Radio Transmission into Buildings at 35 and 150 mc

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Investigations of radio propagation at 35 and 150 mc into large city buildings have disclosed that, on the average, a loss in the order of 20 to 25 db may be encountered on the first floor. This loss, which represents the reduction from the median field in the city streets at the same distance from the transmitter, is known as building loss. Losses were found to be slightly smaller and more uniform at 150 mc than at 35 mc. Losses also were found to be appreciably less on higher floors in a building.

Methods of using this information for engineering radio systems to serve people in buildings are described. Some sample problems demonstrate that, with equal receiver performance, the effective coverage range in buildings for a 150-mc system will be greater than that for a 35-mc system.

I. INTRODUCTION

1.1 *Background*

With the advent of mobile telephone service has come a considerable fund of information concerning the nature of VHF radio propagation in city and suburban streets.[1]

Plans are now being made to extend the use of the mobile land transmitters to provide one-way personal radio signaling services. In these services, the transmitter signals will be detected by small pocket-carried receivers issued to subscribers. Coverage will be desired not only in the streets but also in the various buildings and other structures which subscribers might normally be expected to frequent.

The extent of useful coverage from a mobile land transmitter will be somewhat less for personal signaling than it is for mobile voice transmission. This is primarily due to two factors: (1) the inherently poorer sensitivity of a pocket-carried receiver due to its small antenna and (2) the increase in path loss to a location inside a building in comparison with that to an outside location at the same distance from the transmitter. To offset this reduction in coverage, satellite transmitters will be required in large metropolitan areas to assure that reliable service is offered throughout. For a signaling system in which the receiver sensitivity is known, the spacing of the transmitters is largely a function of path loss.

Estimates of path loss can be made using the results of the measurements made by W. R. Young, Jr.,[1] if the additional losses in propagation caused by buildings are known.

1.2 *Scope of Study*

The losses encountered in propagating an RF field into a building were measured at eleven different locations in downtown New York City. Two of the mobile telephone channels, one in the 35-mc highway band and the other in the 150-mc urban band, were chosen for these measurements.

Most of the field-strength measurements were taken at various points on the main floor of each building. This was done because the first floor has been found to be the most difficult portion of a building to cover. The number of measurements taken varied from building to building, depending on the amount of floor space and the complexity of the floor plan.

A number of measurements at each of the two frequencies were also made in the streets adjacent to each of the buildings. For a given distance from the transmitter, the difference between the *median* field intensity in the *streets* and the field intensity at a location on the main floor of a building is defined as the *building loss* for that location. Thus, building loss is a factor which can be applied to the field intensity in the streets to assist in the prediction of the performance of a radio service in buildings.

II. OBSERVATIONS

The heterogeneous nature of the environment — both inside and outside the buildings — has been found to create extensive and erratic space variations in the RF field; accordingly, the measurements of building loss are presented statistically. The fields in the upper stories of buildings were generally found to be stronger than those near street level. Therefore, measurements made on the main floor of a building would give limiting values of building loss.

An approximate relationship between the architectural characteristics of a building — e.g., the height of the ceilings or the area of external glass — appeared to exist in certain cases.

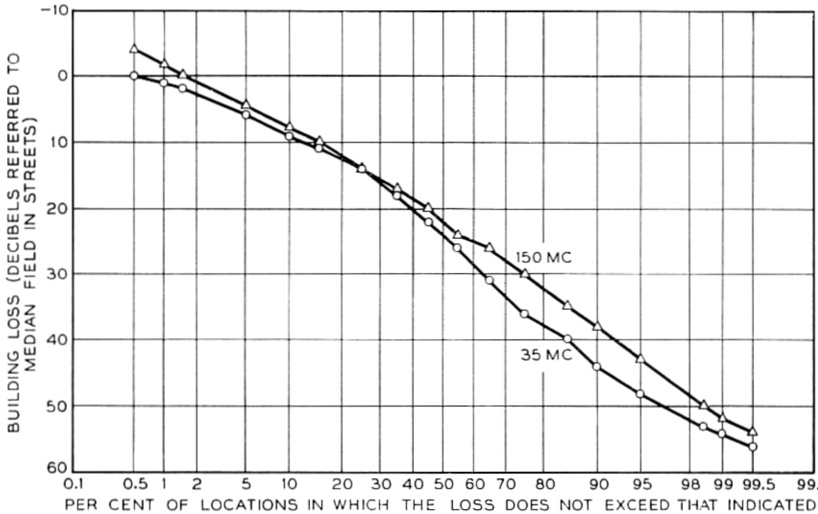

Fig. 1 — Over-all distribution of building losses at 35 and 150 mc.

The building losses at 35 and 150 mc tended to follow a log-normal distribution (see Fig. 1). At 35 mc, the over-all average building loss was found to be about 24 db; at 150 mc, it was found to be about 22 db.

Variations in signal at the lower frequency were found to be slightly greater than at the higher. Thus, the standard deviation of the building losses was found to be about 14 db at 35 mc and about 12 db at 150 mc. These variations are reversed from signal variations in the city streets, where the standard deviation of the field distributions appears to be about 7 db at 35 mc and 9 db at 150 mc.

A comparison of the useful ranges* in New York City, from transmitters of equal power to receivers of equal sensitivity, in terms of field strength in microvolts per meter, shows that the expected range of coverage into buildings is somewhat greater at 150 mc than at 35 mc. Expected ranges into buildings of almost one mile at 35 mc and almost one and one-half miles at 150 mc appear reasonable between a 250-watt transmitter and a pocket-carried signaling receiver with a sensitivity of 30 db greater than one microvolt per meter. In contrast, the useful range in city streets was found to be greater at 35 mc than at 150 mc. Service could be provided in streets over a radius of about eight miles at 35 mc and four to five miles at 150 mc.

* Useful range is defined as the distance at which there is a certain specified probability, such as 99 per cent, of successful signaling.

III. DISCUSSION OF RESULTS

3.1 *Nature of RF Field in Buildings*

It became apparent as the RF field intensities were being measured that their geometry was exceedingly complex. Variations sometimes as great as 20 db were encountered between locations a few feet apart. Since it was apparent that a point-by-point display of the field intensities would be neither useful nor meaningful, a statistical analysis of these data has been carried out to emphasize their trends.

The wide variations in field intensity can be attributed to the nature of the physical surroundings. The RF field may enter the building directly from the transmitting antenna or may be bounced in off the many reflecting surfaces presented by the surrounding buildings. Once inside, the field encounters a heterogeneous array of objects, such as walls, ceilings, floors, furniture and equipment of many kinds. Such items present lossy, shielding or reflecting media to the RF field. As a result, the field not only encounters varying degrees of attenuation in reaching a specific location, but it also arrives over a multiplicity of paths with random phase and random polarization.

Spot checks of polarization have been made by comparing the field measured at several points in a building with the antenna oriented vertically and horizontally. Differences of 10 db or more were found between the vertical and horizontal components of the field when compared on a point-by-point basis. However, when the median of the vertical components, measured at several locations, was compared with

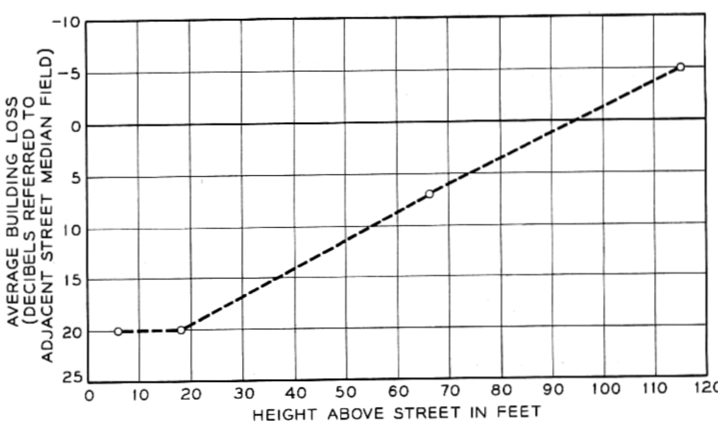

Fig. 2 — Average building loss at 150 mc on various floors in a building (463 West Street, New York City).

the median of the horizontal components, the difference was found to be negligible. This points to the interesting possibility that an omnidirectional and nonpolarized antenna might be best for reception in buildings.

Some preliminary measurements were made on various floors in a couple of buildings to determine what effect the height in a building might have on the field strength. It was found that the interference caused by adjacent structures diminished with increasing height so that the RF field was commensurately stronger on the upper floors (see Fig. 2). Therefore, it was felt that concentration could be made on the first floors with confidence that, if an adequate radio field for a system existed there, coverage in the rest of the building would be generally assured.

All the buildings surveyed were constructed of reinforced concrete or brick. Some had large window areas on the first floor. Some had large open corridors and vestibules with high ceilings. Others were more confined, with smaller external apertures on the first floor. These characteristics probably had a tendency to affect the field intensity inside the building.

A thumbnail description of characteristics which might affect propagation into each of the buildings is given in Table I, with arbitrary building identification numbers being used.

TABLE I — LOCATION AND ARCHITECTURAL CHARACTERISTICS OF BUILDINGS

Building Number	Location	First Floor Characteristics
1	463 West Street	Low ceiling height, below average window area, many halls and partitions
2	Broadway and Bowling Green	High ceilings, average window area, very thick walls
3	140 West Street	High ceilings, above average window area
4	1 Peck Slip	High ceilings, large window area, large unobstructed areas
5	130 East Broadway	High ceilings, average window area, large unobstructed areas
6	395 Hudson Street	Warehouse type building, medium ceiling height, small window area
7	432 East 14th Street	High ceilings, large window area, large unobstructed open areas
8	40 Irving Place	High ceilings, average window area, many halls
9	26 Cortlandt Street	High ceilings, large window area, large unobstructed areas
10	195 Broadway	Very high ceilings, large window area
11	220 Church Street	Medium ceiling height and window area

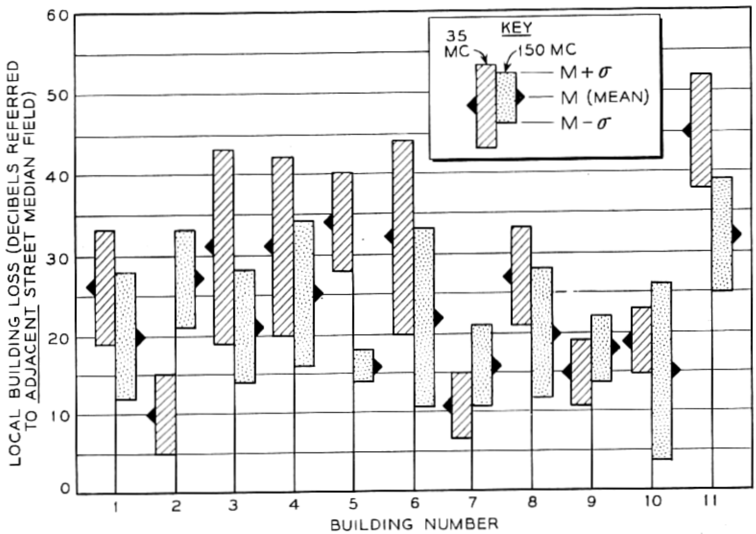

Fig. 3 — Distribution of local building losses at 35 and 150 mc for eleven buildings.

It was found that, in certain cases, a qualitative prediction might be made concerning the lossiness of a building based on the architectural characteristics just cited. For example, it may be seen from Fig. 3 that buildings 7, 9 and 10 were all found to have mean *local building losses** below 20 db at both 35 mc and 150 mc. These three buildings all had high ceilings, large windows and large unobstructed areas on their main floors. Conversely, building 11, the only one found to have an average loss exceeding 30 db at both frequencies, has lower ceilings, smaller window area and an abundance of furniture.

However, such guesses as these must necessarily be considered inconclusive because other buildings have loss effects which appear to be in direct contradiction with this hypothesis. Building 4 is an example. This building was found to present a high loss at both frequencies. Yet it is characterized in the table as being a building in which the losses might be expected to be low.

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* Local building loss, distinct from the building loss defined on page 198, is defined as the difference between the median RF field in the streets *adjacent* to the individual building and the field intensity at a location on the main floor of the building. Building loss is a concept useful for the estimation of service range. Local building loss is a concept useful in evaluating the coverage of an individual building. As will be shown, the local building losses for all buildings measured together with the known variations in path losses into the streets have been combined to provide an estimate of the over-all *building loss*.

3.2 *Local Building Losses*

The local building losses at 150 mc were found to be somewhat lower than those at 35 mc. The average of these losses in the buildings ranged from 15 to 32 db at 150 mc, while at 35 mc the average ranged from 10 to 45 db. The over-all average of the local losses for the 11 buildings was found to be about 20 db at 150 mc and 25 db at 35 mc.

The distribution of the measurements at both frequencies was found to be roughly log-normal. The standard deviation in the various buildings ranged from 2 to 11 db at 150 mc and from 4 to 12 db at 35 mc. The combined standard deviation for the 11 buildings was found to be about 9 db at 150 mc and 14 db at 35 mc. Medians and standard deviations for the individual buildings are presented in Fig. 3. The distributions of local loss for the group as a whole are shown in Figs. 4 and 5.

3.3 *Determination of Building Loss*

In the preceding section, the discussion has been confined to the local building loss — referred to the median field around the particular building in question. However, a person who wishes to estimate the limiting range at which a given transmitter will propagate a field of a certain

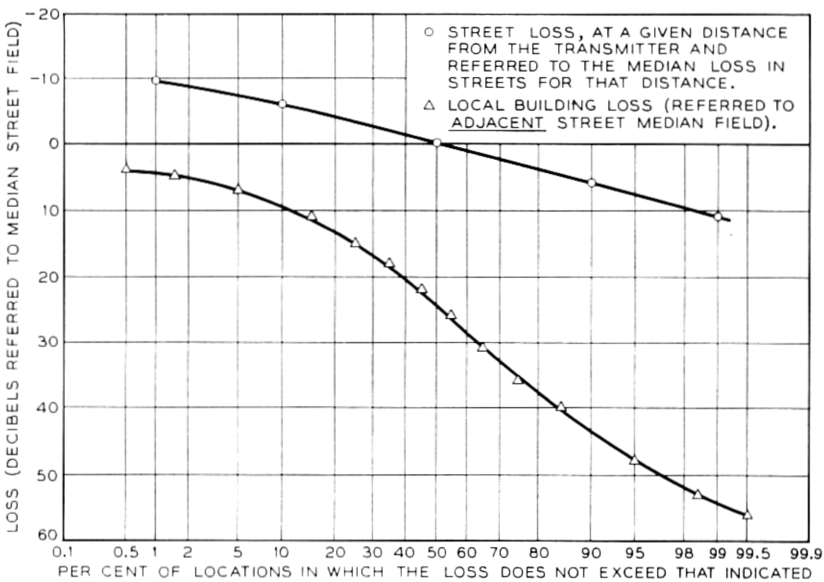

Fig. 4 — Over-all distribution of local building and street losses at 35 mc.

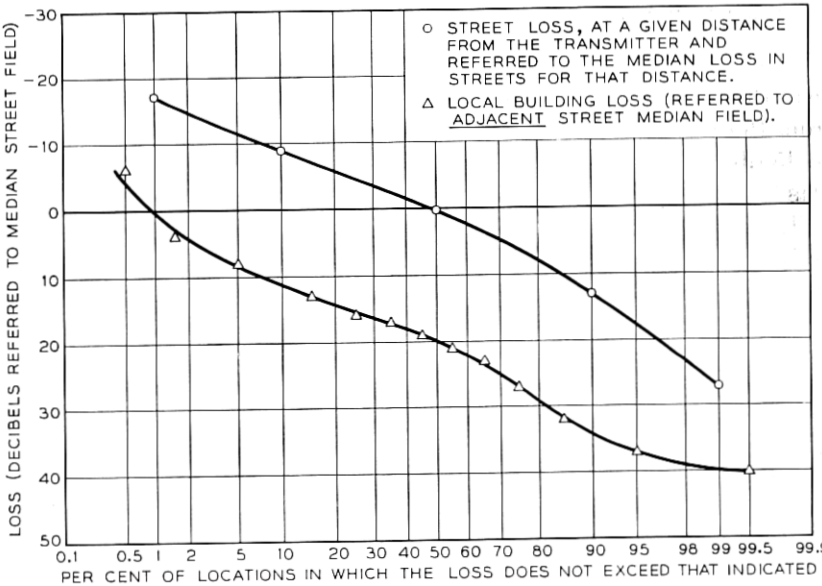

Fig. 5 — Over-all distribution of local building and street losses at 150 mc.

minimum intensity with a certain degree of reliability is concerned with building loss on the over-all basis. He would be interested in the field intensities within the buildings on the periphery of a circle. The radius of this circle around the transmitter would be the useful range of the system.

Each one of these buildings on the circle would have local building losses with respect to the median field in the streets adjacent to it. The variations in these local losses would differ from building to building. However, the variations in the local losses of a "typical building" could be approximated by combining the measurements taken in the eleven buildings. This has been done graphically to obtain the lower curves in Fig. 4 for 35 mc and in Fig. 5 for 150 mc. It is possible to determine from these figures the probability that the field at any point on the main floor of any building in a heavily built-up metropolitan area will be equal to or greater than some given level with respect to the median field intensity in the streets adjacent to that building. So, if the median of the adjacent street field is known, the coverage in the building can be estimated.

As a general rule, however, the median field in the streets adjacent to any particular building will not be known, whereas the over-all characteristics of propagation into city streets have already been determined (see Figs. 6 and 7). The median field intensities in the streets adjacent to various buildings will vary from building to building, due to interference caused by the local terrain and nearby structures.

If the field intensities were measured in the streets adjacent to a large number of buildings, all equidistant from the transmitter, it is expected that the distribution of the medians of these groups of measurements would approach the distribution of all street measurements at that distance, i.e., the upper curves in Figs. 4 and 5. Now, if it is assumed that each of these many buildings is one of the "typical buildings" for which the local loss characteristics are shown in the lower curves of Figs. 4 and 5, it follows that the expected building losses for all the buildings on the circle with respect to the median field in streets at that distance from the transmitter may be determined by statistically combining the two curves on each of these two figures. This was done graphically in Fig. 1 for each of the two frequencies. The percentage of locations within all buildings, on a circle of a given radius, in which the field intensity will not be lower than a given level with respect to the median street field at the same radius may be determined directly from this figure for either frequency.

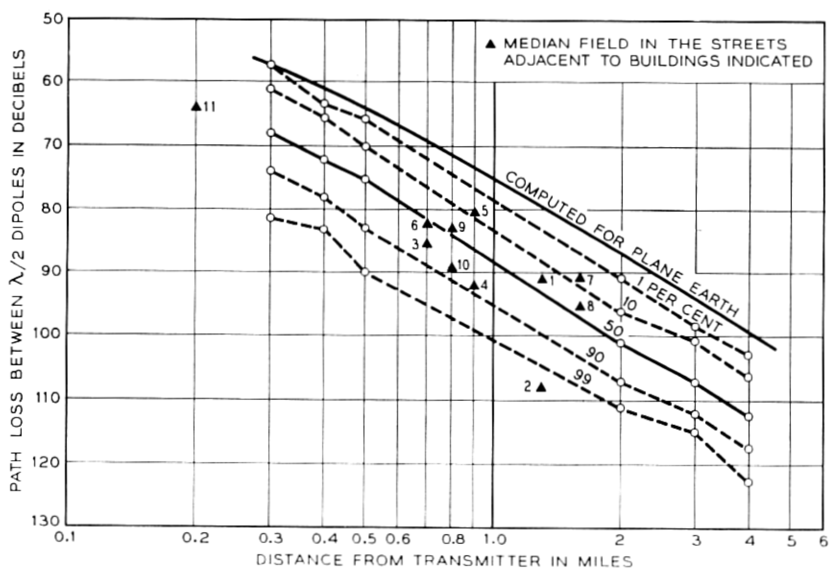

Fig. 6 — Measured path loss at 35 mc between half-wave dipoles in city streets in Manhattan. Antenna heights: transmitter—450 ft.; receiver—6 ft.

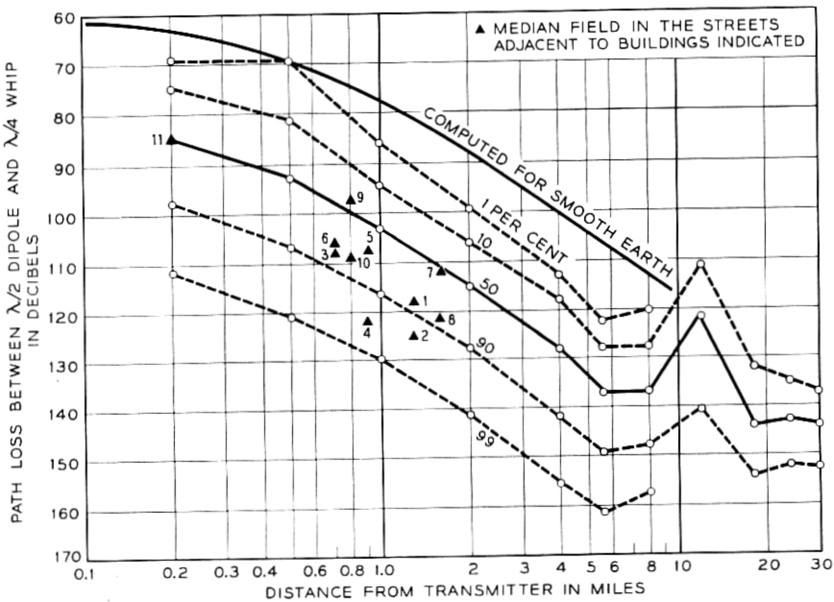

Fig. 7 — Measured path loss at 150 mc between a half-wave dipole and a quarter-wave whip in Manhattan and the Bronx and suburbs. Antenna heights: transmitter – 450 ft.; receiver – 6 ft. (All data except the 11 adjacent-street medians taken with permission of W. R. Young, Jr. from Ref. 1).

3.4 *Test Equipment Arrangements*

The New York Telephone Company's mobile telephone facilities at 32 Avenue of the Americas were used as a signal source for measuring building losses.

The field measuring equipment for work in buildings had to meet three principal requirements: portability, stability and selectivity. The available commerical field-intensity measuring apparatus was not selective enough to reject the adjacent mobile channels in New York City. Therefore, the limiter grid current in standard, battery-powered, crystal-controlled receivers was used as an indication of field strength. Provisions were made to insure that the battery aging did not upset the calibrations of the grid current meter. Prior to use, each receiver was equipped with the antenna to be used during the measurements and was calibrated in a known field by varying the field and noting the limiter current for each field intensity. The same receivers were used to measure the fields in the streets adjacent to the buildings. Antennas mounted on automobiles were connected to the receivers and the sets were recalibrated.

IV. APPLICATION TO THE ENGINEERING OF RADIO SYSTEMS

Building loss can be utilized in the engineering of a radio system in much the same way as other propagation losses. One aspect of building loss — its amplitude distribution — has an important effect on the range of reliable coverage into buildings. Inasmuch as building loss has been defined as the difference between the levels of RF field in the building and the *median* field in the streets at a given range from the transmitter, the distribution of the field intensity in the buildings must be the same as the distribution of the building loss.

The amount of building loss that can be tolerated by a system depends on the required degree of reliability. This reliability is numerically equal

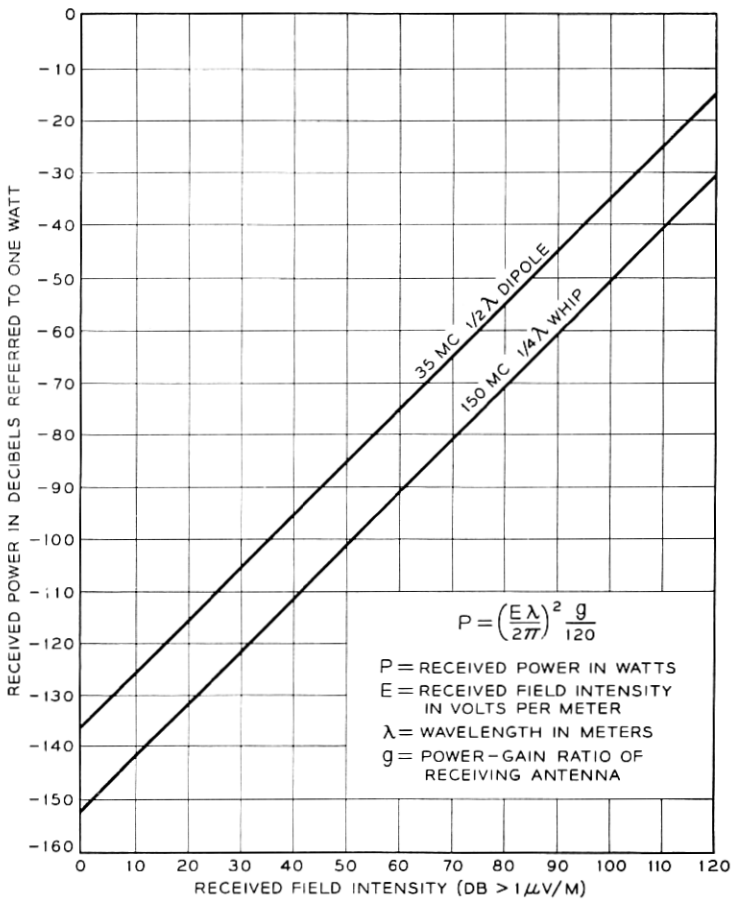

Fig. 8 — Received power at 35 and 150 mc versus received field intensity (Ref. 2).

to the percentage of the locations in the peripheral buildings in which the building loss must not exceed a certain threshold value. This threshold loss may be determined directly from the ordinate of Fig. 1 for any given per cent of reliability on the abscissa. When the maximum allowable path loss to the receiver and the threshold building loss are known, their difference represents the *median* path loss in streets that can be tolerated and still provide the minimum acceptable coverage in the buildings. The determination of such factors as required transmitter power or maximum range of coverage can be handled in any convenient manner, in terms of median losses to the adjacent streets.

The following five steps describe one method for determining the service range of a transmitter in a large metropolitan area such as New York City. The procedure consists of the determination of first the maximum allowable path loss and then the range at which this path loss is not exceeded for a given system reliability.

1. Determine the *minimum usable received power* from a half-wave

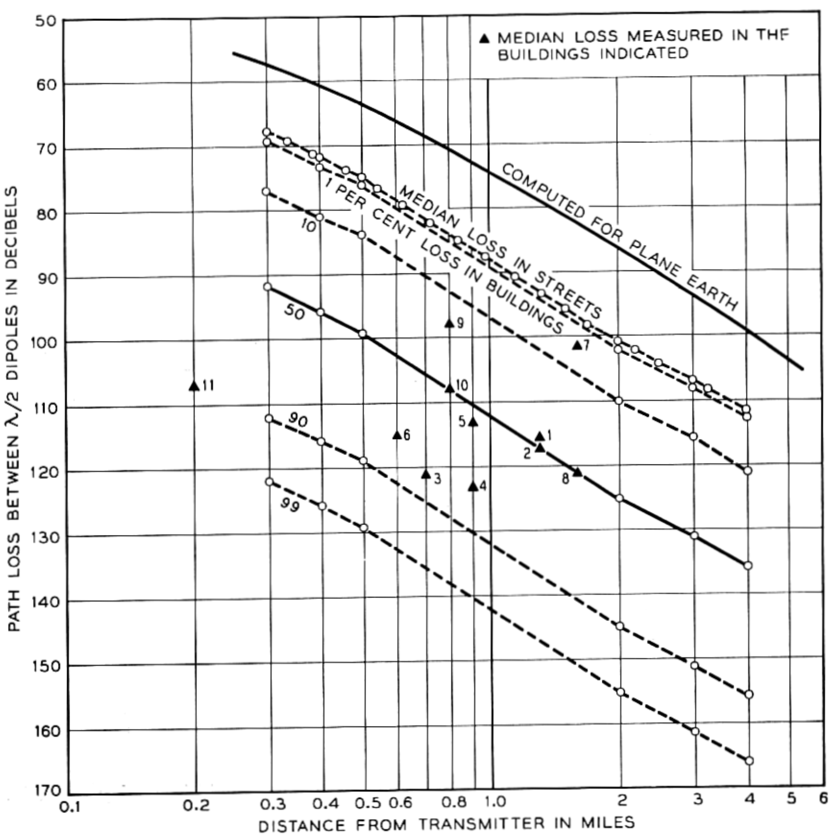

Fig. 9 — Path loss at 35 mc between half-wave dipoles into large city buildings.

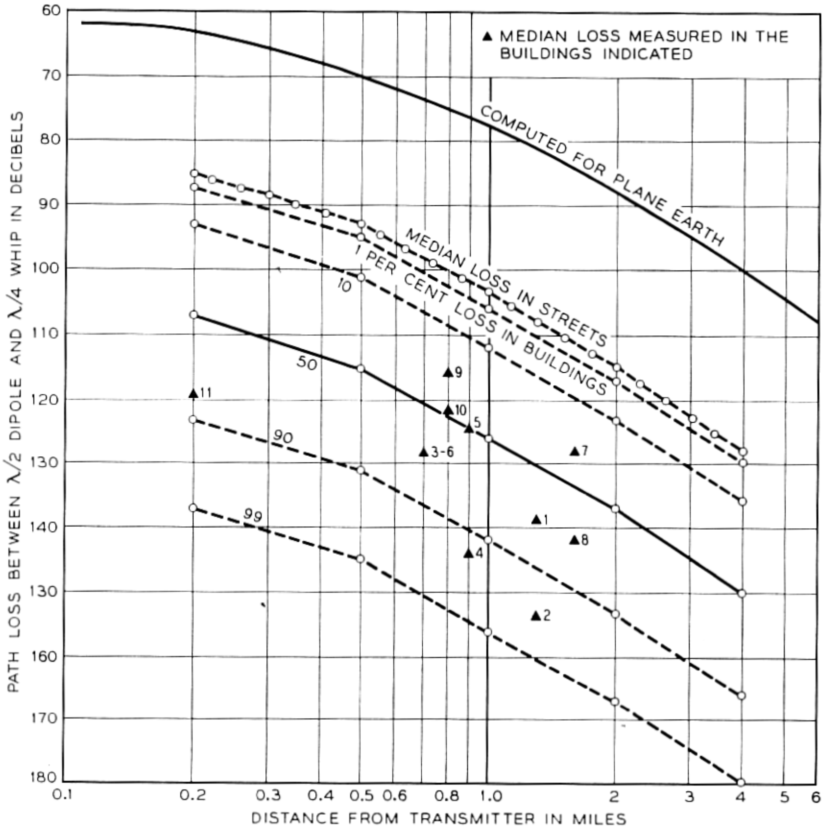

Fig. 10 — Path loss at 150 mc between a half-wave dipole and a quarter-wave whip into large city buildings.

dipole (for 35 mc) or a quarter-wave whip (for 150 mc). Fig. 8 can be used for this purpose when receiver sensitivity is known in terms of minimum required field intensity.

2. Subtract the minimum usable received power (in dbw) from the equivalent transmitted power from a half-wave dipole to determine the *maximum allowable path loss* between the two pairs of antenna terminals.

3. Determine the *building loss* from the ordinate on Fig. 1 which corresponds to the required system reliability. (The system reliability in per cent is numerically equal to the scale on the abscissa of this figure.)

4. Subtract the building loss from the maximum allowable path loss to determine the equivalent *median loss in streets*.

5. Determine from Fig. 9 (for 35 mc) or 10 (for 150 mc) the *range* at which this median loss in streets occurs. Use the curve labeled "Median Loss in Streets". This is the useful range of the system for coverage into buildings.

Table II — Examples of Estimation of Range at Which Radio Service Can Be Offered in Metropolitan Buildings

Assumptions:

Receiver sensitivity — 30 db > 1 microvolt per meter

Effective radiated power from dipole 450 ft above ground — 24 dbw (250 watts)

System reliability* — 90 per cent

* This is the system reliability for a nonrepetitive system. Signals may be sent out more than once in a personal signaling system. If two signals are sent to a subscriber moving about in a marginal field, the system reliability for this problem would be 99 per cent; if three signals are sent, 99.9 per cent.

Frequency	Step Number						
	(1)		(2)		(3)	(4)	(5)
	Receiver Sensitivity, in db < 1 μv per meter	Minimum Usable Received Power, in dbw (Fig. 8)	Radiated Power (Dipole), in dbw	Maximum Allowable Path Loss in db	Building Loss for 90% Reliability, in db (Fig. 1)	Equivalent Median Loss in Streets, in db	Estimated Service Ranges in miles (Figs. 9 & 10)
35 mc	30	−106 (dipole)	24	130	44	86	0.9
150 mc	30	−122 (whip)	24	146	38	108	1.3

If only a rough estimate is required, steps 3 and 4 may be eliminated by interpolating between the 50 per cent, 90 per cent and 99 per cent curves on Figs. 9 and 10 and determining directly the range corresponding to the maximum allowable path loss found in step 2. Here again, the percentages are numerically equal to the system reliability.

Some numerical examples of range estimation are given in Table II in order to illustrate the use of this procedure. The step numbers correspond to those listed above.

By comparison, for the conditions given in the table, the expected coverage in streets may be in the order of 8 miles at 35 mc and 4 to 5 miles at 150 mc.* It is of interest to note that, while better coverage may be expected in streets at 35 mc than at 150 mc, the higher building losses at 35 mc attenuate the field so much that better coverage in buildings can be expected at 150 mc.

V. ACKNOWLEDGMENTS

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* From the 90 per cent curves of Figs. 6 and 7.