RADIO ENGINEERING

MOBILE RADIO

TRANSMISSION

PROPAGATION NOTES

INTRODUCTION

The purpose of this section is to present a series of short discussions on subjects related to the transmission aspects of mobile radio engineering. This section is somewhat unique in that it will be viewed as being continually open-ended so that as new material suitable for inclusion in the series becomes available it will be added immediately.

The plan for this section envisions that each of the articles will be complete in itself and, for the most part, will be limited to one or two printed pages.

The subject matter to be included in this series will cover a range of interest but each article will be addressed for the most part to a single important concept of radio transmission or propagation. It is hoped that these discussions will contribute to an increased overall comprehension and interest in radio matters.

CONTENTS

ARTICLE I--FIELD INTENSITY

This article discusses the basic relationship between field intensity, distance, and radiated power. An easily visualized approach is to temporarily overlook the presence of the earth and consider the transmitter power as radiating uniformly in all directions from a point in space. It follows that at any distance from this point, the power density per unit of area is simply the power radiated from the transmitter divided by the area of a sphere with a radius equal to the distance in question. For example, at 1 mile or 1609 meters, the power is distributed uniformly over $4\pi\,(1609)^2$ square meters. The resulting power per square meter may then be translated into field intensity by applying the familiar expression $P = E^2/R$. Here, P is the power intensity in watts per square meter, E is the field intensity in volts per meter, and R is 120π ohms, the characteristic impedance of free space (derived from dielectric and permeability properties of space). For a radiated power of 1 kW, the field intensity at 1 mile is 107.6 millivolts per meter.

While it is impossible to radiate uniformly in all directions as assumed, since an isotropic radiator does not exist, actual antennas have radiation patterns which may be described in terms of gain or loss with respect to an isotropic radiator in specified directions. A half-wave dipole has a pattern which provides a gain in directions normal to the antenna axis of 2.15 dB. Using the equivalent voltage ratio of 1.28 to adjust the 1-mile, 1-kW isotropic field, a figure of 137.6 millivolts per meter is obtained for the field intensity from a dipole. This is a benchmark figure frequently appearing in texts on propagation.

This derivation points to some useful facts about free-space field intensity; viz, it is independent of frequency, and varies inversely with distance and directly with the square root of radiated power. Insofar as mobile services in the VHF and UHF bands are concerned, these relationships for free space are only a starting point in considering those actually found in the presence of the earth's surface.

ARTICLE II--TRANSLATION OF TERMS

Propagation references relating to VHF and UHF mobile services use several forms of expression to describe radio transmission, the choice depending largely on the author's preference. Engineers are frequently called upon to translate from one to another of the expressions listed below.

Field intensity, or field strength, in microvolts per meter or, more commonly, in dB from 1 microvolt per meter

Received voltage at receiver input, expressed in microvolts or in dB from 1 microvolt

Received power, in dB below 1 watt or below 1 milliwatt

Path Loss in dB

This article reviews the principles involved in making conversions and offers a tabulation of conversion factors for handy reference. The key factor here is the relationship between field intensity at the site of a receiving antenna and the resulting power or voltage delivered by the antenna to the receiver input. This may be approached in either of two ways, both of which have a common basis in antenna theory. Regardless of which method is used, it is sufficient to consider only the properties of a half-wave dipole receiving antenna, since the results may be readily adjusted for any antenna of interest by applying its gain or loss with respect to a dipole.

"Area Approach"

One approach relates the power density in space to the power delivered to a receiver, using the term "effective area" to describe the power intercepting ability of the receiving antenna. For a half-wave dipole, the effective area is about $0.13\ \lambda^2$, where λ is the wavelength in meters. If for example $\lambda = 2$, which corresponds to 150 MHz, the effective area is 0.52 square meters. In Article I it was shown that power density in watts per square meter is equal to $E^2/120\pi$ where E is the field intensity in volts per meter. Accordingly, the power in watts delivered to a matched receiver by a 150-MHz half-wave dipole in a field of one microvolt per meter, neglecting any line losses, equals 0.52 square meters multiplied by $(10^{-6})^2/120\pi$ watts per square meter. This works out to be 0.138 (10^{-14}) watts or 148.6 dB below 1 watt.

"Voltage Approach"

The second approach uses the theoretical voltage relationship in a half-wave dipole, by which the voltage induced is $E\ \lambda/\pi$, making the voltage across a matched receiver $E\ \lambda/2\pi$, where, again, E is the field intensity. If E is 1 microvolt per meter and λ is 2 meters, as in the previous example, the received voltage is 0.319 microvolt. This voltage across 73 ohms, matching the theoretical impedance of a dipole, represents power of 148.6 dB below 1 watt, as was obtained by the "area" method.

This approach stumbles a bit over the fact that actual VHF and UHF mobile antennas, transmission lines, and receivers are universally characterized by an impedance of 50 ohms. If this impedance is simply substituted for the theoretical value of 73 ohms in the E^2/R formula, the computed received power is increased 1.7 dB, which ascribes better performance than that of the ideal dipole. One way to reconcile this (a method used in FCC Report No. R-6406) is simply to scale down the received voltage to a value which, across 50 ohms, represents the same received power as given by both the "effective area" approach and the $\lambda/2$ voltage relationship when applied to 73 ohms. This seems entirely acceptable as an expedient for dismissing a question of little or no practical significance. The following table lists numerical conversion factors calculated for midband frequencies in the three mobile bands currently in use and the projected 900-MHz service.

Path Loss, the last of the expressions listed in the opening paragraph, is simply the ratio of transmitted power to received power and will be further covered in Article III. For 1 watt of transmitted power, path loss in dB is numerically equal to the received power in dB below 1 watt.

ARTICLE II – TRANSLATION OF TERMS (Cont)

More typically, for example, if 100 watts (+20 dBW) is transmitted and -130 dBW received, the path loss is 150 dB.

CONVERSION TABLE

Field Intensity:	in dB from 1 microvolt per meter (dBu)
Received Voltage:	in dB from 1 microvolt (across 50 ohms)
Received Power:	in dB from 1 watt (dBw)

TO CONVERT		ADJUSTMENT IN dB			
FROM	TO	35 MHz	150 MHz	450 MHz	900 MHz
Field Intensity	Received Voltage	+2.7	–10.0	–19.5	–25.5
Received Voltage	Field Intensity	–2.7	+10.0	+19.5	+25.5
Field Intensity	Received Power	–134.2	–147	–156.5	–162.5
Received Power	Field Intensity	+134.2	+147	+156.5	+162.5
Received Voltage	Received Power	–137	–137	–137	–137
Received Power	Received Voltage	+137	+137	+137	+137

Example: Given a field intensity of 10 microvolts per meter find the equivalent level in terms of received voltage and received power at 150 MHz.

First, convert 10 microvolts per meter to 20 dB above 1 microvolt per meter (See Fig. 2, Section 940-230-100). To find received voltage subtract 10.0 dB per conversion chart above to obtain a level of 10 dB above 1 microvolt across 50 ohms. To convert to received power subtract 147 from +20 to obtain a level of –127 dB below 1 watt.

ARTICLE III--PATH LOSSES

Radio path loss is the ratio of transmitted power to received power over a radio path. In seeking a broad understanding of the nature of path losses encountered in VHF and UHF mobile services, a useful approach is to review the basic theory applicable to the idealized case of elevated antennas over a flat earth surface. The basic conclusions indicated may then be altered with adjustments to account for discrepancies between the ideal and the practical situation of interest.

As shown in Article I, in free space the field intensity diminishes with increased distance from a transmitter in accordance with the way radiated power spreads out over a larger area. Whenever the distance is doubled, the power per unit area becomes one quarter as great, and the field intensity one half, that is to say there is a 6-dB loss. In passing, it may be startling to reflect on the fact that 6 dB per octave of distance is lost whether going from 1 mile to 2 mile or from 100,000 to 200,000 miles. (The wire-line "dB per mile" relationship has no place in radio propagation.) In this light, an explanation for the astonishing distances covered by radio in connection with space activities becomes apparent.

Propagation at VHF and UHF frequencies undergoes drastic alteration from that in free space when, as in the mobile services, the transmitting and receiving antennas are placed in proximity to the reflecting surfaces of the earth. Here, path losses take on a slope of 12 dB, rather than 6 dB per octave of distance, starting quite close to the transmitter and extending to distances at which the effect of earth curvature imposes an even higher rate of loss.

This increase in path loss may be considered as resulting from the received signal being a resultant of two waves, one arriving by the direct path through space and the other by a longer ground-reflected path. The phase difference between the two waves is determined by the difference in path lengths and the phase change, typically 180 degrees, which accompanies reflection.

For antenna heights and distances of usual interest in the land mobile service, the ground-reflected wave arrives in partial opposition with the direct wave. Over flat earth, when the distance between transmitting and receiving antennas is doubled, and antenna heights left unchanged, the path length difference is halved, and the amount of phase cancellation is doubled; thereby adding 6 dB to the 6-dB increment in free space loss of the direct wave.

In addition to this 12-dB relationship, two other significant conclusions may be drawn from the direct-reflected wave concept. One stems from an examination of path geometry which shows that the path length difference varies as the product of transmitting and receiving antenna heights. For an important range of heights this results in a "height-gain" of 6 dB when the height of either antenna is doubled.

The remaining conclusion concerns the independence of path loss with frequency. It was shown in Article II that with any fixed value of field intensity the received power at a half-wave dipole decreases as the frequency is increased. Accordingly, in free space where field intensity is independent of frequency, dipole path losses increase with frequency. The presence of a ground-reflected wave changes this situation completely. As the frequency is increased, the shortened wavelength results in increased difference between the electrical length of the direct and reflected paths. For typical mobile heights and distances this increases the resultant field intensity and tends to provide constant dipole path losses.

To summarize, idealized basic concepts indicate that mobile path losses tend: (a) to be independent of frequency, (b) to increase 12 dB for doubled distance, and (c) to decrease 6 dB for doubled antenna height at either terminal. These principles are valid only within certain limits of frequencies, heights, and distances. Nevertheless, for conditions commonly encountered in the land mobile service, they provide a good basis on which to build a more complete view of path losses by adding adjustments for the effects of earth curvature, topography, and a variety of other factors.

ARTICLE IV--SHADOW LOSSES

In real life the idealized concept of path losses as discussed in Article III is confronted by the fact that the earth is curved, not flat, that topographic irregularities commonly abound, and that the earth's surface is typically cluttered with trees, buildings, and other objects which influence propagation in the land mobile radio services. These deviations from the ideal introduce substantial uncertainties in mobile propagation calculations. In this article some broad principles are discussed relating to two factors, earth curvature and intervening hills. The everyday performance of working mobile systems demonstrates that signals do indeed surmount such obstacles notwithstanding the occasional statements in popular literature that coverage is limited to line-of-sight paths.

The curvature of the earth does not suddenly put an end to land mobile signals at the horizon because in wave propagation the edges of a shadow are not truly sharp but blurred, especially at lower frequencies. This results from the phenomenon of diffraction which occurs even at the frequencies of light, as evidenced by a gray region, the penumbra, separating the deep dark of a shadow from the bright area. Propagation around the earth is further aided by refraction from the atmosphere which, under normal atmospheric conditions, tends to bend the radiowave so as to follow the curvature of the earth. The amount and direction of this bending is subject to wide variations under abnormal weather conditions. The net effect on losses over near-grazing and longer paths may be judged by comparing the smooth-earth path loss curves in Section 940-230-100, Fig. 4 through 9, with straight lines anchored to the curves at the left-hand end and drawn with a slope of 12 dB per octave of distance. This will show, for example, that between a 200-foot-high base station antenna and a car 35 miles away, which is about 12 miles beyond the grazing distance, diffraction and normal refraction effects combined will result in earth curvature adding about 5 dB to flat earth path losses at 40 MHz, 8 or 9 dB for 160 MHz, and 12 dB for 460 MHz. These added losses increase with distance, but communication is possible until distances are reached for which total losses become too large to tolerate with the transmitter power available.

Diffraction also accounts for the propagation of signals over hills. Here, precise calculations are not generally possible because of the variety of hill configurations encountered and the effects of reflections from neighboring hills. A useful guide is provided, however, by the charts of Section 940-230-100, Fig. 14 through 16, which were developed by Kenneth Bullington of Bell Telephone Laboratories from the optical theory of diffraction over a knife edge. These charts show that for an important range of hill heights and placements, shadow losses increase 6 dB with a doubling of hill height, and 3 dB with either a doubling of frequency or a halving of the distance between an obstructing hill and the nearer terminal of the radio path. Hill shadow losses may be quite substantial: 25 or 30 dB is not uncommon in rugged terrain and such losses obviously have severe reaction on mobile system coverage.

While theoretical aspects such as these have been found to furnish a reasonably good basis for estimating path losses and the attending coverage performance of land mobile radio systems, a better technique continues to be a desirable objective. As realized for some time, this would involve the development of a catalog of terrain characteristics and of corresponding information on path losses experienced in practice. This promises to become feasible as the volume and scope of measured data increases.

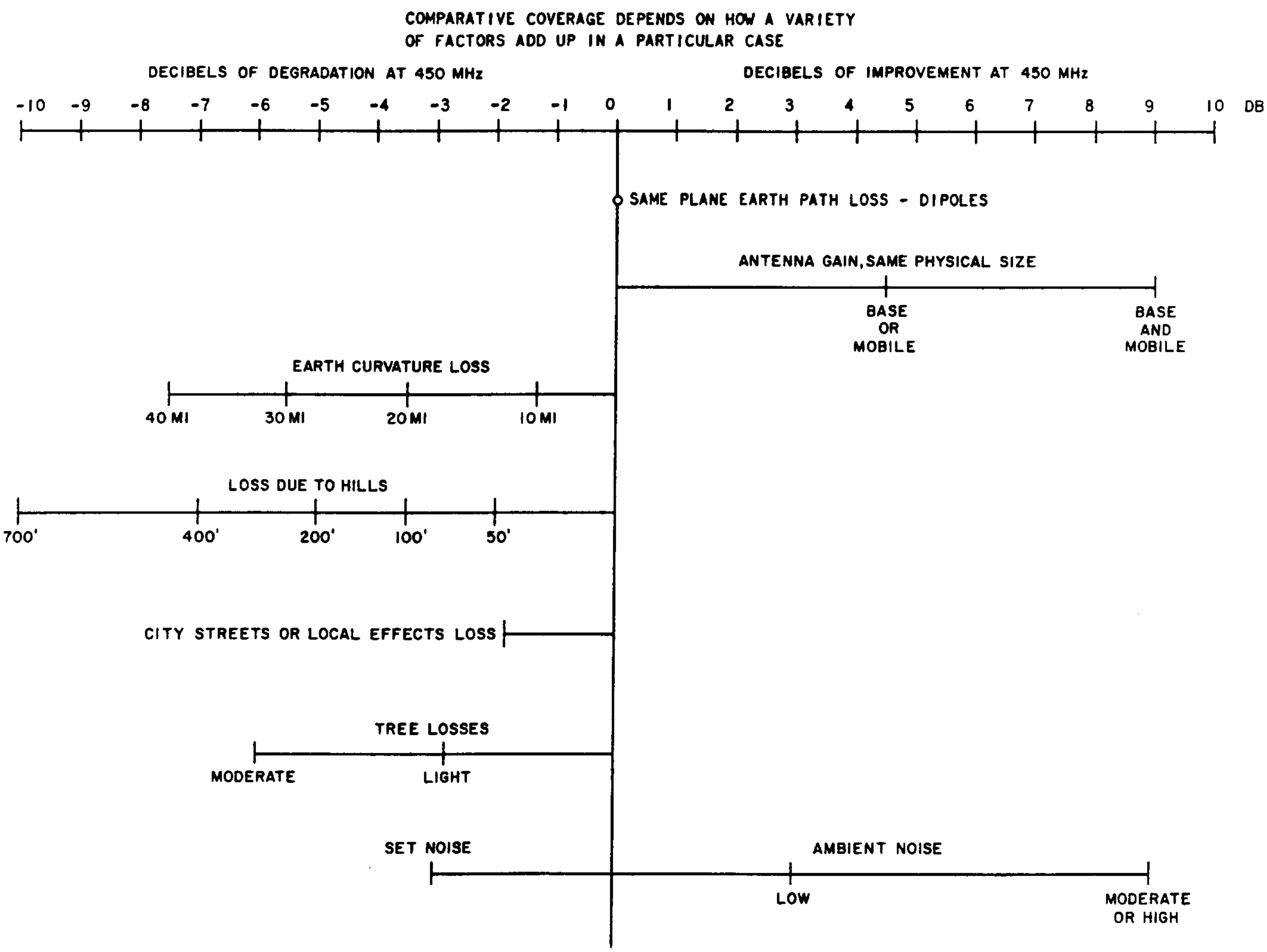

Fig. 1 — Coverage Comparison — 450 MHz Versus 150 MHz

ARTICLE V--COVERAGE COMPARISON--150 MHz and 450 MHz

The current availability and use of land mobile service radio channels at both 150 MHz and 450 MHz frequently brings up questions concerning the relative coverage obtainable in these two bands. Answers depend on a number of factors which may vary widely from one case to another, as is evident from a detailed examination of the information in Section 940-230-100. However, a broad view may be gained by considering three points:

(a) Over idealized flat earth, path losses are the same for both bands. (See Article III.)

(b) Most real environments cause higher path losses at 450 MHz which act to diminish the relative coverage range.

(c) At 450 MHz, lower ambient electrical noise levels and the availability of larger antenna gains act to increase the relative coverage range.

The manner in which items (b) and (c) offset one another in a particular situation will determine the relative coverage performance. This is diagrammed in Fig. 1 with assignment of some rough dB values.