Comparison of Mobile Radio Transmission at 150, 450, 900, and 3700 Mc

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Based on a series of experiments, a comparison is made of the transmission performance of 150, 450, 900, and 3700 mc in a mobile radiotelephone type of service. This comparison indicates that 450 mc is superior transmission-wise to the presently used 150-mc band in urban and suburban areas. In fact a broad optimum in performance falls in the neighborhood of 500 mc It is concluded that this range of frequencies would be well suited for providing coverage to meet the large scale needs which are anticipated in and around metropolitan areas. Although higher frequencies are less desirable, the tests indicate that 900 mc is somewhat to be favored over 150 mc from a transmission standpoint if full use is made of the possible antenna gain. Above this frequency, transmission performance falls off even assuming the maximum practical antenna gain. Transmission at 3700 mc suffers an additional impairment in that the fluctuations in received carrier level occur at an audible rate as the mobile unit moves at normal speeds. It is concluded that while transmission above roughly 1000 mc for these services is not impossible, it would be decidedly more difficult to employ these frequencies satisfactorily.

INTRODUCTION

From the beginning of mobile radiotelephone services offered by the Telephone Companies, both "general" and "private-line" types, it has been apparent that the number of channel frequencies then allocated for these uses would not be sufficient to meet the service needs in the near future.

The bulk of these needs will be for service in urban and suburban areas, where business activities are concentrated. These areas are now served on a few individual FM channels in the vicinity of 150 mc. However, a larger number of channels, needed to meet anticipated demands and to develop a more efficient system, are not to be found in the

150 mc region. This space is already allocated fully and permanently to a variety of other services. In fact, this situation extends up to about 400 mc. The larger number of channels for these services apparently will have to be found, therefore, above 400 mc.

However, it is essential to know whether these higher frequencies would be suitable for urban mobile telephone service, or whether there exists an upper limit to the suitable frequencies. In order to answer these questions, a series of tests has been made to compare the adequacy of coverage that could be provided at several representative higher frequencies. These tests were conducted in and around New York City. This location is considered to be typical of the larger metropolitan areas.

THE PROBLEM OF EVALUATION

It became apparent early in the tests that it would neither be practical nor accurate to compare service results for the different frequencies by the method of determining the coverage at the various frequencies, and then comparing these. This would have required, among other things, that "coverage" be defined precisely and then measured accurately in order to determine the differences with the desired accuracy.

Instead, it was recognized that commercial coverage is at present considered to extend into areas wherein a small percentage of the locations will have less than commercial grade of transmission. This might be ten per cent, for example. It was further recognized that, while there existed a trend of performance with frequency, comparative tests at any one location showed variations from that trend. Thus, even if transmitter powers were adjusted so as to offset the transmission effects of that trend, performance at any location would not be equal at all frequencies. But while one frequency might give relatively poor transmission in one location, it might give good transmission at another location, etc. Thus, while the locations of poor transmission were found to be different at the various frequencies, the number of such locations would be the same at all frequencies, provided the trend had been offset by adjustment of transmitter power.

Viewing the problem in this way, it was sufficient to test at enough locations in representative territory to establish this trend in a statistical manner.

Other problems in evaluating differences in suitability of different frequencies lay in how to take into account differences in practical antenna gains and differences in frequency stability. These will be discussed in the next sections.

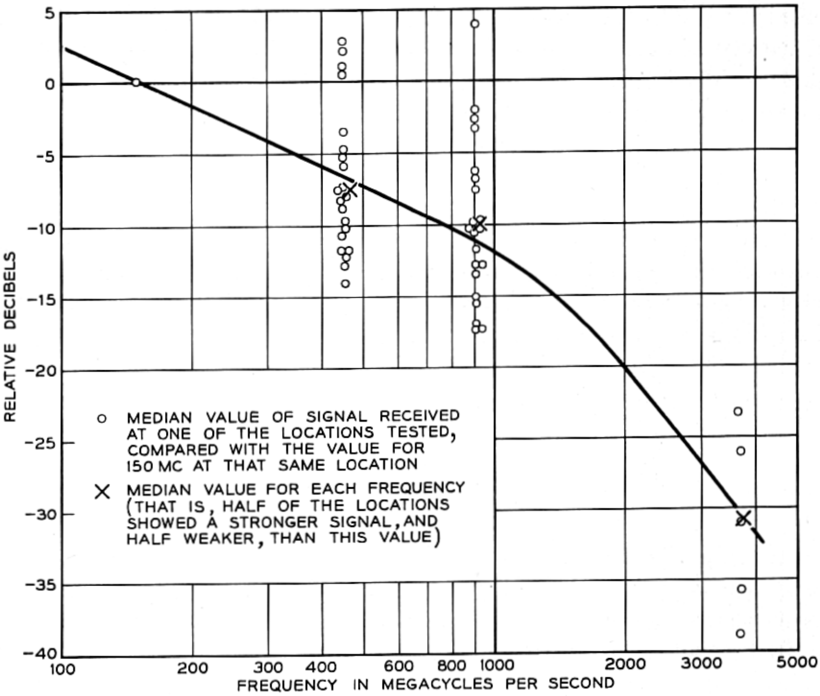

Fig. 1—Median values of received signal power at suburban locations. (Assumes the same power at all frequencies radiated from a dipole and received on a quarter-wave whip.)

OVER-ALL RESULTS

The results of many measurements of path loss between a land radio transmitter and a mobile receiver establish a trend of loss increasing with frequency. This is illustrated in Fig. 1 by the "crosses" which show the strengths of the received signal at higher frequencies as compared with those at 150 mc. The derivation of the values given by the crosses will be discussed in a later section. In the other direction of transmission it appears justified, based upon reciprocal relationships, to assume that path losses from mobile transmitter to land receiver will follow the same trend.

However, although the received signal is seen to decrease with frequency, the amount of received signal which is required to produce satisfactory communication also changes with frequency. The median level of signal required at a mobile or land receiver at various frequencies to override RF noise is given in Fig. 2. The dots here represent the average of many measurements.

Transmitter power required to achieve the same service result at various frequencies has been derived by taking into account the changes of path loss with frequency and also the changes of signal required with frequency. Fig. 3 shows the amounts of power that are required in order to achieve the same coverage in all cases as is now obtained at 150 mc with 250 watts of land transmitter power radiated from a dipole. As shown, the use of an antenna having gain can appreciably lower the land transmitter power that is required. The mobile transmitter power is much less than required of a land transmitter due to the assumption that there are six land receivers located appropriately in the coverage area, rather than just one.

It is apparent from Fig. 3 that the required transmitter power is a minimum in both directions of transmission at around 500 mc. It is also apparent that above this point the required transmitter power increases rapidly with frequency.

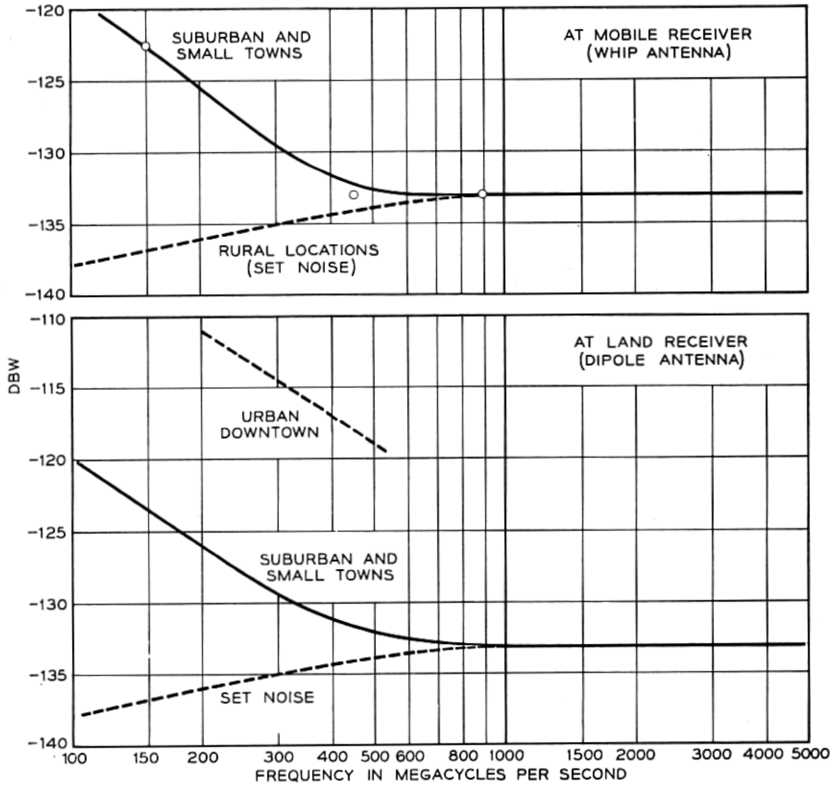

Fig. 2—Median value of signal required to over-ride noise.

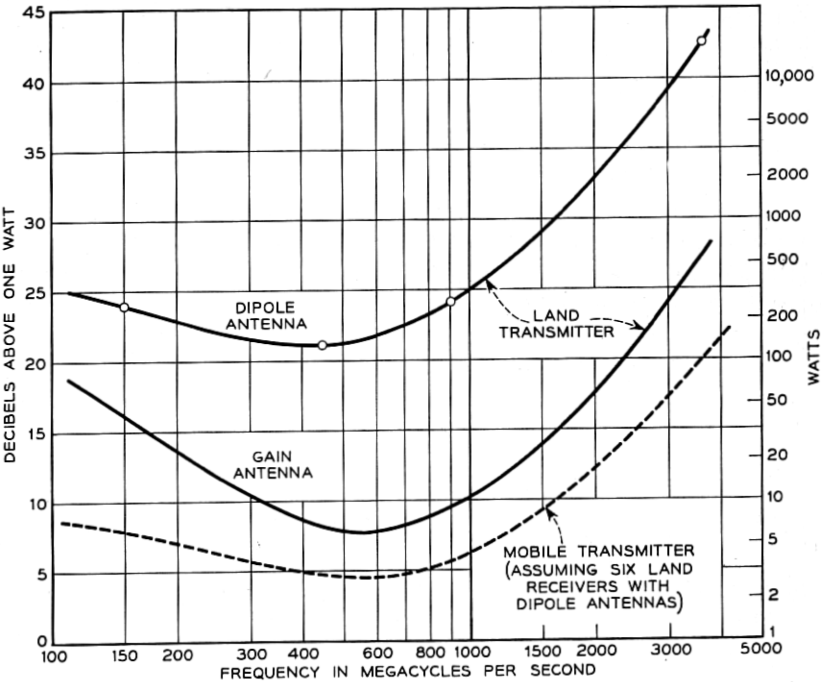

Fig. 3—Transmitter power at antenna input required for urban and suburban coverage. (Mobile antennas are assumed to be quarter-wave ships.)

A word of explanation is needed at this point about the gain antennas which were assumed in one of the curves of Fig. 3. These are antennas which tend to concentrate radiation toward the horizon in all directions. Limits for the amount of gain were based upon the considerations (1) that a set of radiating elements greater than about 50 feet in extent would be impractical to build for this service, and (2) that the vertical width of the beam should not be less than about 2 degrees in order that valleys and hilltops will be covered. The amounts of gain possible within these limits are as follows:

Frequency mc.	Gain-db
150	8
450	13
900	15
3700	15

The mobile antennas were assumed to be quarter-wave whips or the equivalent.

Use of gain antennas for the land receivers would result in still further lowering the required mobile transmitter power. This is not shown on Fig. 3 because the amount of reduction cannot be accurately stated on the basis of present knowledge. It appears certain that the reduction will be at least equal to the antenna gain, and may be appreciably more than this, as indicated later.

The system modulation and pass-band were assumed in the above discussion to be the same at all frequencies. This would not be realistic if the tolerance allowed for frequency instability were a fixed percentage of operating frequency. It may be justified, however, because the necessity for frequency economy and for best transmission performance demands better percentage stability at higher frequencies.

A spot check of transmission, observing circuit merits by listening, has been made to determine the validity of the above results in a very general way. Land transmitter powers were adjusted so that the equivalent dipole power at 450 mc was 3 db less than at 150, and power at 900 mc was 1 db less than at 150 mc. This approximates the powers shown on the "dipole" curve of Fig. 3. The map of Fig. 4 shows the results of this test. While the comparison of circuit merits generally shows a preferred frequency at any given location, the performance appears to be about equal when all locations are considered.

TEST EQUIPMENT ARRANGEMENTS

Tests of transmission outward from the land transmitting station were made on signals radiated from antennas on the roof of the Long Lines Building, 32 Avenue of the Americas, New York City. These antennas were 450 feet above ground. One of the existing Mobile Service transmitters served for the 150-mc tests. Special experimental transmitters were set up for the 450, 900, and 3700-mc tests. All were capable of frequency modulation.

The mobile unit was a station wagon equipped to receive and measur- signals at the various frequencies. The receiving equipment was arranged for rapid conversion from 150 to 450 to 900 mc. The bandwidth (about 50 kc) and system modulation (±10 kc) were identical at all three frequencies (equal to the existing standards at 150 mc). The 3700-mc tests were handled separately. It was not possible to employ the same bandwidth and deviation, but this does not invalidate the comparison of signal propagation at the various frequencies.

A most useful tool in making these measurements was a device known as a "Level Distribution Recorder", or simply "LDR". This was built

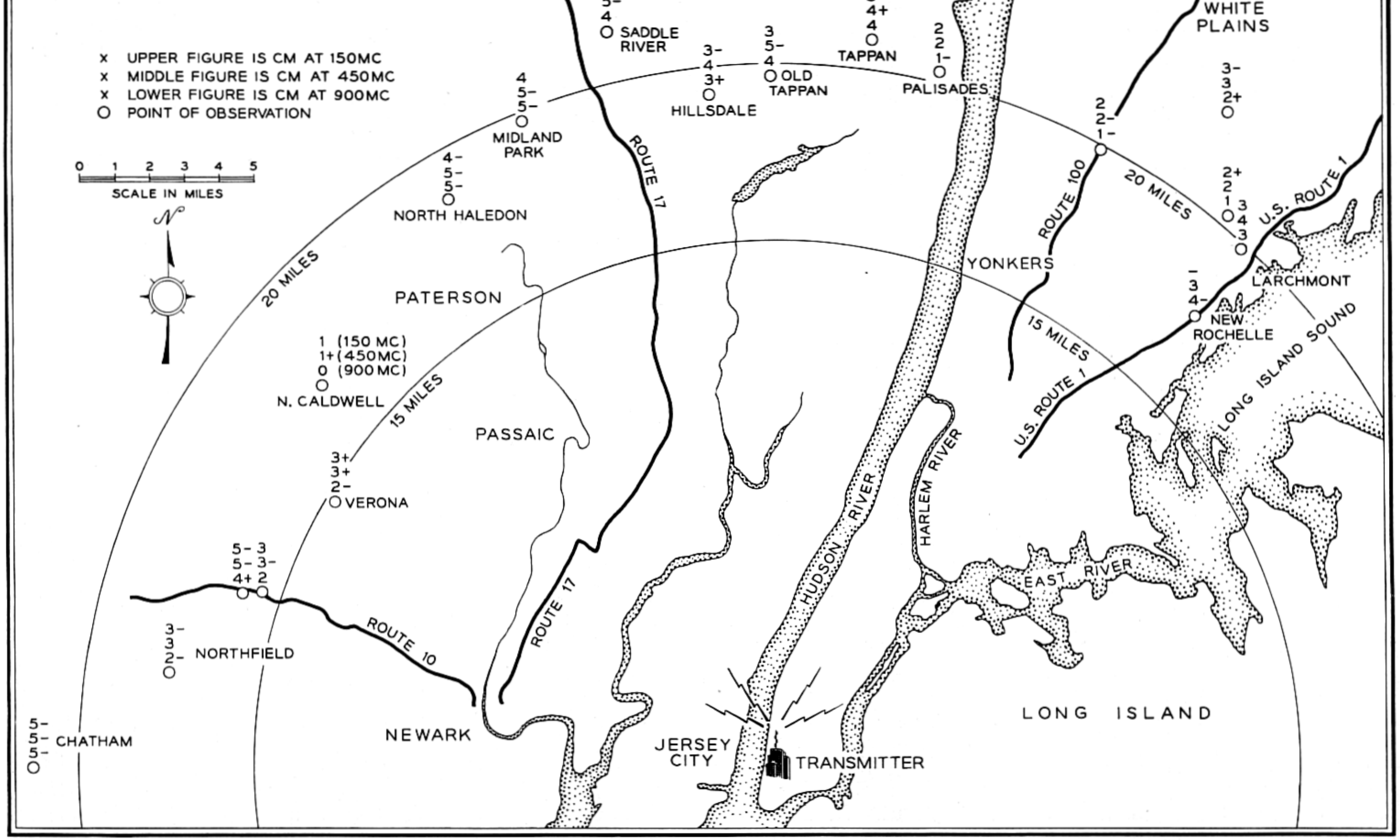

Fig. 4—Circuit merit observations in New York suburbs. Radiated transmitter power was as follows: At 150 mc, 250 watts to a dipole; at 450 mc, the equivalent of 125 watts to a dipole; and at 900 mc, the equivalent of 200 watts to a dipole. Circuit merit grades are as follows: 0—Undetectable; 1—Hopeless, signal unintelligible; 2—Poor, signal understood with much repetition; 3—Fair (commercial); 4—Good, impairment noticeable but not objectionable; and 5—Excellent, no discernible impairment.

especially for these tests and is similar to its forerunners which have been used in the past for measuring atmospheric static noise. The LDR, in combination with a calibrated radio receiver, is capable of taking as many as twenty instantaneous samples of radio signal strength per second, sorting the samples by amplitude, and rendering information on a "batch" of samples from which a statistical distribution curve can be plotted. The LDR was also used for measuring the statistical distribution of audio noise in the output of the radio receiver. The LDR was, in this case, associated with a special converter whose characteristics resemble those of a 2B noise measuring set.

No arrangements were made for measuring radio propagation from mobile unit to a land receiver. It was felt that the comparison by frequencies would be substantially the same as in the outward direction of transmission. It does not follow, however, that the background electrical noise, against which an r-f signal must compete, will be the same at mobile and land receivers. Strength of r-f signal required at land receivers for satisfactory transmission was measured at several typical locations.

RECEIVED R-F SIGNAL STRENGTHS AND PATH LOSSES

The first factor in evaluating mobile radio transmission is the strength of the r-f signal which is received. This is inversely related to the loss in the r-f path. The mobile units of a mobile system are either moving around or, if stationary, are located at random. Since the effects of the many geographical features, buildings, and the like, which influence propagation can combine differently for different locations of a car, even where the locations are only a fraction of a wavelength apart, the only meaningful measure of signal strength is a statistical one. Such statistical answers were obtained by making and recording many instantaneous samples of field strength with the aid of the LDR, mentioned above.

It is of interest to note that whenever the sample measurements were confined to a relatively small area, say 500 to 1000 feet or less in extent, the amplitude distribution of these samples tended strongly to follow along the particular curve known as a Rayleigh distribution. Such a curve and a typical set of experimental points are shown in Fig. 5. The same distribution was obtained at all of the frequencies tested, including 3700 mc. The rapidity of signal fluctuation, as the car moved, was proportional to frequency, but this does not affect amplitude distribution. Such a distribution could have been predicted if it had been postulated that the transmitted signal reached the car antenna by many paths having a random loss and phase relationship. It is thus inferred that in general the signal reaches a car by many simultaneous paths.

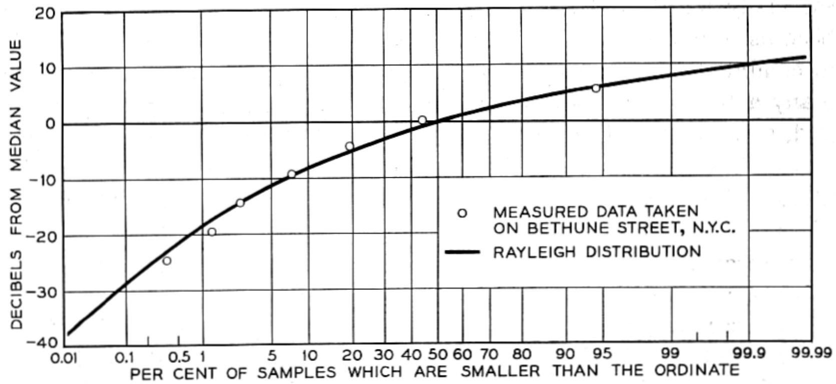

Fig. 5—Typical distribution of test samples of r-f signal strength taken over a small area.

With the shape of the distribution known, only one other value need be given in order to specify the propagation to such a small area. This might be the median, the average, the rms, or any single point on the curve. The one used most often here is the median, that is, the value which is larger than 50 per cent of the samples and smaller than the other 50 per cent. Measurement of the median value by this statistical method was found to be accurately reproducible, and therefore is presumed to be reliable. Successive batches of 200 samples each, all covering the same test area, yielded median values which differed not more than 0.5 db when none of the conditions changed; i.e., transmitter power, antenna gain, and receiver calibration remained the same. This accuracy may seem surprising when it is realized that individual samples differ frequently by 10 db, and often as much as 30 to 40 db.

It was presumed at the outset of the tests that the different frequencies would exhibit different propagation trends with distance. For this reason the samples have been grouped by distance. In presenting these results, it was convenient to express the measurements of received RF signal in terms of path losses. By this it is meant the loss between the input to a dipole antenna at the transmitter and the output of a whip antenna on the test car. These path losses will have, of course, the same distribution as the received r-f signal.

The results of the path loss measurements are given in Figs. 6, 7, and 8 for 150, 450, and 900 mc respectively. These values represent the loss between the input to a half-wave dipole antenna at one end of the path and the output of a quarter-wave whip at the other end. They are shown here as a function of distance from the land station. For distances under ten miles the data are the result of tests in Manhattan and the Bronx. For each distance a test course was laid out approximately following a circle with that distance as a radius. The data for ten miles and greater distances were obtained on two series of tests along radials from the land transmitter, one of which followed Route 1 through New Rochelle, N. Y., and the other followed Route 10 toward Dover, N. J. For reference, a curve has been given on each of these figures which shows the computed loss based upon the assumption of smooth earth.

A curve labeled "1 per cent" means that in one per cent of the sample measurements the loss was less than that indicated on the ordinate. The meaning of the labels on the other curves is similar. The curve labeled "50 per cent" is, of course, the median.

It will be apparent that the assumption of smooth earth is not applicable to the area tested. The data for median losses are in the order of 30 db greater than the value computed over smooth earth. This additional loss may be thought of as a "shadow" loss arising from the presence of many buildings and structures.

The distribution of losses given in these three curves is wider than the Rayleigh distribution of Fig. 5. This is because the data for each

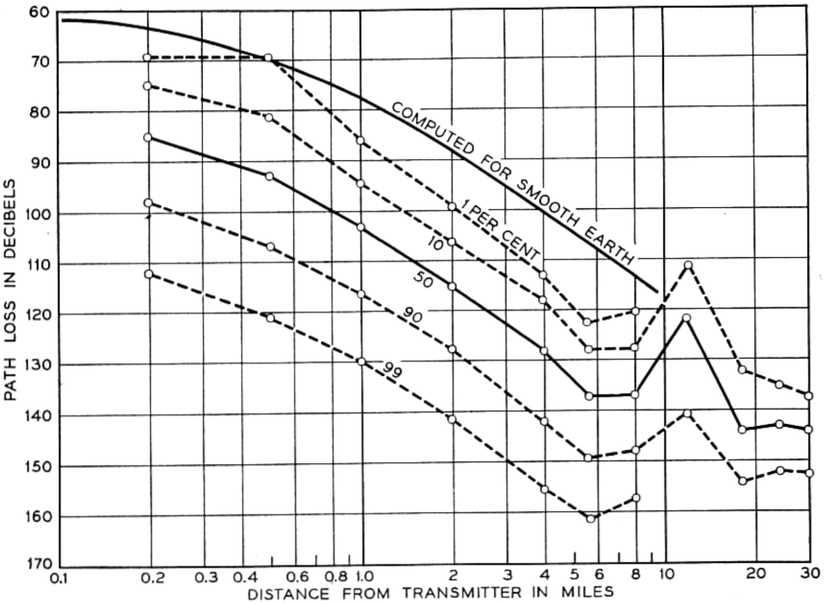

Fig. 6—Measured path loss at 150 mc in Manhattan and the Bronx and suburbs. (Note: Data for 10 miles and greater were taken on Route 1 toward New Rochelle and on Route 10 toward Dover.)

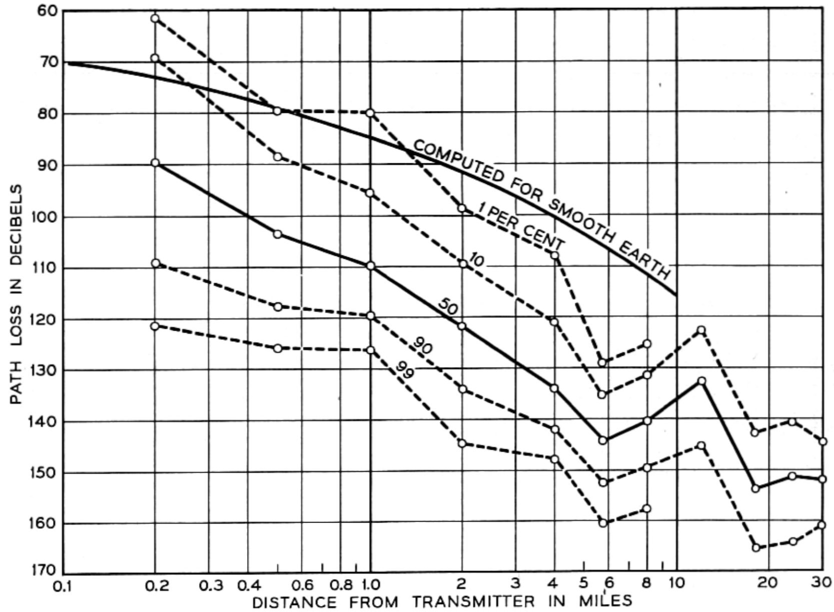

Fig. 7—Measured path loss at 450 mc in Manhattan and the Bronx and suburbs. (Note: Data for 10 miles and greater were taken on Route 1 toward New Rochelle and on Route 10 toward Dover.)

distance are a summation over many different locations rather than a set of samples covering one location.

The data for ten miles and further from the transmitter were taken on routes through suburban areas. The losses at twelve miles appear to be less than the average trend indicated by the curves. This is because data taken at the top of the First Orange Mountain weigh heavily at this distance. It is of interest to note that the losses at distances of ten miles and over are 6 to 10 db less than might have been predicted from the trend at smaller distances, where the measurements were made in city areas. This probably reflects the fact that there is a considerable difference in the character of the surroundings, such as height and number of buildings in the suburban territory as compared with the city itself.

The median curves of loss have been replotted for three frequencies on Fig. 9. This permits a better comparison with frequency. Except very close to the transmitter, the performance at the various frequencies seems to differ by an essentially constant number of db, while exhibiting the same trend with distance. The similarity between frequencies is apparently much greater than the similarity between the median value and the value computed over smooth earth for any given frequency.

It was not possible to get complete enough data to plot a curve for 3700 mc similar to the ones mentioned above. The test setup at this frequency was limited by transmitter power and receiver sensitivity. Only those locations for which path loss was relatively low could be tested. A comparison of results at these locations is given in Figure 10. The curves labeled "1 mi.", "2 mi.", and "4 mi." for Manhattan are the median values obtained along test routes which followed circles of 1, 2 and 4 miles radius from the transmitters. The other curves refer to selected small areas at greater distances on the Hutchison River Parkway and New Jersey Route 10, as indicated. Although the data at 3700 mc not extensive, the trend with frequency seems clear.

More specific data for path losses measured along the routes toward Dover and New Rochelle are given in Fig. 11. Each value plotted here is the median of about 200 samples taken in a small area at the distance indicated. The strong effect of the First and Second Orange mountains at fourteen and sixteen miles on the Dover route is of interest.

The coverage desired in these mobile telephone systems extends into suburban locations. It follows that a comparison of coverage by the

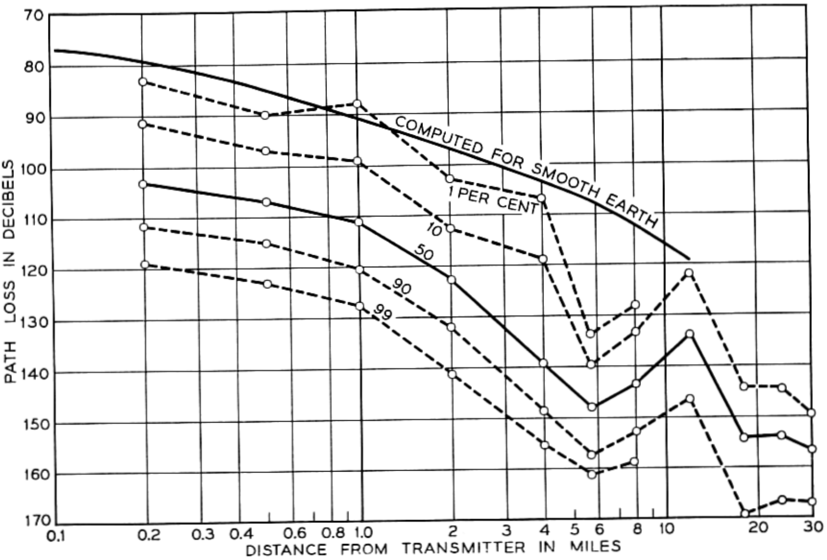

Fig. 8—Measured path loss at 900 mc in Manhattan and the Bronx and suburbs. (Note: Data for 10 miles and greater were taken on Route 1 toward New Rochelle and on Route 10 toward Dover.)

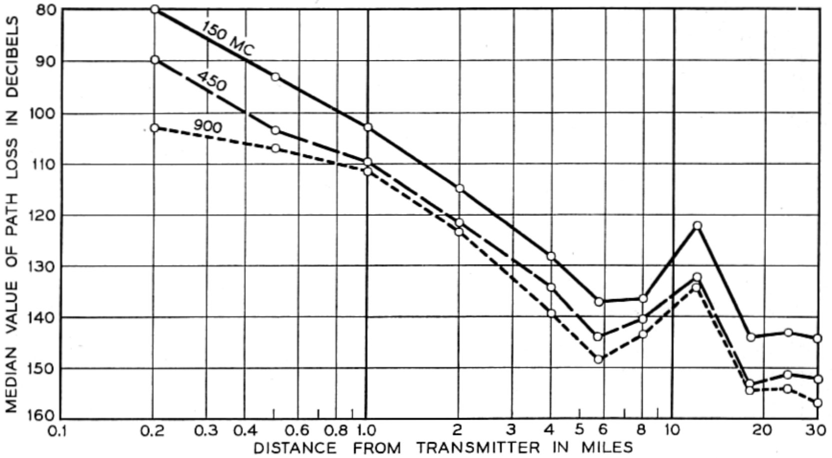

Fig. 9—Median values of measured path losses. (Note: Data for 10 miles and greater were taken on Route 1 toward New Rochelle and on Route 10 toward Dover.)

various frequencies should be based upon measurements taken in the suburbs. The data from the New Rochelle and Dover series have been used as a basis for the points and the curve given in Figure 1. Each of the circle points shows the path loss at a given frequency relative to that at 150 mc for a particular location. Their spread indicates that the

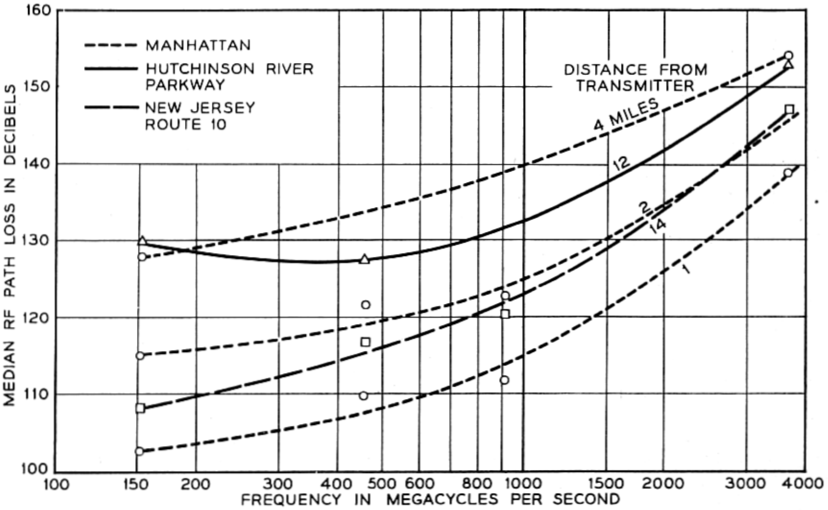

Fig. 10—RF path losses at locations for which 3700 mc measurements were made.

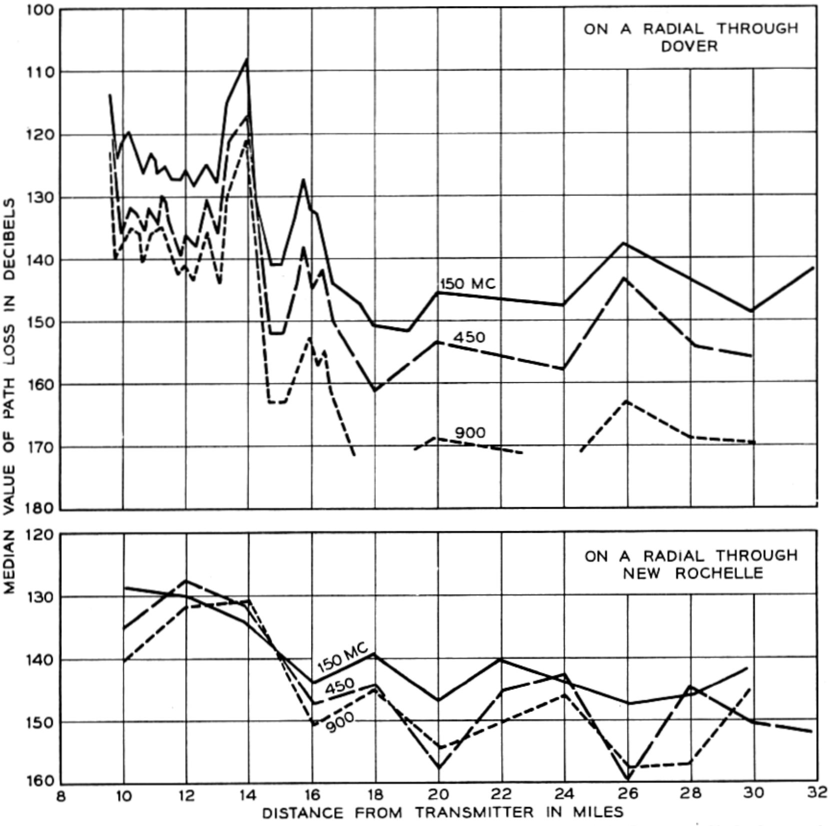

Fig. 11—Median r-f path losses along selected routes. (a) On a radial through Dover. (b) On a radial through New Rochelle.

comparison of frequencies is different at different locations. The "crosses" are the median values of these points, so placed that there are as many points above as below. The points for 3700 mc are taken from the data of Fig. 10. The crosses of Fig. 1 are considered to be the most reliable all-around comparison of propagation at the different frequencies.

RELATION OF SPEECH-NOISE RATIOS TO R-F SIGNAL POWER

Speech-to-noise ratios were measured at all of the test locations by the use of the level distribution recorder as described earlier. During the course of any given test the audio noise from the receiver varied considerably and these variations were recorded on the LDR. It was found by correlation between subjective observations of circuit merit and the median value of noise that the latter is equivalent in noise effect to a steady random noise of the same value. In the FM receiver, the level of speech is essentially not affected by the strength of RF signal and so a measurement of the output noise is directly related to the speech-to-noise ratio. The speech-to-noise ratios given here are computed from noise measurements by assuming that speech of −14 vu level is applied to the system at a point where one milliwatt of 1,000 cycles tone would produce a 10-kc frequency deviation. The strength of the speech signal at the receiver output is expressed in the same units as are used for the noise.

As might have been expected the median speech-to-noise ratios correlate strongly with the amounts of r-f signal received at the various locations. This correlation has been evaluated in order that the most likely relationship between speech-to-noise ratio and received r-f signal may be known for the different frequencies. These are shown in Fig. 12, where each circle represents the median speech-to-noise value measured at one test location plotted against the median r-f signal received at that location. The solid lines have been drawn in to show the trend. The bending at the top of the curve is inconsequential. It only represents the limit imposed in the test setup by tube microphonic noise, vibrator noise, etc. The curves show, for example, that in order to produce a commercial grade of transmission, which requires a 12 db speech-to-noise ratio, the median r-f signal must be 122.5 db below one watt at 150 mc.

The data given in Fig. 12 pertain only to the suburban locations. Measurements in Manhattan have not been included, even though they indicate that larger signals are required, because the limit of system coverage is to be found in the suburbs. The data on the solid curves of Fig. 12 have been used to derive the curve of Fig. 2 which plots the value of r-f signal required at the mobile receiver for a commercial grade of transmission. The dotted curve of Fig. 2, which shows the median signal required in locations where noise picked up by the antenna is less than set noise, is based on the assumption of an 8 db noise figure for a practical 150-mc receiver, 11 db at 450 mc, and 12 db at 900 mc and higher.

Measurements have been made of the effect of noise picked up by the antenna at land receiver stations. These are expressed here in terms of the carrier strength required for just-commercial grade of transmission (12 db speech-to-noise ratio) as compared with the value required when there is no antenna noise and only receiver noise is present. These comparison measurements were made by injecting a steady carrier into the receiver with an antenna connected normally, and again with a dummy antenna connected. Although these tests were made with a steady rather

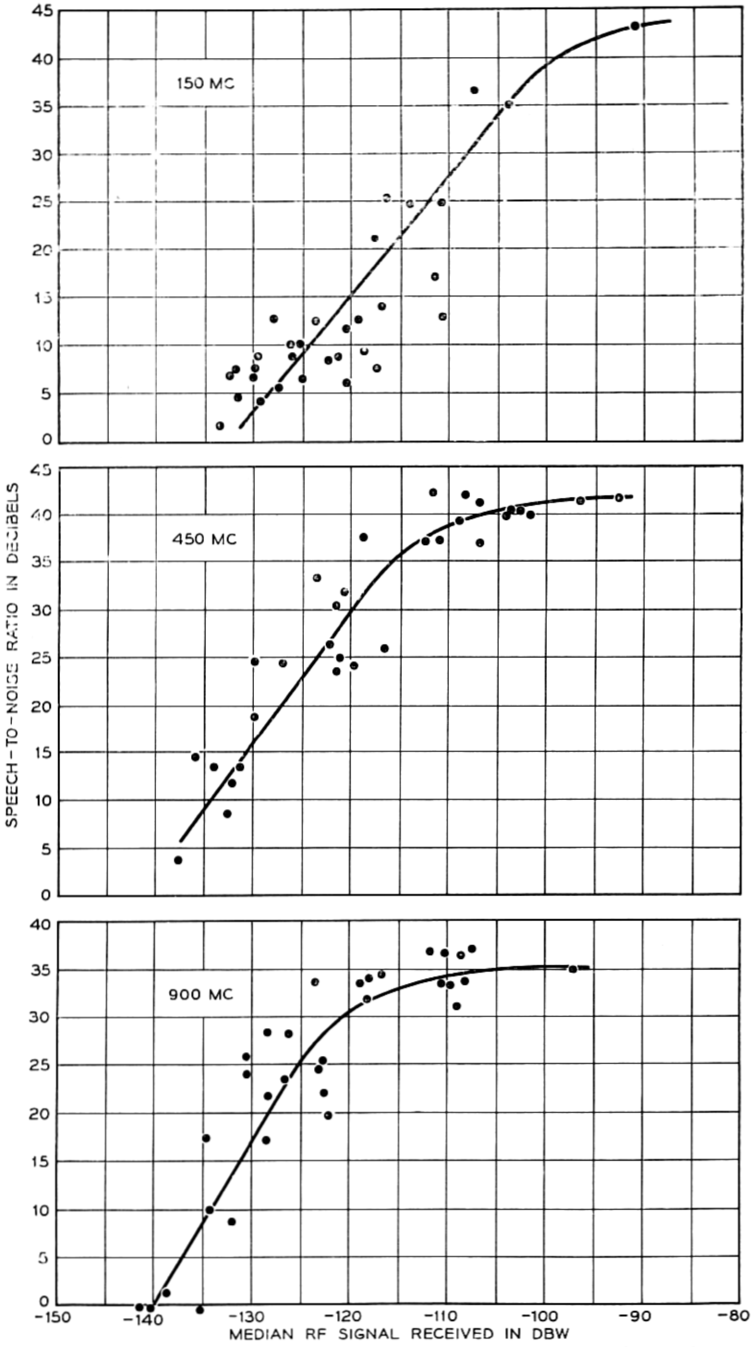

Fig. 12—Correlation between median values of speech-to-noise ratio and r-f signal strength in suburban locations. (Note: Each point represents the speech-to-noise ratio and the r-f signal received at one location. (a) 150 mc. (b) 450 mc. (c) 900 mc.

than randomly varying signal, it is felt that the comparative results will apply to the random signal case as well.

Tests were made at 150, 450 and 900 mc, at four locations of interest, and with dipole and 7 db gain antennas. Not all combinations were tested, but enough to permit some interesting comparisons. The locations tested were as follows:

A: On the Long Lines building, a 27-story building in downtown Manhattan.

B: On the Graybar-Varick building, a 16-story building in downtown Manhattan.

C: On the telephone building which houses the Melrose exchange, a 7-story building in the center of the Bronx.

D: On the 3-story telephone exchange building in Lynbrook, Long Island.

Table I describes the generally prevailing noise situation at these locations. Higher noise was encountered occasionally at some of the sites, due in at least one case to operation of elevators in the building. However, these occasions were so brief and infrequent that the general background of noise is considered to be a better value to use in estimating systems performance.

The trend toward lower site noise at higher frequencies, already noted for mobile installations, is seen to apply to land receivers as well.

TABLE I—R-F SIGNAL INPUT TO RECEIVER FOR 12 DB SPEECH-TO-NOISE RATIO (GIVEN IN DB ABOVE THAT NEEDED TO OVERRIDE SET NOISE*)

Station	Frequency	Antenna	
		Dipole	7-db Gain
A	150 mc	10	—
	450	1	0.5
	900	—	1.5
B	150	12	—
	450	4	—
	900	0	—
C	150	11	2.5
	450	1	1
	900	1	—
D	150	5	4
	450	0	0
	900	0	—

* Noise figures in the test receivers were 9, 12 and 12 db for 150, 450, and 900 mc, respectively.

These data bring out another interesting and significant fact. Where noise collected by a dipole antenna is discernible over set noise, the noise collected by the 7 db gain antenna at the same site is, surprisingly, less. This means that the gain antenna picks up *less* noise power than a dipole. Since it picks up 7 db more signal from a distant car, a gain antenna thus provides a double improvement in transmission at those sites for which ambient noise is controlling.

An explanation of this behavior may be surmised if it is assumed that the sources of noise are numerous and are scattered around at street level (motor vehicles, mostly). The overall noise received is a sum of contributions from all sources, weighted for distance and the receiving antenna pattern. A gain antenna of the type considered here tends to ignore the strong nearby noise sources because they are below the antenna beam. The sources, which are nearly enough in the beam to count, are also further away and are attenuated by distance.

The amount of data given in Table I does not seem sufficient to warrant stating a firm figure as to the amount of improvement obtainable from a gain antenna. However, substantial improvement at 150 mc is indicated, and this might have the effect of bringing the value of mobile transmitter power required at 150 mc down to the value required at 450 mc, assuming gain antennas in both cases.

ACKNOWLEDGMENTS

A number of people participated at one time or another in setting up and carrying through these tests. It is not possible to name them all, but the principal participants were R. L. Robbins, R. C. Shaw, W. Strack, D. K. White, and F. J. Henneberg. The program was supervised by D. Mitchell. The special radio equipment required was designed and furnished by W. E. Reichle and his group.