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The Swiss Mobile Radio Telephone System

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Summary. *The system here described has been designed for connection to the public network and is capable of working to automatic exchanges over standard telephone lines. Its principal advantages are an excellent use of available channels, limited susceptibility to interference, easy location of mobile subscribers and flexible extension capability. The system therefore enables large radiophone networks to be built economically, with a minimum of materials and frequencies.*

1. Introduction

In recent years the interest in mobile radio services has considerably increased. Among the principal reasons for this development are the steady improvement in miniaturisation and semi-conductor techniques as well as the growth in traffic and the need for faster communication. Often messages and orders are only of use if they immediately reach the person for whom they are intended whilst he is travelling, for example, in his car. As a result of rationalisation and automation new requirements are continually arising.

Unfortunately, with the increase in installations, the limited number of available rf channels become more scarce. The reduction is not only proportional to the increase, since each radio installation has the disagreeable property of being able to interfere with other radio installations. Thus when a certain channel has been assigned to a given location a whole series of other channels are no longer available for this location (adjacent channels, channels liable to cause interference due to intermodulation, channels corresponding to image frequencies of receivers etc). Moreover the channel in question can only be re-used at a very great distance from the place to which it has been assigned (co-channel interference). Such interference can be partly avoided by improvement in equipment but one can also combat it effectively by choosing an adequate transmission system. In making this choice it is necessary not only to consider the economic viability of the system and its ability to comfortably handle a certain traffic; of equal importance is its economical use of frequencies.

The Swiss system of mobile radio telephones has been developed with these points in mind. Its effectiveness has been confirmed by practical tests and its commercial development is planned.

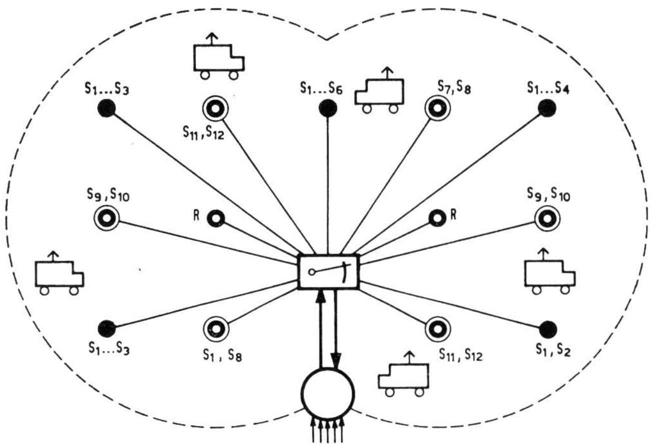
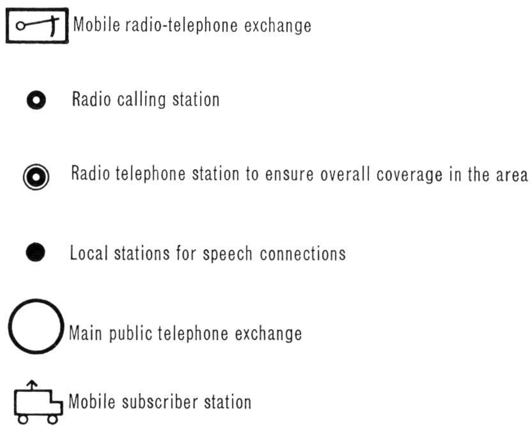


Fig. 1
Principle of the structure of a mobile radio-telephone network comprising a calling (or control) channel R and 12 speech channels $S_1 ... S_{12}$ (the numbers assigned to the channels are chosen at random)



2. Structure of the System

The Swiss mobile radio-telephone system will be operated in conjunction with the public telephone network. Consequently it must satisfy the basic demands of line telephony; in particular the relation of levels must be respected as well as the conditions required for automatic selection, for charging by means of the usual signals and for obtaining a transmission of equal quality in both directions. In addition the user should not be able to notice in practice any difference between the use of a mobile station and that of an ordinary telephone.

Figure 1 represents schematically a mobile radio-telephone system. Its principal elements are: the mobile stations, the fixed radio network and the connecting exchange whose role it is to switch the calls through, to charge outgoing conversations, and to transmit, after appropriate conversion, the call, dialling, control and monitoring signals between the radio stations and the telephone exchange.

Connections between fixed radio stations and the mobile telephone exchange are made by 4-wire lines or by duplex radio-relay links. For mobile connections phasemodulated radio-telephones are used exclusively.

The installations of mobile radio-telephones with connection to the public telephone network often extend to regions where, over large areas, the density of vehicular traffic is slight and also to towns within which the density of traffic is great. It is not possible in such a case to provide the service by means of only one fixed radio station. It is advantageous to establish for the general requirements a covering radio network of large mesh and only catering for a few channels by means of stations located on the higher points. In areas where the population and traffic are dense one can install local stations of short range and a larger number of channels, such as to ensure that the available channels are everywhere proportional to the density of the traffic. Naturally the mobile stations must be able to work on all the channels. The Swiss mobile telephone system is equipped with an automatic selector which chooses in each case the most suitable of the channels available. If the same channels are re-used in places sufficiently distant from one another to avoid interference, one can thereby serve a given region with a minimum of equipment and channels. Thus 12 duplex channels for approximately 40 fixed stations, equipped with approximately 90 transmitters/receivers, are sufficient for example to establish a radiotelephone network covering the whole of Switzerland and catering for 5,000 to 10,000 mobile subscribers [3].

The automatic channel selector chooses, according to a prearranged code, a usable channel from those available. In this way the auxiliary (or fill-in) fixed stations are always used first in regions with a high-density circulation. The long range channels are thus left free for areas with light traffic which are served exclusively by them. For manufacturing and technological reasons all channels used must lie within a band of approximately 1 MHz.

The location of a required subscriber presents a problem in a large networks equipped with several fixed stations. A good solution is to use a single calling channel. It is advantageous to use the various calling transmitters with a slight carrier offset, as in the Swiss radio-paging system [1], and to transmit the call simultaneously throughout the whole network. The calling channel is then correctly loaded from the point of view of the traffic. In overlapping zones in which the field strength of two transmitters is approximately equal there is a danger of call failure if their modulations are not in phase. An appropriate phase correction must therefore be provided for the modulation path. The range of a call by means of coded signals is generally greater than that which a transmitter can give for speech; it is thus not necessary to equip all the fixed stations with calling transmitters. Should the need arise one can even reduce still more the number of transmitters by using greater power for the call signal than for the transmission of speech (to serve the whole of Switzerland approximately 18 call transmitters are required [3]).

In principle the system described should permit the establishment of one network to serve the whole country through one central exchange. It would not then be necessary to know the location of mobile subscribers from moment to moment. They could even move throughout the whole country during a conversation, passing from one radio sector to another without perceptible interruption. However, in general, one must forego the advantage of a single network because of the planning requirements of the telephone cable network and the charging system. It is therefore necessary to create groups of networks like those of the ordinary telephone. Each group of networks constitutes a separate unit with its own radio telephone exchange which can be reached by dialling its special code number.

Each mobile station is identified by a normal telephone subscriber's number, which is allocated only once within the country. For radio transmission these numbers are transformed into a frequency code. Each number is expressed by a combination of 3 frequencies taken from a group of 20 within the range 300...1200 Hz. It is never possible in this code to have two consecutive pulses with the same frequency and each coded number is transmitted twice in order to increase the reliability of the call.

The call indicator operates when at least one of the two coded groups has been correctly received. The diagram at *figure 2a* indicates the time sequence of the call signal. The same coded number serves as an identification signal for the exchange when the mobile subscriber makes a connection. In this case the signal is completed by a master pulse of the frequency f_o *(fig. 2b)*.

The dialling signals of the mobile stations are also changed into ac pulses for transmission by radio as is shown in *figure 2c*. The dialled pulses are represented by the frequency f_i and the intervals between pulses by the frequency f_p. Before and after each dialled digit a pilot pulse of the frequency f_o is transmitted. The reliability of transmission is adequate in spite of the relative simplicity of the transmission system and the dialled signals, since, in the Swiss system, the quality of connection is automatically and permanently supervised. This is achieved by modulating the fixed transmitters either by a «free» tone or a control tone. The «free» tone f_o lies above the code-frequency band and the control tone f_u is situated at its lower end. When there are several neighbouring radiotelephone networks it is necessary to reverse the positions of the «free» and control tones to avoid reciprocal interference. It is also necessary to change the calling channels in passing from one radio network to another. In this way the conversation is always established via the exchange which has initiated the call.

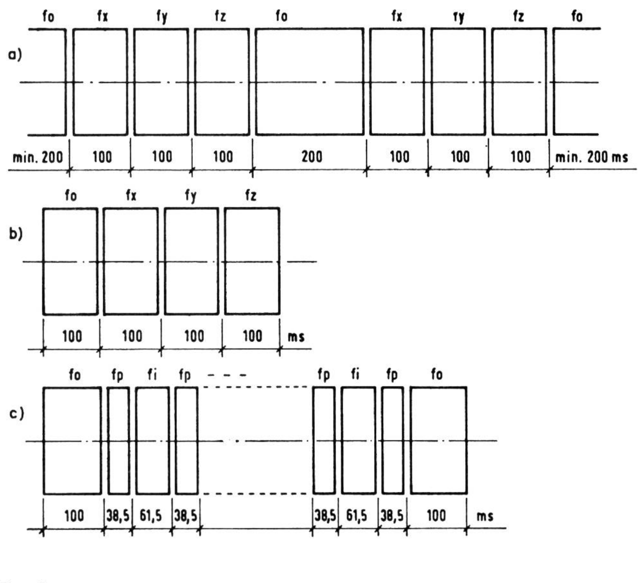


Fig. 2

a) Call signals (f_x, f_y, f_z: 3 code frequencies/f_o: free tone during the pauses)
b) Subscriber numbers (f_y, f_x, f_z: 3 code frequencies/f_o: free tone used as control pulse)
c) Dial signal (f_i: dial pulse frequency/f_p: dialling pause frequency/ f_o: «free» tone for control pulses)

3. Method of Functioning

Figure 3 shows schematically how the various elements of an installation function together. This diagram enables one to get a clearer idea of the nature of the main circuits which are described in the following.

3.1 Standby Position

In the standby position the fixed transmitters are continuously modulated by a «free» tone f_o, and the receivers are ready to receive. The receivers of the mobile stations are tuned to the calling channel to await calls. The free tone is used to check the intensity of the received field strength. The mobile transmitters are switched off.

3.2 Call Initiation

Calls are initiated by the caller dialling the code number of the mobile radio-telephone network followed by that of the required subscriber. The calls reach the radio-telephone exchange via the public telephone exchange in the form of dc pulses. These are then coded in accordance with figure 2, stored and sequentially transmitted to modulate the calling transmitter. Immediately after the entry of the number the register is released and the coded number marked in a calling code comparator circuit. To give the caller the impression of a normal telephone call he receives from the exchange a normal ringing tone. This lasts until the mobile subscriber replies. If the mobile does not do so within 2–3 minutes the call is disconnected and the caller hears a continuous tone (unobtainable Number tone).

During this time the call signal is received, demodulated and code-evaluated by all free mobile stations. Each station is equipped with a decoder which only reacts to its own special number, in the case of which an audible or visible signal advises the mobile subscriber that there is a call for him.

3.3 Establishment and Switching of a Speech Connection

Each speech connection is established from the mobile station when the mobile subscriber lifts his handset either to make or receive a call. This operation releases in his station an electronic channel selector which moves from one channel to another at the rate of one channel every 100 ms. If the selector encounters, on one of these channels, a carrier modulated by the free tone, it stops, causes the mobile transmitter to be switched on and modulates the carrier by a 100 ms long control pulse of the frequency f_o. This pulse is immediately followed by the vehicle's code signal which, in accordance with figure 2b, is identical to the calling code. The control pulse and code signal reach the switching centre via the fixed station that intercepts them, and the modulation line. The control pulse causes the fixed station transmitter to be modulated by a control tone f_u instead of the free tone and then activates a decoder for identity signals in the exchange.

To avoid double checking, evaluation is suppressed when two codes arrive simultaneously. According to whether the identity code signal is already marked in the centre or not, the connection is made with the calling customer who has caused the marking or passes to the dialling apparatus of the public exchange. In the first case the connection is made between fixed and mobile subscribers respectively and the conversation can begin. In the second case, after the charging mechanism has been activated, the exchange dialling tone is transmitted to the vehicle to indicate that the required number can now be dialled. In both cases the radio connection is supervised by the control tone which originates in the fixed station, is sent to the mobile station, evaluated, and then relayed back to the fixed station. If, in this way, the control tone is interrupted for any reason for more than 300 ms, the transmitter of the mobile station disconnects and the channel selector renews its searching process. In the fixed station the interruption of the control tone for more than approximately 1s renders the channel free by re-emission of the free tone. As soon as the selector finds another free channel, connection is re-established by means of this channel. A conversation, once begun, can thus be continued practically without interruption. It is necessary to avoid false selections when a change of channel occurs while dialling a number. To this end the pulses of each digit are entered into a register by means of the first control pulse and in accordance with figure 2c. The register will only relay the number further if it also receives the control pulse at the end of the number – if not, the selection is automatically interrupted.

3.4 Disconnection

Disconnection is usually effected when one of the callers replaces the handset. If this is the mobile subscriber his station reassumes its standby position on the call channel and the control tone is then interrupted. If it is the fixed caller the modulation of the fixed transmitter passes from control to free tone.

If a call lasts too long, a timer disconnects it in the mobile station. The timer starts as soon as the handset is lifted and cuts off after the required duration, eg after 3 or 6 minutes. The disconnection causes the mobile station to revert to standby and the mobile subscriber is concurrently advised through an intermittent tone signal to replace his receiver. The time switch also prevents a channel from

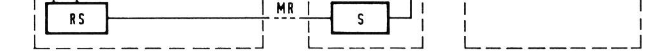


Fig. 3
Block diagram of the radio-telephone installations

Autotelefon-zentrale	Radio-telephone exchange
Fixstation	Fixed station
Mobilstation	Mobile station
OZ	Local exchange
HZ	Main exchange
MS	Speech modulation line
MR	Calling modulation line
S	Transmitter
E	Receiver
ST	Control apparatus
EL	Input circuit with calling code register
ER	Call register
RS	Call circuit
RA	Call register switch
AL	Output circuit with identity code evaluation device and register
VS	Connecting switch
M	Marker with comparator of coded numbers
T	Charging apparatus and tape registration

remaining inadvertently engaged, through, for example, a mobile subscriber forgetting to replace his handset.

3.5 Charging

Conversations are charged according to the usual criteria of the public telephone system. The solution is simple when the period of the charge pulses is determined by the network code number. There is thus a uniform system of charges within each group of networks; the smallest for one's own and the greatest for the most distant. All conversations within a radio network are then charged according to the same uniform rate. This system of charging is also applicable to local calls from a vehicle, since to use the public telephone network it is necessary to dial the trunk code number of the corresponding main exchange. It is practical to charge the conversations of mobile subscribers by means of a tape recorder situated in the radio-telephone exchange. One can thus record very easily with each charge the identity code number of the subscriber concerned.

3.6 Passing from one Radio Network to another

In passing from one network to another the driver must press a button in order to switch the call channel, free tone and control tone evaluator. If he forgets to do so, as soon as the field strength becomes too weak, he is made aware of the fact by an alarm signal: «Please change over, you are now in another network!» The mobile subscriber is naturally only to be reached here when the caller selects the new network code number. When the location of the vehicle is absolutely unknown, the individual network code numbers must be tried in turn in order to make contact.

4. Automatic Channel Selector

One of the most important features of the Swiss radio-telephone system is the automatic channel selector in the mobile stations. It makes for an appreciably better traffic flow and use of frequencies than the usual systems. That is why we wish to examine its main characteristics.

4.1 Commutation Criterion

To ensure that the channel selector functions satisfactorily in every respect it is important to choose correct commutation criteria. The channel selector should stop as soon as an effective telephone connection can be made. In the public telephone system a connection is considered viable when the definition of individual speech components (sounds) reaches a level of at least 80%. If the definition is below this standard the channel selector must function accordingly. Since it is complicated to measure the intelligibility of sounds, one measures instead a level of reference. Tests have shown that with a modulation of 1000 Hz with maximum frequency deviation [2], one obtains an equivalent level when the signal-to-noise ratio measured at the low-frequency output of the receiver, by means of a psophometer equipped with a CCITT telephonic filter, reaches approximately 20 dB [2]. It is thus possible to control the channel selector by means of a suitably adjusted low-frequency noise muting circuit. The channel selector is set in motion when the low-frequency noise muting circuit blocks the low-frequency channel and thereby interrupts the control tone. In accordance with *figure 4* the required low-frequency signal-to-noise ratio of 20 dB is achieved by means of a typical 25 kHz pulse-modulation receiver in the 160 MHz Band with an antenna terminal voltage of approximately 0.6 µV.

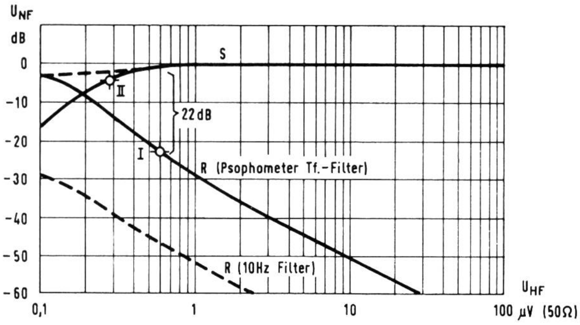


Fig. 4

Low frequency levels of wanted signal and interference in relation to radio frequency levels in the case of a phase modulated receiver for speech connections (rf bandwidth: 17 kHz; LF bandwidth: 3000 Hz and 10 Hz for LF level measuring; Modulation frequencies: 1000 Hz; frequency swing: 2.8 kHz)

I Threshold of noise muting circuit
II Threshold of tone evaluator

4.2 Commutation Times

When the vehicle is in motion the antenna terminal voltage varies continuously according to the field distribution. If the channel selector were swift enough to follow the field variations it would operate with a probability equal to that with which the field exceeds the threshold of the muting circuit (*figure 5* shows a typical field variation in a 1 km long street section).

In pratice it would be uneconomical for the selector to operate so rapidly. Each short break in the field strength would result in a change of channel, even when the level of intelligibility was still good. In effect it is not the momentary value of the S/N ratio which determines intelligibility but its average value throughout the conversation. In principle therefore one should choose this average value as the commutation criterion. Experience has shown that unsatisfactory intelligibility during one second is, as a rule, scarcely noticed; the integration time should therefore be of this order.

Tests have however established that the same result can be achieved more simply; instead of integrating the S/N ratio it is sufficient to design the switching device so that it only operates if the signal remains for at least 300 ms below the operating threshold. With a time lag of 500 ms instead of 300 one finds that, when travelling at speed, there are areas where intelligibility falls below 80% before commutation is made. During this relatively long 'observation time' the field strength at times exceeds the operating

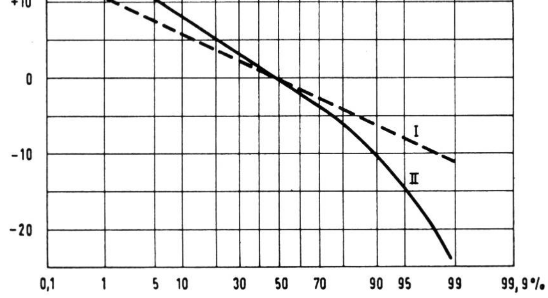


Fig. 5

Typical field variation in a 1 km long street section

I Coarse structure
II Fine and coarse structure
F Median field strength

threshold, so that the required commutation does not take place.

In using the chosen operating time of 300 ms it has been established, by observing the interval between the operating threshold and the median field strength of a typical 1 km long street section, that there is a 99% assurance of no commutation being required. (The intelligibility is then $\geq$ 80% with a security of 99%.) The required interval is approximately 12 dB. Thus for a testing station with an operating threshold of 3 μV/m a median field strength of $\geq$12 μV/m would be required. The required interval for other operating times can be ascertained from *figure 6*.

The operating time of the free-tone evaluator which stops the channel selector is also important. On the one hand it should be as short as possible since it determines the operating speed of the selector; on the other it must be long enough to prevent impulse noise being evaluated as the free tone. If we proceed once more from the hypothesis that an interruption of approximately 1s is not disturbing, and that during this time up to 10 channels will be scanned, the resultant selector speed per step will be 100 ms. With a ratio of 1:1 between the operating time of the evaluator and the pauses, the operating time should not exceed 50 ms. This duration permits the application of an evaluator filter for the elimination of unwanted pulse and noise components.

4.3 Operational Thresholds

Another important point is the operational threshold. It is advantageous to fix it in relation to the maximum frequency deviation. For speech connections the greatest possible frequency deviation is always used so that, even with conversation at a great distance and lesser field strength, the S/N ratio will permit a usable transmission quality. If one wishes to transmit a control tone simultaneously with conversation, the frequency swing alloted to it must be as small as possible.

In 160-MHz phase-modulated installations with channels separated by 25 kHz the maximal usable frequency deviation is in the region of 3.5 kHz [2]. Assuming that the operating threshold should lie at least 10 dB above the noise level and 5 dB under the deviation of the control tone, this latter can be ascertained from figure 4. With a bandwidth applicable, in practice, of 30 Hz the required control tone deviation is approximately 0.7 kHz. In this case one

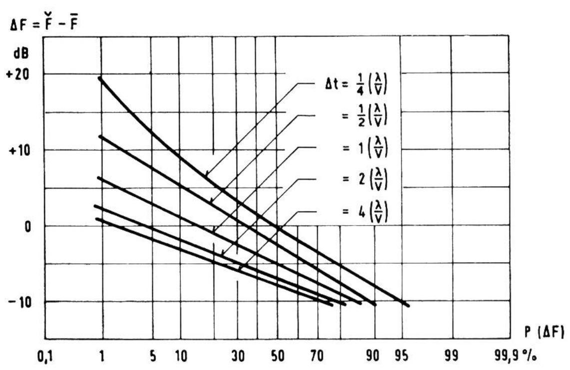


Fig. 6

Probability of channel commutation P ($\triangle$F) on a 1 km long street section in relation to the deviation of the average field and the tone-evaluator threshold for different operating times

$\triangle$t operating time
λ HF wave length
v vehicle speed

will be below the threshold with an antenna terminal voltage of 0.3 μV. In principle the same values could be applied for the evaluation of the free tone. Since this however is not transmitted during conversation it is better to choose a greater deviation for it, for example 2.8 kHz. The operating threshold is again fixed at 5 dB under this value so that the rf operating level is also 0.3 μV. By using the greater deviation there is a favourable increase in the noise threshold for impulse interference.

5. Particular Advantages of the System

Finally it is appropriate to indicate some of the particular advantages of the Swiss system not highlighted in the foregoing text.

5.1 Utilization of Channels

In the interest of frequency economy every rf channel should be used to its full potential. This is the case when the holding time is practically restricted to the duration of call and conversation, and the pauses between connections are very short.

The system described permits an almost optimum fulfilment of these conditions. The call duration is 1s at the maximum. The channels then remain unoccupied until the mobile subscriber takes the call. Approximately 1s after connection commutation or the end of conversation the channels are once more free; a call register enables occupation of the call channel to follow in an uninterrupted series. Conversations however cannot, unfortunately, be registered and arranged one after the other. On the other hand it is possible to obtain a certain compensation by following current telephony practice, where several lines are put at the disposal of an automatic selector. This principle is also applied here. In high density traffic areas several channels are made available from which the automatic channel selector can choose. The number of channels necessary is determined in relation to the traffic just as the number of groups in an ordinary telephone cable. Curve 1 of *figure 7* shows the relation which exists between the number of channels and the traffic when the subscriber is 95% sure of finding a free channel during peak hours.

If one supposes that the mobile subscriber does not hang up immediately on receiving the 'engaged' tone, then a considerable better utilisation of channels is achieved. The channel selector in effect continues to function until it finds a free channel. This will occur as soon as a conversation ends. In principle therefore the channel selector does arrange, to a certain extent, the order of conversations. Since all connections are established from the mobile station, this possibility exists in each case. An additional occupation of the channel does not result, since the mobile transmitter is always cut-out during the waiting time when the channel selector is turning.

The improvement which can be obtained in relation to the waiting period is also included in figure 7. One can, for example, read from it that by introducing a waiting period equal to the average occupation time of 2 available channels, one could tolerate a traffic six times greater than if there were no waiting period.

5.2 Reaction to Interference

Even with good network planning it is probably unavoidable that the useful signal will be disturbed by unwanted signals. This can arise as a result of co-channel inter-

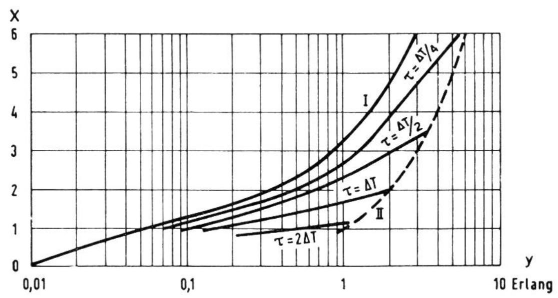


Fig. 7
Tolerable traffic y when one demands 95% assurance of finding a free channel from x channels available for use (△T: average occupation time; △τ: average waiting time)

I Lower limit (without waiting time)
II Upper limit (all channels occupied)

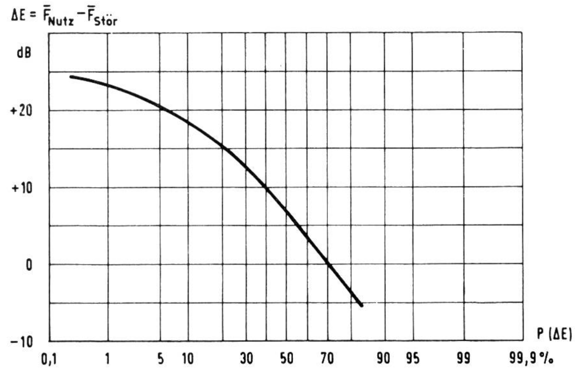


Fig. 8
Probability of channel commutation P (△E) in a 1 km long street section in relation to the average HF S/N ratio

ference from widely separated transmitters or interference form nearby transmitters on other channels. These occur when protection of the receiver against intermodulation or the selectivity or the blocking performance is insufficient, or when the spectra of the modulation and noise of the interfering transmitter are too broad. In every case we are concerned with interference which can be avoided by changing channel. In the system here described the channel selector automatically undertakes this task. As soon as interference occurs the free tone or the control tone is suppressed. This causes the channel selector to change to a channel free of interference, and the conversation is continued on the new channel practically without interruption. The abandoned channel is immediately rendered free and at the disposal of subscribers outside the areas of interference, which are usually small in extent. Moreover the same channels are not disturbed in different areas. One can therefore say that the traffic and utilisation of the channels are almost free from the influence of selective interference.

It is obvious that one can take advantage of this situation in frequency planning by allowing a greater degree of interference. Thus, for example, the distance between transmitters operating on the same channel can be reduced; also there is no need to take such severe precautions against interference originating from intermodulation or neighbouring channels.

By way of information *figure 8* illustrates the experimentally-established relation between the average rf S/N ratio and the probability of channel commutation in a typical 1 km long street section.

5.3 Possibility of Extending the Area Served and Probability of Contacting Mobile Subscribers

The call is transmitted simultaneously in a single channel by all transmitters. There is no difficulty in reaching a mobile station; one can extend at will the area covered by the call by adding supplementary transmitters working on the same channel. The area of vocal communication can also be extended by means of additional fixed stations. Even if no new channels are used the mobile stations remain unchanged. These can in principle establish a connection via any fixed station equipped with one of the existing channels. The vehicle can even pass throughout the whole area served from one station to another without interruption of connection, provided always that the channel selector finds a free channel.

(Translated by British Post Office)

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