

COVER SHEET FOR TECHNICAL MEMORANDA

SUBJECT: Mobile Telephony - Wide Area Coverage - Case 20564

COPIES TO:

- 1 - R. Bown - Dept. 1200 Files
 2 - Case Files ← *THROUGH FOR*
 3 - H.T. Friis-Holmdel File
 4 - Patent Dept.
 5 - B.W. Kendall
 6 - H.A. Affel
 7 - G.W. Gilman
 8 - R.K. Potter
 9 - J.R. Wilson
 10 - J.W. McRae
 11 - E.L. Nelson
 12 - C.B. Feldman
 13 - A.C. Dickieson
 14 - D. Mitchell
 15 - F.B. Llewellyn
 16 - G.C. Southworth
 17 - J.C. Schelleng
 18 - W.R. Young
 19 - K. Bullington
 20 - D.H. Ring

MM- 47-160-37
 DATE 11 December 1947
 AUTHOR D. H. Ring

H.J. Jones

XXXXXXXX
 ABSTRACT

ABSTRACT

In this memorandum it is postulated that an adequate mobile radio system should provide service to any equipped vehicle at any point in the whole country. Some of the features resulting from this conception of the problem are discussed with reference to a rather obvious plan for providing such service. The plan which is outlined briefly is not proposed as the best solution resulting from an exhaustive study, but rather is presented as a point of departure for discussion and comparison of alternative suggestions which may be made.

The discussion in this memorandum is limited to some problems connected with the efficient utilization of a given frequency allocation for wide area coverage. Only a portion of the total allocation is available at any one point in the plan discussed. It is hoped that a future memorandum can be prepared dealing with the most efficient utilization of the frequency band assigned to a particular small area, i.e., methods of modulation, multiplexing, etc.

In the plan outlined above frequency discrimination is used to avoid interference between adjacent primary areas, and amplitude discrimination due to attenuation with distance is used to avoid interference between like primary frequencies in adjacent secondary areas.

Time and directivity discrimination can be used to advantage in many radio problems, but these methods do not appear to be applicable to broadcast area coverage systems. We might attempt to apply time discrimination by sending pulses from adjacent stations so timed that they do not arrive simultaneously at any one point. It will be found that this is impossible without wasting more than half the time. Since we must cover an area, antenna directivity can only change the shape of the primary station coverage. Interference is most likely around the perimeter of a coverage area, and the normal circular coverage of a non-directional antenna (horizontally) will cover the greatest area for a given perimeter.

There is an interesting speculative possibility in this field, however. In channel sample transmission systems 8000 short pulses per second suffice to carry one telephone channel. If each primary station had a highly directive beam which rotated at 8000 rps, a number of adjacent stations might be operated on the same frequency without serious interference if the instantaneous angular positions of the various beams were coordinated. Since the extra bandwidth required for the pulse system would probably be comparable with the saving due to fewer primary frequencies, and since we do not know how to build a highly directive rotating beam, this does not seem to be a very promising line of attack at the moment.

In order to lay out a system according to the plan outlined at the beginning of this section, we must know how far apart stations operating on the same frequency must be in order to obtain enough attenuation due to distance to avoid interference. With this knowledge we will be in a position to determine how many separate frequency bands will be required.

Amplitude Discrimination Due to Distance

The relative amplitude of two signals received from different transmitters is a function of the ratio of the distances of the transmitters from the receiving point. It is a complicated function involving a number of parameters and it is beyond the scope of this discussion to examine it in detail. Fig. 1 is a plot of the attenuation vs. distance for transmission between

half wave dipoles. This curve was plotted from the nomographs given by Bullington* for a frequency of 450 mc and antenna heights of 6' and 200'. Using the information from Fig. 1 we can plot a set of curves as shown in Fig. 2 which indicate the amplitude discrimination obtained as function of the ratio of the distances to each transmitter $\frac{D_2}{D_1}$, and the distance to

the nearest transmitter, D_1 . For the antenna heights chosen, the horizon just intercepts the direct line of sight at 23 miles. When D_2 is less than 23 miles the amplitude difference is about 12 db for $D_2/D_1 = 2$. As D_1 approaches 23 miles D_2 becomes greater than 23 miles and the amplitude difference becomes greater for a distance ratio of 2, reaching about 24 db when D_1 is just a line of sight path.

The curves of Fig. 2 indicate the way the amplitude discrimination due to distance varies in one specific case under idealized conditions. In practice transmission will be subject to wide variations due to atmospheric conditions and surface irregularities. Most of these variations can probably be included by reducing the values given in Fig. 2 by 20 db, although there will certainly be exceptional times and places where even greater departures will be recorded. These considerations lead to the conclusion that it is desirable that the transmission system be one which has the property of increasing the amplitude discrimination in the audio output as compared with that existing in the antenna circuit. FM and PCM are examples of transmission systems which have this property. Such systems will result in more frequent duplication of similar primary systems, smaller secondary areas, and less complicated switching circuits.

Frequency Plans

As pointed out by W. R. Young in his report to the RMA Systems Committee, the best general arrangement of frequency assignments for the minimum interference and with a minimum number of frequencies is a hexagonal layout in which each station is surrounded by six equidistant adjacent stations. The important dimensions in such a layout are shown in Fig. 3. In this figure the normalized distances to distant transmitters from the edge of the service area of a given transmitter give directly the minimum value of the distance ratio D_2/D_1 which determines the level of an interfering signal. D_2/D_1 is the ratio for a car on the parameter of a service area circle rather than one midway between adjacent stations.

* Proceedings I.R.E., October 1947.

Wide area coverage can be obtained with minimum interference with a given number of frequencies repeated according to a systematic plan. Such plans can be worked out in which the minimum value of D_2/D_1 has any of the various values indicated in Fig. 3. These values of D_2/D_1 and other possible values can be calculated from the relation derived in the appendix (12).

$$D_2/D_1 = (\sqrt{3i^2 + 2.25j^2} - 1) \quad (1)$$

In this equation i and j are positive integers, including zero, with the restriction that i and j must both be even or both must be odd for any value of D_2/D_1 . It is also shown in the appendix (11) that for any value of D_2/D_1 given by (1) the number m of primary stations required is given by

$$D_2/D_1 = \sqrt{3m} - 1 \quad (2)$$

$$m = \frac{1}{3} \left(\left[\frac{D_2}{D_1} \right]^2 + 2 \frac{D_2}{D_1} + 1 \right) \quad (3)$$

Fig. 9 is a plot of m vs. D_2/D_1 with the possible values of D_2/D_1 from (1) circled. Symmetrical plans can be constructed based on any of the circled points. In these plans each station will be surrounded by 6 stations at a distance $(D_2+1)D_1$ away, and the secondary area covered by the m stations of different frequency will be approximately, from appendix (4),

$$A_S = \frac{\sqrt{3}}{2} (D_2+D_1)^2 \quad (4)$$

Figs. 4 and 5 show examples of symmetrical coverage plans for 3, 4, 7 and 9 frequencies. These plans yield the minimum value of D_2/D_1 at six symmetrical points on the periphery of the service area. The best plans with 5, 6, and 8 frequencies will have the same minimum value as the next lower symmetrical case, but this minimum will not occur at six points, so the disturbed area will be smaller.

A study of these plans and Fig. 2 indicates that at least 4 frequencies will be required for a high quality system in which extra suppression is obtained by other than distance discrimination. Probably 9 or more frequencies will be required for systems such as straight SSB where no extra discrimination is available. A great deal of study will be required to ascertain which type of system will lead to a minimum total bandwidth with satisfactory quality.

Channel Coverage

In general, we can see from Fig. 2 that for a given required amplitude ratio the distance ratio must be increased as the service area of a primary station is made smaller. For example, if a particular system required an amplitude ratio of 26 db for channel interference plus fading and shadow effects, a distance ratio of 2.5 would be adequate with a 15 mile service radius, while a distance ratio of 3.6 would be required if the service radius is 5 miles. A distance ratio of 2.5 can be obtained with 4 primary frequencies while 7 frequencies are required for a ratio of 3.6. While these figures are only approximate, they clearly indicate the general trend. We conclude that a large primary service radius leads to a minimum number of primary frequencies.

A minimum number of primary frequencies may not be the best arrangement, however. If more than one primary band is used, means must be provided for switching the car receiver and transmitter to the various bands. Once such means are provided the difference between 4 and 7 positions may not be great, and there may be other reasons for using smaller primary areas. We desire to blanket a wide area so that all parts of the area have service. Another problem is to provide enough channels to take care of the maximum number of simultaneous calls that will be encountered in a primary area. It is obvious that a large primary area covering a large city will require a large number of channels. Therefore, the smaller the primary areas the smaller number of channels and the band required for each primary frequency. For instance, suppose 120 channels are required simultaneously in New York City. We might arrange the primary areas so that 3 of the 15 mile radius areas shared the New York traffic, but they would also extend well into New Jersey, Long Island and Westchester, and probably at least 65 channels per primary area would be required yielding a total of 260 channels. With 5 mile radius primary areas about 5 primary areas could be used to share the New York load and still take in less outside territory. In this

case 30 channels per primary area might suffice. With the 7 primary frequencies required for 5 mile radius this gives a total of 210 channels required in the basic plan. These are very crude estimates, but they indicate that the total bandwidth required for a wide area system might be smaller for a smaller primary area radius. Fig. 6 shows how 15 mile and 5 mile radius areas might be used to cover the New York area. The advantage of the 5 mile plan in concentrating the channel capacity of the primary areas is obvious.

It should be pointed out that a large primary radius such as 15 miles will require 4 or more land receivers per land transmitter due to the limited power of the car transmitters. Thus, the area of a 15 mile radius primary area is 708 square miles, and at least 5 station sites would be required, or one site per 141 square miles. The area of a 5 mile radius primary area is 78.5 miles, but in this case a single site could presumably be used for both the land receiver and transmitter. This arrangement will lead to easing some receiver selectivity problems as will be mentioned later.

It may appear that the writer is attempting to build a case for 5 mile radius primary areas. It should be emphasized that this is not the objective, and that the 5 and 15 mile radii are simply round numbers that have been used to illustrate some of the general problems associated with small and large radius systems. It is believed, however, that a number of practical considerations tend to at least partially balance the apparently overwhelming advantage of large radius systems indicated by Fig. 2.

It has already been shown that at least twice, and quite possibly considerably more than twice as many total channels will be required for uniform wide area coverage as will be required in the highly concentrated New York City area alone, if the same plan is used over the whole country. This will result in a great deal of excess capacity in most areas outside big cities. However, there are enough big cities scattered over the country so that most of the frequency space required for the N.Y. area will be required at other points. Most other services that might use this frequency space will also be concentrated in the big cities, and therefore does not seem to be too unreasonable for the telephone company to ask for the allocation of the full band for the whole country rather than on some regional basis.

Serious consideration should be given to the possibility of using the excess capacity of the mobile system in rural areas in the local plant in these areas. For fixed stations directive