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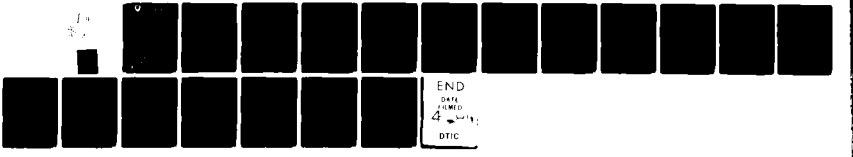

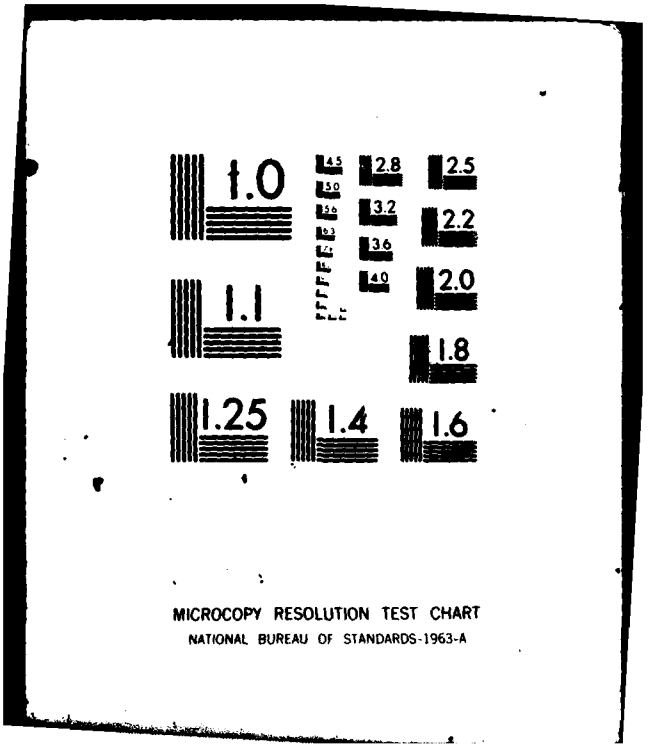
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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM-81-1

AD A096257

DIFFRACTION OF MILLIMETER WAVE COMMUNICATION SIGNALS INTO SHADOW REGIONS

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N. ROKKOS
R. A. JOHNSON
CENTER FOR COMMUNICATIONS SYSTEMS

FEBRUARY 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study was conducted to determine the order of magnitude of edge diffraction effects at mm-wavelengths. Theoretical and experimental results were found to be in good agreement; both show, however, that the shadow boundary of mm-waves is well defined and that distances by which a mm-wave receiver may be moved into the shadow zone are limited.

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1. INTRODUCTION:

It is well known that millimeter wave (mm-wave) links require unobstructed line-of-sight transmission paths. However, if a mm-wave beam hits the corner of a building, or skims over the top of a small hill, edge diffraction will scatter a certain amount of power into the geometrical shadow region. Hence, in principle, mm-wave transmission into shadow zones is possible. This may be used to advantage for camouflage purposes or when line-of-sight transmission is blocked by a large obstacle.

A study was conducted to determine the order of magnitude of edge diffraction effects at mm-wavelength. Theoretical and experimental results were found to be in good agreement; both show however that the shadow boundary of mm-waves is well defined, and that distances by which a mm-wave receiver may be moved into the shadow zone are limited.

2. THEORY:

The theory of knife edge diffraction is well understood; see for example Ref (1). Fig. 1 shows the geometry of the problem. The knife edge (perpendicular to the plane of the paper) is the top of the obstruction, which is assumed to be opaque to electromagnetic waves.

The power received by an antenna placed in the space range behind the obstruction will be modified by a factor

$$Q = \left| \tfrac{1}{2} \, (1=F(u) \right|^2 \qquad (1)$$

when compared to the power received via an unobstructed path of the same length $d_1 + d_2$. Here

$$F(u) = C(u) + iS(u) = \int_0^u e^{\frac{1}{2}\pi i t^2} \, dt$$

is the complex Fresnel integral and u is the (normalized) distance measured from the geometrical shadow boundary:

$$u = \left(\frac{kd_1}{\pi (d_1 + z) z} \right)^{\frac{1}{2}} y \qquad (2)$$

u is counted positive in the illuminated region and negative in the shadow zone. $k = 2\pi/\lambda$ is the wavenumber. The assumption $|y| \ll d_2$, which is implied in eqs. (1) and (2), is well satisfied in practical cases. Fig. 2

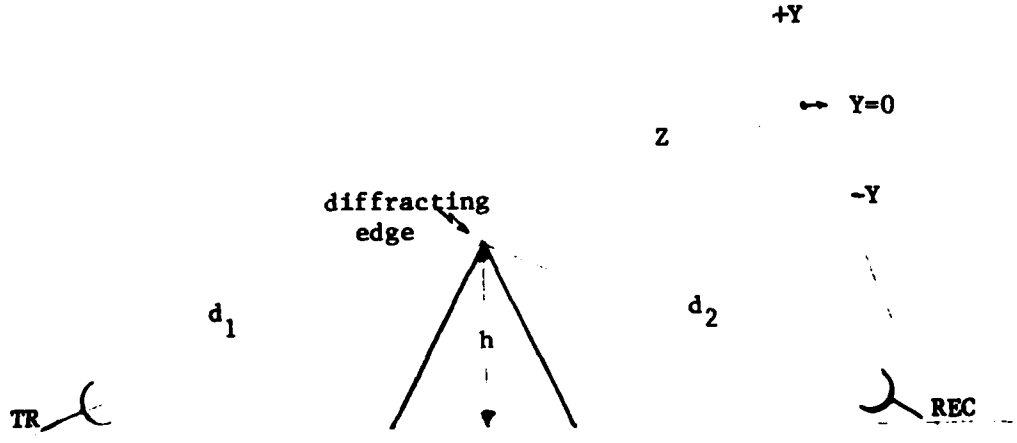


Fig. 1 - Geometry of Diffraction Problem.

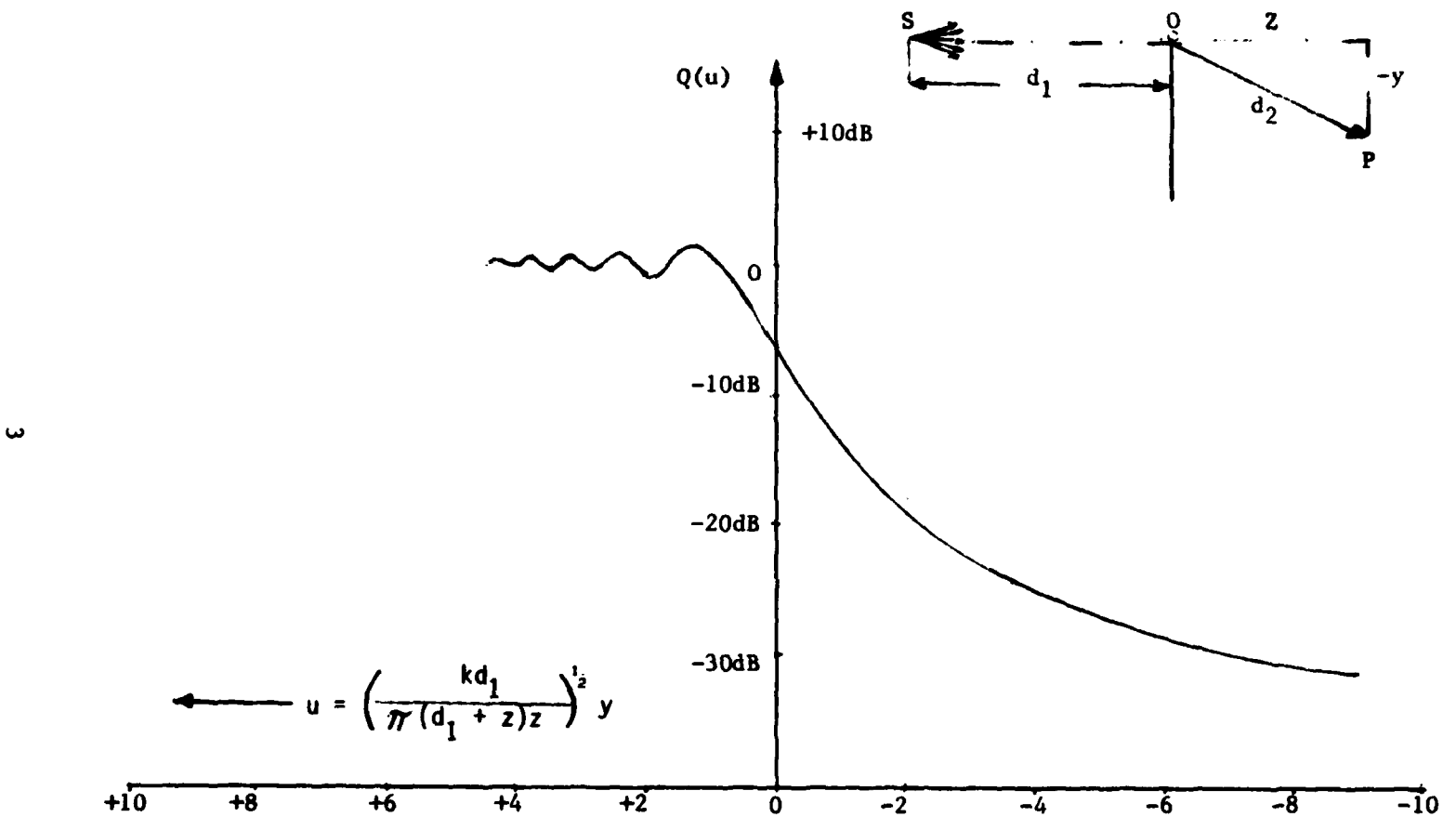


Fig. 2 - Edge-Diffraction Coefficient Q vs. Normalized Distance u

shows a plot of Q vs. u.

When the receiving antenna is located in the illuminated region, line-of-sight conditions are maintained, and edge diffraction effects have very little influence on received power; we have $Q \simeq 1$ for $u > o$. It is very interesting to note, however, that at certain distances (e.g. u = 1.25) - edge diffraction may actually increase signal levels, though such increases remain small. At u = y = o, i.e. where the line-of-sight just skims over the edge, and the lower half of the incident beam is "cut-off", the received signal level is reduced by 6 dB. For negative u, as the receiving antenna is moved into the geometrical shadow region, the signal level decreases rapidly.

The attenuation factor Q is in good approximation independent of the nature of the edge, whether it is sharp or rounded, metallic or dielectric. As long as the obstruction remains opaque, these characteristics are of secondary importance only.

Figure 3 answers the question to which depth -y the receiving antenna can be moved into the shadow zone if a given attenuation Q (10dB, 20dB, 30dB) is acceptable. This depth, of course, increases with radial distance d_2 from the edge, but even at a distance of 1 km remains comparatively small, in the order of 1 to 10 m. Table 1 lists typical values taken from Fig. 3. It is seen that the shadow boundary at mm-wavelength is well defined and narrow.

Substantially larger values for |y| should become possible if an attenuation of 40dB or 50dB is permissible. Fig. 2 shows that the curve for Q vs. u "flattens out" substantially in this range. However, at this level of attenuation, second order effects caused by shape, conductivity, etc. of the obstruction should become noticeable or dominant so that Fig. 2 is not expected to yield reliable results.

TABLE 1: Depth |y| by which receiving antenna can be moved into geometrical shadow zone for given attenuation Q. (d_1 = 100m, f = 60 GHz)

Q	|y| z=100m	|y| z=1000m
10dB	0.35m	2.5m
20dB	1.6m	11.8m
30dB	5.0m	37.3m

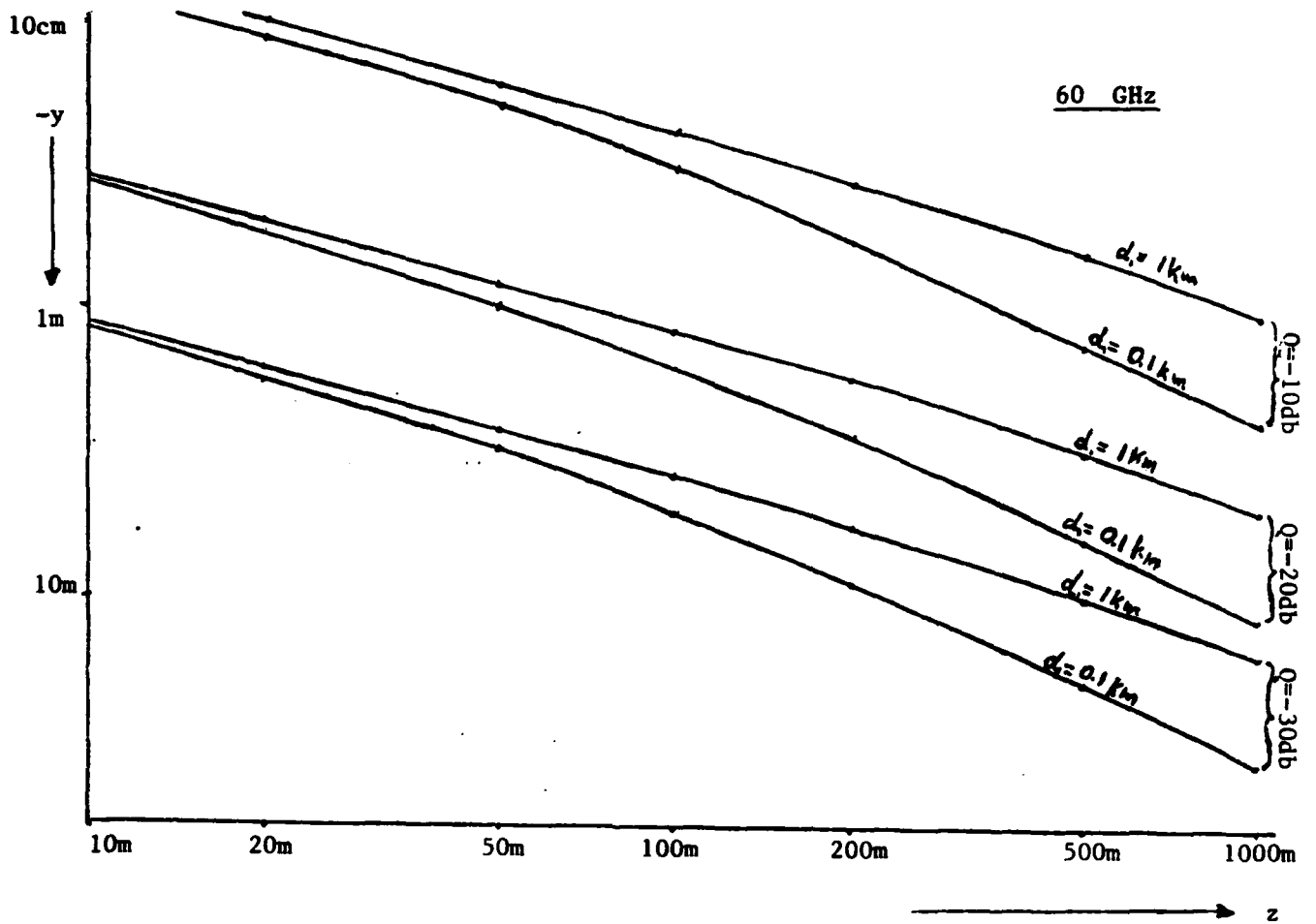


Fig. 3 - Depth into a geometrical shadow-zone for Given Attenuation Q

As indicated, Fig. 3 applies to a frequency of 60 GHz. The figure remains valid at other frequencies provided the ordinate scale is appropriately modified. According to eq (2) we have $|y| \sim k^{-\frac{1}{2}} \sim f^{\frac{1}{2}}$. At 30 GHz, for example, $|y|$ would be larger by a factor $\sqrt{2}$.

Fig. 4 applies the theory to a tactical example: A tank with a 60 GHz mm-wave radio is transmitting near the corner of a building. The input power of the radio is assumed to be at a level where reliable communication with an identical second radio can be established over distances of up to 1.5km under LOS conditions. The figure shows the depth to which the second radio at any given distance d_2 from the edge can be moved into the shadow zone while maintaining reliable communication i.e. a received power level equal to the LOS level at 1.5km. In the range where d_2 is much smaller than 1.5km (as assumed in the figure), the depth $|y|$ is limited to a few meters only but increases with radial distance from the edge. When d_2 approaches 1.5km, the trend reverses since the power margin which permits placing the radio in the shadow region decreases with distance from the transmitter.

3. EXPERIMENTAL RESULTS:

Experiments were conducted at 38 GHz and 60 GHz using available mm-wave radios developed at CENCOMS for voice/data transmission (contractor: Norden). Attenuation levels were measured by reading the AGC voltage displayed on those radios and using a calibration chart to determine the received power. The antennas of the radios have a directivity gain of 29dB at 38 GHz and 34dB at 60 GHz corresponding to a 3dB beamwidth of 5.5^{o} and 3^{o}, respectively. Distances from the edge were sufficiently large for far field experiments.

The tests were performed at three locations:

(1) A corner of the Hexagon building was used as a vertical diffracting edge.

(2) Similar measurements were made at building 1204 at Fort Monmouth.

(3) A small hill at the Wayside test area was used to provide a rather gradual horizontal edge.

The geometry of the test sites is shown in Fig. 5.

Test results are plotted in Figs. 6 to 10. The two experimental curves in each figure were taken by alternation of the two radios as transmitter and receiver, respectively.

In the experimental curves, the point is indicated where the signal level was -6dB below the level measured in the illuminated region. The theoretical curves were plotted assuming that, at this point, the line-of-sight between the radios skimmed the diffracting edge.

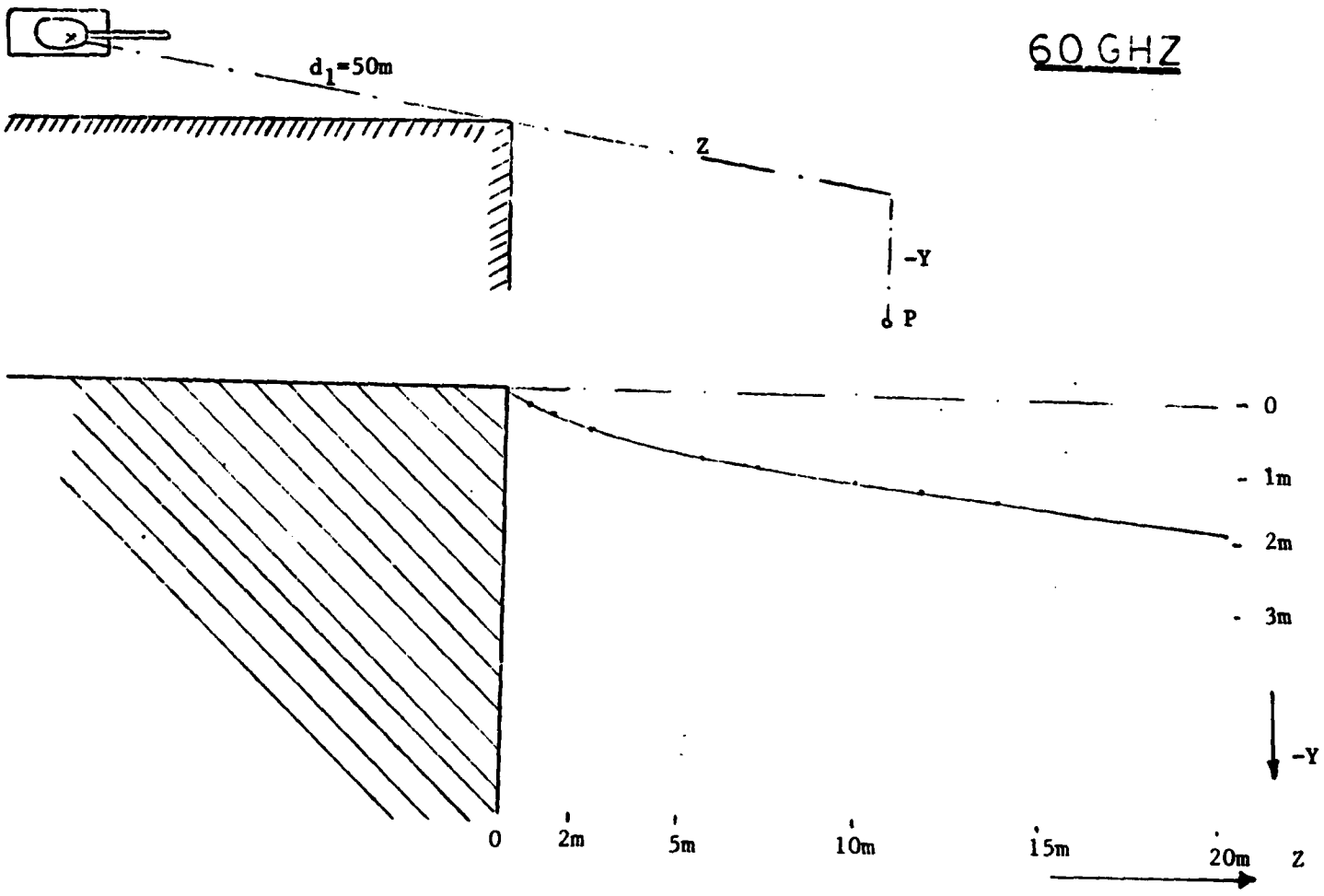
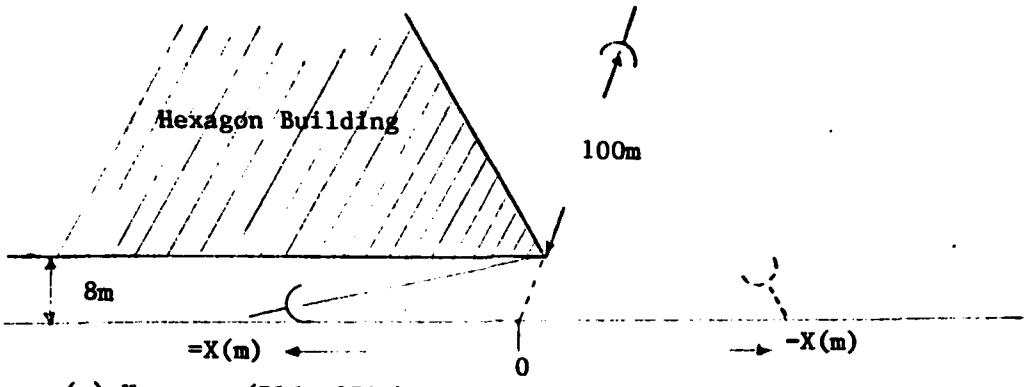
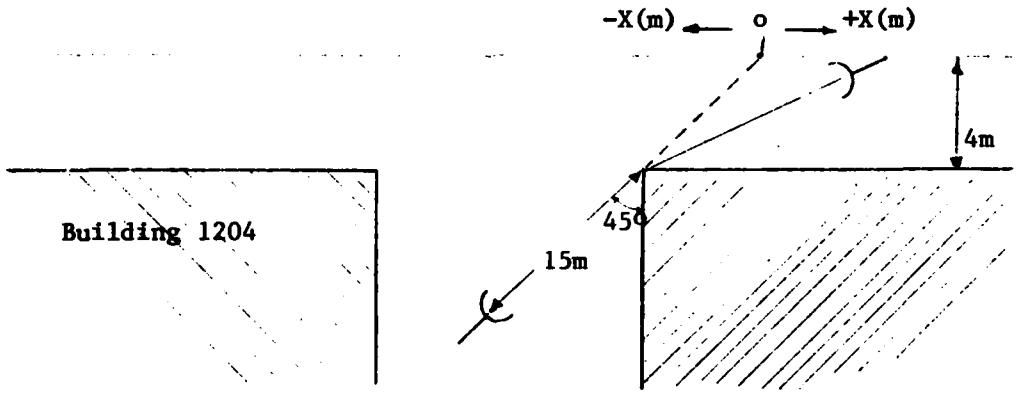


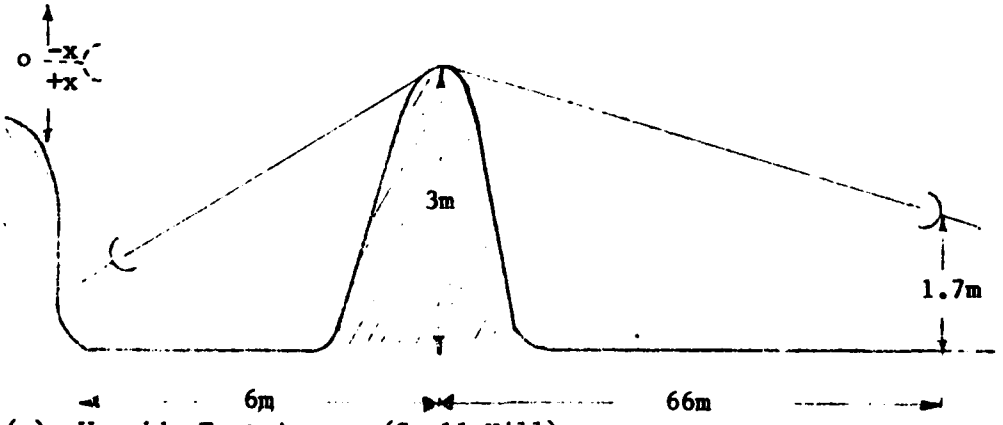
Fig. 4 - Transmission Into Shadow Region: Tactical Example (tank with mm-wave radio).



(a) Hexagon (Bldg 2700)



(b) Bldg 1204 (Ft Monmouth)



(c) Wayside Test Area. (Small Hill)

Fig. 5 - Test sites and geometry of experiments.

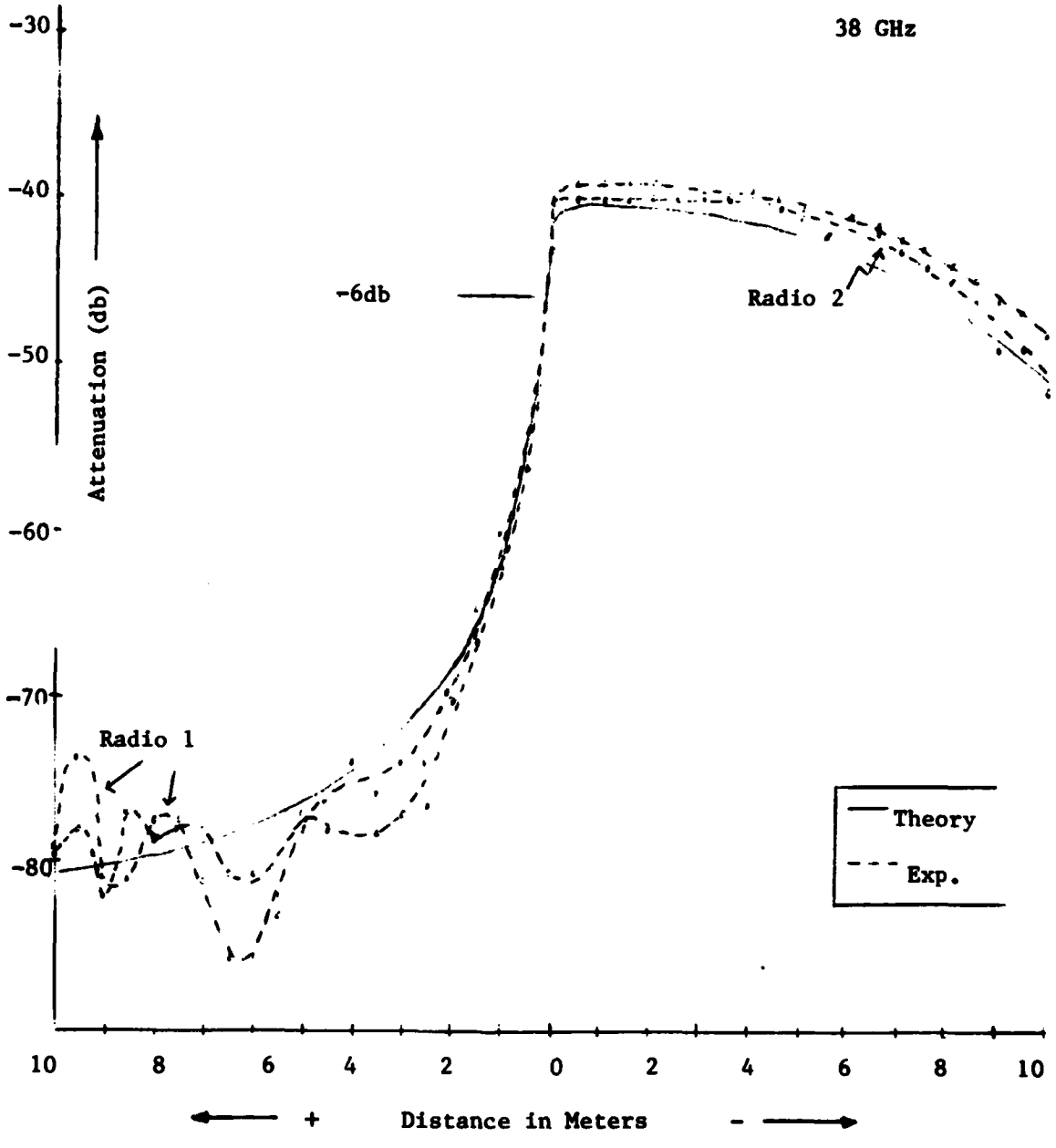


Fig. 6 - Signal attenuation (db) vs. distance (meters) from corner of Hexagon building (see Fig. 5a).

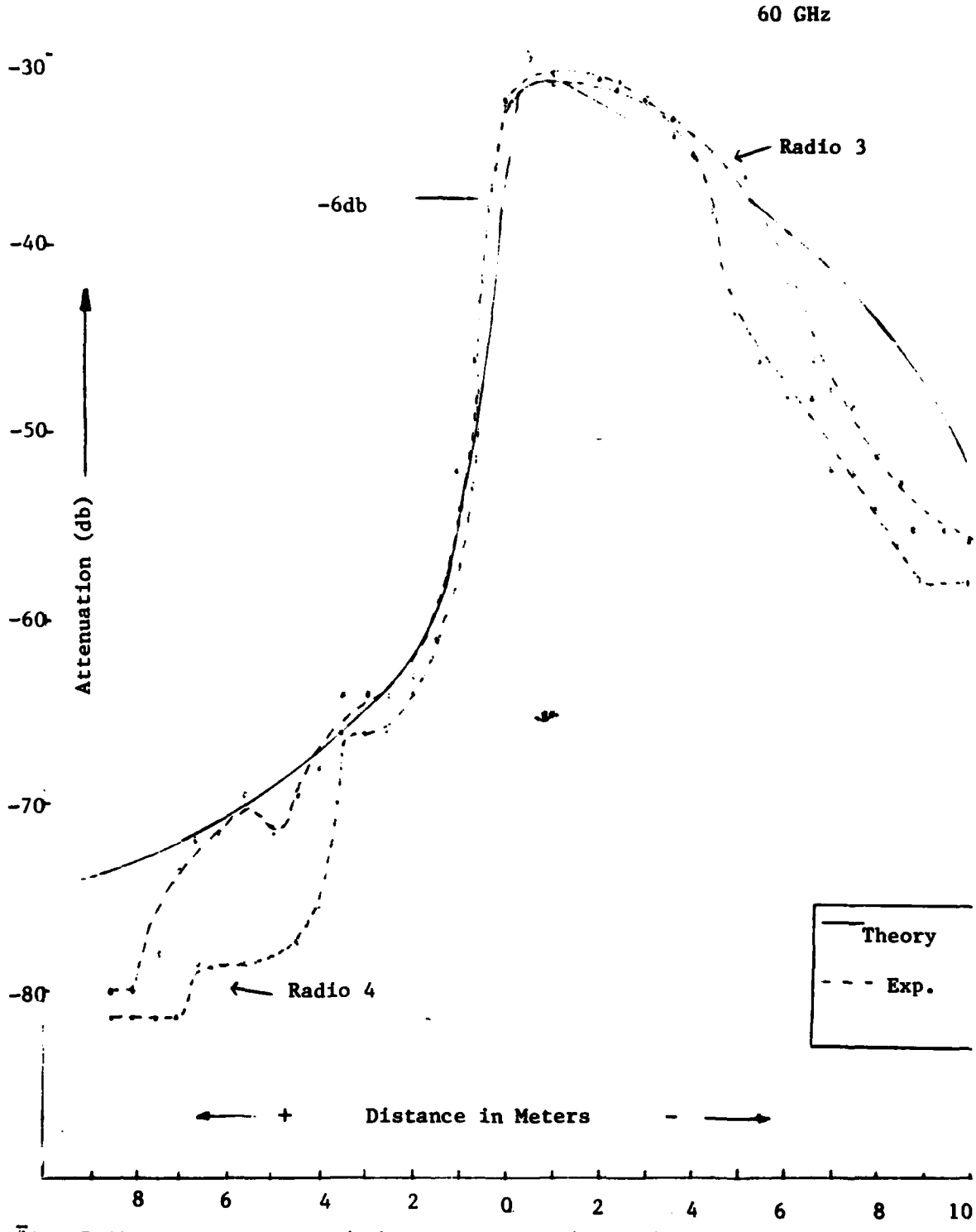


Fig. 7-Signal attenuation (db) vs. distance (meters) from corner of Hexagon Building (see Fig. 5a).

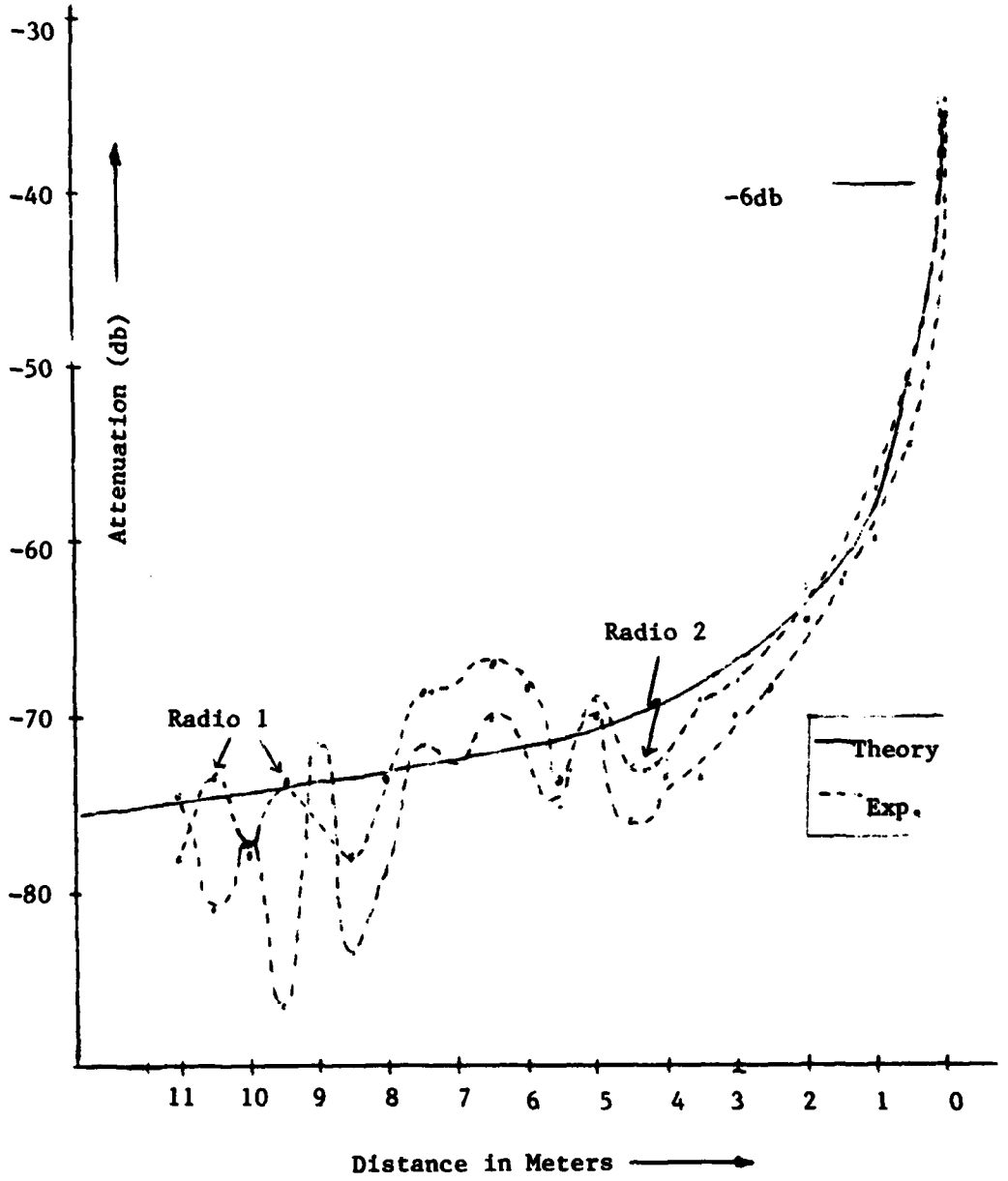


Fig. 8 - Signal attenuation (db) vs. distance (meters) from building 1204 at Fort Monmouth, (see Fig. 5b)

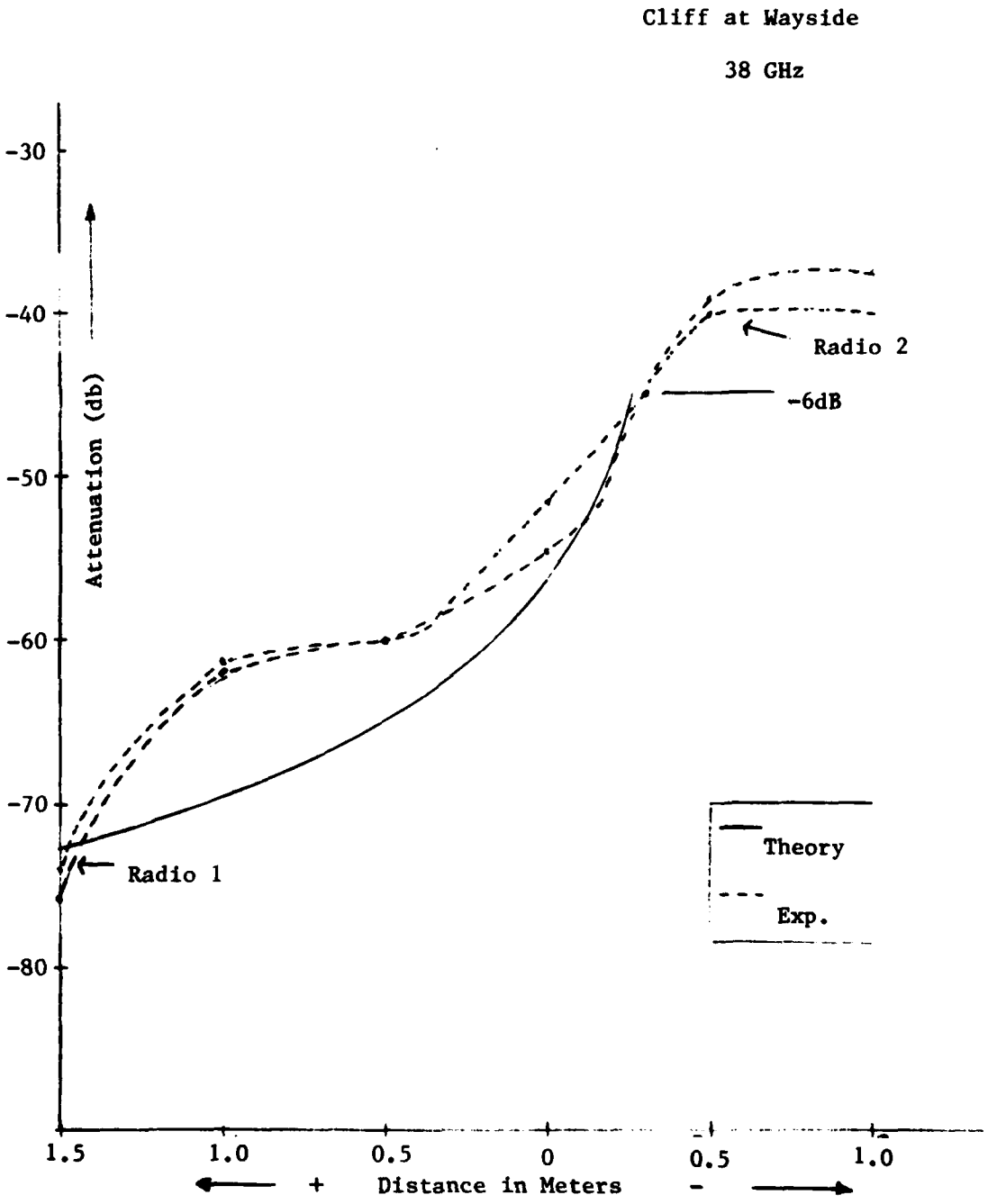


Fig. 9 - Signal attenuation (db) vs. distance (meters) from small hill at Wayside Test Area (see Fig. 5c)

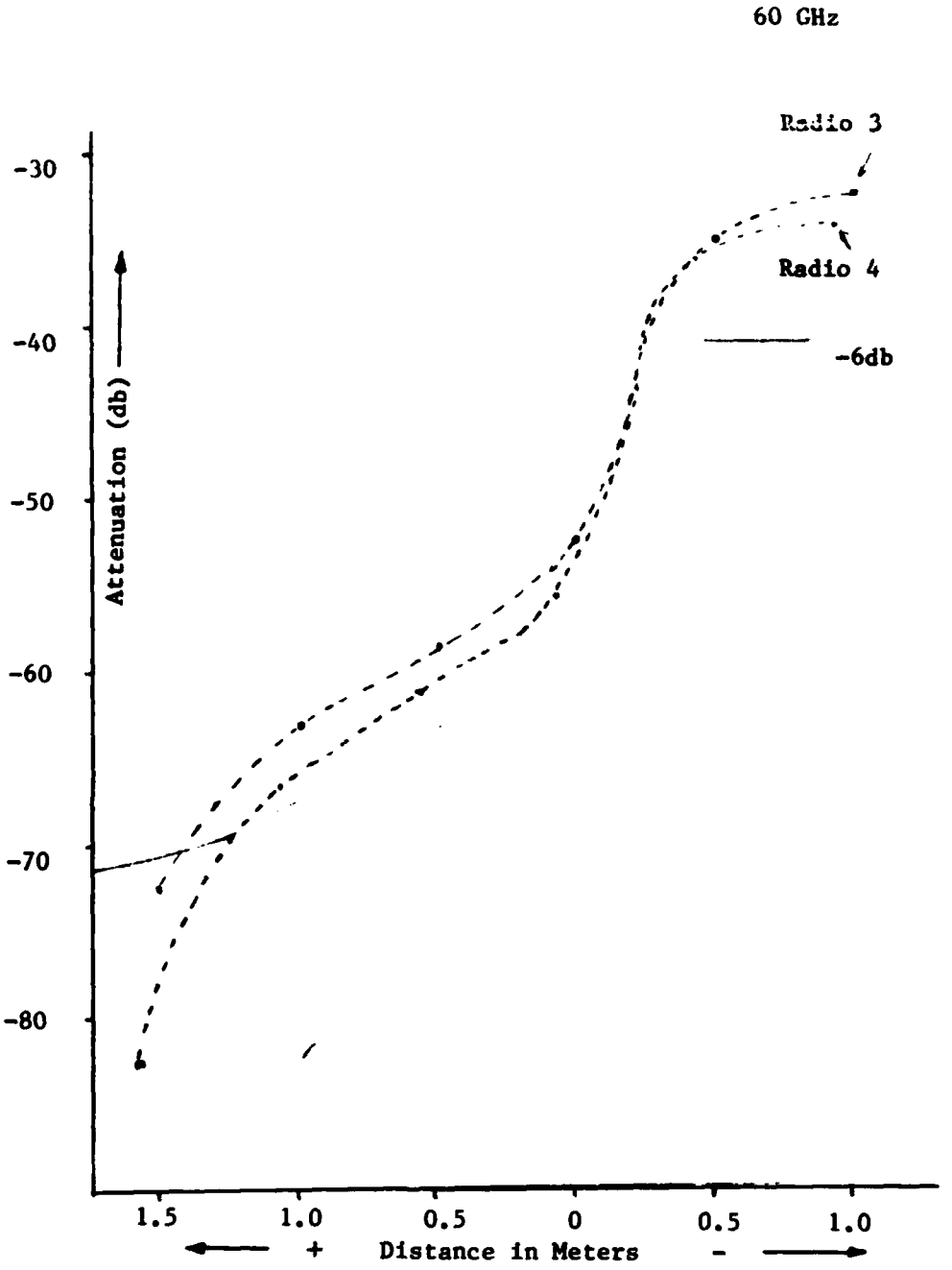


Fig. 10 - Signal attenuation (db) vs. distance (meters) from small hill at the Wayside Test Area, (see Fig. 5c)

It is seen that, in general, the experimental results are in very good agreement with theory. A notable exception is the 38 GHz data taken at Wayside (Fig. 10) where a small, rather undefined hill was the intervening object.

4. CONCLUSIONS:

a. Agreement between theory and experiments is good. Edge diffraction effects can be estimated realistically from theory.

b. The shadow boundary at mm-wavelength is well defined and narrow; the depth to which a receiving antenna can be moved into the geometrical shadow zone of an obstruction is limited. If signal attenuation due to shadow effects is restricted to 30dB, this depth is in the order of a few meters or a few tens of meters depending on frequency and radial distance from the edge of the obstruction.

c. In general, radio communications at millimeter wavelengths cannot be expected to provide coverage into areas much beyond the line-of-sight. However, in short range applications, there is a shallow shadow zone where non-line-of-sight camouflaged type communications can be maintained.

ACKNOWLEDGEMENT

The authors wish to express their sincere appreciation to Dr. Schwering for providing the theoretical analysis for this report.

Reference:

(1) K. Bullington, "Radio Propagation Fundamentals", Bell Systems Technical Journal, Vol. 36, No. 3, 1957.

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