ANTENNA CONSIDERATIONS FOR CONTROLLING CABLE SYSTEM LEAKAGE

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ABSTRACT

The success of a cable leakage maintenance program is keyed to the ability of the cable operator to monitor, categorize and locate leakage within the system. The antenna plays an important part of controlling cable leakage since system leakage exists outside the cable system. This paper reviews various antenna alternatives and suggests how they may be used in a leakage maintenance program. Several references are given so that the cable system technical personnel may further understand the considerations of antenna selection.

INTRODUCTION

The required methodology for making field strength measurements in determining the Cumulative Leakage Index or CLI is well described in section 76.605 of the FCC rules. It states the following:

> " The resonant half wave dipole antenna shall be placed 3 meters from and positioned directly below the system components and at 3 meters from the ground."

While this measurement technique will ensure a consistent standard in terms of the law it does present certain logistical problems if the cable operator is to perform the measurement process on a routine basis. What is important for any alternative measurement method is that cable system is controlled by cable leakage operator. Any measurement alternative should have traceable performance to the legal standard.

An antenna will provide a terminal voltage when placed in an electric field according to the following relationship:

Equation 1 $\quad dB\mu V = dB\mu V/m - K$

Equation 2 $\quad K = 20 \, Log(f) - G_{dB} - 31.54$ dB

- K = antenna factor in dB
- f = frequency in MHz
- G_{dB} = gain of the antenna over an isotropic

Any antenna should be able to be used for field strength measurements if its antenna factorcan be established. The antenna factors can relate the measured terminal voltage to that obtained with a dipole. The user can then be assured that the field strength measurements made with the alternative antenna are representative of those he would have obtained using a dipole. More suitable measurement techniques will encourage routine quantitative characterization of leaks resulting in better control of cable leakage.

Currently there are two measurement alternatives which are accepted for the CLI process. First is the use of the inverse distance law which relates field strength to the distance from the RF source. By using this relationship measurements can be made from a more practical distance and the measured results extrapolated to the actual distance. The assumption is more sensitive to parasitic effects such as reflections from conductive elements such as power and phone lines as well as any other reflective elements such as buildings.

The second alternative is the placement of the measurement dipole on a vehicle roof at a height of 1 meter. An antenna height of less than several wavelengths above ground or a reflective element acting as ground causes a distortion of the antenna pattern and the resulting gain at various radiation angles. Knowledge of how the pattern is affected will ensure that the proper interpretation is made of the field strength readings.

The purpose of this paper is to present information about alternative antennas which may be used for cable leakage measurements. Antennas can be classified by their polarization: horizontal, vertical, or circular. This paper will discuss antennas which have vertical and horizontal polarization. Additionally, direction finding (DF) and near field antennas will be discussed.

HALF WAVE DIPOLE

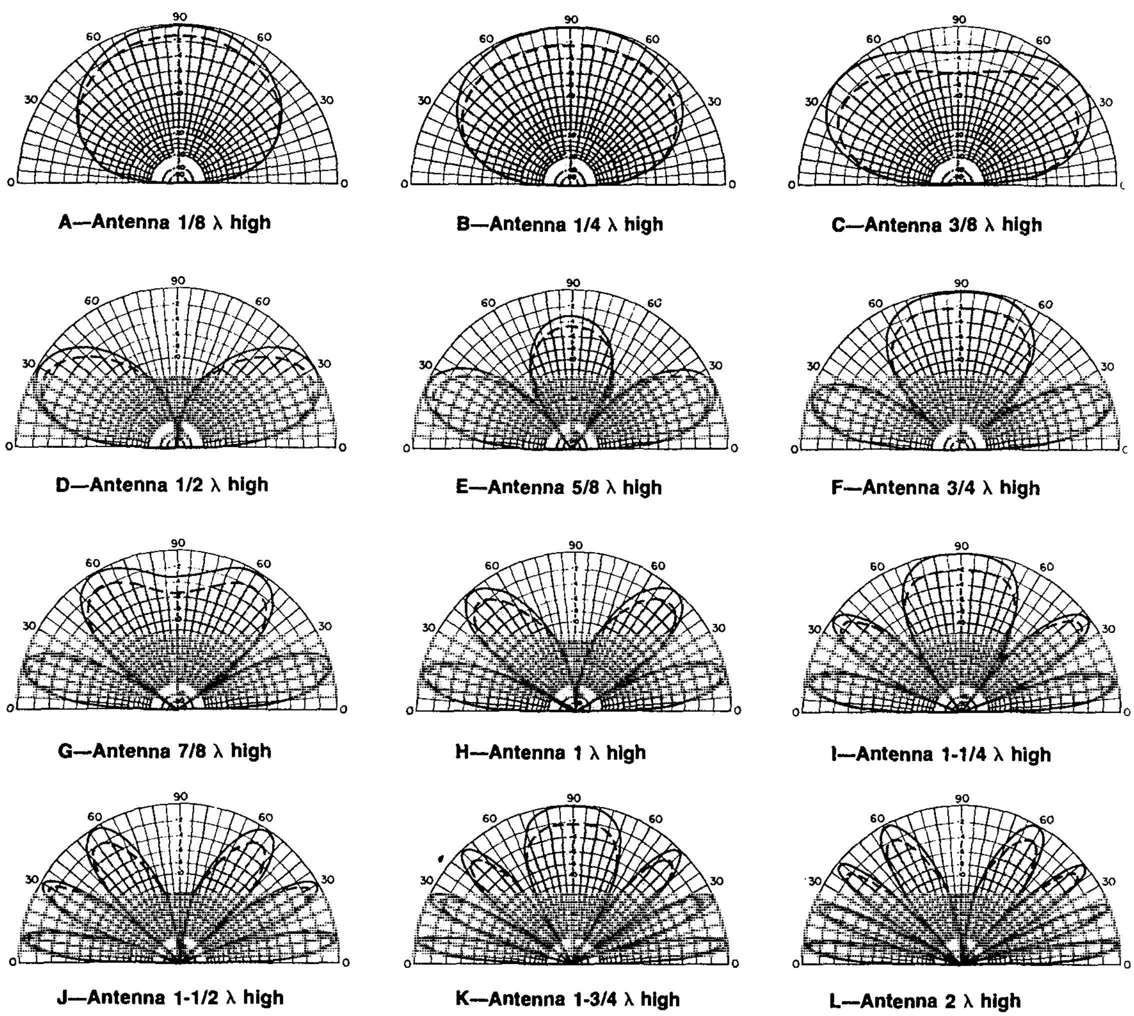
The half wave dipole is a well characterized radiating element which exhibits a gain of 2.15 dB over an isotropic. It is the practical standard that is used for most antenna work. Most other antennas are related to it. However, it can not be used blindly. The radiation pattern and overall gain are easily affected by parasitic reflective elements. The strategic placement of parasitic elements and the resultant affect on the overall antenna pattern is of course the basis of the Yagi-Uda design.

Using Equation 2 the antenna factor for a half wave dipole is given as $K = 20\ \mathrm{Log}(f \times 0.021)$.

Figure 1 illustrates the pattern distortion which can occur for various antenna heights. What results is that the gain of the dipole varies at different angles of radiation. A certain antenna height has advantages over other heights when measuring cable emissions. Cable leakage measurements in an easement made from the street will have a low angle of radiation. Cable leakage measurements made on a strand directly above the CLI vehicle will have a high angle of radiation. These pattern distortions should be taken into account if CLI measurements are to be directly correlated to those made with a dipole outlined in 76.605.

One way to minimize pattern distortion is to select a measurement frequency which is compatible with the desired antenna height. There are two measurement scenarios. First is with the dipole three feet above the roof of a vehicle and second that outlined in 76.605.

FIGURE 1.



A—Antenna 1/8 λ high
B—Antenna 1/4 λ high
C—Antenna 3/8 λ high
D—Antenna 1/2 λ high
E—Antenna 5/8 λ high
F—Antenna 3/4 λ high
G—Antenna 7/8 λ high
H—Antenna 1 λ high
I—Antenna 1-1/4 λ high
J—Antenna 1-1/2 λ high
K—Antenna 1-3/4 λ high
L—Antenna 2 λ high

Table 1 has the antenna heights in wavelength for each of these scenarios at different frequencies.

TABLE 1
ANTENNA HEIGHTS
RELATED TO FREQUENCY OF MEASUREMENT

f	L	10/L	3/L	0.666/L
72 MHz	13.0 ft	0.76	0.231	0.051
108 MHz	8.6 ft	1.20	0.349	0.078
118 MHz	7.9 ft	1.30	0.378	0.084
137 MHz	6.8 ft	1.50	0.439	0.098
225 MHz	4.2 ft	2.40	0.721	0.159
400 MHz	2.3 ft	4.30	1.280	0.290

Note the patten variation between heights at 118, 225 and 400 MHz (3/8, 3/4 and 1 1/4 wavelengths). The pattern at 118 MHz gives a good overall coverage except at low radiation angles. Low radiation angles will be experienced when the leak is in the easement. Leaks in an easement will be covered better with higher antenna heights.

In a similar manner, leaks directly above a vehicle will be covered well with an antenna height which has a predominant response at high angles of radiation.

A popular vehicle configuration is to mount a dipole a very short distance (eight inches) above the roof. Although somewhat difficult to characterize, the resultant antenna pattern will be similar to that of the eighth wave pattern for the frequencies in Table 1.

As the dipole is raised above the ground reflections become less predominant and the free-space radiation pattern emerges. The nulls will be less distinct since there is rarely prefect reflection from the ground surface. The patterns for low antenna height will be typical for vehicle configurations while the patterns for high antenna height will be typical for walk arounds.

YAGI-UDA

The Yagi-Uda or Yagi antenna has two characteristics which can aid in cable leakage measurement and detection. The antenna gain can be used to overcome problems that a dipole will have with increasing frequency as well as extend the measurement range. An improved front-to-back ratio as well as reduced gain on the sides of the antenna will aid in locating cable leaks by minimizing the effects of interference from reflections and other leak sources.

A Yagi's multi-element configuration and resulting size dictates that a high frequency of operation be used. However, at 225 MHz the total boom length of a four element Yagi is less than three feet. A four element Yagi will exhibit approximately 8 dB of gain, 20 dB of front-to-back ratio and good side lobe performance. A four percent bandwidth can be expected at the frequency of interest.

One might consider modifying a commercial off-air channel 13 antenna for operation in the upper aeronautical band. The antenna can then be trimmed for the operating frequency of interest. A return loss bridge and a bench top sweep can be used to retune the antenna. Overall guidelines are listed in Table 2 below for a four element Yagi.

TABLE 2
FOUR ELEMENT YAGI DIMENSIONS

Driven element to reflector	0.20 wavelength
Driven element to 1st director	0.20 wavelength
1st director to 2nd director	0.25 wavelength
Reflector length	0.51 wavelength
Driven element length	0.47 wavelength
1st director length	0.45 wavelength
2nd director length	0.44 wavelength

VERTICAL ANTENNAS

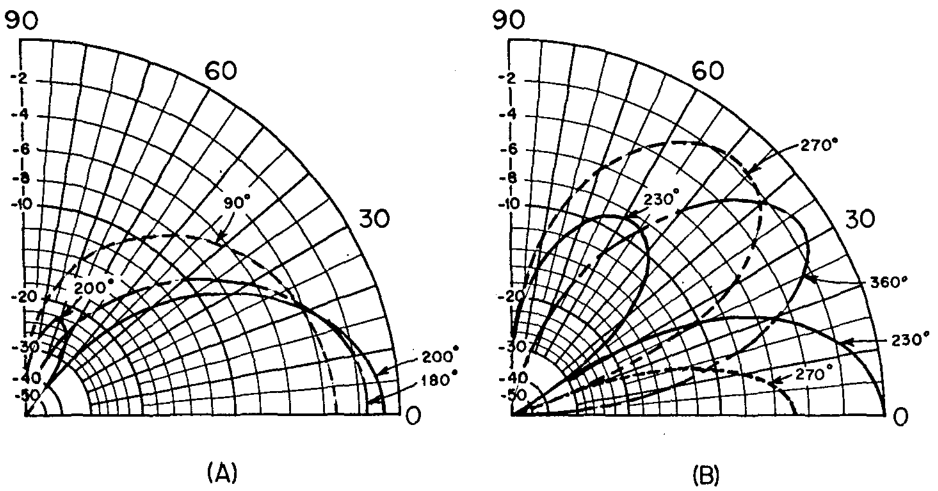
The use of vertical antennas for use in all leakage activities will always be in doubt. The predominant polarization of a leak has been argued for some time. According to the law the use of a vertical antenna is not acceptable. However, it has been shown that most leaks will exhibit both polarizations when measurements are made at a distance. In terms of controlling leakage a vertical antenna can be used to make a field strength measurement. Some determination of the leak severity can then be made. However, decisions should be made on the pessimistic side.

The use of a vertical antenna should be done with the same caution as that for horizontal antennas. Parasitic reflectors on a vehicle will cause a distortion of the antenna pattern which could result in nulls in the response. These parasitic reflectors can come from other antennas or metal objects such as booms and ladders. The objects should either be moved or the overall pattern of the vehicle characterized. Figure 2 shows the antenna patterns for vertical antennas of different lengths. The lengths are given in electrical degrees.

QUARTER WAVE VERTICAL

The use of a quarter wave vertical is a popular choice. It exhibits 3 dB gain over a dipole and is easily configured on a vehicle. It does, however, exhibit a null at high angles of radiation as shown in Figure 2.

FIGURE 2.



This antenna can be configured for multiple frequencies to give coverage in all three aeronautical bands.

5/8 WAVE VERTICAL

The 5/8 wave vertical exhibits 3 dB of gain over a quarter wave but has a significant lobe at high angles of radiation. This can be a benefit since leaks directly overhead will be covered better.

A matching network is built into the antenna base since the 5/8 wave is not resonant at the desired operating frequency. The antenna will also resonate at frequencies at which the physical element is 1/4 and 1/2 wavelength. The result is that offair signals will be received and may show up as intermodulation components in the receiver.

The multiple response of a 5/8 wave antenna can also be used to an advantage. Monitoring frequencies can be picked so that several frequencies are scanned. This can give more coverage with one antenna.

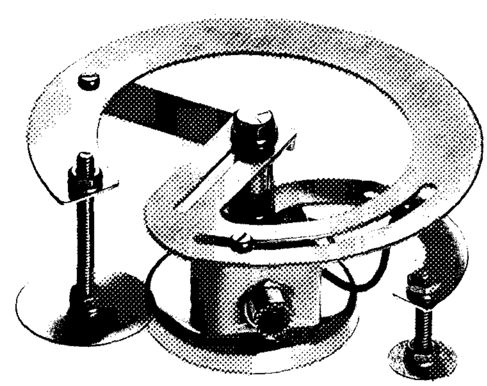
DIRECTIONAL DISCONTINUITY RING RADIATOR

An interesting variation of a vertical antenna is the DDRR. This antenna shown in Figure 3 has an overall antenna height of 2 1/2 inches and a diameter of 8 inches for a unit tuned to the aeronautical band (121.25 MHz). The DDRR is intended for use on a vehicle. A radome is available to protect it from the weather.

This antenna has a similar radiation pattern to a 1/4 wave whip. It exhibits unity gain, however, its high Q gives it an narrow bandwidth. The narrow bandwidth makes it ideal for areas with high intermodulation from offair signals. For a 2:1 SWR the DDRR has a 3 MHz bandwidth versus the 10 MHz bandwidth of a 1/4 wave vertical.

The DDRR has the advantage that it requires very little ground plane area to achieve its characteristics. The ground plane requirements suggest that this antenna could be mounted on the front of a vehicle. This may be a consideration if roof space is a premium.

FIGURE 3.



RUBBER DUCKIES

A popular antenna for use in portable detection is the "rubber duckie" antenna. These are resonant antennas which have a somewhat broad band characteristic. Their gain is not well characterized however, they do display characteristics which make it suitable for detection and location of leaks.

The most important characteristic is the null on the end of the antenna. This antenna will exhibit a 15 to 20 dB null on the end of the antenna and a maximum response perpendicular to antenna. The null can be used to locate a leak. The antenna will be pointing in the direction of the leak source when a null is found after detection is noted.

DIRECTION FINDING ANTENNAS

Several direction finding antennas are possible. The references contain many examples of DF antennas and their application.

One of the simplest vehicle based DF techniques is to use two Yagis at a frequency in the high aeronautical band. The gain of the antenna will makeup for any anticipated free-space losses and the directional characteristics will allow isolation of the leak. The initial direction of the leak can be determined with each Yagi oriented toward each side of the vehicle. Switching between each antenna will tell the technician where to start his search.

A more sophisticated approach is to use multiple vertical antennas and doppler techniques. Several antennas can be switched electronically and the direction of the incoming signal determined from the relative phase of the signal at each antenna. The relative bearing can be read out on an indicator device giving the initial direction of the search. These devices seem to be very sensitive due to multipath and require a lot of patience to use. False indications while the vehicle is in motion as well as at rest are very common.

These systems usually use an audio tone as the antenna commutating signal. The recovered audio is then used to determine the bearing of the signal. This audio tone is usually placed at the lower corner frequency of the audio response of most receivers. Its placement causes some problems if the receiver does not have adequate response at the commutating frequency.

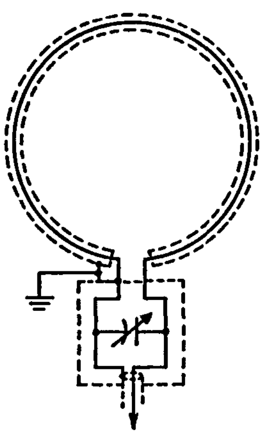
Future possibilities include real-time processing of the recovered doppler signal to determine the validity of the reading. Another possibility is to place the commutating tone within the audio passband of the receiver to ensure as reliable bearing indication.

NEAR-FIELD LOOPS

Once a leak is detected it must be located, isolated and finally repaired. Isolating a leak is usually the most difficult part of the task. Near-field probes can aid in this process by using the magnetic field of the leak instead of the electric field. The magnetic field has a more pronounced attenuation effect with distance and does not seem to exhibit the same extreme standing wave effects that electric fields demonstrate.

The classic near-field loop is shown in Figure 4. It is easily constructed and is commercially available. It is usually tuned to one frequency. There is n specific calibration requirement except that it be tuned for maximum response.

FIGURE 4.



Once connected to a sensitive RF voltmeter it is moved along the strand until a maximum response is achieved.

Another type of near-field probe is a very short vertical antenna. These are usually used with portable detection equipment to locate a leak when the receiver is very near to the source. They take the form of short single element attached to the input of the receiver. The effect is to desensitize the receiver and allow variations in field-strength to be noted.

FURTHER READING

Several references are given at the end of this paper. The best reference for a practical and theoretical understanding of antenna behavior is the ARRL Antenna Book. This reference is revised on a regular basis so that some of the material may not be repeated every issue. However, much of the basic material has not changed since the early 50's and is repeated unchanged. Much of what is changed is related to current work in the amateur arena. It is this authors view that the 1988 and 1970 issues represent good overall references for any technical personnel who has to deal with antennas.

ACKNOWLEDGEMENTS

Several of the illustrations used in this paper are used with permission of the ARRL.

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