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Indoor Television Antenna Performance

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Indoor Television Antenna Performance

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The ability of a television receiving antenna to deliver adequate signal power to the terminals of its receiver is determined by its gain relative to a lossless half-wave dipole antenna. This report presents measured gain data for indoor television receiving antennas in the VHF and UHF bands and discusses the effects of building attenuation and height gain on a power budget used to compare antenna performance.

1. INTRODUCTION

Antenna performance is generally characterized by antenna gain and input voltage standing-wave ratio, VSWR. Gain is a measure of both the directional properties of the antenna radiation pattern, called directivity, and the radiation efficiency. This efficiency is a measure of dissipative losses in the antenna elements, which are negligible for antennas fabricated with good dielectrics and conductors with dimensions on the order of one-eighth wavelength or larger. A result of television receiving antenna dimensions being on the order of one-half wavelength or larger is that their gain is basically due to directivity.

When antenna gain is measured relative to that of a tuned half-wave dipole antenna, mismatch loss becomes part of the measured gain. The term "tuned" implies that these losses are essentially eliminated from the reference dipole by adjusting its dimensions to obtain an input impedance providing a conjugate match to that of the transmission line to the test system receiver. This receiver is assumed to be perfectly matched to the transmission line. Conventional television receiving antennas are not tuned at all channel frequencies, and the resulting decrease in antenna gain caused by mismatch loss is minimized by the antenna design

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as much as possible. The optimum design has minimum mismatch loss and maximum directivity over the frequency band of interest.

Unless a frequency independent antenna design is employed, such as a log-periodic dipole array, television receiving antenna gain usually peaks near the middle of the frequency bands of interest. At this peak, the directivity and mismatch are nearly optimum. Below this peak, the antenna becomes electrically smaller, the directivity approaches that of a dipole, and mismatch losses tend to increase. Above this peak, the antenna becomes electrically larger, the main beam of the radiation pattern may become multilobed, and mismatch loss may increase.

Antenna VSWR is generally used in performance specifications rather than mismatch loss because it is an easily measured scalar quantity. The VSWR is related to mismatch loss by the following equation:

$$\text{Mismatch Loss (dB)} = 10 \log_{10} \left(1- \left(\frac{\text{VSWR}-1}{\text{VSWR}+1} \right)^2 \right)$$

when the antenna is attached to a receiver with an input VSWR = 1. Table 1 relates a range of mismatch loss and VSWR.

TABLE 1. VSWR vs. Mismatch Loss

VSWR	Mismatch Loss dB
1.0	0.0
1.5	0.2
2.0	0.5
4.0	1.9
8.0	4.0
16.0	6.6

The directivity and mismatch loss can be calculated for a linear dipole antenna in free space (FitzGerrell, 1967). The sum of these quantities is antenna gain and, as used in this report, is relative to that of a lossless half-wave dipole. Data plotted in Figure 1 illustrate the relation between these quantities versus frequency for a dipole one-half wavelength long at 177 MHz, the middle of Channel 7, with a 1 cm diameter. The data show that a gain of 0 dB at 177 MHz could be realized by tuning the dipole to the 100 ohm balanced transmssion line assumed in these calculations. A lossless tuning device would be required to eliminate the 0.4 dB mismatch loss resulting from a VSWR of 1.8 at 177 MHz.

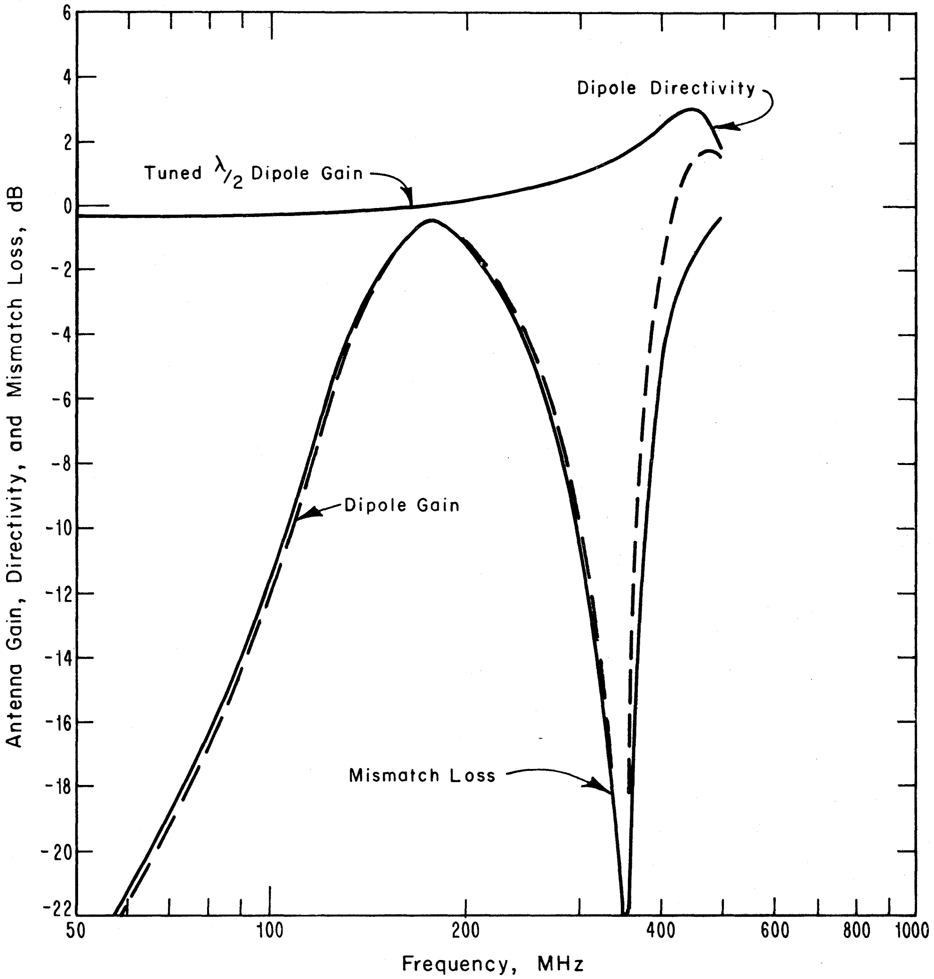

Figure 1. Gain, directivity, and mismatch loss for a dipole 84 cm long, 1 cm diameter connected to a 100 ohm balanced transmission line.

Measured length and loss data versus frequency for an extensible reference dipole is shown in Figure 2. A minimum VSWR is obtained at 177 MHz with a length of 81 cm. This reference dipole is attached to the out-of-phase ports of a hybrid junction with two equal length, 50 ohm, coaxial cables. Measured insertion loss of the hybrid junction used as a balanced-to-unbalanced line transformer, or balun, is 0.74 dB. Measured mismatch loss of the antenna at the balun input port is 0.18 dB caused by a VSWR of 1.5 giving a total correction due to losses of 0.92 dB to add to the dipole gain, yielding an actual tuned dipole gain of 0 dB. In the actual data processing, this correction is subtracted from measured test antenna gain because a relative gain measurement technique is employed. This correction is important because a lossless half-wave dipole is the standard of reference and uncorrected losses will make the relative gain of the antenna being tested greater by an amount equal to the correction factor.

All but one of the indoor antennas measured for this report had balanced transmission line terminals, thus requiring the use of a commercial television balun to connect them to the receiving system. Corrections to the test antenna gain data were made for losses in this balun as was the case for the reference dipole. Balun insertion loss and mismatch loss, with a 300 ohm resistor between the balanced line terminals, were measured using a 75 ohm bridge. The sum of these losses is plotted versus frequency in Figure 3. Insertion loss predominates and increases with frequency to relative maximums of 0.9 dB at 195 MHz and 2 dB at 750 MHz; it decreases to 1.2 dB at 900 MHz. Mismatch loss increases uniformly with frequency to 0.45 dB at 900 MHz; it is less than 0.1 dB below 650 MHz.

The calculated data in Figure 1 show that a 1.3 wavelength dipole (88 cm at 450 MHz) may have 3 dB more directivity than a tuned half-wave dipole. Therefore, a dipole type of television antenna may have a gain of 3 dB if some method of reducing mismatch loss is used in its design. For single element antennas the shape and length are changed from those of a linear half-wave dipole to those of a loop, which is a circular folded dipole, and those of a bow-tie, which is a triangular dipole. Various arrays of simple antenna elements are used to obtain antenna gains greater than 3 dB.

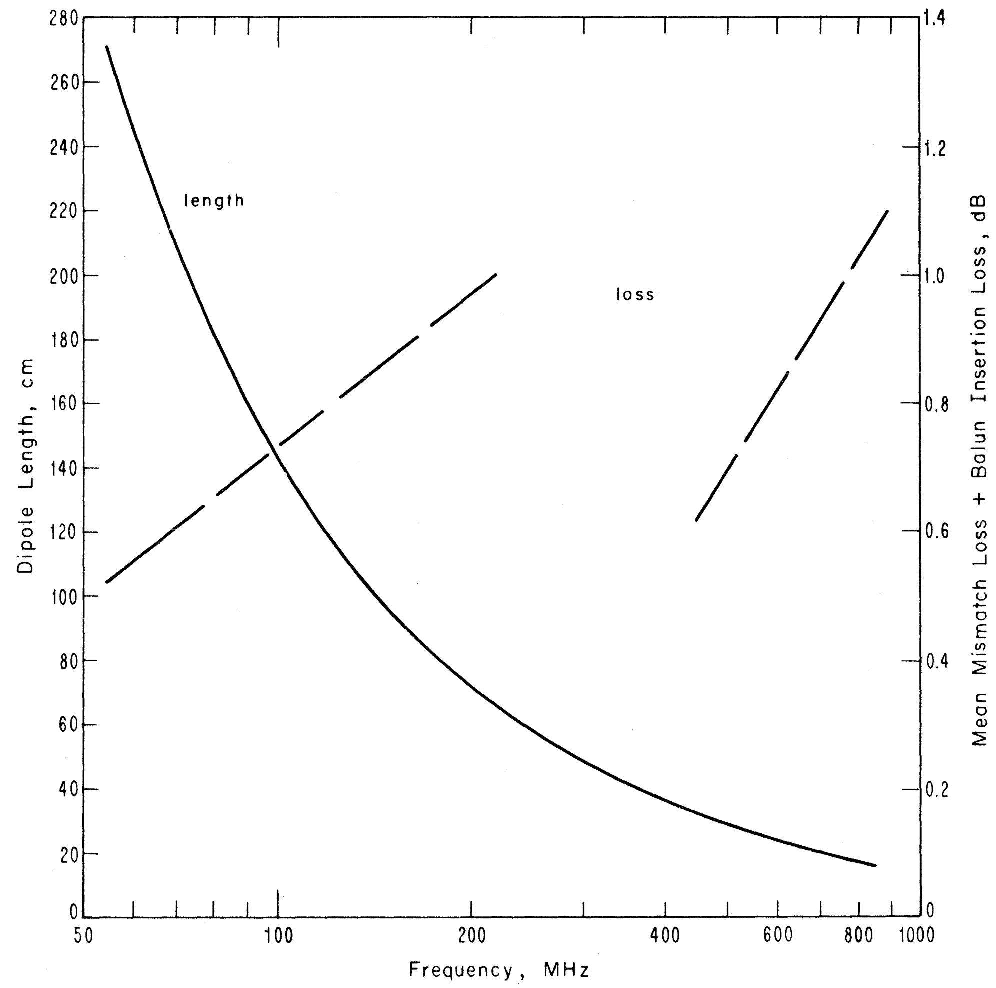

Figure 2. Measured reference half-wave dipole length and mismatch loss plus balun loss.

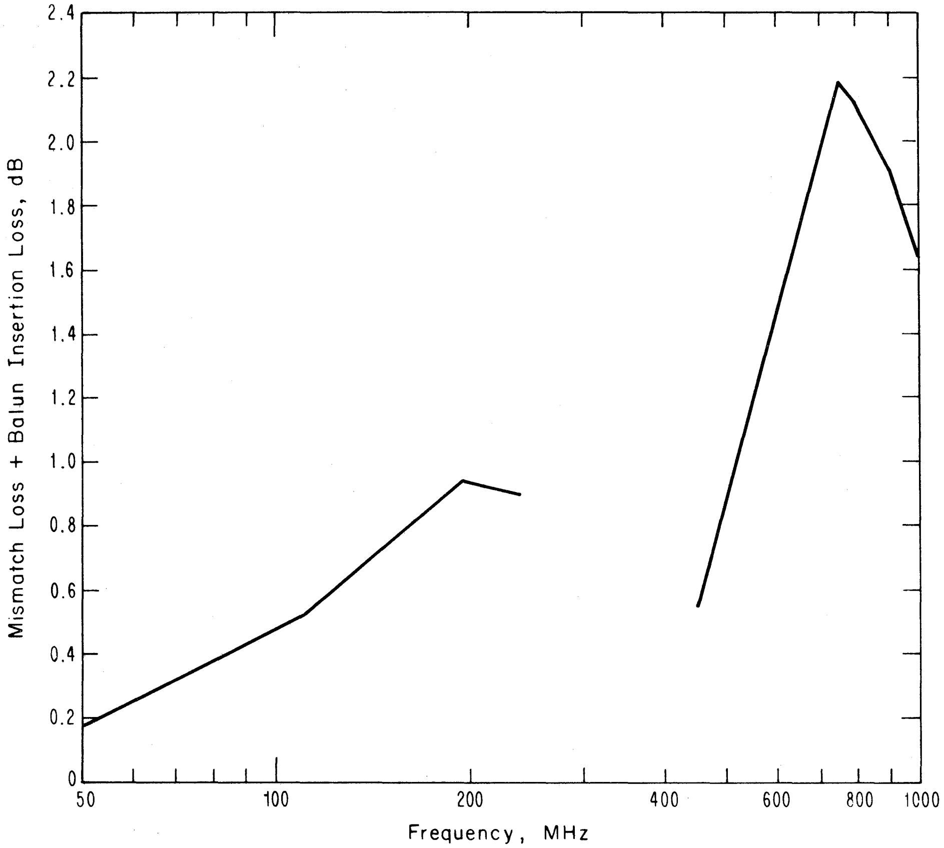

Figure 3. Measured test antenna balun mismatch loss plus insertion loss.

2. THE GAIN MEASUREMENT TECHNIQUE

The Table Mountain antenna test range consists of a large turntable, flush with test range ground, illuminated by a VHF/UHF television antenna erected 6 m above ground about 700 m away. A frequency synthesized signal generator provides a CW signal to the illuminating antenna. A reference dipole antenna is placed on a tripod, centered on the turntable, at heights on the order of 2 m to 4 m and a reference signal level is measured. This level is entered in the receiving system computer and a radiation pattern is measured to check for proper dipole pattern and for maximum gain at the -15 dB plot amplitude - a result of a computer normalization based on the reference signal level. The reference dipole is replaced by a test antenna and another radiation pattern is produced with receiving system gain levels unchanged. The gain of the test antenna relative to that of a lossless half-wave dipole at the same height is the decibel level on the plot above (+) or below (-) the reference level minus the dipole loss correction from Figure 2 plus the balun loss correction from Figure 3. Note, the balun is not used for the UHF monopole or the secondary reference antennas discussed later.

According to Cottony (1958), the resulting gain is numerically equal to free-space gain if the test antenna radiation pattern is symmetrical in the vertical plane, the plane of symmetry passes through the base of the illuminating antenna, and the terrain at the test site is smooth and flat. It is assumed that these conditions prevail at the Table Mountain test site and that the accuracy of the main beam gain data presented in this report are on the order of ± 0.5 dB.

Figure 4a is a plot of the reference dipole radiation pattern and 4b is a plot of the gain pattern, relative to that of the dipole maximum gain, for a double bow-tie antenna at 653 MHz. For this particular example, the relative gain is 7.1 dB, the reference dipole correction is -0.88 dB, and the balun correction is +1.72 dB, thus giving a gain relative to a lossless half-wave dipole of 7.9 dB.

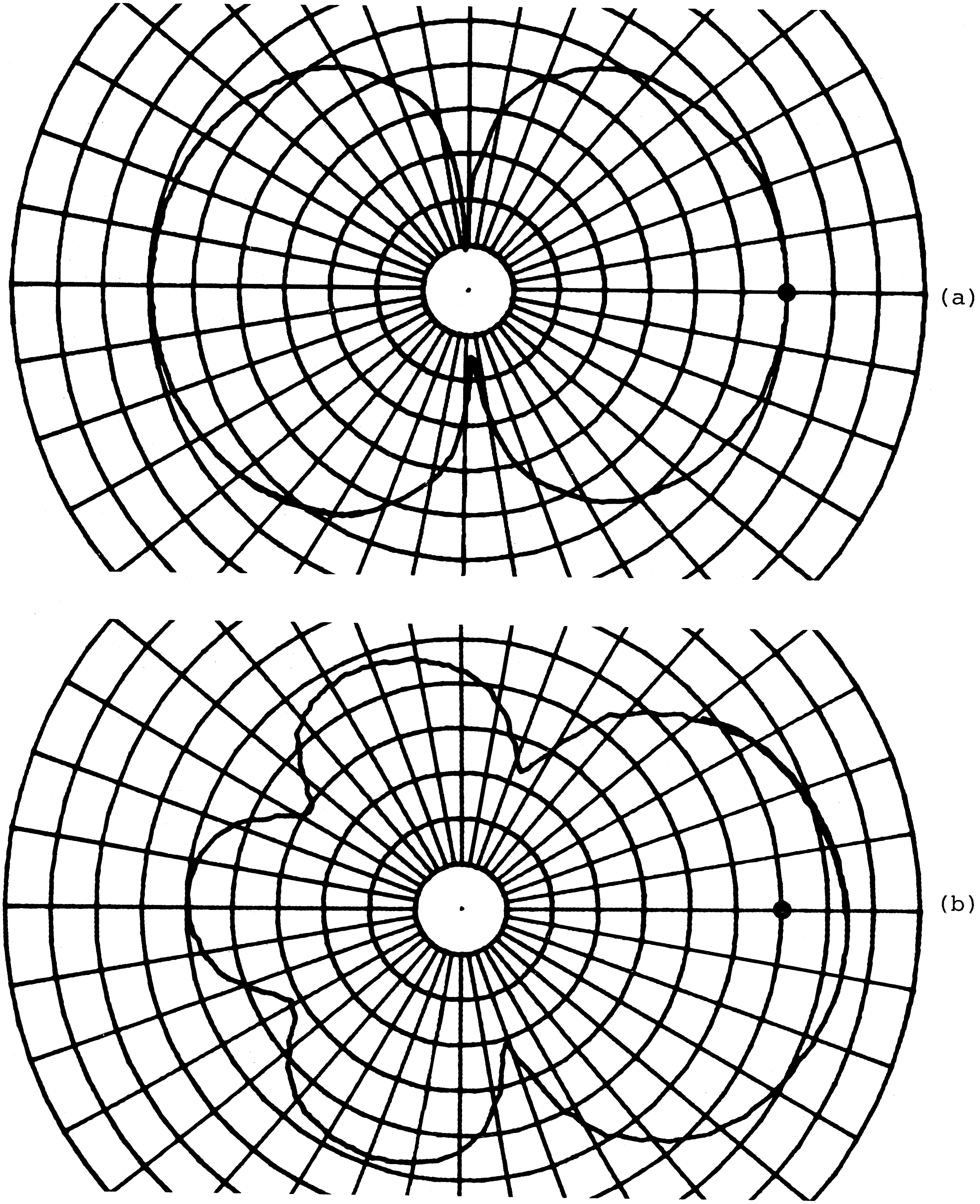

Figure 4. (a) Reference dipole gain pattern normalized to the -15 dB plot level (5 dB per amplitude increment) measured at 653 MHz. Reference level is circled.
(b) Double bow-tie array gain pattern measured at 653 MHz.

3. INDOOR ANTENNAS AND MEASURED GAIN

Six indoor antennas purchased for this gain measurement effort are listed below.

A. A conventional VHF extensible "rabbit ears" antenna measured with both elements fully extended to their 110 cm length and oriented in the vertical plane 45 deg above horizontal.

B. A VHF/UHF indoor antenna consisting of extensible VHF "rabbit ears", with a VHF 12 position tuning switch, combined with a UHF loop and rotatable coupling loop. The VHF elements were fully extended to their 115 cm length and oriented in the vertical plane 45 deg above horizontal. The tuning switch was adjusted for maximum received signal level, corresponding to minimum mismatch loss, at each test frequency. The UHF gain was measured with the VHF elements at their shortest length. The UHF pattern changed somewhat with rotation of the coupling loop, but the gain remained essentially constant.

C. A monopole antenna consisting of a portable television replacement rod assembly mounted on a wire grid model of a receiver. This element was extended 44 cm and oriented 45 deg above horizontal. This length minimized mismatch loss over the UHF band.

D. An original equipment UHF loop, with a 17.5 cm diameter, supplied with portable television receivers.

E. An original equipment clip-on UHF bow-tie dipole 33.5 cm long.

F. A bow-tie array consisting of two UHF bow-tie dipoles arrayed vertically 21.5 cm apart and 5 cm in front of a 32 cm square reflector grid.

A combination VHF/UHF antenna for use as a secondary reference antenna for field measurements was fabricated using a 4-bay UHF bow-tie array and a modified, VHF, log-periodic dipole array. The UHF array has a 42 cm by 91 cm reflector and the VHF array has a 160 cm boom length. A 61 cm spacing between these antennas results in a modest sized, lightweight antenna, on a single supporting mast.

The antennas are electrically connected to a single 50-ohm coaxial cable with a VHF/UHF splitter and balun combined in a small weatherproof box. Gain of the outdoor antenna provides a useful comparison for judging the gains of the indoor antennas.

Figure 5 is a plot of measured antenna gains versus frequency and Figures 6a and 6b are plots of measured antenna VSWR versus frequency. As discussed in Part 1, mismatch loss caused by VSWR values greater than unity are an intrinsic part of gain as defined in this report.

Indoor VHF antennas with a 90 deg angle between the elements in the vertical plane are quandrant antennas. The antennas have gain for both vertically and horizontally polarized field components thus reducing their gain below that expected of a purely horizontally polarized dipole. The VHF tuning on the VHF/UHF indoor antenna does reduce mismatch loss by improving the VSWR as shown in Figure 6. The gain of the indoor VHF antennas is 4 dB to 10 dB below that of the combination VHF/UHF outdoor antenna.

The UHF monopole and UHF portion of the VHF/UHF indoor antenna have similar gains 2 dB to 20 dB below that of the combination VHF/UHF outdoor antenna. Loop antenna gain appears to have been sacrificed for the ability to steer the ill-defined radiation pattern of the VHF/UHF indoor antenna. Low monopole gain is also due to an ill-defined radiation pattern and the fact that this antenna should have a substantial amount of gain for verticaly polarized field components.

The indoor UHF loop and clip-on bow-tie have similar gains over a relatively broad frequency band for such simple antennas. Their maximum gains are comparable with that of the maximum dipole directivity shown in Figure 1.

The double bow-tie indoor UHF antenna has a maximum gain 6 dB greater than that of the single bow-tie antenna, which is exactly the value simple array theory would predict if the reflector grid behind the dipoles was very large. An infinitely large reflector places all of the radiation pattern into one hemisphere, thus resulting in a 3 dB increase in directivity. Doubling the number of elements also doubles the directivity, approximately, giving another 3 dB increase. The same reasoning should result in a 4-bay bow-tie antenna gain 3 dB greater than that of the double bow-tie array. Measurements indicate 1.6 dB greater gain because the balun and splitter, which are an integral part of the outdoor VHF/UHF combination antenna, have an insertion loss on the order of 1.5 dB.

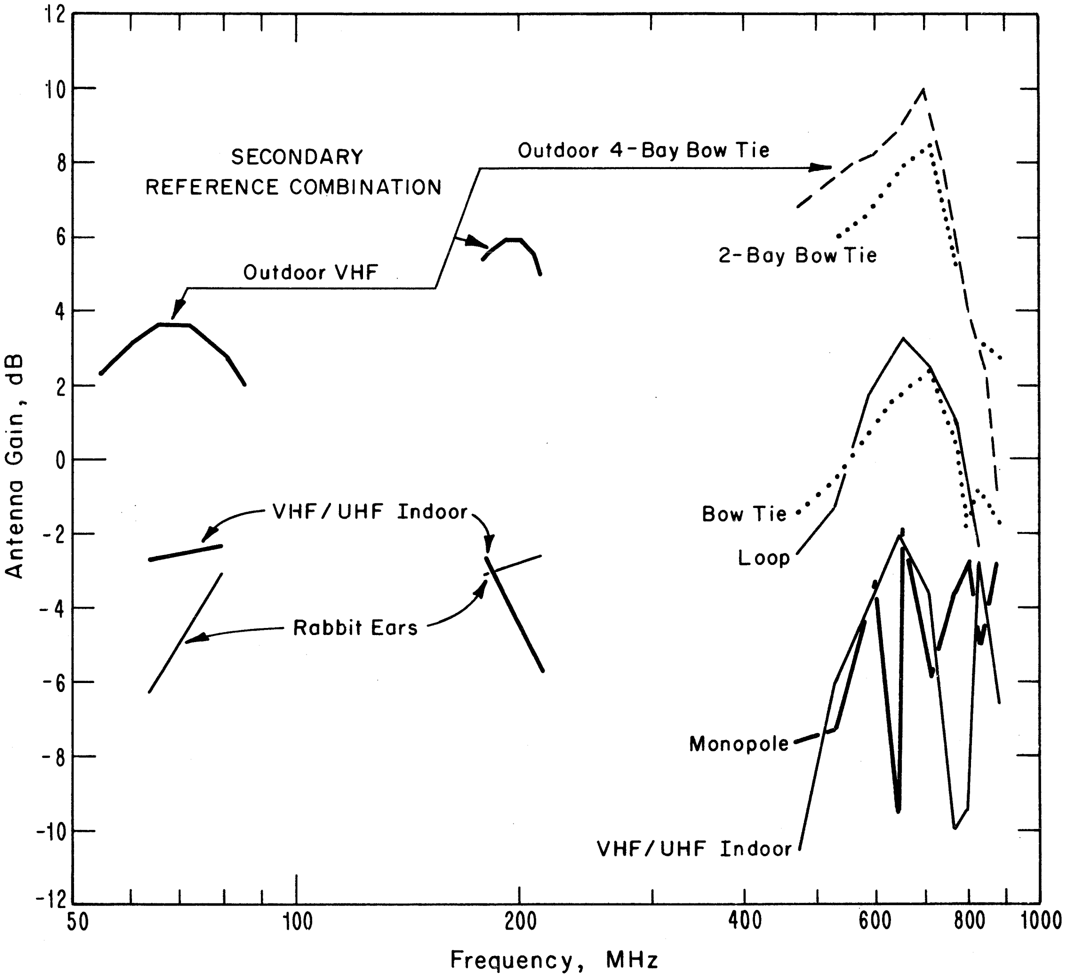

Figure 5. Measured gain versus frequency of the eight antennas.

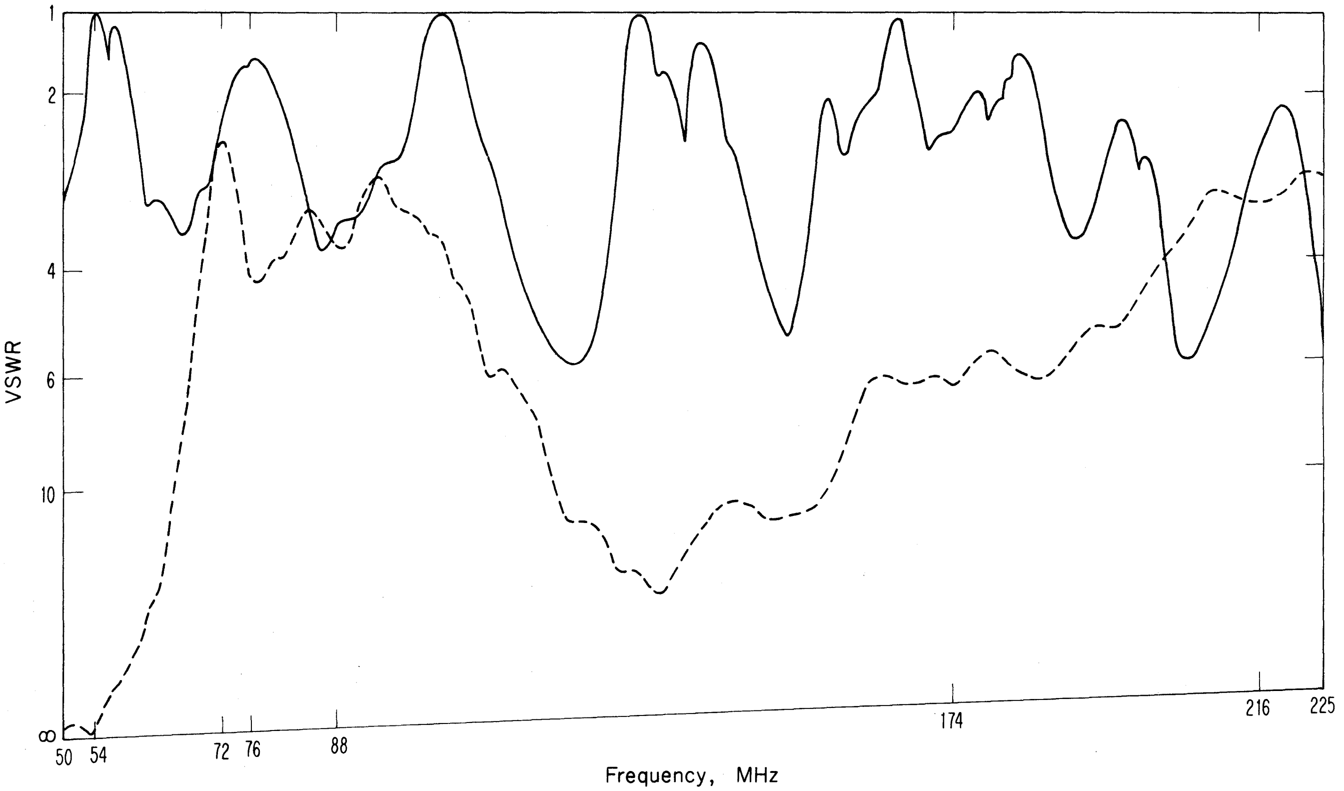

Figure 6(a). Measured VHF antenna VSWR for the VHF/UHF indoor antenna, solid line, and the rabbit ears, dashed line. Note the solid line is the minimum VSWR envelope for twelve tuning switch positions.

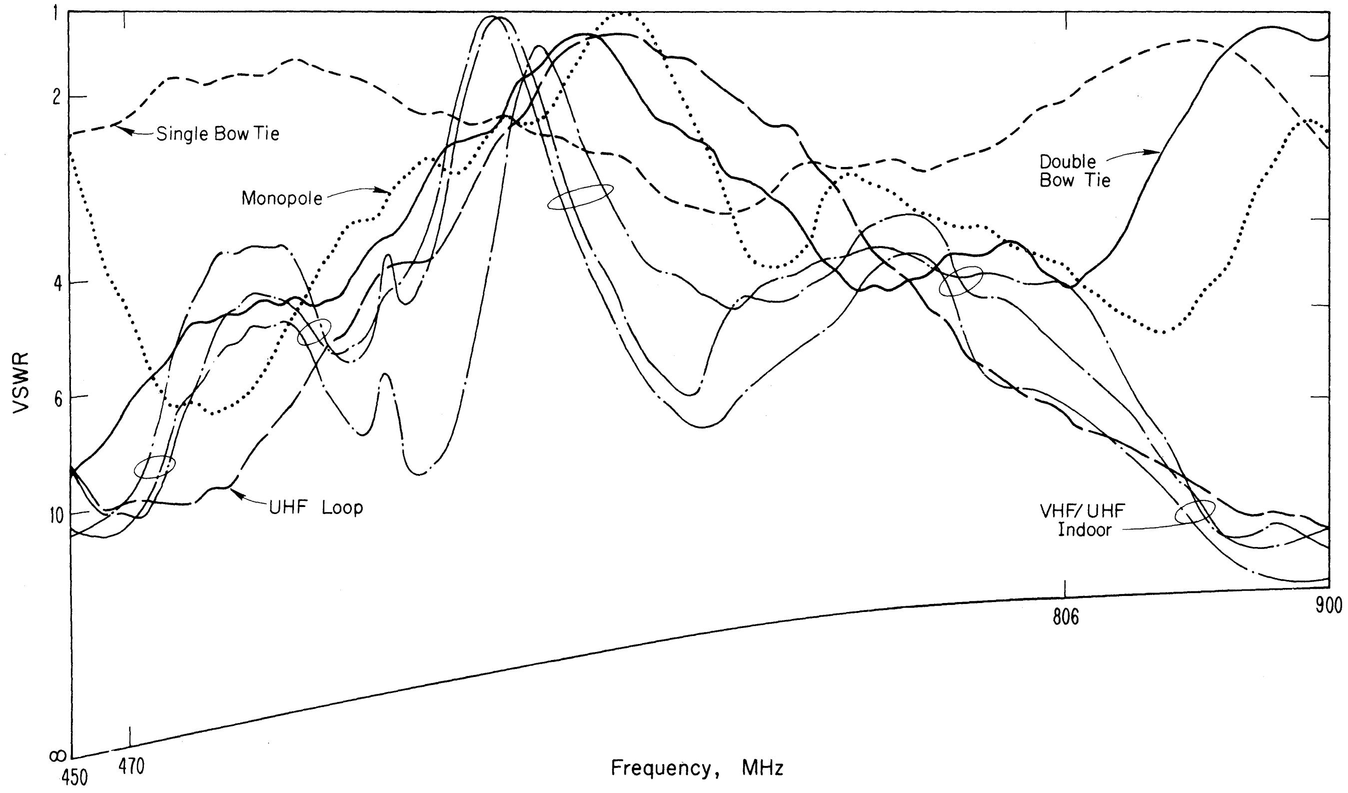

Figure 6(b). Measured UHF antenna VSWR. The VHF/UHF indoor antenna was measured for three different coupling loop orientations.

4. SITING LOSSES

Television reception using indoor antennas will be affected by all normal propagation phenomena plus building attenuation. Limited building attenuation data are available. An excellent review of pertinent literature prior to 1975 is given by Wells, et al., (1975). Wells and Tryon (1976) report 6.3 dB average attenuation measured in single family homes at 860 MHz using ATS-6 as the source of site illumination. Snider (1965) reported median losses of 5.5 dB at 180 MHz and 7.8 dB at 750 MHz in buildings on the University of Colorado and Colorado School of Mines campuses. An average value of 6.6 dB building attenuation for VHF/UHF television is probably a good assumption based upon the cited data. This loss is offset somewhat by the loss in the transmission line to an outside antenna. These losses average 0.3 dB at the low end of the VHF band to 1.1 dB in the UHF band for 10 m of new, dry transmission line according to Swinyard (1960). The net loss caused by indoor antenna siting rather than outdoor siting is about 6.3 dB at VHF and 5.5 dB at UHF.

The field strength at the indoor antenna may be less than that at an outdoor antenna because of the antenna height over ground. Typically an outdoor antenna may be 6 m to 12 m above ground while the indoor antenna may be 2 m to 6 m above ground depending upon the height of the building and antenna location.

To obtain realistic field strengths as a function of antenna height, the Institute for Telecommunication Sciences, Radio Propagation Over Irregular Terrain, Version 5.00 (9/8/77), computer program was used to calculate field strengths at 70 MHz and 700 MHz for randomly sited receiving antennas 10 km to 50 km from a 7.85 dB gain transmitting antenna, 450 m above average terrain, with an input power of 100 kW. Three different terrain roughness factors, ΔH, were used to indicate rolling plains, $\Delta H = 40$ m; hills, $\Delta H = 80$ m; and mountains, $\Delta H = 160$ m. Other propagation parameters were chosen to match those of the Aurora, Colorado area where ΔH happens to be 83 m. These calculated data are presented in Table 2, where the field strengths are expressed in decibels relative to 1 microvolt per meter, or dBu.

Also presented in Table 2 are the field strength differences between the 2 m and 9 m receiving antenna heights at 70 MHz, Δ_{70}, and at 700 MHz, Δ_{700}. The overall average of Δ_{70} is 6.4 dB with a range of only 2.2 dB. The overall average of Δ_{700} is 5.2 dB with a range of 10.9 dB.

The relative loss incurred by siting a VHF antenna indoors at a 2 m height rather than outdoors at a 9 m height is about 12.7 dB as a result of a net loss of 6.3 dB for building attenuation and 6.4 dB for the decrease in field strength with height. This relative loss is 10.7 dB at UHF as a result of a net loss of 5.5 dB for building attenuation and 5.2 dB for the decrease in field strength with height.

TABLE 2. Field Strength (FS), dBu,

For ΔH = 80m

	Receive Antenna Height = 2 m		Receive Antenna height = 9 m		Δ_{70} dB	Δ_{700} dB
Distance	Frequency, MHz		Frequency, MHz		FS @ 9m	FS @ 9m
km	70	700	70	700	-FS @ 2m	-FS @ 2m
10	99.9	102.7	106.1	102.7	6.2	0.0
20	88.4	96.5	95.6	96.5	7.2	0.0
30	80.5	92.9	88.0	92.9	7.5	0.0
40	74.2	90.3	81.5	90.4	7.3	0.1
50	68.7	82.8	75.8	87.1	7.1	4.3
For ΔH = 80m						
10	97.4	102.4	102.7	102.4	5.3	0.0
20	86.9	96.3	92.5	96.3	5.6	0.0
30	79.4	91.9	85.2	92.7	5.8	0.8
40	73.1	84.2	79.0	90.2	5.9	6.0
50	67.6	77.1	73.5	83.2	5.9	6.1
For ΔH = 160m						
10	94.2	97.9	98.2	102.2	5.8	4.3
20	82.4	87.3	88.5	96.1	6.1	8.8
30	75.2	79.2	81.5	90.1	6.3	10.9
40	69.1	72.1	75.5	82.8	6.4	10.7
50	63.6	65.7	70.2	76.1	6.6	10.4

5. DISCUSSION AND CONCLUSIONS

Power budget equations relating the power flow in the plane-wave field incident on an antenna to the power available at the receiver terminals are useful for comparing antenna system performance at different frequencies. The only component of power budget equations for simple antenna, transmission line, receiver systems not discussed so far is the antenna constant which is equal to the ratio of power available at the terminals of a properly oriented half-wave dipole antenna to the power flow per unit area in the incident field (FitzGerrell, et al., 1979). The antenna constants at 70 MHz and 700 MHz for a power flow of 1 W/m^2 at the antenna are +3.8 dB and -16.2 dB. The calculated field strengths at the receiving antenna for a middle value path in Table 2, ΔH = 80 m and distance = 40 km, are converted to power flow relative to 1 W/m^2 in Table 3. Note that, for this path, Δ_{70} = 5.9 dB and Δ_{700} = 6.0 dB which are close to the average values.

TABLE 3. Calculated Power Flow Values for the 40 km Path With ΔH = 80 m in Table 2.

Antenna Height, m	Frequency MHz	Field Strength, dBu	Power Flow, dB rel to 1W/m^2
2	70	73.1	- 72.7
9	70	79.0	- 66.8
2	700	84.2	- 61.6
9	700	90.2	- 55.6

Power budget equations for power at the receiver terminals in dB relative to 1 W, dBW, can now be written using the power flow data from Table 3.

POWER BUDGET

Indoor Antennas, 2m Above Ground

Frequency, MHz	70	700
Power Flow, dB rel to 1W/m^2	- 72.7	- 61.6
Antenna Constant, dB	+ 3.8	- 16.2
Range of measured gain from Fig 5, dB	- 4.8, -2.5	- 5.0, + 8.4
Building attenuation, dB	- 6.6	- 6.6
Transmission line loss, dB	0	0
Range of Power received, dBW	- 80.3, -78.0	- 89.4, -76.0

Outdoor Antennas, 9m Above Ground

Frequency, MHz	70	700
Power flow, dB rel to 1 W/m^2	- 66.8	- 55.6
Antenna constant, dB	+ 3.8	- 16.2
Measured gain from Fig 5, dB	+ 3.6	+ 10.0
Building attenuation, dB	0	0
Transmission line loss dB	- 0.3	- 1.1
Power received, dBW	- 59.7	- 62.9

From these power budget data it is apparent that adequate indoor antenna gain is available to make signal levels delivered to the television receiver comparable at VHF and UHF for the particular conditions assumed in these power budget equations.

Outdoor antenna power budget data for 9 m antenna heights are at least 13.1 dB greater than corresponding indoor data. A significant factor in the difference is the 6.6 dB building attenuation. To overcome 6 dB of this attenuation, the size of the double bow-tie array would have to be doubled in width and height. That is, an eight element bow-tie array in front of a 65 cm square reflector might have a gain of 14.4 dB versus 8.4 dB for the double bow-tie array.

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