ERICSSON REVIEW

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Transmission Maintenance System ZAN 101
EDNET for the Supervision of Data Transmission Networks
LPB 110, a System for Controlled Test Traffic
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TELE-X, the Nordic satellite for TV and data communication

TELE-X — a Satellite System for TV and Data Communication

Sievert Bergman, Krister Ljungberg and Lars-Gunnar Sundin

TELE-X is the designation of a complete telecommunication system covering the Nordic countries. The system includes a satellite with different transmission channels for direct broadcasting of television and for data and video transmission.
The authors describe the characteristics of the system, some of which are unique, different types of earth stations, the traffic control, the satellite payload and the implementation of the whole project.

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The initial studies for TELE-X were started in 1980, and two years later the Swedish Parliament adopted a budget for the whole project of 1250 M Swedish kronor. Later on an agreement was concluded which led to Norway's participation in the project, corresponding to 15% of the project cost. Finally, in the autumn of 1983 Finland decided to participate to a value of approximately 4% of the project cost. The Swedish contribution is thus 81% of the final sum. The system requirements have been prepared jointly by the Swedish Space Corporation, the Telecommunications Administrations (initially only the Swedish) and the industry.

In the middle of 1983, when the Nordic basis for the project had been extended, a Nordic telecommunication satellite consortium, NOTELSAT, was formed. It is owned jointly by the participating countries, and is responsible for both procurement and operation.

NOTELSAT has delegated the procurement and project management of TELE-X to the Swedish Space Corporation but intends to take over the operation of the system after launch.

The satellite has the same type of platform as that now being developed for the French and German direct broadcast satellites, but it has a different payload since TELE-X also includes data and video communication. The main supplier is the French company Aerospatiale, and Ericsson Radio Systems AB is responsible for the payload. The ground segment will be delivered by Ericsson Radio Systems in collaboration with Norwegian and Finnish industry.

Facilities

System TELE-X is intended for data and video communication between small earth stations as well as for direct broadcasting of television. Within the Scandinavian coverage area the power flux density of the television transmission is sufficient for receivers equipped with 90 cm parabolic antennas. Such home receivers are expected to be generally available in the market by the time the TELE-X satellite is launched, and are not included in the development program for TELE-X.

As regards the data and video service the aim is to supplement the Nordic telecommunications networks with wideband facilities, which would otherwise have been impossible to realize for reasons of time and cost.

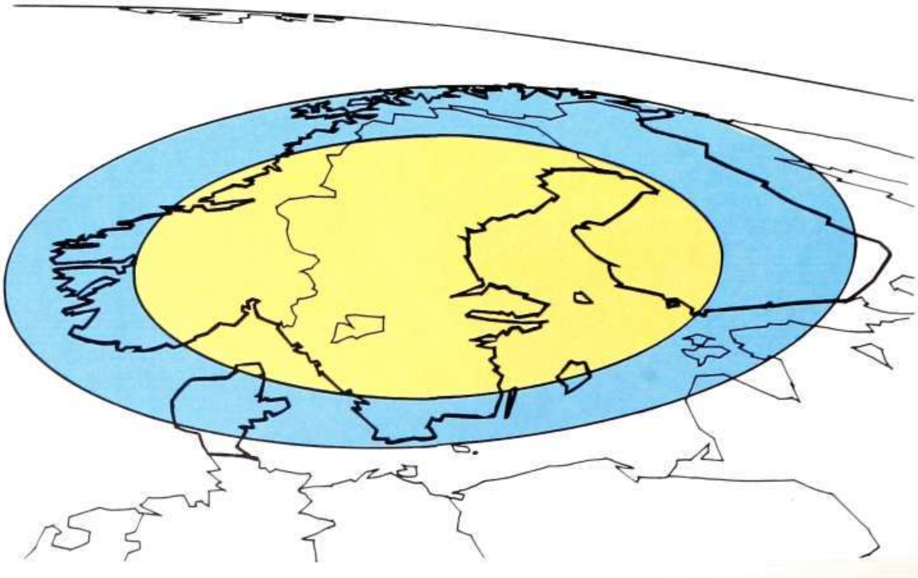
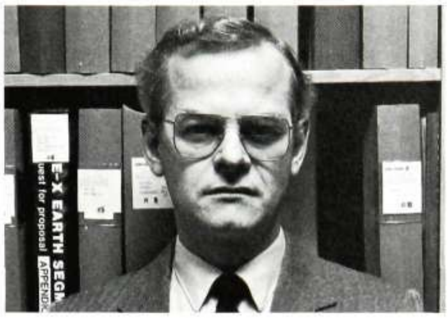


Fig. 1
The coverage area for the data and video service



SIEVERT BERGMAN
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Ericsson Radio Systems AB

The unique facility of a satellite system in providing immediate coverage of the whole service area is thus of paramount importance. The applications now considered for these wideband data services are:

Business services
- private business networks
- electronic mail
- high-speed telefacsimile

Video conferencing

Communication between computers
- high speed transmission of data bases
- fault tracing in computers
- sharing of computer resources and standby computer facilities
- electronic document retrieval and delivery

Distribution of pictures, for example from satellites for remote analysis of earth resources

Remote printing of newspapers.

In addition to these business data services there are also interesting video and broadcasting possibilities:

Video services
- tele education
- tele medicine
- televised events (transmission to special video theatres)
- video distribution, for example within a hotel chain
- security television
- distribution of pay television to cable television networks

TV and radio program contribution
- from permanent transmitters
- from mobile transmitters (outside broadcasting).

The business data services can be combined in one and the same business station with the standardized transmission capacities 2 Mbit/s and n × 64 kbit/s. The 2 Mbit/s channel can then be shared in time between data transmission and video conferencing, while the 64 kbit/s channels can be used simultaneously and independently of each other for, for example, high-speed facsimile, data or speech.

Choice of systems and networks

The TELE-X data and video systems must be able to work with small and simple earth stations. This makes it possible to place the station with the user, unlike present-day satellite systems, which require large earth stations and hence a great concentration of traffic in order to warrant a station.

In certain areas there may be good reasons for connecting limited Local Area Networks (LAN) to an earth station, in order to provide direct communication within the LAN without having to use the satellite. This releases satellite capacity for long-distance communication. This is illustrated in fig. 2, where an industrial

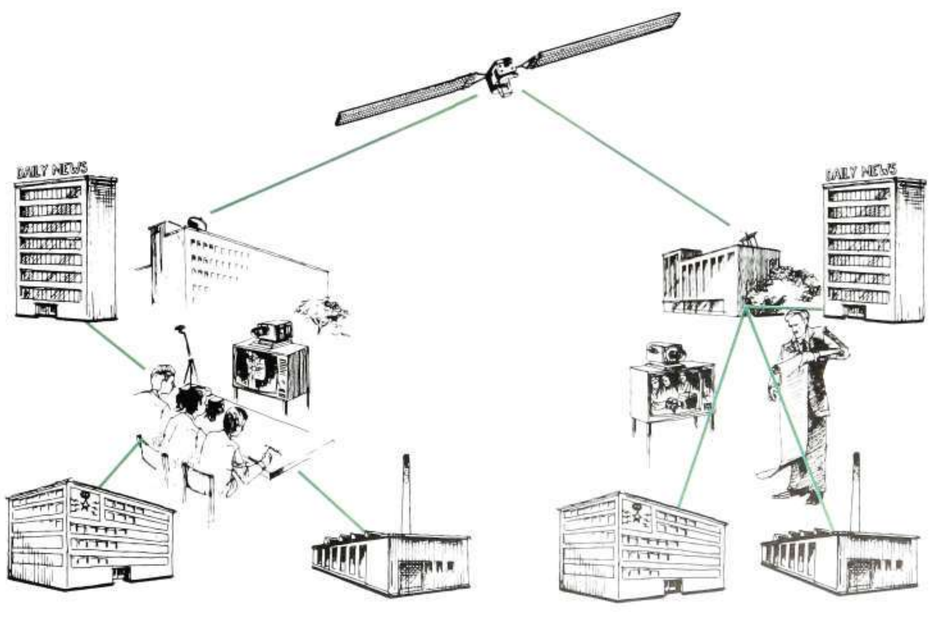
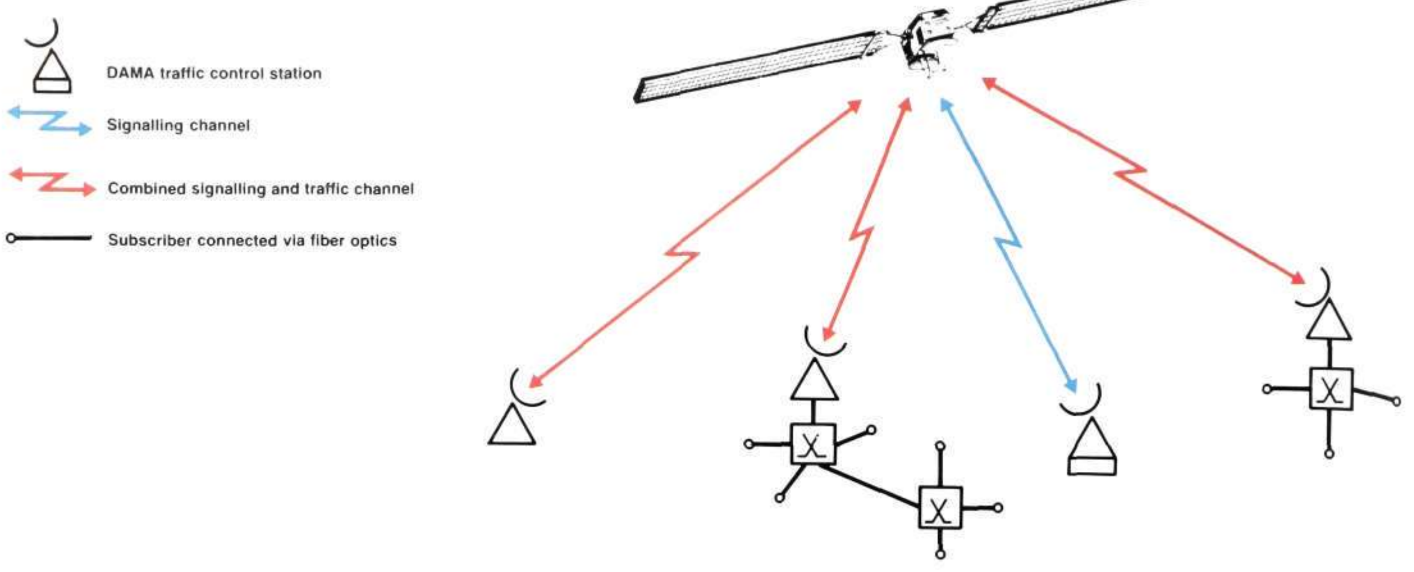


Fig. 2
An example showing the business communication facilities

Fig. 3
A sketch of the network



area is internatlly connected via an optical fibre network.

The demand for small and simple stations has led to the use of the best of both old and new satellite technologies. For example, the most modern of high-power satellites is combined with the simple but effective SCPC (Single Channel Per Carrier) transmission method.

With the SCPC method the transponder signal is frequency divided into a number of carriers, which form a pool used by all stations in the network according to need. For example, the distribution of 64 kbit/s and 2 Mbit/s carriers is dynamic, i.e. it can be adapted to the current traffic requirement by blocking or releasing 64 kbit/s channels so that the number available corresponds to the traffic load.

When a station calls another station a channel is allocated, and when the transmission is finished the channel is returned to the pool.

Each cannel is independent of the others and is modulated on its own carrier. This makes for flexible allocation of channels to the stations, without complicated signal processing.

All stations in the system (can be thousands) therefore have full access to each other when required. This arrangement is designated DAMA (Demand Assignment Multiple Access).

Fig. 3 shows a sketch of the network.

SCPC/DAMA can be compared with the now very popular TDMA (Time Division Multipel Access) systems. Such a com-

Comparison between SCPC/DAMA and TDMA

Full transponder TDMA
With full utilization of the TDMA (Time Division Multiple Access) method all traffic in the system passes through the satellite transponder and the earth stations via one carrier. The carrier is time divided into short bursts and thus a high momentary data rate is obtained. Since only the one carrier is present it is possible to drive the earth stations as well as the satellite output stage to saturation, which gives good utilization of their high-power transmitters.

Another advantage is that with TDMA all subscribers in the network have access at any instant to all exchanged information. This provides unique facilities in a large number of traffic situations because of the possibility of varying the length or periodicity of the bursts.

One drawback is that the advantages of TDMA are closely connected with the fact that at any moment all earth stations handle and sort all the traffic in the network. The radio parts in the earth station must be dimensioned for the full amount of traffic in the network, and the complexity of the "sorting equipment" increases very rapidly with the number of earth stations and the number of traffic elements per earth station.

Small-scale TDMA
The designation TDMA is sometimes also used for rather trivial multiplex-type systems, whose network structure and capacity allocation are set during installation and cannot be adjusted afterwards to suit the traffic requirements.

The relative simplicity is attractive for small-scale TDMA in which the satellite transponder signal is divided into several carriers with different frequencies, like in the SCPC (Single Channel Per Carrier) method.

Each carrier is time divided, as with full TDMA, but with a lower data rate per carrier. This demands less from the individual earth station as regards data rate and power, but means a loss of connectivity between the TDMA carriers, and a limited upper data rate for each station.

The method is economical in systems with a medium data rate and a fairly small number of stations in a closed user group.

TDMA or SCPC system?
TDMA stations with full transponders are complicated and expensive, as the stations must handle all traffic in the network regardless of the needs of the individual station. The method is economical when the network consists of a few earth stations, each with a large amount of traffic. In order to achieve this it is often necessary to concentrate the traffic. However, it has been found that just the cost of connecting a subscriber to an earth station via a cable or radio relay link can be higher than the cost of a complete TELE-X SCPC earth station. For reasons of economy TDMA is thus not suitable for wide-mesh networks with many subscribers.

The SCPC concept means that each station is dimensioned for its own traffic (not the total network traffic), and it is therefore much cheaper than a TDMA station.

Small-scale TDMA with several carriers in the same transponder can make full use of the TELE-X system. This combination may be attractive for different types of company networks in which, for example, a 2 Mbit/s channel within the SCPC system is used for TDMA traffic. The TELE-X traffic control system DAMA (Demand Assignment Multiple Access) makes possible such a combination of pure SCPC and TDMA.

New services, such as data and video communication, will be used fairly sparsely even in cities. The possible users of such facilities will be numbered in tens of thousands, unlike the telephone subscribers which number millions. This fact favours TELE-X SCPC, perhaps combined with small-scale TDMA.

Technical data for a DS/MDVS station

Antenna diameter	1.8–2.5 m
Modulation method	Differentially coded OQPSK
Frequency (Special Service Band)	
up link	14 GHz
down link	12 GHz
G/T	19/22 dB/K
EIRP	44-63 dBW
Data rates	64 kbit/s 2 Mbit/s

Designation	Maximum simultaneous channel capacity, sending/receiving 64 kbit/s	2 Mbit/s	8 Mbit/s	34 Mbit/s
DS	1/1	–	–	–
MDVS	1/5	1/3	–	–
FVSS	–	3/3	–	1/2
TVDS	1/1	1/1	1*/1	1*/1
VROS	–	–	–	–/1

*) 8 and 34 Mbit/s cannot be transmitted simultaneously

Table 2
Traffic stations for data and video communication, main types

	2 Mbit/s	64 kbit/s
Up link		
EIRP/channel (dBW)	+ 60.2	+ 46.8
Space loss, EOC (dB)	−207.8	−207.8
K (dBW/K)	+228.6	+228.6
Satellite G/T, EOC (dB/K)	+ 7.6	+ 7.6
Data rate (dBHz)	− 63.1	− 49.3*
Eb/No (dB)	25.5	25.9
Down link		
EIRP/channel, EOC, (dBW)	+ 39.8	26.4
Space loss, EOC, (dB)	−206.7	−206.7
K (dBW/K)	+228.6	+228.6
Earth station G/T, (dB/K)	+ 22.0	+ 22.0
Data rate (dBHz)	− 63.1	− 49.3*
Eb/No (dB)	20.6	21.0
Total link		
Up link Eb/No (dB)	25.5	25.9
Down link Eb/No (dB)	20.6	21.0
Total Eb/No (dB)	19.4	19.7
Theoretical Eb/No for $BER=10^{-6}$ QPSK+differential coding	10.8	10.8
Gross margin (dB)	8.6	8.9

*) For the data rate modified by the error correcting code to 4/3 x 64 kbit/s

Table 1
Link parameters

parison is made in a separate panel. This gives the background to an essential part in the choice of system for TELE-X.

Link budget

It is essential that the transmission services planned via TELE-X have a minimum of errors. A bit error rate (BER) of less than 10^{-6} must be obtained for more than 99% of the time during the calendar month with the highest rainfall.

In order to achieve this with the small antennas of 1.8 to 2.5 m of the low-cost earth stations, forward error correction, FEC, has been introduced for the 64 kbit/s channels. The 2 Mbit/s channels have been equipped with adaptive output power at the earth stations in order to compensate for rain attenuation on the satellite uplink.

Table 1 shows nominal link parameters for these two data rates for stations on the outskirts of the coverage area. The link margin to $BER=10^{-6}$ is approximately 9 dB for 2.5 m antennas. The same value applies for 1.8 m antennas in an inner coverage area comprising the central parts of Scandinavia, fig. 1. This gross margin is to cover attenuation and disturbance from rain, antenna alignment errors, power variations, scrambling, interference, intermodulation, ageing etc. With the aid of the further 3–4 dB improvement provided by FEC or adaptive output power the specified availability is obtained with a satisfactory system margin. These methods can be combined in a subsequent operating system in order to considerably reduce the satellite power for the data/video services while maintaining the same link margin.

Earth stations

The development within the framework of the TELE-X project comprises a station for the control of the satellite and its payload, and different types of communication stations. The latter are either user stations placed on the subscribers' premises or centrally located main stations.

Data and video

The main types of traffic stations, which will be included in the first ground network, are:

- DS (Data Station), which is a single-channel solid state station that cannot be extended
- MDVS (Multi purpose Data/Video Station), which is a modular multi-channel station. It can be equipped as required, and is available in a stationary and a transportable version. Its range of application includes data communication, two, three or four-party video conferences, tele education and the contribution of stereo radio programs
- TVDS (Transportable Video and Data Station) and FVSS (Fixed Video and Sound Station), which are modular transportable or stationary high-speed stations. Applications include data communication, video conferences, outside broadcasting, televising of events and video distribution
- VROS (Video Receive Only Station), which is a specialized receiving station that cannot be extended. It can be used for, for example, video theatres and reception of videograms.

Table 2 gives the capacity of the different stations. Fig. 4 illustrates the technology, in the form of a block diagram of MDVS showing the signal path through a station.

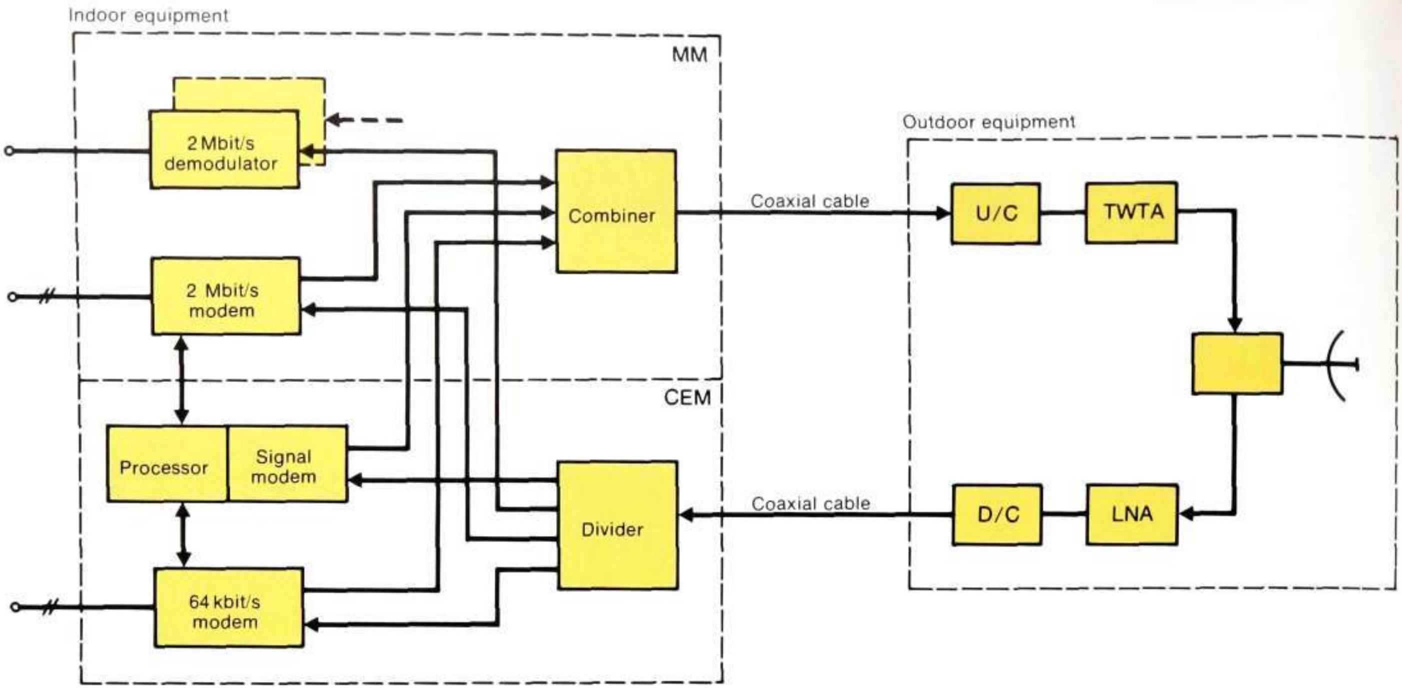


Fig. 4
Block diagram for a data and video station, MDVS

MM	Modem shelf
CEM	Central electronics unit
U/C	Up-converter
TWTA	Travelling wave tube amplifier
D/C	Down-converter
LNA	Low noise amplifier

The station is designed to set up connections automatically. This is done with the aid of an X.21 high-level protocol, which means that the subscriber equipment either uses X.21 itself or that it is equipped with an auxiliary signalling unit for this protocol.

The incoming data signal is first taken to the data circuit equipment, DCE, in the station, fig. 4. The signalling part is processed by DRP (DAMA Remote Processor). DRP sends out signalling data in the form of bursts, which are OQPSK (Offset Quadrature Phase Shift Keying) modulated and are then fed to the station transmitter.

Common channel signalling in accordance with the ALOHA access method, based on random access, is used between the traffic station and the control station. When receiving a request from a calling station the control station signals to the other traffic station via its BSC (Broadcast Signalling Channel) and then tells the two stations which pair of channels they are to use. BSC works continuously with time division for the stations in the network.

Each station is equipped with a signalling receiver for BSC. This channel is BPSK (Binary Phase Shift Keying) modulated, and the incoming signals are therefore fed through a BPSK demodulator, and then a decoder for the error correction code (FEC) used. The incoming signals are processed by the DCE, which sets up the pair of channels indicated by the control station. This is done by setting the traffic modem to the allocated frequencies. The traffic modem uses OQPSK modulation in combination with FEC and scrambling. After a handshake procedure with the other traffic station the traffic data can be transmitted. Afterwards the two channels are disconnected and returned to the pool of free channels in the control station.

The station transmitter is equipped with TWT (Travelling Wave Tube) amplifiers (except DS, which has a GaAs-FET semiconductor amplifier). Stations with TWT are provided with active output power control, in order to compensate for the effect of weather on the link to the satellite.

All IF/RF electronic equipment is placed in a cabinet behind the antenna. The electronic equipment for indoor installation consists of between one (DS) and three (fully extended MDVS) 19" magazine shelves of type BYB, which can be placed in an ordinary office environment.

The high-speed stations have more extensive electronic and microwave equipment, but they normally have the same antennas as the low-speed stations.

The control station DVCS (Data/Video Control Station) is complex, and a detailed description would be outside the scope of this article. It consists of a radio part and a switching part, which is similar to a switch in an ordinary data network. It works in accordance with the SCPC/DAMA method and handles the switching and supervisory functions in the data and video network. The control station does not transmit any traffic, as this is the task of the traffic stations. The capacity and facility level of the control station can be enlarged during operation. The station can be unmanned and remotely controlled from, for example, an AOM 101 centre.

Technical data for the feeder link station, FLS

Number of channels	3
Redundancy	3+1
Modualtion method	MAC-C
Frequencies	
up link	18 GHz
TV channels according to WARC	26, 32 and 40
down link for alignment and link control	12 GHz
EIRP	84 dBW
Antenna diameter	8 m
High power klystron amplifier per channel	1 kW

The main functions of the control station are to
- establish connections between traffic stations by allocating traffic channels on request and to handle the necessary signalling via a common signalling channel
- supervise the traffic stations and carry out the necessary measures to deal with traffic disturbances and different types of faults
- gather traffic statistics and charging data
- automatically connect 64 kbit/s and 2 Mbit/s circuits
- semi-automatically connect 64 kbit/s, 2 Mbit/s, 8 Mbit/s and 34 Mbit/s circuits
- automatically supervise the network.

The main features of the control station are
- high reliability, since redundant capacity is included for computer and radio subsystems
- automatic network supervision
- equipped for small-scale TDMA and packet switching in future extensions
- maximum capacity 5000 remote stations, 30 calls/s
- initial capacity 500 remote stations, 3 calls/s
- an approximate call set up time of 1–2 s including the satellite delay
- toll ticketing charging
- the types of calls available are: point-to-point, point-to-.multipoint, simplex-duplex and broadcast.

Ericsson Radio Systems is the main supplier of the stations for data and video traffic. The control station and low-speed traffic stations for data and video are developed in close collaboration with Elektrisk Bureau AS, Norway. The Finnish company Teleste OY collaborates in the development of video receiver stations (VROS).

Broadcasting of TV

The feeder link station, FLS, for transmitting programs to the satellite is also being developed as a part of the TELE-X project.

The station must have the capacity to broadcast three TV channels via the satellite. A new modulation system, MAC-C, which uses division for the chrominance and luminance components and multi-channel digital sound has been proposed. The station can be unmanned and remotely controlled.

Satellit data

Total mass	2130 kg
Dry mass (excluding fuel)	~ 1000 kg
Payload	~ 420 kg
Height	5 m
Solar panel span	19 m
Solar panel power (minimum)	3.2 kW
Length of life	>7 years

The satellite will be placed in a geostationary orbit 36000 km above the equator, at a longitude of 5° east, where it will remain on station within ±0.1°. The alignment is stabilized along three axes with the aid of momentum wheels and control rockets.

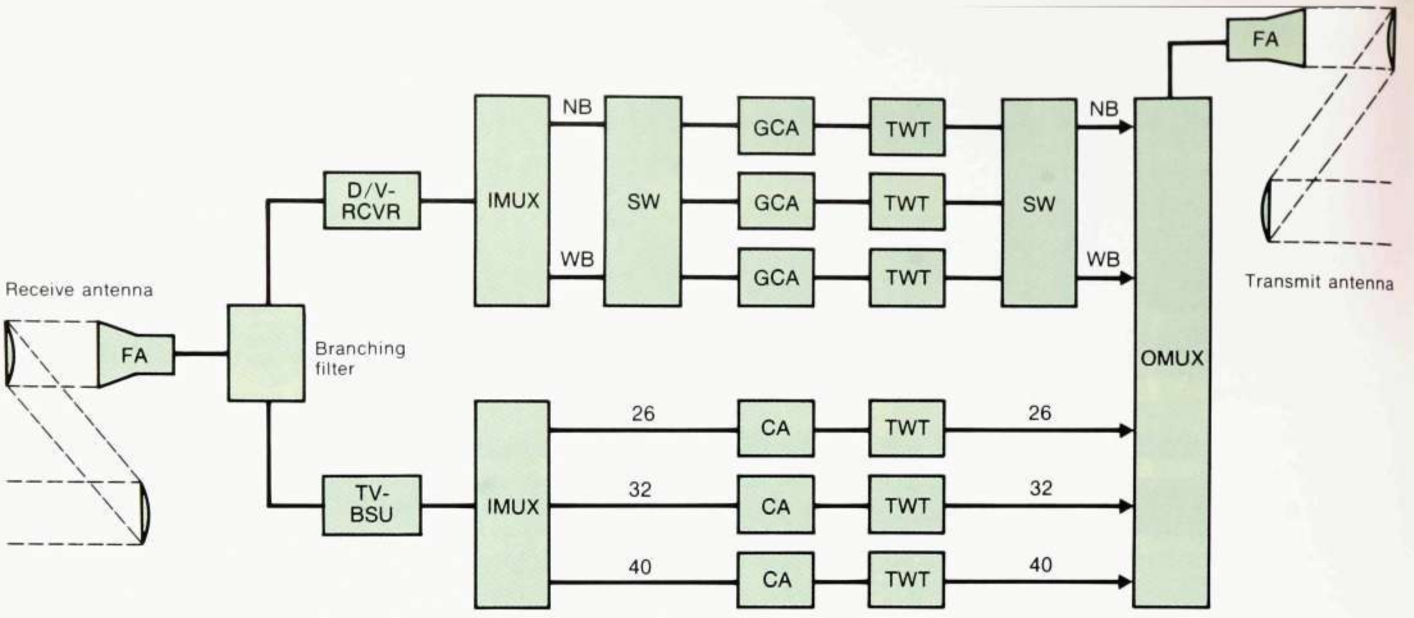


Fig. 5
Block diagram of the payload with its transponder and antenna systems
Data and video transponders (upper half of the diagram)
The signal received from the antenna is pre-amplified and frequency shifted in one of two receivers (redundancy). The signals are filtered and divided between a wideband and a narrow-band transponder. The subsequent amplification takes place separately at 12 GHz and uses a common standby channel. The final amplification takes place in travelling wave tubes of the same type as the TV tubes and with the same saturation power, 220 W. However, the operating point used for the TWTs is approximately 7 dB lower than for the TV tubes, which gives a linear characteristic with an output power of approximately 45 W. Additional improvement of the linearity is obtained by means of amplitude and phase correction in a linearity unit placed before the final amplifiers. This is necessary in order to avoid intermodulation (crosstalk) between the many carriers in the transponder.

TV transponder (lower half of the diagram)
The incoming signal is amplified and frequency shifted, and then divided between the three TV channels 26, 32 and 40 according to the WARC plan. The final amplification is provided by travelling wave tubes, which increase the total amplification to 220 W. Because of the restricted power supply only two of the three channels are normally used. All TV, data and video transponder signals are combined in a filter at the output and fed out to the common transmit antenna. Like the separate receive antenna this is a Cassegrain antenna with a half power lobe width of 1.6 x 0.8°. The system also contains a receiver ("RF sensing") which senses the transmission direction to the control station on the ground. The antenna can thereby be directed towards the desired point and kept to within 0.05°.

FA	Antenna feeder
D/V-RCVR	Data/Video receiver (with redundancy)
IMUX	Input filter
NB	Narrow-band channel for 40 MHz
WB	Wideband channel for 85 MHz
SW	Switch
GCA	Channel amplifier with linearizer
TWT	Travelling wave tube
CA	TV channel amplifier
OMUX	Output filter
TV-BSU	Wide-band preamplifier (with reduncancy)

Ericsson Radio Systems is the main supplier of the FLS station. The Finnish company Valmet OY and the National Finnish Technical Research Centre supply the antenna.

The space segment

The TELE-X satellite will be launched by an ARIANE rocket in February 1987 and placed in a geostationary orbit at a longitude of 5° east.

The satellite consists of two main parts, the payload and the platform. The payload consists of the communication equipment on board.

The platform includes functions for propulsion, attitude and orbit control, power supply, temperature regulation and also telemetry and command. The platform is almost identical to those used in the German and French TV satellites TV-SAT and TDF-1. They have all been produced by the same group of companies (mainly Aerospatiale and Thomson-CSF, France, MBB and AEG-Telefunken, West Germany, and Ericsson Radio Systems and Saab Space, Sweden). However, the Swedish share of the production is much greater in TELE-X than in the French and German satellites.

The platform parts are being tested and space qualified in the French-German projects, whose time plans are approximately one year ahead of TELE-X. The payload is to a great extent new, but as far as possible it has been based on previous experience.

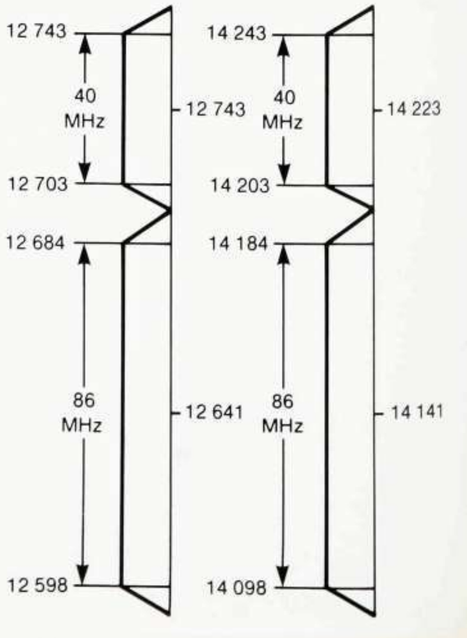


Fig. 6
The division of traffic between the data and video channels in TELE-X.
The earth stations are designed so that traffic at 34 Mbit/s and 8 Mbit/s is transmitted in the wideband transponder (WBT). WBT is designed to handle data rates of up to 140 Mbit/s.
The 64 kbit/s transmission takes place via the narrow-band transponder (NBT), which can take 500 simultaneous carriers (channels).
2 Mbit/s traffic can be transmitted in either WBT or NBT. WBT can take 25 channels and NBT 20. Transmitting 2 Mbit/s traffic via NBT reduces the number of available 64 kbit/s channels. Each 2 Mbit/s carrier occupies the same frequency bandwidth as 25 different 64 kbit/s channels

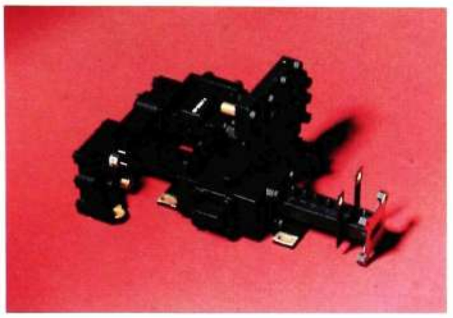


Fig. 7
Mixer and preamplifier
The dimensions of high-frequency electronic equipment are small. The low noise mixer with a noise factor of 6 dB at 18 GHz is 100 mm long. This mixer, like the oscillators and receivers that have been developed by Ericsson Radio Systems, is included in several different equipments on board, for example, TELE-X, TV-SAT, TDF-1 and the British UNISAT

The equipment and units in the transponder receive and transmit chains have mostly been space qualified in other satellite projects (in those already mentioned and also the French TELECOM project). The modifications that have been made at this level are, for example, frequency changes, which do not affect the space qualification status.

The quantity of equipment is similar to that of TV-SAT and TDF-1. For example, the number of final amplifiers (travelling wave tube type) is the same. The transponder parts with the associated structure have therefore been made so similar as regards mechanical and thermal properties that the overall construction can be verified by means of calculations.

As regards the antenna reflectors the same technology is used in all projects. However, the electrical design of the transponder and the whole antenna system are new. The following development models are therefore being manufactured in order to be able to verify the design before manufacture of the flight hardware is started:
- a model of the transponders for testing the electrical function and verification of the performance
- a structural model of the antenna system and tower for environmental testing, mainly testing of its ability to withstand the vibrations of the launch
- an electrical model of the antenna system for measuring the antenna pattern.

The final testing will take place in connection with the integration of the whole satellite. The purpose of the development program is to ensure that this test will only be a verification of the performance before the satellite is sent to Kourou in South America for launching.

Conclusion

The Nordic coverage of the television service provided by TELE-X makes it a factor to be considered in cultural policy. Technically it is wholly in line with the current international trend. On the other hand the choice of system for the data and video services is singular and is motivated by the desire for a system with small, cheap earth stations placed on the subscribers' premises.

TELE-X is a first step towards a Nordic satellite communication system which, if the market development is favourable, can lead to a general use of satellite terminals for data an video in the Nordic countries by the end of the 1980s.

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Integrated Maintenance of Transmission Systems in AXE 10 Networks

Mats Eneborg, Jan Insulander and Walter Widl

The maintenance of digital telephone networks, built up of AXE 10 exchanges and the digital transmission systems between them, can be rationalized by combining the maintenance functions of the exchanges with other computer-controlled maintenance systems. The rationalization can include several routines in the field of operation and maintenance.
This article, however, only discusses functions concerned with fault-location in digital transmission systems. The fault location can be carried out from centralized work stations or locally, near the equipment. The flexibility of the maintenance systems makes it easy to adapt them to different network structures and maintenance organizations. A paper with mainly the same content will be presented at ICC'84 in Amsterdam, in May 1984.

UDC 621.395.74.004.54

From the point of view of maintenance digital transmission systems are divided into a number of maintenance entities, ME[1]. Each maintenance entity has an input, an output and one or several functional units in between. The function is tested by means of internal measurements, the results of which can be read off, either continuously or on request. A basic principle is that if a fault occurs in the system it must be possible to trace the fault to the correct maintenance entity or part of an entity. How well a fault can be pinpointed depends on the efficiency of the internal maintenance functions of the particular entity.

The basic methods for the maintenance of digital transmission systems recommended by CCITT are performance monitoring and alarm based maintenance[2].

Performance monitoring uses direct measurements, such as the bit error rate, which are a measure of the transmission quality. Alarm based maintenance, on the other hand, is based on the principle that an alarm is initiated automatically as soon as the quality levels fall below preset values.

Which method is to be preferred depends on such factors as the structure of the network, type of equipment and the maintenance philosophy used within the maintenance organization.

In AXE 10 networks alarm-based maintenance is used for the digital system terminals, and performance monitoring for the maintenance of digital repeaters and cable sections.

Alarms and monitoring results can be presented at the maintenance entity, locally in exchanges or, with the aid of computer-controlled maintenance systems, in specially arranged transmission maintenance centres.

AXE 10 networks

Fig. 1 shows a hypothetical section of an AXE 10 network with digital network components for switching and transmission. The AXE 10 components consist of

- local exchanges, LE, transit exchanges, TE, and combined local/transit exchanges, LE/TE
- remote digital subscriber stages, RSS, for between 64 and 2048 subscribers
- remote subscriber multiplexers, RSM, for the connection of 30 subscribers.

The connecting line systems, the multiplexers and the transmultiplexers can belong to the 1544 or 2048 kbit/s hierarchy.

Within an area with only one AXE 10 exchange, for example in a rural or local network, faults in the connected digital transmission systems can be located from the work station in the exchange. The maintenance is centralized and the transmission maintenance system ZAN 201 ensures efficient fault location, fig. 2.

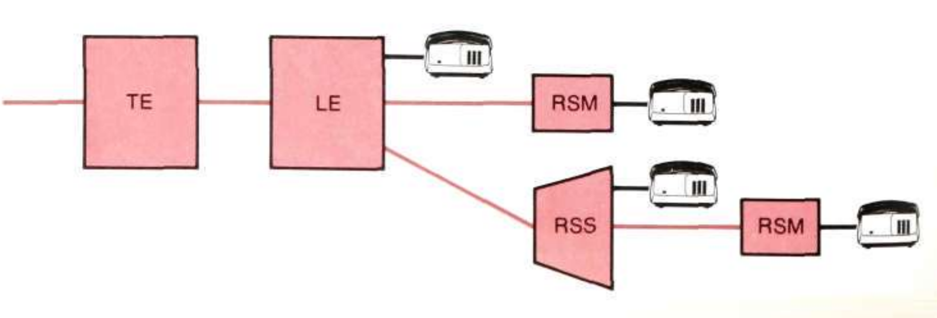


Fig. 1
Components in an AXE 10 network

TE Transit exchange
LE Local exchange
RSS Remote digital subscriber stage
RSM Remote subscriber multiplexer
— Digital line systems

MATS ENEBORG
Fibre Optics and Line Transmission
JAN INSULANDER
WALTER WIDL
Public Telecommunications Division
Telefonaktiebolaget LM Ericsson

In an area with several AXE 10 exchanges, for example a junction or trunk network, fig. 3, or an urban or metropolitan network, fig. 4 fault location can be carried out from a centralized work station, with the aid of the operation and maintenance system AOM 101 and the transmission maintenance system ZAN 101.

The degree of integration is open to choice. Separate work stations can be arranged for fault location in digital transmission equipment, or alternatively all maintenance activities can be fully integrated.

Digital line systems are terminated in exchange terminals, ET, in exchanges and RSS, and in PCM multiplexers and signal conversion equipment in RSM.

Exchange terminals are included in the exchanges, but from the point of view of maintenance they form part of the connected digital transmission systems. Thus a digital transmission path usually consists of both internal and external maintenance entities, i.e. entities placed in an exchange and remote from exchanges respectively. In the case of a fault each maintenance entity initiates the alarms and has the functions defined in CCITT recommendations series G and Q.

Maintenance of transmission equipment

A fault that occurs in a transmission system can be located by analysing the alarms from the internal and external transmission equipment. In certain cases, for example when a fault occurs in a line system containing regenerators, the alarm information must be supplemented by measurements of the line bit error rate (BER). The alarms and measurement results are collected, processed, interpreted and then transmitted to and presented at a work station for fault location. This process can include

- AXE 10 exchanges
- the operation and maintenance system AOM 101
- the transmission maintenance systems ZAN 101 and ZAN 201.

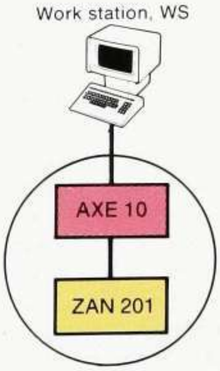
The choice of a maintenance system or combination of systems is dependent on such factors as the type and size of the network and the desired degree of automation. Moreover the suitability of different systems is dependent on the actual siting of the transmission equipment. Different placing of transmission equipment leads to slighty different alarm routines, for example:

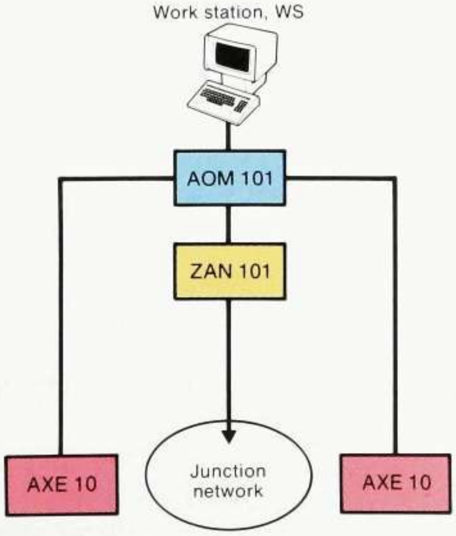
- internal AXE 10 equipment, in which the alarms detected in exchange ter-

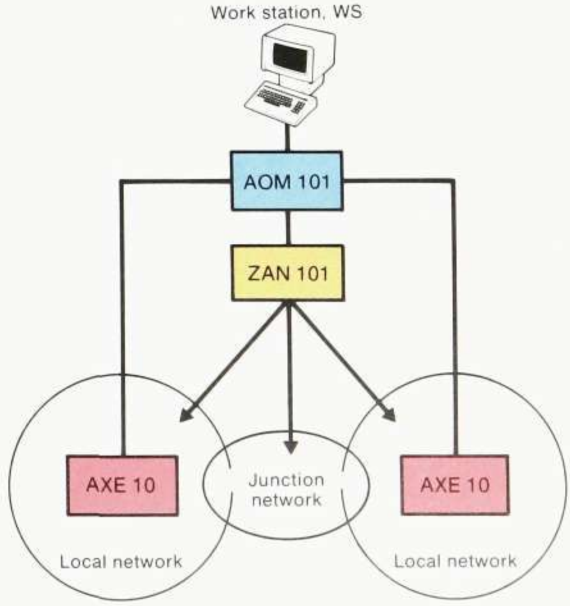
Fig. 2, left
An example of a rural or local network (a network with a single AXE 10 exchange)

Fig. 3, centre
An example of a trunk or junction network (a network with several AXE 10 exchanges)

Fig. 4, right
An example of an urban or metropolitan network (a network with several AXE 10 exchanges)







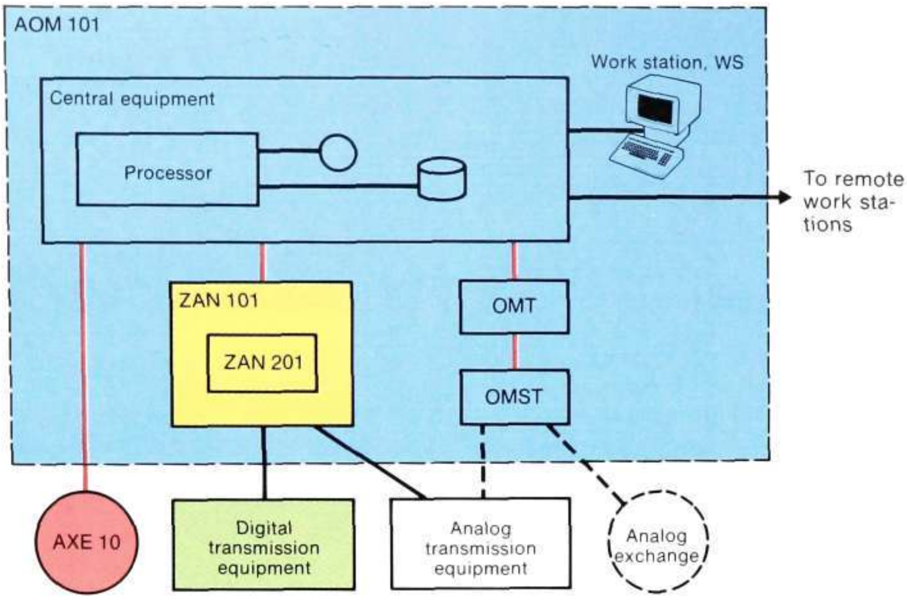


Fig. 5
Operation and maintenance system AOM 101

—— Data link
OMT Operation and maintenance terminal
OMST Operation and maintenance sub-terminal

Maintenance systems for digital transmission equipment

AXE 10

The extensive and sophisticated operation and maintenance functions of AXE 10 have been described in a previous article[3]. Only the functions that concern the maintenance of digital transmission systems will therefore be described here. They include

- termination of digital links in exchange terminals
- interfaces for collection of external alarms
- man-machine interfaces for alarm presentation and operator communication.

The incoming bit streams from digital line systems are monitored by the exchange terminals ET in accordance with the relevant CCITT recommendations. For maintenance alarms a choice can be made as to alarm class, i.e. the degree of urgency of the actions required. There is also a choice as regards the threshold level for the bit error rate. Faults of short duration are considered as disturbances and are recorded for each digital link. The slip rate is also monitored, and an alarm is given when a preset value is exceeded.

The values of the transmission parameters can be read out by means of commands, and are presented as the number of disturbances per hour, number of slips per hour and the current bit error rate. It is also possible to test the fault detection functions of the exchange terminal.

The AXE 10 system provides an interface for receiving alarm information from external equipment, for example power, cooling and transmission equipment. Alarms received via the interface are included in the exchange alarm system, and all facilities for the presentation and routing of alarms will thus also be available to alarms from external equipment.

Typewriters or visual display units are used at the man-machine interface towards AXE 10 for all operation and maintenance activities, including fault locating on digital transmission systems. The following transmission maintenance functions can be performed via this interface:

- presentation of alarms from the exchange terminals
- presentation of collected external alarms
- fault location by means of commands.

The man-machine interface can be remotely connected by means of modems e.g. to the network operation and maintenance system AOM 101. It is also possible to connect a portable typewriter terminal temporarily to the remote subscriber stage. Such a terminal would primarily be used for functional verification on site after repairs.

Operation and maintenance system AOM 101

AOM 101 provides centralized operation and maintenance of complete telecommunication networks.

minals are handled by the exchange itself

- equipment external to AXE 10, installed together with and connected to AXE 10 units. In this case alarms from, for example, line terminals can be handled by and presented in AXE 10 with the aid of its interface for receiving external alarms. Alternatively such alarms can be collected by the alarm concentration equipment in the transmission maintenance systems ZAN 101 and ZAN 201
- equipment external to AXE 10, installed together with but not connected to AXE 10 units
- equipment external to AXE 10, neither installed with nor connected to AXE 10 units. In such cases alarms from transmission terminals and results from quality measurements on regenerators can be collected by ZAN 101 or ZAN 201.

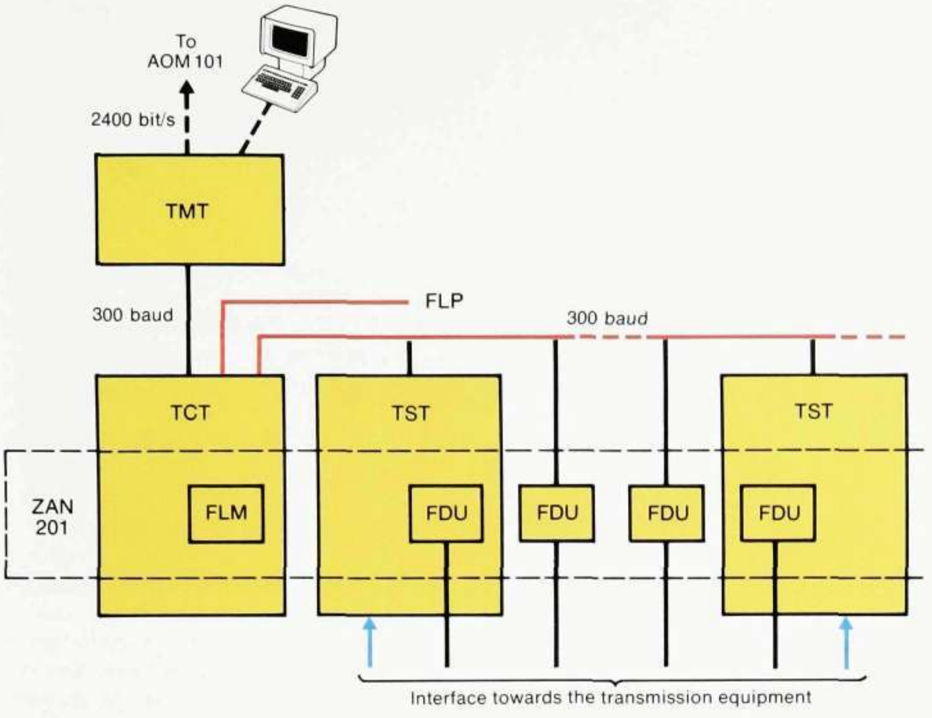


Fig. 6
The structure of system ZAN 101
Capacity of TMT: 5 000 maintenance entities with *a maximum of 32 TCT/TMT*
Capacity of TCT; 200–300 maintenance entities for the following maximum numbers of units:

FLP/TCT	2
TST/TCT	32
FDU/TCT	254
Test points/TST	896
Two-way regenerators/FDU	48

AOM 101 is built up of a central processor system, *work station terminals* and a number of terminals of different types which constitute the interfaces towards the supervised equipment. Work stations for transmission maintenance are usually equipped with video display units, semigraphic colour displays for alarms and typewriters. Fig. 5 shows the part required for transmission maintenance. The main functions of the system can be summarized as follows:

- Man-machine communication for commands to connected network components and for presentation and routing of information from the network, for example alarms. All commands are checked as regards syntax and authorization
- Handling of alarm information, with the aid of system functions for receiving, analysing, distributing and presenting alarm data in different ways
- Data collection, with the received data being stored and displayed in accordance with the operator's requests
- Data communication via synchronous data links. The links use the X.25 protocol defined by CCITT and data speeds of up to 9600 bits/s.

With AOM 101 it is possible to concentrate alarms from transmission equipment inside and outside the exchange to a single work station or to duplicate them for transmission to other work stations. Fault location can also be initiated from the work stations, by means of commands, in order to establish the type of fault and its location. The fault data obtained are used to determine the most suitable repair team and spare parts, and when the repair should be undertaken.

Transmission maintenance systems ZAN 101 and ZAN 201

Transmission maintenance systems ZAN 101 and ZAN 201 can be used either autonomously or as subsystems of AOM 101. The systems collect alarms from transmission terminals, such as line terminals, digital multiplexers and transmultiplexers. Their functions also include performance monitoring of digital regenerators in line systems on pair, coaxial and optical fibre cables.

ZAN 101 provides automatic alarm collection, and automatic as well as command-controlled fault location. Stored network data are used to identify and interpret equipment alarms. Faulty maintenance entities can thus be pinpointed.

ZAN 201 can be used either independently or as a subsystem of ZAN 101. The system *provides command-controlled* alarm collection and fault location. Faulty maintenance entities are identified manually by the operator with the aid of external network data.

Both systems can work autonomously or under external control. They are equipped with internal control functions, and they do not affect the supervised networks during alarm collection and fault location, or if there should be a fault in the supervision. The results of fault location are presented in the same man-machine language as is used in AOM 101 and AXE 10.

Alarms can be collected from all types of equipment that are equipped with suitable alarm interfaces. This means that analog transmission equipment or equipment intended for other purposes can also be supervised.

ZAN 101

The network data stored in ZAN 101 are updated by means of operator commands, so that at any time the system can provide information regarding the structure of the supervised network. Alarm test points in transmission terminals are scanned continuously. Alarms from digital line systems initiate the collection of bit error rate values from regenerators for the location of a faulty

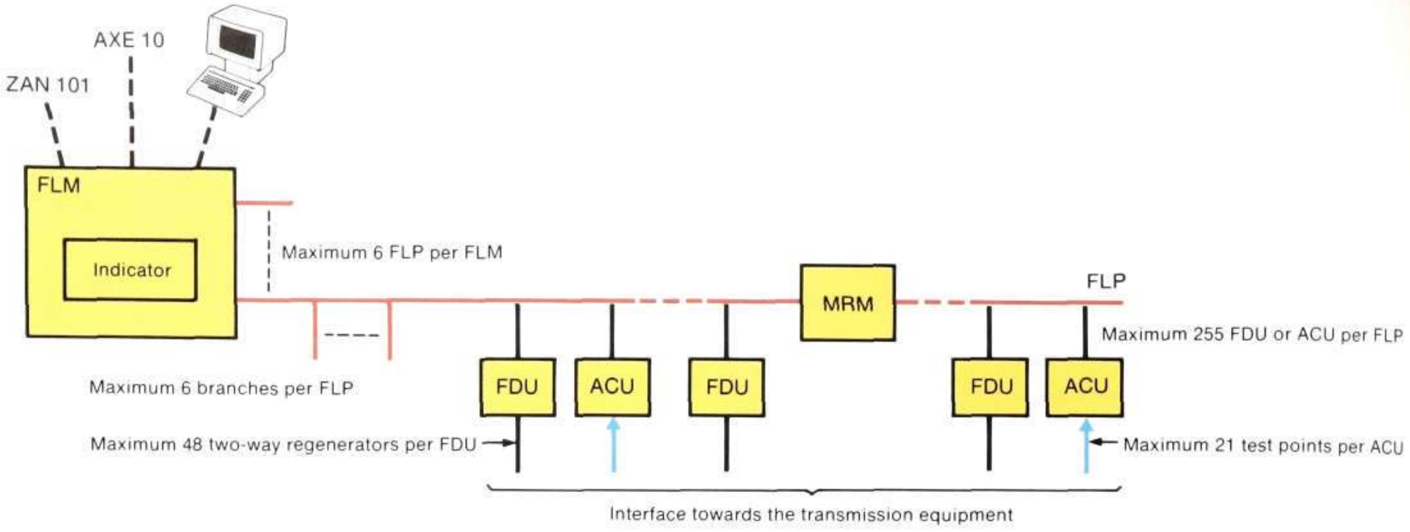


Fig. 7
The structure of system ZAN 201

regenerator section. ZAN 101 printouts specify the faulty maintenance entity. ZAN 101 has the hierarchic structure shown in fig. 6, with the units:

- Transmission maintenance terminal, TMT, (central terminal), for processing alarm messages and alarm lists, and for communication control
- Transmission maintenance control terminal, TCT, (regional terminal), for collecting and interpreting alarms and locating faults
- Transmission maintenance sub-terminal, TST, for sensing test points and operating control points
- Fault detector unit, FDU, for bit error rate measurements.

Separate fault location channels are required for the data links used for the communication between TCT, TST and FDU. The channels used are either included in the transmission medium used for the supervised system (e.g. optical fibre or coaxial cable) or are separate transmission channels (e.g. fault location pairs, FLP, on physical pairs).

ZAN 201

Command-controlled location of faults on digital line systems is initiated by the operator when a fault is detected in the supervised system. The fault can give rise to an alarm, which is reported from an AXE 10 work station or is collected by ZAN 201 over a special alarm report channel. During the actual fault location the bit error rate values from the regenerator sections are compared with preset threshold values. After an iterative process the address of the faulty regenerator is obtained. The network data enable the operator to determine which maintenance entity contains the regenerator fault.

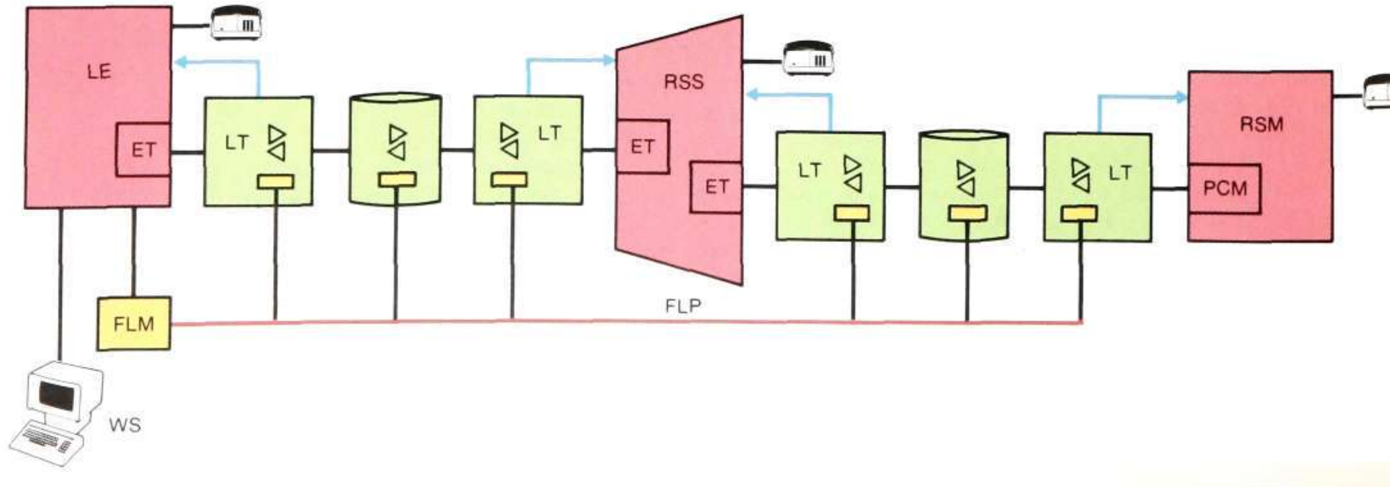
In the case of a cable cut that affects the remote power feeding, a fault indication is obtained from every regenerator that has lost its power. However, the faulty cable section can be located by means of analysis of test signals generated at each regenerator site.

ZAN 201 consists of a fault locating magazine (circuit pack), FLM, fault detector units, FDU, and alarm collection units, ACU, fig. 7. All units are connected to a fault location pair, FLP, or other types of fault location channels.

Variants of FDU have been developed for different line systems using different transmission media and speeds. A variety of transmission systems (over cables and radio relay links) can be supervised via one and the same fault location channel.

Fig. 8
Part of a local network

ET	Exchange terminal
FLM	Fault location magazine
WS	Work station
PCM	PCM terminal
FLP	Fault location pair
▷◁	Regenerator housing
—	Alarm generated in a terminal
▭	Fault detector



Several FLMs can be connected to one fault location channel, and alarm collection and fault location can therefore be carried out from different places. This feature, together with the possibility of duplicating the channels between FLMs and modem regenerator magazines, MRM, increases the system availability.

The signals in a fault location channel can be regenerated with the aid of MRM. Extensive networks can thus be supervised from one and the same FLM.

When working autonomously the system is normally controlled from a keyboard with its associated digit indicators, built into FLM. Alternatively FLM can be connected to a separate operator terminal or to system ZAN 101, and in future to the AXE 10 exchange in order to obtain access to different types of local and remote control.

Some examples of transmission maintenance

A high addressing capacity and facilities for branching and signal regeneration mean that maintenance of complete networks can be carried out from one or several work stations. The hypothetical networks described here illustrate the transmission maintenance in networks with one or more AXE 10 exchanges.

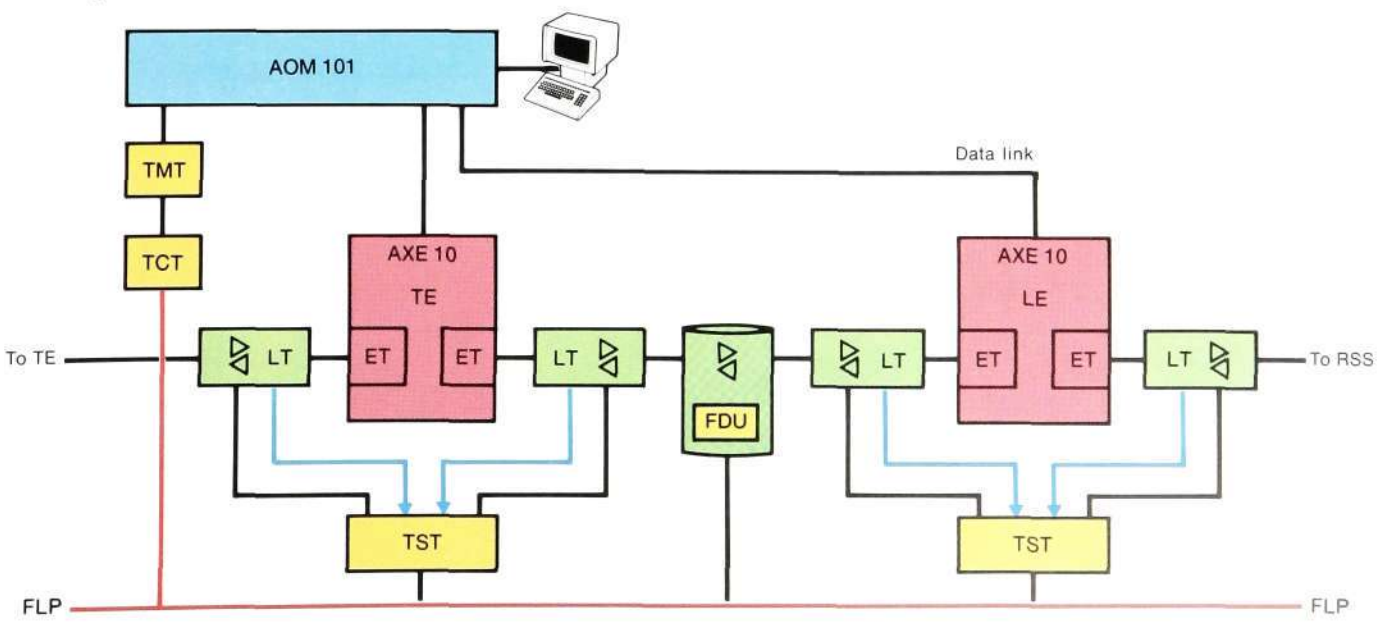
Transmission maintenance of local and rural networks

A network can consist of an AXE 10 local exchange with RSSs and RSMs connected via 2 Mbit/s transmission systems over cables and radio relay links. Digital line systems over cable contain line terminals with signal regeneration and remotely powered regenerators. Fig. 8 shows a network with an RSS connected to LE and an RSM connected to RSS. The following alarm routines apply for the network:

- Internal transmission alarms in AXE 10 are transmitted to the work station, WS, via normal signalling links (time slot 16 with 2 Mbit/s transmission)
- Alarms external to AXE 10 are received from transmission terminals placed in the vicinity of the AXE 10 exchange. The alarms are fed to external alarm interfaces with which LE, RSS and RSM are equipped. These alarms are also transmitted to the work station via ordinary signalling links
- Command-controlled location of faults in regenerators in line terminals and remotely powered regenerator housings is carried out using the transmission maintenance system ZAN 201. The fault location is initiated by the operator via the work station.

If RSS is connected to LE over a radio relay link system the fault location sig-

Fig. 9
Part of the junction network



nals are transmitted over the service channel of the link. The fault location channels are regenerated in a modem regenerator magazine, MRM, which makes it possible to locate faults in transmission equipment between, for example, RSM and RSS.

Alarms from radio relay link terminals are handled in the same manner as alarms from other transmission terminals. However, at present radio relay link alarms are not standardized in the same way as alarms from line terminals.

Transmission maintenance of trunk and junction networks

A characteristic feature of such networks is that alarms relating to one and the same link are always collected by two different AXE 10 exchanges. The example in fig. 9 shows two exchanges with trunk and junction networks. The fault location takes place from an AOM 101 work station and the following routines are used:

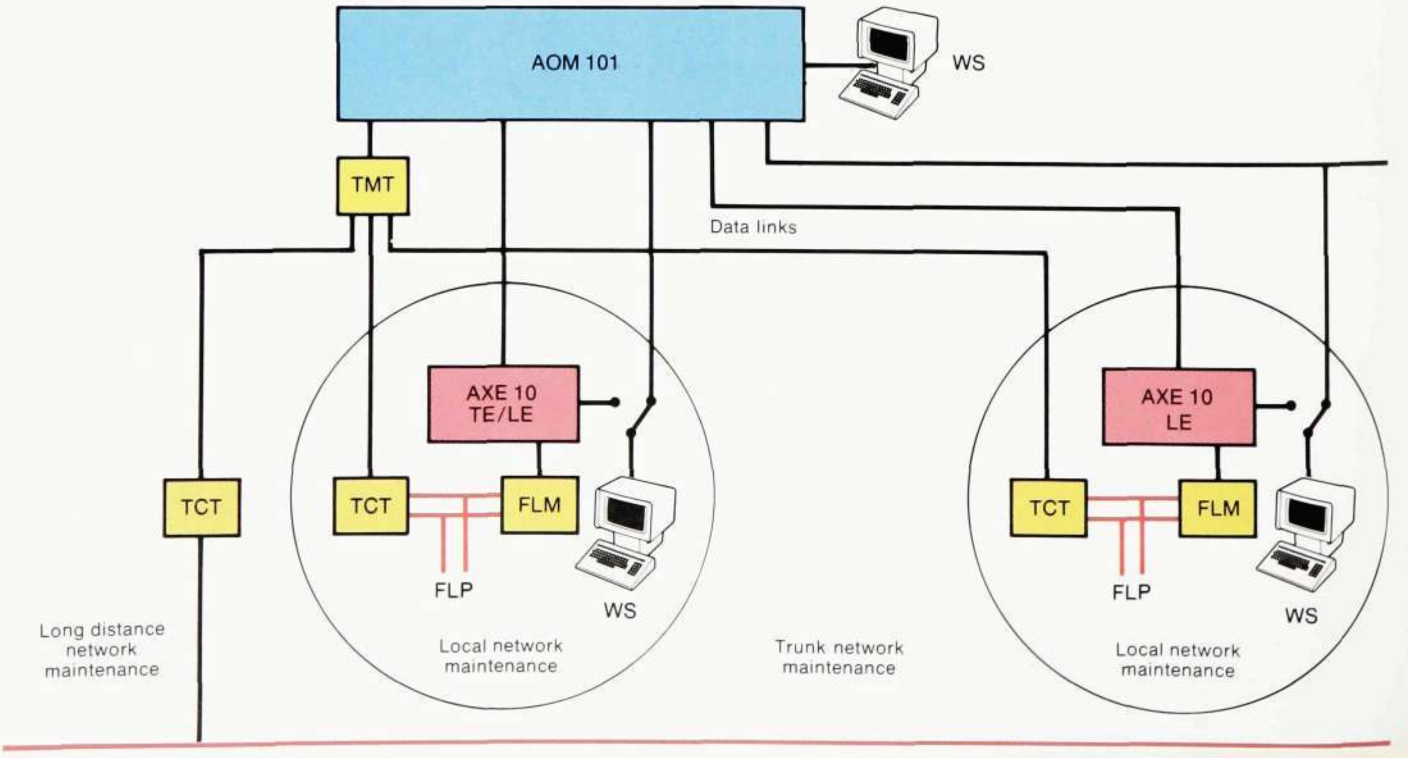
- alarms from ETs in local exchanges and the transit exchange are transmitted via a data link between AXE 10 and AOM 101
- alarms from LTs and bit error rate values from regenerators are collected with the aid of ZAN 101.

In a network containing local, junction and trunk networks, fig. 10, the fault location is usually carried out from AOM 101 work stations. One station is then placed adjacent to the central AOM 101 equipment, and the others in AXE 10 local exchanges.

Centralized transmission maintenance can be carried out from any AOM 101 work station. In addition the maintenance of each individual local network can be centralized to an AXE 10 work station, with optional connection to the AOM 101 system. In this case the fault location pair of the local network is reached via FLM, which forms part of ZAN 201, and without any assistance from AOM 101 or ZAN 101. This makes it possible to retain transmission maintenance even if faults should occur in AOM 101 or ZAN 101.

Centralized fault location is possible even without AOM 101 and ZAN 101, with the aid of ZAN 201, fig. 11. A trans-

Fig. 10
Part of an urban and trunk network in which the transmission maintenance is carried out using AXE 10, AOM 101 and ZAN 101



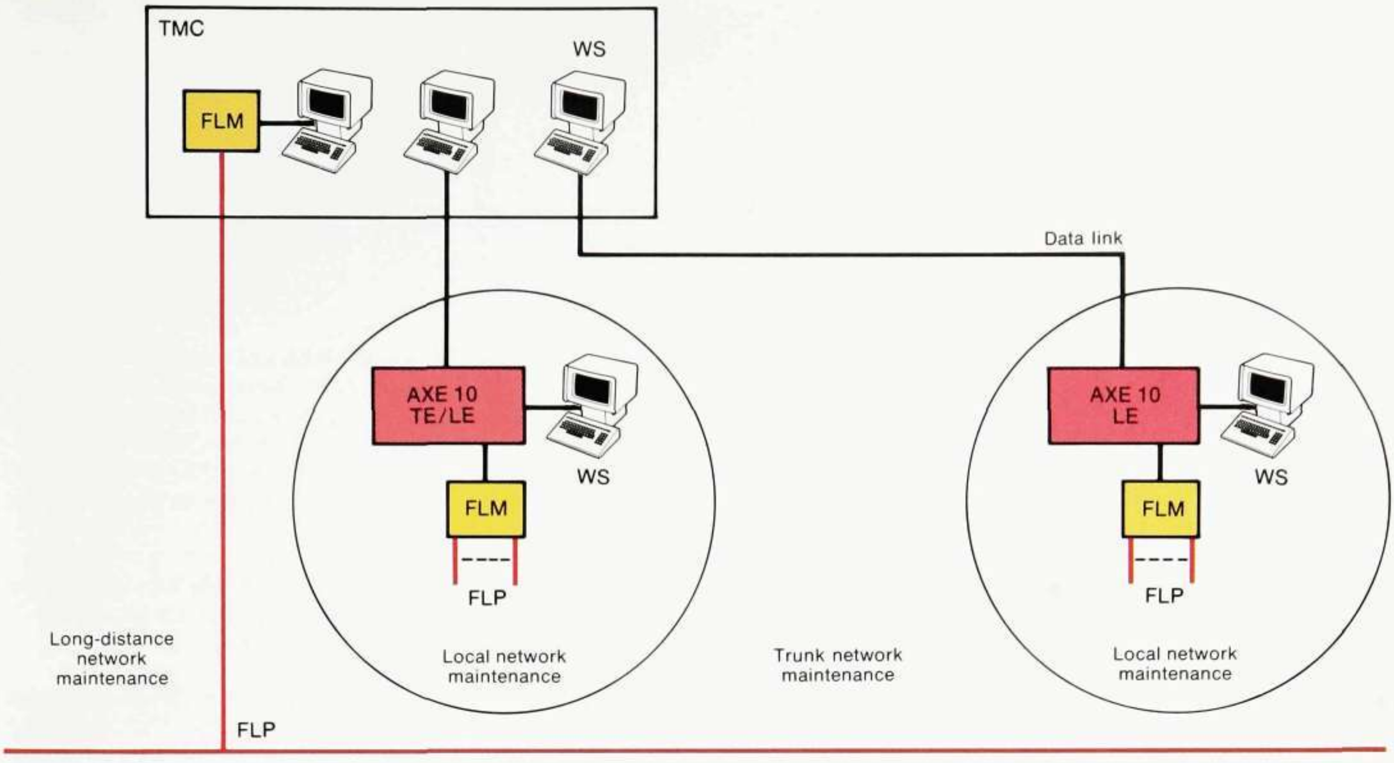


Fig. 11
Part of an urban and trunk network in which the transmission maintenance is carried out using AXE 10 and ZAN 201

TMC **Transmission maintenance centre**

mission maintenance centre, TMC, is then used to collect information from ZAN 201 and AXE 10 terminals.

Summary

The maintenance of digital transmission equipment in AXE 10 networks can be made more efficient if the exchanges are supplemented by the operation and maintenance system AOM 101 and the transmission maintenance systems ZAN 101 and ZAN 201. The maintenance methods described here make it possible to improve the quality of service and provide a choice of varying degrees of automation and centralization. The maintenance routines can therefore readily be arranged to provide optimum adaptation to each Adminstration's organization for the maintenance of digital or mixed networks.

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2. Draft Rec. M.2Y and M.2Z.
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Transmission Maintenance System ZAN 101

Mats Eneborg and Björn Johansen

Transmission maintenance system ZAN 101 is used to supervise transmission networks and to locate faults[1]. Connection to operation and maintenance system AOM 101[2] for telephone exchange equipments makes it possible to coordinate the operation and maintenance for whole telecommunication networks.
The authors discuss the reasons for centralizing maintenance and describe the features and structure of ZAN 101.

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The maintenance aspects have always been very important in the development of new systems within Ericsson. The introduction and use of a maintenance system, ZAN 101, with centralized operators' work stations, which serves all transmission equipment, reduces the operation and maintenance costs for the network as a whole.

Telecommunication networks containing Ericsson's standard system for locating faults in digital line systems can easily be connected to ZAN 101.

Why centralize the supervision and maintenance?

The use of digital exchange systems in the telecommunication networks justifies rapid introduction of digital transmission systems, fig. 1. The large amount of transmission equipment justifies the use of efficient maintenance systems.

Some characteristic features of transmission equipment are that it has low fault rates and is usually scattered geographically. Equipment is placed not only in the exchanges but also between them, such as intermediate repeaters in buried housings. Faulty intermediate repeaters are located with the aid of fault location systems.

The reasons for introducing centralized control of the transmission network maintenance can differ because of different local conditions. However, in all cases the cost can be minimized in the long run because trained staff are stationed centrally in the network and have access to efficient tools. Moreover the staff are used more efficiently. The immediate impetus to install ZAN 101 can for example be that it is difficult to get the necessary number of qualified employees.

More efficient maintenance means less out-of-service time, which increases the availability of the transmission systems and hence also the income. The importance of high availability is emphasized by the rapid increase in the number of leased lines.

Faults in the network can arise from many different causes, for example:
- equipment faults
- handling faults
- cable faults as a result of excavator damage, corrosion or lightning strokes.

The type of fault that predominates depends on local conditions.

Centralized maintenance gives a considerably better overview of the network and greatly improved facilities for handling complicated faults.

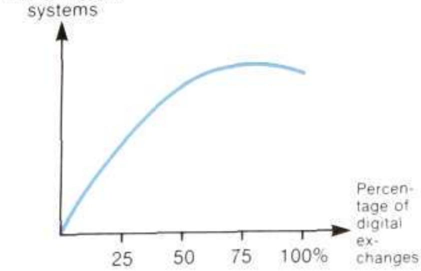
System properties

The main functions of the maintenance system are to:
- Centralize alarm data, and on the basis of these indicate the faulty equipment.
- Initiate, from a central point, automatic fault location, and thus indicate faulty repeaters and faulty cable sections.

The system is prepared for the operation of control points.

Administrative organizational features
The system can be adapted to the organization and operation of the Administration concerned since:
- The system can be used autonomously as a maintenance centre for transmission equipment, or it can be connected to AOM 101 for coordinating maintenance of transmission and exchange equipment, figs. 2a and 2b.
- The system permits optional siting of a number of independent work stations. From these the operators can work towards different parts of the telecommunication network, for example towards different types of systems or regions, fig. 3.
- The system can readily be installed in a network without interfering with the traffic.

Fig. 1
The need for digital transmission systems when converting analog telephone exchanges to digital



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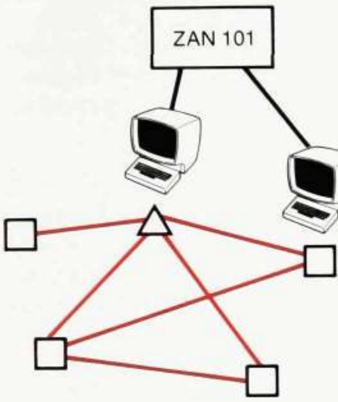


Fig. 3
Centrally situated supervisory equipment does not prevent operator work stations being placed in other exchanges

□ Local exchange
△ Transmit exchange

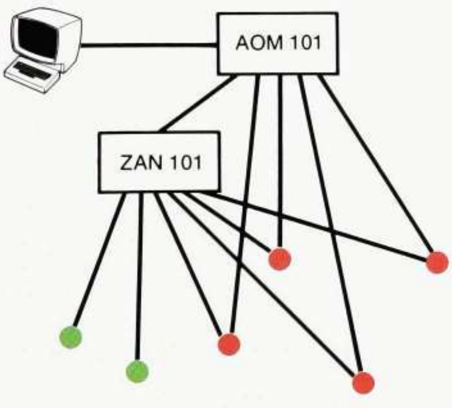


Fig. 2a
Communication paths between AOM 101, ZAN 101 and the supervised network

● Digital exchanges with digital transmission equipment
● Analog exchanges, not connected to AOM 101 but containing digital or analog transmission equipment

Fig. 2b
Operator's work stations

Operator communication

The man-machine communication is extremely important with respect to the efficiency of a system. Effective communication is achieved by:

- Using standard MML *(Man Machine Language)* in accordance with the relevant CCITT recommendations, in the same way as in AXE 10 and AOM 101. A common language makes it easier for operators to work with several systems and reduces the amount of training required.
- Identifying the supervised transmission equipment in clear text.
- Not loading the operator with more information than is necessary at any moment.

Operator qualifications

The simplified handling procedures in ZAN 101 mean that most of the work can be carried out by staff who do not have expert knowledge of each individual type of transmission equipment.

Supervised equipment

In addition to all Ericsson transmission equipment many other types of equipment can be connected to ZAN 101. The only requirement is that the alarm interface is designed as a relay or transistor closure or break of negative voltage to earth. This means that usually alarms from other manufacturers transmission equipment as well as alarms from, for example, pressure protection, power supervision, fire detectors and security systems can be connected.

However, fault location in line systems is limited to faults in digital pair, coaxial and fibre systems from Ericsson, since there are no international standards for fault location systems.

Approximately 5000 alarm initiating systems and equipments can be connected to a ZAN 101 system.

Other characteristics

System ZAN 101 does not affect the supervised equipment or its traffic, neither during operation nor when faults occur in the system. Any faults in ZAN 101 itself are indicated automatically.

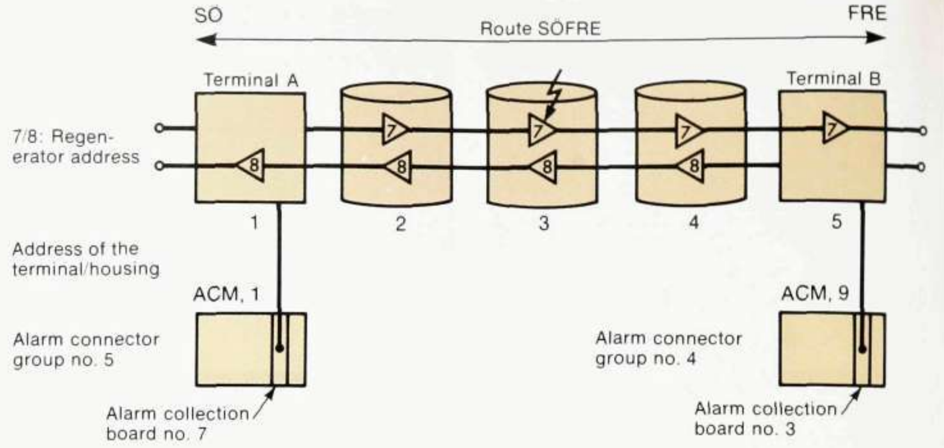
Handling

The operator's tasks include mainly network data processing, alarm processing and fault location.

Network data processing

When delivered system ZAN 101 contains no information that is specific to the particular network or the customer. Network data must be loaded before the system is put into operation. The network data comprise descriptions of and designations for the supervised transmission equipment and information regarding how alarm conditions and fault location results are to be processed by the system. The system obtains this information from the operator in a standardized manner. Work on extending or modifying network data takes place during operation, without interfering with the function of ZAN 101.

Fig. 5
2 Mbit/s line system ZAD 2-6. The different parts are identified with the aid of addresses. Alarms are connected to ZAN 101 and identified by the physical position in the alarm collection magazine



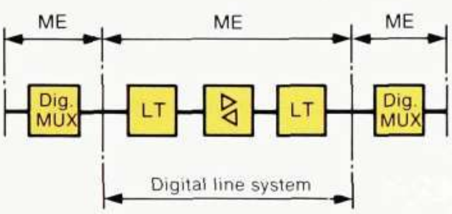


Fig. 4
Maintenance Entities, ME, in accordance with the CCITT recommendation

The grouping of the supervised equipment is in accordance with the maintenance entity concept recommended by CCITT, i.e. the equipment is divided into independent maintenance entities, ME, fig. 4, which can consist of:

- a line system consisting of two line terminals and intermediate repeaters
- a multiplexer.

Other equipment, which is not included in the CCITT recommendation, for example analog transmission equipment, pressure protection systems, security systems and fire detectors, are divided into similar MEs.

Digital equipment is designed so that a fault that disturbs the traffic will normally only initiate an alarm in the faulty or the adjacent equipment.

Each ME is identified with the aid of

- its geographical position, i.e. a station or a route between two stations
- the type of device
- a numerical index within the type of device.

Fig. 5 shows a 2 Mbit/s line system comprising two line terminals and three intermediate repeaters. Fig. 6 shows a printout of the network data. The examples in figs. 7–10 show what happens when a fault occurs in an intermediate repeater.

Alarm processing

ZAN 101 continuously scans the alarm status of all connected devices and initiates printouts of all alarms. For each ME the network data includes the seriousness of each alarm condition, the alarm class and the category for routing of alarms to the desired work station.

Alarms from a device which has already been identified as faulty and alarms that are generated in connection with fault tracing can be suppressed.

When ZAN 101 is connected to AOM 101 the alarm display in AOM 101 receives an initial alarm report, which provides information as to which station or route is initiating the alarm and how serious the fault is, fig. 7.

By acknowledging the alarm the operator can then receive information regarding the faulty system, fig. 8, and various traffic activities can be initiated. Depending on the circumstances the operator can then either try to locate the fault immediately or leave it until later. More detailed alarm information can be obtained by means of commands, and will simplify the tracing of the fault. The alarm information then received is of the type "loss of power", "loss of signal", etc.

Locating faults in line systems

The purpose of the fault location is to indicate the position and type of faulty devices in order to enable the maintenance personnel to be directed to the right place, equipped with the right spares.

When an alarm occurs a fault location command is given either automatically or manually by the operator. The operator requests fault location by giving the

Fig. 7
The alarm display in AOM 101 is divided up so that each sector represents the transmission equipment either in a station or on a route between two stations

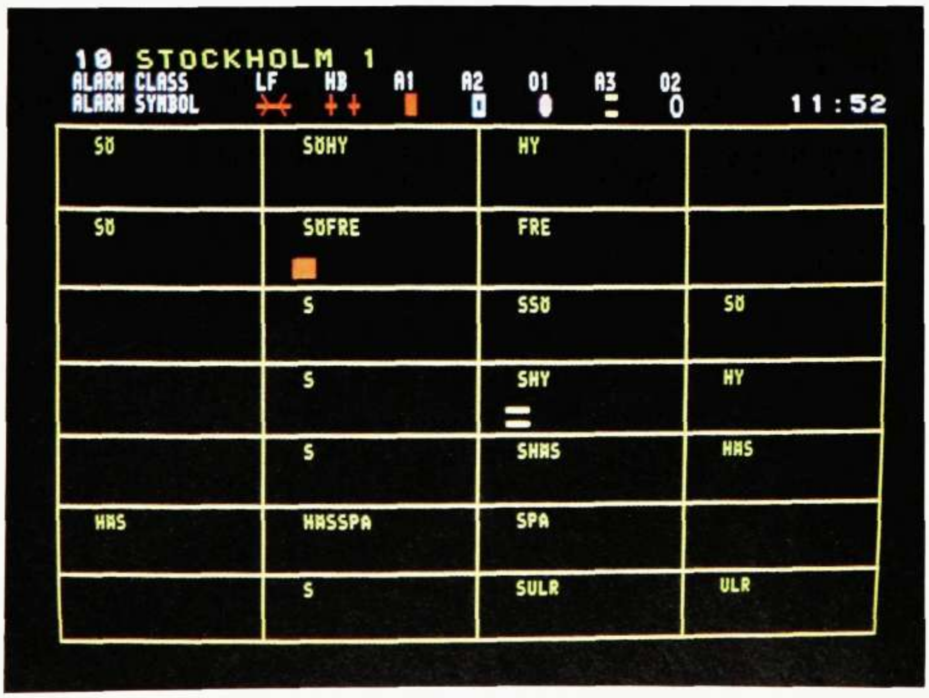


Fig. 6

An example of a printout of the network data for a 2 Mbit/s line system consisting of two line terminals and three intermediate repeaters

SCM 1	The identity Supervision Control Magazine in TCT
STN/RTE	The designation of the station or route
DEVICE TYPE	Type of device
NO.	Number index of the maintenance entity within the given type
NEIGHBOUR	With line systems in two-cable operation, this information specifies the other line system sharing the common power feeding loop
ACM	Alarm collection magazine
BOARD	Alarm collection board
8 GROUP	Alarm connector group
1ST	Gives the alarm connector within the 8 GROUP and is used when several maintenance entities share one and the same 8 GROUP
SUB-SECTION DATA	Only one subsection is included in the example
CH	Fault location channel or fault location pair. Each TCT has a maximum of two channels and/or pairs
1ST	Indicates the first terminal/housing
LAST	Indicates the last terminal/housing

```
SöFRE     1983-10-26      1015
ME PRINTOUT
STN/RTE    DEVICE TYPE              NO
SöFRE      ZAD2-6                   17
SCM 1      VERSION 1

ME NETWORK DATA
STN/RTE    DEVICE TYPE              NO
SöFRE      ZAD2-6                   17

ME DESCRIPTION
STN/RTE    DEVICE TYPE              NO             NEIGHBOUR
SöFRE      ZAD2-6                   17

ALARM INTERCONNECTION DATA
TERMINAL   ACM      BOARD      8GROUP      1ST VAR POS
   A        1         7         5
   B        9         3         4

SUBSECTION DATA
NUMBER          DIRECTION A-B              DIRECTION B-A
        CH   1ST   LAST   REPEATER   CH     1ST   LAST    REPEATER
1       1     2     5        7        1      4      1        8

ALARM DATA
URGENT ALARM CLASS:                A1
NONURGENT ALARM CLASS:             A3
ALARM CATEGORY:                    13

END
```

Fig. 8

Alarm printouts contain information regarding the station or route and the ME causing the alarm. The class and category of the alarm are also indicated

```
SöFRE     1983-10-26     1059
ALARM                  A1/13
TRANSMISSION SUPERVISION
SCM 1
DEVICE TYPE           NO
ZAD2-6                17

END
```

Fig. 9

When a fault has been located the faulty unit or cause of the fault together with the primary alarms are indicated

PRIOR	There are three priority levels for commands: HIGH indicates top priority MEDIUM indicates intermediate priority and is allocated to automatically generated fault location commands LOW indicates low priority The operator can choose the priority level for a given command
DIR	Direction of transmission between stations A and B: ALL indicates both directions A–B indicates the direction from A to B B–A indicates the direction from B to A
HOUSING	Specifies the position of the repeater by means of the address of the housing or terminal
REP	Gives the repeater address within the housing or terminal. Maximum capacity 96 addresses, corresponding to 48 two-way intermediate repeaters
TERM	Specifies the line terminal
PRIMARY ALARM	Indicates one of the following primary alarms: BFL3, bit error rate larger than 10^{-3} LST, loss of signal in the transmit direction LSR, loss of signal in the receive direction PFL, loss of power feeding

```
SöFRE     1983-10-26     1100
TRANSMISSION, REPEATER FAULT LOCATION
SCM 1

DEVICE TYPE           NO    PRIOR
ZAD2-6                17    MEDIUM

DEVICE TYPE           NO    DIR  CH  HOUSING  REP  TERM PRIMARY ALARM
ZAD2-6                17    A-B  1   3        7    B     BFL3
ZAD2-6                17                           A

END
```

Fig. 10
The operator can obtain detailed information regarding bit error rates by means of a command

BERTHR Gives the threshold value for bit error rates for which a printout is to be initiated
RELBER Gives the increase in bit error rate caused by a certain intermediate repeater
ABSBER Gives the accumulated bit error rate up to and including the specified intermediate repeater

```
SöFRE     1983-10-26     1102
TRANSMISSION, REPEATER SUPERVISION
SCM 1

DEVICE TYPE            NO   DIR  CH   HOUSING  BERTHR  PRIOR
ZAD2-6                 17   ALL  ALL  ALL      1E-05   LOW

DEVICE TYPE            NO   DIR  CH   HOUSING  REP     RELBER   ABSBER
ZAD2-6                 17   A-B  1    3        7       2E-03    2E-03

END
```

identity of a line system, followed by a fault location command. This is sufficient for ZAN 101 to automatically analyse alarms and then, if required, initiate measurements of the bit error rate at different intermediate repeaters, make comparisons, draw conclusions and generate a printout, fig. 9. To indicate a faulty intermediate repeater the identity of the line system is supplemented by the housing and repeater numbers. Alarms in the two line terminals of the system are also given.

Other commands are used for long-term measurements on a specific repeater, for measuring the bit error rate in one or several systems and for locating a cable break. Fig. 10 shows an example of a bit error rate measurement.

The operator can request intermediate reports during fault location and can thereby supervise the work better.

System structure

ZAN 101 has a hierarchic structure with clearly defined interfaces between different levels. The system has a modular design which ensures effective adaptation to different network sizes and structures.

The system for locating faults in the line system actually constitutes a subsystem in ZAN 101. This means that initially a transmission network can be equipped with an independent fault location system. When the need for centralized maintenance arises, the fault location system can be built out to form a ZAN 101 system. The installation of the extra equipment will not affect the traffic and fault locating work in progress.

The great flexibility of the system is only limited by the total amount of equipment that can be supervised.

Each module, Transmission Maintenance Terminal, Transmission maintenance Control Terminal or Transmission maintance Sub-Terminal, fig. 11, works independently and is not dependent on the number and positions of the other terminals. Information is fetched from subordinate terminals, and orders are received from one superior terminal. Information concerning changes in alarm status is the only type reported upwards. This ensures efficient information processing at each level.

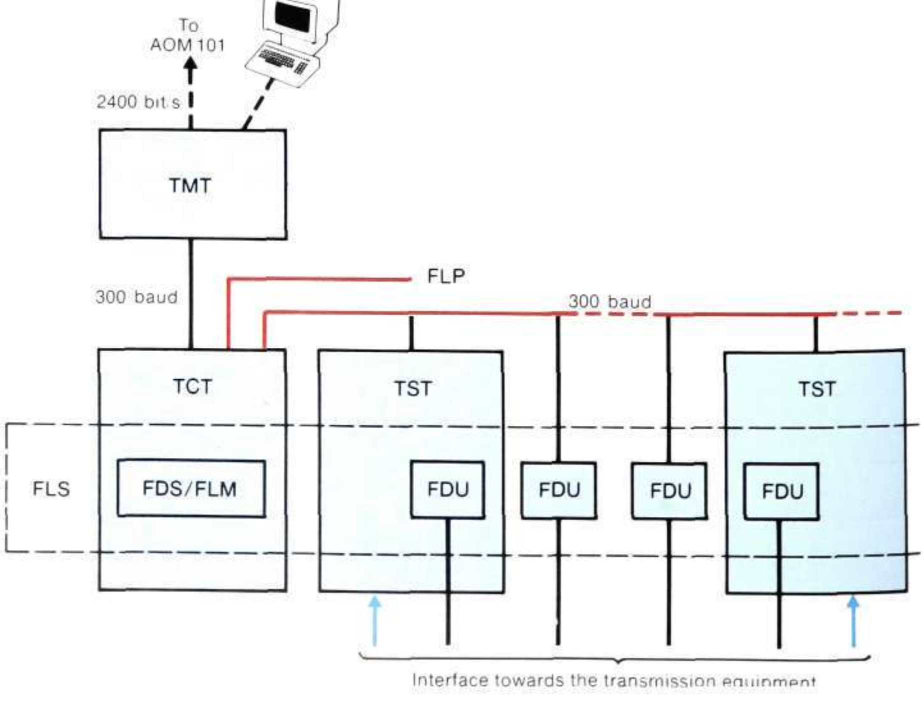


Fig. 11
ZAN 101 has a hierarchic structure and a modular design which greatly facilitate adaptation to different network sizes and structures

TMT Transmission Maintenance Terminal
TCT Transmission maintenance Control Terminal
TST Transmission maintenance Sub-Terminal
FDU Fault Detection Unit
FLS Fault Location System
FDS Fault Detection Shelf
FLM Fault Location Magazine

Technical data for ZAN 101

Maximum recommended number of maintenance entities, ME	5000
Number of work stations that can be connected to an independent ZAN 101	4
Number of TMTs	1
Number of TCTs per TMT	32
Number of MEs per TCT (depending on the type of supervised MEs)	200–300
Number of TSTs per TCT	32
Number of alarm points per TST, divided between 16 alarm collection boards	896
Number of control points per TST, divided between 15 control point boards	240
Alarm collection boards and control point boards are interchangeable	
Number of fault location pairs per TCT	2
Number of FDUs per fault location pair	
M5 construction practice	32
BYB construction practice	127
Number of two-way intermediate repeaters per FDU (2 Mbit/s)	
M5 construction practice	24
BYB construction practice	48

Table 1
Transmission speed, transmission protocol and maximum distance or attenuation for different links in transmission maintenance system ZAN 101

Link	Speed	Protocol	Maximum distance or attenuation
TMT–AOM 101	2400 bit/s	X.25, level 2	43 dB
TMT–TCT			
alt 1	1200 bit/s	asynchronous	1 km
alt 2	300 bit/s	asynchronous	20 dB
TCT–TST	300 baud	asynchronous	43 dB
TCT–FDU			
alt 1 (M5)	50/750* baud	asynchronous	43 dB
alt 2 (BYB)	300 baud	asynchronous	43 dB

* In the M5 construction practice 50 baud transmission is used for addressing FDU, whereas 750 baud is used for the fault reporting to TCT

Connection to AOM 101

Connecting ZAN 101 to AOM 101 gives access to many useful functions, such as authorization checking, calendar control of operations and alarm indication. Different work stations can easily be connected to AOM 101 or ZAN 101, with no restrictions as regards distance.

In the case of integrated operation, the network data are stored in AOM 101 for the starting up of ZAN 101. AOM 101 can be used to coordinate several transmission maintenance systems and thereby supervise even larger transmission networks.

Transmission Maintenance Terminal
In an independent ZAN 101 system the central part is the Transmission Maintenance Terminal, TMT. Each system contains only one TMT, in which all central system control functions are assembled, and also all functions for communication with up to four operators. Each operator's work station functions independently of the other work stations and can be located as desired.

The main functions of TMT are to:
- process alarm messages and administer an alarm list
- administer network data for the supervised equipment
- administer fault location and measurement of bit error rates
- initiate fault location
- control the communication channels to the operators and the next level below.

All loading, editing and modification of network data is carried out in TMT from any work station with the aid of simple commands. General network data are stored in TMT but detailed network data are transferred to the subordinate terminals concerned.

For independent ZAN 101 systems all the data necessary to start up the system (back-up data) are stored on a cassette tape.

Transmission maintenance Control Terminals
Detailed network data for the supervised equipment are stored in regional Transmission maintenance Control Terminals, TCT. Several TCTs are used in large transmission networks.

The main functions of TCT are to:
- collect alarm data and evaluate the information
- carry out fault location in line systems
- carry out qualitative bit error rate measurements.

For each line system the collection of alarms and fault location for the system is carried out by one and the same TCT, but the siting of each TCT is optional and not tied to the supervised equipment.

Transmission maintenance Sub-Terminals
The alarm points of the supervised equipment are scanned by Transmission maintenance Sub-Terminals, TST. Each TST is installed in the same location as the supervised equipment. The network configuration and the number of devices to be supervised determine whether one or more TSTs are required in each station.

The main functions of TST are to:
- scan alarm contacts
- measure the bit error rate of terminal repeaters.

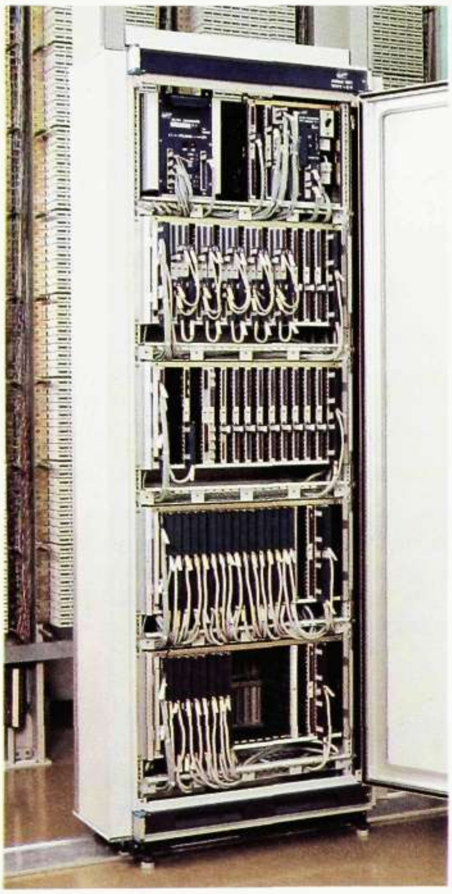
Fault Detection Unit
Line systems with fault location interfaces can be supervised in each repeater point by means of a Fault Detection Unit, FDU. This unit forms part of fault location systems that are integrated with ZAN 101.

Communication

The communication between ZAN 101 terminals takes place over modem links and can, depending on the choice of transmission channel, span large distances. The communication interfaces between the different parts have been designed to suit the quantity and type of data to be transmitted. The same type of modem links that are used in AOM 101 are also used in ZAN 101 between TMT and AOM 101 and between TMT and TCT. Table 1 lists the communication links in ZAN 101.

There are two alternatives for the communication link between TMT and TCT.

Fig. 12, below and to the right
The Transmission Maintenance Terminal, TMT, is mounted in a BYB 201 cabinet, and up to four work stations can be connected



For example, if TMT and TCT are placed in the same exchange a short-haul modem can be used. It permits higher transmission speeds, which above all helps to reduce the system start-up time. The difference is not noticeable during ordinary operation.

For the communication between TCT and TST a separate loaded pair, the fault location pair or any speech channel can be used.

The type of communication link used between TCT and each FDU is determined by the type of fault location system. If the fault location system in the M5 construction practice[3] is used, the relevant protocol also includes d.c. signalling.

With fault location system ZAN 201 in the BYB construction practice[4] the fault location pair can be utilized more efficiently by means of a common protocol for alarm collection and fault location.

Alarm collection and fault location take place in time multiplex.

Equipment

TMT

TMT consists of several magazines, one of which contains a processor, and memory and communication units. TMT also includes between one and four magazines with communication units for connection to TCT. When ZAN 101 is not connected to AOM 101 a magazine for cassette and file administration and

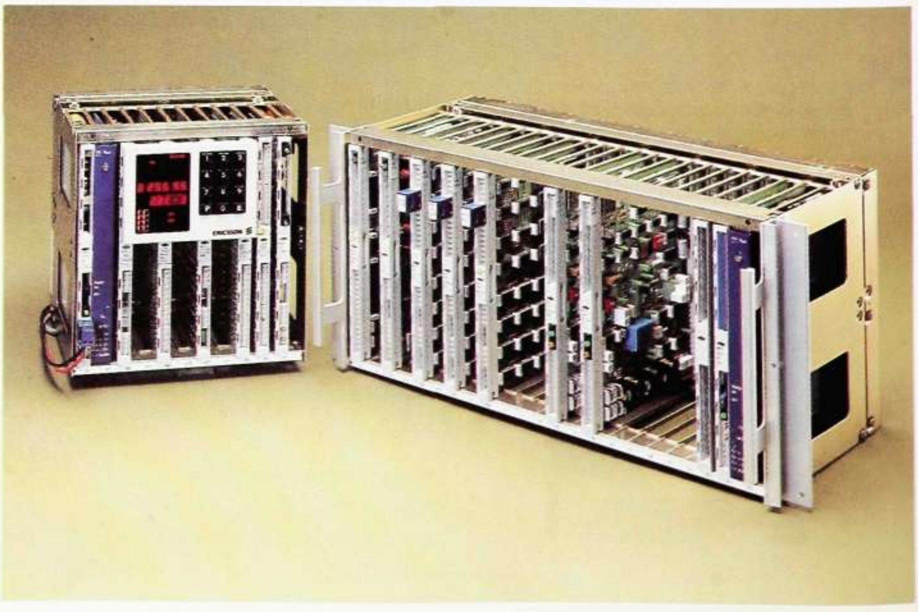


Fig. 13
The Transmission maintenance Control Terminal, TCT, consists of a Supervision Control Magazine, SCM, and a Fault Location Magazine, FLM, which is included in ZAN 201. FLM can also be controlled direct by means of a push-button set. All communication takes place via connections on the fronts of the boards. Alternatively Fault Detection Shelves, FDS, can replace the fault location magazine

Fig. 14
The Transmission maintenance Sub-Terminal, TST, consists of an Alarm Collection Magazine, ACM, and fault detection units. Each alarm collection magazine can be equipped with up to 16 alarm collection boards giving a total capacity of 896 sensing points

a cassette tape unit are also required. All magazines are placed in BYB 201 cabinets.

TMT is controlled by an APN 163 central processor, and the same type of processor is also used for the cassette and file administration.

Each operator's work station connected to TMT can be equipped with a printer and a visual display terminal or typewriter terminal as required, fig. 12.

TCT

TCT, fig. 13, consists of a Supervision Control Magazine, SCM, and one or two fault location shelves in the M5 construction practice, or a fault location magazine in the BYB construction practice. The SCM contains an APN 166 processor, memory units and units for communication with TMT and TST. The fault location shelf/magazine contains a remote power feeding unit and a unit for communcation with FDU.

TST

TST includes one or several Alarm Collection Magazines, ACM, and one or more FDUs for error rate measurements on terminal repeaters. In many cases FDUs are integrated in the line systems. The alarm collection magazine, fig. 14, contains an APN 166 processor, a modem and alarm collection boards. It can also include boards for the operation of control points and alarm repetition.

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EDNET for the Supervision of Data Transmission Networks

Björn Lengquist and Per Åke Wiberg

EDNET is a system developed by Ericsson Information Systems for the supervision of data transmission networks. The system increases the operational reliability and availability of such networks. The system, which belongs to the same system family as ERIPAX and ERIMAIL, can readily be adapted to a number of different types of data networks. EDNET can supervise both private and public data transmission networks.

The authors give a number of examples of system applications and describe the structure, handling and capacity of EDNET.

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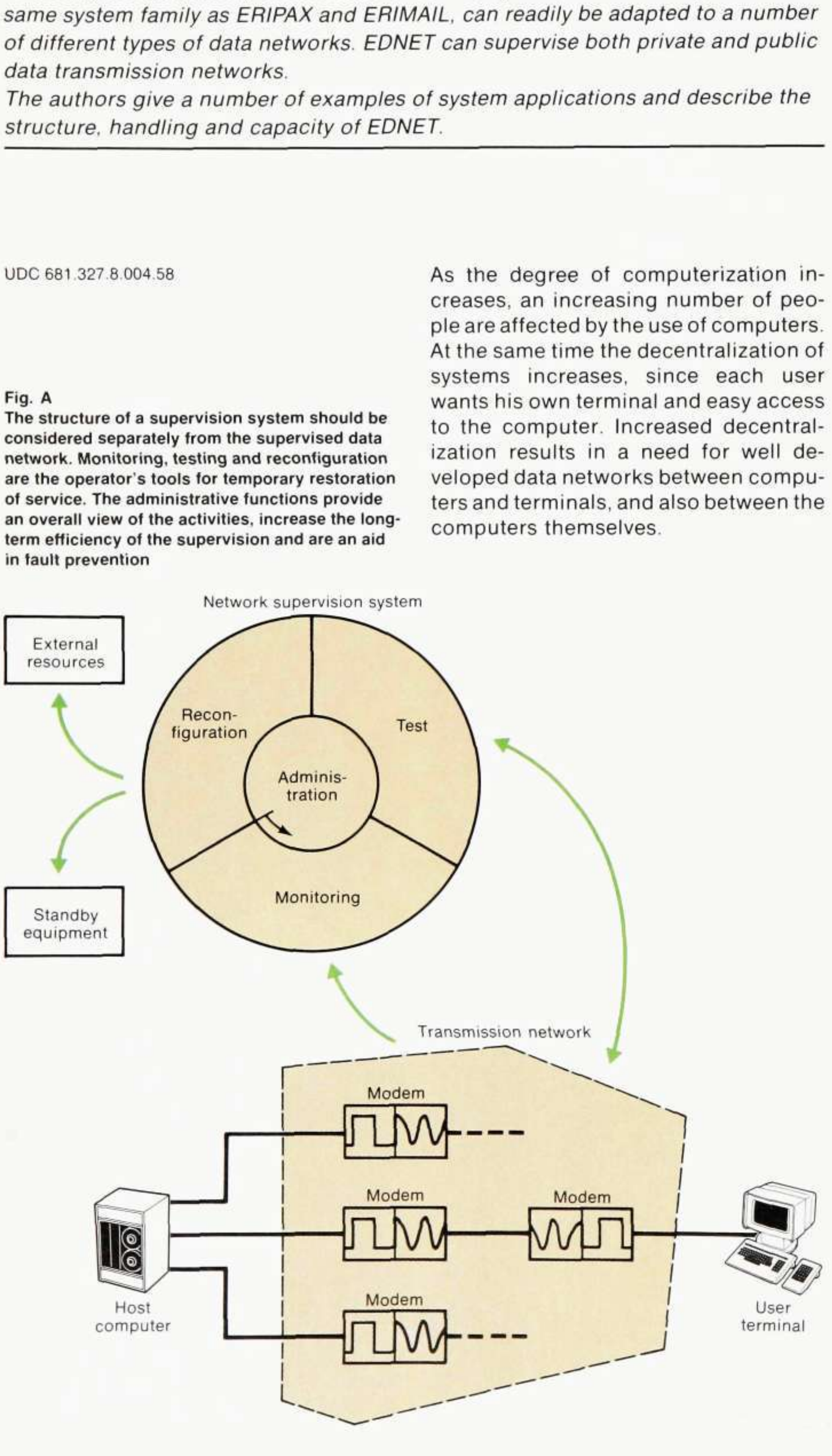
Fig. A
The structure of a supervision system should be considered separately from the supervised data network. Monitoring, testing and reconfiguration are the operator's tools for temporary restoration of service. The administrative functions provide an overall view of the activities, increase the long-term efficiency of the supervision and are an aid in fault prevention



As the degree of computerization increases, an increasing number of people are affected by the use of computers. At the same time the decentralization of systems increases, since each user wants his own terminal and easy access to the computer. Increased decentralization results in a need for well developed data networks between computers and terminals, and also between the computers themselves.

If the data networks are to operate efficiently it is necessary to ensure high availability for all parts of the system and also to have a supervisory system that simplifies the detection and location of faults. EDNET has been developed for such supervision of data transmission in both private and public networks.

Ericsson has previously developed several supervision systems for, for example, public telephone exchanges, PABXs and other types of telecommunication systems. This experience, together with 20 years' experience of data transmission, has provided a firm basis for the development of EDNET.

Each EDNET installation must be adaptable to different user requirements and different data networks. It must also be flexible, so that it can satisfy future demands. It is important to be able to modify existing systems to include newly developed functions. The necessarily great flexibility is achieved by giving the system a modular structure throughout.

The division into modules is of particular importance for the functions included in the software in the central equipment. In EDNET the modular structure has been exploited to a relatively great extent, and experience gained from, for example, the development work on Ericsson's public telephone system AXE 10 has been utilized in the design work.

Since the different software functions are confined to separate modules, a modification will only affect the module in question, regardless of whether the modification means an extension or reduction of the function.

For the user of the system this design provides a guarantee of flexibility, high reliability and low service costs.

An important demand made on a network supervision system is that the supervising system must be separate from the system being supervised. The diagnostic units with their channels, which are the sensors of the central equipment, are separated functionally from the network to be supervised. This design makes it possible to choose different degrees of integration, and to use

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Functional separation

A network supervision system has to continuously collect and present information regarding the operation of the network. It must also be able to detect faults and advise on how to clear these, fig. A.

The supervision system includes an administrative function in order to facilitate the operation and maintenance of the network equipment.

The data transmission network, which provides the circuits between the data terminal equipments, consists of modems, multiplexers and lines. The modems convert the digital data flow to signals that can be transmitted over long distances via telecommunication lines. The multiplexers exploit the transmission capacity of a line so that it can be used for several different purposes simultaneously.

The data terminal equipments, DTE, can be of different types. In a large network some terminals, for example communication and host computers, take a bigger load than others. Other terminals are of the work station type (visual display units, personal computers).

The supervision of the terminals is usually separated from the network supervision. However, it is not advisable to separate these functions entirely. With integrated supervision it must be possible to check the function of a whole system from a single point.

Supervisory functions
Monitoring, fig. B, means that the system collects data continuously from the supervised devices and compares the values with values stored in a memory. If the data deviate from the expected values, an alarm is sent to the operator. With the aid of a number of test functions he can then trace the cause of the fault. The operator can eliminate the fault temporarily by making reconnections in the network. He can also connect in standby equipment if available.

The monitoring requires a signalling channel between the supervision centre and each device in the system. This channel, designated the diagnostic channel, is used to transmit values from the devices to the supervision terminal, and to send commands to the parts that carry out tests and functional checks.

The diagnostic channel can be designed in different ways, as a separate channel or a secondary channel. If it is built as a secondary channel, it is possible to utilize the frequency band on the line between the two modems. If the transmission equipment does not permit a secondary channel, as in the case of baseband modems, a separate channel is set up. This means that either a separate line is installed or a temporary circuit is connected up.

The central equipment controls the communication with the monitoring and test devices. It also holds information regarding the current state of the system, since all changes are recorded. The operator's work station includes a visual display unit, a printer and a keyboard.

Administrative functions
One of the major problems in large communication networks is how to get access to information concerning all the supervised devices in the system. The system must be able to distinguish between the various devices as regards type, function, supplier, when it was bought, service contract and history. Moreover the system must also be able to maintain a register of fault reports and the actions to be taken when an alarm is obtained.

The administrative functions in a supervision system should include aids for analyzing the large amounts of data collected, for example as regards the intensity of a certain type of fault during a specific period.

The system should also include a program that measures (and outputs) the load on a specific component in the network, e. g. the number of characters of commercial traffic per unit on a transmission route. Such a function would be of great assistance to the administrator, since it would give the amount of traffic at different times.

Graphic presentation contributes to efficient interworking between the operator and the supervision system. The display shows the position of every device in the network, its function and place in the system. All deviations from the normal, as well as the actions taken, are shown on the screen in different colours or with different intensity.

The development of aids for administrative functions is based on products from Ericsson Information Systems.

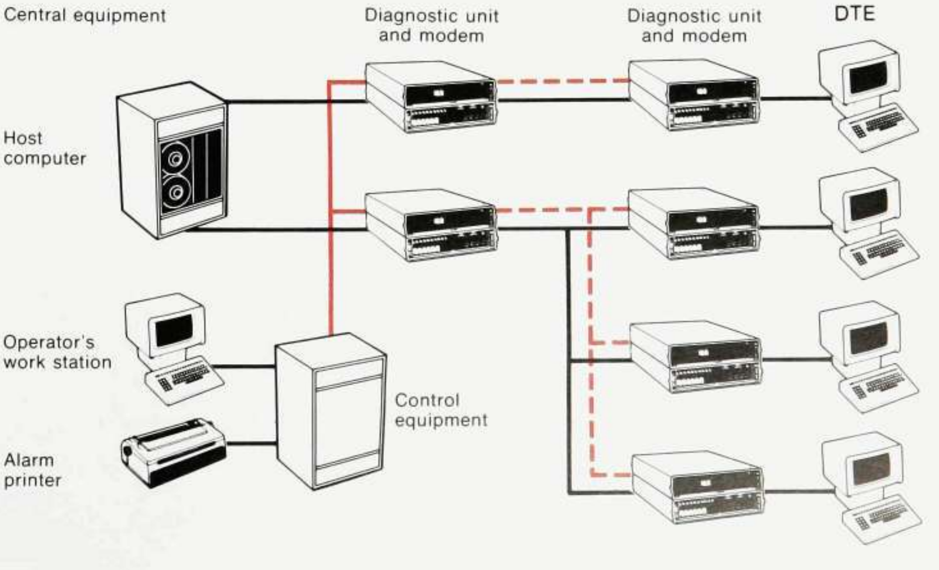


Fig. B
Monitoring is carried out with the aid of units placed at the modems and other supervised devices. The central control equipment is connected to the monitoring units via a signalling channel, and informs the operator about the current state of the system via a visual display unit or printer

either secondary channels between the modems or separate transmission lines for supervision and control signals. The same degree of freedom cannot be obtained with systems that use the supervised data channel for the transmission of signals.

The need for network supervision systems varies greatly for different countries and applications, depending on the industrial structure and the conditions laid down for the use of the public network.

In cases where the telecommunications administrations own and lease the data networks they are also responsible for fault location and repairs. The customer's part in the supervision is to ascertain, before the fault is reported to the administration, that the fault is located in the equipment owned by the administration. In markets where the users also own the transmission equipment they are also responsible for the supervision of the network.

The way that EDNET is used depends on the network structure. Fig. 1 shows a network containing the three most common elements: point-to-point links, multipoint links and multiplexing links.

It has been found that the network structure varies with the type of business. For example, multipoint networks are predominant in the bank and transport sectors, whereas manufacturing industry, insurance companies and administrations usually have point-to-point and multiplexer networks.

Public and large private switching networks are particularly attractive applications for such data transmission networks. In Ericsson's ERIPAX system the subscriber connections can be built up using primarily point-to-point and multipoint circuits[1]. The supervisory functions for transmission and nodes are brought together in a centre using a uniform interactive method for the input of commands and processing of alarms.

Previously developed components from the product family ASK 101 and from other Ericsson products have been used in the development of EDNET. It has therefore been possible to design EDNET so that it fits in with integrated communication systems, where the products interact to give the optimum result.

EDNET consists of diagnostic units and central control equipment. The diag-

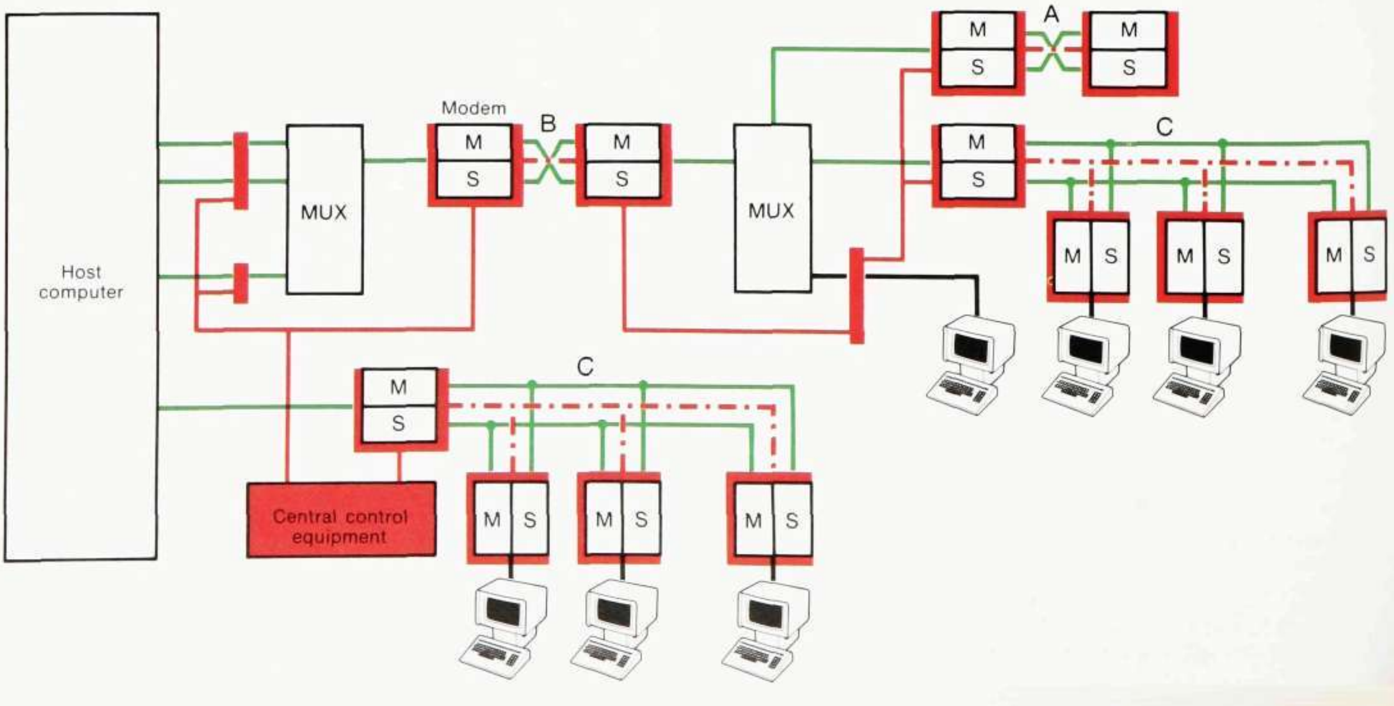
Fig. 1
The figure shows three of the most common types of circuits: point-to-point (A), multiplexer (B) and multipoint (C). The diagnostic channel, which connects the supervised units to the central equipment, is in the form of a secondary channel

Diagnostic unit (DU)

Data transmission channel

Diagnostic channel

Diagnostic channel arranged as a secondary channel



Supervision of the digital interface

The following signals in the V.24 interface are monitored in DU-1

103	Tx data
104	Rx data
105	Request to send
106	Clear to send
107	Data set ready
108	Connect data set to line
109	Carrier detector
111	Rate control
113/114	Tx timing
115	Rx timing
140	Remote loop 2 request
141	Loop 3 request
142	Test condition.

When the modem is installed conditions are set up in accordance with the function of the modem in the network. For example, for a point-to-point circuit signals 103, 104 and 105 are monitored for each modem. If there has been no activity for a certain, preset length of time, the alarm NO ACTIVITY will be initiated.

The same signals are monitored on multipoint circuits, but the condition is then that long-term activity from a terminal should initiate the alarm STREAMING. The operator can then use the command ANTISTREAMING to disconnect the terminal. Alternatively this function can be carried out automatically.

Regardless of the set conditions, the operator can at any time request a check and presentation of the state of all signals. The operator can also request the transmission of other values in order to deblock a device or to carry out tests.

DU-1 provides facilities for the monitoring and control of up to eight external signals.

nostic units, DU, are installed at or form part of the devices that are to be monitored, for example modems. There are variants of DU for different tasks. The operator's work station, which is connected to the control equipment, consists of a visual display terminal and a printer. The functions built into the system can be supplemented by including auxiliary equipment, for example for more advanced testing.

The diagnostic unit, fig. 2, comes in two versions, DU-1 and DU-2. DU-1 contains basic functions, such as monitoring of the signals in the digital interface V.24, loop connection, sending and receiving test information and also scanning and controlling up to eight external signals.

The additional functions in DU-2 include analog monitoring of signal levels. The signal quality, represented by a signal compounded of the signal/noise ratio, frequency jitter and phase jitter, can also be monitored. It is also possible to arrange for the connection of a standby circuit or modem.

DU-1 and DU-2 are built using the same construction practice as modems, and they can be supplied as individual units or units for installation in cabinets. The diagnostic units can be used with Ericsson modems and also with modems of different manufacture.

The signalling channel, which provides the connection between the diagnostic unit and the control equipment, can be arranged as a separate or secondary channel, see the information panel "Functional separation".

Central control equipment

The central control equipment is made up of components from the data communication system ASK 101. The equipment consists of a computer module, CM, a line module, LM, and a storage module, SM.

The computer module is based on the Motorola microprocessor 68000. The line module is used to connect operator equipment and signalling channels to diagnostic units. The storage module is used to store all programs and data concerning the network and the equipment in it. This information is used when the system is started up, and also as a back-up for the memory in the computer module. The storage module can be equipped with floppy disc units only, or units for both floppy discs and Winchester discs. ASK 101 has been described in previous issues of Ericsson Review[1,2].

The central equipment of the system is mounted in magazines which are installed in a standard cabinet.

Operator's work station

The operator uses a visual display terminal and printer. Alarms that are initiated when a fault occurs in a monitored device are output on the printer. The printer also records the commands given by the operator, via the terminal keyboard, concerning changes in the data transmission network.

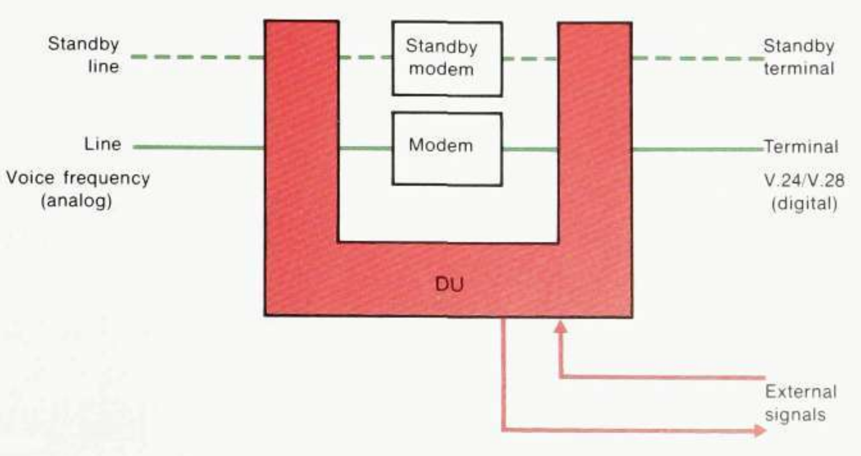


Fig. 2
The diagnostic unit circumscribes the supervised device, for example a modem, so that digital and analog signals are available for monitoring, test and also reconnection if required

All interactive work with the input of commands takes place via the visual display terminal. The commands have been designed on the basis of the CCITT *Man Machine Language* (MML).

The MML command structure is frequently used in telecommunications, where it has proved very suitable because of its systematic construction. One of the main advantages of MML is that the same language can be used in all subsystems in large integrated systems.

Auxiliary equipment
External equipment can be connected via connector panels (patch units) when more extensive measurements or tests are required over long periods, for example for measuring the signal quality. The equipment, which is connected in at the terminal and line interface, includes switched functions for monitoring the traffic in progress and for cutting off the connection, for example when generating a test pattern.

Most measurement and test equipment in the market can be connected to the patch units.

Modular design

During the development of EDNET great importance was attached to the modular structure of the system. The same principles were used as for the design of the AXE 10 telephone system and all similar design work within Ericsson.

The system is built up of modules consisting of either software or hardware. The modules have well defined interfaces. The system is extended or equipped with new functions by adding new modules or exchanging existing modules for others with new functions. This facilitates maintenance and enables the system to be kept up to date for a very long time.

The modular structure makes it easier for staff without programming knowledge to understand the system. This furthers the possibility of quickly reaching a good agreement between requirements and functions, which is particularly important for the administration and maintenance of the system.

ASK 101 makes it possible to duplicate the computer and storage modules, which means that the system is able to function even if a fault occurs in such a module.

Capacity

The basic version of EDNET is suitable for the supervision of networks of greatly varying sizes, from small ones with few devices up to extensive networks with up to 700 devices. Extension mod-

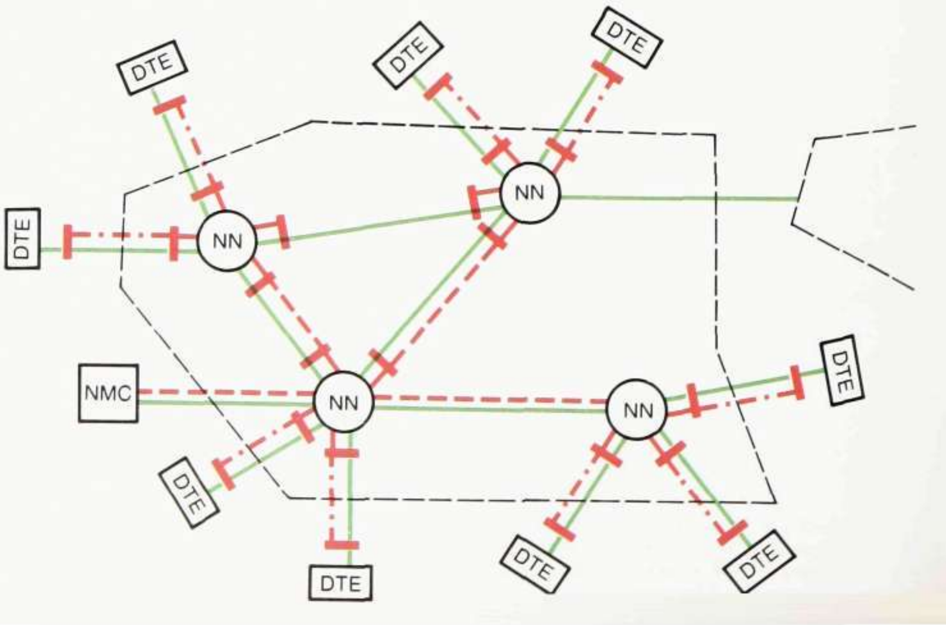


Fig. 3
In a packet switching network built up with ERIPAX the modem supervision and traffic supervision in the nodes are combined in the network management centre, NMC, of the system. The diagnostic channels to terminals are designed as secondary channels, otherwise as virtual connections in the network

NMC — Network management centre with operators
NN — Network node (packet switch)
DTE — Data terminal equipment
▬ — Modem and diagnostic unit

Diagnostic channel

Diagnostic channel, on a secondary channel

Diagnostic channel, on a virtual connection in the packet switching network

Data channel, link

ules can be used to successively increase the number of devices supervised by a single EDNET centre to about 3000. If this is not sufficient the system can be extended with more computer and line modules, each of which has a capacity of approximately 2500 supervised devices.

Integrated applications

In addition to EDNET the product family ASK 101 includes the data communication system ERIPAX, the message transmission system ERIMAIL and network management centres, NMC. ERIPAX transmits data in packet form between the terminals, which are connected to the nodes in the network. If necessary, the system carries out adaptation of the communication between the network and the terminals. NMC contains functions for the supervision and administration of the different units in a communication network, i.e. nodes and switches. It can be used in pure ERIPAX networks and in networks containing other components, for example MD 110, the PABX for both speech and data transmission.

Such networks can contain between a few hundred and several thousand terminals. The number of connected modems is at most twice that number. Geographically the equipment in one and the same network can be situated in different countries throughout the world.

The NMC and EDNET functions can be built into common ASK 101 equipment, fig. 3. An alarm from any one of the many devices in the network is transmitted to the centre via the network and presented to the operator, who via his terminal selects one of the alternative actions offered by the combined systems. Pure EDNET applications, which include many devices and which are spread over large areas, can be arranged by means of a combination of ERIPAX and EDNET.

Further development

The fact that EDNET has been made available in the market does not mean that development has ceased. It is the intention that the system will undergo successive development. The next items under consideration are a graphic colour terminal for the operator, and menu handling for the choice of function and as an input aid. New administrative aids will also be developed.

It is essential that in the further development work the system retains the possibility of supervising networks built for both telephony and data communication. The operator at the EDNET centre is thereby given standardized working methods for all components in the system. It also means that the different communication services can be operated jointly.

Summary

The function of EDNET is to supervise data transmission networks. The main features of the system are:

- Modular structure, designed in the same way as AXE 10. The system can therefore be kept up to date by successive adaptation to new requirements.
- The system meets the more stringent requirements for operational reliability and maintenance support made by large and complex networks.
- The supervisory functions are kept separate from the supervised network by special diagnostic units and channels.
- The division into functions for supervision, diagnosing and reconfiguration provides a good overall picture and makes it easy to train operators.

References

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LPB 110, a System for Controlled Test Traffic

Bengt Jansson, Kent Johansson and Tommy Östlund

In the testing of telecommunication systems demands are made for shorter test times and at the same time the equipment being tested becomes increasingly complex. Powerful and efficient aids are therefore required, primarily for the testing of whole systems. Ericsson has developed such a test system, LPB 110, which has been designed to generate and terminate test traffic.
The authors describe LPB 110 and how it can be used for design, production and installation testing of Ericsson systems and also other systems.

UDC 621.395.2/.3.001.4

Over the years various types of devices have been used for testing telephone equipment at system level. These test devices have often been developed for specific applications, fig. 1.

The need for more general test equipment has arisen for various reasons, partly because of the rapid technical development in the field of telecommunications. New demands have been made on existing test equipment, and new test requirements have arisen for newly developed system parts. Demands from the users have led to a modular structure, so that the equipment can easily be modified for different requirements, and the same facilities for man-machine communication as in stored program controlled telephone exchanges.

In order to exploit design resources efficiently they were brought together in a project, in which all requirements were formulated in collaboration with representatives from the system and installation testing departments. The test system developed in accordance with these requirements, LPB 110, can be used for all autonomous testing at signal interfaces towards telephone equipment, for example towards MDF, where LPB 110 can simulate the environment of a telephone exchange, fig. 2.

Test facilities

LPB 110 has been designed to generate and terminate controlled test traffic, primarily in connection with design, production and installation testing, including acceptance testing, but it can of course also be used for testing equipment in service, for example for traffic route testing.

LPB 110 can simulate the functions of the subscriber and junction lines in the surrounding network and hence can simulate all connection types, i.e. local, incoming, outgoing and transit calls.

Fig. 1
Test equipment developed during the 1930s, 1950s and 1970s

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Each connection can be controlled and checked both at the originating and the terminating side.

The test object can be a telephone exchange, a telex exchange, a data switch or any other telecommunication system, regardless of type. The traffic functions and signalling systems that can be simulated by the equipment are:
- Subscriber line signalling (dial or push-button)
- Conventional junction line and register signalling systems (e.g. d.c. loop, E&M, MFC or decadic signalling)
- PCM signalling, of the first and second order and for I/O channel
- Common channel signalling (CCITT nos. 6 and 7)
- Digital subscriber line signalling
- Signalling in mobile telephone networks
- Signalling in telex and data networks (AXB 20 and AXB 30).

The system can easily be adapted to new signalling systems since the basic system permits the connection of equipment to the AXE 10 device bus interface (the EM bus). This means that equipment (e.g. IT and OT) developed for AXE 10 can also be used in LPB 110. This will reduce the cost of adapting LPB 110 to special signalling systems considerably.

Applications

LPB 110 is an efficient aid for
- traffic case testing in an exchange
- individual testing of line equipment
- operational testing
- acceptance testing.

Traffic case testing

Traffic case testing means systematic testing of all permitted traffic combinations between incoming and outgoing lines. Such functions as digit analysis, route analysis and tariff analysis are checked, and, of course, also all general functions, such as B answer, speech connection, time supervision and disconnection.

Individual testing of line equipment

Only a few lines are normally tested during traffic case testing, which means that each individual line must be tested separately. The individual testing is basically the same as traffic case testing, but fewer functions are tested.

Operational testing

The purpose of operational tests is to verify that the equipment is satisfactory for connection to the network. A number of tests are carried out in which normal operating conditions are simulated. This requires controlled test traffic, preferably generated by an LPB 110 system. The connections of the system are then distributed over the test object so that the greatest possible part is activated.

Acceptance testing

The Ericsson policy for the acceptance of a plant is that the customer will accept the equipment when the service quality has reached the level specified in the contract. This quality level can be verified with the aid of controlled test traffic from an autonomous LPB 110 system.

In an acceptance test a large number of connections 0.5−1 million) have to be generated in a fairly limited time.

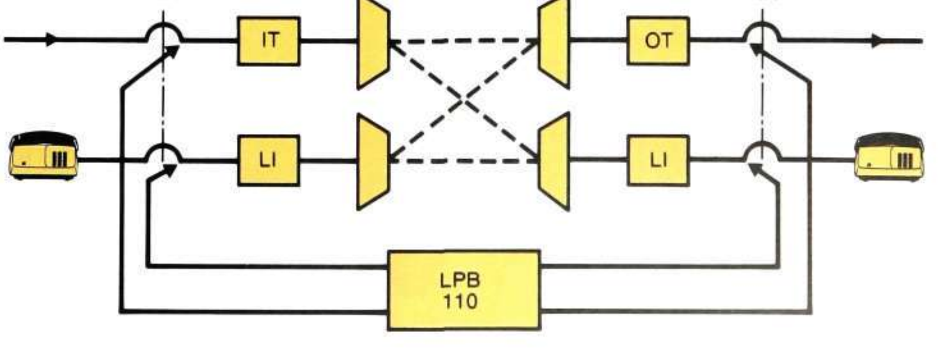


Fig. 2
Test facilites

IT Incoming junction line
OT Outgoing junction line
LI Subscriber line
KK Main distribution frame, MDF

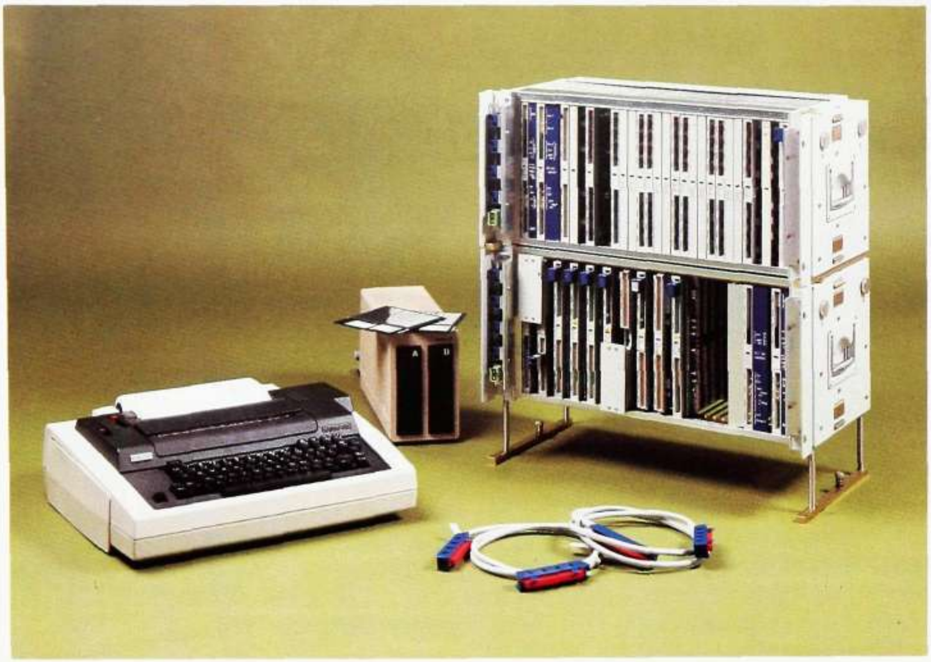


Fig. 3
LPB 110

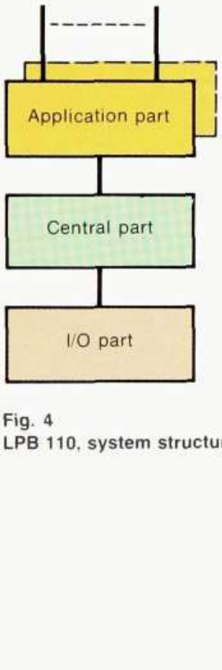


Fig. 4
LPB 110, system structure

System structure

LPB 110 consists of hardware and software, and is controlled by microprocessors, fig. 3. The system has a modular structure both as regards functions and capacity, which means that new functions can easily be added.

The software is stored in RAMs which are loaded from floppy disc units. The use of RAM makes the system very flexible. When programs are updated new floppy discs are sent to the users.

CPU contains administrative routines, statistics and I/O functions. Slave processors are used to relieve CPU of certain scanning routines in the interface hardware.

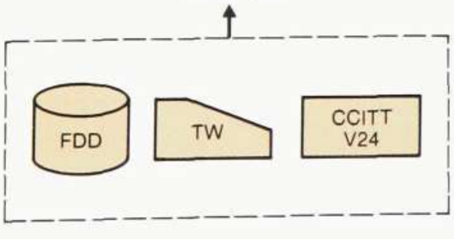
LPB 110 consists of a central part, one or more application parts and an I/O part, fig. 4.

Central part

The central part in LPB 110, fig. 5, is a computer system developed by Ericsson, APN 167, which has a Motorola 68000 as CPU. The programming language is a high-level language, ERIPASCAL, which is a Pascal language adapted for real-time application. In addition a control language has been developed with which the users of LPB 110 can program their own test sequences. The execution of test sequences controls the interface hardware for the different test objects.

Fig. 6
LPB 110, I/O part

FDD Floppy disc drive unit
TW Typewriter, digtial LA 12
CCITT V.24 Interface towards the AX systems



The central software consists of a number of program modules, each of which handles one or several functions. Modules have been developed for, among others:

- Operating system
- Loading
- Control program
- Fault handling
- Statistics

I/O

The I/O units in LPB 110 are portable typewriters, and two floppy disc storage units for 5 1/4″ discs, fig. 6. Interworking with the AXE 10 system takes place via a signalling interface (CCITT V.24). The I/O system of the AXE 10 exchange can therefore be used to communicate with LPB 110. All program modules are stored on floppy discs, and they are automatically read into LPB 110 when the system is started up. A built-in editor enables the user to design new control programs or modify the supplied programs.

Application part

Special hardware and software has been designed for use in LPB 110 as interface to different signalling systems. An interface can be used for more than one signalling system. For example, the same interface module is used for both CCITT R1 and R2, fig. 7.

The hardware can be controlled via one of two buses, either the I/O bus of APN 167, which is used in new designs, or the EM bus in AXE 10 via a specially developed bus interface.

When the EM bus is used LPB 110 can utilize the hardware in AXE 10 (for example the signalling terminal for CCITT signalling system no. 7).

Each hardware interface has a diagnostic program, which monitors the connected hardware and initiates a printout if a fault should occur. The faulty board can then be changed.

Traffic functions

In LPB 110 each test object is considered as a control individual, for example an A or B subscriber or a line signalling equipment. A set of hardware, control

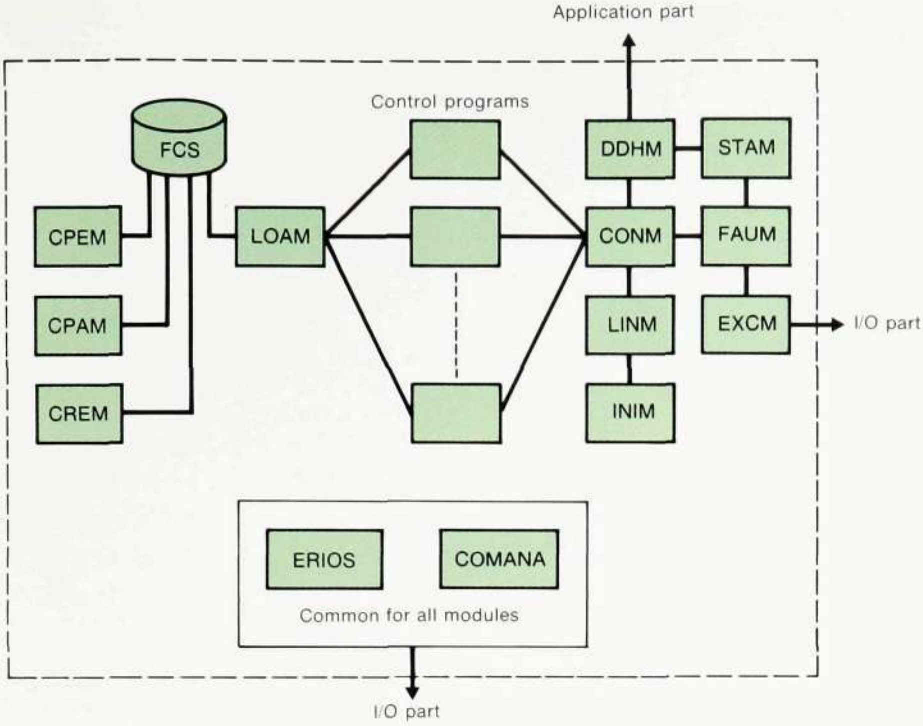


Fig. 5
LPB 110, central part

FCS	File control system
CPEM	Control program, editor module
CPAM	Control program, analysis module
CREM	Command read file execution module
LOAM	Control program, loading module
DDHM	Device driver handler module
CONM	Test control module
LINM	Linking module
INIM	Traffic initiating module
STAM	Statistics module
FAUM	Fault handling module
EXCM	AX exchange module
ERIOS	Ericsson operational system
COMANA	Command analysis module

programs and data are associated with each control individual. However, the control programs are common for a number of control individuals. Each type of signalling has its own control program. The data are specific for each control individual, and vary depending on the type of connection the individual represents.

For example, the data for a local subscriber line include:
- type of subscriber (A or B)
- subscriber number
- type of dialling tone
- type of ringing control tone
- type of control program.

The control individuals are divided into groups, test batches, which are processed together as regards statistics, fault handling, start and stop. The control individuals are allocated to a batch by means of commands.

Within a test batch originating and terminating control individuals can during traffic be linked either permanently or dynamically. Permanent linking means that the control individuals to be linked are specified in a table, which is set up by means of commands. Several different tables can be set up and used in a given order during the traffic processing. Dynamic linking means that the control individuals are linked together at random. A test batch can include control individuals which belong to several different signalling systems.

Traffic volume

The traffic volume can be regulated as follows:
- Even, given by a command
- Poisson distribution
- As much traffic as the connected lines permit (no traffic regulation).

In each case the number of simultaneous calls can be preset. The total number of calls in a test batch is specified by means of a command.

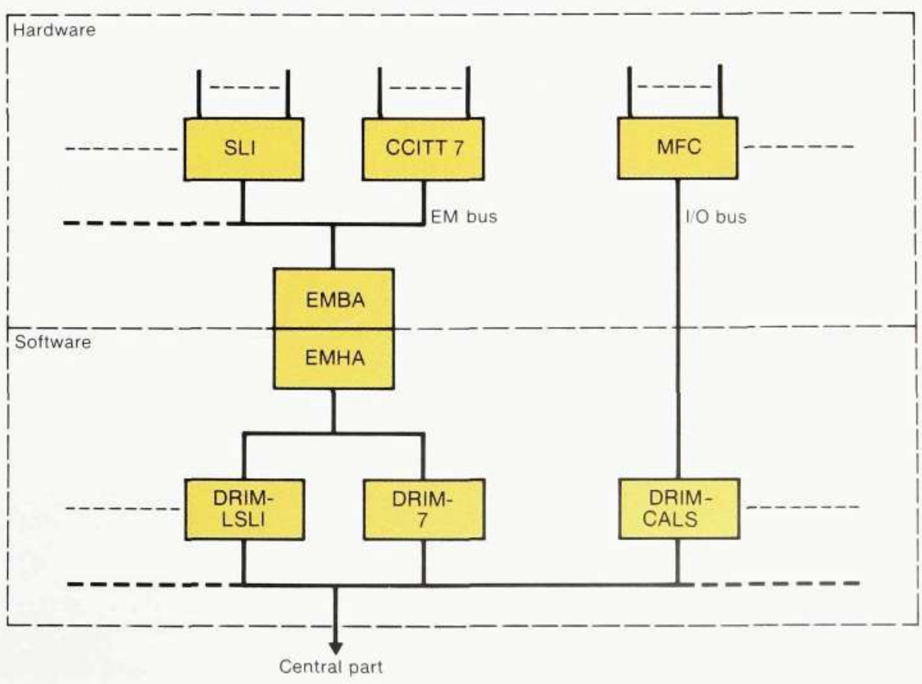


Fig. 7
LPB 110, application part

EMBA	EM bus adaptation unit
EMHA	EM bus handler module
SLI	Subscriber line interface
CCITT 7	Junction lines with CCITT nr 7 signalling
DRIM-LSLI	Device driver module for local lines
DRIM-7	Device driver module for CCITT 7 signalling
DRIM-CALS	Device driver module for MFC signalling

```
FAULT PRINTOUT  TBA 2        1983-12-19    164027
WRONG RING TONE ON CIN = 16  FAULT CODE : 6
ORIGINATING PROGRAM MFCPROG, LINE NUMBER 158
FAULT INDICATOR = 3

END
```

```
TSCNP:CIN=1&&3;

STATISTICAL COUNTERS FOR CIN             DATE: 1983-08-25  TIME: 130530

CIN     INITIATED   INITIATED   FAULTS     FAULTS
        ORIG.CALLS  TERM.CALLS  ORIG.SIDE  TERM.SIDE

 1             48           0          0          0
 2             37          23          3          6
 3          11678       46544          1          7

END
```

Fig. 8
Examples of fault and statistics printouts

Start/stop
Start and stop can be given for:
- control individuals
- test batches
- all programmed and open control individuals.

At start up, the system can be ordered to reset statistics counters and fault report buffers for the control individuals being started. Start and stop at preset times can also be arranged by means of commands.

Supervision

For LPB 110 different types of supervision are used. The generated traffic, and the internal functions are monitored, for example the syntax checking of control programs and the monitoring of hardware. Faults detected during traffic generation result in fault printouts, for example if a wrong backward signal is received with MFC signalling or a dialling tone is not received for a local call. In other cases alarm printouts are initiated.

In LPB 110 it is possible to control the handling of different fault situations during the traffic processing. All faults that are detected during traffic handling result in a printout and are recorded on counters. After the recording the lines in question are disconnected unless some other action has been ordered. Instead of being disconnected the connection can be handled as programmed.

If a fault is detected in LPB 110 a hardware diagnostic program can be started. A printout specifies the faulty board.

During the traffic handling, statistics are collected per test batch, per control individual and for the total amount of traffic. The statistics can be output by means of a command. Periodical statistical printouts can also be ordered, fig. 8.

Construction practice

The construction practice used for LPB 110 is LTR 331, characterized by its compactness. The system includes two units, built up of magazines of 12 BM (approx. 50 cm wide and 25 cm high), the first with one magazine and the second with three stacked magazines, fig. 9.

The top and bottom covers are removed when the unit is used, and the resultant chimney effect ensures good cooling. For equipment with very high power dissipation a fan unit can be added, which provides forced cooling.

The equipment is delivered in transport cases in accordance with the Ericsson standard for test equipment. The units are provided with sturdy handles and can easily be carried by two men.

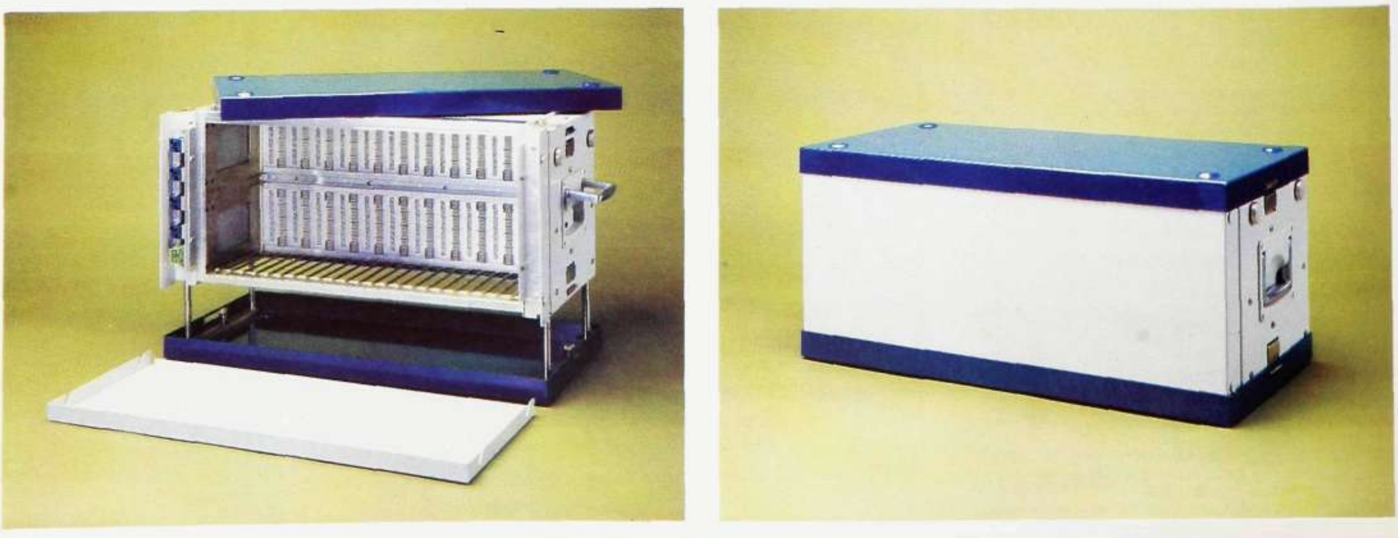


Fig. 9
Construction practice LTR 331 is used for portable equipement

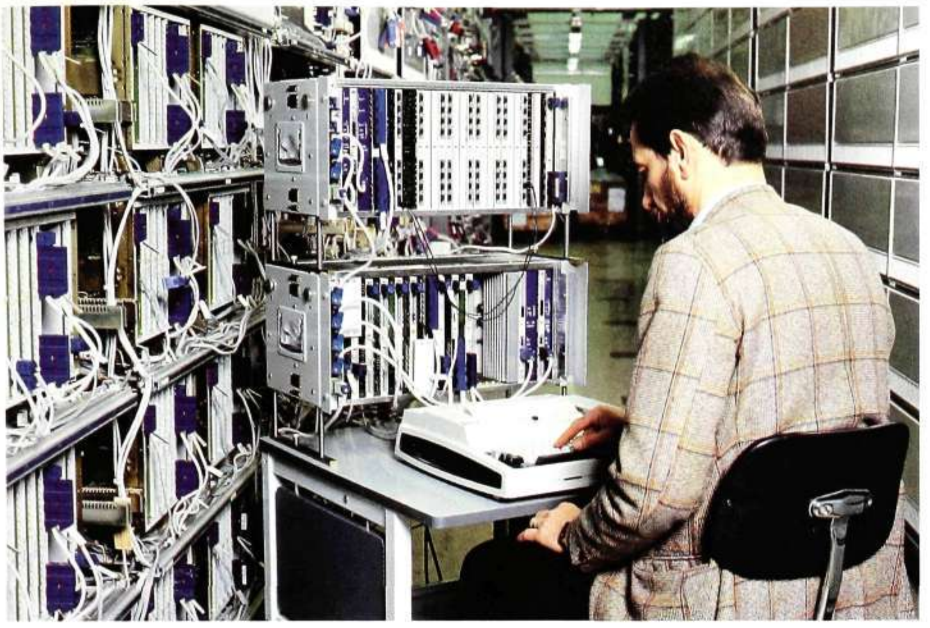


Fig. 10
LPB 110 used in an AXE 10 exchange

Technical data for LPB 110

Number of lines	≤256
Number of signalling system types used simultaneously	≤24
Power	−48 V DC and mains
Construction practice	LTR 331
Processor	APN 167
Programming language	ERIPASCAL
Operating system	ERIOS
Memory medium	5 ¼" floppy discs
I/O interface	CCITT V.24
I/O device	Digital LA 12 (Standard)
Interworking with AX	CCITT V.24
Commands	CCITT MML
Printouts	Fault printouts Larm printouts
Statistics printouts	No. of initiated calls No. of terminated calls No. of faults No. of faults per type
Signalling systems	Analog subscriber line signalling Line signalling E&M Register signalling R1, R2 and decadic CCITT no. 6 CCITT no. 7 PCM 32 and 24 channels

Starting up

The task of putting LPB 110 into operation can be divided into a hardware and a software stage.

The hardware stage comprises voltage connection, internal cabling and connection to the test object. The exchange voltage is connected to the central and application parts, and mains voltage to the I/O devices. The internal cabling consists of bus cabling between the different units.

The software stage consists of loading the LPB 110 software from floppy disc units and loading hardware data, control programs and control data.

The hardware data constitute the software reproduction of the hardware towards which the programs work. It can be compared to the exchange data in a telephone exchange. The data remain the same as long as no change is made in the hardware configuration.

The control programs are transcripts of signalling diagrams for the signalling systems included in LPB 110, and are supplied individually for each LPB 110. If necessary, modifications to control programs and new control programs can be input direct from the typewriter.

Control data are not supplied with the equipment but are compiled by the user. The control data specify, for example, which subjects are to be included in a test batch, the handling of fault situations, the number of connections and the type of printouts. The control data are stored on floppy discs for quick loading when required.

After connection the testing can start. The start command is given from the typewriter or any other I/O device.

LPB 110 for AXE 10

LPB 110 is equipped with an interface for connection to the I/O system of AXE 10 for the purpose of testing the exchange. This means that commands can be transmitted from LPB 110, both manually from the terminal and automatically from user programs. In the first case the operator works towards AXE 10 in the same way as from an ordinary terminal, and in the second case user programs in LPB 110 can, for example, initiate tracing, and the result can be received by and utilized in the user program.

Communication with LPB 110 can also take place from a terminal in AXE 10. This means, for example, that LPB 110 can be placed at the MDF and be operated by an operator in the control room. This provides great flexibility in the testing.

Summary

The demand for short test times and powerful test functions, and the trend towards testing of complete systems have led to the development of the general test system LPB 110 for the generating of controlled test traffic. The modular structure of the system makes it readily adaptable for different applications, both as regards technology and operation. The system has a wide range of applications in design, production and installation testing.

Digital Multiplexers for 24 Channels

Bengt Lagerstedt

Ericsson has developed two digital multiplexers, ZAH 1.5/45-1 and ZAH 45/140-1, which together with the previously introduced multiplexer E-D4[1] form a complete multiplexer program for 24-channel applications.
The author outlines the position of multiplexers in the digital hierarchy, and describes their reliability, function, design and structure.

UDC 621.395.4

As the number of digital exchanges in the telephone network grows, the need for digital transmission systems increases. Compared with analog transmission, digital transmission gives lower costs and means that new facilities can be introduced in the network more easily and economically.

The transmission links require multiplexers for the connection between the basic level and the final transmission level. The equipment must multiplex between different levels in a simple and flexible way, and offer through-connection at an arbitrary level in the hierarchy.

Table 1 gives a comparison between the two digital hierarchies, for 24 and 30-channel PCM multiplexers respectively. The 24-channel hierarchy has successively been adapted to the available transmission systems, and new hierarchic levels have gradually been introduced. Levels 4 and 5 in the 30-channel hierarchy are also incorporated in the 24-channel hierarchy (4E and 5E).

Fig. 1 shows the positions of the new multiplexers in the digital hierarchy.

Multiplexer ZAH 1.5/45-1, fig. 2, provides compact and flexible multiplexing up to level 3, which is the normal through-

	24-channel hierarchy			30-channel hierarchy		
Hierarchy level	Designation	Transmission rate Mbit/s	Equivalent speech channels	Designation	Transmission rate Mbit/s	Equivalent speech channels
1	DS1	1.544	24	D1	2.048	30
1C	DS1C	3.152	48			
2	DS2	6.312	96	D2	8.448	120
3	DS3	44.736	672	D3	34.368	480
4E	DS4E	139.264	2 016			
4	DS4	274.176	4 032	D4	139.264	1 920
5E	DS5E	564.992	8 064			
5				D5	564.992	7 680

Table 1
Summary of the 24 and 30-channel hierarchies

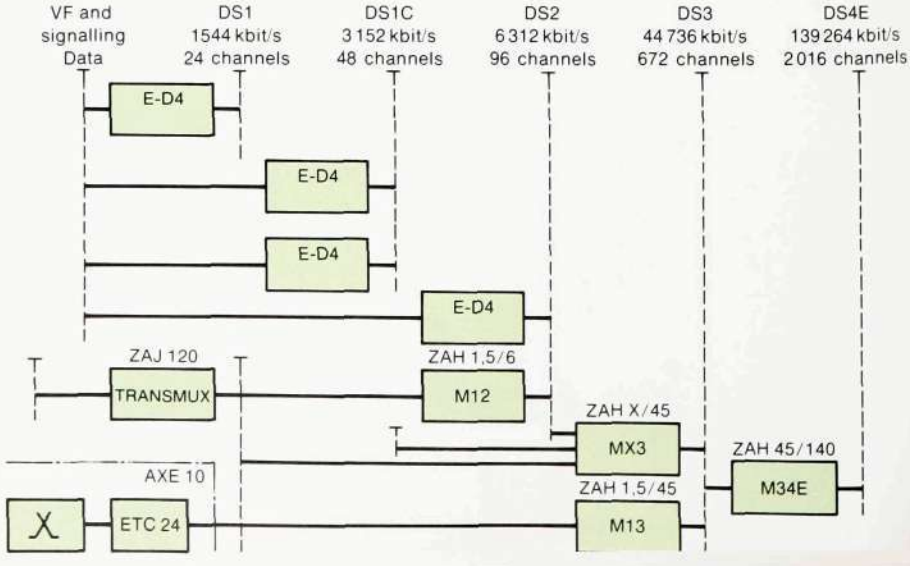


Fig. 1
The digital hierarchy of equipments for the 24-channel markets

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connection level. 28 DS1 tributaries can be multiplexed to one DS3 signal in a magazine (M13 multiplexer).

The multiplexing takes place in two stages via level DS2, which means that the multiplexer can receive up to 14 DS1C tributaries, or up to seven DS2 tributaries, or a combination of different tributaries (MX3 multiplexer).

Multiplexer ZAH 45/140-1, fig. 3, converts between level DS3 in the 24-channel hierarchy and level 4 for 140 Mbit/s in the European hierarchy. The multiplexer thereby makes it possible to utilize the European line systems for coaxial cable, fibre and radio relay links. Line systems for 140 Mbit/s provide economical transmission over short to medium-distance routes.

Reliability

The reliability requirements for transmission equipment must be stringent. Faults in transmission equipment mean loss of traffic, which can be very costly.

Ericsson has long experience of the development of digital multiplexers. Several generations have been produced.

Fig. 2
Multiplexer ZAH 1.5/45-1 equipped for 28 DS1 tributaries

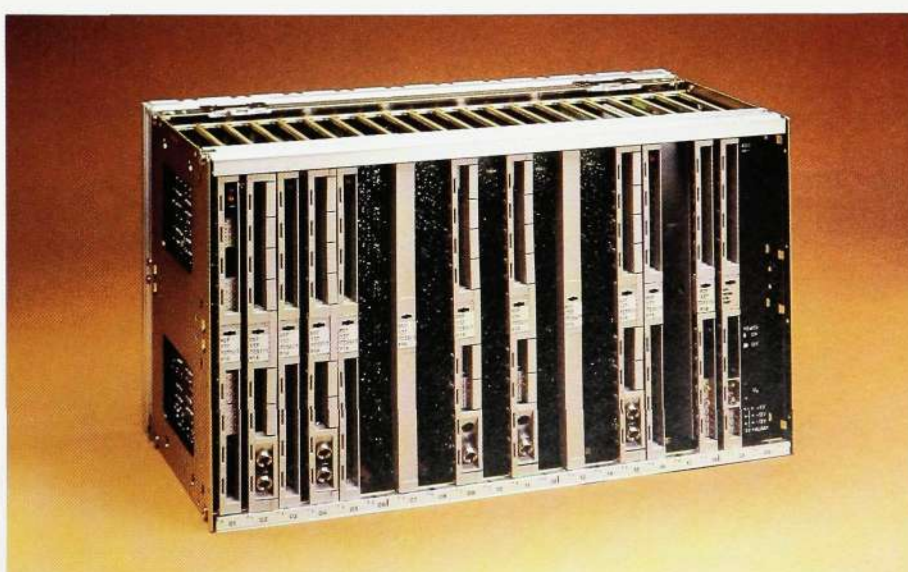

Fig. 3
Multiplexer ZAH 45/140-1 equipped for three DS3 tributaries

Fig. 4
A multiplexer magazine in a rack. The exchange cabling is run along a cabling shelf below the magazine and fixed there. It is connected to the fronts of the boards by plug-in connectors. The equipment is covered by a front plate. Alarms from the shelf are indicated by a light emitting diode (LED) placed inside the slits in the front plate

One of the main aims in the development work has always been to obtain high reliability. In order to achieve this target, strict design rules have been laid down, and all components undergo comprehensive evaluation before they are used in a construction. The power dissipation in the multiplexers is minimized in order to maintain a fairly low temperature in the equipment, which makes for higher reliability. The construction practice has been designed to ensure good cooling.

Reliability calculations show that ZAH 1.5/45-1 and ZAH 45/140-1 satisfy very high demands. Operational experience from previous multiplexers shows that the calculations are reliable and that traffic disturbances caused by faults in digital multiplexers are extremely rare.

Construction practice

The construction practice used for the multiplexers is Ericsson's BYB[5]. It provides good transmission characteristics at high frequencies, and also good cooling, which is essential for digital multiplexers.

Each multiplexer is mounted in a magazine having a width suitable for installation in racks in accordance with US standards. The magazines can also be installed in Ericsson row or rack equipment.

All external cabling, i.e. cables for digital signals, alarms and power, are connected up at the board fronts. The cables are run along and fixed to a cabling and ventilation shelf below the magazine, fig. 4. Among the advantages of

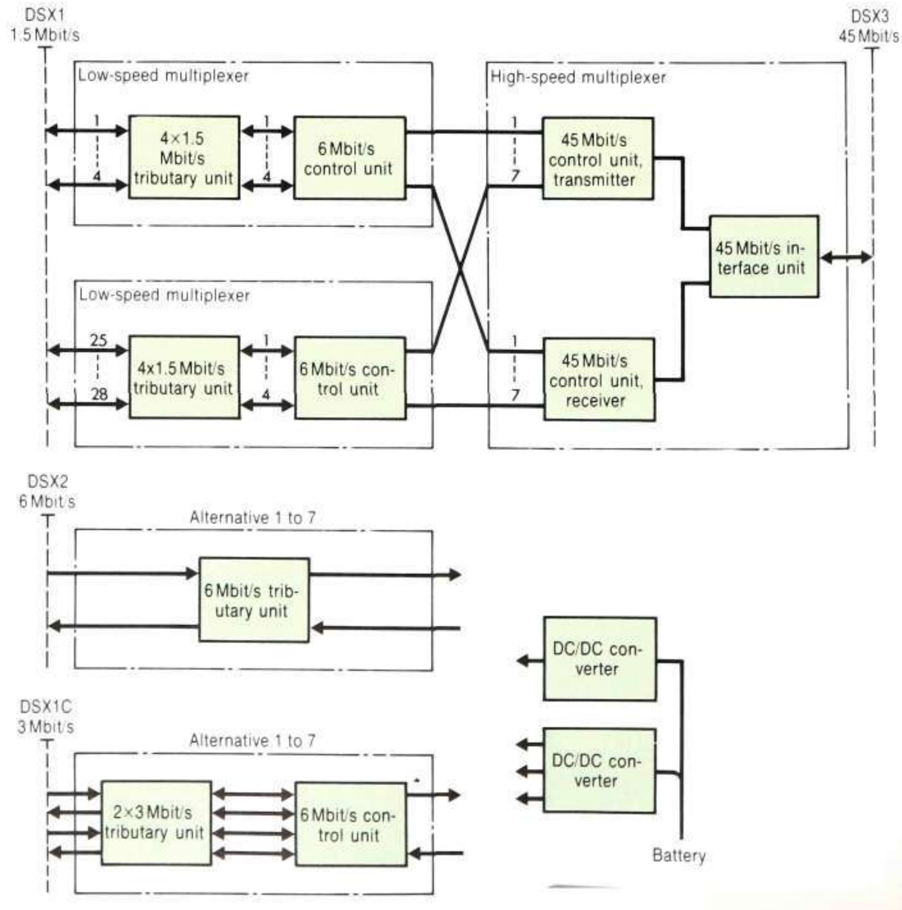

Fig. 5
Block diagram of multiplexer ZAH 1.5/45-1. The multiplexer is divided into a low-speed and a high-speed part. In the low-speed part multiplexing up to 6 Mbit/s is carried out. Connection to the low-speed part can be made for DS1, DS1C or DS2 signals depending on the units equipped

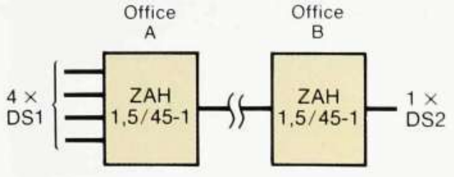

Fig. 6
With multiplexer ZAH 1.5/45-1 the tributary speed can be different at the two ends. In this example one end of a circuit is equipped with units for four 1.5 Mbit/s tributaries and the other with a unit for a 6 Mbit/s tributary

this connection method are that

- the installation is simple. All cabling can be run before the equipment is installed
- reconfigurations are easily made
- racks can be arranged back to back, which reduces the amount of space required
- the electrical design is simpler and safer, with uncomplicated and logical transmission paths.

ZAH 1.5/45-1

Fig. 5 shows a block diagram of ZAH 1.5/45-1. The multiplexer converts 28 DS1 signals to one DS3 signal flow and vice versa. Alternatively the multiplexer can be equipped for multiplexing DS1C or DS2 tributaries or a combination of all three. The multiplexing is carried out in two stages via the DS2 level, which means that different tributary bit rates can be used at the two ends of a circuit. For example, connection can be made at the DS1 level at one end and at the DS2 level at the other, fig. 6.

In the low-speed part of the multiplexer four DS1 signals are connected to the 4x1.5 Mbit/s tributary unit. Timing recovery and synchronization of the DS1 signal with the multiplexer timing are carried out by means of pulse stuffing in a special LSI circuit. The four synchronous DS1 signals are then sent to the 6 Mbit/s receiver control unit, where they are multiplexed, together with control bits for frame alignment, pulse stuffing and alarms, to form a DS2 signal. This signal is then synchronized with the timing of the high-speed multiplexer in a LSI circuit.

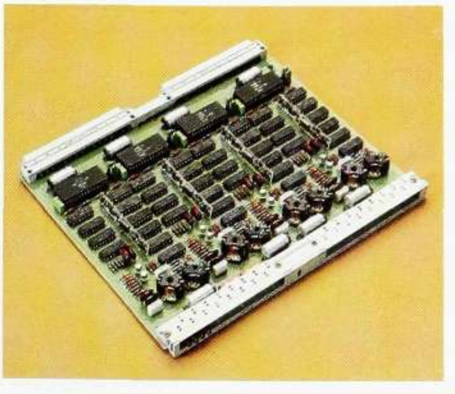

Fig. 7
4x1.5 Mbit/s tributary unit. Straps for LBO networks are placed on the front, together with light emitting diodes for indication of faults in each tributary

Synchronous DS2 signals are sent from the seven low-speed multiplexers to the 45 Mbit/s transmitter control unit, in which the signals are multiplexed, together with control bits for frame alignment, pulse stuffing and alarms, to form a DS3 signal. This signal is then sent to the 45 Mbit/s interface unit, where it is line encoded and adapted for the cable length to the digital crossconnect by means of a strappable equalizer.

The incoming DS3 signal is taken to the 45 Mbit/s interface unit, where the timing is recovered and the data are regenerated and converted to a unipolar signal. The 45 Mbit/s receiver control unit then carries out frame alignment and analysis of the alarm and pulse stuffing contol bits. The control bits are removed, and the bit flow is divided into the seven DS2 signals. Each signal is sent to its own buffer in the 6 Mbit/s control unit. The buffering is followed by DS2 frame alignment and analysis of the alarm and pulse stuffing control bits. The control bits are removed and the bit flow is divided into four DS1 signals, each of which is fed to a buffer in the 4x1.5 Mbit/s tributary unit. In the buffer the original DS1 timing is recovered by slowly regulating the read-out from the buffer, so that on average the buffer always contains the same number of bits. This regulation method minimizes high frequency jitter on the signal. After the buffer the DS1 signal is line encoded and adapted for the cable length to the digital crossconnect in a strappable attenuator.

Alternatively the connection can be made at the DS2 or DS1C level. With a DS2 signal only a 6 Mbit/s tributary unit is required, in which the DS2 signal is synchronized with the DS3 multiplexer. A DS1C signal must first be demultiplexed to the DS1 level in a 2x3 Mbit/s tributary unit. Each 3 Mbit/s signal is demultiplexed to two DS1 signals. These signals are then multiplexed to the D2 level in the 6 Mbit/s control unit in the way described above.

The use of special circuits and hybrid circuits for the oscillators has reduced the volume of the equipment considerably. One printed board assembly, fig. 7, contains the line interfaces and synchronizing buffers for four tributaries.

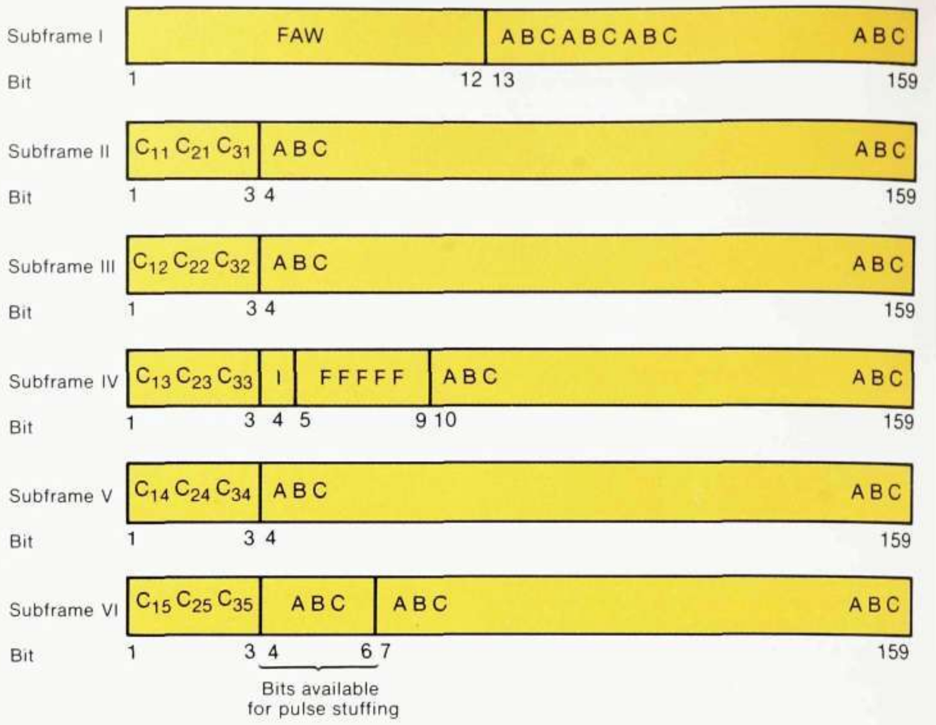

Fig. 8
The frame structure for multiplexer ZAH 45/140-1

FAW	**Frame alignment word (111110100000)**
ABC	**Bits belonging to the tributaries A, B, C**
C_{ij}	**Control bits for pulse stuffing**
I	**Alarm bit**
F	**Bits for optional use**

This should be compared with the printed board assemblies with discrete components, where each printed board was only able to house the equipment for a single tributary.

ZAH 45/140-1

The digital multiplexer ZAH 45/140-1 converts three 45 Mbit/s (DS3) signals to a 140 Mbit/s (DS3E) signal corresponding to level 4 in the European hierarchy, and vice versa. No definite standard has been established for the frame structure of this multiplexer. The chosen frame is identical to that used by AT&T. The frame structure is shown in fig. 8. The interfaces meet the requirements of CCITT Recommendation G.703 and AT&T Technical Advisory No. 34.

The function of the multiplexer is illustrated by the block diagram of fig. 9. The function is similar to that of ZAH 1.5/45-1.

Emitter-coupled logic (ECL) has been used to obtain sufficient reliability at the high bit rates (⩾45 Mbit/s). The ECL circuits have excellent transmission characteristics at high bit rates. Unfortunately they have a high power consumption, so that ECL is only used in the transmission path, while the control information is processed in TTL circuits, containing low-power Schottky circuits. Moreover the data flow is processed in parallel form, which means that the highest bit rate in the magazine is 45 Mbit/s. This design has been op-

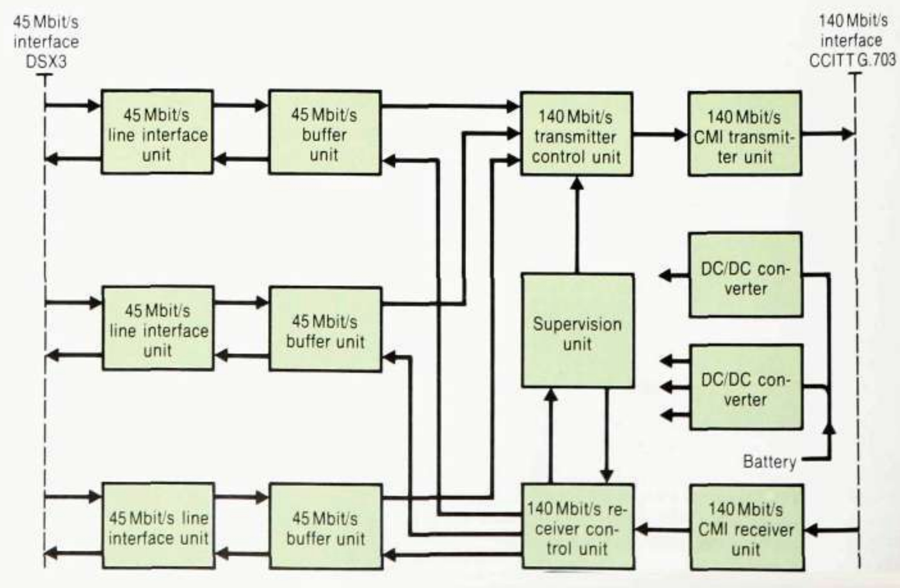

Fig. 9
Block diagram of multiplexer ZAH 45/140-1

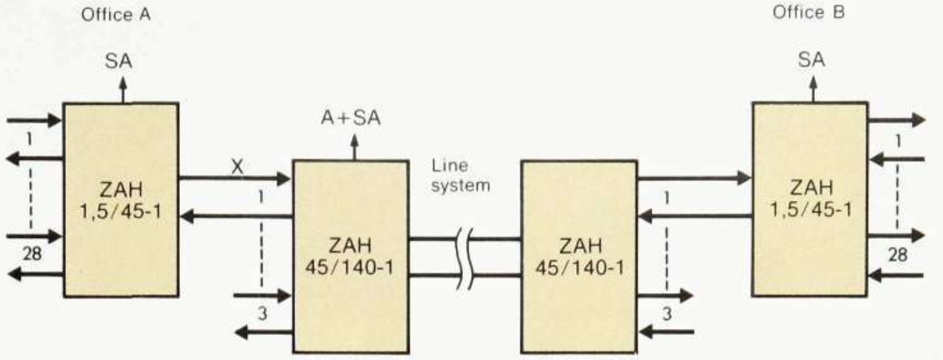

Fig. 10
In this example of the use of AIS it is assumed that a DS3 tributary to a ZAH 45/140-1 multiplexer disappears (X). ZAH 45/140-1 replaces the missing signal with an AIS having the correct frequency, and sends an alarm (A = prompt maintenance alarm). The AIS is transmitted in the normal way to the other end of the circuit and is detected in ZAH 1.5/45-1. The latter gives a system alarm (SA) for network information and AIS is sent out on the tributary outputs. In addition an alarm bit is sent to the opposite end, where a SA is also given. In this way only one maintenance alarm is obtained, and at the same time information that the transmission between two multiplexers is still functioning is given continuously

timized as regards reliability and power consumption.

Maintenance and alarms

The meticulous construction of the multiplexers has meant that no preventive maintenance is required.

The multiplexers contain built-in fault monitoring circuits and LED alarms, which simplify fault supervision and maintenance. Fault tracing and repair consist of changing printed board assemblies until the alarms disappear. The equipment is also arranged for connection to operation and maintenance systems, such as Ericsson's transmission maintenance system ZAN 101.

Circuits for the AIS method recommended by CCITT are included in the multiplexers in order to suppress maintenance alarms and to keep line systems in continuous operation. The method means that when the multiplexer detects that a signal is missing or faulty the signal is replaced by an *Alarm Indication Signal* (AIS), which is a continuous stream of ones. Since all signals that carry traffic always include zeros because of the frame alignment bits, AIS will be unique and can therefore be identified. When a multiplexer receives AIS, all alarms are inhibited that necessitate the sending out of maintenance staff, and only a system alarm is transmitted for network information. The multiplexer in its turn will send out AIS in its tributaries. A maintenance alarm will only be given in the equipment where the fault was detected. Fault tracing will therefore start as near to the fault as possible. The method is illustrated in fig. 10.

Summary

With the introduction of these new multiplexers Ericsson is now able to offer a complete range of digital multiplexers for 24-channel markets.

Technical data

	ZAH 1,5/45-1	ZAH 45/140-1
Frame structure	Compatible with AT&T MX3 and CCITT G.752	See fig. 8
Max. number of tributaries	28 DS1, 14 DS1C or 7 DS2	3 DS3
Interface in accordance with AT&T Technical Advisory No. 34 and CCITT G.703	DS1, DS1C, DS2, DS3	DS3, DS4E
The line code for DS1 is strappable for AMI or B8ZS (bipolar, with 8 zero substitution)		
Power supply		
Power consumption	≈ 45 W	≈ 90 W
DC voltage	−42 to −56 V	
Environment		
Ambient temperature	0 to 50°C (32 to 122°F)	
Maximum relative humidity	90%	
Dimensions		
Rack width	600 mm (23")	
Magazine		
height	244 mm (9.6")	
width	488 mm (14.2")	
depth	220 mm (9")	

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Synchronization of Digital Telecommunication Networks

Harald Brandt and Aleksander Marlevi

Precise time control of a digital telecommunication network is the basis for disturbance-free operation. Insufficient control can result in an unacceptably high rate of slips, which impairs the transmission quality.
The authors describe how these slips arise and how they can be reduced with the aid of buffers and very accurate or automatically controlled clocks. Different methods for network synchronization and the application of these in a telephone network are also discussed.

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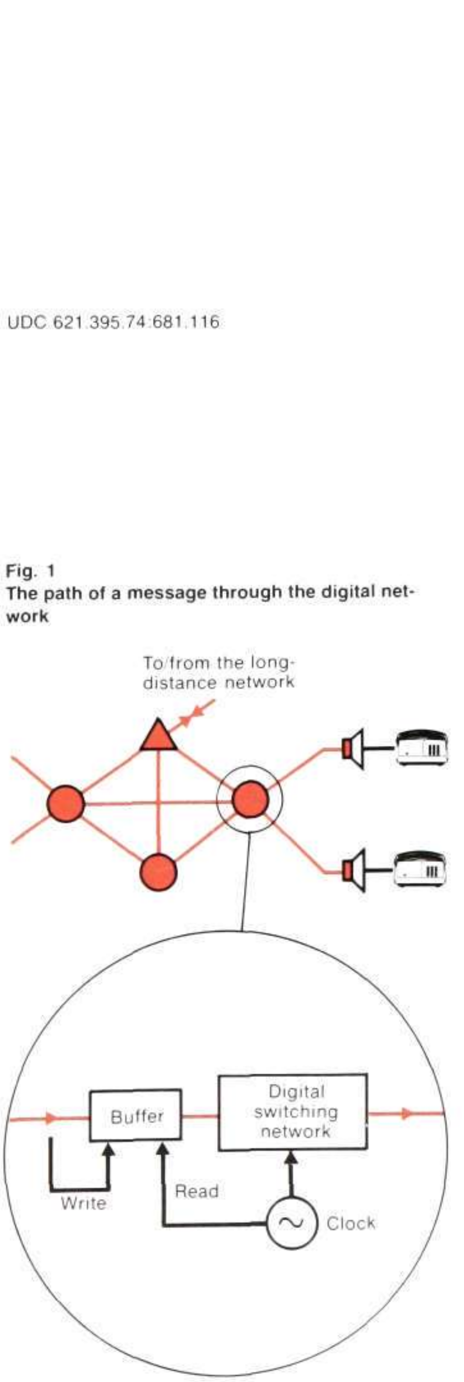
Fig. 1
The path of a message through the digital network



The need for network synchronization

How slips occur

Following a message through a digital telecommunication network makes it easier to understand the need for network synchronization. The description is based on fig. 1, which shows an idealized network. Digital exchanges, here considered as the sources of information, inject messages into the system in the form of evenly spaced electric pulses, bits. Each message is sent through the transmission system and is occasionally switched to a new route in order to reach the called subscriber. In each exchange bits are received with their own incoming bit rate and stored in a buffer. The buffers can only store a limited number of bits, for example 8 or 256 bits, corresponding to a time slot and a frame respectively. The stored bits are switched at a frequency determined by the exchange clock.

When the incoming bit rate is higher than the clock rate there is no time to send on the stored bits before new bits arrive. When the incoming bit rate is lower than the clock rate the stored bits will instead be sent twice before new bits arrive. Thus, it is obvious that the incoming bit rate and the exchange clock rate must have the same long-term mean value, otherwise the transmission through the exchange becomes distorted. The distortions are called slips and occur when the incoming bit rate is higher or lower than the exchange clock rate.

Slips are counted per channel as slip of an 8-bit time slot.

The number of slips per day in the traffic between two digital exchanges is proportional to the frequency difference of the local clocks. For example, if two atomic clocks with a frequency inaccuracy of 10^{-11} are used, a slip occurs every 72 days. With two crystal controlled clocks having a frequency inaccuracy of 10^{-6} the slip rate is one per minute. Additional slips can also occur because of jitter on the transmission links.

Automatic clock control can be used to avoid slips caused by frequency differences. Slips caused by transmission links can be avoided with the aid of buffers.

The effect of slips

The effect of a slip can be illustrated by the simile of a commuter who relies entirely on his own watch. Unfortunately his watch is slow compared with the railway station clock, and the commuter therefore misses his train. By synchronizing clocks it is possible to communicate without losing essential information.

Slips have different effects in different telecommunication services, such as speech, data and facsimile. One reason for this is the difference in coding redundancy. The higher the redundancy the smaller the effect.

Facsimile constitutes a good example. In this field the amount of disturbance caused by a slip is greatly dependent on the encoding technique used. A slip can result in a displacement or in black or white streaks in the line being scanned. At worst a single slip can ruin the whole picture and make retransmission necessary. Fig. 2 shows the effect a slip can have on a certain type of facsimile transmission.

Different types of clocks

Two types of clocks are used in telecommunication: cesium and quartz crystal clocks.

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Performance level	Local exchange	National transit	Inter-nat. transit	Total
Satisfactory[1]	12 h	7 days	70 days	5 h
Degraded	2 min	2 min	2 min	2 min
Unacceptable[2]	2.5 s	1.25 s	1.25 s	1.25 s

Note 1
The total slip rate is a mean value over 24 hours (which gives 5 slips per 24 hours). A suitable period for assessing the mean value for the individual exchange is one year. However, the smallest time between slips in the individual exchanges should be larger than approximately 5 hours in order to be considered as satisfactory.

Note 2
The slip rate at the unacceptable performance level is based on the requirement for frequency accuracy in the specification for a PCM link. The requirement is then ±50 ppm.

Table 1
The table gives the time between slips and the limits for the highest permissible slip rate through digital exchanges on a 64 kbit/s international connection. Overall for the connection, degraded performance should not occur for more than 1 % of the time, whereas the unacceptable level should not occur for more than 0.1 % of the time

Cesium clocks have a limited short-term stability, but on the other hand they have very high long-term stability. Two-year old clocks showed no change in frequency when compared with recently manufactured clocks, measured with a resolution of 3×10^{-12}.

Quartz crystal clocks are the simplest, most reliable and most economical of all available frequency sources. Their properties are the reverse of those of cesium clocks. Their short-term stability is very good, but their long-term and thermal stability are poor.

The feature that makes the quartz crystal clock so popular is that its frequency can be controlled continually by changing a voltage. Several methods have been developed for automatically adjusting the clock frequency, thus overcoming the problem of the long-term stability.

The purpose of network synchronization

The purpose of network synchronization is to ensure a sufficiently low slip rate. CCITT Recommendations G.811 and G.822 for international connections[1] can be used to derive threshold values for the slip rate for different types of exchanges. Table 1 gives some such values.

Network synchronization methods

Three network synchronization methods are used in AXE 10, namely plesiochronous, master-slave and mutual single-ended synchronization.

The plesiochronous method is normally only used on international digital links. The master-slave method is primarily recommended for small star-shaped networks, e.g. rural networks, but it can also be used in growing networks until they reach a size suitable for mutual single-ended control. The latter method is recommended for fully extended national junction networks, urban meshed networks etc.

With the plesiochronous method the clocks are independent of each other. That causes slips because of the limited accuracy of the clocks. If the slip rate is low, its effect on the transmission quality will be negligible compared with the effect of other error sources. When cesium clocks are used, as in international digital exchanges, the slip rate is negligible.

The master-slave method is based on the principle that only one exchange, the master exchange, is equipped with an independent clock. The clocks of all the other exchanges are phase-locked to the master clock. Each slave clock will thus follow the master, and if the control circuit is suitably designed no slip should occur.

Master-slave control is easy to implement and has no network stability problems. However, clocks in slave exchanges should have relatively high frequency stability in order to keep the slip rate low even during master clock failures. This increases the cost of the method.

An improved master-slave method is obtained using a limited number of masters, e.g. a primary, a secondary and a tertiary master. Only these masters require the costly high frequency stability. The links terminated in slave exchanges are arranged in a fixed hierarchy, with one executive and several standby links. In a completely mesh-shaped network the executive link would be connected to the primary master exchange, whereas the standby links would be connected to the secondary and tertiary master exchanges.

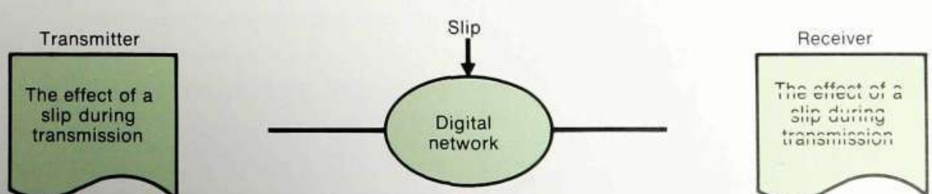


Fig. 2
An example of the effect of a slip during facsimile transmission

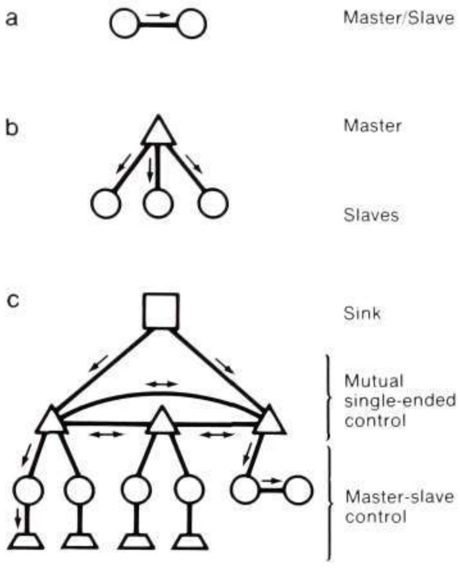
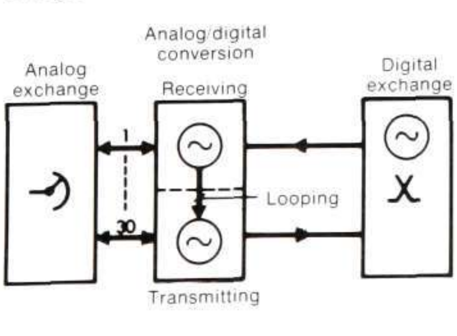


Fig. 3
Network synchronization in an expanding digital network

Fig. 4
Interworking between digital and analog exchanges



With mutual single-ended control every exchange clock is locked to the average of all incoming clock frequencies. A common system frequency is thus obtained by forcing a number of clocks to be interdependent. This ensures a reliable synchronization system, which makes it possible to use clocks having lower stability than the clocks in a master-slave network.

Fig. 3 shows how the different synchronization methods can be used in a growing digital network. Initially, when two digital exchanges are connected by a PCM link, they are most suitably connected as master and slave, fig. 3a. When a transit exchange is added it becomes the master, fig. 3b. When the network has been extended to include several transit exchanges and a large number of local exchanges, mutual single-ended control should be introduced between the transit exchanges for reasons of reliability, fig. 3c. But, in order fo ensure the stability of the network and the accuracy of the steady state frequency, one of the transit exchanges is left uncontrolled, as a *sink*.

Interwork between digital and analog exchanges

PCM links between analog and digital exchanges are equipped with PCM terminals at the analog end. Such a terminal has a send and a receive side. The frequency of the bit streams coming into the receive side is determined by the digital exchange. The send side contains a clock which, if not controlled, has a frequency accuracy of 50×10^{-6} (50 ppm). This clock must be controlled or else the slip rate may be as high as one slip every two seconds. The control is accomplished by interconnecting the send and receive sides of the PCM terminal, looping, fig. 4. This means that the PCM terminals in the analog exchanges are slaved to the digital exchanges.

Higher order multiplex systems between digital and analog exchanges should be looped in the same way as a first order multiplex.

Network synchronization in AXE 10

The AXE 10 system is an example of how plesiochronous, master-slave and mutual single-ended control can be implemented in a telephone exchange, fig. 5.

Each method uses a time-discrete regulator realized in software. This facilitates almost identical implementation of all three methods. In fact, the hardware is identical (oscillators, phase measurement, D/A converters). Only the software parameters are different. They vary according to the method actually used. The realization of the control in software also makes it easy to change the synchronization method during operation. In both master-slave and mutual single-ended control the regulator is proportional plus integrating (PI). It should be noted that in a mutual network all regulators must be identical, i.e. all PI.

For detailed discussion of integrating regulators for mutual control, see references 5 and 6. Apart from regulator algorithm, many other functions are included in the software, for example a programmed list of standby links to be connected if the link from the primary master fails. All links are also monitored for phase variations and disturbances. The input to a mutual regulator is the sum of the phase errors from up to ten connected exchanges.

In the case of mutual control based on integrating regulators, the steady-state system frequency is secured (in spite of jitter) by having one of the exchanges unregulated. Such an exchange is called a sink because its buffers will accommodate the total phase error of the network. The plesiochronous international exchanges will very well serve as sinks, fig. 3c. An additional advantage of using a sink is that it gives the network an absolute frequency reference and makes mutual single-ended control immune to delay variations.

Clock types

In AXE 10 three types of clocks are used, CLM, RCM and CCM.

CLM

The internal clock of every AXE 10 exchange consists of three clock modules (CLM), each with a voltage controlled crystal oscillator at a frequency of 24.576 MHz. The modules are phase-locked to each other. The signals from all three modules are fed to the digital group selector. The executive clock signal is obtained by majority decision in logic circuits.

The internal clock may be phase-locked to one of several different reference sources, such as a reference clock module (RCM), a cesium clock module (CCM) or a PCM-link. With mutual control a number of PCM links regulate the clock simultaneously.

RCM

In addition to the three clock modules AXE 10 may be equipped with up to three reference clock modules (RCM) having a frequency stability of 10^{-10} per day. These are used in master exchanges, and in certain transit exchanges with only one physical synchronization path.

CCM

CCITT recommends that digital international links have a slip rate of less than one slip per 70 days. This can be achieved by the plesiochronous method when using cesium clocks. AXE 10 may be equipped with up to three cesium clock modules (CCM), but normally the exchanges are equipped with only two CCMs and one RCM. This combination gives high reliability due to the triplication, and cost savings due to the substitution of a RCM for one CCM.

Performance when a failure occurs

EXCHANGE FAILURES

No single failure or exchange restart will degrade the timing performance. Even the loss of two regional processors will not disrupt the timing within the exchange, although the slip rate may increase.

SYNCHRONIZATION REFERENCE FAILURES

The synchronization functions are designed so that the network performance will meet or exceed the intentions of CCITT Rec. G.822[1], provided that the appropriate synchronization planning principles are followed[7]. One of the planning principles is that, where possible, each exchange should have at least two and preferably three independent sources of reference. Hence failure of single synchronization link will normally not cause slip.

However, total failure of all synchronization links to an exchange may increase the slip rate if the exchange is digitally connected to other exchanges which are synchronized to the primary master. The slip rate performance in such a situation is described below.

Exchange without RCM

Initially a total loss of synchronization links is not likely to cause more than one slip in 3.5 hours. Even if the loss lasts for more than a week, the slip rate will not exceed one slip every two minutes, even with large temperature variations.

Exchange with RCM

Total loss of synchronization links may cause at the most one slip per ten hours. As an option (a frequency memory realized in software) the performance can be improved so that a total loss of synchronization links can cause at the most one slip during the first three days of failure.

Fig. 5
Stored program controlled synchronization in AXE 10

ETC	Exchange Terminal Circuit
RCM	Reference Clock Module
CCM	Cesium Clock Module
VCXO	Voltage controlled crystal oscillator

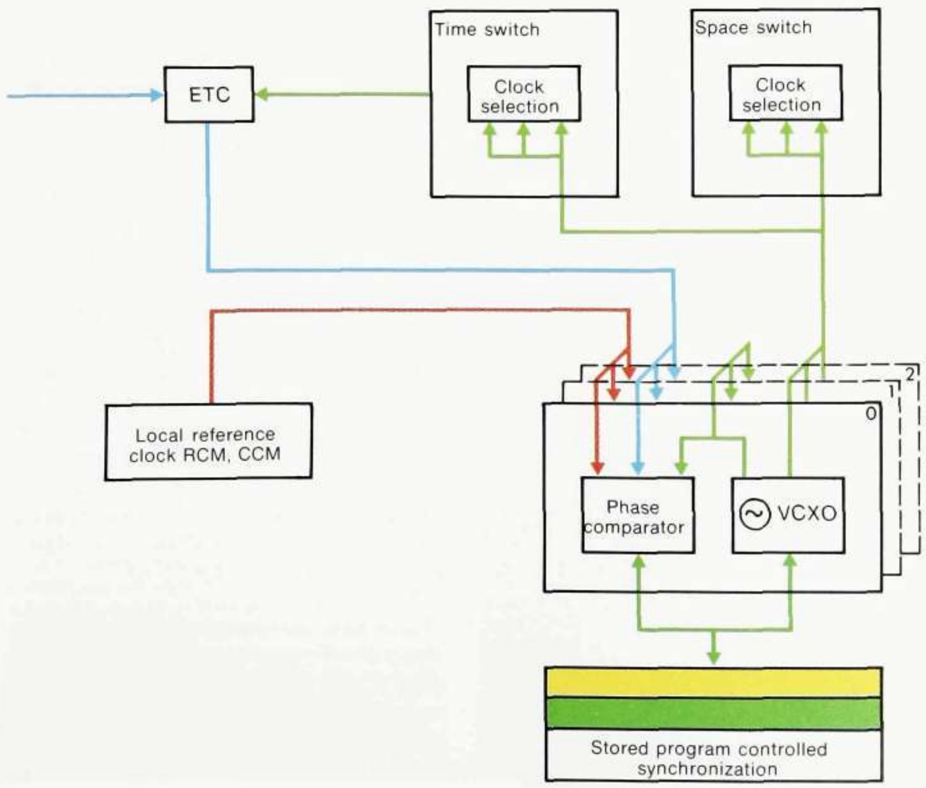
Green line: Clock control and clock distribution

Blue line: Master-slave and mutual single-ended synchronization

Red line: Plesiochronous and master synchronization

Green box: Standard programs

Yellow box: Extra programs for master-slave, mutual single-ended, plesiochronous or master synchronization



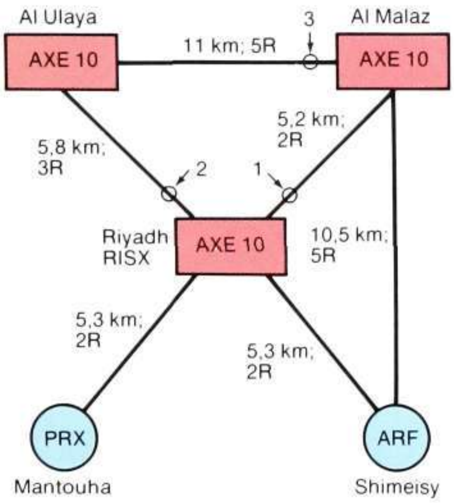


Fig. 6
Master-slave network in Riyadh, Saudi-Arabia

Field experience of the master-slave method

Experience of network synchronization was gained when the first digital public telephone network was taken into service in the Kingdom of Saudi-Arabia on December 13, 1978. The network consists of three interconnected AXE 10 exchanges; one transit exchange (Riyadh) and two local exchanges (Al Malaz and Al Ulaya). The local exchanges are slaved to the transit exchange, see fig. 6.

After six months of stable operation, the network synchronization was evaluated by measurements on site. These showed that all objectives had been fulfilled. For example, the slip rate was recorded during twelve days. The number of slips per 20 hours and channel was:

- between Riyadh and Al Malaz: 0
- between Riaydh and Al Ulaya: $4 \cdot 10^{-3}$
- between Al Malaz and Al Ulaya: $7 \cdot 10^{-3}$

The allowable slip rate was one slip per 20 hours on a 6 kbit/s channel between any pair of exchanges. Thus the recorded slip rates were very much lower than specified.

Since 1978 master-slave networks with AXE 10 have been taken into service in nine countries.

Analysis of mutual single-ended control

The mutual network is a linear and dynamically simple system, but also a large and unknown one, in which the number of control and information channels are restricted. The basic problem is how to achieve stable linear control of large systems, comprising a set of buffer storages, which are continuously tapped and replenished through a network of channels. The problem therefore belongs to the field of decentralized control. A fundamental and well known difficulty of decentralized control is that the several autonomous control devices, even if individually well tuned, may each counteract or amplify the consequences of the actions of the others. This is because of lack of information about the state of the whole system, and this can cause instability.

This difficulty is aggravated by the many unknown elements in the system. For example, the network may be extended by the addition of nodes or links, regulators may fail temporarily etc. Consequently all that has been aimed for is to find the simplest local regulator that can handle the disturbances and retain network stability in the worst possible case of network structure and regulator breakdown. In order to find the most suitable regulator, mutual control has been investigated in two ways: by means of theoretical analysis and by computer simulations[8].

Theoretical analysis of mutual control

The theoretical analysis provided the answers to the following questions:

1. Is it possible to use mutual synchronization in a network of oscillators which are subject to disturbances such as phase and frequency shifts, linear frequency drift or jitter?
2. What would be the most suitable regulator algorithm?

Theoretical analysis of mutual control by time-discrete and integrating regulation has been carried out by T. Bohlin[5]. He proved that stable clock regulation is feasible even in the event of unpredicted changes in the network configuration.

The regulator algorithm found to give the best result is used in the PI regulators. They can handle clock frequency differences in such a way that no permanent phase errors occur.

An important prerequisite for the use of a PI regulator, or any other regulator having integrators, is that one of the oscillators in the network must be unregulated. Otherwise, if all oscillators are frequency regulated and the sum of all phase differences in the network is not zero, the system frequency will drift. With PI regulators the drift would be linear. It should be noted that while the *system* frequency drifts there are no frequency differences *between oscillators* and therefore no slips occur.

The mutual single-ended control, with integrating regulators and a sink, is a very stable method since it synchronizes both the phase and the frequency of a network without causing steady-state errors. No phase jumps, no frequency jumps and no transmission delay changes will permanently offset the network frequency or phase between the network nodes.

Computer simulation of mutual single-ended control

A program acts on a model of an AXE 10 network with mutual single-ended control. The simulations have two purposes:

A. To test the behaviour of the control method in extreme conditions.
B. To find the most suitable regulator and its optimum gain.

Type A simulations examine the dynamics in typical networks which are subject to large stresses such as phase or frequency jumps, non-linearities in the oscillators, network changes through node or link failures, transmission delays etc. Stresses are applied one at a time, and each time a question is asked: How large can each stress be without making the regulation unstable, or without overshooting the control ranges of the clocks? For example, the case of sink node failure was investigated. The problem was easily overcome by disconnecting a regulator at a standby sink node as soon as the original sink failed, fig. 7. The time available for disconnecting a standby sink is inversely proportional to the integrating (I) gain and is about two hours when the I-gain is 1 % of the maximum stable value.

In type B simulations the PI regulator gains are trimmed to the optimum performance, by which is meant that equal use is made of elastic buffer sizes and the control ranges of the clocks.

Summary

Timing is vital if a digital telephone network is to operate without disturbances. Inadequate timing may eventually result in slips, which reduce the transmission quality.

Clocks in digital exchanges may be either atomic or quartz crystal clocks. All clocks suffer from frequency disturbances due to ageing, environmental effects etc.

Digital networks can be operated either plesiochronously or synchronously. Plesiochronous operation means that the exchanges are equipped with independent clocks which are so stable that the slip rate will be lower than specified. Synchronous operation means that the network is equipped with a clock control system, in order to ensure that the slip rate will be zero and that the system frequency will have a stable long-term mean value. Short-term phase instabilities, mainly caused by jitter and delay variations, are taken care of by memory buffers.

In order to obtain optimum cost and performance, a network solution for synchronization may consist of a combination of three different methods, namely plesiochronous, master-slave and mutual single-ended control. The three

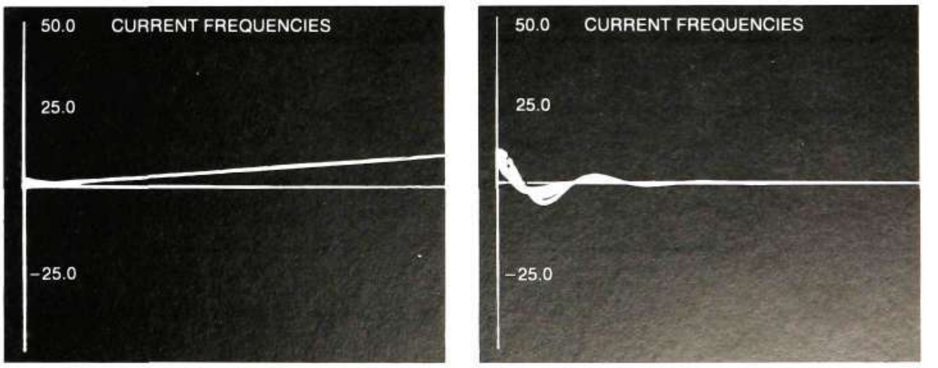


Fig. 7
Loss of the sink node (on the left) and its subsequent recovery (on the right) in a mutually controlled network in Sweden with the sink in Stockholm. The linear system frequency drift to the left is the result of the absence of a sink, with the smallest phase deviation being integrated by the PI regulators. The integrating gain is 1 % of the stable range. The right-hand picture shows how the system recovers when the sink is restored

methods have distinct and complementary advantages. The general recommendation is to use the plesiochronous method on international connections, master-slave in star-shaped rural networks or temporarily in networks that are not yet fully built out, and mutual single-ended control in fully extended meshed networks.

All three methods are provided in the AXE 10 telephone exchange system. They are realized in common hardware but differ as regards regulator algorithms, which are implemented in software.

In AXE 10 the master-slave method is augmented with several facilities. For example, slave exchanges have programmable changeover to standby links in the event of the failure of a master link. This method has been in operation in the Saudi-Arabian network since 1978 and has since been introduced in many other networks.

Mutual single-ended control is based on integrating regulators which require a minimum of elastic buffer storage. This method requires that one of the exchanges is left unregulated, a so-called sink. A sink gives many other advantages. For example, the network frequency becomes independent of delay variations. Computer simulations show that mutual single-ended control is well suited for large complex networks.

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Hotel Communication System

Robert Dietsch

Ericsson has developed and now supplies integrated hotel systems for telecommunication, service and administration. The systems are based on the PABXs ASB 100 H and ASB 900 H, Ericsson's Series 2000 computers, the office communication systems DIAVOX 824 and 2836 and alarm and supervision systems.
The author discusses the need for such integrated systems and describes the system structure and facilities provided.

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The hotel market shows a strong expansive trend in all countries. In South East Asia the development is practically an explosion, and the demands for different services are very high. In areas nearer home, such as Europe, the hotel market is the second largest sector. With an annual growth of approximately 3% it has an interesting potential. Europe today has approximately 57 000 hotels with more than 25 rooms.

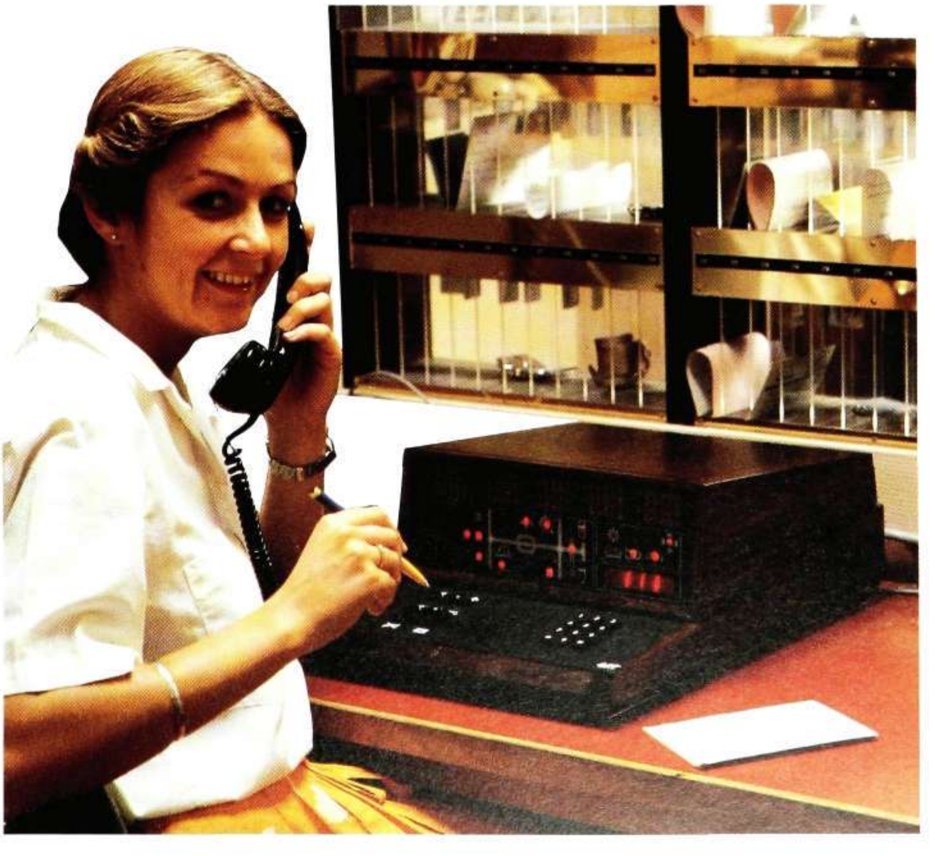
Ericsson has supplied telecommunication systems specially adapted for hotels since the 1930s. The possibilities of satisfying the stringent requirements of the hotel market have increased considerably since Ericsson branched out into the field of office automation.

Ericsson's hotel communication system enables the hotels to improve their service by increasing the efficiency of their administration and extending the guest services. The system also provides the hotels with a number of facilities for supervising and checking the telephone traffic, partly in order to avoid losing income from telephone calls.

System design

Ericsson's hotel communication system is based on hotel PABXs, computer systems and office communication systems from Ericsson Information Systems AB, together with alarm and supervision systems from Ericsson Security and Tele Systems AB.

Fig. 1
Ericsson's hotel system, the key to improved guest service



Studies of the hotel market have shown that the demands of hotels for services and functions do not depend primarily on their size but rather on the type of custom they attract: business hotels, tourist hotels, conference hotels etc. The hotel communication system has therefore been built up of modules related to different requirement levels. This fact, in combination with the considerable hardware flexibility of the PABXs of type ASB[1-3], means that the requirements of practically every hotel can be met in an economical manner. Three requirement levels have been considered:

- Standard requirements have to be met for, for example, small tourist hotels. These seldom require auxiliary systems, since the hotel facilities in the PABXs of type ASB are usually adequate.
- Medium requirements apply to, for example, large tourist hotels and conference hotels. Normally their requirements for services and functions are met by the ASB hotel PABXs, but an Ericsson Series 2000 computer may be needed for specified call charging.
- Very high requirements apply to most business hotels, whose needs are met by a system consisting of an ASB hotel PABX, combined with a Series 2000 hotel computer.

Functions and facilities

The activities in a hotel, from when a guest books a room until the bill has

Fig. 2
Different requirement levels give a system that is suited to the needs of each individual hotel

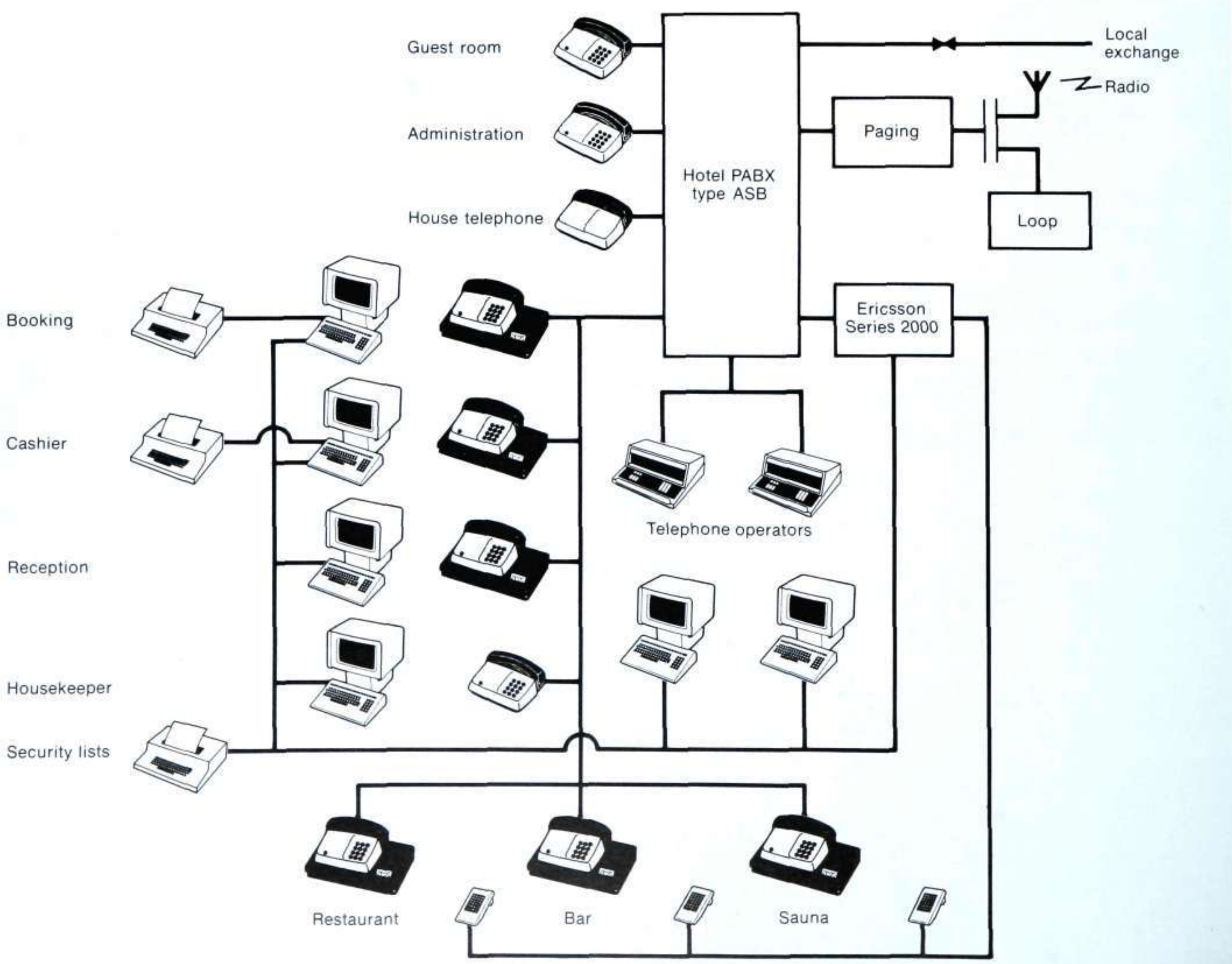


Fig. 3
The answer telephones at the service quarters are equipped with a base containing a digit indicator

been written out and paid, can be divided into three periods:
- the time between booking and checking in
- the time the guest stays at the hotel
- the time between checking out and the invoicing and payment.

The first and last periods are mainly concerned with administrative services, whereas the middle period is mostly devoted to guest service.

In order to make the administrative work during the first period easier, the system has been equipped with special functions for
- booking
- room status reporting
- check-in.

During the middle period great importance has been attached to guest service, with special functions for this purpose, such as
- communication with service quarters
- message waiting
- automatic wake-up
- do not disturb
- Port-A-Bel (for staff and guests)
- reporting of room status
- specified call charging.

The third period includes administrative facilities, which simplify the work associated with
- check-out
- accounting
- invoicing
- statistical data processing.

In addition to the hotel functions most of the standard functions in the ASB systems are available to the administrative staff, and to a limited extent also to the guests, for example
- automatic call back
- three party conference
- call forwarding
- abbreviated dialling
- night connection
- trunk traffic control
- inquiry and transfer.

Check-in

When guests check in the receptionist can, with the aid of the information stored in the PABX, automatically locate unoccupied and cleaned rooms of a specific category, for example a single room with shower.

When a suitable room has been found with the aid of the PABX the guest can be checked in, which means that the room is registered as being occupied, the resetting of the call meter is checked and the room extension is opened to automatic external traffic. Blocking of external traffic when the room is unoccupied prevents unauthorized use of the telephone. However, internal calls can always be made from room extensions.

Room status

The hotel PABX system contains codes for reporting the following types of room status:
- unoccupied room
- occupied room
- cleaned room
- the room has to be cleaned
- the cleaning has been checked.

In addition there are three codes which the hotel can use as desired, for example to indicate:
- the room is out of order
- luggage to be picked up
- special cleaning required.

All room status information except occupation is reported by means of the room extension, which means that the information is updated continually and immediately. This in its turn means that unoccupied and cleaned rooms do not remain empty any longer than is absolutely necessary. In order to ensure that all rooms are cleaned regularly the system automatically gives all occupied guest rooms the status code *the room has to be cleaned* every morning.

If the PABX is integrated with a hotel computer all room status information is automatically transferred to the computer for the room administration functions. Otherwise the status information can be shown on the operator's display or on displays at different service quarters.

Service quarters

A number of service quarters are normally available to the guests in a hotel. Such service quarters can include information, cashier, room service, bar, restaurant and laundry. The guest calls them by means of single-digit numbers.

The need for answer telephones at a service quarter varies considerably for the different services, and each service quarter can therefore be equipped individually with the required number of telephones.

Service quarters can also be grouped in different ways in the PABX in order to meet special service requirements, for example:

- Individual service quarters with one or several telephones
- A common service group, in which up to four service quarters, e.g. information, checking in and booking, collaborate and can answer each other's calls
- Floor groups, for example for room service, where the floor from which a call is made determines the service quarter.

The answer telephones at a service quarter are normally equipped with a base containing a digit indicator. When a call from a guest comes in, the indicator shows the room number, and if the call has been forwarded from a temporarily closed or unmanned service quarter, the indicator shows the identity of that service quarter (the service quarter originally called by the guest). If new calls come in during an existing call, the indicator gives gueue information and the calls are automatically put in a queue.

Message waiting

Guests are informed about waiting messages by means of a ringing signal or the lighting of a lamp (LED) on the room extension. The ringing signal is repeated every 15 minutes and is also sent out immediately after the telephone has been used.

When a guest answers a ringing or lamp signal he/she receives recorded information that a message is waiting and how to obtain it. The recorded message is stored digitally in RAM circuits in order to avoid having to maintain tape recorders etc.

The *message waiting* information is initiated from a service quarter telephone or from the operator's instrument.

Automatic wake-up service

The automatic wake-up is ordered and programmed by the guest from the room extension, by the receptionist from the service telephone or by the telephone operator. The programmed wake-up time is then supervised by the PABX, which automatically calls the guest.

When the wake-up call is answered the guest receives a recorded *good morning* in one or several languages. This message, like the *message waiting* information, is digitally stored. If the call is not answered, three more call attempts are made automatically within ten minutes. If none of these calls is answered, an alarm is sent to the receptionist or the telephone operator, who can then ensure that the guest is called manually.

Fig. 4
The telephones in the guest rooms are equipped with symbols that show the different service quarters reached by means of the various digits

The capacity of the hotel PABX is more than sufficient to wake up all 960 extensions in 15 minutes.

A printout can be obtained of all, or certain, specified wake-up orders within eight hours of the ordered wake-up time, in order to be able to check what wake-up orders have been given, if and when they were carried out, if and when the calls were answered and if alarms were given. This means that any doubts can be settled if a guest should claim that he was not woken up at the time ordered.

Do not disturb
The *do not disturb* function gives a guest privacy for a certain time. During this period all calls to the room in question are rerouted to the telephone operator. The operator's instrument provides the information that the extension has a *do not disturb* order. However, if the guest so desires, the operator can bypass the *do not disturb* order for particularly important calls. The *do not disturb* service is normally ordered from the room extension, but it can also be ordered by the operator. In order to remind the guest that the service has been ordered, a special dial tone is obtained if a call is made from the room extension during this period.

The PABX also includes another *do not disturb* function. It blocks all traffic between rooms at night, between two optional times. During this period internal calls have to be set up by the telephone operator.

Port-A-Bel
The portable bell, Port-A-Bel, greatly simplifies communication with administrative staff as well as special guests, who must be easy to reach.

Signalling to the portable bell takes place via radio or an inductive loop. When the sought person's telephone rings the portable bell beeps or vibrates, and the call can be answered at the nearest telephone by means of a simple procedure.

Different signals can be used to distinguish between internal and external calls, a facility which is also available for ordinary calls through the PABX. A special, operator-initiated signal is also availabele.

Specified call charging
In order to facilitate checking and verification of the telephone calls made from both guest and administrative telephones the exchange continually provides specified call data immediately

Fig. 5
The portable bell, Port-A-Bel, makes it possible to reach people anywhere in the hotel

at the end of a call. The data include:
- who made the call (guest room number)
- when the call was made (date and time)
- to whom the call was made (area code and subscriber number. If desired, an optional number of digits can be suppressed)
- the duration of the call, in hours, minutes and seconds, and the number of metering pulses if this information is available.

The specified information can, in the simplest case, be output in chronological order on a printer. It can also be processed in a computer.

Check-out
When a guest checks out, the room status is changed to unoccupied and the room extension is barred for outgoing calls. At the same time the accumulated number of metering pulses can be read out. This procedure prevents external calls from being made from a room after a guest has checked out and thus not being paid for, which does happen.

Integrated hotel system

The services described above are included in the standard versions of the ASB hotel PABXs. The hotel facilities can be extended by integrating the PABX with a Series 2000 computer.

In addition to the standard functions the integrated hotel system offers both reception and office functions. The reception functions include:
- Booking system with facilities for booking several years in advance, group bookings, unique booking numbers, special bookings (e.g. for disabled people or V.I.P.s), automatic pricing, booking plans etc.
- Housekeeper functions with room status indication and information regarding the chambermaid etc.
- Charging system with automatic charging functions for restaurant, bar, shops
- Telephone charging system with printout of the total and, if desired, detailed printout, on the guest's invoice
- System for checking in/out with automatic room allocation, automatic bill print-out in optional languages and with currency conversion.

Standard programs for the Series 2000 computers, such as accounting, stock keeping, invoicing and statistics routines, are used together with the hotel software for the office functions.

DIAVOX 824 and 2836 in hotel applications
Office communication systems DIAVOX 824[5] and DIAVOX 2836[6] are very suitable sub-systems in hotel PABXs. They help to increase administrative efficiency, particularly in the cases where there is a need for a combination of external lines and lines from the hotel PABX, e.g. in a booking office or for executive-secretary functions.

Alarm and supervision systems
Security, alarm and supervision systems can easily be integrated in the hotel PABX. An alarm centre and the PABX are used to connect different types of alarms to predetermined extensions equipped with portable bells, or to external subscribers, such as the police or fire brigade. The information regarding checking in and checking out can be used to control the temperature in the guest rooms in order to save energy.

Security, operation and maintenance

The hotel system is built up of Ericsson's standard products, which means that Ericsson's standard requirements re-

Fig. 6
Printout of the invoice for a guest

Fig. 7
The hotel computer, Ericsson Series 2000

Fig. 8
A DIAVOX system for booking offices

Fig. 9
An alarm and supervision system

garding quality and function also apply for the hotel system.

The hotel computer prints updated security lists every night in order to ensure the very high levels of reliability and security demanded by hotels. These lists contain up-to-date information regarding the guests' accounts, the booking situation, the hotel accounts etc., and are intended to enable the hotel to operate for a short time even if the computer is out of service, for example because of a mains failure. The hotel management decides what information is to be included in the security lists.

Turnkey system

With the development of Ericsson's hotel communication system Ericsson can supply complete turnkey systems that contain all the functions which are required today in a modern and efficiently administered hotel.

Present-day situation and references

The hotel PABXs ASB 100 H and ASB 900 H were put on the market at the beginning of 1982, and since then about a hundred systems have been taken into service, both with and without a hotel computer. The system sizes vary from about 50 to 960 extensions. The PABXs have been installed in hotels with greatly varying requirements, from small tourist hotels to large business hotels.

In Sweden the Telecommunications Administration has chosen ASB 100 H and ASB 900 H as the standard PABXs for hotels.

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Hardening of Telecommunication Networks against Electromagnetic Pulses

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Nuclear explosions at high altitudes generate strong electromagnetic pulses (EMP), which can induce large currents and voltages, for example in power and telecommunication networks over a whole continent simultaneously.
The author describes the increasing EMP threat and why it concerns telecommunications administrations and the electronics industry. He also describes the generation mechanisms and pulse waveform. The EMP impact on telecommunication facilities is discussed, together with hardening and testing methods.

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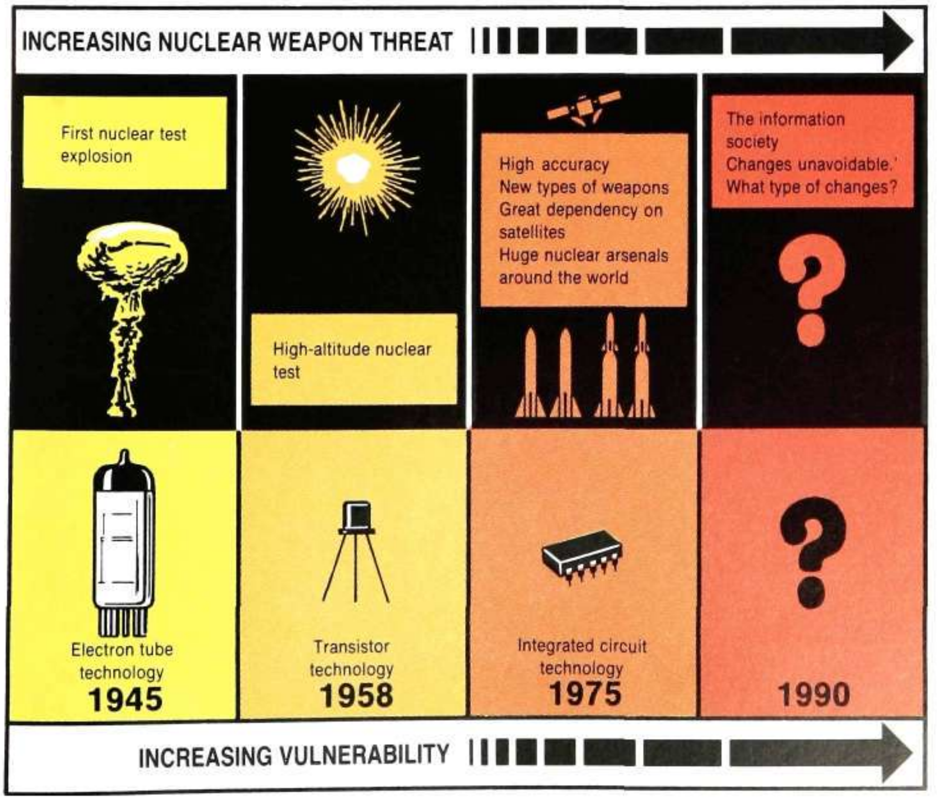
Nuclear explosions can generate very strong electromagnetic pulses (EMP, or nuclear EMP = NEMP). Such pulses can in certain cases dominate over other more well-known effects, such as nuclear and thermal radiation, blast and shock. For high altitude explosions (above 30 km) EMP is practically the only effect apparent at ground level, and the following description is mainly concerned with this case.

A nuclear EMP can roughly be compared to the electromagnetic field very close to a lightning stroke, but the field can extend much further and cover whole countries. It also has a broader frequency spectrum covering the whole radio frequency communication band. Currents and voltages are induced in metallic objects. Large aerial or buried power and telecommunication networks can absorb considerable amounts of energy and be damaged, but even short radio antennas and other lines can be sufficient to cause serious damage to the connected equipment. Consequently telecommunications administrations and electronics designers – civil as well as military – have every reason to consider the problems posed by EMP.

Fig. 1
Diagram showing the increasing EMP threat posed by the development of nuclear weapons technology and electronics



The threat

The continuous development of nuclear technology over the years has resulted in new generations of nuclear devices and weapon systems. Outer space has become increasingly important as satellites having important tasks in communication and surveillance have been launched. Intercontinental ballistic missiles (ICBM) with nuclear warheads have been programmed for high trajectories, and so have other weapons intended to combat ICBMs. All in all the probability of nuclear explosions at high altitudes (tens to hundreds of km) has increased considerably.

In 1963 the limited test ban treaty came into force, which prohibits atmospheric nuclear test explosions. Before that time both the US and the Soviet Union had started to carry out test explosions at high altitudes. It was then discovered that the nuclear EMP effect, which was already known from explosions closer to the ground, occurred with great intensity over enormous areas at ground level. The information was classified as secret, and after the test ban agreement the superpowers were confined to theoretical calculations and simulations. However, some information leaked out, such as the following newspaper report about a US high-altitude test over the Johnston Island in the Pacific Ocean in 1962:

– The quiet predawn in Honolulu was shattered by the simultaneous pealing of hundreds of burglar alarms. At

> the same time circuit-breakers on the power lines started blowing like popcorn. Not a cloud in the sky, so lightning could not be blamed. The power company failed to trace any gigantic electrical surge able to blow out virtually the entire systems simultaneously. The mystery was solved later – then promptly sealed under a "top secret" stamp. The culprit: A high altitude nuclear test burst more than 500 miles away.

More than twenty years have passed since then, and society has developed and changed in such a way that the nuclear EMP threat has grown. The development in electronics has gradually led from transistors to large and very large-scale integrated circuits (LSI, VLSI) that work with low signal and power levels in the range 10^{-3} to 10^{-8} W per transistor. Susceptibility thresholds are increasing and the pulses and energy surges need not be very high in order to cause damage (junction burnout), only of the order of 10^{-3} to 10^{-6} J.

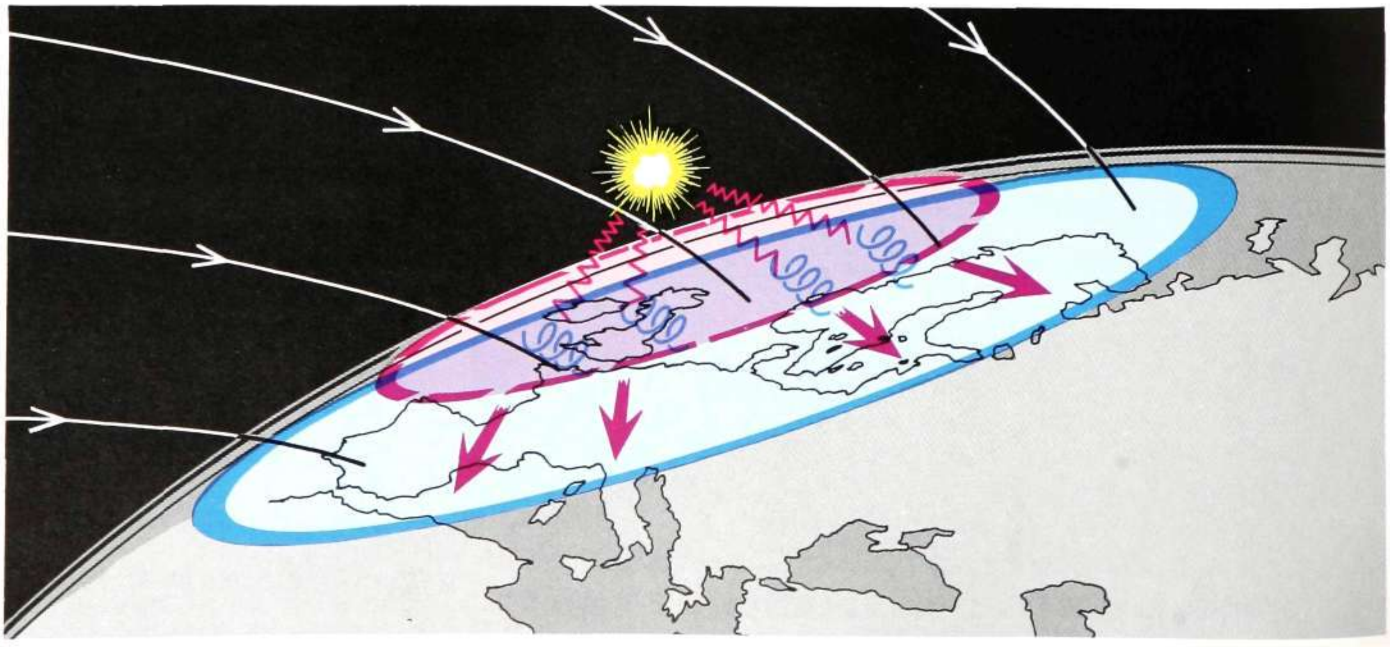
At the same time society has become much more dependent on electronics. For example, telecommunication networks, high-voltage power supply networks, railway networks, air traffic, water supplies and process industries are all controlled and regulated by equipment which usually contains susceptible semiconductor components. The increasing anxiety about nuclear EMP has recently been mirrored in the increase in newspaper articles and TV reports on the subject.

The greater vulnerability makes EMP attacks more attractive. It is quite possible that special EMP weapons already exist. An attacker could find it profitable to start military operations with an EMP attack. This would create such chaos that subsequent measures would be more effective and counter-offensives made more difficult. A high-altitude explosion can be triggered at a large distance from the borders of the country to be attacked and still have a great impact on that country. The country attacked might not even realize that a nuclear explosion had occurred, let alone who set it off. With a high-altitude explosion (at above 30 km) effects other than EMP could be negligible at ground level, and perhaps be impossible to detect without special equipment.

Large sums have been invested in EMP protection. Ten years ago the US was spending over 250 M US$ a year on EMP protection and testing. In October 1981 president Reagan stated that the US defense project with the highest priority was not the MX system or the B1 bombers but "to strengthen and rebuild our communications and control systems –

Fig. 2
An example of the impact area of EMP from a high-altitude nuclear explosion over Europe

- Gamma radiation
- EMP generation region (altitude 20–40 km)
- Electrons in spiral paths along the earth's magnetic field
- The direction of propagation of the EMP field
- The earth's magnetic field
- The EMP impact area at ground level



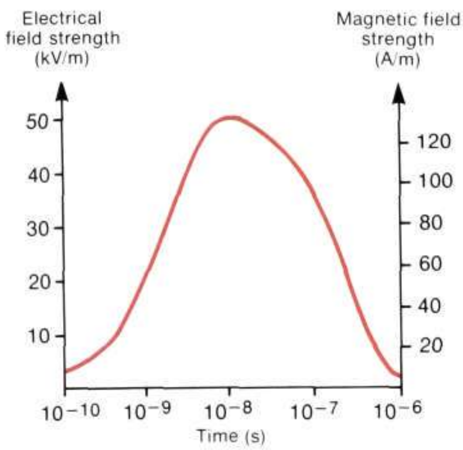


Fig. 3
The electrical and magnetic EMP field from a high-altitude explosion, plane wave and horizontal polarization. The time dependency is generalized

a much neglected factor in our strategic deterrent". 20 billion (10^9) US$ was earmarked for this project, a large part of which is intended for EMP hardening. In the Soviet Union EMP protection has even been provided for facilities of less than top priority for about 20 years.

Telecommunication networks that still function after high-altitude explosions are vital if diplomatic and political communication between nations is to be possible so as to avoid the military escalation of a limited nuclear confrontation into a total nuclear war. In the case of a nuclear war elsewhere a country needs a working telecommunication network, partly in order to be able to collect and process weather and nuclear radiation reports. It must be possible to inform the population of the country about the situation if chaos and exposure to nuclear radiation are to be limited. This could save many lives. Without a secure telecommunication network it would also be very difficult to rebuild and reconnect the country's electric power system before chaos arises and spreads. Disruption of electric power would seriously affect pumping of water and fuel supplies, and many other vital functions.

The generation of nuclear EMP

From a nuclear explosion an intense gamma radiation pulse propagates at the speed of light. The gamma radiation consists of photons (radiation quanta) which collide with air molecules or other matter and release free electrons. The so-called Compton electrons leave positively-charged ions behind and move on in the direction of propagation. They are slowed down by collisions, and each Compton electron thereby generates tens of thousands of secondary electron-ion pairs. The charge separation causes a strong electric field and the charging movements produce a current.

For explosions close to the ground, conditions are strongly asymmetrical. There is a net electron current with a strong upward component from ground zero. Electrons travelling outward in the air from the burst return toward the burst point through higher-conductivity ground and ionized air paths. The current loops generate very large azimuthal magnetic fields. For exo-atmospheric explosions Compton electrons are not generated until the gamma rays that travel downward reach the denser atmospheric layers, at a height of 20 to 40 km above ground. This is known as the deposition layer. The electrons encounter the earth's magnetic field and are deflected, producing a transverse electric current. This results in electromagnetic radiation which is directed radially out from the explosion point, adding in phase. This EMP has a tremendous coverage. In the case of large explosion yield, the higher frequency part of EMP extends to the horizon. The lower frequencies will follow along a duct between the earth and the bottom of the ionosphere as well as along the surface of the earth far behind the horizon. For example, with a height of burst of 100 km, large parts of Europe could be covered (impact radius approximately 1200 km along the surface of the earth; 400 km altitude would give a radius of approximately 2200 km). The EMP effect would be noticeable even outside this area.

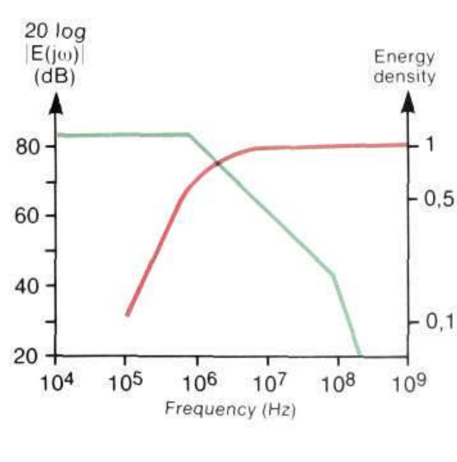


Fig. 4
The spectrum of the electrical field and the corresponding normalized cumulative energy density of EMP from a high-altitude explosion

Magnitude of the EMP

The EMP from a high-altitude explosion consists of a plane wave (E/H = 377 ohms), which is propagated along the line of sight from the explosion point. The E and H fields are perpendicular to each other and to the direction of propagation. A part of the pulse is reflected by the ground, and the rest is propagated into the ground and is gradually attenuated. The strength and polarization of the field vary within the impact area due to various factors. Vulnerability and

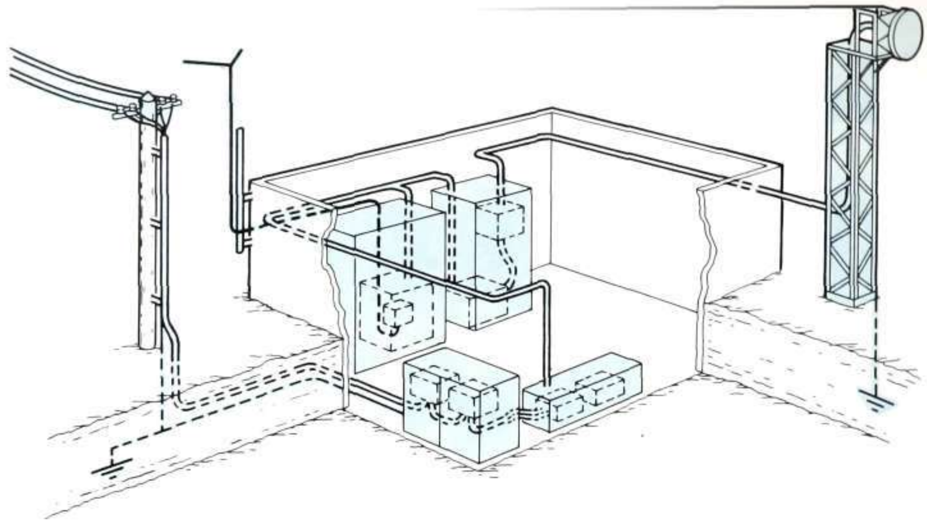


Fig. 5
Simplified picture of a communication installation with internal and external cabling

hardening calculations are often based on an electromagnetic field in free space before reflection, in accordance with fig. 3. The high amplitude (50 kV/m) and the short rise time (5 ns) are of particular importance for the effects. For comparison purposes it may be mentioned that a field amplitude of approximately 200 V/m is obtained near radar stations and approximately 0.01 – 0.1 V/m in urban areas. A generalized, time-dependent E field is often given as

$$E(t) = 5.25 \times 10^4 \times (e^{-4 \times 10^6 t} - e^{-4.76 \times 10^8 t})$$

Fig. 4 shows the frequency spectrum of the pulse. The energy density in this case is 0.9 J/m², and 99.9 % of the total energy lies below 100 MHz.

The effect on telecommunication facilities

Generally speaking the electromagnetic field induces currents and voltages in all sorts of conducting objects, which act as antennas, intentionally or unintentionally. The induced energy can find its way to connected objects where it is dissipated as heat, in some cases in combination with flash-overs. In a widespread network, pulses will be able to destroy or interfere with connected devices almost simultaneously in a number of places. The conductors can be compared to magnifying glasses which gather solar energy and focus it on points where heat is concentrated to such an extent that it is destructive. EMP energy is transmitted primarily by means of electromagnetic coupling (radiated field) and secondarily through galvanic coupling, inductive coupling ($u = M \times di/dt$) and capacitive coupling ($i = C \times du/dt$). In view of the circumstances all paths must be considered as risks. The current and voltage rise rates are considerable.

In order to give a more detailed picture of the EMP effects a communication facility with a microwave radio tower, fig. 5, is used as an example. This model is not necessarily typical, but is used to make the description more concrete.

The large external conductors are the power mains, telephone cables, antenna cables, waveguides and antennas. In addition there are large metal structures such as microwave radio towers, grounding conductors, fences, reinforcing netting in concrete walls, as well as air conditioning, water and sewage installations in the building. The building also contains internal cabling with electric power and telephone lines and cable ducts, racks and power and telecommunication equipment.

This model can be represented by a topological diagram as shown in fig. 6. The external environment includes air and ground.

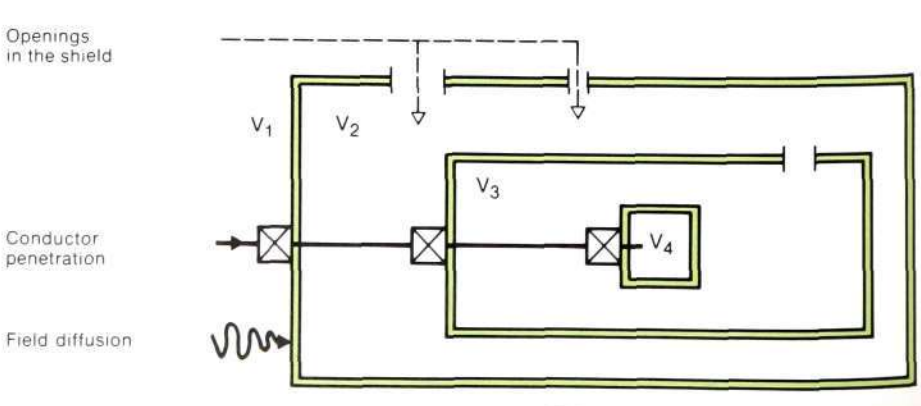
Fig. 6
A topological diagram

Volume	External boundary	Attenuation	Total
V_1	Air	0	0
V_2	Concrete	20 dB	20 dB
V_3	Shielded cabinet	20 dB	40 dB
V_4	Shielded unit	20 dB	60 dB

-⊠- Transient protection

‖ Shielding boundary

— Penetrating conductor



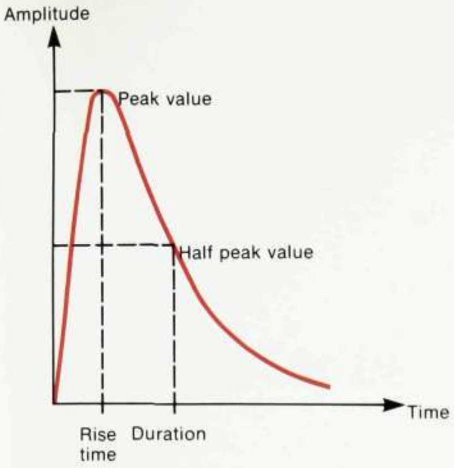
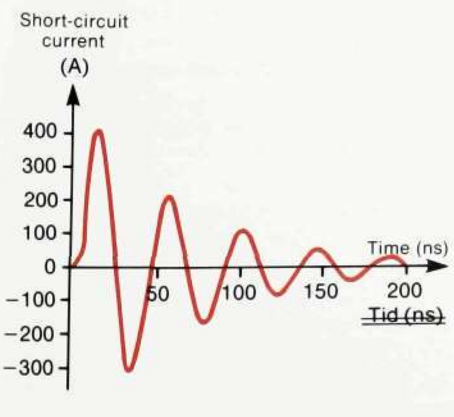


Fig. 7
Double exponential pulse waveform from induced currents in aerial and buried cables caused by EMP from a high-altitude explosion. If the lines are long, the pulses can have long decay (not included in the table below)

		Aerial line	Buried cable
Peak current	kA	5	1.5
Rise time	µs	0.1	0.1–0.5
Time to half value	µs	1	1–5
Rate of rise	kA/µs	50	15

Fig. 8
Short-circuit current for a 3 m long monopole antenna excited by an EMP field in accordance with fig. 3



Overhead power lines and telephone cables are severely exposed to EMP. The voltage to ground can be between 10 and 1000 kV and is limited primarily by the insulation resistance. The current is limited by the characteristic impedance of the conductors, which can be a few hundred ohms. At discontinuities, for example a transition from an overhead to a buried cable or to a transformer connection, strong pulse reflections occur. Buried cables obtain a certain amount of protection from the ground and cable sheath, and the induction is therefore less than for overhead lines. Fig. 7 gives some examples of EMP values for overhead and buried cables. *The pulses have a double exponential waveform.* Antennas and other short conductors that are exposed to EMP respond with an oscillating current and voltage, determined by the natural resonant frequency of the antenna or conductor. The oscillation has an exponential decay. Fig. 8 shows an example of a 3 m monopole antenna. Fig. 9 gives the voltage, current and energy as a function of the resonant frequency for excitation of conductors that can be considered as monopole antennas. The microwave radio tower in fig. 5 also acts as a large antenna, and peak currents of the same magnitude as for overhead lines can be induced. The long overhead lines and the microwave radio tower thus give rise to the largest induced currents, and buried lines to somewhat lower currents.

The conductors carrying the induced currents penetrate the building. The EMP field can also penetrate the building, through openings and, with some attenuation through the roof and walls. This field causes induction in the internal cabling. Concrete walls can attenuate the field by between 5 and 35 dB depending on their construction, the size of the building, frequency etc. If the building is equipped with a Faraday cage made of steel sheet the field attenuation can be some 50 to 100 dB. The higher frequencies are attenuated more than the lower, which makes the internal pulse rise time longer. However, the resultant attenuation is strongly dependent on how the shield penetrations are implemented.

The residual field can induce currents of the order of 1 to 20 A on internal cabling. But large currents entering via a lead-through can induce higher values in other cables which run parallel. The currents in the internal cabling can be a damped oscillation of between 1 and 10 MHz and with a time constant of between 1 and 10 µs, cf. fig. 8.

Reduction of induced pulses on conductors largely depends on whether the conductors have been equipped with some form of transient protection (surge arrester, gas tube spark gap, filter etc.), and on the design of the potential equalization. Special power conversion equipment (e.g. rectifiers and d.c./d.c. converters with accumulators) can in *favourable cases provide attenuation of* some 35 to 70 dB. Specially screened isolating transformers, in combination with filters, can provide even higher attenuation. If good protection is to be ensured, power supply lines must be shielded or at least installed at a considerable distance from other installations. It must also be ensured that other conductors do not form loops that can be closed by flash-overs.

The internal cabling terminates in various kinds of equipment cabinets. At best these can provide electromagnetic shielding, but whether the shielding is effective depends to a great extent on the cabling and how it is terminated. Inside the cabinet there is the equipment wiring, which leads to printed board assemblies and similar modules. In the best designs these are screened and the wires are terminated satisfactorily from an electromagnetic point of view, but often this is not a rigorous requirement. *The equipment power supply can in* favourable cases provide good supplementary attenuation of external transients. Finally the wiring on the printed board assemblies, in its turn, is terminated in components. However if the latter consist of integrated circuits there is a still lower level of wiring and components.

Knowledge of the threshold levels of the equipments and components for functional damage and operational interference is necessary in order to be able to assess the possible effects of EMP. The induced EMP energy must be compared with the energy threshold failure level of each component in order to esti-

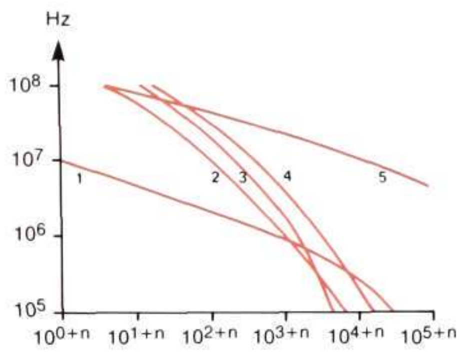


Fig. 9
Estimated voltage, current and energy as a function of the resonant frequency (f = c/4l, where c is the speed of light and l is the line length) when conductors that can be considered as monopole antennas are excited (field in accordance with fig. 3)

Curve		Abscissa, n =
1	EMP energy dissipated in a 50-ohm load (J)	0
2	Short-circuit current (A, peak value)	1
3	Open-circuit voltage (V, peak value)	3
4	Voltage across a 50-ohm load (V, peak value)	2
5	EMP energy dissipated in a 50-ohm load (J)	4

For example, for a conductor with a resonant frequency of 100 MHz:
- the peak short-circuit current is 50 A
- the peak open-circuit voltage is 15 kV
- the peak voltage across a 50-ohm load is 2 kV
- the EMP energy dissipation in a 50-ohm load is 0.5 mJ

The fraction of this energy that reaches sensitive semiconductor components in the connected equipment can be sufficient to cause damage.

mate the probability of damage. The charge or voltage can also be the limiting factor for thin oxide layers in semiconductors and electrolytes. In addition EMP energy can trigger dissipation of the system's own energy in inadmissible places, thus causing serious secondary damage. For short pulse widths, failure usually depends on the energy content of the pulse. Table 10 gives typical minimum threshold energy levels causing permanent damage. In semiconductor devices failure modes are typically junction burnout, oxide punchthrough and metallization burnout. With short pulses (less than approximately 1 to 0.1 μs) breakdown occurs in the semiconductor at a constant pulse energy regardless of the pulse duration, because the energy does not have time to disperse. Local melting occurs, particularly at any manufacturing defects. Such defects may be due to poor quality, which has not been detected during routine production control. Good quality and good control can give at least a tenfold improvement of the threshold energy compared with the values for low-quality circuits.

Although semiconductor components are particularly susceptible to transients, damage must also be expected in other components such as resistors (particularly metal oxide), capacitors (particularly tantalum electrolytic), relays, and indicator instruments. During the first nuclear tests in the middle of the 1940s many measuring instruments suffered EMP damage. Since then EMP simulations in communication facilities have resulted in false alarms, subscriber services outages, program interruptions in computers and certain permanent damage to the systems. However, it is difficult to make EMP simulations correctly on such large objects as communication installations so as to simulate high-altitude explosions correctly.

Among the conclusions from EMP simulations are:
- Permanent damage or impaired performance may be caused, particularly for active components (especially high-frequency transistors, integrated circuits and microwave diodes), passive components (particularly those with very low power or voltage ratings or precision components), semiconductor diodes and silicon controlled rectifiers (especially in power supply units connected to the mains) and insulated high-frequency and power cables (especially if they operate close to their maximum power and voltage levels, or are exposed to humidity or abrasion).
- Functional interference and status faults may be caused in low power or high speed digital processing systems, in memory units, control and alarm systems and in subsystems employing long integration or recycling times for synchronization, data acquisition or signal processing.

Hardening methods

A system that has to survive in an EMP environment must not undergo such disturbances or permanent damage as lead to functional failure. In order to reduce the effects of EMP on a system it will generally be necessary, either to limit EMP exposure or to increase the EMP susceptibility threshold. This can be achieved in various ways, most of which are well known and well proven e.g.:
- Electromagnetic shielding
- Potential equalization
- Isolation
- System delimiting (topological and/or functional)
- Well-designed cabling and wiring
- Transient protection
- Filters
- Availability of repair facilities and spares
- Use of more robust electrical components
- Use of non-electrical functions (e.g. mechanical, pneumatic, hydraulic, optical, acoustic, thermal)
- Disconnection of cables that are for the moment not absolutely necessary
- Redundancy.

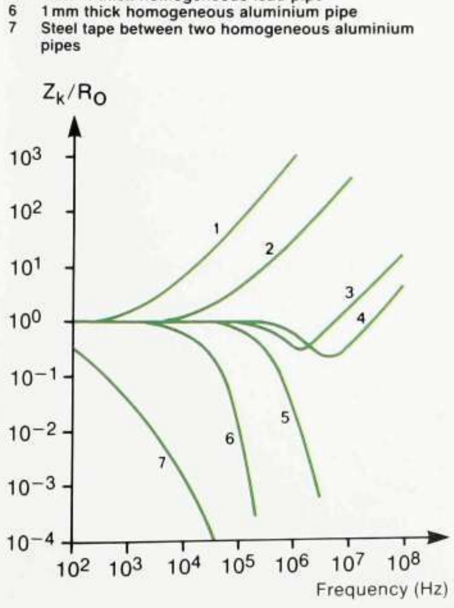
Several of the measures derive from methods of protection against lightning, static electricity, network transients and high frequency interference, as used in electromagnetic compatibility (EMC) technology. Hardening must be effective both for radiation and for

Component	Typical threshold energy levels (mJ)
Microwave diodes	$10^{-4}-10^{-2}$
Digital IC circuit	$10^{-3}-1$
Low power transistors	$10^{-2}-1$
Switch diodes	$10^{-2}-1$
Electroexplosive devices	$10^{-2}-1$
Tantalum electrolytic capacitors	$5\cdot10^{-2}-$
Metal oxide resistors	$10^{-1}-10$
High power transistors	$10^{-1}-10$
Silicon-controlled rectifiers	$10^{-1}-10$
Zener diodes	$10^{-1}-10^{2}$
Rectifier diodes	$10^{-1}-10^{2}$
Metal film restistors	$5\cdot10^{-1}-10$
Carbon film resistors	$5\cdot10^{-1}-50$
Electron tubes	$1\ -10^{4}$
Fuel-air mixture	3
Relays	$10\ -10^{3}$
Carbon composition resistors	$50\ -$
Wire-wound resistors	$10^{3}\ -$

Table 10
Typical minimum threshold energy levels (mJ) to cause permanent damage for pulse durations ≤ 1 μs. Threshold energies for temporary functional interference are 10 to 100 times smaller than the values for permanent damage

Fig. 11
Relative transfer impedance as a function of frequency for different cables. The d.c. resistance of the sheath, R_0, is often 1–10 mohm/m

1. Aluminium tape wound with a helix angle of 25°
2. Power cable EKFR (10 x 1.5)
3. Braided coaxial cable RG 11
4. Mains cables (EKLR or FKLR)
5. 1.4 mm thick homogeneous lead pipe
6. 1 mm thick homogeneous aluminium pipe
7. Steel tape between two homogeneous aluminium pipes



conduction effects. Good EMC practice can be regarded as a step towards EMP hardening, but many methods must be applied more rigorously and systematically than is otherwise customary.

The principles of protection are quite simple. The problems arise in applying them without incurring excessive costs. Since it is difficult to predict, calculate and verify the effects of EMP exactly, it is often easier to choose better protection than may be absolutely necessary. Detailed analyses and simulations can turn out considerably more costly. A compromise consisting of a combination of a reasonable number of analyses, tests and protective measures is usually to be recommended.

The protection level should be related to the required probability of survival. For example, a survival probability of 99% for the worst possible EMP case for a large complex system would require an enormous investment. With more reasonable probability requirements and with protection planning included right from the start of the planning of a new system, the protection costs can be reasonable and quite acceptable. However, when modernizing old systems the costs can be unrealistic unless the measures are limited primarily to protecting certain parts, or raising the survival probability to a more moderate level.

EMP protection methods can be exemplified with the aid of the communication installation described above. The choice of action for a given overall result must be based on an assessment of the cost effectiveness of the various measures in relation to each other. The hardening alternative chosen must be documented in a project plan which gives instructions in the greatest possible detail, based on a topological decription of the object to be hardened, figs. 5 and 6. This work has to be systematic and disciplined. There is a much wider choice of action if the communication site and the associated telecommunication network are in the early planning stage. It might then even be possible to choose non-metallic optical fibre cables and microwave radio connections that work in high frequency bands. Aerial lines should be avoided if possible.

We face a rapid changeover to optical fibre cables in the telecommunication networks during the next few years. This provides a unique opportunity for planning an exclusive network with EMP protection, superposed on the ordinary network. The cables can be equipped with extra fibre pairs (single mode), which are run to subscribers of major importance for the administration and maintenance of the country. The optical-electrical conversion should take place as close to the exchanges, telephones, computers, video terminals etc. as possible. All such associated electrical functions must be equipped with EMP protection. The power supplies for cable repeaters, exchanges and subscriber terminals must be separate and protected. If the suggested EMP-protected network is to be implemented in a reasonable way it must be included in the planning for the optical fibre expansion right from the start. A new EMP-protected network for top priority subscribers will then be obtained at a relatively marginal cost as the ordinary telecommunication network is extended. The new protected network can be commercialized and justified for top priority subscribers for a number of reasons, such as very low congestion in crises and conflicts, very high capacity and flexibility as regards transmission of different types of information (including wideband services), and good protection against listening-in and disturbances (lightning, power failures etc.).

The power distribution lines connected to the EMP-protected network must be equipped with large primary surge arresters at the point where transition is made to buried cable. This point should be remote from the communication facilities, and the connecting cable should be shielded if possible. The external power line system should be isolated from the installation by means of, say, rectifiers, accumulators and d.c./d.c. converters connected up for maximum transient attenuation, or by motor-generator transmission on an insulating shaft. The installation should be equipped with a standby power generator which starts up automatically if a mains failure occurs. The electrical installation must be carried out with great care, since external transients must be attenuated as much as possible by surge arresters, filters and other devices before they can reach standby power systems and finally internal loads.

The building could perhaps be constructed so that it provides electromagnetic shielding. This can be done by using small-mesh reinforcement and ensuring that the bars are in contact with each other wherever possible (may give 20 to 30 dB), or by supplementing the basic structure with metal sheets which are all welded or permanently joined in any other way (may give 50 to 80 dB).

The layout of external and internal wiring can also be modified during the planning stage. External power lines and telecommunication cables and grounding conductors can then be planned so that they are all run into the building at the same point. At this common entry point, cable shields and grounding conductors should be connected to the outside of a common inlet plate, which in its turn would be connected to the metal framework of the building. This arrangement diverts some of the currents induced in the lines to the outside of the installation, and only a minor part would penetrate inside.

At the inlet plate, transient protectors for the power and telecommunication lines should be installed with the shortest possible connections to the plate. The protective effect of even top quality overvoltage protectors is ruined if their connections are not as short as possible. The length of the connecting lead gives an additional voltage $u = L \times di/dt$, which can be of the order of 1 kV/cm. The transient protectors give potential equalization between different conductors and between the power and telecommunication networks, and thus reduce the risk of flash-overs in the internal installation.

If possible, cables should be shielded or run in shielded ducts or conduits. In some countries cables are run in iron conduits with threaded joints. A measure of the shielding effectiveness is the so-called transfer impedance. It is defined as the voltage drop, per unit length along the cable, along the inside of the cable shield in relation to the current on the outside of the shield. Fig. 11 shows typical values as a function of the frequency. Braided or in other ways transparent shields give considerably less protection against rapid transients which contain high frequencies than homogeneous (solid-walled) shields. Special sheath designs have been developed for EMP-hardened telecommunication cables. As regards the internal cabling it may be easier to run the cables together in special shielded cable ducts. However, such common cable runs must not include any conductors that can bring in large EMP currents from outside into the installation. Neither should the cabling be run near openings in the building shield, for example doors.

In shielded facilities the feed-through for air, light, fuel, water and sewage should be arranged with special care, e.g. by using waveguids. These are often sectioned and given a honeycomb structure, which makes them short and makes the overall attenuation the same as the attenuation of each individual cell.

The grounding or potential equalization in a telecommunication installation must be designed in accordance with

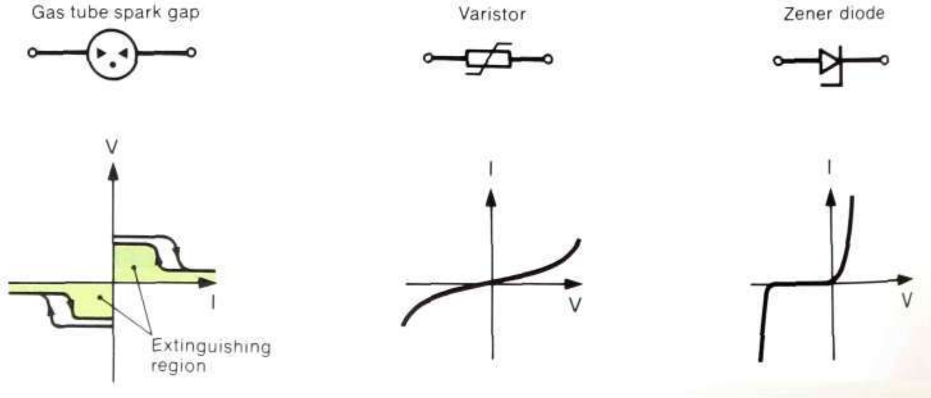


Fig. 12
Common components for transient protection

electrical safety regulations, and also in such a way that the grounding does not become a source of disturbances to the electronic equipment, or a conductor of EMP and lightning transients to susceptible points. In order to avoid damage from lightning or from earth faults in the power system the Swedish Telecommunications Administration now designs its installations so that external power and telecommunication cables are brought in as close to each other as possible. The power and telecommunication terminal grounding strips are joined together at the point of entry, either direct or via gas-type arresters, and the cables are equipped with overvoltage protection. If possible the internal cabling is arranged so that the power and telecommunication cables cannot form loops.

The protective measures are repeated at each new topological barrier, fig. 6. Some type of transient protection is usually required at equipment cabinets, and sometimes also at internal modules. The protective measures must be coordinated, which can be difficult. The type of transient protection varies from the outer barrier (primary protection) to the subsequent barriers (secondary protection), but the connection principles are the same. The final protectors must be placed as close as possible to the devices they are to protect. Protection components, such as gas-type arresters, varistors, zener diodes and filters, are often combined. Resistor fuses and protection diodes are sometimes used on printed boards. Fig. 12 shows some protections against transients. Circuits with differential coupling can suppress EMP induction by the order of 100 times (40 dB) as compared with circuits which are sensitive to common mode voltages.

The protection levels of the transient protectors and of the shielding barriers must be effective both for conducted and for radiated effects. It might be more economical to arrange protection in several topological steps of approximately 20 to 30 dB each. However good an electromagnetic shield is, its protective ability is largely lost if a cable is led through it without special protection being arranged at the point of entry.

The amplitude limiting given by overvoltage protectors is a function of time, whereas that given by filters is a function of frequency. Transient protectors can consist of one of these types or a combination of both. Power filters become larger and more expensive with increased power level. It is therefore more economical to use filtered power only for very sensitive equipment, and to connect units with lower sensitivity or priority to less well-protected power lines. This implies that conductors having different protection levels must be run in such a way that the mutual induction is negligible.

If a transmission equipment only uses a relatively narrow frequency band, it may be economical to install filters that attenuate the signal outside the operating range. At high frequencies, where a quarter wave corresponds to a reasonable length, a quarter-wave shunt can be used. It consists of a short-circuited transmission line connected in parallel with the ordinary transmission line. The

		Gas tube spark gap	Varistor	Zener diode
Ability to withstand energy with 1 ms pulse	J	10^2-10^3	$1-10^3$	$10^{-2}-10^1$
Ability to withstand current with 1 ms pulse	A	10^4	10^2-10^3	1–500
Leakage current	A	$10^{-9}-10^{-12}$	10^{-3}	$5 \cdot 10^{-3}-10^{-6}$
Response time	s	$10^{-9}-10^{-6}$	10^{-9}	10^{-9}
Capacitance	F	$10^{-11}-10^{-12}$	$10^{-10}-10^{-8}$	$10^{-10}-10^{-8}$
Voltage range	V	$75-3x10^4$	20–1 500	2–300
Polarity		bipolar	bipolar	unipolar
Failure mode		open or short-circuit	degradation and short-circuit	short-circuit
Operation mode		short-circuit	voltage clamping	voltage clamping
Ability to extinguish		*)	yes	yes

*) Can require combination with a non-linear resistor

Table for fig. 12
Comparison chart of common transient protection devices. These are typical values; deviations can occur

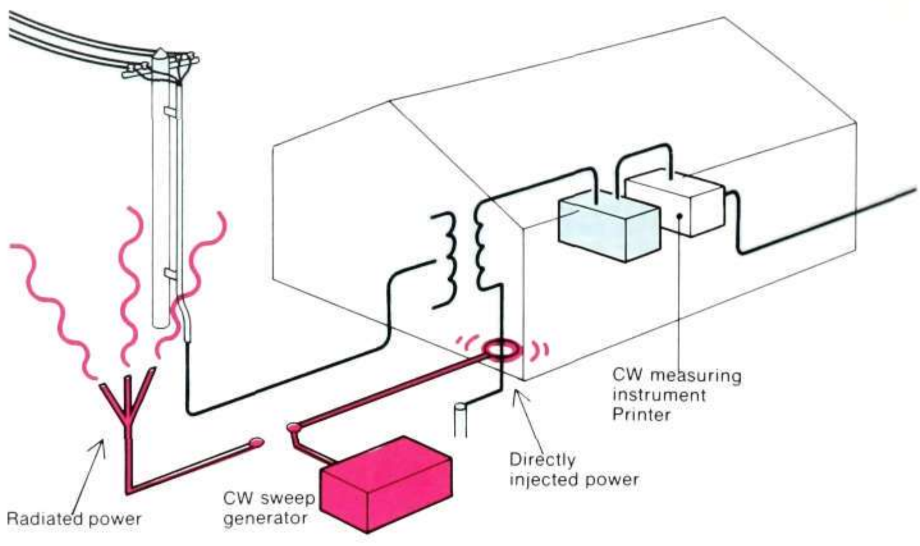


Fig 13
A telephone exchange can be tested by means of low-level simulation with continuous wave (CW)

short circuit acts as an open circuit for frequencies corresponding to an odd number of quarter wavelengths. For other and lower frequencies it acts as a shunt.

In order to simplify the introduction of EMP hardening, detailed requirement specifications are needed to form the basis for a standardized range of protective devices. It will then also be easier to plan and estimate the cost of hardening plant or systems. Although a multitude of protective devices are now available, there is a lack of requirement specifications which could lead to homogeneous and standardized protection systems. This important omission must be remedied soon if EMP protection is to be more widely undertaken.

An EMP protection standard for radiated and conducted effects is being prepared. The proposal is similar to the current military EMC standard specifications. A number of different classes of radiated EMP environments, starting at 50 kV/m and divided into steps of 20 dB, are defined in the proposal. Cable-associated EMP environment is defined for a number of classes of double exponential and damped sinusoidal currents respectively. Test procedures for the various classes are also being prepared.

Most protection methods described here also provide protection against lightning. The handbook "Practical Methods for Electromagnetic Interference Control" published by Ericsson's Networks Department contains detailed instructions for protection against lightning strokes and EMP.[7]

Hardening verification

It must be possible to verify the hardening level in connection with installation and commissioning, and later periodically during service life. Protectors can deteriorate with time for environmental reasons (e.g. wear or corrosion of contacts) as well as maintenance and modification reasons (e.g. installation of new cables, which are run straight through a Faraday screen without any protection at the entrance).

The operating staff must be trained and have access to instructions and spare parts in case the EMP threat becomes a reality. The protective arrangements must be simple, clear and readily accessible. Training is also needed in order that the personnel should not incapacitate any protection by improper action. Test equipment needed for routine tests could be built into the equipment. The shielding effectiveness can, for example, be tested regularly with the aid of permanent measuring loops around the main body of the building. Surge devices can be used to test the transient protection. Fig. 13 shows one way of testing a communication installation at the time of commissioning.

The nuclear power nations, particularly the US, have extensive programs for EMP testing and simulations. Much work is also being carried out in Europe, for example in the UK, France and West Germany. A number of nations that do not have nuclear weapons also have EMP hardening programs, for example Sweden and Switzerland. Practical measurements are supplemented by theoretical calculations. A number of computer programs have been developed to aid complicated calculations of EMP environments, propagation penetration, induction response in different structures from macro (e.g. country-wide networks) to micro (e.g. amplifier stages, integrated circuits, simple components), and for respective threshold levels for interference of function and permanent damage (for final comparisons). Statistics programs have also been developed for determining the accuracy and reliability etc. of the data.

The classes of EMP tests include:
- low-level mapping of currents induced in subsystems that have not been activated
- high-level current injection
- high-level exposure of operational subsystems to pulse-shaped electromagnetic fields.

Simulators are available for the free radiation of pulse or CW (continuous wave) fields. Current injection test equipment for pulse and CW is also available. Since the systems to be tested are usually too large to be accommodated within the test volume of the simulators, it is often necessary to carry out extrapolations and supplementary tests, for example a combination of radiation and current injection, or scale tests.

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