CORRELATING MEASUREMENT RESULTS MADE WITH A HORIZONTALLY POLARIZED DIPOLE AND A VERTICALLY POLARIZED MONOPOLE IN A CABLE TELEVISION ENVIRONMENT

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ABSTRACT

When making absolute measurements of radio frequency field intensity, the most important criterion is to establish an undisturbed field pattern at the point of measurement. Unfortunately, in the quest to quantify the magnitude of signal egress from a cable television plant source, the engineer is faced with a situation which is far from ideal. This paper will explore a few of the possible equivalent transmitting antenna configurations that make up the real cable world, how these hardware models affect propagation parameters and finally how the results are viewed by commonly used receiving antennas. A method of simulating a leakage field for dipole/monopole measurement correlation will be disclosed.

INTRODUCTION

Signal leakage—a term preferred by the cable television industry to describe the emission of energy from the imperfectly shielded environment which transports entertainment and commercial information in a point to multipoint manner—is the single remaining cable television technical parameter enforced by the Federal Communications Commission (FCC) as defined in Part 76 of the rules.

The task of maintaining leakage limits below the maximum specified by the Commission falls on the shoulders of industry engineering personnel. Providing leakage quantification within or close to the aeronautical bands of interest following measurement procedures provided in CFR 76.609(h) can result in the use of a receiving half-wave dipole which becomes quite cumbersome, i. e., about four and one-half feet at 108 MHz, particularly if the intent is to monitor the plant condition from a vehicle.

Aerial construction practices, in particular, place the coaxial system within close proximity to other conductors and structures, each of which provides the mechanism for potential field pattern disturbance. Such interference with the theoretical propagation phenomenon promotes the idea that the prediction of the plane of radiation may be arbitrary.

Given that the last idea has merit, it becomes far more convenient to use a quarter-wave vertically oriented whip (monopole) antenna as a monitoring tool. As will be shown later, results obtained through the use of this device can be equally accurate with those obtained through the use of a horizontal half-wave dipole.

Field strength patterns from fundamental antennas will be explored briefly, followed by a more comprehensive discussion of the disturbances caused by close proximity objects and their effect on typical patterns.

The study will conclude with a discussion of a test site and equipment used to provide dipole/monopole signal interception correlation, along with supporting tabular data.

TYPICAL UNDISTURBED ANTENNAE PATTERNS

Two antenna types, typical to the pursuit of signal leakage minimization within the cable television industry, have already been mentioned; the horizontal half-wave dipole and the vertical quarter-wave whip or monopole. Because of the physical properties involved, pinpointing the source of leakage requires yet a third pick-up device, the operation of which is very different from that used for signal leakage level quantification.

Within the plant, of course, are the transmitting antennas which are more obscure and thus less simple to define. Most all have at their root, however, the long wire antenna type.

The Near-Field vs The Far-Field

Before beginning more detailed discussion of field patterns from the various antennas types associated with CATV plant signal leakage control, it is necessary to briefly touch on electromagnetic fundamentals. The engineer is faced primarily with two problem types; to quantify the magnitude of the leakage signal and to locate the point source of this undesirable bi-product of cable television system operation in order to bring the first element to within specified boundaries. Effective solutions to the described problems require working within both the *far-field* and the *near-field* environments. Proper field intercept for the respective types involve the use of very different tools.

It is a fact that any time current passes through a conductor, an electric and a magnetic field is created some of which is radiated. Radiated electromagnetic energy is self-perpetuating by virtue of the alternating collapse and build-up of electric (E) and magnetic (H) fields comprising the energy unit that has broken loose from its parent. It is, therefore, no longer dependent upon or influenced by any **subsequent** energy emitted from the parent fields. That notwithstanding, even though the energy has become independent, it is subject to loss in the form of heat, generated because of the perpetually alternating interaction between the E and H fields. As a result, the radiated field eventually becomes infinitesimal.

From the point that radiation occurs, the magnitudes of electric and magnetic fields, theoretically and practically, follow rather rigid rules. If the two field energies necessary for signal propagation are provided names, the progenitor could be called the *induction* field and of course the free spirit will be called the *radiation* field.

The induction field loses intensity very rapidly (proportional to between the third to the fifth power of the distance) at points much less than one wavelength from the conductor and at intermediate distances, the intensity drop is less dramatic but still proportional to the square of the distance. Figure 1 demonstrates that by the time several wavelengths are reached, the induction energy remaining is so small that the radiation field intensity becomes dominant and remains that way until the signal becomes undetectable. The radiation field disburses at a rate of half the intensity for each distance doubling.

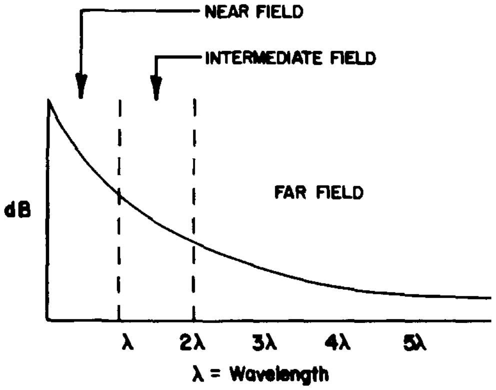


Figure 1 - Near-Field and Far-Field Attenuation

Several important things to note:

There is no magic, single point boundary delineating the near-field from the far-field zones. At the point where the drop in field intensity is sufficiently close to the rate of one-half per frequency doubling, a far-field condition exists;

Accurate quantification of field intensities can be made only with appropriate far-field receiving antennas;

Devices made to intercept near-field energy **do not** provide accurate indication of far-field absolute intensities, regardless whether such devices are used in the far-field **or in the near-field**. Attempts to quantify the absolute intensity value of the near-field energy surrounding an emitter requires the insertion of a probe directly into the flux with a special aperture designed for this purpose. In this manner, this tool is used to locate the source of the energy.

The Horizontal Half-Wave Dipole

The half-wave dipole is a fundamental antenna type which, when segmented into very small unit lengths, is often used to define the current distribution and related electrical characteristics along the entire length of other linear antennas.

When a half-wave dipole is suspended in free space such that no external factors infringe upon its ability to radiate freely, the field pattern appears as shown in Figure 2a and Figure 2b. It is difficult to do justice to the actual appearance of the pattern on the simplistic two dimensional view offered by the page on which it is drawn. However, a mental three-dimensional image might be described as a doughnut with a hole no larger than the diameter of the dipole element at the center. The items are oriented such that the dipole has been thrust into the hole in a manner allowing the doughnut to spin on the dipole element with the dipole element parallel to the surface of the Earth.

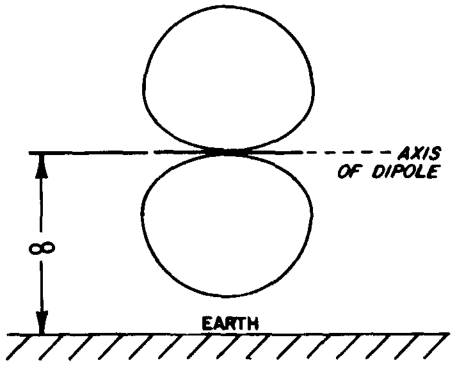


Figure 2a - Field strength pattern of half-wave dipole as viewed perpendicular to the axis of the dipole

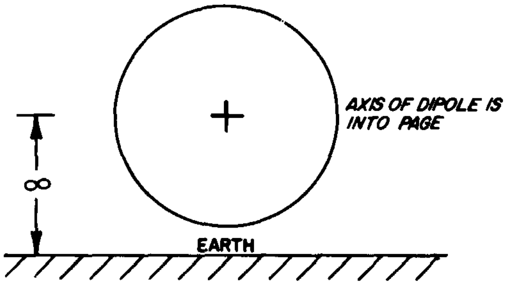


Figure 2b - Field strength pattern of half-wave dipole as viewed parallel to the axis of the dipole

The horizontal half-wave dipole transmits and is most sensitive to the reception of horizontally polarized waves (Figure 3).

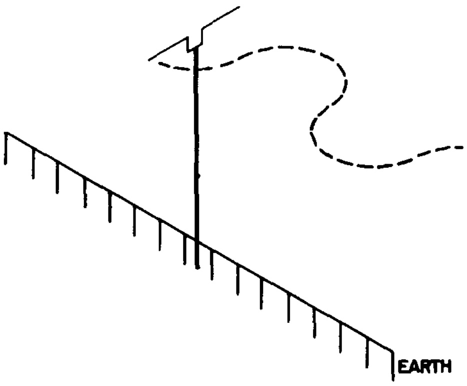


Figure 3 - Horizontally polarized waves emitted or received by a horizontal half-wave dipole

The Vertical Half-Wave Dipole

Rotating the horizontal half-wave dipole so that the elements are perpendicular to the Earth's surface creates a vertical half-wave dipole. The pattern created precisely duplicates that shown in Figures 2a and 2b except, of course, the doughnut is now parallel rather that perpendicular to the Earth's surface.

It follows that the vertical version transmits and is most sensitive to the reception of vertically polarized waves.

The Vertical Quarter Wave Whip (Monopole)

A more practical variation of the vertically oriented dipole, the radiation pattern of the quarter-wave whip antenna is again very similar to its parent. There are, however, several significant differences which affect the performance.

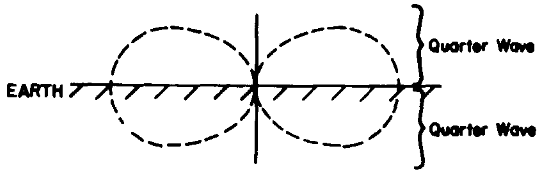


Figure 4a - Field strength pattern of a quarter-wave monopole as viewed perpendicular to the axis of the dipole

In order for the quarter-wave antenna to behave like its parent, the shorter counterpart must be closely associated with earth, whether natural or artificial. The earth then acts as the missing quarter wavelength to again reconstruct a half-wave antenna with one significant difference; the image does not contribute to overall power and sensitivity for transmitting and receiving, respectively. Figures 4a and 4b demonstrate the radiation pattern and Figure 5 provides an image of the vertically polarized transmitted or received signal.

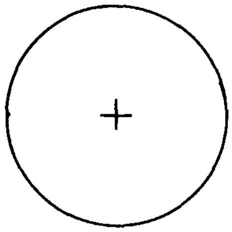


Figure 4b - Field strength pattern of a quarter-wave monopole as viewed parallel to the axis of the monopole

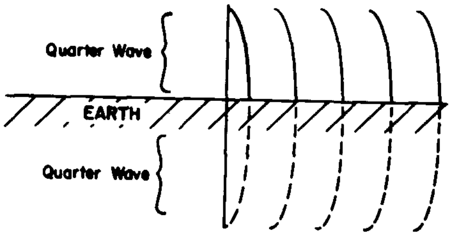


Figure 5 - Vertically polarized waves emitted or received by a vertical quarter-wave monopole

The Long-Wire Antenna

As the name implies, in its most primitive form, the long wire antenna can be made from any length conductor. There are some advantages if the length happens to correspond to a wavelength or some multiple thereof, particularly if the multiple is odd, i. e., 1, 3, 5, etc. Considering that the cable industry makes use of frequencies from 5 MHz to 600 MHz (wavelengths of 197 feet to 1.6 feet), the probability is high that, at some point in the system, this condition will be satisfied for one or more operating frequencies.

Consider a few of the long wire antenna transmitting possibilities which exist within real world aerial CATV construction. Figure 6 is a condensed segment of a situation which occurs frequently in the typical plant.

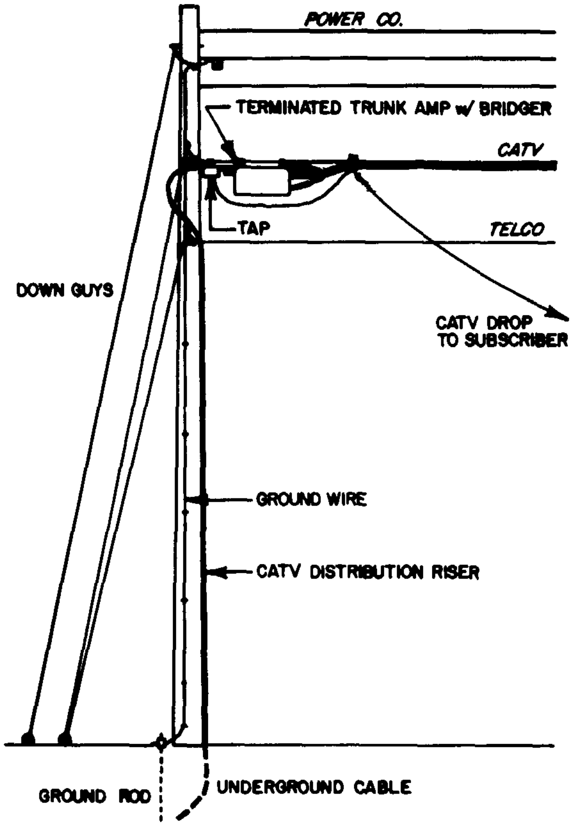


Figure 6 - Typical CATV construction with non-exclusive pole use

The lashed feeder/strand combination, the house drops, the grounding wire and the down guy each serve as examples of individual long wire antennas. Adaptations are easily constructed: The down guy, in reality, is a grounded *inclined* antenna, the lashed feeder/strand in combination with any one of the house drop wires can form a *"V"* antenna, as can any two house drops or the strand/grounding wire pair, so long as each combination contains a common angle.

Each segment deals with propagated currents in a different manner and the radiation effectiveness in any particular instance is totally dependent upon the configuration. Giving no regard to the conductor lengths and other factors such as included angles, etc., general radiation patterns for each segment type are provided in Figures 7a, 7b, 7c and 7d.

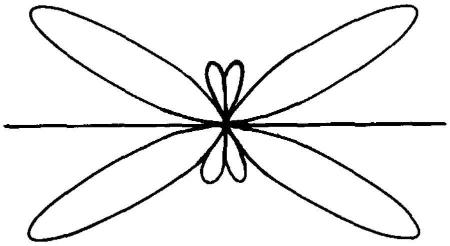


Figure 7a - Radiation pattern of an unterminated long-wire antenna

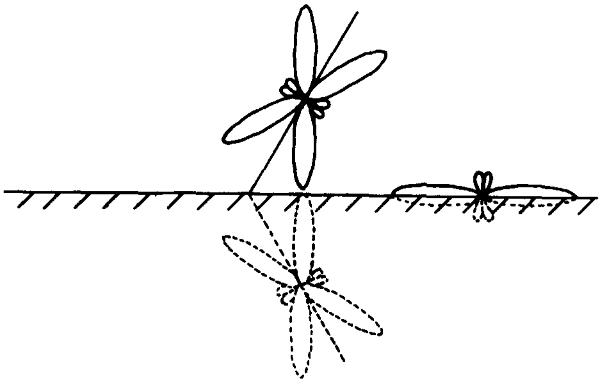


Figure 7b - Radiation pattern for a grounded inclined antenna

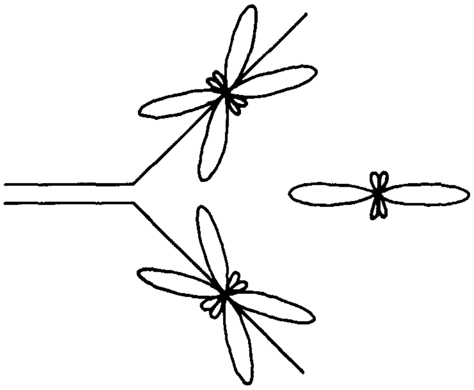


Figure 7c - Radiation pattern for an unterminated "V" antenna

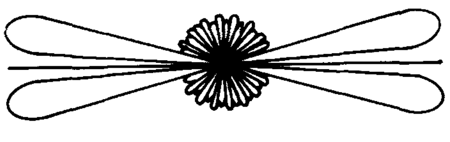


Figure 7d - Radiation pattern for extended length, unterminated long wire antenna

Figure 7a shows the radiation pattern of the fundamental element of the series, the simple straight wire which, if oriented horizontally, produces horizontally polarized wave propagation and if arranged vertically, produces vertically polarized waves.

A slight variation is considered in 7b which makes use of the Earth to create an image of the above ground inclined antenna. The geometrical summation of the field strength values individually occurring on each incline causes the resultant pattern drawn to the side.

Much the same response is achieved with the "V" antenna configuration (Figure 7c), except that the emitted energy is higher when compared to the incline due to the reality of both elements constructing the "V." In all cases, extending the length of the radiating element will cause the main lobe to narrow and more tightly hug the radiating element as well as cause a larger number of narrower sidelobes as shown in Figure 7d. Keep in mind that drawings provided are simple, two dimensional views. Under ideal conditions, when sighting along the axis of the radiating element, the lobes form a symmetrically conical pattern.

Even though it has been mentioned earlier, it is also important that antennas unintentionally assembled as a result of normal plant construction practices propagate both horizontally and vertically polarized wavefronts. The dominant polarity is determined primarily by the physical angular rotation of the radiating element(s) about an axis parallel to a surface which appears as an infinitely conducting earth. This may take the form of Earth itself or any surface in any plane which is sufficiently reflective to act as a ground plane, i. e. some buildings, vehicles, etc. The difficulty to predict the magnitude or the polarization of the field pattern at any given frequency increases with normal field disturbance obstacles.

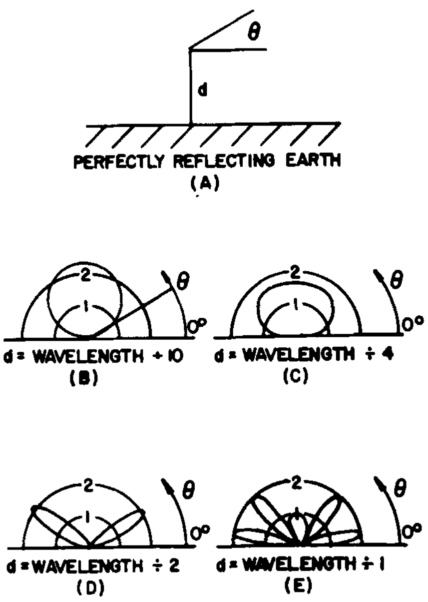
DISTURBANCES TO NORMAL RADIATION PATTERNS

There are many causes of disturbance to the normal radiation patterns of intentional and unintentional antennas. Perhaps the most dominant effect is that caused by the position of the conductors with respect to the earth and with large conductive structures (buildings, vehicles and the like). In addition to antenna configurations, Figure 6 also illustrates that typical cable plant is normally in close proximity to other conductors that are either **virtually** coupled (no direct electrical connection) as in the case of primary and secondary power lines or **directly** connected as power and telephone neutrals

The Effect of Earth and Equivalent Infinite Ground Planes

For those antennas which require grounding, i. e., vertical monopoles and inclined antenna, the effects of the Earth or other suitable ground plane is essential for proper operation and have already been discussed. Recall that the free space pattern of a half-wave, horizontal dipole was described as a doughnut, completely surrounding the element in a vertical plane (if given a push, the doughnut would roll down a street and the dipole element would become the axle). Figure 8 examines the effects of the Earth on the ideal doughnut, **assuming the Earth is a perfect conductor**.

Figure 8a defines the ground plane as earth but could be equally effective in any plane while "d" defines the distance the dipole element rests from the surface. Tracing through the various distances (Figure 8b - 8e), it becomes apparent that as the distance (d) increases, the number of lobes surrounding the dipole element increases thus dividing the available power equally among them and reducing the overall



PERFECTLY REFLECTING EARTH
(A)

d = WAVELENGTH ÷ 10
(B)

d = WAVELENGTH ÷ 4
(C)

d = WAVELENGTH ÷ 2
(D)

d = WAVELENGTH ÷ 1
(E)

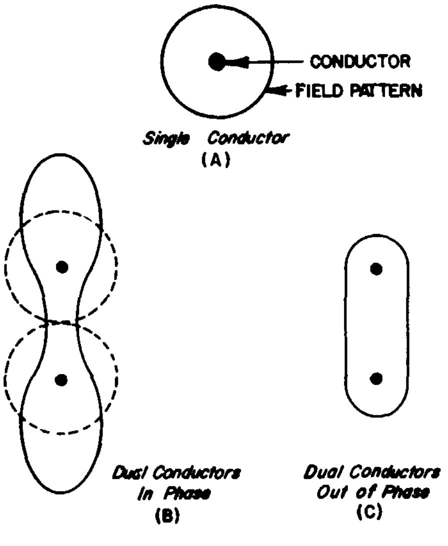
Figures 8 a-e - Ground plane effect on half-wave horizontal dipole pattern field strength in any given direction. As the distance (d) eventually reaches about 10 wavelengths, the free space value is reached.

Results of measurements made with a horizontal dipole are, in varying degrees, subject to the effects pointed out in this section. In most cases, the dipole is held at a position three meters (approximately 10 feet) from the ground while measuring normal distribution plant. At 108 MHz, 10 feet is 0.91 wavelengths which would very nearly duplicate the condition in Figure 8e. Given a perfect ground plane, the nulls shown do reach zero albeit they are very, very sharp allowing the field strength to increase quite rapidly when moving from them. At the peak of a lobe maxima, the field strength is actually double that of the dipole in free space.

In geographical areas where the Earth's conductivity is high, i. e., boggy coastal plains and over water, large excursions in signal level readings may occur. At the opposite end of the spectrum, measurements made in dry desert would tend to act much more as though the antennas were in free space. And then there are all the variations in between. In all cases, the basic pattern remains essentially the same but suffers sensitivity reduction.

The Effect of Parallel Conductors

Those conductors which are bonded directly to the coaxial cable plant sheath circuit are treated as variations of the long line and "V" type antennas. Signals propagated onto adjacent conductors through mutual coupling act as either reflecting or directing elements of an ordinary antenna.



Figures 9 a-c - Extreme effects of phase related, parallel conductors

The extent to which the radiation patterns are affected by these conductors in both cases depends entirely upon the phase relationship of the offending signal which must be computed on a case-by-case basis. Figures 9a, 9b and 9c show the extreme effects from any **single parallel conductor**. Doubling the field strength at a given monitoring location would represent the worst case. Signal cancellation would provide the best case, significantly reducing the field strength.

The probability of either single conductor pair being completely in phase or out of phase is very low resulting in a practical effect which falls somewhere between the two extremes. Geometric summation of two individual field patterns will result in a composite which is fairly broad nosed and therefore probably will not contribute to overall measurement inconsistency. However, when dealing with a larger number of parallel conductors, each with a slightly different phase, the summation at any point is nearly impossible to predict. The situation is further complicated if multiple transmitting points (leaks) are uncovered within close proximity.

DIPOLE AND MONOPOLE CORRELATION

Logistically, it is more practical to use a whip antenna than a horizontal dipole when making measurements from a vehicle. But more importantly, for electrical reasons which have been explored in earlier paragraphs, the use of a quarter-wave monopole is desirable.

The Arguments

Review for a moment the field patterns of the two respective antenna types **as they are used**. Since the leakage monitoring task will be ground based, both antennas will be operated in fairly close proximity with earth. Indeed, if the procedures in CFR 76.609(h) are followed, the maximum height achievable with a horizontal dipole is three meters (≈10 feet) directly above the cable under test which is typically six meters (≈19 feet) from the Earth or nine meters (≈ 30 feet) from the Earth. At that distance, the antenna is about three wavelengths above the earth, increasing the number of lobe maxima and minima shown in Figure 8e. True, the pattern peaks and valleys will probably be less intense than those shown depending upon the tangential loss associated with the Earth or ground plane recognized by the antenna at the point of measurement, thus reducing the overall error possibility. But the possibility does exist.

In the case of the grounded vertical monopole, the ground plane, whether natural (Earth) or artificial (vehicle), is an essential part of the electrical circuit as opposed to a disturbance. The field pattern illustrated in Figure 4a is normal for this antenna while operating in close proximity to a ground plane.

There are no perturbations to cause questionable measurement accuracy.

Two valid variables must be contended with in order to further justify the feasibility for use of the quarter-wave antenna as a measurement tool. First, by its very nature, the grounded quarter-wave whip antenna has a power sensitivity which is one-half that of the half-wave dipole, thus creating a possible error of 3 dB. Second, the quarter-wave whip is far more sensitive to vertically polarized signals.

The Cases

Making a case for the last item first, it is abundantly clear from previous discussion that the vast majority of a cable television plant is built within an environment where the polarization of the unintentionally propagated signaling is at least unpredictable. Adding to the case, the highest signal levels are carried within these plant segments and therefore represent the geographical areas of greatest uncertainty. Given these factual uncertainties, it is equally difficult to defend one method over the other therefore neutralizing the notion of unipolar signal leakage from the vast majority of a CATV plant.

A reasonable evaluation of the difference in sensitivity between the two antenna types is still required. Theoretically, the three decibel difference in power sensitivity is more than offset by an average measurement made with a half-wave dipole whose field pattern is undeniably distorted by the Earth or any other ground plane and perhaps a combination of both.

To provide evidence that there is some degree of substance to this hypothesis, practical tests were conducted.

The Test Site

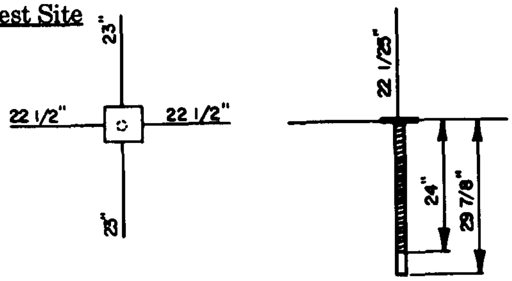


Figure 10 - Modified turnstile antenna

A transmitting antenna was constructed as shown in Figure 10. The purpose of the device is to produce a field pattern which closely approximates that of unintentional fields produced as a result of signal leakage within a cable television plant environment.

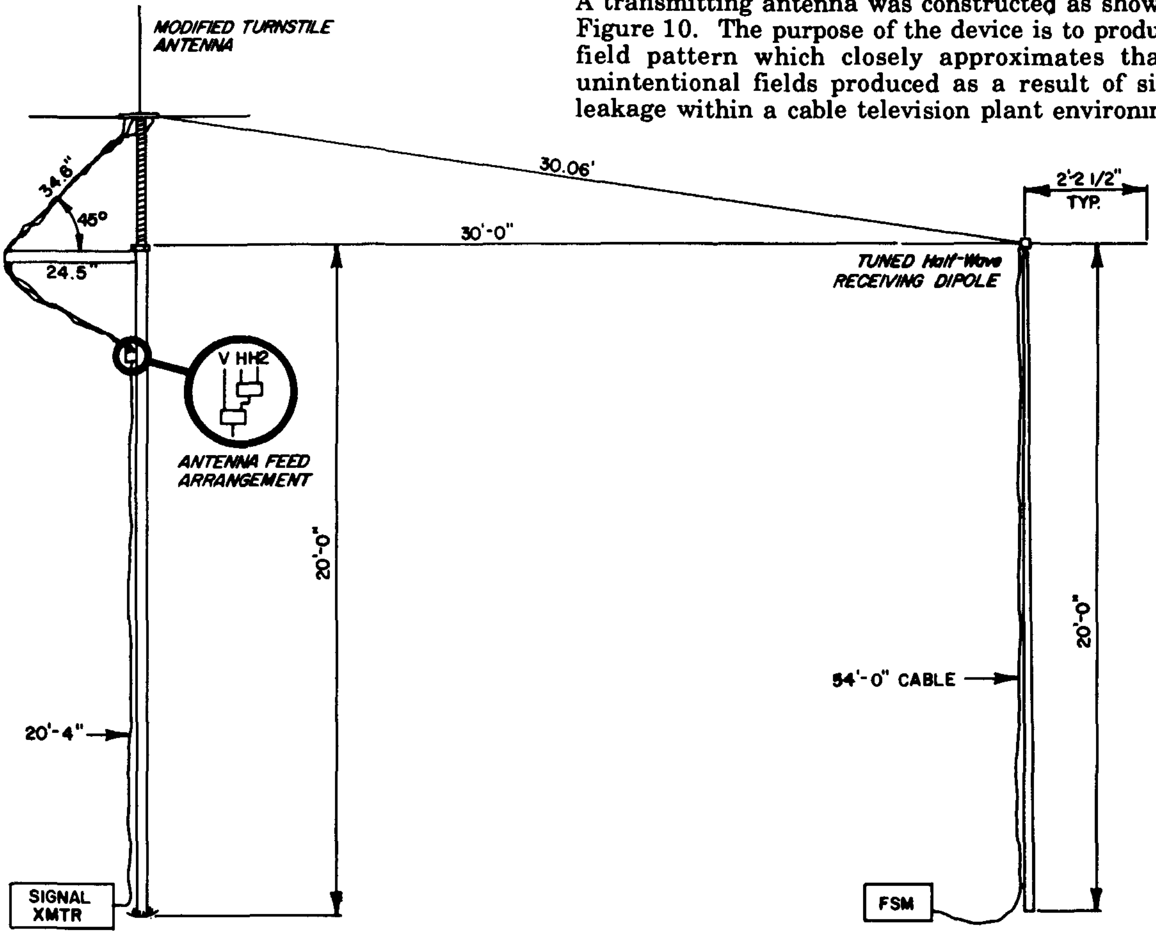


Figure 11 - Antenna test site

As closely as is practical, the modified turnstile antenna models this environment in that it produces a field pattern which is nearly spherical. By delivering equal power to the orthogonal pair of horizontal dipoles and the stub-grounded vertical monopole, nearly equal power is produced in both the horizontal and vertical planes.

The Measurements

Conformation of this was discovered during field measurements on a site described in Figure 11. Having anchored the test transmitting antenna, a tuned, horizontally positioned half-wave dipole was rotated about a 30 foot perimeter, making incremental measurements.

Relative Angle (°)	Horizontal Polarity (dB)	Vertical Polarity (dB)
0	3.4	3.0
45	3.2	2.8
90	3.5	3.0
135	3.5	3.0
180	3.5	3.0
225	3.2	2.9
270	3.5	3.0
315	3.4	3.0

Table 1 - Data recovered from Figure 11 site measurements

The process was then repeated with the half-wave dipole in the vertical plane. Results of the measurements are provided in Table 1.

Having qualified the transmitting source, one final set of measurements were made at the test site shown in Figure 11. A field strength reading was made using a typical service vehicle alternately equipped with a magnetically mounted quarter-wave whip antenna and a directly mounted quarter-wave whip at a distance about 36 feet from the transmitting source. There was no noticeable difference between the two whips. To close the loop, the vehicle was removed from the field and a horizontal half-wave dipole substituted at the same height and rotated about a vertical axis for maximum pick-up. The measurements were within one decibel of those recovered with the vertical quarter-wave monopoles.

Theoretically, there should be a 3 dB difference between the two readings since the receiving sensitivity of the quarter-wave antenna is one-half that of the half-wave dipole. As can be seen, data taken under previously described conditions does not confirm this theoretical difference.

CONCLUSIONS

Given the architecture of typical aerially constructed cable television systems, the polarization of propagated leakage signals is usually mixed. In addition, the disturbance caused by the Earth and/or any other apparently infinite ground plane acting upon the field sensitivity pattern of a half-wave dipole affects the absolute magnitude of a perceived signal. Further complications arise for horizontal half-wave dipole measurements because seldom are ground planes perfect thus providing a loss which can vary from one day to the next, depending upon the weather.

As a result, there appears to be substantial evidence to support the premise that leakage signal magnitude measurement uncertainty exists. This is particularly true when using a horizontally polarized half-wave dipole. Therefore, it is advantageous, both electrically and mechanically, to use the more pattern stable vertically oriented quarter-wave monopole for ground based measurements and it is shown that doing so will not significantly sacrifice intercepted signal accuracy.

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