

Operational telephony

Power utilities require highly secure and reliable voice communications for load dispatching and switching to ensure proper control and operation of the power network. Control centres need facilities to establish voice communications quickly and easily with operational staff in generating stations, in switching substations and in maintenance centres. A private, highly secure telephone system is usually needed to provide the facilities required.

The traffic which the operational telephone network has to handle is usually not high but is vital for the safe and secure operation of the power system. Consequently, the operational telephone network must be designed to the highest standards of reliability and availability. In addition, it must have facilities to allow calls to be established easily and quickly even under abnormal traffic conditions. These requirements can be met by using dedicated (non switched) telephone circuits in some special cases. Usually, however, a highly secure switched telephone network equipped with the necessary facilities is provided to meet these requirements. The following facilities are typical of modern operational telephone networks

- very rapid call connection
- priority override, with call intrusion and force down facilities
- alternate routing and automatic rerouting of calls
- access restriction for unauthorised users
- closed numbering system
- conference facilities

To provide facilities of these kind requires exchanges of special design. The signalling system must be fast and reliable so that the time spent in setting up a call is kept to a minimum. The signalling system must also be able to transfer information on call priority and call routing between exchanges in the network. Stored program controlled exchanges are usually provided to meet these requirements.

Telecontrol

Power utilities also require highly secure and reliable data communications for supervision and control of the power network. Telecontrol includes all the functions involved in monitoring, supervising and controlling the state of the power network. The acquisition of data from remote stations (teleindications and telemetry) and the sending of instructions from control centres (telecommands) are fundamental requirements of power network telecontrol systems. Because the operation of large power networks is highly complex, control is usually exercised from a number of control centres which operate with different levels of control in an organised hierarchical structure. A three tier structure in which control is exercised at (a) national or power pool level (b) regional or major utility level (c) distribution or area level has been found to be appropriate for implementing telecontrol functions in many power networks. The functions performed at the different levels in the control hierarchy can vary depending on the size and complexity of the network. However, data acquisition and display, being a fundamental requirement of control centres is performed at every level. The remote control function is also a basic feature of control centre operations but is not performed at every level in the control hierarchy. The more sophisticated functions such as security monitoring, economic dispatch and scheduling are generally performed at the higher control levels and there is a general preference to centralise these functions at the highest level of control. In many networks, the main control centre does not execute commands directly via the telecontrol system but indirectly through the lower level control centres. In some networks, the scheduling and dispatch of reactive power and voltage is performed at the second level of control.

The communication links required to handle data flow between the substation and the control centres and between the centres operating at the different levels of control, may be structured in different ways:

1. Data coming from the power system may reach the higher control centre by way of the lower levels

2. Data from the power system may be communicated directly to the control centre, irrespective of which control level is involved

3. Data from the power system may be centralised at the highest level of control and distributed to the lower level control centres as appropriate.

In some utilities, communication of data is by a combination of the methods described above. For example, a structure which enables a control centre to obtain data from the power system directly as well as via a lower level control centre is not uncommon. Utilities which perform remote control functions at the upper levels of the control hierarchy can adopt a structure which permits direct communication with the substation.

Utilities having a large number of substations tend to adopt a radial or tree type structure, in which data required for the higher level control centres is obtained via the lower levels. The data obtained in this manner is not generally processed at the intermediate levels but is merely reassembled for onward transmission via high speed data links to the higher level control centre. Power system telecommunication networks are required to handle data flows between remote stations and the control centres and between control centres operating at different levels in the control hierarchy.

Telecontrol systems have stringent requirements for data transmission. These include

- very high availability
- very high data integrity
- short transfer time to allow real time monitoring and control
- high information transfer efficiency
- proper operation in the presence of noise

The protocols used for data transmission usually compromise between the need for high data integrity and high speed transfer which are conflicting requirements.

Teleprotection

Secure and reliable communication facilities are required for the transmission of teleprotection signals. To adequately protect a power line, co-ordination between protection equipment at both ends of the line is necessary and a communication link between the terminals at each end of the line is required for teleprotection signals. Teleprotection signals may be classified into one or two types depending on the kind of information to be transmitted between the ends of the protected power line viz. (a) analogue protection systems (b) command protection systems. In analogue protection systems power quantities (such as amplitude and phase of power currents) are measured and compared at each end of the line. The communication links are required to transmit the quantitative information to the distant terminal with sufficient speed and accuracy to be effective. To compare individual phase currents, three teleprotection signals are needed for each power line. By combining phase currents the number of signalling channels may be reduced to one per power line but greater accuracy of signal transmission is needed in this case.

In command protection systems, the transmitted signal contains command instructions instead of quantitative information. The command protection system may operate in one of two ways i.e. it may give a command to trip (intertripping mode) or it may give a command not to trip i.e. to block (blocking mode). In the intertripping mode a command to trip may be used at the receiving end to cause tripping without regard for the status of local protection equipment (direct intertripping) or alternatively, it may be used to effect a tripping only if local protection equipment has operated (permissive tripping). In the blocking mode the transmitted signal is used to prevent the operation of local protection. In all cases, fast, reliable and secure telecommunication facilities are essential for teleprotection functions.

Mobile radio and radio paging

Power utilities require mobile radio systems to extend communications to staff on the move and to provide communications at remote locations which are inadequately served by other communication facilities. Mobile radio plays an important part in a power utilities operation, particularly in emergency situations and the safety of personnel very much depends on its availability. Mobile radio provides essential communication facilities for maintenance and repair crews who need to be reached when on the move and who need to communicate with one another to co-ordinate their activities, see Reference (6).

Surveillance video

Power utilities are making increasing use of video facilities for surveillance and security purposes, particularly for critical installations such as a nuclear power plant. The transmission of pictures over channels of very narrow bandwidth (i.e. 4 kHz) is possible but only with very slow update period (approx. 20 sec.). Use of 64 kbit/s channels allows faster updating and use of 2 Mbit/s link allows full motion pictures of good quality and resolution to be transmitted. Secure communications are essential for these functions.

Load management

To improve system load factor and minimise peak demand power utilities may restrict supply to some customers of certain times of the day. This can be done by switching off non essential supplies remotely from a load management centre, and requires suitable telecommunication facilities for implementation.

Telecommunications management services

Telecommunications management centres which are needed to supervise and control large telecommunication networks give rise to requirements for service/auxiliary channels which must also be considered when planning the telecommunication network. Telecommunication channels may also be required for remote diagnostics and for remote reconfiguration of the network and provision for these facilities should be made at the network planning stage (refer to Section 8).

3.1.2 General services used by power utilities

Administrative telephony

Power utilities are large organisations having offices, stations, depots and other premises located at different places and often spread over a wide area. There is a need within a power utility for telephone communications both between and within these locations to meet the normal corporate and administrative requirements of the organisation. There is a need also for voice communications with the public and these facilities are particularly important during electrical power outages, when calls from the public may be both frequent and demanding.

Computer data communications

With the increased use of computers in all areas of business, power utilities are facing growing requirements for data communication facilities. There is a need to handle large amounts of data transfers between main frame computers and a need for facilities to handle large amounts of interactive traffic, arising from greater use of computer terminals. There is a need also to provide facilities for computer networking, use of which is growing.

Telex, facsimile, electronic mail and video conferencing

Telex, facsimile and electronic mail will give rise to traffic which may be handled by the power utilities telecommunication network, or the public telecommunication services, depending on economic and reliability considerations. The increased use of telefax for communications can influence voice traffic requirements and this should be allowed for when planning power utility future telephone networks.

3.2 Implementation of services in digital environment

Services using digital connections

The services provided by a digital telecommunication network can be divided into two major categories e.g. bearer services and teleservices. The network provides a bearer service by virtue of its connection capabilities. The connection mode is defined to be independent of the use which is made of it and hence arises the concept of a bearer service. A teleservice provides the user with a standardised communication mode at all layers of the OSI model. A teleservice therefore includes the network bearer services and enhanced services which may be provided by the network itself or as a value added service.

The requirements of the different services are accommodated in the telecommunication network through use of switched (circuit/packet) and dedicated circuits and by use of networking where appropriate. While most telecommunication services can be adequately met by using switched circuits, there are certain critical services such as teleprotection and telecontrol which have exacting requirements in terms of availability, security and response time which may require use of dedicated (non switched) circuits.

Telecontrol systems whose performance requirements are less demanding can more economically be met by using switched/networked solutions. It is expected that circuit/packet switched networks will be used increasingly in future for telecontrol functions.

For services which use switched circuits there are additional functions associated with setting up and terminating the connections which may need to be considered.

In the case of basic voice and data services these functions are performed by the exchanges and/or data circuit terminating equipment (DCE). In the case of computer networks, the link establish/release function may be contained within the higher level protocols of the communication process or within the link layer protocols of the telecommunication network. In packet switched networks, there are two basic types of service viz. datagram and virtual circuit service. The virtual circuits are store and forward analogies of physical circuits. Hence they can also be fixed or switched. Switched virtual circuits require special link establish/release functions while datagram services do not.

Many of the services which use analogue telecommunication networks need adaptation to work in a digital environment if the more advanced features of digital networks and the facilities which they offer are to be used to best advantage. Equally, the undesirable characteristics of digital transmission must also be understood and their impact on services clearly recognised. The advantages of digital transmission include

- potential for high bit rate transmission

- a much improved noise performance in comparison to analogue systems. Allows signals to be recovered from noisy environments

- facilitates the transmission of information over paths comprising a mixture of different media (e.g. cable, optical fibre and microwave)

- facilitates performance monitoring (i.e. BER monitoring) and transmission management

Some impairments in digital transmission and their effect on services are outlined below. (For numerical considerations, refer to Section 4).

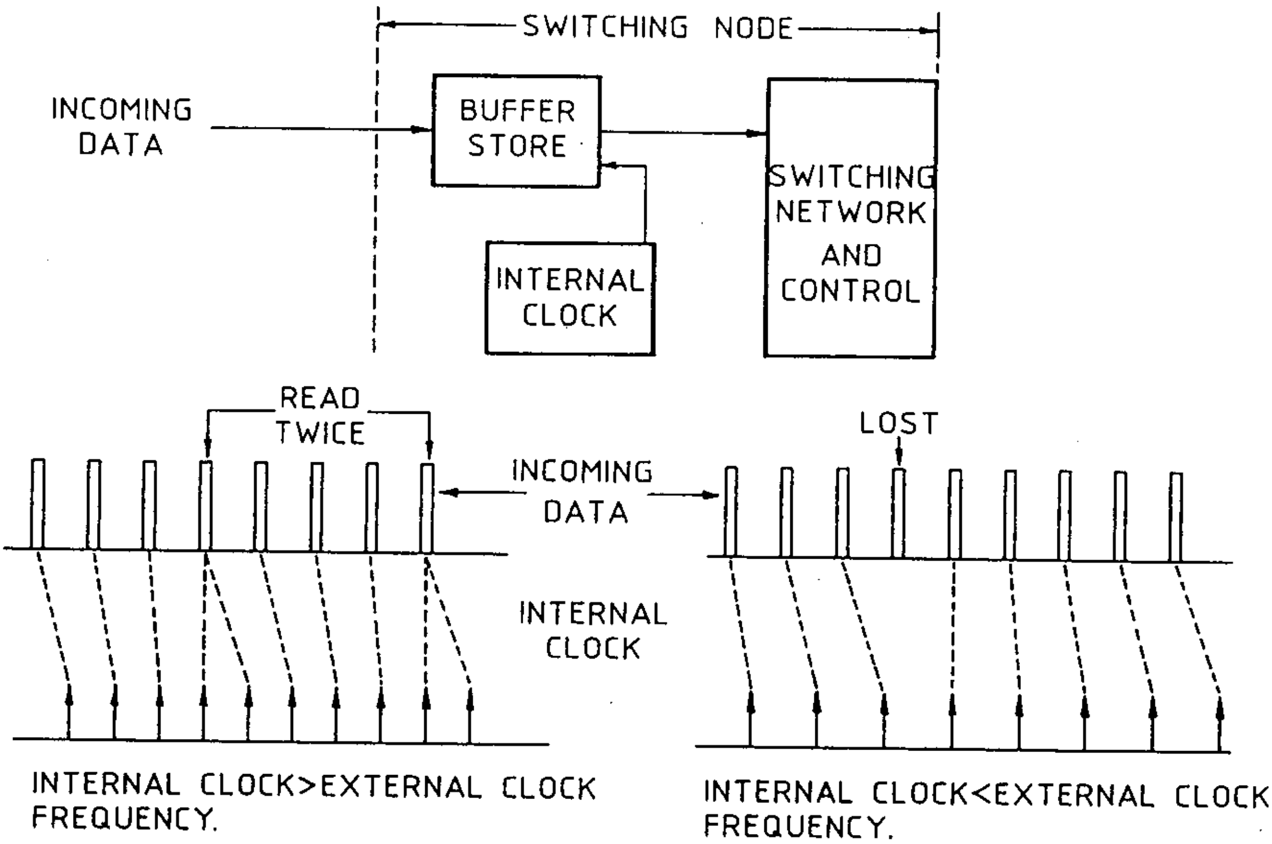


FIG 3.1 SLIP MECHANISMS

Slip (See figure 3.1)

Slips may be either controlled or uncontrolled. Where slips are executed in a controlled manner usually by repeating/deleting a complete octet (corresponding to one sample in the case of speech) they are said to be controlled. Unless the slip rate is abnormally high, the impairment is not normally perceptible in voice communications. It is however more significant in the case of data communications.

Uncontrolled slips occur when unplanned and unforeseen events cause bits to be repeated/deleted. Whereas controlled slips are carefully implemented to avoid subsequent loss of frame alignment, uncontrolled slips are almost certain to cause loss of alignment down stream. This can result in relatively long recovery times (lasting several milliseconds) while multiplexers realign. Consequently uncontrolled slips can have a more serious affect on services being carried.

Jitter

Jitter is a short term variation of digital signals which can be caused by the way in which timing is extracted from the signal or as a consequence of using justification in higher order multiplex equipment. Low frequency jitter tends to accumulate in the network and is most significant at the end of the digital connection where it can cause phase modulation of the sample reconstruction process in D/A convertors. Digitally encoded video services are quite sensitive to this effect.

Delays

Delays are a feature of digital networks and arise from the nature of time/space switching which is characterised by an inherent delay. The use of store and forward and sophisticated signal processing techniques in the network contribute to the overall end to end delay. Services whose response times are critical are sensitive to delay impairments. The performance of teleprotection and telecontrol system in particular can be seriously impaired by transmission delays. Equipment designs for these systems must include provision for overcoming impairments caused by transmission delays.

Short breaks

A short break in transmission can cause an interruption to services. Digital networks are affected by breaks in transmission differently from analogue networks. In digital networks, a short break of a few microseconds which affects a high bit rate system can result in a much longer break of several tens of milliseconds being perceived at the terminals.

The increase in delay arises because of the time needed by the chain of multiplexers to recover frame alignment and for associated phase locked loops to stabilise. As in the case of delays, short breaks in transmission can have serious consequences for teleprotection, telecontrol and other critical services which are sensitive to delays.

Errors

Errors occur whenever there are inconsistencies between transmitted and received bits. The effects which errors have on services depends not only on the number of errors which occur in a given time, but also on the distribution of errors with time. Data is particularly sensitive to 'bursty' errors and the performance of telecontrol systems in particular can be seriously impaired by their presence. If error ratios exceed 10^{-3} in each second for more than ten consecutive seconds, a complete failure is deemed to have occurred, see References (7) and (8), and consequently availability is affected. Teleprotection, telecontrol and voice services are therefore seriously impaired by non-availability of transmission.

3.3 Services Integration

3.3.1 Possible integration of services

Many of the present day telecommunication networks have evolved from basic telephone networks and require enhancements to support the non voice services. Historically, because of technical limitations, separate purpose built networks were developed for the different forms of communications (e.g. voice, data and text). In recent years however, the advent of new technology has produced developments which will allow services to be integrated in future telecommunication networks.

The use of digital techniques for both switching and transmission has led to the development of integrated digital networks in which switching, multiplexing and transmission functions are all part of an integrated digital process. These integrated digital networks provide a natural infrastructure for evolution towards the integrated services digital network (ISDN).

The more significant advantages of service integration are

- better overall network performance
- more effective use of network resources
- more extensive range of service possibilities

Two important questions which power utilities are faced with by service integration are

1) Should services which are crucial for the safety and security of operations be integrated with non-critical services?

2) Should service provided by power utilities private networks be integrated with public network services?

Traditionally for reasons of security and reliability, critical services such as teleprotection, telecontrol and voice communications for load dispatching have required separate networks for their implementation. The use of dedicated networks also have the advantage of providing high availability for these services, since network resources were not shared with other services. It is likely that separate networks will still be required for critical services in the immediate future. However, in the longer term developments in technology are expected to produce equipment architectures having the necessary redundancy and resilience to allow the security, reliability and availability objectives to be achieved in an integrated network. Consequently the need for separate networks for critical services should be reviewed as these technological developments are adopted. While integration of telecontrol data with data of other services is feasible with present day technology, the integration of teleprotection with data of other services is seen only as a longer term future development.

A factor which will influence integration of telecontrol and teleprotection in the telecommunication networks is the integration of these functions in the substation. Although substation control and protection are undertaken by independent systems at present, the future integration of these functions can be anticipated. The integration of control and protection in the substation with access to the network via a common interface will facilitate integration of these services in the telecommunication network, see Reference (9).

Another factor to influence service integration is the availability of suitable communication protocols. Telecontrol systems, for example use short message structures characteristic of systems which require rapid response and control in real time. The protocols developed for SCADA/EMS systems are very different from those of other applications (e.g. high speed data transfers between computers) and integration of these services is hindered by the lack of suitable protocols. The absence of standards in this area is also likely to prove a further constraining factor.

The use of networking can facilitate service integration. Where packet switching is used for telecontrol and other data services, integration of SCADA data with data of other services is effectively achieved. However, prioritisation of telecontrol functions is necessary if acceptable response times are to be achieved.

The telecommunication services of power utilities have different network topology requirements which can influence service integration. Services which involve centralised control functions such as telecontrol, load dispatching and load management usually require a star type network topology. Other services such as voice and electronic mail are better served by a mesh type of network. Protection of a transmission line usually requires communication channels provided directly between both ends of the line. The different topology requirements of services may detract from the merit of their integration.

For these reasons, it is unlikely that a single network, which integrates the many and varied requirements of the different services will be implemented in the near future. Separate networks will continue to be required for certain services, at least for the foreseeable future, and these requirements should be given due consideration when planning power utilities telecommunication networks.

3.3.2 Integrated services digital networks (ISDN)

The integration of services in the public network will be carried out by the introduction of the ISDN. The key features of the ISDN will be

- End to end digital connectivity

- Integrated access. Basic rate access will be by two 64 kbit/s channels (B-channels) and one 16 kbit/s channel (D-channel) in both directions.
- A universal user network interface which will allow connection of a variety of terminal devices via a common "communication's socket". A limited number of standard interfaces will be a feature of ISDN.

- Out of band digital signalling

The CCITT blue book 1988 is the definitive document for CCITT ISDN. The ISDN will offer a considerably improved range of services which are defined by CCITT in the I.200 series. These include:

- Facilities to allow both voice and data communications with one or a number of terminals either simultaneously or in turn

- Facilities for displaying information such as call waiting or for displaying of call charges

- Facilities for connection of terminals of different manufacture

- Common access for multiservice terminals

- Integration of user services under one identification number.

The availability of these services in the public network will influence the development of private network services and it is expected that private networks of the future will include ISDN capable PABXs. Access to data networks and value added services will then be possible via ISDN exchanges in public networks or via ISDN capable PABXs in private networks, and the designer of private networks must choose between these alternatives.

Implementation of ISDN PABXs as a centrex feature of a public exchange is another development which may be expected in environments where centrex facilities are available. In these environments it is possible that economic considerations may require power utilities to use ISDN capable PABXs only at their large locations and have ISDN PABX services provided via centrex at their smaller sites.

The use of ISDN capable PABXs will also influence requirements for local area networks since many of the LAN functions (e.g. packet switching, 2 Mbit/s primary data rate access) will be available in ISDN capable PABXs. With these developments, it will become increasingly difficult to identify boundaries between voice and data communications as the technologies converge and integrated services becomes a reality.

3.4 Services Available In Other Networks

3.4.1 Value added networks

In addition to the basic voice and data services, many public telecommunication networks can provide a range of enhanced services to meet special need of power utilities.

These services include

- enhanced voice service (recorded information services, conference calls, call diversion facilities etc.)
- cellular mobile radio service
- leased digital circuits (2 Mbit/s, 64 kbit/s and submultiple data rates)
- enhanced data service message switched networks (X.400, electronic mail, electronic cash transfers etc.)
- Alphanumeric paging (with facilities for short message transfers).

In addition to PTT's, there are private companies which use the bearer services of the public network to provide value added network services (VANs) to power utilities and other users. The extent to which VAN providers are permitted to supply these enhanced services depend on regulations which apply in a particular country. In countries where private companies are free to provide VANs, the range of services can be considerable and include

- Data VANs (including services such as on-line data base access, electronic mail, electronic fund transfer at the point of sale etc.)
- Voice VANs (including recorded information services, audio conferencing, voice messaging)
- Video VANs (including video conferencing, slow scan T.V. etc.)
- Mobile VANs (including paging services and mobile data)

Some VAN providers operate extensive networks and can supply these services internationally. It is expected that power utilities will make increasing use of enhanced services in future particularly where data exchanges with other organisations are involved.

It is envisaged that power utilities will have increasing requirements to access external data bases for information in future and adequate provision should be made for these requirements at the network planning stage.

SECTION 4 DIGITAL NETWORK PERFORMANCE

4.1 Performance Parameters

CCITT (Blue Book) has two concepts for the performance area in digital networks, see References 7, 9A, 9B and 9C.

- Quality of Service (QOS)
- Network Performance (NP)

Quality of Service is meant to define the degree of satisfaction of a user of the service. Network performance is meaningful to the network provider for the purpose of system design, configuration, operation and maintenance. Both QOS and NP are important but for network design purposes NP is more suitable. NP has three primary performance parameters:

- Speed
- Accuracy
- Dependability

Derived performance parameters are defined based on primary parameters. Availability is one of the derived parameters. The definitions of CCITT may be too detailed for CIGRE purposes. Therefore network performance is defined here as follows. The essential performance parameters of digital telecommunication network are shown in Figure 4.1.

Network performance depends mainly on the availability of the connections and on the transmission performance. There are many other parameters but they are not so important or clearly defined.

4.1.1 Availability

Availability of connections and equipment depends upon the reliability of the equipment, organisation of maintenance and redundancy in the network. Poor transmission quality can also be seen as unavailability.

Reliability is a parameter which deals with the quality of the equipment. Digital systems have no special features in this respect. The reliability is calculated and specified as in other kinds of techniques.

Maintenance organisation, fault location facilities, reserve part storages and skill of the maintenance personnel will also influence the availability. Digital techniques do not essentially differ from analogue as regards maintenance.

Planning of the network influence the availability also. The most important services have normally two independent routes and one fault should not sever the whole connection.

4.1.2 Transmission performance

Transmission performance is influenced, in addition to the normal quality criteria of the analogue channel, by the pure digital and mixed analogue/digital network characteristics. The most important parameters of transmission performance are indicated in figure 4.1. The most important parameter is error performance.

Although the definition of an individual bit error is very straightforward, the identification of suitable parameters is more complicated. The concept of long term mean bit error ratio and error probability are widely used but these measures alone do not contain any information regarding the distribution of errors with time. For many services the distribution of errors is as equally important as the number of erıors.

Three parameters are developed by CCITT to describe the error performance of 64 kbit/s connection in ISDN:

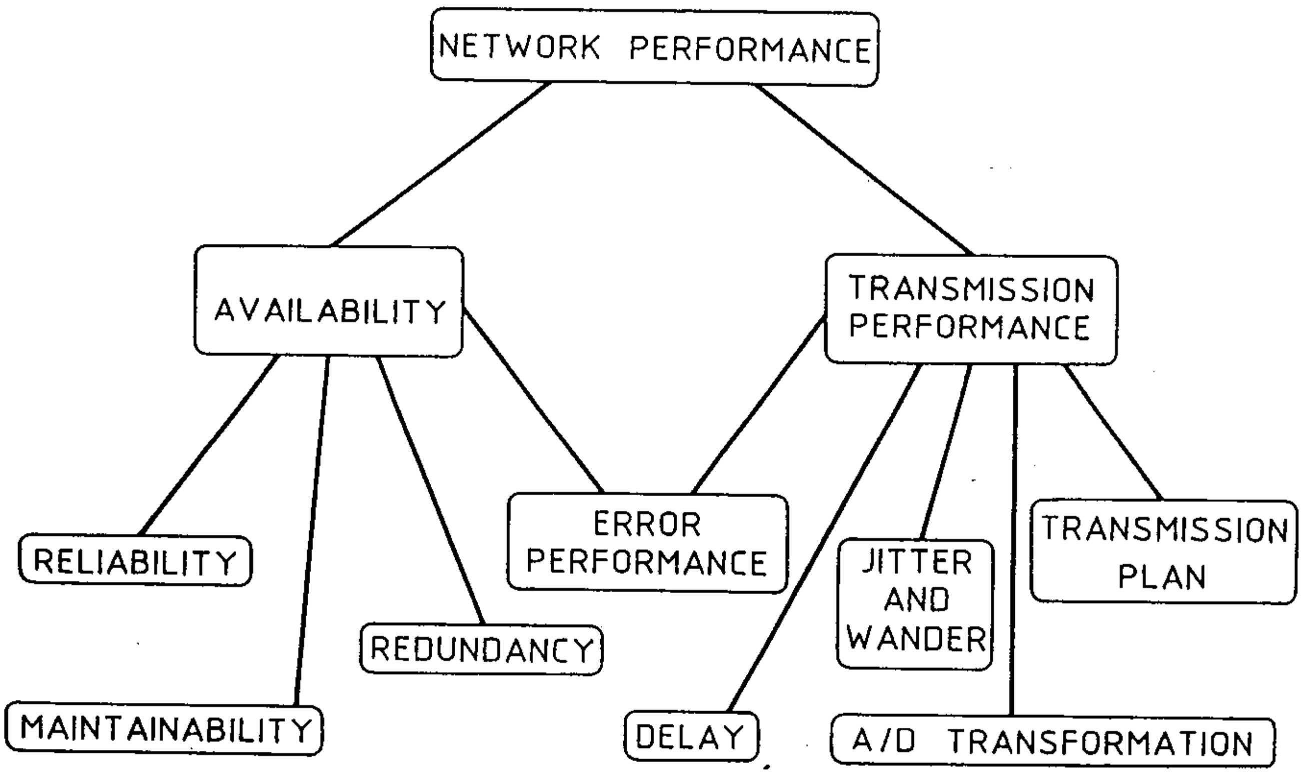


FIG 4.1
PERFORMANCE PARAMETERS OF DIGITAL NETWORK

1. Degraded minute
(A 1-minute period where the short term bit error ratio, evaluated over 1 minute, exceeds 10^{-6})

This parameter is most appropriate for telephony. The bit error ratio 10^{-6} is a boundary between virtually unimpaired transmission and the onset of more significant impairment, as likely to be perceived subjectively.

2. Errored second
(A 1-second period that contains one or more errors)

For data services the information is commonly transmitted in blocks containing error detection mechanics. Blocks received with one or more transmission errors are subject to retransmission. Maximisation of throughput therefore requires the minimisation of the number of errored blocks, 1-second period is adopted as a compromise value for data block size.

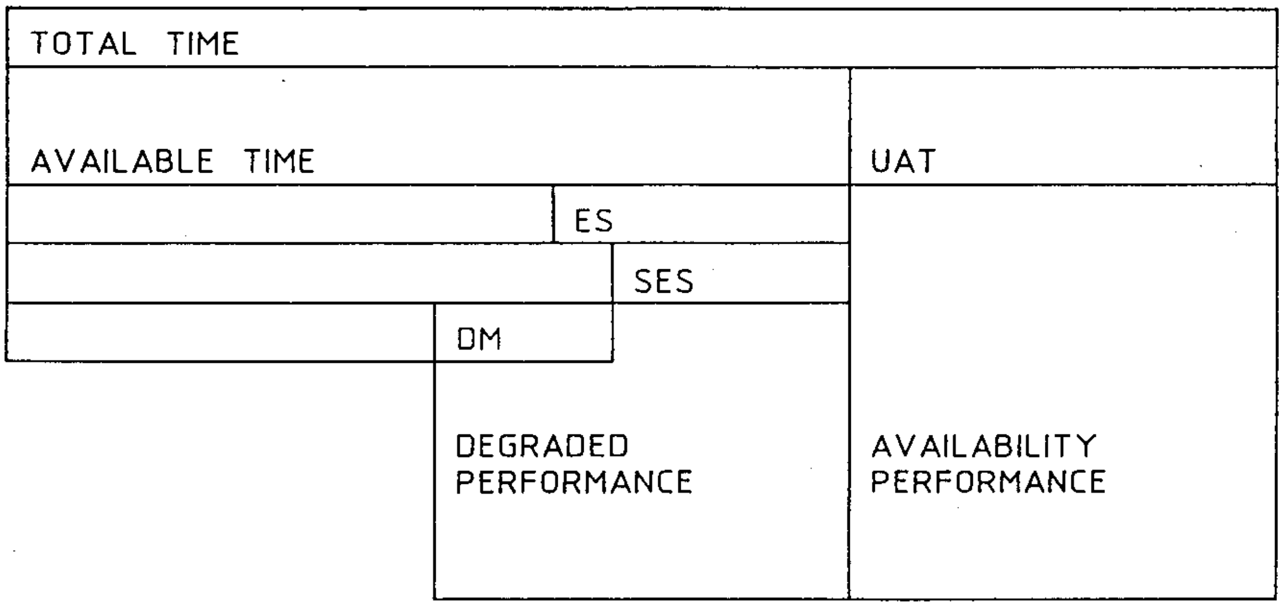
3. Severely errored second
(A 1-second period where the short term bit error ratio, evaluated over 1 second, exceeds 10^{-3})

While some degraded minutes are likely to occur, it is considered necessary, for telephony, to place some further bounds on the occurrence of the more severe error bursts. It is seen particularly appropriate for digital systems which are operating virtually error free for most of the time but with occasional, fairly intense, error bursts. This parameter is intended to be the means for controlling the occurrences of loss of frame alignment in multiplex and other equipment within the network.

4.1.3 Available time

One method to describe the performance of the network is to divide the total time into different categories. CCITT has defined the time limit between unavailability and degraded performance as 10 seconds. This means that if the bit error ratio exceeds 10^{-3} for more than 10 seconds, the connection is unavailable for that time. If the time is less than 10 seconds, the connection is available but the performance has degraded.

Availability/time concept is shown in Figure 4.2.



UAT = UNAVAILABLE TIME
ES = ERRORED SECONDS
SES = SEVERELY ERRORED SECONDS
DM = DEGRADED MINUTES

FIG 4.2 AVAILABLE TIME DEFINITIONS

The counting of degraded minutes is carried out only in that time when the connection is available, and the severely errored seconds are excluded. Unavailable time begins when the bit error ratio exceeds 10^{-3} during every consecutive ten seconds. Unavailable time ends when the bit error ratio falls down below 10^{-3} every second during ten consecutive seconds. These latter seconds are counted into the available time.

CIGRE has given availability objectives for telecontrol systems as follows:

Network level	Available time
NCC - ACC (RCC)	99.99%
ACC - DCC (RCC)	99.99%
DCC - RS (Class A)	99.9%
DCC - RS (Class B)	99%

Availability requirements are divided between the availability of the equipment and the connection. Over 10 second breaks and severe disturbances are classified into unavailable performance.

Degraded performance can be divided into the different parts of the network and, to describe its constituent parts, the following reference connection for the studies of degraded telecontrol performance is shown in figure 4.3. The number of hops may be chosen as required in every case.

4.2 Error Performance

4.2.1 CCITT recommendations

The main criterion for the digital transmission system has been the bit error ratio. The measurement of bit error ratio is straightforward either using test sequence, monitoring the fixed bits in the frame (frame alignment word), monitoring the code used or using the free bits of the frame. The meaning of the bit error ratio has been based on the assumption that the errors are randomly distributed. The errors occur in practice in bursts. The bit errors in radio systems are normally caused by disturbances or fading.

If there are considerable errors in cable systems, (especially optical cables) there is usually something wrong. The bit error ratio for burst errors is irrelevant, because the bit error ratio may be satisfactory, although the system may be part of the time unsuitable for normal operation.
Reference (7) deals with the error performance of the international ISDN connection which is based on a 64 kbit/s circuit switched connection (used for voice traffic or data) and operating over an all digital Hypothetical Reference Connection. The purpose of this recommendation is to define both bit error ratio and the time distribution of the errors. The time distribution is defined by the degraded minutes, severely errored seconds and errored seconds. These limits are shown in the following table 4.1.

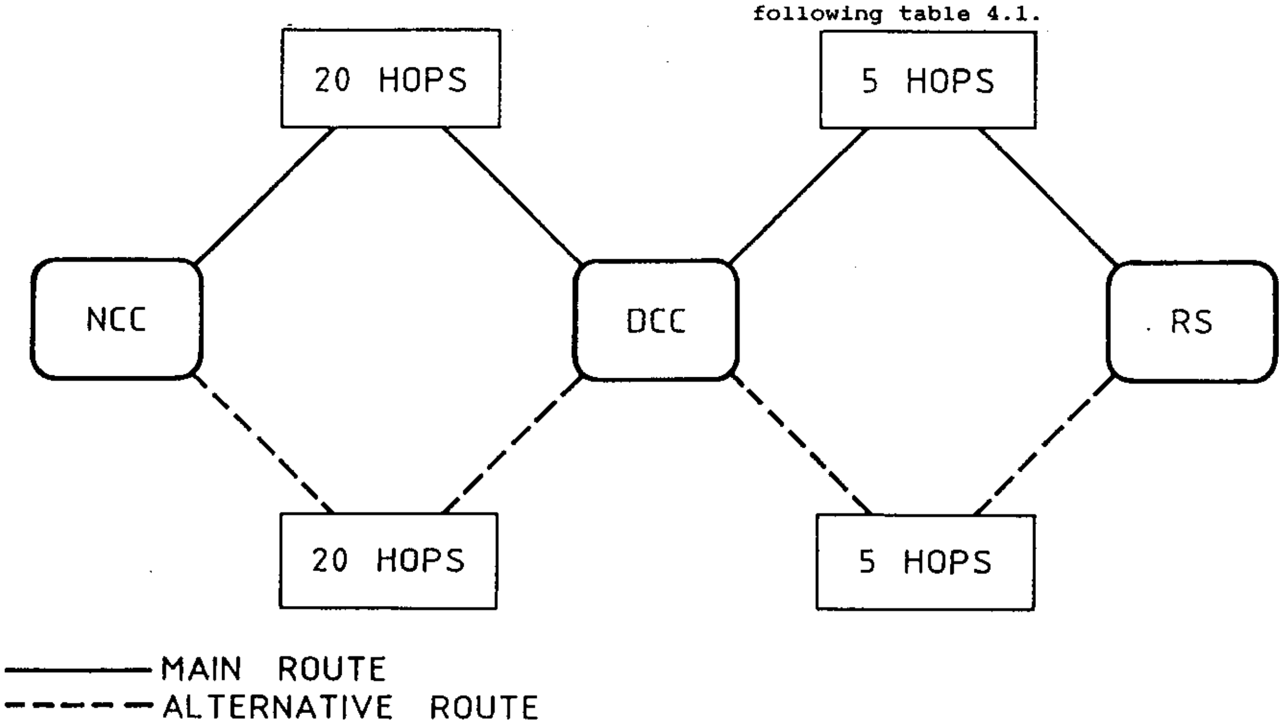


FIG 4.3
EXAMPLE OF REFERENCE CONNECTION
FOR TELECONTROL PERFORMANCE

Performance Classification	Objectives
(a) (Degraded minutes)	Fewer than 10% of one-minute intervals to have a bit error ratio worse than 1.10^{-6}
(b) (Errored seconds)	Fewer than 8% of one-second intervals to have any errors equivalent to 92% error-free seconds
(c) (Severely errored seconds)	Fewer than 0.2% of one-second intervals to have a bit error ratio worse than 1.10^{-3}

Table 4.1 Error performance of international ISDN connection

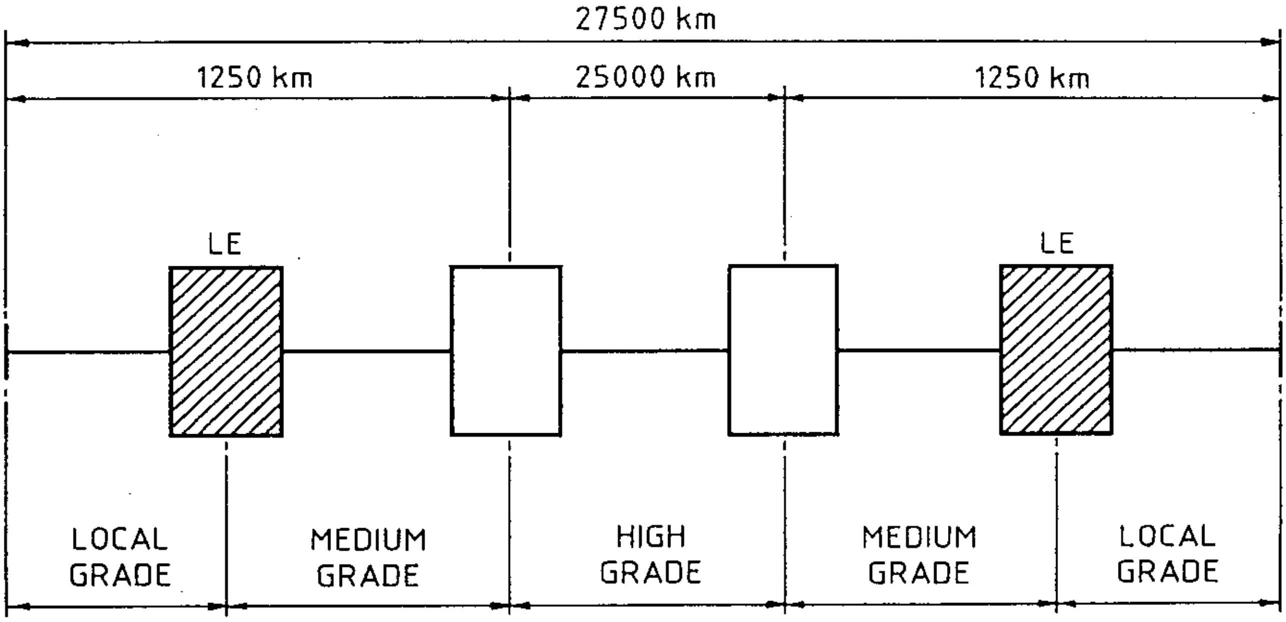


FIG 4.4
CCITT HYPOTHETICAL REFERENCE CONNECTION
FOR ERROR PERFORMANCE

The distribution of the performance requirements into the different parts of the network is made by CCITT taking into account the following criteria:

- When dividing the requirements into different parts of the connection, only the requirement of time percentage is divided.
- The division of degraded minutes and errored seconds is made in a similar way.
- The bit error ratio threshold has not been divided. This is based on the fact that the performance of the normal connection is clearly better than the threshold of the degraded minute.
- The error accumulation from the digital switching systems or digital multiplexing equipment has not been taken into account because the bit error ratio of the digital transmission systems are higher.

The hypothetical reference connection for bit error performance is shown in figure 4.4.

The connection consists of three performance classes. The 25,000km long international portion is the highest-grade one. At both ends of the connection are the medium-grade and local-grade portions which are 1250km long. The degraded minutes and errored seconds have been divided into the various portions in the following way:

Circuit Classification	Allocation of the degraded minutes and errored seconds objectives
Local grade (2 ends)	15% block allowance to each end
Medium Grade (2 ends)	15% block allowance to each end
High grade	40%

Table 4.2 Allocation of the degraded minutes and errored seconds objectives.

The division between the medium and local grades (together 30%/end) can be carried out as chosen. The division of the severely errored seconds is different compared with the other parameters. The whole 0.2% portion is equally divided. One half is divided in the same ratio as the other parameters (0.015%, 0.015%, 0.04%). The other 0.1% is divided for the high and medium grade portions for the occurrance of adverse network conditions occasionally experienced (the worst month in one year).

The error performance table of the severely errored seconds gives the following form:

Circuit Classification	Allocation of severely errored seconds objectives
Local grade	0.015% block allowance to each end
Medium grade	0.015% block allowance to each end
High grade	0.04%

Table 4.3 Allocation of severely errored seconds objectives

4.2.2 Requirements of power utilities

The division of the error performance for power system telecommunication networks can be carried out using the terminology and methodology described in the previous chapter.

However, when designing a digital network system the following factors must be taken into account:-

- Type and configuration of reference connection.
- The threshold for availability and bit error ratio.
- Network components and constituent parts.
- The needs of various services may be different.
- The interface between private and public network may have special features.

The division between the parameters of transmission performance and available time are specified theoretically in a certain way. The application of power utility networks probably varies considerably between different countries.

The hypothetical reference connection could be the one presented in figure 4.3. The correlation between CCITT and CIGRE models could be made in the following way:

- The power system telecommunication network is in the same class as the medium and local grade classes in the CCITT model.
- The connection between NCC and DCC have the same performance as the medium grade.
- The connections between DCC and RS are comparable with local grade performance.

For convenience it can be defined that the error behaviour of connections is mainly caused by the transmission path and nodes. Items such as front-end computers, packet-switching nodes, digital multiplex equipment or switching equipment are not taken into account. The connection between NCC and DCC is normally longer than the connection between DCC and RS, because the aforementioned are more important. However, the division between these parts of the network could be made in two equal parts.

The degraded minutes and errored seconds can be defined in accordance with the CCITT recommendation. The severely errored seconds could be defined in such a way that the 0.1% which CCITT has reserved for medium and high-grade network will be allocated for these two levels. The above assumptions define the following requirements for the connections of power utilities.

Class	Performance at 64kbit/s connection		
	Degraded minutes	Errored seconds	Severely errored seconds
RS-DCC	< 1.5%	< 1.2%	< 0.03%
DCC-ACC(RCC)	< 1.5%	< 1.2%	< 0.03%

4.2.3 Requirements for digital hops

The requirements for digital hops can be defined either dividing the requirements of the whole connection by the number of hops or using reference connection. When specifying a part of the network many things must be taken into account. It is not so easy to specify the whole network based on a few special point-to-point connections. Therefore the reference connection may be helpful. The reference connection described in figure 4.3 may be used.

The error performance per digital hop is then in the following form for one digital hop.

Class	Performance per link hop		
	Degraded minutes	Errored seconds	Severely errored seconds
RS-DCC	< 0.3%	< 0.24%	< 0.006%
DCC-ACC(RCC)	< 0.075%	< 0.06%	< 0.0015%

The same bit error ratio threshold for availability could then be made as CCITT has used. The measuring equipment has been made to this specification. There are no special reasons to change this limit in this case, but for future consideration this limit could be modified. The same threshold may be suitable for various services. The limit for available time is ten seconds which is recommended for use. One cycle of the telecontrol system is normally only a few submultiples of ten seconds, with switch-over into the spare routes taking place inside ten seconds.

In connection with teleprotection signalling the following aspects should be considered.

Teleprotection signalling is a real time task and it is characterised by three major requirements:

- Dependability i.e. will operate when required

- Security i.e. will not operate unnecessarily

- Low transmission time, typically less than 10 ms with digital transmission systems.

Although the error performance of a digital hop may fully comply with the requirements in terms of errored seconds and severely errored seconds they may be correlated with the time instance when protection signalling has to take place (e.g. during burst errors due to line faults and therefore successful operation of the protection system may be prevented (Dependability).

On the other hand excessive bit errors occurring during normal conditions (switching activities) or loss of incoming signal must not cause false tripping (security). Suitable measures in the teleprotection channel like message coding, monitoring circuits with fast blocking facilities are necessary in order to achieve the required performance in terms of dependability and security.

The specification of digital hops demands the definition of the availability and transmission performance numbers. The reliability part is quite clear. The degraded performance specification can be made as described above. The difficulty is to put the correct requirements for fading: which part of the fading falls in the unavailable category and which part present the degraded performance.

Variable future services may demand some additional specification of performance, especially the video transmission using effective coding which must be carefully studied. Any modifications must also be carried out later.

The above-mentioned definition of performance characteristics guarantees that the power utilities telecommunication network is comparable with the national part of the international connection. No formal difficulties should be present when connecting the private and public networks.

4.3 Delay (See also Section 3)

The effect of delay in the power utility network is more important than in the public network. In particular teleprotection and telecontrol are the most demanding services. The delays of different digital transmission equipment are depending on the techniques used. The following table shows the typical range of the one way delays:

Equipment	Delay (us)
Radio link terminal	5...15
Optical terminal	0.4...1
PCM codec	130...300
Digital multiplex (2/8)	10.....15
Digital branching	22...760
Local exchange	1500
Packet-switching node	1000..20000
Satellite	270000

Table 4.4 Delay in various telecommunication equipment

The reference connection for the delay may be the same as shown in Figure 4.3.

4.4 Jitter, Wander and Slip (See also Section 3)

Jitter is defined as the short-term variations of the significant instants of a digital signal from their ideal positions in time. Jitter can accumulate to such an extent that the following impairments can arise:

- An increase in the probability of introducing errors into digital signals at points of signal regeneration as a result of timing signals being displaced from their optimum position in time.

- The introduction of uncontrolled slips into digital signals through store spillage and depletion in certain types of terminal equipment incorporating buffer stores and phase comparators, e.g. jitter reducers and certain digital multiplex equipment.

- A degradation of digitally encoded analogue information as a result of phase modulation of the reconstructed samples in the digital to analogue conversion device at the end of the connection, see figure 4.5.

Wander is defined as the long-term variations of the significant instants of a digital signal from their ideal position in time. It is, in fact, very slow jitter. Wander is the main source of the slips in the network. The network nodes which demand synchronous operation must have the phases of the timing signals within the specified limits. If the limits are exceeded, slips will occur. Wander is caused by the changes in the clock oscillators of the network nodes and the delay variations with temperature in the transmission paths.

The wander and slip characteristics are the main features when planning the synchronisation method of the whole network or separate connections.

The jitter performance of the network must be defined using the following principles:

- To recommend a maximum network limit that should not be exceeded at any hierarchical interface.

- To recommend a consistent framework for the specification of individual digital equipments.

- To provide sufficient information and guidelines for organisations to measure and study jitter accumulation in any network configuration.

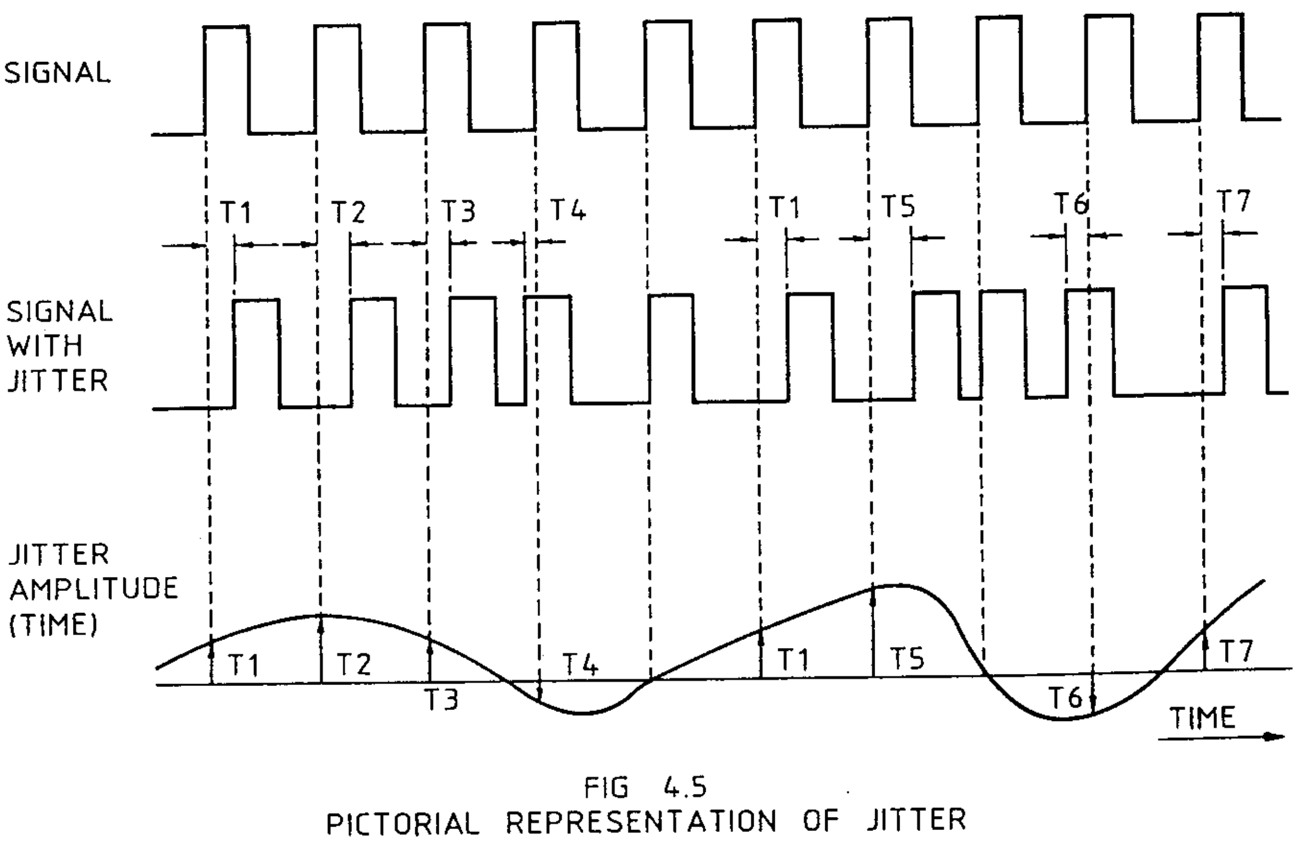


FIG 4.5
PICTORIAL REPRESENTATION OF JITTER AND ITS EFFECT ON A DIGITAL SIGNAL

CCITT has specified the highest limits of the network interfaces for every hierarchical interface from 64 kbit/s upwards. These limits are valid in the whole network.

The incoming jitter tolerance of various digital interfaces has been defined. This input jitter specification is independent on the type of equipment. For practical measurements the input jitter has been specified by the following figure. Jitter tolerance is measured using sine-wave principles.

Digital multiplex equipment and transmission systems also specifies jitter transfer function. Accumulated network jitter can exceed the specified limits, but this can be reduced by special low bandwidth equipment called jitter reducers.

The main sources of the jitter are digital repeaters in the transmission equipment and digital multiplex equipment.

Jitter increases in digital repeaters where the signal will be regenerated in proportion with the square root of the number of repeaters. The repeaters exist mainly in metallic pair cables. The applications of metallic pair cables are limited in power systems but, however, the jitter from this source is probably low. Optical systems do not normally have repeaters except for long links. Radio systems have repeater stations but the jitter characteristics of the radio terminals are confined to the digital multiplex equipment.

The plesiochronous digital multiplex equipment specified by CCITT operate as low-pass filters for jitter. The phase-locked loop in the demultiplexer filters the high frequency jitter components. On the other hand this equipment can accumulate low-frequency jitter. This phenomenon is caused by the justification process of the digital multiplex equipment. These instances depend on the actual phases of the clock signals of the tributaries. The phase changes in the incoming signals, including the incoming jitter, cause low-frequency jitter in the output signal clock. This jitter is normally called waiting-time jitter and is estimated to accumulate proportionally with the number of digital multiplex equipment. Synchronous multiplex equipment is not a jitter source.

The number of digital multiplex and radio terminal equipment in the same connection may be very high and jitter may exceed the specified values. The jitter specifications are not actually dependent on the use of the network but they are more dependent of the techniques. Thus the same specifications are also suitable for dedicated networks.

4.5 A/D-Conversion

CCITT has specified the basic PCM coding using 8 bits. The deterioration caused by this basic quantity is defined as one quantitive distortion unit, reference (10). N consecutive basic quantity thus equals N qd. This is only an estimated definition because the deterioration caused by quantisation is difficult to measure. In addition the deterioration influences the speech and data in different ways. CCITT has defined 14 qd as the maximum deterioration in an international connection and five is reserved for each national portion. However seven qd is allowed for the intermediate period.

The following table 4.5 has been prepared to help network planning.

Digital process	Quantizing distortion units
Processes involving A/D conversion	
8-bit PCM codec-pair (according to Recommendation G.711 (2) A or u-law)	1
7-bit PCM codec pair (A or u-law)	3
Transmultiplexer pair based on 8-bit PCM A- or u-law (according to Recommendation G.792)	1
32 kbit/s ADPCM (with adaptive predictor) (combination of an 8-bit PCM codec pair and a PCM-ADPCM-PCM tandem conversion)	3.5
Purely digital processes	
Digital loss pad (8-bit PCM, A- or u-law)	0.7
A/u-law or u/A-law converter (according to Recommendation G.711 2)	0.5
A/u/A law tandem conversion	0.5
u/A/u law tandem conversion	0.25
PCM to ADPCM to PCM tandem conversion (according to Recommendation G.721)	2.5
8-7-8 bit transcoding (A- or u-law)	3

Table 4.5 Quantifying distortion of various digital processes.

The power systems telecommunication networks contain non-standard coding probably more often than public networks. The number of them, however, is normally limited in the same connection. The CCITT value 5 may be suitable. Speech requirements allow a higher qd value but, for possible high-speed modems, the quantitive distortion is limited.

4.6 Transmission Level Plan

CCITT has given the specifications concerning the connection of private network into the public telecommunication network, reference (11), which deals only with analogue techniques.

The four-wire connection may in principle be without loss except in terminal exchanges where the connection is changed to a two-wire type. If the connection contains two-wire transit exchanges it may be necessary to add loss to keep the stability.

Digital exchanges are in key positions as for the transmission plan in the network. If the A/D-conversion is made in the exchange it is possible to adjust the signal levels in the analog side of the exchange. The use of digital loss circuits (PADs) should be avoided if possible.

SECTION 5 DESIGN CONSIDERATIONS OF DIGITAL NETWORKS

5.1 General

The main requirements to be considered in the design of a telecommunications network are:-

- capacity
- quality
- availability

In order to define correct targets for these requirements, one should analyse:

- user services to be provided
- transmission facilities required by each user service
- switching connectivity
- traffic availability characteristics for each user service
- error performance required by each user service
- services integration

The planning engineer must also have in mind other factors such as regulatory constraints, access conditions to this network, ability for interconnection to other networks, economic aspects, and so on.

5.2 Digital Hierarchy and Network Levels

5.2.1 Network levels

Digital transmission of both telephony and data is a well known transmission mode. The standard form of transmitting digital signals is by Pulse Code Modulation (PCM). PCM is the name given to a process of sampling an analogue signal, quantifying the sample amplitudes then encoding to generate a digital signal representing the quantified analogue samples. Time division multiplex (TDM) is used to assemble a number of channels together ready for transmission.

A number of digital hierarchies do exist, the ITU through CCITT recommend the bit rates and channels as follows:-

HIERARCHY	EUROPE		U.S./CANADA		JAPAN	
LEVEL NO.	MBIT/S	CHS	MBIT/S	CHS	MBIT/S	CHS
1	2.048	30	1.544	24	1.544	24
2	8.448	120	6.312	96	6.312	96
3	34.368	480	44.736	672	32.064	480
4	139.264	1920	274.176	4032	97.728	1440
(5	565	7680	-	-	392.200	5760)

Level 1 is called the primary multiplex
Level 2 is second order
Level 3 third order and so on

Table 5.1 CCITT recommended bit rates/channels

Generally accepted synchronous hierarchial data rates are:- 48, 56, 64, N x 56 and N x 64 kbit/s.

In the CCITT primary multiplex system there are 32 time slots, number 0 to 31 that make up each frame. Time slot 0 is used for frame alignment and time slot 16 is used for signalling. This leaves slots 1 to 15 and 17 to 31 i.e. 30 slots or channels for telephony or telemetry. A frame structure for CCITT 2 Mbit/s digital systems is shown in figure 5.1.

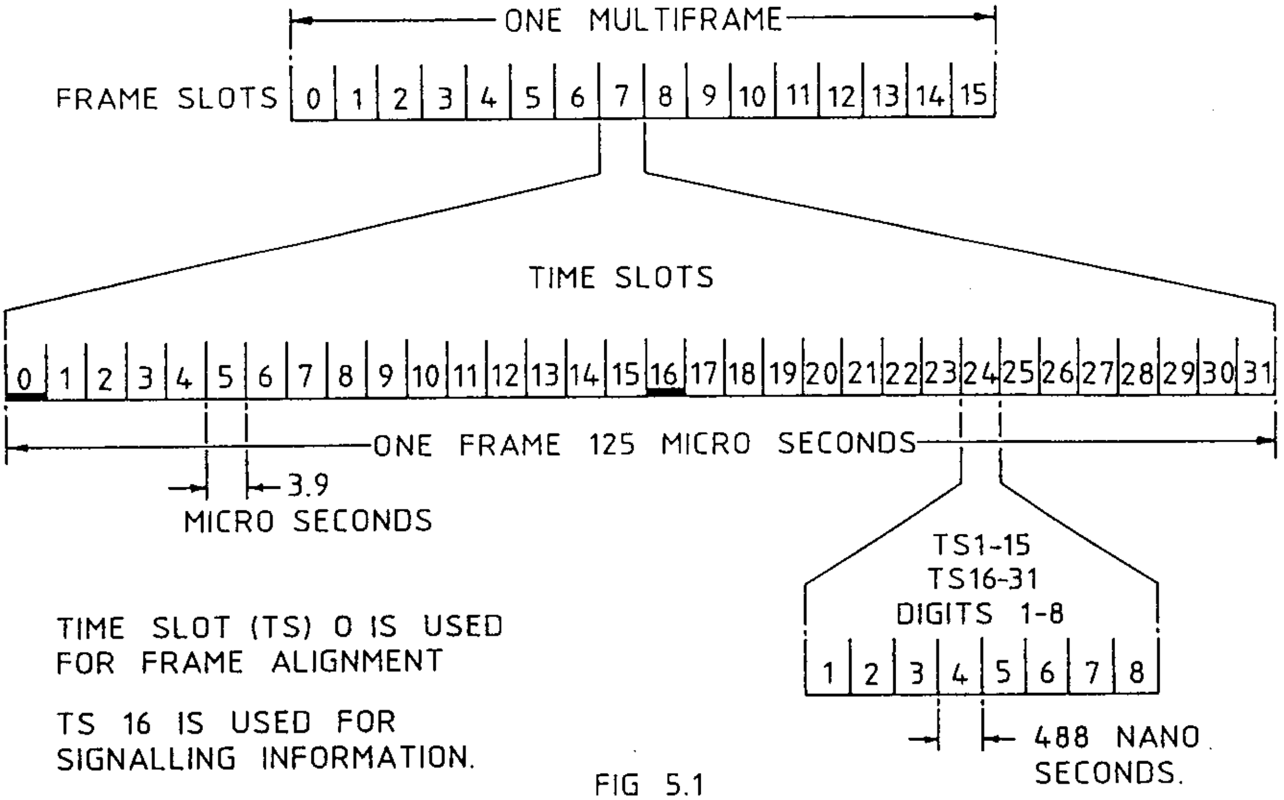


FIG 5.1
FRAME AND MULTIFRAME STRUCTURE
FOR CCITT 2 Mbit/s DIGITAL SYSTEM

In the same way that analogue frequency division multiplex systems are arranged in groups and supergroups so digital multiplex is arranged in hierarchy levels. The equipment used to combine digital multiplex into hierarchy levels is called muldex.

5.2.2 Synchronous digital hierarchy (SDH)

CCITT have recently introduced recommendations specifying details of the new synchronous digital hierarchy namely G.707, G.708 and G.709.

The basic advantages of SDH are:-

1. Simplified multiplexing/demultiplexing techniques

2. Direct access to lower speed tributaries without the need to multiplex/demultiplex the entire high speed signal

3. Enhance operations administration and maintenance capabilities

4. Easy growth to higher bit rates in step with the evolution of transmission technology.

5. SDH drop/insert multiplexers offer significant cost benefits.

Whilst the design of the synchronous digital hierarchy has been based primarily on considerations of high speed optical fibre transmission, it is important that radio relay systems should also be a transmission option if the systems designer is to have the maximum flexibility and economic alternative. With radio relay systems it will be important that they should be capable of carrying the new hierarchy whilst retaining compatibility with existing radio frequency channelling plans.

The basic bit rate of the new SDH is 155.52 Mbit/s known as the synchronous transport module -1 (STM-1). The next higher level bit rate is 622.08 Mbit/s or STM -4 and comprises four STM -1 signals. Higher levels of STM -8, -12 and -16 are at present under study by CCITT.

The basic STM -1 frame structure provides overhead capacity for operations and maintenance functions such as performance monitoring, automatic protection switching and engineering order wire.

It will be necessary for radio systems supporting the new SDH to use high order modulation methods such as 64 QAM and 256 QAM in order to be accommodated in existing frequency channelling plans. Future short haul systems operating at frequencies above 17 GHz and providing 155 Mbit/s transmission could use simple modulation systems such as QPSK.

5.3 Digital Network Components

The different elements of the digital network are assembled in transmission links and nodes, and digital switching nodes. The various elements of the digital network are covered in other sections but care must be taken at the design or project definition stage in particular to the network nodes. It is essential that all components associated with network nodes provide standard interfaces but other node functions requiring special attention such as:

A) Synchronisation
At a nodal switch digital signals will require to be handled, which even if formats are standard, will be referenced to separate clocks, Section 5.6 covers this aspect in a little more detail.

B) Digital Cross Connection
Many nodes will be used for the drop and insertion of digital information but a more difficult problem is that of cross connection of the signals from the transmission path to another to ensure the correct channel connections are made.

C) Digital Switching
With the advent of software controlled switching systems (PABX and multiplexers) there has been a trend towards digital switching.

Most trunk networks today are digital with any analogue to digital conversion necessary being done as close to the tail circuit (e.g. the telephone instrument) as possible.

These digital networks consist of digital pulse code modulated (PCM) streams which are frame aligned into channels, 24 channels in North America (T1) and Japan and 30 channels in the rest of the World.

Each channel in either of these frame types consists of eight bits with a transmission rate of 8 kbit/s to give a total transmission rate of 64 kbit/s for each channel. Digital switching is the process of operating on these digital channels, thus a switching matrix with four incoming and outgoing digital streams each consisting of 24 or 30 (64 kbit/s) channels can switch, under micro-processor control, any one incoming channel to any outgoing channel position. Generally each 64 kbit/s channel contains only one voice or data call, however the latest techniques such as voice compression and sub-rate multiplexing mean more than one call can be carried in each 64 kbit/s channel and the latest digital switch technology enables the switching of individual 8 kbit/s within a 64 kbit/s channel, to take fullest advantage of these schemes.

The transmission links can be provided by the following system

- copper cable
- radio link
- optical fibre
- satellite

If cable is required for the transmission medium then optical fibre cable is preferable because of the wide bandwidth capability. With the ever improving production techniques the capital cost of optical fibre is reducing and their operation is now well defined and documented, see Section 6. However, when copper cables already exist, they can be the most economic and simple way to interconnect nodes, avoiding the usually high prices of new cable installation. In these, care should be taken with the length of the regenerative sections and the regenerator installation.

Radio Link Systems form an important part of modern telecommunication networks. In highly developed countries they complement line transmission systems to form an integrated transmission network. The use of two transmission media (radio and optical fibre) will improve the reliability factor for the network as a whole, since there is no significant correlation between the occurrence of a fault on either medium. In less well developed countries where the terrain between cities is often difficult, radio systems are sometimes the only practical means of providing multichannel transmission medium. The properties of radio links are determined by the mechanisms affecting the propagation of the radio waves and these depend on the frequencies used for transmission.

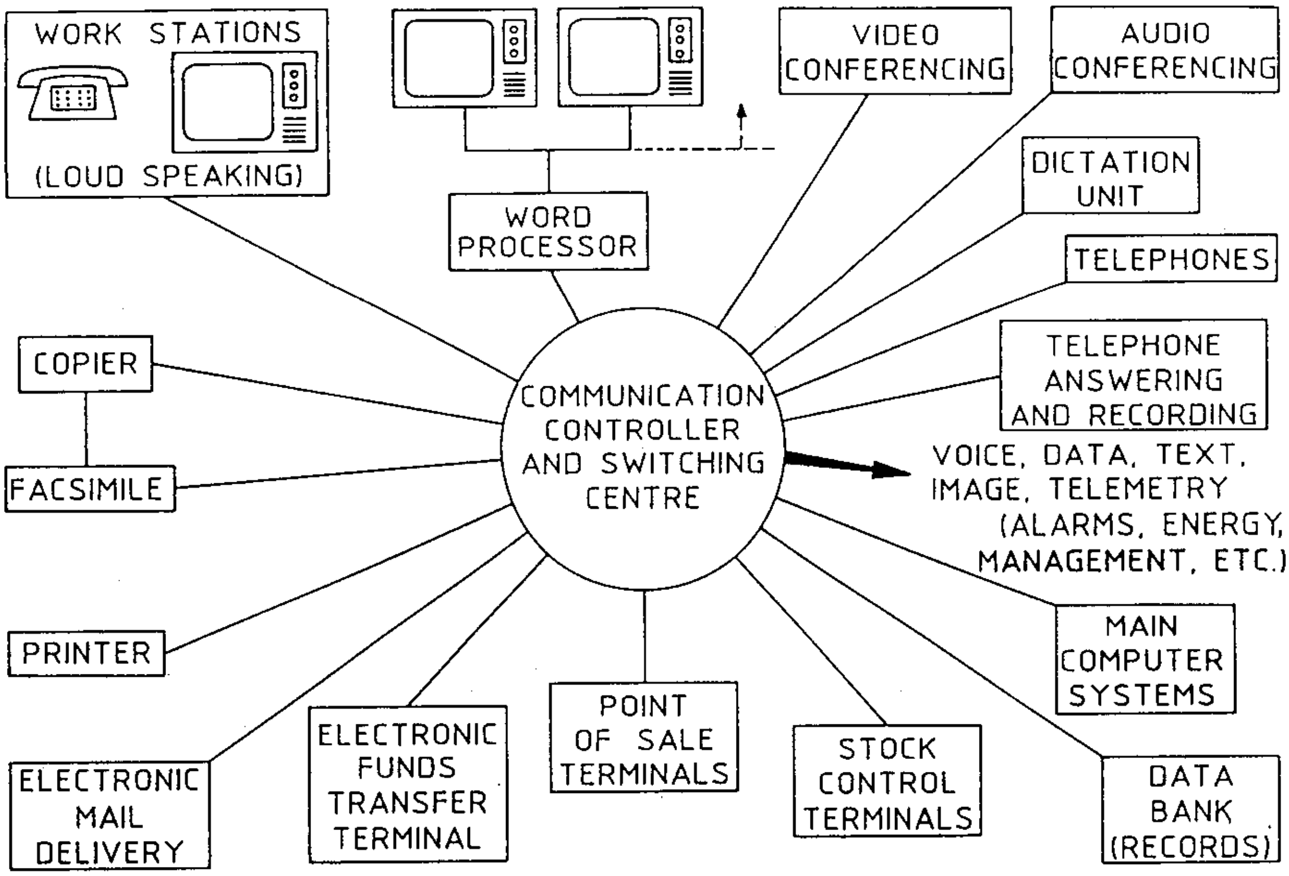


FIG 5.2

TYPICAL BUSINESS INTEGRATED SERVICES DIGITAL NETWORK.

There are a great variety of telephone exchange systems in the world. The reason is that until recent years, the system differences have not had much to do with the types of service to be provided. Rather they have arisen from a drive for capital and maintenance economy in exchange and external plant.

New systems now being introduced are attempting to go beyond the fundamental requirement of telephony and to increase the range of marketable facilities available, hence the network shown in figure 5.2 where the central point is the switching centre or exchange.

Although the switching mechanism is still a significant factor, its importance in system design has, in the newer systems, receded somewhat in relation to that of other factors, such as the concentration and enhancement of the intelligence of the switch. Until comparatively recent times exchange switches have relied exclusively on space division switching. That is, different calls are connected through different paths separated in space. A switch contact connects a conversation at the beginning of a call, remains operated throughout, and handles no other calls until the end.

An alternative method of switching is called time division switching. If speech is sampled by a periodic train of short duration pulses, so that intelligence is passed in small slots of real time, the switch for a particular call need only be operated at the corresponding time slots. For the remainder of the time the switch is available to handle calls carried out in other time slots. A saving in switches may thus be achieved, although storage is required to retain the switch operating instructions for each call. A further advantage is that the switches will be electronic using semi-conductor devices, and hence not subject to mechanical wear.

Time division switching aligns perfectly with digital transmission because the incoming and outgoing signals on the junction are already in time division multiplex form.

The time division switch or digital switch as it is commonly called is the control point around which the modern integrated digital services network (ISDN) is built. It is capable of stored program control, fast signalling methods and switching of all forms of telecommunications including telegraphy, telephony, high speed data and television.

5.4 Digital Network Types

Usually three types of digital networks are considered. The differences between them deal with the ways in which they satisfy the multiple services required for the networks and the degree of integration to be achieved.

In the first type, the classic one, the services are provided by separate systems, possibly using common carriers but with separate system functions and switching equipment.

In the second type, the so-called Integrated Digital Network (IDN), the digital transmission and digital switching systems are interconnected, without need for analogue/digital conversion between the two processes.

The digital switching nodes and digital transmission links are combined and integrated, simplifying the network, increasing the reliability and reducing costs.

Within the third type, the Integrated Services Digital Network (ISDN), the users have access, by a limited set of standard multi-purpose user-network interfaces, to a wide range of services, including voice and non-voice services. Here all services are achieved in one single network, with significant reduction in the transmission capacity required. The integrated services digital network (ISDN) is the currently accepted version of the future telecommunications network. It is the logical end result of the progressive introduction of digital technology through transmission switching and local loops. The concept of ISDN has created great interest in business and commerce.

Such is the importance of this development in communications that CCITT study group XVIII have a mandate to produce guidelines and recommendations on ISDN's. (Refer also to Section 3.3.2).

There are many variations and possible types of service that can be offered, a selection is shown in figure 5.2. It could be the case that this is a small business office or it is one of many centres to be connected together. If this was one of many centres, it would be counted as a nodal point in the system. The system can be connected together by the public service telecommunications network or by private transmission links provided by the user. Transmission can be achieved by using cable, preferably optical fibre or radio links.

5.5 Network Topology

The topology or architecture of a communications network identifies how the various locations within the network are interconnected. The most common topologies used are point to point, the star, the bus or multidrop, the ring or loop and the mesh as shown in figure 5.3.

The design of the network configuration is largely dependent on the hierarchy of the operating structure and philosophy of the undertaking as well as the power generation and transmission network, the services to be provided and correspondent availability targets. It is known that system availability can be achieved either with single routing and high availability demands on every route, or with alternative routing with less rigorous demands on each route.

5.6 Protection

Because of financial considerations or more important for health and safety reasons more stringent reliability requirements are demanded for the transmission of telecommunications traffic. To achieve satisfactory performance, protection switching equipment may be necessary. The protection and high availability traffic or resilience of a system can take several forms and these are now discussed further:-

(a) The transmission link equipment can be protected by using standby equipment, in the case of line systems this can take the form of a second cable switched into use on the failure of the main cable. Radio links can be protected by employing two transmitter receivers using one as the main equipment and the second in a standby mode ready to be switched on in the event of failure of the main equipment.

(b) The latest type of digital multiplex is being designed to include microcomputers which give the potential for built in intelligence. This event has opened up a new range of facilities on digital multiplex one of which is route protection switching. In effect, the combination of digital multiplex and a microcomputer makes a network manager which can be programmed to operate automatic adaptive route selection. If any route had a malfunction in a particular link which was unuseable, then the multiplex would route all traffic round the loop to ensure the inoperative link was not used. After repairs the system would revert back to normal. Software could be produced to cater for many system configurations.

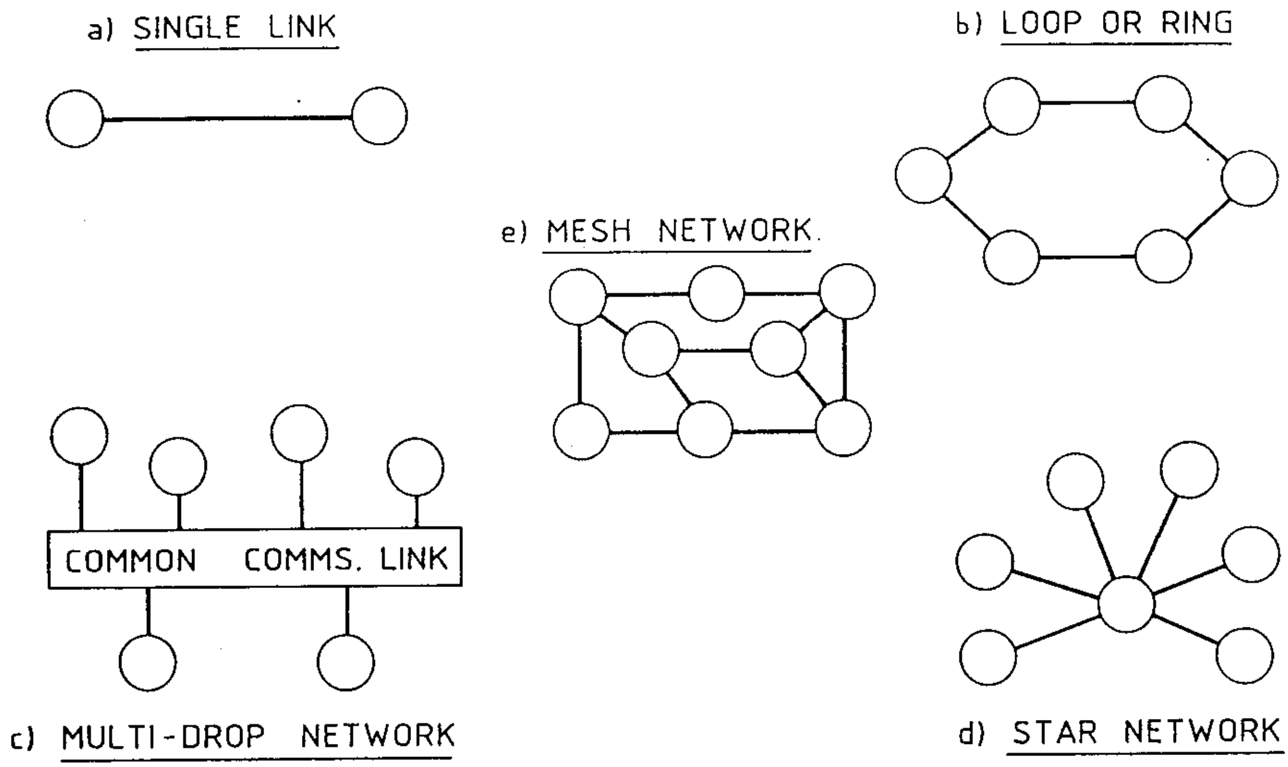


FIG 5.3 NETWORK CONFIGURATIONS

5.7 Synchronisation

In a network, synchronisation is one of the more important problems since an inadequate timing control of signals and processes can lead to a significant rate of slip occurrences, and an unacceptably impaired transmission performance. It is important to have a single source of network timing. Without this single source of timing the network will experience slips on inter-node links.

When the rate at which data is clocked into and out of a node differs, the receive buffer will overflow or underflow causing an impairment to be introduced into the bit stream. This is referred to as slip, see Sections 3 and 4.

Voice services are relatively insensitive to slips. Slip rates as high as 100 per hour can be tolerated. Where the network is carrying data traffic, e.g. facsimile, data or video services, high slip rate cannot be tolerated as it will result in lost information and degraded service.

When designing a network the objective is to select a primary source of timing which is the most accurate available. Most public telephone organisations offer a national reference clock, termed a stratum 1, which is accurate to 1×10^{-11}. Once this primary source of timing has been selected the rest of the network, no matter how remote from the primary source, should be designed to derive its timing from the source.

Designing a network synchronisation plan requires a lot of thought, most designs of PABX and multiplexer offer alternative sources in the event of failures. The multiplexer could offer a primary source and a number of alternatives, when assigning alternatives care must be taken not to set-up synchronisation loops or choose situations where two nodes are trying to synchronise to each other. Some designs of network management systems can assist in the design of synchronisation plan by advising at the programming phase of possible problems and clashes. Some multiplexers also offer a feature called automatic alternate clock selection. This facility allows nodes in the network to talk to each other and decide on the most appropriate path to the primary source of synchronisation. This may mean over-riding the node selection procedure.

There is a situation where slips cannot be avoided, for example when a network crosses international boundaries. In this case there will probably be a primary source of network synchronisation in each country.

The objective must be to keep slips to a minimum. This is achieved by selecting the most accurate source available in each country. If a stratum 1 clock is available in each country a slip will occur only once every 70 to 80 days. If on the other hand both clocks meet the minimum CCITT requirements, ± 50 ppm, a slip will occur every $1.2\overline{5}$ seconds. The important thing is to plan your network, talk to your supplier of the equipment and use available network management tools to make sure your problems are minimal.

In most Countries bit rates and primary clock frequencies are governed by CCITT. Recommendation (12) requires that the transmit clock frequency of a primary multiplex terminal be within the limits of 2048kHz $\pm$50ppm and also that the absolute bit rate of any basic nominal 64kbit/s traffic channel will be derived from the transmit clock timing source of a primary multiplex terminal.

The same recommendation also states that the transmit timing signal (clock) should be capable of being derived from an internal source from the incoming structured digital line signal or from an external source.

Most manufacturers meet these requirements by providing a simple crystal controlled internal source which is capable of being locked to a synchronising signal as defined in (13).

There are two forms of basic synchronising system, systematic or master/slave synchronisation and mutual synchronisation. Figure 5.4 shows the general arrangements of the 2 basic systems. In systematic or master slave systems a hierarchy of system levels is formed, each node of a particular level extracting its network timing information from a higher level node. The network reference node resides at the level one node and would normally be protected by the provision of a standby source. Figure 5.4a indicates how synchronisation is achieved by conveying a timing reference from one clock to the next via a suitable transmission system and phase locking the slave clock to the reference. Hierarchies of clocks can be established with some clocks being slaved from higher order clocks and in turn acting as master clocks for lower order ones.

The arrangement ensures that the network is stable by preventing any clock receiving a reference derived from its own content and generally matches the topology of the network of clocks with the hierarchy of exchanges in communications networks. This network is vulnerable to faults in the transmission links interconnecting clocks, outages cause frequency errors and, therefore, slips.

If the importance of the traffic warrants it this limitation can be overcome by replicating the links interconnecting the clocks so that at least two simultaneous transmission system failures are required to disrupt the operation of a synchronisation network.

Figure 5.4b shows an example of a practical network with mainly duplicated transmission links, following diverse routes, where possible, between clocks. Only one of the synchronisation references available to any clock is selected as a working reference and the details of this process vary from network to network.

A mutual synchronisation system is shown in figure 5.4c. It contrasts with the master slave system in that all clocks are interconnected. There is no unique reference clock and there is no underlying hierarchical structure. In this system, each clock is phase locked to a reference derived from several other clocks. Whilst a mutually synchronised network can provide an extremely robust timing system the complexity and cost generally restricts its use to military or revenue earning common carrier networks. It is not unusual in PTT networks to find hybrid synchronisation systems in use, where a form of mutual synchronisation is used at high level switching or transmission nodes and master slave synchronisation at the lower level nodes.

Alternative network arrangements

It should be noted that digital telecommunications network applications may be both plesiochronous or synchronous. In the case of plesiochronous operation, clocks are not synchronised and may vary at rates contained within specified limits.

The arrangement for 2 Mbit/s streams into an 8, 34 or 140 Mbit/s stream may be undertaken with a plesiochronous solution, slip occurrence may be avoided by a justification and buffering technique. It is, however, normal practice that the insertion/extraction of 64 kbit/s streams in a single 2 Mbit/s stream would be synchronous.

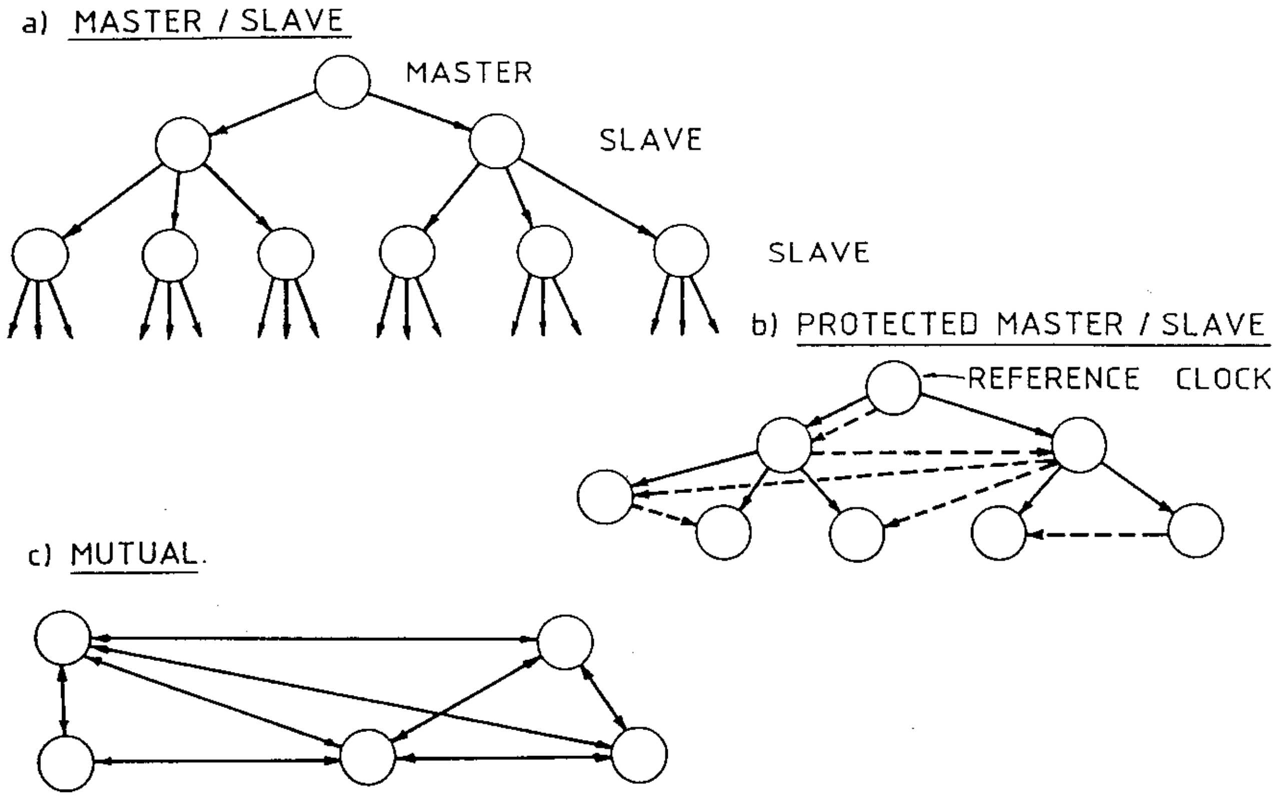


FIG 5.4 SYNCHRONISATION ARRANGEMENTS

This would apply when voice coding requires the full 64 kbit/s capacity, or where data is transmitted in the 64 kbit/s stream as recommended in Reference (13A). CCITT X.51 Recommendation recognises this situation and allows plesiochronous arrangement of the 64 kbit/s streams into a single 2 Mbit/s stream using a positive - zero - negative justification process. Each stream is partitioned into 60 kbit/s payload for speech/data (e.g. 32 kbit/s ADPCM) with 4 kbit/s of padding for justification and link control. This arrangement does not require the clocks to be synchronous.

5.8 Interconnection between Digital Networks

It will be necessary to provide an interface between digital systems. To try and gain some uniformity of interconnection of digital networks, CCITT have produced a set of recommendations for bit rates, levels and impedance. Basically, two types of interconnection exist, one for the multiplex/line/radio level and the other at the data level, reference (13).

CCITT Recommendation G.703, Reference (13) also defines general aspects of the interface and interconnection of 64 kbit/s, 2.048, 8.448, 34.368 and 139.264 Mbit/s. The definition of HDB3 code is also given.

5.9 Access to Digital Networks

CCITT have a V series of recommendations for data communications over the telephone network. The series is numbered V.1 to V.57. Very useful ones in the series are V.24, which contains a list of definitions for interchange circuits and V.28, electrical characteristics for unbalanced double current interchange circuits. The CCITT X series of recommendations deals with data communications network services and facilities, terminal equipment and interfaces. The series are numbered X.1 to X.21.

Much useful information is contained in this series; two are selected for particular interest: X.21 - General purpose interface between data terminal equipment and data circuit terminating equipment for synchronous operation on Public Data Network; X.25 - Interface between data terminal equipment and data circuit terminating equipment for terminals operating in the packet mode on Public Data Networks.

It is also worth mentioning the RS standards, in particular RS232C (13B) which defines the interface between data terminal equipment and data communications equipment employing serial binary data interchange. This standard defines signal levels and pinout on connectors. The EIA RS232C counterparts for CCITT are Rec.V.24 and V.28. (Reference 13C).

5.10 Regulations

5.10.1 Introduction

In addition to the fundamental technical and economic constraints, which must be considered when planning the telecommunication networks, there are a variety of regulatory restrictions which apply in many countries to the construction and use of telecommunication networks. These regulatory constraints must also be given due attention at the network planning stage.

The regulations which exist in different countries in this regard vary a good deal depending on the structure and organisation of the telecommunications industry in the country and are most restrictive in countries where the provision of public telecommunication services is a monopoly of the PTT.

In these countries, telecommunication regulations are generally restrictive in nature and are designed to limit the extent of private networks in the interest of preserving the monopoly of the national telecommunication carrier. In countries where regulations have been relaxed, power utilities have considerably more freedom in their choice of alternatives and the decision on whether to lease services or develop a private network and on the extent and type of network to be established is usually based more on economic and reliability considerations than on regulatory constraints.

5.10.2 Regulatory regimes

There are a variety of regulatory regimes which exist in different countries for the control and organisation of the public telecommunication networks.

The regulatory environment is rapidly changing and the organisations involved in regulatory matters are having to adjust to the changing environment. Hence any clarification of regulatory regimes is likely to be valid only for a limited period. The following types of regulatory regimes currently exist:

(a) PTT Monopoly. In countries where a PTT Monopoly exists, a government department or agency has an extensive monopoly of public telecommunication networks.

(b) Monopoly with Concessions. In these countries, a private company is given a monopoly of basic 'carrier' service. The Monopoly may be general or confined to some particular service or geographical area. Private Telecommunication Networks are permitted only as a concession.

(c) Deregulated Arena. In countries where deregulation has been introduced or is proposed, the provision of public telecommunication network services is by private telecommunication companies, either in open competition, or in a licenced arrangement.

5.10.3 Restrictions on network services

In countries where the provision of public voice and data networks is the exclusive privilege of the PTT, private telecommunication networks are permitted only as an exception to the monopoly and only under special circumstances. In these countries power utilities are permitted to operate private telecommunication networks but usually only for communications relating to the control and operation of the power supply system. The use of the power utilities private network for corporate, administrative and general purpose communications is generally prohibited.

While there is some variation between different countries in what is regarded as an operation need, the communications required for SCADA, load dispatching, protection, operation and maintenance of the power network are generally accepted as being sufficiently critical to be included in this category. In general, the power utilities administrative communication needs must be met by using the public telecommunication network.

There are some exceptions to this general rule. To improve the reliability of communications, power utilities in some countries are permitted to use channels on their private networks as a back up to PTT channels. In these situations, traffic is normally routed via the public network and under fault conditions it is routed over the private network. In remote areas, where public service facilities do not exist, power utilities in some countries are permitted to use their private networks for administrative communications.

5.10.4 Restrictions on interconnection

In countries where private telecommunication networks are used to carry administrative traffic, there are usually restrictions placed on the extent of interconnection permitted with the public network. These restrictions are generally designed to prevent by passing of the PTT network by private systems. Different regulations apply in different countries in this regard. In many countries, PABXs must be programmed so that connections between users in the public network cannot be established via the PABX (c.f. Section 7). Most countries prohibit the interconnection of PLC and public network circuits because of safety reasons. In one particular country, Public Switched Telephone Network (PSTN) traffic is permitted on private networks only if the network is constructed entirely of leased circuits.

In addition to identifying restrictions on the physical interconnection of public and private networks there is a need to distinguish between services which networks can provide. The basic network services have traditionally been provided by the PTTs, but value added network (VAN) services which include more advanced telecommunication services such as electronic mail and store and retrieval message systems are increasingly being provided by private companies. There is a growing acceptance by regulatory authorities that private companies should be free to provide VAN services and regulations are being formulated accordingly.

5.10.5 Restrictions on network construction/ownership

In some countries, where public telecommunications are a monopoly of the PTT, the construction and ownership of certain types of telecommunication equipment by private users is restricted. Radio equipment in particular has been subject to special regulations and in certain countries must be supplied and maintained for the power utility by the PTT.

5.10.6 Restrictions on use of broadband media

(a) Microwave Links

In almost all countries, power utilities must obtain the approval of the PTT or a regulatory body such as the Department of Communications (DOC) to operate a private radio network. There are regulations governing band allocations and frequency assignment plans which stem from CCIR recommendations and regulations covering licencing and general administrative matters. The regulations are often complex and the approval procedures involved can be complicated and time consuming.

In general, power utilities must take application to the appropriate authority for permission to operate fixed link radio equipment in the same way as other private users. Frequencies are generally reserved for this purpose and are usually allocated according to internationally recognised RF channel arrangement patterns. Power utilities are often restricted in the capacity of the systems which they are permitted to use by the bands assigned to them by the regulatory authorities. The bands which are made available to power utilities are usually those for which narrow spaced frequency allocation plans are specified, and are therefore suitable only for small capacity systems.

Because of congestion in the lower frequency bands power utilities, in common with other private users have been obliged in recent years to seek frequencies in the higher bands for fixed link communications, and are often encouraged to do so by the regulatory authorities particularly where short hops in urban areas are concerned. Because the radio spectrum is a finite resource, regulatory authorities are conscious of the need to preserve frequencies and often favour the use of landlines wherever these can be provided. In some instances it may be necessary for the power utility to justify its application for a licence to operate a private radio link on the grounds of safety and security of operations. Difficulties in obtaining frequency assignments for power utilities can be experienced in some countries. However, the position has improved in recent years as the importance of efficient telecommunications, and the special needs of power utilities have become more widely recognised.

In addition to band limiting constraints there are other restrictions imposed on the capacity of microwave links which power utilities are permitted to use. In one particular country, the capacity of the microwave link permitted for power utilities applications is determined by the functions for which it is required.

(b) Optical Fibre

Optical Fibre has the advantage over microwave radio of being free from spectrum management considerations and from regulations which govern spectrum usage and power utilities therefore may have more freedom to use optical fibre systems.

In countries where public telecommunications are a monopoly of the PTT, the use of optical fibre is, of course, subject to the same restrictions as other telecommunications media, where administrative or corporate telecommunications is concerned. In countries where telecommunications have been de-regulated, power utilities are generally free to use optical fibre systems for corporate and administrative communications.

The wide bandwidth characteristic of optical fibre allows high capacity links to be used and in some countries where regulations do not restrict use, some power utilities have found it advantageous to install high capacity optical fibre systems and lease/sell surplus capacity to other users. The legality of doing this in a particular country should be investigated locally at the planning stage.

Where it is proposed to install optical fibre cable on existing power line/cable routes, the original right of way and local planning approval may require modification to allow use of optical fibre cable. Safety regulations relating to loading of towers/poles and regulations covering the minimum free distance of the cable from ground (i.e. minimum clearance distance) must also be observed.

5.10.7 Fees

In some countries, power utilities are required to pay a fee for operating a private telecommunication network and different fee structures exist. In some countries the fee is charged on the basis of bandwidth occupied, in others the fee is charged on the basis of traffic lost by the PTT and in other countries a flat rate applies. There are also licence fees required for radio equipment and these are usually charged on an annual basis.

5.10.8 Deregulation

Revised and more liberal legislation regulating private telecommunication networks has been enacted, or is about to be introduced in a number of countries at the present time. In general, the new legislation aims at removing many of the restrictions which apply to private telecommunication networks and abolishing the monopoly which some PTTs currently enjoy. Because the legislation is new, the full extent of deregulation and its effects on power utilities telecommunication networks is still unclear. However, it is likely that the new regulations will allow power utilities to use their private networks for corporate and administrative traffic as well as operational needs and to sell/lease surplus capacity in their networks to other users.

It can be expected that deregulation will provide a more liberated environment for private network users and will allow power utilities considerably more freedom to design, construct, operate and maintain private telecommunication networks for both operational and administrative needs of their organisations.

5.11 Design of Power Utility Digital Networks

5.11.1 General

To design power utilities digital networks several important questions must be examined:

- use of public or private telecommunications networks
- type of telecommunication service required by each user service
- quality of service requirements for each user service
- possibility to use the same network resources for different user services

(EXAMPLES OF ACTUAL POWER UTILITY NETWORKS ARE CONTAINED IN APPENDIX B OF THIS GUIDE)

5.11.2 Use of public/private networks

The choice between public or private networks mainly relies upon regulatory constraints, quality of service requirements and economical considerations:

- for user services classified as critical ones, according to Section 3, telecommunications networks are usually exclusively private (links, nodes, switching equipment) because of quality of service requirements

- for user services classified as general ones, telecommunications networks are usually undertaken by public carrier because of regulatory constraints. In some areas, depending on public telecommunications policies and user traffic requirements it may be cost effective to undertake private networks based upon public links, private nodes and private switching equipment.

5.11.3 Characteristics of telecommunications networks required by user services

Telecontrol

Telecontrol networks have a hierarchical structure with several levels (NCC - ACC - DCC - RS)

Telecommunication service required may be permanent point to point links (sometimes point to multipoint in lower levels) or packet switching networks with very short connecting times and transit delays.

Link capacities are usually low (lower than 64 kbit/s even in the higher levels NCC-ACC).

In order to obtain sufficient availability in the network, protecting techniques are used such as

- duplication of transmission links implemented on diverse bearers with automatic switching

- alternate routing in case of use of a packet switching network

Topology of the network is usually starlike or treelike.

Teleprotection

Teleprotection requires a permanent point to point transmission service between the ends of a power line; a very high availability and reliability is required which may require duplication of the transmission media.

Traffic capacity required may be up to a few voice channels or 64 kbit/s data channels.

For analogue type teleprotections transit delay must be very short (typically lower than 4 ms) and stable (typically $\pm$ 0.5 ms).

Operational telephony

Operational telephony telecommunication networks have usually a hierarchical structure similar to the one of telecontrol (NCC, ACC, DCC).

Typical features for this kind of network are:

- starlike structure at the lower levels
- mesh structure on higher levels
- duplication of links with use of diverse bearers in order to perform good availability
- alternate routing between the most important nodes
- limitation in the number of exchanges involved in a connection in order to reduce connecting time.

Traffic capacity required is rather low from a single voice channel on lower level to a few voice channels on higher levels.

Power system load management

This requires high speed multipoint transmission service between a control centre and outstations.

Connections may be established through the telecontrol transmission network.

Traffic capacity required is low (less than 64 kbit/s).

Mobile radio

Power utilities often use mobile radio networks composed of several base stations installed in hill sites managed by a local control unit usually installed in the maintenance centre. Control units and base stations are interconnected.

The telecommunications service required is usually a permanent point to point transmission service. Capacity of traffic on a link between a base station and a control unit is usually one low speed data channel for signalling and a few voice channels to allow interbase station communications.

Video surveillance

The telecommunication service required comprises of a circuit switched transmission service between a critical installation and a surveillance site.

Capacity of traffic required for a connection depends on the quality of the picture (from 64 kbit/s to N x 64 kbit/s).

General services

Services needs of power utilities are very similar to those of other large organisations:

Administrative telephony relies mainly upon the use of PSTN for long distance connections. When the internal traffic of the power utility is important between sites, these may be interconnected by direct inter-exchange links or private circuit switching networks undertaken through private transit exchanges and private or public links.

Some permanent links may also be used to interconnect several switching units of large PABX having a distributed architecture. Traffic capacity required on the links of those networks may be very important (up to a few stacks of 30 voice channels).

In computer data communications, exchanges between computer centres are usually achieved through public packet switching networks. Computer centres exchanging large amounts of data may be interconnected through high speed point to point permanent links. When several computer centres can be found in the same area it may be cost effective to use a private packet switching network composed of nodal packet switching equipment interconnected by high speed digital links and offering an access to the public packet switching network.

These networks usually have tree like or mesh structure. Speeds on the accesses to the packet switching networks may be typically from 4.8 kbit/s up to N x 64 kbit/s.

Telex, facsimile, electronic mail

Facsimile is usually carried by the same network as administrative telephony. When planning the administration telephony network, consideration should be given to the fact that traffic generated by facsimile terminals is growing very rapidly. Telex is often carried on a dedicated network (a public one, or a private one with gateways to the public one).

However the tendency is to integrate all these services in a value added network providing general message exchange facilities. These networks are able to manage a large variety of terminals (computer terminals, teleprinters, facsimile terminals, microcomputers) and provide code conversion facilities.

A power utility may use a PTT value added network or a private one. For private ones the transmission network used may be the same as the one used for computer data communications.

5.11.4 Sharing telecommunication resources

For critical user services requiring a switched telecommunications service it is better to use dedicated switching units and trunk lines because of quality of service requirements (short connecting time, short transit delay).

It should be possible however to share links and nodes between different user services (critical or general). For general services even trunk lines and switching units may be shared between different user services.

SECTION 6 CHOICE OF SYSTEMS FOR TRANSMISSION NETWORK

6.1 Transmission Systems

6.1.1 General

Digital transmission capacities in the telecommunication networks of power utilities are usually small to medium (i.e. up to 8 or 34 Mbit/s), on one hand because of the intrinsic dimension of the supported traffic and on the other hand because a relevant part of this traffic is made up of data signals. As a matter of fact it is well known that data signals are transmitted in a much more efficient way on digital transmission media than on the analogue ones, thereby requiring a smaller global capacity.

Telecommunication networks use, for the transmission of their signals, appropriate transmission systems based on bearers and interfacing equipment. The purpose of the transmission system is to carry signals from one end to the other with as little an impairment as possible, being the impairment expressed in terms of error performance (see Section 4) since the signals are digital ones.

The specific task of the interface equipment is to adapt the digital signal to the electrical characteristics which are typical to the bearer to be used (this operation is normally known under the name of "channel coding").

In the following paragraphs we shall deal briefly, from the point of view of error performance and channel coding, with the transmission systems on copper cables, radio links and optical fibres. (Choice of system depends upon optimum solution link by link).

6.1.2 Transmission using Copper Cables

In the field of transmission using copper pair cables the symmetrical pair cables are more widespread and in practice the only ones that should be taken into account because of their wide use before the advent of digital transmissions. Pairs of cables historically have been the main medium for introducing using digital transmission.

A) Electrical characteristics of symmetrical pair cables

Attenuation and crosstalk as functions of frequency are the fundamental parameters that affect the transmission of digital signals over these bearers.

The attenuation is a function of the characteristic impedance (practically constant with frequency) and of the resistance, which is proportional to the square root of the frequency; the attenuation has therefore this same trend (see fig. 6.1).

On the other hand crosstalk originates from residual couplings due to imperfect balance between the pairs in the practical implementation of the cable.

Two types of crosstalk can be defined:

- far-end crosstalk, characterised by an attenuation proportional to distance and to frequency increasing for both at a rate of 6 dB per octave.

  Rather than far-end crosstalk attenuation (ratio of received crosstalk to transmitted signal) it has become more usual to define the far-end crosstalk ratio (ratio between received crosstalk and received signal) which is dependent of the frequency only.

- near-end crosstalk, characterised by an attenuation depending on frequency only (increasing at a rate of 4.5 dB per octave) and independent of distance.

It should be emphasised that, because of the non controllable nature of the coupling phenomena that cause crosstalk, data relevant to both of these parameters are usually of statistical nature, expressed in terms of mean value and standard deviation. Moreover, in most practical cases, where the pairs used for both directions belong to the same cable, far-end crosstalk is much less limiting impairment than near-end crosstalk, so that we only need to deal with this latter parameter.

Table 6.1 shows for the same cables in fig. 6.1 some data on the near-end crosstalk at the frequency of 1 MHz and in relation with the different possible choices of the pair allocation for the two opposite transmission directions within the same cable.

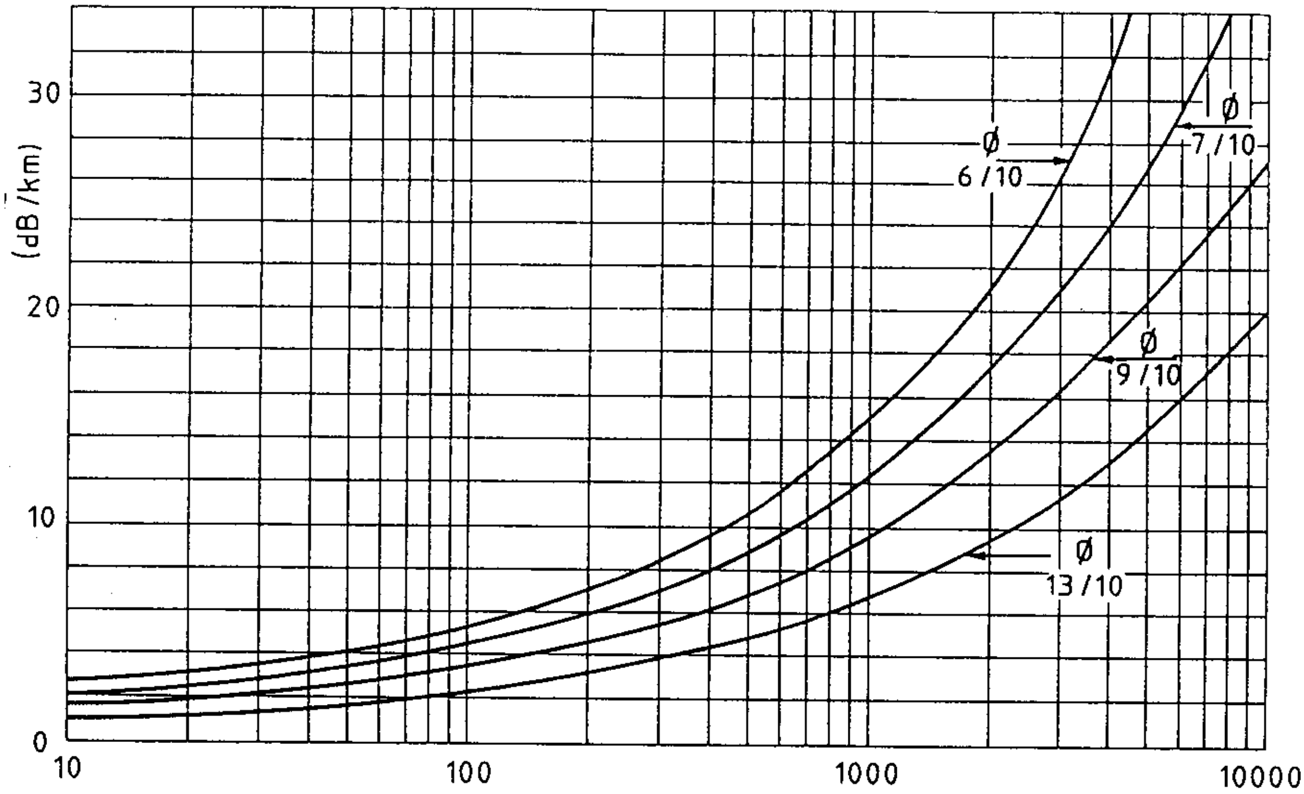


FIG 6.1

MEAN VALUES OF ATTENUATION FOR POLYETHYLENE INSULATED CABLES

Choice of pairs	near-end crosstalk attenuation mean value (dB)	standard deviation(dB)
A	73	11
B	62	8
C_0	56	7
C_1	47	8
C_2	69	7
D	60÷66	11

A = pairs for opposite directions chosen in non-adjacent groups or layers

B = pairs for opposite directions chosen in adjacent groups or layers

C = pairs for opposite directions chosen in the same group or layer:

C_0 = two pairs in adjacent quad
C_1 = two pairs separated by one quad
C_2 = two pairs separated by two quads

D = random choice

Table 6.1 Near-end crosstalk attenuation in low-capacity, plastic insulated, quad cables (Ø = 1.3, 0.9, 0.7, 0.6, 0.4mm)

The examination of the characteristics of attenuation and of near-end crosstalk as a function of frequency show at once that the symmetrical pairs are not suitable for the transmission of digital signals beyond bit rates of 2 Mbit/s and therefore they are limited to the transmission of multiple signals for 30 channels or less (e.g. 10 channels with an aggregate bit rate of 704 kbit/s).

It must be pointed out that other transmission media on copper i.e. coaxial cables, can be used in order to convey greater aggregate bit rates, but taking into account their low usage in power utility networks in most cases it would be necessary to install them now for this purpose. Faced with this necessity, if capacities greater than 2 Mbit/s are required they must be transmitted on optical fibre cables because of the advantages indicated later in this Section and Section 9.

B) Characteristics of the transmission systems on symmetrical pairs

Digital transmission systems have as a common feature the presence of the process of regeneration, i.e. reconstruction of the transmitted digital signal starting from the received one distorted and corrupted by noise during the transmission on the bearer.

A regenerative repeater carries out three functions: reshaping (i.e. amplification, equalisation and filtering of the input signal in order to be able to take a decision on the level), retiming (i.e. timing extraction in order to establish the optimum decision instants) and regeneration (i.e. final reconstruction of the digital signal). It must be pointed out that for efficient retiming it is of course necessary that the received signal contains sufficient energy at the clock frequency.

Regeneraters/repeaters must be placed along the bearer at specified distances to work with a signal to noise ratio that will guarantee a virtually error free transmission. Over the symmetrical pair cables, both because of the attenuation and because of the impairment due to crosstalk, these distances do not go beyond a few kilometres for the range of frequencies we are dealing with. When it is required to cover greater distances, the necessity rises for intermediate regeneraters between the two ends of the connection.

Because regeneraters are active they must be remotely powered using the same pairs over which the main signal is transmitted to avoid the necessity of an additional pair for the power supply. Moreover it will be convenient to terminate the symmetrical pairs in a balanced manner, by the use of transformers, through which it will also be easy to insert the continuous current of the remote power feeding on the same pairs of the main signal. Also it will be a requirement to add to the transmission system a supervisory system for evaluating the behaviour of the transmission system during the service. This may be obtained by taking advantage of peculiar characteristics of the line codes in order to measure the error performance.

C) Scrambling

The advantages of using a scrambler as an integral part of a digital transmission system gives the following advantages:

- Ensure that the accumulation of jitter is not correlated with the signal

- Reduce the effects of low frequency jitter accumulation

- Reduce the effects of crosstalk levels on symmetric-pair cable produced by synchronous systems, by supressing discrete spectral components of periodic bit patterns.

The basic scrambler circuit produces a pseudo-random sequence and the input sequence is exactly duplicated at the descrambler output in the absence of transmission channel errors. Recommendation for scramblers designs for modems is given in CCITT Recommendations V.26 and V.27.

One disadvantage of using scramblers is that they cause error extension effects. This means that any transmission error which under non scrambled conditions would cause only one error in a system, will when the system is in the scrambled condition cause further errors. This is due to the basic operation of the scrambler and the use it makes of a feedback path. CCITT Recommendation G.954 shows the circuit of a re-set scrambler and multiplexer for a 565 Mbit/s digital line system. The scrambler is re-set at the start of each frame and, after resetting generates the frame alignment signal.

The advantages of such a scrambler over a free running or self synchronised type are that there is no error multiplication.

D) Choice of line code

For the efficient transmission on a symmetrical pair cable with regenerative repeaters the binary information must be coded into a suitable symbol sequence (line code), that meets all the requirements established in the previous paragraphs (i.e. easy timing information extraction, low-frequency cut-off, limitation of transmitted bandwidth, in-service monitoring).

All of these requirements may be met by introducing a suitable redundancy in the coded signal. Moreover such a redundancy may be obtained at no increase of the occupied bandwidth by the proper use of suitable multilevel signals, see reference 13 for line codes e.g. 'high density bipolar 3' Code (HDB3).

E) Practical example of determination of regenerative sections on symmetrical pairs

When undertaking practical problems in planning a transmission system using symmetrical pairs, and to establish the maximum length of the regenerative section the following parameters must be taken into account:

- maximum attenuation that can be recovered by the regenerative repeater

- near-end crosstalk and attenuation characteristics of the cable

- maximum number of transmission systems that must be supported by the same cable

- bit error ratio objective

Two of the previous parameters are usually fixed: 10^{-7} as a bit error ratio objective and approximately 40 dB at 1 MHz as maximum acceptable attenuation for 2 Mbit/s repeaters (45 dB at 350kHz for 704 kbit/s systems).

The other two parameters are those on which the actual choice is carried out. In particular as far as the crosstalk characteristics is concerned it is a question of establishing a method to be adopted for the choice of the relative position, inside the cable, of the pairs for the two directions of transmission since the values of the impairment greatly depend on this choice. An easy way to work out the problem is to use the graphs especially developed for this purpose and then take into account the practical implementation of the regeneraters.

Figure 6.2 shows one of these graphs applicable to 2 Mbit/s transmission systems on the same plastic cables for which fig. 6.1 and table 6.1 have already shown the characteristics.

By means of the curves plotted in fig. 6.2 it is possible, starting from the maximum number of systems in the cable and from the criteria of choice of the pairs, to establish the maximum value of the attenuation in dB at 1 MHz allowed in a regenerative section and correspondingly the physical length in km, as a function of the diameter of the pairs used. It can be seen that the limiting factor, when more than one system are supported on the same cable, is near-end crosstalk rather than attenuation.

It must be emphasised that this procedure is based on conservative values, therefore it is possible to establish the length of the regeneration section on the basis of statistical characteristics of cable parameters without the necessity to detail measurements. Better values can be obtained where the limited number of systems involved allows for proceeding to simple in-field measurements.

Example of calculation based on fig. 6.2:

- two 2 Mbit/s systems supported by the same cable

- opposite directions of transmission are supported by pairs in separate layers, even adjacent (i.e. curve b)

- cable diameter of 1.3mm

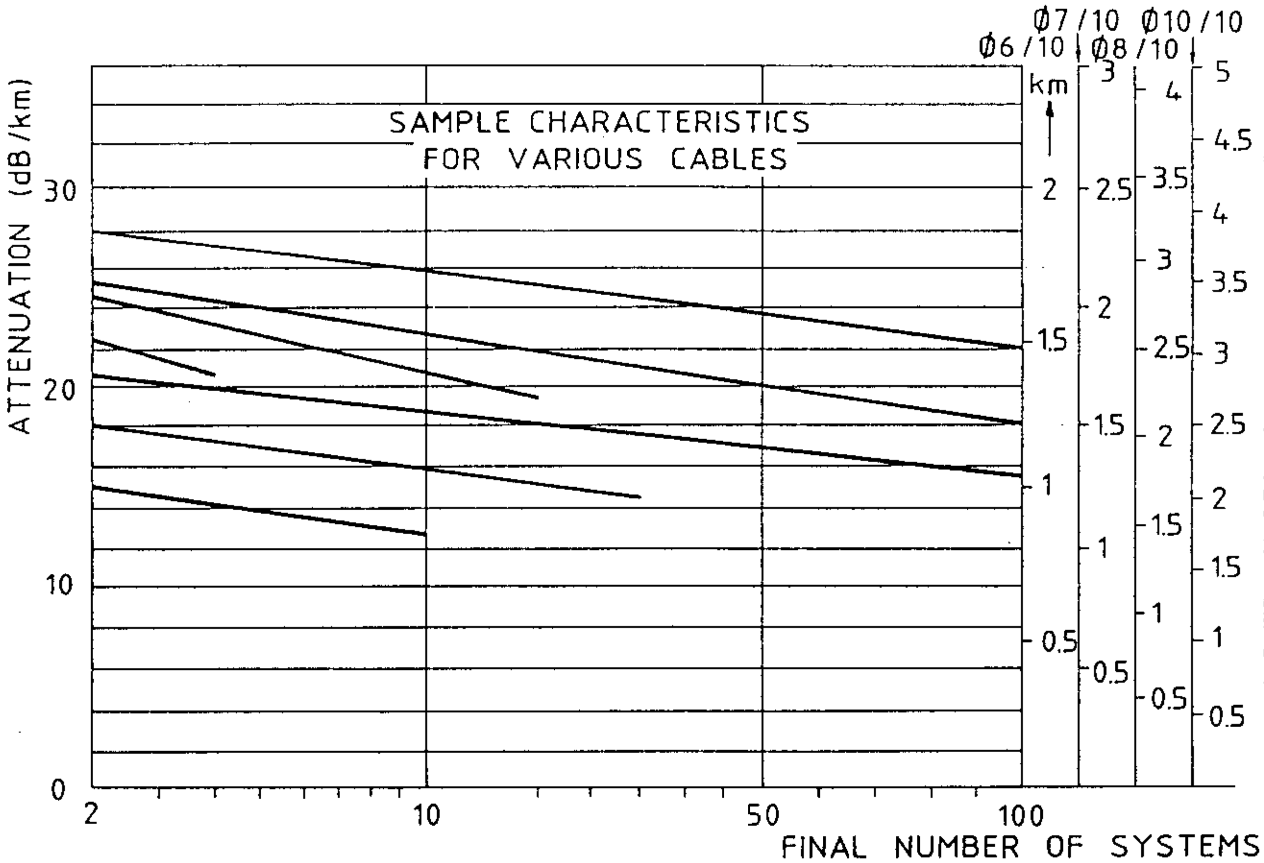


FIG 6.2 2Mbit/s REGENERATION SECTION FOR PLASTIC QUAD CABLES.

The maximum length of the regenerative section is 4km, corresponding to an attenuation of about 26dB.

It must be pointed out that for 2 Mbit/s systems it may be economically convenient, from the point of view of the installation, to reduce the repeater spacing to 1.83km (i.e. to the loading coil span) in such a way that the regenerative points are exactly located at the loading points in case they are already present on the pairs used for voice frequencies.

For 704 kbit/s systems a double distance between loading points may be used as a repeater spacing.

F) CCITT recommendations

The most important CCITT Recommendations relevant to the subject of digital transmission on symmetrical pairs are:

References (13), (15), (16) and (17).

6.1.3 Radio relay systems

Historically, the radio link is the medium which has been used to achieve long and medium distance communications quickly and inexpensively whatever the geographical characteristics of the terrain.

A) Electrical characteristics of the transmission medium

The frequency spectrum available for microwave radio link communications spreads from UHF band (0.3 GHz) up to SHF/EHF band (70 GHz).

The transmission of an electric signal in the atmosphere is characterised by the free space attenuation and by various propagation phenomena, which are a function of the transmitted frequency and of the distance between the receiving and transmitting stations.

Communications at VHF and UHF depend mainly on direct mechanism. If this wave travelled in a true straight line, the range of communication would be strictly limited to line of sight distances. However, the path of the wave is affected by radiation with height of the refractive index of the troposphere. The waves are refracted as they travel through the troposphere and this increases the range beyond the optical horizon.

In planning routes, this effect can be allowed for by assuming that the earth has an effective radius which is approximately 3 to 4 times its actual radius. The behaviour of the transmission medium is not constant with respect to time, but is variable. In fact the propagation attenuation is influenced by multipath propogation, extreme climatic conditions, in-band dispersion and reflections from the ground.

In the case of a small to medium capacity transmission, the effect of in-band dispersion is negligible. Therefore the factors limiting propagation are mainly:

- Attenuation due to multipath fading, reference (18)

- Fixed reflections from the ground (depending on the geometric profile of the link and on the sidelobe radiation pattern of the antennas employed), which can be compensated for only with an accurate design of the hop.

- Attenuation due to rain, particularly important at frequencies above 10 GHz.

  In this respect the CCIR has defined maps of the areas at constant rainfall, reference (19).

As a result of theoretical studies, computation procedures have been defined, which predict the availability of the link in presence of multipath fading or rain. The performance of the link in presence of multipath fading is a function proportional to the link frequency and a function of the third order power of distance.

Performance in the presence of rain is mainly a function of the rainfall intensity. It can be calculated by the attenuation due to rainfall intensity per length unit times the "effective hop length", L_e(km). The "effective hop length" is defined as the actual hop length, L (km), reduced by a factor r = 1/(1+0.042 L).

To design the link properly, that is to comply with the standards of quality (see Section 4), it is necessary to take into account the following main parameters:

- Antenna gain
- Feeder/Waveguide Losses
- Transmitted power
- Receiver performance (related to noise figure and demodulator performance).

The final performances, however, can be improved, for the limitations due to multipath propagation, by suitable system configuration, such as space and/or frequency diversity. In space diversity systems two or more aerials are used, and the output is selected from the aerial receiving the strongest signal. The method relies on the fact that since fading is due to small changes in the path lengths of multipath signal, it is unlikely to occur simultaneously at two separate receiving aerials.

Since the path difference producing correlation depends on frequency, protection against fading can also be obtained by using two or more carrier frequencies received once on a single aerial. This is known as frequency diversity reception. In general space diversity is a more efficient counter measure against multipath fading than frequency diversity.

B) Characteristics of the transmission system

Digital radio links, have the characteristic of regenerating the signal at each radio link hop.

The quality of performance of microwave links is usually judged by the channel signal/noise ratio for analogue equipments and the bit error ratio (BER) for a digital equipment. Both parameters are functions of performance against receiver signal input level but figure 6.3 illustrates the difference of an analogue and digital receiver.

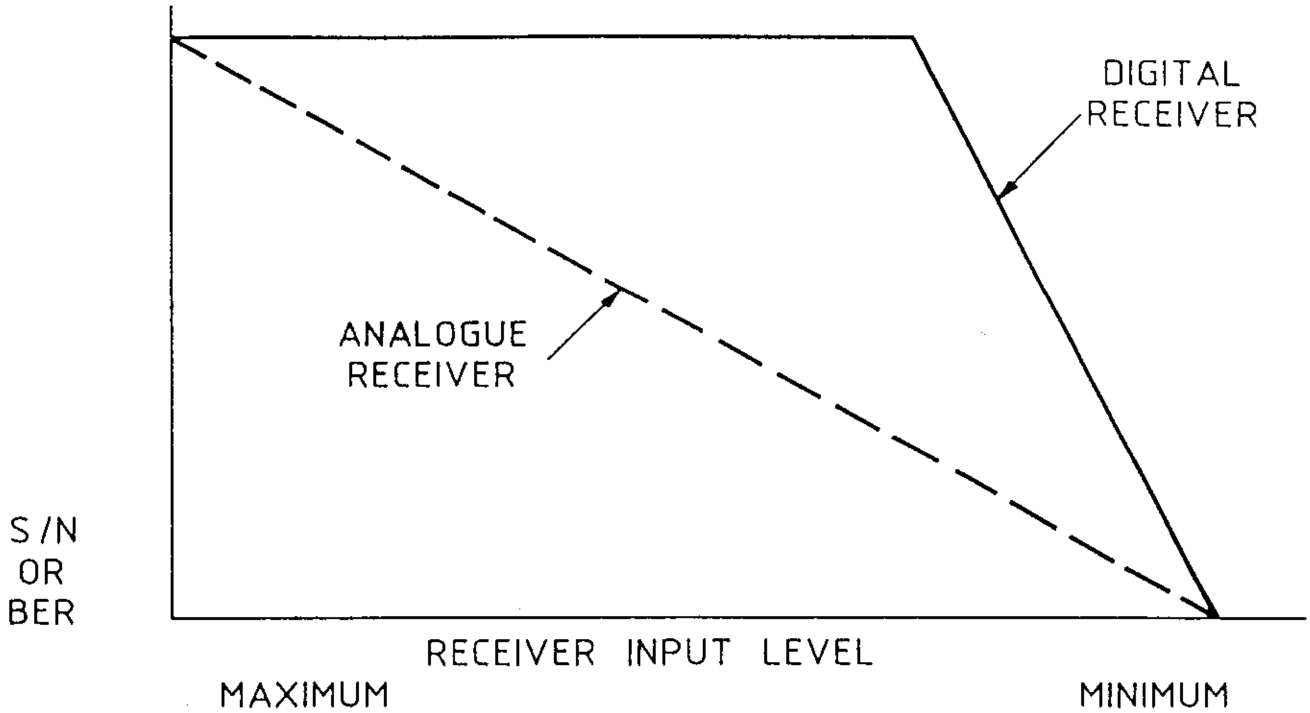


FIG 6.3
CHARACTERISTICS OF
ANALOGUE AND DIGITAL RECEIVERS

The type of modulation chosen is a function of both the capacity to be transmitted and of the available frequency bandwidth.

As a result of the increasing demand of RF frequencies, it is essential to optimise the use of the spectrum.

Most of the equipment available today employs simple robust modulation schemes such as FSK or 4 PSK in the upper SHF band (where the frequency plans have been designed only for digital carriers). A spectral efficiency greater than 2 bit/Hz can be achieved by 4PSK. This result is reached due to the capacity of PSK modem schemes to withstand very high interferences (BER 10^{-3} threshold degradation less than 1 dB for: C/I = 15 dB), so that it is possible to transmit at the same frequency both on vertical and horizontal polarisation.

In the frequency bands, where the frequency plans are also used for analogue carriers, co-existence between analogue and digital radio must be taken into account. Therefore more complex modulation schemes are proposed (such as 16 QAM etc.), capable of transmitting the same number of 64 kbit/s channels as the analogue telephone channels.

With reference to those frequency bands, where the existing frequency plan has been designed to transmit 60 telephone channels with a frequency spacing of 2 MHz, the digital version will transmit 2 x 2 Mbit/s with the same spacing. To achieve this requirement of using existing analogue frequency plans it is necessary to properly shape the generated spectrum with a well defined roll-off factor, (See Reference 14).

Theoretically, the spectrum may be shaped through RF, or IF, or by premodulation filters. Excluding RF filters, which are too complex, we are left with the solution of generating the spectrum shaping at the modulator level and obtaining the radio frequency signal by conversion and amplification.

Radio links, operating at bit rates higher than 34 Mbit/s are likely to require adaptive equalisation, in order to counteract the in-band distortions caused by multipath propagation (selective fadings). They can be used either to recover the bandwidth flatness (IF equaliser), or at BB level, by removing the intersymbol interference.

C) Regulatory requirements

In general these are mandatory requirements upon which national allocation and assignment of radio frequencies are made by the Government regulatory body, often the PTT. The areas of concern are those which are likely to create interference problems with other users.

Typical of these requirements are:-

Maximum transmitter output powers and maximum/minimum receiver input levels

Maximum EIRP (Effective isotropic radiated power of the Antenna) - function of transmitter power, feeder losses and Antenna gain.

Directivity of the Antenna

Maximum Carrier Frequency Error

Spurious Emissions

Bandwidth of the emission specified e.g. using spectrum mask.

Receiver Selectivity

D) Transmission code

To guarantee the transmission of an adequate number of service channels avoiding any degradation in transmission quality (as usually occurs in services employing FM carrier modulation), it is necessary to transmit also the service channels in digital form. This solution has the further advantage of a greater efficiency in channel utilisation in case of service data transmission.

Moreover in order to monitor the continuity and quality of the radio link without interfering in any way with the information transmitted it is necessary to generate a transmission code through the bit-insertion technique: the capacity of the transmitted signal is increased with the addition of other information such as service bits, parity bits and the necessary frame word.

The composite signal, thus obtained, is subsequently scrambled to guarantee the transmission of a uniform spectrum to ensure successful receiver encoding whatever the content of the signal to be transmitted. This allows an optimum control of all interferences local or distant, in the case of co-existence of digital with digital or digital with analogue systems.

Finally, in the more recent and complex modulation schemes the function of Forward Error Correction (FEC) has been introduced in order to further improve the link performance and specifically to strongly reduce the RBER (Residual Bit Error Ratio). Typically in systems with FEC and a redundancy of about 3% we have:

$$BER_{FEC} = K\,(BER)^2$$

where $K = 300 \div 1000$ depending on the type of FEC used.

E) Examples of hop calculations

The most significant parameter for evaluating the quality of an additional link in a digital radio system is the "Outage Time", per link that is the time period exceeding a stated "Threshold" Bit Error Ratio and consequently when the Microwave radio link system is considered in "out-of-service" or in "degraded" conditions. An example hop calculation is contained in Appendix C.

The outage time, for the portion depending on the RF propagation, can be evaluated starting from the knowledge of the "Fade Margin". This parameter is defined as the power margin for acceptable RF receiver level attenuations and corresponds to the difference between the RF nominal receiver power (P_R), in standard propagation condition, and the RF threshold level (P_{TH}) specified by the supplier and corresponding to a wanted Bit Error Ratio (usually 10^{-3} or 10^{-6}). Therefore the "Fade Margin" is: $M = P_R - P_{TH}$.

The main parameter characterising each RF transceiver equipment towards the power budget is the System Gain, $SG = P_{OUT} - P_{TH}$, i.e. the difference between the transmitter power and the receiver threshold (including the branching filters losses).

Examples of system performance calculation in the 13 and in the 2/17 GHz bands are contained in Appendix C.

The evaluation of outage due to multipath fading and of unavailability due to rain has been made for a link at 17 GHz with 2 Mbit/s capacity, 4PSK modulation and a transmitter power of 18 dBm for various hop lengths and antenna gains.

Distance (km)	Antennas (diam m)
5	2 x 0.6
10	1 x 0.6 and 1 x 1.2
15	1 x 0.6 and 1 x 1.2
20	2 x 1.2

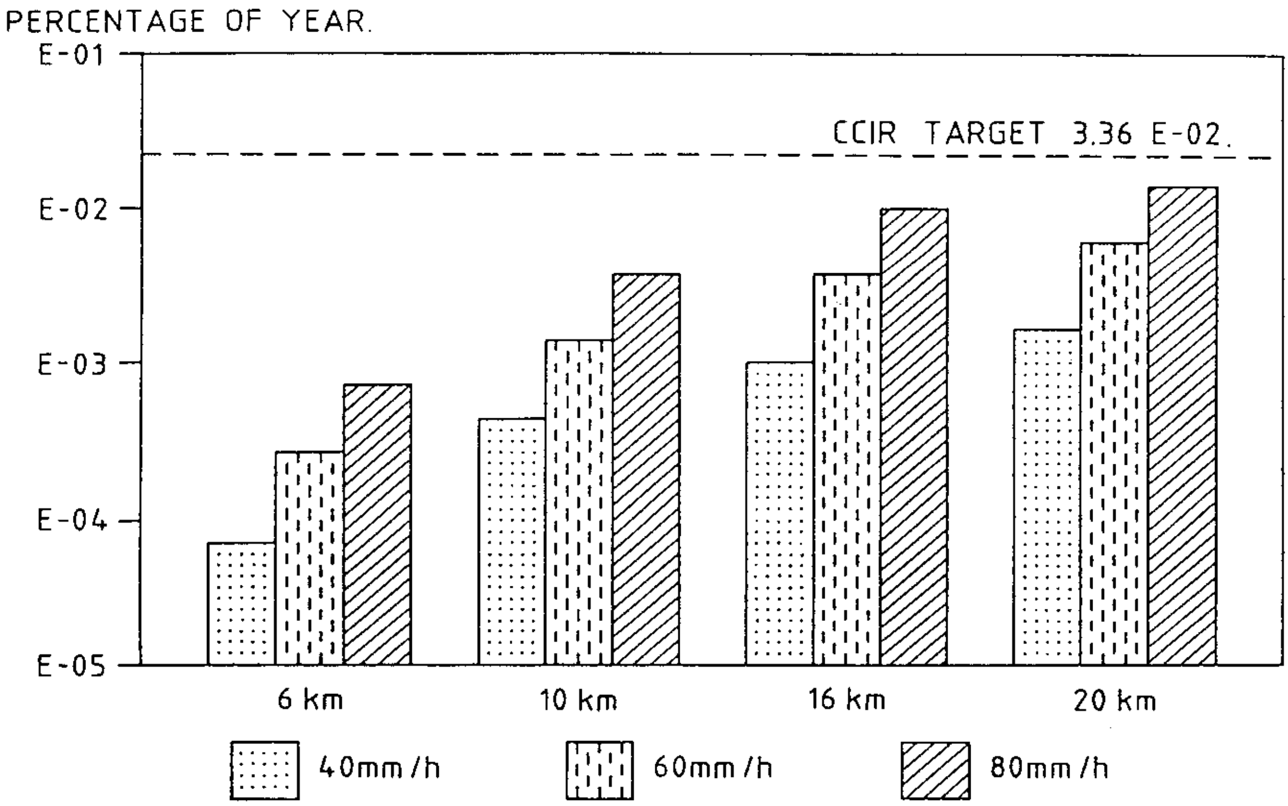


FIG 6.4

TYPICAL SYSTEM AND AVAILABILITY DUE TO RAINFALL 17GHz-2Mbit/s.

Figure 6.4 show a typical system availability curve, specific maps exist for each country, showing the geographical regions where the various rainfall intensities apply.

F) CCIR reports and recommendations

The most important CCIR references relevant to this subject are (8), (35), (36) and (18) - (26).

6.1.4 Transmission systems on optical fibre (Refer to CIGRE Working Group SC35.04)

The recent introduction of the optical fibre, is rapidly changing the scenario of modern telecommunications. The optical fibre appears as a waveguide for electromagnetic fields at optical frequencies; being glass-made, it is dielectric and therefore it assures galvanic insulation and it is highly immune from electromagnetic interferences.

If cabled without metallic parts, it avoids all the problems of interference due to the potential differences associated with connections relevant to electric plant. The fibre has a light weight, it has small dimensions, and it has excellent mechanical characteristics when suitably cabled. But the most attractive characteristic of the fibre is its large transmission capacity and the possibility of implementing links of some tens of kilometres without intermediate regenerators; the transmission of high bit-rates, up to some Gbit/s, with very good and stable performances becomes also economically attractive. On the other hand, other aspects must be taken into account, i.e. the problems related to laying the optical cable. These problems for power utilities mainly correspond to the necessity of supporting the fibre by means of the high voltage line.

A) Characteristics of the optical bearer

Optical fibres for telecommunications are made of silica glass of very high purity degree. The inner part of the fibre, called core, has higher refractive index than the outer part, called cladding; that index variation is obtained by a suitable doping of glass; an optical ray may be guided that way, by total internal reflection at the core-cladding interface. The main characteristics of an optical fibre carrier are attenuation and dispersion.

The attenuation is a characteristic of the material, of the doping, and of the purity degree of the glass, obtained during the manufacturing process. The attenuation (see fig. 6.5) is a function of the wavelength of the optical source. The practical regions with low attenuations, called windows, are those around 800-900nm, 1300nm, 1550nm; the last shows the lowest value, for silica glass fibres (0.2 - 0.3 dB/km).

The limitation of the useful bandwidth in a fibre link depends on dispersion phenomena.

For single mode and multimode fibre characteristics see the following table 6.2.

	MULTIMODE		SINGLE MODE	
Window	1st	2nd	2nd	3rd
Wavelength(λ) [nm]	800-900	1270-1340	1270-1340	1550
Dispersion(D) [ps/km.nm]	(Complex Definition)		3	20
Attenuation [dB/km]	<4	<2	<1	<0.5

Table 6.2 Fibre Characteristics

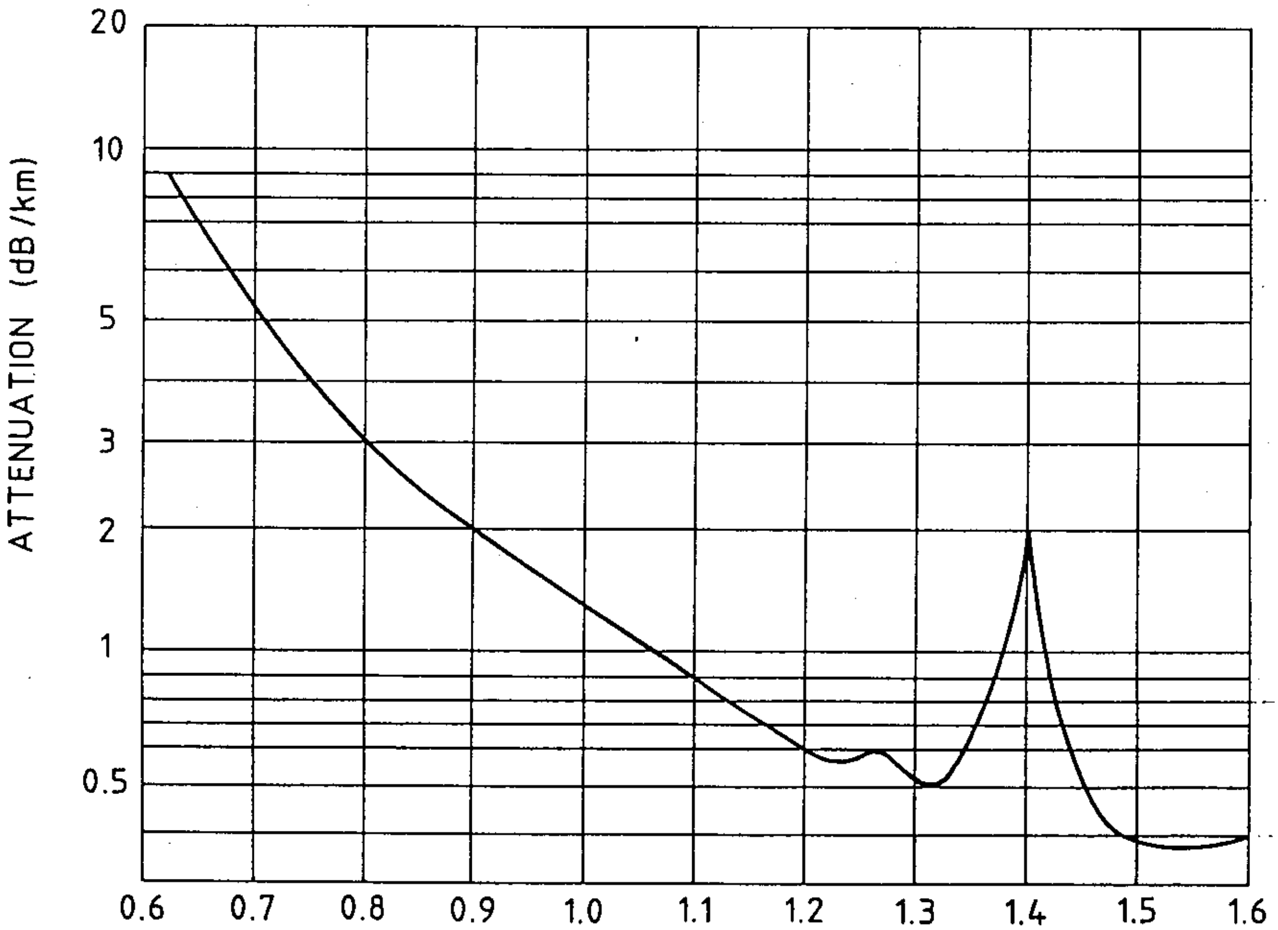


FIG 6.5

ATTENUATION VERSES WAVELENGTH FOR SILICA GLASS FIBRES

B) Characteristics of the optical emitter

	MULTIMODE FIBRE				SINGLE MODE FIBRE		
Source	LED		LASER		LED	LASER	
Window	1st	2nd	1st	2nd	2nd	2nd	3rd
coupled peak power (dBm)	-10	-10	3	3	-24	0	0
spectral width [Delta Wavelength] (nm)	60	100	3	5	100	5	0.1

Delta Wavelength as FWHM = Full Wave Half Maximum; Delta Wavelength of the emitter, together with the dispersion of the fibre, conditions the available bandwidth per unit length.

C) Characteristics of the optical receiver

Device Technology	Si	Ge	InGaAs
Wavelength at peak quantum efficiency [nm]	600:900	1100:1500	1200:1600
Window	1^{st}	2^{nd}	2^{nd} 3rd
Typical receiver sensitivity (BER=10^{-9}) at 34 Mbit/s [dBm]	-51	-45	-45

D) Characteristics of the equipment and line code

Taking into account the characteristics of the optical transmission systems and of their electro-optical devices together with the bearer parameters, the line code will need to show the following characteristics:

- no more than two modulation levels because of the non linearity of the optical emitters and because the occupied band is not a severely limiting factor
- redundancy for quality transmission supervision
- support of the service capacity either through an analogue amplitude modulation added on the digital on-off modulation (but this solution entails degradation of the signal to noise ratio of the receiver), or again through a redundancy added to the main digital stream.
- guarantee of the presence of the timing signal obtained either by the addition of a suitable redundancy, or by a process of scrambling of the digital to be transmitted.

A possible line coding that meets all above mentioned requirements without introducing excessive redundancies, which may be penalising because of the power consumption and of the complexity of the code converters at the higher bit rates, is represented by the technique named "bit insertion". As already mentioned with regard to the radio links where the same technique is used, the bit insertion allows to introduce, in a totally digital manner, the needed redundancy on the transmitted signal.

Other line codes used are also the ones named block codes.

E) Calculation of the regenerator section length

A line equipment on optical fibre is described by two power levels: the mean output power from the transmitter, specified after the line connector, and the minimum permissible level at the receiver input, specified before the line connector.

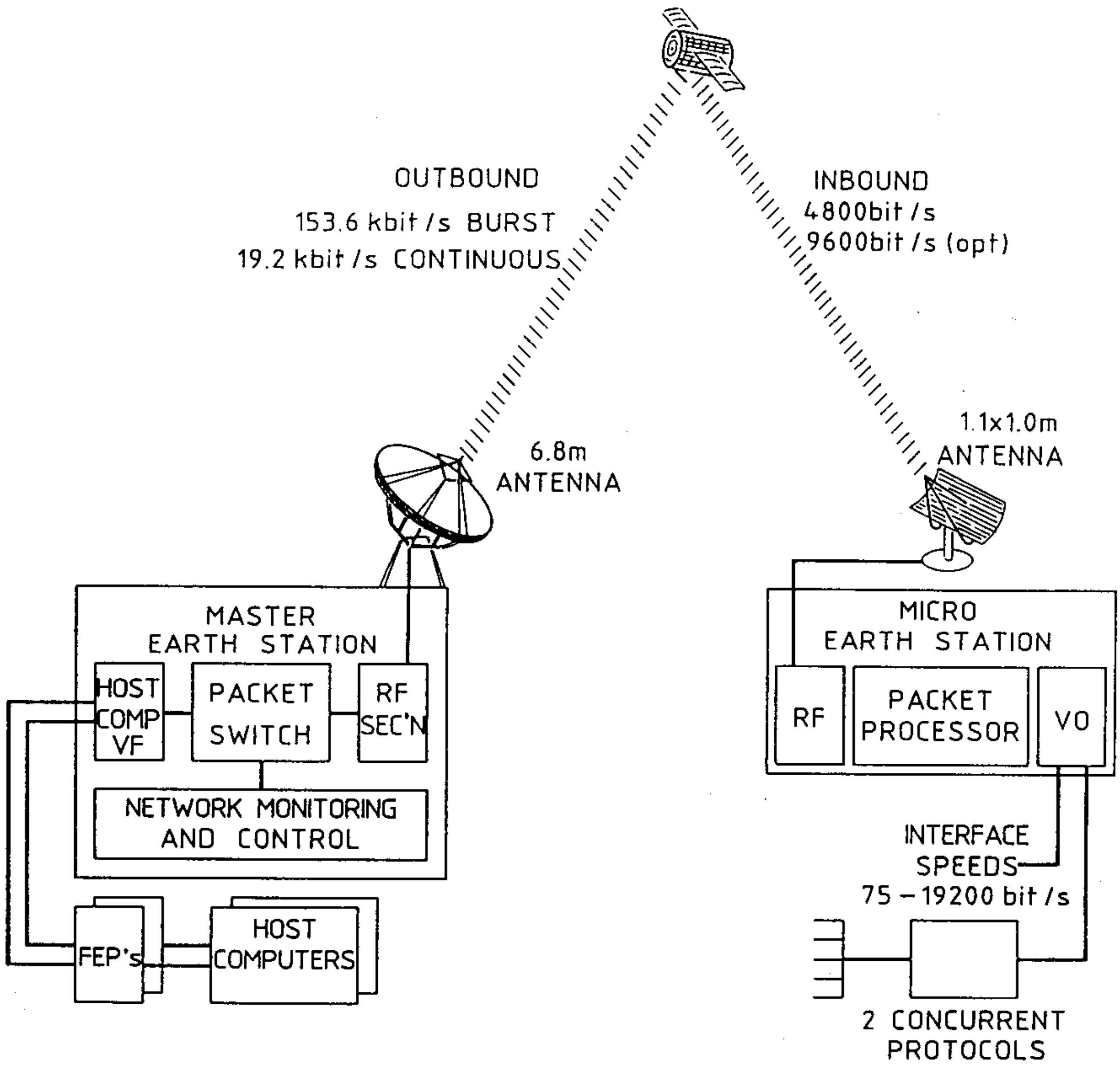


FIG 6.6 VSAT SATELLITE NETWORK

The available attenuation between TX and RX must cover the loss of the line, that means of the fibre cabled, installed, spliced and with extra connectors, if required. Moreover, a margin must be allowed for the equipment, covering effects of time and ambiental factors; another margin is allowed for the cable, for possible cable repairing, for changes due to aging and ambiental factors, and for connector degradation. It will also be necessary to check that the fibre bandwidth, related to the emitter type meets the bandwidth requirements of the bit rate to be transmitted.

See Appendix C for example of typical optical calculations. Typical References for optical cables see (13) and (27)-(30).

6.1.5 Transmission systems via satellite (See figure 6.6)

In countries where access is available to a national or shared international satellite service, the option exists for the transmission of voice or data over this medium.

A satellite communications link differs from traditional terrestrial links in 3 important ways:

i) It is a multi-destinational, i.e. signals transmitted from a satellite can be received simultaneously at many earth stations over wide geographical areas. Communications can therefore be provided anywhere within the satellite's coverage area as required.

ii) It is flexible, i.e. the amount of satellite capacity used can be tailored to match the users needs in terms of performance, availability and future growth requirements.

iii) It suffers time delay, i.e. the total propagation delay over the satellite link from transmitting earth station to receiving earth station is about 270 msec.

Channel capacity is significantly smaller than on other transmission media and the ongoing charges for the use of the 'space segment' are typically high. Nonetheless under certain conditions, satellite transmission offers a viable alternate choice to terrestrial systems.

It is of most value:

- For very long distance transmission

- In (or into) remote areas without normal infrastructure support (reticulated power supply, access road, etc.)

- As an alternative to services which otherwise must be rented from a monopoly carrier.

- For large, slow speed data collection networks (e.g. SCADA) where it becomes directly economic.

- For multi-drop or broadcast requirements.

A) System characteristics of the satellite transmission media

The Satellite link is formed by:

- a radio link from the ground to the satellite (the 'Uplink')
- a radio transponder, and
- a radio link from the satellite to ground (the 'Downlink')

In each satellite, a number of transponders form a number of independent channel repeaters. Frequency allocations conform with CCIR specifications.

The behaviour of the total link is dependent on:

- The transponder performance and the gain characteristic of the highly contoured antenna patterns. During design, consideration can account for the known antenna pattern profile but allowance must be made for variation in

  - satellite saturation flux density
  - Receiver G/T Ratio
  - EIRP of both ground station and satelite
  - Attenuation caused by rain in both uplink and downlink
  - paths
  - Unwanted noise reception

A sample link calculation is shown in Appendix C.

The primary advantage of satellite links is that the combination uplink/transponder/downlink path calculation is the total definition of the path between any two points in the satellite coverage area, regardless of the terrestrial distance between them. Compared with the multi-hop engineering for distant locations in a terrestrial radio link system, the satellite solution offers significant advantages.

B) Characteristics of the transmission system

For practical purposes, satellite digital links are limited to 2.048 Mbit/s, 64 kbit/s, or multiples of 64 kbit/s between these limits. Higher order bit rates occupy excessive transponder bandwidth, and satellite operators rarely offer this except for television broadcast purposes.

Target performance for direct links conforms to the relevant CCITT recommendations noted in Chapter 4.

Whilst it is possible,and in some cases desirable, to provide point-to-point digital links via satellite to form part of a wider digital network, more common usage is to provide a service on a total system approach.

Of most interest to power utilities is the multi-station Time Division Multiple Access (TDMA) data networks for SCADA systems. Because SCADA systems are inherently polling systems the use of TDMA networks is particularly appropriate.

Satellite networks can be constructed with a single computer based major main station, and low cost very small aperture terminals (VSAT) at the out-stations. These networks use a form of packet transmission, and store and forward data handling at both the main and the outstation. This permits an apparent data speed of 9.6 kbit/s for the polled (non-continuous) transmission to and from each station (albeit with significant end to end transmission delay). However within the system the actual data speed is quite different with the outbound direction working as 19.2 kbit/s (or 153.6 kbit/s burst), and the inbound direction at the much slower speed of 4800 bit/s. This enables the system to operate with only one large size antenna at the main station with high gain and high power, whilst at the outstation the cost is contained by use of lower power and small antenna.

Fig. 6.6 depicts this system.

6.1.6 Performance comparison for different transmission media

The following table 6.3 summarises the comparison between digital transmission media.

6.1.7 Cost comparison for different transmission media

The comparison is restricted to radio and optical fibre systems, due to the convenience of fibre over copper bearers because of the higher repeater number that the copper requires. If the comparison is performed at the same capacity for the two transmission media (in terms of bit rates) it can be noted that:

- the cost of the multiplexing equipment is the same;
- radio requires coupling devices to the transmission medium, i.e. antennas, feeders, towers and their installation, with no cost. for the medium;
- optical fibres require no cost for coupling devices (considered as part of the line terminals) while they present the cost of the optical cable and its installation;
- considering the propagation characteristics in the most used radio frequency bands and the attenuation characteristics of optical fibre, on the average the repeater distribution and cost can be about the same, even if specific orographical conditions could affect this situation;
- the physical dimensions and the power consumption of electronic equipment is about the same for both solutions, so that even the needs and the costs of buildings, or shelters required to house the equipment will be about the same.

Given the above, comparison can be restricted to the comparison between:

a) radio terminals (comprising baseband processors, input/output stages, service channels, etc.), antennas, feeders and towers (installed) for radio;

b) line terminals (comprising baseband processors, input/output stages, service channels, etc.) and cable (installed) for optical fibre systems.

Dealing with radio, the cost of towers can be shared among different links. A terminal or repeater station could serve several fixed links and a mobile radio network, therefore the cost of item a) can lie in a wide range, e.g. from 1 to 6.

Dealing with optical fibres, the cost per length unit of the cable and of its installation can lie in a wide range, depending on whether the cable is installed on a H.V. line, or a separate support, or buried.

In general the price differences between radio and optical fibre systems can vary depending upon geographical conditions (e.g. length of link and degree of difficulty of the terrain). Each project hop should be taken on their individual merit. This is even more true if we take into account also the operational costs. Besides the equipment failures (which can be estimated to be the same for both radio and fibres), there is a small probability of fibre breaks, which may take some time to repair.

	RADIO LINKS	OPTICAL FIBRES	SYMMETRICAL COPPER CABLES	SATELLITE
Capacity	$\leq$ 140 Mbit/s typically $\leq$ 34 Mbit/s	from 2 Mbit/s	Up to 2 Mbit/s	Up to 2 Mbit/s
Span length at $\leq$ 34 Mbit/s	tens of km (in some cases many tens)	tens of km	2 - 3km	thousands of km
Average performance(BER)	good	excellent	good	good
BER stability	subject to fading	very stable	fair	quite stable, some fading possible
Co-ordination effort	frequency allocation to be co-ordinated by central authority	not necessary	not necessary	frequency allocation to be co-ordinated by central authority
Terrain survey	necessary if path clearance is not ascertained on maps	necessary for fibre cable installation on overhead lines or underground systems	necessary for new cable installations	not necessary
Vulnerability	only on terminals	on terminals and on optical fibre cable	on terminals and on cable	Only on terminals (Satellite often duplicated)
Fault location	restricted to terminals	extended to terminals and optical fibre	extended to terminals and cable	Restricted to terminals
EMC	possible interference with other radio systems if lack of co-ordination	Excellent	possible interference with other systems on the same cable	possible interference with other radio systems if lack of co-ordination
Installation flexibility	very good	fair	fair	very good

Table 6.3 Comparison between Digital Transmission Media

6.2 Transmission Network Nodes

Nodes are obviously needed at various levels of a digital transmission network. The largest nodes are situated in the most important parts of the trunk network, and the smallest nodes are to be found in the very small stations, often in rural areas.

In a power utility digital network the largest nodes may terminate several medium or even high capacity links. The actual total capacity of a node depends, of course, very much on the network size and on its traffic volume. It may be in large countries and networks in excess of 100 Mbit/s (e.g. 3-4 links with 34 Mbit/s each, or a star point with 6-8 links at 8-16 Mbit/s each).

The smallest nodes, on the other hand, in a very thin network or at a digital network extension, may terminate a single 64 kbit/s channel and sub-divide it into several user channels (e.g. for slow speed data and/or 32 kbit/s voice). Examples of typical power utility applications are shown in figures 6.7 and 6.8.

6.2.1 Basic functions of the nodes

While the task of transmission links is to carry signals unaltered from a location to another, the transmission network nodes handle the transmitted information in many ways. The basic functions of the nodes are:

1. adaptation of user signals for the digital network: providing standard user interfaces, A/D conversions for analogue signals, and for digital signals bit rate adaptation and synchronisation arrangements (including separate clock signals where needed)
2. multiplexing of user signals to higher bit rates, either for a transmission link or to interface a higher order multiplexer, and corresponding demultiplexing in the other direction
3. dropping and inserting of signals within a trunk system at smaller nodal points as well as branching of signals at nodal points with 3 (or more) transmission links

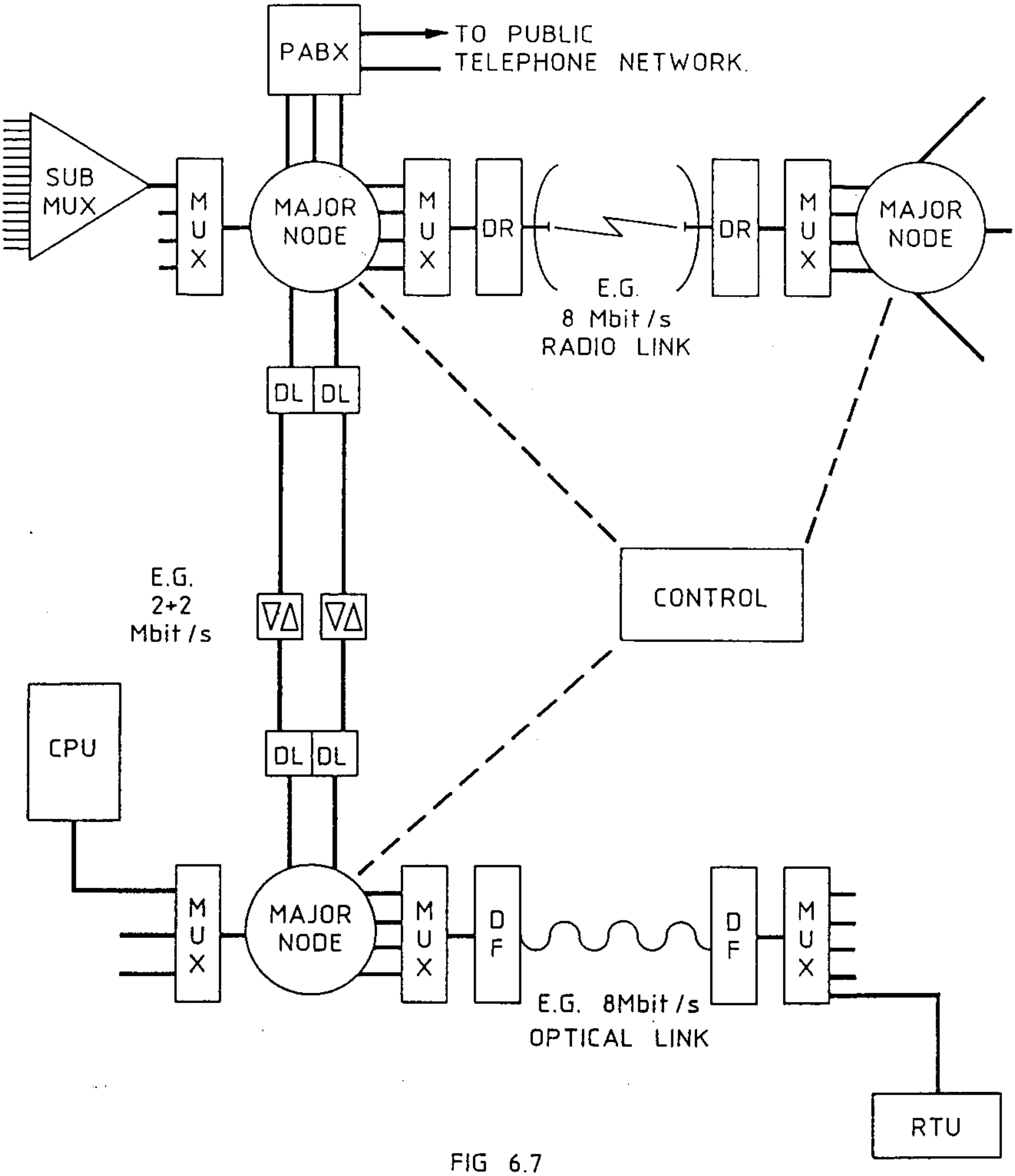


FIG 6.7
EXAMPLE OF A MEDIUM CAPACITY POWER UTILITY DIGITAL NETWORK.

4. cross-connection of signals in nodal points with several transmission links so that the required channel connections are formed

5. protection switching between alternative signal paths, either on the receiving end only (1+1 systems) or on both originating and terminating nodes (more sophisticated protection systems)

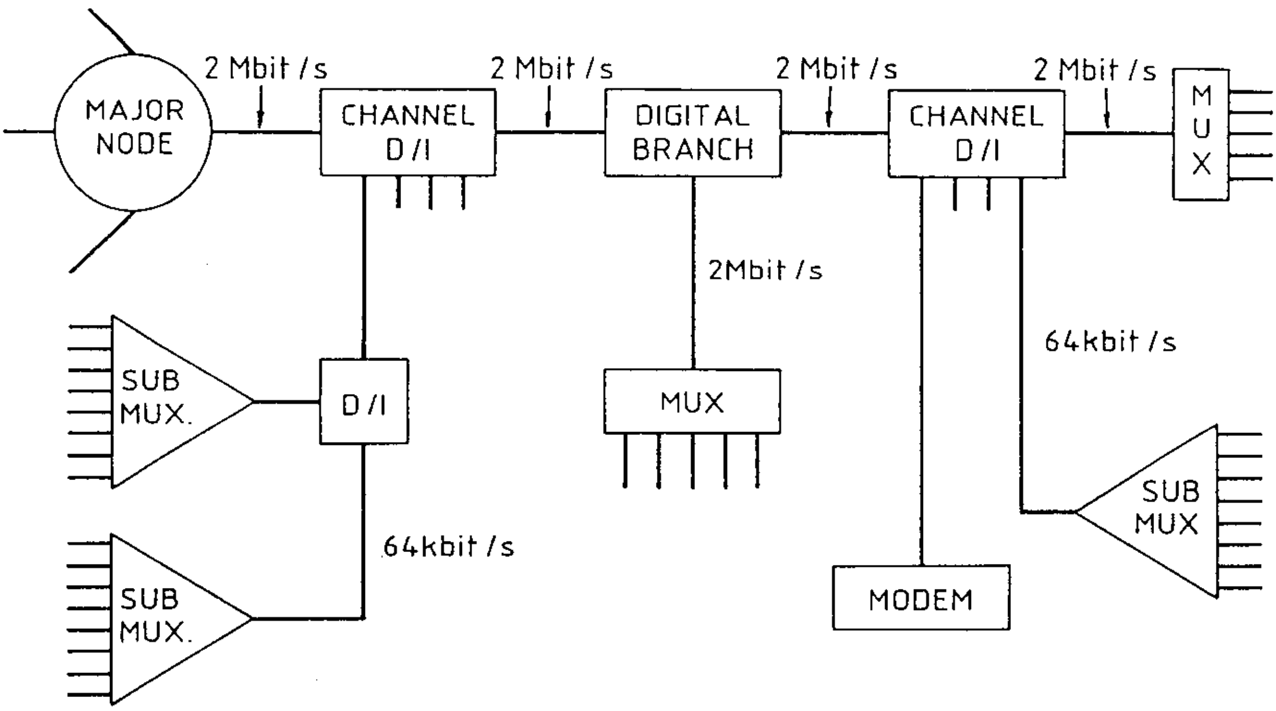


FIG 6.8
EXAMPLE OF A LOW CAPACITY PART OF A POWER UTILITY DIGITAL NETWORK

Adaptation of user signals and the first stage of multiplexing

These functions are usually combined into one equipment which has standard interfaces for the user signals, and carries out necessary conversions for adapting them into the digital network. This equipment is typically a primary multiplexer with the 2048 kbit/s output signal according to CCITT Recommendation G.703 and multiplexing and frame structure according to Recommendation G.704, or

- a sub-multiplexer with a 64 kbit/s output signal according to G.703 (or V.11 or V.35) and bit rate adaptation and multiplexing according to V.110, X.50, X.51 or some proprietary standard.

Also in some cases multiplexers with various non-standard output bit rates are used, e.g.

- data multiplexers (and gateways) with nx64 kbit/s output signal, typically with V.11 or V.35 electrical interface and proprietary multiplexing, or

- primary multiplexers with 704 kbit/s output signal with modified G.703 interface and with a proprietary multiplexing and frame structure.

Analogue signals are first coded into a digital format. The most common digitalisation method used today is PCM-coding (see Section 2). Other coding methods are also available and will become more common in future (particularly ADPCM for coding 4 kHz channels to 32 kbit/s and 7 kHz channels to 64 kbit/s. Analogue signals having larger bandwidths (e.g. video signals) are usually coded in separate equipment.

When converting analogue voice channels signalling must also be taken care of. Between analogue exchanges channel associated E & M signalling is most common, but particularly when connecting remote subscribers there are many possible systems with many variants. This information is handled either by the multiplexer itself or by a separate signalling converter, and it is transmitted in the time slot 16 of the 2 Mbit/s signal using a multiframe structure (described in Rec. G.704).

Low to medium speed digital signals (such as data) are usually connected to the multiplexers through CCITT V-series or X-series interfaces. Other interfaces are also used, for example interfaces for baseband modem data. Data signals up to 56 kbit/s may be either synchronised with the digital network (data clocked by the digital network clock) or be independent of the network clock.

Higher speed digital signals (64-1920 kbit/s) can be connected directly to primary multiplexers using V-series interfaces or using partially empty 2048 kbit/s signals and G.703/G.704 interfaces. At these speeds data signals are always synchronised with the digital network.

The primary multiplexer equipment have differences on the interface types available and in the way the digital lower speed signals (data) are packed into the 2048 kbit/s signal. Moreover, the functionality provided (e.g. remote supervision and control of operation) may have large differences.

Further multiplexing of digital signals

The signals originating from submultiplexers are always multiplexed first into the primary rate of 2048kbit/s before further multiplexing.

The higher bit rates signals and their frame structure, stuffing methods etc. are described in CCITT Recommendations G.702 - G.754. In the 2048 kbit/s digital hierarchy the higher bit rates are 8448, 34368 and 139264 kbit/s. Positive stuffing is used to adapt the tributary i.e. the lower bit rate signals into the higher one. It is important to note that these higher bit rates are therefor totally independent of the digital network synchronisation (they are transparent to it) and the network synchronisation is thus always done wholly at the 2 Mbit/s level.

Basic operation of all higher order multiplexer equipment is similar due to well defined standards; differences between equipment are in supervision capabilities and in technical implementation (size, power consumption etc.).

Drop/insert and branching

Drop/insert and branching of signals at smaller nodal points may be achieved using either usual multiplexers back-to-back or special equipment for this purpose (cf. figure 6.7).

Demultiplexing and remultiplexing of signals using back-to-back multiplexers is a simple straight-forward solution where consideration is only needed on the number of successive D/A and A/D conversions for voice channels (if connections are in analogue format) as well as on interfaces and synchronisation arrangements for digital signals.

Digital drop/insert and branching equipment make it possible to avoid the de- and remultiplexing of through-going signals and to reduce the number of equipment required. They can also contribute to network flexibility through new functions as described in Section 6.

An important consideration in both cases is the network operation during various unusual situations (link or node failures), particularly in networks with long chains with many drop/insert or branching points and with closed digital loops.

Cross-connection

Cross-connection of signals is needed in almost all bigger network nodes. Cross-connections of multiplexed digital signals at 2 Mbit/s (or at even higher rates) might be sufficient in some cases but in most cases, especially in smaller capacity networks, cross-connection of individual channels is needed. Today cross-connections are most often done physically, connecting the proper interfaces by cables (larger cross-connections are made using distribution frames).

A new possibility in digital networks, adding much flexibility to the networks, is to use digital cross-connection systems (DCS).

Such systems are, or will become, available for cross-connections at the primary (or even higher) bit rates and especially for cross-connections at the 64 kbit/s level or even lower bit rates.

Protection switching

Protection switching may be a function of the transmission links (e.g. radio links with protection systems 1+1 or N+1), or it may be left as a task of the network nodes.

In the latter case protection switching is accomplished by the same equipments which are also otherwise responsible for the connections in the nodes, that is by the digital branching and cross-connect equipments. This offers the advantage that the whole network situation can be taken into account, and therefore e.g. switching between alternative routes is easier to arrange.

6.2.2 New facilities available

Dynamic transmission network

Digital transmission networks offer new possibilities giving effective utilisation of the network, never possible in the analogue environment. These are based on two important principles:

- similarity of all signals after digital coding which enables transmission of different kinds of signals alternatively over the same transmission channels (without any equipment adjustment), and

- new node equipment (multiplexers, branching equipment and cross-connect systems) which can change channel connections based on remote (and local) control or based on time of date or on alarms.

These combine to give dynamic transmission networks.

Dynamic multiplexers mean that the user channels may be connected to any time slots of the multiplexed output signals. Multiplexers may be equipped with more channel interfaces than can be simultaneously multiplexed into the output signal (e.g. 2 Mbit/s) - these channels are connected alternatively to the output signal. In this way the use of the capacity can be adapted to changing needs. For example video conferencing equipment may be connected continuously to a primary multiplexer but transmission capacity is only used when needed (during video conferences).

Dynamic branching and cross-connect equipment mean that the multiplexed channels e.g. in the 2 Mbit/s signals may be cross-connected at the network nodes based on remote control. This enables reconfiguration of the network without actually visiting any of the network nodes. Thus it adds a greater amount of flexibility to the network and makes changes much easier e.g. when the network capacity is increased, channels re-arranged for new services, new transmission links added or in case of failures. Furthermore, it makes possible to provide capacity for temporary needs at lower costs.

Network supervision and management

Supervision of digital networks is possible with much higher accuracy and more detail than in analogue networks. This is also to some extent necessary, because digital links do not give "early warnings" in the form of degraded performance as often as analogue links do.

Supervision includes inter alia such items as quality of signals (bit error ratio, BER or full quality description according to CCITT Rec. G.821, see Section 4), equipment alarms, other alarms from equipment rooms and stations (external alarms such as power supply system or building alarms) etc. The aim is to obtain an overall picture of the network situation with status of stations, in one place. Supervision should be possible, as far as practical, using only one system (one terminal/workstation and similar operation procedures for several sub-systems). Transmission network supervision is considered more comprehensively in Section 8.

Network management becomes important in dynamic transmission networks. In addition to the traditional supervision tasks mentioned above, network management systems (NMS) will have the configuration management as a totally new task. It means that the connections within the network are managed from a single site, a network control centre and it requires sophisticated network management tools - both advanced computer systems with good man-machine interfaces (MMI) and easy-to-use management software - to make possible in reality to take advantage of the new flexibility of the transmission network. Network management systems are also considered more comprehensively in Section 8.

6.2.3 Choice of strategy and systems

Planning of the network nodes is strongly related to the planning of the whole network: e.g. what are basic principles in the digital network, how will sites be linked together, why large capacities are needed, how protection will be arranged, how the network is synchronised etc. Therefore the general network plan should be at an advanced stage before the nodes can be finalised. On the other hand, technology and equipment used for implementation of nodes may strongly affect the network structure, so that the planning is in fact an iterative process.

Basic choices

There are, of course, alternative approaches to the planning and implementation of digital network basic structure and its nodes. The following list tries to describe some important first choices to be made, but is not in any case exhaustive:

- obviously one of the first things greatly affecting the whole network is the capacity of the links: it depends upon, in addition to the network size, the volume of traffic that is planned (particularly whether administrative traffic is also carried within the same network, or if an allowance for selling of excess capacity to third parties is made.

- topology of the network, or how the different sites will be connected to each other (star sub-networks, tree or ring sub-networks etc.) and how connections are arranged for the smallest stations.

- what are the availability targets for connections and how they are to be planned: protection philosophy of connections (on which connections protection is needed, and division of tasks between transmission links, transmission nodes and terminal equipment)

- synchronisation of the digital network: e.g. which master clock is used (own/PTT network clock), how clock is distributed, how this distribution is protected, how accurate local reserve clocks are used, and to what extent applications (e.g. data systems) are synchronised to the digital network

- to what extent dynamic characteristics are utilised in the transmission network, e.g. transmission channels used for different signals at various times and how temporary services and network protection are arranged

Basic alternatives available

The basis alternatives are related to various multiplexing solutions: what multiplexers stages are used, where are they located (and, consequently, what transmission capacity transmission links are needed)?

The same user signals can for example first be multiplexed into 64 kbit/s signals which are transmitted to a bigger node for multiplexing into 2 Mbit/s signal, or alternatively, the 2 Mbit/s signals may be distributed to all network nodes. In the same way other multiplexers may be located in different places in the network, relative to the overall solution adopted.

Evaluation of alternatives

Evaluation of the alternative solutions is unfortunately always strongly dependent on the local conditions. The main criteria is, of course, the same but the optimum solutions vary. The most important variable factor may be the regulatory matters (see Section 5) and pricing policies of the public network operators. For example, the economy of different solutions may be strongly affected by the different pricing levels for leased lines in various countries. Use of these lines (other factors permitting) might be therefore in some countries very attractive and in other countries un-attractive with a preference for their own system. Even the relative prices e.g. for the 64 kbit/s and 2 Mbit/s leased lines vary so much, that in some countries costs for a 2 Mbit/s line is 30 times that of 64 kbit/s, while a more common price is 10 times and in some countries the cost is even as low as 6 times that of 64 kbit/s lines. It is obvious that in these environments the most economical solution will vary depending upon local conditions.

Generally, where the economical factors are not against them, networks based on 2 Mbit/s links are more flexible and easier to manage and provide more room for future expansion and new services, than networks consisting of many smaller capacity connections. In these environments the 2 Mbit/s signals are distributed to all network nodes (Fig. 6.9.b). In the contrary cases where 2 Mbit/s lines, either own or leased, are expensive, a network with just an optimum number of slower speed lines can be used (Fig. 6.9.a).

Similar considerations apply also to higher network levels. For example in optical fibre transmission systems the cost of the transmission multiplex equipment (e.g. up to 34 Mbit/s) is small compared with the cost of the optical cable and its installation. When the prices of multiplexing equipment have also been reduced with new technology, it is reasonable to build links with large reserve capacity initially. On the other hand, on radio links the available bandwidth is always limited and the system capacity should be more closely adjusted according to expected needs. Thus in these two cases the network nodes will have somewhat different configurations and number of multiplexers.

Other considerations are related to need and/or advantages of remote control of the node equipment. Clearly in all cases good remote supervision of the systems is required; in many cases today this is all that is needed but in future the advantage of a more flexible network with shorter times for changes and more efficient utilisation of available capacity are increasing. In each case this need, or advantage, should be evaluated and decisions on new node equipment should be based on these considerations.

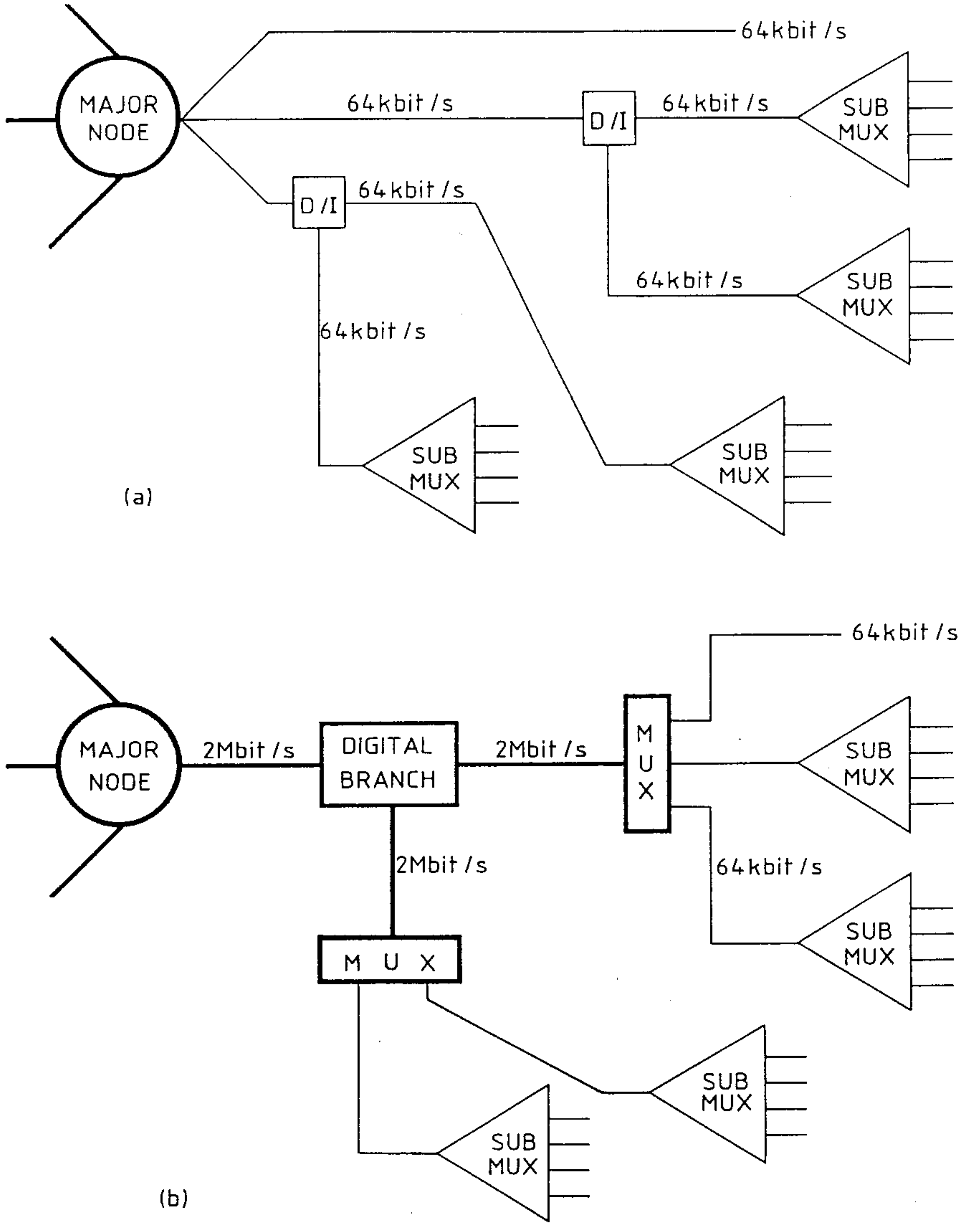


FIG 6.9
EXAMPLES OF TWO ALTERNATIVE SOLUTIONS
FOR A LOW CAPACITY NETWORK

6.3 Data Interfaces

6.3.1 Introduction and references

State-of-the-art digital transmission equipment should provide a suitable range of digital data interfaces which comply with the relevant CCITT V and X recommendations. This is most attractive from the economical and technical point of view as no costly analogue modems are required. Also the degrading effect of the A/D/-D/A conversion is eliminated.

In order to gain access to a 64 kbit/s bearer channel a single bitstream of less than 64 kbit/s has to be rate adapted. Multiple information streams of lower bitrate may be multiplexed together in the same 64 kbit/s channel.

CCITT defines several multiplexing schemes and rate adaption methods for conveying low speed asynchronous and synchronous data through a 64 kbit/s bearer channel.

R.111	Code and speed independent TDM system for asynchronous telegraph and data transmission.
X.50	Fundamental parameters of a multiplexing scheme for the international interface between synchronous data networks.
X.51	Fundamental parameters of a multiplexing scheme for the international interface between synchronous data networks using 10-bit enevelope structure.
I.460	Defines multiplexing, rate adaption and support of X- and V- series type interfaces for connection to an ISDN user interface.

The CCITT V recommendations define services, facilities and interfaces for data communication over the telephone network. V-series type interfaces are still widely used and therefore have to be supported for some time.

The main characteristics of the interfaces are specified by the following recommendations:

V.5/V.6	Data signalling rates for synchronous data transmission. Note: For telecontrol application quite often low speed asynchronous channels are used.
V.24	List of definitions for interchange circuits between DTE and DCE. Only a subset of the circuits defined by V.24 are normally used.
V.10/V.11 /V.28	Electrical characteristics for balanced and unbalanced interchange circuits.
V.31	Electrical characteristics for single-current interchange circuits controlled by contact closure.

For high speed data transmission the following recommendations may have to be considered:

V.35	Data transmission at 48 kbit/s using 60-108kHz group band circuits Interchange circuits V.35/V.24 Electrical characteristics V.35/V.28
V.36	Modems for synchronous transmission using 60-108kHz group band circuits Data signalling rate 48/56/64/72kbit/s Interchange circuits V.36/V.24 Electrical Characteristics V.10/V.11

The CCITT X recommendations define services, facilities and interfaces in data communication networks. Data terminal equipment having V-series type interfaces are supported by X.20 bis and X.21 bis type interfaces.

X.1	User classes of service
X.20	Interfaces between DTE and DCE for start-stop transmission services Interchange circuits X.24 Electrical characteristics X.26/X.27
X.20 bis	same as X.20 but Interchange circuits V.24 Electrical characteristics V.28/X.26
X.21	Interface between DTE and DCE for synchronous operation. Interchange circuits X.24 Electrical characteristics X.26/X.27
X.21 bis	same as X.21 but Interchange circuits V.24 Electrical characteristics V.28
X.24	List of definitions for interchange circuits between DTE and DCE on public data networks
X.25	Interface between DTE and DCE for operating in the packet mode Physical interface characteristics X.21/X.21 bis

X.26 equivalent to V.10
X.27 equivalent to V.11

The most important electrical characteristics of the different interfaces are listed in Table 6.4.

A simplified interchange circuit is shown in Figure 6.10.

CCITT Recommendation	V.28	V.35	V.36	V.10/X.26	V.11/X.27	V.31
Max. modulation rate	≤ 20kbit/s	48kbit/s	48/56/64/72kbits	≤ 100kbit/s	≤ 10Mbit/s	≤ 75bit/s
Cable	unbalanced	balanced	balanced	unbalanced	balanced	unbalanced
Signal states	$V_A - V_B$ pos. : 1; off $B_A - V_B$ neg. : 0; on					contact closed: 1; on open: 0; off
Generator: Open circuit voltage Uo Load Voltage under load condition	 ≤ 25V 300 z ≤700 5V ≤ U ≤ 15V	 not specified 100 Ω 0.55C ± 20%	 ≤ 6V 100 Ω ≤ 0.5 Uo	 4V ≤ Uo ≤ 6V 450 Ω 500 Ω ≥ 0.9 Uo ≥ 0.5 Uo	 ≤ 6 V 100 Ω ≥ 0.5 Uo	
Receiver: Significant levels Switching threshold	≤ 3V	not specified	≤ 0.3V	≤ 0.3V	≤ 0.3V	DCE < 15mA DTE ≤ 50mA
Connector	ISO 2110 (25 pins)	ISO 2593 MIL C-2285-7C (34 pins)	ISO 4902 (37 pins)	ISO 4902 ISO 9403 (37 pins) (15 pins)	ISO 4902 ISO 9403 (37 pins) (15 pins)	-
Distance between DCE and DTE	15m	-	1000m	1kbit/s 1000m 10kbit/s 100m 100kbit/s 10m	10kbit/s 1000m 100kbit/s 1000m 1Mbit/s 100m 10Mbit/s 10m	-

Table 6.4 Electrical characteristics of interchange circuits

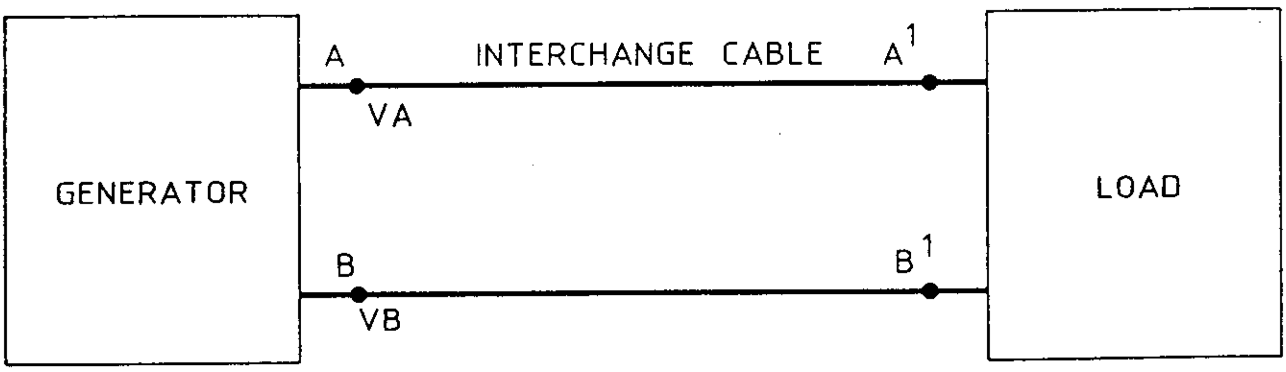


FIG 6.10

SIMPLIFIED INTERCHANGE CIRCUIT

6.3.2 Cross Reference CCITT V - and X - Recommendations versus EIA (US) Standards

Digital interface circuits meeting the requirements of CCITT V.24/V.28 are compatible with those meeting EIA Standard EIA-232-D (revision of EIA RS-232-C).

Digital interface circuits meeting the requirements of CCITT V.10/X.26 (electrical characteristics) are compatible with those meeting EIA RS-423-A.

Digital interface circuits meeting the requirements of CCITT V.11/X.27 are compatible with those meeting EIA ES-422-A.

EIA RS-449 defines a digital interface circuit for signalling rates >20 Kbit/s. The electrical characteristics correspond with CCITT V.10/X.26 and EIA RS-423-A for unbalanced circuits and with V.11/X.27 and EIA RS-422-A for balanced circuits.

SECTION 7 SWITCHING STRATEGIES AND SYSTEMS

7.1 Switching Services

7.1.1 General

If every one of the N subscribers of a telecommunication network has to be able to communicate with any of the N-1 other subscribers, this means that each subscriber should have N-1 devices joined by N-1 lines to the other N-1 subscribers. The total number of connections grows as N(N-1)/2 which is unpractical for economic and technical reasons even for moderate values of N. Thus it appears the concept of switching which according to the IEC, is "the establishment, on demand, of an individual connection from a desired inlet to a desired outlet within a set of inlets and outlets for as long as required". This definition is very broad. It makes no reference to the information to be transferred over the connection, nor to the type of connection and its method of establishment.

Switching by its nature is an algorithmic problem and historically the major aim of the public networks optimisation has been to reduce the overall average length of subscriber's lines (this represents about two-thirds of the cost of such networks). The situation could be different for power utilities because of technical constraints and capacity. For references on Electronic Switching and Computing Networks/ISDN systems, see References 37 and 38.

7.1.2 Requirements for switching services

Of the different telecommunication services described in Section 3, the power utilities, as well as the public networks, only had at the end of the 1960's some networks with switching capacity e.g. the telephone networks. The remainder, for their functional demands: response time, availability, security, etc., was carried out by means of networks without switching capacity, or at the most the transmission medium ended in a way that would facilitate the manual cross-connection to adapt the network to changing conditions, and to obtain a high availability.

Nevertheless the progressive digitalisation of the transmission and switching media, the enormous increase of information services, the appearance of systems such as LAN and office automation, the necessity to obtain more economical, secure and flexible networks, caused some power utilities to start implementing switched networks for other types of services in addition to telephony.

Some utilities find that a private switching network is economical and effective, others that use leased links from public carriers for their networks may be obliged by regulatory constraints to change to public switched networks. Also in some countries, in which private networks are permitted for the operation of the electrical network, the back up has to be carried out by the public data switched network. Thus the foreseeable short and medium term tendency is the movement to switching networks for different telecommunications services because they allow several benefits:

- network design, development and control closely matching the power utilities needs
- precise network parameters and growth requirements featured in the design
- a sense of greater security and control
- the possibility of more cost-effective management

It has to be considered that the traditional division of the telecommunication networks between switching and transmission is going to disappear in the future and it will be replaced by a division between the basic transport capability and the service capability of the network.

7.1.3 Types of switching techniques

Circuit switching, see figure 7.1

This involves establishing a temporary connection between (usually two) terminals and assigning this connection for their exclusive use throughout a call. The connection can be real, as in space-division switching: a continuous, physical (often metallic) communication path is reserved exclusively for the call throughout its duration. The connection can also be virtual, as in time-division switching: there is no physical continuity and the communication path exists only for short periods at regular intervals. Some commercial equipment is based on a mixture of both.

At each circuit switching centre, there are three main phases of operation for a call.

- Establishing the connection in accordance with signalling information from the terminals and/or other switching centres.

- Holding the connection throughout the call and supervising it to detect release conditions.

- Releasing the connection, again in accordance with signalling information from the terminals and/or other switching centres.

Circuit switching is thus controlled by signalling information and acts directly on the communication path. Other features include the following:

- The useful information and the signalling information are transmitted separately and independently in time, but possibly over the same transmission media and paths.

- Once established, a connection is transparent. Within limits that depend on transmission parameters (e.g. bandwidth, attenuation and distortion in space-division switching, or bit rates and error ratio in time-division switching) the information is transferred between terminals without verification and without constraints on its nature (speech, data, etc.) or distribution in time.

- Transfer is direct and takes place in real time. Information is transferred without delay between the terminals (approximately 20 ms on terrestrial links).

- The actions at all the switching centres involved in a call are co-ordinated, through signalling information.

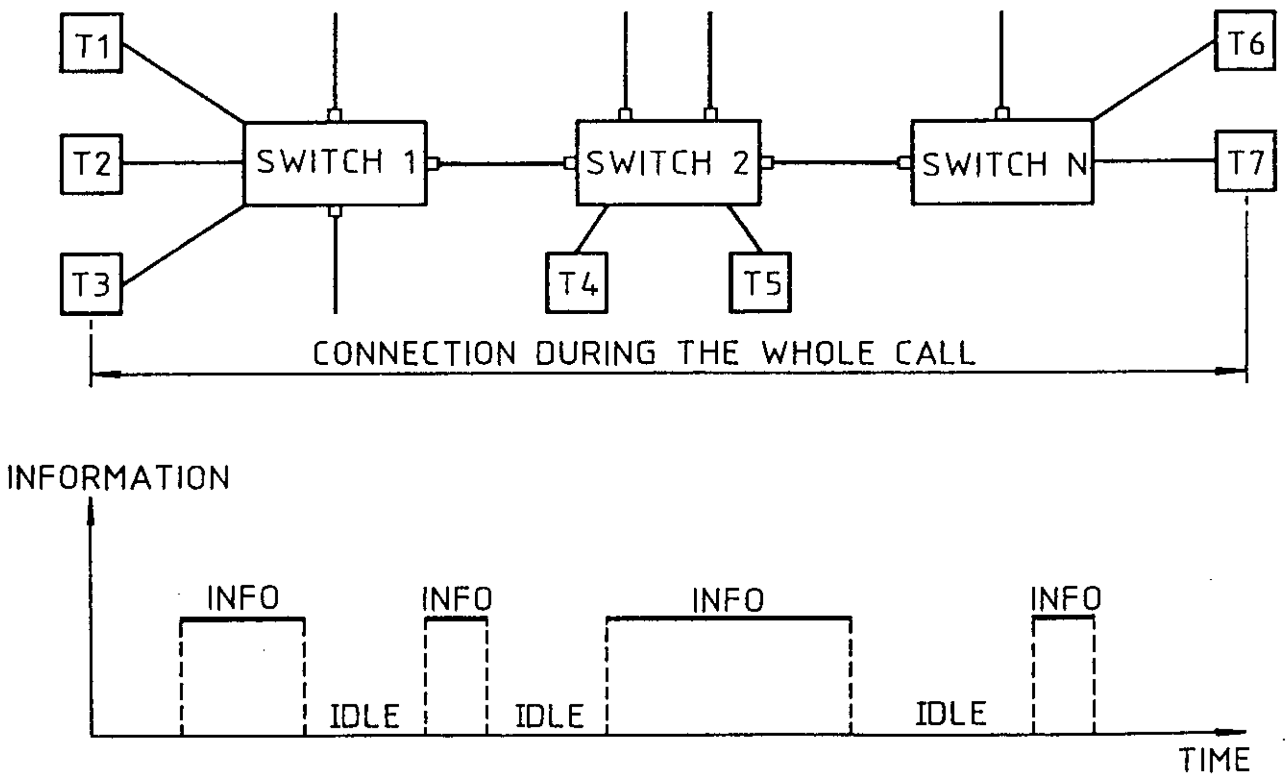


FIG 7.1 CIRCUIT SWITCHING

- The communicating terminals must be directly compatible. The network does not process or otherwise act on the signals interchanged by the terminals once the connection has been established. Each terminal receives signals exactly as transmitted by the other terminal, with no conversion of speed or any other parameters.

In general, circuit switching is better suited for voice rather than for data applications because most data is usually active only for a small percentage of the total time. The holding time becomes comparable to the call set-up time and circuit switching does not have the capability of node-to-node error checking.

delay at each switch but increase the percentage of the packet taken up by the header bits.

There are two basic operation modes: the datagram mode and the virtual mode.

Datagram Circuit Mode - Each packet containing address information, is transmitted by the sending terminal independently of network conditions. It can be routed separately through the network; the size of the information blocks (packets) is not related to the total amount of useful information to be transferred and depends on the design of the network. There are no procedures for traffic control (datagrams can be lost in the network in the event of congestion).

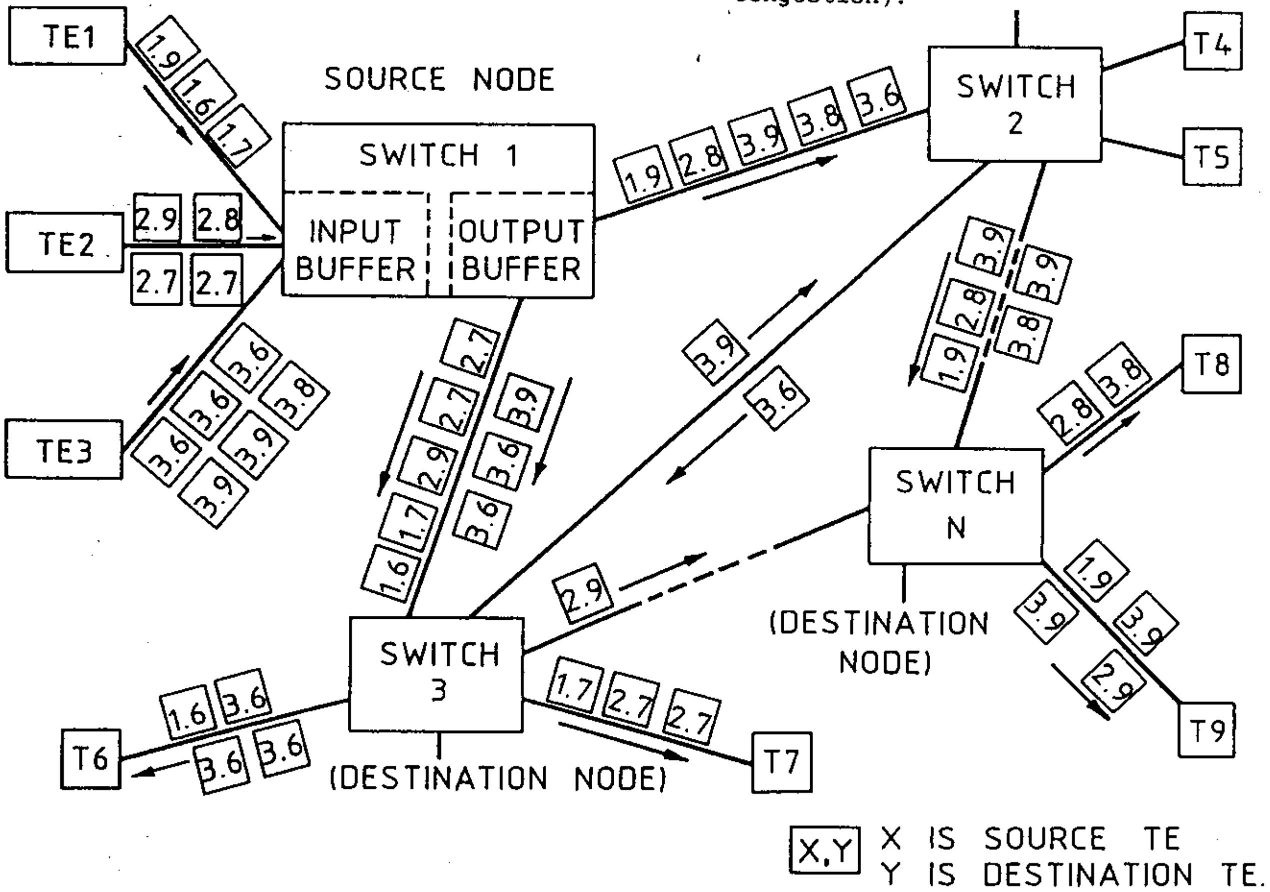


FIG 7.2 PACKET SWITCHING

Packet switching

It is a kind of logical evolution of the message switching in which complete messages are sent from source to destinations without establishing end to end connections. Instead of sending a full message to the next node and then progressively to the destination, the message is split into small units, called packets and each packet is sent individually into the network through the various nodes, see figure 7.2. The exact length of the packet is a trade-off between delay and overhead. Shorter packet lengths decrease the queueing

Virtual Circuit Mode - The network is aware of the calls in progress and provides virtual circuits for information transfer between the terminals as in time-division circuit switching. The term "virtual" refers here to the fact that there is no continuous, physical connection between two communicating terminals. Instead, a logical connection is established through the network before the terminal begins sending data packets. There are, however, several important differences between a virtual circuit mode packet switched network and a time-division circuit switched network.

Firstly, the capacity of transmission links is assigned only when the terminals are actually transmitting information. Secondly, each connection is identified by a reference number in the header of each packet, rather than by a time reference (this is also the key difference with datagram switching. In the virtual circuit mode, the network determines the delivery point from the connection reference number in each packet's header. In the datagram mode, each packet explicitly contains the delivery address). Thirdly, the network controls the maximum rate at which packets are input from terminals, as a function of the speed with which earlier packets are transferred. When necessary, the network prevents the transmission of packets from sending terminals, this is called flow control.

The virtual circuit mode is the most common packet switching mode in modern networks. At each switching centre there are again three main phases of operation:

- Establishing the virtual circuit: The switching centre reserves buffer memory to set up a logical connection between the input and output ports corresponding to the communication request.

- Forwarding data packets: Each time a "ready to receive" signal from the next switching centre is detected, a packet is transferred from the incoming queue to the outgoing queue, and a "ready to receive" signal is sent to the preceding switching centre.

- Releasing the virtual circuit: The logical connection is ceased by releasing the buffer memory.

Packet switching in the virtual circuit mode is thus controlled by signalling information. It acts on the communication path during the establishment and release phases and on the transmission of signals during the actual information transfer phase. It has features in common with circuit switching (transfer is very fast because buffer storage times are kept very short, actions are co-ordinated at all switching centres involved in a call, and separate signalling information is employed to control switching). Other features include the following:

- The loading of transmission links can be extremely high, even if the traffic relative to each call is highly intermittent.

- The physical characteristics of the transmission links and switching centres can be independent of the individual transmission rate for each communication.

- Information is transferred in a very secure manner, due to procedures for systematic error correction and automatic flow control.

- Set-up and release times can be very short.

Besides these two basic switching techniques, there are other different switching procedures and equipment (burst switching, hybrid switching, fast circuit switching, fast packet switching, digital cross-connection, dynamic multiplexers and branching equipment for different applications) that makes it difficult to distinguish between switching nodes and transmission nodes (refer to Section 6).

Digital cross connecting systems (DCS)

It can be viewed as a device consisting of interface units, a non-blocking switch matrix, a control channel and an observation channel. The digital signals are terminated in the line interfaces and cross-connected in the switching matrix. The configuration of the system is manipulated by using the control channel, while the observation channel provides means for assessing various status and performance information. Thus a DCS is a channel switch with a variety of rates and holding times - per channel - of hours, days or years, and it receives the signalling information not embedded in the traffic signals but from a control channel.

Fast packet switching

The application of packet switched techniques has been agreed by CCITT for bit rates up to 155 Mbit/s and, at a later stage, even 620 Mbit/s in conjunction with Broadband ISDN under the term Asynchronous Transfer Mode (ATM), also known as fast packet switching. This is an advanced version based on optical fibre links and simplification of the lower layer protocols of the OSI model. The function of error correction and flow control can be removed from the lower layers because of the abundant bandwidth and low error rates possible with optical fibre links and they are provided on an end-to-end basis by higher layer protocols as required (i.e. for data but not for voice). This technique uses asynchronous "on demand" short fixed size time slots called cells. ATM is regarded as a technique intermediate between circuit and packet switching by combining their advantages in order to cater for delay sensitive application and flexible bandwidth resulting from statistical multiplexing.

From the use of virtual channels, ATM is able to support a large variety of 64 kbit/s based and broadband services and combinations thereof over a single broadband user-network interface without requiring a corresponding proliferation of physical channel types and interface structures, see figure 7.3.

7.1.4 Message handling systems (MHS)

There could be a little confusion between MHS and the message switching technique as it has been described in paragraph 7.1.3. This could be considered as a primitive way of packet switching. MHS also is referred to as a computer-based message system (CBMS) which lets a user (person or machine) prepare messages, send them to other users and receive messages from them. The sending system must be prepared to hold the message until the user finds it convenient to receive it. Hence the term "store and forward" and also the frequent and confusing "message switching".

Application layer 7 is utilised by the user when communicating with a similar application or another system. One example is MHS. Rec. X.400 is the number of the first of a series of CCITT recommendations which specifies how a standard MHS system is to work.

7.1.5 Traffic integration

All communication systems need a certain type of transmission channel. Channels are connected to one another by way of transmission or switching nodes. The system functions are often undertaken by these connections, or in the end user equipment.

Planning systems for voice or non-voice services is relatively uncomplicated; the difficulty in designing an integrated network for voice, data and other services lies in the different requirements of each one and its particular application.

There are three different levels of traffic integration:

- Integrated access: Voice and non-voice services are accessible through a single user interface allowing voice and data terminal equipment to share a common network interface. Voice and data are carried on the same local loop to the network switch.

However, traffic within the network is routed to different transport networks which are separately optimised for the type of service. (At this moment ISDN can be viewed as an example of integration at this level).

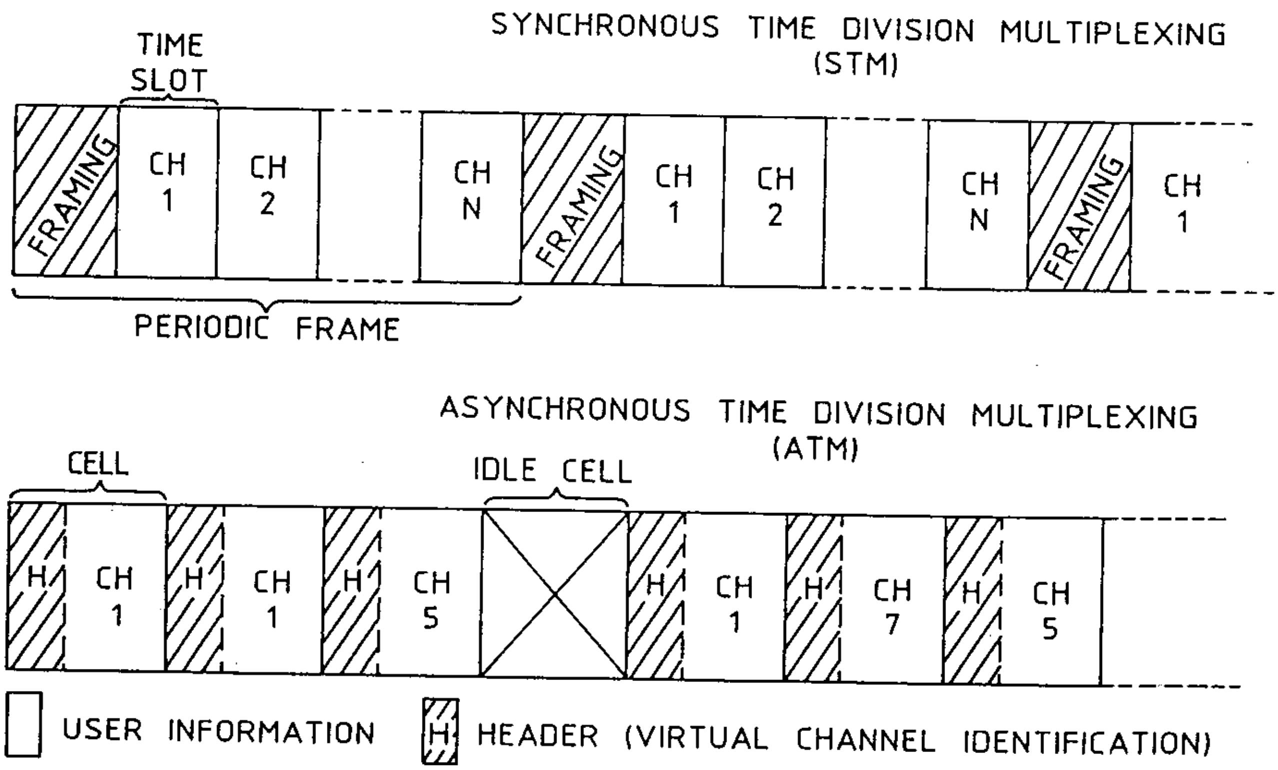


FIG 7.3 FAST PACKET SWITCHING

- Integrated transmission: The transport networks share common transmission facilities between switches but maintain separate switching facilities.

- Integrated switching: Switching facilities are shared as well as transmission links and network access. This level is the complete integration since all types of traffic are handled entirely by the same facilities. For this level the fast packet switching is now the most promising approach.

In Section 3 the advantages of services integration are described together with the actual and short term tendencies for power utilities.

7.1.6 Developments in switching technology

In accordance with improved technology the switching function can be undertaken in a variety of ways:-

1. Manual

2. Electromagnetically controlled space division (analogue)

3. Computer-controlled space-division (analogue)

4. Centralised architecture time-division (digital)

   Centralised architecture time division with added data capability

5. Distributed architecture time-division (digital) designed to serve voice and data.

6. Optical Switching

In a general way, an optical (or photonic) switching system could be described as a system where both the inputs and outputs to an interconnected network are information encoded streams of photons optically controlled. There are three approaches for this development

- Time-division photonic switching (TDS)
- Space-division photonic switching (SDS)
- Wavelength-division/ Frequency-division switching (WDS/FDS)

Probably its use will be restricted to public networks at least in the foreseeable future.

7.2 Circuit Switched Services

7.2.1 Subscribers/site and traffic between sites

The main factors that can influence the design of a circuit switched network are:

- Number of subscribers
- Routing plan, which defines the logical path between two subscribers for a call
- Blocking plan, which defines the network's grade of service
- Transmission plan
- Topology
- Types of traffic (voice, data etc.)
- Total switched traffic (usually referred to the busy hour and considering the local, transit, outgoing and incoming traffic).
- Type of synchronisation (in digital systems)
- Security, flexibility and adaptability
- Centralised or distributed control

These points are strictly related to the structure of each individual network. Also, for small systems the application of these units and mathematical models used for designing the public networks can bring false results. The main differences between switching centres of the public networks and the private ones are:

- Smaller size of the switches (2 to 3 orders of magnitude smaller than those of the public ones)
- Number of users per switch below those of the public network (1 to 3 orders of magnitude below).
- Higher relation of the number of links between the switches/number of subscribers that are served by the public networks
- Different topology
- Need of special services
- Medium-low traffic that can reach very high peaks in emergency situations (it is essential to plan for this at the time the network is dimensioned).

- The level of grade of the service (the loss probability in trunks or in exchanges) varies, in the public networks, between 0.5%-1% and 10% in the worst case. For private networks, non-blocking transit exchanges and the existence of alternate routes and backward re-routing helps to reduce the loss probability.

The relation between non voice and voice services is at least an order of magnitude greater in power utilities networks than in public networks.

7.2.2 Network topology and hierarchy (Refer also to Section 5)

A public network has an infrastructure that is planned and constructed with the aim of providing only general services of communication that are adapted to the interests of the social environment instead of giving specific or convenient services only to some groups of the social framework. In other words, a planned, constructed and exploited network to offer common services (telephony, transmission of data, etc.) to the maximum number of users possible, in the most economical way possible, compatible with a quality and a level of service defined previously as acceptable by the means of the users.

A private network is planned, constructed and exploited in contrast to satisfy the specific necessities of a determined sector, company or group of users with more strength in the achievement of technical requisites that motivated it than in the purely economic aspects.

These considerations mean that the public networks have a hierarchic structure and a topology in star. Usually, and according to each country, there are 3 to 5 hierarchical levels. This considerably simplifies network management and dimensioning and provides a structure to which simple routing rules may be applied to ensure that a call can always reach a given called party through no more than a specified number of transit centres.

The circuit-switched networks for power utilities do not usually have more than 3 hierarchical levels (in small networks 2, and even 1) and these usually have a mesh topology since some of the links between switches are intimately related to the topology of the electrical network because it serves as a physical transmission path (PLC, optical fibres, etc.) or by the necessity to reach the power sites (plants, substations etc.). Other topologies such as indicated in Section 5 could be switched or non-switched networks.

7.2.3 Signalling systems

There are two different types of signalling in a telecommunication network:

- Subscriber Line Signalling. It is a form of channel associated signalling as all signals are carried by the subscriber's line. There are two categories of signals:
- subscriber line signalling: i.e. power feed, loopbreak signals, ringing current, metering pulses, etc.
- in band signalling: i.e. speech or data signals, DTMF push-button signalling etc.
- Interexchange Signalling. The interchange of information between exchanges is by channel associated signalling (with in-band and/or out-band signals) or common channel signaling.
- in band channel-associated signalling. In space-division systems the signals are typically multi-frequency signals. In time-division systems in-slot signalling is employed; signals are carried in the channels and sampled and coded like the speech or data signals.
- out of band channel-associated signalling. In space-division systems signals may be transmitted by varying the trunk loop impedance or by separate E and M wires. In this case transmitted signals are basically earth pulses on the M wire while received signals are earth pulses on the E wire. In time division systems each speech or data channel is assigned one or two 500 bit/s (1 bit per multiframe) signalling channels multiplexed in time slot 16.
- common channel signalling. A data transmission link shared by several trunks is used to transmit signalling information between exchanges. All messages interchanged are in accordance with a procedure specific to the signalling system defining in particular the message format and the error correction method.

The signalling link is controlled and procedures implemented through common channel signalling terminals at the respective ends of the transmission facility.

To date, two common channel signalling systems have been defined by the CCITT: The No. 6 system, in 1972, for analogue systems and the No. 7 system in 1980 for digital networks. Some of the key features of the No. 7 system are:

- The signalling links are data links with bit rates of 4,800 bit/s or more when transmission is analogue and 64 kbit/s when transmission is digital.
- The signal repertoire can be much larger than with channel-associated signalling. This makes it well suited to dialogues between the stored program control processor of electronic exchanges.

- Messages can be transmitted at high speed between exchanges, allowing call set-up time to be reduced.

- The CCS links can form an information transport network independent of the speech transmission network. Signalling can concern not only call establishment and release, but also network administration and maintenance.

It has to be said that Recommendation Q.931 is at present defined only as a public access signalling system and has not yet been adapted for private network signalling. With the appearance of the digital PABX, also called ISPABX (integrated services PABX) several options are possible to link public and private networks.

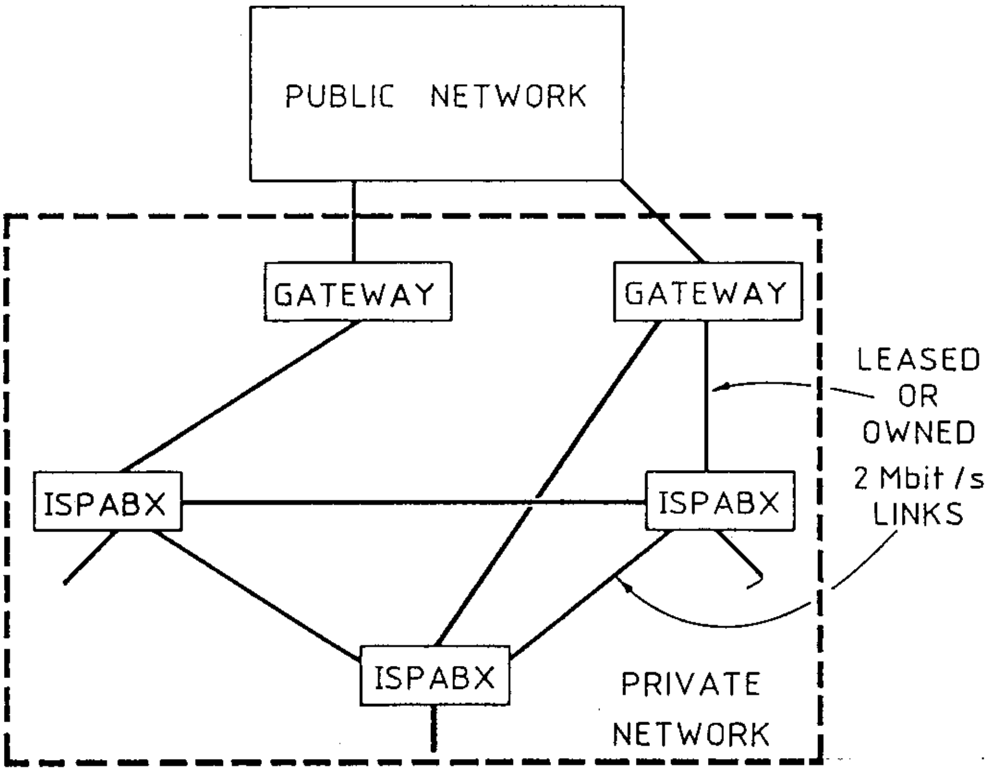


FIG 7.4 NETWORK LINKS (OPTION 1)

- The separation of message transfer on the one hand, and message processing on the other hand, permits the two functions to evolve independently and allows multiple users to access the same signalling terminal.

The CCS does not only have advantages, because each signalling link is common to many trunks, special procedures are necessary to guarantee the continuity of service in the event of link failure and to check the signal continuity of established paths.

The CCS No. 7 system has been specified as a modular system providing for independent evolution of its constituent parts and for the independent definition of sub-systems for specific applications.

Figure 7.4 represents the U.K. system which defines the Digital Private Network Signalling System (DPNSS), that is an inter-ISPABX, while Digital Access Signalling System 2 (DASS2) is a protocol for connecting ISPABXs to the public network. The terminal interface is according to X.21 and the service provides two B channels (but one is at 64 kbit/s while the other is at 8 kbit/s) and one D channel, used purely for "mapping" the X.21 in-band signalling into common channel signalling for controlling the calls. Probably and besides DPNSS other supplier-specific standards will undoubtedly emerge in the period before the full CCITT Q series of standards will be available. (e.g. Telecom TeLinc an Australian-developed signalling protocol for linking ISPABXs. It can be used to interconnect ISPABXs either over dedicated circuits or over the ISDN). However, it is almost certain that the different emerging standards will have some commonality and the possibility to move to the CCITT standards when needed modifying their proprietary protocols of layers 2 and 3, see figure 7.5.

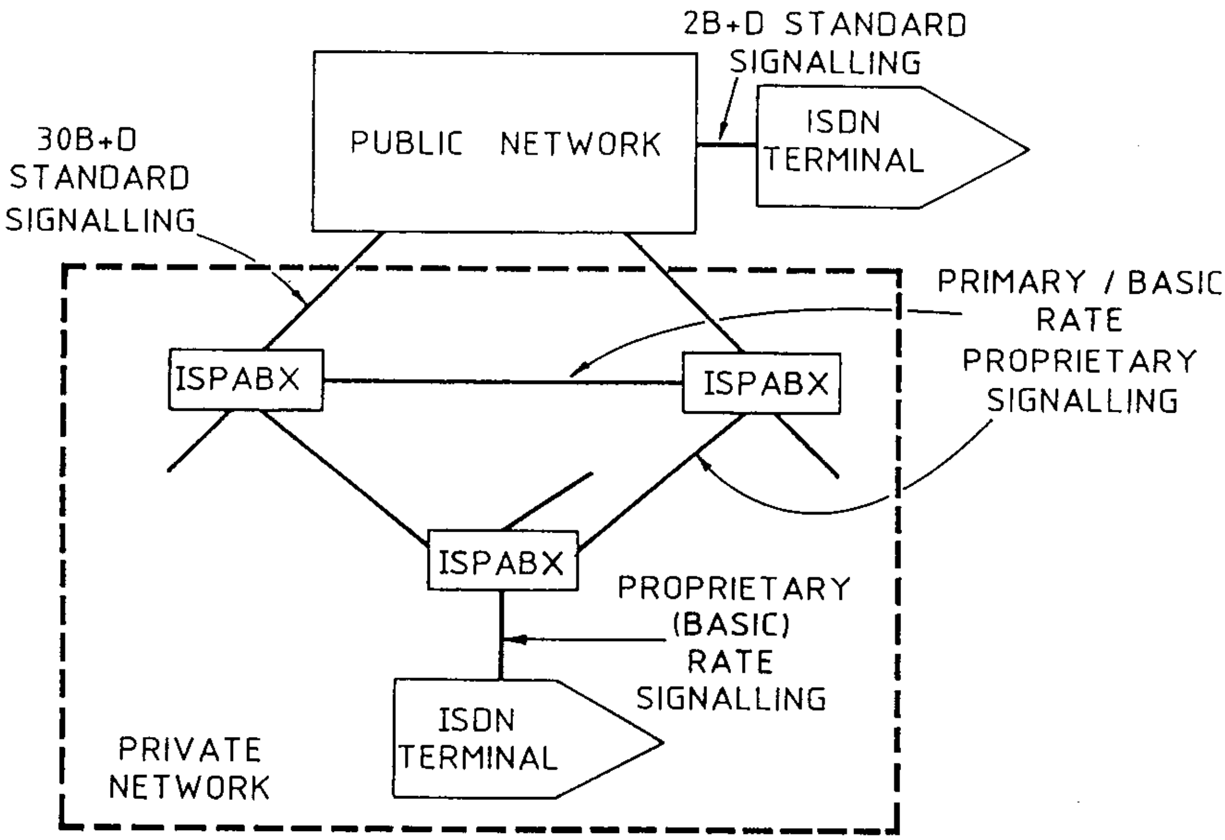


FIG 7.5 NETWORK LINKS (OPTION 2)

The interface between ISPABX and terminals is more of a problem. It is only in Germany that some effort has been made to standardize the interfaces behind the ISPABX. (The trend in both types of signalling is to incorporate the principles of the D-channel in private networks both on the subscriber ISPABX lines and between exchanges). However a certain amount of proprietary interfaces exist but they utilize a short-range four-wire transmission system which is quite different from those used for the public network basic-rate interfaces.

In the public ISDN interchange signalling is affected via a super-imposed centralised common channel signalling network (CCSN) while the signalling between ISDN and terminal equipment is achieved by layer 3 of the D-channel protocol. These are also binding for the connection of ISPABX's to the public ISDN. The D-channel protocol specifications are provided for extensions. This fact is basic for their size within private networks. The CCITT has defined a set of functions that can be common for both public and private networks. For additional functions they provide sufficient regulations to guarantee transparency within networks but not the capability to cater for functions that are provided in the private network.

For these type of functions, additional agreement has to be reached to enable suppliers to develop systems capable of being used in a multivendor's mode. Such standardisation work is currently carried out in other organisations, such as ECMA and could be the basis for further work carried out within the CCITT. Another possible solution to link private ISPABX to public systems is Centrex, (Centrex is short for central exchange) (Fig. 7.6.) in environments where this facility is available see Section 3. The switching system is shared by one or more utilities close to one another but not necessarily in the same building, and it is programmed in a way that every utility or every group inside one utility has the impression of possessing its own exchange. Interworking of ISDN and existing data networks has been preserved through agreement and inclusion of Recommendation X.25.

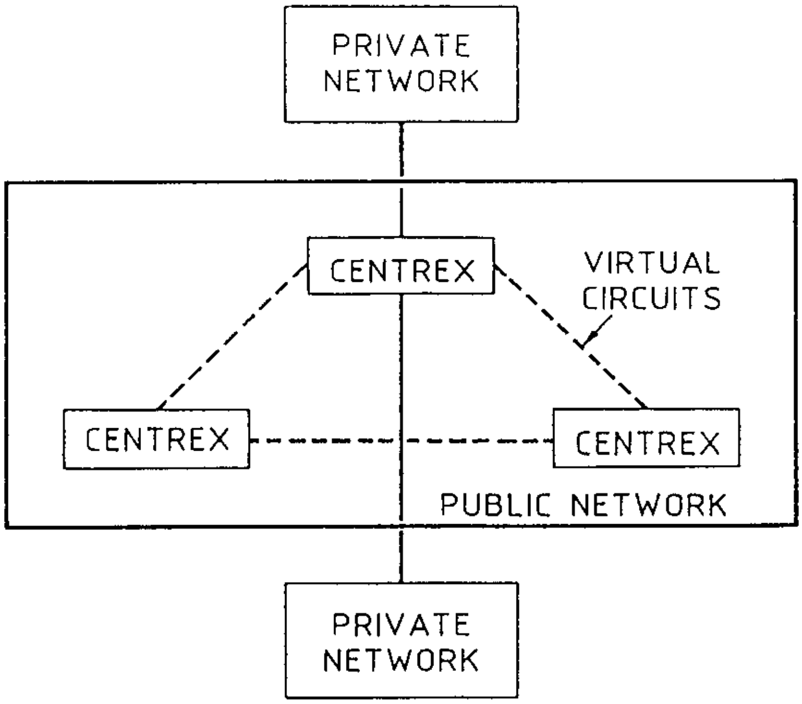


FIG 7.6 NETWORK LINKS (OPTION 3)

7.2.4 Circuit switching systems

There are two options to implement circuit switching systems: public and private networks (See Section 5) and these are

- space division switching (electronic and mechanical)
- digital time division

Probably both types will co-exist for an interim period, although it is considered that digital time division will be the dominant one in the near future. Today, the digital PABX is basically a circuit switch. Subscriber connections could be analogue (e.g. analogue telephone set) or digital.

Since digital PABX and ISDN equipment use the same architecture and support the same set of standards, it is to be expected that these two systems will be optimally tuned with each other.

The ISDN architecture has two parts: the customer access and the network access. The ISDN switch is the critical point separating these two architectures.

The access side is shown as illustrated in figure 7.7 and there are few reference points: R, S, T and U. Network Termination 1 (NT1) performs OSI layer 1 functions. NT2 perform OSI layers 2 and 3 (may be a digital PBX, a LAN, a terminal controller or a multiplexer). Terminal Equipment 1 (TE1) is an ISDN terminal (i.e. a device that complies with ISDNs interfaces recommendations, such as a digital telephone).

TE2 is non ISDN terminal that requires a Terminal Adaptor (TA) to connect to the reference points S or T (e.g. ordinary voice telephone and devices with RS-232 interfaces).

Rec.I.430 deals with the layer 1 part of the Rec.I.420 basic rate interface and, for private systems, has two disadvantages: one is that it is not a 2-wire interface (and most of the existing networks are still 2-wire) and the other is that it could not cope with the terminal to ISPABX distance requirements. These two aspects can be avoided with the introduction of a "private network termination" (PT) that is a functional grouping which performs similar functions to the NT1 in the public ISDN, see figure 7.8.

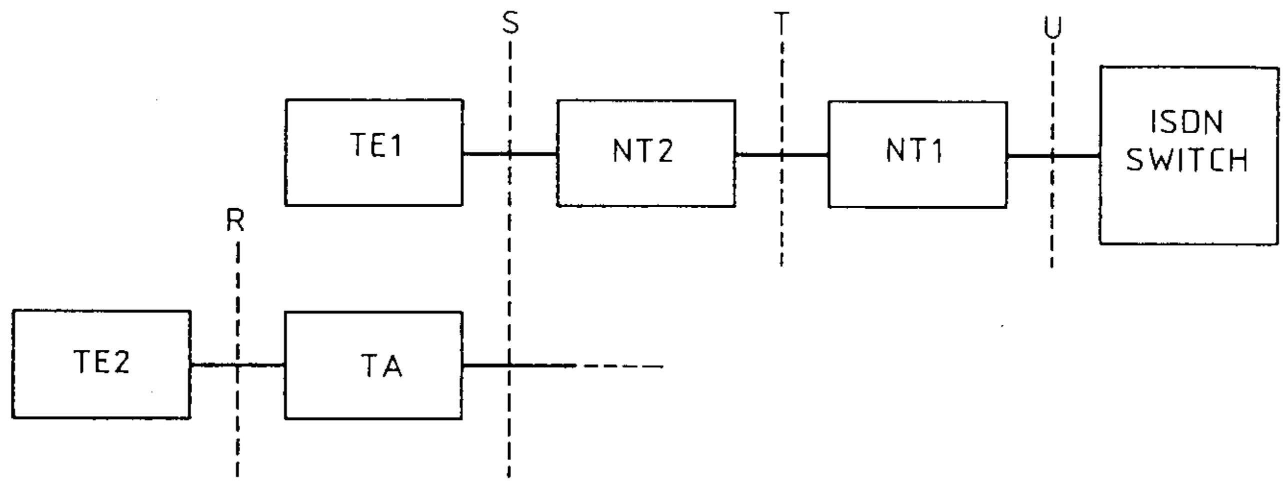


FIG 7.7
INTERFACES (TERMINAL-PUBLIC ISDN NETWORK)

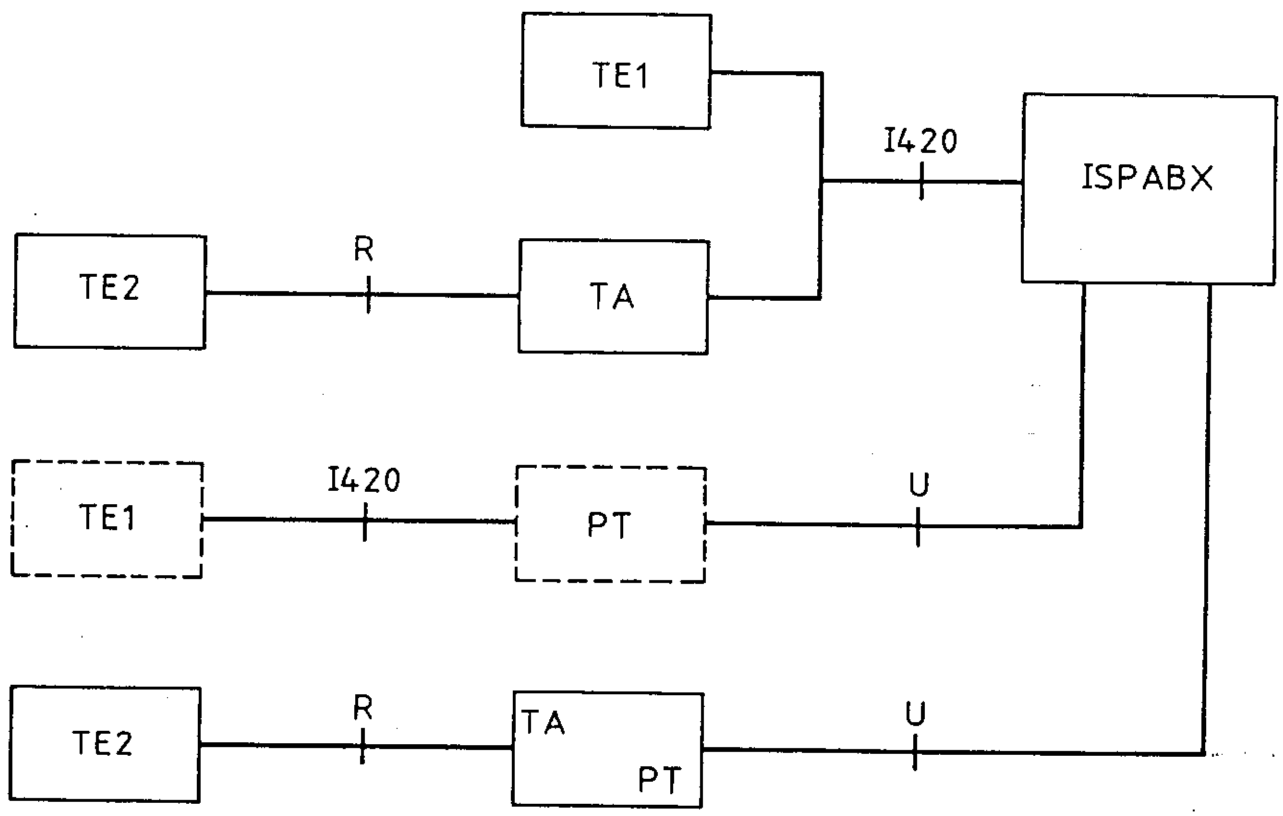


FIG 7.8 INTERFACES (ISDN TERMINALS-ISPABX)

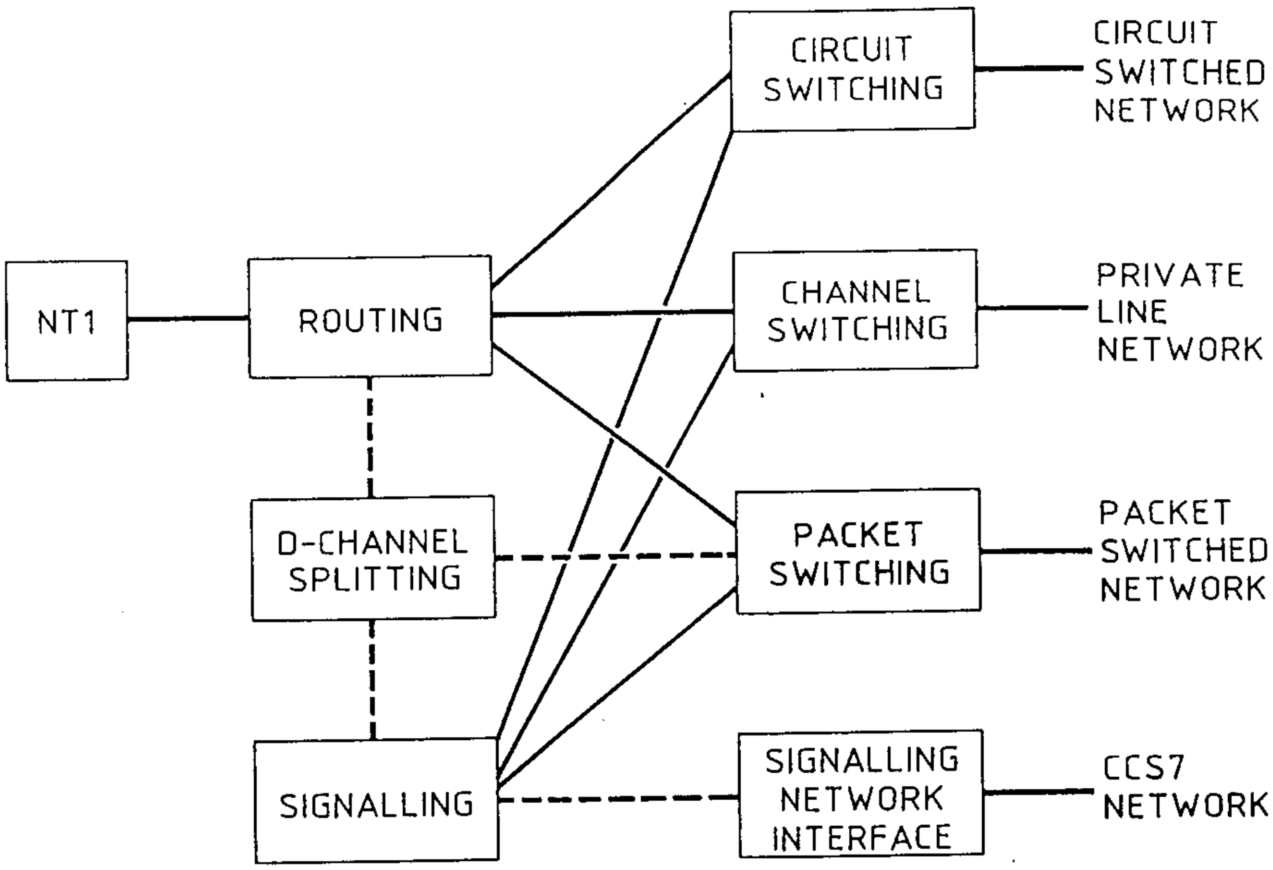


FIG 7.9 ISDN NETWORK SIDE.

The use of separate PT boxes is not very cost-effective. For this reason basic rate terminal equipment with proprietary U-type interfaces that incorporates the PT function is common practice (e.g. 2-wire 2B1Q U-type standard as in the USA).

On the network side of the ISDN interface, the switch must separate the channels and route them appropriately see figure 7.9. The B channel is routed to a circuit-switched network, packet-switched network or private-line network. The circuit-switched networks need not be wholly digital; however, it must be able to support clear digital transmission.

The D channel may contain both signalling and data and therefore it is split accordingly. The signalling information is diverted to the signalling network and the data part is routed to the packet-switched network. Data transmission over the circuit switched part of an ISDN network can be asynchronous or synchronous.

- A circuit switched connection for start/stop terminal requires at both sides of the 64kbit/s link, an ECMA 102/V.110 TA which converts the X.1 data transmission rate to 64 kbits. Apart from rate adaption, a TA also handles the ISDN-D channel protocol. If the start/stop terminal has on top of the regular V.24/RS232 interface, a V.25 bus auto-call interface, then the terminal adapter converts the V.25 bis protocol to D-channel signalling. In the absence of V.25 bis, the terminal adapter may support proprietary call set up as hot line connections.

- A circuit switched connection for the synchronous X.21 type terminal requires an X.30 type TA. The rate adaptation method for the TA is in line with the ECMA 102/V.110 scheme.

Apart from the rate adaptation, this X.30 type TA also handles the signalling of the X.21 (bis) interface and the D-channel.

As it has been said in this section, several kinds of private circuit switching systems exist both for voice and non-voice services, see Section 3.

7.3 Packet Switched Services

7.3.1 Number of ports/sites and traffic between sites

The usual packet switch is one or more orders of magnitude smaller in terms of throughput than a circuit switch, however, but, as the holding times are generally an order of magnitude shorter, the total number of path setting and clearing operations could be of a similar order.

The packet traffic is characterised as bursty and unpredictable. In practice, neither the datagram nor the virtual circuit modes can effectively prevent traffic congestion. As a result, in most of todays networks, the performance is largely dependant on the offered load. It has been common experience that the performance degrades rapidly whenever traffic fluctuations reach a moderate level.

These fluctuations could be due to normal statistical fluctuations or to unexpected peaks at some points of the network(s) (equipment failure, emergency situations, etc.) and can be limited by the use of a hierarchical set of flow control techniques that apply to different parts of the network. One of these is the windowing. A window is defined so that the number of packets sent and not yet acknowledged by the receiver cannot exceed the window size and this has to be taken into account in the design stage of networks.

Today, there are relatively few power utilities that use packet switching networks for application of telecontrol, although they exist or are planned for future administrative and other purposes. The most significant characteristics of present systems for telecontrol are:-

- packet size : 256 - 1024 bit
- throughput : 50...1000 packets/s
- protocol : CCITT X.25
- transmission speeds: 1.2...64kbit/s
- priorities (when existing):

1.- services for power system operation
2.- facilities for maintenance
3.- facilities for management
- average delay : 100...300ms
- average delay priority messages: 100 ... 300ms

For other applications the above figures could be different, according to the size and design of the network.

The median traffic generated by a Remote Terminal Unit (RTU) varies widely as a function of its size and the type of system. For a typical RTU, values of 120 bit/s have been given as an average for a period of 5 minutes. The maximum values reported during this period of time are 3 times the normal value. This has to be taken into account at the time of implementing a packet switching system for this purpose.

An interesting concept to measure the capacity of a PSN is one of power which is defined as the global capacity of the network (number of packets delivered per second) divided by the average delay suffered by a packet when passing through the network.

7.3.2 Network topology and nodes

The topology often used in packet networks is of the non-structured or mesh type. With such a topology and non-fixed routing strategy (packet pipelining), some packets may traverse many nodes, whereas others will traverse relatively few before reaching their destination. Furthermore, different queuing delays are likely to be encouraged at each node. Thus packets can arrive at an exit node at random and may be out of sequence and therefore require packet sequencing and message reassembly.

An alternative which minimises the above difficulties is to use a structured topology which deliberately limits the maximum number of nodes that a message traverses before reaching its destination. The existing switched telephone network has a topology of this nature and consists essentially of a hierarchical system of star-like subnetworks.

For large networks (national) subscribers could be connected to minor nodes (local level). These local levels are connected to some major nodes conforming to the regional level, and the major nodes connecting to the national level. Depending on the connectivity of the major nodes, the total number of links necessary to reach any node from any other can be as small as three (for the special case of fully connected major nodes) to as high as two plus half the number of major nodes (for minimally or ring connected major nodes). Such a topology, therefore, provides a structured means by which major node connectivity (cost) can be traded against the total number of links traversed (delay).

In addition to the above benefit, a more general observation is that a hierarchical approach is highly desirable for large, multinode networks in order to simplify and economise the addressing and routing as well as operational, maintenance and administrative functions.

7.3.3 Protocols and connection types

Originally, perhaps the most important objective for implementing packet switched networks was to increase the efficiency in the utilisation of expansive transmission facilities such as satellite frequency bands or long hauls terrestrial links. Another objective conveniently achieved by packet systems is robustness with respect to blockage in particular links in the network. Packets are time stamped or numbered serially to aid the receiving station in reassembling the message; the receiver can identify any packets that failed to arrive and request retransmission. Besides, and closely related, is the assurance of the accuracy of all the bits in a received message by use of error-detection codes.

Today nearly all the existing systems are based on the Rec. X.25, and therefore it seems logical that for interworking with any network, either public or private, the most convenient choice will be to choose this standard. The problem for some applications of the power utilities is that the X.25 has not been designed for them (i.e. telecontrol).

Most of the remote terminal units (RTU) existing nowadays have different protocols, not standardised, asynchronous transmission, and work in polled mode. To accomplish their adaptation to a packet switching network, the following possibilities can be considered:

- to design new RTUs able to use the present X.25
- to design new RTUs with special codes for Telecontrol modifying the X.25
- to use the present systems using the PAD referred to in the Recs. X.3, X.28 and X.29
- to use the present systems, the PAD, and the transport layer (ISO layer 4) to overcome the constraints of the X.25 protocol for Telecontrol.

The last one is the one that looks most logical since it doesn't modify the X.25, and avoids the problems that can arise (answering time, possibility of undetected errors, etc.).

7.3.4 Access to packet switching systems

The adaptation of X.25 based packet switching techniques to ISDN as contained in CCITT Recommendation I.462 (X.31) will be the standard method for many years (till the introduction of ATM packet-switched techniques into Broadband ISDN).

Also CCITT Recommendation I.122 refers to a far-reaching integration of packet communication into ISDN by employing the signalling procedures designed for circuit switching to the setting up and clearing of virtual connections (called additional packet node bearer services). The ultimate step will be the introduction of ATM which can be considered as combining the relative advantages of circuit and packet switching and could therefore substitute both as a universal switching technique in the longer term. The characteristics can be viewed in Table 7.1.

Basically, there are two possibilities for supporting existing X.25 terminals at the ISDN access in accordance with CCITT I.462 (X.31):

- Access to data transmission services provided by a separate packet-switched public data network (PSPDN).

- Provision of a virtual circuit bearer service within the ISDN.

Both differ mainly in terms of where the switching function for the X.25 terminals connected to the ISDN user network interface is handled; in the switching nodes of the PSPDN or in the ISDN. In the first case the only support an ISDN gives to packet calls is the provision of a physical 64 kbit/s circuit mode transparent connection (B-channel connection) between an X.25-TA and the appropriate ISDN port of the PSPDN. Even though physically connected to ISDN, X.25 terminals logically remain users of a data network regarding numbering and user facilities. In the second case, call establishment is performed in two steps:

- Set-up of a physical 64 kbit/s B-channel connection to the Packet Handler (PH) of the ISDN by means of the ISDN D-channel protocol (I.451)

- Set-up of virtual calls via the established B-channel connection by means of X.25 call control i.e. end-to-end performance of the X.25 link and packet level protocols between the X.25 DTE on the one hand and the packet handler on the other.

Either B or D channel can be used for this access. For D channel access the X.25 packets and the ISDN call control signalling messages share the physical transmission capacity of the D channel. This is effected by frame multiplexing at layer 2 by differentiating in the HDLC LAPD address field: Service Access Point Identifier (SAPI) = 16 for packet information and SAPI = 0 for circuit switching information see figure 7.10.

The connection of an OSI terminal requires a X.31 type terminal adapter, X.31 supports virtual circuits via both B and D channels. Two rate adaptation methods are specified: the X.30 and rate adaptation by means of flag stuffing. X.31 also specifies the relation between the signalling of the X.25 interface and the signalling of the D-channel.

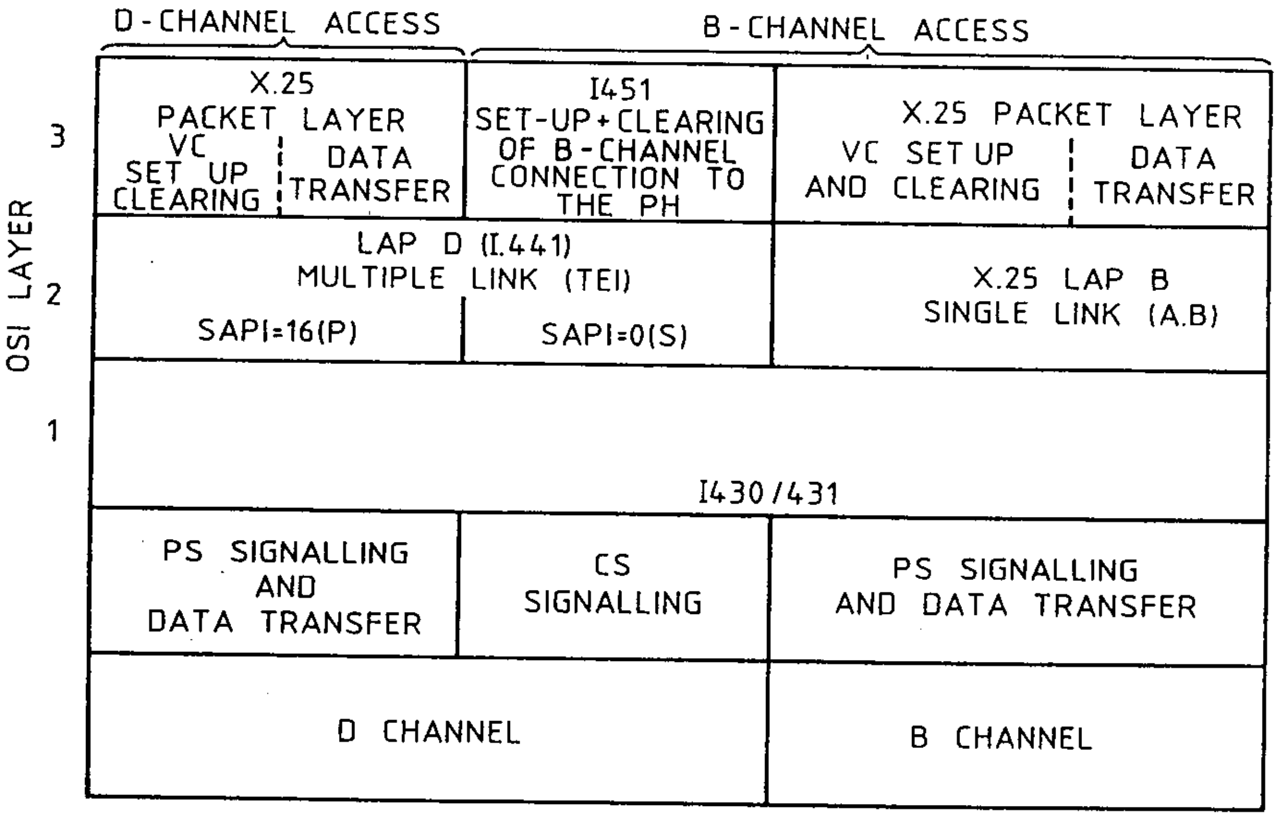


FIG 7.10
PACKET MODE ACCESS TO ISDN
PROTOCOL ARCHITECTURE

The connection of a character mode terminal to a packet switched ISDN bearer service requires both TA and Packet Assembler - Disassembler (PAD) function.

The PAD function may or may not be co-located with the TA but if they are dissociated the TA is identical to the ECMA -102/V.110 type terminal adapter.

Some access possibilities for data services for transit and interworking network are shown in figure 7.11. Table 7.1 indicates possible packet switching techniques.

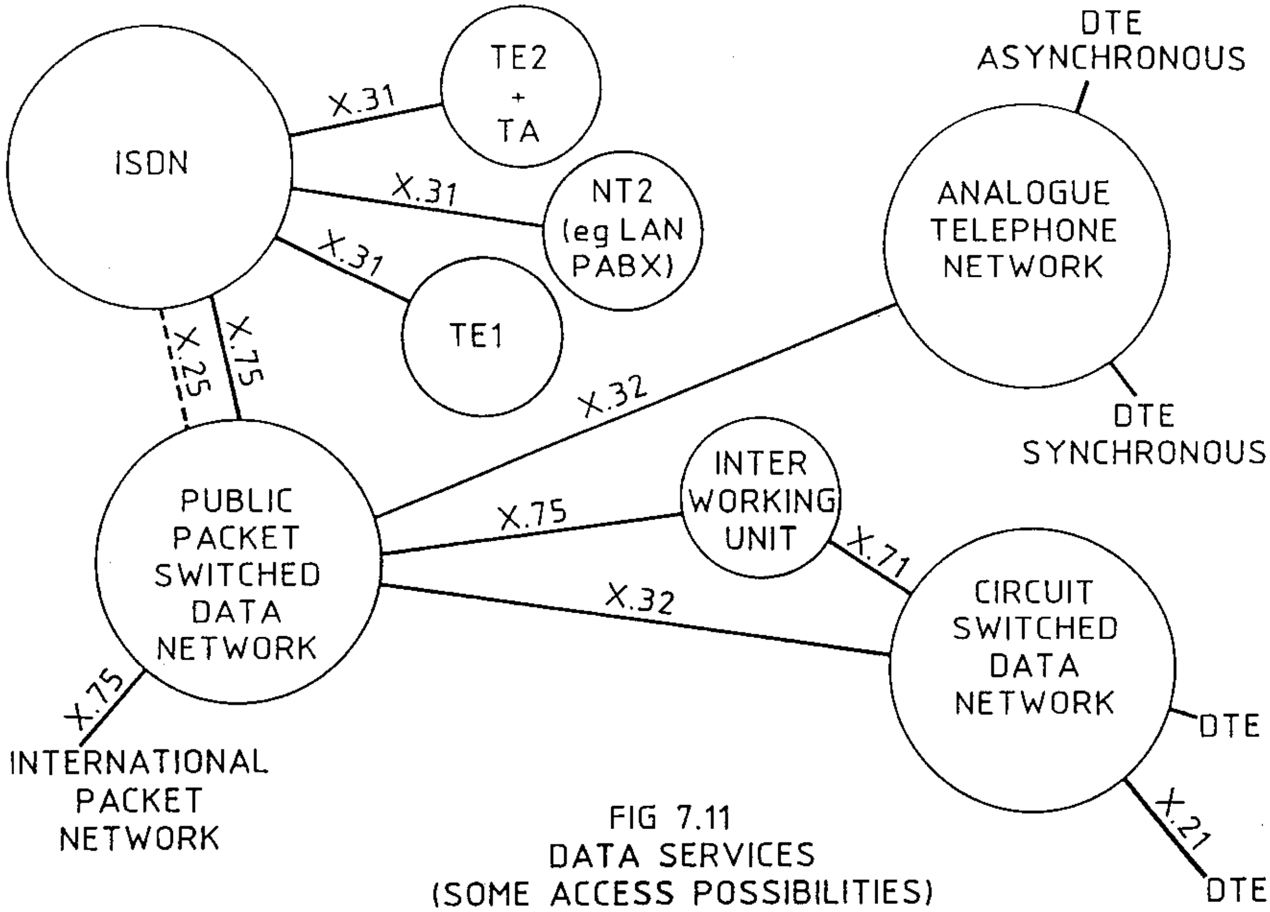


FIG 7.11
DATA SERVICES
(SOME ACCESS POSSIBILITIES)

TABLE 7.1

PACKET SWITCHING TECHNIQUES

	X.25 PACKET MODE BEARER SERVICES	ADDITIONAL PACKET MODE BEARER SERVICES	ASYNCHRONOUS TRANSFER MODE (ATM)
CCITT Recommendations	I.462 (X.31)	I.122	I.121
Set-up and clearing of virtual connections	X.25/X.75	I.451/ISUP	I.451/ISUP
Multiplexing of virtual connections (OSI layer)	3 (packet)	2 (HDLC frame)	1 (time slot)
Packet Length	Variable	Variable	Fixed
Degree of Integration of packet switching techniques	Separate switching equipment two-step call establishment	ISDN - exchange common call control for CS and PS single step call establishment	ISDN - exchange common switching network universal switching technique (combination of CS and PS)
Application	Data networks 64 kbit/s ISDN	64 kbit/s	Broadband ISDN
	Data traffic (Burst) $\leq$ 64 kbit/s (B)	Data traffic (Burst) $\leq$ 2 Mbit/s (B HO H1)	Burst (data traffic) and Stream (video, voice) $\leq$ 150 (600) Mbit/s (B HO H1 H2 H4)

CS Circuit switching
PS Packet switching
ISUP ISDN User Part (CCS No. 7)

SECTION 8 MANAGEMENT OF DIGITAL TELECOMMUNICATIONS NETWORKS

8.1 General

Different digital systems are included in the transmission network, radio links, optical fibre links and cable links. The equipment modules comprise of multiplexers, branching equipment, concentrators and end terminals for different kinds of services. Networks for telephone and data communication are built up by switching nodes and designed either by circuit switching or packet switching techniques. The main nodes in these networks are built up by single or redundant computer systems. Digital transmission systems are more comprehensively considered in Chapter 6. See also reference (32) in relation to previous CIGRE Guide.

The change from separate point-to-point connections to integrated telecommunication and data communication systems has made new demands in terms of co-ordination of operation and maintenance of the telecommunications systems. In order to be able to direct and co-ordinate the operation and maintenance it will be more and more important to install network management systems for the telecommunications networks.

Significant improvement in network operation is often the reason for justifying a network management system. Network downtime can be reduced by using network restoral equipment in critical sites. Increased diagnostic capability of network management systems can facilitate the development of preventative maintenance techniques that spot troubles before they reach crisis proportions

The definition of telecommunications network management is the function of supervising the network and taking action to control the flow of traffic so as to ensure the maximum utilisation of the network in all situations. Network management requires real-time monitoring and measurement of network status and performance, and the ability to take prompt action to control the flow of traffic when necessary.

The following are considered to be the main functions of network management, see figure 8.1.

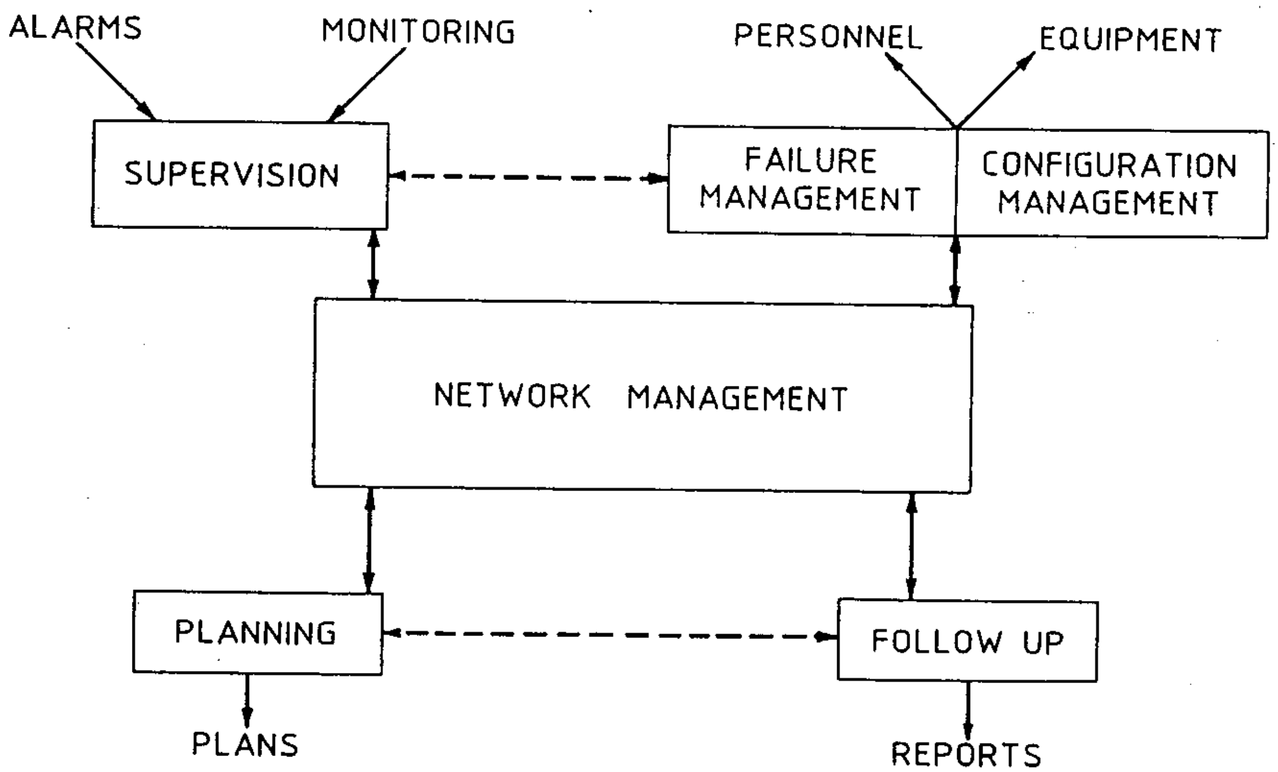


FIG 8.1 NETWORK MANAGEMENT FUNCTIONS

SUPERVISION
- monitoring the status and performance of the network on a, real-time basis
- collect and analyse network performance
- detect abnormal network conditions

FAILURE MANAGEMENT
- investigate and identify the reasons for abnormal conditions
- initiate corrective action and/or control
- co-operate and co-ordinate actions with other centres, on matters concerned with network management and service restoration

CONFIGURATION MANAGEMENT
- change the network configuration, channel connections in the nodes (Due to varying traffic needs or for temporary connections).

PLANNING
- provide advance planning for known or predictable network situations.

FOLLOW-UP
- issue reports of abnormal network situations, actions taken and results obtained to higher authority and other involved departments and utilities, as required
- review current plans for predictable network situations to ensure changes and additions in the network

Effective network management requires good communications between the various network management elements within a utility and similar elements in other utilities. Such information can be exchanged by voice communication (using dedicated service circuits and/or the public telephone network) or by network status indicators which are transmitted by special telemetry arrangements, data circuits or common channel signalling systems. The receiving management location may then use this information to determine manual control actions, or to apply controls automatically. When network management signals are used for automatic control at the receiving location provision must be made to automatically identify and ignore false signals so that inappropriate control actions may be avoided. Telex or similar media can be used to transmit reports, other data and to confirm verbal agreements.

CCITT recommendation (31) deals with management of international networks for telephone services. Whenever applicable these recommendations could be useful when planning, implementing and operating network management systems. The principles for network management are the same for analogue, mixed or digital networks.

8.2 Transmission Network Management

8.2.1 General

Power utilities telecommunications networks are mainly designed and used in the same way as telecommunications networks operated by the PTT. The main differences are that they are mainly not so comprehensive or traffic intensive as the PTT networks, but they have often much higher requirement on availability.

Referring to Section 4, availability very much depends upon organisation of maintenance and redundancy in the network. Using network management functions will reduce network downtime by guiding maintenance activities and/or change the network configuration.

CIGRE Reference (32) and Sections 5 and 6 deals more fully with availability and MTTR.

Considerable benefits may be obtained by close co-operation and co-ordination between the network management organisation and the network maintenance organisation. For these reasons, the power utilities very often integrate the network management organisation into the maintenance organisation.

It is most important that there is an overall policy for the utilities telecommunications networks and their supervisory systems. They should be built up by modules with clear and standardised interfaces in order to be easily changed, or expanded, according to new organisational and other demands.

There should be an opportunity to consider a maintenance management plan during the designing stage of a new digital telecommunication network, or at the same time as converting from analogue to digital.

CCITT rec. M series deal with aspects of the maintenance organisation and its work. These recommendations deal with maintenance of international telephone networks but certain parts may be usual to utilities (especially the general rec. M.15, 20, 22, 24, 700 and 710). In particular (33) deals with maintenance of digital networks but in fact there are no significant differences between maintenance of analogue, mixed or digital networks as regards the organisation.

It is recommended that every telecommunications system or network has its own supervision system with detailed information for maintenance purposes, but also, if the telecommunications network is comprehensive or consisting of different interconnected networks, an overall supervision system with central presentation of only essential information from every sub-system. The overall supervision system is usually operated from a Telecommunication Management Centre (TMC) with responsibility for all interconnected transmission networks, see figure 8.2.

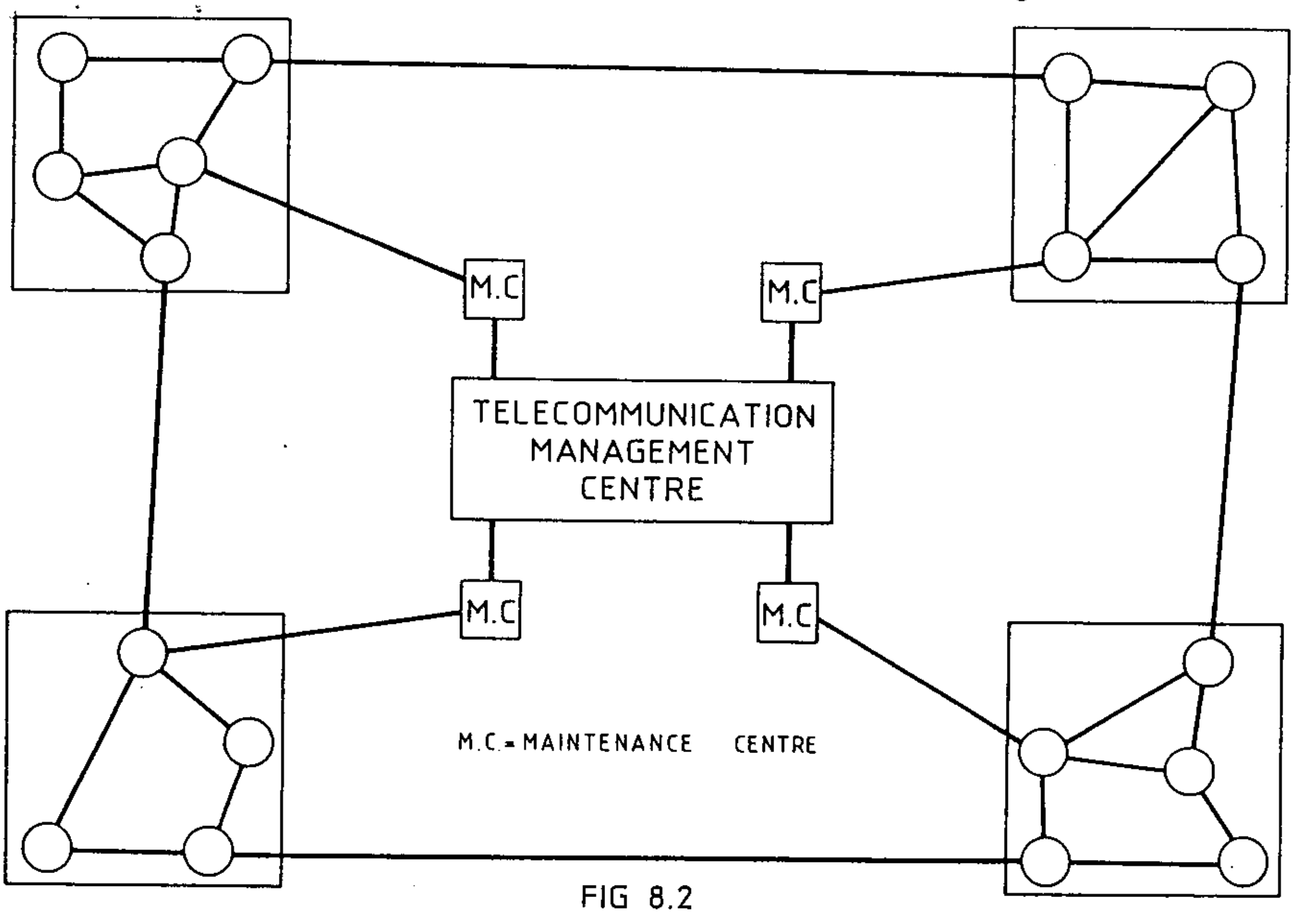


FIG 8.2
MANAGEMENT OF INTERCONNECTED NETWORKS

8.2.2 Supervision

Each equipment should be supervised in order to give information on its operational status and performance.

The introduction of digital technology has made it possible to integrate the monitoring functions and fault location into the transmission equipment. Equipment without integrated monitoring functions can be connected to a digital supervisory system by external interfaces (e.g. relay contacts). In a digital transmission network the monitored information could be transferred via data channels made by spare bits in the frame structure of the digital equipment.

The TMC should be equipped so that the real-time data processing capability of the network management system matches the volume of expected network status information for presentation and recording of processed data.

A major problem in the supervision of diverse network elements occurs when both hardware interfaces are different and disparity exists in the diagnostic data format. A network management user needs to access all network data from one console rather than have several control consoles for various network segments. Which means that it is important to have a conformed and well defined man-machine interface in the TMC, although the systems must be compatible.

In the TMC the following main features should be included:

- continuous monitoring of unit status and performance,
- collection of failure information from the network and presentation of processed information.
- registration and recording of failure information and storing for statistical analysis

In the TMC central service functions for the network management such as a database or a register of all communications channels and system functions should be available. Also a database or register of the addresses to maintenance personnel and spare part resources. The TMC should be equipped with good communications facilities between maintenance elements within the utility and similar elements in other utilities. To fulfil requirements for availability, both the utilities' own dedicated circuits and the PTT network should be connected.

8.2.3 Failure management

The basis for the decision on whether any network control action should be taken will depend upon real-time information on the status and performance of the network. It is essential that the user be able to react quickly and precisely to reported network events. This real-time response is the essence of failure management.

The first step for the user is to further isolate and identify the individual network elements which are causing the problem.

The following actions may be needed:

- remote performance measurement of transmission equipment in response of commands from the TMC.
- remote control of transmission equipment in response from the TMC e.g. looping and re-routing of traffic paths in the network

In order to improve maintenance and trace faulty substations it is useful to be able to loop transmission equipment and transmission circuits. It should be possible both locally and by remote control. Loop functions cause interruption in the traffic circuits therefore it is important that correct operation is achieved rather than by unintentional operation or by un-authorised personnel. This function, for instance, must be opened by a password. Different loop functions are considered in (34). When the problem is diagnosed restoral actions such as activating hot-spare or redundant equipment or re-route traffic paths in order to by-pass the failed unit or circuit are an important part of failure management.

8.2.4 Configuration management

Introduction of digital networks and development of new digital node equipment have given increasing possibilities to utilise the telecommunications networks more efficiently and improve the systems performance and availability.

Dynamic branching and cross-connecting equipment means that such nodes in the telecommunications network with integrated facilities can change the routing and/or utilisation of the channels by local command or remote control from the TMC. Another possibility could be to automatically change channel connection by programming functions based on time or alarm function. These functions are more comprehensively considered in Section 6.

8.2.5 Planning management and follow-up

A failure or planned outage of a system has the potential of isolating a large portion of the network. For planned events predetermined network management plans should be developed and agreed between involved organisations and personnel. While it is almost impossible to plan in advance for every possible failure situation, a reasonable number of functions should be possible. These should include initial actions which are taken as a first step when the extent of the failure is not clear, and subsequent actions which are applied after the diagnosis of the resulting network conditions has been determined.

It is important to follow-up and review these plans periodically to ensure that they reflect changes and additions that have occurred in the network. These include changes in alternate routing, the addition of new routes or nodes and/or the addition of new network management capabilities.

It is also important to follow-up planned outages and maintenance activities and when the element or route returns to service take the required actions to verify the function and move back into normal operation.

8.2.6 Network maintenance functions

Transmission supervision includes the acquisition of information on the actual status of the network and the acquisition of information for the correction of faults. Events in the transmission systems should be classified and recorded by the supervision system. Based on this information the maintenance personnel should be directed to the site of defective equipment. It should be possible to select spares and miscellaneous auxiliary aids required, prior to maintenance personnel leaving for the specified site.

The following information should in principle be available:

- stations name
- designation of the equipment
- type of alarm
- alarm category
- time and date of the alarm's actuation

Equipment for presentation and recording of detailed information for maintenance purposes from all equipment should be available in a central and manned site. The absence of standards for these supervisory functions means that every system or network has its own system with separate presentation.

The number of such Maintenance Centres depends on the network design and the maintenance organisation, see Fig. 8.2.

In principle the central maintenance equipment should be designed so that:

- the alarm indications can be arbitrarily grouped into collective alarms, for presentation at some other locality
- independent interfaces should be available for collective or individual alarms.

The following alarm information is typical for each equipment and useful for maintenance purposes:

- alarms for the absence of input or output signals
- alarms for the loss of frame and phase locking
- alarms for the exceeding of maximum limits of bit error ratio
- alarms for loss of power supply
- alarms concerning control commands in response from the user, e.g. looping

It should be possible to carry out some remote measurements in response to commands from the maintenance centre.

Typical measurements:

- bit error ratio
- signal levels
- operating voltages

The possibility to process information concerning faulty or disturbed circuits and equipment and presented as statistical reports could be useful for technical follow-up.

For local maintenance in the transmission network, each station location should be equipped with alarm indication equipment for the presentation of events within the station.

In principle, the equipment should be designed so that:

- faulty equipments or sub-units are easily located
- fault alarms can be sub-divided into categories
- fault alarms can be individually acknowledged for each individual fault
- it should be possible to receive and transmit a number of external event alarms (e.g. mains failure, diesel generator running).

8.3 Management of Switching Systems

Digital switching systems for voice, data and integrated traffic are controlled by processor based stored programmes and external data access is provided for operation and maintenance of the programme and data base.

Switching systems are considered more fully in Section 7.

A management system can provide the operator with the following functions:

- structural configuration of the switch
- construction of the numbering plan and abbreviated number patterns
- extension port definition (analogue/digital)
- extension facilities control
- definition of group working and queue operation
- night service conditions
- direct connection (hot line) calls
- external route definition
- trunk route sizing
- trunk port definition (mode of operation/signalling forms/etc.
- call re-routing
- operator console configuration and facilities
- blocking and enabling of ports
- traffic measurement and reporting
- call detail recording
- electronic telephone directory

and for data switches:

- port bit rate and protocol

Because of the extent of these facilities it is often appropriate to connect the switching system access port through a management computer to reduce man/machine interface tasks. Such management computers can provide processed reports on call data and traffic flow for detailed analysis, and provide a data base for inventory control of the system.

In power utilities the switching systems and transmission networks are often supervised and operated from the same TMC. If separate management or maintenance computers are used for different systems it is important to conform and optimise the man/machine interface in the TMC and it is desirable to have direct data links between systems.

The maintenance staff should have considerable flexibility in its activities providing such functions as:

- monitoring status and performance of nodes and communication channels
- down loading of programmes/programme changes from the centre without a site visit
- routine dumping of the volatile memory to hard form memory
- indication of problem areas analysed internally by the switch software
- re-configuration, blocking of faulty circuits/ports
- patching or re-starting software routines

and in the extreme:

- restarting part, or whole, of the exchange software

The management/maintenance computer should process and provide reports on the switching system equipment status and performance, together with statistical information.

8.4 Service Networks

The increasing demands for management facilities of Data Communication Networks and their nodes, such as remote updating of programmes and data-bases, remote measurement of different values, reconfiguration of network paths and collecting information for detailed analysis and statistical reports will provide an increasing flow of data communication for that purpose.

Power utilities have very high requirements for redundancy and reliability concerning their operational data networks, which means that the cost for data transmission will be rather high. To use the operational data communication networks for management data communication is unsuitable for economical reasons, especially if the network has to be expanded for that reason.

The utilities telecommunications networks include many types of equipment and systems developed by different vendors. In modern digital telecommunications networks, very often the monitoring functions are integrated into the equipment and systems. That means there would be various monitoring systems to handle without a common standard for interconnection and presentation. Therefore it would be practical to produce a common management network for operation and maintenance of all the utilities telecommunications systems and equipment, which make up the telecommunications and data communications networks. Such a Telecommunications Management Network (TMN) could include all the management functions, or only the supporting and maintenance functions if the monitoring functions already are integrated in equipment and systems.

The monitoring functions could then be interconnected to the TMN, for instance in a maintenance centre, and transferred to the Telecommunication Management Centre.

A Telecommunications Management Network can include different types of Data Communications Networks such as private lines, circuit switched networks, packet switched networks and ISDN. The basic idea behind a TMN concept is to provide an organised network structure to achieve the interconnection of various types of nodes and systems using standardised protocols and interfaces. The TMN functions could also be part of a common service network including administrative services and operational functions with lower priority e.g. a power utility ISDN.

SECTION 9 CONVERSION FROM ANALOGUE TO DIGITAL NETWORKS (Refer also to Sections 3 and 5)

9.1 Existing Analogue Networks

The existing analogue networks are generally organised on many hierarchical levels, according to the structure of the primary system and of services to be provided. The higher level network should cover a large geographical area and provide communication paths of various length within this area. This network has, as a rule, a meshed or ring type structure to meet the high availability requirements posed on the communication system.

The nodes of the transmission network are situated either in relation to a lower system node, or in a control centre, or in the radio repeater stations.

The quality of every single link is such that the overall system requirement is fulfilled even when the maximum number of links is connected to form a transmission path.

The lower level network connects substations and other sites not situated in the higher level network. Typically, it has a radial or tree-like structure, starting from a node in the higher level network. Even in this case the requested availability levels are achieved by adopting, as far as possible, alternative paths connecting one station to two nodes of the higher level network. When such a solution is not possible, duplicated links, employing diverse routes are used. The requirements, in terms of links quality, for peripheral networks are not as onerous as those for higher level ones.

The networks transmission media include:

- Transmission media owned by the Power Utility:

  Power Line Carrier (PLC)

  Analogue Radio Links with capacity ranging from 1 to 12 channels (in the lower level network) and from 12 to 300 channels (in the higher level network).

  Cable carriers with capacity not exceeding 12 channels.

- Circuits leased from the PTT:

  2-wire audio cables

  CCITT M.1020 and M.1040 type circuits (speech and data up to 9600 bit/s

  Low speed data circuits

In the nodes of analogue transmission networks the cross-connections (always 4-wire) are typically implemented at single-channel, or group of channels level, rarely at supergroup level. The connections are implemented through the use of branching equipment (based on multiplex equipment and/or filters) or party-lines.

The use of branching equipment allows maximum network flexibility, but it implies the presence of filters for extraction/insertion of single channels with consequent need for phase and amplitude equalisation.

To efficiently exploit and use the low-capacity transmission media, mainly PLC, the analogue band channel can be split into a lower band (typically 300 to 2000/2400 Hz) dedicated to the speech and an upper band dedicated to signalling and to telegraphy for telecontrol and teleprotection purposes.

Dedicated equipment installed in the network nodes perform separation of the two bands, possibly extracting, at single level, the various low-rate telegraph channels (50 - 600 Baud) allocated in the upper band.

Within the network there are generally more identifiable independent services sharing the same transmission media, these are:

- Automatic Trunk Dialling networks, commutated and meshed, typically dedicated to speech communications.

- The nodal points of this network are equipped with Transit Exchanges (PAX) which guarantee the redundance level requested by the service, automatically providing the communication routing, in more or less sophisticated form, depending on the traffic, on the communication priority level and on the transmission media availability.

- The connection between two nodes, particularly in the main ones, are multiple and employ transmission media diverse in nature and/or route.

- Networks for packet-data transmission.

- These are also meshed type networks with various alternative connections between nodes and between nodes and concentrators (PAD).

- The equipment for packet-data transmission automatically provides for the routine selection, according to the specific situation. Packet network can be used also for telecontrol.

- Networks for data transmission, consisting of fixed connections of point to point or point to multipoint type, employed for telecontrol and teleprotection services. The high availability level requested for these services is typically obtained through redundant structures using various paths, possibly through different transmission media.

- Networks for data transmission other than telecontrol and teleprotection services.

9.2 Transition Strategies

The analogue to digital transition of power utilities telecommunication networks usually occurs in a gradual mode, either through the employment of additional new digital links, or by replacing the equipment in the existing links with that of up-date digital type. The digital transmission equipment can be adopted, according to specific needs of each power utility and equipment available, both in low-capacity peripheral networks and in high-capacity higher hierarchical level networks.

Generally speaking the transmission media digitalisation does not simultaneously occur when replacing the telephone exchanges (PAX and PABX) and the telecontrol performances made available through the employment of fully digital systems.

During the transitory period the two types of equipment co-exist in the network, therefore maximum care must be paid to ensure the service continuity and to safeguard the investments already made, particularly with reference to telephony and telecontrol.

For the interface between the digital and analogue media, three different solutions are possible:

- Transition at low-frequency level

  Each channel of the TDM multiplex terminates with analogue interfaces and all connections are implemented at this level. The solution, though apparently simple, does not provide high quality performance and it does not gain advantage from the particular characteristics of digital interfacing.

- Use of transmultiplexer

  This solution provides good-quality performance but expensive due to the complexity of equipment. Moreover it does not exploit the whole throughput capacity of digital media for data transmission.

- Use of CODECS

  A primary group of 12 channels (60-108kHz) is allocated in a 2 Mbit/s digital tributary

  This solution is preferable since it is inexpensive and provides high quality performance, even though the digital tributary is not fully exploited.

  However, this solution is applicable only when both ends of the connection belong to the analogue network.

The previously mentioned solutions allow, in any case, interface between the diverse types of transmission media, independently of the supported services. Nevertheless, to optimize the use of transmission capacity (throughput) it is necessary that the interface problems arising at different service level (telephony, data transmission) are separately considered.

Typical steps in the conversion of transmission equipment from analogue to digital could be as follows, taking into account the figures 9.1 - 9.5.

a) Substitution of analogue radio transceiver or line terminal equipment with digital equipment.

   The interfacing with FDM multiplex can be accomplished by the use of Basic Group Codecs, which convert the 60-108 kHz band of a basic group in a 704 or 2048 kbit/s.

b) Substitution of some FDM multiplex equipment with digital apparatus. The interface to the users remains analogue.

The interface with the remaining analogue multiplex can be by using transmultiplexers, that convert a 2 Mbit/s tributary to 30 analogue (and associated signalling) channels.

c) Substitution of all the FDM multiplex equipment with the digital ones, maintaining the analogue interface at the user termination.

d) Digital termination of the multiplex equipment towards digital submultiplexers, that allow the full utilisation of each 64 kbit/s flow by many tributary digital data or voice channels at lower speed.

   Digital interfacing at 2 Mbit/s or 64 kbit/s level with the telephone exchanges, by providing suitable signalling systems.

In the transmission network digitalisation some of the above steps can be skipped or implemented jointly.

A question can arise whether it is better to begin the digitalisation process in the network backbones or in peripheral links.

The following reasons suggest a start from the highest levels of the network:

- the better performances and the higher capacity allowed by digitalisation are first introduced where the information traffic is higher, so that the obtainable advantages are extended to a wider range of users and applications;

- the number of analogue-to-digital conversions on signals are minimised;

- the synchronism architecture provided for the highest network level (if needed) makes it easier to further extend at later stages the synchronisation to the most peripheral layers.

For the case of backbones, if particular traffic and application conditions are concentrated in an area, it may be convenient to provide the digitalisation in all the areas, creating a "digital island".

When several digital islands have been implemented, their final interconnection can be easily accomplished providing suitable solutions for the mutual synchronisation requirements (if needed).

Digitalisation by means of a gradual implementation of digital islands is more convenient if the information flows are mostly confined to the area of the island, making it possibly a quicker conversion from analogue to digital of all the systems in the island.

9.2.1 Telephony

The interface between the existing transit exchanges (PAX) and the transmission media may be implemented either by equipping analogue interface in the TDM multiplexes or, in the case of digital PAX, directly at 2 Mbit/s (or 64 kbit/s) level.

Each channel of the TDM multiplex analogue or digital interfaces feature independent wires for the E & M signalling information.

For 2 Mbit/s connections the signalling is inserted in the tributary through the associated channel technique or through the common channel one.

For the analogue interface, if the signalling is of E & M type, there are no problems, since the multiplex features such inputs. Even more so there are no interface problems if the signalling occurs by means of tones in band (DTMF).

For the 64 kbit/s digital interface, signalling may be transmitted over the E & M wires, or by allocating through a dedicated protocol both the signalling and the speech information over the 64 kbit/s channel time slot.

The conversion into digital of telephone equipment can be achieved as follows (see fig. 9.1 - 9.5):

LEGEND FOR FIGURES 9.1 TO 9.5

DTE	=	DATA TERMINAL EQUIPMENT
TC	=	TELECONTROL EQUIPMENT
(exchange symbol)	=	TELEPHONE EXCHANGE (PAX OR PABX)
VFM	=	VOICE FREQUENCY MODEM
MUX a	=	ANALOGUE MULTIPLEX EQUIPMENT (FDM)
MUX d	=	DIGITAL MULTIPLEX EQUIPMENT (TDM)
TR a	=	ANALOGUE TRANSMISSION EQUIPMENT (RADIO TRANSCEIVER)
TR d	=	DIGITAL TRANSMISSION EQUIPMENT (RADIO TRANSCEIVER)
PLC	=	ANALOGUE POWER LINE CARRIER
Bd	=	DIGITAL BRANCHING OR DROP-INSERT EQUIPMENT
BGC	=	BASIC GROUP CODEC
TMX	=	TRANSMULTIPLEXER.
S	=	SUBMULTIPLEXER (DIGITAL).

NOTE: SYMBOLS FOR DIGITAL EQUIPMENT ARE SHADED. ANALOGUE CIRCUITS ARE INDICATED BY DOTTED LINES , CONTINUOUS LINES INDICATE DIGITAL CIRCUITS.

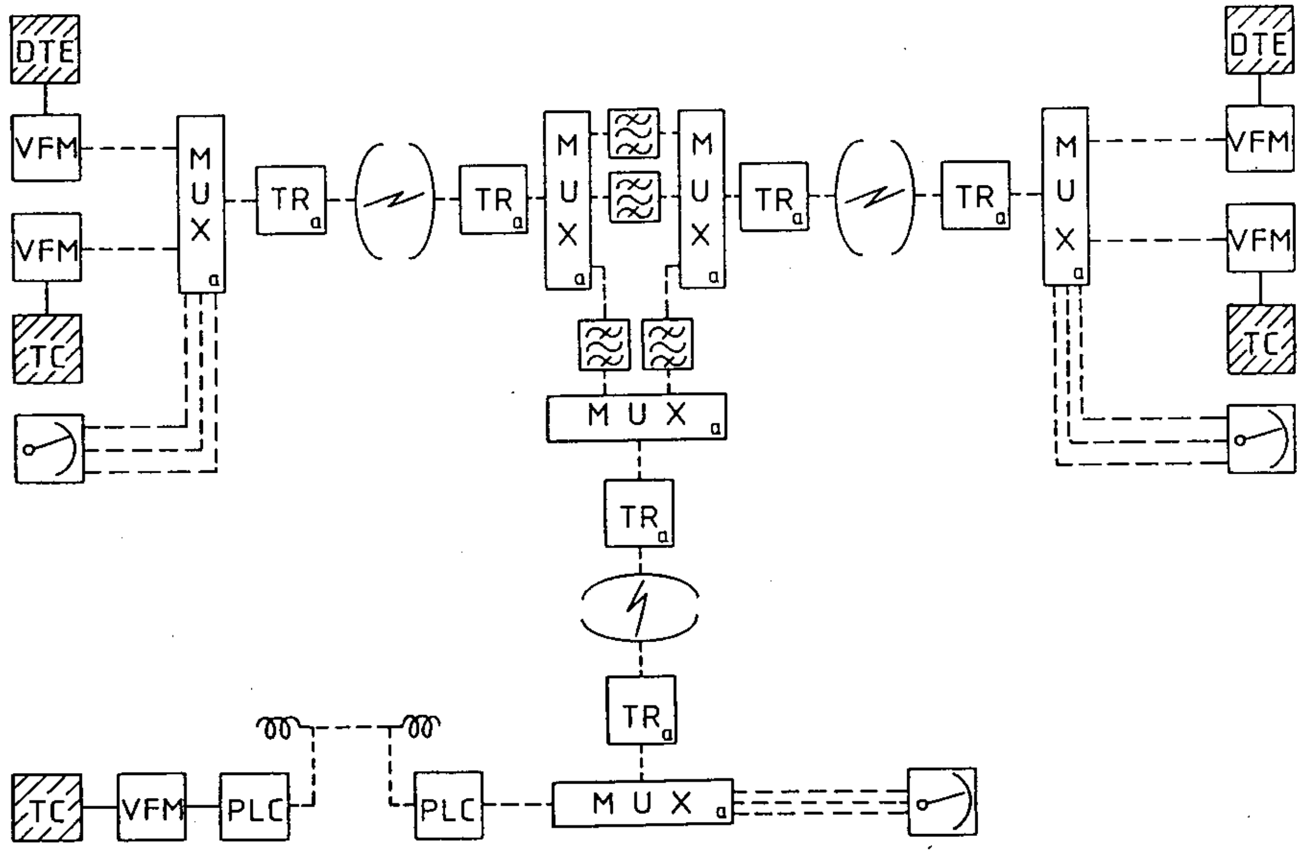


FIG 9.1 FULL ANALOGUE NETWORK.

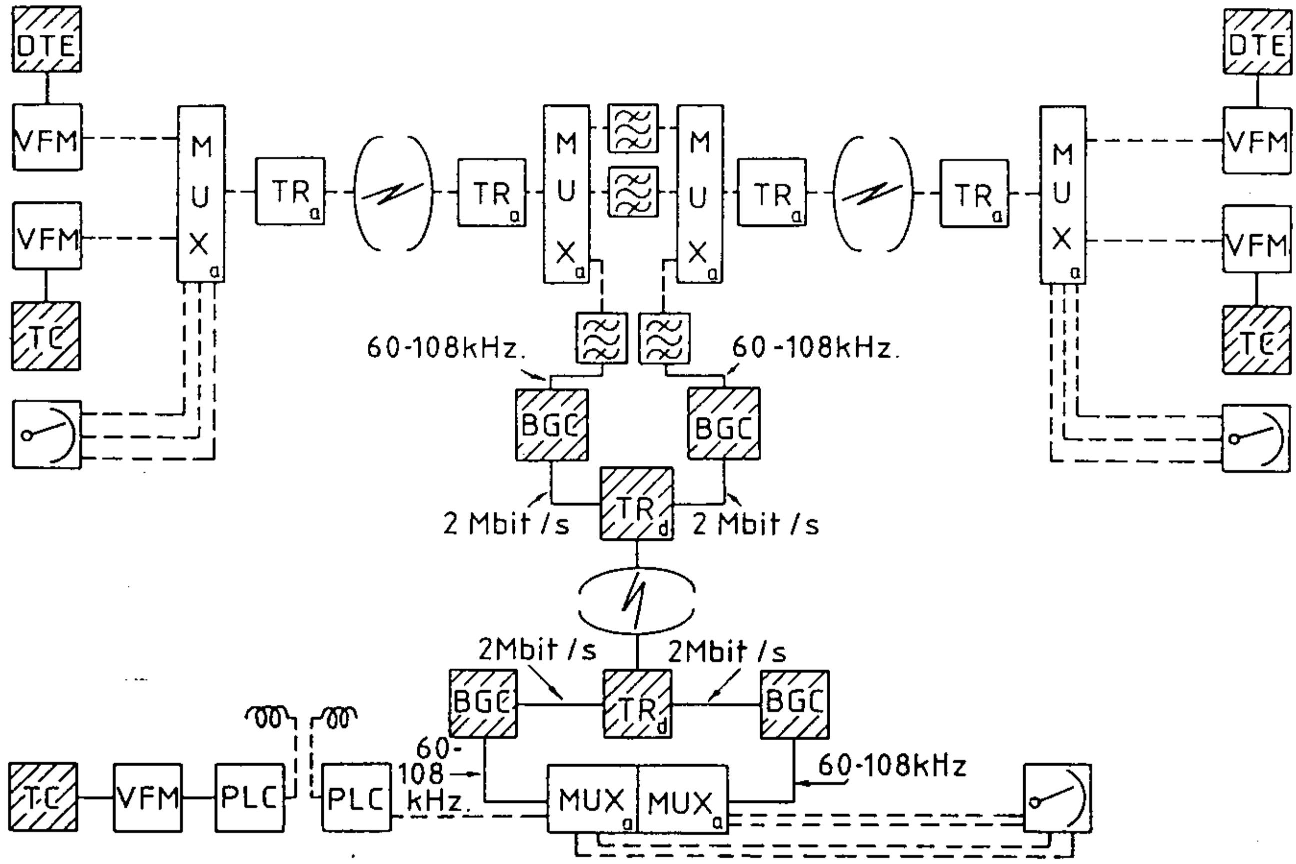


FIG 9.2 ONE DIGITAL RADIO LINK

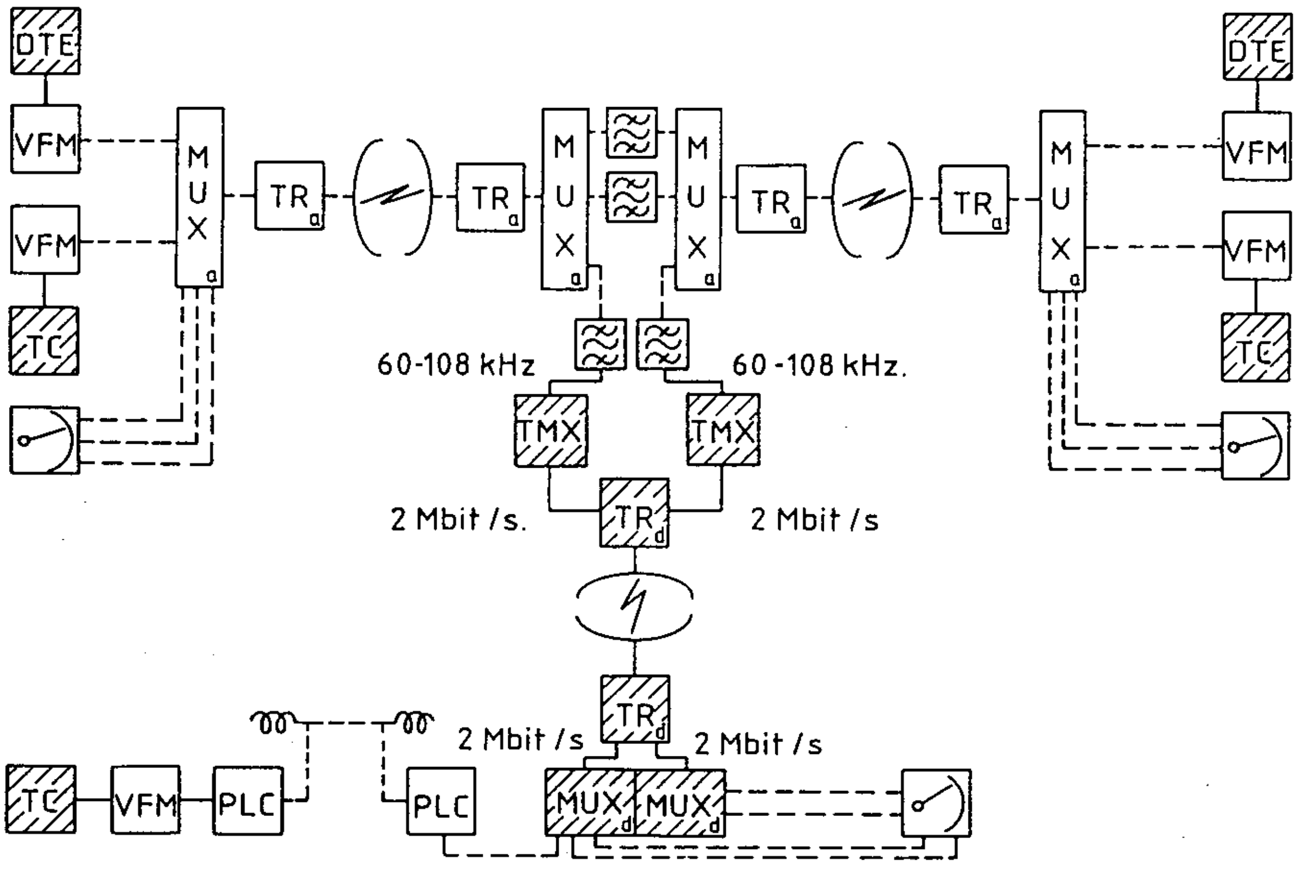


FIG 9.3 CONVERSION OF ANALOGUE (60-108kHz) INTO 2Mbits DIGITAL STREAMS

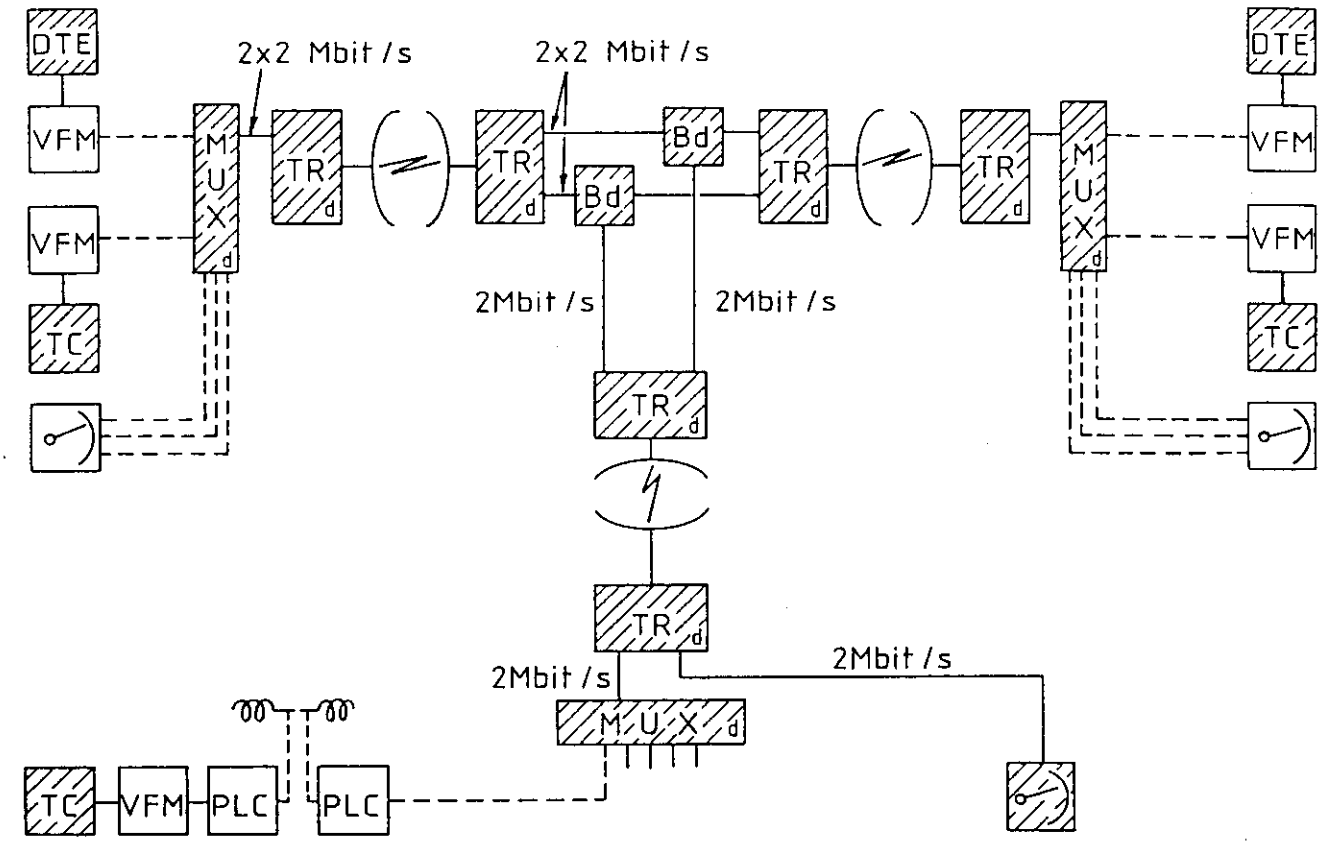


FIG 9.4 2Mbit /s BRANCHING EQUIPMENT

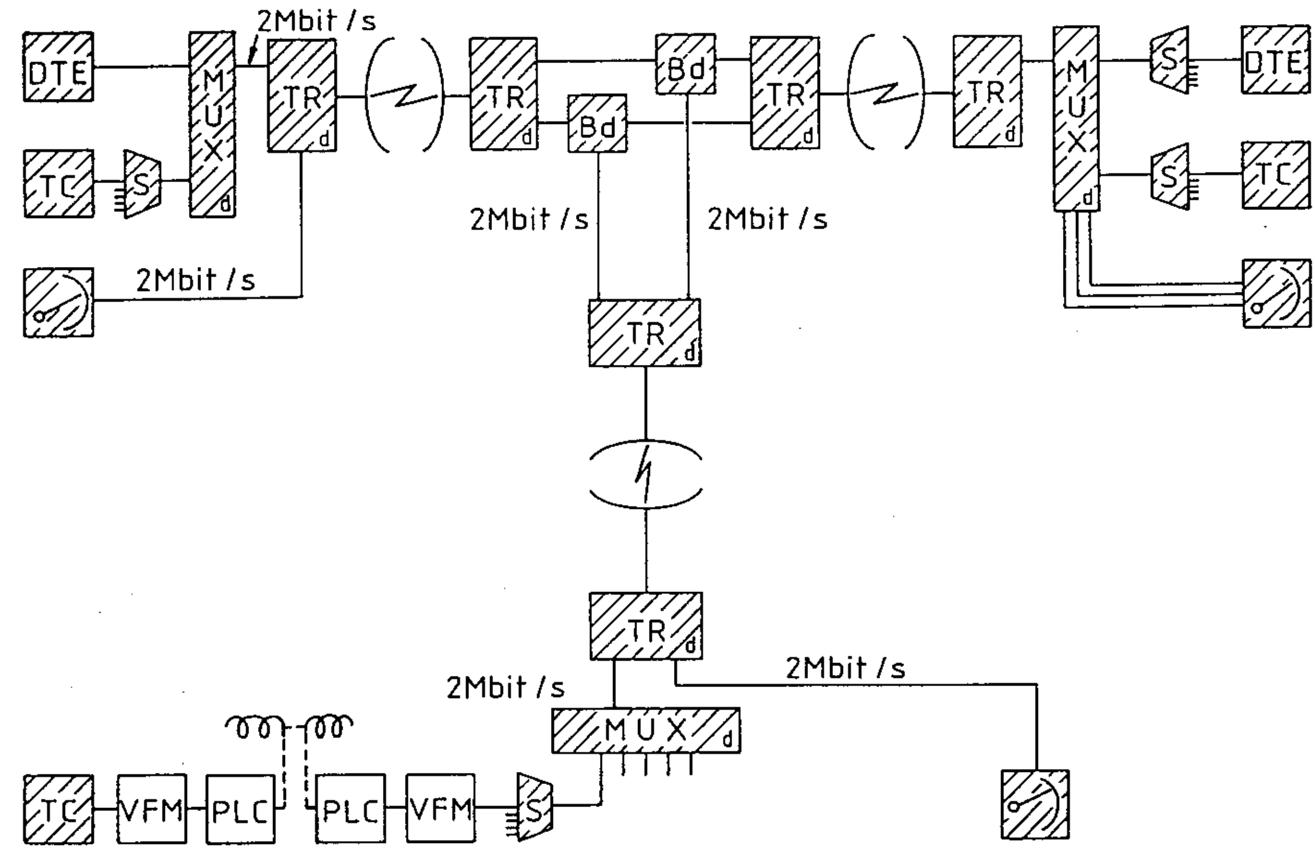


FIG 9.5
INTERCONNECTING DTE's FOR DATA TRANSMISSION AND TELECONTROL.

a) The first step is the use of equipment using PCM techniques, which are already more convenient than other solutions, considering their performances for data switching and their flexibility towards an all-digital solution. The interfacing with the transmission equipment can initially remain analogue.

b) When a digital PABX is used, it can be equipped with digital interfaces towards the users, so that the PABX can switch data between users, being an attractive alternative to Local Area Networks which would require dedicated building wiring. The provision of Voice Frequency Modems allows the data users to transmit data in the connected public or private transmission network.

c) When the transmission network becomes digital the exchanges can be connected digitally, at 2 Mbit/s or 64 kbit/s levels.

   Given that it is unlikely that simultaneous conversion into digital of the switching equipment or the interfaces to the transmission network, the transition period will feature a mix of analogue and digitally interfaced exchanges. In order to allow or to keep their connectivity it is necessary, at this stage, that the signalling remains compatible with that required by the analogue interfaces equipment.

   Mostly signalling will remain of the associated channel type (e.g. E/M).

d) The final solution provides full digital interfaces to the network, both at 2 Mbit/s or 64 kbit/s, with full signalling compatibility.

   In the case of 2 Mbit/s interfacing the signalling can be implemented by the common channel technique. In the case of interfacing at 64 kbit/s channels the associated signalling channel seems preferable for a better use of the equipment capacity.

9.2.2 Data transmission

In order to fully exploit the characteristics of the digital channel the use of submultiplexers is foreseen. This equipment allows to allocated on each 64 kbit/s flow, more data flows of different nature and speed (from 50 Baud anisochronous to 19200 bit/s isochronous) according to e.g. CCITT Ref. X.50 or X.51.

The interfaces between the submultiplexers and the DTE will therefore be of digital type, diverse depending on the speed-rate in compliance with relevant CCITT Recommendations (e.g. V.24, V.28, V.11, V.35 etc.).

Generally not all circuits featured by the CCITT Rec. are used or available, but a limited set of these (typically with reference to CCITT Rec. V.24 only 102, 103, 104, 105, 106, 107, 108/2, 109 circuits and, in some cases, 140, 141, 142, 113, 114, 115 circuits) cover the majority of applications for data interchange.

Each interface point between a digital link and an analogue one must necessarily be equipped with a submultiplexer, for the extraction of various data flow on one side and the voice frequency modems or telegraph channels for the allocation of same flows on the other side. Even in this case the interface will be implemented in compliance with CCITT Recommendations.

For data transmission equipment the conversion into digital can be done as in the following steps:

a) DTE (Data Terminal Equipment) remain as they are while the input/output of the multiplex equipment is analogue. Their interfacing is provided by suitable voice frequency modems. (CCITT Rec. V.24-V.28).

b) The direct digital interfacing can be introduced with the digital termination of multiplex equipment at both the terminations of a channel.

   Terminations can be direct at 64 kbit/s for higher speed applications e.g. slow scan video or interconnection between nodes of a high capacity packet switching network.

   The terminations at lower speeds require that the 64 kbit/s flow of the multiplex is terminated on suitable equipment, e.g. a submultiplexer which sums the flows of many tributaries into a single 64 kbit/s channel.

   The submultiplexer is the equipment that allows the maximum utilisation of the net bit rate of the digital transmission equipment.

9.2.3 Telecontrol data transmission

The conversion of Telecontrol equipment can be undertaken as for data transmission, with some modification.

Telecontrol systems are often point to multipoint systems, and a same channel can serve many peripheral telecontrol equipment. In a system having a main station controlling many peripheral stations, the ports of the network must be all digital.

Dealing with the digitalisation of telecontrol systems it is considered that the transmission network reproduces, as far as possible, the operational simularities of the previous analogue systems. It is quite acceptable that during the transition period, telecontrol systems can be implemented having some outstations connected via digital networks and others via analogue networks or that a section of the link between one outstation and the centre is of analogue type and a section of digital type. To allow a gradual substitution of telecontrol equipment, the equipment that can remain with an analogue interface must be connected to its digital termination via a suitable voice frequency modem.

The submultiplexers must incorporate all the necessary command signals.

The main points are outlined as follows:

- It must be possible to configure the submultiplexing unit as "drop-insert" for each tributary channel. This gives the possibility of simultaneously extracting a channel for local use and sending it towards the next outstation.

  Alternatively, it must be possible to insert the locally produced data in the channel, replacing the flow coming from other outstations. In point-to-multipoint systems where collision can occur, this must be adequately managed, for instance by temporary priority; using the circuits 105 and 109 of CCITT Rec. V.24.

- The channels made available must be totally transparent, thus without restraints to particular structure or length of the messages to be transmitted.

- The transmission delay and the isochronous distortion on the transmitted bit must be kept, as far as possible, to values within those available on the analogue telegraph channels with same speed-rate.

If these conditions are verified, the telecontrol systems may employ the digital network as the bearer by simply replacing the telegraph channels associated with the telecontrol equipment with a data interface, implemented in compliance with CCITT Recommendations. For mixed links, this can be achieved by equipping submultiplexers and telegraph channels at the interconnection points between the digital and analogue sections.

9.2.4 Teleprotection

As teleprotection systems normally operate on a point to point basis the problem of mixed circuits e.g. tandem connection of analogue and digital sections does not exist.

When dealing with command teleprotection systems the following options are available for the connection of a protection relay to a digital transmission equipment:

(a) The protection relay interfaces to a classical analogue teleprotection signalling equipment which converts the digital command into an analogue signal by means of modulation methods such as FSK, F6 etc.

    The analogue input/output of the TPS equipment is then connected to the analogue interface of the digital transmission equipment.

    Several low-speed FSK signals may be multiplexed together into the same 0.3-3.4 kHz channel.

(b) The teleprotection relay interfaces to a digital protection equipment which does the necessary signal processing, i.e. channel coding, multiplexing, rate and signal level adaption. The teleprotection equipment provides a digital 64 kbit/s G.703 interface which can be connected to the corresponding interface of the transmission equipment.

(c) Some digital transmission systems have this protection equipment integrated in the multiplexer part where the input/output of it directly accesses to the internal 64 kbit/s interface.

For analogue protection systems (e.g. phase comparison, longitudinal differential protection) there is also a variety of different possibilities:

(d) The analogue 50Hz quantity is to be frequency converted into the 0.3 to 3.4 kHz range (e.g. by means of FM modulation) and then given to the analogue interface of the transmission equipment. This frequency conversion is necessary because standard PCM Codec cannot deal with signals below 300Hz. Several protection signals may be multiplexed together into the same 0.3-3.4kHz channel.

(e) There is transmission equipment available which directly digitalise the analogue signal from the relay (e.g. by making use of adaptive delta modulation) into a 64 kbit/s signal which is then multiplexed together with other 64 kbit/s tributaries into a 2Mbit/s aggregate signal.

(f) New methods suggest the analogue quantities to be already digitalised and processed in the protection relay. The resulting bit stream which may have a rate of 64 kbit/s or a multiple thereof can access to a suitable interface of the transmission equipment.

9.3 Factors Affecting Digitalisation Conversion

The general policies outlined in the above paragraphs, can be applied with the time scale required by the power utilities, taking into account the obvious economical and financial constraints.

In addition to the financial aspects other constraints are found e.g.

- PTT licence regulations dealing with the use of frequency bands for radio links;
- PTT limitations on the allowed bearer capacity;
- compatibility between analogue and digital radio links using the same frequency bands;
- feasibility of installing optical fibre cables on overhead lines;
- compatibility with the public telecommunication network, if interconnection is required;
- ability of the technical staff to design and operate the new equipment;
- availability of a sufficient number of suppliers of the equipment, mainly for the special facilities required by power utilities.

All the above constraints suggest the need for careful planning for digitalisation, that requires suitable medium and long term programmes.

SECTION 10 ELECTROMAGNETIC COMPATIBILITY

Digital transmission equipment located in the harsh electromagnetic environment of power installations has to comply with stringent insulation and electromagnetic compatibility (EMC) requirements.

The problem is slightly reduced with optical fibre terminals because of the dielectric nature of the optical wave guide. But nevertheless the other interfaces to the outside world (power supply cables user interfaces, alarm outputs etc.) are of the electric type and may be exposed to severe electromagnetic interference.

In order to prevent equipment failure, maloperation and damage due to interference galvanically or electromagnetically from power installations (e.g. ground potential rise and induction due to fault currents, transients and bursts caused by isolator and circuit breaker activities, lightning etc.) the equipment should provide for a sufficiently high electromagnetic immunity.

State-of-the-art highly integrated electronic equipment has increased the danger and importance of maloperation damage which can arise from electric and electromagnetic disturbances.

In order to avoid or reduce the impact of this problem IEC and CCITT have established immunity levels and tests which the equipment should withstand.

It is beyond the scope of this planning guide to give a comprehensive list of all IEC and other standards dealing with the subject. A great deal of work has already been done and work is still going on in defining the different sources of interference and to establish severity levels and to standardise immunity tests. As work is still continuing in this field it would be unwise to give quantitive figures on test values. The following list gives IEC Committees and documents relevant to EMC:

TC77: Electromagnetic compatibility between electrical equipment including networks.

TC65/WG04: Industrial process equipment-Electromagnetic interferences. This Committee has produced IEC Recommendations 801-1 to 801-5 on EMC.

TC57(Sec)88: Draft-Revision of IEC Publication 495 "Recommended values for characteristic input and output quantities of single sideband power-line carrier terminals".

IEC 870-2-1: Telecontrol equipment and systems, Part 2: Operating conditions, Section 1: Environmental conditions and power supplies.

IEC 870-2-2: Telecontrol equipment and systems, Part 2: Operating conditions, Section 2: Electromagnetic compatibility.

IEC 834-1/2: Performance and testing of teleprotection equipment of power systems.

TESTS	Power Supply	Digital Line Interface	User Interface: Analogue Voice Frequency Interface	User Interface: Digital Data Interface	Teleprotection Interface	Alarm Outputs	Accessible Measuring Points
Insulation/Dielectric strength /Insulation resistance	IEC 255-5 IEC 870-2-1	CCITT K.11.K.17 /K.20	IEC 255-5	IEC 255-5	IEC 834-1	IEC 255-5	n.a.
Voltage fluctuations. Harmonics. Ripple. Voltage dips and interruptions	IEC 870-2-1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Voltage and current surges	IEC 255-4 IEC 870-2-1 IEC 801-5	CCITT K.11/K.17 /K.20	IEC 255-4	IEC 255-4	IEC 834-1	IEC 255-4	n.a.
Fast transient bursts	IEC 801-4	n.a.	IEC 801-4	IEC 801-4	IEC 801-4	IEC 801-4	n.a.
High frequency disturbance (Damped oscillatory waves)	IEC 255-4	n.a.	IEC 255-4	IEC 255-4	IEC 834-4	IEC 255-4	n.a.
Electrostatic discharge	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	IEC 801-2
Radiated electromagnetic field	IEC 801-3: Systemtest						

TABLE 10.1 RECOMMENDATIONS FOR THE CHOICE OF ELECTROMAGNETIC IMMUNITY TESTS

IEC 255-4: Single input energising quantity measuring relays with dependent specified time.

IEC 255-5: Insulation tests for electrical relays.

IEC 255-22-1: Electrical disturbance tests for measuring relays and protection equipment.

Table 10.1 provides a general overview on the type of immunity tests which the equipment should pass without failure. For the individual tests to be carried out at the different interfaces reference is made to the relevant IEC and CCITT recommendations.

Attention is drawn to the fundamental difference between two kinds of tests:

- Insulation tests are intended for the protection of persons or equipment against the dangers of damage that may be caused by high voltages. These tests are always carried out with equipment not connected to the power supply.

- Immunity tests are intended to check the operation of equipment under the influence of electromagnetic disturbances. During these tests the equipment is always powered and operating normally.

SECTION 11 CONCLUSIONS

The planning and management of digital telecommunications networks is a complex subject. When transferring to digital transmission one of the first considerations is the method of conversion from analogue together with the voice and data facilities, appropriate to a typical power utility, to be implemented in an integrated speech and data network environment.

The parameters for the assessment of such a network must be based on the specifications and recommendations of CCIR and CCITT. Digital networks made up of elements based on CCITT digital hierarchy levels are already established and considerations of such typical networks will be of assistance to any design engineer in the process of planning a new network.
Based on these basic considerations successful network planning can be made. The main points to be considered in this phase are the network topology, protection synchronisation and interconnection issues. Various differing levels of regulatory constraints must also be considered in this phase. After the network planning phase, individual transmission links and nodes as well as switching systems can be planned. Selections in this phase should be made system by system, considering their merits and drawbacks in the actual environment they will be used.

In all planning a smooth and economically feasible transition through each phase is most important. The last section of this Guide describes some possible paths to follow, and the Appendices give examples of already implemented networks, as an aid to the planning of digital networks for different needs and environments.

Finally, the provision of a Network Management System, to provide continuous monitoring of network performance, is an essential consideration. Network Management techniques will achieve optimum network performance, and enable necessary maintenance procedures to be carried out along with an overview of the allocation of network resources.

SECTION 12 ACKNOWLEDGEMENTS

CIGRE Working Group SC35.02 would like to record its grateful thanks and appreciation to all people who have assisted in the formulation of this Planning Guide.

In particular help and assistance has been freely given by the Chairman of Study Committee 35 R. Koskinen and U.K Member G. Carlton and, also, corresponding members of SC35.02, namely Messrs. G. Vincent, Australia and J.N. Aguiar, Portugal.

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Acknowledgement is also recorded to the various Power Utilities and Telecommunications Companies represented by Members of this Working Group who have also assisted in the preparation of this Planning Guide.

SECTION 13 REFERENCES

1.	CCITT	Recommendation	G.711
2.	"	"	G.721
3.	"	"	G.761
4.	"	"	Q.701 741
5.	"	"	I.211

6. CIGRE Study Committee 35, WG04 "Guide on Mobile Radio for Electricity Utilities" (1987)

7.	CCITT	Recommendation	G.821
8.	CCIR	"	557 (Vol. IX)

9. CIGRE SC35 WG06 "The Overall Impact of Digital Techniques for Transmission Systems - Substation Control" (1989)

9A	CCITT	Recommendation	G.801
9B	CCITT	Recommendation	G.822
9C	CCITT	Recommendation	G.823
10.	CCITT	Recommendation	G.113 (qd Unit)
11.	"	"	G.171
12.	"	"	G.732
13.	"	"	G.703
13A	CCITT	Recommendation	X.50 and X.51
13B	EIA	Standard	RS-232-C
13C	CCITT	Recommendation	V.24, V.28
14.	CCIR	Report	610-1
15.	CCITT	Recommendation	G.613
16.	"	"	G.921
17.	"	"	G.952
18.	CCIR	Report	721-2
19.	"	"	563-3 Vol. V
20.	CCIR	Report	721.2 "
21.	"	"	338.5 "
22.	"	Recommendation	525.1 "
23.	"	"	341.2 "
24.	"	Report	376.5 (Vol. IX)
25.	"	"	594.1 (")
26.	"	"	634 (")
27.	CCITT	Recommendation	G.651
28.	"	"	G.652
29.	"	"	G.956
30.	"	"	G.921
31.	"	"	E.410-413

32. CIGRE Study Committee 35 "Guide on Planning Power System Telecommunication Networks" (1985)

33.	CCITT	Recommendation	G.803
34.	CCITT	"	X.150
35.	CCIR	"	556 (Vol. IX)
36.	CCIR	Report	930-1

37. Computer Networks and ISDN Vol. 14.1987

38. Electronic Switching, GRINSEC Vol. 2 (ISBN 0-444-86448-2)

APPENDIX A

GLOSSARY OF TERMS

ACC	Area Control Centre
Adaptive Channel Allocation	A method of multiplexing where the information capacities of channels are not pre-determined but are assigned on demand.
ADPCM	Adaptive Differential PCM, a more efficient coding method than PCM (e.g. coding of 4 kHz signals at 32 kbit/s or 7 kHz signals at 64 kbit/s)
Address	The part of the signal which indicates the destination of a signal.
A/D Conversion	Conversion of analogue signals into digital format (and vice versa) usually using a standardised method (e.g. PCM).
Alignment	Frame alignment, sychronisation of receiver with incoming frames.
Asynchronous	Signals not synchronised with each other (cf plesiochronous) or, in data transmission, signals with independent symbols (interface type).
Automatic Alternative Routing	A facility whereby a call, which cannot find a free circuit is automatically diverted to a secondary route.
Availability	Probability that a system, or a resource is not in a state of congestion or failure at any given point in time.
Backward Channel	A data-transmission channel used for supervisory and/or error-control signals and associated with the forward channel, but with a direction of transmission opposite to that in which information is being transferred. Note - In case of simultaneous transfer of information in both directions, this definition applies with respect to the data source under consideration.
Bearer Services	Transmission of signals, e.g. data, without regard on their content and with no guarantee on end-to-end compatibility (only OSI layers 1....3).
BER	Bit Error Ratio, number of erroneous bits divided by total bit number.

Bit	The unit of selective information, i.e. the amount of information derived from knowledge of the occurrence of one of two equiprobable, exclusive and exhaustive events.
Bit Error Ratio	The ratio of the number of bits incorrectly received to the total number of bits sent.
Blocking (Congestion)	The state when the immediate establishment of a new connection is impossible owing to the inaccessibility of any of the resources of the system being considered. Note 1 - When blocking or congestion is used as an abbreviation for probability of blocking or probability of congestion, it should always be made clear whether it refers to time congestion or call congestion probabilities. Note 2 - Blocking does not necessarily result in the loss of a call attempt, because it may be possible to establish the connection after a certain delay or by using alternative resources.
Byte	A group of binary digits normally operated upon as an entity (usually 8 bits).
CCIR	The International Radio Consultative Committee
CCITT	The International Telephone and Telegraphic Consultative Committee
Centrex Service	The provision to subscribers, by means of a specially equipped public telephone exchange, of services normally available only in PABXs (e.g. automatic internal dialling, operators' desk, client access to network, direct dialling-in, transfer of calls).
Channel Associated Signalling	A signalling method in which the signals necessary for the traffic carried by a signal channel are transmitted in the channel itself or in a signalling channel permanently associated with it.
Channel Time Slot	A time slot starting at a particular phase in a frame and allocated to a channel for transmitting a character signal and possibly in-slot signalling or other information. Note - Where appropriate a description may be added, for example "telephone channel time slot".
Check Bit	A bit or bits associated with a character or block for the purpose of checking the occurrance of error(s) within the character or block.
Circuit Switching	The switching of circuits for the exclusive use of the connection for the duration of a call.

Cladding — All the optical material of an optical fibre except the core.

Cladding Centre — The centre of the smallest circle within which the whole of the cladding can be contained.

Cladding Diameter — The diameter of the circle defining the cladding centre.

Clock — Equipment providing a time base used in a digital telecommunication system to control the timing of certain functions.

Closed User Group — A facility assigned to specified users of a (data) network service(s), which permits such users to communicate with each other but precludes communication with all other users of the service or services.

Note - A user (DTE) may belong to more than one closed user group.

Codec — A contraction of encoder-decoder. The term may be used when the encoder and decoder are associated in the same equipment.

Note - When used to describe an equipment the function of the equipment should qualify the title e.g. voice codec, hypergroup codec.

Codirectional interface — An interface across which the signals to be transferred and their associated timing signals are transmitted in the same direction.

Contradirectional interface — An interface across which the timing signals associated with both directions of transmission of the signals to be transferred, are directed towards the same side of the interface.

Common Channel Signalling — A signalling technique in which signalling information relating to a multiplicity of circuits, and other information such as that used for network management, is conveyed over a single channel by addressed messages.

Compression — A method of coding where the relationship of coded samples and their corresponding analogue values is non linear.

Controlled Slip — The controlled irretrievable loss or gain of a set of consecutive digit positions in a digital signal to enable the signal to accord with a rate different from its own.

Core — The smallest cross sectional area of a fibre (excluding any "centre dip") contained within the locus of points where the refractive index n_3 is:

$$n_3 = n_2 + k(n_1 - n_2)$$

where

n_1	is the maximum refractive index of the fibre core
n_2	is the refractive index of the homogeneously external region of the fibre cladding
k	is a constant

The centre region of an optical waveguide having a refractive index higher than that of the cladding through which it is intended that the majority of the optical power be transmitted.

Critical Services — Services on which power utility operation directly depends on.

Cyclic Code — A code in which every cyclic shift of a code word is itself a code word.

Data Adaptation — Direct adaptation of data into digital network (without modems)

Data Channel — An undirectional transmission path for data, with transmission terminal equipment at both ends.

Data Circuit — A means of two-way data transmission between two points comprising associated "transit" and "receive" channels.

Note 1 - Between data switching exchanges, the data circuit may or may not include data circuit-terminating equipment depending on the type of interface used at the data switching exchange.

Note 2 - Between the data terminal installation and a data switching exchange and/or concentrator, the data circuit includes the data circuit-terminating equipment at the data terminal installation end and may also include equipment similar to a data circuit-terminating equipment at the data exchange or concentrator location.

Note 3 - Either physical or virtual data circuits may be established.

Data Circuit - Terminating Equipment (DCE) — The equipment installed at the user's premises which provides all the functions required to establish, maintain and terminate a connection, the signal conversion and coding between the data terminal equipment (DTE) interface and the line. It may or may not be a specific, or separate piece of equipment.

	Note - When the data circuit is provided in a specialised data network, a simplified form of DCE may be provided and this has been referred to as a network terminating unit.
Data Signal	Signal representing a set of digits used to convey information and/or service functions and which may include check digits.
Data Terminal Equipment	Equipment Comprising of: - a data source - a data sink - or both
Datagram	A datagram is a self-contained, independant entity of data carrying sufficient information to be routed from the source DTE to the destination DTE without reliance on earlier exchanges between the source or destination DTE and the transporting network.
Dedicated Circuit	Direct non-switched circuit (modified only be network management)
Delta Modulation	A form of DPCM in which the magnitude of the difference between the predicted value and the actual value is encoded by one bit only, i.e. where only the sign of that difference is detected and transmitted.
DCC	District Control Centre
Differential Modulation	A type of modulation in which the choice of the significant condition for any signal element is dependent on the choice for the previous signal element.
Digit Time Slot	A time slot allocated to a single digit.
Digital Circuit	A circuit which transmits information signals in digital form between two exchanges. It includes termination equipment but not switching stages.
Digital Distribution Frame	A structure that provides flexibility of semi-permanent interconnection of digital channels or digital circuits. Note - Digital sections and digital links may terminate at digital distribution frames.
Digital Hierarchy	Set of digital multiplexing stages, with specified bit rates.
Digital Hop	Part of digital link, e.g. radio link hop or optical line system section.
Digital Multiplex Equipment	The combination of a digital multiplexer and a digital demultiplexer at the same location.

Digital Multiplexer	Equipment for combining by time-division multiplexing two or more tributary digital signals into a single composite digital signal.
Digital Network	Link and nodes operating at 64 kbit/s or higher bit rates.
Digital Signal	A signal constrained to have a discontinuous characteristic in time and a set of permitted discrete values.
Digital Switching	A process in which connections are established by operations on digital signals without converting them to analogue signals.
DM	Degraded minute (4 or more errors in 60 seconds at 64 kbits/s).
Duplex (circuit, connection)	A circuit permitting simultaneous both-way transmission of signals.
Duplex Operation	In data transmission, a method of working between two data terminal equipments in which the transmission of digital data may take place simultaneously in both directions.
Erlang	The unit of traffic intensity.
Error Burst	A group of bits in which two successive erroneous bits are always separated by less than a given number (x) of correct bits. The number x should be specified when describing an error burst. Note - The last erroneous bit in a burst and the first erroneous bit in the following burst are accordingly separated by x correct bits or more.
Error-Correcting Code	A code in which each data signal conforms to specific rules of construction so that departures from this construction in the receive signals can be automatically detected, permitting the automatic correction, at the receiving terminal, of some or all of the errors. Such codes require more signal elements than are necessary to convey the basic information.
Error-Detecting Code	A code in which each telegraph or data signal conforms to specific rules of construction, so that departures from this construction in the received signals can be automatically detected. Such codes require more signal elements than are necessary to convey the fundamental information.
Error Performance	Measure of bit errors, e.g. BER or using DM, SES and ES.

Error Ratio	The proportion of the number of digital errors to the total number of digits. Numerical values of error ratio should be expressed as follows: $n.\ 10^{-p}$
ES	Errored second (second with at least one error at 64kbit/s)
Exchange (switching exchange, switching centre)	An aggregate of traffic carrying devices, switching stages, controlling and signalling means at a network node that enables subscriber lines and/or other telecommunication circuits to be interconnected as required by individual callers.
Flow Control	The procedure for controlling the rate of transfer of packets between two nominated points in a data network, for example between a DTE and a data switching exchange.
Forward Channel	A data-transmission channel in which the direction of transmission coincides with that in which information is being transferred.
Four-Wire Switching	Switching using a separate path, frequency band or time interval for each direction of transmission.
Frame (multiplex structure)	A set of consecutive time slots in which the position of each time slot can be identified by reference to a frame alignment signal.
Frame Alignment Recovery Time	The time that elapses between a valid frame alignment signal being available at the receive terminal equipment and frame alignment being established. Note - The frame alignment recovery time includes the time required for replicated verifcation of the validity of the frame alignment signal.
Frame Alignment Signal	The distinctive signal inserted in every frame or once in every n frames, always occupying the same relative position within the frame, and used to establish and maintain frame alignment.
Frequency-Division Multiplex	A multiplex in which the available transmission frequency range is divided into narrower bands, each used for a separate channel.
General Services	Services used mainly for administrative purposes (i.e. non-critical).

HDB3 Code	High Density Bipolar three state code
Hierarchy	Set of multiplexing stages, with specified number of channels.
High Grade	Highest quality part of the network (long distance links).
In-Band Signalling	A signalling method in which signals are sent over the same transmission channel or circuit as the user's communication and in the same frequency band as that provided for the users.
Integrated Digital Network	A set of digital nodes and digital links that uses integrated transmission and switching to provide digital connections between two or more defined points to facilitate telecommunication between them.
Integrated Services Digital Network	An integrated digital network in which the same digital switches and digital paths are used to establish connections for different services, for example, telephony, data, etc.
Jitter	Short-term variations of the significant instants of a digital signal from their ideal positions in time.
Justification	A process of changing the rate of a digital signal in a controlled manner so that it can accord with a rate different from its own inherent rate, usually without loss of information.
Local Grade	Lowest quality part of the network, mainly subscriber lines etc,
Master Clock	Clock which is used to synchronise other clocks (master-slave)
Medium Grade	Medium quality part of the network (e.g. regional main lines)
Message Switching	The transfer of stored messages so as to minimise queue and idle times of traffic carrying devices.
Modem	A contraction of "modulator-demodulator".
Muldex	A contraction of multiplexer-demultiplexer. The term may be used when the multiplexer and demultiplexer are associated in the same equipment. Note - When used to describe an equipment, the function of the equipment should qualify the title e.g. PCM muldex, data muldex, digital muldex.

Multifibre Cable	An optical cable that contains two or more optical fibres, each of which provides a separate information channel. It may contain electrical conductors in addition to optical fibres.
Multimode Optical Fibre	An optical fibre that is capable of sustaining the propagation of more than one mode at a given wavelength.
Multiplex	Use of a common channel in order to make two or more channels, either by splitting of the frequency band transmitted by the common channel into narrower bands, each of which is used to constitute a distinct channel (frequency-division multiplex), or by allotting this common channel in turn, to constitute different intermittent channels (time-division multiplex).
Mutually Synchronised Network	A synchronised network in which each clock exerts a degree of control on all others.
NCC	National Control Centre
NP	Network Performance, quality measure for the network operator.
Out-Band Signalling	A signalling method in which signals are sent over the same transmission channel or circuit as the user's communication but in a different frequency band from that provided for the users.
Out-of-Frame alignment Time	The time during which frame alignment is effectively lost. That time will include the time to detect loss of frame alignment and the alignment recovery time.
PABX	Private Automatic Branch Exchange
PSK	Phase shift keying
Packet	A group of binary digits including data and call control signals which is switched as a composite whole. The data, call control signals and possibly error control information are arranged in a specified format.
Packet Assembly/ Disassembly	A user facility which permits nonpacket mode terminals to exchange data in the packet mode.
Packet-Mode Operation	The transmission of data by means of addressed packets whereby a transmission channel is occupied for the duration of transmission of the packet only. The channel is then available for use by packets being transferred between different data terminal equipments.

Note - In certain data communication networks the data may be formatted into a packet or divided and then formatted into a number of packets (either by the data terminal equipment or by equipment within the network) for transmission and multiplexing purposes.

Passband	A band of frequencies in which the attenuation (or gain) is less than (or greater than) a specified value.
PAX	Private Automatic Exchange
PCM	A process in which a signal is sampled, and the magnitude of each sample is quantised independently of other samples and converted by encoding to a digital signal.
PCM Multiplex Equipment	Equipment for deriving a single digital signal at a defined digit rate from two or more analogue channels by a combination of pulse code modulation and time division multiplexing (multiplexer) and also for carrying out the inverse function (demultiplexer). The description should be preceded by the relevant equivalent binary digit rate, e.g. 2048kbit/s PCM multiplex equipment.
Performance	General term for network or link quality, availability etc.
Permanent Virtual Circuit	A user facility in which a permanent association exists between two DTEs which is identical to the data transfer phase of a virtual call. No call set-up or clearing procedure is possible or necessary.
PLC	Power Line Carrier, transmission of signals on power lines.
Plesiochronous	Signals are plesiochronous if their corresponding significant instants occur at nominally the same rate, any variation in rate being constrained within specified limits. Note 1 - Two signals having the same nominal digit rate, but not stemming from the same clock (see the definition of clock) or homochronous clocks, are usually plesiochronous. Note 2 - There is no limit to the phase relationship between corresponding significant instants.
Positive/zero/ negative justification	A combination of positive and negative justification in which the two justification states are separately indicated by unique signals and the state of no (zero) justification is indicated by an additional signal.

Primary Level	Lowest level in a digital multiplexing stage, with specified bit rates.
Priority facility	A facility which gives a user preference over the other users. Priority may be given for instance to handling of the call, packet transfers, and other services provided by the network.
Protection	Protection of telecommunication connections (cf teleprotection).
Protection Switching	That category of restoration in which one transmission path is substituted for another to permit maintenance operations either for the protection against component failure or to remedy temporary conditions such as fading. This is also intended to reflect a configuration in which m paths protect n paths on the same route.
PTO	Public Telecommunications Operator, e.g. British Telecom, Mercury Communications Limited.
PTT	Post, Telephone and Telegraph used as a generic term, for various telecommunication Administrations and/or PTOs.
Public Data Network	A network established and operated by a PTT for the specific purpose of providing data transmission services to the public.
Pulse code modulation (PCM)	A process in which a signal is sampled, and the magnitude of each sample is quantized independently of other samples and converted by encoding to a digital signal.
Pulse duration	The interval of time between the first and last instant at which the instantaneous value of a pulse (or of its envelope if a carrier frequency pulse is concerned) reaches a specified fraction of the peak amplitude.
QAM	Quadrative amplitude modulation.
QOS	Quality of Service, degree of user satisfaction of the sevice.
QPSK	Quadrative Phase Shift Keying, equivalent to 4PSK.
Quantizing	A process in which the magnitude of a sample is classified into one of a number of adjacent intervals. Any sample magnitude falling within a given interval is represented by a single value.
Quantizing distortion	The distortion resulting from the process of quantizing.

Random errors	Errors distributed over the digital signal so that they can be considered statistically independent from each other.
RCC	Regional Control Centre
Redundancy	The existence of more than one means for performing a required function.
Reference clock	A clock (see definition of clock) of high stability and accuracy that is used to govern the frequency of clocks of lower stability. The failure of such a clock does not necessarily cause loss of synchronism.
Reference connection	Ref. connection is a model e.g. for bit error performance objective specifications
Regeneration	Reshaping a digital signal into its original form so that waveform distortions are removed (may produce some bit errors).
Repeater	An equipment essentially including one or several amplifiers and/or regenerators, and associated devices, inserted at a point in a transmission medium (see Figures 1/G.601 and 2/G.601). Note - A repeater may operate in one or both directions of transmission.
Residual error rate	The ratio of the number of bits, unit elements, characters or blocks incorrectly received but undetected or incorrected by the error-control equipment, to the total number of bits, unit elements, characters or blocks sent.
Route	A collection of circuits uniquely identifiable for engineering, routing or traffic purposes.
RS	Remote Station
RTU	Remote Terminal Unit (e.g. Substation in a telecontrol system).
Sample	The value of a particular characteristic of a signal at a chosen instant.
Sampling rate	The numer of samples per unit time.
SCADA	Supervisory Control and Data Acquisition
Scrambling	Randomisation of Signals, see Section 6.1.2(c)
SDH	Synchronous Digital Hierarchy, which is the new recommendations proposed by CCITT (See Section 5.2.)
Second Order Mux	A Multiplexer producing second level in a digital hierarchy, e.g. 8448 or 6312 kbit/s.
Service bits	Those overhead bits which are not check bits.

	Example: request for repetition, numbering sequence etc.
SES	Severely errored second (64 or more errors in 1 second at 64 kbit/s).
Signal element	Each of the parts constituting data signal and distinguised from the others by its nature, magnitude, duration and relative position (or by one or some of these features only).
Signalling system	The procedures for the interpretation and use of a repertoire of signals together with the hardware and/or software needed for the generation, transmission, and reception of these signals.
Signalling time slot	A time slot starting at a particular phase in each frame and allocated to the transmission of signalling.
Single Mode Fibre (SM) Optical Fibre	An optical fibre that is only capable of sustaining the propagation of a single mode at a given wavelength.
Synchronised network	A network in which the corresponding significant instants of nominated signals are adjusted to make them synchronous. Ideally the signals are synchronous, but they may be mesochronous in practice. By common usage such mesochronous networks are frequently described as synchronsied.
Synchronous	Signals are synchronous if their corresponding significant instants have a desired constant phase relationship with each other.
Synchronous data network	A data network which uses a method of synchronization between data circuit-terminating equipment (DCE) and the data switching exchange (DSE) and between DSEs, the data signalling rates being controlled by timing equipment within the network.
Telephone circuit	A permanent electrical connection permitting the establishment of a telephone communication in both directions between two telephone exchanges.
Telephone signal	Any signal which pertains to a particular telephone call or to a particular speech circuit.
Teleprotection	Protection of electrical network based on use of telecommunications, command or analogue type (cf protection).
Teleservices	Services involving all OSI layers, ensuring end-to-end compatibility (e.g. telephony, facsimile).
Terminal	Abbreviation for man-machine terminal.

Time slot	Any cyclic time interval that can be recognised and defined uniquely.
Transcoding	Conversion from a digital code to another (e.g. PCM - ADPCM).
Transfer time	The time that elapses between the initial offering of a unit of the user's data to a network by a transmitting data terminal equipment and the complete delivery of that unit to a receiving data terminal equipment. A unit of data may be a bit, byte, packet, message etc. A specific example of transfer time applied to packet mode operation may be defined as follows: packet transfer time is the time that elapses between the initial offering of a packet to the network by a transmitting data terminal equipment and the complete delivery of that packet to a receiving data terminal equipment.
Transit traffic	Traffic passing through the network considered, generated by sources outside it and destined for sinks outside it.
Transmission	Transfer of signals (information)
Transmultiplexer	An equipment that transforms frequency-division multiplexed signals (such as group or supergroup) into corresponding time-division multiplexed signals that have the same structure as those derived from PCM multiplex equipment. The equipment also carries out the inverse function.
Transparency	The property of a digital transmission channel, telecommunication circuit or connection, that permits any digital signal to be conveyed over it without change to the value or order of any signal elements. Note - The digital transmission channel, telecommunication circuit or connection concerned may introduce delay and may contain reversible code conversion functions.
Two-wire switching	Switching using the same path, frequency band or time interval for both directions of transmission.
Uncontrolled slip	The uncontrolled loss or gain of a digit position or a set of consecutive digit positions resulting from an aberration of the timing processes associated with transmission or switching of a digital signal.
Uniform encoding	The generation of character signals representing uniformly quantized samples, compared with compression.
Uniform quantizing	Quantizing in which all the intervals are equal.

Virtual call	A user facility in which a call set-up procedure and a call clearing procedure will determine a period of communication between two DTEs in which user's data will be transferred in the network in the packed mode of operation. All the user's data is delivered from the network in the same order in which it is received by the network. This facility requires end-to-end transfer control of packets within the network. Data may be delivered to the network before the call set-up has been completed but it will not be delivered to the destination address if the call set-up attempt is unsuccessful. Multi-access DTEs may have several calls in operation at the same time.
Wander	Long term variation of the significant instants of a digital signal.

APPENDIX B1

EXAMPLES OF POWER UTILITY NETWORKS

SOUTH OF SCOTLAND ELECTRICITY BOARD, U.K.

INTEGRATED SPEECH AND DATA NETWORK (SEE FIGURE B1)

INTRODUCTION

Initial development of the Network began in 1981 and necessary extension and additions to improve diversity and resilience have been the subject of a continuous programme since then. The voice and data services supported by this network are listed below:-

NETWORK SERVICES

Some forty digital S.P.C. telephone exchanges, operated in a PABX mode, are interconnected on the network. Four Transit exchanges located at Cathcart House, Waterloo Street, Edinburgh and Hamilton DCC's are digitally interconnected and all PABX exchanges connect to their local Transit. Approximately 15% of the exchanges have full digital interface with the remainder connected on leased analogue lines or on lines derived from a separate private galvanic cable system. Those exchanges with a digital interface have access to a private I.S.D.N. menu of the advanced features and facilities of modern digital telephone exchanges across the network. The network also supports in part a separate Control Telephone System used for operational purposes and this is likely to increase when this system is uprated in 1990/91.

Telecontrol services both for Transmission and Distribution are extensively served by the Network.

Major Processors for this application are sited at GCC and the DCC's and are interconnected and extended to their R.T.U.'s numbering 100 for Transmission and ultimately in excess of 400 for Distribution. H.V. Protection services using up to 64 kbits/second channel allocations are also a feature of the Network.

CAD systems at Glasgow, Edinburgh and Hamilton operate on a common data base at Cathcart House via the Network. Another application being developed is Office Automation for dispersed offices again based on a common data base at Cathcart House.

However the major share of Data Traffic is catered for by an X25 packet Switching Network. Packet Switching Exchanges are sited at Cathcart House, Kirkintilloch GCC and Edinburgh and Glasgow DCC's. These exchanges have a data throughput of 1000 Packets/second and are interconnected on a diverse basis with 64 kbits/second trunks. Applications operated over the Packet Switching Network include automated Stock and Ledger systems at some 70 shops. Similarly automated customer record and accountancy systems at public customer interface points in Service Centres of which where are currently eighteen. All Power Stations operate a common data base Materials on Line system over the Network. Separately sited Main Frame Computers are operated on a Main and Standby mode and the

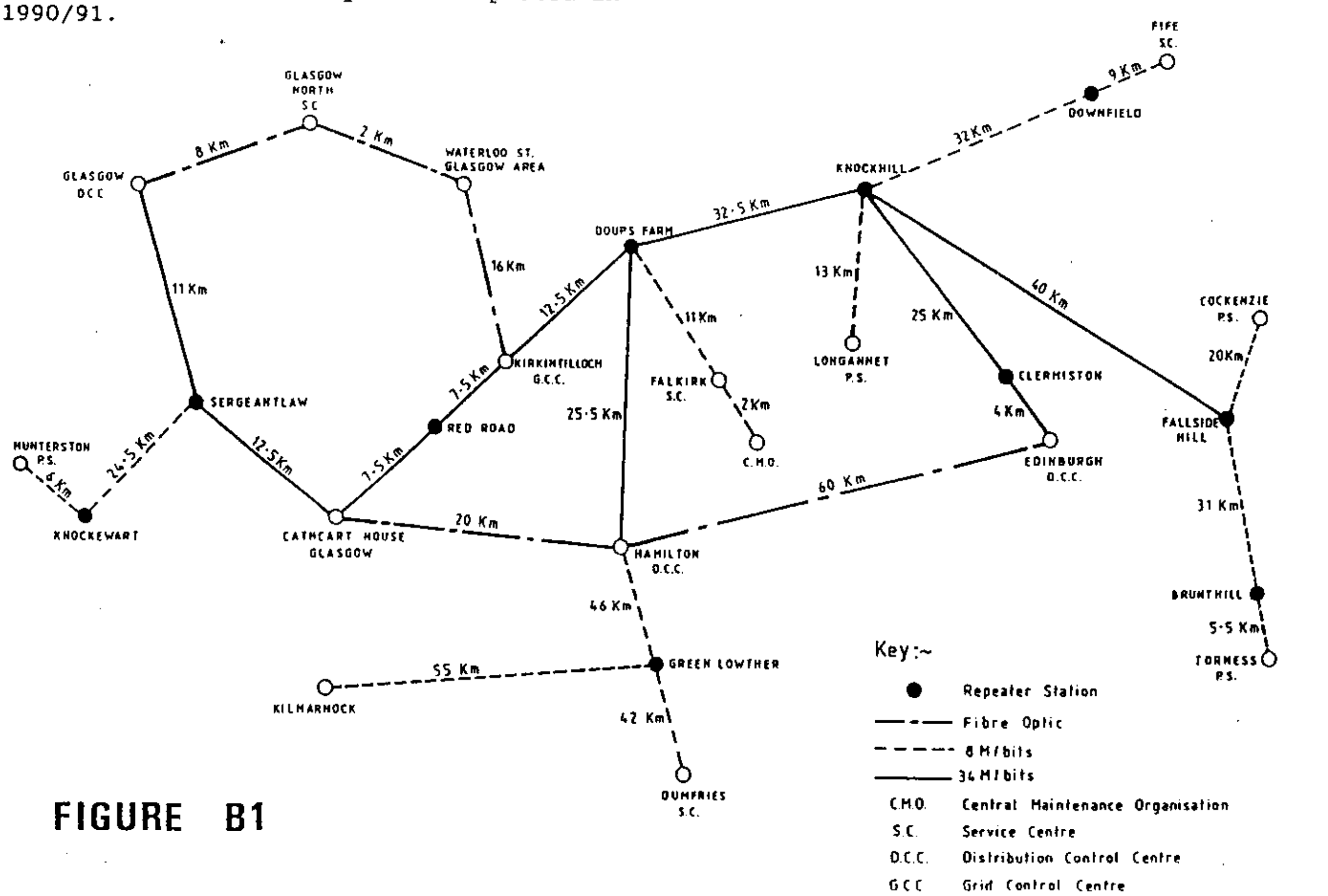


FIGURE B1

Packet Switching Network allows all users to be automatically connected to either site as required. The two host sites are interconnected by means of 64kbit/s and 2Mbit/s trunks.

APPENDIX B2

EXAMPLES OF POWER UTILITY DIGITAL NETWORKS

ELSAM, DENMARK

RADIO LINK SYSTEM

1. Structure

The radio link system is used for exchange of data among ELSAM's central control centre and the seven regional power utilities in the ELSAM service area as well as all 400kV and 220kV substations and HVDC converter stations.

The system structure is outline in fig. B2, and the design of the individual hops, each with a capacity of 8 Mbit/s, is as shown in fig.B2[1].

The length of the hops ranges from 8km to 73.5km.

The frequency range is 7.2GHz, and transmission takes place at two frequencies which are polarised separately at 7MHz frequency distance. This is not sufficient to achieve frequency diversity, so instead space diversity is used on all hops.

The data is transmitted in parallel by the two transmitters, and at the receiving end the digital signals are passed on to a digital "switch" which selects the best of the signals and transfers them on to the multiplexer. This switching is bit error-free as the two bit streams from the receivers are kept synchronous in an "elastic" memory.

The system further contains a service channel which is frequency modulated onto the radio signal. This service channel is used to monitor the radio link system.

2. Reliability

The radio link system has been extended to Sweden via two hops across open water. One of the hops is 73.5km long, which have Errored Seconds for 0.016% of the time during a measuring period. In the same period on all the other land-based hops the system has Errored Seconds for 0.00023% of the time.

Except for the two hops across the sea the radio links meet the requirements that apply to High Grade Circuits.

FIGURE B2

Representation of ELSAM's
Digital 8 Mbit/s telecommunications system

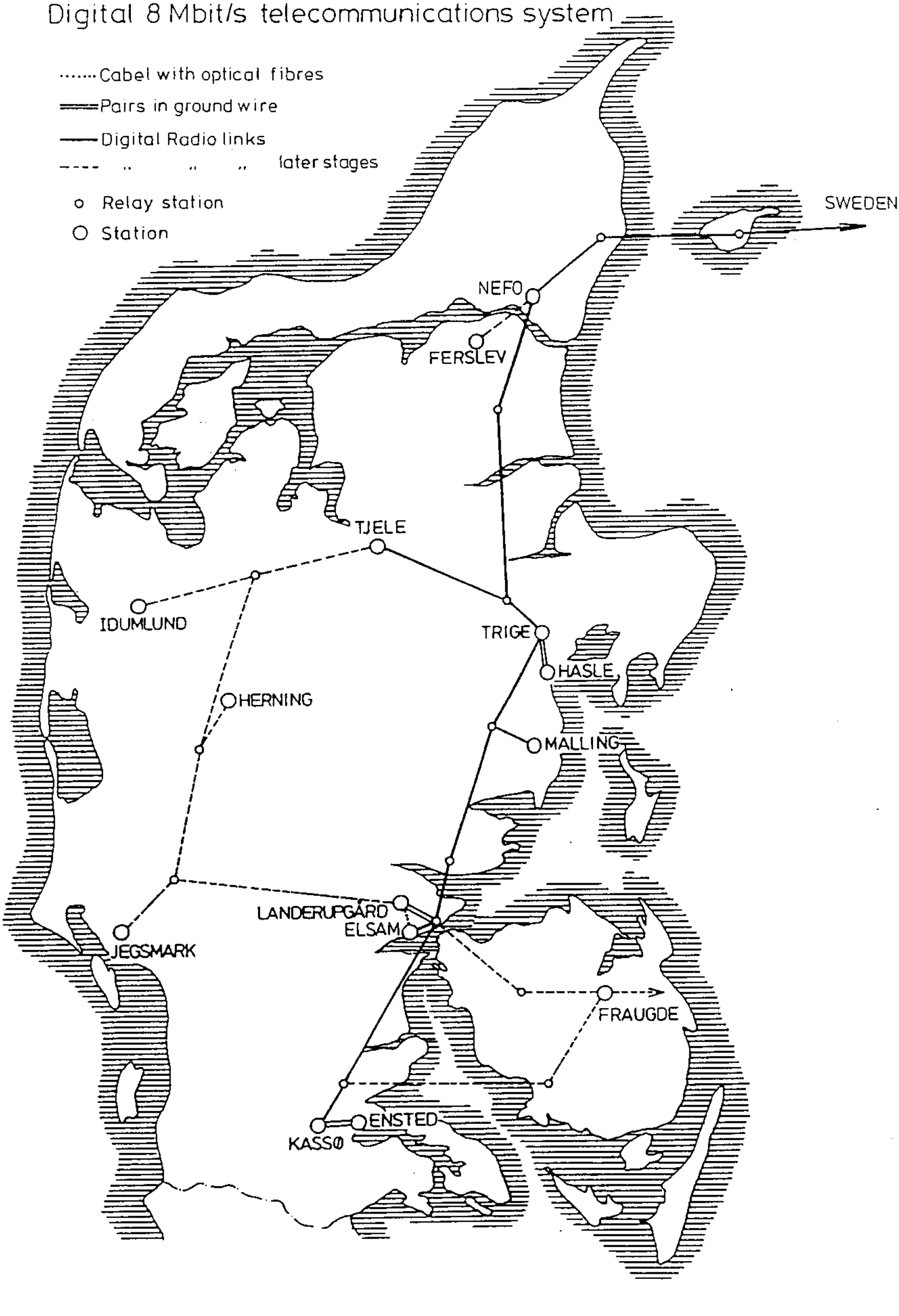
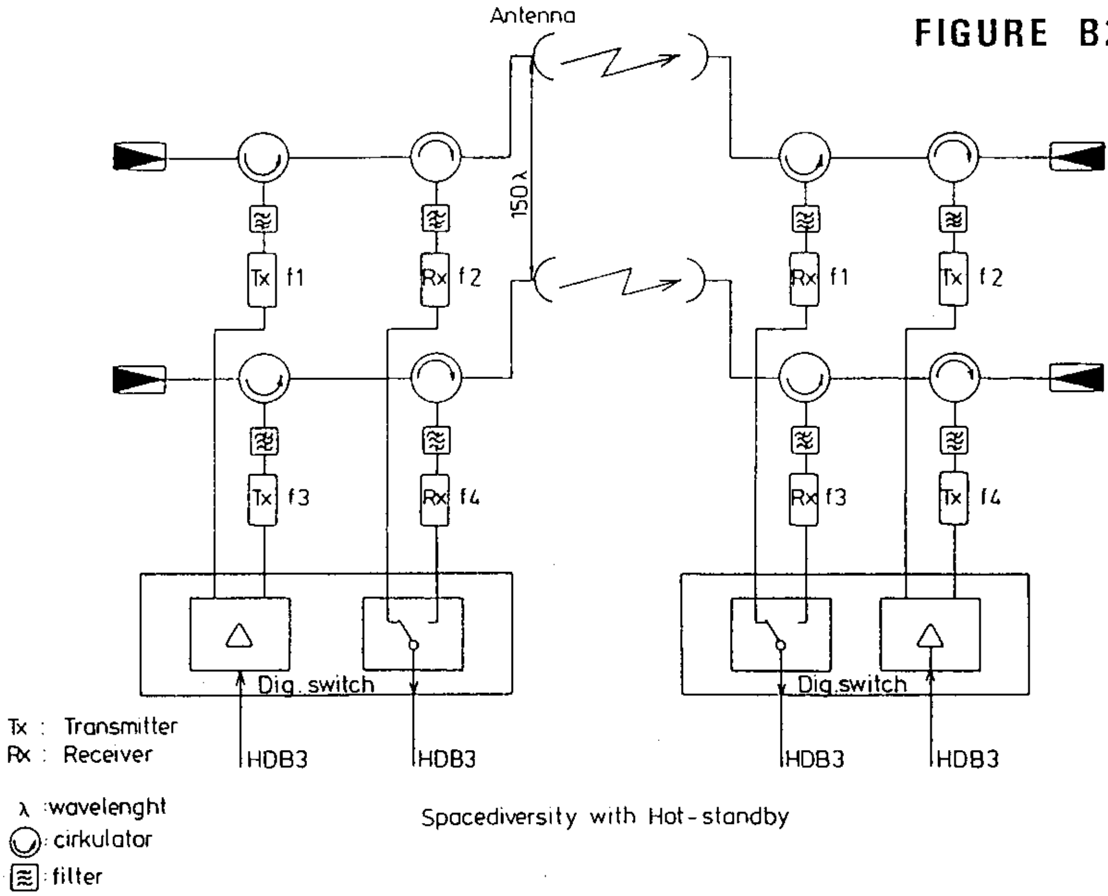


FIGURE B2[1]



Spacediversity with Hot-standby

APPENDIX B3

EXAMPLES OF POWER UTILITY DIGITAL NETWORKS

ELECTRICITY TRUST OF SOUTH AUSTRALIA

DIGITAL RADIO NETWORK (See Figure B3)

The power transmission system of ETSA is a long linear system with coal fired thermal generation at Pt Augusta, gas fired thermal generation in Adelaide - the capital city and principal load centre, and an interconnection with the power utility in the adjacent state of Victoria for opportunity import, near Mt Gambier.

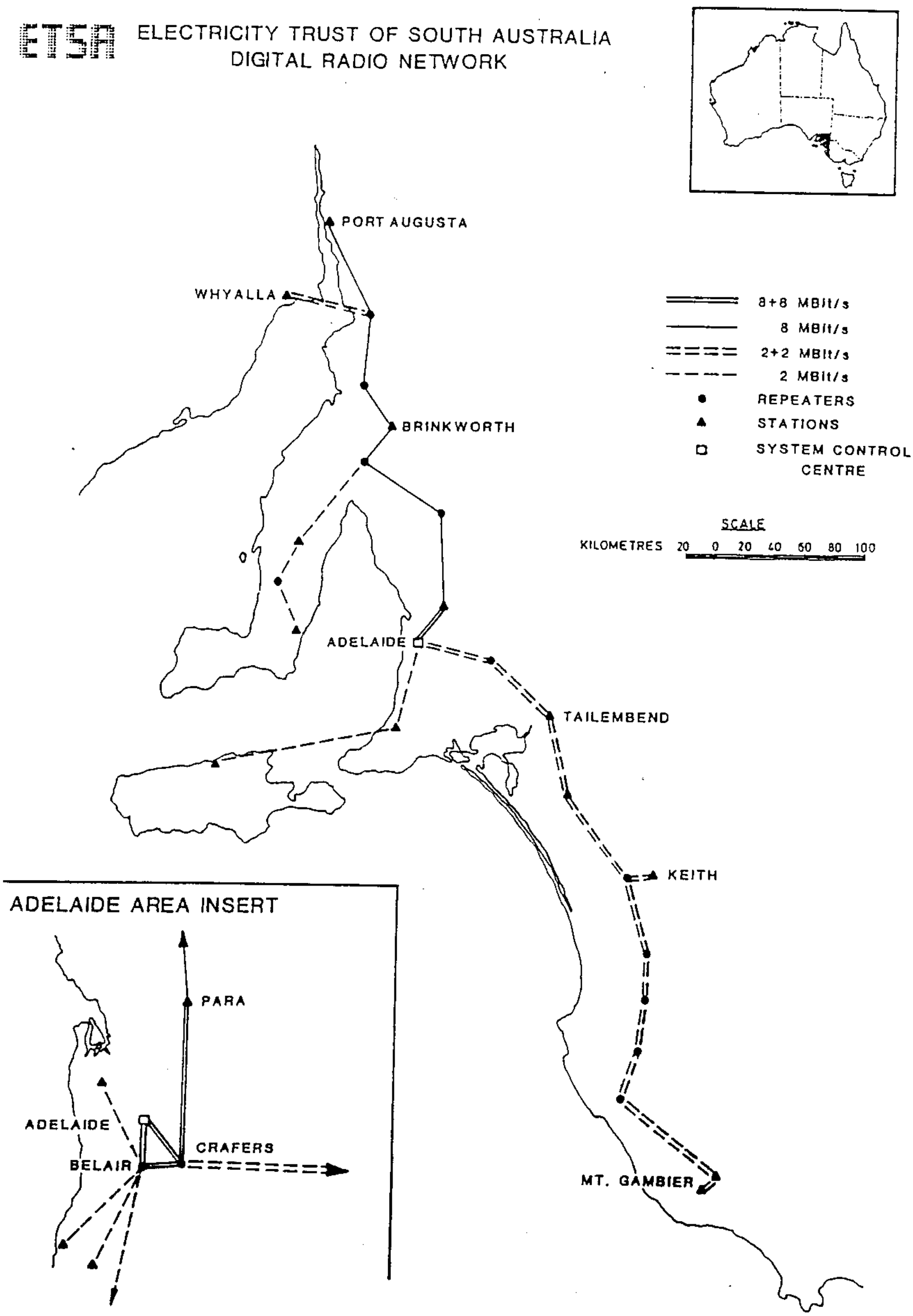
Communications prior to 1980 consisted of multi-channel analogue radio links in and near Adelaide, and power line carrier (PLC) for the longer distance country services. Because of extensive power system intermeshing PLC channels were becoming increasingly difficult to reuse and analogue radio was being extended out from Adelaide to split the PLC systems into separated north and south sections. Analogue radio routes had reached Tailem Bend in the south and Brinkwork in the north.

Communications have traditionally been provided to carry operational telephony, mobile radio station interlinking, SCADA, independent load shedding control and teleprotection signalling. With the commissioning in 1989 of the power system interconnection with Victoria came the additional requirement to transport Automatic Generation Control information. Insufficient secure bearer capacity was available for this new function and it was therefore decided to build a new backbone radio route linking the three critical locations (Pt Augusta, Adelaide, Mt Gambier) and major substations en route.

The southern route (which services substations only) uses 2+2 Mbit/s radio and is unique in Australia in that for part of the route, it has been provided on an equity provision basis with the local police authority, with each party using one of the 2 Mbit/s streams.

The northern route (which services power stations as well as substations) uses 8 Mbit/s radio capacity. On this route, in addition to the services listed above, a 2 Mbit/s stream is dedicated to interconnection of PABX in Pt August and Adelaide.

FIGURE B3


ETSA
ELECTRICITY TRUST OF SOUTH AUSTRALIA
DIGITAL RADIO NETWORK
PORT AUGUSTA
WHYALLA
BRINKWORTH
ADELAIDE
TAILEMBEND
KEITH
MT. GAMBIER
8+8 MBit/s
8 MBit/s
2+2 MBit/s
2 MBit/s
REPEATERS
STATIONS
SYSTEM CONTROL CENTRE
SCALE
KILOMETRES 20 0 20 40 60 80 100
ADELAIDE AREA INSERT
PARA
ADELAIDE
CRAFERS
BELAIR

Various branch routes are connected to the backbone with analogue and digital radio, and multiplexed cable services. Analogue radio branches which pre-existed are connected at channel level, but digital branches are all performed with 2 Mbit/s branching units.

In the immediate vicinity of Adelaide, routes are established with 8+8 Mbit/s radio capacity to the 'first out' repeaters at Belair, Crafers and Para where many existing analogue routes depart.

The total network is centred in the System Control Centre in Adelaide where hierarchical master/slave synchronising is commenced from a stable external source.

The network is provided with Network Management facilities remotely located at the engineering centre in an Adelaide suburb.

APPENDIX B4

EXAMPLES OF POWER UTILITY DIGITAL NETWORKS

INTEGRATED DIGITAL TELECOMMUNICATIONS NETWORK OF FINNISH POWER UTILITIES IVO, OJO, AND KEJO, FINLAND

1. Introduction

Finnish power utilities IVO, OJO and KEJO have constructed an integrated digital telecommunications network for all the services needed in power utility environment, see figure B4.

2. Transmission Systems

Transmission systems of the backbone telecommunications network are mainly digital radio link systems. Optical systems are applied also. They are applied in shorter distances in the beginning, but their application will increase in future.

The capacities of digital radio systems are 2*8 Mbit/s and 2*2 Mbit/s. The frequency ranges are 1.8 GHz and 2.6 GHz. Main part of radio terminals are protected using hot stand-by principle (and space diversity, when needed). Multiplexing techniques is based on normal CCITT terminals. Digital branching techniques is applied very widely.

3. Telephone Systems

Private telephone network consists of digital operational telephone network, aerial PABX networks (OJO and KEJO), local PABXs and mobile telephone network. There will be 16 digital PAXes in the whole network. In all control centre stations PAX is interconnected with local PABX. In certain stations, PAX and PABX are integrated into the same equipment. The numbering of the PAX and PABX networks is closed. In addition to speech services switched 64kbit/s data connections are available in the network. Trunk between PAXes are branched 2 Mbit/s digital connections. Alternate trunks are available between PAX'es. Interconnections between PAX'es and PABX's are mainly 2 Mbit/s digital lines.

4. Data Services

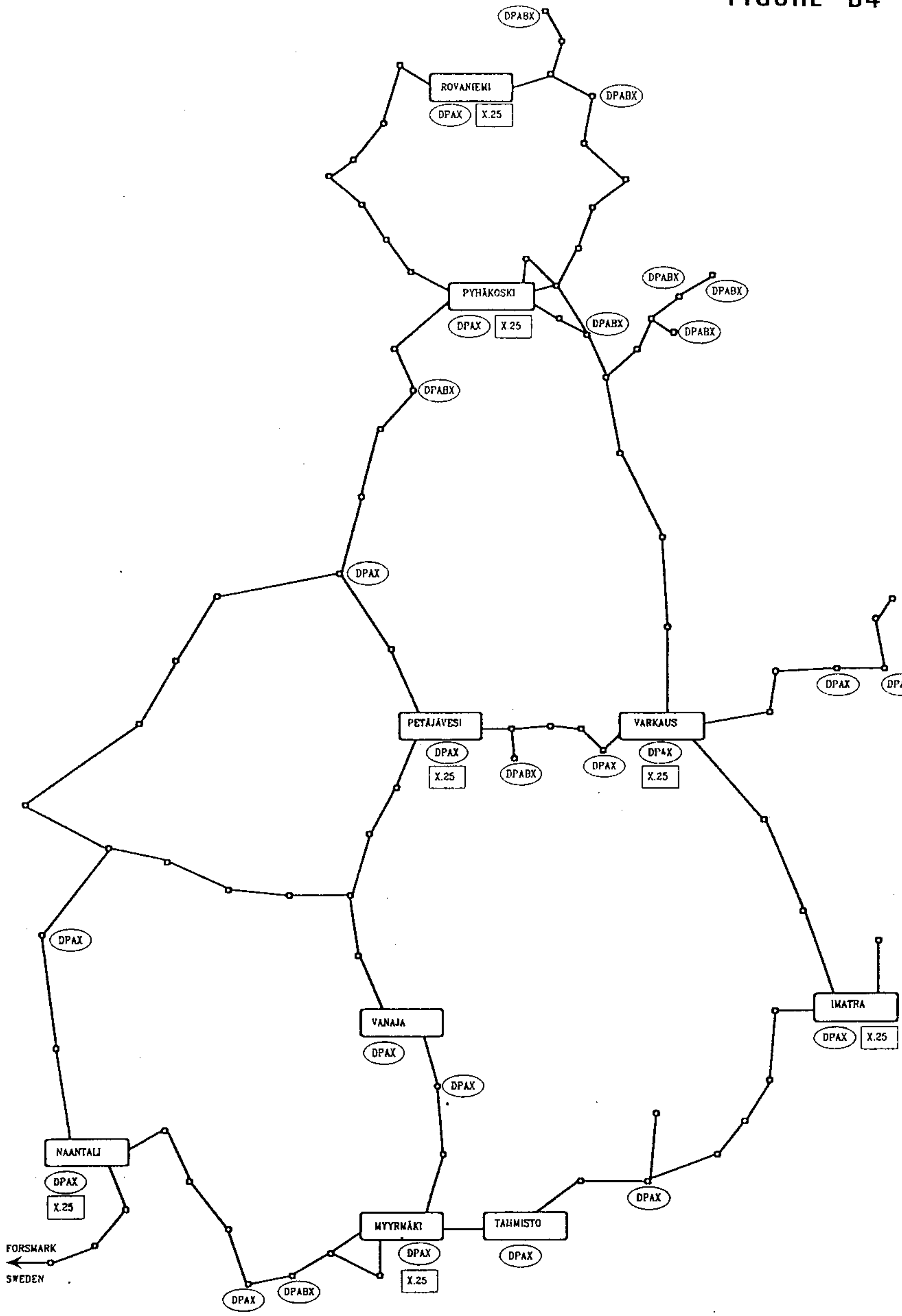
Private packet-switched data network will be constructed for all kind of data services in power utilities. Performance, delay and availability specifications are based on power network control needs. Maximum capacity is defined based on the combined use of SCADA/general purpose data transmission. Trunk speeds are 64...256 kbit/s. Use of 2 Mbit/s trunks will be possible later.

5. Other Services

Teleprotection signals for distance protection relays will be transmitted in digital transmission systems using digital adapters.

Video transmission based on 2 Mbit/s codecs is applied for both video conferences and remote surveillance purposes.

FIGURE B4



DPABX
ROVANIEMI
DPAX
X.25
DPABX
PYHÄKOSKI
DPAX
X.25
DPABX
DPABX
DPABX
DPABX
DPABX
DPAX
DPAX
DPABX
PETÄJÄVESI
DPAX
X.25
DPABX
DPAX
VARKAUS
DPAX
X.25
DPAX
VANAJA
DPAX
DPAX
IMATRA
DPAX
X.25
NAANTALI
DPAX
X.25
FORSMARK
SWEDEN
MYYRMÄKI
DPAX
X.25
TAHMISTO
DPAX
DPAX
DPAX
DPABX

APPENDIX B5

EXAMPLES OF POWER UTILITY DIGITAL NETWORKS

DIGITALIZATION OF THE TELECOMMUNICATION NETWORK AT ENEL (ITALIAN NATIONAL ELECTRICITY BOARD)

The fig. B5 represents the multichannel radio telecommunication network in the ENEL's Florence Area, comprising of two administrative regions of Toscana and Emilia-Romagna.

The drawing shows the 2.3GHz hops (continuous lines) and the 18GHz hops (dashed lines).

The digitalization process begun with the installation of the 18GHz systems, which can provide capacities of 704 kbit/s or 2048 kbit/s.

On the whole Italian territory ENEL has in operation about 300 hops at 18GHz.

At the moment this band is the only one authorised by the Italian PTT to be operated with digital equipment.

The next step will probably commence in 1990 with the substitution of the present FM-FDM 2.3GHz systems, allowing 60 channel capacity, with digital terminals operating in the same band. The need to ensure in the 2.3GHz band compatibility between the present analogue and the future digital radios, implies for these a capacity of 2+2 Mbit/s with 16 QAM modulation.

ENEL network comprises also a few 34 Mbit/s links on optical cables and some tens of 2 Mbit/s carriers on pair cables, mainly used as connections between PABX.

Besides the above mentioned systems ENEL will resort even to single channel 64 kbit/s radios at 440MHz. They operate with 35kHz channel spacing.

These single channel systems will substitute the present 300 hops FM 440MHz single channel radios.

The 2.3GHz radio links are the main bearers in the higher network layers, while the 18 GHz and the single channel radios are mostly used in peripheral links.

For peripheral links ENEL forecasts the possibility to convert into digital of Power Line Carriers, for which a 64 kbit/s capacity has to be tested.

The ENEL network is mainly exploited for operational services and does not require high capacity except in a small percentage of the routings. This, together with the presence of bearers capable of 64 kbit/s, requires the availability of nodes able to route the single 64 kbit/s streams, by means of suitable multiplex equipment.

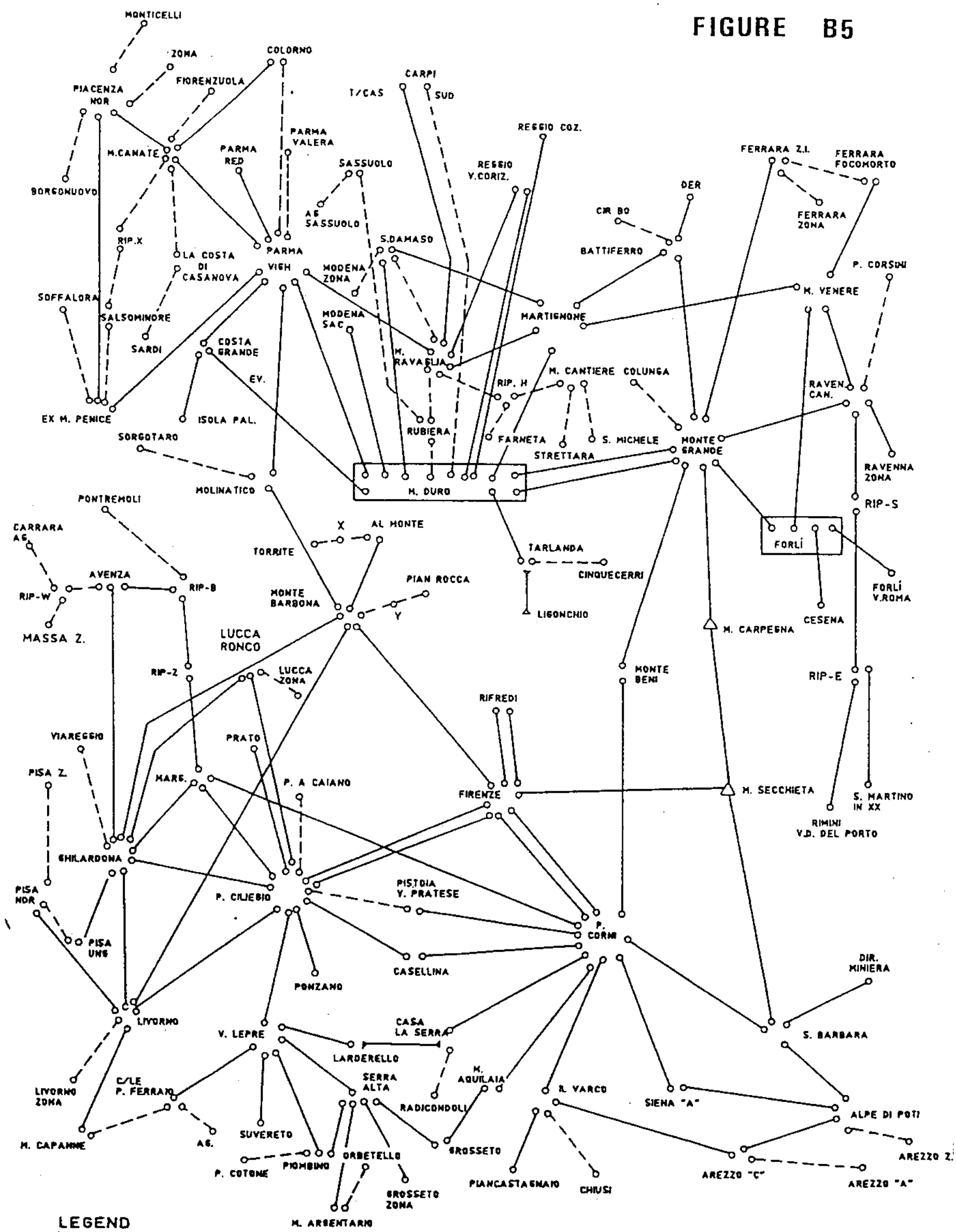
Each single 64 kbit/s stream can be sub-divided into many tributary flows at lower bit rate. Speech signals are coded at 64 kbit/s as well as at lower speeds, like 32 kbit/s ADPCM.

Network nodes operate justification and buffering processes on the elementary flows. This allows plesiochronous operation without slips, avoiding any synchronisation.

Dealing with the carried services, about 70% of the 800 ENEL's transit telephone exchanges are already digital PCM, as well as 60% of the above 500 PABXs.

Channels of the network are also used as connections between nodes of the packet switching X.25 network ENELPAC, based on more than 150 nodes and serving more than 15000 PC terminals.

FIGURE B5



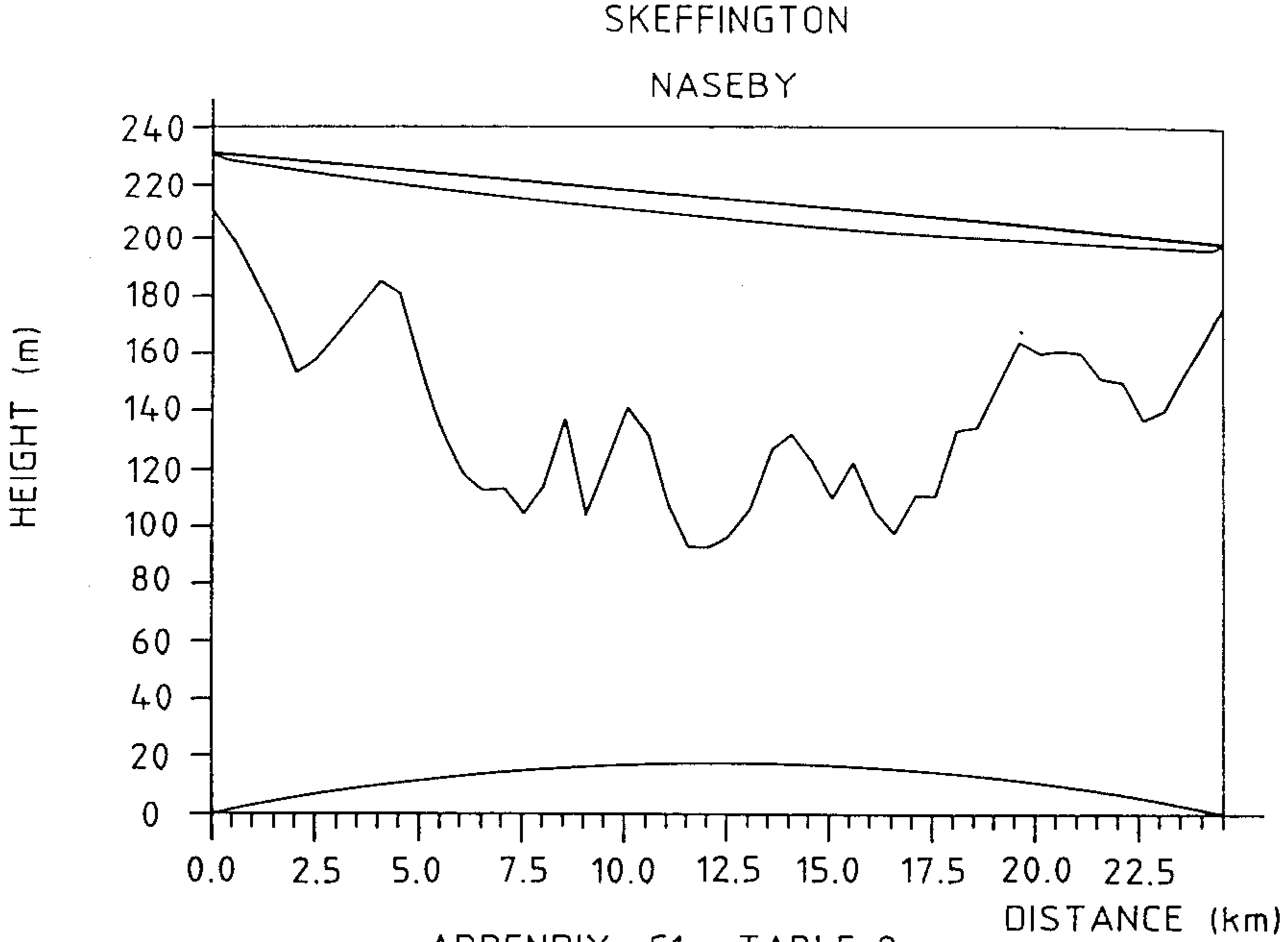
LEGEND

RADIO LINK – 2.3 GHz ———— RADIO LINK – 18 GHz – – – – –

TABLE 1

RADIO PATH PERFORMANCE ESTIMATE   ISSUE   DATE

	SITE A		SKEFFINGTON	SKEFFINGTON
	SITE B		NASEBY	NASEBY
1	Configuration		PROTECTED	PROTECTED
2	Path Length	kms	26.50	26.50
3	Frequency	GHz	13.00	13.00
4	Bit Rate	Mbit/s	8.00	8.00
5	Roughness Factor		27.40	27.40
6	Climatic Factor *E-8		1.60	1.60
7	Absorption Attenuation	dB/km	0.044	0.044
8	Feeder Attenuation	dB/100m	11.50	11.50
	Losses			
9	Free Space Loss	dBi	143.14	143.14
10	Obstruction Loss	dB	0.00	0.00
	Losses Site A			
11	Feeder Length	m	41.00	41.00
12	Feeder Loss	dB	4.72	4.72
13	Additional Loss	dB	0.50	0.50
	Losses Site B			
14	Feeder Length	m	33.00	33.00
15	Feeder Loss	dB	3.80	3.80
16	Additional Loss	dB	0.50	0.50
17	Total Loss Path A-B	dB	152.66	152.66
18	TX O/P Power Nominal	dBW	-9.00	-9.00
19	TX O/P Power Corrected	dBW	-10.00	-9.00
	Gains Site A			
20	Antenna Diameter	m	1.80	1.20
21	Antenna Gain	dBi	45.20	41.00
	Gains Site B			
22	Antenna Diameter	m	1.80	1.20
23	Antenna Gain	dBi	45.20	41.00
24	Total Gain Path A-B	dB	90.40	82.00
25	Site A EIRP	kW	1.00	0.48
26	Site B EIRP	kW	1.23	0.59
27	RX I/P Level Median	dBW	-72.26	-79.66
28	D.T.I. Regulatory Limit	dBW	-71.00	-71.00
29	RX I/P Ref. D.T.I. Limit	dB	-1.26	-8.66
30	RX Threshold 1 *E-6 BER	dBW	-105.50	-105.50
31	RX Threshold 1 *E-3 BER	dB	-109.00	-109.00
32	Absorption Loss	dB	1.17	1.17
33	Flat Fade Margin 1 *E-6 BER	dB	32.07	24.67
34	Net Fade Margin 1 *E-6 BER	dB	32.07	24.67
35	Flat Fade Margin 1 *E-3 BER	dB	35.57	28.17
36	Net Fade Margin 1 *E-3 BER	dB	35.57	28.17
	Worst Month Performance Data			
37	BER 1* E-6 Not Exceeded *E-4	%	6.59	36.23
38	BER 1* E-6 Not Exceeded	sec	17.09	93.90
39	BER 1* E-3 Not Exceeded *E-4	%	2.94	16.18
40	BER 1* E-3 Not Exceeded	sec	7.63	41.94



APPENDIX C1 TABLE 2

APPENDIX C1

TABLE 3

RADIO PATH PERFORMANCE ESTIMATES - EXPLANATORY NOTES

Path performance estimates are produced in conjunction with path profile drawings for a specific combination of effective earth radius correction factor 'k' and the path clearance criteria adopted for the link under consideration. The estimates are produced from a range of data and parameters defined and entered by the planning engineer responsible for the design and performance specification of the system. The various lines used are described below and where the term 'a system or site defined parameter' is indicated, this is a direct manual entry and not a calculated value. The estimates given below assume the following:

1. That the antennas will be aligned to give optimum performance.
2. That the support structure has a twist and tilt specification better than 1/4 of the 3 dB beam-width of the antenna.

Line 1: Configuration

The link will normally be configured for single path (unprotected), hot standby (protected) or space diversity working.

Line 2: Path Length

A system defined paramter.

Line 3: Frequency

A system defined parameter.

Line 4: Bit Rate

A system defined parameter.

Line 5: Roughness Factor

A system defined parameters taken from the path profile calculations and drawings for the particular case. For a general case where path information is not available, a figure of 25 will be used.

Line 6: Climatic Factor

Climatic factors, appropriate to the regional location, are entered to assess the probability of deep fading. The actual factors used are derived from CCIR Report 338-4.

Line 7: Absorption Attenuation

For 13 GHz working the specific attenuation due to gaseous absorption at a mean water vapour density of .5/cu.m is taken as 0.044 dB/km. No allowance is made for gaseous absorption at 7.5 GHz or below.

Line 8: Feeder Attenuation

The specific attenuation is due to the particular feeder (waveguide) proposed is entered, in dB/100m.

Line 9: Free Space Loss

The free space loss, between isotropic radiators, is calculated from the formula:

$$L(f) = 92.4 + 20 \, Log(10) \, (d.f.)$$

Where d and f are defined in Lines 2 and 3.

Line 10: Obstruction Loss

A system defined parameter. Determined from the path profile drawings.

Line 11: Feeder Length (A)

A site defined parameter.

Line 12: Feeder Loss (A)

The actual feeder loss at Site A, calculated from Lines 8 and 11.

Line 13: Additional Loss (A)

An allowance entered to take into account the additional losses due to connectors, waveguide bands and other associated items.

Line 14: Feeder Length (B)

As for Line 11 above for Site B.

Line 15: Feeder Loss (B)

The actual feeder loss at Site B, calculated from Lines 8 and 14.

Line 16: Additional Liss (B)

As for Line 13 above for Site B.

Line 17: Total Loss Path A-B

The calculated sum of Lines 9, 10, 12, 13, 15 and 16.

Line 18: Tx O/P Power Nominal

The rated transmitter output power at the feeder/equipment interface flange.

Line 19: Tx O/P Power Corrected

The transmitter output power at the feeder/equipment interface flange. Where the output powers shown in Lines 18 and 19 differ it indicates that the transmitter has been derated to comply with regulatory limits on EIRP or receive signal levels.

Line 20: Antenna Diameter (A)

A system defined parameter.

Line 21: Antenna Gain (A)

A system defined parameter.

Line 22: Antenna Diameter (B)

As for Line 20 above for Site B.

Line 23: Antenna Gain (B)

As for Line 21 above for Site B.

Line 24: Total Antenna Gain Path A-B

The calculated sum of Lines 21 and 23.

Line 25: Site A EIRP

The EIRP calculated from the algebraic sum of the Tx O/P Power and the associated losses and gains for Site A.

Line 26: Site B EIRP

As for Line 25 for Site B.

Line 27: Rx I/P Level Median

The median Rx level calculated from Lines (19 - 17 + 24) at the equipment/feeder interface flange.

Line 28: Regulatory Limit

Regulatory limits as defined by the Regulating Authority.

Line 29: Rx I/P Ref. DTI Limit

Calculated from Lines (27 - 28) to show the variance from the regulatory limit. When the figure indicated is positive the antennas and/or transmitter power should be changed to meet the statutory limits.

Line 30: Rx Threshold 1.E-6 BER

An equipment specified parameter at the equipment/feeder interface flange.

Line 31: Rx Threshold 1.E-3 BER

An equipment parameter defined as Line 30- 3.5 dB (for QPSK modulation).

Line 32: Absorption Loss

The mean absorption loss, calculated from Lines 2 to 7.

Line 33: Flat Fade Margin 1.E-6 BER

The uncorrected fade margin calculated from Lines (27 - 30 - 32). Where a regulatory limit exists the Median Level, Line 27 must not exceed the regulatory limit figure given in Line 28 and must be corrected in accordance with the variance figure given in Line 29.

Line 34: Net Fade Margin 1.E-6 BER

The corrected fade margin (for 34 Mbit/s working only) as extracted from CCIR Rep. 338-4 Figure 5. This is to correct for selective fading at the higher bit rates.

Line 35: Flat Fade Margin 1.E-3 BER

The uncorrected fade margin calculated from Lines (27 - 31 - 32). Where a regulatory limit exists the Median Level, Line 27 must not exceed the regulatory limit figure given in Line 28 and must be corrected in accordance with the variance figure given in Line 29.

Line 36: Net Fade Margin 1.E-3 BER

As Line 34 for a BER of 1.E-3.

Line 37: BER 1.E-6 Not Exceeded

Worst month performance, calculated by substitution of the net fade margin, Line 34, in the general formula for the prediction of the probability of deep fading given in CCIR Report 338-4, para. 4.2.

Line 38: BER 1.E-6 Not Exceeded

As Line 37 but expressed in seconds per month.

Line 39: BER 1.E-3 Not Exceeded

As Line 37 for a BER of 1.E-3.

Line 40: BER 1.E-3 Not Exceeded

As Line 39 but expressed in seconds per month.

RADIO LINK SYSTEM PERFORMANCE CALCULATION EXAMPLE

Let us suppose a single hop between two stations A and B.

Frequency	GHz	17.5	2.3
Capacity	Mbit/s	2	2 x 2
TX power	dBM	18	25
Path length	km	18.5	100
Free Space Loss	dB	142.6	139.6
Feeder and branching attenuations	dB	0	8.8
TOTAL ATTENUATION	dB	142.6	148.4
Antenna A diameter	m	0.6	3.7
Antenna A gain	dB	38.7	37.1
Antenna B diameter	m	1.2	3.7
Antenna B gain	dB	44.7	37.1
NET PATH LOSS	dB	59.2	74.2
Received Power P_R	dBm	-41.2	-49.2

MULTIPATH COEFFICIENTS

The occurrence factor, i.e. the probability of multipath, may be calculated from the frequency, the hop length, the climate and terrain characteristics as per CCIR, Rep. 338-5. In our example:

- OCCURRENCE FACTOR		5.2E-02	9.8E-01

BER 10^{-3}

Threshold P_{TH}	dBm	-92	-90
Fade margin FM	dB	50.8	40.8
OUTAGE (UNPROTECTED)	%	4.9E-05	4.8E-03
OUTAGE (with space diversity 15m)		-	6E-05

These values have been calculated from the occurrence factor and the face margin, using the procedure indicated in Rep. 338-5 and Rep. 376.-5 of CCIR.

BER 10^{-6}

Threshold P_{TH}	dBm	-88	-86
Fade margin FM	dB	46.8	36.8
OUTAGE (UNPROTECTED)	%	1.2E-04	2.1E-02
OUTAGE (with space diversity 15m)		-	3.7E-04

RAIN UNAVAILABILITY CALCULATION

Fade margin FM	dB	50.8	40.8
Wet radome losses	dB	2	-
Rainfall area	mm/h	60	60
Polarization (H or V)		V	
Effective hop length L_e	km	10.4	19.2
UNAVAILABILITY	(%)	7.0E-03	NEGLIG.

TYPICAL OPTICAL CALCULATIONS

These examples are based on the numerical values given in Section 6.1.4.

Overall attenuation on one-way connection between optical transmitter and receiver is the difference of couples (launched) power and receiver sensitivity. For practical specifications, the overall attenuation is normally divided into several components:

Attenuation of the fibre, attenuation of splices, attenuation of connectors, cable margin and equipment margin. Cable margin covers allowances for future modifications to the cable configuration (additional splices, increased cable lengths) and fibre cable performance variations due to environmental factors.

Equipment margin covers allowances for the effect of time and environmental factors on equipment performance (launched power, receiver sensitivity, equipment connector degradations).

Attenuation reserved for the cable is the overall attenuation minus equipment margin. CCITT has given some values for the cable attenuation in Rec. G.956. Cable attenuation consists mainly of the attenuation of the fibre and splices and of cable margin.

Some numerical examples are calculated in the following examples. These calculations are fairly conservative and in practical terms better values are probable. The limitations caused by other phenomena than attenuation are not taken into account.

The following parameters are used in the following examples below:

- equipment margin 13 dB
- attenuation of a splice 0.3 dB
- length of a cable section 2km
- cable margin 6 dB

Allowed attenuation of the cable is then the launched power minus receiver sensitivity minus equipment margin minus cable margin. For convenience, the attenuation of splices is divided per kilometer (0.15 dB/km).

<u>2 Mbit/s system:</u>

- multimode
- 850 nm
- LED transmitter

Launched power -10 dBm
Receiver sensitivity -51 dBm
Attenuation of the fibre 3 dB/km

Allowed attenuation for the cable is then
-10 dB + 51 dB - 13 dB - 6 dB = 22 dB

Maximum length is
22 dB/3.15 dB/km = 7km

<u>8 Mbit/s system:</u>

- multimode
- 1300 nm
- Laser transmitter

Launched power 3 dBm
Receiver sensitivity -45 dBm
Attenuation of the fibre 1.5 dB/km

Allowed attenuation for the cable is then
3 dB + 45 dB - 13 dB - 6 dB = 29 dB

Maximum length is
29 dB/1.65 dB/km = 17km

<u>34 Mbit/s system</u>

- single mode
- 1300 nm
- Laser transmitter

Launched power 0 dBm
Receiver sensitivity -45 dBm
Attenuation of the fibre 0.7 dB/km

Allowed attenuation for the cable is then
0 dB + 45 dB - 13 dB - 6 dB = 26 dB

Maximum length is
26 dB/0.85 dB/km = 31km

<u>140 Mbit/s system:</u>

- single mode
- 1550 nm
- Laser transmitter

Launched power 0 dB
Receiver sensitivity -45 dBm
Attenuation of the fibre 0.4 dB/km

Allowed attenuation for the cable is then
0 dB + 45 dB - 13 dB - 6 dB = 26 dB

Maximum length is
26 dB/0.55 dB/km = 47km

EXAMPLE OF SATELLITE LINK PERFORMANCE CALCULATION (SEE SECTION 6)

Link Specification

2 Mbit/sec digital link from Sydney (Australia) to Adelaide (Australia) via the Australian National Satellite - AUSSAT 1, with a bit error ratio of better than 10^{-6} for an availability of 99.9%.

Assume QPSK modulation and adopt a Forward Error Correction Rate of 1/2.

General Design

The circuit design is a noise power limited design with the Uplink and Downlink paths calculated separately. The total path budget is calculated initially for Clear Sky conditions and then repeated for Uplink and Downlink rain attenuation fade conditions to assess availability.

Once the target performance has been specified the only parameters that can be changed are the antenna sizes (and hence gain) of the transmitting and receiving ground station antennas, and the transmit power of the ground transmitting station.

'Clear Sky' link design

i) Uplink path

$$C_R = P_E - L_{UP} - L_{UR} + G$$

Where C_R = RF Carrier Power received at the satellite
P_E = Earth transmitting station EIRP
L_{UP} = Uplink path loss
L_{UR} = Uplink rain attenuation loss
G = Satellite receiving antenna gain

$$N_T = K_B + T + B_C$$

Where N_T = RF thermal noise power
K_B = Boltzman's Constant
T = System temperature
B_C = Occupied Bandwidth

Thus C/N (Thermal for the Uplink) =

$$P_E - L_{UP} - L_{UR} + G - K_B - T - B_C$$

or expressing G and T as a ratio

$$C/N = P_E - L_{UP} - L_{UR} + G/T - K_B - B_R$$

P_E : Choice of an assumed 4.6m antenna providing 74 dBw EIRP

L_{UP}: Free space path loss (refer CCIR rec. 525) and Clear Sky atmospheric loss (refer CCIR Report 719) are both dependent on path length and elevation angle (for this example 37 060km and 50.3° respectively). Resulting value: 205.8 dB.

L_{UR}: 0 for Clear Sky conditions

G/T : Site location dependent. Published by satellite operator in contour map form: +1.60 dB.

K_B : -228.60 dB/°K.Hz

B_C : $B_C = K_F \times R_S$

Where K_F = 1 filter factor (1.4)

R_S = Symbol rate

$$R_S = \frac{R_I}{E_F \times B/S}$$

Where R_I = information bit rate (2.048 Mbit/s)

E_F = forward error correction (1/2)

B/S = Bit/Symbol which for QPSK = $\log_2 4 = 2$

$$B_C = 1.4 \times \frac{2.048 \times 10^6}{1/2 \times 2} = 2.87 \text{ MHz}$$

$= 64.57$ dB

C/N = $74.0 - 205.8 - 0 + 1.60 - (-228.60) - 64.57$

thus Thermal Uplink C/N = 33.83 dB...............a)

C/I (The Uplink RF carrier to RF interference noise ratio) is dependent on interference received at the satellite and can be advised by the satellite operator.

For this link: 21.90 dB...............b)

ii) Downlink path

$$C/N = P_{SS} - P_B - L_{DP} - L_{DR} + G/T - K_B - B_R$$

P_{SS} : Saturated satellite EIRP: 37.00 dBW

P_B : Output power back-off to allow for multi system mixing: set at 12.33 dB

L_{DP} : 206.90 dB

L_{DR} : 0 for clear sky case

G/T : Earth station G/T = 27.15 dB

$C/N = 37.00 - 12.33 -206.90 - 0 + 27.15 - (-228.60) - 64.57$

thus Thermal downlink C/N = 8.95 dB.............c)

C/I = (the downlink RF carrier to RF interference noise ratio includes cross polar and adjacent satellite interference)

For this link: 27.60 dB..............d)

C/I_M (the downlink RF carrier to RF intermodulation ratio)

For this link: 19.00 dB..............e)

iii) Total link budget

$$R_T = \frac{1}{\frac{1}{R_a} + \frac{1}{R_b} + \frac{1}{R_c} + \frac{1}{R_d} + \frac{1}{R_e}}$$

where R = the C/N, C/I and C/I_M values expressed in ratio

$$R_T = \frac{1}{\frac{1}{2415.5} + \frac{1}{154.9} + \frac{1}{7.85} + \frac{1}{575.4} + \frac{1}{79.4}}$$

Thus the Total equivalent C/N = <u>6.72 dB</u>

iv) Value assessment

The relationship between BER and Carrier/Noise ratio is modem dependent, and modem suppliers typically provide graphical information of BER v Carrier to Noise density ratio (C/N_O)

By applying $C/N_O = C/N + B_N$

where B_N (noise bandwidth) = $K_{F1} \times R_S$

where K_{F1} = Nyquist filter fact (1.14)

$C/N_O - 6.72 + 10 \log (1.14 \times 2.048 \times 10^6)$

$= 6.72 + 63.68$

$= 70.4$ dB

an assessment can be made of the adequacy of the circuit.

In practice the calculation is often made in reverse, taking this value and working backwards to find the required earth station transmitter EIRP which can be adjusted to meet the need by choice of antenna size and transmitter power module.

Availability

i) Downlink faded with rain attenuation

The link budget calculation is repeated with the uplink unchanged. A loss, dependent on site information on rain attenuation for 0.1% of time, is introduced as term L_{DR} (or for any other % of time if the availability demands are different). The earth station G/T ratio is also affected by the rain and typical values for this link are:

L_{DR} = 3.10 dB G/T = 25.19 dB

Recalculation shows Total Equivalent C/N = 3.65 dB........f)

ii) Uplink faded with rain attenuation

The link budget calculation is repeated with a value entered for L_{UR} (typically for this path: 4.20 dB).

This directly affects the uplink thermal C/N and also the uplink C/I.

It is then necessary to consider an additional power back off on the downlink = L_{UR} and the resultant power back off reduces the C/I and C/I_M downlink values by this amount.

Naturally the rain does not affect the satellite G/T ratio.

Recalculation shows Total Equivalent C/N = 4.09 dB........g)

Final Analysis

Values f) and g) must then be compared with the BER for the likely outage times and identify if this meets the availability criteria.

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