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GUIDE ON MOBILE RADIO FOR THE ELECTRICITY UTILITIES

Working Group 04
of
Study Committee 35
(Communication and Telecontrol)

October 1985

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1 INTRODUCTION

A reliable and effective communications network is an essential feature of an electricity undertaking's operational and engineering functions, contributing to the safety of personnel, the public and plant, and optimising the available resources of the organisation. As a result, the quality of service to the customer is considerably enhanced.

Mobile radio enables the communications network to be extended to the man in the field, whether he be on the move or located at some remote part of the organisation. It provides a communication facility which is continually available and adaptable to meet the needs of routine operational activity or to cater for the unpredictable requirements of an emergency. Radio communication has achieved a place of considerable importance in the activities of electricity supply operational work, and safety is to a very large extent dependent upon its availability. The telecommunications engineer therefore has a responsibility to ensure that the mobile radio network is designed to provide full terrain coverage of the undertaking's area of supply, or as near to this as can economically be achieved, and to maintain the performance of the network to the highest standards, so that an efficient and reliable communication service is always available.

At the time that this Guide was in preparation, considerable progress was being achieved in the development of mobile radio equipment of advanced design, taking advantage of new solid state technology and making available at comparatively low cost novel features which would increase the speed of communication and add to the versatillity of the networks. Microprocessors were being introduced into the calling and connect circuitry, and considerable effort was being expended to optimise the use of frequency spectrum because of the increasing demands by a wide variety of users for more radio frequencies.

On the question of mobile radio network design, users were taking conscious steps to reduce interference between networks by paying more attention to the location of main station transmitter sites, antenna configurations and heights, and radiated powers. The well established idea of using the highest available sites, masts and towers, and radiating the maximum power was fast losing favour, and one was aware of a greater sense of responsibility in the use of radio spectrum. Computer aided design of radio networks, using topographical data bases and propagation models had been widely applied in some countries with considerable success, and with new laser methods of compiling topographical data coming into use, it can be expected that this aspect of network design will become increasingly used.

This Guide has endeavoured to provide information on every facet of mobile radio communications in the service of the electricity supply undertakings, in order that telecommunication engineers can design the type of network best suited to their needs, and at the same time the Guide seeks to draw attention to the responsibilities of those who are making use of an extremely valuable commodity, radio spectrum.

It has not always been found possible to provide a great deal of practical information on some of the newer developments such as trunking and cellular radio, because of the limited operational experience so far available, but it is hoped that the Guide demonstrates possible applications of these techniques to the future needs of the undertakings, and provides sufficient technical detail to enable readers to research more widely into these subjects should they so wish. Otherwise the document brings together a very wide range of experience from many different countries, and the reader will find in the following pages technical material which has been carefully and thoughtfully compiled by telecommunication experts from the mobile radio manufacturing industry and from the electricity supply undertakings.

Finally, it is hoped that power engineers and telecommunication engineers who wish to improve their knowledge on the subject of mobile radio, will find that this Guide makes an instructive and useful addition to their technical knowledge.

2 NETWORK CONFIGURATON

The best network configuration takes into account a wide variety of factors, many of which are peculiar to the local situation. Other factors include the coverage area, the number of control points and the frequencies to be used. This Section deals with the basic common factors.

2.1 Types of Systems

2.1.1 Simplex Systems

The simplest form of a communications system is the single frequency simplex network - where a radio channel utilizes a single frequency, see Fig. 2.1. Every party within the system may participate in the communication as long as sufficient coverage is present.

A different type of a simplex system is the two frequency simplex network, where a radio channel consists of two different frequencies i.e. the transmitted frequency is different for the two different directions of transmission, see Fig. 2.2. In this type of system the mobiles can communicate with the main station but cannot normally communicate with each other.

2.1.2 Semi-Duplex Systems

To enable mobiles to intercommunicate and to simplify the provision of other facilities, the semi-duplex system is preferred, using two frequencies. In the semi-duplex system the main station operates in the duplex mode and the mobiles operate in the two frequency simplex mode. The main station is further provided with a "talk-through facility", see Fig. 2.3. Now all mobiles can communicate directly with the main station and via the main station, with the "talk-through facility" switched on, with each other.

"Talk-through" is an optional facility, whereby signals received at the main station on f2 are re-transmitted as f1. In effect, the main station operates as a repeater for the mobiles, which is the mode normally used for electricity supply industry networks.

The semi-duplex arrangement can be further developed to provide remote control of the main station form a fixed location, as shown in Fig. 2.4. Here, the main station is either in a permanent "talk-through" condition or can be switched into the conditon by a suitable coding arrangement.

2.1.3 Duplex Systems

In duplex systems the mobiles and any remote control sites, together with the main station all operate in the duplex mode, see Fig. 2.5. This arrangement is not yet available for hand-portable equipment. The main station can communicate with all mobiles, but the latter cannot communicate with each other. If, however, communication between two vehicle sets is required, two channels are necessary, each mobile utilizing a separate pair of frequencies (a channel) and the main station supplied with talk-through facilities, enabling the two channels to be linked together.

This arrangement uses more frequencies and may therefore be undesirable. It is possible to establish a talk-through facility using a single channel. The mobile duplex sets must be able to operate in the two-frequency simplex mode.

Link systems with or without back-to-back repeater stations (talk-through stations) are mainly operated in the duplex mode, see Fig. 2.6.

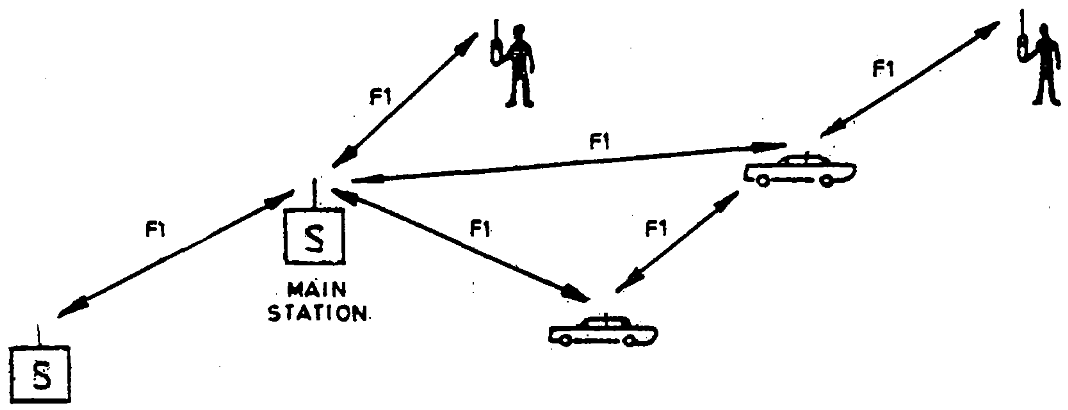


FIG. 2.1. SINGLE FREQUENCY SIMPLEX NETWORK

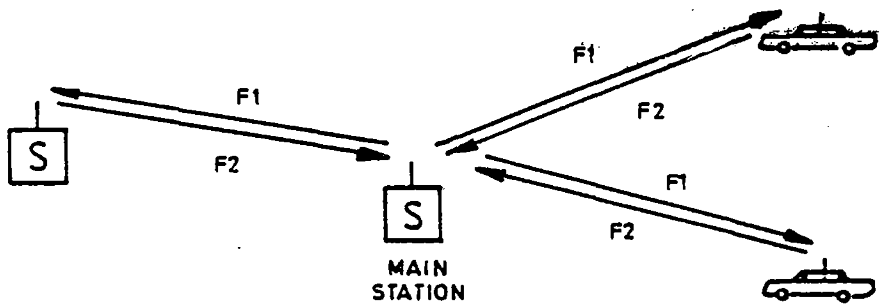


FIG. 2. 2. TWO FREQUENCY SIMPLEX NETWORK

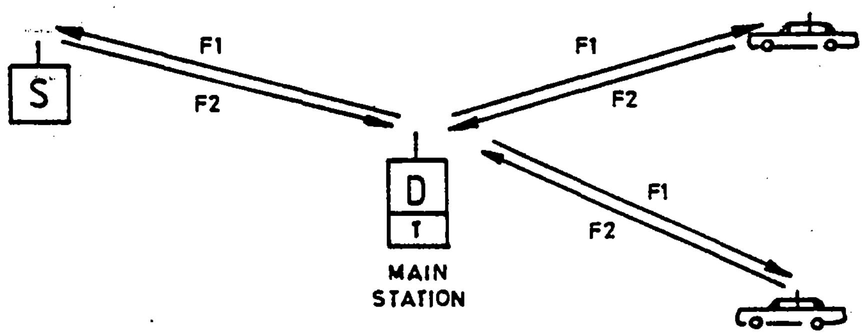


FIG. 2.3. SEMI-DUPLEX SYSTEM

LEGEND

FIXED STATIONS

SIMPLEX MODE S

DUPLEX MODE D

FIXED STATION WITH TALK - THROUGH FACILITY D / T

VEHICLE SETS

SIMPLEX MODE 

DUPLEX MODE  D

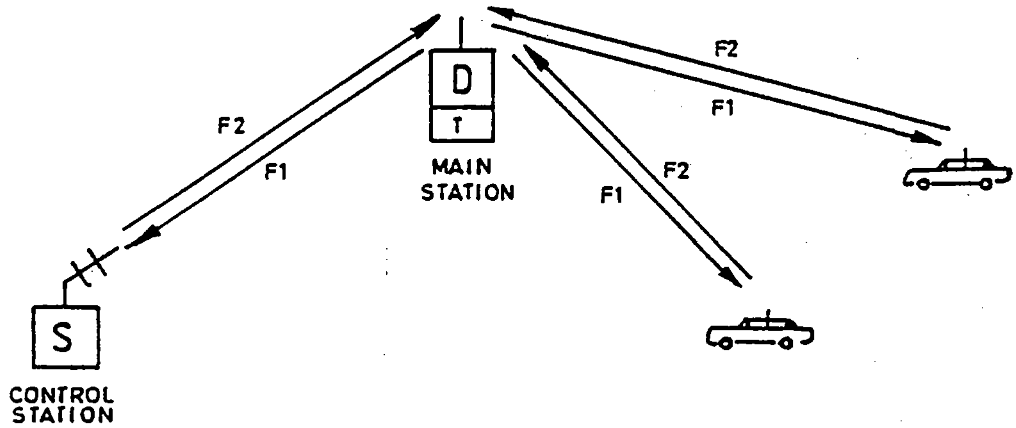


FIG. 2. 4. SEMI-DUPLEX SYSTEM WITH REMOTE CONTROL

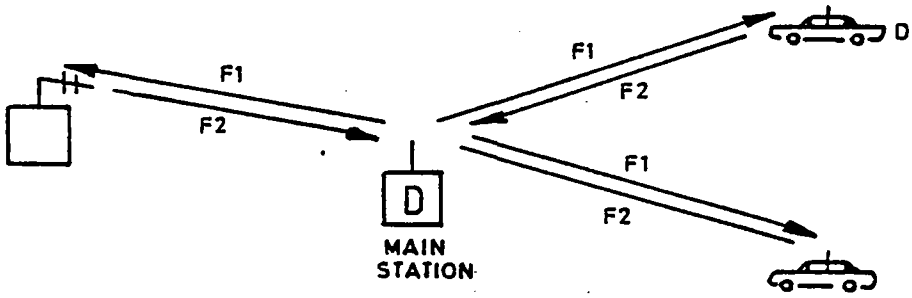


FIG. 2.5. DUPLEX SYSTEM

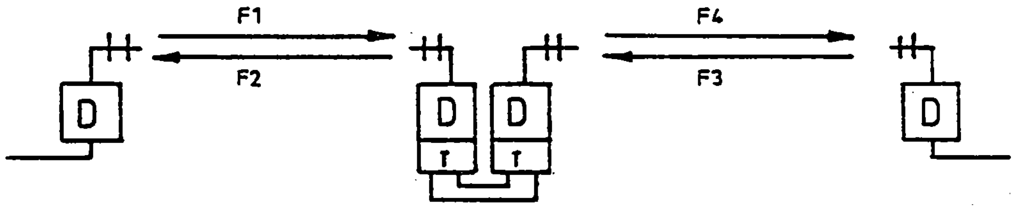


FIG. 2. 6. LINK SYSTEM WITH BACK-TO-BACK REPEATER STATION.

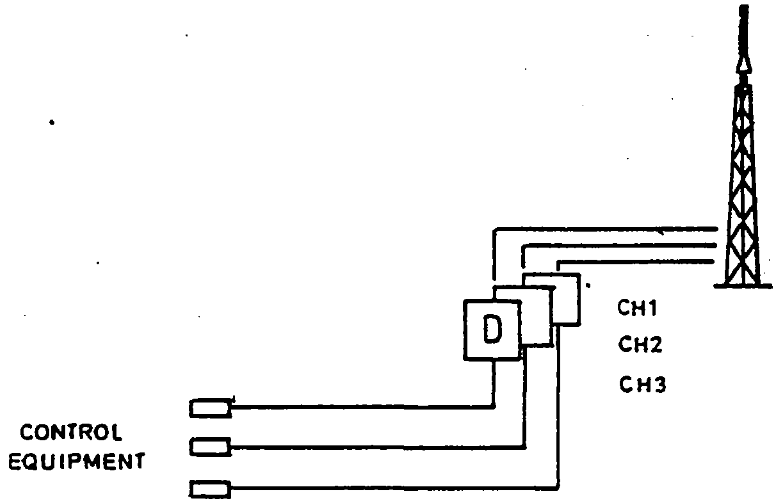
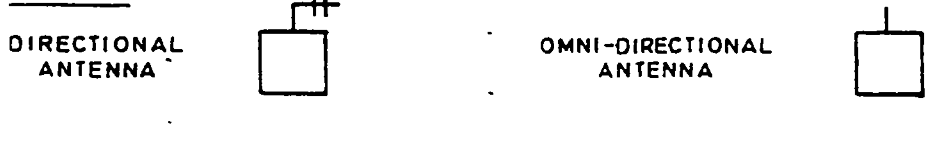


FIG. 2 . 7. SIMPLE MULTI-BASE STATION ARRANGEMENT

LEGEND



2.1.4 Simplex/Duplex Arrangements

The selection between single frequency/two frequency simplex, semi-duplex or duplex systems is normally not the choice of the user alone. National preferences and conventions together with national PTT assignment policies may dictate the final arrangement.

As a general rule, a semi-duplex network as compared with simplex or duplex networks is more economical to establish and is preferred.

2.1.5 Multi Base Station/Control Networks

When an established network becomes overloaded due to the number of mobile sets, a high calling rate per vehicle, extended duration of calls, all resulting in an unacceptable high waiting time for establishing calls, extra channel capacity is needed. The easiest way of adding channels to an existing network is to add extra transmitters and receivers at the main stations, each with its own control arrangement, see Fig. 2.7.

This type of independent control arrangement is very limited in its facilities, due to the permanent connection between the control and the associated main station.

A modern multichannel network with enhanced flexibility is shown in Fig. 2.8. The common switching terminal (CST), connected between the operator positions and the main stations, is based on a modular concept. A common cabinet with a common power supply carries the necessary modules for each channel; switching modules (AC and DC), signalling equipment, audio circuits for each operator and for each channel together with common switching units to cross-connect operators and selected channels. This expandable design allows all normal control functions for each channel such as transmitter keying, connect voice signal to transmitter, generate selective call, transmit selective call, receive and decode vehicle identity, receive voice signal, together with the all or some of the functions:

- All incoming calls can be monitored by all operators, one of whom can respond whilst the remaining operators are automatically disconnected from the call but receive lamp indication on their consoles showing that the particular channel is busy.

- An operator can broadcast an emergency or other type of call on all channels.

- A particular channel can be switched to one operator on a pre-arranged basis.

- Remote main station alarms can be signalled automatically and displayed on the CST.

2.1.6 Fully Automatic Systems

All the networks so far have required the participation of an operator to establish the connection between a mobile and some fixed location.

The problem of manning a control or main station for 24 hours a day with three shift operation, makes heavy demands on manpower. This fact, combined with the increasing costs, has led to the establishment of switched networks with fully automatic operation. Fig. 2.9 shows an example of such a system.

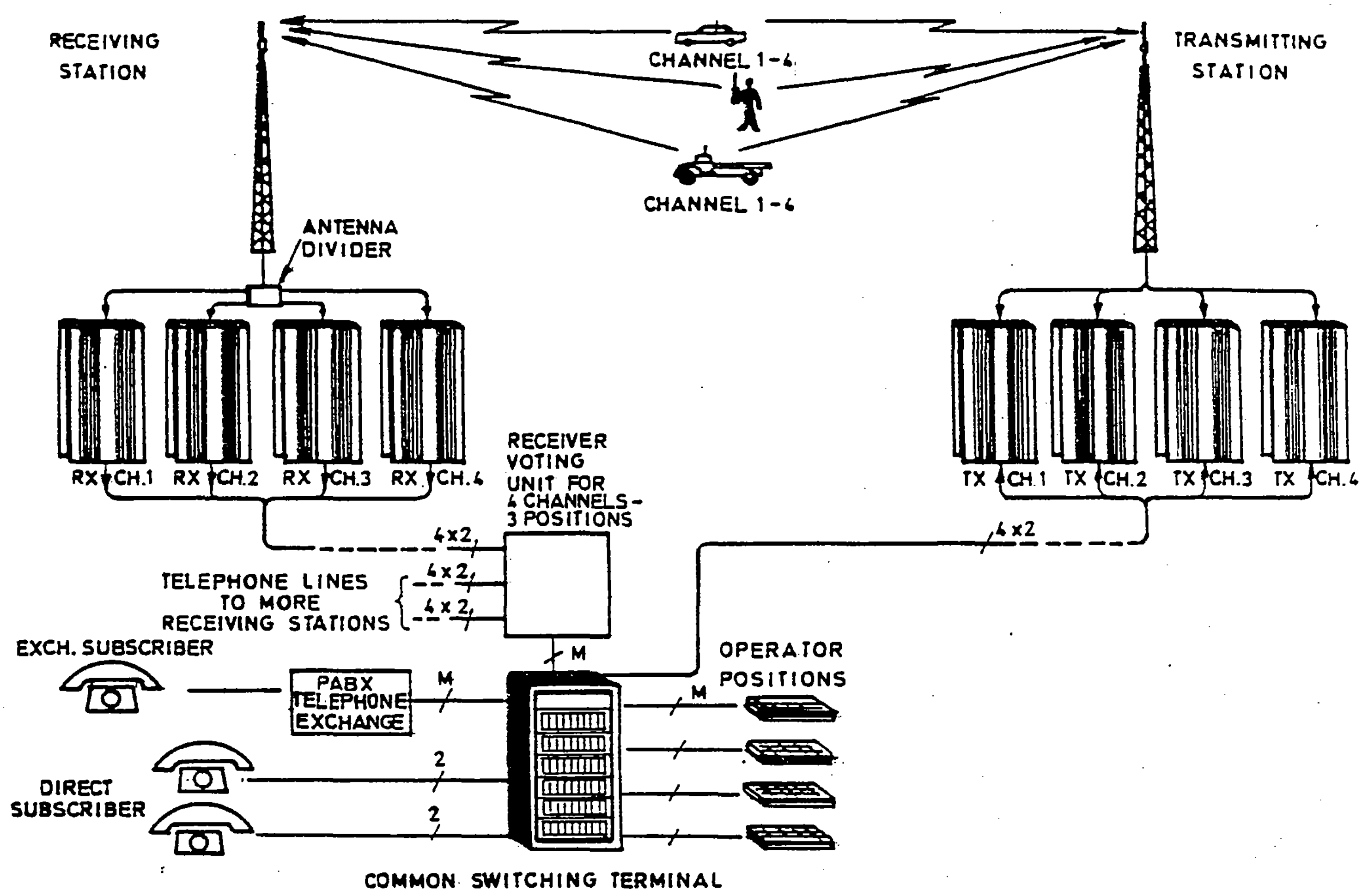


FIG. 2.8. MULTICHANNEL DISPATCHING TYPE OF NETWORK

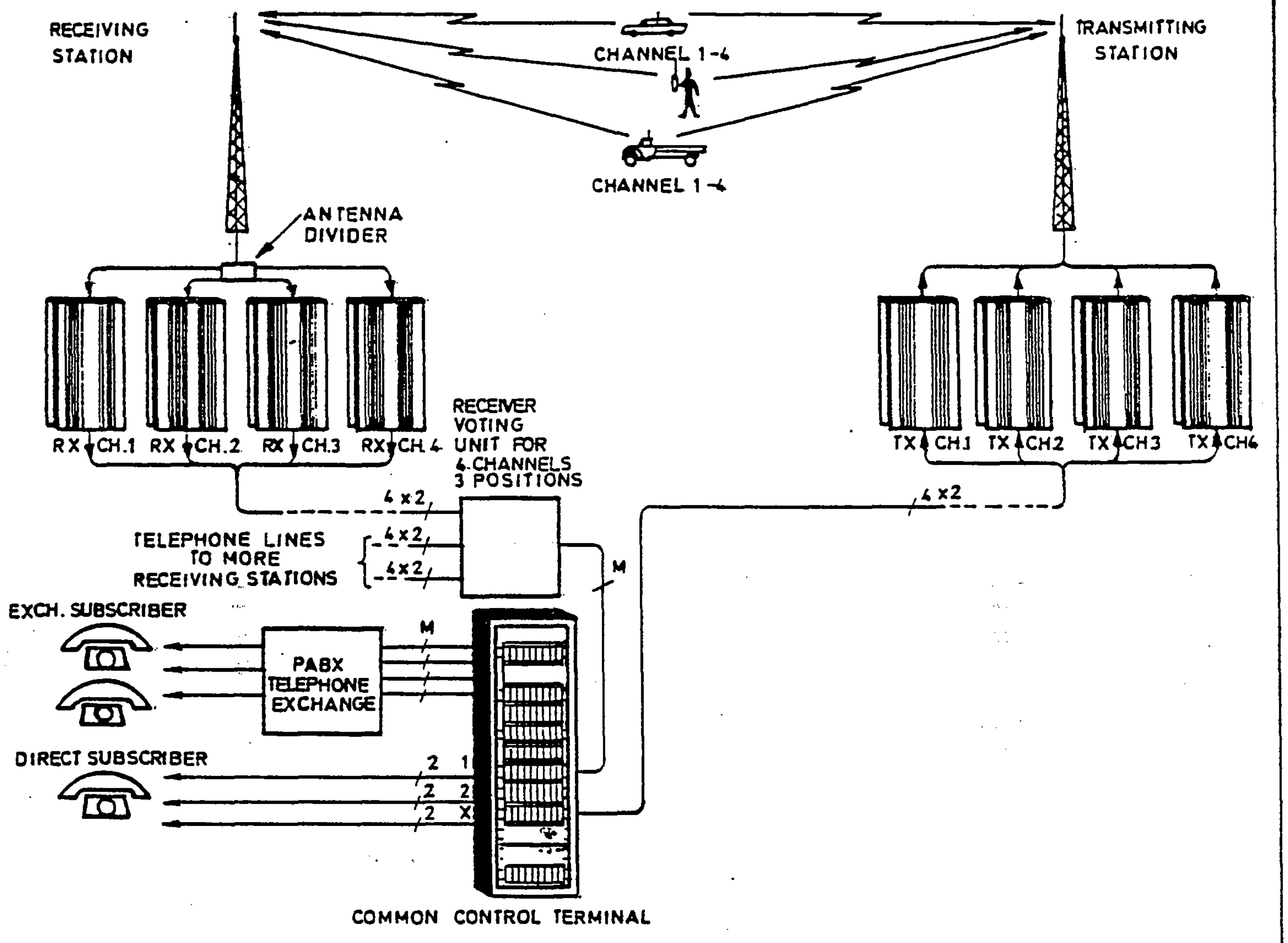


FIG. 2.9. MULTICHANNEL FULLY AUTOMATIC NETWORK

The common control terminal (CCT) is a microprocessor controlled switching device based on plug-in modules for all switching, encoded and voice signal handling. Being the heart of the main station equipment, it is connected to several exchange lines from the company PABX or PAX, to several internal telephone extension lines, or via rented land lines to the remote controlled transmitters and finally connected to the receiver voting units (see below). The receiver voting facility overcomes the difference in signal levels of high power main stations and lower power mobiles and personal sets.

The operation of this type of system resembles that of a standard automatic telephone system. The vehicle operator is relieved of the burden of manually selecting channels. The vehicle set automatically searches for incoming calls and automatically selects a free channel when originating calls. This random access utilization of channels allows maximum traffic to be carried and further allows traffic/channel capacity calculations to be made as for wired telephone systems.

This type of system provides three paths for calls:

(i) telephone extension to mobile,

(ii) mobile to telephone extension,

(iii) mobile to mobile (with the conditions stated in the previous sub-section).

It should be noted that personal handheld sets may also be used in this type of system. The vehicle sets utilize a control unit with push button dialling facilities.

2.2 Principles of System Management

2.2.1 Signalling - Selective Calling

Even with a small number of vehicles on a channel, the task of constantly monitoring the channel for incoming calls becomes tedious. One way to relieve the problem is to introduce selective calling. Selective calling automatically allows a mobile in the stand-by mode to have its loudspeaker switched off. Only when the proper code, transmitted as tone signals in the voice frequency range, is received and decoded will the loudspeaker switch on to enable the speech message to be heard. The mobile thus hears only those messages which are intended specifically for it. Each mobile has its own discrete code, and other codes can be arranged to call groups of mobiles or all the mobiles.

This subject is dealt with at greater length in Section 9.

2.2.2 Remote Control

To enable the optimum sites to be used for main stations or control station transmitters/receivers, remote control is an essential feature of the system.

Typical reasons for remote control are:

- Main station control must be situated in a city, but the position is too noisy for receiver purposes.

- Main station transmitters and receivers may be separated in order to minimize interference problems.

- Several groups of receivers may be widely separated from each other (receiver voting system).

2.2.3 Remote Control using a Telephone Line

This form of control uses a telephone line pair (TLP), which may be rented or privately owned. A TLP is normally a two-wire audio circuit, nominal impedance 600 Ohms with a loop resistance preferably not exceeding 2000 Ohms. The minimum frequency response should preferably extend from DC to 3000 Hz with a reasonably flat frequency response between 300 and 3000 Hz. The DC-path provides a simple method of transmitting control functions such as: key transmitter, change channel, "enable talk-through" facility, RF-carrier is being received, power failure, field-strength equivalent DC-current (for receiver voting facility). Fig. 2.10 shows both the transmitting end (M) and the receiving end (E) for a remote control arrangement. The principle used is based on line transformers with tapped secondary, a DC-current generator, a relay circuit and a frequency response/amplitude compensation unit for re-establishing the overall frequency response/audio level, when a line of poor quality is used. By using a combination of different current levels and polarities, several remote functions may be combined on the same line pair.

With the introduction of PCM and the introduction of digital telephone networks, it is becoming increasingly difficult to achieve remote control by means of DC on rented lines. In such cases AC-control is used. At the transmitting end (M) a tone, with the audio band is superimposed on the voice signal, at a low level. At the receiving end (E) the tone is filtered from the combined voice/tone signal - amplified, rectified and can thus operate as a DC-control function, as shown in Fig. 2.11. This method is much to be preferred in view of the increasing difficulty of obtaining DC line circuits. It also enables a larger number of control facilities to be obtained.

2.2.4 Radio Links

Where line control is undesirable or impossible to establish, a radio link is used. The link can be established using standard VHF or UHF main station or mobile equipment on the same frequencies as the mobiles. Alternatively, special radio link frequencies may be used. Fig. 2.6 shows a link system with one back-to-back repeater station (2-way talk-through station added to extend the length of the link connection). The link system shown provides a duplex transmission circuit. If several ciruits over the same path are required, multichannel link equipment must be used, allowing several audio channels to be transmitted on one radio channel. This type of equipment operates on specific radio link frequency bands.

2.2.5 Receiver Voting (RV)

When large areas must be covered using low powered mobiles operating within the range of a higher powered main station transmitter, RV enables a path to be established from the mobile transmitter.

The system uses several receivers working on the same frequency, placed within the coverage area of the main station transmitter. For instance each receiver is supplied with a control unit which converts the received signal strength to an equivalent DC-current and all receivers are connected to a common voting unit by means of land lines. The voting unit selects the receiver with the best signal.

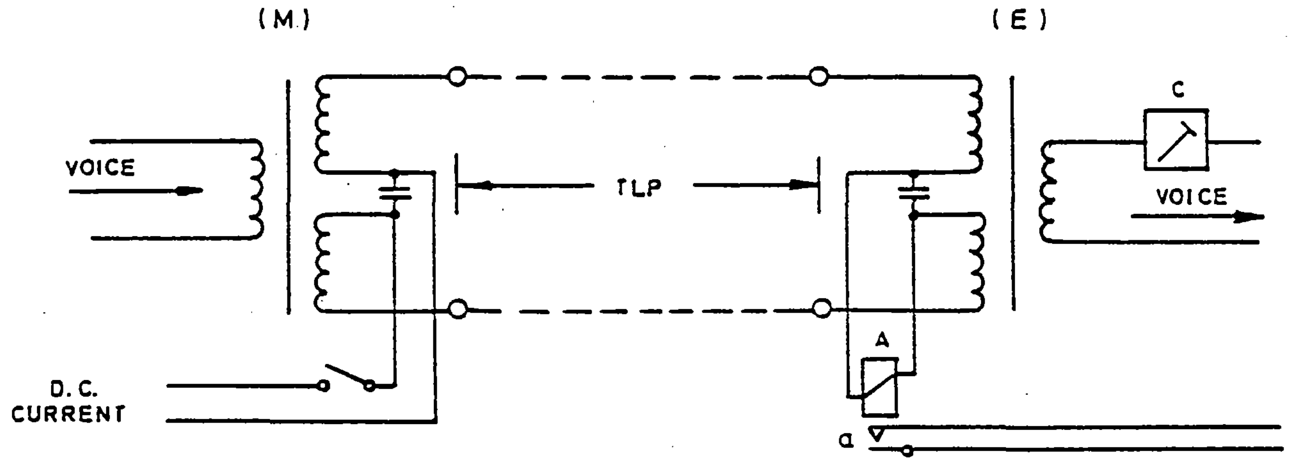


FIG. 2.10. PRINCIPLE FOR DC-TYPE OF REMOTE CONTROL ARRANGEMENT.

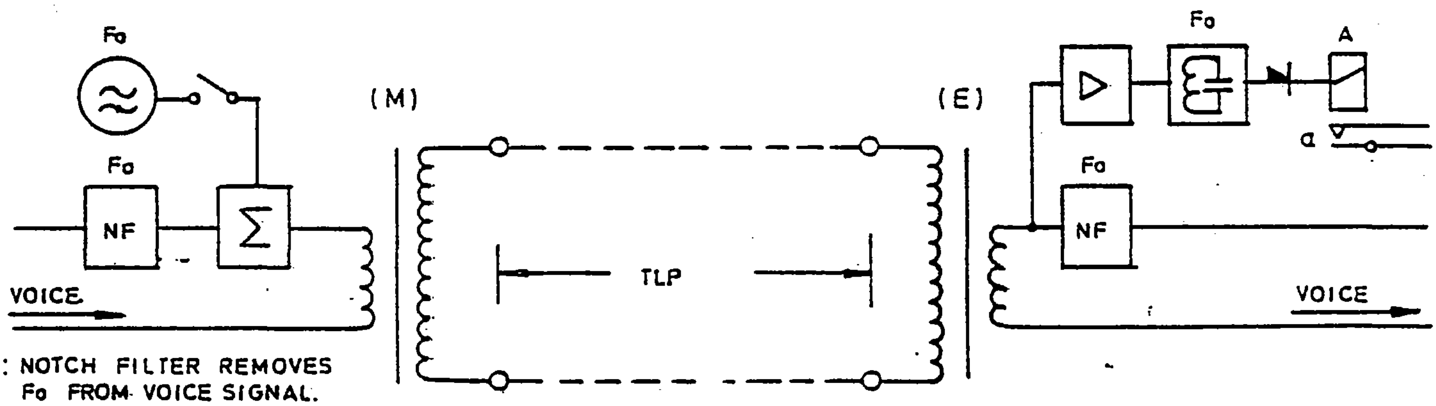


FIG. 2.11. PRINCIPLE FOR AC-TYPE OF REMOTE CONTROL ARRANGEMENT.

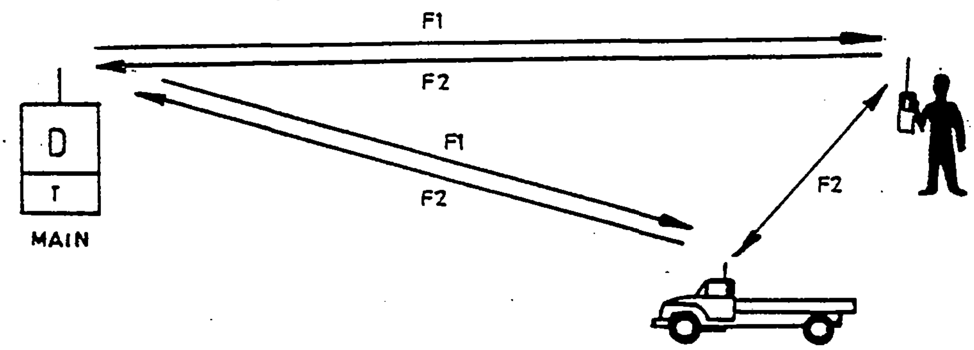


FIG. 2.12. NETWORK WHERE THE RECEIVER IN THE VEHICLE / PERSONAL SETS ARE OF THE WIDE-BAND OR DOUBLE RECEIVER HEAD TYPE

For technical details consult Section 10. Examples are shown in Fig. 2.8 and 2.9.

2.2.6 Quasi-Synchronous Transmission (QST)

Where difficulties are experienced in obtaining full radio coverage of an area by a single main station transmitter/receiver, QST together with receiver voting may be a solution. QST enables several transmitters to operate simultaneously on the same channel, controlled remotely from a common control centre. For technical details consult Section 10.

2.2.7 Wide-band receiver operation

It is often required that vehicle/personal sets of the two-frequency simplex type should operate together, with direct communication between the units. As described in 2.1.1 and 2.1.2 this can only be achieved if the main station is equipped with a talk-through facility.

If, however, the vehicle/personal sets are provided with a receiver with wide-band (or double receiver head) facility, enabling the sets to operate both in the two frequency and the single frequency simplex mode, the requirement can be met.

Fig. 2.12 illustrates this. The frequencies F1 and F2 form the two frequency channel when communicating with the main station, but frequency F2 is also used for both transmit and receive between vehicle and personal sets.

3. COMMUNICATION TRAFFIC REQUIREMENTS AND CONSIDERATIONS

3.1 General

Mobile radio systems, from the point of view of the service and traffic, can generally be considered as waiting type systems with random calling. If the user did not have continuous indication of the occupancy status of the network and was only made aware of channel occupancy after each call request, a percentage of call attempts would be abortive. It is also very desirable that the user knows if he is in the area covered by the main or repeater station and whether satisfactory communication is possible. These very desirable features require that the user's equipment continuously provides indications on channel or network availability.

In systems providing this facility, it follows that each call is sent only after the network availability has been ascertained by the user. As a consequence, the sending process of calls (emission process) is of the "waiting" type: the user who has found the network unavailable waits and sends his call as soon as an indication of network availability is received. However, whilst in classic telephone systems calls are automatically stored and then sent according to a pre-determined pattern, in mobile radio networks the calls are sent manually by each user. The users therefore do not gain access to the network in accordance with any set criteria, even if with delay; they have access to the network only by a random process.

This process depends on calls from other users who have successfully obtained access, or on sending a call more rapidly than other users or on the probability of reaching the main or repeater station with a stronger RF signal.

Therefore mobile radio systems usually belong to the category of waiting type systems with random service.

In evaluating the performance of a mobile radio system, or in designing it, the main parameter to be considered is the Mean Waiting Time (Tm). This is one of the important parameters in calculating the number of channels needed to carry a given traffic.

Another important parameter to be considered is the Waiting Probability (Pa).

Nevertheless, when designing mobile radio networks, considering the wide variation in waiting times around their mean value due to the random calling, it may be convenient to verify other parameters, such as the probability that the waiting time is greater than a given value. Appendix A gives more detailed information on these parameters, on their relation to the traffic intensity and the number of channels that form the network.

It is usual that the dimensioning of a network takes into account the average traffic intensity in the busiest hour of the day (peak hour). The ideal case for the system designer is when he knows by experimental tests the traffic offered by the users. If this does not apply, the designer must be satisfied with forecasting the traffic intensity in the peak hours by calculations, in which case it is necessary to be very careful in choosing, interpreting and extrapolating data.

Moreover in private mobile radio networks, the traffic generally falls into predetermined groups within specific Operating Units, whereby the calls are generated mainly between an Operating Centre and its mobile units or between a leader and his staff. This generates traffic unsymmetry. Appendix A contains information on these subjects.

3.2 Normal traffic conditions

A research carried out in the United Kingdom on a number of private mobile radio networks, reports (1) that the average traffic intensity offered by each mobile user is about 5.10^{-3} Erlang.

The same report estimates that on the average, during the peak hours, the percentage of "active" users, those who are effectively working and can generate traffic, is nearly 30%.

This means that the mean traffic intensity offered by an active user is about 1.5×10^{-2} Erlang. For mobile radio networks in the service of Electricity Utilities, the traffic offered by each user in normal conditions is estimated to be something less than the above figures.

3.2.1 Single channel networks. Extensive tests carried out in Italy on 12 mobile radio networks serving about 540 users, has shown the following results (note that Saturdays and Sundays have been excluded from the test):-

The long term average traffic offered by each user in the peak hours amounts to about 3.5×10^{-3} Erlang.

Each network, having on the average 45 users, shows a long term average traffic intensity in the peak hours of about 0.16 Erlang.

The standard deviation of the mean traffic intensity in the peak hours relative to its long term average is nearly 82%, in such networks.

The average call duration, better expressed as the "average service time", is about 20 seconds. This figure is typical for private mobile radio networks. The distribution of the service time around the long term average is exponential.

Corresponding to the above values, single channel networks are characterized by the following performance parameters in normal (average) traffic conditions in the peak hours (see also Appendix A):

Waiting probability	15%	(approx)
Mean waiting time	4 sec	(approx)
Mean waiting time when there is waiting	25 sec	(approx)
Probability that the waiting time exceeds 20 sec	7%	(approx)
Probability that the waiting time when there is waiting exceeds 20 sec	37%	(approx)

The distribution of peak hours during the working days usually occurs as follows:

There are two peak hours in the morning, between about 9 and 11 am

There is another peak hour in the afternoon

In the remaining working hours the traffic is about 30% of the peak hours traffic

The traffic in the non-working hours is less than 20% of the peak hours traffic.

3.2.2 Multi-channel networks. Having discussed single channel networks, it is of interest to consider multi-channel trunked networks.

In the case of the tests in Italy mentioned in the previous sub-section, the 540 users of the 12 single channel networks can be served by a single multi-channel network. In order to ensure that performance parameters are not degraded, the new network must have at least K=4 trunked channels.

In this case the service in normal traffic conditions is characterised by:

Waiting probability	12.5%	(approx)
Mean waiting time	1.16 sec	(approx)
Mean waiting time when there is waiting	9 sec	(approx)
Probability that the waiting time exceeds 20 sec	1.4%	(approx)
Probability that the waiting time when there is waiting exceeds 20 sec	12%	(approx)

The table below compares the service with 12 channel networks and a single 4-channels network.

	a) 12 SINGLE CHANNEL NETWORKS	b) SINGLE 4-CHANNEL MULTIPLE ACCESS NETWORK	ADVANTAGES OF THE MULTIPLE ACCESS SOLUTION
Total Traffic	1.836 Erlang	1.836 Erlang	-
Total Traffic Standard Deviation in each network (in percent of the average)	82.3%	24.8%	The traffic variability around its value is reduced: 3.32 times
Waiting probability P_a	15.3%	12.5%	The Waiting Probability is reduced:1.22 times
Mean Waiting Time T_m	0.2 Dm	0.058 Dm	The Mean Waiting time is reduced: 3.4 times
Probability that the waiting time excedes the Mean Service Time (P T D_m)	7	1.4%	The probability is reduced: 5 times
Efficiency for channels in use in the time	0.153 E/ch	0.465 E/ch	The efficiency is 3 times greater

D_m = channel occupancy mean time per call
Pa = Waiting probability
T_m = Mean waiting time
[illegible]

The benefits of trunking systems as against single channel systems are clearly shown.

One of the advantages is the reduction of the standard deviation for the mean traffic in the peak hours. This factor allows an easier and more reliable dimensioning of the networks.

3.3 Channel Arrangements for Emergency Conditions

Emergency conditons can occur when serious or multiple faults occur on the electricity supply system. In these instances, communication traffic may increase dramatically, the performance of the mobile radio networks may be degraded and the waiting times increased as a result. The traffic intensity in an Operating Unit having some tens of users can increase five to ten times above the average.

This situation occurs mainly in those cases when each Operating Unit has a dedicated single-channel network. It is sufficient for the traffic intensity to increase and remain over 0.6 to 0.8 Erlang to cause unacceptable waiting times. From the graphs in Appendix A, it can be seen that the waiting probability can exceed 70% and the mean waiting time can exceed 60 to 80 seconds in single channel networks.

In systems where the traffic is always between a fixed dispatching station and mobile units, two solutions can be considered in order to provide acceptable service conditions.

The first policy requires the introduction of particular rules for access to the network. As an example, calls that are not associated with the emergency situation can be forbidden. Alternatively, all calls from mobile users can be forbidden, whilst calls originated by dispatching centres only are allowed. These rules may depend on the type of service organization, and even when applicable they are scarcely effective.

A more effective technique is to resort to emergency channels. In normal conditions each network operates on a single channel, but in emergency conditions the users can switch to another channel, the emergency channel. This channel can eventually be shared with other networks in the same or adjacent areas, provided that the probability of emergency situations occurring in the different network at the same time is low. The use of emergency channels may complicate calling procedures and channel switching, unless automatic tuning facilities are provided.

It should be noted that, when the traffic is between mobile and base station, waiting may be caused by the unavailability of the dispatcher rather than by channel unavailability. This condition demands some consideration in the design of the system:

> if the traffic is only between a single dispatching desk and mobiles a single channel is sufficient,
>
> if the dispatching centre has more than one operator, then the system can be equipped with more channels.

In some systems it is possible to transmit identification signals from a mobile to the base station, in order to force entry into the network in emergency conditions.

Depending upon system configuration this possibility could appear more theoretical than actual, because if more users ask for the channel, the winner is always the one having the best signal path to the base or repeater station at the moment of sending, independently of any other considerations. For the same reason, mainly in the case of angular modulation, when the channel is occupied a user cannot enter it unless his RF signal overreaches that of the other user occupying the channel.

The following solution appears more effective. Single channel networks can usually serve up to some tens of users in normal traffic conditions. Traffic variations however, are much reduced by trunking the channels in a multi-channel network serving many different Operational Units. The entire traffic pattern arising from a number of Operational Units each having many users operating independently, is much more stable, even in emergency conditions, than for small networks each serving a single Operational Unit.

It therefore appears advisable to implement systems using trunking techniques and multi-access. Trunking some channels in a multiple access network that can be shared by more services, not only results in better system performance in normal and heavy traffic conditions, but also improves system performance in emergency situations.

A system serving n different operational units that offer about the same traffic but work independently, results in a traffic standard deviation relative to the average value about n times smaller than for each single Operational Unit. Better uncorrelated conditions for the traffic offered by n different Operational Units are obtained if the Units operate independently and possibly in non-coinciding areas.

Moreover, failures and interference may be catastrophic in single channel networks, causing their complete unavailability. Multi-channel trunked networks, on the other hand have an element of redundancy, since the failure of a channel does not result in a complete failure of the system, even if in some way it is impaired. This intrinsic reliability of multi-channel networks is of fundamental importance in emergency conditions.

4 FREQUENCY BANDS AND PROPAGATION CHARACTERISTICS

4.1 VHF and UHF Frequency Bands

Fixed and mobile radiotelephone traffic uses in general VHF and UHF bands. Characteristic of these bands is a relatively short propagation range which is normally less than 100 km. The communication occurs on ground wave and therefore the reliability of the communication is very little dependent on weather conditions or day and night times.

VHF and UHF bands are in the radio spectrum range 30-3000 MHz. VHF band consists of the frequency between 30-300 MHz, which is divided into two bands, lower VHF 30-100 MHz and higher band 100-300 MHz. In the UHF range, the frequency bands for radiotelephone purposes are 440-470 MHz and 890-960 MHz. Lower frequencies than VHF can be used for short-range communication but the reflection of the radiowaves from the ionosphere and other reflected man-made noise renders radiotelephone communication on these frequencies impractical.

The use of VHF and UHF for radiotelephone services makes it possible to use an efficient antenna in mobile stations because of the relatively short wavelength at these frequencies. Also because of the limited propagation of VHF and UHF frequencies, it is possible to repeat the use of frequencies at close geographical distances. As radio spectrum is a restricted natural resource the repeating possibility of the frequencies is an important and useful feature of these bands.

The purposes for which radio frequencies may be used are determined by the International Telecommnication Union (ITU). The world is divided into three regions and the frequency allocations are defined in detail in the"Radio Regulations" handbook, published by ITU (2). For further information see Appendix B.

4.2 Features of Radio Wave Propagation at VHF and UHF frequencies

The VHF radio waves in theory propagate in the same way as light waves, but because of diffraction by the earth's atmosphere they follow to some extent the curvature of the earth.

The theoretical maximum distance for VHF or UHF wave propagation tangential to earth surface is called the radio horizon. The distance to the radio horizon is dependent on the wavelength.

The theoretical distance to the radio horizon can be calculated from the equation

$$rh = k\sqrt{2 \cdot R} \cdot (\sqrt{H_1} + \sqrt{H_2})\,m$$

where rh = the distance to the radio horizon, in metres
k = a coefficient depending on frequency
R = the radius of the earth in metres (6,370,000)
H_1, H_2 = the heights of the transmission and reception antennas, in metres

According to this equation, the distance to the radio horizon is dependent on frequency and antenna height. Coefficient k decreases when the frequency increases, but it is also to some extent dependent on surface and weather conditions. The average values of coefficient k are

- at lower VHF range: 1.3 - 1.2
- at higher VHF range: 1.2 - 1.15
- at 450 MHz range: 1.15 - 1.1
- at 900 MHz range: 1.05 - 1.0

In addition to the theoretical radio horizon, the propagation distance is dependent on the nature of the terrain. Hills or other high obstacles between the main station and mobile station can reduce the range considerably. A wet and thick forest causes substantial attenuation. Terrain obstacles also cause reflections of the VHF waves, which can be useful if they add to the waves arriving at the aerial, but reflections are harmful if they interfere with the wanted wave and cause distortion or field strength fading. It is therefore necessary to carry out a physical survey to determine actual propagation. For further information see Section 5.2.

The VHF waves can sometimes propagate to a much greater distance than is normal. This happens if warm and cold layers of air constitute a tropospheric duct forcing the VHF wave to propagate parallel to the earth's surface. Tropospheric ducting does not occur often, at most 4 - 5 times a year, and lasts for 1 - 3 days at a time in Europe, depending upon climatic conditions. In other areas, abnormal VHF propagation is more frequent and co-channel interference can be much more serious. The literature should be consulted for further information.

The UHF radio waves propagate according to the same basic rules as the VHF waves. Because of the shorter wavelengths, they more closely resemble light waves. The radio horizon for UHF waves is typically only about 10 per cent beyond the optical horizon. For VHF waves the radio horizon is 20 - 40 per cent farther away than the optical horizon. It is evident therefore that the range is greater at VHF than at UHF.

Reflections are more typical of UHF than of VHF. In cities the UHF systems have proved to be more efficient because the reflections from the buildings cause the waves to propagate along the streets. The radio waves thus follow the same routes as the vehicular traffic. Rain, snow and terrain obstacles reduce the coverage range and cause shadow regions at UHF. Tropospheric ducting is possible but less likely to occur than at VHF.

4.3 Suitability for Mobile, Personal, Paging, Short Range or Long range Use

4.3.1 Mobile use

The optimum frequency band for mobile use is dependent on the required coverage area under certain conditions. The conditions include different obstacles for radio wave propagation as well as interfering radio waves. The reliability of the radio connection is also affected by the construction of the antenna and its location in the vehicle. The main sources of disturbance are:

- electrical interference from the vehicle
- electrical interferences from other vehicles
- other man-made interference
- fading

The electrical interference from the appliances of the vehicle is a specific type of disturbance for a mobile station. Careful interference suppression can eliminate much of the disturbance from the vehicle in which the mobile station is installed. Little can be done about the interference from other vehicles, which may be considerable in city traffic. Electrical noise is also generated by corona and insulation leakage on power transmission lines, contact lines of railways and trams or other sparking appliances close to the mobile station. These disturbances impair the quality of the signal within 20/25 metres, and can be considerably worse at VHF than at UHF. The level of electrical noise is an inverse function of the frequency. The disturbances are worse in the lower VHF range and almost unnoticeable in the 900 MHz range.

Other radio signals at the same frequency or close to it also interfere with radio communication. Signals at the same frequency can interfere with one another if the transmitters are too close to each other, or if exceptional propagation causes abnormally long radio-wave propagation. The latter can result from tropospheric ducting or (at lower VHF) from ionospheric reflection. Tropospheric ducting can cause interference between stations that are as much as one thousand kilometers apart. Ionospheric reflection occurs mostly during the maximum phase of the sunspot cycle, which is repeated at 11-yearly intervals, but it does not occur at higher VHF or UHF. (Reference Marconi Propagation Prediction Quarterly) (3)

Other radio signals can cause interference when they are close to the receiver frequency, for example on an adjacent channel, and the interference level is dependent on the strength and quality of the signal. Two high-level signals close to the reception frequency may cause intermodulation disturbance in the receiver. Adjacent channel interference and intermodulation disturbances can be minimized with receiver design and careful frequency allocation.

Fading is a typical disturbance of a mobile station operating at VHF and UHF. The field strength varies periodically as the vehicle moves in an area with terrain obstacles and reflections. The frequency of the variation is directly proportional to vehicle speed and to radio frequency. Fading is especially harmful when the radio path is used for data transmission.

The following conclusions can be drawn therefore:

(a) The lower VHF band is suitable for mobile use if large coverage area is required and there are low electromagnetic noise levels and comparatively flat terrain.

(b) The higher VHF band is in principle similar to the lower VHF range but the coverage range is slightly smaller and electromagnetic noise less harmful.

(c) The UHF band 440 - 470 MHz is suitable for areas with high electromagnetic noise levels. The coverage range out of town is smaller than at VHF but the suitability for city areas is considerably better than at VHF.

(d) The UHF band 900 MHz is particularly suitable for small-cell networks in densely populated areas and cities. (See Section 10) To some extent this band can also be used in tunnels and gorges.

4.3.2 Personal handheld radio

The frequency bands used are the same as for the mobile services, but the effectiveness of handheld radio is reduced because of the practical limitation of the antenna system.

The higher VHF band and the UHF bands are most useful for personal radio equipment because the full-length effective antenna can be used due to the length of the wave. The shortened antenna is adequate and the effect of electro-magnetic interference is greatly reduced. It is also possible to use a gain antenna which improves performance and increases the operational distances.

4.3.3 Paging receivers

The most suitable frequency band for a paging system depends on the user's requirements. When it is to operate in rural or urban districts, where the distances between the paging transmitter and receiver are about 1 - 10km, the lower and higher VHF areas are more suitable. As paging receivers normally have an integral antenna system, the receiving characteristics are about 15-30 dB worse than for a mobile or handportable radio on the same frequency and therefore the reliable communication distance to a paging receiver is only about one third of the mobile system in the same conditions.

The UHF band 440 - 470 MHz is suitable for paging but the distances are somewhat shorter. In urban areas and in the locations, where interference is high, paging receivers on UHF are preferred.

The 900 MHz band is well suited to paging systems as the equipment can be made small and the antenna characteristics will be satisfactory. It is highly immune from static. When connected to small cell mobile networks, the paging equipment can be extended to cover the network area.

4.4 Noise-RF, Environmental, Ignition, Electrical, other Man-made noise

The main types of external noise are man-made interference, atmospheric noise, cosmic noise and thermal noise, that is, one produced by the heated atmosphere and earth surface.

4.4.1 Man-made noise

The man-made noise illustrated in Fig. 4. is caused primarily by operation of electric switches, ignition noise, fluorescent lighting etc., and may be a significant factor at frequencies below 400 MHz. Since radio transmission in this frequency range is primarily tropospheric (ground-wave), man-made noise is severely attenuated 15 to 30 kilometres from its source. In rural areas, the controlling factor is more likely to be equipment noise or cosmic noise.

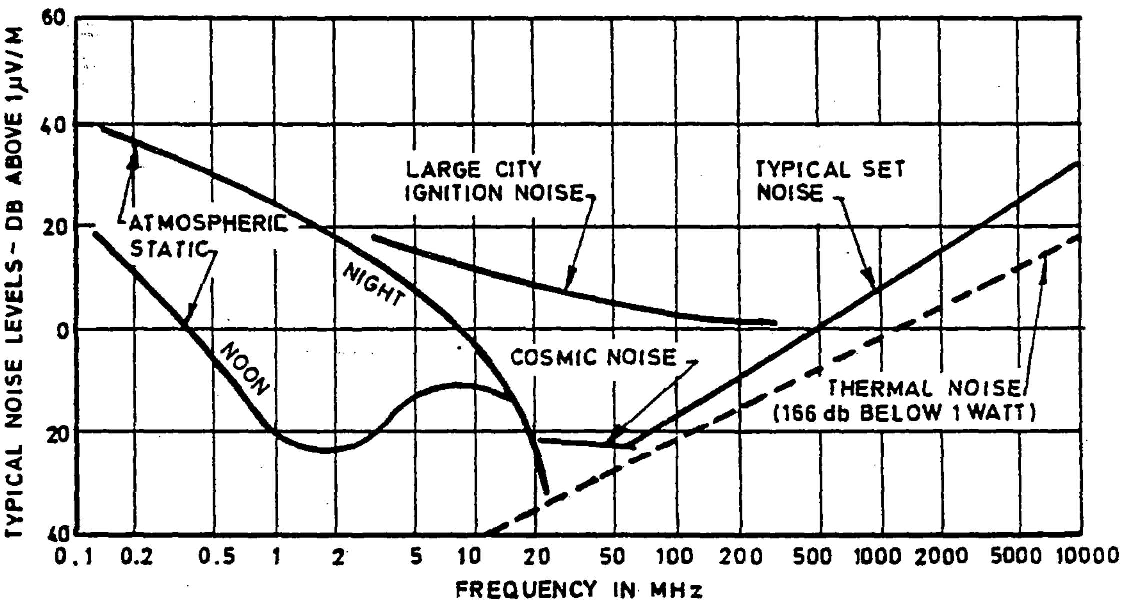


FIG. 4. TYPICAL INTERFERENCE LEVELS FOR MAN-MADE COSMIC AND ATMOSPHERIC NOISE

The best way to reduce the level of man-made noise is to suppress it at the source by use of filters and screens which will prevent the emission of radio waves and the propagation of radio waves in the power supply wires. The level of man-made interference can be measured by suitable instruments which can also locate the offending equipment and check on the efficiency of the preventive measures taken.

4.4.2 Atmospheric noise

Atmospheric noise is electrical static caused by lightning and other natural electrical disturbances and is propagated over the earth by ionospheric transmission. Static levels are generally higher at night than in the daytime, and the effect is more noticeable in tropical areas where storms are more frequent.

Typical average values of noise in a 6 kHz band are shown in Fig. 4. The atmospheric static data are approximate yearly averages for a latitude of 40°. Typical summer averages are a few decibels higher than the values shown and the corresponding winter values are a few decibles lower. The average noise levels in the tropics may be as much as 15 dB higher, while in the arctic and antarctic regions, the noise may be 15 to 25 dB lower. The corresponding values for other bandwidths can be obtained by adding 10 dB for each tenfold increase in bandwidth.

4.4.3 Cosmic noise

As we have seen, at frequencies exceeding 30 MHz the level of atmospheric noise is drastically reduced because the associated waves (atmospherics) cannot be propagated by the ionospheric mode. Therefore in the metric band the main source of interference is the radio emission originating from various radio sources in and outside the Galaxy and from the sun. This is cosmic noise, but its effect on mobile radio systems is sufficiently reduced not to warrant further consideration.

4.5 Underground and Shielded Systems

Radio communication in tunnels

Where there is a requirement for reliable mobile communication in poor proagation areas such as tunnels, antennas or leaky coaxial cable (LCX) can be used for the radiating system to convey radio signals into and out of the tunnel. The antenna system is superior to the LCX system from the viewpoints of reliability, simplicity and constructions costs. The LCX system, however, is more suitable than the antenna system for long tunnels containing curves or partitions between lanes. Section 10 gives further information on the subject and refers to the frequency bands most suited to this mode of propagation.

5 TRANSMITTER STATION SITE PLANNING

This section should be read in conjunction with Section 14 on "System Availability".

5.1 Topography

To cover the greatest possible land area with broadcast radio signals, the ideal main station site would be on the summit of a high peak or mountain which stands alone, above the centre of a broad flat plain. Certain reasons, however, make the selection of such an elevated site undesirable. High altitude transmitters may interfere with distant users who have been allocated the same frequency, and it may be possible to receive their signals. The location of a main station should thus be determined in relation to a frequency assignment plan, using standard propagation calculations. The topography can be used to optimise the re-use of the same broadcast and link frequencies many times over without mutual interference between the various users.

The higher the altitude of the radio station the greater will be the effects of wind, ice, snow, and precipitation static. Thus the advantage of the increased range of a high station may be partially offset by signal attenuation due to ice accretion on aerial equipment, and a higher level of precipitation static may require reduced receiver sensitivities.

Construction costs at high altitudes will generally be greater for buildings, towers, special antennas, power supplies, and access roads, as will subsequent maintenance costs. Access in winter conditions may be difficult or impossible for essential repair work. It may be possible to build two or more radio stations at lower altitudes for the same cost as one high altitude station and thus provide radio coverage which is technically more acceptable.

A radio station which is situated about 300 metres above the general level of the surrounding terrain, integrates well with the transmitted power levels and receiver sensitivities of VHF/UHF radio equipment currently produced. Sites which are too low do not give good penetration of urban areas and may require the use of high towers or stayed masts which can be environmentally undesirable.

If radio link paths cross tidal waters, it may be possible to use the local topography at both ends to minimise path fading.

5.2 Area Coverage Surveys - Manual and Computerised

The area coverage pattern of transmitting and receiving antennas depends on the location of the site, the height of the antenna above ground level, the proximity of adjacent support structures, and the mechanical design of the antennas. The most practical way to measure the coverage is to continuously transmit a modulated carrier at the frequency to be used, and take measurements with a mobile receiver suitably equipped to plot the signal to noise ratio and field strength over the area.

The performance of receiving antennas must be measured in a similar fashion at the appropriate frequency. Radiation patterns can be altered by using specially designed antennas, or altering the distance between dipoles and the support structure in accordance with published data. In the latter case, care must be taken to ensure that the radiation resistance of the antenna feed point remains within acceptable limits. It is technically more acceptable to create specific radiation patterns by using properly designed antennas whose performance is not influenced by the proximity of the support structure.

Computer programs have now been developed which enable the field strength of a transmitter over the coverage area to be predicted with a reasonable accuracy. These programs are used in conjunction with a terrain data base for the area, and are of considerable value to the planning engineer since he can obtain quickly, easily and at little cost, information on the propagation pattern of a station at a given site. Further information is given in Appendix C.

5.3 Control Arrangements

The availability of land lines may influence the selection of a radio station site if the distance between the control station and the main station is short, eg up to 5 kilometres. With increasing distance, the cost of installing or leasing land lines becomes uneconomic and the use of radio links is justified if suitable radio paths exist between the stations. Sites for radio link stations should be chosen at the minimum heights necessary to give adequate Fresnel zone clearance. Consideration should be given to the possiblity of severe signal attenuation due to rain or snow when deciding path lengths between stations. The use of alternative routes rather than duplicated link equipment allows the use of longer paths for the same overall reliability.

5.4 Antenna Design

On exposed sites it is advisable to design antennas and support structures to withstand the maximum wind speed experienced over 50 years. Heated antenna elements and heated radomes prevent ice accretion from causing unacceptable signal attenuation on marginal link paths. The effect of precipitation static and corona discharge can be minimised by using folded dipoles and placing transmitting antennas above associated receiving antennas. The horizontal stress on multi element co-linear antennas, which are subject to ice loading and high winds, makes it advisable to use horizontal stays and these should be included in wind load calculations. If multipath fading is anticipated, adequate vertical separation between space diversity antennas is required according to path length, frequency, and link station altitudes. Circular polarisation will give improved link performance over long sea paths.

5.5 Tower/Mast Design

To support antenna equipment at a specific height above ground, stayed masts cost less than self supporting towers. Unfortunately they require a larger site area, are not as mechanically stable, are not easy to work on, and are not easy to maintain. Self supporting towers can support several antenna equipments at various heights, and their mechanical stability can readily meet the rigidity requirements of large parabolic antennas. Climbing ladders and working platforms are easily incorporated in the structure for safer working conditions and towers are easily inspected and maintained. Angular construction gives more versatility than tubular construction for mountings and support brackets.

5.6 Feeder Losses

Power loss in antenna feeders is proportional to increase in frequency. It is usual to locate lower frequency broadcasting antennas above higher frequency link antennas. The power loss in the extra feeder length to the top of the tower for a link antenna is not usually offset by an improved signal level at the distant station except for very low altitude radio stations. If only very low powers are available then feeder loss can be eliminated by mounting the transmitter and receiver equipment beside the antennas on the tower structure. At SHF, feeder loss can be reduced by radiating from the ground to a directional reflector at the top of the tower.

Co-axial feeders are designed with varied physical dimensions and differing dielectric materials. In general, larger dimensions with minimum solid dielectric reduces power loss. Co-axial cables are almost universally used at VHF and UHF, and waveguides and passive reflectors at SHF.

Co-axial feeders which use braided outer conductors are easier to handle, but have appreciable radiation and are susceptible to the ingress of moisture. Solid outer conductors have minimal radiation and can be gas pressurised to prevent the ingress of moisture. It is usual to gas pressurise waveguides.

5.7 Effective Radiated Power and Received Signal

Effective radiated power levels are usually determined by the Radio Regulatory Authority. Radio link powers are calculated in relation to specified received signal levels at the distant station and broadcast powers are usually limited to around 25 watts omnidirectionally radiated. Receiver input sensitivities range from 0.1 to 2 microvolts depending on local conditions and generally a sensitivity of 1 microvolt will meet most needs without experiencing too much interference and ensuring reasonable signal to noise ratios. However, with the ever-increasing use of radio and the need to share main station sites with other users, it may not be practical to operate with very sensitive receivers due to high levels of local interference. For satisfactory operation in the future, it may be considered desirable to design systems to operate with receiver sensitivity levels up to 5 microvolts PD, to provide the required signal/interference ratios.

Co-linear, broadside, and parabolic antennas can provide considerable signal enhancement requiring very low power inputs, and where possible, these should be used to reduce the power required from storage batteries and to reduce decreasing unnecessary radiation.

5.8 Lightning Protection

Tower and mast structures, antennas, feeders, and all internal equipment should be connected to a common earthing network, whose buried conductors should radiate from the station in several directions to provide an earthing value preferably less than 10 ohms. Care should be taken to eliminate loops and bends in earthing connections, since these offer high impedances to the steep wavefront of a lightning stroke, increasing the possibility of flashover.

Transient overvoltages on incoming supply lines can be reduced by surge suppressors. Incoming land lines may need barrier transformers and surge suppressors, if the site is subject to frequent rises in earth potential which can cause damage to land lines.

5.9 Power Supplies

If the main power source for the station is taken from the electricity supply network, the power transformer should be located remotely from the station and the supply taken to the station by underground cable. This will give an element of physical protection to the transformer and ensure that high voltage insulator discharge does not cause interference at the station. If the supply voltage is unstable, it may be necessary to fit a voltage regulator, although modern equipment is much less susceptible to supply voltage fluctuations.

If the radio station is operationally important, all radio equipment should be operated from large capacity storage batteries to provide a "no break" supply. The capacity of the batteries should relate to the load and the longest time period for which operation without power supply may possibly occur.

Stand-by power can be conveniently provided by a diesel generator with "mainsfail" automatic starting facilities, and there should be enough fuel for the anticipated "no supply" period. The duration of the continuous running period will be determined by the quality and quantity of the lubricating oil. The auto-start circuit should not be initiated until the incoming supply has failed for 10 seconds, and should remain operated until the supply has been restored for 10 seconds, provided that the generator has been running for a minimum of 15 minutes. This method of starting will ensure that the "start" circuit will not be confused by fluctuating power supplies, and that the starting battery will receive a compensating recharge at a high level.

Gas operated thermo-mechanical generators produce moderate amounts of power for charging batteries and are maintenance free for extremely long periods, up to one year. Solar panels and wind generators can be used to charge batteries if the environment is favourable. Other systems using thermo-couple principles may also be used.

5.10 Site Access in All Seasons

Steeply graded roads with good surfaces can be dangerous in ice and snow conditions and may sometimes be unusable for long periods if filled with deep snow. Essential visits can be made by snow tractor or helicopter if there are suitable landing facilities adjacent to the radio station. The ground should be level, circular, 50 metres in diameter with a large white H in the centre, and with perimeter reflector posts for use when the H is obscured. The surface at the centre should be suitable for skids or wheels. Natural ground adjacent to radio stations is frequently suitable for helicopter landing with very little preparation.

5.11 Site Sharing

Radio sites can be shared by a number of users with advantage, although it is preferable for an electricity undertaking to own the site and thus have full control over the operation, maintenance and development of the site. It is very important that the arrangements with other users are legally contractual and that these cover all aspects of rent, access, and installation and maintenance of the users' radio equipment.

The main technical problems which are likely to be encountered on a site accommodating a number of transmitter/receiver installations are

- Radio interference
- Positioning of antennas on the mast or tower

5.11.1 Interference Although all forms of interference can be encountered on a shared site, co-channel and adjacent channel interference can be avoided by careful selection of frequencies. The most commonly occuring form of interference is intermodulation, caused through the simultaneous reception of a number of strong carrier frequencies interacting to produce an unwanted resultant frequency which itself creates the interference.

Intermodulation interference may be difficult to eliminate or even to reduce to acceptable levels, since the solution may ideally involve a change of frequency or frequencies, or removal of one of the offending carriers to another site.

The subject is dealt with in greater detail in Section 7 and Appendix E.

5.11.2 Positioning of Antennas There is a practical limit to the number of antennas which may be mounted on the same mast or tower, from considerations of weight, wind loading and physical separation.

A solution is to utilise an antenna combining network connected between the various transmitters and one common antenna. The combining network ensures impedance matching and provides some isolation between transmitters. However, losses are increasingly introduced as the number of transmitters increases. The loss can be compensated for by means of a booster amplifier between the combiner and antennas.

In a similar way the receivers for a main station may also share a common antenna. The solution in this case is to connect a resistive distribution network to all receivers and the common antenna. The loss from the inserted network is compensated for by the addition of a low noise amplifier between the common antenna and the distribution network. It is further recommended to place the receiver antenna and receivers at a position with a low level of electrical noise.

5.12 Site Maintenance and management

If buildings are properly designed, heated and ventilated and towers and masts are of galvanised steel, the maintenance of station property can be minimal. Antenna installations will require periodic examination for physical damage and electrical performance. In some locations the highest maintenance costs will be for access road upkeep and repair.

6 MODULATION METHODS AND CHANNEL BANDWIDTH

6.1 Modulation and Modulation Methods

When information is to be conveyed by radio waves, it has to be impressed on a high frequency sine wave carrier. This process is called modulation. In the modulation process some characteristics of the high frequency sine wave are varied in accordance with the instantaneous value of the modulation signal.

A sine wave may be represented by the equation

$$e = E \sin (wt + \phi)$$

where e is the instantaneous value of sine wave, the carrier
E is its maximum amplitude
w is the angular velocity and
ϕ is its phase relation with respect to some reference.

Any of these three parameters of the carrier may be varied by the modulating signal, giving rise to amplitude, frequency or phase modulation and single side-band modulation.

In the radiotelephone system, the most utilized modulation method is the phase or frequency modulation. Amplitude modulation is also used, especially in UK and in aeronautical radiotelephone communication. Due to the cost and complexity of the equipment, single side-band (SSB) modulation is not yet generally in land mobile communication use. SSB, however, is an excellent method for radiotelephone communication and probably will be more widely used in the near future in the land mobile communication systems.

A short description of each of the modulation methods and a comparison of the methods follows.

6.1.1 Amplitude Modulation (AM)

In AM the amplitude of the carrier frequency is made proportional to the amplitude of the modulating signal, as shown in Fig 6.1.

In the spectrum of an AM signal there are the carrier frequency and the first pair of sideband frequencies. The frequencies of the lower and higher sidebands are fc-fm and fc+fm, where fc is the carrier frequency and fm the modulating frequency. The sidebands are equal in amplitude but opposite in phase.

In AM the sidebands contain the transmitted information. Due to the sidebands, the necessary radio frequency bandwidth for an AM modulated signal is twice the highest modulating frequency. The signal is fully modulated when the envelope amplitude reduces to zero, which in this case is 100 per cent. In conditions of weak signal reception, the quality of communication is highly dependent on the degree of modulation. An AM transmitter must be provided with an effective modulation limiter to avoid overmodulation which would otherwise distort the transmitted signal and interfere with the transmissions on adjacent channels.

For correct AM reception, the receiver has to be carefully designed. The most important features are a wide dynamic range of the receiver front end and good automatic gain control (AGC) as well as a good noise filter to suppress man-made interference. For optimum performance, the noise filter should be designed into the RF section of the receiver.

The main advantages of an AM system are: relatively narrow bandwidth, large coverage area and relatively simple design features.

The main disadvantages are the poor man-made interference attenuation and the co-channel interference behaviour.

Most of the man-made interferences have elements of amplitude modulation. It is therefore difficult to attenuate AM receiver interferences which have similar characteristics to the desired signals. Much may be done by using noise filters and other noise suppressing methods. Man-made interference is particularly serious when the received signal level is weak.

Co-channel disturbance is directly proportional to the interfering co-channel signal.

6.1.2 Frequency (FM) and Phase (PM) Modulation

FM is a system, where the carrier frequency is varied in accordance with variations in frequency of the modulating signal as shown in Fig 6.2.

PM is a similar system in which the phase of carrier is varied instead of frequency. In both cases the amplitude of the carrier is constant.

The average power associated with the frequency modulated carrier is independent of the modulating signal and is the same as the average power of the unmodulated carrier.

In FM the amount by which the carrier frequency is varied from the unmodulated value is called deviation. The deviation is made proportional to the instantaneous value of the modulating signal. The rate at which this frequency variation takes place is equal to the modulating frequency.

In AM, the required bandwidth is independent of modulation depth but in FM the required bandwidth is proportional to the modulation depth. The minimum bandwidth which is needed for frequency modulated signal is twice the deviation plus the highest modulating frequency.

The main advantage in FM systems is that it can produce a higher outward signal-to-noise ratio than the input carrier-to-interference ratio.

As mentioned earlier, the frequency modulated carrier amplitude remains constant during modulation. This feature makes it possible to use nonlinear limiting amplifiers in transmitter and receiver.

In an FM receiver, limiting amplifiers are used to suppress man-made interferences which are of an amplitude modulation nature, and an AM rejection of 40 dB should be obtainable. In addition, AGC systems are not needed in FM receivers because of the limiter amplifiers and constant carrier amplitude of the modulated FM signal.

To improve the signal to noise ratio performance of FM systems, a pre-emphasis stage in transmitter and a de-emphasis stage in receiver are generally used in the audio circuity. This is inherent in phase modulation systems.

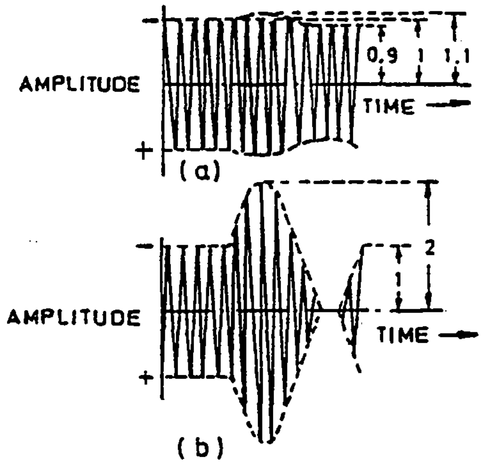


FIG.6.1. AN A.M. CARRIER WAVE
(a) 10% MODULATION
(b) 100% MODULATION

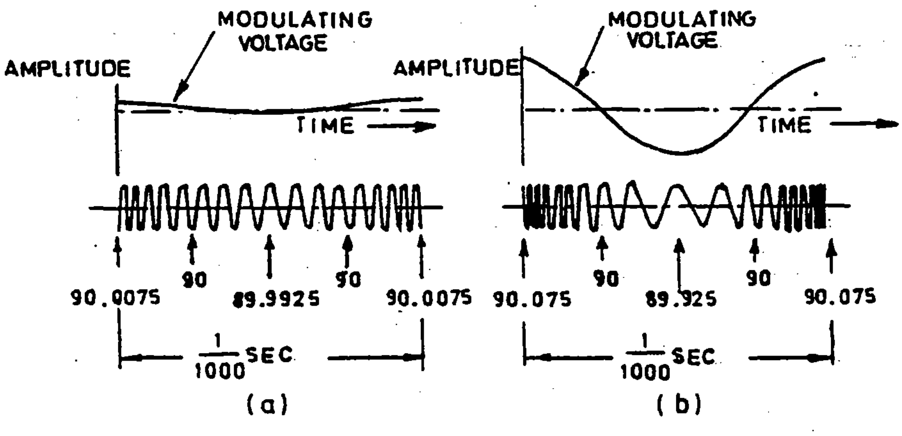


FIG. 6. 2. FREQUENCY MODULATED CARRIER WAVE
(a) 10% FULL MODULATION
(b) 100% MODULATION

In an FM transmitter, frequency multiplication may be achieved without distortion to the modulation, since the deviation will be similarly multiplied. Frequency multipliers are used to generate to the required final carrier frequency. It is thus possible to design more stable oscillators at lower frequencies.

From design considerations, the use of nonlinear amplifiers and multipliers in FM transmitters and receivers is a considerable advantage.

6.1.3 Single-Sideband Modulation (SSB)

The theory of AM showed that a carrier and two sidebands are produced in AM generation. It is not necessary to transmit the whole of the modulated carrier to provide the receiver with enough information to reconstruct the original modulation.

In the SSB system the carrier may be removed or attenuated and also one of the sidebands. Because the sidebands are equal, either upper or lower sideband may be used. The resulting signals will require less transmitted power and will occupy less bandwidth, and yet perfectly acceptable communication is possible.

In practice, SSB modulation is used to save power in applications where such a power saving is essential, ie, in mobile system, (particularly hand held radios) in which weight and power consumption must be kept low. SSB is also used in applications where the radio frequency bandwidth is at a premium.

Three main systems are employed for generation of SSB:

(a) the filter method

(b) the phase cancellation method and

(c) the phase shift method.

They differ from one another in the suppression of the unwanted sideband, but all use some form of balanced modulator to suppress the carrier.

6.1.3.1 The filter system gives a sideband suppression of 40-50 dB and the sideband filter also helps to attenuate the carrier frequency. The bandwidth is sufficiently flat and wide and gives a good ultimate spurious frequency attenuation. The carrier attenuation in the filter system may be as high as 60 dB.

In the filter system, the SSB modulation usually generates in the 2-10 MHz band, where suitable crystal filters are available in small size and with good performance. After generation of the SSB signal on lower frequencies, it converts by mixing to the desired higher frequencies. The filter system has a good long term stability and high reliability in use.

6.1.3.2 The phase-cancellation system was originally developed to overcome the bulky filter system using LC filters. Since these have now been replaced by much smaller filters, this initial advantage no longer applies. However, the phase-cancellation system has two advantages: the ease of switching from one sideband to other, and the ability to generate SSB at any frequency, rendering mixing unnecessary.

The disadvantage in this system is the critical audio-frequency phase-shift network. The radio frequency phase shifter operates at one frequency only, and is therefore a very simple RC circuit. The audio phase shifter isa more complex device since it has to work over a large frequency range. If the phase shifter provides a phase change other than 90° at any audio frequency, that frequency will not be completely removed from the unwanted sideband.

6.1.3.3 <u>The phase shift system</u> is similar to the phase cancelling SSB method. It gives somewhat better results with regard to the unwanted sidebands. Due to the complexity and the superiority of the filter system, the phase shift system is not much used in commercial systems.

6.2 Comparison of Forms of Modulation

6.2.1 Some of the main advantages of FM over AM are as follows.

6.2.1.1 The amplitude of the frequency-modulated wave in FM is independent of the depth of modulation, whereas in AM it is dependant on this parameter. This means that in FM, low-level modulation may be used, and all succeeding stages can be more efficient by using Class C amplifiers. The amplifiers handle constant power and so need not be designed to carry up to four times the average power. Moreover, all the transmitted power in FM is useful, whereas in AM most of it is in the carrier, which does not contribute to the modulation changes.

6.2.1.2 FM receivers can be designed with amplitude limiters to remove amplitude variations caused by noise.

6.2.1.3 It is possible to reduce noise still further by increasing deviation. This is a feature that AM does not have.

6.2.1.4 FM transmitters operate in the VHF and UHF ranges, and at these frequencies the space wave is used for propagation, so that the radius of reception is limited to slightly more than line of sight. It is thus possible to operate several independent transmitters on the same frequency with considerably less interference than would be possible with AM.

6.2.2 Some of the main advantages of AM over FM are as follows.

6.2.2.1 AM requires less bandwitth than FM. This is its most significant advantage.

6.2.2.2 AM transmitting and receiving equipment tends to be less complex, particularly for modulation and demodulation, and hence it is less expensive.

6.2.3 Some of the main advantages of SSB over other modulation forms are as follows.

6.2.3.1 The SSB modulation is superior as regards the required channel width. Only one half of the AM bandwidth is required in the SSB system. SSB is therefore far more efficient in its use of spectrum, compared with AM or FM.

6.2.3.2 Because SSB does not contain carrier and utilises only one sideband, information can be transmitted with one quarter of the power required in AM systems. Therefore the power economy of SSB systems is significant. This feature is very valuable, particularly in hand held portables.

6.2.3.3 The main disadvantage of SSB systems is the high standard of frequency stability which is required. Frequency shift has to be less than 100 Hz. If this is not achieved the speech quality will be poor or at worst, completely unintelligible.

6.2.4 As the channel spacing in mobile radio systems is reduced from 50 kHz to 25 kHz to 12.5 kHz, the advantages of FM over AM are reduced.

SSB offers many advantages, to meet the requirements of the electricity supply authorities, which is the subject of this document, but at the time of writing (ie, 1985) commercial equipment in the private VHF land mobile radio bands had not been manufactured, nor had national specifications been produced.

6.3 Channel Spacing

The modulated signal requires a certain RF bandwidth, which is dependent on the modulation method. The following factors therefore are relevant:

(i) effectiveness of the modulation method used,

(ii) radio spectrum requirements,

(iii) technical requirements of the equipment.

Hence, the choice of channel bandwidth will be more or less a compromise. For instance, the best advantages of FM are obtained with relatively large deviation normally corresponding to an RF bandwidth of 50 to 100 kHz. For effective usage of radio spectrum a narrower bandwidth must be used.

When very narrow bandwidth, 5 kHz or less, is used, technical problems become difficult to overcome. It may be difficult to achieve the specifications for the necessary adjacent channel attenuation and adjacent channel attenuation and adjacent channel power, for instance. Also, frequency stability may be a problem in narrow band systems.

The following table shows the most common channel spacings of various modulation methods.

Modulation Methods	Channel spacing kHz							
	50	30	25	20	15	12.5	10	5
FM	x	x	x	x	x	x	-	-
AM	-	-	-	-	x	x	x	-
SSB	-	-	-	-	-	-	x	x

The 50 kHz channel spacing has been widely used for FM systems, but the need for more channels forces the introduction of narrower channel bandwidth.

Channel spacings of 30, 25, 20 and 12.5 kHz are an acceptable compromise between economical spectrum utilisation and technical limitations. The 25 kHz spacing seems to offer the best characteristics in FM systems, unless a very large number of channels is required.

Further information is provided in Appendix D.

7 INTERFERENCE

7.1 Introduction

With the growth of all radio services and the increasing use of radio spectrum, comes an increasing problem of radio interference. This Section provides some information on the subject, describing the more usual types of interference which cause difficulties in mobile radio networks. Interference caused by vehicle ignition and electrical equipment is not discussed here, since this can usually be dealt with using suppression coils and capacitors in accordance with the motor manufacturers' recommendations.

7.2 Interference Defined

Interference is defined in the British Standard Glossary of Telecommunication Terms (4) as "A disturbance experienced in the reception of a wanted signal, caused by (an) unwanted signal(s) or noise".

Spectrum conservation and interference reduction are conflicting considerations in radio frequency planning. To achieve an interference free situation would obviously require an extensive number of channels, and therefore to achieve a realistic spectrum economy, there must be a certain risk level of interference. One might consider that a given level of interference is tolerable in practice, whereas another might not agree, and this is where the subjective nature of the problem arises. What is an acceptable level to one user, might be objectionable to another.

To quote an extract from the American literature (5), "Radio frequency interference has gradually become the most important problem to consider in design, operation, and maintenance of mobile communication systems. Interference problems have been increasing at a faster rate than equipment performance improvements. Except in rare cases, it is no longer possible to operate an interference free-system". Whilst the writer is concerned with mobile services, he could equally be thinking of all types of radio communication systems.

Generally, equipments used must be of the type which conform in all respects to the relevant national technical performance specifications. It should be remembered however, that these specifications do not attempt to define the physical form of the equipment nor the quality of reception, but are limited to setting out those characteristics which are important from the point of view of planning services, so as to avoid intolerable mutual interference between systems, and to make optimum use of the frequency bands. With increasing use of radio for national and private communication services, eg broadcasting, television, the public radio telephone services and private mobile and link systems, it may be that certain existing performance specifications will need to be revised, perhaps with a leaning to more stringent parameters.

7.3 Interference Forms

Interference occurring on mobile radio networks and point-to-point radio links, falls mainly into the following categories:

- a Co-channel
- b Adjacent channel
- c Intermodulation
- d Spurious radiation

e Intermediate frequency
f Image channel
g Blocking
h Cross modulation

7.3.1 Co-channel interference

This arises where more than one transmission on the same frequency is being received.

Ideally, spectrum planners would try to avoid consigning identical frequencies to different transmitters within interference range, but this becomes necessary in circumstances where sufficient spectrum is not available to give every service its own discrete frequencies. Separating the transmitters by distance and making use of terrain features assists in reducing the effects of the channel sharing, and further relief can be obtained by reducing the height of the transmitter antenna to the minimum necessary to achieve the required coverage, and likewise limiting the radiated power.

Co-channel interference is also experienced under abnormal radio propagation conditions for periods during the year and is referred to as "trough propagation" and sometimes as "ducting". As the name implies, it provides a medium of transmission with a low loss characteristic, caused by the junction of two air layers, one cold and the other hot, over the earth. It cannot be controlled, and therefore the situation has to be accepted.

7.3.2 Intermodulation

If two signals are applied to a non-linear device, mixing will occur and additional spurious signals will result. The amount of non-linearity and strength of the wanted signals will of course affect the amplitude of the unwanted signal or carrier.

Intermodulation is basically harmonic modulation, ie where a harmonic of one signal interacts with any other and produces difference frequencies.

Multiple effects with several interacting signals are not uncommon. The effect can be produced in any non-linear device, including the receiver radio frequency stages, transmitters, antenna masts and stays. In cases other than the receiver, a non-linear device radiates product frequencies which then appear at the receiver antenna.

Further information on intermodulation products is given in Appendix E.

7.3.3 Adjacent Channel Interference

This form of interference is usually of significance only within a kilometre or two of a transmitter site, with a mobile receiver tuned to an adjacent channel. If proper care is taken in the assignment of frequencies to a common user site or to transmitters in close proximity, the problem of adjacent channel interference is unlikely to reach unacceptable levels.

The adjacent channel rejection of a receiver is typically 70 dB above the required carrier in accordance with the national specification requirements.

7.3.4 Second Channel (Image) Interference

The mixer in a super-hetrodyne stage produces an output at intermediate frequency when a signal is applied to the input which differs by the correct amount from the local oscillator frequency. It follows that two distinct frequencies may be applied, one above and one below the local oscillator frequency, which will provide a signal at intermediate frequency. One or other is chosen by the equipment designer as the "tune" frequency and the other becomes the "image". The radio frequency tuned circuits preceding the mixer provide attenuation of the image, and typically this is 70 dB down on the wanted signal.

7.3.5 Intermediate Frequency Interference

This is direct reception at the IF frequency, by-passing the mixer and RF stages, and again the response is typically 70 dB down on the wanted signal.

7.3.6 Blocking of Receiver

As the natural selectivity of the radio frequency stage of a receiver is always much wider than that of the intermediate frequency (typically 10 dB down at 500 kHz), signals close to the tune frequency may be accepted up to the first mixer circuit.

If such unwanted signals have sufficient magnitude, they can cause overload of the radio frequency stages, which in turn will "block" the receiver to the tune frequency, often to the extent that no modulation is perceptible.

7.3.7 Cross Modulation

Cross modulation is similar to blocking in that it occurs in the radio frequency stages of the receiver. When one or more unwanted signals within the radio frequency pass band are of sufficient magnitude, overloading takes place, resulting in the radio frequency stages becoming non-linear, which in turn allows the unwanted signals and/or the wanted signal to be modulated together.

7.4 Identification of Interference

Identification of the type and origin of interference requires a careful and logical approach, as there may be similarities of effect between different types, although the remedies could differ considerably. Special equipment, including a High Q tuneable RF filter and spectrum analyser, is necessary.

Appendix E provides more detailed information on methods of identifying and resolving types of interference.

8 FREQUENCY PLANNING AND SPECTRUM UTILISATION

8.1 Introduction

Responsibility for planning of radio spectrum resides with the government appointed authority. However, although it may specify equipment parameters and conditions of licensing of sites, there are some matters in which operators can help to avoid problems of interference and poor performance. This Section deals with aspects of spectrum planning and utilisation, directed towards achieving the best results in each.

It should be borne in mind that in order to obtain the best use of the spectrum, constraints are imposed upon the network design which may curtail its performance. There is, therefore, a conflict of interest between the spectrum planner and the spectrum user, but this is inevitable and applies to every type of radio service. By paying attention to the following points, the network planner can improve the performance of his system, although this may well lead to higher cost.

It should be noted that the following is only a brief treatment of the subject, but more information is available in the literature.

8.2 Factors Affecting Frequency Planning

The following factors need to be carefully considered by planner and user alike.

(a) Single or two frequency systems?
(b) Channel spacing.
(c) Area coverage required.
(d) Transmitter site location.
(e) Antenna height.
(f) Radiated power.
(g) Antenna configuration.

All of these are treated in detail in other Sections of this Guide, but it cannot be over-stressed that the design engineer of any network must take into account items (c) - (g). These are generally within the capability of the designer and failure to deal properly with each will undoubtedly lead, in the course of time, to problems for himself and other users of the spectrum.

8.2.1 Transmitter Sites

Transmitter site location should be carefully selected so that the signals are confined to the required coverage area. This cannot be achieved precisely, of course, but excessive radiation far beyond the required area must be avoided. The site should therefore be chosen accordingly.

Although high sites are attractive in terms of propagation distances which can be achieved, they are also the source and the recipient of interference. Very often a carefully chosen site at a lower altitude can be quite suitable. Although the cost of this network will be increased, it may be possible to find two or more suitable low altitude sites to give the coverage. Such an arrangement may in the end prove to be economically acceptable if the performance and freedom from interference give a better quality of service.

8.2.2 Antenna heights

There is often a great temptation to use a high antenna if this can be provided at low cost, as in the case of an installation on an existing site. However, for the reasons given in the preceding sub-section, high antennas should be avoided, and lower, cheaper masts can then be used.

8.2.3 Antenna Configuration

In some circumstances, an antenna with directional properties can assist in achieving coverage of part of an area with poor signal levels, or in reducing interference from a particular direction.

Various patterns of field strength can be produced using multi-element antenna arrays. The precise position of an antenna on a mast or tower will also produce its own propagation pattern, and it may be necessary to experiment with both an array and its positioning.

The plot of a directional (or yagi) antenna is called a polar diagram, typical examples of which are shown in the figure.

8.2.4 Radiated Power

Radiated power should be restricted to the minimum necessary to achieve the required coverage, and should not be allowed to exceed the maximum permitted by the national authority. In most countries, the maximum effective radiated power permitted is 25 watts, but in the majority of cases lower powers can be used to good effect.

The use of excessive power creates unnecessary interference problems and results in poor spectrum utilisation. It also makes heavier demands on the power source, which can be disadvantageous in some circumstances.

8.3 Protection Ratio

Efficient planning in the use of the radio spectrum demands that frequencies be re-used as often as possible, to the limits of tolerable interference between systems. This interference level is expressed as the protection ratio.

The World Administrative Radio Conference, 1979 defined protection ratio as "The minimum value of the wanted-to-unwanted signal ratio, usually expressed in dBs, at the receiver input, determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output". The protection ratio will vary, depending on the types of modulation concerned. The table below gives some suggested values for a minimum grade of service.

Wanted emission	Unwanted emission	Protection Ratio (dB)
A3E	A3E	17
A3E	NB F3E) WB F3E)	8-17*
NB F3E	A3E	10
WB F3E	A3E	8
NB F3E	NB F3E	8
WB F3E	WB F3E	8

* depending upon the deviation of the unwanted signal,

where (i) designations of emission have their usual meaning
(ii) NB = narrow band FM (deviation $\pm$ 4 - 5 kHz)
(iii) WB = wide band FM (deviation $\pm$ 12-15 kHz)

From the figures above it can be seen that FM systems require less protection, due to the "capture effect", than for AM. For a higher grade of service, a greater protection ratio should be adopted in the planning of systems (10).

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9 FACILITIES

9.1 Selective Calling

Once the structure of a mobile radio communications network has been resolved it is necessary to ensure that facilities to meet operational requirements are provided. Various arrangements are available, as described in the following sub-sections.

9.1.1 Network without signalling

In this type of network, control is carried out manually, being dependent upon one or more operators who manage all the incoming radio traffic to the Control Centre as well as the outgoing traffic. In order to communicate over the network, the operator must make an oral call through one or several radio channels until he receives an oral reply.

This has the major disadvantage of requiring the users to listen constantly for a call addressed to them, although most of the traffic may be of no interest to them for much of the time.

9.1.2 Network with sub-audio pilot tones signalling

With this type of signalling, using frequencies below the audio band, the most commonly used system is the CTCSS (Continuous Tone Coded Squelch Signalling), which employs tones in frequencies ranging from 70 Hz to 210 Hz. This type of signalling allows the users to make "selective group calls", so that the Control Centre operator can select the user group with which he wants to make contact by means of tone selection. A user then needs only to listen to the calls addressed to his group and is not troubled by calls which are of no concern to him. In order to be really effective, careful selection of individual mobiles to each of the 'users' groups is necessary to ease the Communication Control Centre operator's task.

One disadvantage of systems of this type is that instability in the equipment may create audible harmonics of the signalling tones which interfere with the intelligibility of the received messages.

	Table of Signalling Formats				
	ZVEI	Modified ZVEI	CCIR	Modified CCIR	EEA
TONE MS	70	70	100	70	40
Freq Nr	Hz	Hz	Hz		
1	1060	970	1124		
2	1160	1060	1197		
3	1270	1160	1275		
4	1400	1270	1358		
5	1530	1400	1446		
6	1670	1530	1540		
7	1830	1670	1640		
8	2000	1830	1747		
9	2200	2000	1860		
0	2400*	2200*	1981*		
R	2600	2400	2110		
G	970	825			1055
A	2800	2600	2400		

NOTE: A = Alarm or other special facility
R = Repeat tone
G = Group call tone, EEA signalling has special tone assigned for this function. However, other signalling systems use the tone frequencies marked* for zero-override group call.

9.1.3 Network with signalling by in-band tones

This type of network generally makes use of sequential tone signalling, the most common being the system of two sequential tones for low capacities, as specified by EIA (Electronic Internation Association) and secondly, the system of five sequential tones as specified by EEA (Electronic Engineering Association), CCIR (Committee Consulting International Radio) and ZVIE (Zentralverban der Elektrotechnichen Industrie). The format of the frequency code is shown in the table above.

Stabilising Time is adjustable time according to the response time of the system, see table.

Addressing Time varies from 40ms., see table.

These systems normally allow the Control Centre to call a particular user, or a given user group.

When a call is made to a selected user, he obtains similar facilities to those found on a telephone network, ie when he receives audio at the loudspeaker, he knows that the call is addressed to him. These systems also present other very useful features, such as automatic answering of a call with the user's identification code, or automatic identification of the caller.

Automatic Answering enables the Control Centre operator to determine whether a call is unanswered because the called party is out of range or whether it is due to the absence of personnel from the vehicle, because in the latter case an automatic "unattended" signal would be generated by the mobile.

Automatic identification of the caller provides further enhancements such as call queue management in the event of system congestion in emergency situations.

9.1.4 Digital signalling networks

Once the advantages of the sequential signalling systems become apparent, it can be appreciated how useful it could be to add a few options, such as status indication and call priorities, remote control of auxiliary elements, including repeater stations etc. These require a large number of tones, so that there is enough capacity for the increased information which is to be transmitted, resulting in an increase in calling time. Alternatively, systems with digital signalling may be used.

There are different types of digital signalling systems for mobile radio communications networks, the most widely used being those which modulate an in-band subcarrier with the digital signal. Among the most common modulation types available are Frequency Shift Keying (FSK), Fast Frequency Shift Keying (FFSK), Phase Shift Keying (PSK) and Differential Phase Shift Keying (DPSK), depending upon the manufacturer and the application. The bit rate ranges from 50 bps to 1200 bps in the most common systems. Typical modulation frequencies lie between 1000 and 2500 Hz.

The main disadvantage of these systems is the need for a good quality audio channel with average S/N relationship, in most cases around 18 to 20 dB, unless suitable signal processing is privided. This disadvantage is largely counter balanced by the advantages that digital signalling brings, allowing automation of the management functions of the network, the transmission of a greater volume of data over any other type of channel, very fast signalling, selective or group calling with dynamic assigning of groups, access by priority levels or special codes to some facilities of the system, such as automatic connection to telephone line and user to user calls. Most of the network management and control facilities in the following paragraphs make considerable use of digital signalling systems.

Another characteristic of digital signalling systems is that they can be protected against "false calls" by means of digital processing techniques, such as error detection and correction. They can also send cryptographic data through the network. Furthermore, the supervison and/or telecommand of the network equipment, such as repeaters, can be achieved.

A system with digital signalling is essential in the case of large networks with a number of repeaters, or multichannel networks with automatic multiple access, because the slow speed and inflexibility of other systems makes their use quite impossible.

9.2 Multichannel Systems, Trunking, Channel Hunting, Calling Channel

Generally these types of system require a high standard of engineering design for the signalling system and for the Control Centre, whether automatic or semi-automatic.

9.2.1 Multichannel systems

These use more than one radio channel to communicate with their mobile stations, and can be of two types

(i) Rigid access systems, where different user groups have different channels assigned.

These have the advantage of not requiring group calling signalling in small networks, because this feature is provided by the radio frequency channel selected.

For larger networks this arrangement presents serious disadvantages, such as the large number of frequencies that are required in order to give a reasonable service to users. It is also possible to have waiting queues in some of the channels, whilst the rest may have little or no traffic.

(ii) Multichannel systems with a multiple access feature overcome some of the problems of a rigid access system. Optimum use of all the network's resources is achieved. It is applicable to large networks, having a substantial number of users, and has the advantage that it does not saturate until all channels are engaged.

However, with this arrangement there is a problem of dynamic channel assignment. In order to have a channel assigned, the mobile station must contact the Control Centre to request permission to use a free channel. In order to achieve this, two principal methods exist:

(a) Free Channel Identification. This method is based on the principle that the main station chooses a free channel, by means of an in-band or out-or-band tone, or by the transmission of a special cyclic code.

The mobile station searches for the free channel signal and locks on. When the mobile requires to send a signal, the main station responds by transferring the free channel tone or code to the next free channel.

This system is suitable for a small number of channels, since the search time is short and all the channels can be used for conversation purposes.

(b) Calling Channel. In this type of system a dedicated signalling channel is used. Any mobile station which wants to initiate a conversation, sends its request through the calling channel and gets a free channel assigned.

Where the Centre has the initiative, a call is transmitted over the signalling channel which is constantly monitored by all mobiles.

This configuration is suitable for complex networks with a large number of channels, because it eliminates the need to search over every channel, only one channel being used for calling in all cases. Furthermore, if a large number of channels is used, no significant loss of efficiency results from one channel being used to set up a call.

9.3 Management of a Mobile Radio Network: Control Centre

A modern mobile radio network presents a number of very different problems, basically at two levels in the communication heirarchy:-

(i) Communication network with mobile radio stations, repeater stations and the radio main station.

(ii) Transmission and operations control centre.

9.3.1 For the communication network the following needs arise:

(i) Management of the signalling between the mobile stations and the Control Centre for the assignment of a free channel for each new call, where there is a multichannel automatic system.

(ii) Management of a communication protocol between the Control Centre and the mobile or fixed stations, so that the reception of interchanged data is achieved without error.

(iii) Ability of the Control Centre to adjust the transmitted power of the mobile station, if they interfere with nearby radio stations.

(iv) Communication between the Control Centre and the control units of the main and repeater stations to respond to alarm conditions of equipment and local plant, or intruder alarms.

(v) Transmission by the mobile stations to the Control Centre of coded information about identification, status, incidents, location etc.

(vi) Reception by mobile stations of instructions to perform a set of given functions, such as to receive a selective call, carry out an equipment test, give their location, voice transmission upon base operator request etc.

9.3.2 In the Transmission and Operations Control Centre it is recommended that consideration is given to the provision of a supervising device which performs the following functions:

(i) Management of an adequate signalling protocol, so that data and signalling interchange are achieved without error.

(ii) Assignment of incoming calls from mobile stations to any free operator, or to a selected operator if previously some mobile stations have been assigned to a particular operator.

(iii) Indication to the operator about the channel occupation by data or voice, in order to signal when a channel is free.

(iv) Quality analysis of the incoming signals selection of the answering channel for the transmission of an acknowledgement signal and connection to the operator answer, when signals are received from several repeaters simultaneously.

(v) Control of the main station transmitters.

(vi) Periodic testing, in order to detect equipment defects.

(vii) In systems which provide for communication between mobile stations and PABX's or directly with telephones connected to the communication controller, the system must perform all the telephone signalling with is needed in both directions, including control of the connecting network.

(viii) Information interchange with the operators, which can be achieved by using a console with alphanumerical display of a few received messages. Alternatively, by employing a video terminal equipped with keyboard, it is possible to increase the display and transmission capability between operators.

(ix) Dialogue with the system, which can be performed by the use of functional switches or by the use of a man-machine language when there are complex orders where variable fields must be expressed.

(x) A printer which automatically records messages received from the mobile and repeater stations and prints out:

(a) The mobile station identification.

(b) Service assigned to each mobile station.

(c) Messages received or sent from/to a mobile station of group mobile stations.

(d) The meaning of the coded messages which are received from the mobile stations.

(e) The alarms sent by the radio stations and the results of the diagnosis being carried out.

(f) Operations performed by the Control Centre operators upon the system, and which must be stored in case further analysis is required.

(g) Data about the incoming and outgoing traffic, number of correct and incorrect messages received, etc.

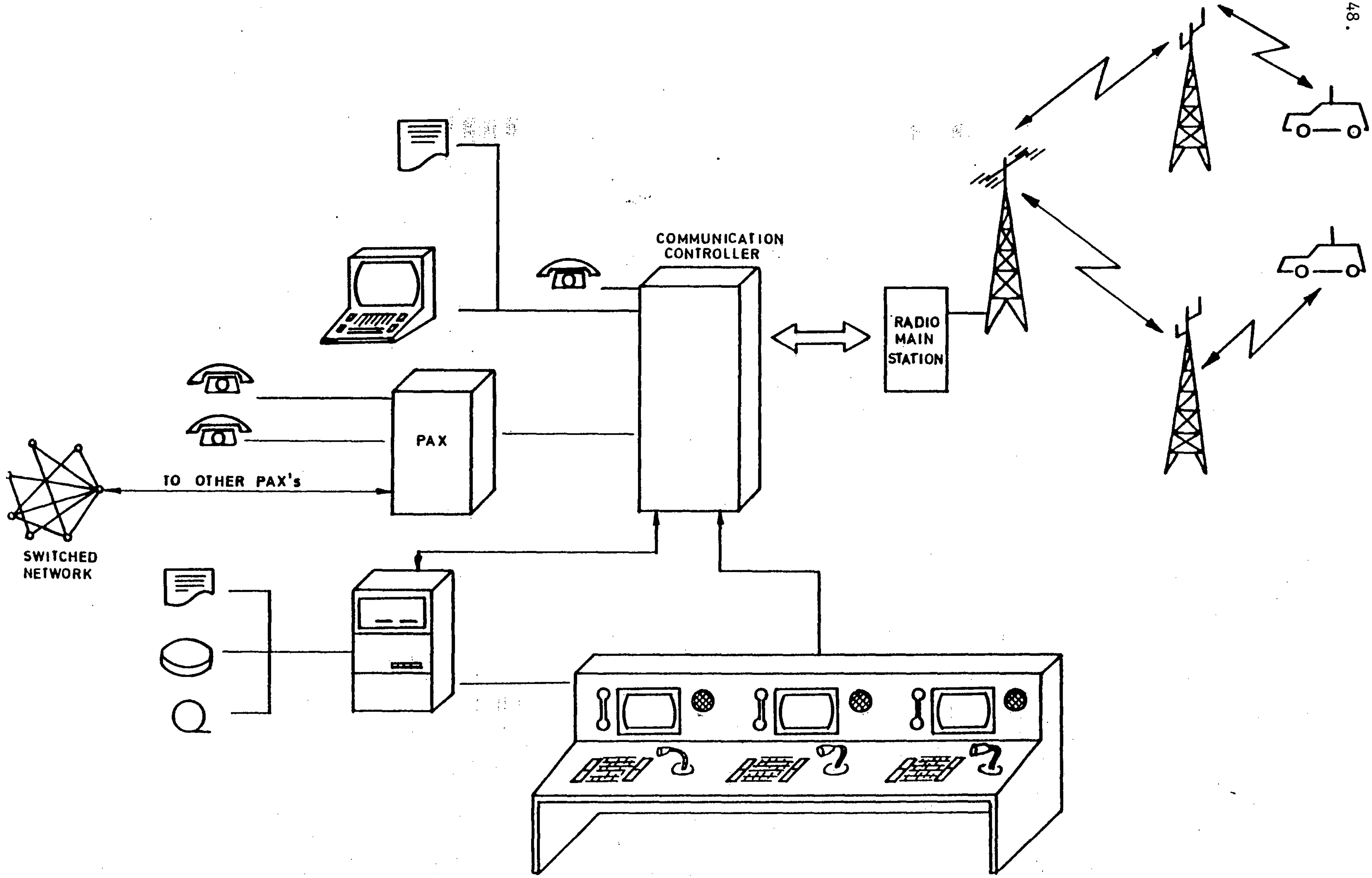


FIG. 9 SCHEMATIC DIAGRAM OF SYSTEM CONTROLLER

The main core of the Communication Controller, shown schematically in Fig 9 consists of a microprocessor, which performs the functions mentioned above, together with the interchange of information with the input/output devices. In order to achieve faster management of the signalling protocols with the mobile stations and for networks with heavy traffic, the controller could be equipped with a microprocessor for each channel. In this way, the message error detection, the quality analysis of the received signal and radio transmitter control, are achieved independently of the main microprocessor, which should perform the centralized functions of the Control Centre, leaving to the peripherial microprocessors the functions listed (a) to (g) above.

The main microprocessor therefore would perform the following functions:

(h) Manage the dialogue with the channel microprocessors.

(i) Select from a number of audio channels, the signal with the best qualities.

(j) Establish the connection network for communications between mobile station to mobile station, or mobile station to telephone line.

(k) Perform automatic tests on system components, indicating the faulty units and carrying out a network reconfiguration in order to prevent the loss of communications.

(l) Management of man-machine dialogue.

(m) Management of input/output peripherals such as consoles, video sets, printers etc.

If the Centre controls a large number of mobile stations, stores the received information for a long time, and also controls a number of remote operator points, it is necessary to connect the central processor at the Communication centre to a minicomputer which is made responsible for all functions which are not strictly related to real time control of the network. In this case, a communication channel is provided between both processors, by which the minicomputer will receive all information from the network and the operators. All functions pertaining to the management of consoles, input/output devices, data storing, administrative control of the mobile stations etc is performed by the minicomputer.

This system evolution, apart from allowing for growth according to needs, has many advantages for maintenance.

9.4 Interconnection to Telephone Lines

In systems with mobile radiotelephones, the interconnection of a radio channel to a telephone line can be achieved either by manual dialling by the Control Centre operator, or in advanced systems, automatically by direct dialling from the mobile station with sequential tone or signalling as described in sub-section 9.1.

The most serious problems occur when it is necessary to switch the main station transmitter on and off by voice operation control (VOX). The problem arises from varying levels of speech in the telephone line, with the associated problems of variation of speech level that can occur from call to call.

9.5 Reliability of Operation

Reliability in communications affects different levels, because, for example, the breakdown of a mobile equipment affects only itself. The malfunction of the main station equipment or repeater stations however, implies a large number of users being isolated from the Control Centre. The most critical is the Communications Controller, where all network management is concentrated.

In order to reduce fault probability, various solutions are possible. At the mobile stations one must use equipment with low failure rates, low burden solid-state components, and able to perform local diagnostic tests. This includes preventive tests which make it possible to shorten the elapsed time from a failure appearance to its detection. The use of microprocessors at the mobile stations to perform the functions already mentioned, allows complex testing over the digital and analogue circuits of the mobile stations, not only when the equipment is switched on, but upon operator request or periodically by initiation of the equipment itself. To complete these tests and transmit the results to the Control Centre, the control operator can order the transmission of information which verifies correct operation of the equipment.

The design of equipment with this self diagnostic philosophy reduces the out-of-service times, because it greatly facilitates the detection of malfunctioning parts in the repair workshop, thus reducing maintenance costs. The use of programmable instrumentation and test programs allows rapid measurement and detection of failures which cannot be achieved so easily by other methods.

In a network with powerful signalling and control, each repeater station should be fully duplicated, and the change-over to the standby equipment telecontrolled from the Control Centre in the event of a breakdown. It is thus possible to increase the reliability to a very high standard of performance.

In addition, an associated supervisory system allows detection of deteriorations in operation before irreversible situations arise. These data are transmitted to the Control Centre, where action is taken.

The communications Control Centre represents the most important point of the system. For that reason, solutions that prevent its total breakdown must be applied. For less critical networks, a modular design with an easy identification and replacement of the faulty units may be enough. In cases when the availability must be very high, the Communications Controller should include duplicated main core, in order to reduce the possibility of a total breakdown.

If the system also has a microcomputer as indicated above, it is possible to obtain a very safe system without having to operate two minicomputers in parallel, with all the additional costs that this implies. A minicomputer breakdown implies only a temporary loss of the peripheral management storing capacity, since the duplicated Communication Controller requires minimum operation of input/output devices until the minicomputer is restored to service.

9.6 Alarms and Telecontrol Superimposed on the Network

When a Control Centre of the type discussed in sub-section 9.3 is available, data different from that of the mobile network can be processed through it.

Mobile terminals can conveniently be modified to send pre-determined information, such as intruder or malfunctioning alarms, and also to receive telecommands. These may be used in the repeaters of the mobile network itself, and in some fixed terminals in locations where the ambient electrical noise permits.

Using these facilities, the operator can also supervise ancillary equipment which has no relationship with the mobile network.

9.7 Protection Against Unauthorised Use. Access Code

In more sophisticated systems, the network can be protected against attempts of unauthorised use, by continuous monitoring of the state of the system. This detects any abnormality by analysing system statistics. In addition, before a mobile can gain access to the network, its preset digital identity code has to be recognised and acknowledged by the central processor. An even higher level of security can be obtained by requiring the calling mobile to key in a discrete identity code which has to agree with that of the programmed equipment code.

The same system of access coding can be used to allow selected mobiles to have access to some special system facilities, such as direct connection to the public telephone network without operator intervention.

10. SPECIAL SYSTEMS AND NETWORKS

10.1 Wide Area Networks

10.1.1 Multiple Main Station Co-Channel Networks

When a group of users must operate in an area that requires more than one main station, the system must provide as many suitably sited repeater stations as are needed to ensure coverage of the whole territory. Let us consider co-channel networks for half-duplex operation, and suppose that:

(a) each station that serves a sub-area is equipped with the same group (K) of radio frequency channels as the other stations,

(b) the stations that serve the territory are interconnected by a radio link of K channels, so that at each repeater station the transmitter/receiver units are connected in the same channel sequence,

(c) the traffic in the interconnecting network and the operation of the equipment of each channel in each station is governed by suitably distributed or centralized control devices.

Two fundamental alternatives exist:-

(i) The reception of RF signals emitted on the same channel by different repeaters may be prevented.

In this case, transmitters on the same channel must operate one at a time, not simultaneously. If mobile users cannot use more than one channel, there are two possibilities.

Firstly, if the system does not know before the call the position of a user, the call is transmitted by all the repeater stations in sequence. When the link is established, the system recognizes the positions of "calling" and "called" users and operates only the repeaters serving those two users.

Secondly, if the system knows the position of users, the call is transmitted only by the repeater station serving the "called" mobile. When the link is established the operations are as in the former case.

Group calls and conferencing between groups are not allowed with this type of system.

(ii) The simultaneous transmission of signals on the same channel by different repeaters is required (or allowed).

This system, called SIMULCAST (Simultaneous Broadcasting Network) does not require the prior knowledge of the sub-areas in which the mobiles are. The case is treated with more detail in the following sub-section and represents a very efficient use of radio frequency spectrum.

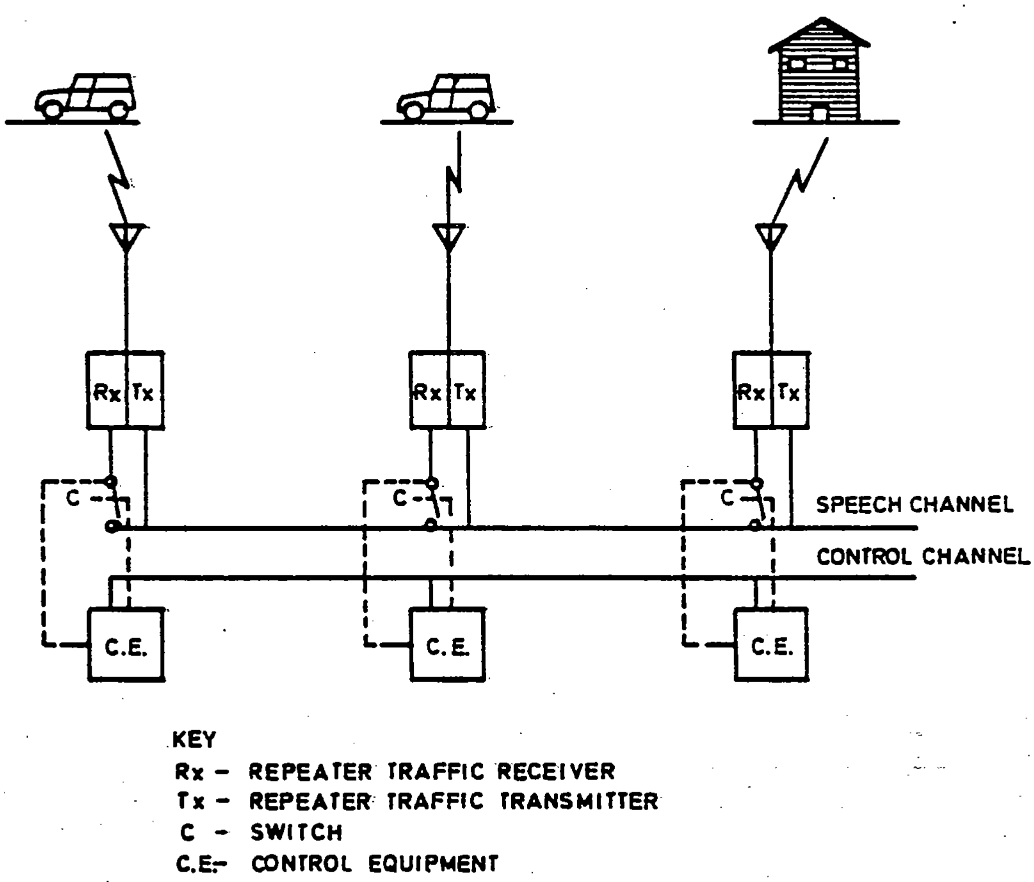


FIG. 10.1. BLOCK DIAGRAM FOR AN ISOFREQUENTIAL (SIMULCAST) SINGLE-CHANNEL NETWORK WITH DISTRIBUTED CONTROL EQUIPMENT.

Even if in single channel (iso-frequential) networks the simulcast operation is not required, the simultaneous iso-frequential emission by repeaters is needed for "group" or "conferencing" communications that involve many users located in more than two different sub-areas.

When the links are restricted to no more than two users at a time, simultaneous transmission by all the stations is avoided.

Since the communication is required to be in half-duplex, it is sufficient that at any time only the station serving the mobile is in use, if one of the following conditions is realized:

(a) the mobiles are all in the sub-area served by a given station;

(b) the network is controlled by an automatic system which determines which of the main stations must be used to connect with the mobile moving within the area.

Such solutions, apart from what has been observed about the "conferencing" of groups of users, are technically very complex and costly. They increase the problems of transmitter switching-on times in half-duplex operations, and require centralized control of the entire system.

Simulcast systems provide a more efficient solution, and meet the requirements for conferencing. They are also less complex, more reliable and can tolerate low quality transmission paths. Simultaneous transmission by many stations moreover, allows better coverage, because overlapping of the sub-area served by different stations can be provided.

10.1.2 Simulcast, Isofrequency Networks

For half-duplex mobile radio networks with typical traffic density values, the greatest efficiency in the use of frequencies is achieved by introducing isofrequential cells. These are cells served by only one set of RF channels and large enough to require more than one station in order to cover them. Fig. 10.1 provides a schematic diagram of a single channel simulcast isofrequency network which operates as follows.

When the receiver Rx receives the RF signal from a mobile, the control equipment CE closes the switch C. The received signal is distributed to all the transmitters Tx of the network by means of an interconnecting speech channel. All the transmitters Tx in the repeater stations simultaneously broadcast the signal over the whole territory.

When the called mobile answers, the control equipment opens switch C in the station serving the first user and closes switch C in the station of the second user.

The control equipments in the example are distributed, and are interconnected by means of a control channel. This channel is dedicated to interchange control signals, and ensures that signals coming from more than one receiver Rx simultaneously are not connected to the broadcasting transmitters Tx. Various criteria are taken into account in establishhng the priority choice, such as time, RF field strength and signal origin.

With careful design, a failure in one repeater station or in the interconnecting links will not affect the operation of other parts of the system, although some service degradation may occur.

The configuration in Fig. 10.1, where distributed control equipment and direct interconnecting channels between the stations are shown, may be improved by the modified configuration shown in figure 10.2. In this case the control and switching devices for the selection of the transmitter station are grouped centrally. This configuration is generally used when direct channels between main stations and the control unit are available. The system is simpler than that of figure 10.1, but because the control equipment is centralised, system reliability is reduced. Moreover, when an area coverage requires a large number of stations, the configuration shown in Fig. 10.2 often requires a more complex interconnection system which brings with it its own problems of provision, reliability and maintenance.

It is possible with this scheme to effect interconnection between the various channels by means of the control equipment at each main station, which is a useful feature in the event of failure of a transmitter or to re-direct traffic between different channels. When the interconnection is by microwave links, frequency bands other than those used for the links between main stations and mobiles should be used. Very high gain antennas should also be used in order to ensure the maximum frequency re-use and minimum interference with the mobile service.

Appendix F provides technical information relating to the choice of modulation methods and frequency offset effects in multi-main station systems.

10.2 Cellular Systems

Most of the mobile radio telephone systems used by the electricity undertakings are designed to cover large areas. Let us look at a specific geographical area which has to be covered by a radio telephone network. We need a certain number of radio channels to obtain a reasonable traffic capacity, and this number is closely related to the number of mobile units in the system. Let us assume that we need five channels. Each channel has a limited range and it is possible to repeat each channel accordingly. If we consider the total area to be a square and each channel (main-station) coverage area also a square, we can distribute the channels over the area as shown in Fig. 10.3.

Each square represents the coverage area of a main-station (repeater) which allows one communication at a time in every square. If we had 10 or 15 channels instead of only five, we could double or triple the capacity in every square.

As mobile radio telephones are used for communication between cars and public telephones or other cars, it is natural that the number of radio channel needed is larger where there are many cars, which we will find in cities and suburban areas.

If area B in Fig 10.3 represents an area where most of the cars are, there will be a problem with the system capacity. As we have only five channels one solution is to allocate all channels in area B, by using a number of base stations with very small coverage area ("small cells") as shown in Fig. 10.4 (16 base stations in area B).

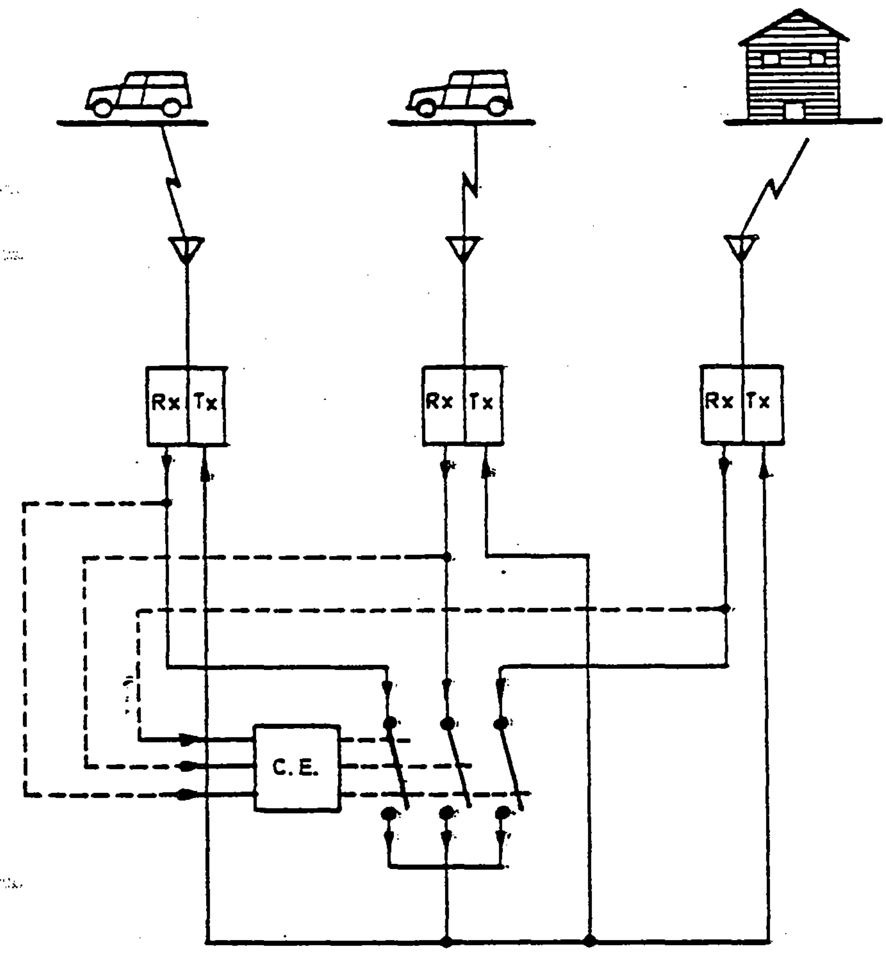


FIG. 10.2. BLOCK DIAGRAM FOR AN ISOFREQUENTIAL (SIMULCAST) NETWORK WITH CENTRALIZED CONTROL EQUIPMENT.

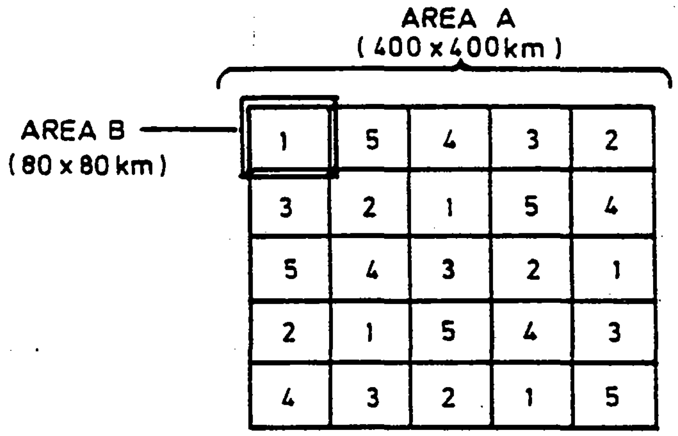


FIG. 10.3. LARGE CELLS

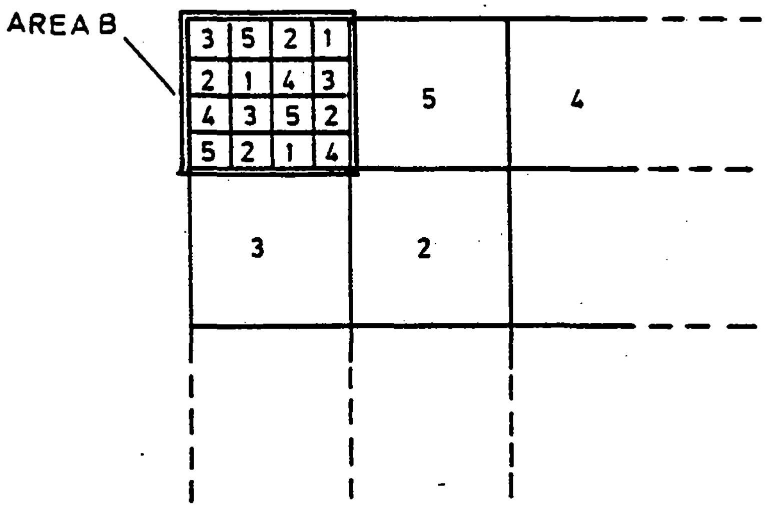


FIG. 10.4. CELLULAR CONCEPT

Now it is theoretically possible to have up to sixteen simultaneous communications in area B, provided that the range of the main-stations and mobiles in area B is limited. The mobile units can also operate in other areas if a facility can be provided making it possible to change their output power, preferably automatically whenever the mobile leaves or enters area B. When the mobile is moving in area B it is most likely that it will have to switch between main stations during its passage as it moves from one cell to another, because of the restricted size of each cell. This could happen also outside area B, but the probability is much less.

This means that we need a system where all base-stations are connected to a central computer and remotely controlled in such a way that the described changes can take place. The computer must be able to command the mobiles to change channel during operation and to change transmitter output power according to coverage needs.

The cellular concept therefore, provides a viable method of increasing the system capacity in an area, making better use of available channels. It is primarily used in large public radiotelephone systems, where the number of users per unit area is very high. Frequencies are allocated for these purposes in the low (400 MHz) and high (900 MHz) UHF bands. The system requirements for confined and well determined coverage areas are more easily met in those frequency bands than in the VHF bands.

In the electricity supply undertakings, the sporadic nature of the traffic and the large coverage areas required of individual networks, do not at the present time favour the use of small cell systems.

10.3 Receiver Voting

For a typical land mobile radio transmitter the effective radiated power (ERP) could be up to 100W at the main station and the power of a handheld portable less than 1 Watt. This unbalanced situation can be overcome with a receiver voting system, where receivers are distributed over the area where radio communication is wanted, as in Fig. 10.5. This type of system can be considered as a special case of space diversity reception. Let us look at the principle of diversity reception

Diversity reception is a method of radio communication which counteracts the effects of unbalanced situations mentioned above and also overcomes problems of fading. This is done by combining or comparing several signals all bearing the same information.

Firstly, let us look at a simple radio communications link where we have one transmitter and one receiver as in Fig. 10.6.

If the signal was traversing a vacuum there would be no variations of the signal and no fading. In reality this is never the case. The signal is affected by the weather, and hills and buildings cause diffraction and radio shadows. The signal also reaches the receiver antenna by different paths due to reflections which occur when the radio wave strikes objects such as houses, mountains, cars and aeroplanes. As a result, we end up with a signal which is, with time, varying in strength. This is called fading. In order to reduce the effects of fading we introduce diversity reception. All such systems are based on the principle of receiving two or more signals instead of one, comparing them and presenting the best signal.

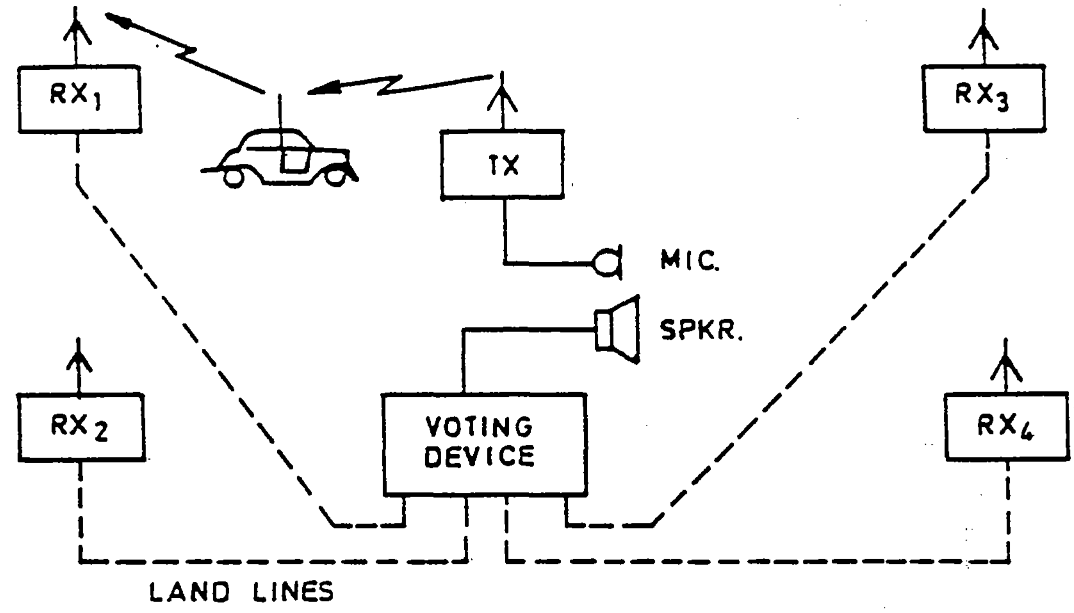


FIG. 10.5. RECEIVER VOTING

FIG. 10.6. SIMPLE RADIO LINK

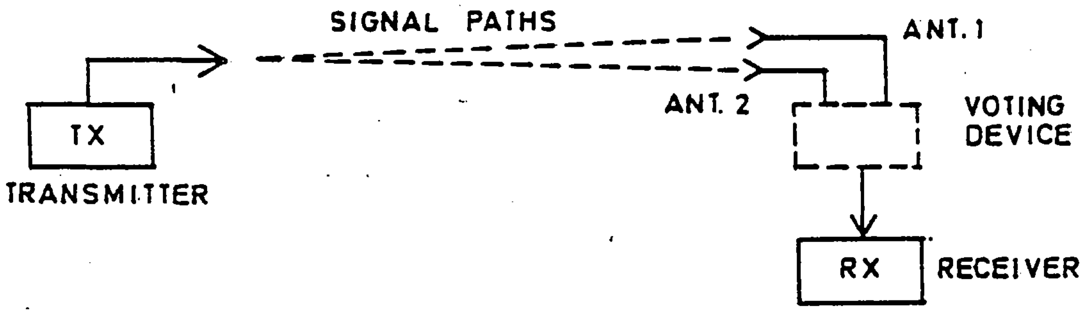


FIG. 10.7. DIVERSITY RECEPTION

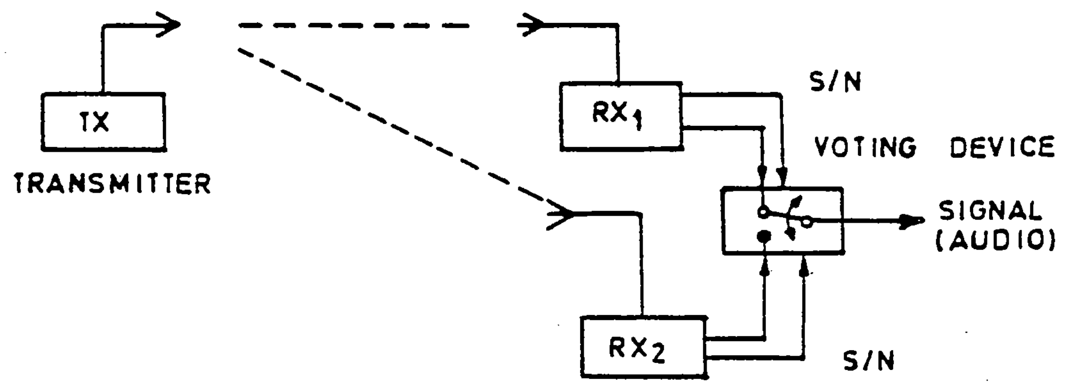


FIG. 10.8. DIVERSITY RECEPTION WITH SEPARATED RECEIVERS

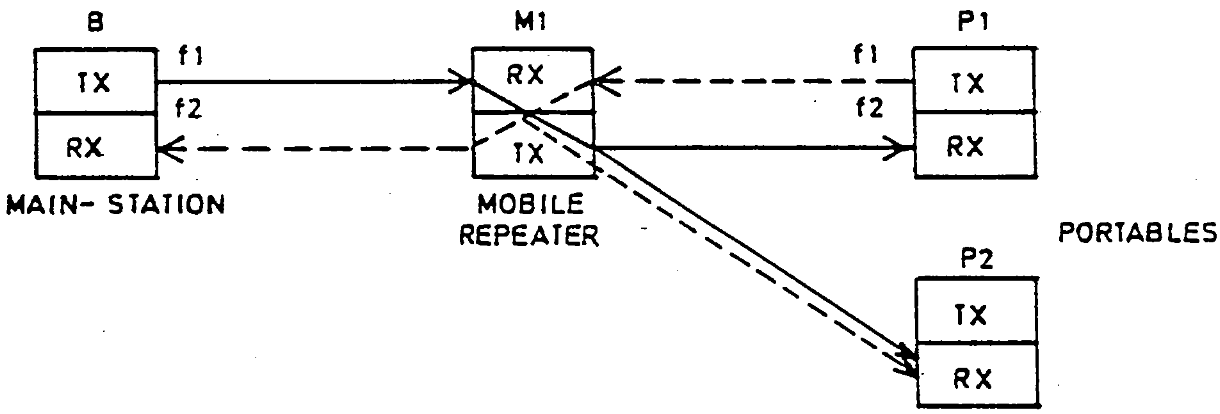


FIG. 10.9. MOBILE REPEATER WITH ONE TRANSMITTER/RECEIVER.
END UNITS WORKING IN TWO FREQUENCY SIMPLEX.

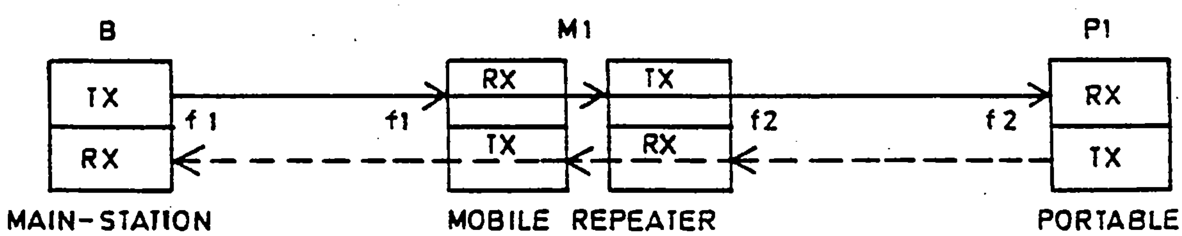


FIG. 10.10. MOBILE REPEATER WITH TWO TRANSMITTER/RECEIVER.
END UNITS OPERATING IN ONE FREQUENCY SIMPLEX.

The receiver in Fig. 10.7 is equipped with two antennas and a voting device that switches the antenna with the best signal to the receiver. The two antennas should be separated by more than a quarter of a wavelength.

The signals are not only varying in amplitude, they differ also in phase. Obviously it is desirable for optimum performance to arrange to bring the signals into phase, then combine and add them. This is achieved by inserting a phase correcting circuit between antenna and receiver.

Instead of one receiver with two or more antenna, it is also possible to use two or more complete receivers, each with one antenna, and a voting device, which connects the receiver with the best signal as shown in Fig. 10.8.

The voting device is fed with information about signal to noise ratio (S/N) from the receivers. This method, which is used only when the antenna sites are separated by several kilometers, and is the receiver voting case referred to at the beginning of this sub-section and shown in Fig. 10.5. The receiver voting solution is very often used to improve radio communication between high power main stations and low power portable units but the cost can be quite high if large areas are to be covered. It is also very often used for radio systems in confined spaces such as underground power stations, where the distances are small and the line network cost is comparatively low.

10.4 Mobile Repeater

10.4.1 The System Balance Problem

A simple mobile radio communications system consists of one main-station and a number of mobile units. The mobiles can be units mounted in vehicles and/or portables, handheld stations, so called "walkie-talkies". The portables do not always have to contain both transmitter and receiver. In paging systems only receivers are used.

A balanced two-way radio communication system has the same range in both directions; main station to mobile and mobile to main. If there are both vehicle-mounted and portable stations in the system, there is a problem of unbalance, which is to give the portable the same range (in both directions) as the vehicle mounted stations. This is not easily solved, since the portable always has less output power and a less efficient antenna than the vehicle mounted station. The low output power is due to the capacity of the battery source with respect to weight and duty time, and the antenna problem is one of portability and weight.

There are two ways to overcome the problems. One can use receiver voting systems as discussed in the previous section, or mobile repeaters.

10.4.2 Mobile Repeaters - Simplest Case

In many cases the portables are used by vehicle personnel, for instance a crew in a service van belonging to a power company. Constant and good communication with the main station operator or a foreman is essential in this type of work. The work environment may be inside buildings of reinforced concrete which have a shielding effect on radio waves, and it can be difficult or impossible to use the portable for direct communication with the main-station, although it may be possible for the station to retransmit what is received. There are a number of solutions to the problem. Figs. 10.9 and 10.10 show typical signal paths using mobile repeaters.

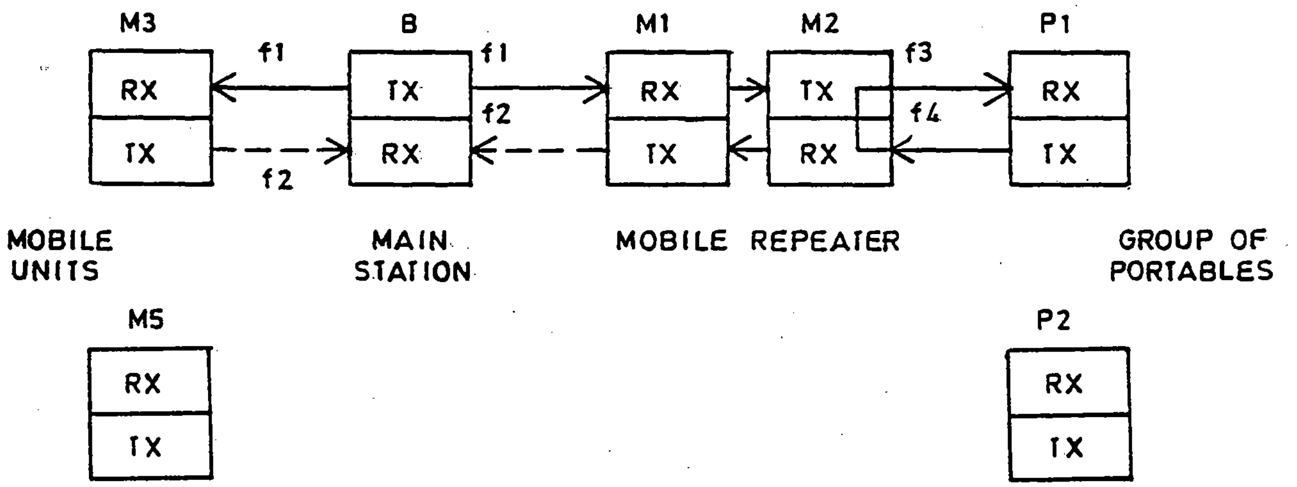


FIG. 10.11. MOBILE REPEATER - TWO DUPLEX CHANNELS

The following conditions have to be considered:

(i) Two frequencies are necessary.

(ii) The difference in frequencies must be sufficient (preferably several MHz) to allow duplex operation of the vehicle radio.

(iii) Two antennas or a duplexer in the vehicle are necessary.

(iv) The whole system is simplex The main-station and the portables operate on a push-to-talk basis.

(v) It is not possible to communicate directly between portable and the control station.

The system in Fig. 10.9 allows radio communication between portables in a rather limited area and is very much dependent on the location of the portables. The main station also receives this traffic between portables and therefore simultaneous communication between main station and some other mobile unit in the system will be disturbed or made impossible.

10.4.3 Mobile Repeater with Two Duplex Channels

If we add one more duplex transceiver to the one we have in the vehicle we get an arrangement as in Fig. 10.11. We also introduce a new pair of frequencies f3/f4, preferrably in a different frequency band to f1/f2, to avoid interference.

In this system we have several possible traffic-routes, depending upon how we connect transmitters and receivers in the mobile repeater. In Fig. 10.11, M2 is working as a simplex repeater, making it possible to communicate between portables and also between main station and M3. This traffic is monitored in M1 and M5 and as well in other vehicles in the system. If the main station is switched to work as a repeater, radio traffic is possible between all vehicles (M1, M3, M5 etc) without interfering with the portables. It should be possible to control this repeater function by the main station-operator.

If M1 and M2 are connected as shown in Fig. 10.12, communication between main station B, mobiles M3 etc and portables is possible. The main-station operates as a repeater, and only one communication at a time is permitted. It is possible to have more than one mobile repeater in the system.

Provided that each mobile repeater is out of range of the portables belonging to the other mobile repeaters, it is possible to have three separate radio communications at the same time. The main station can work as a repeater or on a push-to-talk basis. Fig 10.13 shows a communication path within the two portable groups via their repeaters M2 and M4, and between the mobiles M1, M3 etc and the main-station.

Under some circumstances it might be required to connect the portable groups to each other. The connections between transmitters and receivers in the mobile repeaters are arranged as in Fig. 10.14.

With this arrangement, all vehicles and portables can participate in the communication. The base station works as a repeater and the other units in the system on a push-to-talk basis. The transmitter in the mobile repeater is switched by the carrier received in the connected receiver.

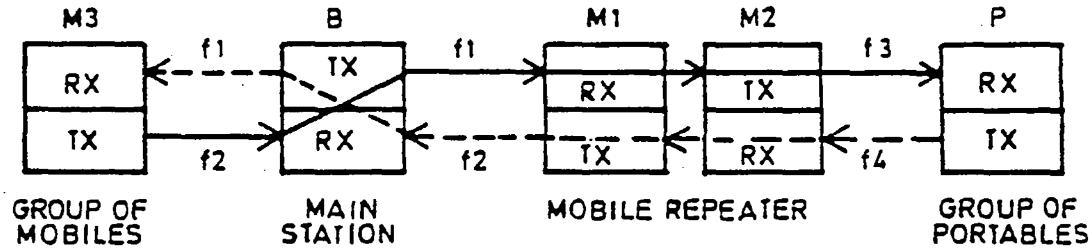


FIG. 10.12. MOBILE REPEATER SHOWING TRAFFIC ROUTES

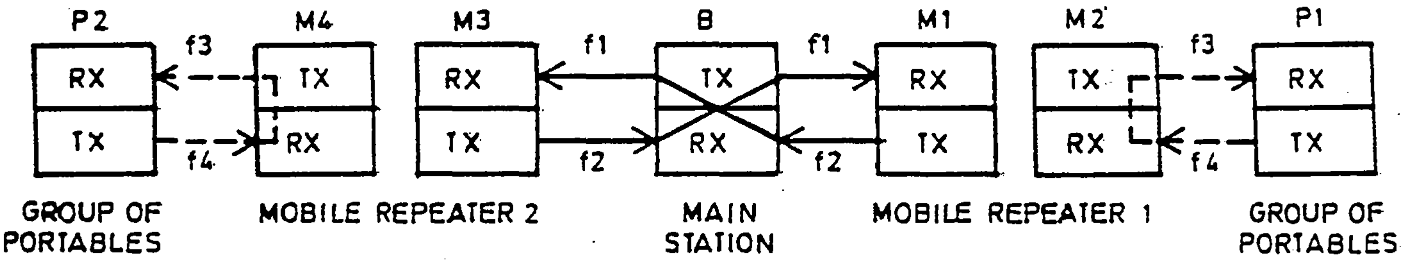


FIG. 10.13. SYSTEM WITH MORE THAN ONE MOBILE REPEATER

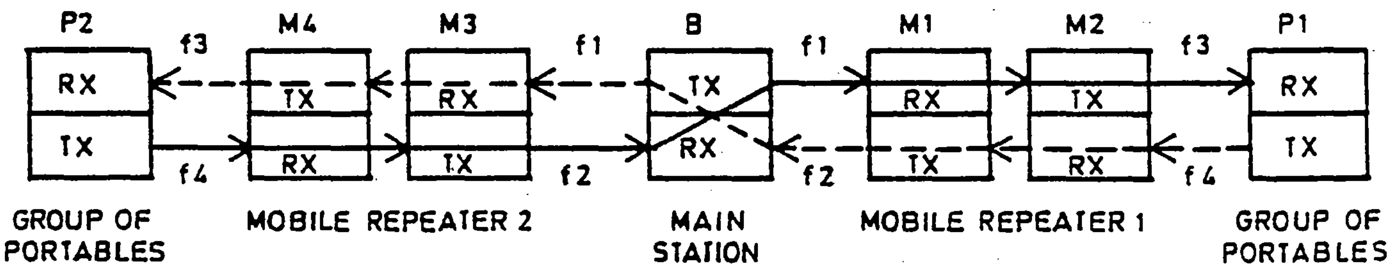


FIG. 10.14. SYSTEM USING MOBILE REPEATERS TO INTERCONNECT GROUPS OF PORTABLES

In the systems described, the portables have a limited working range and the mobile repeater's main function is to provide communications between portables and base station and/or between a group of portables. The disadvantages of these systems described are the use of two pairs of frequencies and units which cannot be used for direct communication to the main station. An alternative arrangement using two frequencies is shown in Fig. 10.15.

M1 and M3 are out of range of main station B1.

From a system point of view only one main station can be operated at a time.

This solution is used to extend radio range between main station and mobile units.

10.4.4 Mobile Repeater in a System with Fixed Repeater Main Station

It is possible to design a system with fixed repeater and mobile repeaters which have only one transceiver. The system is arranged as in Fig. 10.16.

When personnel leave their vehicle, they switch the mobile to work as a repeater and use the portable for communication. Several communication paths are possible by equipping the mobiles and portables with suitable frequencies. The difference in frequency between f1/f3 and f2/f4 is that normally required for duplex operation.

As the mobile repeater has only one transceiver, it receives and transmits on one frequency at a time. During the standby time, the receiver is scanning both frequencies f1/f3 and will stop on one if a signal is received. The signal is retransmitted on the corresponding transmitter frequency. The mobile repeater is designed to allow the signal from the portables to override the signal from the fixed repeater.

The advantage of this system is that all mobile units are similar and can be used as repeaters.

In the example in Fig. 10.16, the communication is between a mobile and portable via fixed and mobile repeaters. It is also possible to communicate between portables via the mobile repeater or direct portable-portable as shown in Figs. 10.17 and 10.18.

The different traffic routes in the examples above are normally operating with remote control in the form of selective calling, using sequential or pilot tones.

10.5 Small Local Networks In Power Stations And Undetground Including Closed Loop Systems

10.5.1 General

Radio communication in confined spaces such as buildings, underground stations and power stations is faced with problems that in certain respects differ from those of normal mobile radio communication. These problems are mainly:

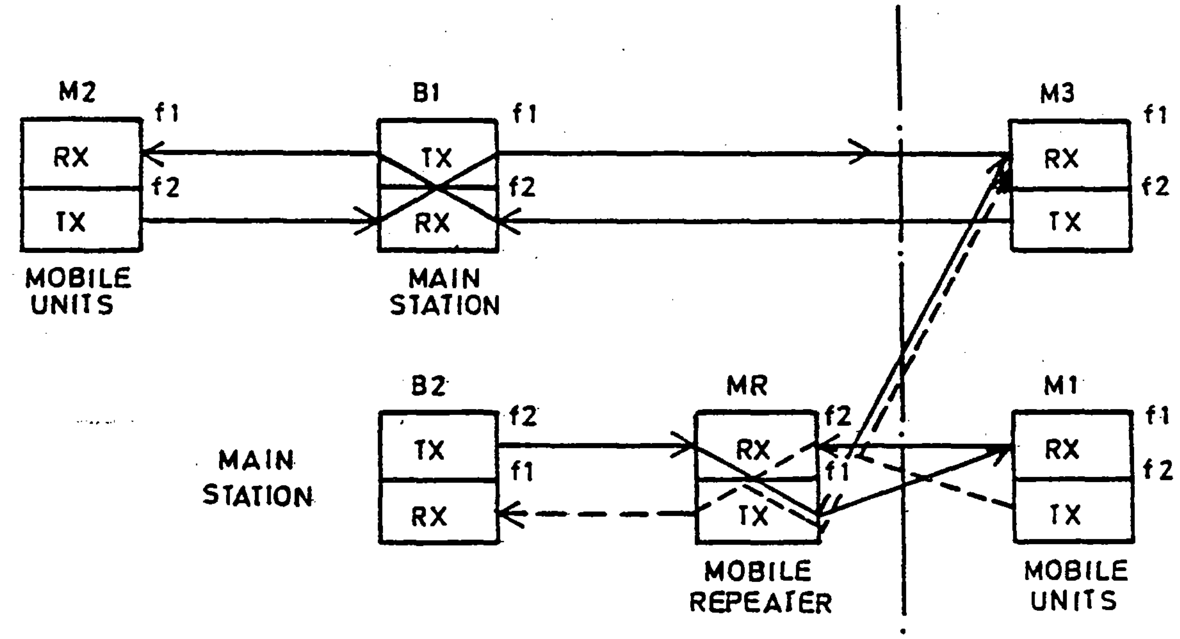


FIG. 10.15. SYSTEM USING MAIN STATION AND MOBILE REPEATERS TO EXTEND RANGE

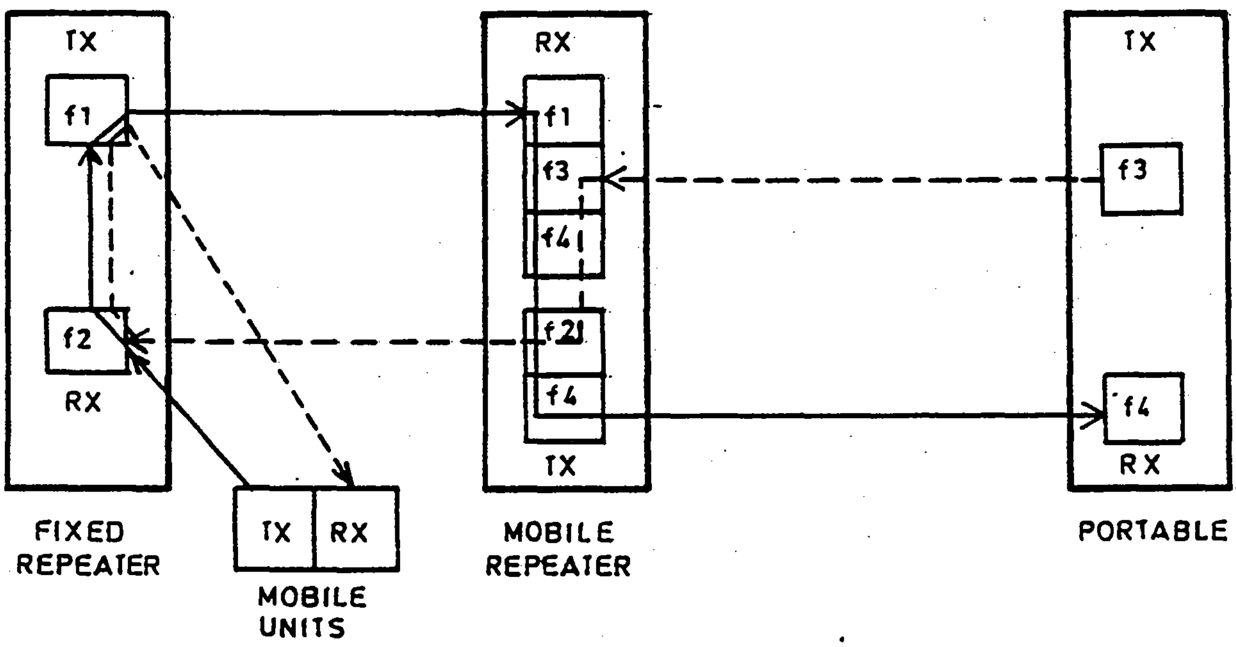


FIG. 10.16. SYSTEM WITH FIXED AND MOBILE REPEATERS

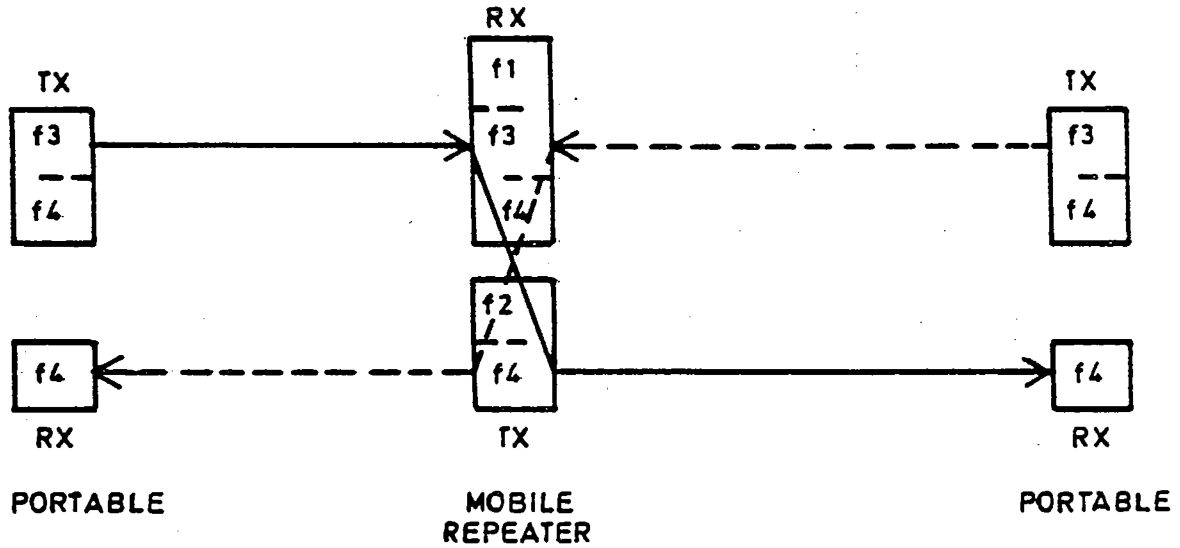


FIG. 10.17. TRAFFIC ROUTE PORTABLE-PORTABLE VIA MOBILE REPEATER

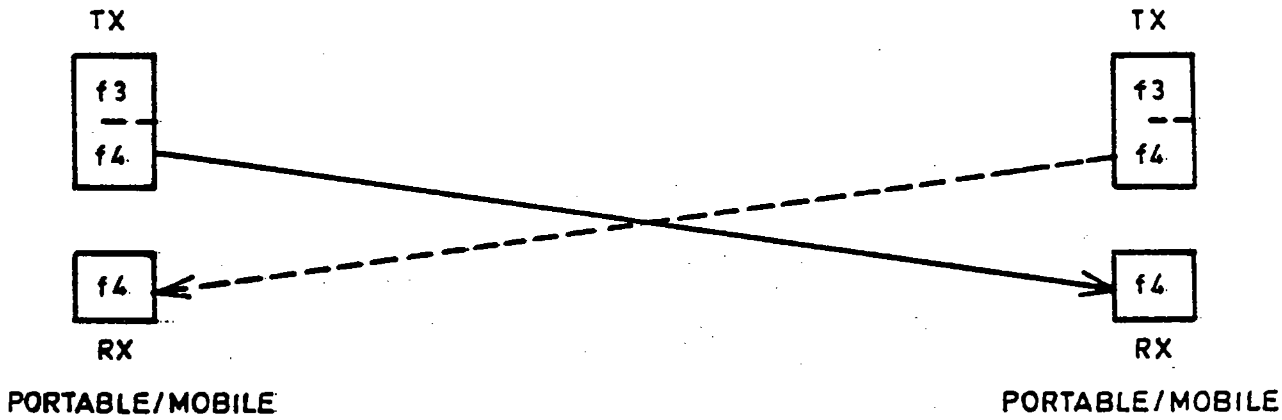


FIG. 10.18. TRAFFIC ROUTE PORTABLE-PORTABLE DIRECT.

THE DIFFERENT LAYOUTS OF TRAFFIC ROUTES IN THE EXAMPLES ABOVE ARE NORMALLY OPERATING WITH REMOTE CONTROL IN THE FORM OF SELECTIVE CALLING WITH USE OF SEQUENCE OR PILOT TONES.

- radio wave propagation
- choice of frequency band
- network structure
- environmental conditions.

In the following sections, the propagation or transmission problem is addressed first, followed by the system configuration problem.

10.5.2 Transmission Methods

The simplest transmission method is by means of ordinary radio communication, from antenna to antenna, using conventional systems. However, the distances that can be bridged by antennas in underground constructions and tunnels are comparatively short, say 100 to 1000 metres, and various methods have been tried during the last 25 years to obtain greater ranges in these conditions using a radiating cable, the so called "leaky feeder". This technique is now in use for communication in mines, underground trains, and train and road tunnels, and the technique is also used in communication systems in surface buildings. A third method of transmission is the closed or inductive loop system.

In the following sections all three methods of radio communication are described.

10.5.2.1 Transmission antenna-to-antenna

Frequency dependence - Propagation distance increases in proportion to the frequency for radio communication in straight tunnels up to a certain limit for which the optimum frequency is within the 400-1,000 MHz frequency range (11). Propagation also depends on the cross section dimensions of the tunnel, better coverage being obtained in a wide tunnel than in a narrow one. For a wide road tunnel the optimum frequency range is within the frequenty range stated, whereas for narrow mine drift tunnels with a cross section of say 3 x 3 metres, the optimum is around 1,000 MHz.

Polarization - A radio wave in a tunnel tends to adopt a polarization parallel to the greatest dimension of the tunnel, irrespective of the polarization it had when excited. Therefore in a tunnel with a greater width than height, horizontal polarization is preferred, both in respect of the transmitter antenna and the receiver antenna. If one of the antennas has to be vertical for practical reasons, it is advantageous to arrange the other one horizontally. In tunnels with equal width and height the depolarization effect can be ignored, but both antennas should have the same polarization. For communication between a fixed and a portable station in tunnels, it would be preferable to use a circularly polarized directional antenna at one end of the tunnel.

Side alley branching and large halls - An interesting question in the planning of a power station system is the wave propagation in the transition between a tunnel and a large underground hall as in power plants housed in large underground halls. In these situations, tunnel bends and side alley tunnels increase the attenuation of the radio waves, as do the walls, doors, and gratings separating different areas. Tests carried out in comparatively narrow mine drifts (3 x 3 m) have indicated that a 90° branching causes signal attenuation of about 25-45 dB. This applies to 160 and 450 as well as 900 MHz (11).

Where there are metallic walls and doors between underground constructions these cause additional signal attenuation. Normally several antennas are required to cover rooms separated in this way.

Typical coverage - the table below provides results obtained from tests for antenna-to-antenna communication in tunnels.

Practical coverage in metres (150 dB system value)				Cross section (width + height) metre	Remarks
80 MHz	160 MHz	450 MHz	900MHz		
		600		Double track drift	
		400		Bend in double track drift, 30 m radius	Fixed 5W to locomotive
50	125	125		Raise lift	
	150	450	600	3.3x3 straight	Fixed 10W to portable
	150	450	600	3.3x3 bend	Gentle bend
	300	650	800	6.0x3 straight	
	ca 400			7.5x5 concrete	
40	170	600	700	4.7x2.3 coal mine	Horizontal polarization
		100		4.7x2.3 coal mine	Round a 90° bend Horizontal polarization
400	800			9.0x5 (approx)	Reinforced concrete Horizontal polarization
			1600	4.8x1.8 coal mine straight	

10.5.2.2 Transmission with Leaky Feeder

General - Leaky feeder technology implies a cable functioning as a continuous antenna, ie all along its length it radiates part of the energy fed into it. Similarly, a signal transmitted near the cable can be picked up and transferred to a receiver at the end of it.

The coupling to a short antenna in the vicinity is similar along the whole length of the cable. As the RF signal level has its highest value in the cable near the transmitter, the coverage from the cable to the mobile unit is greater near the fixed station and smaller at the far end. The same condition applies to the opposite transmission direction. This matter will be further discussed in a following section.

Another essential difference between the leaky feeder and the ordinary antenna, is that the leaky feeder is of the broadband type, making it suitable for various frequency ranges, for example the VHF and UHF bands.

It is possible to distinguish between two main types of leaky feeders, namely twin feeder and coaxial cable. The twin feeder is a balanced dual conductor ribbon with a characteristic impedance of 200-300 ohm. A leaky coaxial feeder is an ordinary 50, 60 or 75 ohm coaxial cable made leaky by providing the outer conductor with openings of one form or another. Fig. 10.19 illustrates a number of varieties of leaky feeders.

Dimensioning of Leaky Feeder Systems - The total attenuation between the transmitter output and the receiver output in a leaky feeder system can be divided into two main parts, namely (a) the attenuation in the leaky feeder from the transmitter output to the point of propagation, and (b) the coupling between the cable and the antenna of the mobile station at the point of propagation. The latter part of the attenuation is considered constant along the cable and depends on the following factors:

Radio frequency	(no pronounced dependence)
Distance between cable and antenna	(attenuation increase by 6 dB/octave)
Antenna gain	
Type of leaky feeder	
Type of mounting	

Usually the coupling losses between a leaky feeder and a normal portable or vehicle mounted antenna at a distance of 2-10 m is somewhere between 60 and 100 dB.

The attenuation in the cable, constituting the other main part of the total attenuation, is generally specified in the manufacturer's data sheet. It increases with increasing frequency and is usually stated in terms of dB/100 m. Leaky coaxial cables have a somewhat higher attenuation than the corresponding non-leaky cable types. Careful consideration must be given to the mounting of the cable. This is particularly the case for twin feeder cables, since not only is the twin feeder type of cable extremely sensitive in respect of the installation mounting, but also coaxial cables with small outer conductor coverage are subject to increased attenuation when mounted directly on to conducting materials.

The following example illustrates the dimensioning of a simple system employing a leaky feeder (figures from a manufacturer's data sheet):

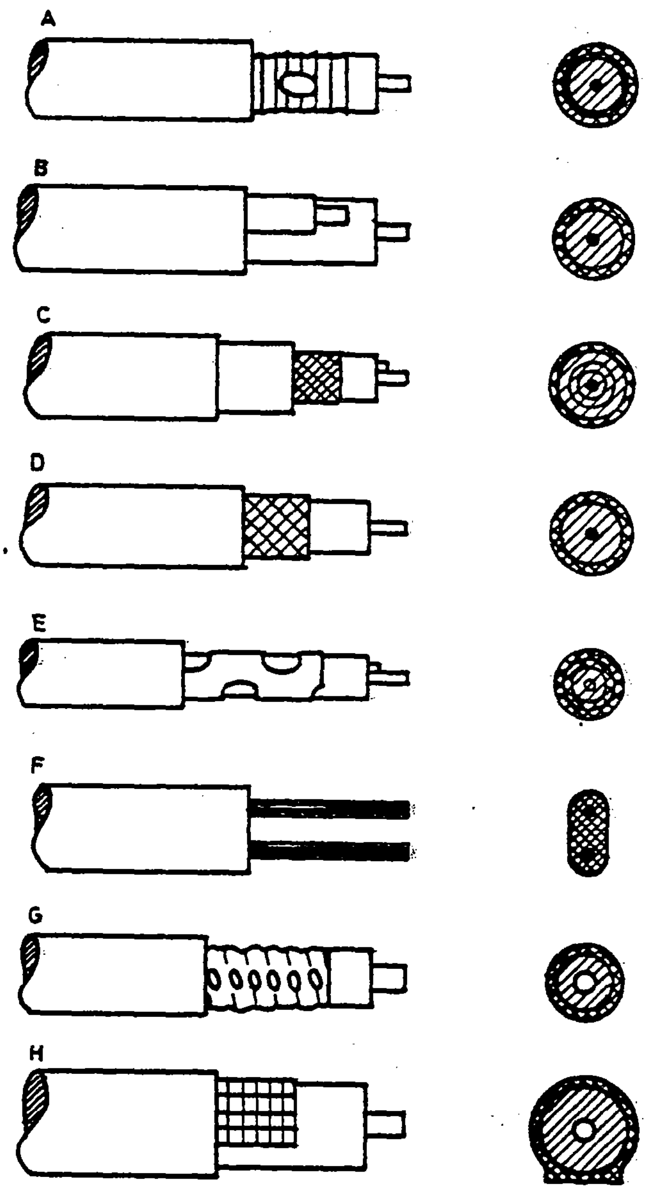


FIG. 10.19. TYPES OF LEAKY FEEDER

It is required to provide a tunnel with radio coverage by means of a leaky feeder system. The frequency of 160 MHz has been selected and RG-86/U twin feeder will be used in the system. The output power of the portable stations, which will communicate from inside the tunnel with a fixed station at the end of the leaky feeder (the tunnel entrance), is 1W. Due to the fact that this power is lower than that of the fixed station, the transmission direction mobile-to-fixed determines the coverage. The receiver sensitivity is 1 uV emf (-143 dBW). The twin feeder cable is mounted with a distance of 20 cm to the tunnel wall. Fig. 10.20 shows that the cable attenuation, with this mounting distance considered, will be 3 dB/100 m. The coupling between the portable antenna and the leaky feeder has been set to 85 dB for the distances prevailing in the tunnel.

The system can suffer an attenuation from transmitter output to receiver input of 143 dB (output power minus the receiver's sensitivity). 85 dB out of these 143 dB is accounted for by the coupling loss antenna - leaky feeder. 58 dB remain, which implies that the maximum coverage will be 58/3 x 100 m = 1,930 m, since the cable attenuation was set to 3 dB/100 m.

If, somewhere along the tunnel, there is a need for communication over a greater distance between the leaky feeder and the antenna, then the fixed station should be located as near this place as possible, since propagation distances are greater closer to the fixed station.

Selection of radio frequencies for leaky feeder systems - As previously stated, the cable attenuation becomes greater with increasing frequency, whereas the coupling between the leaky feeder and the antenna is practically independent of the frequency within comparatively wide limits, provided that the mobile station's antenna has unchanged dimensions, measured in wavelengths. This suggests that the performance range increases with reduction in frequency, but this only applies within certain limits, since at the lower end of the VHF band the length of the antenna would reach impractical dimensions. Thus, the selection of the frequency band will mainly be a question of balance between the desired performance range on one hand and the practicalities of antenna dimensions on the other.

Therefore the optimum frequency of systems employing leaky feeders is somewhere within the VHF band, in the lower portion of the band if portable antennas with long elements can be tolerated, and in the higher portion if smaller antennas are favoured. The 400 MHz band is also useful for leaky feeder systems, particularly in view of the short antenna required, but the coverage will be somewhat reduced in comparison with the VHF band.

Selection of cable types for leaky feeder systems - A number of suppliers manufacture specially designed leaky feeder coaxial cables. Alternatively, a twin feeder cable can be used, typically the RG-86/U type which meets the MIL-specification.

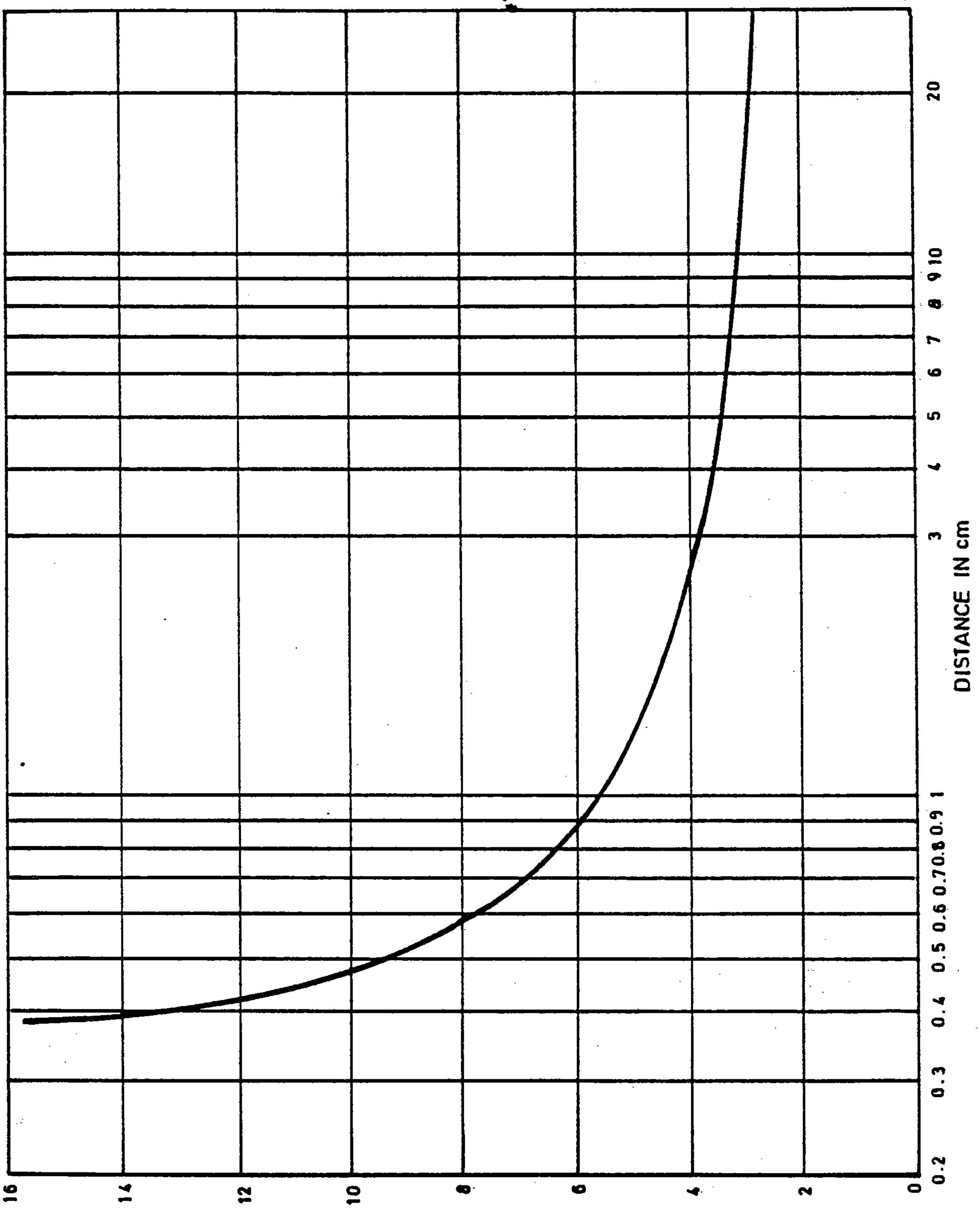


FIG. 10. 20. ATTENUATION DATA FOR TUNNEL MOUNTED LEAKY FEEDER AS A FUNCTION OF THE DISTANCE TO THE TUNNEL WALL (CEILING). STOCKHOLM LOCAL (SL) TRAIN TUNNEL RADIO. TWIN FEEDER CABLE RG-86/U. FREQUENCY 160 MHz.

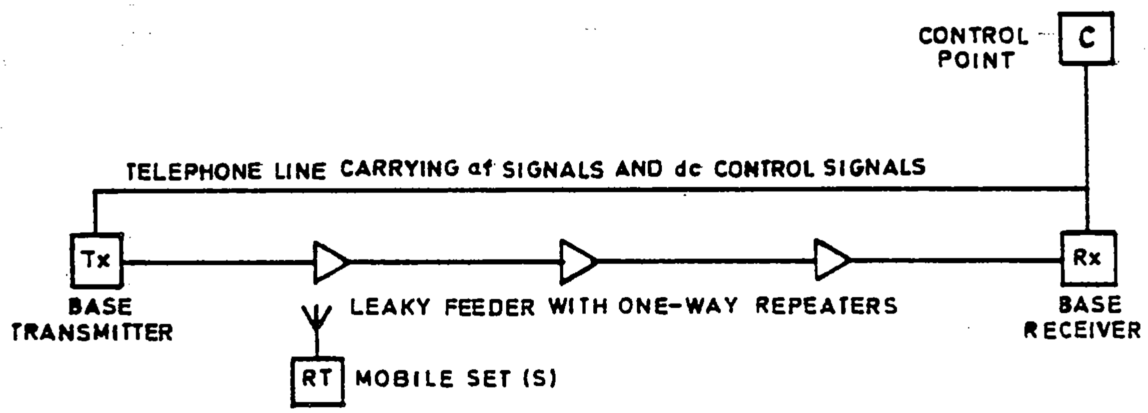


FIG. 10.21. SIMPLE "DAISY-CHAIN" SYSTEM WITH LEAKY FEEDER AND AMPLIFIERS.

In the table below, the essential differences between twin feeder cable and leaky coaxial cable are illustrated. There are also differences between leaky coaxial cables of different design and make. Differences are to be found in the prices and the attenuation per length unit, which does not depend on the method of construction, but on the type of dielectric used, and the cable dimensions. Differences may also exist in respect of the cable's sensitivity to installation and mounting.

These differences can broadly be summarized as follows: cable types with a loosely woven outer conductor are least sensitive to the method of mounting, and types with a broad longitudinal slot are most sensitive. In this case the sensitivity of a cable mounted against the surface, a rock wall or a conducting object, has its attenuation per length unit considerably increased in comparison with other methods of installation mounting.

Quality	Twin feeder Cable	Leaky feeder coaxial cable
Mounting	Must be mounted at a certain distance from the wall. Lead-through arrangements give non-desired effects.	Can generally be laid on existing cable shelves, though better result if laid or suspended separately.
Attenuation per length unit	Depends to a great extent on mounting, lead-throughs, nearness to metal objects. Ca 3 dB/100 m at 160 MHz and ideal mounting. Increasing with frequency.	Increasing with frequency. Decreasing with thickness and air contents in dielectric. 2-5 dB/100 m at 160 MHz. Comparatively independent of mounting.
Attenuation between cable and antenna at a distance 2-10 m	Increasing by 6 dB/octave with increasing frequency 60-80 dB at 160 MHz. To a great extent dependent on mounting and cleanliness of cable.	Increasing by 6 dB/octave with increasing frequency 70-90 dB at 160 MHz, depending on leak method and dielectric. Air dielectric gives lower attenuation than homogenous dielectric. Comparatively independent of mounting and external environment.

Table 2 Comparison between various types of leaky feeder.

Typical coverage - As shown from the example above, it is possible to obtain a range of about 2 km with VHF communication and a leaky feeder system, whilst UHF is less effective. However, by means of amplifiers the range can be extended, as shown, in Fig. 10.21. This method requires that the transmitter is located at one end of the cable and the receiver at the other. At regular intervals along the cable, broadband amplifiers are installed. Owing to the fact that the amplifiers, as well as the cable, are linear and of the broadband type, a system of this kind can be used for transfer of many channels, as well as radio signals in different frequency bands.

10.5.2.3 Transmission via Inductive Loop System

This type of transmission from main station to mobile is obtained by inductive coupling between a fixed current loop cable and a portable unit with an inductive loop antenna. The function is similar to that of a transformer with loose coupling. When a current is flowing through the fixed loop, a magnetic field is created within and around the loop. A corresponding current is then induced into the portable loop antenna.

In these types of system, the information normally modulates a carrier of something less than 100 kHz in frequency.

The size of the fixed loop can be in the order of 200 x 200 m and a number of such loops can be arranged to give total coverage of a building or an underground power plant.

The main disadvantage with this type of transmission is that it works well only in one direction, from fixed to portable. In the other direction, from portable to fixed, the high noise level together with the problem of deriving enough power in the portable to achieve the required currents, makes it practically impossible to achieve a working two-way system. Another feature of closed loop systems is very confined range, limited to the coverage area of the fixed loop. Depending on the application, this can be either an advantage or a disadvantage.

Because of these inherent characteristics, the closed loop mode of transmission is used mostly for paging systems. When a return channel is required, this is normally achieved by radio, antenna to antenna transmission.

10.5.3 System Configurations

General - Radio systems for communication in confined areas such as power plants and underground transformer stations can be arranged in many ways, depending on the application and type of building or underground structure to be covered. A few examples of system configurations are very briefly described below.

Autonomous underground system with standard antennas - A closed radio system for an underground power plant, with fixed wire connection to a manned operator's console is shown in Fig. 10.22. In this case the radio frequencies can be selected independently of other mobile radio systems.

Since the system is covering a rather limited area, and the radio traffic is limited, the system has only one two-frequency channel and the transmitted signal from the fixed station is fed through only one exciter and a number of amplifiers.

Autonomous underground system with antennas and several TX/RX

The system shown in Fig. 10.23 is used in an underground mine, but can also be used in other underground structures.

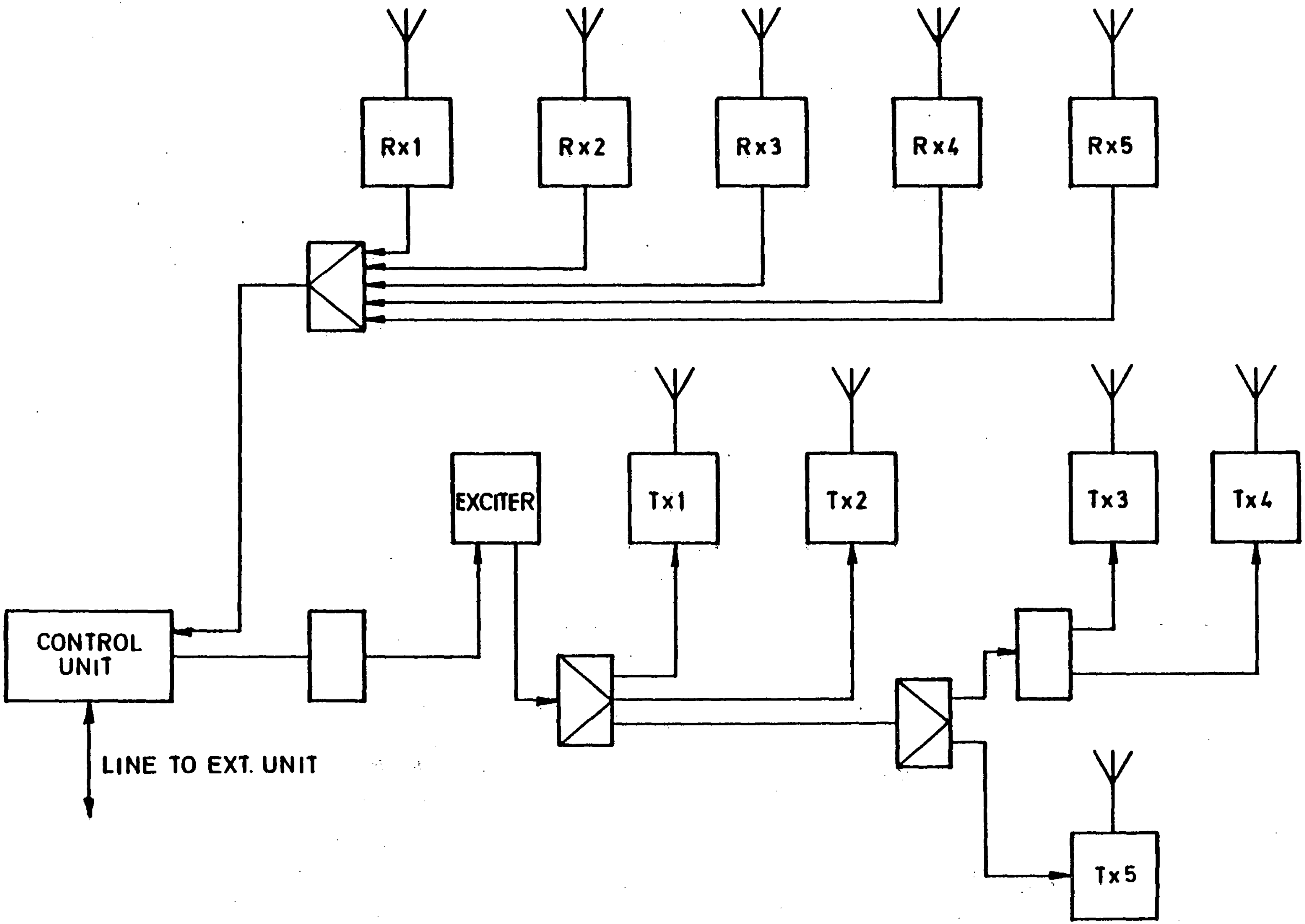


FIG. 10. 22. UNDERGROUND SYSTEM STANDARD ANTENNAS

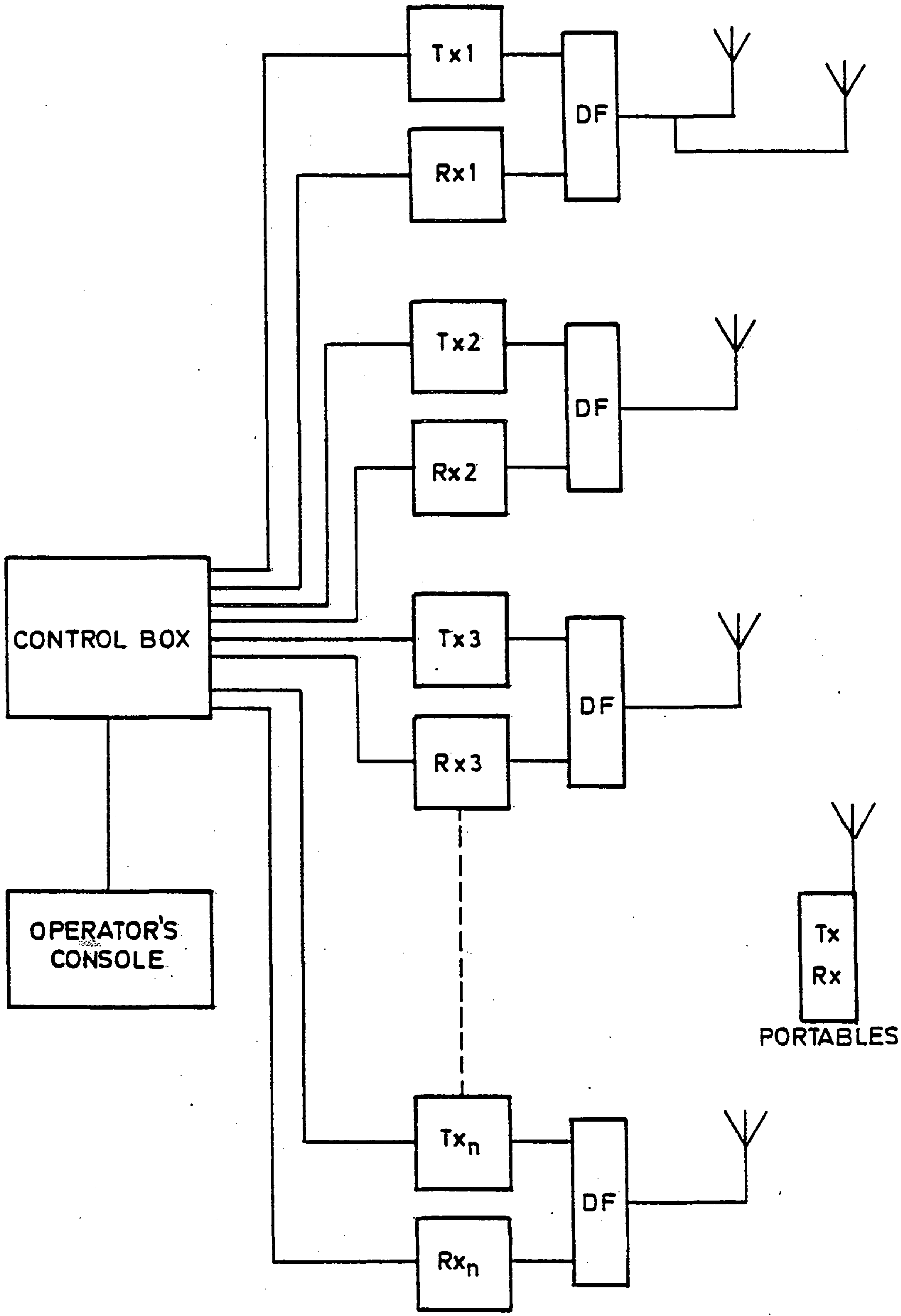


FIG. 10. 23. UNDERGROUND SYSTEM WITH ANTENNAS & MANY Tx/Rx

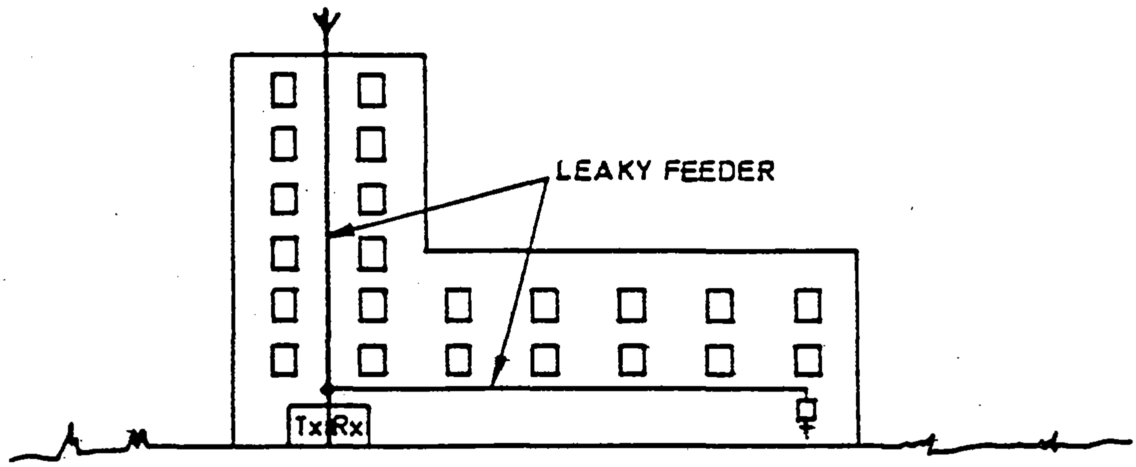


FIG. 10.24. LEAKY FEEDER SYSTEM IN BUILDING

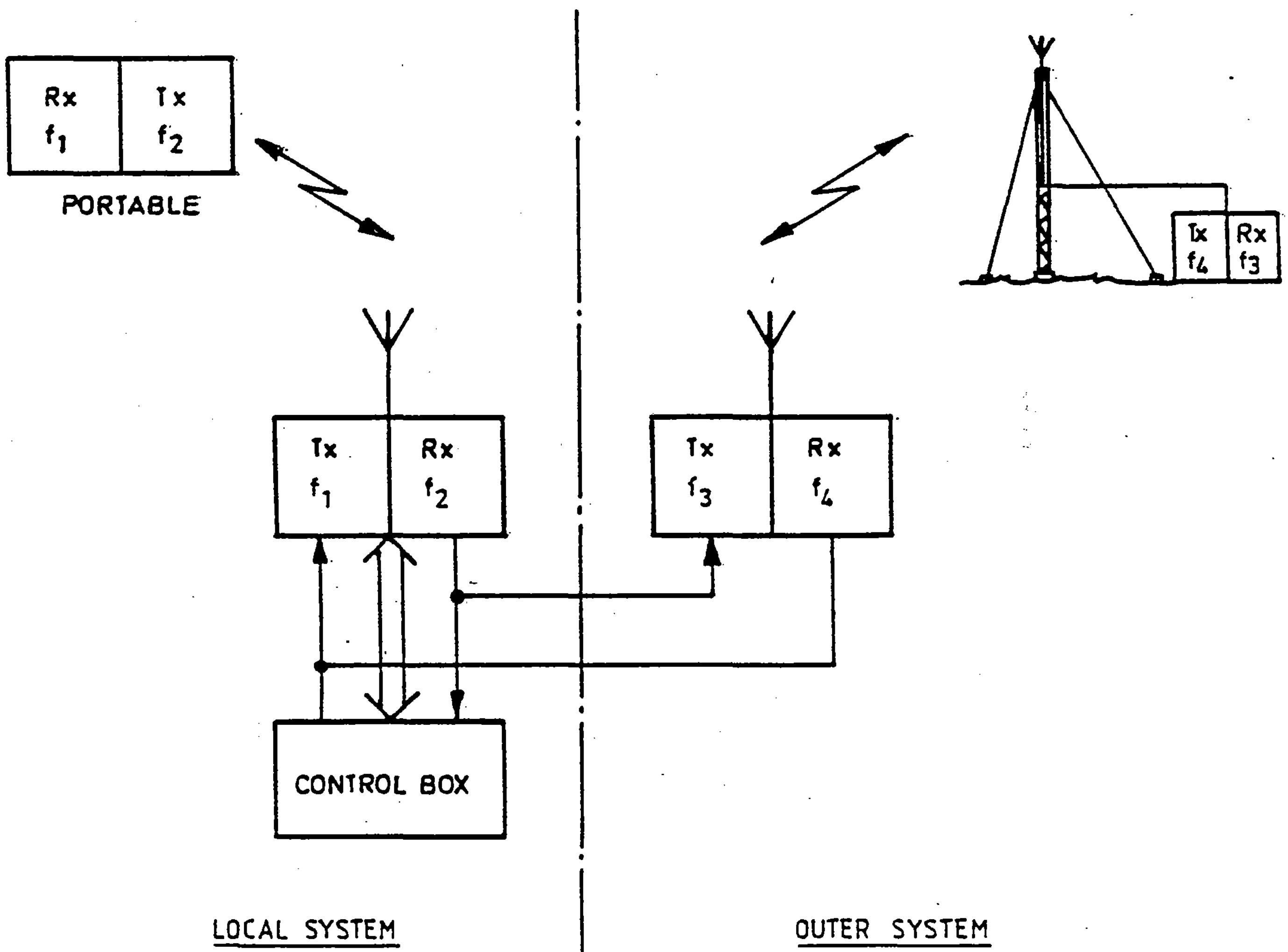


FIG. 10.25. PRINCIPLE CROSS BAND ARRANGEMENT

Autonomous leaky feeder system - Fig. 10.24 shows a leaky feeder system in a large building. The leaky feeder can be terminated with an antenna, which will provide coverage of the area surrounding the building. The leaky feeder can preferably be installed in an elevator shaft or similar, but the possible shielding effects must be carefully considered. This system can of course also be applied in an underground installation.

Underground system with cross-band arrangement for connection to common system - A radio system in an underground installation can be integrated with an external mobile radio network using a "cross-band" arrangement, as is illustrated in Fig. 10.25

11 DATA TRANSMISSION

11.1 Transmission Rate and Modulation Methods

It is necessary, in treating this subject, to consider in detail the behaviour of mobile radio networks when used for the transmission of digital signals to convey data.

It must first be noted that the maximum transmission speed possible is related to the RF useful bandwidth, ie 16 kbit/s with a direct modulation method in a system using channel spacing of 25 KHz. This is a bit rate that requires the data to be fed into the transmitter in the baseband. For this reason the system is not suitable for simulcast networks using standard telephone channels for the interconnection of the main/repeater stations with data systems.

Most digital mobile systems use the principle of transmission of a voice frequency modulated in frequency or phase on standard FM/PM/AM/SSB radio equipment.

The performance of a mobile radio data system is subject to Rayleigh fading. For very low speed bit rates of about 50 bauds, the bit error rate (BER) is excellent, because for such low bit rates the bit length is similar to the length of the time slots in semi-analog signalling, which are also characterized by excellent performance. Increasing the bit rate to 300 bit/s, the BER rapidly increases, until at higher speeds it remains nearly constant. Taking into account the audio bandwidth of modern mobile systems, the maximum useful speed today is 2400 bit/s, for 25 KHz channels. For narrow band systems (12.5 KHz channels), or systems in which the interconnection channels are used both for traffic and control signals by subdividing the low frequency channel bandwidth, the maximum useful speed, in practice, is 1200 bit/s.

The modulation systems used for the data modems are:

Differential Phase Shift Keying (DPSK) for two phase levels, with carrier at 1800 Hz.

Phase Shift Keying (PSK) with two phase levels and carrier at 1200 Hz.

Frequency Shift Keying (FSK) with frequencies of 1300 Hz and 2100 Hz, as in the CCITT standards for public telephone networks.

Fast Frequency Shift Keying (FFSK) with frequencies of 1200 Hz and 1800 Hz.

The system which provides an acceptable compromise from both technical and economic considerations is the FFSK, with a speed of 1200 bit/s. Many countries have now adopted this as a standard and it is generally accepted by many manufacturers. FFSK modulation concentrates the power density spectrum nearer the channel centre frequency than do other forms of modulation.

Fig. 11 illustrates the behaviour of the BER in a mobile radio radio link with and without Rayleigh fading. It can be seen that the link performances are good in the absence of fading, but that they are degraded with fading.

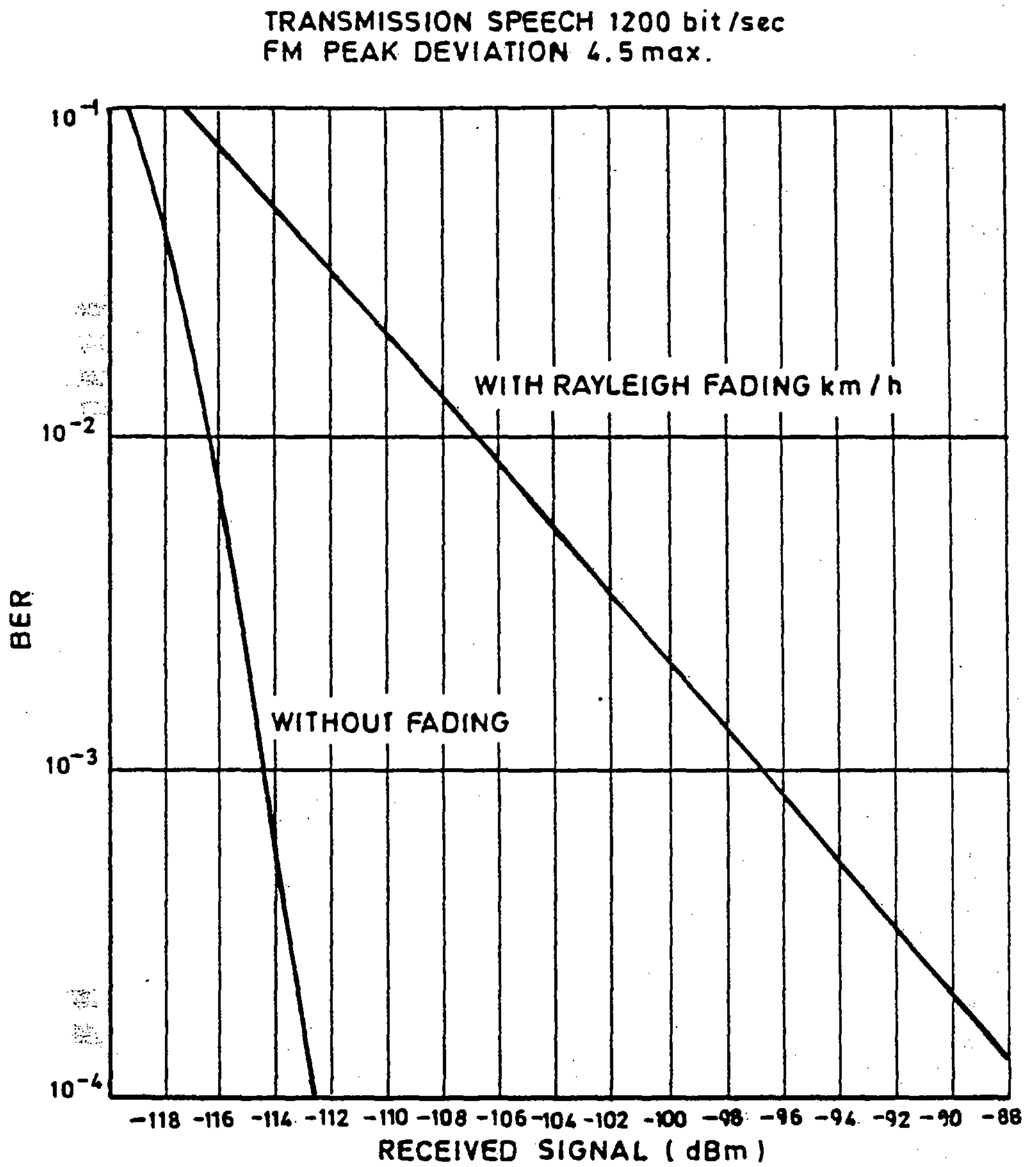


FIG. 11. BIT ERROR RATE (BER) WITH AND WITHOUT FADING.

In the case of simulcast quasi-synchronous networks, data transmission gives rise to some complexities. With this type of network, as in the Rayleigh fading situation, when a vehicle is moving the received signal presents a periodically variable envelope, the amplitude of which can reach levels below the receiver sensitivity, thus making the data transmission signal unserviceable. The effect of this is to generate noise bursts which obliterate the received RF signal. The duration of the bursts depends on the RF signal level and on the speed of the vehicle.

Data transmission links, other than those on mobile links, are characterized by the presence of randomly distributed errors, with BER not exceeding about 1.10^{-4} and they are generally provided with error detecting but not error correcting systems. In mobile networks, where there are error bursts which can recur periodically, error detection is not sufficient and some error correction is usually needed. Ideally, it is necessary to provide the data modem with a system of error and error burst correction, matched to the actual error distribution. This requires the coding system to carry redundant information, which, in extreme cases can reach a value of 3 redundant bits per information bit. Such coding and error correcting methods for the error distribution typical of mobile networks, are very efficient, but comparable results can be reached with other techniques such as message repetition.

Another important choice that affects the BER in digital transmission on simulcast networks using FSK or FFSK, is that linked to synchronous (coherent) or asynchronous (non-coherent) detection. Synchronous demodulation is essential in the presence of fading and in simulcast operation when error bursts arise, but is not so important when a single constant level RF signal is received.

The introduction of error correction systems and use of coherent modulation clearly influence the complexity, the dimensions and costs of equipment, especially vehicular or portable equipment.

In the case of multiple access networks, the use of suitable techniques eliminates error bursts and spreads the distribution of residual errors, so that error distribution is similar to that of conventional fixed transmission systems.

The advantages of each of the available techniques for improving the BER must be carefully evaluated since, for instance, it is very necessary to decide which provides the optimum transmission rate.

11.2 Interfacing Techniques

In the previous sub-section some constraints that the operational mode of a mobile radio network impose on the data transmission have been discussed. They are mainly due to the message format and to the optimization of the data processing in relation to the network performance, taking into account fading and error burst distribution and length. In addition, there are constraints due to half-duplex operation, to the access keys, and to the time sequences that are to be observed in the transmit/receive operations of each user terminal and between two user terminals. These constraints affect the protocol of the interchanging message and in particular the signalling protocols.

In multiple access networks, the exact identification of users, the address identification, is necessary for each user class (speech users, data users, speech plus data users). This implies the following:

- the DCE (Data Circuit Terminating Equipment) which includes the data modem, and the circuits for data processing and data interchange, when it exists, is a part of the transmission network and should be integrated into the user equipment.

- the DCE that acts as link controller in the data exchange, must perform the selective calling functions which enables the user to enter the channel and to respond to a call.

Implementation of these two requirements, depending upon the characteristics of the network, ensures the correct performance and operation of the network.

The user's transmission equipment acting as DCE, must be provided by a standard interface with the Data Terminal Equipment (DTE), which is the source and/or the destination of the data. The interface must be transparent to the network and the messages, and to the operation of the data system in accordance with the requirements of multiple access networks.

It is convenient to consider some basic factors, beginning with the need for an interface to be designed so as to allow access to the network by a number of users. There is considerable merit in meeting this requirement by standard techniques rather than to introduce a non-standard solution which could prove more costly.

Taking into account the fact that private mobile radio networks operate mostly in the half-duplex mode, the recommended method would be to refer to the generally accepted international standards, eg EIA RS 232 C, CCITT V-24 and V-28.

For high level data requirements such as telecontrol systems, computer systems and polling data acquisition systems, the DCE will directly provide for access to the networks and channel assignment features. For lower level data transmission requirements, including information transfer between non intelligent terminals such as printers and keyboards, the use of standard equipment is again recommended.

In the case of lower level data transmission the calling functions, and more generally the functions of access to channels and channel assignment, can be carried out by the same circuits serving that function in the telephone system.

11.3 Data Transmission Applications

A mobile radio equipment, when equipped with a suitable DCE can be used in conjunction with any of the following DTE:

- equipment for transmission/reception of short pre-formed messages

- alphanumeric keyboards and displays

- alphanumeric keyboards and printers

- alphanumeric keyboards and video display units (VDU)

- personal computers

- telecontrol equipment

Using this type of equipment, the following facilities can be provided:

- transmission and reception of short pre-coded alarm and/or instruction messages
- transmission and reception of written messages
- transmission of commands
- transmission and reception of telemetering signals
- automatic or semi-automatic status monitoring of single mobile units, groups of mobiles or all the mobiles in a network
- setting up of emergency mobile telecontrol or dispatching centres.

In addition to the mobile applications listed above, the mobile network can provide an economic solution for the transmission of telecontrol signals, where there is normally low channel occupancy, and some delay in the transmission of the telecontrol signal, due to mobile message traffic, can be accepted.

For these applications the stations can be equipped with the same equipment as that used for the mobile service. Among the services which such an arrangement can provide are:

- alarm transmission/acquisition
- data acquisition for environmental pollution and seismic control
- telecontrol, mainly for fault location and isolation
- load management
- telemetering

12 RADIO PAGING SYSTEMS

12.1 General

Paging systems make it possible to contact from a telephone, persons whose precise location may not be known but who are assumed to be within the coverage area of the radio network. These systems do not normally provide a return speech or signal path. Electricity utilities make extensive use of paging systems to contact roving personnel in fairly confined locations such as:

Power stations
Administration complexes
Construction sites
Depots and stores

Wide-area paging is often used to alert personnel who are "on-call" over distances of several kilometres, if an emergency arises outside of normal working hours.

Radio paging systems are of two types

(1) Inductive loop (see section 10)

(2) Broadcast

12.2 Broadcast Radio Paging

Broadcast radio paging is usually allocated to the mobile radio bands 80, 150, 450, and 900 MHz, but there are some systems which operate in the 27 to 50 MHz band. Selective calling, similar to that described in Section 9, is generally used so that each receiver may be addressed individually or on a group basis.

Paging system may be tone-only or tone-and-voice. Tone-only receivers have a typical sensitivity of 5-10uV/m, whilst tone-and-voice receivers have a typical sensitivity which is worse by more than 10 dB, with a reduced service area as a consequence. The output of tone-only sets may be in the form of a tone or series of tones, or preferably a form of display (either LCD or LED) which contains a digital or alphanumeric message. A receiver may be designed with a digital memory to enable a number of different messages to be stored and displayed as required.

When ambient noise levels are too high to permit the use of a normal alerting tone, it is possible to use a set with an inbuilt miniature vibrating motor to act as an alerting device in place of the acoustical method. The receiver is worn on a belt or carried near the body.

Tone-only systems permit a greater number of messages to be transmitted in a given time than tone-and-voice systems. Where a large number of users is associated with a system, store-and-forward processor control enables calls to be sent in queuing order during busy periods. In a voice only system, the access code needs to be dialled followed by the voice message, but unless the paging receiver user is always available to receive the voice message, there is a probability that the message will be lost.

As individual receivers may be out of use due to faults or for battery recharging operations, it is desirable that the interface between the telephone systems and the paging transmitter be programmable, to enable a user to change receivers but still be called by the same number.

12.3 Overlay Paging System

The use of an existing mobile radio system for paging has many advantages, particularly if it is already equipped with selective calling:-

- No new main stations or frequency allocations are required (unless the paging traffic is very high)
- Range of the system is already known
- Costs are limited to pager costs alone
- The user may select either a pocket pager with receiver only or a hand-held portable with talk-back options

Such systems are referred to as overlay paging systems.

There are two main types of overlay paging systems, Primary and Secondary.

12.3.1 Primary overlay uses pagers which are on the same receive frequency as the mobiles and are called and addressed in the same manner. The main disadvantage is that the field-strength sensitivity of a body-worn receiver is considerably worse than that of a vehicular mounted mobile with a standard antenna.

Furthermore, the paging receiver may be inside a building which can attenuate the signal strength by typically up to 20 dB. The useful range of a primary overlay paging system is therefore some kilometres from the main station transmitter, the actual distance depending on the usual factors of main station transmitter power, antenna height, building density, receiver sensitivity etc. A further variable is whether tone-only or tone-and-voice coverage is required. Tone-only systems have approximately twice the range (four times the area) of tone-and-voice systems, since talk-back requires a transmitter, and as it will normally have less power than the base station transmitter, its range is further reduced. An additional problem with talk-back systems is that the battery must be larger, thereby increasing the size and weight of the pager, although tone systems which return only a confirmatory tone minimise these problems.

12.3.2 Secondary overlay paging systems involve using a mobile which is selectively called to relay a message to a pager.

The simplest system uses the automatic answer-back of a mobile to selectively call the pager, with the pager receiver on the same frequency as the main station. The advantage of this method is that a considerable increase in range is possible. Compared with the range of the main transmitter station to mobile, the range of the mobile to the pager will be quite small, typically less than one km, due to the low antenna height and reduced output power of the mobile as against that of the main station.

The operational advantages of secondary overlay are considerable for power utilities, since the principle duties of operational staff involve the use of vehicles simply as a means of transport from one location to another, and on arrival at their work location they may be out of contact by telephone or by their mobile radio. Secondary paging also allows the called user to reply over the mobile units, which means that the caller is likely to receive a more prompt reply. It is, of course, possible to have direct talk-back from a hand-held portable if the mobile is connected as a mobile repeater, as described in Section 10.4.

12.4 Typical specifications for wide-area radio-paging receivers

Frequency bands, MHz	87, 150, 450, 900
Channel spacing, kHz	25
Modulation format, kHz, NRZ FSK	±4.5 (system dependent)
Data rate, bit/s	500
*Sensitivity, u V/m	10
Adjacent channel rejection, db	65
Adjacent channel blocking level, db	60
±20 MHz blocking level, db	100
Spurious response rejection, db	70
Battery life, week	13
Temperature range, deg C	-5 to +50

* tested at 8 positions on the body

12.5 Environmental Requirements

Portable receivers should be capable of operation within the temperature range -10° to +55°C, although they may not meet the full specification as indicated above.

Receivers intended for installation in vehicles should be capable of operation within the temperature range -25° to +55°C. The receiver should not emit alerting signal under the influence of such environmental factors as mechanical shocks, pressure or static electricity.

It is recommended that portable receivers be designed to withstand:

a) Fall test according to IEC publication 68-2-32. The height of fall should be 500 mm and the number of falls two.

b) Bump test according to IEC publication 68-2-29. 1000 bumps in each of three perpendicular directions with the accelertion 98 m/s^2.

It is further recommended that receivers, intended for installation in vehicles, be designed to withstand a vibration test according to IEC publication 68-2-6:

10 - 55 Hz	± 0.15 mm
55 - 150 Hz	20 m/s^2
Sweep rate	1 octave per minute
Duration	2 hours in each of 3 directions

13 EQUIPMENT DESIGN

13.1 Present Design Technology

The growing demand for communications has created increased design effort all over the world, and the technology has benefited greatly from the highly advanced military designs. These factors have brought private mobile communications to a level which reflects the present level of modern electronics. One technology in particular accelerated the development of the facilities needed in communications to produce reliable, easy to handle equipment - the semiconductor. This further advanced the computer and its offspring, the microprocessor, which in mobile communications permitted the introduction of new facilities which simplified operation and made possible some of the known principles, such as frequency synthesis, which is now in wide use in vehicle/personal equipment.

Nowadays, radio equipment is all solid state. The thermionic valve is no longer used in mobile radio communications. High power transistors are utilized in the final stages in transmitters and in power supplies. For low power signal application, eg, RF-signals, audio signals, tone signals, control signals/functions, transistors, IC's, customized LSI circuits, thick-film circuits and thin film circuits are all used.

The main advantages of semiconductors, when compared with valves are:

- Lower power consumption
- More robust
- Smaller size
- Improved reliability

whilst at the same time giving access to new improved facilities, providing a radio equipment of greater versatility.

The introduction of the microprocessor into VHF/UHF mobile radio, has changed the equipment design radically. The microprocessor in mobile radio allows transmitter/receiver units, or signalling/control units to function in a variety of modes by means of different stored programs - normally contained in a PROM (Programmable Read Only Memory) or EPROM (Eraseable Programmable Read Only Memory).

The use of a microprocessor in this context allows:

High flexibility
Fewer components in the control-logic
Changes in frequencies/functions to be easily performed
Optional functions to be easily installed
Complex functions to be added with economical advantages.

A single PROM is, in some designs, replaced by two different PROMs where the first defines the basic mode of operation together with the basic functions, eg, duplex/simplex, with or without selective calling, or type of control, and the second, the "personality PROM" defines the individual users requirements, eg, specific RF-frequencies, selective calling codes, signalling functions and codes.

When more than one RF channel is needed, Frequency Synthesis has shown itself to be a more economical way of generating frequencies, thereby replacing conventional crystal oscillators. The principle of operation is shown in Appendix G.

Frequency synthesis allows the generation of a vast number of frequencies, but normally only a reduced number is made available, depending upon the number of positions on the channel selector on the equipment, the available bandwidth of the radio equipment, and the number of frequencies (channels) granted by the PTT-authorities. By means of burning (removing) diodes in the diode-matrix, or encoding of the personality PROM, only permitted frequencies are made available. Separate frequency synthesis can be provided for the transmitter and receiver, or common frequency synthesis can be arranged for both, depending upon the requirement.

All types of equipment described below, eg, vehicle, transportable or personal sets, and main stations, all contain the same basic elements: transmitters, receivers and power supplies. The receivers are either double or single conversion super-heterodyne types.

The power supplies vary greatly from heavy duty mains/battery supplies for high powered base stations to battery supplies for low powered personal sets.

13.2 Vehicle/Transportable Equipment

The majority of mobile equipment used in the systems described in Section 2 consists of vehicle equipment. Designs vary according to the requirements but two main types can be derived:

(i) the single unit type with local control,

(ii) the extended control type.

In the first type the control unit is an integral part of the set. The housing is steel or aluminium alloy provided with a front frame of plastic or aluminium alloy. These sets are typically non-splash-proof, less ruggedized design, usually mounted above or below the dashboard, or in some cases fitted into the dashboard through a standardized cut-away opening (DIN-standard DIN 75.500, found in several European continental vehicles).

With the extended control type, the radio unit may be installed in the vehicle boot or underneath a seat, and the control unit, which may be supplied in various designs suited to the requirement, mounted separately, wherever the user finds it most convenient. The two units are interconnected by a multicore cable supplied with connectors. The radio unit is normally of a more ruggedized design and usually splash-proof.

Principal electrical data for both these types are:

(i) Transmitter power: 5 to 40W for simplex types and 5 to 25W for duplex types (The lower power ratings for duplex types are due to unavoidable losses in duplex filters or diplexers).

(ii) Receiver audio output typically from 1 to 5W and in special cases 10W for public address purposes.

(iii) Battery voltages: 12V nominal, usually negatively earthed 12V with reversed polarity, 6 and/or 24V operation can be supplied with optional power packs mounted internally or externally to the set. A few designs allow the built-in power supply to be switched to different voltages, with negative or reversed polarity.

(iv) The channel capacity ranges from 1 to 100 or more if required, utilizing frequency synthesis.

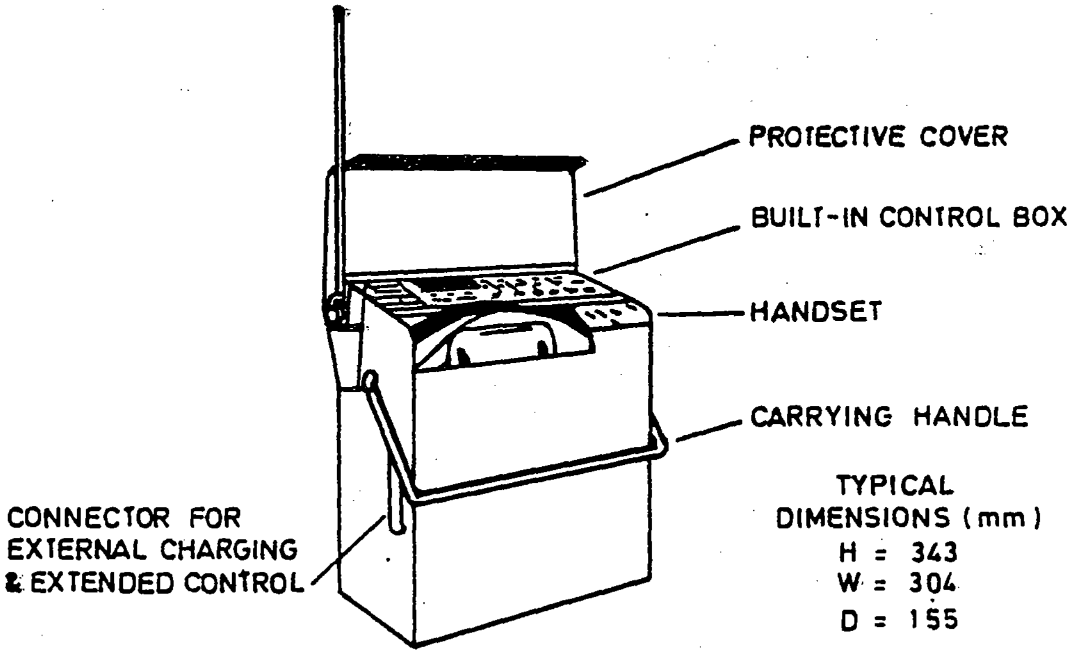


FIG.13.1. TRANSPORTABLE TYPE RADIO SET

13.3 Vehicle/Transportable Accessories and Facilities

A large range of accessories is available for vehicle sets:

(i) Various types of loudspeakers for different applications inside a vehicle or outside (waterproof), high power types for hailing purposes.

(ii) Microphones or microtelephones (handsets) for use inside a vehicle, telephone handsets for outside use (waterproof). NB: Handsets are imperative for duplex operation.

(iii) Antennas with or without gain, flexible or non-flexible, antennas with magnetic base for easy removal or installation.

(iv) Control units (only necessary for remote controlled sets) with or without facilities for selective calling control, either with rotary switches or push-buttons for channel selection, optional numeric or alpha-numeric displays for indicating operating mode, call received etc.

(v) Selective calling devices: transmitters only, receivers only, combined transmitter/receiver units, optional group call or all call facility, mobile identification facility or precoded messages facility ...... CTCSS (Sub-audio pilot tone) transmitter/receiver or combined units, DTMF for telephone system access.

(vi) Mobile identification (MI) is normally programmed into a personality PROM, eg, the MI is permanently associated with the radio set. If, however, it is desired that the actual user's identification should be displayed at the main station whenever the vehicle is transmitting, code-plugs can be inserted in a slot on the set or on the control box. The code plug enables the set to transmit or receive the identity of the user.

(vii) A facility allowing the receiver in a vehicle set to operate both in the single frequency simplex and the two frequency simplex mode, eg, wide band-receiver operation. (See Section 2).

(viii) A facility allowing a vehicle set to be provided with extra functions enabling the set to operate in fully automatic systems. Hard-wired controlled sets utilize additional logic circuitry, mounted in an extra unit, connected to the radio unit by means of multicore cable with connectors, whereas software controlled sets, based on the utilisation of micro-processors, singly are provided with different PROMS.

(ix) Transportable equipment, see Fig 13.1, consists of a vehicle set supplied with a rechargeable battery pack, often combined with a mains-operated charging device, all housed in one common unit. The electrical data are as for a vehicle set, given in section 13.2 above. The main application is as a standby mobile set, with an antenna with magnetic base and a microphone/loudspeaker (Monophone) as the necessary accessories.

Another application, but only if permitted by the PTT, is as a temporary main station, for use in a small, independent mobile system for intstance.

13.4 Personal Equipment

Personal sets are scaled-down vehicle sets where size and weight have been reduced to to a minimum, in order to be easily portable. Transmitter power is also reduced, as a compromise between the conflicting requirements of high power, demanding large, heavy batteries, and the need for reduced weight to allow easy handling. Transmitter power varies from 1 to 5W, depending on manufacturer and frequency range. The batteries are nickel cadmium (Nicad) types, being rechargeable. Most suppliers deliver batteries with different capacities, to enable the user to choose either low weight with reduced operating time or greater weight with extended operating time.

Receiver specifications are as for vehicle sets except for the audio output power which is reduced to between 0.1 and 1W. The channel capacity ranges between 1 to 100 or more, utilizing frequency synthesis. Personal sets vary in design, depending on the manufacturer, but two main types of control may be derived:

(i) The local control type, where the radio unit and the control part eg, control buttons/ knobs, microphone and loudspeaker are contained in a single unit.

(ii) The extended control type, where the primary control functions, transmitter keying button, microphone, loudspeaker, tone call (or identity) transmit button, volume control, call received lamp are operated from a separate control box, small enough to be held in the hand. The control box is interconnected with the radio unit via a short multi-core cable supplied with a connector at the radio unit end. The radio unit carries the remaining control functions.

(iii) A universal type of equipment is now also available. Basically the set operates as a local control type, but, when an extended control unit is connected to the set, the primary control functions listed above are transferred to the control unit.

13.5 Personal Equipment, Accessories and Facilities

A large range of accessories is available:

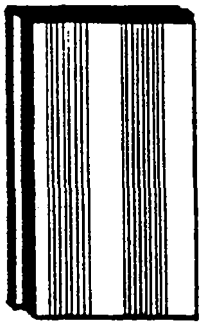
(i) Various types of extended control boxes with different combinations of the following control functions: transmit key button, 1 to 3 selective call transmit buttons, loudspeaker on/off button, receiver squelch opening button, socket for earpiece connection, volume control switch and connector for antenna.

(ii) Units for selective calling (as for vehicle equipment).

(iii) Different types of earpieces for connection to the set or to the extended control box.

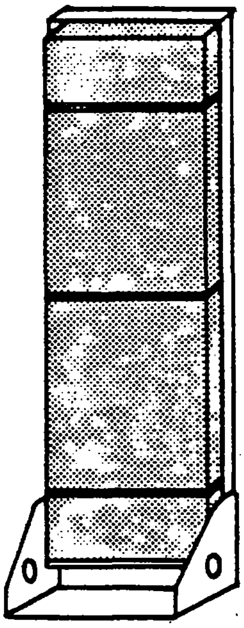
(iv) Microphones with amplifying devices allowing hands-free operation (voice controlled keying).

(v) Digital displays showing the selected calling codes and channel number.



TYPICAL
DIMENSIONS (mm)
H = 550
W = 365
D = 135

FIG. 13. 2. MAIN STATION (WALL-MOUNT TYPE).



TYPICAL
DIMENSIONS (mm)
H = 1650
W = 520
D = 250

FIG. 13. 3. 19" RACK WITH 2 RACK-TYPE MAIN STATIONS AND 2 LINE CONTROL PANELS MOUNTED.

TYPICAL
DIMENSIONS (mm)
H = 65
W = 300
D = 215

CONTROL UNIT

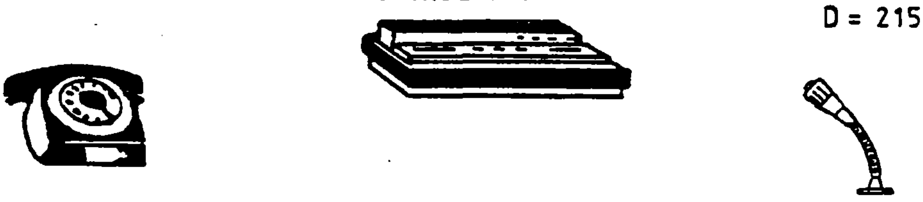


FIG. 13. 4. CONTROL EQUIPMENT FOR SINGLE OPERATOR EXTENDED CONTROL.

(vi) Different battery sizes eg, batteries with different capacities and batteries with extra contact bushings enabling the set to be operated while the batteries are being charged.

(vii) Different battery chargers such as single position, multi-position, chargers allowing fast charging.

(viii) Various types of carrying harness.

(ix) Shortened or full length antennas with connection to the set or to the extended control unit.

(x) Slip-in car adaptors, to be fitted permanently into a vehicle. When the set is slipped into the adaptor, the control functions of the set are transferred to microphone and loudspeaker, using the antenna and power supply of the vehicle. The battery on the personal set will be charged automatically. Some adaptors allow further booster amplifiers to be added, both for the transmitter and for the receiver audio.

(xi) For individual control of personal sets, the control section can be fitted with different combinations of rotary switches allowing changes in the selective calling codes to be transmitted.

(xii) A facility allowing the receiver in a personal set to operate both in the single frequency simplex and the two frequency simplex mode eg, wideband receiver operation. See Section 2, for operating details.

(xiii) Facilities allowing the unit to be extended to take additional circuitry and logic, eg, to enable the set to operate in fully automatic systems.

(xiv) The personal sets can also be adapted to work as personal receivers only, for application as call-out receivers, or as personal transmitters only, for application as personal alarm-transmitters.

13.6 Main Station Equipment

The simplest type of main station is a vehicle set, possibly with a local control unit, mounted and powered from a suitable mains-operated source. This type is normally used only in single channel systems without selective calling facilities.

In more advanced systems, in particular multichannel or multi-operator systems, the main station equipment consists of one of the following types:

(i) Wall-mount type (see Fig 13.2). A heavy steel or alloy cabinet contains the transmitter, receiver and power supply, with space for control panels possibly for remote controlled operation if required.

(ii) Rack type (see Fig 13.3) where receivers, transmitters and power supplies are either fitted on to plates provided with covers, or are assembled in drawers which can be pulled out for maintenance purposes.

Transmitter output powers range from 6 to 100W for simplex types, and from 6 to 40W for duplex types. The lower duplex ratings are due to unavoidable losses from duplex branching filters or diplexers. The maximum permissable power is a national decision of the authority concerned.

Transmitter and receiver units are important building-blocks when designing multi base stations.

The audio output from main station receivers is produced as line output from a balanced transformer. The level to line is approximately 0 dBm for reference deviation, with an output impedance of 600 Ohms. Control of loudspeaker audio level is provided at the control positions.

The following Section on accessories and facilities, covers the vast range of equipment necessary to multichannel/multicontrolled main stations. Since the majority of such designs are usually tailored to the users' specifications, only very occasionally can they be considered as standard products. Fully automatic networks, operating without main station operators, can to a greater extent be designed from standardized, highly expandable basic terminals.

13.7 Main Station Accessories and Facilities

13.7.1 Control equipment

For single operator, extended control of one base station, a control unit (with built-in loudspeaker), and its associated telephone or microphone is shown in Fig 13.4. The telephone is for duplex operation which allows through connection of a telephone network with the radio systems, and the microphone is for simplex operation.

Fig 13.7 shows a microprocessor operated control box provided with key-pads, and a VDU for displaying transmitted and received call code numbers, or received and decoded alpha-numeric messages (see Section 2 for further details).

If extended control, allowing a maximum distance of 100m between control box and base station is insufficient, remote control must be added. This is achieved by connecting the control box with a small terminal unit, converting the control functions to line signals. At the main station, a control panel is added which converts the line signals back to control functions. (The principle is described further in Section 2). In multi main station/control, the control box may be designed as a large desk top type, see Fig 13.5, or as a console as in Fig 13.6, or as a push-button panel to be fitted into the operators desk.

The common switching terminal described in Section 2 and shown in a system lay-out in Fig 2.8, may be designed as a hardware type, based on modules wired together, using IC- or relay-logic as in Fig 13.8, or be designed as a microprocessor controlled type, based on standardized plug-in modules controlled by a customized program, see Fig 13.9.

13.7.2 Selective calling units

These will include push-button operated tone transmitters for selective calling, and decoders with alpha-numeric displays for showing received mobile identification numbers (see also Sections 2 and 9).

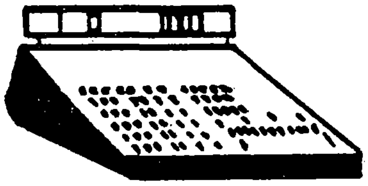


FIG. 13 .5. LARGE DESK TOP TYPE CONTROL BOX FOR MULTI-BASE STATION / CONTROL

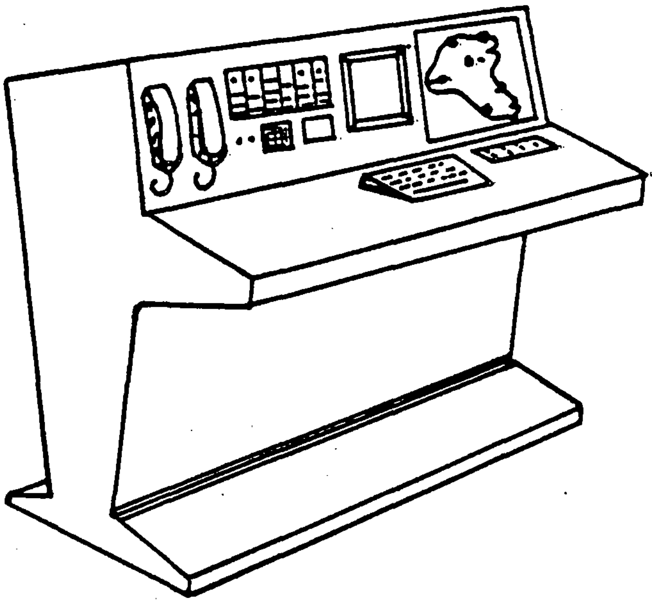


FIG. 13.6. CONSOLE TYPE CONTROL BOX FOR MULTI-BASE STATION / CONTROL

CONTROL UNIT
TYPICAL DIMENSIONS (mm)
H = 90
W = 330
D = 325

FIG. 13.7. MICROPROCESSOR TYPE OPERATED CONTROL BOX & VDU.

TYPICAL
DIMENSIONS (mm)
H = 710
W = 490
D = 155

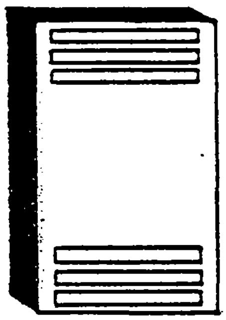
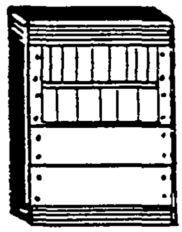


FIG. 13.8. COMMON SWITCHING TERMINAL.
(HARDWARE TYPE)



TYPICAL
DIMENSIONS (mm)
H = 900
W = 600
D = 600

FIG. 13.9. COMMON SWITCHING TERMINAL.
(MICROPROCESSOR CONTROLLED TYPE)

TYPICAL
DIMENSIONS (mm)
H = 400
W = 600
D = 600

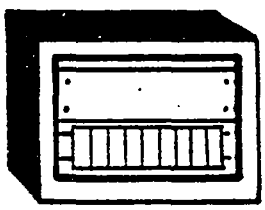
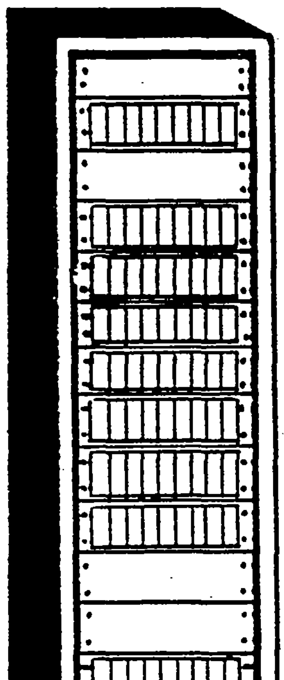


FIG. 13.10. SINGLE CHANNEL TERMINAL FOR ONE EXCHANGE LINE.



TYPICAL
DIMENSIONS (mm)
H = 1800
W = 600
D = 600

FIG. 13.11. MULTI-CHANNEL TERMINAL EXPANDABLE FROM 1 - 8 CHANNELS AND 1 -12 EXCHANGE LINES

13.7.3 Switching Modules

There are many variations, but in general, facilities are provided for DC-control signals, AC-control signals and telephone lines.

13.7.4 Power Supplies

For electricity mains supply operation of main stations and control equipment. Battery power supplies for 12, 24, 48 or 60V. Battery chargers with or without trickle-charging facility (See also Sections 5.9 and 14.1.2).

13.7.5 Antennas

To obtain the necessary area coverage from main stations it is necessary to consider the full range of available antennas: Omnidirectional and directional antennas with or without gain, antennas with or without DC-ground connection and radiating cable antenna for tunnels (see Section 8).

13.7.6 Other Accessories

Microphones, handsets and loudspeakers with associated amplifiers, tape recorders with extended control facilities, for recording all communication taking place.

Receivers only, with voting equipment for enlarging receiver coverage areas, see Section 2 for details.

Transmitters only, with equipment for quasi-synchronous transmission to extend transmitter coverage areas, see Section 2 for details.

Processor-controlled, expandable terminal equipment for fully automatic systems. See section 2 for operating details. Fig 13.10 shows a single channel terminal for 1 exchange line (private or public) with 1-8 directly connected subscribers.

Fig 13.11 shows a multi-channel, expandable terminal with from 1 to 8 channels, 1-12 exchange lines and from 1-20 directly connected subscribers.

13.7.7 Intrinsically Safe Equipment (ISE)

Equipment to be used within hazardous areas, where explosive liquids or gases are present, must be tested and approved as being intrinsically safe. The specifications state the maximum limits for currents, voltages, energy absorbed in capacitors or inductances, together with the minimum permissable leakage distance between uninsulated conductors.

The original national standards for ISE such as BASEFA (UK), VDE (WG), have been replaced in all EEC-countries by new CENELEC standards. Due to the many limitations described, only 1W personal sets with a very limited range of modified accessories have been approved at the present time (1985).

14 SYSTEM AVAILABILITY

14.1 Main Station Reliability

The reliability of main stations will depend on the mechanical, thermal and electrical stability of the component parts of the station and this, in turn, will depend on the quality of the housing for the radio equipment, the structure of the antenna equipment and the method of power supply. Reference should be made to Section 5 on "Transmitter Station Site Planning".

a The building, or container, must be capable of protecting the radio equipment against the kind of weather conditions most likely to be encountered, eg, rain, snow, ice, high winds, high humidity, extreme temperatures, earthquakes, dust, corrosion, direct sunlight and electrical discharge. All access points and ventilation should be designed to exclude wild-life which could feed or nest within the equipment.

b The antennas, feeders and their support structure must be able to withstand extreme weather conditions, thermal cycling, resonant vibration and electrical discharge and carry aircraft warning lights if required.

c The power supply voltage for the radio equipment should not vary, even if the basic source of the energy is changed. Incoming electricity supplies should have surge-limiting equipment fitted to reduce the effects of lightning or faults on the electricity system. Internal electrical plant should not create radio interference, or cause mechanical vibration of the radio equipment.

Solid state equipment will function almost indefinitely if operated within its designed parameters and the reliability will almost wholly depend on maintaining the correct ambient working conditions. However, in spite of this, occasionally the equipment will fail. Depending on the degree of importance of the main station it may be considered advisable to duplicate equipment and provide automatic changeover when the monitoring equipment indicates failure. Automatic changeover may be limited to only the main component parts, eg, link and broadcasting transmitters and receivers, or applied to all equipment including antennas, feeders and power supplies. The degree of complexity will depend on the importance of the station within the network, ease of access to the site, or the responsibility to others for radio services. Thought should be given to the possibility that the complexity of the monitoring and automatic changeover equipment could, in itself, reduce the reliability of the station and it may be considered adequate that standby equipment is available on site which can be put into service quickly by local semi-skilled staff. If, for economic reasons, no standby equipment is available on site, then failures can usually be quickly diagnosed by centrally-based, highly-trained staff interpreting alarm data and observing the effect of the "failure" on the radio facilities. By preparing replacement units held at the depot and then travelling quickly to the defective base station, the "down time" can be minimised. Attempting to diagnose and repair faults on site using small discrete component parts may cause unacceptable delays to the restoration of the radio facilities.

14.1.1 Antenna Systems

The radiation from antennas is greatly reduced by melting ice on the elements and it inevitably follows that there will be a period of signal attenuation during the melting period. Types of antenna which are prone to this effect should be heated to prevent the attachement of ice, or suitably protected from the weather. Antenna heaters should be controlled by sensing the combination of external low temperature and high humidity, and activating the heaters before the occurrence of icing conditions.

14.1.2 Power Supplies

Main station equipment should be operated from batteries of suitable capacity which can be charged from the electricity supply system, internal combustion engine generators, gas operated thermo-mechanical and thermo-electrical generators, solar panels, or wind generators. Each of these sources has different characteristics which may affect main station performance, and the choice will depend upon local conditions and requirements.

a The electricity supply system can supply large amounts of power for battery charging, space heating, ventilation, lighting, test equipment socket outlets, etc, but may occasionally fail.

b Internal combustion engine generators are expensive to run continuously, have a limited fuel storage capacity, require frequent maintenance and are comparatively unreliable especially when required to operate infrequently. However, they can produce large amounts of power and could therefore meet the full power requirements of a station.

c Gas operated thermomechanical and thermo-electrical generators produce moderate amounts of power for continuous battery charging and other light duties, and will operate for very long periods with little maintenance.

d Solar panels produce small amounts of power for battery charging but the output varies with the light available. Their efficiency is affected by snow, ice and atmospheric pollution. They are less suitable at higher latitudes but are a useful source of energy at lower latitudes.

e Wind generators can produce large amounts of power which can be stored in batteries to cover periods of calm weather. They can be affected by ice deposits and have to withstand considerable mechanical stress when working normally.

It is preferable that all radio equipment in a main station has a "no break" power supply from a suitable battery, which is normally charged from the electricity supply system, with a standby diesel generator which automatically starts on failure of the normal supply. A large battery effectively protects the radio equipment from transient over voltages because of its very low source impedance. If both charging supplies fail, an immediate "charge fail" alarm should initiate remedial action by local staff before the battery becomes discharged. The ampere-hour rate of the battery should relate to the calculated time required to restore the charging supply.

If it is anticipated that there may be long periods when access to the main station is not possible, consideration should be given to the use of a gas operated thermomechanical or thermo-electrical generator with gas storage for several months of continuous operation. Gas can also be used for heating or cooling the radio equipment building or container.

14.1.3 Remote Control Circuits

Main stations can be controlled by:-

a Underground or overhead telephone lines.

b Radio links using directional antennas aligned to adjacent control or repeater stations.

c Broadcast radio signals using the reverse frequencies of the main station.

14.1.3.1 Telephone lines are used to control main stations if the distance between the main station and the control station is reasonably short, otherwise the capital cost of the line or the annual rental may be economically unacceptable. Underground telephone lines have a high reliability but overground or overhead lines to high altitude main stations are susceptable to damage by lightning, bad weather or physical destruction by animals. If telephone lines are rented, the Authority may not be prepared to give priority to repair work on main station control circuits. Duplicating the circuits will not appreciably increase the reliability if the circuits follow the same route, particularly if the most vulnerable part of the route is common to both. Using totally separate routes to ensure higher reliability may more than double the cost.

14.1.3.2 Radio links and repeater stations become economical when the distance between the control station and the main station increases, provided that suitable radio paths exist between them. Radio links can be easily duplicated and automatically changed over on failure, if continuous carrier operation is used, and space or frequency diversity will maintain serviceability if the radio paths are subject to fading or multipath attenuation. If switching is operated by the carrier on/off method then coded signals can be used to changeover to duplicate equipment. If an alternative route is available in an integrated radio network, coded signals can be used to connect the alternative circuit and no duplicated equipment is nneded. The "alternative route" method is more reliable in operation and can be more cost effective overall. All equipment failures should initiate alarms indicating the location of the faulty equipment, which should then be recorded and the alarm cancelled. Control systems can become unserviceable due to distortion or interference on the line, conditions which are not easily monitored for automatic changeover or the initiation of alarms. Out-of-band signalling with error detection may be applied to important circuits to initiate changeover or alarms.

14.1.3.3 Reversed Frequency Control A control station using the reverse frequencies of the main station is the simplest method of main station operation. Several control stations can operate one main station using the same discipline as mobile users. Under normal conditions, the power requirement of the main station is that of the receiver only, with occasional periods of repeater operation, and such a station can operate without an external electricity supply and occupy very little space. Batteries can be charged using gas, sun or wind, and the station will be very reliable if the charger output exceeds the total repeater load.

Some radio regulating authorities do not view free running reverse frequency talk-through with favour because it approximately doubles the transmitter "on air" time. Talk-through can be triggered by interference from distant outstations and mobiles, thus causing mutual interference between radio systems using the same frequencies. It is thus sometimes mandatory to employ operator control of talk-through, or to use one of the many methods of tone triggering available (see also chapter 13).

Perhaps the most versatile and economic method of operation is a form of "control override" whereby the main station is always on talk-through and the controller superimposes his speech on top of mobile users if necessary. Should the normal control link fail the controller uses reverse frequency equipment at the control centre and adopts mobile procedures.

High altitude main stations can become electrically charged and flash-over can occur between the station earthing and incoming telephone lines which are seen as remote earthing circuits. Where this occurs it is usual to employ telephone barrier equipment to prevent damage to equipment internal and external to the station.

14.2 Control Station Reliability

Control stations are usually located in population centres at comparatively low altitudes and thus do not have the environmental problems associated with main stations and repeater stations. There is usually a concentration of communications equipment located within the control station building which is operated by remote control equipment conveniently placed beside the controllers in an operation room. The equipment room and the operations room should be well heated, ventilated and illuminated and the antenna equipment mounted on the roof or on an adjacent self-supporting steel tower. With ideal environmental conditions, and the availability of trained staff to put standby equipment quickly into service, the reliability of a control station should be very high.

All essential radio and telephone equipment should be powered from batteries of adequate capacity to provide a "no-break" source of supply which could also be used for automatic emergency lighting in the operations room if the normal electricity fails. Mains operated reverse frequency standby radio equipment may be provided for use if the battery supply fails. Standby power supplies should be provided, as described above in Section 14.1.2. Suitable precautions should be taken to ensure that the normal and standby power supply systems do not create interference to the radio or control room equipment.

14.3 Mobile Equipment Reliability

Radio equipment installed in vehicles has a failure rate averaging one fault every three years and will function satisfactorily over a wide range of temperature, tolerate considerable mechanical vibration and work with a very variable power supply voltage. Unserviceability is usually due to mechanical damage to antennas and microphones. The loss of one mobile may not noticeably affect the performance of the radio system and faulty equipment is easily replaced and repaired.

If mobile repeaters are used, system unserviceability is most likely to be caused by failure of the repeater vehicle rather than the radio equipment, which should be readily transferable to another vehicle. Although the operating range may be considerably reduced single frequency equipment does not have this problem.

Transportable, hand-portable and withdrawable radio equipment has a comparatively high fault rate due to mechanical mishandling or exposure to weather conditions. Withdrawable mobile radios frequently fail when replaced in the vehicle due to faults in the connections caused by the ingress of dirt.

For further information on availability, reliability and maintainability, see the CIGRE Guide on Planning of Telecommunications for Power Systems (12).

15 ORGANISATIONAL POLICY

15.1 General

A mobile radio system should be designed to allow the users to communicate with each other in the quickest possible time with the minimum operation of interconnecting equipment. This concept applies to a simple mobile to mobile arrangement using a single radio frequency as much as to a large computer controlled multi-main-station network using many methods of selective calling and covering an entire country.

There are many operational techniques which eliminate or minimise the need for a human intermediary between the end users and thus reduce the "on air" time to little more than the duration of the message content, but all speech messages must include the identity of the user for administrative monitoring by the regulating authority.

It is usual for various parts of an organisation to have separate radio channels allocated to its various functional departments, but restrictions on the use of the radio spectrum, and economic factors, may require a compromise whereby there is common usage of the radio network by departments which have no direct inter-relationship in their daily work pattern.

So that sharing of the radio network can be made with the minimum of mutual interference between departments, it is usual to employ selective calling systems whereby end users can interconnect themselves without the use of intermediaries, and without reference to other users, using the principle that if the radio system is available then it can be used by anyone who has access to it. Most mobile radio networks are designed to accommodate the day to day workload without undue delays and can claim to be efficient and economic.

From time to time emergency situations will arise on the electricity system, and some parts of a shared radio network may become overloaded because of the abnormal concentration of work in one or more areas. Under these circumstances, all messages do not have the same degree of importance and there must be an arrangement whereby priority can be given to very important messages possibly by using part of the network which may normally be used for less important traffic.

The decision regarding the degree of importance of a message is usually taken in the control centres of the hierarchical structure and not by the mobile user. The control centre receives information from several sources, eg, other control centres, remote alarm systems, other mobile users, and the public telephone network, whereas the mobile user is usually only aware of his particular local situation.

When more mobile users wish to communicate with the control centre than the control centre can handle, the mobiles should be able to indicate their availability in a visually presented queue in timed order so that the controllers can determine which caller is the most important in the existing situation. It is psychologically important that mobile users know that they are in an orderly queue and that, all other things being equal, they will receive attention in that order. If they call again to confirm that they are still in the queue, they should receive verification without losing their place in the queue. By comparing the earliest queue time with a real time display, the control centre staff can assess the need to increase the number of controllers before the delays become unacceptably excessive.

It is unlikely that any mobile radio system can be technically designed and operationally staffed to cope instantly with all emergency situations which arise, and it would probably be economically unjustified to attempt to do so. However, an operational plan must be available to operational staff in which the key decision points are clearly stated, whereby technical changes are made to the radio network and staffing levels are increased quickly to minimise delays in the restoration of electricity supplies during emergencies, with due attention to replacement staff levels should the emergency be prolonged.

If the radio system is used for long periods exclusively by staff on emergency operations, this may seriously affect the day to day radio operations of departments less affected by the emergency. Adequate spare capacity must, therefore, be designed into the radio system to minimise the effect, and operational procedures must be agreed and recorded prior to the occurence of emergencies, so that all departments are aware of the results of their implementation.

If there is a dangerous situation, selective calling systems should provide a means of defeating the normal first-come first-served facilities, such that a mobile user can communicate with the appropriate part of the hierarchical structure for immediate attention and subsequent action. This facility should never be used for other than dangerous situations and should be treated in the same manner as 999 emergency calling on the public telephone network.

15.2 Disciplines

The object of operational discipline by users of mobile radio is to minimise the time occupied by a message. Call signs, radio telephone procedures, selective calling, coded signalling, visual display units, message printers, etc., are all designed to reduce the time taken to pass the information from one person to another with the greatest possible accuracy of content and in compliance with the conditions of the radio regulatory authority.

Radio telephone procedures are universally used and accepted as the most efficient way to conduct a speech conversation, and any tendency to depart from adopted procedures should be discouraged by disciplinary action. The use of the local vernacular should be discouraged as generally this will cause misunderstandings and repetitions, particularly if the end users are separated by some distance and not acquainted with each other's local accents.

With selective calling, the mobile user must be instructed to ascertain that the channel is not being used by another mobile before initiating a call. Alternatively, the arrangement may be that the mobile user is prevented from making a call if the channel is in use.

During high traffic periods, a mobile near the main station can seize the channel quickly when it becomes available because of his higher signal level, to the exclusion of a mobile some distance away. This may be operationally undesirable. It is preferable that selective calling systems should enable waiting mobiles to indicate their availability during a control centre transmission and thus prevent a scramble to seize the channel at the end of the preceding call. This requires an element of training and discipline by the mobile user.

Coded signalling can convey information in a very short period of time, and can then display a stored message in plain language to the staff at the control centre and an "acknowledge" signal back to the mobile. The mobile users then await their messages from the controller in the order decided by the controller.

The use of a "transmission duration limiter" can effectively discourage mobile users from making unncessarily long calls. With the knowledge that their mobile transmitter will automatically close down after a specified time, the user consciously makes the effort to be brief, to everyone's advantage. This facility also eliminates the jamming of a channel by a mobile with a faulty press-to-talk switch, which can be exceedingly difficult to locate even with good radio direction finding equipment. Mobile users should be instructed to operate their radios at the minimum volume required, particularly during the night, and switch them off when not on duty.

15.3 Operational Flexibility

The traffic on a mobile radio network varies in relation to the time of day and the occurrence of emergency situations, and can be categorised into specific periods:

(a) Normal day to day working with minor emergencies

(b) Night and weekend service

(c) The onset of a major emergency situation

(d) The peak of a major emergency situation

(e) The sustained peak of an emergency situation beyond the duration of an acceptable duty period for local operational staff to continue working effectively and safely.

Each specific period will require a different arrangement of the mobile radio network and a different number of operational staff. The technical capability of the network must match the availability of trained operational staff, and operational procedures must be clearly defined and published prior to any anticipated situation, to ensure that correct key decisions are taken at the right time for optimum use of the radio network.

15.3.1 Normal Day-to-Day Work

Most mobile radio systems are designed to meet the needs of day-to-day operations, with spare capacity for anticipated emergency operations. Priority access to specific parts of the system is given to appropriate controllers who, with due consideration, use the network overriding facilities in the common interests of the majority of the consumers.

An emergency in one department does not necessarily affect the day to day operations of another department and, if radio facilities are shared, the design should ensure that extra capacity exists, or emergency operations are controlled on special emergency channels. The latter may be technically or economically unacceptable and it may be necessary to achieve a balance which will mean the loss of some facilities to departments not directly affected by the emergency. This compromise is usually acceptable in the general interests of the consumers. Operational improvements are usually based on past experience and the knowledge of others engaged in similar operations. Staff levels are determined by the need to eliminate unacceptable delays in work procedures. Automatic traffic handling techniques are used when this can be economically justified.

15.3.2 Night and Weekend Service

Minor loss of electricity supply is usually reported by the consumer using a published number on the national telephone network. This requires at least one person to accept the call and initiate action, which may subsequently involve radio communication with a mobile or a radio pager, located anywhere within a large geographical area. Thus, it is preferable that a network, which may be operated during the day as several separately controlled systems, can have these systems concentrated into one central control point for night and weekend service. This method of operation ensures that remedial action is co-ordinated using the minimum designated staff necessary for the work, while providing effective and informed service to the consumer. This type of single control centre can originate a quick call-out of control staff and field staff in anticipation of a major emergency, which may be indicated by a sudden influx of consumer calls from a widely dispersed area, reinforced by remote alarms.

15.3.3 Onset of Major Emergency Situation

Major electrical emergencies are caused by a variety of circumstances which can quickly develop and are not always predictable. A large number of electrical faults may subsequently cause a sudden increase in mobile radio traffic and require a rapid division of the radio network and an increase in control staff. The radio network should be capable of subdivision, preferably into distinct geographical areas, to allow each controller to operate as few channels as possible. Ideally this would be one channel to one controller, but most systems provide more channels than there are multiple access points for control staff.

In the initial stages of a major emergency, messages are usually associated with fault location and isolation, and the system availability is high because the messages are brief. Later, when permits-to-work are being written the availability falls and traffic delays increase.

15.3.4 The Peak of an Emergency Situation

As the activity of the repair squads increases, there is an increase in messages related to work which does not involve control staff, particularly during the mid-day period, and much of this traffic will be mobile to mobile or mobile to local office. The use of single frequency radio equipment can reduce the traffic on the main network and improve the message rate at the repair location. Because of the decrease in range of single frequency ground-located equipment there is usually very little mutual interference between separate repair teams using the same radio frequency.

15.3.5 The Sustained Peak of a Major Emergency Situation

As emergency repair work continues, and relief control and relief field staff take over these duties, the radio network may require to be adjusted for operation by fewer staff and resort to a method of working similar to that for day-to-day. Although a large number of consumers may still be without electricity supply, the information situation will have stabilised and the mobile radio traffic will have reduced.

If repair teams have been brought in from adjacent electricity organisations, they should be able to integrate into the radio network using their own radio equipment. The use of frequency synthesisers has made the multichannel mobile possible at no extra cost, and all electricity authority mobile users should be able to switch to any channel required and operate to any control centre, provided they adopt open channel working or their selective calling equipment is compatible. The method of modulation is pre-programmed in relation to the channel number selected, although it is likely that all electricity authorities in the same country will have the same method of modulation.

16 MAINTENANCE AND TESTING

16.1 Introduction

Mobile radio networks, regardless of size or complexity, provide problems of maintenance not experienced in other forms of telecommunications. When used in power system operation and administration, the problems are compounded by higher than normal demands of availability being placed on the systems. Failure of mobile equipment used to direct power system switching can at the least cause serious disruption and at the worst danger to life.

It is paradoxical that fixed telecommunication services are often provided with alternate trunking or back-up equipment for call rates that may be only occasional, whilst mobile services, with high calling rates and critical message handling, depend on single items of equipment, and manual assessment of fault conditions by operators.

Special techniques must be developed to attain necessary system availability. High quality equipment should be chosen where possible, dedicated staff must be provided on call to respond quickly to fault reports, and adequate test instrumentation must be available. A carefully structured organisation is needed to permit correct fault analysis to be made, using despatch staff with suitable expertise and ability to record fault details. If mobile units are simply exchanged in the field and repaired subsequently in workshops, careful recording of equipment movement is necessary to ensure that units are not misplaced, and that the maintenance effort is carried out with the minimum number of unproductive spare units.

16.2 Network fault detection and analysis

Commercially manufactured equipment for mobile radio services, usually contains little or no fault detection or alarm equipment. Historically, manufacturers seem to have taken the view that a failure will be obvious because of the inability to pass a message.

Even in simple systems however, this takes some time to establish and in more complex networks often used by power authorities, operators are rarely in a position to assess the location of faulty equipment. Networks may consist of interconnected main stations, voting receivers, talk-through repeaters, systems carrying data, multipoint landline control points, multichannel control centres, etc, and in such systems network fault analysis is far from straight-forward.

For example consider the difficulty faced by an operator or service technician confronted with the relatively simple case of two mobiles attempting to communicate through a single talk-through repeater. If contact between the mobiles is not established, seven questions have to be resolved:

Is this unit faulty?
Is the other unit faulty?
Is the first unit in range of the main station?
Is the other unit in range of the main station?
Is the main station faulty?
Is the other unit unattended?
Is the other unit switched off?

A minimum of a third party is required to resolve this analysis problem. Assessment is made all the more difficult by the mobility of the field equipment (mobiles and portables) and occasional abnormalities of propagation conditions.

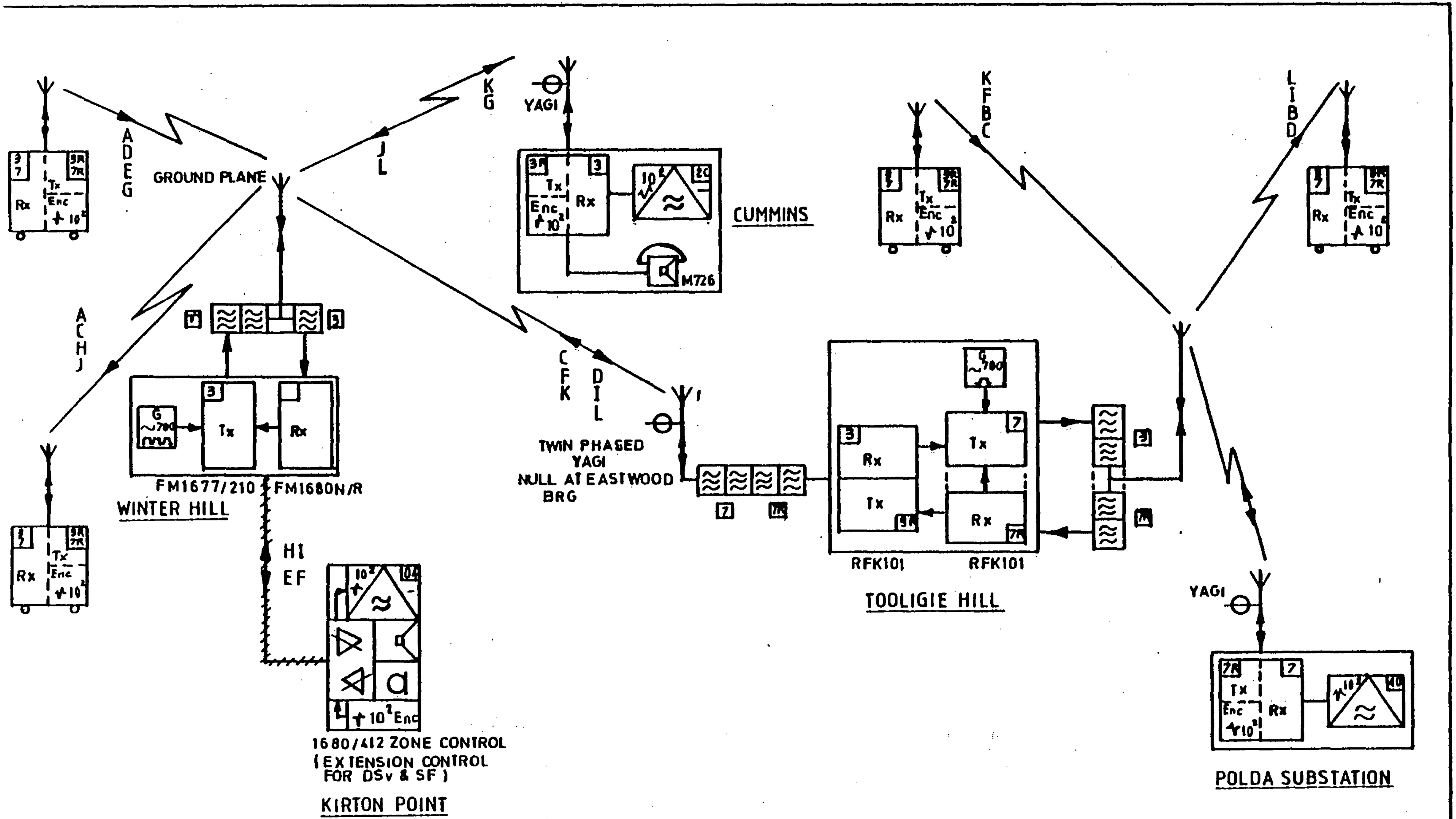


FIG. 16. TYPICAL SYSTEM DIAGRAM

It is therefore necessary to give careful consideration when establishing a network, to the means that will be adopted for fault detection and analysis. Equipment may be purchased with fixed stations that can detect degradation of transmitter forward power, excessive reflected power from an antenna or antenna system, loss of received carrier on permanently keyed systems, failure of primary power supply, loss of circuit integrity on paths connecting remote receivers to voting comparators etc. Where duplicate equipment is provided, a comparison can be made between two receivers to evaluate the presence/strength/quality of the incoming signal and where necessary to generate an indication of a substandard receiver.

Alarms generated from this type of peripheral equipment should be extended to a control centre or maintenance depot for appropriate assessment. Many of these indications will give advance warning of impending interruption to the service and prompt action can minimise loss of service.

Useful fault detection in field equipment has in the past been almost non-existent - limited to low battery voltage indicators on hand held portable radio equipment. With the introduction during the '80s of processor controlled mobile radio equipment, front panel indications of internal fault conditions are being offered on better quality models. Such indications will clearly assist in early fault detection, but as yet examples by leading suppliers show that only minimal detection is provided and that it is exclusively associated with power supply and transmitter conditions.

One failure that is potentially most damaging to the operation of a network, is for a mobile to have its transmitter "lock on". Operators of simplex mobiles are generally unaware of the occurrence and if the vehicle is mobile it may well take a considerable time to locate. "Time-out" transmit timers should be considered essential on all mobiles (See also Section 15.2)

A valuable aid in network analysis is the continuously running, or signal triggered, message logging recorder. This device should preferably monitor the network directly off-air via a dedicated receiver and have one channel recording time of day marking. This facility provides the ability to re-examine message content or analyse signal composition, repetitively if necessary, to detemine the chain of events and the most likely faulty unit.

Thus, given a report of apparent failure, the maintenance co-ordinator must build up the analysis of the fault from the best possible reporting source available in that network. This work is made easier if clearly drawn, current network diagrams are at hand (see Fig 16.).

16.3 Maintenance

16.3.1 Fixed Equipment

Most mobile radio systems are dependent on the fixed stations for the correct operation of the system. It is therefore essential to maintain a high order of availability for these stations. When planning new systems, the choice of good quality equipment with predicted large values of Mean Time Between Failure (MTBF), assists in establishing high inherent availability, and further improvement is obtained where systems are equipped with redundant stations or standby plant (See also Section 14)

However, the on-going quest for high availability depends on

- a continuing programme of preventive maintenance and qualitative assurance testing, and

- rapid response of adequately trained service personnel to fault reports.

Preventive maintenance is necessary to detect degradation of equipment parameters before they decay below minimum values acceptable for correct operation. However, frequent visits can also be the cause of failure. Because of the difficulty of performing complete system checks in a mobile radio system, it is possible to return a station to service after a routine test and unwittingly introduce a fault. For this reason, regular inspections should be restricted where possible to tests and readings that can be achieved without disconnecting in-service stages of the equipment. In particular, it is important not to disturb antenna connections, especially when associated with multicoupler diplexers. Incorrectly tightened connectors can introduce loss, mismatch and power reflection, thus causing the transmit power from the station to be below requirements.

With most equipment it is possible to record, and adjust if necessary, output power and drive voltages to various stages of the transmitter. Permanently installed in-line power measuring devices can also be used to observe reflected power from the antenna system. Land line or link connections can be expected to have plug-in break points where audio line-up may be performed. Modulation is best checked by connection from a permanently installed tap in the transmission line.

Clearly then, the most difficult component to test without disturbance is the receiver sensitivity and a compromise is usually necessary to permit instrument connection. A specified point for this break-in connection is desirable and BNC connectors provide a safer, more positive, connect point than the N series fittings normally preferred for the remainder of the antenna system components.

Such preventive maintenance should be programmed for periods of minimum likely traffic, as it is usually necessary to interrupt service to complete the work.

Rapid response to fault reports involves continuous availability of staff, tools and instruments, and staff levels must be managed accordingly. If equipment is modular and similar at all stations under a depot's control, it is usually adequate to have a supply of modules that can be taken on each call. Variety in equipment type may require stocking of modules or parts at each location. Regardless of the type of visit to a fixed station, stringent inspection procedures should be undertaken before leaving the site, including as far as possible, tests to establish that normal working modes are operational.

16.3.2 Mobile Equipment

Whilst the failure of mobile equipment obviously has a less wide-spread effect on the communication system than fixed equipment failure, it can be just as inconvenient to a particular user as the failure of the main station.

Administrations commonly resist purchasing highest quality mobile equipment because of the multiplication of cost penalty. In any case, equipment in the mid-range of quality is now achieving performance with failure appearance rates as low as 0.3 occasions per unit per year. If local "service agents" with restricted radio background can be established within operating groups, and can be trained to deal with peripheral maintenance such as

battery supply problems,
antenna and feeder cable problems, and
microphone and microphone cord problems,

preventive maintenance visits can be restricted to about one every three years. On such visits, technicians can move into an operating area and check and adjust where necessary, mobile units in batches, usually as an after-hours activity.

Fault maintenance on demand then becomes the primary mobile equipment task. Spare units are normally held for each mobile equipment variety and are simply changed in the field, with the faulty unit being returned for workshop repair. Since this repair is a standard function, the authority may choose between conducting this activity itself and contracting the maintenance to an agency. This choice will depend on availability of satisfactory contractors, the permissible equipment repair time, and internal labour cost structures.

16.4 Testing

16.4.1 Fixed Equipment

Other than for purchase acceptance testing, fixed equipment tests by definition must be carried out in the field. Further, this testing covers a wide range of communication disciplines, including testing of audio levels, processing and AGC adjustment in remote control station, attenuation measurement, frequency response, continuity testing and signalling levels on land line or radio link connections, frequency, modulation and power measurments on transmitters, proof of antenna and feed line integrity, receiver sensitivity and distortion measurements, with or without sub-audible tone signalling, and power supply and battery status measurements.

Instrumentation is now commonly available as a combined test set capable of measuring most of these parameters in the one instrument. Usually of rugged construction and with inbuilt battery supplies, these form the ideal basis for transportable test units. Whilst most types provide for the basic measurements and some extend to the addition of spectral analysis, users of talk-through main repeaters should take care to purchase a test set with two separate RF oscillators - one dedicated to RF signal generation and one to modulation measurement. This facility permits simultaneous testing of the complete receiver transmitter combination, and makes for particularly simple overall line-up procedure.

All inclusive test sets are ideal for main stations etc, but depots will need equipping with a number of additional instruments to permit end-to-end line or link line-up measurements and for other ancilliary functions.

16.4.2 Mobile Equipment

When mobile equipment is maintained by field changeover followed by workshop repair, it is often difficult to convey detailed complaints from the operator through to the repair technician. In any event, the complaint is likely to be in layman's terms and often less than informative. If the unit is then to be maintained by contract, the information transfer becomes even more difficult.

There is thus a case for performing pre-repair tests to determine the state of mobile equipment on its arrival.

After repair and adjustment to bring the equipment within specified limits, particularly if the work has been performed by others, it is necessary again to acceptance test the unit. There is no point in purchasing mobile equipment to exacting specifications if it is to be reissued to service after repair in a condition that does not meet the original specification parameters.

In large systems, quantity of equipment passing through a workshop makes the mundane repetitive task of testing unattractice to perform manually, from both an industrial relations and economic point of view. Automatic test equipment that can perform complete specification parameter testing in minutes, is available at costs that can be justified by the saving in labour alone. With this type of test equipment, pre-repair tests can reveal areas of the equipment requiring attention, and post-repair tests can test the completed work, thus providing assurance of the state of units reissued to service.

Reports can be printed automatically and test details can be stored on tape or disc for later statistical analysis.

17 RADIO REGULATORY REQUIREMENTS

The responsibility for the allocation of radio frequencies internationally, rests with the International Telecommunications Union (ITU), a specialised agency of the United Nations. Almost every country in the world is a member, and they meet at world conferences at regular intervals to plan the allocation of radio frequencies to the various services requiring them, e.g sound and television broadcasting, telecommunication links, aeronautical and marine navigation, mobile radio etc. The last World Administrative Radio Conference (WARC) was held in Geneva in 1979, and the present allocation of frequencies for mobile radio services was decided at that meeting. The next Conference will be held in 1999.

Each member country has its own administrative arrangements for the assignment of frequencies for particular types of service. The use of every frequency has to be registered with the International Frequency Registration Board in Geneva, and it is the responsibility of each administration to see that each assignment is duly notified. This arrangement exists in order that interference between the services of different countries can more easily be traced and eliminated, and also enables the best arrangements to be made to optimise the use of radio spectrum.

As the frequency assignment and licensing arrangements are not the same in every country, it is not possible in this Guide to define precisely the procedure which a potential user of radio frequency spectrum must follow, in order to obtain a frequency allocation. However, the user should obtain information on the following, in the early stages of planning a private mobile radio service:

(a) national policies concerning the frequency bands available for private mobile radio,

(b) frequency application procedure,

(c) licensing arrangements and fees payable,

(d) whether there are any national preferences for type of modulation,

(e) maximum permitted effective radiated power,

(f) national policy concerning the use of reversed frequency talk-through and control.

In some countries, it may also be necessary to provide the Regulatory Authority with details of the proposed main station site or sites, and of the antenna mast or tower construction and antenna heights above sea level.

<u>It must be understood that the operation of a radio transmitter, whether from a fixed or mobile site, without the proper documented authorisation is illegal and may carry heavy penalties.</u>

18 REFERENCES AND BIBLIOGRAPHY

References

1. Report of the Home Office Mobile Radio Committee, 1982
"Terrestrial Land Mobile Services"
Her Majesty's Stationary Office, ref. ISBN 0 11 340778 5.

2. International Radio Regulations
International Telecommunications Union, Geneva

3. Marconi Propagation Prediction Quarterly
GEC-Marconi, Chelmsford, England

4. Glossary of Telecommunication Terms
British Standards Institute, Park Street, London W1

5. Hamsher
Communication Systems Engineering Handbook
McGraw-Hill Book Company, USA

6. Pageter H O
Radio Interference Analysis
Journal of the Royal Signals Institution, Vol VII, Spring 1966
pp. 189-192

7. Edwards R and Durkin J
Computer Prediction of Service Areas for VHF Radio Networks
Proc. IEE, Vol 116, no. 8, September 1969, p. 1493

8. Edwards R and Durkin J
Selection of Intermodulation-Free Frequencies for Multiple-channel Mobile Radio Systems

9. CCIR Draft Recommendation D2d (XIII)
Interference due to Intermodulation Products

10. CCIR Study Group 8
Report 358-3 (1980)

11. Lejdal J O, AB Teleplan, Solna, Sweden
Radio Communication in Tunnels and Underground Constructions in Rock
Technical Report BTA R 10035

12. CIGRE Study Committee 35 Working Group 04
Guide on Planning of Telecommunications for Power Systems 1983

Bibliography

13. Berndorf, Schindele, Schaller
Simulcast Network with Receiver Selection for Mobile Radio Voice and Data Transmission
CIGRE 1984, Session 35-01

14. CCIR Report 358-1
Signal-to-Interference Ratios and Minimum field Strengths Required in the Mobile Services
Volume VL, p. 27, XII Plenary Assembly, New Delhi, 1970

15. Cooper R G and Nettleton R W
Cellular Mobile Technology; the Great Multiplier
IEEE Spectrum, June 1983

16. Davis and Mitchell
Traffic Handling Capability of Trunked Land Mobile Radio Systems
IEEE Proceedings, 1979

17. Garner
Co-channel and Quasi-synchronous Characteristics of SSB Relative to FM in Mobile Radio Communication Systems
Philips Research Laboratories, Redhill, England

18. Lee W C Y
Mobile Communications Engineering
McGraw-Hill Book Company, USA

19. Nordic Mobile Telephone System Description
NMT Doc 1, 1980, Swedish Telecom Administration

20. Ongaro D and Pace E
RIAM; an Integrated Multiple-access Radio Network System for Electric Power Utilities
CIGRE 1984, Session 35-02

21. Pace E
Introduction to Simulcast Multiple-access Mobile Radio Systems
ENEL, Italy, November 1983

22. Pannell W M
Frequency Engineering in Mobile Radio Bands
Granta Technical Editions, Cambridge, England

APPENDIX A
(Section 3 refers)

BASIC PARAMETERS FOR EVALUATION OF SYSTEM PERFORMANCE

1 Introduction

In this Appendix, the fundamental parameters for traffic evaluation are examined, starting from some basic definitions:

Traffic Intensity (E)

The Traffic Intensity represents the mean number of channels engaged at a certain time.

For single channel systems the Traffic Intensity coincides with the time percentage for which the channel is occupied.

More generally, if t_i is the time percentage in which the i-th channel is occupied, the Traffic Intensity for a system consisting of n channels is the sum

$$\sum_{i=1}^{n} t_i$$

The Traffic Intensity is expressed in "Erlang" units.

$$E = \sum_{i=1}^{n} t_i$$

In the system dimensioning, it is usual to make reference to the average Traffic Intensity in the busiest hour in the day.

Mean Service Time (Dm)

The Mean Service Time (average channel occupancy for each information exchange between two users) is the mean value of the time between the channel engagement by a user sending a call and the channel release at the end of the information exchange. It is usually expressed in seconds.

Arrival Rate (λ)

The Arrival Rate λ is the average number of calls offered by the users in the time unity.

It is usually expressed as:

number of calls per second

Service Rate (μ)

The service rate μ is the average number of times that a channel is released in the time unity. It is usually expressed as:

number of releases per second

The above parameters are connected by the following expressions:

a) $$E = \frac{\lambda}{\mu} \qquad \text{(A.1.2)}$$

It means that the Traffic Intensity is equal to the ratio between Arrival and Service Rate;

b) $$\mu = \frac{1}{D_m} \qquad \text{(A.1.3)}$$

The Service Rate is the inverse of the mean Service Time;

c) $$\lambda = \frac{E}{D_m} \qquad \text{(A.1.4)}$$

The Arrival Rate is equal to the ratio between Traffic Intensity and Service Time.

2 Quality of a Network

To evaluate the traffic quality in a network, it is necessary to introduce an important distinction between "Loss" type systems and "Waiting" type systems.

In system with "loss", the hypothesis is that the arrival and the service processes are both strictly random with poissonian distribution; it is observed that arrivals and channel releases are mutually independent. Consequently, a user who finds the network unavailable renounces the call or defers it until some convenient time later, so that the repeat call will be fully random and uncorrelated to other events in the network.

In the "waiting" type systems, the fundamental hypothesis is that the calls attempted whilst the network is fully occupied are automatically or manually delayed until the network becomes available. For delayed calls, the essential condition of stochastic independence fails, so that the approach applied to "loss" type systems is not valid.

In waiting type systems, the forwarding of delayed calls can be processed either on a first-in first-out basis, in which the users are served in the arrival order, or other criteria may be applied, eg the calls may be processed according to a predetermined priority schedule or they may dealt with on a random basis.

2.1 Waiting type system parameters

Let K be the number of channels in a network and n the number of users that at a certain time requires access to the network.

It can be defined:

$P_a = P_{n \geqslant K}$ the probability that a new user requiring a channel finds the network unavailable, so that he must wait.

$P_{n \geqslant K}$ is therefore the <u>Waiting Probability</u>

<u>Tm, Mean Waiting Time</u> the interval between the instant when a user requires a channel and the instant when he enters the channel.

Tma, Mean Waiting Time when there is waiting the interval between the instant a user finds the network unavailable and the instant in which he obtains access.

$$T_{ma} = T_m/P_a = \frac{Dm}{K-E} \qquad (A.2.1)$$

where D_m is the Mean Service Time (mean duration of a link) and E is the Traffic Intensity.

Lf, Mean Length of the Waiting Time, that is the mean number of waiting users, with:

$$L_f = T_m \cdot \lambda \qquad (A.2.2)$$

Lfa, Mean Length of the Waiting Time when there is waiting, mean number of waiting users when the network is unavailable (that is when a user requiring a channel must wait).

$$L_{fa} = L_f/P_a = K(K-E) \qquad (A.2.3)$$

Lff, Length of the Waiting Time when there is Waiting Time, that is the mean number of waiting users when a user must wait and there are other waiting users:

$$L_{ff} = L_f/P_a - K(K-E) \qquad (A.2.4)$$

Fig A-1 shows the behaviour of the Waiting Probability P_a as function ot the Traffic Intensity for different values of the number of channels K.

Fig A-2 shows the values of the ratio T_{ma}/D_m between Mean Waiting Time with waiting and Mean Service Time as function of the difference (K-E) between number of channels and Traffic Intensity.

Fig A-3 shows the values of the ratio T_m/D_m between Mean Waiting Time and Mean Service Time as function of the Traffic Intensity, varying the number K of the available channels.

The expressions given for the waiting times T_m and T_{ma} are derived from the classic traffic theories, which assume a service of the"First-In-First-Out" kind.

The mobile radio systems for private use are mostly of the waiting type, but with random service, rather than ordered following deterministic criteria.

The waiting time probability distribution is therefore more dispersed and variable around its mean value in the case of mobile radio networks typically having a random call processing than in the case of networks with an ordered calls processing.

Even in the case of random service it is:

$$P(T > t) = P_a \cdot P(T_a > t) \qquad \text{(A.2.5)}$$

being

P_a the Waiting Probability

$P(T_a > t)$ the conditional probability that the Waiting Time when there is waiting, Ta exceeds a certain value t.

$P(T > t)$ the (absolute) probability that the Waiting Time, T, exceeds a certain value t.

P_a maintains the behaviour of Fig A-1 while the exact expression for $P(T_a > t)$ would be extremely complex and difficult to calculate.

The Fig A-4 anyhow shows the behaviour of $P(T_a > t)$ with $t = u \dfrac{D_m}{K}$

Fig A-5 shows the behaviour of $P(T_a > Dm)$, the conditional probability that the Waiting Time when there is waiting, T_a, exceeds the mean Service Time D_m.

Fig A-6, finally assumes the absolute probability $P(T > D_m)$ that the Waiting Time, T, exceeds the Mean Service Time D_m.

3 Effects of the Total Number of Users and of Traffic Unsymmetry

The methods reported in the preceding paragraphs have been developed on the basis that the traffic offered by the users is constant. This is true when the total number of potential users of a system is very high, so that always theoffered traffic is independent of the number of users already entered in the network, or waiting.

Such a condition does not ususally apply in private dispatch networks, where the number of users is generally limited. In this case it can be noted that:

a) on average, when the traffic intensity assumes values around its mean value, the waiting probabilities and waiting times are generally less than those where the number of users is very large;

b) the traffic intensity varies considerably areound its long term average value.

The number of users also influences the frequency of traffic fluctuations so that a small number of users higher than mean traffic can remain for quite long periods.

The situation (a) above emphasises the need to refer to waiting probabilities and waiting times adequately lower than those evaluated, supposing the offered traffic to be constant and a large number.

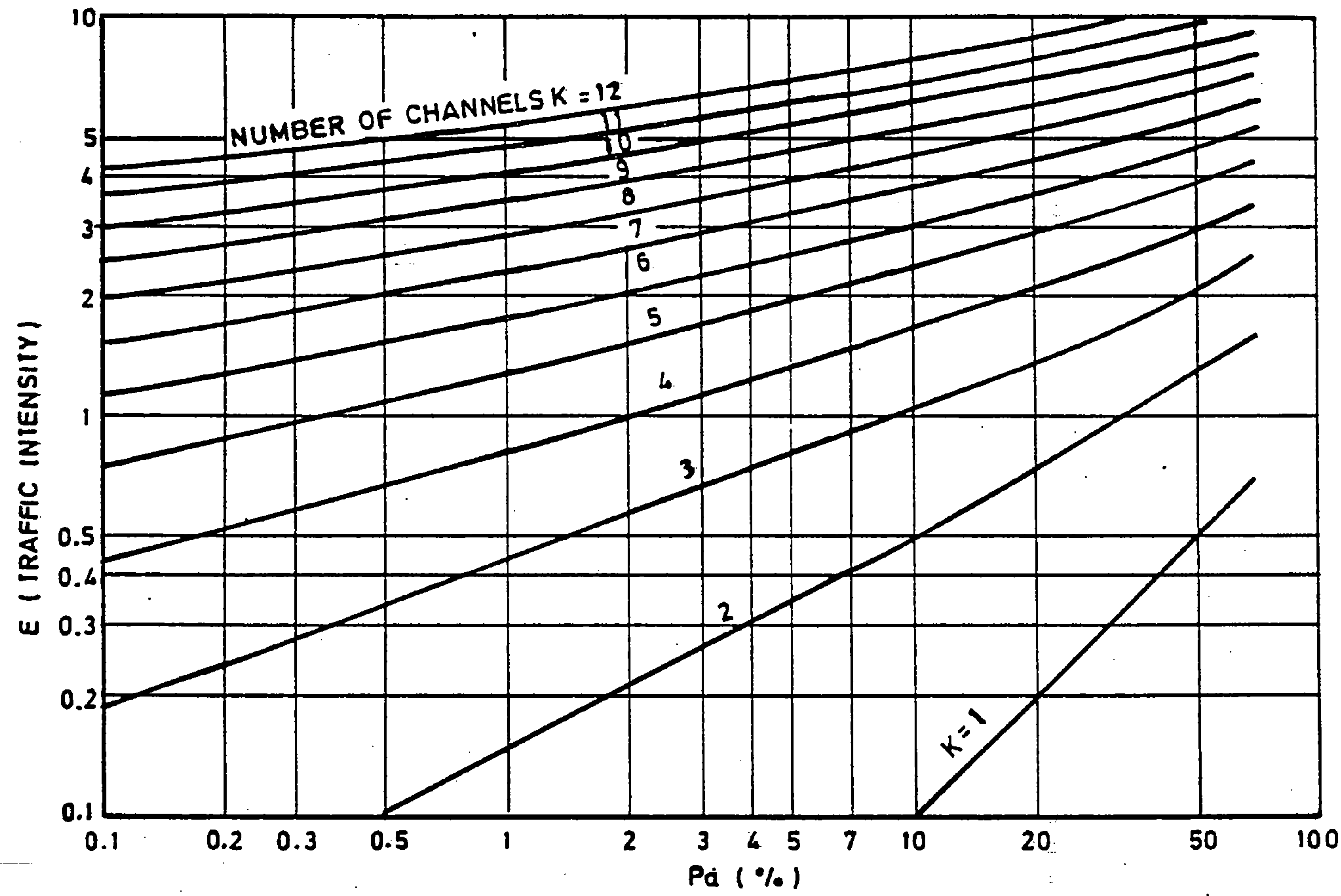


FIG. A. 1. WAITING RROBABILITY Pa

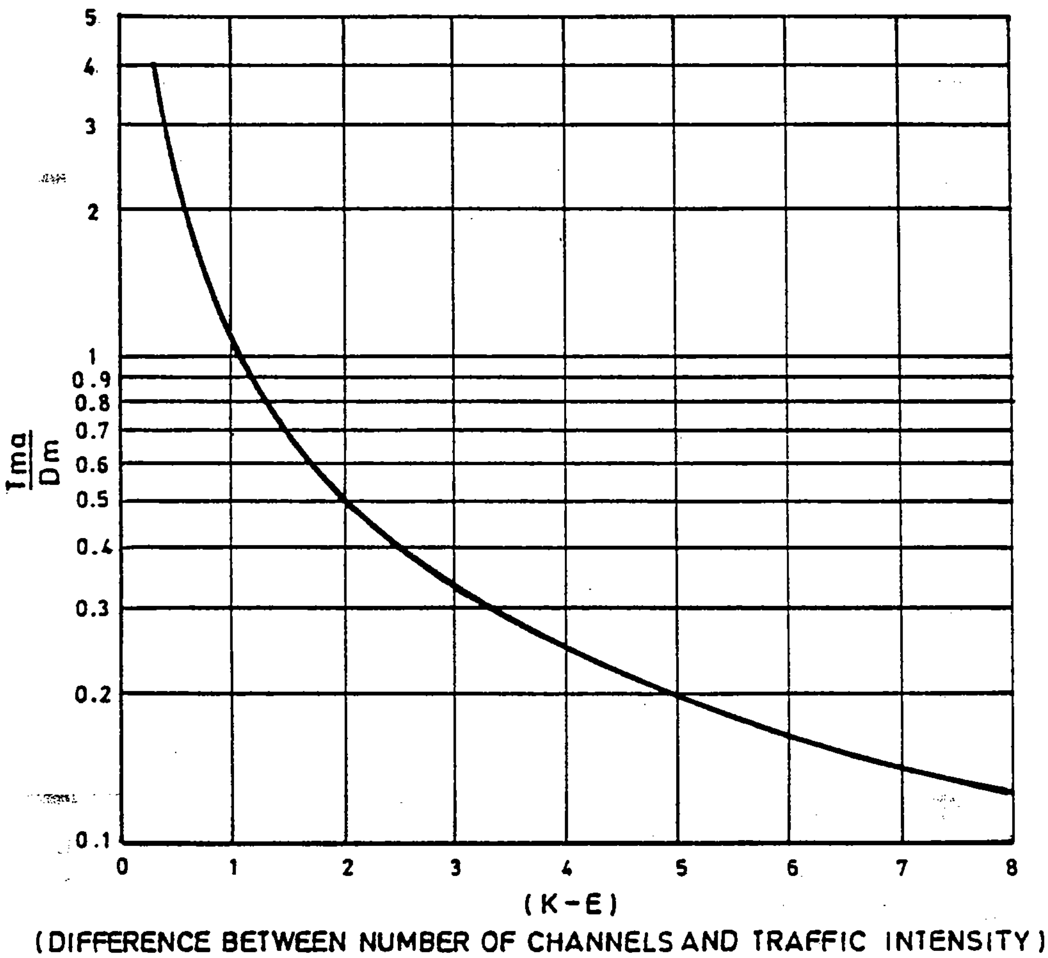


FIG. A.2. BEHAVIOUR OF THE RATIO Tma/Dm

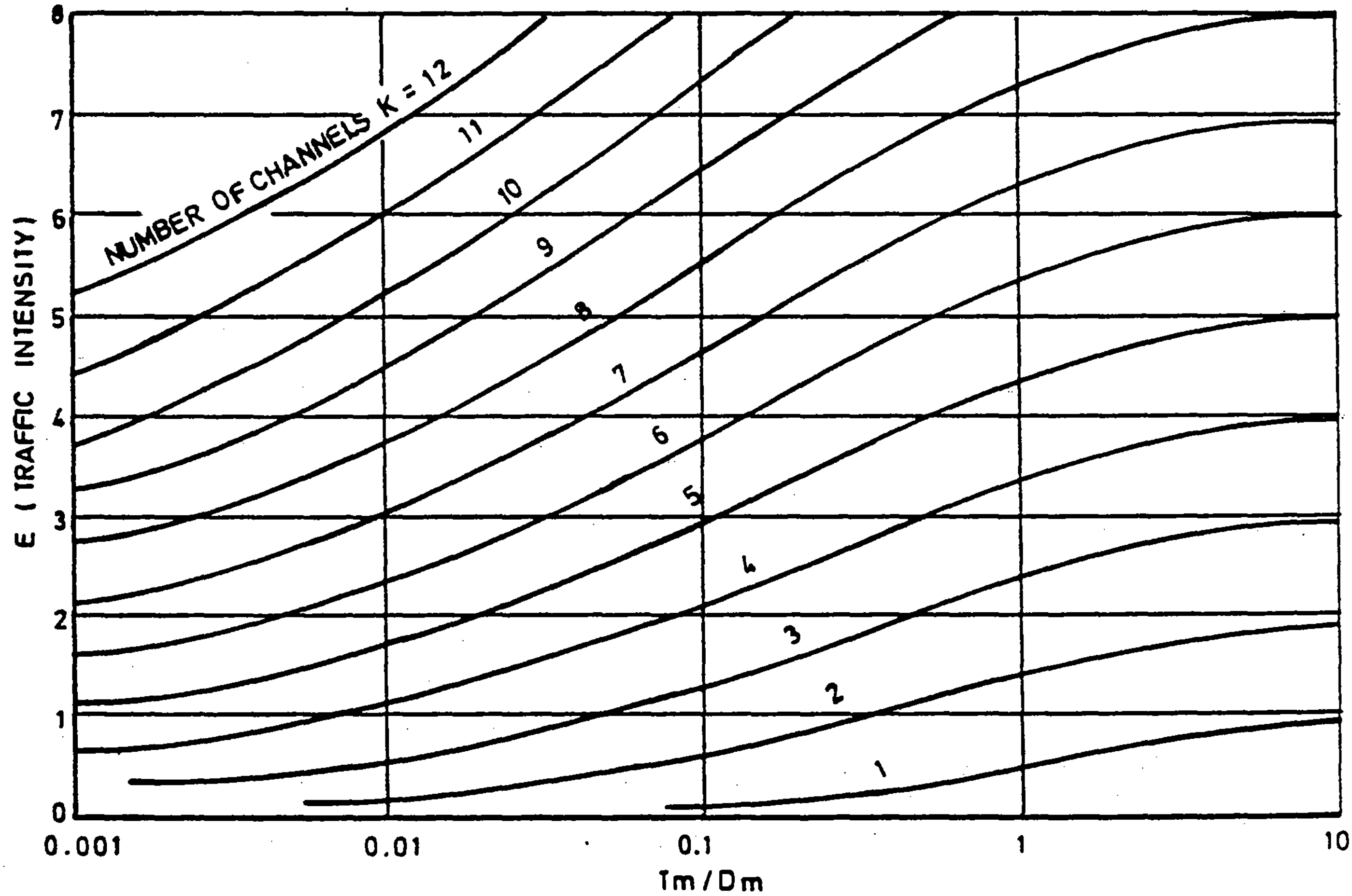


FIG. A.3. RATIO Tm/Dm BETWEEN THE MEAN WAITING TIME AND THE AVERAGE SERVICE TIME.

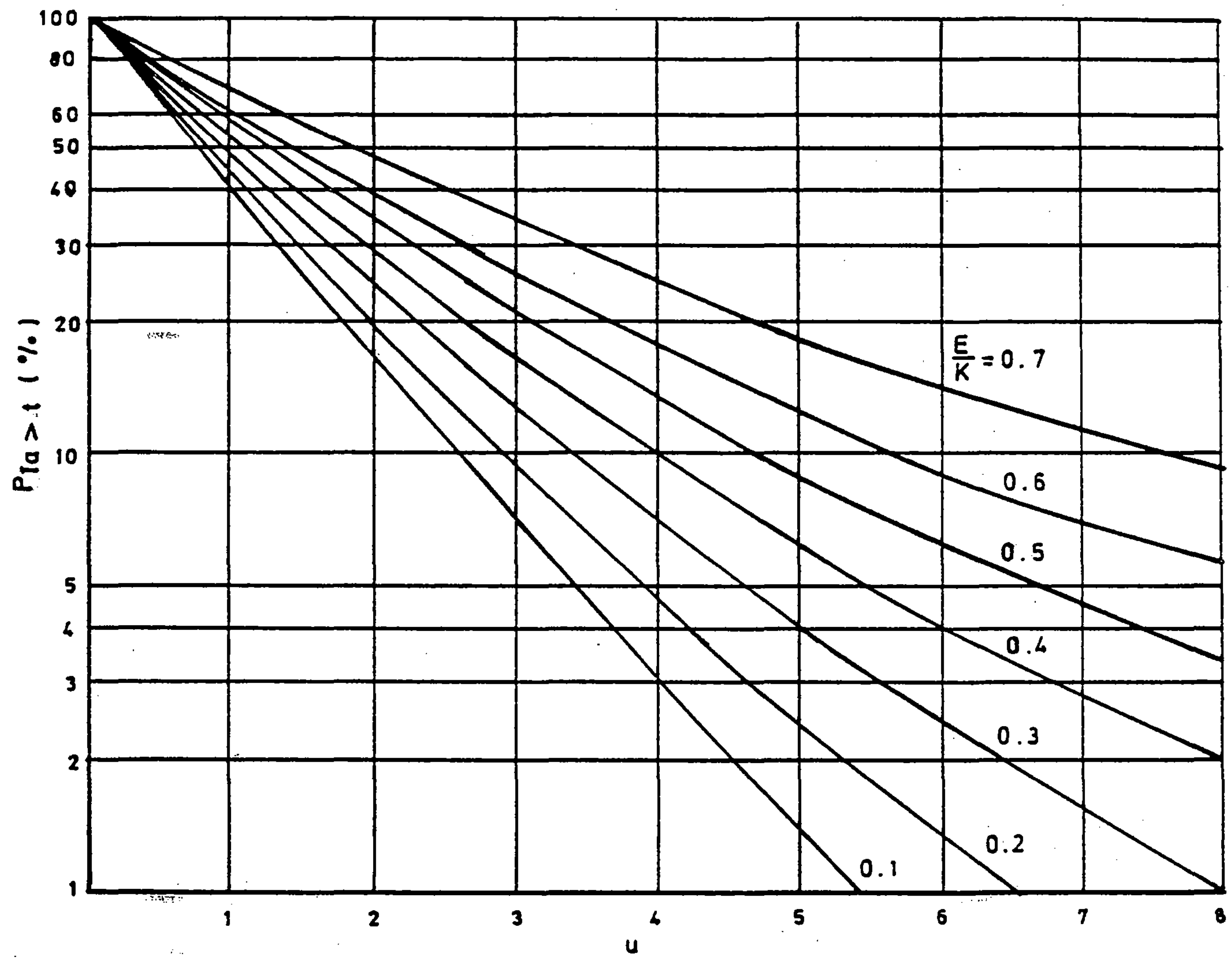


FIG. A.4. CONDITIONAL PROBABILITY THAT THE WAITING TIME Ta, WHEN THERE IS WAITING, EXCEEDING THE VALUE $t = u \frac{Dm}{K}$

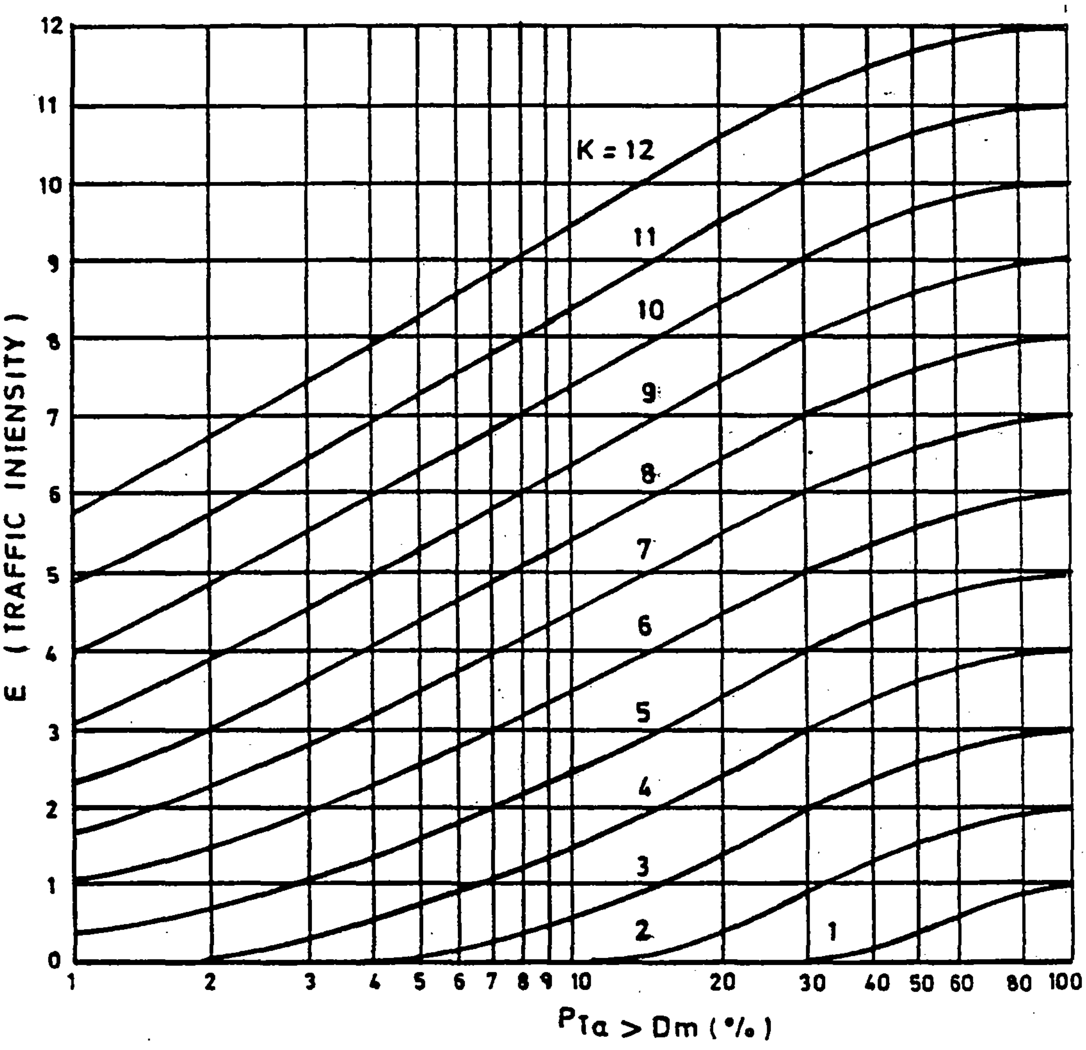


FIG. A.5. CONDITIONAL PROBABILITY THAT THE WAITING TIME Ta, WHEN THERE IS WAITING, EXCEEDS THE AVERAGE SERVICE TIME Dm.

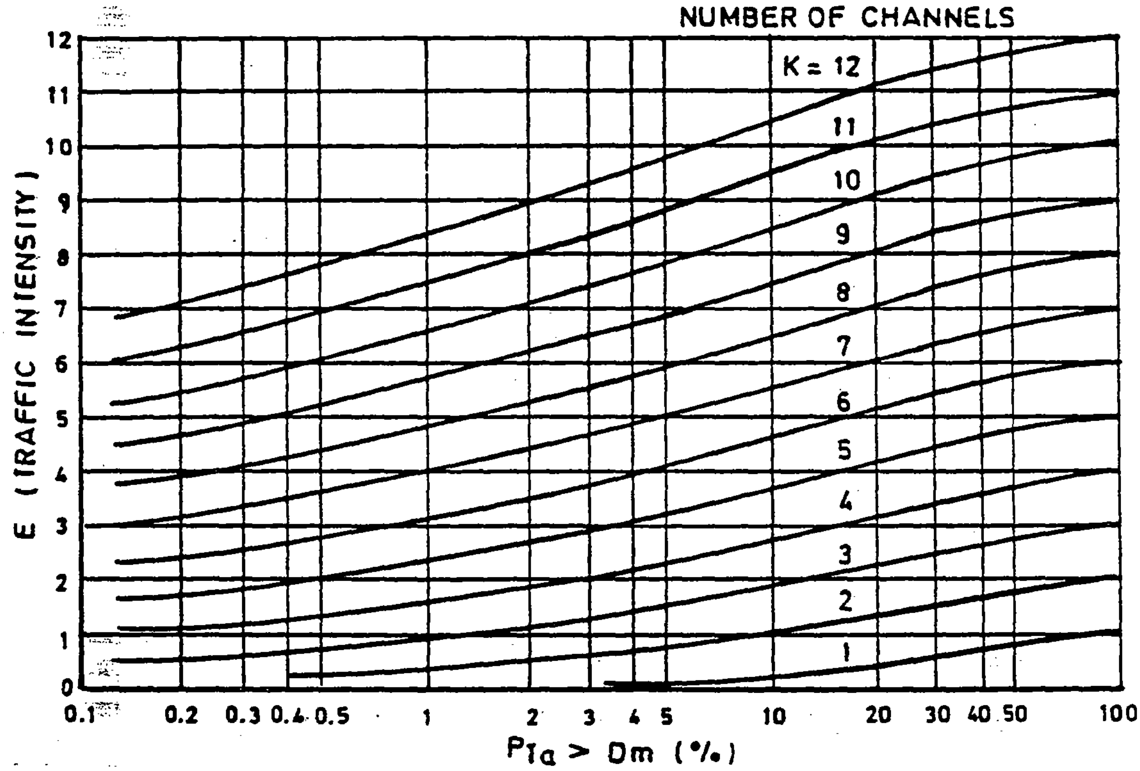


FIG. A.6. PROBABILITY THAT THE WAITING TIME Ta EXCEEDS THE AVERAGE SERVICE TIME Dm P (Ta > Dm)

An expression for this can be obtained by evaluating waiting probabilities and waiting times for a "corrected" traffic intensity $E^* < E$

$$E^* = E(1 - \frac{K}{\sqrt{N}}) \qquad (A.3.1)$$

where N is the number of users, E is the offered Traffic intensity, K is the number of available channels.

Situation (b) above implies that, due to high traffic fluctuations with a small number of users, the waiting probabilities and waiting times can exceed their mean design values even for long time periods.

In networks with a limited number of users, the negative effects of traffic fluctuations appear more substantial than the positive effects. As a consequence it is advisable to avoid any reference to optimistic reduced traffic intensities such as E*, as if the number of users was very high. Moreover, having calculated the standard deviation s for the traffic intensity, it is advisable to refer to a Mean Traffic Intensity evaluated with quite high confidence levels (80 to 90%), increasing the long term average by the quantity:

$$t \cdot s \qquad (A.3.2)$$

where t is a positive factor, reported in Statistics handbooks with reference to the unilateral t (or Student) distrubution.

Another factor influencing the relationship between Traffic Intensity and Waiting Times probabilities is a parameter called "symmetry" of the traffic offered by different users.

The preceding figure, explaining probabilities and waiting times for a large number of users, are evaluated on the basis that all the users offer on average the same amount of traffic. This is quite true in public systems, but does not necessarily apply to private and dispatching networks where the users are usually divided into fleets or groups. For each group there is usually a control or dispatching centre which is the focal point for the majority of the traffic. For this category of user there are two types of waiting:

a) <u>Group waiting</u>, which applies when a mobile user requires to communicate to his dispatching centre which is already busy with another user. Such waiting is independent of the number of mobiles and channels in the network. It can be improved only by equipping the centre with more operators and equipment.

   It should be noted that the mobile user is psychologically more inclined to tolerate group waiting than waiting due to network unavailability.

b) <u>Waiting due to network unavailability</u>, is the waiting due to all the channels in the network being occupied other users.

The traffic unsymmetry (unbalance) of different users can markedly vary the waiting times and the probabilities of (b) above and on the average is a reducing factor.

The average behaviour of unbalanced or unsymmetric systems can be evaluated by using a corrected Traffic Intensity, $E^* \sim E$, expressed as:

$$E^* = E\left(1 - \frac{s}{e_o} \frac{1}{\sqrt{N}}\right) \qquad (A.3.3)$$

or

$$E^* = E\left(1 - \frac{s}{E}\sqrt{N}\right) \qquad (A.3.4)$$

where

e_o = E/N mean value of the traffic offered by each user

N = total number of users

s = unbiased estimate of the standard deviation of the traffic offered by the users.

For e_i the elementary traffic offered on the average by the i-th user, the expression becomes

$$s = \sqrt{\frac{\sum_{i=1}^{N}(e_i - e_o)^2}{N-1}} \qquad (A.3.5)$$

If the system is characterized by two categories of users:

N_1 large users, each offering a traffic e_1

N_2 small users, each offering a traffic e_2 with $N_1+N_2=N$

we have

$$E = N_1e_1 + N_2e_2 \qquad (A.3.6)$$

and

$$s = \sqrt{\frac{N_1e_1^2 + N_2e_2^2 - e_o^2}{N} \frac{N}{N-1}} \qquad (A.3.7)$$

and also:

$$s = \sqrt{\frac{N_1N_2}{N-1}} (e_1-e_2) \qquad (A.3.8)$$

The evaluation of waiting times and probabilities corresponding to the "correct" Traffic Intensity E*, gives results which compare favourably with examples given by Davis and Mitchell (See References). The use of the estimated standard deviation(s) as a parameter for expressing the traffic unsymmetry is confirmed.

Example

Suppose it is required to design a system with:

N_1 = 18 large users, each offering a Traffic e_1 = 0,12 Erland and

N_2 = 198 small users, each offering a Traffic e_2 = 0,011 Erlang.

Suppose the Mean Waiting Time T_m must be: $T_m s < 0.05\ D_m$, ie Tm must be lower than 5% of the Mean Service Time Dm.

The total traffic is:

$$E = 4{,}34 \text{ Erlang}$$

while the mean traffic offered by every user is:

$$e_o \simeq 0{,}02 \text{ Erlang}$$

The estimated standard deviation for the traffic offered by every user can be derived from A.3.5 and is:

$$s = 0{,}03 \text{ Erlang}$$

By using the expression A.3.4 it can be written:

$$E^* \simeq 3{,}89 \text{ Erlang}$$

Without taking into account the traffic unsymmetry, the fig 0.0 shows that K=8 channels are needed to ensure $T_m \simeq 0{,}022\ D_m < 0{,}05\ D_m$, for E-4,34 Erlang.

Conversely, taking into account the traffic unsymmetry it can be seen that K=7 channels are sufficient in order to have $T_m \simeq 0{,}037\ D_m < 0{,}05\ D_m$, considering the correct Traffic Intensity E^* = 3,89 Erlang.

If K=8 channels are maintained it would be $T_m = 0{,}012\ D_m$.

The above example shows therefore that the traffic unsymmetry reduces the Mean Waiting Time T_m by approximately 50%.

Improvements due to traffic imbalance are referred to the average behaviour of the system, but are not equally divided among all the users. The larger users (who offer the largest amount of traffic) are greatly favoured since the traffic unsymmetry reduces their waiting. The smaller users on the other hand are less fortunate, even if not excessively.

Therefore, the traffic unsymmetries, whilst improving waiting times and quality of service for the large users, tend to impair the situation for the small users.

In designing mobile radio networks, it is necessary to evaluate carefully the effects of traffic unsymmetry, and in particular to bear in mind that small users are usually more numerous and less well served than large users.

APPENDIX B
(Section 4 refers)

INTERNATIONAL REGION FOR FREQUENCY ALLOCATIONS

These are defined and regulated by the International Telecommunications Union (ITU) - see reference (2).

Geographical regions

For the allocation of frequencies the world has been subdivided into three regions as shown on the chart and defined below.

Region 1:

Region 1 includes the area limited on the east by line A (lines A, B and C are defined below) and on the west by line B, excluding any of the territory of Iran which lies between these limits. It also includes that part of the territory of Turkey and Union of Soviet Socialist Republics lying outside of these limits, the territory of the Mongolian People's Republic and the area to the north of the U.S.S.R which lies between A and C.

Region 2:

Region 2 includes the area limited on the east by line B and the west by line C.

Region 3:

Region 3 includes the area limited on the east by line C and on the west by line A, except the territories of the Mongolian People's Republic, Turkey, the territory of the U.S.S.R and the area to the north of the U.S.S.R and the area to the north of the U.S.S.R. It also includes that part of the territory of Iran lying outside of those limits.

The lines A, B and C are defined as follows:

Line A:

Line A extends from the North Pole along meridian 40° East of Greenwich to parallel 40° North; thence by great circle arc to the intersection of meridian 60° East and Tropic of Cancer; thence along the meridian 60° East to South Pole.

Line B:

Line B extends from the North Pole along meridian 10° West of Greenwich to its intersection with parallel 72° North, thence by great circle arc to the intersection of meridian 50° West and parallel 40° North; thence by great circle arc to the innersection of meridian 20° West and parallel 10° South; thence along meridian 20° West to the South Pole.

Line C:

Line C extends from the North Pole by great circle arc to the intersection of parallel 65° 30' North with the international boundary in Behring Strait; thence by great circle arc to the intersection of meridian 165° East of Greenwich and parallel 50° North; thence by great circle are to the intersection of meridian 170° West and parallel 10° North; thence along parallel 10° North to its intersection with meridian 120° West; thence along meridian 120° West to the South Pole.

APPENDIX C
(Section 5.2 refers)

AREA COVERAGE SURVEYS

It is possible to obtain reasonable predictions of the probable performance of a mobile radio network in advance of its installation by several methods, but these are based upon two principles:

(a) practical tests,

(b) computer-based predictions.

These two principles are described briefly, but for more detailed information the reader should consult the literature, of which there is a great deal.

Practical Tests

These invariably employ the measurement of radio frequency field strength, using a fixed main station temporarilly installed, to transmit permanently from the test site. The received signal is measured in a mobile receiver moving over the required area of operation.

In some instances, a chart recorder is used, the paper drive of which is coupled to the vehicle odometer, so that a recording of signal level can be referred to the distance over which the vehicle has travelled. A similar method uses a magnetic tape to record the signal level and distance travelled, and this is later analysed on a computer.

Disadvantages of the above methods are:

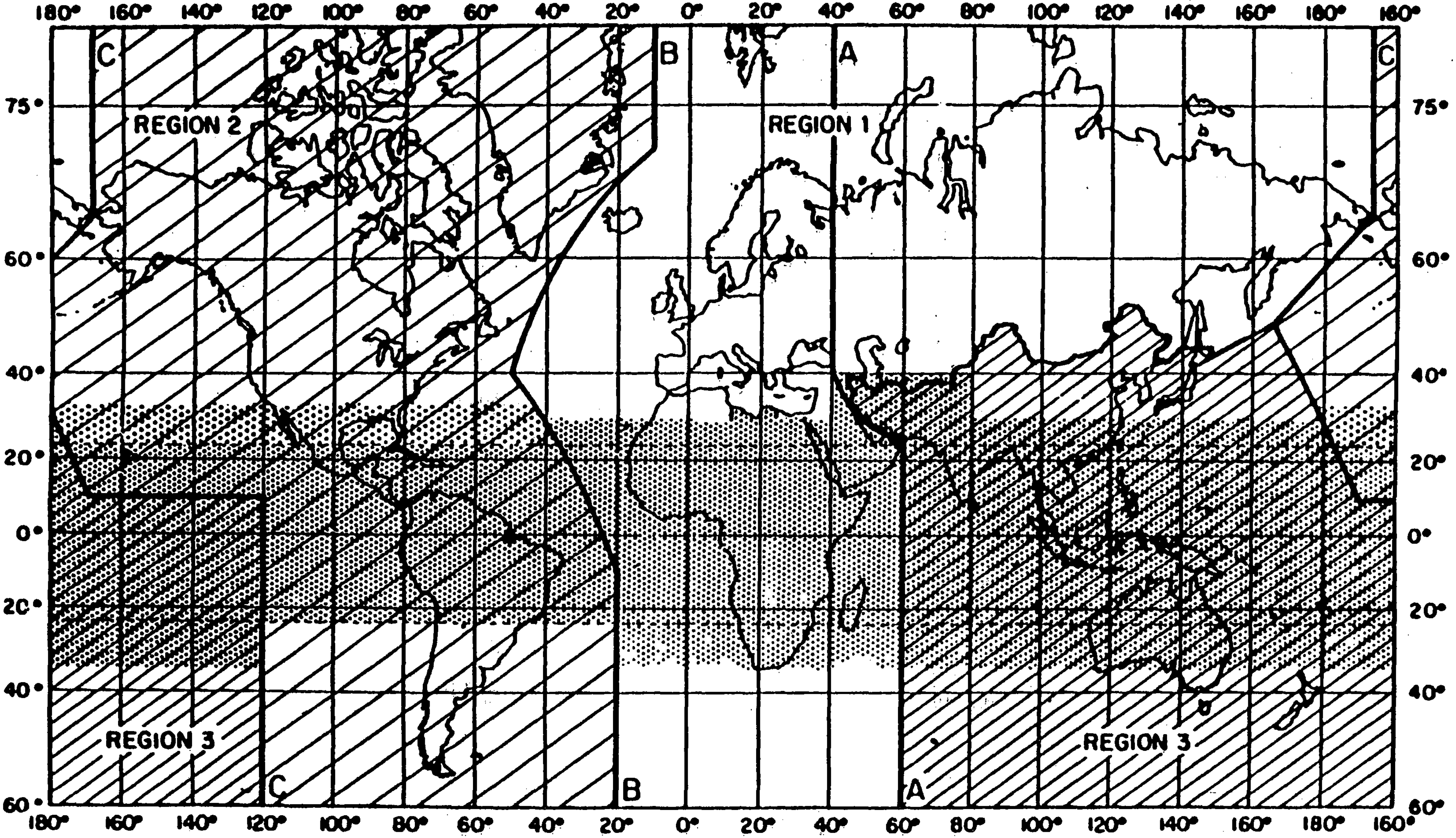
- speech tests are not possible,
- there is no continuous monitoring of no-signal noise levels,
- interfering signals are not identified in the measurements,
- the testing channels cannot be used for normal traffic.

An alternative method is to reverse the procedure, so that the test measurements are made at the fixed station and the test transmissions are made from the mobiles, with the following advantages:

- the background, i.e no-signal, level can be continuously monitored, and any interference easily identified,
- more than one test vehicle may be used, thus shortening testing time,
- tests can include both mobiles and handportable sets,
- the fixed station is a more suitable location for complex test gear,
- speech intelligibility tests can also be performed,
- the channel may be used operationally between tests.

In any of the methods mentioned above, it is essential that all the equipment to be used is thoroughly checked, and the performance of transmitters and receivers is measured and recorded. The tests must also include the main station and mobile station antennas and feeders.

Chart of Regions as Defined in Table of Frequency Allocations



The shaded part represents the Tropical Zone

In order to obtain as accurate a survey as possible, the number of test transmissions should be of the order of several hundreds, and particular attention should be paid to locations which are of operational significance.

Computer-based Predictions

This method has been widely used by the nationalised utilities in UK for a number of years, with considerable success. It is now being introduced into other countries, and will doubtless be more generally used in the future.

The computer method makes use of

(a) a topographical data base,

(b) propagation models.

The Topographical Data Base is usually derived from contour maps of the area to be surveyed. A reference height at given intervals of distance is required, and it has been found that a distance of 0.5 Km is most suitable, and these heights are then assembled in the data base. Considerable care has to be taken in arriving at the heights above sea level, since it is necessary to retain such features as hilltops, valleys and cliff edges, all of which are important factors in radio propagation. In the UK data base, the heights are entered into the computer in 10 Km square blocks, so that each square contains 400 data points.

A referencing system is essential, so that any point can be identified and the reference height at that point obtained. It is also necessary to be able to identify the location of the main transmitter site from the same system of referencing.

As a large area survey is likely to cover more than the area given on one 10 Km square, the data must also be arranged in such a way that the relationship between 10 Km squares can be defined. It is possible that the maps from which the data is derived, will themselves provide a ready means of applying a point referencing and a wide area arrangement.

Propagation Models can be derived from a knowledge of the equations used in calculating propagation behaviour under various conditions, and it is necessary to take into consideration free-space and plane earth losses, whether the path is line-of-site, fresnel zone clearances, and so on.

It should be noted that maps do not normally include any reference to the heights of man-made obstructions, such as buildings, embankments, forests and so on, and it is advisable to take these into consideration when assembing the data base, or to make allowances in the calculated results.

Computer Output comprises a print-out of signal strengths in dB or field strengths in microvolts per metre, as required. The most useful feature of computer derived surveys, however, is the ability to be able to obtain a computer-produced map of the signal levels for use with a map of the area. This Appendix contains a copy of such a print, produced for a mobile radio survey of central London. The map can be designed to show three (or more, if required) levels of received signal, by using different symbols to represent the signal levels. In the example given, a star (*) represents a signal worse than 2 µV/m, a cross (+) is for 2-10 µV/m, and a plain square represents a signal better than 10 µV/m.

The advantages of using a computer to calculate the area coverage are:

- there is no need to set up temporary transmitter sites,
- the results can be obtained very quickly,
- there is no necessity to take up the valuable time of staff, in carrying out field tests,
- the location of a proposed site, and the details of the transmitter station can be changed, and the program re-run, if required,
- once the data base and programs have been obtained, the cost is low.

In practice, it has been found desirable to carry out confirmatory tests at locations where the computer indicates signals approaching the lower limits of what is considered to be acceptable. This is particularly important if such an area includes a location of operational importance.

APPENDIX D
(Section 6 refers)

MODULATION METHODS

The most commonly used methods of modulation for mobile radio systems are:

Frequency (or Phase) Modulation	(F3)
Amplitude Modulation	(A3)

Pulse modulation using digital signals and spread spectrum techniques is also possible and may be increasingly used in the future.

Frequency Modulation (F3)

Frequency Modulation includes both pure frequency modulation and phase modulation. Phase modulation is used more often in mobile radio systems as it has the following advantages.

- Phase modulation can be applied directly to a carrier signal and does not require modulation of the carrier oscillator as in Frequency Modulation. Frequency stability is therefore easier to obtain.

- Higher deviations can be generated relatively easily with Phase Modulation.

- In Phase Modulation, the modulation undergoes a 6db/octave pre-emphasis in the transmitter and a similar de-emphasis in the receiver. The result is an enhanced signal/noise performance.

FM Bandwidth

The ITU Radio Regulations define the FM Necessary Bandwidth B_n by the following expression

B_n = 2 M + DK where

B_n = Necessary bandwidth in hertz

M = Maximum modulation frequency in hertz

D = Half the difference between the maximum and minimum values of the instantaneous frequency.
Instantaneous frequency is the rate of change of phase

K = An overall numerical factor which varies according to the emission and which depends upon the allowable signal distortion. K is normally 1.

CCIR Report 358-3 on the "Signal-to-Interference Protection Ratios and Minimum Field Strengths Required in the Mobile Services" defines wide-band F3 systems as those which normally employ frequency deviations with a maximum value in the range ± 12 kHz to ± 15 kHz. Narrow-band F3 systems normally employ frequency deviations with maximum values of either ±4 kHz to ±5 kHz. If the maximum modulation frequency (M) is 3kHz the necessary bandwidth (B_n) for the wide-band F3 systems is between 30 kHz to 36 kHz and for narrow-band F3 systems is between 14 kHz to 16 kHz.

Amplitude Modulation (A3)

The commonest form of AM signals are double sideband with full carrier. The necessary bandwidth (Bn) is twice the modulation frequency and is therefore equal to 6 kHz for a maximum modulation frequency of 3 kHz. The bandwidth may be reduced by half by employing single-side band (SSB) techniques. Three SSB systems are possible:-

A3A	Reduced Carrier
A3H	Full Carrier
A3J	Suppressed Carrier

A further variation has been suggested whereby two independent sidebands are transmitted (A3B), one being used for normal voice with data being carried on the other.

Channel Bandwidth

The required channel bandwidth will depend on the following factors:

Necessary bandwidth (B_n) as described above

Frequency Error of the transmitter

Frequency Stability of the receiver

Adjacent channel selectivity

Due to the pressure on authorities to provide more channels for the growing number of users there has been a trend since the 1950s, when 100 kHz channel spacing was common, to reduce the channel bandwidth and thereby to reduce the channel separation.

CCIR report 319-A suggests that a common channel separation of preferable 25 kHz be adopted. This report recognises that other channel separations are used but recommends that every opportunity should be taken to achieve the use of common channel separations. It further states "The United Kingdom has drawn attention to the increased number of channels that become available when the separation is reduced. It suggests that, whenever possible, a separation of 12.5 kHz should be adopted and that equipment designed for wider channel separation should be readily adaptable for smaller separations without total replacement.

"Since the introduction of 12.5 kHz channel spacing for the VHF band in the United Kingdom during 1968, there has been no evidence to suggest that the services have been significantly degraded by the change. Both amplitude and frequency modulation systems are used with 12.5 kHz channelling and the proportion of the latter is increasing.

"Impulsive interference has not proved in practice to impose a limit on the use of frequencies in the 80 to 160 MHz bands.

"The USA has provided information concerning disadvantages of decreasing frequency modulation-system deviations from the widely used ± 5 kHz to ± 2.5 kHz."

It concludes:

- that increases in impulsive noise interference will be noted;
- that about seven times increase in the number of intermodulation products can be expected.

Other important factors are also listed as follows:

- problems of required increased frequency stability;
- degradation of receiver performance due to adjacent channel transmitter modulation and noise;
- loss in protection ratio;
- loss in frequency-modulation improvement ratio."

APPENDIX E
(Section 7 refers)

IDENTIFICATION OF INTERFERENCE

For the purpose of this paper it can be assumed that all co-channel, and the majority of adjacent channel, assignments are within the VHF mobile allocation, so that call signs and traffic passed on such systems should in most cases provide the means to identify the origin of interference.

To identify the origin and type of interference, other than in the simplest of cases, requires a careful and logical approach as there are many similarities of effect between the various types, although remedies would differ considerably.

It is not suggested that the number of cases of interference supports the need for special instruments to be purchased by users. However, a high Q tunable RF filter is essential to determine some types of interference. Use of a spectrum analyser or spectrum monitor is highly desirable.

As some mobile networks employ UHF links, these should not be overlooked as sources of co-channel interference.

Generally, it will be apparent from the call signs etc, that the interference is related to assignments to a mobile radio network or broadcasting station.

As a first step, the mobile/link interface should be isolated. For the purposes of the paper, the mobile allocation is to be considered as the source of interference, although the link allocation should be treated in a like manner.

1. Ascertain the tune frequency of receiver by measurement with standard (do not assume assignment frequency).

   A deviation of several kHz from assignment will increase adjacent channel interference probability.

   Check sensitivity of receiver in normal manner.

2. Insert high Q radio frequency pass filter in series with input to receiver. Connect signal generator on tune frequency, ensuring that it "beats" with either an IF or RF frequency standard. Adjust the filter carefully to pass the tune frequency of receiver. Replace antenna, and ensure that the signal generator is not radiating any signal.

Interference remains	Interference reduced or eliminated
Co-channel	Adjacent, image
Intermodulation outside receiver	Intermodulation in receiver Blocking,
Intermediate frequency direct in receiver (not via aerial)	Cross modulation.

3. Set signal generally 12.5 kHz above or below the tune frequency. Adjust filter to pass adjacent channel (two tests require one for each adjacent channel). The only positive result is obtained when interference increases and wanted signal decreases compared with "on tune" setting of filter. This indicates adjacent channel or intermodulation outside receiver.

These two tests will indicate the vast majority of types of interference. Under item 2, if interference remains, then careful check of the antenna and feeder, in conjunction with a detailed examination of all co-channel sites and their field strengths at the receiver, will indicate possible causes. The use by certain government departments of higher power transmitters in the vicinity should be checked, to enable the discounting of interference at intermediate frequencies.

If the interference reduces there are still five possible causes. Investigation as to field strength and position of transmitters of adjacent channels, transmitters at image frequencies, and high power transmitters will indicate the possibilities of three causes definitely and might indicate the causes of the other two.

If none of the above-mentioned possibilities indicates a cause for the interference, a careful series of calculations must be entered upon, on the assumption that the cause must come from multiple intermodulation.

EXAMPLES OF INTERMODULATION INTERFERENCE

1. Combination of amateur and broadcasting frequencies

(a) A typical high power VHF broadcast transmitter at 88.2 MHz.

(b) An amateur's transmitter at 70.2 MHz.

If (a) is doubled, i.e	88.2 x 2 =	176.4 MHz
and (b) is subtracted		70.2 MHz
		106.2 MHz

This Frequency falls in the VHF broadcast band and would therefore create interference with domestic broadcast receivers.

2. Combination of mobile and broadcasting frequencies

(a) A typical high power VHF broadcast transmitter at 89.1 MHz.

(b) A low band mobile transmitter at 72 MHz.

As above,	89.1 x 2 =	178.2 MHz
Subtract		72 MHz
		106.2 MHz

As this interference would occur only when both transmitters were operating, a good indication would be to check the times when the interference occurred and relate these to the programme times.

3. Co-siting interference

(a) One VHF transmitter at 106.2 MHz.

(b) Other VHF transmitter at 106.4 MHz.

As above,	106.2 x 2 =	212.4 MHz
Subtract		106.4 MHz
		106.0 MHz

This is a third order interference frequency, precluding its use on a site shared by the transmitters (a) and (b).

For further information see References 6-9.

APPENDIX F
(Section 10 refers)

MULTI-MAIN STATION SYSTEMS

1. Effects of frequency off-set

It has been stated that a simulcast system can provide an enhanced service over an area, improving the average distribution of the RF field and its mean value at any point. However, it can also produce collateral negative effects which must be carefully evaluated and prevented where possible. In order to analyse these effects in a simulcast system, the case of two repeater stations is examined.

1.1 Synchronous systems

Suppose that the two main transmitters are synchronous, that is they are tuned exactly on the same frequency by means of suitable synchronizing signals.

In this case, the received signal comprising the two RF signals, depending on their phases and amplitudes, generates a resulting field which can vary between a value twice that of each of the two RF signals and zero.

As a mobile passes through the RF field on the fringe of the area of coverage, it receives maximum and minimum signal levels sequentially. This effect is superimposed upon the fading effect that would normally occur with only one transmitted RF signal, and it therefore tends to improve the reception conditions.

On the other hand, the effects of the superimposition of two synchronous RF signals cannot be neglected when the mobile is stationary. In this case, if the RF signals have very similar amplitudes, the resulting field can be very low, which seriously affects reception quality. Synchronous systems therefore, give rise to problems for mobiles which may be in a stationary or very slow moving situation.

Synchronous systems require that the interconnection network between the repeater stations provides the broadcasting transmitters with a synchronising signal. This requires that the interconnection network should consist of "physical" metallic circuits, AM or FM radio links without frequency transposition, or synchronized PCM links. It is possible for a combination of these to be used.

Quasi-synchronous systems are preferred because of the less complexity of the interconnecting circuits.

1.2 Quasi-synchronous systems or simulcast networks

In these systems the frequencies of the broadcasting transmitters are characterized by controlled mutual offsets maintained within certain pre-determined limits.

If δf is the frequency offset between two main transmitters, the superimposition of their signals generates a resulting RF signal characterized by periodical amplitude fluctuations with period equal to $1/\delta f$ between values respectively equal to the sum and difference of the amplitudes. Figure 1 shows the resulting signal at a point in space for two transmitters in a simulcast network. In quasi-synchronous simulcast systems the mean values of the received field are generally near the level of the higher signal. Even in this case the movement of the mobile masks the periodicity of the fluctuations, and experience shows that the received signal is improved because of the superimposition of the signals.

In the case of stationary mobiles, when the RF fields are equal or very similar, beating of the signals causes some disturbances in the receiver. In FM systems it produces a periodic field fluctuation, with noise bursts, while in AM or SSB the field fluctuations produce, in addition to noise bursts, serious distortion of the demodulated signals, which is in effect a spurious amplitude modulation. Frequency or phase modulation is therefore preferred for simulcast networks.

Field tests on actual networks show a superiority of FM and PM over AM and SSB, because:

(a) FM/PM tolerates RF frequency offsets better than AM/SSB. For speech transmissions, many examples of existing networks demonstrate that in AM/SSB the offset cannot exceed values of a few Hertz, while in FM/PM many tens of Hertz are tolerated.

(b) both for AM/SSB and FM/PM the worst conditions arise when the RF signals from two or more transmitters are received at nearly equal levels. When the differences between the RF levels increase, the quality of the signal improves much more rapidly in the case of angular modulation than in the case of AM/SSB.

2 EFFECTS OF LEVEL, PHASE AND FREQUENCY OF MODULATING SIGNAL IN SIMULCAST SYSTEMS

In simulcast networks, when a mobile receives RF signals having nearly equal levels from more than one transmitter, the effect of frequency offsets is always to degrade the signal. This requires, therefore, that the stability of transmitter frequency is achieved by using multiplexing techniques having an exact precision of frequency with an attenuated carrier or similar technique.

Given that the modulation is distributed to all the repeaters with exactly the same frequency, transmission delays have less effect on the received signal for AM/SSB than for FM/PM.

For angular modulation when the RF signals received from two broadcasting transmitters differ in phase by more than 50 μs, distortion effects give rise to increasing intelligibility losses, although 100 μs delay can be tolerated in systems with 25kHz channel spacing.

For SSB or AM, even if noticeable delays impair reception quality, the intelligibility is never compromised since the effect is similar to echo or reverberation in a room.

In simulcast networks therefore, suitable techniques are needed in the interconnection systems in order to equalize the propagation delays on the modulation signals transmitted from stations in the network, so that delays do not exceed about 100 μs at receivers in the area of multiple reception. This requirement is essential for simulcast FM/PM networks, although they complicate the interconnection links between the stations.

Another point in which FM/PM is at a disadvantage as compared with AM/SSB, concerns differences between transmitters of modulation levels. In the case of SSB the differences in the modulation index resemble differences in RF level. For AM systems they modify the modulation index of the resulting signal without introducing distortion. In the case of FM or PM, however, they generate distortion, if the RF levels are comparable. These distortions are nevertheless tolerable if the modulation indexes do not differ by more than some decibels. Normally they are around 2-3 dB for typical systems. It is clear therefore, that these effects can be reduced to acceptable limits by careful design of the network.

The degrading influence of differences in modulation index and delays in FM/PM depends on the r.m.s value of the modulation index. Degradation is greater when the modulation index is low, and tolerable with high modulation indexes.

The relationship between modulation index and resulting distortion due to the superimposition of two RF signals with differences in modulation is largely non-linear, and even limited differences in modulation index give noticeable differences in signal quality. Therefore in simulcast networks, FM/PM systems with 25kHz channel width are much preferred to systems with 12,5 kHz channel width. In system with 25 kHz channels and quite high r.m.s modulation index, the problems due to the isomodulation conditions of the broadcasting transmitters can easily be resolved, and the transmission quality is noticeably better than for other modulation systems.

If the interconnection of the main/repeater stations is by telephone circuits (usually leased from common carriers) so that the stability and precision of levels and the transmission delays cannot be relied upon, AM and SSB are preferred to FM/PM systems, because the former are less sensitive in those circumstances.

On the other hand, if the interconnection can be achieved by dedicated channels on dedicated and well controllable transmission systems, the problems of maintaining levels and phases in the signal transmission can more easily be overcome, and FM/PM systems can be more favourable.

Except for the particular merits or demerits of phase and level of modulating signals, the reasons for preferring FM/PM can be summarized thus:

- reduced complexity and less cost for the FM/PM equipment, and greater efficiency in relation to the linearity of the RF circuits.

  It should be noted that in order to ensure the same signal to noise ratio offered by an FM system with 25 kHz channel bandwidth, an AM system requires RF output amplifiers able to supply linearly a peak envelope power 8-10 dB greater. An SSB system requires linear RF output amplifiers with 2-4 greater peak envelope power.

- greater tolerance in the frequency offset for the broadcasting transmitters. AM and SSB can accept maximum offset of only about 1-3 Hz, while FM/PM can tolerate up to 100 Hz:

- less sensitivity to impulse noise, especially in the case of 25 kHz bandwith;

- better stability in the reception quality in Rayleigh fading conditions (in these conditions AM/SSB systems not only suffer the effects of noise but also modulation distortion);

- better intelligibility in RF signals beat conditions;

- reduced sensitivity to co-channel interferences, with a margin greater than 10 dB in comparison with AM/SSB;

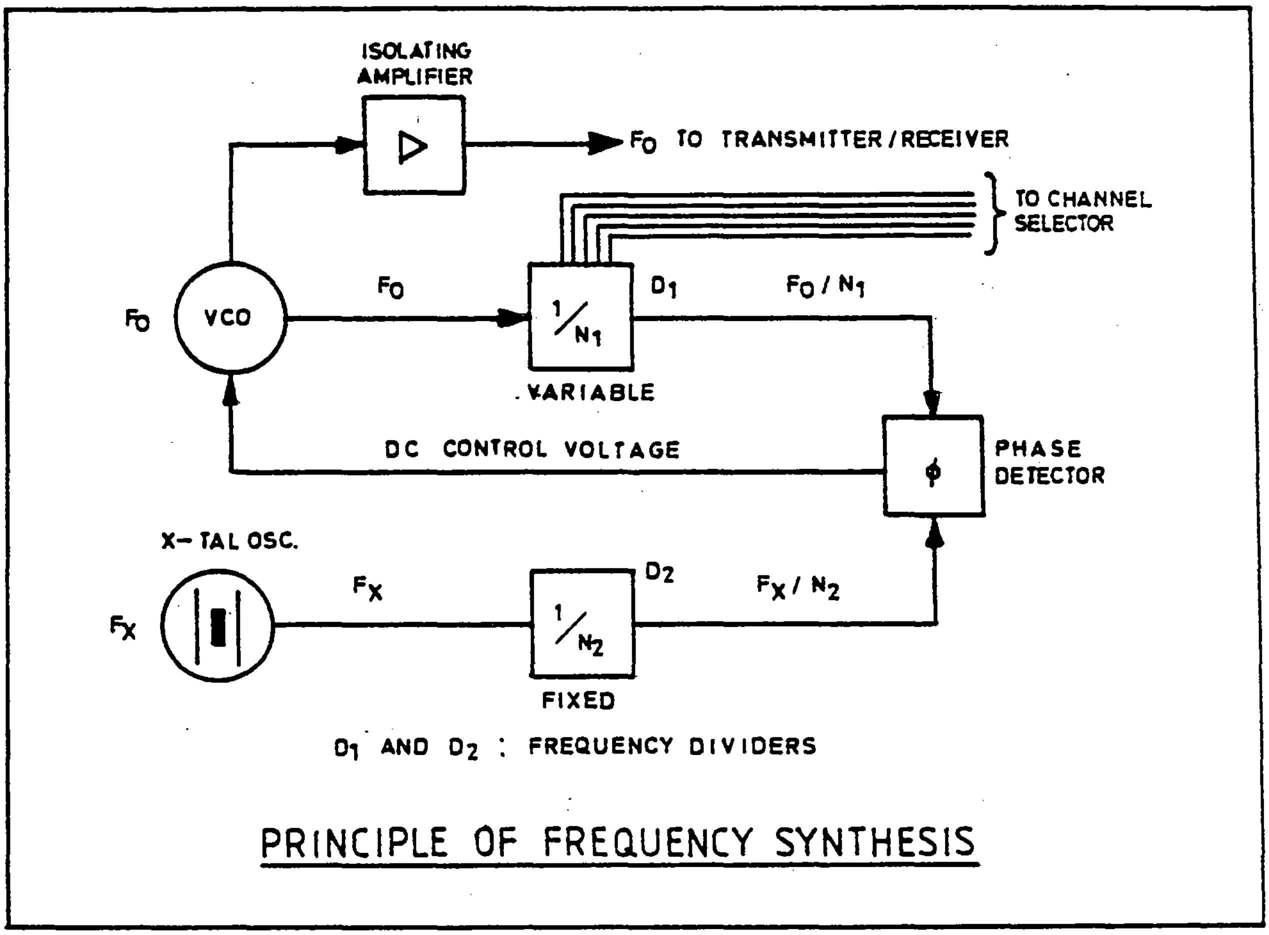
- smaller change-over times for FM/PM than for AM/SSB in the simplex or half duplex operation, due to the absence of receiver automatic level control.

  This characteristic is extremely important in the management of data signals and call signals.

Large scale development of SSB, for systems carrying data does not seem practical in the forseeable future at frequencies higher than 400 MHz.

APPENDIX G

PRINCIPLE OF FREQUENCY SYNTHESIS (Simplified)



PRINCIPLE OF FREQUENCY SYNTHESIS

When the system is in balance: $\frac{Fo}{N1} = \frac{Fx}{N2}$ which leads to: $Fo = N1 \cdot \frac{Fx}{N2}$. If Fx an N2 are kept constant, Fo will vary in proportion to changes of N1. By varying N1, different output frequencies - evenly spaced, are obtainable.

Example:

Fx = 5,o MHz   N2 = 4oo

N1 =	16oo	16o1	16o2	16o3	aso.
Fo =	2o,oooo	2o,o125	2o,o25o	2o,o375	Mhz

The output frequency Fo from above may be used as input signal to a transmitter multiplier chain. If this chain quadruples the input frequency, the following output frequencies Ft are obtained:

Ft =	8o,ooo	8o,o5o	8o,1oo	8o.15o	Mhz

Results:

1. The frequencies are spaced evenly. 2. The channel spacing (Seperation) is 5o Khz.

APPENDIX H

List of Members of CIGRE Study Committee 35
Working Group 04
April 1983 - August 1985

C E Dadson	(Convener)	United Kingdom
S Andersson		Sweden
M Ferrer		Spain
P Fulton		United Kingdom (Scotland)
S E Larsen		Denmark
L Lindroos		Finland
P A Mulhern	(Part time)	Ireland
P Lynch	(Part time)	Ireland
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