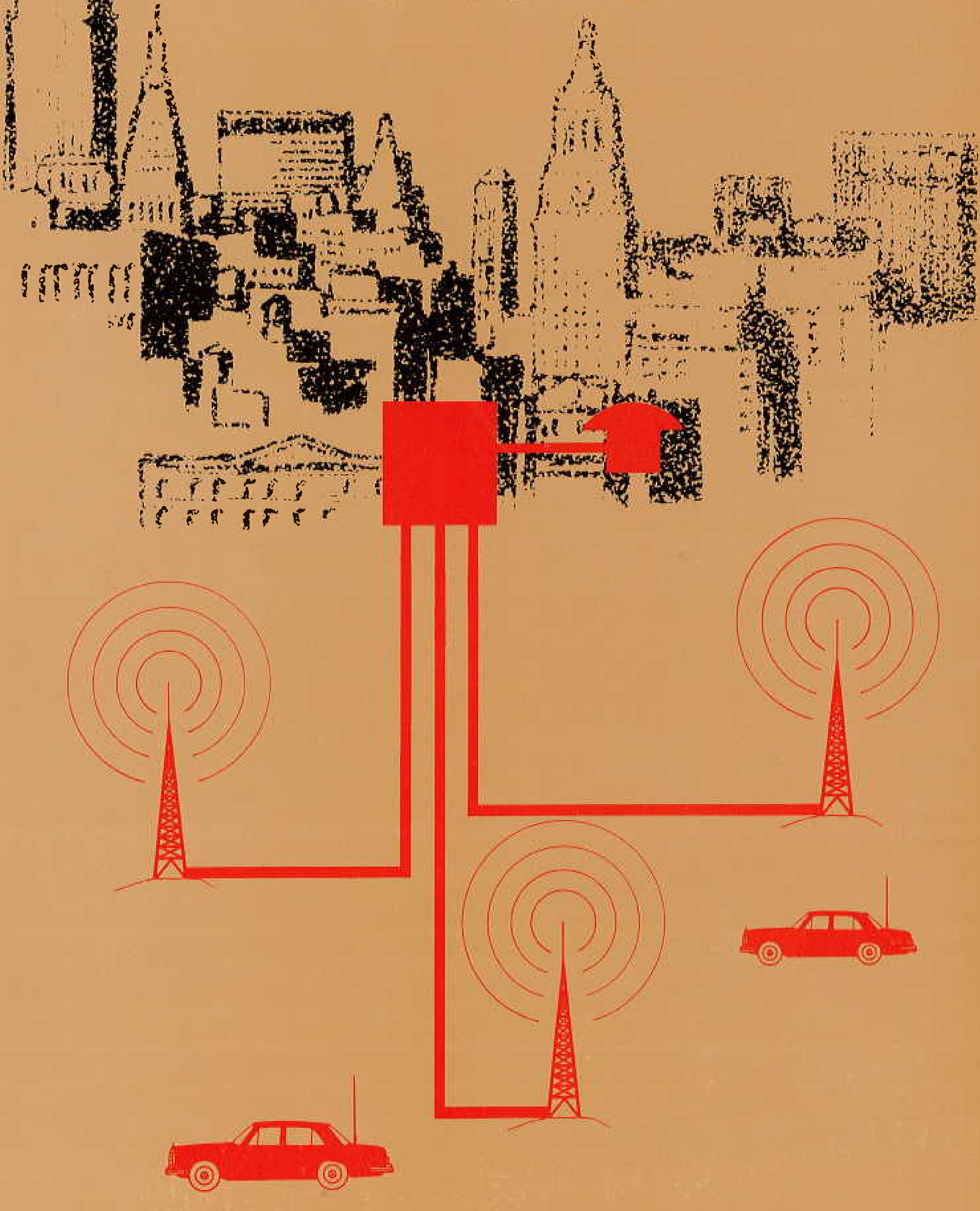
A PUBLIC AUTOMATIC MOBILE TELEPHONE SYSTEM



A PUBLIC AUTOMATIC MOBILE TELEPHONE SYSTEM

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A Public Automatic Mobile Telephone System

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LM Ericsson, together with their subsidiary SRA Communications AB, have developed an automatic mobile telephone system for connecting mobile telephones to the public telephone network. The system gives the mobile subscribers access to all facilities offered by the public network, and also to a number of new services of special value for mobile traffic.

The mobile telephone system can be given the same coverage as the country-wide public telephone network. If a neighbouring country has also installed the same mobile telephone system, telephone calls can be made to mobile units visiting that country via the telephone exchanges in the neighbouring country.

The telephone system has been designed to the sophisticated requirements set by a working party formed by the Nordic telecommunications administrations. Initially the system will be installed in Denmark, Finland, Norway and Sweden.

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The use of mobile radio communication is increasing rapidly all over the world. Transport companies, such as freight and taxi companies, industries, forestry enterprises and local authorities are some categories which have found mobile radio communication very useful. Most automatic systems of today are designed for companies and their internal needs. The public country-wide mobile telephone services that are now in operation in several countries are manual, i.e. they require the assistance of operators to establish the calls.

The development of an automatic country-wide mobile telephone system for connection to the public network has become feasible during recent years through the rapid development in the field of radio technology, for example of:

- digital frequency synthesis, which makes it possible to set the frequency for hundreds of channels from a single control crystal
- LSI circuits and microcomputers which make it possible to construct small mobile radio equipment with complex signalling and control functions at a reasonable cost.

This article describes first the general structure and the special functions of the mobile telephone system, then the three main parts of the system, which are: exchange equipment, which is based on the normal AXE 10 system, base radio stations and mobile subscriber equipments.

The basic elements of the system

The three basic elements of the mobile system, fig. 1, consist of:

Mobile subscriber equipments (mobile stations), which are small radio stations mounted in vehicles. They are equipped with push-button sets so that the drivers can easily establish speech connections through the public network.

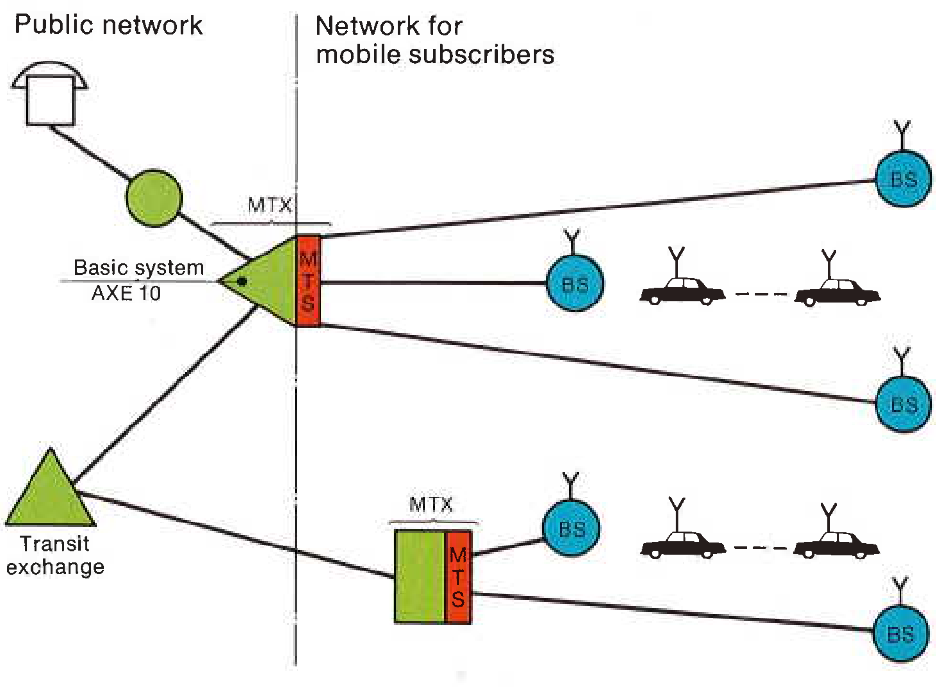


Fig. 1
The basic principles of a network with mobile subscribers, and their connection to the public network via AXE 10

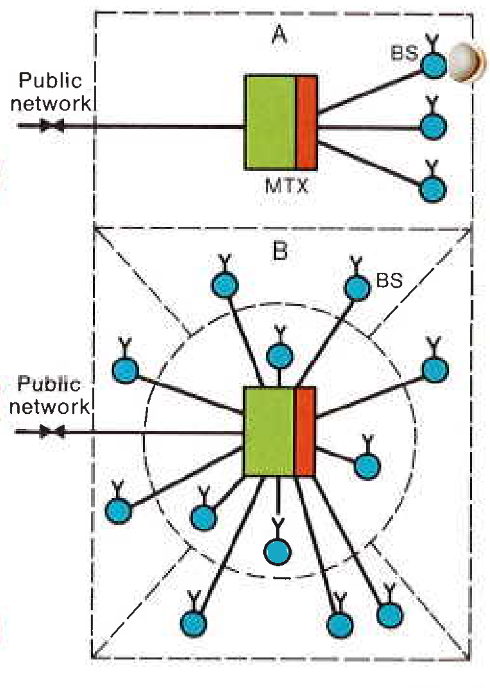
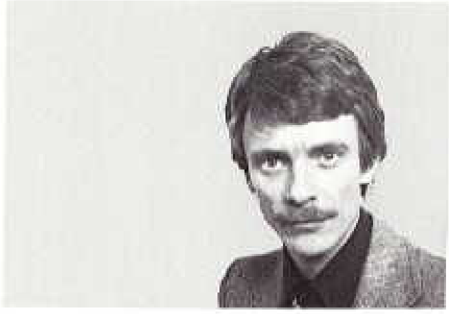


Fig. 2, right
Two examples of the division into traffic areas:
In example A the MTX serves only one traffic area
In example B the MTX serves five traffic areas



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Base radio stations, BS, which handle the radio communication with the mobile subscribers in their own area. They transmit all signals between the radio network and the telephone exchange equipment.

The telephone exchange equipment, which consists of a subsystem, MTS, in the telephone exchange system AXE 10. The subsystem makes it possible to connect the base radio stations to AXE 10 via ordinary telephone lines. Thanks to the functional modularity of AXE 10 it is possible to use these AXE 10 exchanges either jointly for mobile and ordinary telephone traffic, or to use them only for mobile traffic. The part that is used solely for mobile telephone traffic is designated MTX.

Network structure and frequency plan

A network is built up of base radio stations, BS, the number and placing of which are dependent on the size and topography of the country, and on the number of subscribers who are to be served. The radio stations that are connected to one and the same telephone exchange form one or several traffic areas, fig. 2. Within a traffic area a call to a mobile subscriber is transmitted in parallel from all base radio stations in the area.

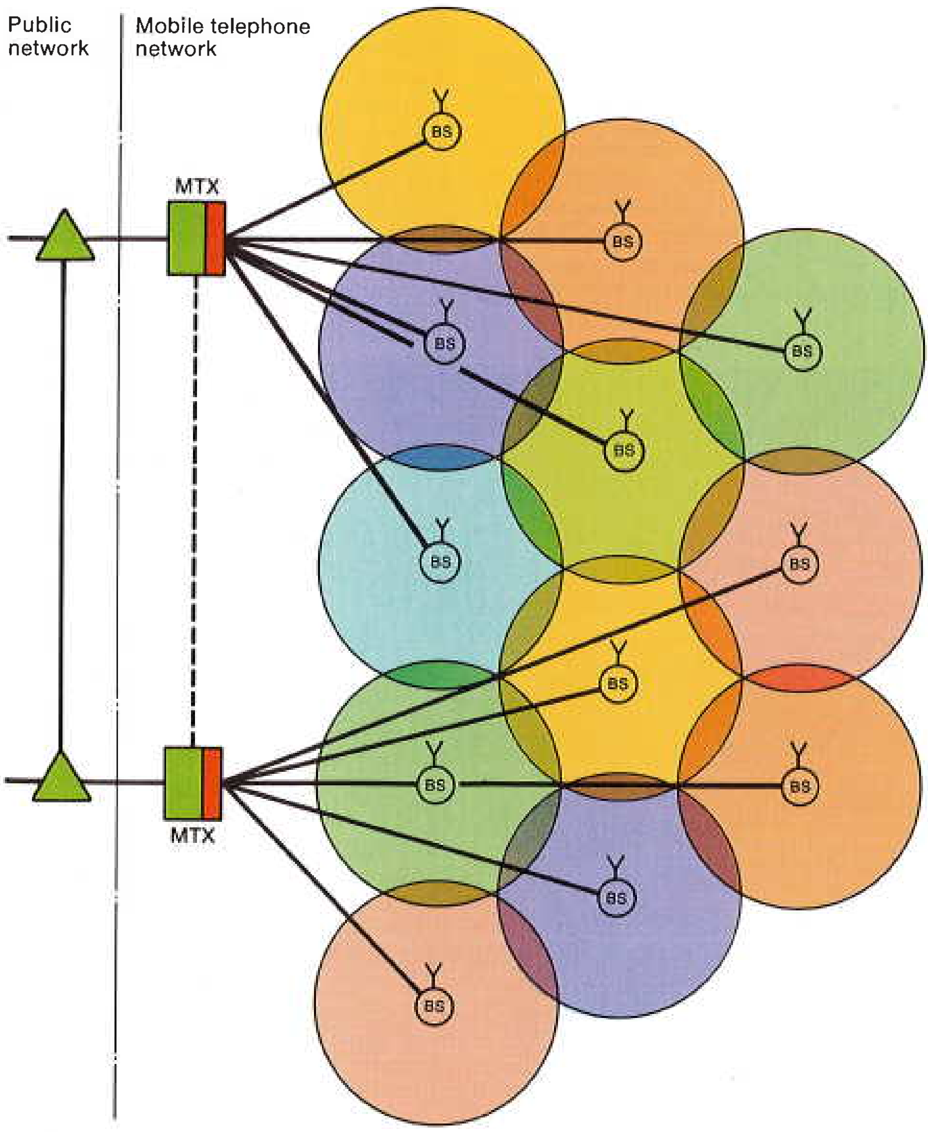

Fig. 3
A typical frequency plan. Adjoining base stations, BS, operate on different frequencies, but stations at a sufficient distance from each other can use the same frequencies. (In a typical case seven different groups of frequencies are required)

Adjacent base radio stations transmit at different frequencies, fig. 3. One channel in each base station is used as the calling channel. The others are traffic channels. The type of channel is indicated by a code in the signalling format. This arrangement is so flexible that a calling channel can be used as a traffic channel and vice versa. This is particularly useful in areas with little traffic and only a few channels per base station. Moreover the system can change channel by altering the channel marking, for example in the case of a fault on the calling channel. The range of a base station is dependent on the height of the aerial and the topography, and it is usually 20–30 km.

Each radio connection uses two channels, one for sending and one for receiving. Together the two channels form a duplex channel. The spacing between the sending and receiving frequency, the duplex spacing, is 10 MHz. The maximum number of duplex channels in the mobile station is 200 with a spacing of 25 KHz between adjacent channels. The total bandwidth required is 2×5 MHz, i.e. 5 MHz in each direction.

Since the same frequencies can be used in different geographical areas, fig. 3, the total number of channels in a country can be considerably higher than 200, with a proportional increase in the traffic capacity. For example, in Sweden it is calculated that about 250 base stations with a total of 1000 speech channels will provide sufficient traffic capacity for approximately 40–50 000 mobile subscribers in a fully extended system.

Calling methods

A call to a mobile subscriber is made in the same way as a trunk call. First the code of the service is dialled, immediately followed by the subscriber number of the mobile station. A call from a mobile station is carried out as if the station was connected direct to the public network.

Call to a mobile subscriber

The mobile telephone system constitutes one number group in the national numbering plan, and the service can be reached by one and the same code from any place in the country. Each mobile subscriber has a unique subscriber number within the number group.

A call to a mobile subscriber is made by dialling the code, which can contain 1, 2 or 3 digits, and then the subscriber number. The code and the first one or two digits of the subscriber number connect the calling subscriber to the correct telephone exchange, MTX. When the whole number has been received, MTX analyzes it with regard to validity, subscriber category (i. e. barring category) and the traffic area of the called subscriber. The exchange then

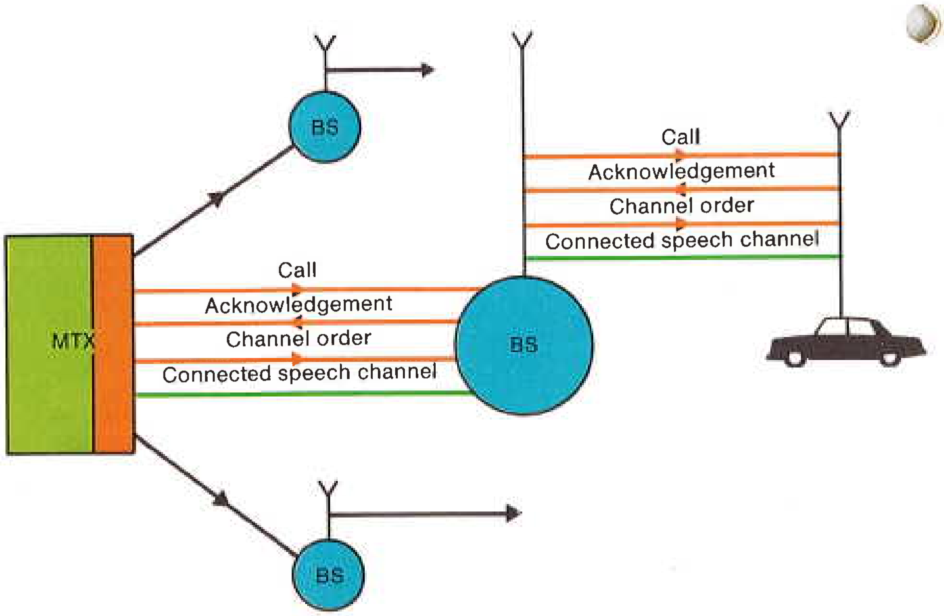

Fig. 4
Call to a mobile subscriber. Signalling takes place on the calling channel, after which a speech channel is connected in

Signalling on the calling channel

Traffic channel, which is seized by MTX and to which the mobile station switches on order

transmits a calling signal over all base radio stations in the traffic area in question, fig. 4.

When the subscriber is free, his mobile station is set to the calling channel from a base station that gives an acceptable transmission quality. When the mobile station detects the call it automatically sends an acknowledgement signal on the same channel. The telephone exchange has then located the base station from which the called mobile subscriber can be reached.

The exchange, MTX, seizes a free traffic channel to this radio station and sends an order, on the calling channel, to the mobile station. The mobile station then switches over to the specified traffic channel, after which a normal identification procedure, "handshaking", takes place on the traffic channel.

Call from a mobile subscriber
A mobile subscriber who wants to make a call first dials the desired number and then initiates the call by lifting the handset. The mobile station then starts to hunt for a free traffic channel to a base station in the traffic area. When the mobile station has found a free channel and called, the normal "hand shake" takes place and the number of the caller is automatically transmitted to the exchange, MTX, which is the local exchange of the mobile subscriber. MTX analyzes the subscriber category and the dialled number, and the call is then set up.

Switch-over methods

Since the subscribers are mobile, a subscriber has to be switched over to another telephone exchange when he has left the area covered by his own exchange. If a subscriber leaves the coverage area of one base radio station during a call, he must be switched over to another station while the call is going on.

Switch-over to another exchange
Each mobile subscriber is registered in a certain telephone exchange, his "home exchange" (MTXH). When a subscriber moves to a traffic area for another exchange, "visited exchange" (MTXV), his incoming calls are automatically transferred to the latter exchange. This procedure is called roaming.

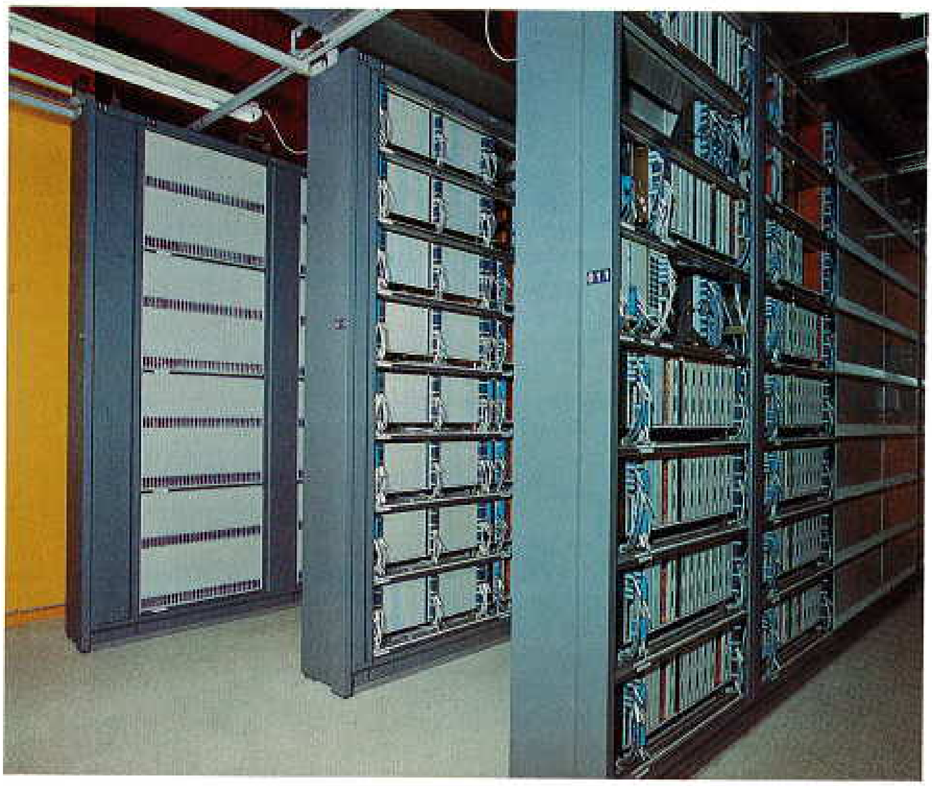

Fig. 5
An AXE 10 exchange

As soon as a mobile station enters a new traffic area, whether it is served by the same or another exchange, the mobile station detects this by identifying the traffic area code given on the calling channel. The mobile station then automatically calls the exchange, which can be MTXH or MTXV. The exchange notes which traffic area the subscriber has now entered. If a new MTXV has been called, this exchange signals to the subscriber's MTXH that the subscriber is in the new traffic area. MTXH acknowledges by sending information regarding the subscriber category to MTXV, which stores the information together with the subscriber number and the traffic area identity.

A call to a mobile subscriber is always first routed to the home exchange MTXH. When necessary, the call is rerouted to the visited exchange MTXV with the aid of the above-mentioned position information.

Switch-over to another base station during a call

When a subscriber moves out of the coverage area of one base radio station into the area of another during a call, the call is switched over from the first station to the second.

The transmission quality of every call in progress is monitored with the aid of a pilot tone (4000 Hz). The signal is transmitted from the radio station to the mobile station and back again.

When a call has to be switched over, the telephone exchange orders a field strength measurement on the relevant traffic channel from adjacent base stations. If another base station offers better transmission quality, the telephone exchange investigates whether there is a free speech channel from this base station. If so, the call is switched over to this channel.

Signalling principles

Binary signalling is used for the exchange of information between the telephone exchange and the mobile station. The same system is used for the remote control of the base station. The modulation method for signalling is frequency shift at a speed of 1200 bit/s. The shift frequencies are 1200 and 1800 Hz. The use of these frequencies means that

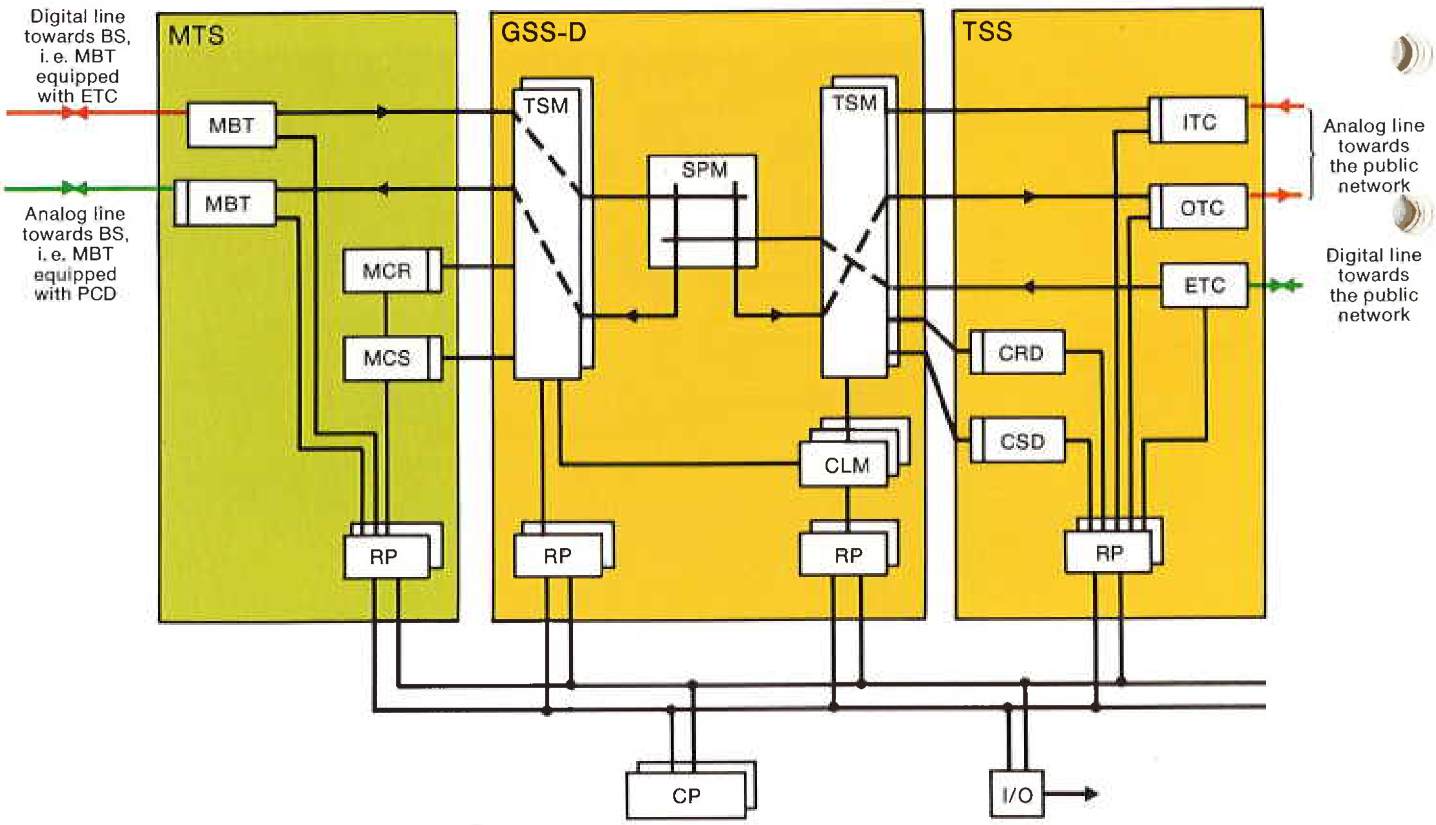

Fig. 6
Block diagram of the hardware in MTX.
The type of hardware is the same when MTX is equipped in an AXE 10 exchange that is used only for mobile telephony, as when MTS is integrated in an AXE 10 transit exchange that also handles public transit traffic

- (red line) Outgoing calls from BS, on a digital line, to the public network on an analog line
- (dark line) Incoming call from the public network on a digital line, to BS on an analog line

MTS Subsystem for matching the mobile stations to the public network
MBT Junction line relay set block
MCR Code receiver
MCS Code sender
RP Regional processor
GSS-D Digital group selector
TSS Subsystem for signalling towards the public network

a lower bandwidth is required than with normal CCITT standard, and higher distortion can be accepted on the point-to-point circuits between the exchange and the base stations. Disturbances caused by fading of the radio signal are counteracted by the use of an error-correcting code for the signalling. See "Fading" on page 36.

The data messages are transmitted synchronously in frames. The frame alignment is achieved with a special 11-bit sequence (Barker), which is sent after 15 bits for bit synchronization. The coded message then consists of 64 information bits and 76 check bits.

Compelled signalling, which is based on the same principles as MFC signalling, is used throughout, which makes the signalling system very reliable.

For the signalling between the telephone exchange and the remainder of the public telephone network, the existing signalling systems are used. The telephone exchange is prepared for signalling system CCITT no. 7, which can be introduced if it becomes necessary to transmit more information between the exchanges.

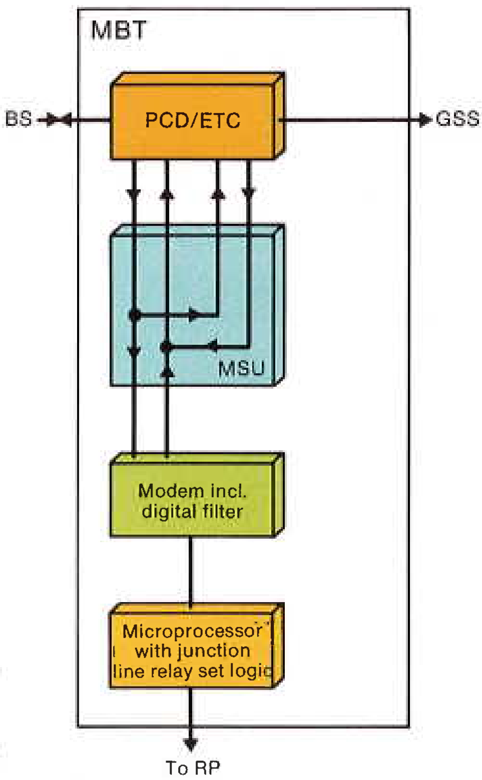

Fig. 7
Junction line relay set block MBT with level regulation, modem and microprocessor

PCD Terminal device for analog lines
ETC Terminal circuit for digital lines
MSU Unit for splitting, tone transmission and level regulation

Telephone exchange equipment, MTX

The exchange equipment consists of the public digital telephone exchange system AXE 10. AXE 10 is a modular, stored-program-controlled system, which covers the whole range of applications from local and tandem exchanges to transit exchanges. Fig. 6 shows the exchange hardware. Previous articles have described both AXE 10 in general[1] and the digital group selector in particular[2].

The use of AXE 10 as a transit exchange will be described in more detail in a later issue of Ericsson Review.

All additional functions that are required when AXE 10 is used as a mobile telephone exchange are assembled in a subsystem. Thus all other subsystems are unchanged. The functional modularity of the AXE 10 structure therefore makes it possible for an AXE 10 to

- handle both mobile telephone traffic and public transit traffic, i. e. an ordinary AXE 10 transit exchange is equipped with subsystem MTS
- handle only traffic to and from mobile subscribers.

In MTS the traffic and calling channels are connected to analog or digital transmission channels. The above-mentioned binary signalling and error correction are then used on all these channels. In MTS the level of the incoming speech signals is also measured and adjusted when required, since the junction line relay set towards the base station contains a modem and a level regulator in addition to the normal relay set functions, fig. 7. The junction line relay set block MBT is controlled by a microprocessor.

The signal to noise ratio on all channels that carry traffic is continuously measured at the base station and reported to the exchange. If this ratio falls below a certain limit value on a traffic channel for a certain time, the exchange orders a field strength measurement on this channel from the base station. The limit value can be set by means of a command from the exchange. The result of the measurement is analyzed, after which the mobile station in question can be ordered to switch over to another traffic channel, if a free one with better transmission quality is available. Such a field strength measurement and analysis, and possibly also switch-over to another channel, are also carried out during the setting up of each call to or from a mobile subscriber.

If a base station has many channels to the exchange, one of the cannels can be designated the signalling channel and used only for signalling information.

Local exchange data concerning both the registered and visiting mobile subscribers are stored in MTS, for example information regarding category, any barring for outgoing traffic or priority level. Furthermore, the geographical position of the subscriber is stored, that is to say the traffic area he is in.

Subscribers with priority always call the exchange via the calling channel, unlike the other subscribers. If there is no free traffic channel, the subscribers with priority are put in a queue. MTS also contains facilities for introducing what is called emergency traffic. This means that for each radio station a percentage of the traffic capacity is reserved for use in an emergency by subscribers with priority. This emergency traffic state in the telephone exchange is ordered and removed by means of commands.

When there is more than one MTX exchange in the country the system must permit roaming. In addition to the storing of data for "visiting" subscribers this function requires the transfer of information between exchanges. This transfer is done by means of special MFC signalling, end-to-end, over the public network. In future CCITT no. 7 can be used if it is necessary to transfer greater amounts of information. The updating traffic between MTX exchanges can also go via point-to-point connections in the

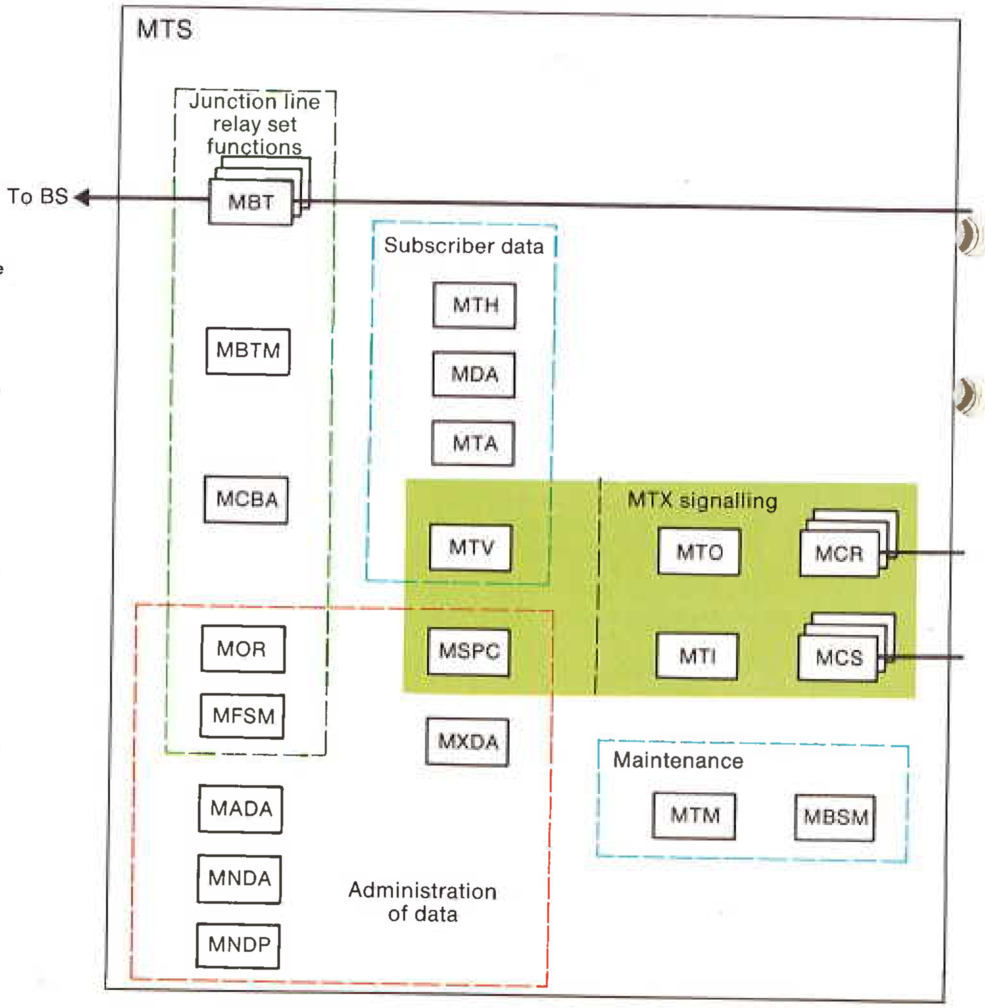

Fig. 8
The basic distribution of the functions in subsystem MTS different function blocks

Blocks required only for roaming

Junction line relay set functions
- MBT Signalling towards BS and mobile stations
- MBTM Operation and maintenance of MBT in accordance with the AXE 10 standard
- MCBA Checks the transmission of calls to mobile stations
- MOR Controls the base stations, executes commands regarding the changeover to and from the emergency traffic state. Calculates and regulates the number of traffic channels that are to be kept free for calls from mobile stations
- MFSM Determines the data for the supervision of call quality. Orders and evaluates field strength measurements

Subscriber data
- MTH Stores information regarding the barring category and traffic area for resident subscribers
- MTV Stores information regarding the barring category and traffic area for visiting subscribers
- MDA Analyzes subscriber numbers and converts them into internal numbers
- MTA Controls the setting up of calls

MTX signalling
- MTO Controls the outgoing signalling
- MTI Evaluates incoming signals
- MCR Code receiver
- MCS Code sender

Administration of data
- MADA Interprets commands for the administration of the analysis table in MDA
- MNDA Administers data for the traffic areas, BS and radio channels
- MNDP Controls the printout of data for the traffic areas, BS and radio channels and supervises the call quality when so ordered
- MSPC Used for the transmission of updating information over point-to-point circuits between exchanges
- MXDA Receives commands for data via MTX

Maintenance functions
- MBSM Receives alarms from BS and commands to reset alarms from BS

public network that are intended solely for this type of traffic.

Subsystem MTS in the exchanges also contains the operation and maintenance functions, including command functions, which are required for MTS, as well as functions for the transmission of alarms from the base stations. Moreover, by means of commands it is possible to indicate individual channels for testing and checking the connection with the mobile station. A block diagram of MTS and brief descriptions of the function blocks are given in fig. 8.

The normal AXE charging subsystem is also used for the mobile subscribers. Outgoing calls are charged by means of toll ticketing. If a country has more than one MTX, the charging data from all MTXs must be processed together, since a mobile subscriber can have made outgoing calls from several of them. If several countries are covered by a common mobile telephone system which permits roaming, the output data from the toll ticketing must be used in the accounting between the administrations in these countries.

If an administration so desires, the mobile subscribers can also be charged for incoming calls or charged an extra fee for calls via "visited" MTXs. Toll ticketing must then be used.

Base radio stations

The base radio stations, which are connected to the telephone exchanges via point-to-point circuits, fig. 1, handle the radio communication with the mobile stations. They function primarily as relay stations for the line signals. They also supervise the quality of the radio circuit with the aid of a pilot tone.

Magnetic AB in collaboration with SRA are developing a base radio station for the Nordic mobile telephone network. SRA is responsible for the important control and supervision parts. Otherwise the base radio station is a slightly modified version of a type that has been in operation for a number of years in manual mobile telephone systems in Scandinavia. These systems have proved to be very satisfactory. The block diagram of a base station is shown in fig. 9.

Each channel has a transmitter TX, a receiver RX and a control unit CU. The control unit matches the base radio station to the exchange. It controls the signalling between base station and exchange. It also controls the transmitter and receiver as well as the fault supervision in the base station. A message is sent to the exchange if a fault occurs in the station. The control unit also generates the pilot tone and evaluates the

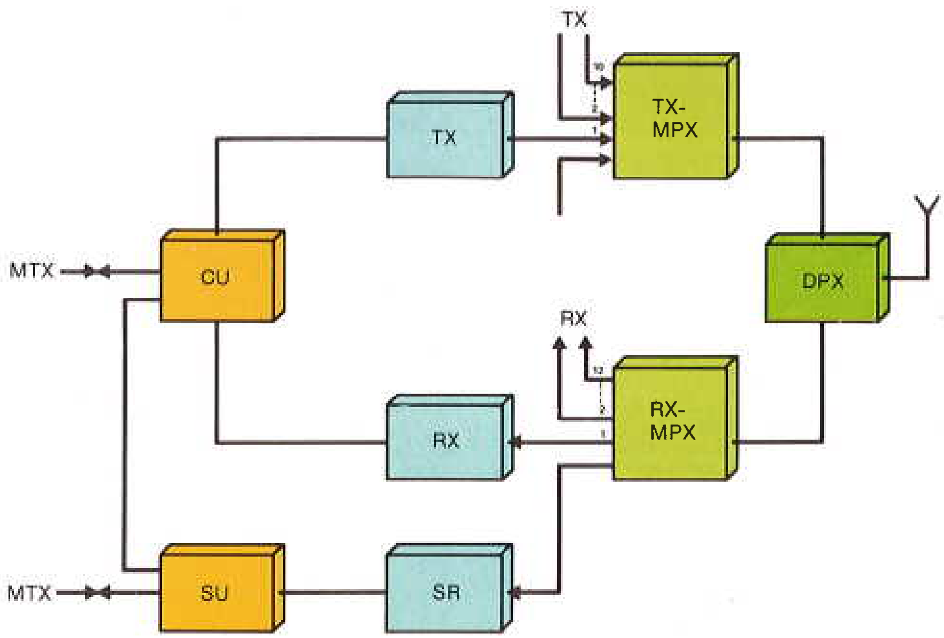

Fig. 9
Block diagram for a base station

CU	Control unit
TX	Transmitter
RX	Receiver
TX-MPX	Multiplex equipment for transmitters; enables several transmitters to be connected to a common antenna
RX-MPX	Multiplex equipment for receivers; enables several receivers to be connected to a common antenna
DPX	Duplex filter; enables transmitter and receiver to use the same antenna
SR	Receiver that measures the field strength
SU	Supervisory unit

Fig. 11
A mobile telephone with a push-button set for dialling, number panel that shows the dialled number, special key HF for changeover to the loudspeaker, on—off switch and volume control. The subscriber number is shown to the right

quality of the tone that is returned from the mobile station. The control unit is built up around a microcomputer.

The transmitter-multiplexor TX-MPX makes it possible to connect up to 10 transmitters to a common antenna. This is an extremely valuable facility, since the masts in which the antennas are mounted can be quite crowded. It is sometimes necessary to use the same mast for up to 100 channels.

The receiver-distributor RX-MPX makes it possible to connect up to 12 receivers to a common antenna. Transmitters and receivers can also be connected to the same antenna if a special duplex filter DPX is used.

The field strength receiver SR measures the field strength on any channel ordered by MTX. The result of the field strength measurement is used to decide whether the call in progress should be switched to another base station.

The supervisory unit SU controls the signalling between the field strength receiver and MTX.

Fig. 10 shows the layout of a base radio station. The station has a modular structure with the channel equipment constructed as plug-in units in cassettes. A rack holds equipment for up to 8 complete channels, with the exception of the transmitter-multiplexor. The latter, which consists mainly of cavity filters, is mounted in a separate rack, one TX-MPX for every five transmitters.

Thus the amount of space required is very small and service and maintenance extremely simple.

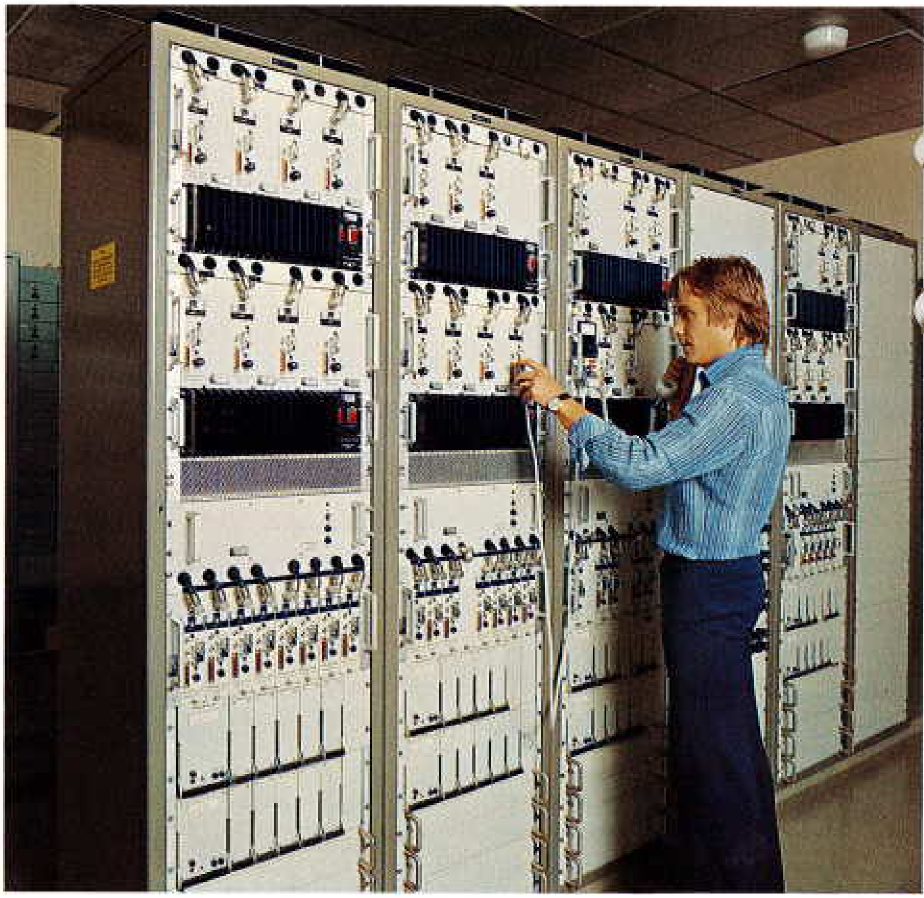

Fig. 10
The base radio station equipment without the transmitter—multiplexor.
Each rack holds four transmitters in the top shelf, a power unit beneath these, and then again four transmitters and a power unit. Below these come the receiver-multiplexor and eight receivers. The following shelves hold eight CU, one SU and one receiver for field strength measurements

Mobile subscriber equipment

The mobile subscriber equipment, the mobile station, is shown in fig. 11. It offers a number of useful facilities for mobile subscribers. A brief summary of them is given here.

- Push-button set, which gives simple and fast dialling.
- Pre-selection, which means that the dialling and checking of the dialled number on the number panel can be done before the subscriber lifts the handset. This prevents many wrong numbers. Furthermore the channel is not occupied during the time it takes to dial.
- Abbreviated dialling with one or two-digit numbers for subscribers who are often called. The number information is stored in the mobile station.
- Loudspeaking telephone, which means that the calling procedure can be carried out using only one hand. However, in this case it is necessary to operate a fixed microphone during the call, for example a microphone mounted by the steering wheel, and equipped with a special speech key, since the interference level is often high in a vehicle.
- A service indicator, which indicates when the subscriber is within reach of the base station network.
- An indicator, which gives persistent indication of incoming calls. If the subscriber has left the car temporarily, on his return he can call the person from whom he expects a call.
- Volume control, for regulating the sound level of incoming call.
- Normal subscriber facilities that are available in AXE 10.

A block diagram of the mobile station is shown in fig. 12. The design is based on the latest development in digital frequency synthesis (see "What is digital frequency synthesis?" on page 36) and LSI and computer technology. The complex mobile station could not have been made so small and been manufactured at a reasonable cost if this revolutionary development had not taken place.

The control unit, fig. 12, is built up around a microcomputer. It is used for complex signalling functions, and also to provide the subscriber with extra facilities, such as abbreviated dialling, without any appreciable extra costs.

The radio part is built up of a number of MSI and hybrid circuits, a total of three monolithic and five hybrid circuits, in order to reduce its weight and volume. The frequency generator of the radio part is based on digital frequency synthesis.

The installation of the mobile telephone station is simple and flexible. It is usually mounted in a cassette, as a single unit, and will then fit in, for example, a normal car radio compartment. However, the station can also be divided up so that the control part is placed where it is easily accessible to the driver, the remainder of the equipment being placed elsewhere in the vehicle.

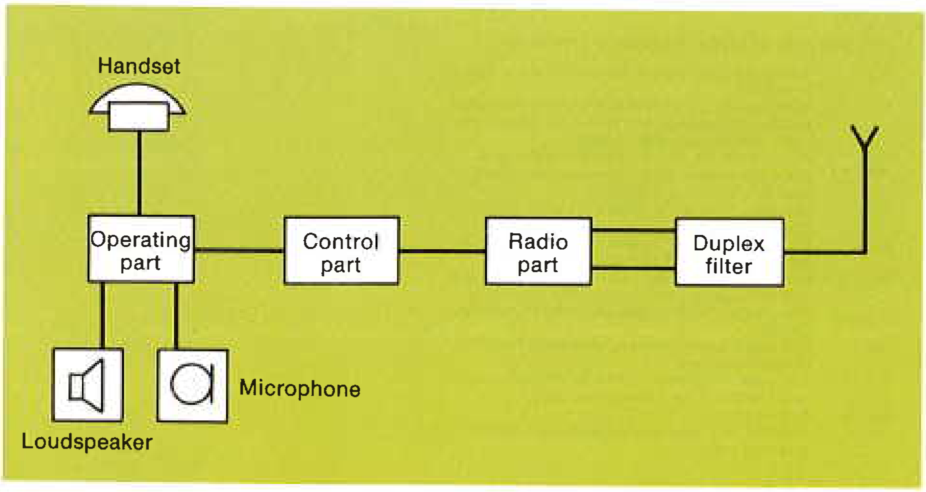

Fig. 12
The function units in the mobile station.
The operating part contains the push-button set and the number panel for checking the dialled number.
The control part handles the necessary signalling towards MTX, for example for setting up and disconnecting calls, and the control of the radio receiver and transmitter, for example channel selection, start of the transmitter, opening of the speech path etc.
The radio part handles the transmission to the base stations. The duplex filter makes simultaneous sending and receiving possible

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2. Ericsson, B. and Roos, S.: *Digital Group Selector in the AXE 10 System.* Ericsson Rev. *55* (1978):4, pp. 140–149.

Fading

Fading of radio transmission, caused by multiple propagation as a result of reflection along the transmission path, makes special demands on the signalling system. Fading often manifests itself as large field strength variations, often 20–30 dB, with deep troughs for some milliseconds (depending on the frequency band and the speed of the vehicle). As regards data transmission this means that bursts of bit errors occur. Modern encoding theory provides special error-correcting codes that give protection against these error bursts. Here a Hagelbarger falting code with a span of 6 is used. This code manages error bursts of up to 6 bits, as long as the distance between two bursts is at least 20 bits. Thus the code can handle most errors caused by fading.

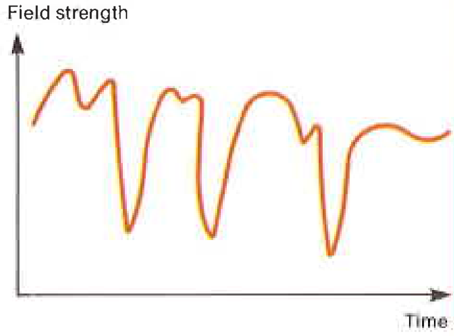

Fig. 13
Typical variation of the field strength with time, as a result of fading

What is digital frequency synthesis?

The traditional method for determining the transmitter and receiver frequency in a radio station was to use a control crystal for each channel. The number of possible channels in a radio station was then limited for reasons of space and cost. One solution for multi-channel stations was to use mixed synthesis. By using a combination of two crystal banks of m and n crystals respectively, it was possible to derive $m \times n$ frequencies. The method requires careful choice of crystal frequencies and poses many production problems if the wanted frequencies are to be sufficiently pure. Moreover it is still expensive and space-demanding.

With digital frequency synthesis, on the other hand, it is in principle possible to derive hundreds of frequencies from a single crystal using the basic diagram shown in fig. 14. The wanted frequency is obtained from a voltage-controlled oscillator in a regulation loop. The oscillator frequency is divided down in a programmable divider and is then compared, in a phase detector, with a reference frequency derived from a stable control crystal. The error signal from the phase detector adjusts the voltage-controlled oscillator until the error signal is zero. If the division factor in the programmable divider is changed, the frequency of the output signal will also be changed.

The version of digital frequency synthesis that is commonly used is slightly modified. An extremely stable oscillator with a fixed frequency is used to reduce the frequency to the programmable divider, so that the practical difficulties of high-frequency dividers are avoided, as shown in the added part of fig. 14.

The basic principle of digital frequency synthesis is not new, but it is only during the 1970s that it has been possible to put it into practice, thanks to the development of fast dividers. There are special circuits available for synthesis, which contain divider and phase detector on the same chip.

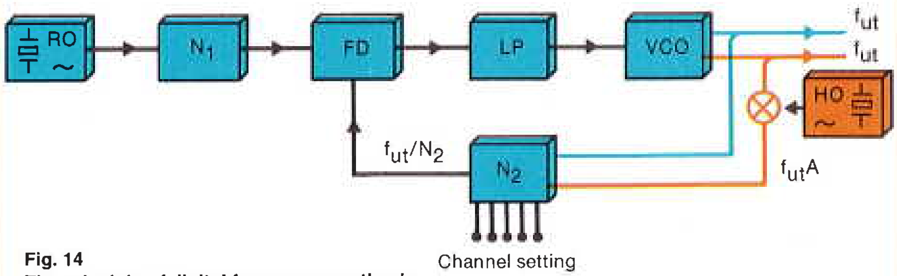

Fig. 14
The principle of digital frequency synthesis

RO	**Reference oscillator, which provides a stable frequency**
N_1	**Fixed divider, which divides down the reference oscillator frequency to a reference frequency (=the channel spacing 25 kHz)**
FD	**Phase detector, which gives an error signal when the divided output frequency deviates from the reference frequency**
LP	**Low pass filter, which filters the error signal from FD**
VCO	**Voltage-controlled oscillator, which is controlled by the error signal from FD**
N_2	**Programmable divider, which divides down the output frequency to the reference frequency. The division factor is determined by the channel setting**
HO	**Extremely stable oscillator with fixed frequency**
f_{ut}	**Output frequency**
$f_{ut}A$	**The output frequency after it has been transposed by HO so that it is matched to N_2**
	Basic version
	Addition for reducing the frequency so that it is matched to N_2

Printed in Sweden. Ljungföretagen, Örebro 1981