LOCATION VARIABILITY OF TRANSMISSION LOSS

LAND MOBILE AND BROADCAST SYSTEMS

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This report summarizes the results of a number of studies of path-to-path, or location, variability of transmission loss at 20 MHz to 10 GHz. The studies show that such variability appears to be normally distributed and can, therefore, be represented by a standard deviation. Location variability increases with increased frequency and terrain irregularity, the standard deviation increasing from about 5 to 25 dB. For non-urban areas an expression is given which defines location variability in terms of radio frequency and terrain irregularity. The effects of tall buildings in highly built-up urban areas, and of trees are discussed.

Key words: Broadcast systems; irregular terrain; location variability; mobile systems; radio transmission loss; urban communications; vegetation.

1. INTRODUCTION

In a broadcast or mobile system, at frequencies above 20 MHz, a great deal of variability in signal level among paths of the same length is to be expected. Such path-to-path or location variability must be taken into account in estimating the coverage of a broadcasting station, or the useful range from a base station to mobile units.

Estimates of location variability are empirical, derived from measurement programs. As a rule radio signals are transmitted from a broadcast or base station with elevated antennas to rather low and randomly located receivers. The receiving antennas are usually from 3 to 10 m above ground, but may be somewhat lower. The measurement programs show that location variability appears to be normally distributed with a standard deviation that ranges from about 5 to 25 dB depending on radio frequency, type of terrain, and whether the path terminals are in open or cluttered surroundings. No clear-cut dependence on antenna heights has been noted.

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2. PREVIOUS WORK

A number of studies of location variability have been made in the frequency range from 20 to 3000 MHz in both urban and rural situations, and over smooth and irregular terrain. The results of several programs are summarized here.

Some early measurements were made by R. S. Kirby and his associates. Kirby and Capps (1956) reported on mobile measurements at frequencies of 72 and 94 MHz in the Washington, D.C. and Baltimore areas. They noted little variability for paths which were largely over water, but 10 to 90% ranges of 11 to 18 and 13 to 15 dB at 72 and 94 MHz, respectively, in urban and wooded areas and in farmlands. If we assume that the measured values are normally distributed this would correspond to standard deviations $\sigma_L \simeq 6$ and 5.5 dB at these frequencies. Kirby et al. (1956) reported mobile measurements in Colorado at frequencies of 60, 95.7, and 192 MHz on four east-west routes 32, 56, 74, and 99 km north of the transmitters in Denver. In all cases higher values of location variability were associated with the rougher terrain, with median values $\sigma_L \simeq$ 6.1 and 9.1 dB in the plains and foothills, respectively. Later measurements at 88 MHz along circular routes around Denver, reported by Kirby (1957), showed that values of variability increased with increasing terrain irregularity. He reported $\sigma_L \simeq$ 6, 12, and 23 dB in average, hilly, and mountainous terrain, respectively.

A large measurement program was conducted mainly in the eastern part of the U.S. by the Television Allocation Study Organization (TASO). Head and Prestholdt (1960) reported that these measurements showed a much wider range of field strength values at UHF than at VHF, and much more variability in rugged than in smooth terrain.

Egli (1957), working with data from mobile units in irregular terrain, found that the signal levels for different paths of the same length appeared to be normally distributed with standard deviations of 8.3 and 11.6 dB at frequencies of 127.5 and 510 MHz, respectively. He suggested that the standard deviation, σ_L, be expressed as a function of radio frequency,

$$\sigma_L = 5 \log f - 2 \text{ dB}, \tag{1}$$

where f is the frequency in MHz.

From a statistical study of data recorded in the lower VHF range, Hufford and Montgomery (1966) reached a similar conclusion, and suggested that location variability be represented as

$$\sigma_L = 3 \log f + 3.6 \text{ dB}. \tag{2}$$

They noted somewhat greater variability in mountainous areas than in plains, but did not suggest a specific allowance for terrain irregularity. From a study of the same data, Longley and Rice (1968) noted a consistent dependence on frequency and terrain irregularity. They derived an expression to show that σ_L increases as the ratio of terrain irregularity to wavelength increases.

From a study of measurements at frequencies from 25 to 400 MHz in tropical jungles, Jansky and Bailey (1965) suggested that location variability be represented as a function of frequency with a standard deviation

$$\sigma_L = 5.7 \log f - 2.6 \text{ dB}. \tag{3}$$

Bergman and Vivian (1970), reporting a series of long-range measurements in heavy foliage in the mountainous terrain of Panama at 49.4 MHz over distances up to 40 km, found much greater path-to-path variability, with $\sigma_L \simeq 12$ dB.

Saxton and Harden (1954), in a series of measurements at 600 MHz over paths up to 8 km in length, observed 10 to 90% ranges in signal level of 19 to 34 dB, or $\sigma_L \simeq 7.5$ to 13.5 dB. They observed the effects of trees and buildings near the receiving antenna with local variations of 2 to 4 dB at open sites and as much as 20 to 25 dB in a hollow with many trees and buildings.

The International Radio Consultative Committee (CCIR, 1970a) reports a variation factor, V, for towns in the United Kingdom, (where V is the 50 to 90% range in field strength). For 121 towns, at frequencies from 700 to 1000 MHz, the median $V = 9.8$ dB, and for 40 towns, at 250 MHz, the median $V = 7.7$ dB. These location variabilities correspond to values of $\sigma_L \simeq 7.9$ and 6.3 dB, respectively. For non-urban areas, the CCIR (1970b) suggests that for irregular terrain the location variability at frequencies from 30 to 250 MHz be represented by $\sigma_L = 8$ dB, but that for frequencies from 450 to 1000 MHz the location variability is also a function of terrain irregularity, with

$\sigma_L = 9.5$, 15, and 18 dB for average, hilly, and mountainous terrain.

From a statistical study of a large number of measurements in Tokyo and its environs, Okumura et al. (1968) proposed curves of σ_L as a function of frequency in urban and suburban areas for frequencies from 100 to 3000 MHz. The urban region in the heart of Tokyo is in flat terrain, while the suburban region is hilly. Their curves show greater variability in the hilly suburbs than in the urban area, but it should be noted that until recently the heights of buildings in Japan were limited by law to about 31 m. The curves show values of $\sigma_L = 5.2$ and 6.7 dB at 100 MHz, increasing to $\sigma_L = 8$ and 10 dB at 3000 MHz for urban and suburban areas, respectively.

In contrast to the studies in Japan, Waldo (1963) observed large location variability in the highly built-up areas of New York City, where the terrain itself is quite flat. He reports location variability with $\sigma_L = 16$, 17, and 18 dB at frequencies of 55, 175, and 573 MHz measured at roof tops. Neham (1974) suggests using values of $\sigma_L = 9$, 11.6, and 14 dB at frequencies of 50, 150, and 450 MHz, respectively, to allow for location variability in an urban area.

The large measurement program conducted by the Federal Communications Commission, and reported by Waldo (1963), also included measurements along several radials to a distance of 128 km. The data from these measurements are reported by Hutton (1963). Signals were transmitted from the top of the Empire State Building in New York City at frequencies of 55, 175, and 573 MHz. The data clearly showed greater variability at the highest frequency, and also more path-to-path variability along radials over mountains than along those over relatively smooth terrain. For paths over smooth terrain values of σ_L are approximately 5, 6, and 7 dB at frequencies of 55, 175, and 573 MHz, respectively. The corresponding values at these frequencies over hilly terrain are approximately $\sigma_L \simeq 6.5$, 7, and 10.5 dB, increasing to 10, 11, and 13 dB over mountainous terrain. Values of field strength measured around a circle with a 37 km radius, where terrain ranged from smooth to mountainous, showed even more variability at the highest frequency, with $\sigma_L \simeq 16$ dB.

In a study in Philadelphia at 836 MHz, Black and Reudink (1972) noted that near the transmitter the location variability of $\sigma_L \simeq 9$ dB was greater than in a region farther away where the buildings were more uniform, with

$\sigma_L \simeq 5.5$ dB. Reudink and Wazowicz (1973) in a series of measurements from a base station in Holmdel, New Jersey, at 836 MHz and 11.2 GHz noted increased location variability with increased frequency, and also with increased distance from the base station. At 836 MHz they estimated values of $\sigma_L = 7$ to 8, 10 to 11, and 15 dB for distance ranges of 1.5 to 2.5, 2.5 to 3.5, and 3.5 to 5.5 km, respectively. Similarly at 11.2 GHz values of $\sigma_L = 8$ to 9, 12 to 14, and 18 to 20 dB were calculated for the same distance ranges. They chose a suburban rather than a truly urban area in order to avoid shadowing by very tall buildings, and the frequently observed channeling of radio signals along streets, with improved reception at street intersections.

These estimates of location variability are plotted in figures 1 and 2. Figure 1 shows the wide spread in estimates of σ_L for urban and suburban areas. The lower values are typical of conditions in Tokyo, Warsaw (CCIR 1969), and medium-sized cities and towns in the United Kingdom and other countries. The higher estimates are for the canyon-like streets of Manhattan and other heavily built-up areas with many trees. For urban and suburban areas we see that although location variability increases with frequency it is also highly dependent on the type and density of surface features such as buildings and trees.

The location variability in non-urban areas, plotted in figure 2, also shows a definite increase with increasing frequency, and an increase with increasing terrain irregularity. Some man-made and natural objects were present in these areas, but their effects were not sufficient to obscure the effects of frequency and terrain irregularity.

Although one might expect changes in antenna height to affect the amount of location variability, the only observed changes could be attributed to clutter. Signals received by a mobil unit with a 1.5 to 3 m antenna height are somewhat more affected by clutter than those received at roof-top levels. Except in heavily built-up areas no consistent change with path length was observed.

3. LOCATION VARIABILITY IN NON-URBAN AREAS

It is obvious from an examination of the values plotted in figures 1 and 2 that a good deal of uncertainty exists as to how much path-to-path

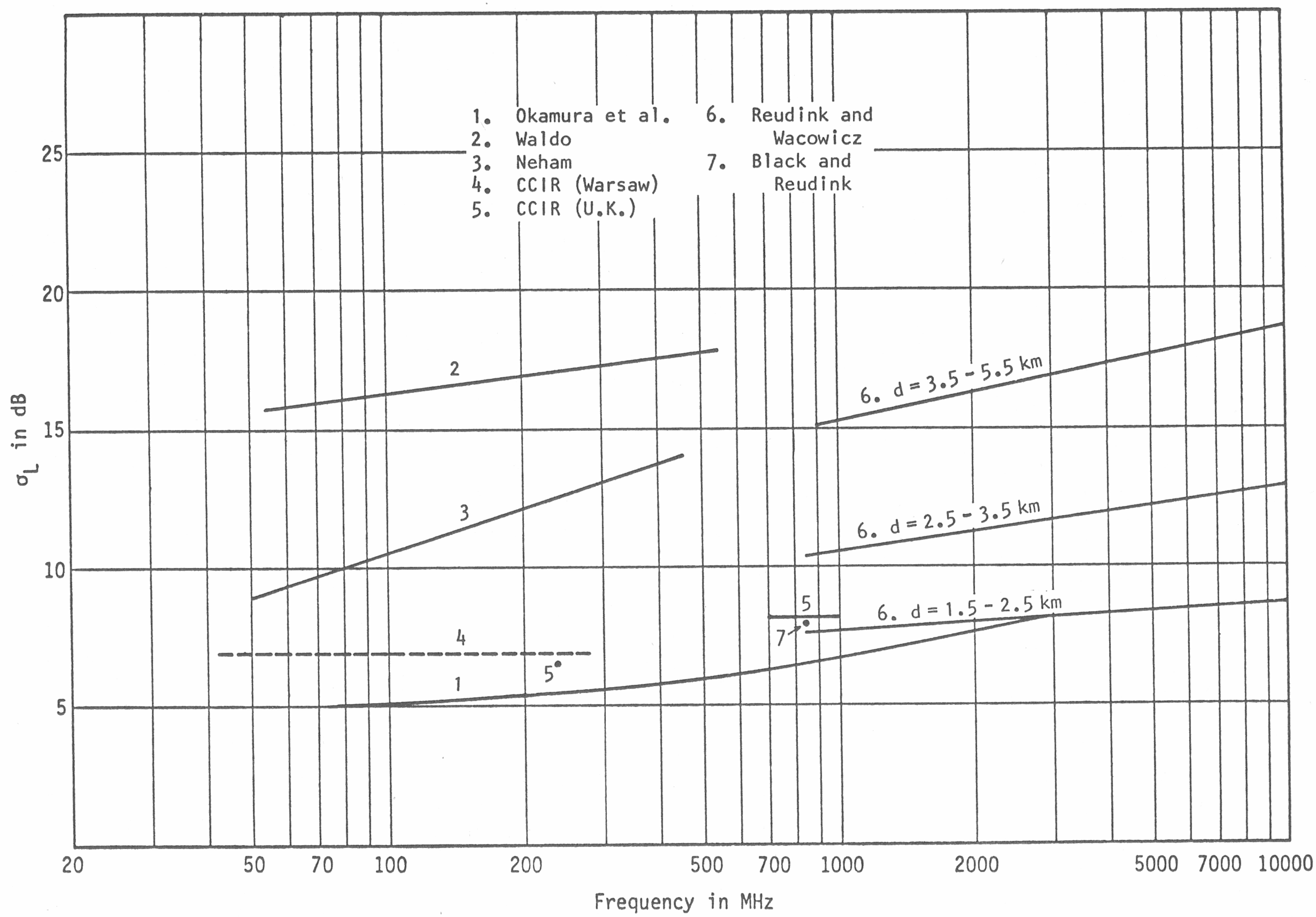

Figure 1. Standard deviation of location variability, σ_L, as a function of frequency in urban areas.