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**The influence of local loop characteristics on services in
intelligent networks**

Ramkumar, Vasant Chandkumar, Ph.D.

City University of New York, 1991

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A

**THE INFLUENCE OF LOCAL LOOP CHARACTERISTICS ON
SERVICES IN INTELLIGENT NETWORKS**

by

VASANT C. RAMKUMAR

A dissertation submitted to the Graduate Faculty
in Computer Science in partial fulfillment of the
requirements for the degree of Doctor of
Philosophy, The City University of New York.

1991

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Abstract**THE INFLUENCE OF LOCAL LOOP CHARACTERISTICS ON SERVICES IN INTELLIGENT NETWORK**

by

Vasant C. Ramkumar

Adviser: Professor Syed Ahamed

Intelligent Networks (IN) are becoming increasingly attractive because of the services they can provide beyond the audio frequency communication now available within the "Plain Old Telephone Network (POTS)." The planning and designing of data networks in the past decade has prompted further study of the detailed network architecture. Design aspects of Intelligent Networks have become specific during the past few years.

There is need to address, design, and create standards for call processing that are supported by an open architecture. Today's switch architecture uses channel units for the line equalization function on the incoming lines and trunks from the Public Switched Telephone Network. This information is forwarded into the proposed Intelligent Networks. Such architectures inherit constraints that limit the adaptability of the switch. Different environments open new problems for the network functions. Any change in application and/or environment results in a hardware modification that is expensive. More often the remodification continues to inherent constraints in future developments.

In this dissertation, it is shown that the introduction of a processor which can be programmed to accommodate environmental changes, such as line dispersions and delays, is needed. Such a design provides an inexpensive way to make modifications to the system to adapt to different line and signaling conditions.

The studies are concentrated on the European Network environment and in specific, the British Telecommunication network. The major conclusions from this dissertation have been characterized in three distinct directions. The findings presented here are novel and yet unpublished for the European ISDN or Intelligent Networks. First, the physical, electrical, and transmission properties of the loops surveyed from the British Telecom environment are presented. Second, the capabilities of the loops surveyed from the areas of Britain to carry basic rate and primary rate ISDN data are investigated at different rates with various echo cancelers. The effects of changing the bit rates are also investigated. Individual loops that are categorized as the outlayers from the survey are studied further for their response to AMI and 2B1Q codes. Third, the software changes to the simulation model for the study of High Speed Digital Subscriber Line for carrying out the major simulations are also reported in this dissertation.

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CHAPTER 1

INTRODUCTION

Intelligent Networks (IN) are becoming increasingly attractive because of the services they can provide beyond the audio frequency communication now available within the "Plain Old Telephone Network (POTS)." The planning and designing of data networks in the past decade has prompted further study of the detailed network architecture. Design aspects of Intelligent Networks have become specific during the past few years. My work assignments in this area have led me to draw enormous knowledge from my own experiences as well as from the experiences of others to substantiate the need for, and to choose this topic for my proposed dissertation under the guidance of Professor S. V. Ahamed.

There is need to address, design, and create standards for call processing that are supported by an open architecture. Today's switch architecture uses channel units for the line equalization function on the incoming lines and trunks from the Public Switched Telephone Network. This information is forwarded into the proposed Intelligent Networks. Such architectures inherit constraints that limit the adaptability of the switch. Different environments open new problems for the network functions. Any change in application and/or environment results in a hardware modification that is expensive. More often the remodification continues to inherent constraints in future developments.

In this dissertation, it is shown that the introduction of a processor which can be programmed to accommodate environmental changes, such as line dispersions and delays, is needed. Such a design provides an inexpensive way to make modifications to the system to adapt to different line and signaling conditions. It is also foreseen to be modular and support the open architecture environment.

The work discussed, in this dissertation, has practical applications in future architectures of the evolving Intelligent Network. The adaptation of the theories that are addressed will lead to reduce the cost and to increase the efficiency of the call processing environment in the Intelligent Network.

It is shown that a line unit which is adaptive to conform to different line and signaling conditions is necessary. An architecture is presented where the line

unit is a functional component of the Intelligent Network node and links. The studies are concentrated on the European Network environment and in specific, the British Telecommunication network. The cables, used in the network, electrical characteristics are presented. Simulation studies of the transmission behavior under different line conditions are discussed. The simulations include; transmitting at different bit rates, using different encoding schemes (AMI, 2B1Q), and varying the signal recovery components of the system such as, line equalizers.

The need for the unit to be easily adaptable to a changing environment is shown. Its programmable functionality in establishing channel capacity and range in providing Intelligent Network services and, its modularity permitting easy development for adaptation to network evolution changes are discussed.

Chapter 2 contains a historical overview, and details on the evolution of the Intelligent Network. The components of an Intelligent Network and their functions in providing network services are explained at a high level to give the reader a quick tutorial on Intelligent Networks. The distinction between the IN and the POTS network becomes clear as the reader is introduced to the benefits of IN. Technological evolution in the "high tech" industry has driven manufacturers to adopt different methods to provide more services with better quality. Researchers have led us through a series of events over the years since the introduction of stored program control applications in networks, to exploit the vast potential for maximizing the utilization of resources used in a network to provide a service. The different views held by AT&T, RBOC, and the European PTTs are examined. The various terminology associated with the IN and the unification of the IN concepts are discussed. The material in this chapter helps the reader to follow the IN theories, concepts and acronyms in subsequent chapters.

Chapter 3 outlines the Intelligent Networks in the field today namely, AT&T's IN in the USA, the Digital Derived Services Network in the UK, Telefonica's Intelligent Network in Spain, and SIP's Intelligent Network in Italy. The services provided by these networks are defined. The architectures and signalling systems used to provide the services are also described. The United Kingdom can be considered to be one of the most advanced countries in Europe in the application of new technology to the various

sectors of the economy. Modernizing their communications network to provide a wide range of services is only one of the many goals. The objective of the Intelligent Network deployed in the UK is consistent with that goal. This chapter went into depth describing the IN implementation in the UK. Spain and Italy, also with similar goals, are expected to have their IN initial phases fully deployed in the early 1990s. The IN implementation in these countries are also described in depth. The difficulties in implementing INs in environments that differ in standards, topology, interfaces, services that are in demand, etc. are left to the readers perspectives. These networks must communicate with existing national and international networks.

Chapter 4 describes the simulator used in the studies of the digital network environment in the UK. The need for simulation studies is emphasised as an important planning step for all PTT's in their deployment of intelligent services via the use of INs. The database organization of the simulator and the processes for the frequency and time domain results, as well as the processes for the equalizer and echo canceler designs are discussed. A discussion on the simulation of different line codes used in the local loop environment helps the reader to follow the simulation results that are presented in the later chapters. The Computer Aided Design (CAD) facilities have proven not only to be an effective planning vehicle for deploying the IN and its services but also, it results in time and cost savings in the deployment process. Time and cost are two key elements to the success of any attempt to meet customer needs.

Chapter 5 discusses the UK local loop environment. The physical and electrical characteristics of the local loops are discussed. In this chapter the sample of the UK local loop environment becomes the basic fabric from which all the experimental study results are derived. The simulation runs produce an enormous amount of data from which detail design aspects of the network can be analyzed. Through a series of comprehensive analytical steps, the results are categorized and the major conclusions are determined. The frequency domain results from the simulation are examined and presented with graphical illustrations from the simulation output. The graphical simulation outputs becomes the basis to explore further design aspects of the network and its services with reference to limitations, performance, and functionality.

Chapter 6 uses eye diagrams and scatter plots to show the quality of digital transmission in the UK local loops. The transmission characteristics are discussed with vivid illustrations using graphical displays from the simulator. Line codes (AMI and 2B1Q) are used to show the variances in the transmission parameters. The entire loop population sample is studied with the intention to generalize the characteristics of the entire loop population. Individual loops are studied to test for best and worst case scenarios. The individual loop studied, help to establish the constraints within which the network can operate to satisfy its initial goals (quality and wide range of intelligent services).

Chapter 7 reviews the functions of equalizers and echo cancelers in transmission circuits. The necessary echo canceler and equalizer for the UK requirements are discussed using the results from the simulator. Given the current network, what are the requirements that when satisfied the modernization goals will be met. An over equipped or an under dimensioned network can both fail to satisfy the basic objective set out to be accomplished. In this chapter it is shown how the simulator can be used to simulate the data transmission capability of the entire network in an office, and to be able to predict the pitfalls before the actual network is implemented.

The major conclusions of the simulation studies, with an insight into how well the current UK local loop environment performs in the ISDN environment, are discussed. The contributions of this work is summarized with recommended future studies. This work is of great importance to those dedicated to the successful deployment of the IN and its services in Europe.

A Glossary is enclosed to facilitate quick reference to abbreviations. The definitions of some commonly used terms in the IN field are given.

CHAPTER 2

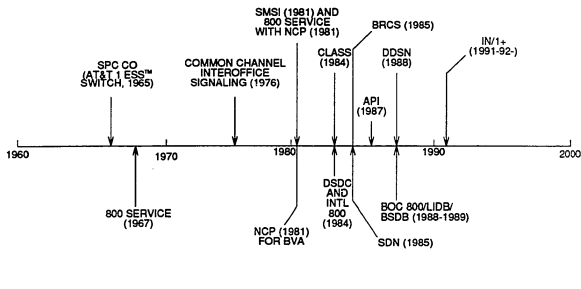
THE INTELLIGENT NETWORK

The Telecommunication Industry is now entering a new era. One that brings along changes, excitement, new services, new technologies and profitability. A new world of communications is emerging and is made possible by the dedication of manufacturers, telecommunications network operations, political bodies, standard committees, and most important, demands from customers for enhanced services over and above those services offered by the Plain Old Telephone Network.

Many researchers, network planners and manufacturers have made a great start. But, much is left to be done to transition the existing network and its services to the network of the future, "the Intelligent Network."

2.1 THE HISTORY OF INTELLIGENT NETWORKS

Intelligent networks are made possible through technological breakthroughs in Stored Program Control (SPC) [9]. The introduction of SPC concepts into the telephone networks brought with it new routing disciplines, overload controls, repeated call attempts, better fault diagnostics, etc. This resulted in controlling the critical behaviors of systems and networks designed with a naive extrapolation from current experiences [12].



API	= ATTACHED PROCESSOR INTERFACE	IN/1+	= INTELLIGENT NETWORK/1+
BOC 800	= BELL OPERATING COMPANY 800 SERVICE	LIDB	= LINE INFORMATION DATA BASE
BRCS	= BUSINESS RESIDENCE CUSTOM SERVICES	NCP	= NETWORK CONTROL POINT
BVA	= BILLING VALIDATION APPLICATION	PVN	= PRIVATE VIRTUAL NETWORK
CLASS	= CUSTOM LOCAL AREA SIGNALING SERVICES	PVN	= SOFTWARE DEFINED NETWORK
DDSN	= DIGITAL DERIVED SERVICES NETWORK	SMSI	= SIMPLIFIED MESSAGE SERVICE INTERFACE
DSDC	= DIRECT SERVICES DIALING CAPABILITIES	SPC CO	= STORED PROGRAM CONTROLLED CENTRAL OFFICE

FIGURE 2.1: TIME LINE FOR HISTORICAL MILESTONES

The time line in FIGURE 2.1 points out the major historical events that contributed to the evolution of the telephone network to a network that can provide intelligent services. Additional information is provided in section 2.1.2.

2.1.1 WHAT ARE INTELLIGENT NETWORKS.

Intelligent Networks are defined as collections of intelligent processors connected in a distributed computing environment, designed to carry information from one point to another. The intelligence of these processors is embedded in their hardware, software, and firmware. More specifically, intelligence resides in the customized integrated circuit chips, their intricate interconnections, and sophisticated layouts. Intelligence is microcoded as

firmware in the memories of the monitoring and signaling components. The distinct algorithmic adaptation that differentiates these networks from others is a result of some of their intelligence coded as programs that exists as software utilities and information modules (databases). The incorporation of mechanisms that allow the modification of system functions in real time, provide the capability for the network to adapt to changes in the processing environment. The network functions are dependent on the different components which include the switches (nodes) used to switch information from point "A" to point "B", the transmission facilities used to transport the information, and the databases that reside at different points in the network containing local and global intelligence. Through such mechanisms, Service Subscribers to the network can change their own environmental variables as often as they like. Such variables may include routing intelligence, customized announcements and various report profiles. Supporting systems used to interface with customers become an integral part of the Intelligent Network [13]. Through such systems, customers can control their own network resources in public networks. In general, it is a requirement of an Intelligent Network to be able to adapt in real time to dynamic changes of the environment. These changes include network overload, switching delays, and equipment failure.

The Intelligent Network can exist as an overlay network or as an integrated network with the existing Public Switched Telephone Network (PSTN). Intelligent Networks are Digital Networks but may consist of some analogue components [10]. By having an open architecture, one can set the stage to implement rules that ensure effective communication regardless of the environment in which the network is deployed or who the vendors may be. As such, there will be a common set of protocols that will be supported by an open architecture and provide for efficient communication among different vendor equipment. One way in which control information can flow in the open architecture environment is by using the Common Channel Signaling System No. 7 as defined by the International Telephone and Telegraph Consultative Committee (CCITT).

Transmission rates can range from 144 Kbps (2B+D) to 384 Kbps (5B+D) or even (23B+D) in the local loops for subscribers. Higher rates for T1 (30B+D) have not yet been verified in the Service Subscriber loop environment.

Higher bit rates also exist for some optical transmission facilities. Rates can be as high as 6 Gbps on fiber optic links between Central Offices. Switching and transmission facilities exist in all networks, but it is only in an Intelligent Network that the controlling mechanisms for the intelligent functions of the network dictate the architecture of such facilities.

The switches (nodes) to be used in the Intelligent Network environment will be the state of the art stored program control Service Switching Points (SSPs). These nodes perform a wider variety of sophisticated functions in comparison to the functions performed by the telephone or computer network. Nodes fall into one of four main categories,

- (a) nodes that serve as originating or terminating points (no through traffic),
- (b) intermediate nodes (only through traffic),
- (c) a combination of (a) and (b), and
- (d) nodes where numerous links meet to permit local and global exchange of channels.

The Intelligent Network nodes will have the capability to operate in an open architecture environment using a common protocol set. An open architecture environment permits a great degree of modularity in development, whereby the functions that these nodes execute can be enhanced easily and cheaply to offer new services [16].

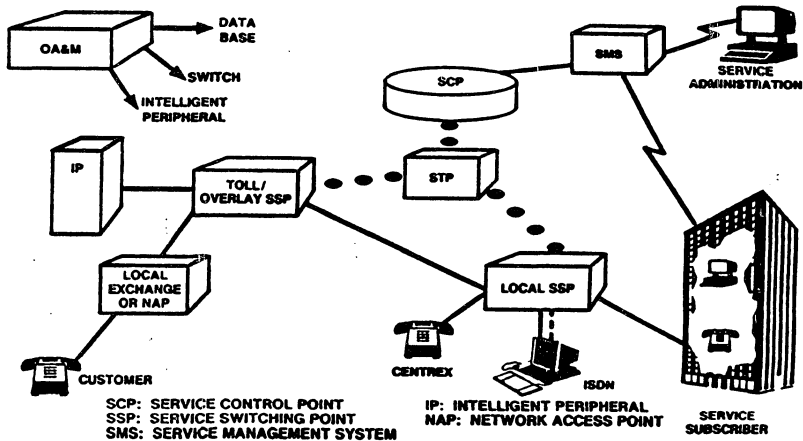


FIGURE 2.2: THE INTELLIGENT NETWORK COMPONENTS

FIGURE 2.2 shows the major components of the Intelligent Network; namely the Service Switching Point (SSP), the Service Control Point (SCP), the Service Management System (SMS), the Intelligent Peripheral (IP), and the Operations, Administration and Management System (OA&M). A brief description of these components are given below.

- **SERVICE SWITCHING POINT:**

The SSP is an access point into the Intelligent Network when Intelligent Network services are requested. The SSP may either process such requests and render the services desired if it has the appropriate intelligence to do so. Or, it may query other Intelligent Network components where the appropriate intelligence resides for further instructions to process the requests and to deliver the require services.

- **SERVICE CONTROL POINT:**

The SCP is the centralized database that contains call processing information for the various Service Subscribers. The SCP is easily accessible from the SMS for the update of customer information with respect to their services, and from the SSP for queries in the processing of the services requested by customers of the Service Subscribers.

- **SERVICE MANAGEMENT SYSTEM:**

The SMS allows the Service Subscribers to control their own resources in the Intelligent Network. Service Subscribers, communicating directly with the SMS, can design their own routing plans to maximize the flow of traffic to their locations that will terminate successfully by using the Intelligent Network features offered. Future work on SMS will allow Service Subscribers to create their own services using the network resources that are available.

- **INTELLIGENT PERIPHERAL:**

The IP provides enhanced services controlled by the SCP or the SSP. Typical IP functions are announcements, speech synthesizing, voice messaging, and speech recognition. These services are normally shared among the Service Subscribers.

- OPERATIONS, ADMINISTRATION, AND MANAGEMENT SYSTEM:

The OA&M system provides the functions necessary to manage and control the various network resources. It provides maintenance functions for the network elements, alarm processing, traffic data collection and processing, and network traffic management.

Specific information relating to various existing Intelligent Network components is discussed in [3]. Conceptual framework and architectural justification of specific networks are discussed in [1].

2.1.2 EVOLUTION OF THE INTELLIGENT NETWORK

In communication networks, the direction of intelligence is highly pointed towards being functional in real time with efficacy and optimality. To some extent, the most primitive telephone networks had these characteristics in their era. Human intelligence and discretion were freely supplemented to make and break the communication paths. Electromechanical and Stowger type systems, major innovations of their time, lacked the programmed intelligence.

The implementation of the first Electronic Switching System (#1ESS) with its Stored Program Control (SPC) in 1965 by AT&T brought conventional programmed intelligence (or simple programs) to the telephone network. The introduction of the 1ESS came in three phases. First was the introduction of the local office switching in 1965 in Succasunna, New Jersey. Second, was the implementation of the tandem switch capable of inter connecting numerous local offices in 1968 at Nashville, Tennessee. Third, the toll switch capable of reaching a wider toll area was introduced in 1971.

The next milestone was the introduction of Common Channel Interoffice Signalling (CCIS) in 1976. CCIS is a signalling protocol that is based on CCITT#6 recommendations for long distance communication. Tests of this signalling system took place on the #4ESS in Chicago, Illinois. CCIS facilitated the network to perform as a single information transfer entity and thus paved the way for making network services becoming independent [9].

The introduction of the national 800 service in the USA in 1967 and the international 800 service in 1984 led to a new era of providing enhanced

intelligent capabilities. In 1981, 800 service in the United States was enhanced by using a centralized networking architecture to provide 800 call routing information. The advanced 800 service was the first member in the set of services provided by this second generation of data base based intelligent network services. Telecommunication managers have predicted that the Intelligent Network of the 1990's will be based only on digital transmission and fiber optics. Integrated voice, data, and full motion video will become available to business and residential customers.

In 1984, a trial began on a new set of intelligent network services with the Harrisburg, Pennsylvania installation of Custom Local Area Signalling Services (CLASS) capabilities in 1AESS® switches. CLASS represents the first common channel signalling-based use of intelligent networks in the local exchange network in the United States.

One of the key functions of the intelligent network also took place in 1984. The custom local area signaling services (CLASS) actually perform the intelligent functions in the SPC based #1ESS central offices by being able to select/reject calls, auto recall or callback services, etc. Once again, the CCIS capability to relay the called party and the caller information was used by programs stored in the central offices to force intelligent network response. Call related information could be exchanged between central offices via the CCIS 6 extended message capabilities, thus providing an automatic number identification (ANI) feature between switches.

In 1985, AT&T began to offer the Software Defined Network (SDN) services. SDN allows private network users to make use of AT&T's switched network facilities while maintaining many of the features in their private network. SDN by itself is a private virtual network. The software defined network service (SDNS) introduced permitted many private network owners to take advantage of the more dramatic advances taking place in the switched network operations, yet be able to keep the advantage of their private network. The virtual network defined by software commands permits private network owners, such as corporations, to use their own network in virtual cooperation with the switched public network.

Also in 1985, the Business/Residence Custom Services (BRCS), was offered and was the first attempt to introduce the concept of service independence

from switching facilities. The business and/or residence custom services introduced permitted users to use the generic programs embedded in the central office. With access, and the option to exercise these powerful central office routines (like computer system utility routines with appropriate input data), the customer was provided with centrex, custom calling, and electronic tandem switching capabilities.

The growth of preconceived algorithmic intelligence into communication network fields has been steady. Numerous developments in other directions such as billing and authorization also facilitated the newly enhanced intelligent functions to be commercially viable. While the network may functionally respond to signals and codes forwarded by the central offices and users, the collection of tolls and revenues for the service provided is also crucial. To facilitate this aspect, the validation of billing information was provided by authorization in the database administration systems distributed within the network. This facility, initially introduced for the 800 calls in 1981, also paved the way for other services such as calling card services. The human (operator) intelligence in handling the queries and call processing was gradually replaced by the software programs. These programs queried the distributed databases for authorization to connect and process calls by algorithmically decoding the long strings of digits to the called numbers through the networks.

The concept of call routing was introduced as far back as 1981. The CCIS 6 provided the 800 service facility to respond to these calls by matching the location of the user to the nearest or the most logical service provider. Intermediate data bases to provide the routing information were distributed throughout the network. Thus the functions of obtaining the appropriate authorization, call routing, switching, and billing were all streamlined into one programmed network operation.

The introduction of Common Channel Signaling System No. 7 (CCS 7) by CCITT permitted the eventual integration of the numerous facilities under one common conceptual and architectural umbrella. By and large, CCS 7 becomes the central focus in streamlining the flow of information between three basic modules, SCP (Service Control Point), SSP (Service Switching Point), and the TAO (Tandem Access Office) of most Intelligent Networks. First, various SCPs are deployed to assist the SSPs through a

query/response process to carry out functions such as routing control, digit collection, billing and recording, and network management commands. The SCP data base contains a wide variety of network service information. Typical examples of the data bases are line information data base, Bell Operating Company 800 data base, and business services data base. Second, the various SSPs which provide basic access and switching facility within the network, also communicate with the CCS 7 network. The SSPs respond in completing the original command from the switch or the new commands after querying the data base. Third, the TAOs provide the exchange of (data base, network and/or service) information to distant locations via interexchange carriers.

It is to be appreciated that this architecture of the new breed of intelligent networks makes the provision of service totally independent of the type of service being provided. The transport of relevant information is the prime objective of ingrained network intelligence. Most of these features are incorporated in the Intelligent Network to be initiated in the early 1990s.

The 800 services network represents the first generation of a public domain network. Being functional and well received in the public domain it provides the three basic features of most INs. First, stored program control of switches is used to provide a software controlled environment. Second, the interoffice signaling is accomplished by common channel signaling system (CCIS 6 and/or 7). Third, some of the service independent features (such as transfer of control, connection control, etc.) can be, or have been incorporated. Compared to the potential and capabilities (as they are understood in the late 80s) of these networks, the 800 services is truly a first generation IN. Architecturally, the 800 network gives users the building blocks that make networks truly flexible and intelligent [11,14].

In February 1985, AT&T announced its vision of the future, the Universal Information Services (UIS). UIS will have the ability to provide a combination of voice, image, and video. Most of the features in the IN, such as Private Virtual Networks (PVN), 911 public emergency service, Automatic Calling Card (ACC), and 900 services eg., televoting, can be included in the UIS. The user's need for critical, accurate, and quick access to information to enhanced productivity are addressed in the design of the network. The UIS Enriched Serviced Tier, an essential tier in the overall UIS architecture,

defines a distributed intelligent architecture, an intelligent network, which is an evolution of previous distributed intelligence. The current IN architectures proposed by the Regional Bell operating companies and conducive to the evolution of UIS concepts closely parallels the IN/1, IN/1+, and IN/2 concepts.

Advances in IN technology are occurring rapidly. These include SPC control and digital switching, Common Channel Signalling, ISDN, Broadband ISDN, and SONET standards. Customers are aggressively exploiting new capabilities such as large private data networks, special purpose information networks, etc. Regulatory environments are also changing globally so as not to hinder development but rather control the explosion. Privatization and deregulation in the US, Germany, UK, and other European countries will naturally encourage a more speedy evolution process.

However, the major changes that are emerging are in the fiber networks. Fiber can enhance the data rate by two or three orders of magnitude. The control and the programmed logic for switching, interfacing, protocol, error control, etc., may be retained at the inception of fibers in public networks. The emergence of fiberonics may eventually facilitate entirely new networks and switches for a distant tomorrow. But in the near term the silicon technology provides all the tools for the INs of tomorrow.

2.2 THE DIFFERENT PERSPECTIVES ON INTELLIGENT NETWORKS

2.2.1 AT&T'S VIEW

AT&T is evolving its Intelligent Network in synergy with the needs of other PTTs. AT&T recognizes the need for International Standards coexisting with national implementations. In the Intelligent Network/1+, the use of intelligent peripherals to interface the intelligent networks of the American Regional Holding Companies and/or other intelligent nodes is provisioned. Service independence, faster feature introduction, and standard node interfaces at various switching centers will also be in operation during early 1990s.

The Universal Information Service/Intelligent Network 2 (UIS/IN-2) is proposed for implementation in the mid 1990s [1]. Voice, visual, and computer data transportation is the ultimate goal of this network. Independence from the origin and destination and the timing of information is an objective of this network. The implementation of this policy permits

interfacing with any third party vendor/user node characterized as Off-Network Node (ONN). In an effort to provide enriched services to the customers, most intelligent peripherals, tandem access offices, and SCPs for IN/2 will be able to function in a service creation environment in which services, concepts, and offerings may be quickly and easily tested before fully introducing them in the market place. The philosophy of UIS is to encourage and support Enriched Service Subscribers via an architecture that accommodates their needs. AT&T sees ISDN as a primary stage in the evolution to the Universal Information Services.

Localized network control information can be derived for the user (provided the authorization exists) or the network management programs. This permits the use of software defined network functions and configurations. Such services become extremely feasible, and could be made for short duration and immediately available. The AT&T IN supports distributed access to IN nodes. This distributed network access along with network management controls supplied by the IN prevent the PSTN from experiencing congestion that may due to IN traffic concentration on a single node.

AT&T expects to remain in the forefront (the leader) of IN evolution by providing a comprehensive evolution plan that encompasses services, architecture, products, standards, and customer support [10]. AT&T's current IN implementation is service independent. Many of the services currently provided use common reusable "service features." AT&T is working in synergy with other organizations such as Bellcore Multi-Vendor Interaction (MVI), ETSI, and CCITT to evolve the IN and its functions. In the USA, AT&T is working with Bellcore MVI to address many IN issues with reference to its evolution. In Europe, AT&T is actively participating through its European affiliates in ETSI IN forums to achieve a common IN solution. AT&T is also participating in CCITT study groups.

2.2.2 THE US BELL OPERATING COMPANY'S VIEW

It is important to note that the prolonged divestiture of the Bell System (1982 through 1984) was effective during the prime evolutionary period (1980 through now) of the intelligent networks. Hence the origin of the seminal concepts can be traced back to the predivestiture Bell System of the early eighties. Some of the techniques specifically evolved towards bringing the

newer services to the local telephone customers. Such facilities and plans correctly fell under the jurisdiction of the Regional Bell Operating Companies (RBOCs) and implemented at the Region's level. Some of these services were introduced by the individual RBOCs. The concepts leading to refined intelligent networks to serve the RBOCs evolved at Bellcore (Bell Communications Research). It is here that the concepts leading towards Intelligent Network/1 (IN/1), Intelligent Network/1+ (IN/1+), and Intelligent Network/2 (IN/2) were developed.

IN/1+ objectives are summarized as supporting full service independence, facilitating faster feature introduction, and implementing standard interfaces among nodes supplied by various vendors. IN/1+ promotes the concept of Functional Components (FC) intended to give greater control over call connection actions at the switch. IN/1+ goes beyond IN/1 by introducing the concept of the Service Logic Interpreter (SLI) located in the SCP and whose function is to interpret Service Logic Programs (SLP).

IN/2 goes beyond IN/1+ in a number of important ways. The Off Network Node (ONN), an intelligent node belonging to a third party, is an explicit part of the architecture. The ONN is expected to perform similar types of functions as the IP. IN/2 architecture supports the concept of placing intelligence and service logic anywhere in the network where it is optimal.

The 800 network uses Service Control Point, SCP/1 (the /1 indicates that it refers to IN/1 for all the building blocks) extensively. The SCP architecture and data may be duplicated throughout the country. The data is managed and maintained by a single Service Management System (SMS/1). Since the features of the 900 network are not completely evolved throughout the country, the SMS/1 can be used to control one or several SCP's. Updates and modifications can be carried out using simple protocols for the SCPs.

Alternate billing service (ABS) and private virtual network (PVN) are additional IN features evolved for the RBOCs. These networks and their specialized features make newer services available more quickly, more economically, and on a more customized basis. The incorporation of INs into the switching environment, together with ISDN in the customer and business environments has made IN services available to the network users, more realizable.

2.2.3 THE EUROPEAN PTT'S VIEW

The need for a modular, low-startup cost and a growable, high performance system meeting international standards is a view that many PTTs hold in Europe. The European PTTs view of the IN closely follow the Bellcore IN/1, IN/1+, and IN/2 models. Vendors whose products follow an evolution strategy consistent with the modernization plans of the various countries in Europe are most likely to be chosen as a supplier of telecommunication products to that country.

With the evolution of telecommunication technologies and the sophistication of large business customers and their end-users, the Public Telephone and Telegraph companies in Europe are faced with the challenge of meeting their customer needs in a timely and cost-effective evolution plan. There is great need to implement new techniques in digital transmission and switching in a multivendor environment. The need for standards as part of the IN solution and a consolidated common understanding and agreement to implement what is applicable worldwide is being sought. The need for standardizing functional components among IN manufacturers, and the need for standard interfaces, protocols, and service definitions are high on the priority list. European PTTs are interested in new services, customized services, switch services, and adjunct services offering. Their needs can be summarized as:

1. Modular, low-startup cost, growable, and high performance network.
2. Customer programmability
3. Standard interfaces and protocols (hardware and software)
4. Ability to connect to any network worldwide
5. Unique services to have the market edge
6. Integrated subscriber local/toll/IN functionality
7. Network management tools
8. Human interfaces.

European PTTs are faced with the decision of implementing an integrated IN with their basic telecommunications network infrastructure, or an overlay

network, in the initial effort to provide IN services without a major restructuring of their existing facilities. They see the IN as a necessary vehicle to offer both new services and new features for existing services to their customers [12]. A flexible and robust architecture taking advantage of new technologies in the areas of photonics, microelectronics, microcomputers, distributed software, and networking is becoming an obsession with most PTTs.

The PTTs seek opportunities to increase their revenue potential by providing services tailored to satisfy individual market segments. They want rapid service introduction in the network without upgrading individual exchanges. The cost of introducing such services must be relatively inexpensive. The first category of service is requested at rates of up to 64 Kbps. The services part of ISDN are still very theoretical, and yet to be proven in the field. Thus, the European PTTs are proceeding with caution and are carefully choosing those services that are likely to succeed from the start, both technically and economically. In their IN implementation strategy they try to answer the questions: What type of services are to be provided? What is the given network configuration? What is the required access capability? Answers to such questions become a part of their evolution strategy.

2.3 TERMINOLOGY

It must be noted that the phased introduction of INs in the 1990s needs considerable standardization and uniformity. The definitions as they exist today tend to remain restricted to the network designers for building the networks rather than being global by considering networks from both the designers' and the users' point of view.

AT&T, being the first IN vendor, referred to the intelligent node as A**CT**ion Point (ACP), the centralized data base as Network Control Point (NCP), the system used to interface with a Service Subscriber has been referred to as the NETwork Subscriber Transaction, Administration and Recording (NETSTAR) system, the system used for the management and operations of the IN has been named MFOS (MultiFunctional Operations System) and the Network Services Comple**X** (NSCX). These systems are defined in Chapter 3, and are synonymous with the names and definitions used by other vendors such as Bellcore, (SSP, SCP, SMS, NMS and IP respectively) which have

been defined earlier in this chapter.

2.4 UNIFICATION OF THE CONCEPTS

The system and architectural proposal for the future INs are not dependent on any major technical breakthroughs. The OSI concept and the detailed CCITT recommendations are adequate and clear to implement the IN functions with the present day technology. The features of the public domain networks are being offered individually by numerous operating companies. Other private networks already have many advanced features.

Network intelligence is distributed. Hence, any end office, tandem access office, SSP, or SCP can communicate with the other. However, in seeking and accessing the information, certain algorithms and optimality are desired. Network configurations and the facilities of each switch, office, or access point defines the immediate step that the network will follow. To this extent, the network responds like a computer system. The hardware for processing, storage, and I/O ports are configured into local operating systems. The system then responds within the hardware and software constraints of that particular system. Networks being far more distributed, resourceful, and user friendly need local and global switches, data bases, and control systems to work in unison and cooperation. In addition to the usual communication functions that the networks need to accomplish, these services also performed the specific task of translating user requests for services and connections to network commands by accessing a network control point embedded within the network itself. Thus, more and more of the functions were being automated and programmed bringing the conventional intelligence or adaptability to the network. The user's need for critical, accurate, and quick access information to enhance productivity are addressed in the design of the network.

The current architectures proposed by the Regional Bell Operating Companies are conducive to the evolution of the UIS concepts. The RBOC's initial goal is to operate effectively within the regions and to work cooperatively with the surrounding regions to enhance the long distance transportation services provided by the various information carriers. The transport services that utilize a vast variety of media to communicate information will be enhanced by UIS. Integration of digital services as it is

evolving with the ISDN will interface with the various intelligent networks by virtue of the more widely accepted Common Channel Interoffice Signaling System (CCISS 7) and via the ISDN Q.931 protocol virtually in place in the various networks.

Service Switching Point (SSP) and Service Creation Environment (SCE) work together at the Universal Services Nodes (USN) within the UIS network. The transport service of the UIS network are monitored by the enriched service layer derived by the coordinated functions of SSP and SCE. Typically the USN would contain the Service Transfer Point (STP), the Service Control Point (SCP), and Service Management Systems (SMS) and work in conjunction with any other Intelligent Peripheral (IP) or the Off-Network Nodes (ONN) as they exist within the framework of the intelligent networks proposed by the RBOCs.

The main direct benefit of ISDN for a network subscriber stems from the unification of investments and operations and maintenance costs for increasingly diverse multiple services. At the same time, a single access line with one bill for all services, and rapid response to all complaints will radically improve the network providers image among users.

Ideas being abstract can only be conceived by the imagination of models derived from reality. The demand in the number and quality of services expected from the network place increased demands upon its capacity to carry more information accurately over longer distances. The functional requirements of the networks places certain stringent demands on the components, algorithms and interconnections. The network functions have to be adaptive, intelligent and command language dependent. The unification of the requirements, components, and adaptation can be most easily achieved in a computer like environment; thus, forcing networks to look like distributed processor computer systems spanning the entire globe.

Since the network functions are becoming more complex, the signalling is also becoming more elegant, efficient, and standardized. More recently the concept of using "out-of-band" signalling has gained wider acceptance and the CCITT recommended Common Channel Signalling System 7 (CCSS7) has been used in most national and international environments. The term common channel refers to the fact that one channel (the D channel) may be

used to carry signalling code of other associated data carrying channels (B channels).

Each country has different billing/charging requirements, signalling (national version of CCITT No. 7), numbering plans, network traffic management and human interfaces. All these differences must be addressed in a global IN.

2.5 SUMMARY

Public Telephone networks around the world are slowly evolving to acquire intelligence. There are three major milestones in this evolutionary path; first, the concept of Stored Program Control introduced by AT&T for local switching in the United States. Second, digital technology evolved to produce the first Electronic Switching System in 1965 for local offices. Third, the ESS facilities developed and applied to tandem switching in 1968 and Toll switching in 1971.

The concept of using one channel to carry control code gave birth to Common Channel Signalling (CCS). Total network control is accomplished by CCS. These highly defined and structured signals flow to and from customers and network elements, such as end offices, central offices, and remote terminals. If one perceives the network as a system of components intelligently monitored for exchanging information and data, then it is possible to classify their functional requirements. The optimality, accuracy and dependability of the functions are embedded in the algorithms used to code the software to control and direct these networks. Improved algorithms and enhanced hardware to implement them are routinely invented due to conceptual breakthroughs and changes in the technology. It is then necessary to incorporate these innovations in the overall framework of providing network intelligence.

Switching functions and the intelligence associated with these functions form a major part of the network operations. The four essential building blocks of any IN are, the interface for the flow of information in and out of the network, the monitoring computers, the switching systems, and the associated transmission facilities.

IN performs in three distinct directions.

1. They actively interface with the users by processing information to respond to the queries and commands of the user.
2. They actively monitor themselves and dispatch control information for the accurate and dependable functioning of the rest of the network.
3. They adapt and fulfill the switching and transmission requirements to convey information from its source to its destination.

IN intelligence can be grouped into its information processing aspects, its monitoring and control aspects, and its switching and transmission aspects. The functional organization of an IN can be classified as:

- (a) user interface functions
- (b) Internal functioning of the network (eg. call processing)
- (c) the handling and transportation of the data over the network.

The need for intelligence in networks has been recognized, and such intelligence is being actively brought into the network environment. The migration of concepts and algorithms is presently underway from the computer field, optoelectronics, circuit, and system sciences. It is interesting to note that the migration was in the opposite direction from electrical network theory while computers were in their infancy. The growth of these Intelligent Networks appears as imminent as the wafer level integration in the semiconductor industry. In fact, all the technological roads lead to the expansion and excellence in the communication industry.

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CHAPTER 3

INTELLIGENT NETWORKS IN THE FIELD

In recent years many telephone administrations and telecommunication vendors have sought a technology that allows them to modernize their network thereby introducing advance services without much disturbance to their existing facilities and services. The Bell operating companies (RBOC) in the United States, British Telecom (BT) in the United Kingdom, Telefonica in Spain, and Societa Italiana per l'Esercizio (SIP) in Italy are no different from adapting similar views. British Telecom is considered to be the most successful in Europe by implementing a modernization plan that includes the Intelligent Network, and is currently marketing the Intelligent Network capabilities.

Telefonica and SIP are following similar workplans, and are planning to have their Intelligent Network architecture in place to begin providing Intelligent Network services in the early 1990s. Although the UK, Spain, and Italy are the only three countries in Europe that made a glimmering start, many other countries are beginning to unveil their modernization plans.

"Intelligent network Technology may have been born in the United States but a series of favorable coincidences may make Europe its first home¹."

In Europe, as it is in the United States, the Intelligent Network is a seductive idea. For computer companies, the Intelligent Network represents a way into the lucrative telecommunications market. For users, the Intelligent Network means faster, cheaper, and more flexible services. European carriers have seen the growth of 800-traffic in the US, and now the European PTTs are allowing themselves to be persuaded to adopt the Intelligent Network. Installation of digital switches and modern transmission facilities are among

1. Peter Purton, the European editor of *Telephony*, August 22, 1988.

most PTT's priorities for the 1990s. PTTs are laying the basic infrastructure for the Intelligent Network, not for the Intelligent Network's sake but, for all the benefits that Signaling System No. 7 (SS7) can offer. Not the least of these benefits is that SS7 is a significant component in the ISDN.

3.1 SYNOPSIS OF THE US INTELLIGENT NETWORK - USA

Domestic AT&T 800 Service is an interstate voice-grade service that provides voice, low-speed data (up to 9.6 Kbit/s) and graphics transmission capabilities to a subscriber's location. The AT&T 800 Service is provided using the AT&T switched network whereby long distance calls are made with no charge to the caller. The centralized databases and customized announcement units are connected to the switched network components to provide the Intelligent Network facilities used to offer the service. The service subscribers are billed for all incoming calls on a bulk rate basis rather than on an individual basis. AT&T has been offering the 800 services since 1967. The service was so named because the special area code "800" was set up to allow a service provider to establish an area within the United States from which the provider can receive telephone calls without charge to the calling party [22].

The US is divided into six geographical service areas to provide the 800 Service. Subscribers requesting 800 Service must have at least one access line from any one of the selected service areas. The access line connects the subscriber to the AT&T telecommunications network. The 800 Service can be provided with a wide variety of subscriber telephone equipment. Service Subscribers can be reached by dialing a "1" then "800" followed by a seven digit subscriber code. Calls originating from outside the service area that is subscribed to are blocked. Within the 48 contiguous states and Hawaii, subscribers can choose from five interstate service areas associated with their business locations. The broadest of the service areas include all 48 states, Hawaii, Puerto Rico, and the United States Virgin Islands. A sixth service area includes Alaska [22].

The AT&T 800 Service rates are based on the user's selected service areas, day of the week, and the number of hours used per month. AT&T also offers an advanced 800 Service. Service Subscribers can use the advanced 800 features in combination with the basic 800 Service features to optimized their

service offering and maximize their profits. These unique optional features include:

- **800 Single Number Service:**
A Single Number is used by the Service Subscriber to provide a service to both intrastate and interstate callers.
- **800 Customized Call Routing:**
This service allows the Service Subscriber to have control over the location where the calls are answered.
- **800 Routing Control Service:**
A customer subscribing to this service would have the capability to add, change, or delete features from the 800 feature set (except the 800 Single Number Service) that is subscribed to without informing the telephone company. With this capability, the Service Subscriber can move traffic from one location to another to maximize the call completion rate.
- **800 Call Attempt Profile:**
This service provides the Service Subscriber with a summary of all call attempts to the 800 number based on the originating Numbering Plan Area (NPA).
- **800 Call Prompter:**
This feature allows for provision of a voice menu to the callers permitting them to select at a finer granulation the service or department they would like to be connected to.
- **Call Allocator:**
The Service Subscriber has the capability to specify the percentage of calls to be routed to each answering location.
- **800 Command Routing:**
This feature provides alternative paths for routing calls in the event of emergencies at any answering location.
- **800 Time and Day Manager:**
With this feature, different routing paths can be used depending on the time of the day, and the day of the week.

- 800 Courtesy Response:
Calls can be completed to a customized announcement.

While the advanced 800 Service features can be used independently, practical applications involve combinations to meet customer needs. There are over 100,000 telemarketing centers in the United States, and this figure is projected to grow to 240,000 by the early 1990s. The 800 Service in the US has grown to maturity in about 15 years since its first introduction in 1967. The 800 services evolved and formed what is referred to as the AT&T Intelligent Network.

3.1.1 SERVICE AREAS

Interstate service areas for the AT&T 800 Service Subscribers are arranged roughly in concentric circles around each subscriber's home state. As an example, FIGURE 3.1 shows the service area 1 for the state of Kansas.

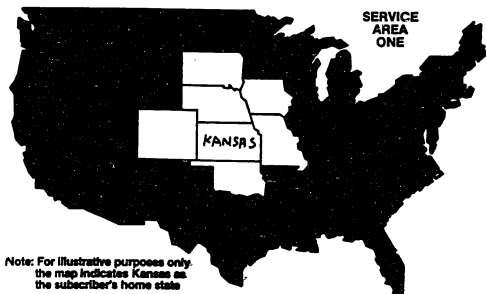


FIGURE 3.1: STATE OF KANSAS SERVICE AREA 1

The service areas can generally be described as [22]:

1. Service area "1" includes those states adjacent to but not including the subscriber's home state. This area represents approximately 10% of telephones in the United States with the exception of those in the subscriber's home state.
2. Service area "2" includes service area "1" above together with neighboring states farther away to make up about 20 % of telephones outside the home state.
3. Each additional service area, namely "3", "4", "5", and "6" expands the subscriber's coverage capability to receive incoming calls in proportions of approximately, 40 %, 60 %, 80%, and 100% respectively, of telephones outside the subscriber's home state.
4. Area "5" includes Hawaii, Puerto Rico, the United States Virgin Islands, and all the 48 states except the subscriber's home state.
5. Area "6" is the largest possible service area that is made up of areas "1" through "5" plus Alaska.

There is also an intrastate 800 Service offered jointly by AT&T and the local telephone companies. This service allows call originations in the subscriber's home state. AT&T 800 Service is customer oriented and helps the Service Subscriber to generate more revenue. The service gives subscribers more control over their business. It is a cost effective alternative to encourage calling from a targeted audience.

3.1.2 ISDN in the USA

During the early 1980s, while the groundwork for the sophisticated Integrated Services Digital Network was being meticulously executed by the T1D1 and CCITT committees, the Bell Operating Companies in the United States and the various networks in Canada, Japan, Europe and Australia were already offering preliminary ISDN type services (such as call forwarding, call waiting, automated redialing, the 800 and 900 services, etc.). Intelligent Networks and ISDN are two key technologies which have shaped the telecommunications industry in the 1980s and will continue to do so in coming years. ISDN standards have led to intensive development efforts by many vendors with an

objective of using this technology effectively to provide economical and commercial benefits to the customers. AT&T has been a leader in this field in both development and the successful introduction of services. Many ISDN trials are being conducted across the United States with a great degree of success. These trials involve the local telephone companies and various subscribers.

The ISDN services are being implemented in stages. Some features are also available on PBXs. Examples of features offered by AT&T's System 75 and System 85 PBXs are:

- **Calling Party Number (Station Identification):**
The calling party number is displayed on the called party's phone.
- **Calling Party Name:**
The calling party name is displayed on the called party's phone.
- **Connected Party Number:**
For transferred calls, the number to which the calling party is being transferred to is displayed on the calling party's phone.
- **Connected Party Name:**
For transferred calls, the name to which the calling party is being transferred to is displayed on the calling party's phone.
- **Primary Rate Interface Network Services (PRINS):**
 - **Distinctive Ringing and Coverage Path Selection:**
Different ringing for external and internal calls is provided. A coverage path treatment dictates where the calls are to be routed after a number of rings at any station in the path, when there is no answer.
 - **Priority Calling:**
High Priority calls are identified by a specific ring.
 - **Leave Word Calling:**
Without the actual completion of a call, as in the case of "busy" or "no answer", a caller can leave a name and/or a number to be called back.

Implementation of ISDN services in the USA is progressing in stages as the features become available and are requested by customers.

3.2 THE BRITISH TELECOM INTELLIGENT NETWORK - UNITED KINGDOM

Major organizational changes within British Telecom have brought about many changes in the provision of services in the United Kingdom telecommunication network. Two business divisions have been established in British Telecom with specific responsibilities: The National Networks (NN) division will plan and provide both the traditional telephony and specialized services, while the Local Communications Services (LCS) division is responsible for the local exchange network.

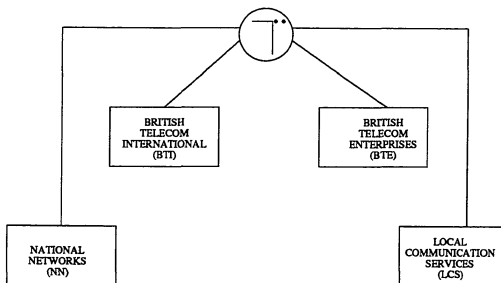


FIGURE 3.2: BUSINESS STRUCTURE OF BRITISH TELECOM

It is important to understand the business structure of British Telecom (see FIGURE 3.2) and the objectives of the organizations that fall within each structure to see the driving forces that are behind the United Kingdom's modernization plan. The overall objectives are to sustain and improve the

quality and range of services available to customers, and to exploit new capabilities to support emerging market opportunities.

To achieve these objectives, British Telecom plans to accelerate the modernization of the network, and to minimize capital and operating costs, consistent with quality customer service.

3.2.1 THE DERIVED SERVICES NETWORK:

In meeting with the modernization plan objectives, the Trunk Services Division of British Telecom National Networks introduced the Analogue Derived Services Network (ADSN) in 1985 as a vehicle to begin to provide Intelligent Network Services. The ADSN was implemented in two stages; first was the offering of the Freephone (0800) service in July 1985, and second was the offering of the premium service (0898) in January 1986 [15].

The ADSN consists of 8 analogue switching nodes. Under the modernization program, these analogue switches were to be replaced with digital switches by 1988. A contract was awarded to AT&T for supply and installation of the digital switches and other components of the Intelligent Network. The introduction of the digital switches occurred in phases to build a network now called the Digital Derived Services Network (DDSN). The DDSN was implemented to provide full Intelligent Network capabilities to the United Kingdom. It was built on the following set of network elements, the 5ESS® Switching System, the Network Control Point (NCP), the Network Subscriber Transaction, Administration and Recording System (NETSTAR), the Network Services Complex (NSCX), and the MultiFunction Operating System (MFOS).

DDSN was installed in phases. Phase 0 consists of installing 3 exchanges used as models for training and experimentation. Phase 1 consists of installing 6 additional exchanges to provide basic LinkLine Service.

DEFINITION:

Basic LinkLine Service is a service which allows the caller to call a Service Provider and have the Service Provider pay for all (FREEPHONE) or part (ECONOMY) of the call. This service is provided without the use of the NCP.

In Phase 2/3² the full Intelligent Network architecture was implemented,

thereby introducing the NCP, NETSTAR, NSCX, and MFOS to allow the introduction of new features and services such as the advanced LinkLine services and switched based Virtual Private Network (VPN). Phase 4 was a study that produced the specification of a protocol that will provide for the flexible implementation of features in future phases of the DDSN. Phase 5 provided enhancements to existing features, and the capability to introduce new features by upgrading the software modules in the switch and/or databases.

Initially the DDSN supported the same 0800, 0345 and 0898 services that the ADSN supported with enhanced network management and customer features. The DDSN enhanced centralized database, improved customer charging and data collection capability, improved customer facilities, and itemized billing gave British Telecom added flexibility in providing services to its customers.

Interworking is maintained between the ADSN and the DDSN in the phase 0, 1, and 2/3 time frame. A gradual change over of the traffic and circuits from the ADSN to the DDSN is planned.

3.2.2 SERVICES

The services offered by the Digital Derived Services Intelligent Network can be partitioned into two feature sets, basic and advanced [15, 19]. The basic feature set only requires the switches within the network to completely provide the service, end to end, while the implementation of the advanced feature set requires the support of the other Intelligent Network components.

BASIC FEATURE SET:

The following service features implemented through phases 0, 1, and 2/3 can be used to build basic Intelligent Network services, i.e., Basic LinkLine. Unlike the advanced feature set, no direct Service Provider control is allowed

-
2. Phases 2 and 3 were combined since they were implemented in the same time frame, and from then on were referred to as phase 2/3.

for these basic service features. Thus, any changes to the customer records can be made only by the Administration at the switch itself.

- *Basic Translation:*
With this feature, each dialed number is translated into only one destination number.
- *Translation Based on Incoming Trunk Group Identity:*
A dialed number can be translated into one of many destination numbers based on the identity of the incoming trunk group at the switch.
- *Call Barring Based on Incoming Trunk Group Identity:*
Based on the incoming trunk group identity, a decision can be made to process the call or terminate it.
- *Translation Based on Percentage Allocation:*
A dialed number can be translated into one of two destination numbers based on a percentage distribution.

ADVANCED SERVICE FEATURES:

The advanced service features are generic call processing capabilities that can be used to build advanced IN services (i.e., Advanced LinkLine) along with other Intelligent Network capabilities.

DEFINITION:

Advanced LinkLine Service is a service that allows the caller to call a Service Provider and have the Service Provider pay for all (FREEPHONE) or part (ECONOMY) of the call. This service requires the use of the NCP.

These service features can be used independently, but the real power of the Intelligent Network comes from being able to use a combination of the features to meet unique Service Subscriber needs. Service Providers may request one or a combination of these service features either through a service order to the Administration or by having direct access (known as the Routing Control Service capability) to their records through NETSTAR. The Routing Control Service (RCS) capability allows Service Providers with advanced Special Billing Services (i.e., Advance Freephone) to build, modify, remove, query, validate, and schedule activation of their call processing

records at NCPs by using a dial-up connection with a Video Display Unit (VDU) and a directly connected optional printer at their premises.

The following advanced service features are made available by the network:

Alternate Destination on Busy:

With Alternate Destination on Busy, the Service Provider can specify a sequence of alternate destinations to which calls will be routed if the primary destination is busy.

Call Allocator:

This service feature allows the Service Provider to specify the percentages of calls to be distributed between two or more Service Provider destinations or alternate call processing treatments.

Call Barring:

This feature gives the Service Provider the capability to bar calls from certain geographic areas.

Call Prompter:

This interactive dialing service feature allows a Service Provider to provide an announcement through an NSCX. Such announcements can be requested to instruct the caller to enter more information (additional digits) that the network requires to complete call processing.

Call Queuing:

For a Service Provider with Call Queuing, a call is held in a queue when all access lines at a destination are busy. Upon entering the queue, the caller receives an announcement that the call will be answered when a line becomes available.

Command Routing:

This service feature allows the Service Provider or Administration personnel to predefine a set of alternate destinations or call handling treatments to which traffic can be directed in cases of emergency or unanticipated demand peaks. Only one of these destinations/treatments can be selected at any given time.

Courtesy Response:

This service feature allows a call to be completed to a custom announcement or a standard Administration announcement provided by the NSCX.

Routing by Calling Subscriber Geography (CSG):

With this feature, a routing or call treatment decision can be made based on the geographic location of the caller, known as the CSG.

Routing by Day of Week:

This service feature provides the Service Provider with the ability to route a call to a different destination or provide alternate call processing treatment depending on the day of the week a call is placed.

Routing by Time of Day:

This service feature provides the Service Provider with the ability to route a call to a different destination or provide alternate call processing treatment depending on the time of the day a call is placed.

The phase 5 feature enhancements that are planned to be introduced into the network in 1990 are as follows:

Digital Private Network Signaling System (DPNSS):

DPNSS is an inter-PBX signaling system. In 1990 the DDSN will provide an interworking with DPNSS. This will allow calls originating on the DDSN to terminate on a PBX and likewise, calls outgoing from a PBX to the DDSN. In either case, only basic telephony calls are supported.

British Telecom Signaling enhancements:

Some of the signaling enhancements that will be made to BT-7 are; prevention of circular routing (MTP), modified time-out values (MTP), enhanced digit analysis capability (TUP), Recent Change and Verify (RC/V) optioning for discrete messages (TUP), and overlap address signaling (TUP).

Call processing enhancements:

The call processing software modules will be enhanced to support, an increased number of Service Providers (network wide), routing or call treatment decisions based on the originating line identity of the caller, and

variable dialed numbers (6-10 digits).

Call transfer:

This service allows the service subscriber to hold an existing call while establishing another call, have a three way speech path with the existing call and the newly established call, and transfer the call thereby allowing the controlling subscriber to request connection of the other two parties and then withdraw from the call.

Call Reporting:

Calls can be monitored using monitoring programs. Detailed information on the calls will be logged according to a set of pre-defined criteria.

NETSTAR Resource Logging and Usage Reporting:

This is an enhancement to previous phases which will monitor the disk space utilized in NETSTAR for all dial file plans and plan support data.

Originating calls signaling:

Service Provider terminations on the DDSN switches will be able to make outgoing calls to the PSTN network, other Service Providers, and to Operator services.

3.2.3 ARCHITECTURE:

The DDSN is an overlay network that provides improved transmission performance since the 2-wire switching element of the analogue call routing were replaced by digital techniques.

The centralized database introduced in phase 2/3 helped British Telecom to monitor and control network performance. The digital units can also be easily enhanced through hardware and software upgrades to support the rapidly changing environment. British Telecom plans to enhance the hardware to support the implementation of more features and increased traffic.

NETWORK CONFIGURATION:

The 5ESS ACPs form the Digital Derived Service Switching Centers (DDSSCs), located at the existing Analogue Derived Service Switching Centers (ADSSC) sites, namely Cambridge, London, Birmingham, Leeds, Manchester, Guildford, Bristol, and Glasgow. FIGURE 3.3 shows the locations of the switches on a map. There are 4 NCPs, 2 NETSTARS, 2 NSCXs and 1 MFOS connected to the DDSSCs to provide a wide range of Intelligent Network services.

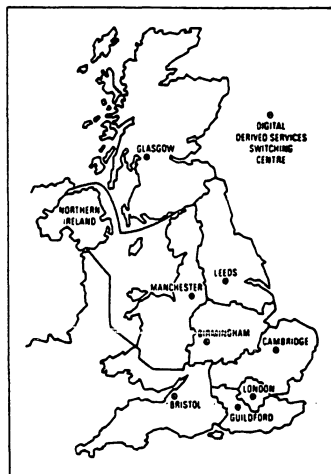


FIGURE 3.3: THE DIGITAL DERIVED SERVICES SWITCHING CENTERS

- **Action Point (ACP):**

The ACTION control Points are the 5ESS switching nodes, which serve as transit and terminating nodes for DDSN traffic. All ACPs are fully interconnected by digital line systems. CCITT No. 7 (BT) signaling links are used exclusively for setting up speech paths both within the DDSN and between the DDSN and the Public Switched Telephone Network.

A totally independent Common Channel Signaling network, utilizing a proprietary form of Common Channel Signaling No. 7 (North American CCS7 (NA)), is used for transporting non-circuit related signaling messages between the ACPs and the NCPs. Upon recognizing an Intelligent Network call, the ACP, which is integrated in the 5ESS switch, either processes the call on its own (for basic LinkLine service(s)) or requests call handling instructions from the NCP (for advanced LinkLine service(s)) through Common Channel Signaling (CCS). The signaling messages are routed between the ACPs and NCPs through a Signal Transfer and End Point (STEP),³ which is also embedded in the switch.

- **Network Control Point (NCP):**

The primary element in providing centralized call management is the NCP, which is a centralized database containing the call handling information of Service Providers, i.e., Service Provider records.

NCPs are usually implemented in mated pairs. Databases are duplicated between the mated pairs and operate as a primary and secondary during call processing. If the primary is down for any reason, the secondary is automatically switched in to provide the same database information, thereby achieving virtually 100 % reliability.

- **Network Subscriber Transaction, Administration, and Recording (NETSTAR):**

NETSTAR is a centralized service management system serving as the interface between the Administration/Service Providers and the NCPs.

3. A STEP provides the combined role of a Signal Transfer Point (STP), serving as a transit node for signaling messages, and a signal origination/termination point.

The Service Provider's call routing plans are created, modified, and loaded onto the NCPs through NETSTAR. Other main functions of NETSTAR are the logging of service management activities, service maintenance (e.g., isolating and resolving problems with the Service Provider data), and system reporting (e.g., Service Provider plan status, test call results, and performance measurements).

- **Network Services Complex (NSCX):**
The NSCX provides the capability to give callers standard or customized interactive spoken information pertaining to the number called, such as call prompting, courtesy response and call queuing announcements. During or after a call prompting announcement, the caller may communicate with the NSCX by keying-in appropriate digits on a multi-frequency keypad. The NSCXs can collect up to 21 digits, which it forwards through the ACP to the NCP via a CCS7(NA) link.
- **Multi-Function Operations System (MFOS):**
MFOS provides centralized Operations, Administration and Maintenance (OA&M) of the Intelligent Network elements. It supports the 5ESS by providing switch maintenance, alarm processing, traffic data collection & analysis, network traffic management, and on-line access to Recent Change and Verify (RC/V) functions. It supports the NCP by providing maintenance, alarm processing, traffic data collection & analysis, and network traffic management. It provides maintenance for the NSCX and NETSTAR.

FIGURE 3.4 shows the DDSN architecture.

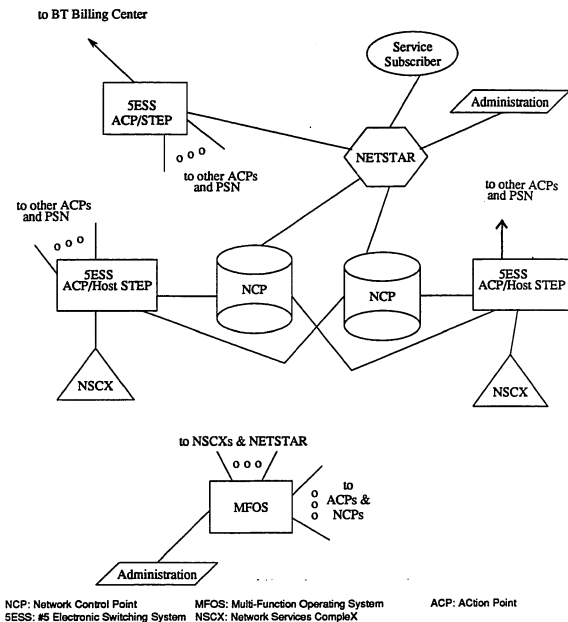


FIGURE 3.4: DDSN INTELLIGENT NETWORK ARCHITECTURE

Calling customers can access the DDSN via their local exchanges. The number dialed by the customer is passed from the local exchange to the associated Main Switching Unit⁴. (MSU). In the British Telecom network, there are both analogue and digital MSUs (AMSU and DMSU). The MSUs examine the dialed digits and route the call to the DDSSC. The DDSSC examines the number upon receiving it from the MSU and determines which DDSSC the called customer is connected to. This is achieved by reference to the individual site office dependent data (ODD)⁵.

FIGURE 3.5 shows the connection of the DDSSC to the MSU level and to the Local Exchange level [15, 17].

-
4. The Main Switching Unit is a toll level office that is between the DDSSC and the Local exchanges.
 5. A software package which contains all call routing, charging, and other miscellaneous parameters for the exchange.

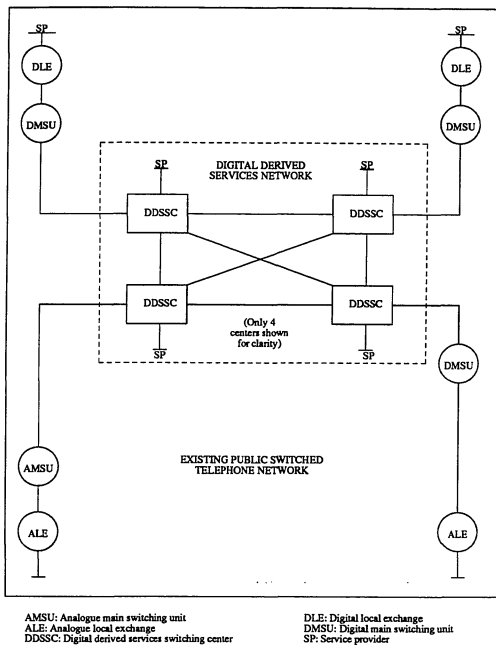


FIGURE 3.5: DDSSC INTERCONNECTION TO THE PSTN

SYSTEM CONFIGURATION:

The 5ESS uses a time-space-time switching structure based on a number of switching modules (SMs) interconnected via a communications module (CM). The SM contains the time switches and the CM contains the Space switch. The modules are interconnected by optical fiber links. One digital exchange will contain many SMs, but only one CM which is connected to an Administrative Module (AM) via hard wire. The AM provides centralized control functions such as operation and maintenance support, inter SM routing, and time slot allocation.

All SP lines, incoming and outgoing analogue trunks, and 2 Mbit/s digital systems terminate on various types of peripheral units within the SM. Calls originating and terminating within the same SM are switched within the module, but calls originating and terminating on different SMs are connected via the CM.

THE LINE UNITS:

Some of the line units used in the British Telecom network are described here to show the varied designs with different capabilities that are implemented.

GRADED DIODE CROSS POINT LINE UNIT:

The Graded Diode Cross Point Line Unit (GDXTLU) provides terminations for conventional Direct Exchange Line (DEL) type telephone lines, that is, providing digital to analogue conversion, battery feed, ringing current, etc. GDXTLUs could also be used for interfacing Signaling System AC No 15 E (SSAC15E) and Signaling System AC No 15 C (SSAC15C) signaling units to the exchange. A GDXTLU is a matrix of semi-conductor switches that are used as an analogue space switch to provide a subscriber's concentration stage. GDXTLUs provided in DDSSCs have a capacity of 256 SP lines with a concentration ratio of 4:1, giving 64 outlets into the exchange.

THE ANALOGUE TRUNK UNIT:

The Analogue Trunk Unit (ATU) provides a 2-wire loop disconnect interface to the exchange. It can be used to provide Direct Dialing In (DDI) access to SPs via loop disconnect circuits, Pulse Code Modulation (PCM) 2 Mbit/s time-slot16 (TS16), or SSAC15A signaling units. ATUs contain analogue to digital

conversion stages and signaling interfaces. An ATU can terminate up to 64 trunks with 64 outlets into the exchange to give a 1:1 concentration ratio.

THE DIGITAL LINE TRUNK UNIT:

The Digital Line Trunk Unit (DTLU) is used for terminating up to 16 x 2.048 bits/s line systems. Each line system is terminated on a digital facility interface (DFI) within the DTLU. The DFI performs coding/decoding of the line bit stream for onward transmission into the exchange, and the insertion /extraction of timing/alignment information into and out of the line bit stream. There is no concentration stage on a DTLU; each traffic time slot on each 2.048 Mbit/s has its own outlet into the exchange

GLOBAL DIGITAL SERVICE UNIT:

The Global Digital Service Unit (GDSU) does not terminate any external links onto the exchange but is capable of providing the internal exchange telephony services:

- (i) conference call facility,
- (ii) transmission test facility for trunks and lines, and
- (iii) trunks and junction routing facility.

3.2.4 SIGNALING

FIGURE 3.6 illustrates the signaling interfaces among the different Intelligent Network elements. Each 5ESS switch in the Intelligent Network is directly connected to every other 5ESS switch with standard 2 Mbit Pulse Code Modulation (PCM) systems using CCITT No. 7 (BT) for circuit-related signaling. The 5ESS switches interface with the NSCXs at 64 Kbit/s by using Common Channel Signaling No. 7 (North America) [CCS7 (NA)] for circuit-related signaling.

A pair of 5ESS ACPs, through their corresponding integrated STEPs, are directly connected to NCPs and are referred to as host STEPs. They perform the Signal Transfer Point (STP) functions for exchanging noncircuit-related signaling messages between the corresponding NCP and any of the other ACP/STEPS. The host STEPs interface with the NCPs at 56 Kbit/s. CCS7

(NA) is used for all noncircuit-related signaling among the Intelligent Network elements.

The 5ESS ACPs interfaces with the PSTN through digital trunk circuits supporting CCITT No. 7 (BT) and loop disconnect-type signaling using time TS16. Intelligent Network calls are allowed on either signaling system. For direct connection to the Intelligent Network ACPs, the Service Providers can choose between Digital Private Network Signaling System (DPNSS), AC No. 15 A and E, loop disconnect through analogue and 2 Mbps PCM systems, and local line subscriber signaling (L7/K7). In addition, to transport call logging data, dedicated CCITT X.25 links are used between NETSTAR and the ACP, and dedicated BT X.25 links are used between the ACP and the Trunk Network Data Collector (TNDC)⁶.

The NCPs are connected by CCITT X.25 data links to NETSTAR. Administration access to NETSTAR is through CCITT V.24 asynchronous, permanent data links or dial-up connections, whereas Service Provider access to NETSTAR is typically through CCITT V.24 asynchronous, dial-up connections.

For Operations, Administration and Maintenance of the 5ESS ACP/STEPS and NCPs, MFOS uses CCITT X.25 data links. In addition, MFOS uses North American Bell System X.25 (BX.25) for the NCP maintenance interface and CCITT V.24 for the 5ESS switch RC/V interface. The NSCX interface to MFOS uses CCITT V.24 asynchronous data links.

All MSUs are connected to their home DDSSC, and all DDSSCs are fully interconnected via a PCM 2Mbit/s TS16 signaling link. Service Providers can be accessed via the DDSSCs. If SPs are located within 2-wire unamplified range, then they can be directly connected to 2-wire subscriber line interfaces in DDSSC. The subscriber line interface is the 2-wire interface within the Switch Module GDXLU. In situations where the SP is outside the DDSSC unamplified signaling range, SSAC15A and SSAC15E, or PCM multiplex can

6. This is a system that periodically polls all the ACPs in the network and collect call logging information to be used for billing.

be used. Service Providers requiring Direct Dialling In from PBXs can be served by PCM 2 Mbit/s TS16 signaling via the Switch Module Digital Facilities Interface in the DDSSC terminating on a signaling unit at the Service Providers' premises. Service Providers requiring Direct Dialling In located outside the unamplified range use SSAC15A signaling which is connected to a 2-wire port on the Switch Module ATU within the DDSSC. All DDSSCs are interconnected to each other and the associated Digital Main Switching Units (DMSUs) by using Common Channel Signaling CCITT No. 7 (BT).

Information generated by users is passed between signaling points over common signaling links in labeled user part messages. The Message Transfer Part (MTP) acts as a transparent carrier for user part message information⁷. It is concerned only with that information required to identify the correct signaling point.

The user part messages are generated by the National User Part (NUP) which contains the function required to convert signals into signaling information fields suitable for transmission by the MTP. The National User Part also contains the protocol which determines the selection and sequence of signals to be exchanged during call control, and the functions required to exchange signaling control information with the MTP.

7. The Message Transfer Part (MTP) is a group of functions responsible for accepting routing and delivering data between signaling points.

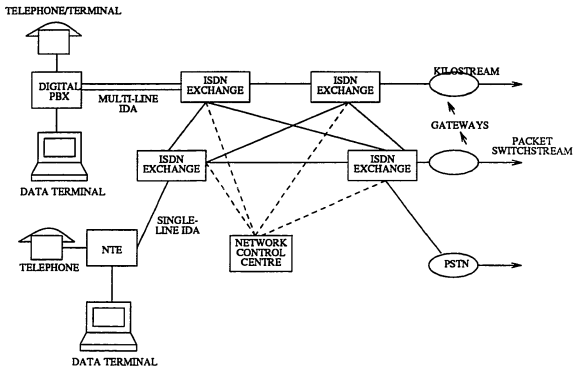
3.2.5 BT-ISDN PLANS

An effective and responsive telecommunications network is essential if customer expectations are to be met, particularly in this information age. Speed in provision of the service, acceptable cost, quality of service, responsive interface between customer and supplier, and a sound evolution plan to meet future needs are key requirements for success [5].

Although much has been achieved through the use of more modern plant equipment and better monitoring systems, the current network technology still leaves room for improvement in terms of calls with poor transmission characteristics and long set-up time.

The availability of common channel signaling will greatly reduce the call set-up times across the network and will be an important element in British Telecom's ability to provide an Integrated Services Digital Network (ISDN). A fully digital network has the inherent capacity to provide a very extensive and diverse range of switched and private services. The ability of the network to handle these services however, will depend on the transmission characteristics of the network [12].

British Telecom's pilot ISDN plan involved switching nodes in London, Birmingham, and Manchester with line extensions to remote locations. The availability of 64 Kbit/s channel, customer-to-customer, opens up an enormous potential for new IN services such as Slow-scan television, Digital Telephony services, and Electronic banking. BT started its pilot ISDN service with the simplest kind of information flow from point to point, and then built on top of it other ISDN capabilities such as the transfer of data and images simultaneously with voice [3].



IDA: Integrated digital access
 NTE: Network terminating equipment
 PSTN: Public switched telephone network

ISDN: Integrated services digital network
 PBX: Private branch exchange

FIGURE 3.7: BRITISH TELECOM'S ISDN INTERCONNECTION PLAN

British Telecom's ISDN planning focuses on three customer access points:

1. Single-line Integrated Digital Access (IDA)
2. Multi-line Integrated Digital Access
3. I.420 Single-line Integrated Digital Access services

The single-line IDA pilot service has been available since 1985. This service is provided over ordinary twisted pair copper cable networks. It offers 64 Kbits/sec digital exchange channel for voice and data communications, and a separate digital exchange channel at 8 Kbit/sec which could be used for data communication customers. These channels are provided with the CCITT X.21

interface. BT announced⁸ its multi-line Integrated Digital Access service in 1988. Customers can interface to their Integrated Services Private Branch Exchanges (ISPABXs) at 64 Kbits/sec. These ISPABXs will be connected to BT's "System X" nodes through 30 channel 2.048 Mbit/sec trunks. The 1.420 single-line IDA service trial planned for late 1988 offers two 64 Kbits/sec digital exchange channels where either one can be used for voice or data. The customer interface is the 1.420 standard. These three services can interwork without any complex network arrangements [6].

The two most important ISDN issues that are being discussed widely in Europe are,

- (i) the lack of defined and compatible private ISDN interface standards and,
- (ii) the question of whether the building's internal cabling infrastructure is of sufficient quality to support ISDN.

British Telecom continues to address the above issues [5].

8. BT links into ISDN via multi-line IDA - Communication/December 1988 p7.

3.3 TELEFONICA'S INTELLIGENT NETWORK - SPAIN

Telefonica de Espana was founded in 1924, and formed in 1946 as a publicly managed private corporation. It is currently Spain's largest company on the basis of total assets, profits, and stock market capitalization. The state holds 33% of market shares in Telefonica de Spain.

The rise in demand for telephone service and the increase in traffic, along with the degradation of quality service provided by an underdimension network, led to the execution of a modernization plan. Due to market pressures, the focus is first to provide quality service.

Spain's digitization program began in 1980 with an evolution towards ISDN. This plan includes the creation of the Integrated Digital Network (IDN), which with Common Channel Signaling System and packet switching facilities, offers its first multiservice ISDN lines in accordance with CCITT recommendations [18].

Installation of new lines takes priority over the deployment of new services. At the end of 1987, the Spanish public switched telephone network provided service for 15,467,000 telephones connected to 10,236,400 lines. The new network services provided by Telefonica are derived from the implementation of the Intelligent Network.

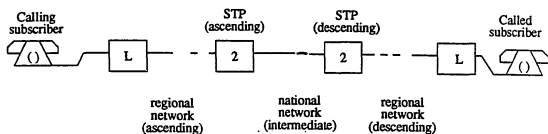
3.3.1 SERVICES

In the initial stages of ISDN deployment, the business community will be the first to be offered services by the Local Exchanges beyond the Plain Old Telephone Services. The services provided by Telefonica, as requested by the business community, are as follows:

- Malicious Call Trace (MCT)
- Call Diversion
 - immediate
 - on no reply
 - absent subscriber signaling

- Traffic Restrictions
 - service restrictions in outgoing direction (outgoing call barring)
 - incoming call barring for individual lines
 - incoming call barring for diverted lines
- Alarm Call Service
 - casual alarm call service
 - regular alarm call service
- Abbreviated dialing subscriber control
- Hot line Service
 - direct connect
 - timed hot line
- Call waiting
- Three party service

FIGURE 3.8 shows a typical call flow for any of the above services.



L: Local Exchange STP: Signal Transfer Point

FIGURE 3.8: NORMAL NATIONAL CALL FLOW

With each stage of the IN implementation in the 1990s, additional services will be added to the network. Spain will also be implementing an advanced feature set similar to that of British Telecom, but will also include the Calling Card, Televoting and Personal Number services.

CALLING CARD:

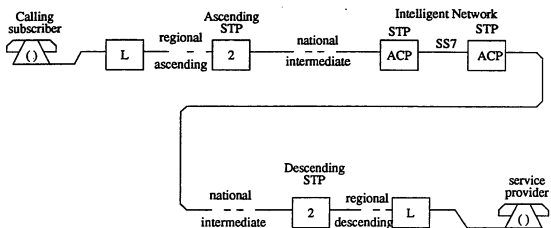
The Calling Card service allows a caller to make calls from any suitable telephone terminal, and to charge the cost of the call to a predefined account.

TELEVOTING:

The Televoting service gives the Telephone Administration the capability to survey public opinion using the telephone network. The Telephone Network by definition includes the Public Switched Telephone Network, the Intelligent Network, and any other private network that is connected to the PSTN or IN.

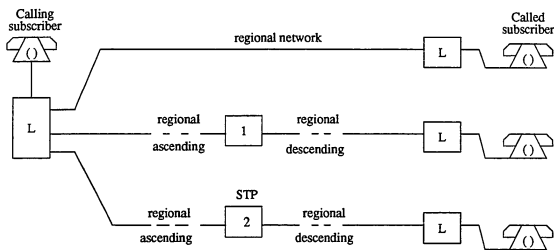
PERSONAL NUMBER:

The Personal Number service provides a call forwarding mechanism to Service Subscribers who move from one location to another, and need a reliable way of receiving their telephone calls.



L: Local Exchange STP: Signal Transfer Point ACP: Action Point SS7: Signaling System 7

FIGURE 3.9: INTELLIGENT NETWORK CALL FLOW



L: Local Exchange STP: Signal Transfer Point

FIGURE 3.10: NORMAL REGIONAL INTER-EXCHANGE CALL FLOW

FIGURES 3.9 and 3.10 show typical call flows for the advance features in the IN.

3.3.2 ARCHITECTURE

Unlike British Telecom, where the Intelligent Network is an overlay network, Spain has implemented an IN architecture that is integrated with the existing PSTN structure. This integrated architecture has become the vehicle to provide IN services [16].

THE PSTN STRUCTURE:

Telefonica's Public Switched Telephone Network (national network) has been divided into Local, Primary, Secondary, and Tertiary areas (see FIGURE 3.11). A classification of the exchanges in the national network is shown in FIGURE 3.12.

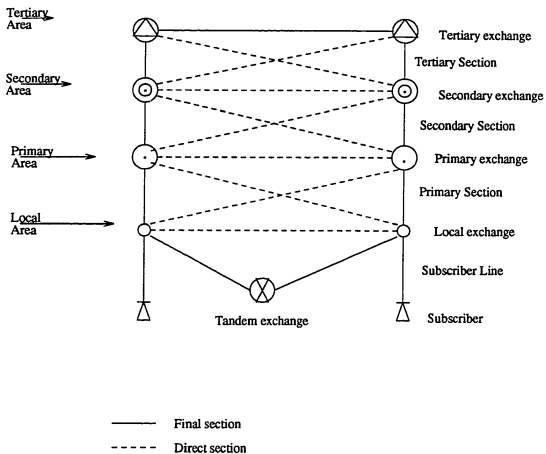
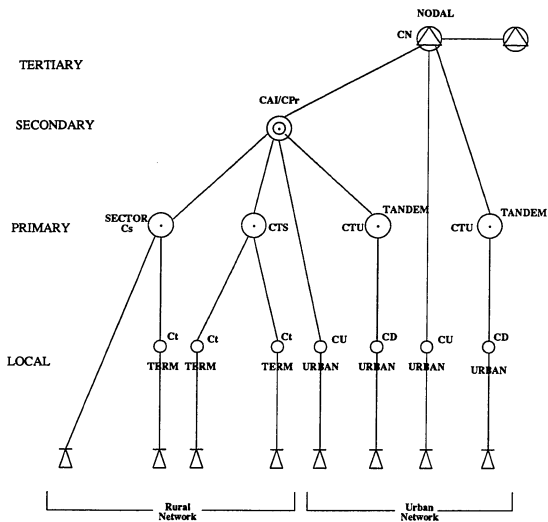


FIGURE 3.11: SPAIN'S NATIONAL PSTN STRUCTURE



CN: Central Nodal Cs: Central sector CTS: Central Tandem Sector CTU: Central Tandem Urban
 Ct: Central toll CU: Central Urban CD: Central Digital CAI/CPr: Central Automatica Interurbana/Cabecera
 Provincial

FIGURE 3.12: CLASSIFICATION OF EXCHANGES IN THE NATIONAL NETWORK

Access to and from the PSTN is always via the local exchanges in the PSTN structure. The higher level exchanges in the PSTN structure are used for inter-exchange routing. The connection from the national structure to gateway switches (digital international exchanges) can be from any level (local, primary, secondary, and tertiary) within the PSTN as indicated in FIGURE 3.13. With Spain's modernization plan, the installation of digital switches within the network, also shown in FIGURE 3.13, is leading up to an integrated structure of analogue and digital facilities, as well as an integrated level architecture.

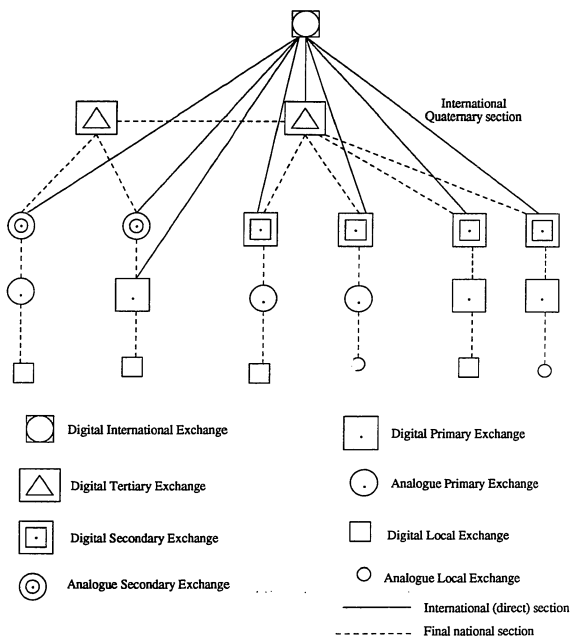


FIGURE 3.13: INTERNATIONAL NATIONAL PSTN STRUCTURE

THE IN STRUCTURE:

The IN integrated architecture adopted by Spain required that the 5ESS ACPs be strategically placed at key locations (switching centers). See FIGURE 3.14.



FIGURE 3.14: LOCATION OF IN SWITCHING CENTERS IN SPAIN

A contract has been awarded to AT&T to provide IN capabilities (hardware and software) to Spain. In the initial stages, a number of 5ESS switches will be installed in the various exchange areas. The IN will be implemented by providing ACP functionality to 5ESS switches placed at the strategic locations. The other IN components, NCP, NETSTAR, MFOS, and NSCX will be deployed to complete the IN architecture shown in FIGURE 3.15.

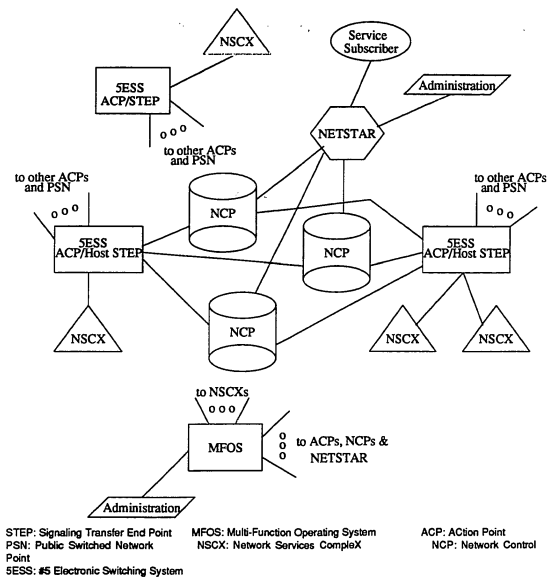


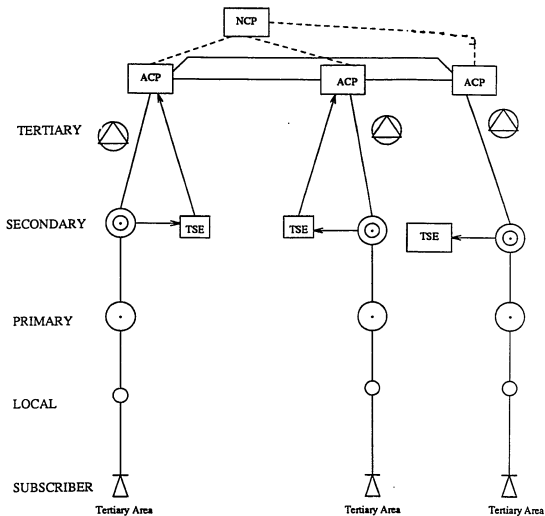
FIGURE 3.15: SPAIN'S IN ARCHITECTURE

With the introduction of digital exchanges, many sections of the national network will be modified. Telefonica has adopted a pragmatic strategy for the introduction of the digital network, which is a compromise between creating a digital overlay structure from the higher hierarchy network levels downwards, and creating digital islands in certain geographical zones.

The future digital network is designed to be a hierarchical structured network adhering to a set criterias such as:

- The distance and dispersion of the areas suggested in general, that networks fundamentally be established in a star shape, except for the highest (ie. tertiary) level where the exchanges are interconnected in a mesh network.
- In the local areas, the local exchanges will be connected to its higher order exchange.

FIGURE 3.16 shows the IN connection to the PSTN.



NCP: Network Control Point ACP: Action Point TSE: Toll Secondary Exchange

FIGURE 3.16: CONNECTION BETWEEN THE PSTN AND IN

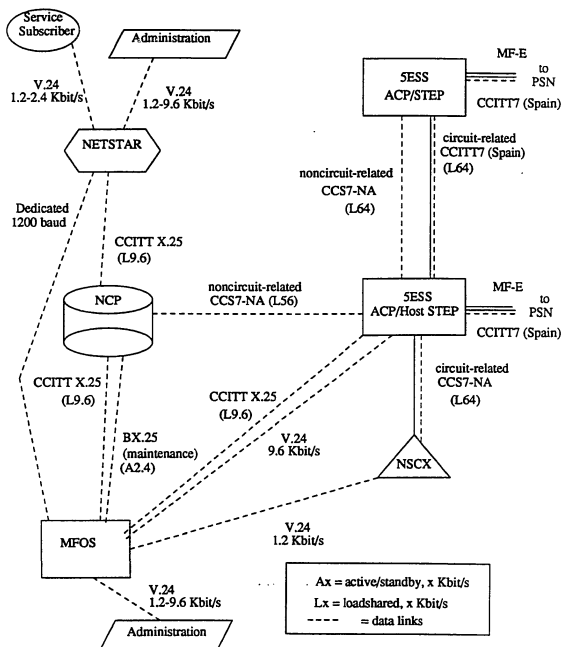
3.3.3 SIGNALING:

The 5ESS ACPs will be fully interconnected with standard 2 Mbit Pulse Code Modulation (PCM) systems using CCITT No. 7 (Spain) for circuit related signaling, while the 5ESS ACPs will interface with the NSCXs at 64 Kbit/s by

using CCS7(NA) for circuit related signaling.

The 5ESS ACPs will interface with the PSTN through digital trunk circuits, supporting CCITT No 7 (Spain) and MF-Espana (MF-E). IN calls will be allowed on both signaling systems.

All other signaling links within the Intelligent Network components remained the same, as explained earlier for British Telecom.



STEP: Signaling Transfer End Point
 PSN: Public Switched Network
 Point
 5ESS: #5 Electronic Switching System

MFOS: Multi-Function Operating System
 NSCX: Network Services Complex

ACP: Action Point
 NCP: Network Control Point

FIGURE 3.17: SPAIN'S SIGNALING SYSTEM IN THE IN

MF-E is widely used in Spain. Telefonica's Switched Telephone Network also supports associated channel signaling (Spanish standards). They have implemented CCITT R2, CCITT No.4, CCITT No.5, and are currently implementing CCITT No.7.

Spain's signaling plan can be divided into two main categories,

- (i) **Subscriber signaling:**
This is the signaling between the subscriber equipment and the local exchange. The connection between the subscriber's equipment and the local exchange is a 2-wire loop.
- (ii) **Trunk Signaling:**
This is the signaling between two exchanges. In Spain, all trunks connected to the 5ESS switch for IN services are digital trunks. Telefonica will be implementing CCITT No.7 for all signaling in the hierarchical routes.

Common Channel Signaling in Spain today only exists between exchanges following SS7-TUP protocol. CCS7 will be installed on all digital exchanges at all levels in the Spanish Network.

3.3.4 SPAIN ISDN PLANS

Spain is yet to publish its ISDN evolution plans in the public domain. It is perceived that with the introduction of digital facilities at the various levels in the network, Spain will be equipped to begin to provide ISDN services (2B+D and 30B+D) in the early 1990s. Spain defined its specifications in accordance with the architecture of the Open Systems Interconnection (OSI), and has closely followed the CCITT recommended standards. Services to be introduced have been identified, and all interfaces (including the user interface) have been specified.

3.4 SIP's INTELLIGENT NETWORK - ITALY

The Italian Postal and Telecommunication Services are controlled exclusively by the state, which may operate these services directly, or may grant concessionary companies the right to operate them. The Italian

Telecommunications Administration organizational structure is complicated by the number of different sub- organizations with varied responsibilities. The Ministry of Post and Telecommunications is a Cabinet- level position that is legally responsible for all telecommunications services. The Ministry currently has two directly reporting autonomous entities, the Posts and Telecommunication Administration, and the Azienda di Stato per i Servizi Telefonici (ASST). ASST is responsible for telephone services, and monitors any functions granted to concessionary companies.

Societa Italiana per l'Esercizio Telefonico (SIP) is an organization within the administrative structure that has the following responsibilities:

- The local telephone customer service relations
- Design and construction of local, sector, and district telephone networks
- Local telephone services for public use as well as auxiliary services
- Jointly with ASST, long distance telephone services
- Border international telephone services, carried out over direct circuits between border countries as agreed by the Italian and Foreign administrations.

ASST provides:

- The design and construction of the domestic telecommunication systems between the compartments and the international network
- Jointly with SIP, long-distance telephone services
- International telephone services with all European countries, Algeria, Cyprus, Egypt, Libya, Morocco, Tunisia, and Turkey.
- Supervisory monitoring and undertaking of any other function reserved to the state relating to telecommunication services for which it has granted concessions.

3.4.1 NETWORK CONFIGURATION

Italy has two public Networks for voice and data services. Rete Pubblica, or the PSTN, and Rete Fonia Dati (RFD). RFD is a circuit switched voice and

data network used commercially since April 1983, and is based on digital switching exchanges (AFD) with peripheral concentrators (UFD). Currently, the AFDs are located in Milan, Turin, Rome, Bologna, and Naples, while the concentrators are distributed all over the country. In 1985, Italy had approximately 16 million subscriber lines for a population of 57.2 million.

In addition to the PSTN and RFD, the following networks are available for data communication services [10]:

- Domestic and international telegraph network
- Telex-dati
- Itapac

3.4.2 THE PSTN

The PSTN is divided into five hierarchical levels of exchanges:

1. Local
2. Sector
3. District
4. Compartment
5. International

There are over 13,000 local exchanges and about 1400 sector exchanges, 231 districts and 21 compartments. A PSTN subscriber can call any RFD subscriber.

In 1978, small analogue electronic exchanges were introduced into the network. In 1983, the first digital local exchanges were put into service. By 1985, there were over 150 digital local exchanges and 35 digital sector exchanges.

There are current plans to consolidate the 5 levels into a 3 level (local, tandem, and toll) network, with an overlay signaling network using CCITT No 7 signaling system.

The following data transmission services are supported on the PSTN.

- 300 bps duplex using CCITT V.21 and V.24 modems
- 600-1200 bps half and full duplex using CCITT V.23 and V.24 modems
- 2400 bps half duplex using CCITT V.22 and V.24 modems

Leased circuits are available to provide data transmission at speeds of up to 9600 bps in either point-to-point or multi-point configurations. The options available include:

- Two-wire circuits which allow simplex and semi-duplex data transmission.
- Four-wire circuits which allow full duplex transmission.
- Standard quality circuits which can be used for two or four wire transmission at speeds of up to 1200 bps
- Special quality circuits which can be used at speeds of up to 9600 bps.

3.4.3 THE RFD NETWORK

SIP provides voice and data services on the RFD network to advanced telecommunication users. There are currently 4-6 thousand RFD subscribers. The RFD network supports two types of service connections, the 2-wire analogue switch connections using a standard telephone set with multifrequency signaling, and 4-wire analogue switched connections, using a special Data Communication Equipment (DCE) called Analogue Data Unit (ADU) which allows speech or data connections (up to 9600 bps).

The RFD switches act as Service Switching Points (SSP) and formulate messages for, and receive messages from an external database, the Service Control Point (SCP). Signal Transfer Points (STP) perform global title translations on the dialed numbers and formulate SSP messages.

There has been a considerable digitization effort towards the evolution of the transmission network. The penetration of switching systems essential for integration is expected to reach 70% in 1994. In 1987 SIP began providing PSTN Services using Stored Program Control (SPC) digital exchanges.

These include:

- Three-party Service
- Call Waiting
- Call Forwarding
- Outgoing calls barred
- Remote meter reading
- Detailed billing
- Conferencing calling

An RFD user will have all the PSTN services, as well as:

- Fast call set-up
- Separate routing from the PSTN traffic
- Abbreviated dialing
- Detailed billing
- Direct dialing for international calls
- Audio conference

Italy National freephone service is commercially known as Green Number (GN) Service, and is provided by SIP. Both National and International GN services have been available since 1987. The international services operate with the United States, West Germany, and the United Kingdom, and are planned to be extended to France, Holland, Denmark, and Sweden.

Two types of International GN Services are available, incoming and outgoing. Incoming GN service allows calls from the countries listed above to be terminated to a Service Subscriber in Italy. An outgoing GN service allows calls to be made to foreign country Service Subscribers who have agreed to receive GN calls from callers in Italy.

The national GN Service has the following features:

- (i) time of day, and day routing,

- (ii) call barring,
- (iii) routing by district code,
- (iv) detailed billing, and
- (v) voice announcement capability.

These services are provided by the RFD digital exchanges, and all subscribers must be connected to the RFD network.

NETWORK CONFIGURATION FOR THE GREEN NUMBER SERVICE:

Two exchanges in the network, one in Northern Italy, and the other in the South, with SSP and SCP functionalities (i.e., SSCP exchange) provide the database support for processing the GN calls for all Service Subscribers. These two exchanges are Ericsson AXE-10 switches, and the signaling used between them is CCITT #7 (Italy)⁹. CCITT #7 (Italy) is also used for signaling between the AXE-10 and other electronic switches that support such signaling. Signaling to all other switches is based on channel associated signaling (e.g., PCM, FB [out of band], MFN signaling codes).

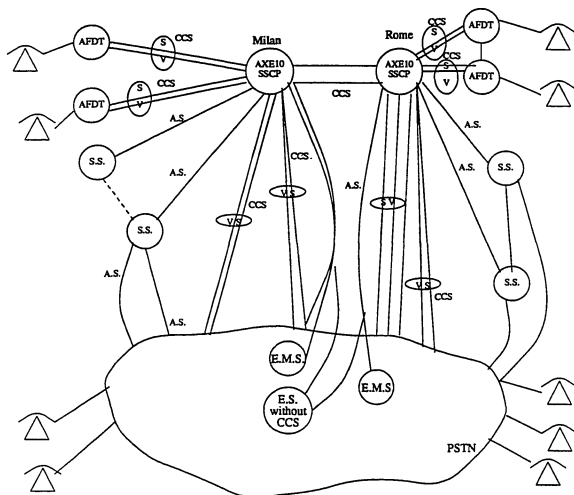
A common database, used in the processing of all GN calls, resides on the AXE-10s. Thus, the AXE-10s serve as backup systems for each other. If the database on one of the AXE-10s is in the failure state, the calls will be routed to the second AXE-10 for processing. With this network architecture, the databases on the two AXE-10s are individually updated manually.

Two types of connections exist for international incoming trunks: dedicated connections and shared connections. The digits received over dedicated connections by the SSCP are of the form 167-XXXXX (where 167 is the GN service incoming international access code, and XXXXX is the GN code). The country code identifier (a two digit code related to the real country code) is derived by the AXE-10, based on the trunk group identity and is

9. The Italian CCS #7 signaling is aligned with the ISPT 698 specifications. The SCCP and TCAP protocols are missing because the dialogue between the SSP and the SCP is within the same machine thus the protocol is a proprietary one.

incorporated into the digit string making it "167-ab-XXXXX." This string is used to query the database. The digits received over the shared connections by the SSCP are of the form "167-ab-XXXXX," (where "ab" represents the digits corresponding to a coded country code, and XXXXX is the GN code.

FIGURE 3.18 shows a diagram of the network for the GN service.



E.M.S. = Electromechanical Switch
 E.S. = Electronic Switch

A.S. = Channel Associated Signaling
 CCS = Common Channel Signaling
 V = Voice
 S = Signaling

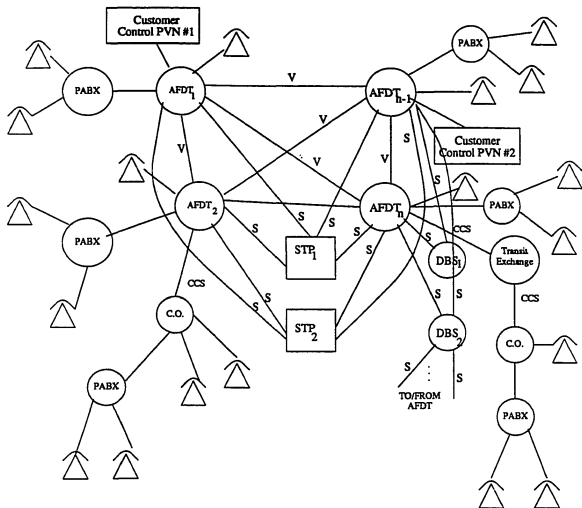
FIGURE 3.18: NETWORK CONFIGURATION FOR GN SERVICE

NETWORK CONFIGURATION FOR THE PRIVATE VIRTUAL NETWORK SERVICE (PVN):

The network used to support the PVN service consists of up to 18 (14 to 18) AFDT switches interconnected via STPs, and equipped with CCITT #7 (Italy) signaling. Each AFDT switch that supports the PVN service has a direct connection to two PVN centralized databases residing on separate systems as shown in FIGURE 3.19. There is no interconnection between the two database systems. The two databases are however, identical with shared access via dedicated connections from all RFD switches that support the PVN service. As mentioned earlier, not all AFDT switches have SSP functionality. AFDT switches that support Subscriber lines and PABX trunk connections are directly connected to AFDT switches with SSP functionality. Central Offices (CO) that support PVN Service Subscribers are connected, directly or via transit exchanges, to the AFDT switches that have SSP functionality. Here, the CO acts only as an access point. For each PVN call, the CO sends to the SSP, the access code (167X) followed by the PVN identity (NNNN, four digits) in the first message. The next message contains the digits dialed by the caller. Note that the digits 167X and NNNN (where NNNN=PVN identity) are not dialed by the service subscriber, but are automatically generated by the CO when the seizure coming from the PVN service subscriber line is recognized.

The service administration personnel are responsible for the simultaneous updating of the two PVN databases. For each PVN network, a customer control feature is provided to the assigned PVN operator for the management of the Private Network. The customer control feature is implemented on the SSP (AFDT switch). The PVN operator can access the database (normally the primary one). If the primary database is out of service, the call will be routed to the secondary one. The CED (Centro Elaborazione Dati=EDP center) of the PVN is also connected to the PVN operator position to obtain the transfer of data (e.g., billing, documentation data, or traffic measurement data). When the PVN operator position feature is missing in a PVN, this function is assigned to personnel in the service administration.

FIGURE 3.19 shows the network configuration for the PVN service.



CCS = Common Channel Signaling
 V = Voice Path
 S = Signaling Link

DBS = Controlled Database
 AFDT = Exchange of RFD

FIGURE 3.19: NETWORK CONFIGURATION FOR PVN SERVICE

3.4.4 ARCHITECTURE

Italy's strategy to modernize its network and to introduce IN enhanced services requires the installation of centralized databases to support the various nodes which will be equipped with SSP functionality. This requires the disintegration of the SCCP concept now used to provide the GN service where both the SSP and the SCP are resident on a common switch.

Italy's IN installation will occur in phases. A centralized database (the SCP) and a Service Management System (SMS), to support the GN and PVN services will be provided. Italy's Intelligent Networking facility will be built on the following network elements; the Service Switching Point (SSP), the Service Control Point (NCP), the Service Management System (SMS), and the Operations, Administration, and Maintenance system which includes Network Management functions. The Intelligent Network will allow Service Subscribers (SS) to advertise a toll-free number that can be used to access their locations anywhere in Italy. The services offered by the initial stages of implementation are Green Number (GN) (advanced and single) and Private Virtual Network (PVN).

Italy's IN architecture is shown in FIGURE 3.20. A brief description of the components are as follows:

- **Signaling Transfer Point (STP):** All signaling messages between any UT and NCP will be sent via the STP. Global Title Translation (GTT) is performed at the STP.
- **SSP:** Upon recognizing an IN call, the SSP requests call handling instructions from the SCP (for GN and PVN services) using SCCP/TCAP messages.
- **SCP:** The primary element in providing centralized call processing is the SCP, which is the centralized database containing the call handling information of Service Subscribers, i.e., Service Subscriber records.
- **SMS:** A centralized service management system serving as the interface between the Administration/Service Subscribers and the SCPs. The Service Subscriber call routing plans are created, modified, and loaded onto the SCPs through the SMS. Other main functions of the SMS are the logging of service management activities, service maintenance (e.g.,

isolating and resolving problems with the Service Subscriber data), and system reporting (e.g., Service Subscriber plan status, and performance measurements).

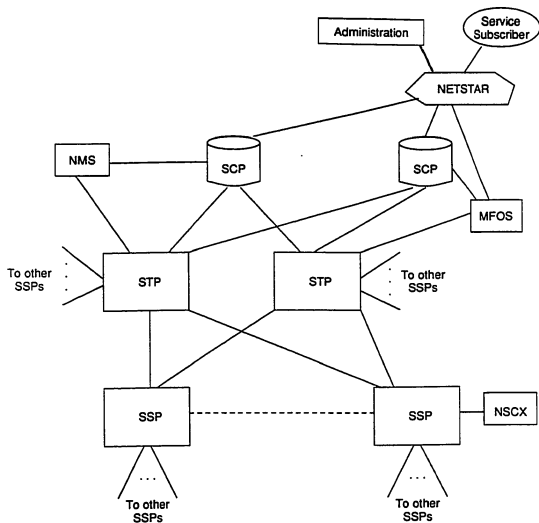
- **OA&M:** This component of the IN provides centralized Operations, Administration, and Maintenance (OA&M) of the following IN elements.
 - **STP Support:** STP maintenance, alarm processing, Recent Change and Verify (RC/V) functions, GTT Table update/management.
 - **SCP Support:** SCP maintenance and alarm processing.
 - **SMS Support:** Alarm processing.

The NMS features provided by the OA&M system are divided into four major functional areas: Surveillance Data Collection, Data Manipulation and Presentation, Control Implementation, and Administration. NMS provides surveillance and analysis of the STP, and surveillance, analysis, and control of the SCP.

3.4.5 SIGNALING

The switches with SSP functionality will be interconnected with standard 2 Mbit/s Pulse Code Modulation (PCM) systems using CCITT No. 7 (Italy) for circuit-related signaling. The same is true for connections with other electronic exchanges in the PSTN that support CCITT No. 7 (Italy). Associated channel signaling is used in cases where the SSPs are connected to electromechanical and electronic switches that do not support CCITT No. 7 (Italy). For the PVN service, CCITT No. 7 (Italy) signaling is mandatory for connections among SSPs, from SSPs to COs, and from SSPs and COs to transit exchanges.

Service Subscriber access to SMS will typically be through CCITT V.24 asynchronous, dial-up connections. For OA&M of the STPs and administration/operations of the SCPs, The OA&M system will interface via CCITT X.25 data links.



SCP: Service Control Point
 System SSP: Service Switching Point

MFOS: Multi-Function Operating System
 STP: Signaling Transfer Point

NMS: Network Management

FIGURE 3.20: ITALY'S IN ARCHITECTURE

3.4.6 SERVICE

The principal services provided by the RFD network are as follows:

SINGLE DESTINATION GREEN NUMBER:

The Single Destination Green Number (SDGN) Service allows Service Subscribers to receive calls placed to a Green Number, and to accept the associated charge for the call. This service provides a simple translation from a Green Number to a Public Switched Telephone Network (PSTN) destination number, and charges the cost of the call to the called number. In some cases, SDGN can utilize announcements to the calling party. There are three call types for the SDGN Service: incoming international, outgoing international, and national.

ADVANCED GREEN NUMBER:

As in the case of Single Destination Green Number Service, Advanced Green Number (AGN) Service allows Service Subscribers to receive calls that will be charged to the Service Subscriber. With the AGN service, subscribers can specify more than one destination number to which calls to a particular GN can be routed. There are three call types for the AGN Service: incoming international, outgoing international, and national. Additional Service Features and Service Capabilities are also available with AGN.

Examples of some of the features that makeup the GN services are, courtesy response on subscription basis, routing by type of day, routing by time of day, routing by country code identifier, routing by district code, barring by district code, and call allocator.

PRIVATE VIRTUAL NETWORK SERVICE:

A Private Virtual Network (PVN) Service Subscriber may use this service to provide its PVN users simplified dialing among themselves via a private numbering plan, and ensured privacy of the communications via appropriate blocking of the calls both inside and outside the PVN. The basic PVN service provides on-net calling with a private numbering plan.

Examples of some of the features that make up the PVN service are on-net calling, off-net calling with selective barring, abbreviated dialing with 3 or 4 digit code, fixed routing, enable/disable of a single subscriber or of a single

PABX, closed user group, audioconference, videoconference, and courtesy response.

3.4.7 Italy ISDN Plans

Italy's Telecommunication modernization plan is oriented towards the implementation of digital techniques and services integration. A strategy is in place to evolve the national telephone network towards ISDN. The evolutionary steps to be taken is to continue the digitization effort in switching and transmission, and to widely introduce CCS7 to the network [9]. In keeping with this orientation, Italy operates in the framework of adopting multiservices signaling systems, interfaces and protocols that are coming from international standards.

Italy's ISDN pilot plan began in 1988 and involved about 2000 subscribers located in seven major cities. The three switch types, the UT Line (Italtel), the AXE (Ericsson) and the TN-16 (Italtel) will be used to provide the ISDN pilot service [7]. It is expected that all digital exchanges throughout Italy will provide the same set of services beginning 1990. FIGURE 3.21 shows Italy's ISDN pilot service plan. Five evolutionary steps are being taken [7] to achieve its goals which are,

1. Transparent Digital end-to-end connectivity at 64 Kbits/sec.
2. ISDN including packet communications, with various multi-service customer interfaces. Integrated services access for voice, data and image processing.
3. Bearer ISDN (OSI), convergence point for existing networks by means of gateways; a reduced set of worldwide standard interfaces.
4. ISDN with high level OSI functions for communication oriented application services; Intelligent network services to meet the needs of the business users and to allow customer control on the network resources.
5. "Intelligent" ISDN with high level functions for application services in general. Enhanced network services, beyond information transport, such as protocol mediation and database access for videotex applications.



FIGURE 3.21: ITALY'S ISDN PILOT SERVICE

It is hoped that the knowledge gained from such ISDN experiments will influence the direction of fully implementing ISDN in Italy. Italy sees ISDN as a general framework for the implementation of an Intelligent Network capable of providing communication services, as well as information handling capabilities. ISDN in Italy is expected to exploit circuit and packet mode operations to provide both voice and non-voice services.

3.5 SUMMARY

Intelligent Network Services were first provided in the United States by the AT&T switched network. Most countries in Europe including The United Kingdom, Spain, and Italy have embarked on modernization plans that will create the Intelligent Networking facilities to offer these services to their customers. The evolution of the IN in Europe follows the combined effect of

successful services deployment strategies, convenient network(s) deployment strategies, applicable standards, and the successful introduction of new technologies as they become available.

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CHAPTER 4

A TOOL FOR SIMULATION STUDIES OF DIGITAL NETWORK ENVIRONMENTS

The design of modern digital communication systems demands both sophistication and flexibility. Computing environments provide different mixtures of sophisticated algorithmic approaches in the solution of engineering problems and database functions for the vendor and component flexibility. Coupled to user friendly software for the interaction and display of results, the CAD facility becomes a necessary tool for the design of most modern digital communication systems.

With the introduction of the Intelligent Network and its services, and with the need to move towards a pure digital transmission environment, it is necessary to study, evaluate, and modify, if required, the existing installation so that quality digital transmission can be achieved. It is with this need that a study of the European environment was attempted. The local loops in the United States have been studied in great detail. We now need to study other environments to determine the modifications on those networks that are necessary to achieve global communication. Different standards have been adopted by the various telecommunication providers in the continents spanning the globe. North America (United States and Canada), Europe (United Kingdom, Italy, and Spain), and Asia (Japan) are examples of continents where different standards are found, ranging from equipment specification to switching and transmission requirements. Different standards make it difficult to provide a service that requires successful and good quality transmission from source to sink in a global network. It is therefore necessary to study those environments outside the United States, and identify the requirements necessary to maintain global connectivity.

The United States local loop environment was studied using an automated tool to simulate the Digital Subscriber System (DSS). Using this tool, scientists at AT&T Bell Laboratories not only documented their findings, but were able to present the data in a form that captured the functions of the entire transmission system.

This CAD environment exists in the following places: In the academic environment, it is known to be at the University of Carleton in Ottawa, Canada, the University of California at Berkley, and the City University of New York, USA. In industry it is known to be available at Bell Communications Research, Morristown, NJ., and AT&T Bell Laboratories in Whippany and Middletown, NJ., USA.

The model that resides with Professor S. V. Ahamed at the City University of New York was used to study the European environment (UK). The results obtained can be generalized for all of Europe, since the standards adopted, and their local loop environments are similar.

The tool was specifically designed to study the United States local loop environment, and as such, was modified for studying the European environment.

4.1 THE SIMULATOR

The seventh CCITT Plenary Assembly has defined ISDN as an evolution from the existing telephone network that provides end-to-end digital connectivity. Wide range of services are anticipated. Both voice and non-voice services will be offered. The network users will have access to these services via the standard multi-purpose customer interfaces. Network Simulation plays a significant role in the services and the capabilities of the future networks. The services and capabilities of any network are direct functions of the switching and transmission systems.

A transmission system response can be characterized by a long periodic sequence of randomly distributed data. Any repetitive periodic phenomenon can be analyzed by Fourier analysis. The flexibility of analyzing the system performance in the spectral domain is available before inverting the Fourier series to obtain the time-domain response. The process is carried out independently for the two directions of data transmission over one pair of wires. Simultaneous bidirectional transmission performance evaluation in the hybrid system entails calculation of reflections arising because of cable and termination mismatch at all harmonics of the overall repetitive period.

Various transmission rates and line codes exist for the local loop plant. In addition, the local characteristics of the loop environment can also vary

significantly from one country to the next, and from one geographical area to the next. In view of the enormous amount of computing required to optimize the system components like the equalizers, echo cancelers, matching circuits, etc., a dependable and inexpensive methodology has been developed to assist the system designer to automatically process each loop simulation as data is transmitted. The techniques are applicable to any simulation environment ranging from time-shared mainframe to stand-alone personal computers. The simulation attempted completely captured the transmission characteristics in the frequency and time domains, for the UK local loop environment. The frequency domain results are discussed in detail in chapter 5. The physical and electrical characteristics are also explored. The time-domain simulations lead to wave shapes and eye diagrams of the received data. The image processing algorithms presented scan the eye diagrams for seven eye statistics; the average positive eye opening, the average negative eye opening, the top eye thickness, the top eye opening, the central eye thickness, the lower eye opening, and the lower eye thickness. These statistics are normalized to the eye height, and the simulation program can then scan many thousands of loop configurations effectively in a single simulation run. The eye statistics are then displayed to indicate broad and significant effects of changing system components like the echo canceler or the equalizer.

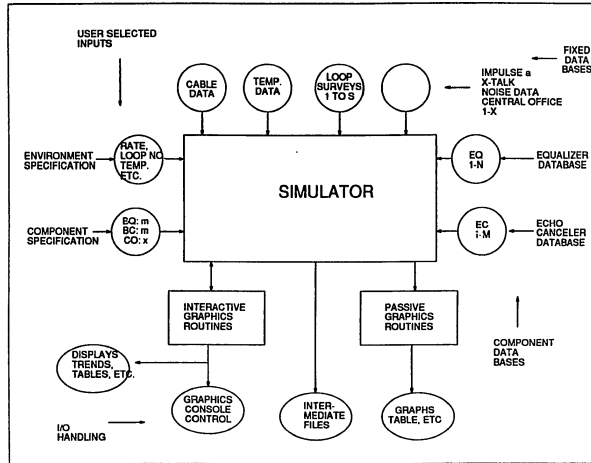


FIGURE 4.1: SIMULATION SYSTEM MODEL

In light of the emerging Intelligent Network to provide a wide variety of services, it becomes necessary for vendors of the network components to ascertain that the network components can perform under a widely varying subscriber loop environment. Experimental verification under laboratory conditions with every possible loop impairment is impractical if not impossible. For this reason, computer simulation studies provide a significant amount of confidence regarding component performance. This approach is highly desirable because the installation of poorly designed components can seriously mar the network performance, and such components can cause bottlenecks in the complete utilization of the network over a period of time.

The simulation models needed for the loop plant are well defined. Loop surveys provide a range of possible loop configurations and loop characteristics. The loop database compiled for the UK (APPENDIX C) was one of the input parameters to the simulator shown in FIGURE 4.1. Echo cancellation and Equalization are two user selected inputs to the simulator module.

The line codes are simulated by providing excitation on both real and imaginary axes. The excitation points are randomly distributed. This periodic, repetitive excitation function is imposed upon the system and the boundary conditions.

The transfer function of the entire system (including filters, equalizers, and echo cancelers), after determining the composite ABCD parameters (see APPENDIX A) of the entire loop (including bridged taps if they exist, and gauge discontinuities), is computed in the frequency-domain. Conversion back to the time-domain is accomplished by performing the inverse Fourier transformation. Results obtained from the simulation are plotted. The graphics software package enables a screen dump with high graphics resolution to a Hewlett Packard (HP) Laserjet Series II printer.

The simulation software assumes an imperfectly equalized channel with imperfect echo cancellation. Initially, the simulations are carried out with a perfect equalizer and an imperfect echo canceler. This is primarily done because varying both the equalizer and the echo canceler results in a highly dispersed cluster. This makes it difficult to study the variation of each parameter separately. The pulse generator generates pulses which provides

the necessary excitation for the simulation module. In the final simulations both the equalizer and echo canceler are assumed to be imperfect.

Automatic eye scanning is desirable in the CAD-oriented component and system development environment. It facilitates the comparison of large cross sections of results. Scanning the eye diagrams, and displaying the pertinent characteristics constitutes only a small part of the overall intelligent CAD facility. The management of permanent, interim and pictorial databases also plays an important part in the conservation and effective use of core and disk space. Vast amounts of information are processed in each simulation run, and only selected amounts of information may be retained for future reference.

The savings in the disk storage is at the expense of processing time. The time required to execute the algorithms presented represents about 60 to 65 percent of the total run time on a typical 80386/80387 based microcomputers. Considerable part of this time is consumed by the disk access. The overall simulation time for the loop can be reduced by allocating additional memory in the mainframe environment or by executing the program in a virtual disk environment.

Computer Aided Design (CAD) in the Data Communication Environment is dependent on necessary features such as a graphical system configuration capability, a set of program selectable simulation routines, management of intermediate cross communication files and databases, and user controlled display programs. To use a particular system for the simulation to provide such functionality, one needs to evaluate the word size (eg. the 32 bit microprocessor systems), the impact of math coprocessors, the high clock rate systems, high capacity disks and Data Base Management Systems, and high quality graphics chips, high resolution graphics adapters, and displays.

Other options required to strike a different balance between the increased execution time and reduction in the storage space are at the discretion of the software designer. When these options are appropriately exercised, simulation runs are rendered feasible. The simulation studies that incorporate eye scanning to generate the eye statistics also yield the Signal to Noise (S/N) ratio for large cross sections of subscriber loops. The increase in the execution time to derive the S/N ratios is minimal.

The local characteristics of the loop environment can also vary significantly from one environment to the next. Experimental verification of the system performance becomes tedious and time consuming in view of the extremely diversified loop conditions and component characteristics. Computer simulation studies prove to be viable, and the system performance may be ascertained in an intelligent computer aided design environment rather than in the laboratory.

The image processing of the eye diagrams obtained with the 2B1Q code for 2B+D rate, and the AMI code will be presented in subsequent chapters. From a designers point of view, it becomes necessary to manage the information that is displayed. At one extreme, when every detail is depicted, the designer is overwhelmed by the quantity of the data displayed. At the other extreme, when the information is too sparse, system performance is not completely depicted. Hence, the number and the type of displays should be matched to indicate the major trends in the performance of the system when any particular design step is implemented.

In addition, enormous amount of computing is required to optimize the system components. Components such as the equalizers, echo cancelers, matching circuits, etc. exert crucial influence on the system performance. These components have to be designed by vendors of channel units at the User (U) interface of the evolving ISDN. It becomes necessary to validate the network performance with the particular components, and the channel units that any proposed system deploys. A dependable and inexpensive methodology which permits the system designer to automatically process each loop simulation is essential. These techniques are applicable to any simulation environment where large amounts of data has to be systematically processed.

4.2 DATABASE ORGANIZATION

The primary aim in establishing the simulation software for any network facility is to evaluate the system performance with the various transmission techniques. The software has to incorporate the following:

- The analysis of electrical circuits (e.g., filters, equalizers, echo cancelers, etc.) which surround the transmitter and/or receiver.

- The systematic simplification of the transmission medium (digital subscriber loops) by suitable network reduction techniques.
- The manipulation of databases to retrieve the pertinent loop and component characteristics.
- The organization of the graphic display files to present the performance characteristics in the appropriate format.

The mathematical techniques like fast Fourier transformations, matrix multiplication, and complex algebra necessary for obtaining the results are well-documented [14]. Techniques for systematic reduction of loops with complex topology are also well established. Dedicated databases containing the loop characteristics were established for this study. Overall system simulation was also feasible. The implementation of the simulation was done on a microcomputer. A three-layer software architecture was used for the Computer Aided Design facility. The first layer, the basic kernel, contains the algorithms necessary for the functioning of the components such as transceiver, loop, data transmitter, encoder, filter, echo cancelers, terminating or matching circuit, timing recovery circuit, filter, equalizers, and decoders. The second layer contains simulated algorithms for the functioning of the echo cancelers and decision feedback equalizers. Loop characterization programs are also a subset of the second layer software. The raw data from the simulation studies is converted into graphic displays to be effectively interpreted. At the third layer, the supporting graphics and utility libraries are implemented.

The most variable component is the subscriber loop. Loop characterization programs thus become a subset of the second layer software proposed here. The influence of loop variations is accommodated by having a global- or region-specific database of the loop make up. When such a database is not available, the database should contain the ABCD matrices (APPENDIX A) for a selected segment of the subscriber loop population. The next element of component variability is due to the spectral variations of the fundamental characteristics (R, L, G and C) of the cables [3] constituting the loops. This, again, is accommodated by having a database of these characteristics at sampled frequencies (APPENDIX B) or, by having library functions to compute the RLGC values, and then computing the ABCD matrices. The

ABCD matrices are derived in APPENDIX A and presented in APPENDIX D (LPABCD) for the entire loop population at the different frequency ranges.

The "ateq" file contains the discrete variables for the equalizers. This file is accessed during the simulation for reading the equalizer values.

The "freq" file contains the various RLGC values at the 0-1 KHz range. This file is accessed during the simulation to read the desired values.

DATABASE MANAGEMENT STRATEGY

Input databases are accessed with a proposed system design to generate system performance. The performance has to be summarized, evaluated, cross compared, reformulated, correlated with the inputs, conceptualized, and optimized by the system designer. In the microcomputer environment, a systematic relational data base methodology is implemented. It also leads to the need for effective graphics to enhance the man-machine communication for the system design optimization.

At the intermediate stages of the system design, the number of databases and active files holding interim results starts to become unmanageable if the results are not used immediately or archived systematically. Thus, a fairly standardized sequence of runs is performed, which use the output of one run as the input of the next. Since the same files are reused for the next run, the demands on the size of the secondary memory may be minimized, and only the final results, generally in the form of graphical files, are saved for system evaluation and cross comparison.

GRAPHICS INTERFACE AND LIBRARIES

The raw data from the simulation studies are processed and displayed by effective graphics. The display of results, and the human element in the feedback process is essential.

ALGORITHM USED - FAST FOURIER TRANSFORM:

The Fast Fourier Transform (FFT), algorithm was presented by Dr. Richard C. Singleton in 1968 to compute a complex Fourier transform [14]. The algorithm is used in the simulation techniques to convert from time to the frequency-domain. The following section provides a detailed background of the algorithm. FFT is an efficient method for computing the transformation [3].

$$\alpha_k = \sum_{j=0}^{n-1} x_j \exp(i 2\pi jk/n) \quad (4.1)$$

for $k = 0, 1, \dots, n-1$, where $\{ x_j \}$ and α_k are both complex-valued, and

$i = \sqrt{-1}$. The complex Fourier transform can be expressed as a matrix multiplication

$$\alpha = Tx \quad (4.2)$$

where T is an $n \times n$ matrix of complex exponentials

$$t_{jk} = \exp(i2\pi jk/n) \quad (4.3)$$

The matrix T can be decomposed as

$$T = PF_m F_{m-1} \dots F_2 F_1 \quad (4.4)$$

where F_i is the transform step corresponding to the factor n_i of n , and P is a permutation matrix. The matrix F_i has only n_i non-zero elements in each row and column, and is partitioned to n/n_i square sub-matrices of dimension n_i . Subscript i is used for a general number between m and 1.

The matrices F_i are further factored to yield

$$F_i = R_i T_i \quad (4.5)$$

where R_i is a diagonal matrix of rotation factors, and T_i can be further partitioned into n/n_i identical square sub-matrices (each is a matrix of complex Fourier transform of dimension n_i). The permutation P is required because the transformed result is in digit-reversed order, i.e., the Fourier coefficient α_j with

$$j = j_m n_{m-1} n_{m-2} \dots n_1 + \dots + j_2 n_1 + j_1 \quad (4.6)$$

is found in location

$$j' = j_1 n_2 n_3 \dots n_m + j_2 n_3 n_4 \dots n_m + \dots + j_m \quad (4.7)$$

The permutation can be performed in place by pair interchanges if n is factored so that

$$n_i = n_{m-i} \quad (4.8)$$

for $i < n-i$. In this case, one can count j in natural order and j' in digit-reversed order, then exchange, α_j and $\alpha_{j'}$ if $j < j'$.

THE ROTATION FACTOR:

The rotation factor R_i following the transform step T_i has diagonal elements

$$r = \exp \left\{ i 2 \frac{\pi}{kk} (j \bmod k) \lfloor j \bmod \frac{kk}{k} \rfloor \right\} \quad (4.9)$$

for $j = 0, 1, \dots, n-1$ where

$$k = n/n_1 n_2 \cdots n_i \text{ and } kk = n_i k \quad (4.10)$$

The square brackets $\lfloor \]$ denote the greatest integer function. The rotation factors multiplying each transform of dimension, n_i

$$0, \theta, 2\theta, \dots, (n_i-1)\theta \quad (4.11)$$

where θ may differ from one transform to another.

DECOMPOSITION OF A COMPLEX FOURIER TRANSFORM:

The complex number $(\alpha_k + ib_k)$ can be decomposed as

$$\alpha_k + ib_k = \sum_{j=0}^{p-1} (x_j + iy_j) \left[\cos(2\pi j \frac{k}{p}) + i \sin(2\pi j \frac{k}{p}) \right] \quad (4.12)$$

$$\begin{aligned} &= x_0 + \sum_{j=1}^{p-1} x_j \cos(2\pi j \frac{k}{p}) - \sum_{j=1}^{p-1} y_j \sin(2\pi j \frac{k}{p}) \\ &+ i \left\{ y_0 + \sum_{j=1}^{p-1} y_j \cos(2\pi j \frac{k}{p}) + \sum_{j=1}^{p-1} x_j \sin(2\pi j \frac{k}{p}) \right\} \end{aligned} \quad (4.13)$$

$$\begin{aligned} &= x_0 + \sum_{j=1}^{(p-1)/2} (x_j + x_{p-j}) \cos(2\pi j \frac{k}{p}) - \sum_{j=1}^{(p-1)/2} (y_j - y_{p-j}) \sin(2\pi j \frac{k}{p}) \\ &+ i \left\{ y_0 + \sum_{j=1}^{(p-1)/2} (y_j + y_{p-j}) \cos(2\pi j \frac{k}{p}) + \sum_{j=1}^{(p-1)/2} (x_j - x_{p-j}) \sin(2\pi j \frac{k}{p}) \right\} \end{aligned} \quad (4.14)$$

for $k = 0, 1, \dots, p-1$.

The remaining Fourier coefficients can be expressed as

$$\alpha_k = \alpha_k^+ - \alpha_k^- \quad (4.15)$$

$$\alpha_{p-k} = \alpha_k^+ + \alpha_k^- \quad (4.16)$$

$$\beta_k = \beta_k^+ + \beta_k^- \quad (4.17)$$

$$\beta_{p-k} = \beta_k^+ - \beta_k^- \quad (4.18)$$

for $k=1,2 \dots, (p-1)/2$, where

$$a_k^+ = x_0 + \sum_{j=1}^{(p-1)/2} (x_j + x_{p-j}) \cos(2\pi j \frac{k}{p}) \quad (4.19)$$

$$a_k^- = \sum_{j=1}^{(p-1)/2} (y_j - y_{p-j}) \sin(2\pi j \frac{k}{p}) \quad (4.20)$$

$$\beta_k^+ = y_0 + \sum_{j=1}^{(p-1)/2} (y_j + y_{p-j}) \cos(2\pi j \frac{k}{p}) \quad (4.21)$$

$$\beta_k^- = \sum_{j=1}^{(p-1)/2} (x_j - x_{p-j}) \sin(2\pi j \frac{k}{p}) \quad (4.22)$$

Altogether, there are $2(p-1)$ series to sum, each with $(p-1)/2$ multiplications, for a total of $(p-1)^2$ multiplications.

4.3 PROCESSES FOR THE FREQUENCY AND TIME DOMAIN SIMULATIONS

Spectral domain analysis is carried out using the ABCD matrix representation of each section in the loop. The matrices are systematically condensed into a single ABCD matrix for the entire loop. From this composite ABCD representation, the transfer functions are extracted and combined with the transfer functions of the other system components such as filters and equalizers. System transfer functions that are generated contain both the attenuation and phase delay information. Hence, at any particular frequency, the system performance can be entirely specified by the transfer functions.

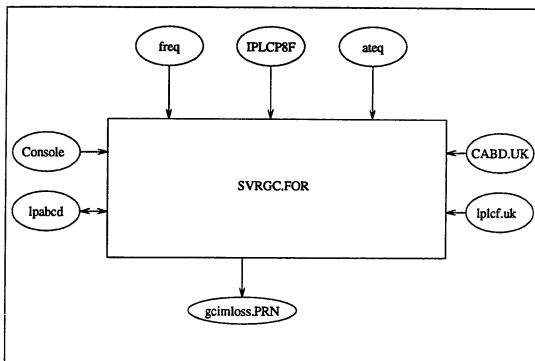


FIGURE 4.2:SIMULATOR FOR GENERATING IMAGE IMPEDANCES AND CABLE LOSSES

FIGURE 4.2 shows a model of the simulator used to study the loop characteristics, and to generate the frequency-domain results discussed in subsequent chapters.

Time-domain simulation that leads to eye diagrams and eye statistics are essential in studying system performance. Two techniques exist. The first technique depends upon calculating the system response over short finite durations of time. Initial conditions are defined, and a predefined sequence of input generates the system response. When steady-state response is desired, the input sequence (of repetitive pattern) is made arbitrarily long, and the output is obtained after the transient conditions have settled down.

In the second technique, the entire system is excited by the repetitive input sequence of an arbitrarily long duration. The boundary conditions at the start and finish of this input sequence are matched, and the system is trapped in a cycle of repetitive performance. The input sequence, with its duration being

user defined, permits one to study the system performance under a wide variety of input conditions. The accuracy of this technique depends upon the number of Fourier components and the sampling interval of the input sequence. These user parameters are generally programmed, and offer the simulationist ample flexibility. In the results presented, the later technique was used with the number of excitation pulses ranging from a minimum of 48 pulses with a sampling frequency of 5 points per pulse, and 65 harmonics. For the 2B1Q code, 96 pulses were used with 10 points per pulse, and 200 harmonics.

EYE DIAGRAMS AND EYE STATISTICS:

Time-domain simulations of the data transmission through the subscriber loop yield the signal pulse shapes at selected points. This signal undergoes a certain amount of processing before the data can be recovered. At the subscriber end, the two major aspects of signal processing include equalization and timing recovery. When the recovered data is superposed in the same time slot, the eye diagram is generated. The loop plant, however, consists of a widely diverse collection of loops. If a given component has to perform with a very large percentage of these loops, then the significant information in the eye diagrams will have to be extracted from the eye diagram of a large number of loops. The eye statistics contain the summary of these significant results.

EYE DIAGRAMS AND LINE CODE:

The line code influences the shape of the eye diagram. Two major line codes for basic rate ISDN transmission are the Alternate Mark Inversion (AMI) and the two Binary to one Quaternary (2B1Q) codes. The standard adopted by the Bell Operating Companies in the US is the latter 2B1Q code [9, 10]. The techniques discussed are limited to these two codes.

THE GENERATION OF EYE STATISTICS FOR THE AMI CODE:

The number of pulses and the number of points per pulse both influence the control parameters necessary for the generation of the eye statistics. These two variables are defined, and held fixed for the simulation of each loop in any particular system configuration. For the purpose of illustration, the eye statistics for a repetitive pulse duration with 48 pulses with 5 points per pulse

are derived. There are three signal levels at +1, 0, and -1 in this code, and two eye openings are generated.

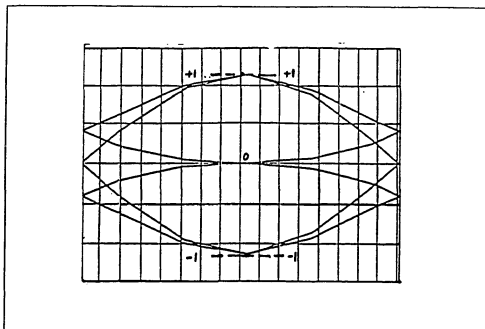


FIGURE 4.3: AN IDEAL EYE DIAGRAM FOR THE AMI CODE

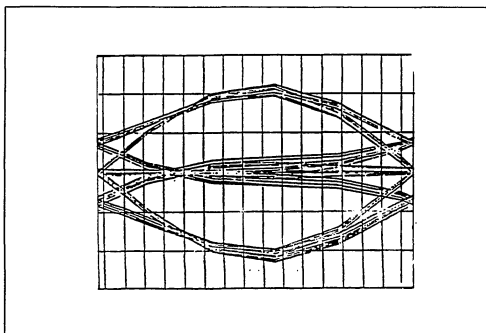


FIGURE 4.4: A PRACTICAL VERSION OF THE EYE DIAGRAM FOR THE AMI CODE

Time-domain simulations for the AMI code lead to wave shapes and eye diagrams for the received data. The eye diagram depicted in FIGURE 4.3 is ideal for the AMI code. There are three levels at +1, 0, and -1, and two eye openings between +1 and 0 and between 0 and -1. Since the ideal eye is not realized in the practical loop environment, a degenerate eye diagram, as shown in FIGURE 4.4, is generally obtained. In this case, the three levels deviate from their idealized values, and form three bands centered at +1, 0 and -1. Superior systems retain integrity of these three levels at the receiver such that the receiver data is clearly discernible. Hence, the system performance may be measured by the thickness of each band of data.

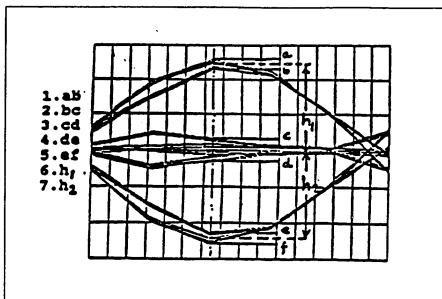


FIGURE 4.5: THE SEVEN EYE STATISTICS OF A TYPICAL EYE

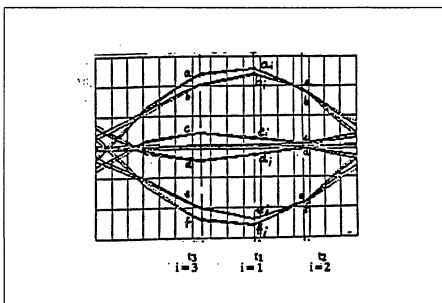


FIGURE 4.6: EYE STATISTICS FROM EYE DIAGRAMS

Two hundred and forty ($= 48 \times 5$) equally spaced instants of time span the 48 pulse period over which the 48 AMI sequence of data pulses is transmitted. The pulses are thus approximated as a sequence of five straight lines (in the time-domain). Out of the 240 instants of time for scanning 48 ones, zeros, or minus ones, 144 ($= 3 \times 48$) instants are selected for the scanning of the 48 data bits. The first set of 48 instants contains the instant at which the absolute maximum value of the incoming magnitude is located. The second set of 48 instants precedes the first 48 instants by $1/5$ the pulse duration, and the third set follows the first 48 instants by $1/5$ the pulse duration.

Next, for each of the three sets of 48 instants at which the scanning can be done, the data is arranged in descending order of magnitude. Three clusters of data are generated: (a) at the upper level corresponding to the plus ones received in the data, (b) at the intermediate level corresponding to the zeros received, and (c) at the lower (minus) level corresponding to the minus ones received. From these clusters, seven eye statistics can be generated (see FIGURE 4.5). In FIGURE 4.6, the three scanning instants t_1 , t_2 , and t_3 , and the three data clusters representing the distances a_i , b_i , c_i , and e_i f_i ($i = 1, 2$ or 3) are indicated. Next, a_i b_i is expressed as a proportion of the average eye height constitutes the top eye thickness. The distances b_i c_i , c_i d_i , and e_i f_i , also expressed as proportions of the average eye height, constitute the top eye opening of the central thickness, the lower eye opening, and the lower eye thickness respectively. Finally, the positive average eye height and negative average eye height constitute the sixth and seventh pertinent eye statistics from the eye diagrams at each of three scanning instants t_i ($i = 1, 2$ or 3).

However, the scanning instant t is selected to have the maximum average top and bottom eye openings leading to a unique scanning instant and a unique set of seven statistics stored for each eye. Two such seven-parameter eye statistical sets for each of the two eyes generated by data from CO to subscriber and from subscriber to CO are thus stored for each loop.

Scanning the eye at three, rather than one instant gives two relevant insights into the functioning of the system. First, the time differential of the opening indicates the horizontal eye opening. Second, the difference in the differential on the positive (i.e., from t_1 to t_2 compared against t_1 to t_3) indicates the asymmetry of the eye. Generally, any tails in the single pulse

response makes the eye opening greater on the t_2 side compared to the t_3 side. These additional numerical quantities govern the timing recovery circuit on the subscriber side. The display of these quantities depends upon the system user.

THE GENERATION OF EYE STATISTICS FOR THE 2B1Q CODE:

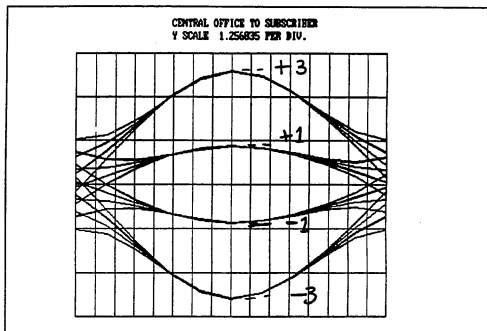


FIGURE 4.7: AN IDEAL 2B1Q EYE DIAGRAM

The ideal 2B1Q code has 4 levels at +3, +1, -1, and -3. These levels correspond to 3 equal eye openings between +3 and +1, between +1 and -1, and between -1 and -3. The idealized eye diagram of this code is shown in FIGURE 4.7.

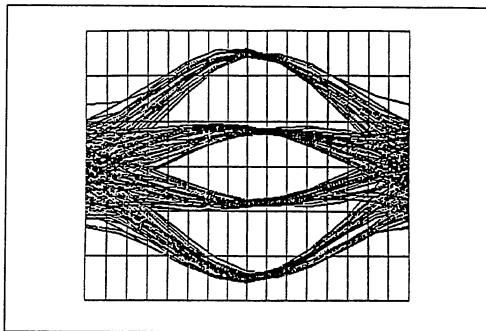


FIGURE 4.8: A PRACTICAL VERSION OF THE 2B1Q CODE EYE DIAGRAM

A practical version of the eye (FIGURE 4.8), has finite bands and associated thicknesses at each of the 4 levels. The number of pulses for the 2B1Q code is 400, and the number of points per pulse is 10. These two variables are predefined, and held fixed for the simulation of each loop in any particular system configuration. These variables will be changed in testing the system for the echo canceler and the equalizer requirements as discussed in chapter 6 and 7. The 2B1Q code has 4 signal levels at +3, +1, and -1, and -3, and three eye openings are generated. The number of eye statistics increases, and the depiction of the composite results for the entire loop population needs reapportionment as the loop database gets larger.

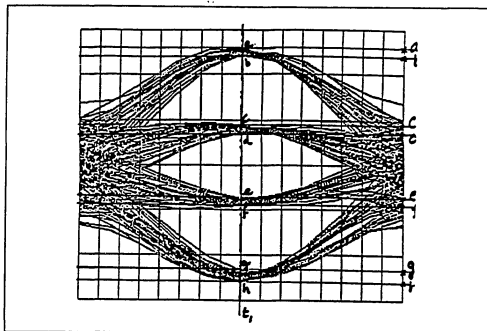


FIGURE 4.9: SCANNING THE 2B1Q EYE DIAGRAM FOR EYE STATISTICS

In FIGURE 4.9, an eye diagram for the 2B1Q code is depicted. At the maximum eye height at instant t , there are seven actual distances ab , bc , cd , ef , fg , and gh which completely characterize the thickness and openings. However, the average heights at the +3, +1, -1, and -3 levels add 4 additional statistics, and there is no elegant way of displaying these 11 statistics even after proportioning the distances to the average values. For this reason, an underlying simplification has been made. All the eye diagrams are rescaled to a maximum eye height from +3 to -3 even if the system cannot perform to yield these extreme values. The seven distances (ab through gh) are then proportioned to generate a composite plot for all the loops. Thus only seven eye statistics are stored for the 2B1Q eye diagrams. The necessity for having seven eye statistics, rather than eleven is to have consistent databases for the AMI and 2B1Q code.

EYE STATISTICS TO COMPOSITE PLOTS:

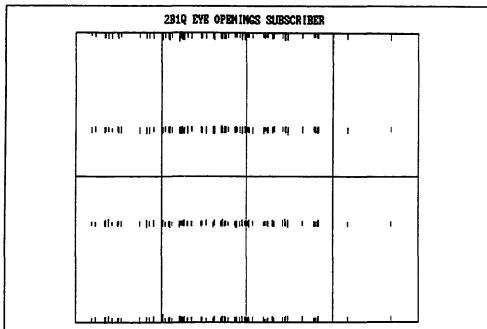


FIGURE 4.10: COMPOSITE SCATTER DIAGRAM OF THE 2B1Q CODE EYE DIAGRAM OF A LOOP POPULATION OF ANY GIVEN LOOP DATABASE

FIGURE 4.10 depicts a composite 2B1Q plot for all the loops in a database for the central office to the subscriber data transmission. Here an ideal 2B1Q eye with zero eye thicknesses would be represented as four points. The eye thicknesses *ab*, *cd*, *ef*, and *gh* in FIGURE 4.9, would be four single points at +3, +1, -1, and -3 levels. However, due to the imperfection of the system, vertical lines of finite length appear at these levels. The eye openings *bc*, *de*, and *fg* in FIGURE 4.9 start to close for a partially closed eye. A completely closed eye would be a vertical line between +3 and -3.

In FIGURE 4.10, the horizontal axis depicts the loop length. Longer loops may display eye closure, since the composite plot becomes dense with longer vertical lines in the left side of the display. Two plots are necessary to depict the bi-directional mode of the ISDN data transmission.

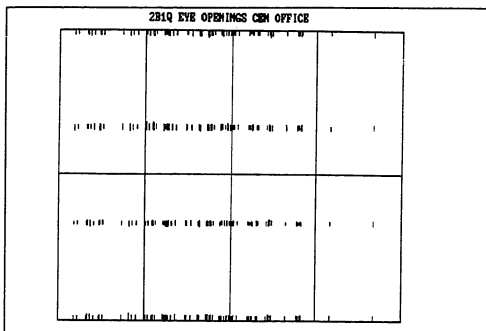


FIGURE 4.11: COMPOSITE SCATTER DIAGRAM OF THE 2B1Q CODE EYE DIAGRAM OF A LOOP POPULATION OF ANY GIVEN LOOP DATABASE

FIGURE 4.11, shows the composite plot at the subscriber side obtained from the eye diagrams at the subscriber. Duplex data transmission with adaptive echo cancellation can suffer more at the subscriber side. Details on the scatter plot will be discuss in later chapters.

4.1 PROCESSES FOR THE EQUALIZERS AND ECHO CANCELER DESIGNS SIMULATION

The simulator shown in FIGURE 4.12 was used to generate the "TIME DOMAIN" results relevant to the design of the design of the equalizer and the echo canceler.

For the time domain simulation, the system is computationally forced into a limit cycle condition. This condition exists when a periodic repetitive excitation function is imposed upon the system and the boundry conditions at the beginning and at the end of the period containing the repetitive excitation

function are identical. In relation to the pulse duration for data transmission, the repetitive period is made arbitrarily long such that a pseudo random sequence of data can be embedded within the period. The simulation capability permits any number of predefined pulse periods to be contained within the repetitive period, thus enabling the long sequences of data (in its entirety) to be resolved into Fourier components.

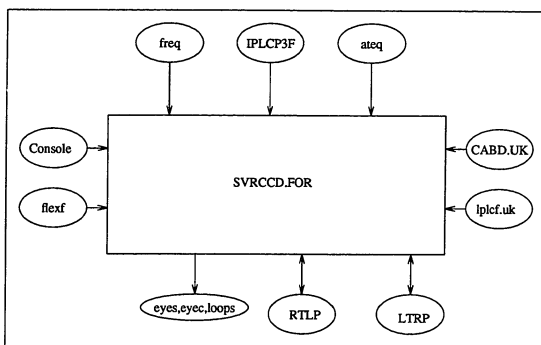


FIGURE 4.12: SIMULATION FOR AMI CODE TIME DOMAIN RESULTS

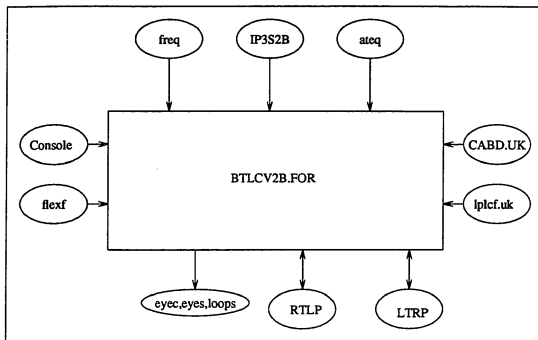


FIGURE 4.13: SIMULATION FOR 2B1Q CODE TIME DOMAIN RESULTS

The circuit capable of canceling the contaminating echo is called the echo canceler. Echoes are generated due to open end reflections of the signal caused by the looping back of the transmitted signal (eg. around a bridge tap). Echo cancellation plays an important role in the subscriber loop environment. The loop performance varies as the echo cancellation in either direction is varied. The echo cancellation in both directions can be the same or different. The maximum echo cancellation realizable in either direction is 60 dB using this simulation. Typical echo canceler configurations are shown in [15].

SIGNAL TO NOISE RATIO:

Signal to noise ratio is defined as:

$$\text{Signal Noise Ratio (S/N)} = \frac{\text{Signal Power}}{\text{Noise Power}} \quad (4.23)$$

where,

$$\text{signal power} = \frac{\sum (\text{individual signal power})^2}{\text{number of points}}$$

and

$$\text{noise power} = \frac{\sum (\text{individual noise power})^2}{\text{number of points}}$$

The above equation can be used to compute the S/N ratio. Individual noise power in the simulation is the deviation of the cluster from its expected position. The S/N ratio can also be represented in decibels as $10 \log (S/N)^2$ or $20 \log(S/N)$.

Loops having a S/N ratio of 20 dB or lower cannot be considered for data transmission. The noise level in such cases is too high for any recovery of the signal at the receiving end. In such subscriber loops, conditioned telephone lines are needed to compensate for the noise. In calculating the S/N Ratio, it is assumed that there is no random noise in the cluster.

CIRCULAR SCATTER PLOTS:

ISDN simulations provide large amounts of significant results. In FIGURE 4.8, the shape and deformity of the eye diagram with 2B1Q code is displayed as data is transmitted over a typical loop. There are three eye openings in this composite diagram between +3 and +1 levels, +1 and -1 levels and -1 and -3 levels.

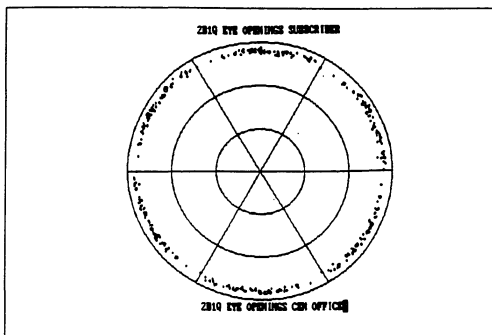


FIGURE 4.14: COMPOSITE CIRCULAR SCATTER DIAGRAM OF THE 2B1Q CODE AT BASIC ACCESS RATE

In FIGURE 4.14, two sets of three scatter plots of the eye openings with this particular code, and 60 dB of echo cancellation for an entire loop population are depicted in a condensed format. The six (60 degree) segments each depict an individual scatter plot. The top half of the plot (FIGURE 4.15) condenses the information for the central office to subscriber transmission. The lower half depicts the subscriber to central office transmission. In each of the 60 degree segments, the loop length is represented as the angle, and the radial distance represents the eye opening. Ideally, the points in the scatter plot should lie on the perimeter of the outside circle for 100 percent open eye diagrams.

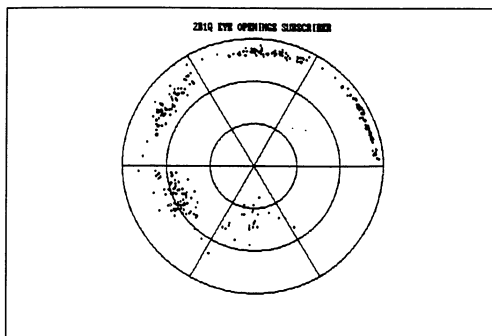


FIGURE 4.15: THE EFFECT OF ECHO CANCELLATION ON THE CENTRAL EYE OF THE 2B1Q CODE AT THE SUBSCRIBER

In FIGURE 4.15, the effect of changing the echo cancellation is depicted. Each of the six scatter plots depict the central eye opening of the 2B1Q code as the entire loop population is equipped with 60 dB, 54 dB, 48 dB, 36 dB, and 30 dB of echo cancellation circuitry. The variety of results and designs becomes enormous. Such results are studied in detail and discussed in chapters 6 and 7.

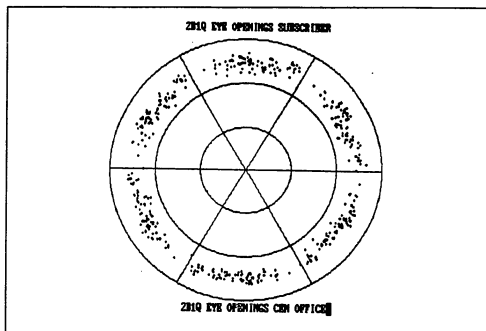


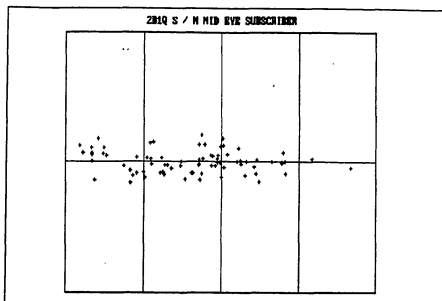
FIGURE 4.16: THE EFFECT OF ECHO CANCELLATION ON THE CENTRAL EYE OF THE 2B1Q CODE AT THE CENTRAL OFFICE SIDE

FIGURE 4.16 depicts the effect of changing the echo cancellation for the data transmission at 400 KHz and 50 db echo cancellation.

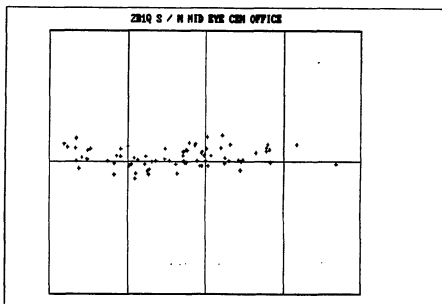
SIGNAL DEGRADATION AND S/N RATIO SCATTER PLOTS:

The echo canceler for the 2B1Q code has to perform dependably over a very wide range of loops and meet the 60-65 dB cancellation requirement. Performance variations at such fine levels can not be depicted by eye diagrams and eye openings, even though they depict gross effects and trends. For this reason, when the components have to be fine tuned, the degradation of the received and equalized signal becomes crucial. The echo that corrupts the signal depends upon the near end loop configuration and the signal suffers a steady attenuation, and degradation depending upon the entire loop configuration. Sometimes it becomes necessary to isolate the component of the noise and correlate it to the particular component, or the function of a circuit in that component responsible for the added noise. In

these circumstances, the signal-to-noise plots become more graphic in their depiction of the cause effect relationship.



**FIGURE 4.17: SIGNAL TO NOISE (FOR THE CENTRAL EYE)
SCATTER PLOT AT THE SUBSCRIBER**



**FIGURE 4.18: SIGNAL TO NOISE (FOR THE CENTRAL EYE)
SCATTER PLOT AT THE CENTRAL OFFICE**

FIGURES 4.17 and 4.18 depict two plots of 400 KHz at 50 db echo cancellation. The signal-to-noise ratio at the receivers (at the subscriber and at the central office) for the 2B1Q code are depicted with a perfect equalizer. The X-axis depicts the length, and the Y-axis depicts the S/N ratio in each of the three eyes. It is possible to vary the parameters for the actual computation, and thus study their effects precisely.

4.1 SUMMARY

An automatic scanning of the eye to evaluate system performance under the highly variable system and loop configuration facilitates the comparison of a large cross sections of results. The algorithms presented generate diagrams and plots which can be easily scanned by the system designer to get a qualitative picture of the acceptance or rejection of a certain system. With this initial inference, the system designer may pursue promising system configurations. When more detailed evaluation is necessary, other scatter plots with signal-to-noise ratios or circular plots may be attempted with additional computing and programming efforts.

The time required to execute the algorithms presented represents approximately 15 to 20 percent of the total execution time. A considerable part of this time is consumed by the disk access. Total overall simulation time for the loop can be reduced by allocating additional memory in the mainframe environment, or by executing the program in a virtual disk within the PC environment.

The simulation studies that have been attempted incorporate these eye scanning postprocessors for generating the eye statistics and to derive the signal-to-noise ratio (20 times logarithm to base 10, of the ratio of eye opening to eye closure).

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CHAPTER 5

SIMULATED FREQUENCY DOMAIN RESULTS OF THE UK LOCAL LOOPS

Digital data transmission over existing loop plant facilities has been envisioned by numerous organizations around the world. In Japan, [1,2] initial designs for digital data transmission rates up to 64 kb/s are being investigated. In Switzerland, there has been initial interest [3] to provide an overall transmission rate of up to 160 kb/s. In Sweden, an 80-kb/s burst system, operating at 256 kb/s in 125- μ s slots has been investigated [4]. In Norway [5], digital pulse-code modulations (CPM) hybrid transmission rates greater than 64 kb/s (up to 80 kb/s) have been analyzed. In Great Britain, hybrid 64-kb/s channels have been proposed [6,7] by superimposing them over the baseband analogue telephone communications. Other Western European countries [8,9] (Germany, France, and Italy) have started discussion of high-speed digital transmission.

5.1 THE UK LOCAL LOOP STUDY

In every telephone loop there is a wire pair (cable) that provides the medium for carrying analogue baseband signals or digital transmission for a major part of the loop. Fiber will most likely replace the copper as the medium for transmission sometime in the future. Wire cable, in amounts of hundreds of billions of conductor feet installed in networks around the world, is connected together to form a global telecommunication network.

Digital switching and digital transmission are two important technologies of the Integrated Services Digital Network (ISDN). Analogue voice or voice band data signals from customer premises transported over the local loop are digitized at the Central Office, using either Pulse Code Modulation (PCM) at 64 Kbps or some other encoding scheme. The digitized signals are time division multiplexed to 2.048 Mbps conforming to European CEPT hierarchy.

Extending digitization to the local loops enables the provision of a variety of new digital services to the customer. ISDN implies digital connectivity among various customers. Customer premises equipment are connected to the

Central Office through digital subscriber lines where the signals are demultiplexed and switched. The digitization of the local loop provides full duplex transmission at speeds of up to 160 Kbps over 2-wire twisted pair which traditionally was used to provide 4 KHz analogue voice or voice band data.

Duplex transmission of data and speech from the Central Office exchange to the customer premise has been proven [10] to be dependent on:

1. The loop length: The length of the conducting path (circuit) from the exchange to the customer premises.
2. Bridge Taps: Extension of the distribution cable beyond the customer premise.
3. Number of bridge taps: The connection of other bridge taps to one or more points along the distribution cable route.
4. Cable size (AWG): The cable size can and will vary along any given cable route.
5. Other properties: Electrical (resistance, inductance, capacitance) and environmental (temperature, number of cables in bundle, insulating medium, etc.) properties may also vary along the cable route.

5.1.1 THE PHYSICAL CHARACTERISTICS

British Telecom subscriber loop plant consists of both copper and aluminum. In this study properties of the copper cables will be addressed since the aluminum cables are being gradually phased out of the network. A sample of eighty-one loops taken from five typical exchanges (Hounslow, Ruislip, Skyport, Uxbridge and Greenford) in the British Telecom network have been studied and the results generalized for the entire British Telecom network. The two databases compiled for the simulation on the UK environment were the UK cable database (cabd.uk) see APPENDIX B, and the UK loop database (lplcf.uk) see APPENDIX C.

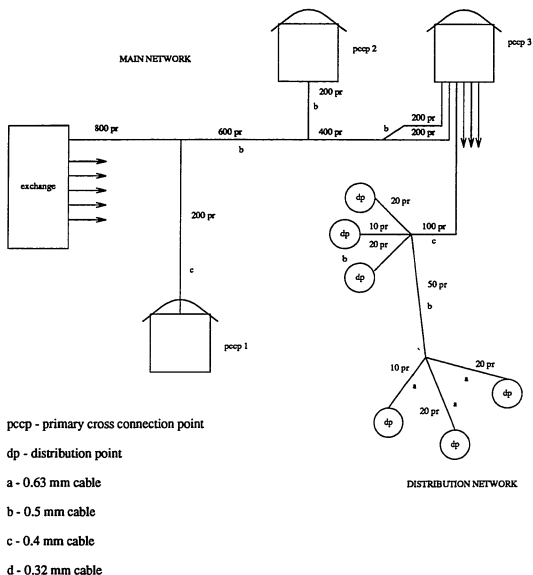


FIGURE 5.1: Typical section of the local loop distribution

The cable section length studied in the local loop database ranges from 950 to 18,000 ft. A typical section of the local loop network is shown in FIGURE 5.1. The wire gauges used in the network are shown in TABLE 5.1. Over 90% of all loops studied left the exchange with a cable size of .32 mm (28 AWG) and increased gradually in size as they approached the customer

premises.

Conductor dia. (mm) UK	U.S.A. Equivalent (AWG)	Average proportion of route length (%)	Typical dc loop resistance per km (Ω)	Typical length per k Ω loop resistance (km) (at dc)	Typical length for 40 dB atten at 100 kHz (km)	Avg. atten of 2.6 km loop at 100 kHz (dB)
0.90	19	< .1	86.9	55	10.6	9.8
0.63	22	13.9	174.3	9.1	7.3	14.3
0.50	24	47.5	277.2	5.9	5.6	18.6
0.40	26	33.2	440.7	3.7	3.8	28.2
0.32	28	2.4	692.9	2.3	2.7	38.6

TABLE 5.1: TYPICAL CABLE GAUGES AND ELECTRICAL CHARACTERISTICS

There is no 28 AWG cable in the United States subscriber loop environment. The Computer Aided Design (CAD) facility [11,12] designed by Professor S. V. Ahamed was not initially designed to handle 28 AWG or loops with a combination of gauges that include the 28 AWG. Hence, it was essential to modify the CAD facility to process British Telecom loop data that include the 28 AWG.

The length of the subscriber loop directly influences the various channel parameters such as signal power loss (propagation loss) and linear (amplitude, phase, and delay) distortion [10]. The compensation for the linear distortion introduced by the twisted pair channel is usually not trivial and requires the use of expensive transceiver functions. Phase distortion introduces different delays between different frequency components of the data signal, thus generating dispersion of the signal and intersymbol interference. Attenuation is also present causing an enhanced susceptibility to noise.

The UK local loops can be characterized as being short with no bridge taps when compared to those in the United States. Fewer number of cable sections are present which results in longer cable lengths in the loop sections. Along a typical cable length there can be as many as 3 to 4 different cable sizes. The number of sections in the loops range from 1 to 23. Table 5.2 lists the physical loop characteristics.

Loop Length (ft)	Avg. Loop Length (ft)	Avg. No. of Sections	% of Loop Representations
0 - 1,000	955	1	1
1,001 - 2,000	1,662	2	9
2,001 - 3,000	2,419	1	6
3,001 - 4,000	3,711	10	1
4,001 - 5,000	4,340	4	6
5,001 - 6,000	5,320	3	10
6,001 - 7,000	6,371	6	10
7,001 - 8,000	7,425	8	3
8,001 - 9,000	8,582	7	14
9,001 - 10,000	9,684	7	11
10,001 - 11,000	10,241	9	8
11,001 - 12,000	11,230	6	7
12,001 - 13,000	12,250	3	5
13,001 - 14,000	13,761	12	5
14,001 - 15,000	14,123	12	2
15,001 - 16,000	15,850	3	1
16,001 - 17,000	—	—	—
17,001 - 18,000	—	—	—
18,001 - 19,000	18,402	15	1

TABLE 5.2: PHYSICAL LOOP CHARACTERISTICS

Note that 14% of the loops in the study fall within 8001 ft. to 9000 ft. About 68% of the loops fall within the range of 5001-13000 ft.

5.1.2 ELECTRICAL CHARACTERISTICS

The cable data (electrical characteristics) that exist for the United States were not applicable for the UK because of the different manufacturer's specifications. Moreover, no data existed for the 28 AWG with regards to its

Resistance, Inductance, Conductance and Capacitance (R, L, G, C). These values were derived¹ and entered into the fixed database named "cabd.uk" of the simulator.

The range of frequencies at which the loop plant characteristics become significant depends upon the mode of transmission and the line code chosen for the application. The mode of transmission influences the line rate while the line code influences the actual symbol rate. In the United States, the Bell Operating companies have chosen the 2B1Q code for the basic rate ISDN access. The AMI and the 2B1Q codes were used in the simulation study. Codes, rates, and extent of equalization and echo cancellation have also been considered.

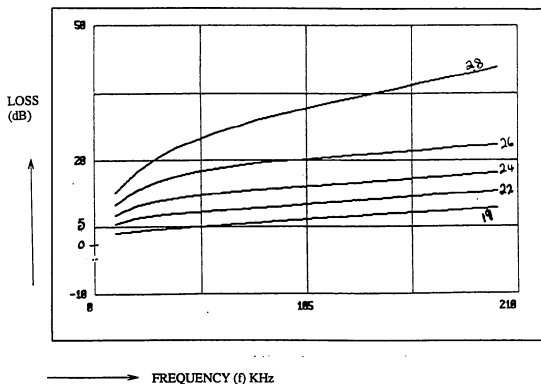


FIGURE 5.2: LOSS IN THE DIFFERENT GAUGE CABLES.

1. Telephone conversations among Mr. Wendel Nut of AT&T in Winston Salem, North Carolina, S. V. Ahamed and V. C. Ramkumar in December 1989.

The frequencies chosen in the simulation of the UK environment to span the spectral band ranges from 10 to 200 KHz. The loops studied have signal losses ranging from 5 to 22 dB at 50 to 200 KHz for the 19, 22, 24 and 26 AWG cables. The 28 AWG cable showed a rise from 25 to 40 dB loss at the 50 to 200 KHz range shown (FIGURE 5.2). These losses indicate the dynamic range for line equalization devices necessary at the line termination unit. They also indicate the loss in the signal strength as it travels to and from the customer. Such losses however, must be interpreted in conjunction with the crosstalk and impulse noise characteristics inherent in the loop plant. Highly attenuated signals resulting from larger loops and high bit rates become prone to inaccurate and noisy signal transmission.

IMPAIRMENTS IN THE DIGITAL SUBSCRIBER LOOPS:

Impairments for the transmission of data in the digital subscriber's loop arise from the electrical and physical nature of the subscriber's network. Three major impairments arising from the electrical characteristics of the grouping and collection of twisted pair wire cables are crosstalk, impulse noise, and the echos and intersymbol interferences introduced at the receiver due to the imperfection of the signal recovery function. The physical nature of a network is generally dependent on:

- the presence of non-continuous cable sections
- bridge taps (none in the UK) and,
- imperfect line conditions resulting in severe attenuation, dispersion, and echo conditions.

These impairments become a limitation on the range and rate at which data can be accurately transmitted. Channel impairment in loop plant are relevant to data transmission even though these impairments may not affect the intelligibility of speech. Their effects become significant for digital transmission at higher frequencies. The dependency of these impairments on physical parameters, such as loop length and wire gauges, and mismatch of impedances and frequencies is discussed in great detail in .

A typical loop has R, L, G and C as the primary constants. In a twisted pair cable the secondary constants can be written as

$$\gamma(\omega) = \alpha(\omega) + j\beta(\omega) = \sqrt{(R+j\omega L)(G+j\omega C)}, \quad (5.1)$$

where $\omega = 2\pi f$ (A complete derivation is given in APPENDIX A).

The transfer function, $H(x, f)$, of a cable with length x is given as a ratio V_x to V_i from equations (A-9a) and (A-9b) (APPENDIX A). The frequency dependence is realized by the Z_0 and γ terms

The attenuation through the cable at a distance x and frequency f is equal to,

$$L_{dB}(x, f) = -20 \log_{10} |H(x, f)| = \frac{20}{\ln 10} x\alpha(f) \approx 8.686 x\alpha(f), \quad (5.2)$$

where the attenuation is expressed in dB. Notice the linear dependency of the loss L_{dB} on the length x of the cable.

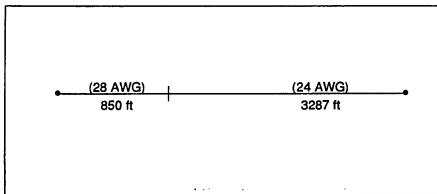


FIGURE 5.3: LOOP #19

Loop #19 in the UK network is made up of two sections, 850 feet of 28 AWG cable and 3287 feet of 24 AWG cable, where the loop leaves the Central Office with the 28 AWG and enters the customer premise with the 24 AWG,

see FIGURE 5.3. This loop was used in the initial simulation work. It was chosen for its short length and the inclusion of the 28 AWG section. The loss experienced by loop #19 increases as the frequency increases as shown in FIGURE 5.4.

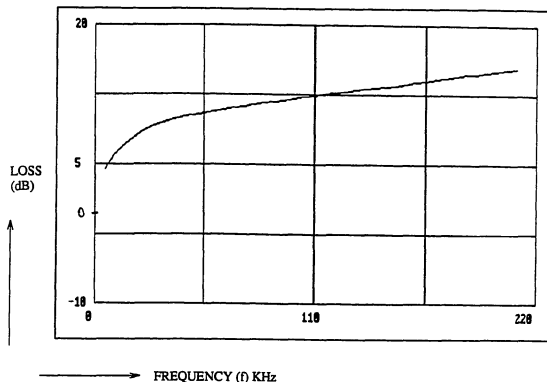


FIGURE 5.4: LOSS IN LOOP #19

The loss on this loop is the same in both directions between the Central Office and the subscriber.

To estimate the loss in power by a data signal transmitted over a twisted pair channel, we let $L_{dB}(d_i, f)$ be the power loss experience by a sine wave with frequency f over a single gauge loop with length d_i , and let $\Delta L_{dB}(d_i, f)$ denote the incremental quantities. Then from eq. (5.2) we have,

$$\frac{L_{dB}(d_i, f)}{L_{dB}(d_j, f)} = \frac{d_i}{d_j} \quad \text{and} \quad \frac{\Delta L_{dB}(d_i, f)}{L_{dB}(d_j, f)} = \frac{\Delta(d_i)}{d_i} \quad (5.3)$$

To a first approximation, the loss in power of a data signal is equal to the loss, $L_{dB}(d_i, f_c)$, experience by a sine wave having a frequency equal to the

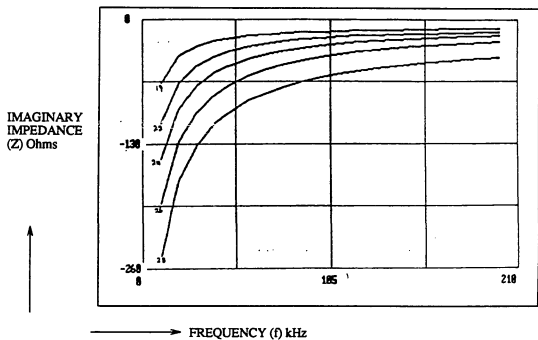
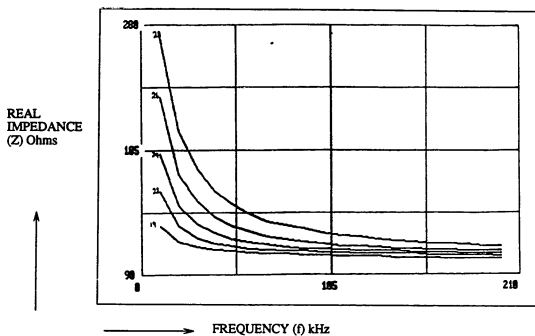
carrier frequency f_c for a signal.

The loss dB introduced by the loop at frequency f can be written as

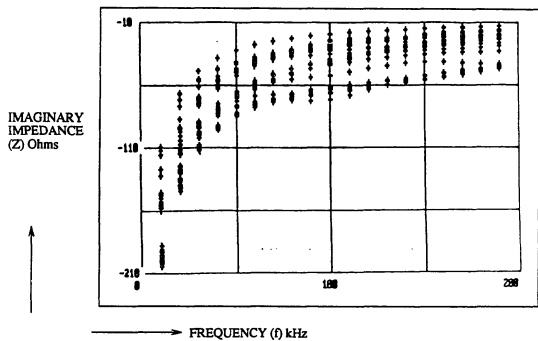
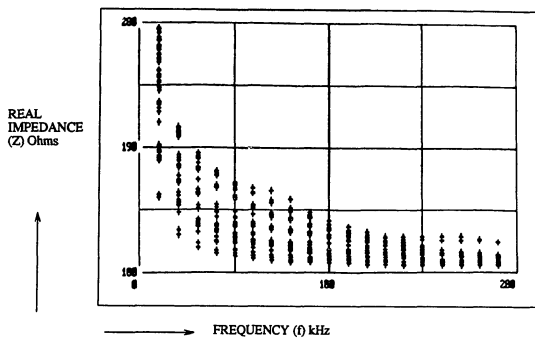
$$L_{dB}^*(d, f) \approx L_{dB}(d, f) + 20 \log_{10} |1 + \rho_I(f)|, \quad (5.4)$$

where, $L_{dB}(d, f)$ is the loss in the absence of impedance mismatch. The 2nd term in the expression provides a measure of the amount of energy reflected by the mismatched load impedance.

As seen in the British Telecom network the wire gauges (APPENDIX C) vary along the loop length. This will generate reflections and introduce an impedance discontinuity at the connection point of any two loop sections where the change in gauges occur. Thus you need to transmit at a frequency where all gauges will have the same characteristic impedance.



FIGURES 5.5 & 5.6: CENTRAL OFFICE to SUBSCRIBER (all AWGs)



FIGURES 5.7 & 5.8: CENTRAL OFFICE to SUBSCRIBER (ALL LOOPS)

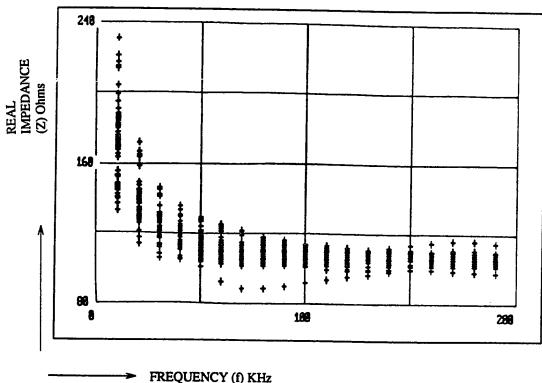


FIGURE 5.9: IMPEDANCE OF LOOP POPULATION FROM SUB TO CO.

FIGURE 5.5 shows the impedance ($Re Z$) of the 19, 22, 24, 26 and 28 AWG cable at frequencies ranging from 10 to 200 KHz. Ideally, we would like to transmit at a frequency where all gauges exhibit the same characteristics. It is in the 150 - 200 KHz frequency range that we begin to see that the characteristics, though slightly different, are stable and monotonic.

FIGURE 5.6 shows the imaginary components of the impedance ($Im Z$) for the same cables. The characteristics also display stable values and are monotonic in the same frequency range.

Simulation results for the electrical characteristics of the entire local loop distribution in the UK network also show a stable environment in the 150-200 KHz frequency range. FIGURE 5.7 shows the ($Re Z$) in transmitting from the Central Office to the subscriber at a frequency range from 10 to 200 KHz. FIGURE 5.8 shows the ($Im Z$). There is however, a relatively more stable

environment in transmitting from the subscriber to the Central Office as seen in FIGURE 5.9. The impedance ranges from 80 to 240 Ohms in the 10-200 KHz frequency range as compared to 100 - 280 Ohms in transmitting from the Subscriber to the Central Office. The best case is when FIGURES 5.7 and 5.9 are identical. The transmitted signal faces an impedance discontinuity as it enters each loop and again where there is a change in wire gauge. This discontinuity prevents the signal to be uniformly attenuated and dispersed throughout the loop thus causing a frequency dependent reflection of the transmitted signal. The reflected signal is now in the same direction as the received signal and can severely contaminate the far end signal (or symbol) recovery process. As these results show, the Central Office and Subscriber end channel units must accommodate this difference in behavior when transmitting the signals.

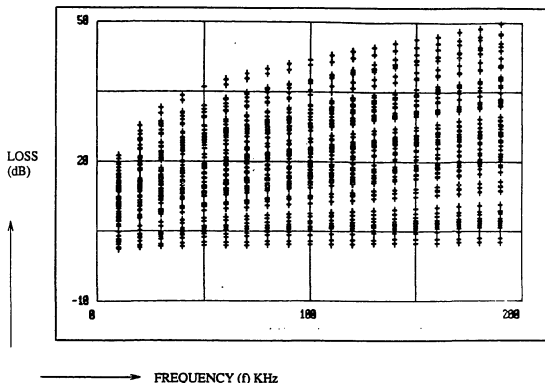


FIGURE 5.10: LOSS IN ENTIRE LOOP POPULATION

FIGURE 5.10 shows the loss in dB for the entire loop population at the frequency range of 10 to 200 KHz. The loss approaches 50 dB as we transmit in the 150 to 200 KHz range. From FIGURES 5.2, 5.4 and 5.5 the cable characteristics though not ideal are still acceptable in the 150 - 200 KHz frequency range, further the successful transmission has to accommodate a significant cable loss. Channel units at the Central Office and at the subscriber end must also be able to dynamically compensate for the losses over the entire spectrum of frequencies.

The characteristic impedance Z_0 is independent from the loop length and can be calculated from

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \quad (5.5)$$

Where, $j\omega L$ and $j\omega C$ are the imaginary components.

The electrical characteristics of loop #19 (Figure 5.3) has been examined and shown here for comparison to the total loop population.

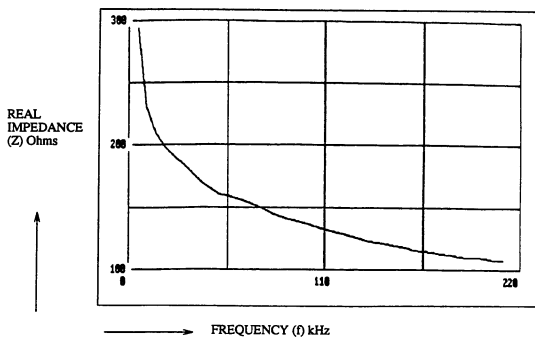


FIG. 5.11

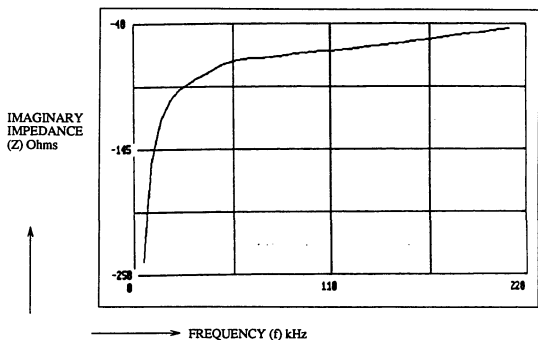
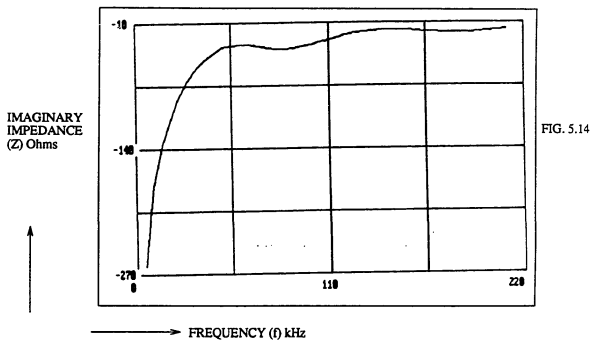
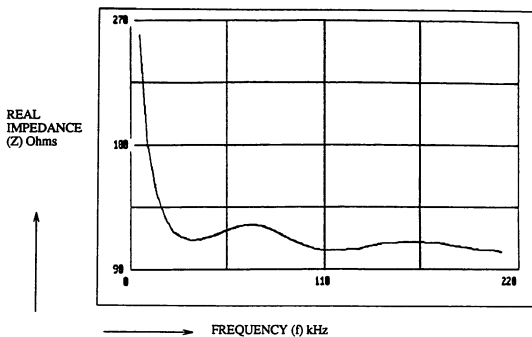


FIG. 5.12

FIGURES 5.11 & 5.12: CENTRAL OFFICE to SUBSCRIBER (LOOP #19)



FIGURES 5.13 & 5.14: SUBSCRIBER to CENTRAL OFFICE (LOOP #19)

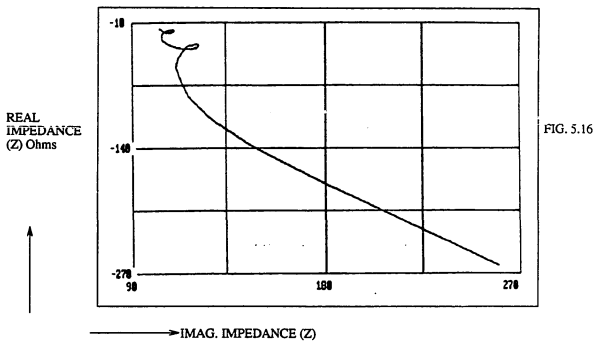
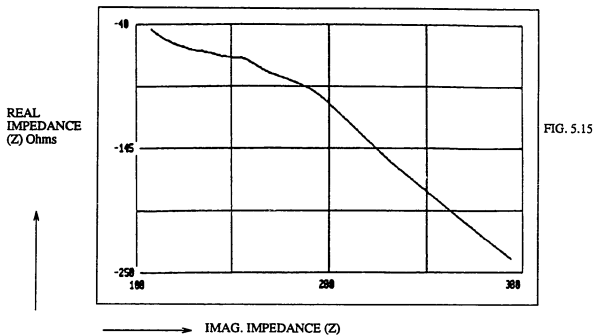


FIG. 5.15:(CO \rightarrow SUB) & FIG. 5.16:(SUB \rightarrow CO) - LOOP #19

FIGURES 5.11 and 5.12 show the real and imaginary impedances respectively for loop #19, over a frequency range between 10 and 200 KHz when transmitting from the Central Office to the Subscriber. FIGURES 5.13 and 5.14 show the real and imaginary impedances in transmitting from the subscriber to the Central Office at the same frequency range. Notice that there is a difference in the impedance in transmitting to or from the subscriber. A plot of the real versus the imaginary impedances from the Central Office and the subscriber, and from the subscriber to the Central Office are shown in FIGURES 5.15 and 5.16 respectively. Ideally the plots in FIGURES 5.15 and 5.16 should be as close to straight lines as possible.

A plot of the real versus the imaginary reactance for the entire loop population is shown in figure 5.17 for the Central Office to the Subscriber and figure 5.18 for the Subscriber to the Central Office. Figure 5.19 shows the real versus the imaginary reactance for the individual cables. Notice the distinction of the 19 and 28 AWG.

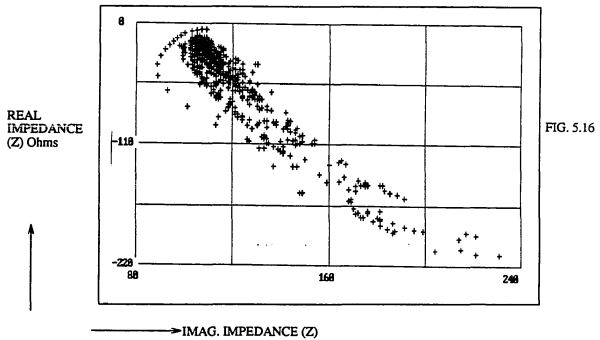
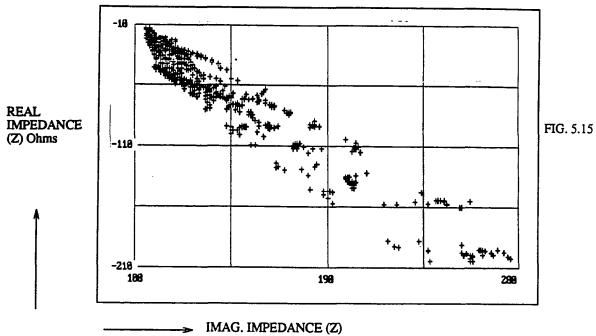


FIG. 5.17:(CO -> SUB) & FIG. 5.18:(SUB -> CO) All loops

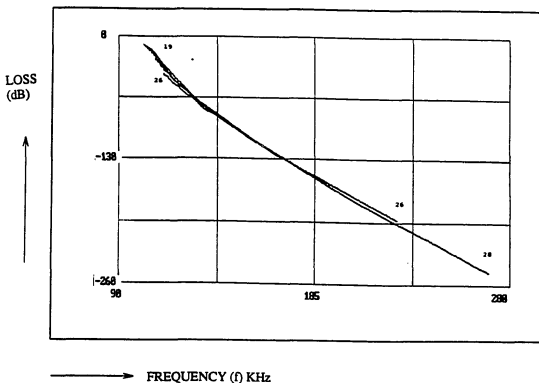


FIGURE 5.19:CO --> SUB. Real vs Imaginary reactance for all Wire Gauges

5.1.3 CSA TYPE ENVIRONMENT

The Carrier Serving Area (CSA) as defined in the American loop environment refers to subscriber loops within a close area served by a central office, and adhering to specific CSA requirements. The five CSA loop requirements are:

- (a) There are no loading coils anywhere in the loop.
- (B) The total length (including the bridge tap length if any) of 26 AWG cable is less than 9000 ft.
- (c) The total length of bridge taps in the loop must be less than 2,500 ft. with no single bridge tap exceeding 2000 ft.
- (d) The number of gauges is limited to two (excluding bridge taps) along the loop.

- (e) The total length of all 24, 22, and 19 guage cables in the loop (including bridge taps) is limited to 12,000 ft.

CSA subscriber loops present a wide range of spectral characteristics which have been studied in great depth in the US. In examining British Telecom's local loop environment, it can be pointed out that there are no bridge taps, there are loops with more than 12,000 ft in length, there are loops with more than two guages, and the finest wire guage (WG) is 28 and not 26. Thus specific requirements on the British Telecom's local loops differ from the CSA loop requirements. These specific British Telecom local's loop requirements are explored in chapters' 6 and 7. It is necessary to examine the CSA requirements in the British Telecom network. We are not aware of any such publications on British Telecom CSA requirements.

5.2 SUMMARY

Many countries around the world are making special efforts to implement ISDN. Extending digitization to the local loops will bring a variety of new services to the Service subscribers.

The transmission of data and speech in the local loops are dependent on the physical characteristics (loop length, bridge taps, cable size, etc.) and the electrical properties (Resistance, Conductance, Capacitance, Inductance, etc.). Both the physical and electrical characteristics of any loop plant must be investigated before a concise specification of the transmission quality can be determined.

Eighty-one loops from 5 exchanges in the UK were studied. The physical and electrical characteristics of the loops are discussed with the aid of diagrams obtained from the simulation runs. The main wire guages used in the UK are 0.32mm, 0.4mm, 0.5mm, 0.63mm, and 0.9mm which are equivalent to the 28, 26, 24, 22, and 19 AWGs respectively. The loops in the UK network are short and free of bridge taps when compared to those in the United States.

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CHAPTER 6

SIMULATED TIME DOMAIN RESULTS OF THE UK LOCAL LOOPS

Transmission of digital data is a time-domain phenomenon. However, electronic circuitry and cable characteristics are better defined in the spectral domain. Hence, to simulate the entire physical process of the data transmission, a limit-cycle [1] approach is used. The entire system, the electronic circuitry, and the individual loop under study is forced into a periodic function in which the boundary conditions at the beginning and the end of a predefined period are identical. The approach facilitates the transformation of the cyclic time-domain phenomenon into its harmonic spectral-domain components by Fourier series. Enough flexibility is provided to alter the mode of excitation to correspond to any random or specified pulse pattern within a sufficiently long period.

In this section, the time-domain results of typical hybrid data transmission systems is presented. The time-domain response of a transmission system is critically important in evaluating its capabilities to carry digital data. Such a response can be obtained from the spectral-domain response of the system by using conventional or Fast Fourier Transforms.

6.1 THE TRANSMISSION CHARACTERISTICS

Line codes influence system performance since the signal energy distribution can be radically different. Line codes affect the range and susceptibility to errors arising from the digital Subscriber line impairments. Many line codes exist. The choice of a particular code for the Integrated Services Design Network applications depends upon the bit rate and characteristic of the loop plant. At the 80 Kbits/s or (B + D) access, the Subscriber loop environment displays features different from those at the 144 Kbits/s or the (2B+D) access. The widely used code in the trunk and loop plant is the Alternate Mark Inversion (AMI) code. For basic rate access ISDN the 2 binary 1 quaternary (2B1Q) has been accepted as a standard in the United States. The AMI is accepted for easy coding, and decoding, and for average zero frequency spectral component. However, its inefficient utilization of the

bandwidth causes increased susceptibility to crosstalk and impulse noise. The average frequency loss of the typical loop at the ISDN rates for the AMI code is too large in relation to the cross talk and impulse noise power as it prevails in the spectral band for carrying digital signals. Block codes are proven to be more efficient.

In the loop plant, where there is ample opportunity to pick up low-power frequency and its harmonics, the average zero frequency signal content of the AMI code provides some immunity at low frequencies. This feature also protects the transceiver against low frequency drifts during signal recovery at the receiver. The features of the AMI code had a favored choice in some of the digital carrier applications, dominantly the T1 carrier system in the USA. It is prevalent in the Circuit Switched Digital Capability (CSDC) offered at 56 Kbits/s and in the T1 carrier system. In Japan, almost all the Nippon Telephone and the Telegraph (NTT) loops are satisfactorily covered by the time compression mode, (basic rate ISDN data transmission with the AMI code for the NTT Subscriber loops [2]).

However, the frequent repeater of the T1 systems cannot be duplicated in the digital Subscriber environment for ISDN. This consideration has prompted the deployment of the more efficient block codes. In this environment, the average frequency loss of the typical loops at the ISDN rates is too large in relation to the crosstalk and impulse noise power as it prevails in the spectral band for carrying the digital signal. Perhaps the simplest of the block codes is the 2B1Q code where two binary bits are coded as one of the four quaternary levels. This code offers the desirable feature of the AMI code of having no zero frequency spectral energy. It also reduces the bandwidth requirement to about half that of the AMI code. However, since there is no zero state in this code as compared to the AMI code, the peak energy content is skewed towards the higher end of the frequency rather than at one half frequency as it occurs in the AMI code. This consideration prevents the 2B1Q code from offering the full 6 dB noise advantage over the AMI code. There are two other penalties associated with this code. First, the encoders and decoders (also abbreviated as codecs) are slightly more complicated. Second, the eye openings are proportionally reduced due to the presence of four levels at +3, +1, -1, and -3 (or three eye openings) as compared to the three levels at +1, 0, and -1 (or two eye

openings). This is not seen as a major disadvantage since the signal processing components for data recovery are becoming more and more sophisticated.

The Alternate Mark Inversion (AMI) code is a ternary line code where each symbol is represented by 1 of three signals. The symbol "0" is represented by 0 volts and the 1's are represented by alternate positive and negative pulses referred to as "marks." The AMI code is used in some 2Mbit/s and 1.544 Mbit/s Pulse Code Modulation (PCM) baseband transmission systems.

6.2 TYPICAL EYE DIAGRAMS

To evaluate the performance characteristics of eye diagrams, the seven eye statistics discussed in chapter 4 are derived. Pictorially one can grasp a quick view of the transmission behavior and then proceed with detail analysis.

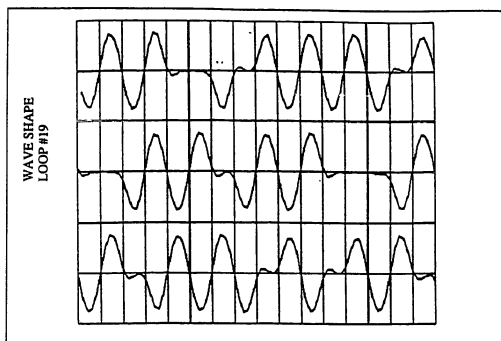
Mismatch impedances at the two end points of a working loop are a transceiver design problem. Impedance mismatches introduce disturbances which are quite similar to those introduced by a change of gauge. Such disturbances affect the shape of the eye. Table 6.1 lists the loops chosen for the AMI study. Loop #19 is one of the shortest loop in the database that contains the 28 AWG. As explained earlier the 28 AWG is important in this study since its transmission characteristics in an ISDN environment is not known.

6.2.1 AMI

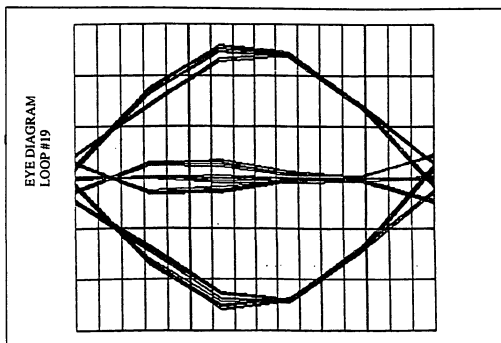
Loop #	# of Section	length (ft)	Gauges
19	2	4,137	28,24
45	15	18,402	28,24,22
27	10	10,188	28,26,24,22

TABLE 6.1: Physical Parameters of loops under AMI simulation at 192 Kbits/s

In examining the transmission behavior of loop #19, shown in figure 5.3, pulses were generated at a rate of 192 Kbits/s using the AMI encoding scheme. FIGURE 6.1 (a) shows the shape of the waves from the transmitter to the receiver.



NORMAL



FIGURES 6.1 (a) & (b): LOOP #19 at 192 Kbits/s and 60 dB Echo Cancellation.

The uniformity of the wave shapes led to the conclusion that the deflections were not noticeable. The eye diagram, FIGURE 6.1 (b), shows that the transmission characteristics were of good quality. The translation of eye diagrams to eye statistics will be discussed later in this chapter. To give a comparison of the transmission characteristics of this loop, a bridge tap of 22 AWG cable was inserted between the two sections.

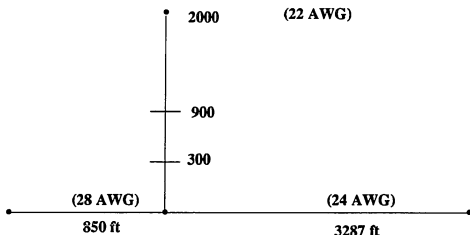
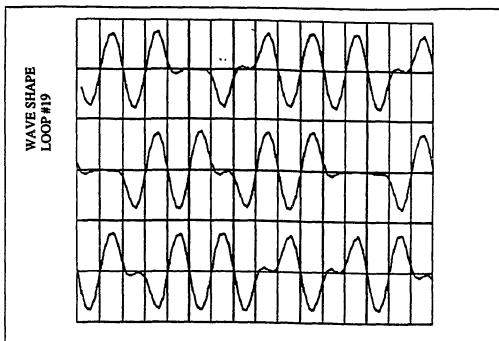


FIGURE 6.2: LOOP #19 WITH BRIDGE TAP ADDED

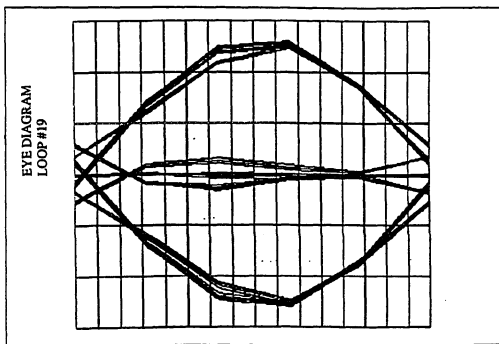
The simulation was done with the bridge tap being 300 ft, 900 ft, and 2000 ft respectively (see FIGURE 6.2). FIGURES 6.3 (a) and (b) show the distortion of the transmission in the waves and eye diagrams when the bridge tap is 300 feet long. The distortion increases (FIGURES 6.4 (a) and (b)) as the length of the bridge tap increased to 900 feet. This distortion becomes unacceptable when the bridge tap was increased to 2000 feet (FIGURES 6.5 (a) and (b)).

Since the simulation of loop #19 was done with echo cancellation of 60 dB, A good quality of transmission at the 192 Kbits/s rate is expected. The later simulations have confirmed these early expectations.



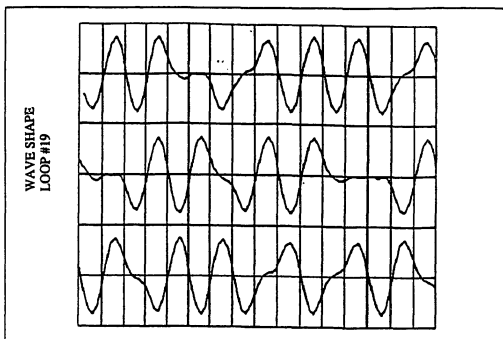
(a)

BRIDGE TAP = 300 ft.

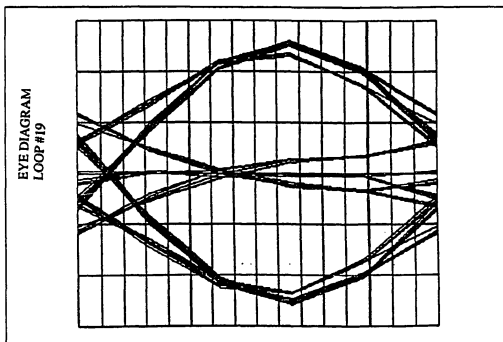


(b)

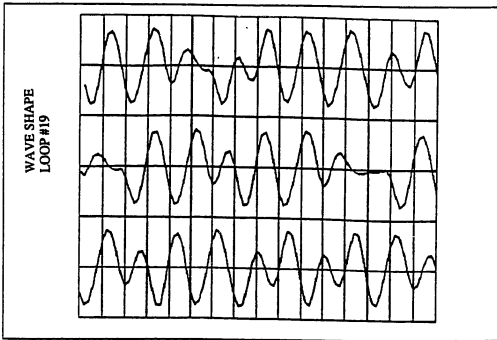
FIGURES 6.3 (a) & (b): LOOP #19 WITH BRIDGE TAP (300 ft.)



BRIDGE TAP = 900 ft.

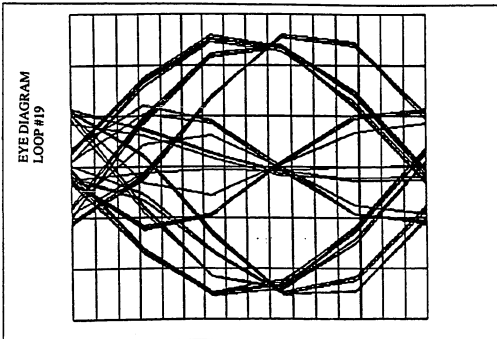


FIGURES 6.4 (a) & (b): LOOP #19 WITH BRIDGE TAP (900 ft.)



(a)

BRIDGE TAP = 2000 ft.



(b)

FIGURES 6.5 (a) & (b): LOOP #19 WITH BRIDGE TAP (2000 ft.)

A 60 dB echo cancellation for loop #19 simulation when no bridge taps were added, can be considered satisfactory and not an over design. the network. However, the performance of other loops is not clear. Further investigation is carried out in chapter 7 when the entire loop population is scanned for eye statistics.

Given the distortion of the eye shown in fig 6.5 (b) one can conclude that the AMI code will be extremely inefficient at the higher rates.

Loop number 45 is the longest loop in the database sample. It consists of 15 sections and contains the 28, 24, and 22 AWG. This loop provides information from one end of the spectrum while loop # 19 provides information from the other end. Loop #27 was chosen as a candidate for the simulation since it consists of all the wire guages that exist in the BT network with the exception of the 19 AWG. Simulations for loops #45 and #27 for the AMI were done at 192 Kbits/s and at 50 dB Echo Cancellation. Loop #19 was done at 60 dB and 192 Kbits/s. A rudimentary equalizer was used for all the loops. This equalizer was initially designed by Professor S. V. Ahamed for Circuit Switch Digital Capability (CSDC) applications in the United States loop environment [8].

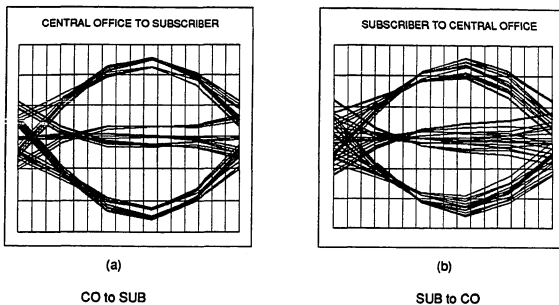


FIGURE: 6.6 Loop #45 Eye Diagram at 50 dB and 192 Kbits/s

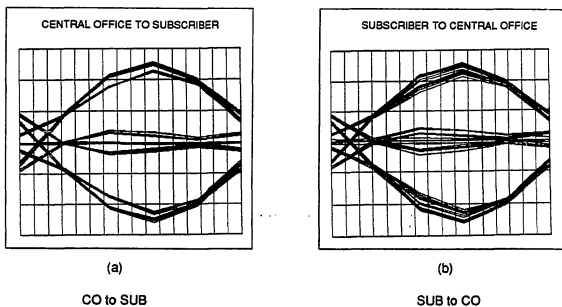


FIGURE: 6.7 Loop #27 Eye Diagram at 50 dB and 192 Kbits/s

Figure 6.7 (a) and (b) shows the transmission quality of loop #27 whose total length is 10,188 feet. This loop is made up of 10 sections and includes the 28, 26, 24, and 22 AWG.

The eye diagram shown in figure 6.6 (a) from the Central Office to the Subscriber can be considered to be of good quality. At 60 dB Echo Cancellation this transmission is even better. However, it is clear from figure 6.6 (b) that the transmission from the Subscriber to Central Office is poor. No symmetry exist in the transmission to and from the Subscriber. Given the fact that the loop itself is not symmetrical, the loop leaving the central Office end at 28 AWG and terminate at the Subscriber end with 22 AWG after having gone through sections of 26 and 24 AWGs, would contribute to such properties. Further, this is a long loop (the longest in the database sample). One can conclude that all loops with such physical characteristics have similar transmission properties.

Loop #27 is fairly long (10,188 feet) with only 10 sections and consists of a combination of the 28, 26, 24 and 22 AWGs. Like loop #45, it also left the central Office with the 28 AWG and terminate at the Subscriber with the 22 AWG. However, different transmission characteristics are displayed when compared with loop #45. Figure 6.7 (a) shows the transmission from the central Office to the Subscriber which is better than the transmission from the Subscriber to the Central Office.. This transmission is also better than its equivalent from loop #45 (compare figure 6.7 (a) with figure 6.6 (a)). In comparing figure 6.7 (b) with figure 6.6 (b), one can easily see that the transmission is better for loop #27 (which represents the transmission from the Subscriber to the Central Office).

6.1 2B1Q

Loop #	# of Sections	length (ft)	AWG
7	1	5059	26
15	1	5226	24
76	1	9498	22
9	2	9635	24,19
19	2	4137	28,24
22	2	1719	28,26
23	2	1673	26,24
73	2	5433	24,22
68	23	10135	26,24,22
45	15	18402	28,24,22
27	10	10,188	28,26,24,22

TABLE 6.2: Physical parameters of loops under 2B1Q simulation at 50 dB and 530 KS/s (Half Primary Rate)

For the 2B1Q code, a series of simulation runs were made to evaluate the transmission quality based on the different physical parameters shown in table 6.2. To normalize the relationship, all the simulations for the loops listed in table 6.2 were done at 50 dB echo cancellation and 530 KS/s (half primary rate). It is not important, at this point, to compare the statistics of the 50 dB and 530 KS/s with other echo canceller and bit rate variables. It is essential to look at the eye diagrams of these loops in relation to each other to evaluate the effect of their physical characteristics while holding the echo canceller and equalizer constant. The rudimentary equalizer was used in these simulation runs.

The loops listed in table 6.2 were chosen for the 2B1Q code simulation based on their physical parameters. Collectively, they represent a good sample which completely specifies the entire loop sample database.

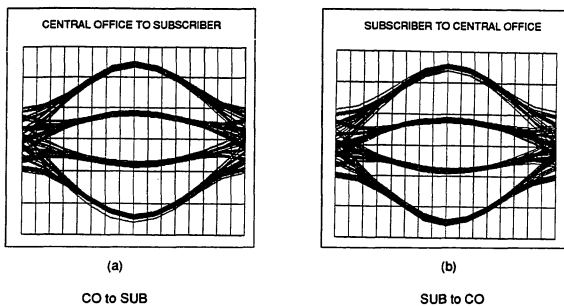


FIGURE 6.8: Loop #7 Eye Diagram at 50 dB and 530 KS/s

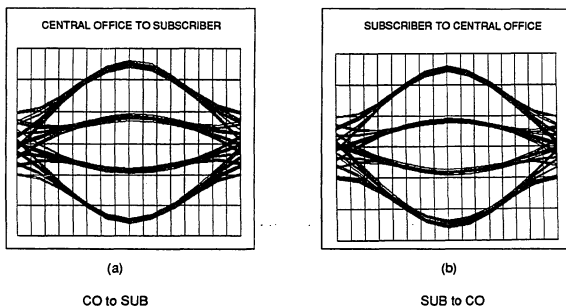


FIGURE 6.9: Loop #15 Eye Diagram at 50 dB and 530 KS/s

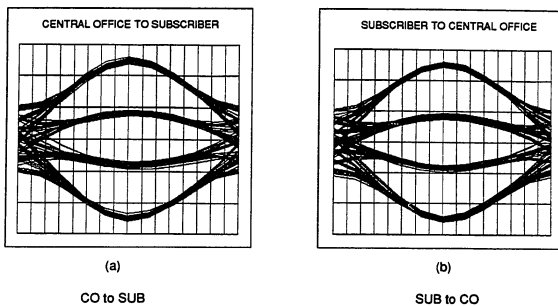


FIGURE: 6.10: Loop #76 Eye Diagram at 50 dB and 530 KS/s

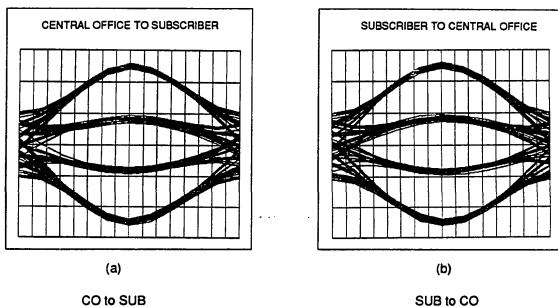


FIGURE: 6.11: Loop #9 Eye Diagram at 50 dB and 530 KS/s

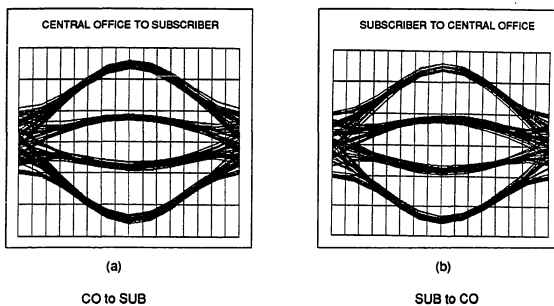


FIGURE 6.12: Loop #19 Eye Diagram at 50 dB and 530 KS/s

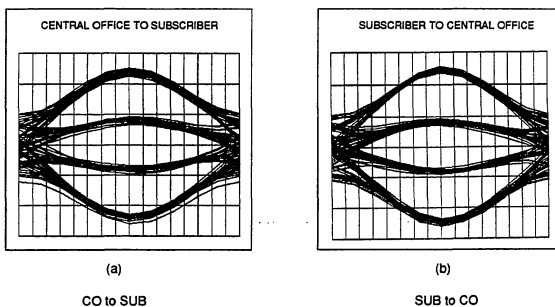


FIGURE 6.13: Loop #22 Eye Diagram at 50 dB and 530 KS/s

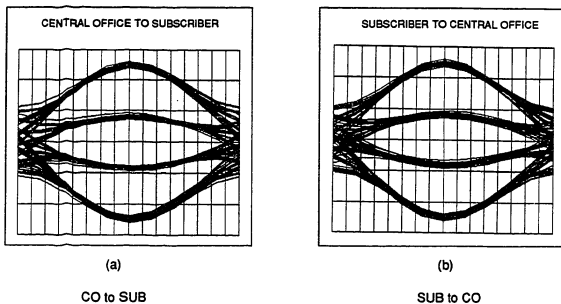


FIGURE 6.14: Loop #23 Eye Diagram at 50 dB and 530 KS/s

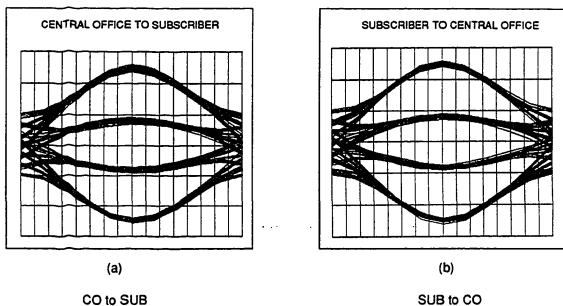


FIGURE 6.15: Loop #73 Eye Diagram at 50 dB and 530 KS/s

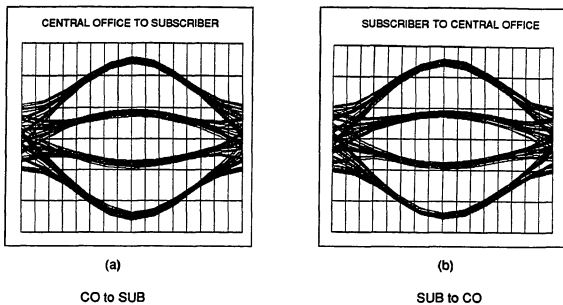


FIGURE 6.16: Loop #68 Eye Diagram at 50 dB and 530 KS/s

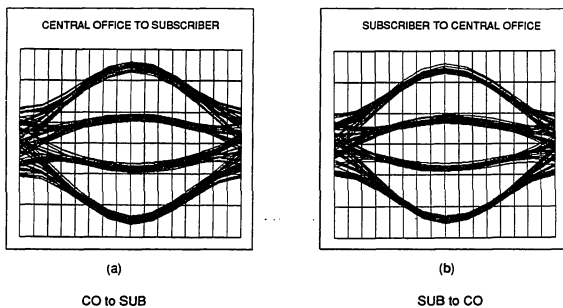


FIGURE 6.17: Loop #45 Eye Diagram at 50 dB and 530 KS/s

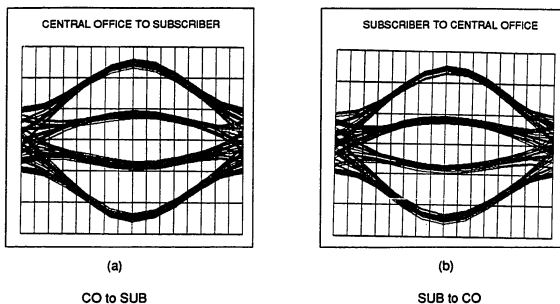


FIGURE 6.18: Loop #27 Eye Diagram at 50 dB and 530 KS/s

Loops 7, 15, and 76 consist of 1 section each with gauges 26, 24, and 22 respectively. In looking at their eye diagrams, there seems to be symmetry in the transmission characteristics from both ends. The transmission are also considered to be of good quality.

There is much symmetry in the transmission from the Central Office to the Subscriber with the transmission from the Subscriber to the Central Office. The transmission quality is good and at the basic rate it is better. Since these loops have length = "1 section" but vary in gauges and section lengths, the eye diagram becomes a function of the cable size and section length in the local loop. All other parameters are held constant for the simulations. It can be noted that the transmission using the 2B1Q code is better in the direction of the Subscriber to Central Office for all three loops. The different gauges does not seem to have an impact on the transmission characteristics. This is not true however, as is noted later, for loops of length = "2 sections".

Loops 9, 19, 22, 23, and 73 consists of 2 sections each. Each loop has a unique combination as shown in table 6.2 namely, 24 and 19, 28 and 24, 28

and 26, 26 and 24, and 24 and 22 AWG, respectively. In comparing the transmission quality of these loops with each other, they all fall in the same category and their transmission characteristics can be considered to be good. These loops represent all combinations of two wire gauges as they exist in the British Telecom network. The loops also show symmetrical behavior in the transmission to and from the Subscriber. However, there are significant differences in the quality of transmission when comparing figure 6.15 (b) with 6.11 (b), 6.12 (b), and 6.13 (b). Likewise figure 6.11 (a) differs from figure 6.12 (a) and 6.13 (a). Many factors can contribute to these differences. That is, the length of the cable, the different combination of gauges, and the length of each section with a particular gauge. For example, as shown in Appendix C, loop #9 has 8478 ft of the 28 AWG and 1174 ft of the 19 AWG, while loop #19 has 850 ft of the 28 AWG and 3287 ft of the 24 AWG.

Loop #68 has the most number of sections (23) in the database sample and is made up of the 26, 24, and 22 AWG. Loop #27 was chosen as a candidate for the simulation because it is the loop with the most number of sections (15) that include the 28 AWG. Loop # 27 also contains the 26, 24, and 22 AWG. This makes a one to one comparison of loops #68 and #27 feasible. Loop #45 is the longest loop (18,402 ft) in the database sample and includes the 28, 24, and 22 AWG. The transmission characteristics of these loops as shown in their respective eye diagrams illustrate the difference in their transmission characteristics.

A great degree of symmetry can be seen in figures 6.16 (a) and (b) representing transmission to and from the Subscriber. From the simulation results of loop #68 one can conclude that the number of sections with the combination of gauges as displayed in loop #68 should not have a great impact on the transmission quality. Of course one must consider the length of each section and the gauge used to make up the entire loop, as this may change the results significantly.

6.2 SCATTER PLOTS

Eye diagrams contain significant information determining the quality of transmission over a single loop. However, in representing the performance of a system covering the entire loop population, the data is extracted from the eye diagrams and presented in the form of scatter plots. Using the scatter

plots, the eye statistics can be cross compared for all loops. Hence, the seven eye statistics discussed in chapter 4 and presented in Figure 4.10 and 4.11 show the scatter plots for the UK loop sample where Figure 4.10 represents the transmission from the Central Office to the Subscriber and Figure 4.11 represents the transmission from the Subscriber to the Central Office. In both figures the line code used is the 2B1Q and the simulation was done at 400 KS/s at 60 dB echo canceler, using a rudimentary equalizer. In this section, a complete set of scatter plot results is presented and discussed.

6.2.1 Scatter Plots for the AMI code

Going from eye diagrams to eye statistics is a process from which one can associate certain parameters of the eye to indicate the degree of transmission quality. The seven parameters of the eye obtained with the AMI code and numbered in figure 6.19. The thickness of the top (2), middle (4), and lower (6) eye represents noise. From the evaluation of the eye diagrams these statistics can be plotted as a "Linear scatter plot" for the entire loop population. Each eye in the loop is therefore transformed to the eye statistics.

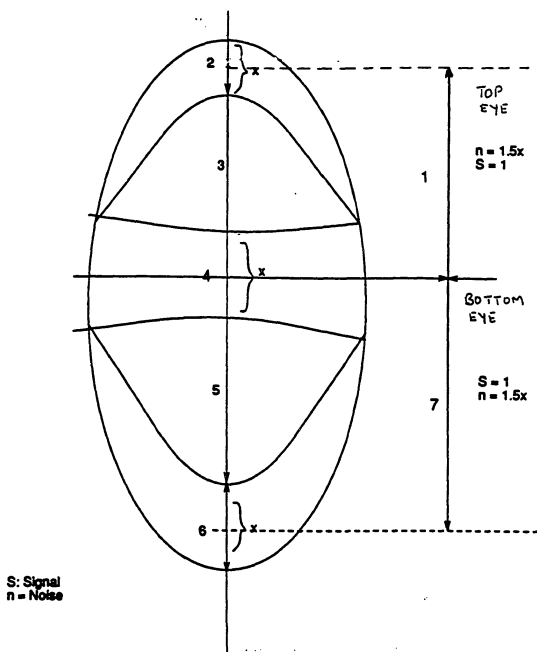


FIGURE 6.19: From AMI Eye Diagram to Eye Statistics

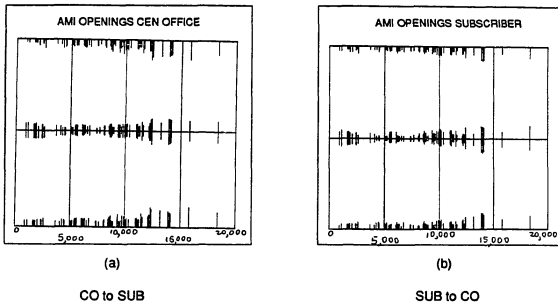


FIGURE 6.20: Linear Scatter plot of Loop sample for AMI at 50 dB and 192 Kbits/s

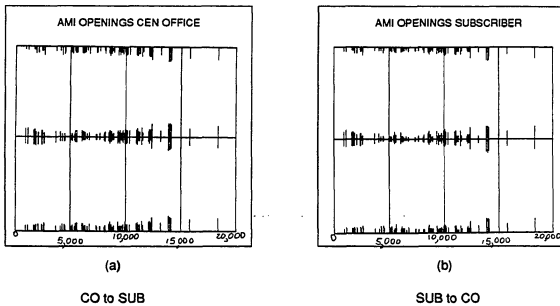


FIGURE 6.21: Linear Scatter plot of Loop sample for AMI at 60 dB and 192 Kbits/s

In figure 6.20 the linear scatter plot is shown for the entire loop population at 50 dB echo cancellation and at 192 Kbits/s. The transmission from the Subscriber to the Central Office (figure 6.20 (b)) for some loops seems to be worse than the transmission from the Central Office to Subscriber (figure 6.20 (a)). The plots are labelled to show all loops in the ranges of 0 - 5,000ft, 5,000 - 10,000 ft, 10,000 - 15,000ft, and 15,000 - 20,000ft. Some loops seems to have more noise in the transmission from the Central Office than from the Subscriber. This is consistent with the conclusions from the eye diagrams.

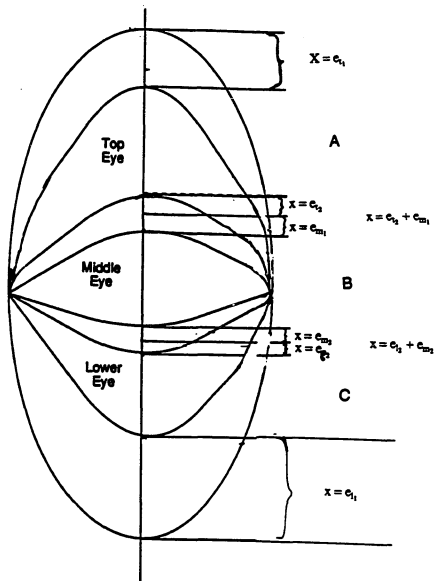
The simulation was repeated at 60 dB. The results, figures 6.21 (a) - (e), are definitely better than their counterparts in figure 6.20. Again, in general there appears to be better quality transmission from the Central Office to the Subscriber than from the Subscriber to the Central Office.

6.2.2 Scatter Plots for the 2B1Q code

EC (dB)	Rate (KS/s)	Figures
60	96	6.23 (a) and (b)
50	96	6.24 (a) and (b)
60	400	4.12 and 4.13
50	400	6.25 (a) and (b)
60	530	6.26 (a) and (b)
50	530	6.27 (a) and (b)

TABLE 6.3: Listing of figures showing the 2B1Q simulation at 50/60 dB and 96/530 KS/s (half Basic/Primary Rates).

Going from the eye diagrams for the 2B1Q code to scatter plots, a similar process as the one described for the AMI code is used. However, the shape of the eye for the 2B 1Q code as shown in figure 6.22 depicts noise at one more level than the AMI code. This is due to the nature of the 2B1Q code. The resulting scatter plots have one more layer than those generated for the AMI code.



S = signal (max strength = 2)
e = error (noise)

<u>TOP-EYE</u>	<u>MID-EYE</u>	<u>LOW-EYE</u>
$A = \left\{ \begin{array}{l} S = 2 \\ e_1 = e_{s1} + e_{s2} = 1.5x \end{array} \right\};$	$B = \left\{ \begin{array}{l} S = 2 \\ e_m = e_{m1} + e_{m2} = x \end{array} \right\};$	$C = \left\{ \begin{array}{l} S = 2 \\ e_1 = e_{s1} + e_{s2} = 1.5x \end{array} \right\}$

FIGURE 6.22: From 2B1Q Eye Diagrams to Eye Statistics

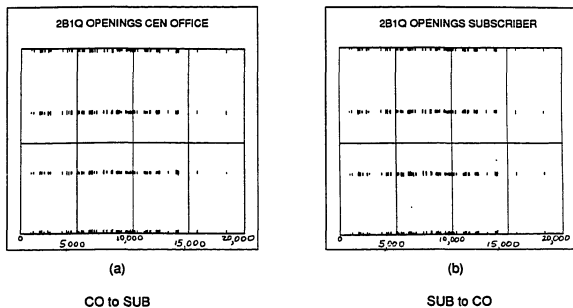


FIGURE 6.23: 2B1Q Linear Scatter Plot for Loop Sample at 60 dB and 96 KS/s

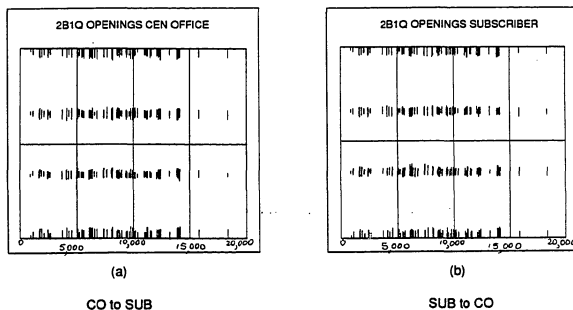


FIGURE 6.24: 2B1Q Linear Scatter Plot for Loop Sample at 50 dB and 96 KS/s

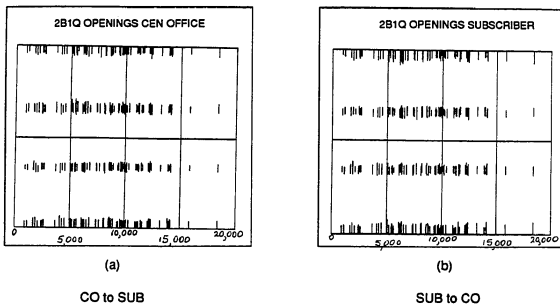


FIGURE 6.25: 2B1Q Linear Scatter Plot For Loop Sample at 50 dB and 400KS/s

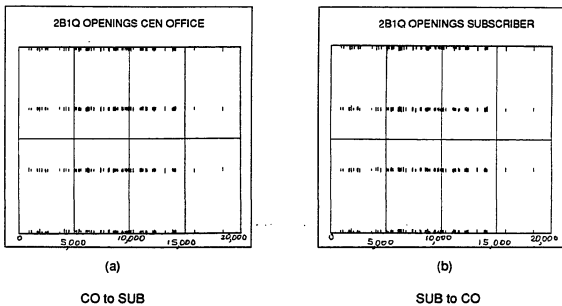


FIGURE 6.26: 2B1Q Linear scatter plot for loop Sample at 60 dB and 530KS/s

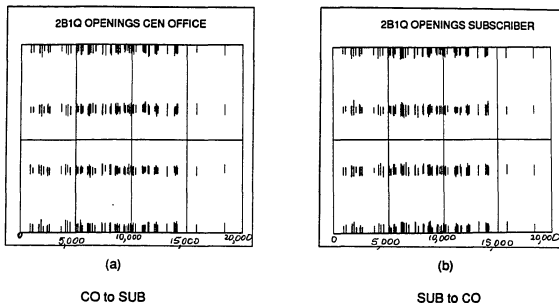


FIGURE 6.27: 2B1Q Linear scatter plot for loop Sample at 50 dB and 530KS/s

To give a complete picture of the 2B1Q scatter plots, the simulation was done at three speeds, 96, 400, and 530 KS/s. For each speed, the data is presented for the 50 dB and the 60 dB echo cancellation as listed in table 6.3. Table 6.3 also directs you to the figures displayed for each simulation.

For each speed within the 50 dB and the 60 dB, it can be easily seen that the performance is much better when using the 60 dB echo cancellation, (see figures 6.23 and 6.24). In both the 50 dB and 60 dB echo cancellation one can see generally, that the quality of transmission is better from the Central Office to Subscriber when compared with the transmission from the Subscriber to the Central Office. This property was not easily seen from the eye diagrams discussed earlier.

The 60 dB echo cancellation for 400 KS/s is not shown as it is not necessary. It falls between the 96 and 539 KS/s range. The data displayed for the 60 dB at 96 KS/s and 530 KS/s is considered good quality. IT can only be concluded that the 60 dB for 400 KS/s is be better than the results obtained for the 96 KS/s.

6.3 SUMMARY

To simulate the entire physical process of data transmission, a limit cycle approach has been adopted. Numerous local loops were selected to investigate the quality of transmission with the 2B1Q and AMI codes. Two independent simulation studies with the AMI and the 2B1Q codes were completely explored. For each code, the echo canceler and the bit rates were also varied. Scatter Plots were then produced for each variation. These plots were then analysed for the display of other transmission characteristics. From the scatter plots, loops that project distinct transmission behavior from other loops were explored further. Their eye diagrams and wave shapes were plotted to give further depth of their transmission behavior.

It can be concluded that echo cancellation is required for ISDN transmission with either the AMI or the 2B1Q codes. Further echo cancellation is required for the basic as well as the primary rate. The physical parameters as studied, are adequate for ISDN transmission provided that the necessary compensation are accounted for in other components (e.g., the line units). The behavior of the individual loops varies and some loops require more compensation than others.

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CHAPTER 7

EQUALIZER DESIGNS AND ECHO CANCELER REQUIREMENTS

The implementation of the ISDN [1] is based upon the use of the existing telephone network to carry data at ISDN rates. The telephone networks around the world have been traditionally designed to carry telephone quality voice having a spectral bandwidth of 200 to 3200 Hz. However, our US experience in the design of T1 at 1.544 Mbit/s, T2 at 3.152 Mbit/s, and T3 at 6.312 Mbit/s, digital carrier systems have provided a very positive reassurance that if a certain amount of adaptive algorithms are incorporated in the transmission and switching facilities of the Plain Old Telephone Services (POTS) environment by simple and rather unsophisticated electronics, then data can be effectively transported at high bit rates. This challenge was successfully met by the communication engineers of the 40's and 50's. These achievements, though significant in that time frame, did not employ the dual impact that the digital revolution has brought about in the fields of communication and computers.

In this era, we are faced with the scenario that the present telephone network is a macrocosmic computer(ized) network with very large hardware (HW), software (SW), and firmware bases. The telephone engineers and designers have been silently pouring their expertise in the design of the telephones, the electronic switching systems, their software, the subscriber loops, and their design rules, etc.

Fortunately, the conceptual tools and techniques at our disposal have expanded equally rapidly. The digital signal processor chips have enormous Central Processing Unit (CPU) capabilities, the Random Access Memory (RAM) chips have enormous storage, and wafer level integration offers minicomputer processor and memories facilities on a chip. The conceptual and algorithmic capabilities have also expanded dramatically. The Artificial Intelligence (AI) techniques incorporating pattern recognition, expert systems, and mechanized learning facilitates us to take on the more monumental challenges. One such challenge we are facing now spans the disciplines of communications and computers in the design of adaptive algorithms,

components, and subsystems for ISDN.

The basic rate ISDN transmission subsystem has to accomplish the following typical functions: (a) maintain effective bidirectional communication at 144 kbit/s under most operating conditions and over most of the subscriber loops, (b) train the channel units at call setup time, and (c) recover from error conditions.

Adaptive Equalization:

Subscriber loops cause a highly variable range of signal attenuation and dispersion [2]. The receiver channel unit has to recover the transmitted information and expects to "see" a clean signal pattern of the encoded signal levels at discrete instants of time. The signal restoration becomes a highly critical adaptive function. A perfect equalizer compensates for the line loss over the entire bandwidth for transmitting the particular code over every loop and exhibit no phase discontinuity. A channel unit equalizer [3] attempts to supply a phase gain characteristic over the most important band for the code for a vast majority of the loops which the ISDN data is transmitted. In general, no phase discontinuities can be expected. Hence, the adaptation can only be acceptable rather than be perfect.

Adaptive Signal Isolation:

In the Time Compression Multiplexing (TCM) mode, the signal (transmit and receive) isolation [4] occurs in the time domain and the process of alternate unidirectional transmission needs little adaptation. However, in the Adaptive Echo Cancellation (AEC) mode, the signal isolation occurs by two active devices (the electronic hybrid and the echo canceller) and the success of the system [5] is based upon a delicate dynamic balance between the magnitude and phase of the echo as it is reflected by the mismatch between the transmitter and the loop and the magnitude and the phase of the cancellation signal supplied by the local echo canceller. These competing signals have to cancel each other to within 60 to 70 dB to offer the low bit error rates (BER's) expected from data transmission in the ISDN. Both the algorithm and the device have to be extremely robust to meet this requirement, especially since the physical and impedance profiles of the subscriber loop have the greatest amount of uncertainty associated with them.

Decision Feedback Equalizer:

The low frequency components of the transmitted signal can suffer very radical attenuations and dispersions in most telephone networks. If the energy content in this band is critical to recovery of the encoded data stream (depending upon the transmission rate and code selected) then some sort of added dc (or very low frequency energy) restoration becomes essential [6]. Once again the extent of the damage the loop and the channel units do to low energy signals depends upon the loop loss, its configuration, and the associated equalizer circuits. Adaptation for the recovery of the signal in this band depends upon the loop makeup, the filter and equalizer characteristics, and the terminating circuitry. The adaptive algorithms have to accommodate the built in characteristics of the composite system rather than the transfer functions of the individual components. Macrocosmic system algorithms rather than component functions algorithms become essential.

Filters:

Filtering of the transmitted and the received signal makes the newly installed ISDN systems compatible with the existing subscriber loop carrier systems and other ISDN systems within the cables and bundles. Limiting the transmitted signal energy in certain spectral bands provides cross talk compatibility with other systems. Limiting overall transmitted energy provides self cross talk compatibility. Limiting the received signal energy in certain bands removes the influence of other carriers and other noise sources in the subscriber loop environment. For example, it is essential to filter out the third harmonic of the power supply frequency from the ISDN data carriers around and about areas when the copper carriers exhibit strong couplings with power lines feeding substations and power distribution plants. This calls for very high signal attenuation at low frequencies using some type of decision feed back equalization. Analogue devices with definite built-in features (poles and zeros) face an uncertain future for the ISDN applications even though certain robust adaptive analogue circuits with floating poles and zeros have found applications in the Tarbox (for the T1 rates) [8,9], T1C [10], and CSCD (circuit switched digital capability) [3] equalizers. On the other hand, the adaptive digital filters hold the promise that the Digital Signal Processing (DSP) chips have to offer as FIR filters [11] and the adaptation of these devices in

conjunction with the adaptation of the other components embedded in the channel units becomes necessary for building the intelligent and adaptive ISDN subsystems.

Timing Recovery Circuits:

Subscriber clock recovery is essential to maintain system synchronization. A 144 kbit/s rate, with bipolar code the clock recovery, is easily achieved with a high quality crystal Phase Locked Loop (PLL). However, at higher rates and with block codes (4B3T and 2B1Q codes, see [12]) the 'Q' (or the ratio of w_L to R) of the PLL plays a significant role [1] in the dependability of the algorithms used in the subscriber channel units. Hence, the possibility of using digital counting techniques for clock recovery in lieu of conventional PLL technique needs an integrated algorithmic approach. This problem becomes especially important during the training sequence of the subscriber channel units. The algorithms and adaptation of these units during and after the start-up need a serious simulation study if the system coherence has to be guaranteed.

The Overall Adaptive ISDN Data Transmission Subsystem:

The adaptation algorithms for satisfactory system performance are interdependent. The usual managerial approach of piece wise optimization of individual components for the ISDN channel unit fails because the systems functioning is too closely intertwined. These simple divide-optimize-recombine-reoptimize CPM and PERT techniques may work for simpler and adaptive human systems, but appear inadequate in this environment because of the large number of local and vendor specified parameters effecting a very stringent set of network requirements and performance criteria. Hence, the computer aided design of the ISDN systems calls for a global optimization approach [13] by the inherent and embedded intelligent features built in the fourth and fifth generation computers. Human and CAD experience that has been gained needs to be iteratively tested out on large loop survey databases to develop the new adaptive algorithms for the network. Powerful AI concepts for recognizing healthy, unhealthy, or unstable network conditions with a large knowledge base for handling such condition facilitate the management of the networks.

7.1 EQUALIZERS AND ECHO CANCELLERS IN TRANSMISSION CIRCUITS

Echo Effects: These arise from the fact that parts of the energy transmitted over a circuit may be reflected back from points of irregularity in it, particularly at the ends. Small amounts of energy may wander back and forth over a circuit two or more times. While these echoes may affect both the talker and the listener. The echoes gradually have the greatest effect on the talker who may have an uneasy feeling by hearing delayed echo effects.

Four types of echoes can be identified in the metallic transmission media during the transmission of data. First, echoes arising from the impedance mismatch between the loop impedance and the source impedance can cause considerable transmission echo signal to be generated at the receiver. Second, the reflections caused by the splicing of cables where different section of cables are joined together cause echo of signal in one direction to appear in the reverse direction. Third, open bridged tap sections cause reflections from the distant end of the tap. These echos are caused by the forward signal splitting at the junction of the cable and the tap. The signal down the cable reaches the receiver at the end of the cable. However, the signal traveling the bridged tap also reaches the receiver as an echo after being reflected at the open end of the bridged tap. This type of echo is not present in the UK local loop network since there are no bridge taps. Fourth, the mismatch between the termination impedance and the loop impedance over the forward signal that has been travelling also causes an echo. It is noted that the reflection paths and the corresponding attenuations of the reflected signals are different for each of the four type of echos.

7.2 ANALYSIS, DESIGN OPTIMIZATION, AND EVALUATION OF ECHO CANCELLERS AND EQUALIZERS

Using the data obtained from the selected simulation runs, one can now evaluate all the transmission parameters and their effect on the quality of transmission. The simulation methodology used to derive the component requirements is shown in Figure 7.3. Different loops are examined with various components. settings. Based on the results obtained, the component selection is varied and the simulation is repeated. Each run is carefully controlled to make sure all other parameters are kept constant.

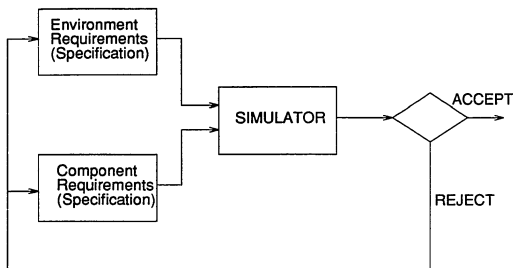


FIGURE 7.1: SIMULATION METHODOLOGY FOR ESTABLISHING REQUIREMENTS

The change in parameters for one loop can affect the transmission in other loops. Thus, the entire loop population must be considered with each run. In earlier discussions, the transmission characteristics for individual loops were depicted by eye diagrams for different echo canceler settings.

Using the circular scatter plots (Figure 7.2), the eye openings of all loops were captured and displayed at the 60 dB, 54 dB, 42 dB, 36 dB, and 30dB echo cancellation. The loops displayed are categorized at 100%, 66%, and 33% eye openings. An ideal situation is when all the dots are concentrated at the outer ring (ie. 100 % eye opening).

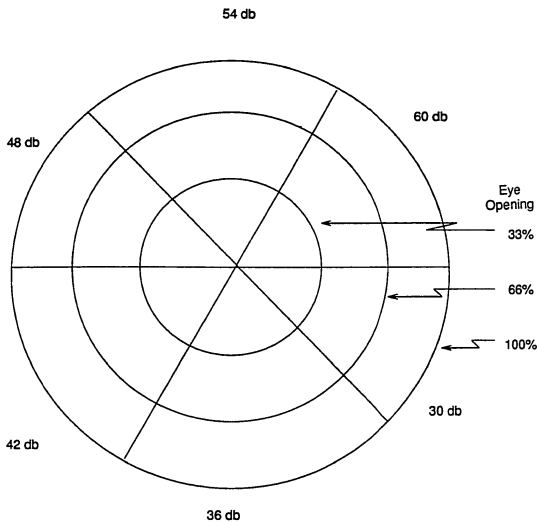


FIGURE 7.2: CIRCULAR DISPLAY OF SCATTER PLOTS AT VARYING ECHO CANCELLATION.

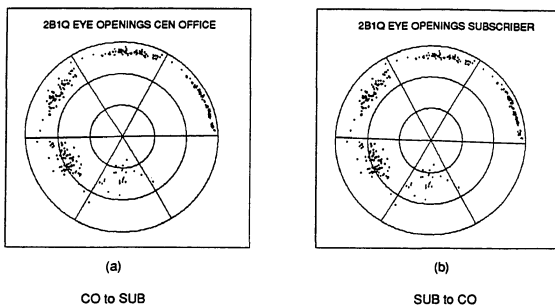


FIGURE 7.3: CIRCULAR SCOTTER PLOTS AT 30-60 dB range and 96 KS/s

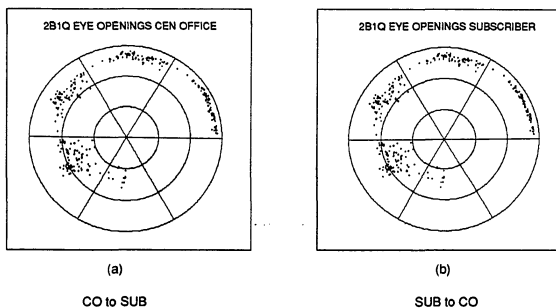


FIGURE 7.4: CIRCULAR SCOTTER PLOTS AT 30-60 dB range and 530 KS/s

Figure 7.3 (a) and (b) show the circular scatter plots for the eye openings of all the loops in the sample database at different echo cancellations, while keeping the equalizer constant (rudimentary) and the speed at 96 KS/s. Notice that at 60 dB all of the loops are open but as 30 dB echo cancellation is approached they are all closed. In Figure 7.3 (a), which shows the transmission from the central office to the subscriber, it is seen that all loops displayed the same characteristics by aligning themselves in a line concentrating near the 100% mark. At 52 dB echo cancellation the loops begin to move away from the concentration towards the 66% mark. At 48 dB almost all loops are midway between the 100% and the 66% mark. However, one loop can be seen to remain closer to the 100 % mark. The dispersion of the dots is indicated with echo cancellation at the 42 dB sector and the 36 dB sectors. Each loop responds differently due to its own physical and electrical characteristics which become distinct from each other. At 30 dB echo cancellation only one loop remains open between the 33% and the 66% mark, while all other loops are closed. At 36 dB most of the loops are completely closed: The number of points in this circular scatter plot diminishes as shown in Figure 7.3 (a).

Figure 7.3 (b) shows the transmission to the Central Office at the same frequency range and at 96 KS/s. Notice that Figure 7.3 (b) has some degree of symmetry with Figure 7.3 (a). Although individual loops have shown different characteristics, from chapter 6 when transmitting from Central Office to Subscriber versus Subscriber to Central Office. The transmission from Subscriber to Central Office was shown to be worse. It can now be concluded that; (1) even at the basic rate the behavior of the individual loops are different from their transmission to and from the subscriber and (2) loops behave the with no no difference in the transmission characteristics when transmitting to and from the subscriber. Hence, adaptive line units are desirable in the British Telecom ISDN environment.

At 530 KS/s using the 30-60 dB echo canceler range. It can be seen in Figure 7.4 that there is no loop with an open eye diagram at 30 dB and that very few are open between the 33% and the 66% mark at 36 dB. Again, there is a great degree of symmetry between Figures 7.4 (a) Central Office to Subscriber, and 7.4 (b) Subscriber to Central Office. It can be seen from Figures 7.3 and 7.4 that most of the loops are approaching complete closure

faster as you move away from the 60 dB echo cancellation with the higher bit rate. At the 54 dB echo cancellation all loops are still within 66% and 100% eye opening. It can be concluded that at the basic rate, while 48 dB may be adequate for a good quality transmission, 48 dB is unsuitable for the primary rate as shown in Figure 7.4, where most of the loops are concentrating nearer to the 66% mark.

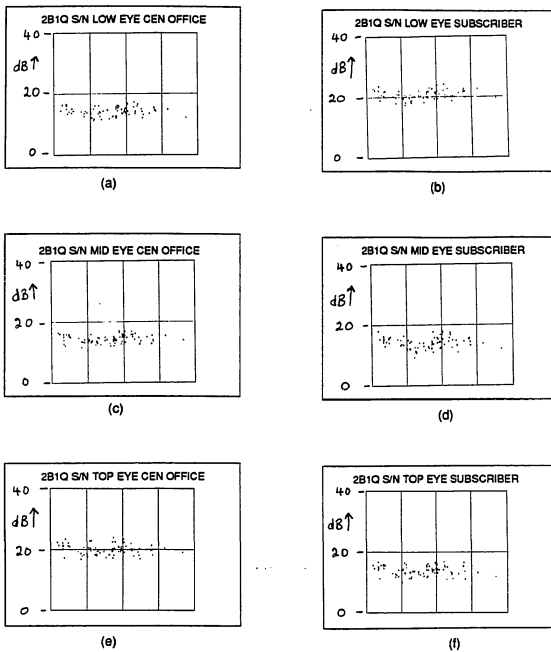
Again, given that there are different echo cancellation requirements at the basic and primary rates, it seems appropriate to have a software control of the line unit to make it applicable for any application.

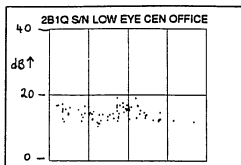
S/N RATIO:

It is important to evaluate the signal to noise ratio to pre determine the error rate. In chapter 6, the noise as referenced to the thickness of the different portions of the eye. This is shown in the scatter plots discussed in Figure 7.4. The quality of the transmission is statistically related to the S/N ratios with eye diagrams. For this reason the S/N ratio in Figures 7.5, 7.6, and 7.7.

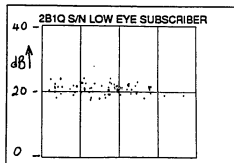
The bit error probability at the output of a coherent detector can be evaluated from S/N statistics [1].

The S/N ratio is plotted for the 2B1Q at 50 dB and 96 KS/s (half basic rate, 400 KS/s, and 530 KS/s (half primary rate). The S/N simulation displayed in Figures 7.5, 7.6, and 7.7 are for the 50 dB EC at 96 KS/s, 400 KS/s, and 530 KS/s. Six displays for each Figure is given. The (a) and (b) displays are for the top eye of the Central Office to Subscriber and Subscriber to Central Office, respectively. The (c) and (d) displays are for the middle eye. The (e) and (f) displays are for the lower eye. The displays are divided to show the loops within the different ranges.

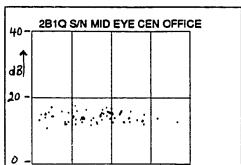
**FIGURE 7.6: 50 dB, 400 KS/s**



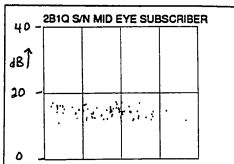
(a)



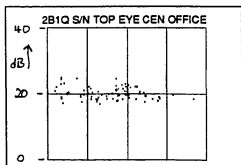
(b)



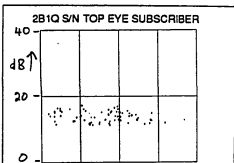
(c)



(d)



(e)



(f)

FIGURE 7.7: 50 dB, 530 KS/s

Figures 7.5 (a) - (e) display the S/N ratio for all loops at 50 dB and 96 KS/s. Notice that Figures 7.5 (a) and (b) showed different transmission characteristics for most of the loops in the different ranges. The mid and lower eye shown in Figure 7.5 (c) and (d) also displays distinct behavior for most loops. This result further confirms that at 96 KS/s with 50 dB echo cancellation, the transmission behavior is different when transmitting to or from the Central Office.

Figures 7.6 (a) - (e) displays the S/N ratio for all loops at 50 dB and 400 KS/s. Again the distinct transmission for individual loops are seen.

Figures 7.7 (a) - (e) displays the S/N ratio at 50 dB and at 530 KS/s. The transmission behavior of individual loops are no more obvious than the 96 KS/s.

In examining the scatter plots shown in the Figures listed in table 6.3, loops of various characteristics are identified for further experimentation.

CASE 1: LOOP 54.

This loop has a unique characteristic that distinguishes itself from the other loops. To further investigate this loop its wave shape and eye diagrams were plotted (see Figure 7.8 (a) - (e)). Loop 54 is 6,094 ft long and has 7 sections, it is comprised of the 28 AWG and the 24 AWG. This loop is the worst loop as shown in any of the scatter plot (more distinct in Figure 6.27).

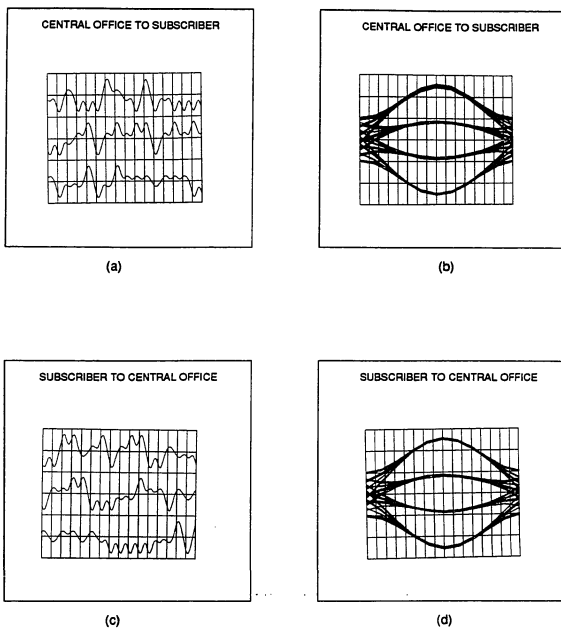


FIGURE 7.8: Loop 54 at 400 KS/S and 60 dB

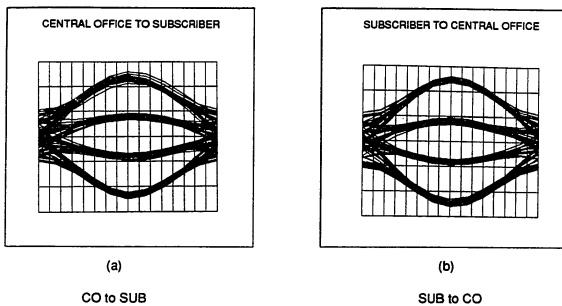


FIGURE 7.9: LOOP 54, 50 dB and 400 KS/s

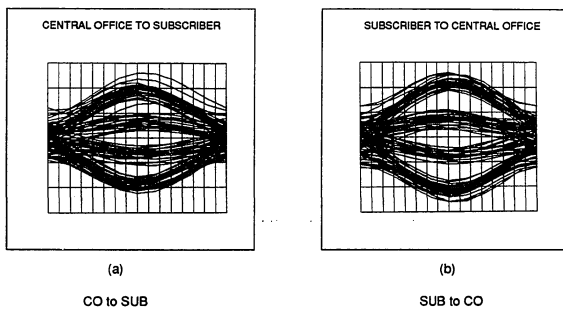


FIGURE 7.10: LOOP 54 at 40 dB and 400 KS/s

The wave shape and eye diagrams were done at 60 dB echo cancellation and 400 KS/s with the rudimentary equalizer. Even at 60 dB one can see the poor quality of the wave shape and eye diagrams from both the subscriber and the central office side. The simulation was repeated at 50 dB and 40 dB for comparison reasons. Figure 7.9 shows the deterioration of the transmission quality at 50 dB. At 40 dB echo cancellation (Figure 7.10) the transmission quality is unacceptable.

CASE 2: LOOP #45

The longest loop within the population sample (18, 402 ft) was studied with 50 dB echo cancellation at 400 KS/s using a rudimentary equalizer. Figures 7.11 (a) and (b) show the eye diagrams for the transmission to and from the subscriber. The quality of transmission is about the same as loop #54 using the 60 dB echo cancellation. The eye diagram is less than satisfactory for this loop.

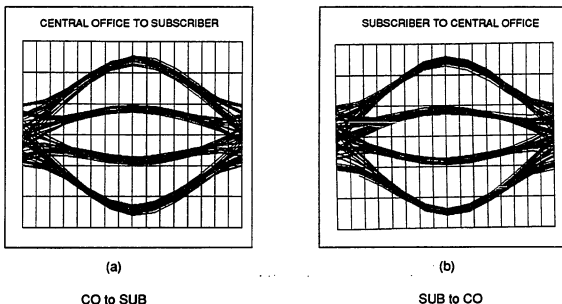


FIGURE 7.11: Loop #45 at 50 dB and 400 KS/s

Component Representation:

Bidirectional data transmission systems generally have a transmitter, a loop,

a filter, an equalizer, a terminating impedance, and a device to limit the near-end reflections. For the delta functions or finite pulse-width multilevel pulses at the transmitter, the excitation functions are defined in Appendix A. The loop is characterized by ABCD matrices (one set for each harmonic frequency). The filter is represented by standard transfer functions. The equalizer is programmed by the distribution of poles and zeros. The matching impedance being passive, has a simpler characterization. Finally, the isolating device which separates the received and transmitted signal is represented in the frequency domain (for frequency-domain cancellation circuits) or in the time domain (for CCD-type, FIR type transversal filter circuits). The technique of the computation of the cancellation signal varies appropriately. In the TCM mode of transmission, the contaminating signal is ignored because the transmitter is inactive during the reception of the signal and vice versa.

Simulation of Echo Cancellation:

During simultaneous bidirectional transmission of data, the near-end echo adds to the received signal within the hybrid. There are two ways of simulating the echo-canceler function. The first one consists of computing the total signal (reflections and the received pulses) and subtracting the reflection out systematically. The second method consists of systematically dropping all, or a large fraction, of the frequency-domain reflected signal before summing the Fourier components.

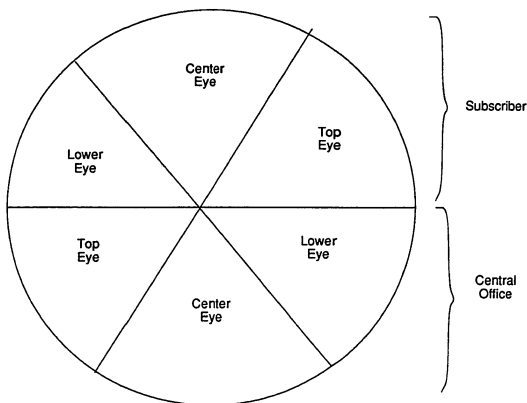


FIGURE 7.12: Model for evaluating the Echo Cancellation Requirements

Echo Cancellation Signal from Single-Pulse Response:

The reflections of a single-pulse excitation from the Central Office side and from the subscriber side are stored. There are 960 time positions covering the 96-pulse period. These responses are then shifted by the same amount that any new pulse is shifted from the original pulse that gave the first reflection. The response of the pulses occupying the 96 time slots of random excitation is obtained as a summation of all the responses suitably displaced from the location of the original pulse. Since the excitation is assumed to be periodic, any overflow beyond the 960 time positions is reaccumulated at the beginning of the period.

The subtraction of the reflected signal from the total signal by the echo canceler is carried out by either of two ways; (i) prespecified fraction

(between 90 to 99.9 percent depending on the echo cancellation, for example, for a 30 dB echo canceler it is 96.84%) of the total reflected signal is systematically subtracted from the total signal at the received end and (ii) a randomly varying fraction averaging to a prespecified number (90 to 99 percent) of the total reflected signal is subtracted from the total received signal. The reason for the use of a second procedure was to reflect the uncertainties caused by the convergence in the tap weight setting of a real echo-canceler device. These settings can change slightly because of the number of iterations the device has experienced at any instant of time. Being an adaptive device, the setting varies by small increments around the average value with time. The second computational procedure reflects this uncertainty. For the illustrations presented here, the first procedure of echo cancellation is used since the second one causes a small random perturbation of the data obtained in the first.

The circular scatter plot is used to show the whole picture of all loops under the same echo canceler (see Figure 7.12). In one plot information for both the central office and the subscriber top, center, and lower eyes is displayed.

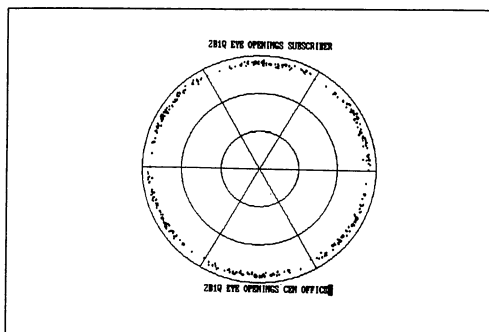


FIGURE 7.13: Circular scatter plot, 60 dB at 530 KS/s

Figure 7.13 shows the circular scatter plot at 60 dB and 530 KS/s. Notice that nearly all the dots are concentrated closer to the 100% eye opening mark. The S/N ratio at 60 dB is also shown in Figure 7.14 (a) - (e). Notice that all the dots are concentrated above the midway line which indicate a very good eye opening (good quality transmission).

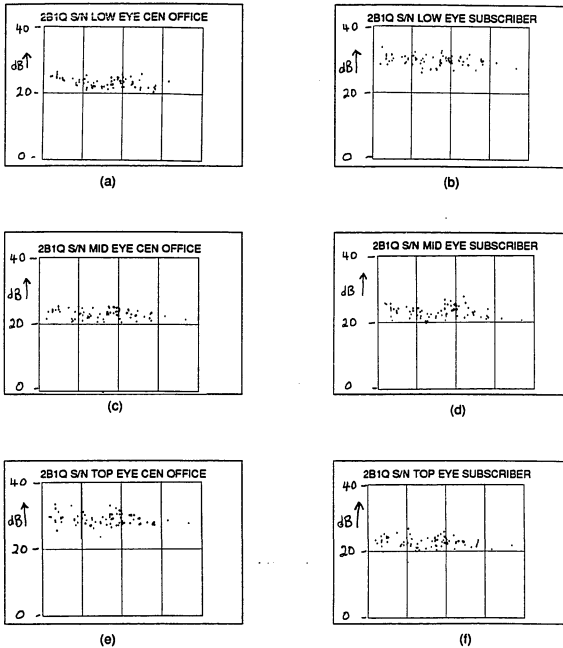


FIGURE 7.14: (a), (b), (c), (d), (e), and (f) at 60 dB and at 530 KS/s

7.3 SUMMARY

The effect of other equalizers was not studied. The simulation indicates that a minimum simple equalization and accurate echo cancellation are necessary. Here, the rudimentary equalizer (basic) is satisfactory. Echo cancellation for basic rate ISDN is also necessary. At the primary rate at least 50 dB echo cancellation is necessary. Compatibility with other systems also needs further investigation. Some of the features incorporated in the initial design and selection of the adaptive algorithms for ISDN system design facilitates the realization of the rather stringent requirements such as bit-error-rate, compatibility, system synchronization, etc.

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CHAPTER 8

CONCLUDING REMARKS

The major conclusions from this dissertation have been characterized in three distinct directions. The findings presented here are novel and yet unpublished for the European ISDN or Intelligent Networks. First, the physical, electrical, and transmission properties of the loops surveyed from the British Telecom environment are presented. Second, the capabilities of the loops surveyed from the (Hounslow, Ruislip, Skyport, Uxbridge, and Greenford) areas of Britain to carry basic rate and primary rate ISDN data are investigated at different rates with various echo cancelers. The effects of changing the bit rates are also investigated. Individual loops that are categorized as the outlayers from the survey are studied further for their response to AMI and 2B1Q codes. Third, the software changes to the simulation model for the study of High Speed Digital Subscriber Line for carrying out the major simulations are reported. Further details of these major findings are presented next.

First, the British Telecom loops surveyed do not have any bridged taps. If such taps (as they exist in US, Canada, Italy, Australia, and Japan) are discovered elsewhere in Britain, then additional characterization and further simulations become necessary. This conclusion is supported by the study of loop #19, described in Chapters 5 and 6. Next, all the loops surveyed leave the exchange central office with the 28 AWG cable and increase to coarser gauges further to a maximum length of 18,500 feet and to a maximum gauge of 19. As many as twenty three sections may be present in a loop. The average loop length is 8,607 feet. The average dc resistance of the loop is about 963 Ohms and at 200 kHz the average impedance is about $(115-j20)$ Ohms. Additional results are presented in Chapters 5 and 6.

Second, the British Telecom loops surveyed need some basic form of equalization and echo cancellation. At present, British Telecom does not have such provision for their 64 Kbits/s lines and this policy may become too constrictive for basic rate ISDN and broadband ISDN. The investigation indicates that echo cancellation is the more critical requirement since the

loops surveyed carry high speed data with a rudimentary equalizer (Ahamed, Bell System Technical Journal 1982, for CSDC data transmission in the US) when the echo cancellation is enhanced to 60 dB. Further as documented in Chapter 7, the transmission quality deteriorates rapidly as the echo cancellation is reduced from 60 dB to 30 dB in steps of 6 dB. Next, the research indicates that the presence of the 28 AWG in the subscriber loop environment of UK does not pose any serious problems in the bidirectional transmission of ISDN data. Investigation of the equalizer was not pursued since the early findings (Chapters 4 and 5) indicate that (a) bridged taps were not common in British Telecom environments and (b) the 28 AWG common in the British Telecom environment was not a serious threat to ISDN type of IN's in Britain. Finally, the channel units in British Telecom have not been designed as yet for ISDN, and the need for echo cancellation and/or adaptive matching terminations appears to be essential.

Third, the earlier version of the simulation packages, were not suitable for the study of European subscriber loop environments. The enhanced model now at the City University of New York is well suited for the data transmission studies for the evolving ISDN and IN's around the globe. The 28 AWG cable is freely used in Europe, Japan, and Australia. Bridged taps exist in numerous countries (Italy, Canada, Japan, Australia, US, etc.) and many extended wide area and regional networks. Transmission in these networks can thus be studied by the enhanced model. In particular, frequency domain and time domain simulation have been performed. In context of this dissertation, a new software environment was created and used to process the physical characteristics of the local loop environment and generate the electrical characteristics of the desired subscriber loop network. More importantly, the 28 AWG has been studied with the enhanced simulator software. In addition, the new environment was used to generate the AMI code time domain results for the UK environment. Loops that include the 28 AWG, have been studied. The features of the simulation environment include the capability to generate the 2B1Q code time domain results for the UK environment. Like the AMI code, that include the 28 AWG, in the loop sections and bridged taps have been studied. Further, the printing and plotting programs used to display broad cross sections results have been modified to display the results in the UK environment. All modules created and used in this study have been added to the simulator library that now

exists with Professor S. V. Ahamed at the City University of New York.

Topics of Further Study:

The study, though limited to British Telecom environment, prompts additional studies for Spain, Italy, and Australia, where 28 AWG is used. Italian and Australian loops also have bridged taps (Miller and Ahamed, Vol II), and the enhanced simulation capability can now be used for the study of these loop environments. Additional research along the lines of this dissertation to evaluate the effects of variable matching impedance in the hybrid termination of the basic and primary rate ISDN loops in the European environment would prove invaluable in the gradual evolution of IN's. Adaptive electronic hybrids (developed by Ahamed and Moschytz) that appear to function satisfactorily for the American CSA loops also need to be investigated in the European HDSL environments. Finite Impulse Response (FIR) filter type of echo cancelers and Decision Feedback Equalizer (DFE) being actively considered in the American loops also need simulation. It is believed that the simulation models presented in this dissertation are particularly suitable for such studies of the evolving IN's around the world.

APPENDIX A

Generalized ABCD Matrix Reduction Techniques for Digital Transmission Lines

Appendix A.1: Transmit-Receive voltage and current relationships for a homogeneous metallic line for data transmission.

Consider a uniform transmission line (Fig. A.1) carrying data signals from a known point at the transmitter to any location at a distance x from the transmit end. If its primary constants are fixed as R ohm per unit length, L Henries per unit length, G mhos per unit length and C Farads per unit length, then the voltage and current relationship for the elemental length δx can be derived. Two cases are considered. First when the transmit voltages and currents are known the voltage and current at any point at a distance x can be derived. This is done in Appendix A.1.1. Second, when the voltage and currents at any point x are known, then the transmit voltages and current can be derived. This is done in Appendix A.1.2.

Appendix A.1.1

Voltage and current at any given point x along a uniform homogeneous data transmission line.

From Fig. A.2, Kirchoff's Current Law* leads to

* Note that the differential with respect to time is taken for current and voltage relations only. The differential with respect to distance x is for evaluating the potential difference and gradient along the transmission line.

$$\begin{aligned}
 I - \left[I + \frac{\partial I}{\partial x} \cdot \delta x \right] &= VG \cdot \delta x + C \cdot \delta x \left[\frac{\partial V}{\partial t} \right] \\
 - \frac{\partial I}{\partial x} &= VG + C \frac{\partial V}{\partial t}
 \end{aligned} \tag{A-1}$$

Similarly, Kirchoff's Voltage Law (Fig. A.2) leads to

$$\begin{aligned}
 V - \left[V + \frac{\partial V}{\partial x} \cdot \delta x \right] &= \left[IR \cdot \delta x + L \cdot \delta x \frac{\partial I}{\partial t} \right] \\
 - \frac{\partial V}{\partial x} &= IR + L \frac{\partial I}{\partial t}
 \end{aligned} \tag{A-2}$$

Differentiating (A-2) with respect to x

$$- \frac{\partial^2 V}{\partial x^2} = \left[R + L \frac{\partial}{\partial t} \right] \cdot \frac{\partial I}{\partial x}$$

Substituting equation (A-1)

$$\frac{\partial^2 V}{\partial x^2} = \left[R + L \frac{\partial}{\partial t} \right] \cdot \left[G + C \frac{\partial}{\partial t} \right] V \tag{A-3}$$

The $\frac{\partial}{\partial t}$ operator can be replaced by p or $j\omega$ at any given frequency f with $\omega = 2\pi f$.

$$\begin{aligned}\frac{\partial^2 V}{\partial x^2} &= [R + j\omega L] [G + j\omega C] \cdot V \\ &= \gamma^2 V\end{aligned}\tag{A-4}$$

The general solution for (A-4) is of the form

$$V = Pe^{\gamma x} + Qe^{-\gamma x}\tag{A-5}$$

where P and Q are length dependent constants to be evaluated. Differentiating (A-5) we have,

$$\frac{\partial V}{\partial x} = \gamma [Pe^{\gamma x} - Qe^{-\gamma x}]$$

From Eq. (A-2)

$$\frac{\partial V}{\partial x} = -I [R + j\omega L]$$

Thus:

$$I = \frac{\gamma}{(R + j\omega L)} \cdot [-Pe^{\gamma x} + Qe^{-\gamma x}]$$

from (A-4):

Now

$$\begin{aligned}
 R+j\omega L &= \frac{\sqrt{(R+j\omega L)(G+j\omega C)}}{R+j\omega L} \\
 &= \sqrt{\frac{G+j\omega C}{R+j\omega L}} = \frac{1}{Z_0}
 \end{aligned}$$

where $Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$

Thus:

$$Z_0 I = \left[-Pe^{\gamma x} + Qe^{-\gamma x} \right]$$

or

$$V_x = Pe^{\gamma x} + Qe^{-\gamma x} \quad (\text{A-6a})$$

$$I_x = \frac{-Pe^{\gamma x} + Qe^{-\gamma x}}{Z_0} \quad (\text{A-6b})$$

At the transmit end of the line we have* $x=0$, voltage $V_x = V_1 = P + Q$ and current $I_{x=0} = I_1 = \frac{-P+Q}{Z_0}$; $P = (Q - I_1 Z_0)$

* Note that we can solve for V_x and I_x in terms of V_1 and I_1 when x is positive.

$$P = V_1 - Q = V_1 - (Z_0 I_1 + P)$$

$$P = \frac{V_1 - I_1 Z_0}{2} \quad \text{---} \quad \text{(A-7a)}$$

$$Q = V_1 - P = V_1 + Z_1 I_1 - Q$$

$$Q = \frac{(V_1 + I_1 Z_0)}{2} \quad \text{(A-7b)}$$

Substituting for P and Q from (A-7a) and (A-7b) in (A-6a) and (A-6b) we have

$$V_x = \left\{ \frac{V_1 - I_1 Z_0}{2} \right\} e^{\gamma x} + \left\{ \frac{V_1 + I_1 Z_0}{2} \right\} e^{-\gamma x} \quad \text{(A-8a)}$$

$$I_x = - \left\{ \frac{V_1 - I_1 Z_0}{2Z_0} \right\} e^{\gamma x} + \left\{ \frac{V_1 + I_1 Z_0}{2Z_0} \right\} e^{-\gamma x} \quad \text{(A-8b)}$$

From Eq. (A-8a) and (A-8b)

$$V_1 \left\{ \frac{e^{\gamma x} + e^{-\gamma x}}{2} \right\} = V_x + I_1 \frac{\left\{ e^{\gamma x} - e^{-\gamma x} \right\}}{2} Z_0$$

$$I_1 \left\{ \frac{e^{\gamma x} + e^{-\gamma x}}{2} \right\} = I_x + \frac{V_1}{Z_0} \left\{ \frac{e^{\gamma x} - e^{-\gamma x}}{2} \right\}$$

or the voltage and current at any point x can be written as

$$V_x = \left[V_1 \left\{ \frac{e^{\gamma x} + e^{-\gamma x}}{2} \right\} - I_1 Z_0 \left\{ \frac{e^{\gamma x} - e^{-\gamma x}}{2} \right\} \right]$$

$$I_x = \left[-\frac{V_1}{Z_0} \left\{ \frac{e^{\gamma x} - e^{-\gamma x}}{2} \right\} + I_1 \left\{ \frac{e^{\gamma x} + e^{-\gamma x}}{2} \right\} \right]$$

Rewriting we have V_x and I_x in terms of V_1 and I_1 ,

$$V_x = V_1 \cos h\gamma x - I_1 Z_0 \sin h\gamma x \quad (\text{A-9a})$$

$$I_x = I_1 \cos h\gamma x - V_1 Z_0 \sin h\gamma x \quad (\text{A-9b})$$

Appendix A.1.2: Voltage and currents at transmit end.

To obtain the values of V_1 and I_1 in terms of V_x and I_x , we make $x = -x$ and $V_x = V_1$, $I_x = I_1$ and $P = P'$; $Q = Q'$ in Eq. (A-6a) and (A-6b).

From (A-6a) if $x = -x$

$$V_1 = P'e^{-\gamma x} + Q'e^{\gamma x}$$

$$= V_x \left[\frac{e^{-\gamma x}}{2} + \frac{e^{\gamma x}}{2} \right] + I_x Z_0 \left[\frac{e^{-\gamma x} - e^{\gamma x}}{2} \right]$$

$$= V_x \cos h\gamma x + I_x Z_0 \sin h\gamma x \quad (\text{A-10a})$$

From (A-6b) $x = -x$

$$\begin{aligned}
 I_1 &= \frac{1}{Z_0} \left\{ -P'e^{-\gamma x} + Q'e^{\gamma x} \right\} \\
 &= \frac{1}{Z_0} \left\{ V_x \left[\frac{-e^{-\gamma x} + e^{\gamma x}}{2} \right] + I_x Z_0 \left[\frac{e^{-\gamma x} + e^{\gamma x}}{2} \right] \right\} \\
 &= \left\{ I_x \cos h\gamma x + \frac{V_x}{Z_0} \sin h\gamma x \right\} \\
 &= \frac{V_x}{Z_0} \sin h\gamma x + I_x \cos h\gamma x \qquad \qquad \qquad (A-10b)
 \end{aligned}$$

The general 2 port network representation of the transmission line leads to

$$\begin{matrix} V_1 \\ I_1 \end{matrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{matrix} V_x \\ I_x \end{matrix}$$

$$V_1 = A \cdot V_x + B \cdot I_x \qquad \qquad \qquad (A-11a)$$

$$I_1 = C \cdot V_x + D \cdot I_x \qquad \qquad \qquad (A-11b)$$

hence

$$\begin{aligned}
 A &= \cos h\gamma x \\
 D &= \cos h\gamma x \\
 B &= Z_0 \sin h\gamma x \\
 C &= (\sin h\gamma x)/Z_0
 \end{aligned}$$

These equations satisfy the law of interchangeability of the input and output ports and $AD - BC = 1$

$$\cos h^2 \gamma x - \sin h^2 \gamma x = 1$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} \rightarrow \text{and} \begin{bmatrix} D & B \\ C & A \end{bmatrix}$$

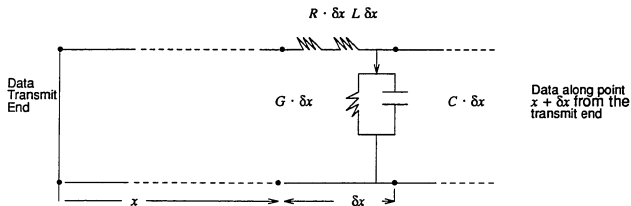


Fig A-1. An infinitely long data transmission line with distributed electrical characteristics R, L, G and C. These four primary constraints are resistances, inductance, conductance and capacitance held constant and uniform along the homogeneous transmission line and declared per unit length of the line.

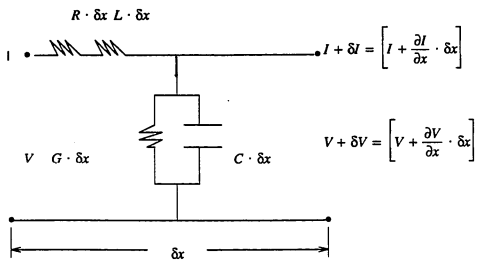


Fig. A.2 voltage and current relations at the boundaries of an elemental length δx located at a distance of x from the transmit end (typically the CO) of the line.

APPENDIX B

UK Cable Database
(CA&D.UK)

FREQ. (HZ)	GUAGE (AWG)	R	L	G	C
1	19	8.6940E+01	9.8610E-01	0.0940E+00	8.3000E-02
5	19	8.6940E+01	9.8610E-01	1.0000E-03	8.3000E-02
10	19	8.6940E+01	9.8610E-01	2.0000E-03	8.3000E-02
15	19	8.6940E+01	9.8610E-01	3.0000E-03	8.3000E-02
20	19	8.6940E+01	9.8610E-01	4.0000E-03	8.3000E-02
30	19	8.6940E+01	9.8610E-01	6.0000E-03	8.3000E-02
50	19	8.6940E+01	9.8610E-01	1.0000E-02	8.3000E-02
70	19	8.6940E+01	9.8610E-01	1.3000E-02	8.3000E-02
100	19	8.6940E+01	9.8600E-01	1.9000E-02	8.3000E-02
150	19	8.6950E+01	9.8600E-01	2.7000E-02	8.3000E-02
200	19	8.6950E+01	9.8600E-01	3.6000E-02	8.3000E-02
300	19	8.6950E+01	9.8590E-01	5.3000E-02	8.3000E-02
500	19	8.6960E+01	9.8570E-01	8.7000E-02	8.3000E-02
700	19	8.6970E+01	9.8560E-01	1.2000E-01	8.3000E-02
1000	19	8.6990E+01	9.8530E-01	1.6800E-01	8.3000E-02
1500	19	8.7030E+01	9.8490E-01	2.4700E-01	8.3000E-02
2000	19	8.7070E+01	9.8450E-01	3.2500E-01	8.3000E-02
3000	19	8.7170E+01	9.8370E-01	4.7900E-01	8.3000E-02
5000	19	8.7420E+01	9.8200E-01	7.8000E-01	8.3000E-02
7000	19	8.7740E+01	9.8030E-01	1.0750E+00	8.3000E-02

10000	19	8.8360E+01	9.7770E-01	1.5110E+00	8.3000E-02
15000	19	8.9740E+01	9.7320E-01	2.2250E+00	8.3000E-02
20000	19	9.1510E+01	9.6860E-01	2.9270E+00	8.3000E-02
30000	19	9.6030E+01	9.5310E-01	4.3100E+00	8.3000E-02
50000	19	1.0761E+02	9.3270E-01	7.0170E+00	8.3000E-02
70000	19	1.2042E+02	9.1710E-01	9.6720E+00	8.3000E-02
100000	19	1.3879E+02	8.9720E-01	1.3593E+01	8.3000E-02
150000	19	1.6650E+02	8.7070E-01	2.0012E+01	8.3000E-02
200000	19	1.8991E+02	8.5070E-01	2.6332E+01	8.3000E-02
300000	19	2.2918E+02	8.2580E-01	3.8769E+01	8.3000E-02
500000	19	2.9146E+02	7.9970E-01	6.3114E+01	8.3000E-02
700000	19	3.4208E+02	7.8520E-01	8.7003E+01	8.3000E-02
1000000	19	4.0589E+02	7.7190E-01	1.2227E+02	8.3000E-02
1500000	19	4.9370E+02	7.5910E-01	1.8001E+02	8.3000E-02
2000000	19	5.6772E+02	7.5130E-01	2.3686E+02	8.3000E-02
3000000	19	6.9190E+02	7.4180E-01	3.4873E+02	8.3000E-02
5000000	19	8.8883E+02	7.3180E-01	5.6771E+02	8.3000E-02
1	22	1.7427E+02	9.8610E-01	0.0910E+00	8.3000E-02
5	22	1.7427E+02	9.8610E-01	1.0000E-03	8.3000E-02
10	22	1.7427E+02	9.8610E-01	1.0000E-03	8.3000E-02
15	22	1.7427E+02	9.8610E-01	1.0000E-03	8.3000E-02
20	22	1.7427E+02	9.8610E-01	2.0000E-03	8.3000E-02
30	22	1.7427E+02	9.8610E-01	3.0000E-03	8.3000E-02
50	22	1.7427E+02	9.8610E-01	5.0000E-03	8.3000E-02
70	22	1.7427E+02	9.8610E-01	6.0000E-03	8.3000E-02
100	22	1.7427E+02	9.8610E-01	9.0000E-03	8.3000E-02
150	22	1.7427E+02	9.8600E-01	1.3000E-02	8.3000E-02
200	22	1.7427E+02	9.8600E-01	1.7000E-02	8.3000E-02
300	22	1.7428E+02	9.8600E-01	2.4000E-02	8.3000E-02

500	22	1.7429E+02	9.8580E-01	4.0000E-02	8.3000E-02
700	22	1.7429E+02	9.8570E-01	5.4000E-02	8.3000E-02
1000	22	1.7431E+02	9.8560E-01	7.6000E-02	8.3000E-02
1500	22	1.7434E+02	9.8530E-01	1.1000E-01	8.3000E-02
2000	22	1.7437E+02	9.8500E-01	1.4500E-01	8.3000E-02
3000	22	1.7444E+02	9.8440E-01	2.1100E-01	8.3000E-02
5000	22	1.7462E+02	9.8330E-01	3.4100E-01	8.3000E-02
7000	22	1.7483E+02	9.8210E-01	4.6700E-01	8.3000E-02
10000	22	1.7522E+02	9.8040E-01	6.5200E-01	8.3000E-02
15000	22	1.7606E+02	9.7780E-01	9.5400E-01	8.3000E-02
20000	22	1.7711E+02	9.7440E-01	1.2480E+00	8.3000E-02
30000	22	1.7986E+02	9.6720E-01	1.8240E+00	8.3000E-02
50000	22	1.8764E+02	9.4910E-01	2.9430E+00	8.3000E-02
70000	22	1.9771E+02	9.3720E-01	4.0320E+00	8.3000E-02
100000	22	2.1555E+02	9.2370E-01	5.6300E+00	8.3000E-02
150000	22	2.4757E+02	9.0550E-01	8.2290E+00	8.3000E-02
200000	22	2.7795E+02	8.8980E-01	1.0772E+01	8.3000E-02
300000	22	3.3339E+02	8.6420E-01	1.5744E+01	8.3000E-02
500000	22	4.2157E+02	8.3090E-01	2.5396E+01	8.3000E-02
700000	22	4.9324E+02	8.1230E-01	3.4796E+01	8.3000E-02
1000000	22	5.8359E+02	7.9500E-01	4.8587E+01	8.3000E-02
1500000	22	7.0791E+02	7.7830E-01	7.1014E+01	8.3000E-02
2000000	22	8.1272E+02	7.6810E-01	9.2958E+01	8.3000E-02
3000000	22	9.8853E+02	7.5570E-01	1.3587E+02	8.3000E-02
5000000	22	1.2673E+03	7.4290E-01	2.1916E+02	8.3000E-02
1	24	2.7719E+02	9.8610E-01	0.0940E+00	8.3000E-02
5	24	2.7719E+02	9.8610E-01	1.0000E-03	8.3000E-02
10	24	2.7719E+02	9.8610E-01	2.0000E-03	8.3000E-02

15	24	2.7719E+02	9.8610E-01	3.0000E-03	8.3000E-02
20	24	2.7719E+02	9.8610E-01	4.0000E-03	8.3000E-02
30	24	2.7719E+02	9.8610E-01	5.0000E-03	8.3000E-02
50	24	2.7719E+02	9.8610E-01	8.0000E-03	8.3000E-02
70	24	2.7719E+02	9.8610E-01	1.1000E-02	8.3000E-02
100	24	2.7719E+02	9.8610E-01	1.6000E-02	8.3000E-02
150	24	2.7720E+02	9.8600E-01	2.2000E-02	8.3000E-02
200	24	2.7720E+02	9.8600E-01	2.8000E-02	8.3000E-02
300	24	2.7720E+02	9.8600E-01	4.0000E-02	8.3000E-02
500	24	2.7721E+02	9.8590E-01	6.3000E-02	8.3000E-02
700	24	2.7722E+02	9.8580E-01	8.4000E-02	8.3000E-02
1000	24	2.7723E+02	9.8570E-01	1.1500E-01	8.3000E-02
1500	24	2.7725E+02	9.8540E-01	1.6400E-01	8.3000E-02
2000	24	2.7728E+02	9.8520E-01	2.1000E-01	8.3000E-02
3000	24	2.7734E+02	9.8480E-01	2.9900E-01	8.3000E-02
5000	24	2.7748E+02	9.8390E-01	4.6600E-01	8.3000E-02
7000	24	2.7766E+02	9.8290E-01	6.2500E-01	8.3000E-02
10000	24	2.7796E+02	9.8160E-01	8.5300E-01	8.3000E-02
15000	24	2.7858E+02	9.7930E-01	1.2130E+00	8.3000E-02
20000	24	2.7935E+02	9.7000E-01	1.5580E+00	8.3000E-02
30000	24	2.8130E+02	9.7230E-01	2.2170E+00	8.3000E-02
50000	24	2.8682E+02	9.5770E-01	3.4580E+00	8.3000E-02
70000	24	2.9429E+02	9.4640E-01	4.6340E+00	8.3000E-02
100000	24	3.0841E+02	9.3470E-01	6.3200E+00	8.3000E-02
150000	24	3.3722E+02	9.2040E-01	8.9930E+00	8.3000E-02
200000	24	3.6903E+02	9.0870E-01	1.1550E+01	8.3000E-02
300000	24	4.3155E+02	8.8850E-01	1.6436E+01	8.3000E-02
500000	24	5.4169E+02	8.5700E-01	2.5633E+01	8.3000E-02
700000	24	6.3208E+02	8.3500E-01	3.4351E+01	8.3000E-02

1000000	24	7.4604E+02	8.1460E-01	4.6849E+01	8.3000E-02
1500000	24	9.0284E+02	7.9470E-01	6.6665E+01	8.3000E-02
2000000	24	1.0350E+03	7.8250E-01	8.5624E+01	8.3000E-02
3000000	24	1.2568E+03	7.6760E-01	1.2184E+02	8.3000E-02
5000000	24	1.6084E+03	7.5230E-01	1.9002E+02	8.3000E-02
1	26	4.4075E+02	9.8610E-01	0.0998E+00	8.3000E-02
5	26	4.4075E+02	9.8610E-01	1.0000E-03	8.3000E-02
10	26	4.4075E+02	9.8610E-01	2.0000E-03	8.3000E-02
15	26	4.4076E+02	9.8610E-01	3.0000E-03	8.3000E-02
20	26	4.4076E+02	9.8610E-01	4.0000E-03	8.3000E-02
30	26	4.4076E+02	9.8610E-01	5.0000E-03	8.3000E-02
50	26	4.4076E+02	9.8610E-01	8.0000E-03	8.3000E-02
70	26	4.4076E+02	9.8610E-01	1.1000E-02	8.3000E-02
100	26	4.4076E+02	9.8610E-01	1.6000E-02	8.3000E-02
150	26	4.4076E+02	9.8610E-01	2.2000E-02	8.3000E-02
200	26	4.4076E+02	9.8600E-01	2.8000E-02	8.3000E-02
300	26	4.4076E+02	9.8600E-01	4.0000E-02	8.3000E-02
500	26	4.4077E+02	9.8590E-01	6.3000E-02	8.3000E-02
700	26	4.4078E+02	9.8590E-01	8.4000E-02	8.3000E-02
1000	26	4.4079E+02	9.8580E-01	1.1500E-01	8.3000E-02
1500	26	4.4081E+02	9.8560E-01	1.6400E-01	8.3000E-02
2000	26	4.4083E+02	9.8540E-01	2.1000E-01	8.3000E-02
3000	26	4.4088E+02	9.8500E-01	2.9900E-01	8.3000E-02
5000	26	4.4101E+02	9.8430E-01	4.6600E-01	8.3000E-02
7000	26	4.4115E+02	9.8360E-01	6.2500E-01	8.3000E-02
10000	26	4.4139E+02	9.8250E-01	8.5300E-01	8.3000E-02
15000	26	4.4187E+02	9.8070E-01	1.2130E+00	8.3000E-02
20000	26	4.4245E+02	9.7890E-01	1.5580E+00	8.3000E-02
30000	26	4.4388E+02	9.7530E-01	2.2170E+00	8.3000E-02

50000	26	4.4781E+02	9.6600E-01	3.4580E+00	8.3000E-02
70000	26	4.5309E+02	9.5460E-01	4.6340E+00	8.3000E-02
100000	26	4.6339E+02	9.4320E-01	6.3200E+00	8.3000E-02
150000	26	4.8580E+02	9.3060E-01	8.9930E+00	8.3000E-02
200000	26	5.1304E+02	9.2120E-01	1.1550E+01	8.3000E-02
300000	26	5.7517E+02	9.0620E-01	1.6436E+01	8.3000E-02
500000	26	6.9961E+02	8.8160E-01	2.5633E+01	8.3000E-02
700000	26	8.1295E+02	8.6140E-01	3.4351E+01	8.3000E-02
1000000	26	9.5665E+02	8.3810E-01	4.6849E+01	8.3000E-02
1500000	26	1.1544E+03	8.1460E-01	6.6665E+01	8.3000E-02
2000000	26	1.3211E+03	8.0010E-01	8.5624E+01	8.3000E-02
3000000	26	1.6007E+03	7.8230E-01	1.2184E+02	8.3000E-02
5000000	26	2.0441E+03	7.6380E-01	1.9002E+02	8.3000E-02
1	28	6.9298E+02	9.8610E-01	0.0940E+00	8.3000E-02
5	28	6.9298E+02	9.8610E-01	1.0000E-03	8.3000E-02
10	28	6.9298E+02	9.8610E-01	2.0000E-03	8.3000E-02
15	28	6.9298E+02	9.8610E-01	3.0000E-03	8.3000E-02
20	28	6.9298E+02	9.8610E-01	4.0000E-03	8.3000E-02
30	28	6.9298E+02	9.8610E-01	5.0000E-03	8.3000E-02
50	28	6.9298E+02	9.8610E-01	8.0000E-03	8.3000E-02
70	28	6.9298E+02	9.8610E-01	1.1000E-02	8.3000E-02
100	28	6.9298E+02	9.8610E-01	1.6000E-02	8.3000E-02
150	28	6.9300E+02	9.8600E-01	2.2000E-02	8.3000E-02
200	28	6.9300E+02	9.8600E-01	2.8000E-02	8.3000E-02
300	28	6.9300E+02	9.8600E-01	4.0000E-02	8.3000E-02
500	28	6.9303E+02	9.8590E-01	6.3000E-02	8.3000E-02
700	28	6.9305E+02	9.8580E-01	8.4000E-02	8.3000E-02
1000	28	6.9308E+02	9.8570E-01	1.1500E-01	8.3000E-02

1500	28	6.9313E+02	9.8540E-01	1.6400E-01	8.3000E-02
2000	28	6.9320E+02	9.8520E-01	2.1000E-01	8.3000E-02
3000	28	6.9335E+02	9.8480E-01	2.9900E-01	8.3000E-02
5000	28	6.9370E+02	9.8390E-01	4.6600E-01	8.3000E-02
7000	28	6.9415E+02	9.8290E-01	6.2500E-01	8.3000E-02
10000	28	6.9490E+02	9.8160E-01	8.5300E-01	8.3000E-02
15000	28	6.9645E+02	9.7930E-01	1.2130E+00	8.3000E-02
20000	28	6.9838E+02	9.7000E-01	1.5580E+00	8.3000E-02
30000	28	7.0325E+02	9.7230E-01	2.2170E+00	8.3000E-02
50000	28	7.1705E+02	9.5770E-01	3.4580E+00	8.3000E-02
70000	28	7.3573E+02	9.4640E-01	4.6340E+00	8.3000E-02
100000	28	7.7103E+02	9.3470E-01	6.3200E+00	8.3000E-02
150000	28	8.4305E+02	9.2040E-01	8.9930E+00	8.3000E-02
200000	28	9.2258E+02	9.0870E-01	1.1550E+01	8.3000E-02
300000	28	1.0789E+03	8.8850E-01	1.6436E+01	8.3000E-02
500000	28	1.3542E+03	8.5700E-01	2.5633E+01	8.3000E-02
700000	28	1.5802E+03	8.3500E-01	3.4351E+01	8.3000E-02
1000000	28	1.8651E+03	8.1460E-01	4.6849E+01	8.3000E-02
1500000	28	2.2571E+03	7.9470E-01	6.6665E+01	8.3000E-02
2000000	28	2.5876E+03	7.8250E-01	8.5624E+01	8.3000E-02
3000000	28	3.1419E+03	7.6760E-01	1.2184E+02	8.3000E-02
5000000	28	4.0210E+03	7.5230E-01	1.9002E+02	8.3000E-02

APPENDIX C

UK LOOP DATABASE
(jpicf.uk)

KEY:

Loop # # of Sections
length of section guage

1	3				
935	28	4324	26	10591	22
2	3				
469	26	3110	24	6506	22
3	3				
837	28	4475	26	6936	24
4	3				
850	28	9439	26	1969	24
5	2				
689	26	9291	22		
6	3				
4469	26	5148	24	148	22
7	1				
5033	26				
8	3				
860	28	6490	26	4744	24
9	2				
8478	24	1175	19		
10	3				
1303	18	371	24	8727	22
11	3				
935	28	4278	24	7185	22
12	3				
469	26	371	24	10263	22

13	3										
935	28	4278	26	6296	22						
14	3										
1709	26	2264	24	7067	22						
15	1										
5226	24										
16	2										
935	28	5348	24								
17	1										
5653	26										
18	3										
856	28	2982	26	295	22						
19	2										
850	28	3287	24								
20	2										
935	28	4157	24								
21	1										
2119	24										
22	2										
443	28	1276	26								
23	2										
1529	26	144	24								
24	1										
1739	26										
25	6										
860	28	1391	26	1083	26	1224	26	1007	26	623	26
26	4										
860	28	1391	26	1083	26	1224	26				
27	10										
860	28	1391	26	1083	26	1224	26	1385	24	164	24
1385	22	938	24	938	24	820	24				
28	9										
860	28	1391	26	1083	26	1224	26	1385	24	164	24
1385	22	1647	22	883	24						
29	10										
860	28	1391	26	1545	26	1470	26	1476	26	607	26

92 26 167 24 1640 24 148 24
 30 10
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 92 26 167 24 443 24 69 24
 31 10
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 92 26 167 24 443 24 1870 24
 32 8
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 1398 24 33 24
 33 10
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 1398 24 2005 24 2005 24 1342 24
 34 9
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 1398 24 1001 24 43 24
 35 10
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 1398 24 1001 24 1473 22 16 22
 36 11
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 1398 24 1001 24 1473 22 1198 22 830 22
 37 10
 860 28 1391 26 1545 26 1470 26 1476 26 607 26
 1398 24 1001 24 1473 22 39 22
 38 6
 860 28 1391 26 1545 26 1470 26 10 26 1296 24
 39 7
 860 28 1391 26 1545 26 1470 26 10 26 1116 24
 10 24
 40 8
 860 28 1391 26 1545 26 1470 26 10 26 1116 24
 200 24 200 24
 41 8
 860 28 1391 26 1545 26 1470 26 10 26 1116 24
 200 24 843 24

42 8
 935 28 1339 26 285 26 1184 26 1470 26 1119 24
 1119 24 253 24 804 24
 43 7
 935 28 965 24 925 24 1394 24 774 24 368 24
 161 24
 44 8
 935 28 965 24 925 24 1394 24 1394 24 774 24
 863 24 935 24
 45 15
 935 28 965 24 925 24 1394 24 1394 24 1119 24
 1532 22 1125 22 1089 22 1119 22 1119 22 860 22
 1539 22 1765 22 1522 22
 46 12
 935 28 965 24 925 24 1394 24 1394 24 1119 24
 1532 22 1125 22 1089 22 1119 22 1119 22 860 22
 394 22
 47 13
 935 28 965 24 925 24 1394 24 1394 24 1119 24
 1532 22 1125 22 1089 22 1119 22 1119 22 860 22
 571 22
 48 13
 935 28 965 24 925 24 1394 24 1394 24 1119 24
 1532 22 1125 22 1089 22 1017 22 971 22 1443 22
 7 22
 49 12
 935 28 965 24 925 24 1394 24 1394 24 1119 24
 1532 22 1125 22 1089 22 1017 22 971 22 1443 22
 50 2
 935 28 965 24
 51 5
 935 28 965 24 925 24 1394 24 108 24
 52 5
 935 28 965 24 925 24 1394 24 873 24
 53 7
 935 28 965 24 492 24 1729 24 1355 24 1811 24

459 24 217 24 230 24 502 24 459 24 128 24
 502 24 771 24 338 24 541 24
 68 23
 256 26 879 24 263 24 302 24 423 24 315 24
 450 24 341 24 43 24 440 24 410 24 331 24
 459 24 217 24 230 24 502 24 459 24 128 24
 1253 24 482 24 433 24 469 24 1050 22
 69 23
 256 26 879 24 263 24 302 24 423 24 315 24
 450 24 341 24 43 24 440 24 410 24 331 24
 459 24 217 24 230 24 502 24 459 24 128 24
 1253 24 482 24 433 24 469 24 289 22
 70 2
 7601 26 1237 24
 71 2
 7601 26 1004 24
 72 3
 269 28 6424 26 4921 24
 73 2
 3166 24 2267 22
 74 1
 2641 24
 75 1
 955 24
 76 1
 9498 22
 77 2
 121 24 9682 22
 78 1
 2438 26
 79 1
 2431 26
 80 2
 256 26 2211 24
 81 2
 932 28 4551 24

APPENDIX D

LPABCD

0.0 0.100E+01 0.110E-10 0.284E+03 0.148E-04 0.737E-07 0.612E-13 0.100E+01 0.751E-11
 5.0 0.959E+00 0.342E+00 0.279E+03 0.524E+02 -.175E-03 0.202E-02 0.965E+00 0.234E+00
 10.0 0.838E+00 0.667E+00 0.262E+03 0.102E+03 -.689E-03 0.391E-02 0.861E+00 0.455E+00
 15.0 0.643E+00 0.960E+00 0.235E+03 0.148E+03 -.151E-02 0.556E-02 0.695E+00 0.651E+00
 20.0 0.387E+00 0.121E+01 0.200E+03 0.186E+03 -.260E-02 0.686E-02 0.477E+00 0.811E+00
 25.0 0.767E-01 0.139E+01 0.156E+03 0.216E+03 -.387E-02 0.770E-02 0.214E+00 0.925E+00
 30.0 -.269E+00 0.150E+01 0.107E+03 0.236E+03 -.524E-02 0.803E-02 -.787E-01 0.985E+00
 35.0 -.630E+00 0.154E+01 0.538E+02 0.246E+03 -.665E-02 0.783E-02 -.382E+00 0.990E+00
 40.0 -.990E+00 0.150E+01 -.384E+00 0.244E+03 -.797E-02 0.708E-02 -.683E+00 0.935E+00
 45.0 -.133E+01 0.138E+01 -.537E+02 0.231E+03 -.913E-02 0.580E-02 -.963E+00 0.823E+00
 50.0 -.163E+01 0.118E+01 -.104E+03 0.208E+03 -.100E-01 0.406E-02 -.121E+01 0.658E+00
 55.0 -.188E+01 0.915E+00 -.149E+03 0.175E+03 -.106E-01 0.189E-02 -.141E+01 0.446E+00
 60.0 -.206E+01 0.594E+00 -.187E+03 0.134E+03 -.107E-01 -.569E-03 -.155E+01 0.197E+00
 65.0 -.217E+01 0.230E+00 -.217E+03 0.862E-02 -.104E-01 -.321E-02 -.162E+01 -.786E-01
 70.0 -.218E+01 -.162E+00 -.236E+03 0.344E+02 -.963E-02 -.591E-02 -.162E+01 -.367E+00
 75.0 -.211E+01 -.568E+00 -.245E+03 -.199E+02 -.835E-02 -.854E-02 -.154E+01 -.657E+00
 80.0 -.194E+01 -.966E+00 -.243E+03 -.740E+02 -.660E-02 -.109E-01 -.139E+01 -.931E+00
 85.0 -.169E+01 -.134E+01 -.229E+03 -.126E+03 -.442E-02 -.130E-01 -.116E+01 -.118E+01
 90.0 -.135E+01 -.166E+01 -.205E+03 -.172E+03 -.189E-02 -.145E-01 -.870E+00 -.138E+01
 95.0 -.950E+00 -.193E+01 -.171E+03 -.212E+03 0.892E-03 -.155E-01 -.529E+00 -.152E+01
 100.0 -.496E+00 -.212E+01 -.129E+03 -.242E+03 0.382E-02 -.158E-01 -.151E+00 -.160E+01
 105.0 -.585E-02 -.223E+01 -.802E+02 -.263E+03 0.681E-02 -.154E-01 0.252E+00 -.162E+01
 110.0 0.500E+00 -.225E+01 -.269E+02 -.272E+03 0.969E-02 -.143E-01 0.657E+00 -.155E+01
 115.0 0.998E+00 -.216E+01 0.285E+02 -.269E+03 0.123E-01 -.125E-01 0.105E+01 -.141E+01
 120.0 0.147E+01 -.198E+01 0.836E+02 -.254E+03 0.146E-01 -.994E-02 0.140E+01 -.119E+01
 125.0 0.188E+01 -.171E+01 0.136E+03 -.227E+03 0.163E-01 -.683E-02 0.171E+01 -.907E+00
 130.0 0.223E+01 -.136E+01 0.183E+03 -.189E+03 0.175E-01 -.326E-02 0.194E+01 -.566E+00
 135.0 0.249E+01 -.933E+00 0.222E+03 -.142E+03 0.179E-01 0.634E-03 0.210E+01 -.181E+00
 140.0 0.265E+01 -.456E+00 0.252E+03 -.883E+02 0.176E-01 0.468E-02 0.216E+01 0.232E+00

145.0 0.270E+01 0.530E-01 0.271E+03 -.290E+02 0.165E-01 0.871E-02 0.213E+01 0.656E+00
150.0 0.263E+01 0.573E+00 0.278E+03 0.327E+02 0.146E-01 0.125E-01 0.200E+01 0.107E+01
155.0 0.245E+01 0.109E+01 0.272E+03 0.946E+02 0.120E-01 0.160E-01 0.177E+01 0.146E+01
160.0 0.215E+01 0.156E+01 0.255E+03 0.154E+03 0.867E-02 0.189E-01 0.145E+01 0.180E+01
165.0 0.175E+01 0.198E+01 0.224E+03 0.207E+03 0.484E-02 0.211E-01 0.105E+01 0.208E+01
170.0 0.127E+01 0.233E+01 0.183E+03 0.253E+03 0.589E-03 0.225E-01 0.588E+00 0.228E+01
175.0 0.717E+00 0.258E+01 0.133E+03 0.288E+03 -.390E-02 0.229E-01 0.805E-01 0.239E+01
180.0 0.117E+00 0.272E+01 0.754E+02 0.311E+03 -.845E-02 0.223E-01 -.452E+00 0.240E+01
185.0 -.504E+00 0.274E+01 0.129E+02 0.321E+03 -.129E-01 0.207E-01 -.985E+00 0.230E+01
190.0 -.112E+01 0.264E+01 -.516E+02 0.316E+03 -.169E-01 0.181E-01 -.150E+01 0.209E+01
195.0 -.170E+01 0.242E+01 -.115E+03 0.298E+03 -.205E-01 0.146E-01 -.196E+01 0.178E+01
200.0 -.223E+01 0.208E+01 -.175E+03 0.265E+03 -.233E-01 0.103E-01 -.236E+01 0.139E+01
205.0 -.267E+01 0.164E+01 -.229E+03 0.220E+03 -.253E-01 0.535E-02 -.266E+01 0.909E+00
210.0 -.300E+01 0.111E+01 -.273E+03 0.164E+03 -.262E-01 -.375E-04 -.286E+01 0.371E+00

GLOSSARY

1ESS	#1 Electronic Switching System
1AESS	#1 Analog Electronic Switching System
4ESS	#4 Electronic Switching System
5ESS	#5 Electronic Switching System
2BIQ	2 Binary 1 Quaternary
2Mbit	2 Mega bit

A

ABR	Announcements Before Routing
ACC	Advanced Card Calling service
ACG	Automatic Code Gap
ACP	Action Point
ADC	Address Complete Message (ACP)
ADOB	Alternate Destination on Busy
ADSN	Analogue Derived Services Network
ADSSC	Analogue Derived Services Switching Center (British Telecom)
ADU	Analogue Data Unit
AEC	Adaptive Echo Cancellation
AEXC	Alternate Exception
AFP	Advanced FreePhone service
AGN	Advanced Green Number
AI	Artificial Intelligence
AM	Administration Module
AMA	Automatic Message Accounting
AMI	Alternate Mark Inversion
AMSU	Analogue Main Switching Unit
ANS	Answer Signal
AP	Adjunct Processor
API	Attached Processor Interface
ATU	The Analogue Trunk Unit
AST	Service Assist
AT&T	American Telephone and Telegraph
AWG	American Wire Gauge

Action Point (ACP): The physical exchange (SESS® Switch, SESS-PRX Switch that performs Action Point functions in addition to all basic exchange functions (e.g. digit collection, announcements, tones, etc.)

Advanced Card Calling Service (ACC): Obsolete. This was the set of Intelligent Network card calling services. It included support of Calling Card and Commercial Credit Card services. These services have been separated.

Alternate Destination on Busy (ADOB): Service

Feature. Routes a call to an alternate destination if the first destination is busy. If all alternate destinations are busy, a default call handling treatment specified by the Service Subscriber will be applied to the call.

Advanced FreePhone Service (AFP): Allows the caller to call a Service Subscriber and have the Service Subscriber pay for the whole call. This service requires a NCP. (See also Basic FreePhone Service, Split-Charging Service, and Premium Service.)

B

BER	Bit Error Rates
BFP	Basic Freephone service
BHCA	Busy Hour Call Attempts
BOC	Bell Operating Company
BRCS	Business Residence Custom Services
BT	British Telecom
BTI	British Telecom International
BTNR	British Telecom Network Requirement
BT7	British Telecom CCITT No. 7 Signalling
BVA	Billing Validation Application
BWM	Broadcast Warning Message
BX.25	Bell System X.25 Protocol

Basic Freephone Service (BFP): Similar to Advanced Freephone with the exception being that the service is provided out of the ACP, not the NCP. Also, only a limited feature set is available. (See also Advanced Freephone Service)

British Telecom: The British Telecommunications Authority.

B (Bearer) Channel: This is the information bearing channel that provides a transparent digital path to a customer premise. The B channel has been standardized at 64,000 bits per second for ISDN.

C

CAD	Computer Aided Design
CC	Calling Card service
CCC	Commercial Credit Card service
CCIS6	Common Channel Interoffice Signalling No. 6
CCITT	Comitee Consultatif International Telegraphie et Telephone
CCS	Common Channel Signalling

CCS7 (NA)	Common Channel Signalling No. 7 (North American)
CED	Centro Elaborazione Dati (Elect. Data Proc. Center)
CEPT	Committee of European Postal and Telecommunication administration
CFA	Customer Features Available
CLF	Clear Forward
CLI	Calling Line Identity
CLLI	Common Language Location Identifier
CM	Communications Module
CO	Central Office
CPE	Customer Premises Equipment
CPM	Critical Path Method
CPS	Call Progress Stopped
CPT	Controlled Product Test
CRT	Cathode Ray Tube
CSDC	Circuit Switched Digital Capability
CSG	Calling Subscriber Geography
CTI	Call Termination Indicator
CUG	Closed User Group

Call Allocator: Service Feature. Allocates calls randomly to alternate call treatments based on the percent allocations assigned by the Service Subscriber.

Call Barring: Service Feature. Bars calls from completing based on the location of the originating caller.

Call Counter: Service Feature. Counts the number of calls to an Intelligent Network number that have reached the NCP.

Caller: Person who makes the phone call.

Calling Card Customer: See Calling Card User.

Calling Card Service (CC): Enables a user to charge calls to a Service Administration issued Calling Card.

Calling Card User: Person who obtains a Service Administration Calling Card to charge phone calls to the account associated with that card.

Calling Line Identity (CLI): Sent from the ACP to the NCP for the Routing by Calling Line Identity service feature. This is the full CLI or the first 10 digits of the full CLI, whichever is shorter. (See also Full CLI, Incomplete CLI, Pseudo CLI and Routing by CLI)

Calling Subscriber: See Caller.

Calling Subscriber Geography (CSG): 3 digit code identifying the location of the originating caller. The CSG is derived from either the Full CLI, the Incomplete CLI, or the Pseudo CLI.

Call Logging: British Telecom Terminology. Refers to AMA recording.

Call Prompter: Service Feature. Allows the Service Subscriber to play an announcement to solicit a response from the caller to determine the next call

treatment.

Call Queueing: Service Feature. Queues the call to a Service Subscriber when the destination is busy.

Card Calling - NCP (CC-NCP): Dedicated NCP that supports the Calling Card (and potentially Commercial Credit Card) service.

Carrier System: A system for the modulating of a periodic carrier signal with the information of one or more channels so as to transmit the combined signal over any specific transmission medium.

Carrier Serving Area: A geographic area served by a carrier's exchange facility.

Channel: A logical connection between any two points in a network for the transmission of information.

Circuit Switching: The switching of logical channels between nodes in a network through logical channel connections.

Command Routing: Service Feature. Allows the Service Subscriber to switch from one active call handling logic to an alternate inactive call routing logic. This service feature allows the Service Subscriber to plan for emergencies and other circumstances by having a validated, but inactive, call handling logic resident in the NCP.

Commercial Credit Card Service (CCC): Allows the caller to place a call and charge it to a commercial credit card (e.g. VISA, American Express, etc.)

Courtesy Response: Service Feature. Terminates the call to an announcement at the NSCX.

D

DASS	Digital Access Signalling System (British Telecom)
dB	decibel
DCE	Data Communication Equipment
DCIS6	Destination CCIS6
DCN	Address Complete Message (ACM)
DDI	Direct Dialing In
DDSN	Digital Derived Services Network
DDSSC	Digital Derived Services Switching Center
DMSU	Digital Main Switching Unit
DN	Destination Number
DPC	Destination Point Code
DPNSS	Digital Private Network Signalling System (British Telecom)
DRCC	Destination Restricted Calling Card
DSDC	Direct Services Dialling Capabilities
DSS	Digital Subscriber System
DSDE	Direct Service Dialing Export

DSP Digital Signal Processing
DTMF Dual Tone Multi Frequency

D (Delta) Channel: A supporting channel that carries out of band signaling information for the information bearing B channels.

Destination CCIS6 (DCIS6): Signalling protocol between the ACP and the NCP.

Destination Number: Routing number of the final destination of the call.

Destination Restricted Calling Card: Sub-service of Calling Card Service that allows the caller to reach a single destination.

Dialled Number: 3-10 digit number that the caller dials to access an IN service.

Digital hierarchy: An ordering of the various lower capacity logical channels thereby providing easy multiplexing and demultiplexing to and from higher capacity channels.

Digital Derived Services Network (DDSN): Intelligent Network provided to British Telecom.

E

EAI Emergency Action Interface
EC Echo Canceled
ECIS6 Embedded CCIS6
EQ Equalizer
ESS Electronic Switching System
ETSI European Telecommunication Standards Institute

Embedded CCIS6 (ECIS6): Signalling protocol between the ACP and NSCX.

Electronic Switching Systems: An integrated switching facility for switching channels within the network by electronic devices operated by stored program.

F

FC Functional Component
FCLI Full Calling Line Identity
FDOC Focused Destination Overload Control
FIR Finite Impulse Response

FOA First Office Application

Flexible Charging Service: Allows alternate charging to be applied to the caller based on the destination number of the call.

Full Calling Line Identity (FCLI): Full CLI received at the Intelligent Network exchange. (See also CLI, Incomplete CLI, and Pseudo CLI)

Functional Components: These components permit the easy introduction of new services in the IN/1+ and IN/2 environments by being modular in their functionality. They are capable of being executed in the interpreter mode by the service logic interpreter (SLI) to build new service quickly and efficiently.

G

Gbps Giga bits per second
GDSU Global Digital Service Unit
GDX Graded Diode Cross Point
GDXLU Graded Diode Cross Point Line Unit
GN Green Number
GSDN Global Software Defined Network
GTT Global Title Translation

Geographically based routing: See Routing by Calling Line Identity.

H

Handoff: Service Support Procedure. Connects the ACP controlling the call with a second ACP connected to an appropriate NSCX. The first ACP relinquishes control of the call to the second ACP. (See also Service Assist)

Host-STEP: A 5ESS[®] Switch with the STEP functionality that is directly connected to the NCP.

I

IAM Initial Address Message
IDA Integrated Services Access
ICLI Incomplete Calling Line Identity
IDN Integrated Digital Network
ILD International Long Distance

ILDS	International Long Distance Service
IN	Intelligent Network
IP	Intelligent Peripheral
ISDN	Integrated Services Digital Network
ISPBX	Integrated Services Private Branch Exchange
ISUP	ISDN User Part
ITA	International Telecommunications Authority of Taiwan
ITC	International Teletraffic Congress

Incomplete Calling Line Identity (ICLI): Used to be known as partial or short CLI. This is a CLI received from another exchange that is not the full national number. (See also Full CLI and Pseudo CLI)

Internal Routing Number: Number that is sent from the NCP to the ACP in a routing command to route a call either to another ACP for a service assist or hand-off, to a line directly connected to the ACP, or to an announcement provided at the ACP.

Intelligent Network/1: One of the first intelligent networks evolved to support the simpler services such as the 800 services. This class of networks provide predetermined service functions whereby users do not have the option to control their network resources.

Intelligent Network/1+ and /2: Newer intelligent network configurations suggested by Bell Communications Research (Bellcore) in the United States. Developed to provide rapid and easy introduction of newer network services through the nineties.

J

Join: A database term used for joining two logical entities.

Justification: A pulse stuffing technique in conjunction with elastic stores, effective for multiplexing the four asynchronous tributary signals in a PCM model.

K

Kbits/s	Kilo bits per second
KHz	Kilo Hertz
KS/s	Kilo Symbols per second

Kokusai Denshin Denwa (KDD): The Japanese Long Distance Telecommunications Authority
Kilo Symbols per second (KS/s): One symbol representing two binary bits

L

LCS Local Communications Services

LINKLINE: British Telecom Terminology. Refers to British Telecom's Advanced Freephone Service.

M

Mbps	Mega bits per second
MCA	Maximum Calls Allowed
MCC	Master Control Center/Console
MCG	Manual Code Gapping
MCQ	Maximum Calls Queued
MCT	Malicious Call Trace
MF	Multi Frequency
MFOS	Multifunction Operation System
MML	Man-Machine Language
MSU	Main Switching Unit
MTP	Message Transport Part
MVI	Multi Vendor Interaction

Multifunction Operations System (MFOS): MFOS is an operations system providing operational support to the Intelligent Network components, except NETSTAR.

N

NA	North American
NANP	North American Numbering Plan
NCP	Network Control Point
NETSTAR	Network Subscriber Transaction, Administration, and Recording system.
NM	Network Management
NMC	Network Management Center
NMS	Network Management Sub-system of MFOS
NNG	National Number Group
NPA	Numbering Plan Area
NSC	Network Services Complex

NSCX Network Services Complex
NTE Network Terminating Equipment
NTT Nippon Telephone and the Telegraph

National Number Group (NNG): British Telecom Terminology. Use Service Access Code (SAC).

NCP Feature Usage: Service Feature. Counts the use of certain service features in a Service Subscriber plan during a call. The maximum count is 3 for each feature node. If any of the service feature nodes is used more than 3 times in completing a call, an flag is set that a service feature node has been used more than 3 times, but the exact usage and the node(s) identity will not be known.

Network Components: Refers to all parts of the Intelligent Network, including non-physical elements such as Network Management.

Network Control Point (NCP): Computer database containing the service call logic or Service Subscriber plan which contains instructions on how to handle an Intelligent Network call.

Network Elements: Obsolete. Use Network Components.

Network Management Sub-system (NMS): The Network Management module of MFOS.

Network Services Complex (NSC[X]): This component plays announcements to the caller and can collect digits to help process the call.

Network Subscriber Transaction, Administration and Recording (NETSTAR): NETSTAR is the component where the Service Administration and Service Subscriber creates updates to the call processing records for the NCP. NETSTAR also provides all of the marketing support reports for the Intelligent Network services.

Network Intelligence: The intelligence of components within a network that allows the network to adaptively, switch, seek, monitor, and interconnect the information bearing channels, information sources and information users.

Network Services: A class of customer services provided by the intelligent networks above and beyond those readily available from conventional networks such as the standard telephone network.

Non Host-STEP: A 5ESS[®] Switch with STEP functionality that communicates with the NCP through a Host-STEP.

O

OA&M Operations, Administration and Maintenance
ODD Office Dependent Database
ONN Off-Network Node
OSPS Operator Services Position System
OSI Open Systems Interconnection
OSS Operations Support Systems

Operations Support Systems (OSS): A generic classification of systems that provide service provisioning, service maintenance, network maintenance, engineering and administration support for network components and services.

P

PABX Automated Private Branch Exchange
PBX Private Branch Exchange
PCLI Partial Calling Line Identity
PCM Pulse Code Modulation
PERT Program Evaluation and Review Technique
PLL Phase Locked Loop
PMBX Manual Private Branch Exchange
PN Personal Number service
PNUT Personal Number Update
POTS Plain Old Telephone Service
PRI Primary Rate Interface
PsCLI Pseudo Calling Line Identity
PSN Public Switched Network
PSTN Public Switched Telephone Network
PTT Post, Telephone, and Telegraph
PVC Permanent Virtual Circuit
PVN Private Virtual Network

Partial Calling Line Identity (PCLI): British Telecom Terminology. See Incomplete CLI.

Personal Number service (PN): Allows Service Subscribers the convenience and freedom of being able to move among locations and yet be reached via a single telephone number.

Personal Number Update (PNUT): Call made by the PN Service Subscriber to update the destination number where the Service Subscriber can be reached.

Pseudo Calling Line Identity (PsCLI): CLI generated at the ACP based on the trunk group

attribute. This attribute is entered by the Service Administration when establishing the ODD.

Premium Charging Service: Allows a caller to call a Service Subscriber, but the caller is charged at a special rate for the call.

Q

QRY Query Message

Query Number: This is the portion of the caller dialed number that is sent from the ACP to the NCP in the initial inquiry message. This is a 6-10 digit number that the NCP will use to identify the service or to locate a service subscriber plan. This number is also known as the Dialed Number in NCP reports and messages. If this number is less than 6 digits it will be padded to have a minimum of 6 digits.

R

RAO Revenue Accounting Office
RBOC Regional Bell Operating Company
RC Recent Change
RCS Routing Control Service
RC/V Recent Change and Verify
RFD Rate Fonia Data
RLG Release Guard
RLS Release

Received Number: 3-10 digit number that the ACP receives from the PSN.

Routing by Calling Line Identity: Service Feature. Routes a call based on the CLI of the caller. There are two capabilities associated with this service feature:

— **Geographically Based Routing:** Similar to Routing by CSG but with finer granularity associated with CLIs

— **Routing by Closed User Group:** Restricts calls to within a Closed User Group (CUG) of CLIs.

Routing by Calling Subscriber Geography: Service Feature. Routes a call based on the CSG of the call originator.

Routing by Day of Week: Service Feature. Routes a call based on the Day of Week the call was placed.

Routing by Time of Day: Service Feature. Routes a call based on the Time of Day the call was

placed.

Routing Control Service (RCS): Service Capability. Allows the Service Subscriber to build, modify, remove, query, validate, and schedule activation of Advanced Freephone Service Subscriber plans via NETSTAR.

S

SAC Service Access Code
SCE Service Creation Environment
SCLI Short Calling Line Identity
SCCP Signalling Connection Control Part
SCCS Switching Control Center System
SCP Service Control Point
SDL Software Definition Language
SDN Software Defined Network
SDGN Single Destination Green Number
SILC Selective Incoming Load Control
SIP Societa Italiana per l'Esercizio
SL Signalling Link
SLC Subscriber Loop Carrier
SLI Service Logic Interpreter
SLIM Subscriber Loop Instrument Measurement
SLP Service Logic Program
SM Switch Module
SMS Service Management System
SMSI Simplified Message Service Interface
SNA System Network Architecture
SP Service Provider
SPC Stored Program Control
SSP Service Switch Point
SSAC15A Signaling System AC No 15 A
SSAC15C Signaling System AC No 15 C
SSAC15E Signaling System AC No 15 E
STEP Signal Transfer and End Point
STP Signal Transfer Point
SU Signalling Unit
SUB Subscriber
SVC Switched Virtual Circuit

Service Access Code: Part of the caller dialed number that signals to the PSTN that the call is an Intelligent Network call.

Service Administration: Administration that has purchased an Intelligent Network to provide Intelligent Network services to its customers. This is not necessarily the Telephone Administration. (Do not abbreviate!)

Service Assist: Service Support Procedure. Connects the ACP controlling the call with a second ACP connected to an appropriate NSCX. The first

ACP retains control of the call. (See also Handoff)
Service Feature: Service logic modules that have parameters that can be set by the Service Administration and/or by the Service Subscriber. These service features can be administered individually.

Service Call Processing Logic: Refers to the service logic resident in the NCP (and NETSTAR) that cannot be modified. (e.g. Call processing logic for Personal Number service and Calling Card service).

Service Provider (SP): British Telecom terminology. Use Service Subscriber instead.

Service Subscriber: Individual or company subscribing to a service from the Service Administration. (Do not abbreviate!)

Service Subscriber Plan: Refers to the service logic resident in the NCP (and NETSTAR) that can be modified by the Service Administration or Service Subscriber (e.g. Advanced Freephone service and Televoting service).

Service Support Procedure: Service logic modules that are accessed by the NCP autonomously when required. An example of a service support procedure is the Service Assist or Handoff service support procedure.

Short Calling Line Identity (SCLI): Obsolete. See Incomplete CLL.

Signal Transfer and End Point (STEP): Exchange functionality that passes circuit and non-circuit related call messages between network components. This functionality is integrated with the ACP in the same ACP. (See also host STEP and non-host STEP)

Split-Charging Service: Allows the caller to call a Service Subscriber and have the caller and Service Subscriber share the cost of the call.

Stored Program Control: The capacity to control the network functions by programs or microcode generated and stored as software or utilities.

Subscriber Loop Carrier: A carrier system used in the loop plant of existing telephone network which is used to carry numerous telephone conversation between an exchange and a remote terminal.

T

TAO Tandem Access Office
TCAP Transaction Capabilities Application Part
TCM Time Compression Multiplexing
TDMA Time Division Multiple Access
TLWS Trunk and Line Work Station
TNDC Trunk Network Data Collector

TS16 Time Slot 16
TSI Time Slot Interchange
TUP Telephone User Part
TV TeleVoting service

Telefonica: The Spanish Telecommunications Administration.

Televoting service (TV): Allows Service Subscribers to conduct a survey of public opinion by soliciting calls to a Televoting telephone number.

Time Division Multiplexing: A method of multiplex a finite number of time slots into individual channels for higher speed transmission.

U

UAN Universal Access Number
UIS Universal Information Services
UK United Kingdom
USS User Support System

Universal Dialed Number: This feature of the Intelligent Network allows callers to reach a Service Subscriber from anywhere within the Service Administration boundaries by dialling a single number.

User Support System (USS): Customer support operations system for AT&T's domestic A800 services. It is similar to NETSTAR.

Universal Information Services Network: An adaptive and intelligent services network proposed by AT&T to provide a wide variety of universal information services. This network covers a super set of all features offered by the many classes of Intelligent Networks.

V

VDU Video Display Unit
VPN Virtual Private Network

V.24: A CCITT physical layer interface specification.

Vendor Services: The services provided by a Service Subscriber to customers as a service or for a fee. The network then communicates the information necessary to complete the transaction.

Vendor Feature Nodes: These nodes are owned

and operated by Service Subscribers. They provide special services (such as polling or opinion surveys) that does not require service resources from the network provider.

W

WG Wire Gauge

X

X.25: A CCITT protocol specification for levels 1 (physical), 2 (link), and 3 (network).

Z

Z Imaginary impedance (ohms)

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