Handheld Direction Finder for Cable Leakage Location

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ABSTRACT

A handheld direction finding system has been developed to aid in the rapid location and pinpointing of leakage sources in a cable system. This paper covers the development of a practical, handheld unit, including the antennas, circuitry and display. Also covered are some of the problems and solutions to the measurement of radio signals in the VHF spectrum.

THE PROBLEM

Pinpointing the exact location of a cable leak has been a continuous problem for the cable technician. Vehicular and portable equipment is available that can detect areas where a leak exists, and near field-probes can be held next to the cable to check for leakage from a connection or housing. In between, a bewildering array of dipoles and directional antennas have been used with signal level meters and portable receivers to try to find the general direction of a leak from the ground. Technicians have, in some cases, spent hours trying to locate a single leak.

My involvement in a solution to the problem of locating leaks in cable systems actually started about four years ago with a tragedy in the Northwest. A group of high school students were attempting to climb Mt. Hood and got caught in a storm. Eight of the group died before they were found three days later in a snow cave. At that time, I started working on an idea I had for a handheld direction finder and coded radio tags that could be worn by climbers.

In the summer of 1989, I decided that the direction finding technique could be applied to the cable leakage problem, and the outcome of this research resulted in the development of a handheld direction finder and field strength measuring instrument, called the Leakage Locator System.

ANTENNAS FOR LOCATING

A number of units with various kinds of antennas have been traditionally used by the cable technician to measure and find leaks. These include the simple dipole and various multiple element gain antennas such as the Yagi antenna. They are analyzed below.

The simplest antenna, the dipole, has a very broad symmetrical pattern as shown in Figure 1. The maximum signal strength orientation lobe is very broad, typically over 100 degrees wide between the 3 dB points. It is symmetrical, which makes it difficult to tell whether the leak is behind or in front of the user without taking multiple readings at different positions, and triangulating. The dipole IS good for measuring field strength since it is easy to characterize the antenna factor, and the directionality is so broad that little error is encountered if the antenna is not exactly oriented to peak.

Various gain antennas which use multiple elements have been proposed or sold for improved beam-width and to make the main lobe directional, eliminating the arbitrariness of the simple dipole. The pattern for a four element Yagi is shown in Figure 2. One lobe of the simple dipole is superimposed for reference. The particular Yagi tested showed a significant improvement in directionality and almost 11 dB of gain compared to the dipole, however, the 3 dB points are still greater than 50 degrees. The Yagi can also be quite cumbersome due to its size, especially if cut for the 108 to 136 MHz lower FCC compliance band.

Other antennas were tested, and the general conclusion reached was that they could barely provide enough directionality to find "the broad side of a barn".

DIRECTION FINDERS

Direction finding techniques have been used since the early 20's, and involve the use of the null that can be obtained from the end of a dipole element or a loop antenna rather than the peak of the main lobe. Early systems were operated by rotating an antenna by hand, and taking multiple readings from different locations to eliminate the front/back arbitrariness.

Modern electronic direction finders with indicators or displays used an antenna array combined with a mechanical or electronic switcher, and a sense antenna to resolve and pinpoint the source of a radio emission.

The significant improvement in resolving power of a direction finder is derived from the null characteristic, which has a rapid rate of change close to the null position,

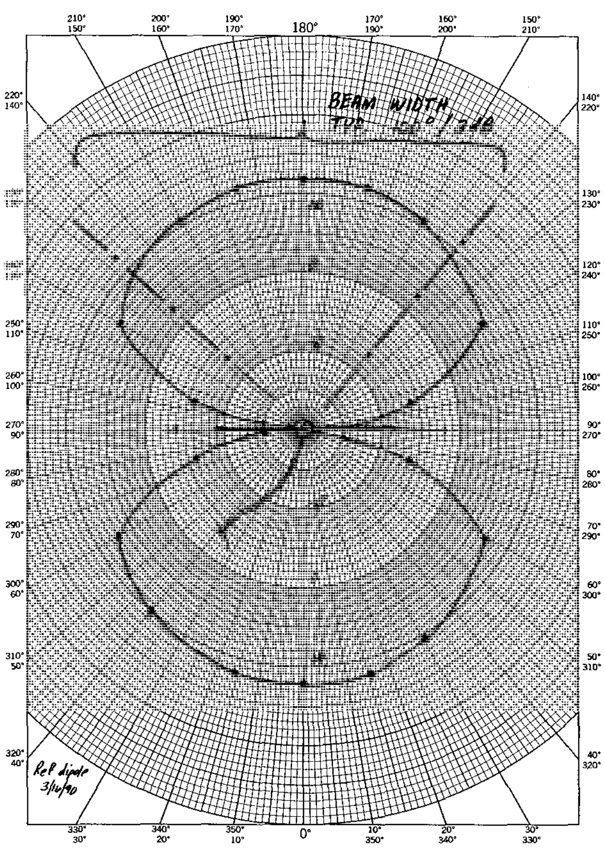

Figure 1 - Antenna pattern for a simple dipole antenna. Typically the 3 dB points of the beam will be over 100 degrees apart.

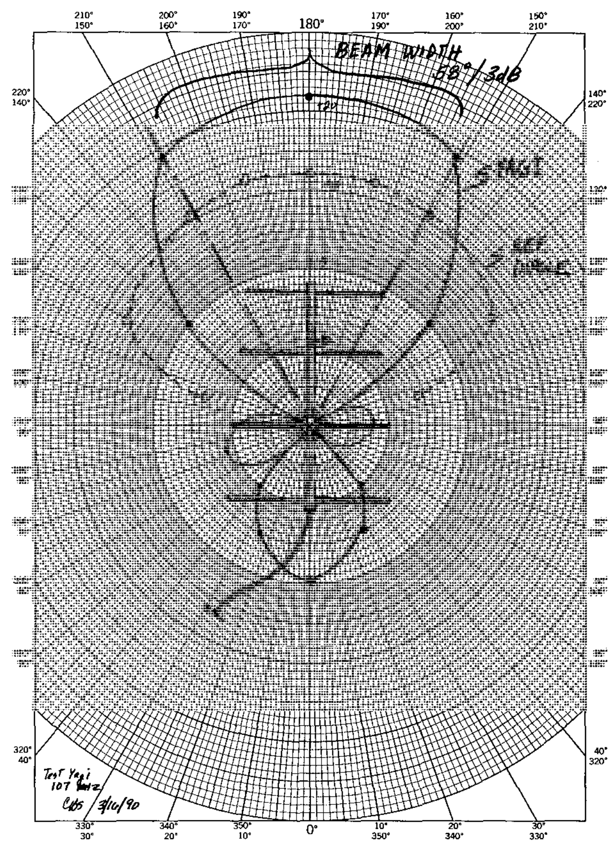

Figure 2 - Antenna pattern for a multiple element Yagi type antenna which shows a 3 dB beam-width of 58 degrees.

as shown in figure 3. The figure shows the pattern of the null and sense elements of the antennas of the actual handheld unit that was developed. Null 3 dB beam-widths of less than 5 degrees are typical, and the unit easily resolves 1 dB changes, giving better than 2 degree of locating resolution.

The handheld direction finder developed by the author, which includes leakage measurement capability, is called the Leakage Locator System. It consists of a receiver, antenna array, direction finding circuitry with a visual peaking display, and a precision field strength meter, allowing a cable technician to quickly pinpoint and measure a leak.

A block diagram of the direction finding circuit is shown in figure 4. The antenna array consists of two dipole antennas, tuned and loaded to frequencies in the 108 to 136 MHz band. One of the dipole elements is the boom, which includes the effects of the human body holding the unit. The photo in figure 5 shows this clearly. The system is horizontally polarized, since this appears to be the predominant orientation of leakage in overhead cable plants.

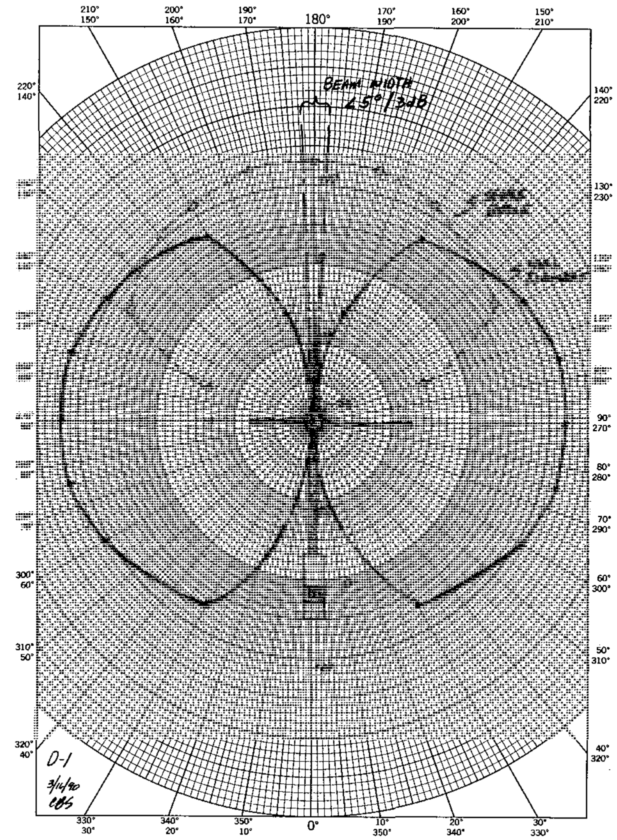

Figure 3 - Null and sense patterns for the Leakage Locator System show a 3 dB beam-width of less than 5 degrees.

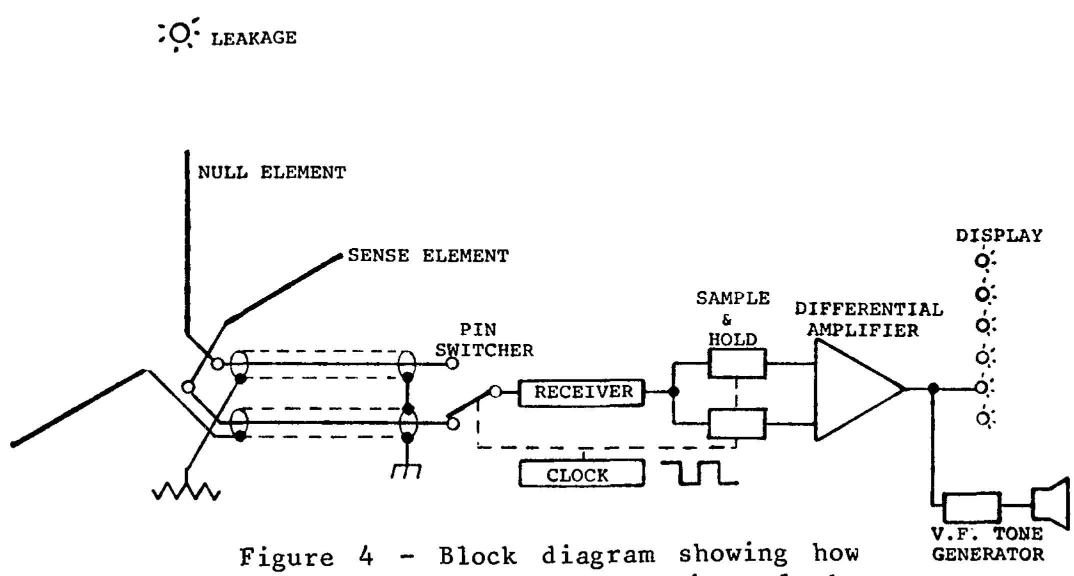

Figure 4 - Block diagram showing how the direction finder portion of the circuit works.

The Leakage Locator operates by measuring the difference between the peak output of the sense dipole, and the null of the second antenna. The unit peak-to-null ratio does not vary with signal strength within the dynamic range of the system. When the array is oriented 90 degrees from a leak, the sense element is at null. This causes the output of the differential amplifier to be negative, causing the display to read zero. When a leak is 180 degrees from the pointed direction, behind the operator, the human body disturbs the null pattern significantly. Therefore, the operator cannot falsely peak the display and will know that he is not pointed at the leak.

The Leakage Locator, as described, is a horizontally polarized device. However, the null antenna actually produces a cone shaped, three dimensional null pattern. This allows the unit to pinpoint in both the vertical and horizontal axis. The actual calibration, as measured,is 2 degrees horizontal and 3 degrees vertical, for each of the last four red dots of the light display.

Figure 5 - Photo of the Leakage Locator shows the position of the human body relative to the unit, which disturbs the rear null pattern.

The block diagram in Figure 4 shows the antennas being toggled by a PIN diode switch into a common receiver. The output is sampled in two hold circuits, then amplified in a differential amplifier. The output of the amplifier feeds a calibrated display and an audio Voltage-to-Frequency converter to aid the user in peaking the display.

The direction finder display and the measurement meter on the unit is shown in figure 6. The actual Leakage Locator System has two modes: the Locate mode which enables the direction finder circuitry, and a Measure mode, which uses the Sense antenna and the receiver system, and is calibrated to read directly in uv/m at 10 feet.

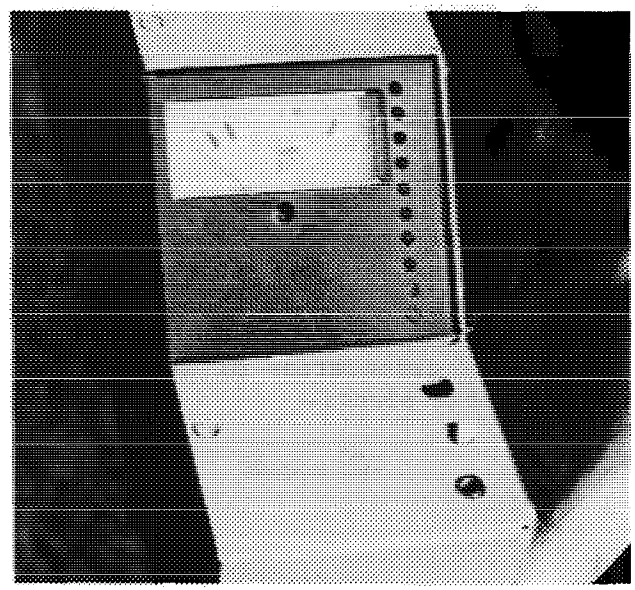

Figure 6 - Photo of the meter face and light display which allow the operator to pinpoint and measure leak sources.

Originally, the meter was going to provide only a simple GO/NO GO type reading with a 20uv/m calibration line in the center of the scale. Subsequently, in field tests, it was found to be most useful if the scale was calibrated to measure the actual field strength, and the 20 to 200 scale and a X10 switch were added to allow the measurements to be made from below 10uv to 2000uv/meter.

Additionally, it was found useful to be able to measure from a distance greater than 10 feet. For example, if the leak were on the side of a residence, or on a rear easement, the technician would not want to enter the property unless there was a problem. The receiver sensitivity of the unit was increased to allow measurement of a 20uv at 10 foot leak, up to 160 feet from the actual leak. The photo in figure 7 shows the calibrated potentiometer that the operator can use to dial the estimated distance to an apparent leak located with the Leakage Locator, and get an idea of the field strength.

The actual design of the Leakage Locator as a product involved the building of a highly sensitive receiver, capable of being calibrated and remaining stable for the Measure mode, and having a high dynamic range for the Locate mode. The sensitivity required to measure and direction find on a leak with the equivalent field strength of a 20 uv leak, 160 feet away, including the antenna correction factor, and further loss for electrically shortening the elements, required a receiver sensitivity of -76 dBmV or - 124 dBm. This dictated the use of a narrowband design to remain comfortably above thermal noise (KTB). A 3 kHz dual conversion receiver was designed, with the theoretical KTB being -144 dBm, allowing adequate margin for front end switching, filter losses, and a high noise figure for the RF preamplifier.

The operating frequency of the Leakage Locator was chosen to utilize the TV carriers already present on the cable. The typical unit can be switch selected for either midband channels B or C, at 127.25 MHz and 133.25 MHz respectively. The offset of +/- 12.5 kHz is also switch selectable. Optional HRC frequencies and offsets can be accommodated by changing the crystals. The 3 kHz narrowband receiver has a specially compensated detector and a 4.2 dB correction circuit to provide signal strength measurements on the TV carriers "equivalent to the RMS value of synchronizing peak" as required in FCC Rules Part 76.609(h).

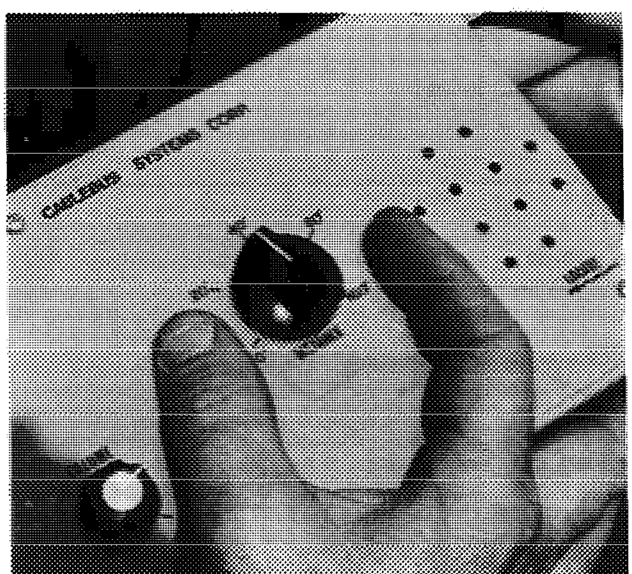

Figure 7 - Photo showing the distance potentiometer that converts the uv/m reading to a 10 foot equivalent.

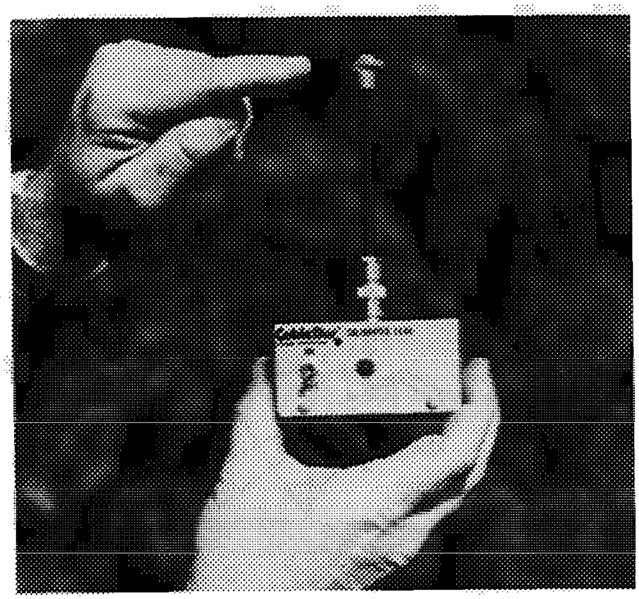

Figure 8 - Photo showing the 20 uv Calibrated Leak supplied with the Leakage Locator System.

During the development of the Handheld Leakage Detector, continuous use was made of a small transmitter that simulated a single point leak of 20uv/meter at 10 feet. The author developed a small point source horizontally polarized antenna to use with the transmitter. This was Calibrated Leak, shown in Figure 8, was found to be a very useful accessory and is supplied with the Leakage Locator System.

FIELD EXPERIENCE

The final part of this paper covers the leakage location field experience gained in both overhead and underground installations, along with a discussion covering some of the myths of leakage location such as multiple leaks causing the detection of "phantom" leak locations. One of the authors main concerns throughout the development of the Leakage Locator System was the question of usefulness. Assuming the unit was capable of pinpointing a single point radio source, would the unit be useful in cable leakage situations?

Field testing bore out the answer. Yes, indeed, the unit has proven to be a very effective tool in locating and measuring leakage. Some interesting situations were encountered, but every situation has an explanation that does not "mysteriously" violate any laws of physics.

One of the first topics to be understood is the ground reflection phenomena, and it's relationship to any field measurements (not limited to those with the handheld direction finder). Figures 9 and 10 illustrate this effect. Within close proximity to the ground, be it wet or dry, sand or grass, the radio wave is reflected off the surface of the ground very efficiently at VHF frequencies.

In the case of measurements being made perpendicular to the ground, such as when the unit is used from the street, aimed at the side of a house, the effect is most pronounced. Figure 9 shows that the direct wave, and the ground wave, follow a path of similar length. Therefore, both waves are of

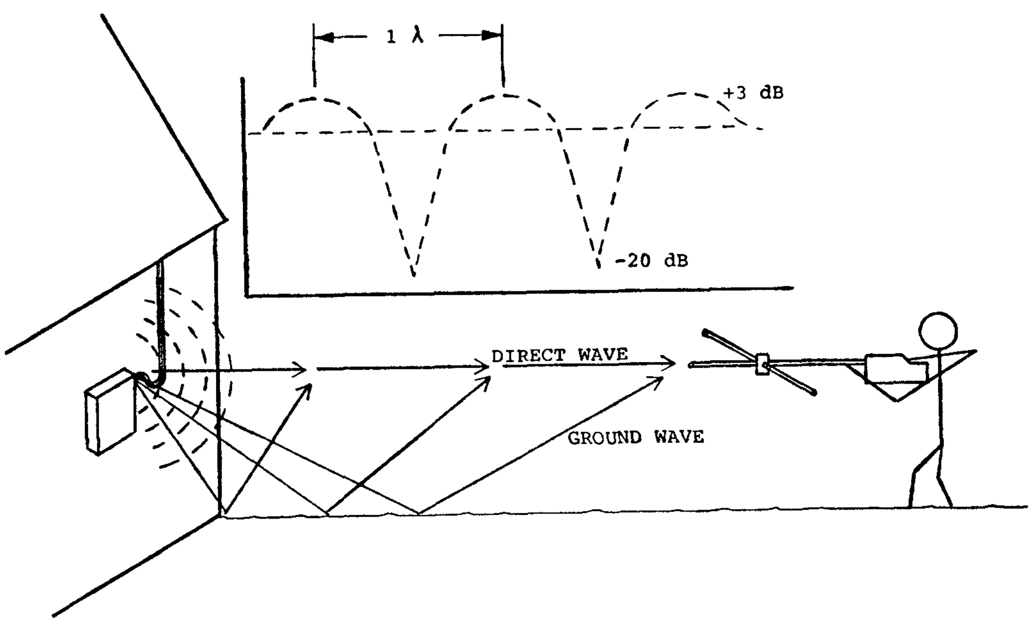

Figure 9 - Illustration showing the ground reflection effect when the measurement is parallel to the ground.

similar strength, particularly as the distance is increased. If they arrive in phase, they can add together, the sum being as much as 3dB greater, and if they are 180 degrees out of phase, they can cancel, sometimes almost perfectly. The error therefore, can be +3dB to - 20db or greater. In practice, moving back and forth a few steps will often cause the meter to vary through the peak and null readings.

The second condition shown in figure 10 is a measurement on an overhead cable. In this case, the ground wave follows a longer path, losing 3dB of strength for each doubling of the distance over the path of the direct wave. If, for example, the strength of the ground wave was attenuated by 1db, the additive and subtractive effect would be much less, in the order of +/- 2dB. Still, it is important to move the antenna enough to verify the peak to valley variation.

Murphy's Law fully applies here. You will always stand in the null to measure and think your system passes, and the FCC will always stand in the peak and fail that location when they measure. Be aware of the problem, particularly when extrapolating distance to a leak from more than 10 foot, and especially when looking parallel to level ground.

Another phenomenon that must be mentioned is the ground proximity effect. As a radio source or test antenna is moved closer to the ground, the signal strength will reduce. Within one wavelength, a drop of 1 dB for each 6 inches is not uncommon. This effect is easily demonstrated if the Calibrated Leak is set on the ground. The measured field will be as low as 1 to 2 uv. Therefore, the calibrator should be used only on top of a 5 or 6 foot wooden post. Alternately,

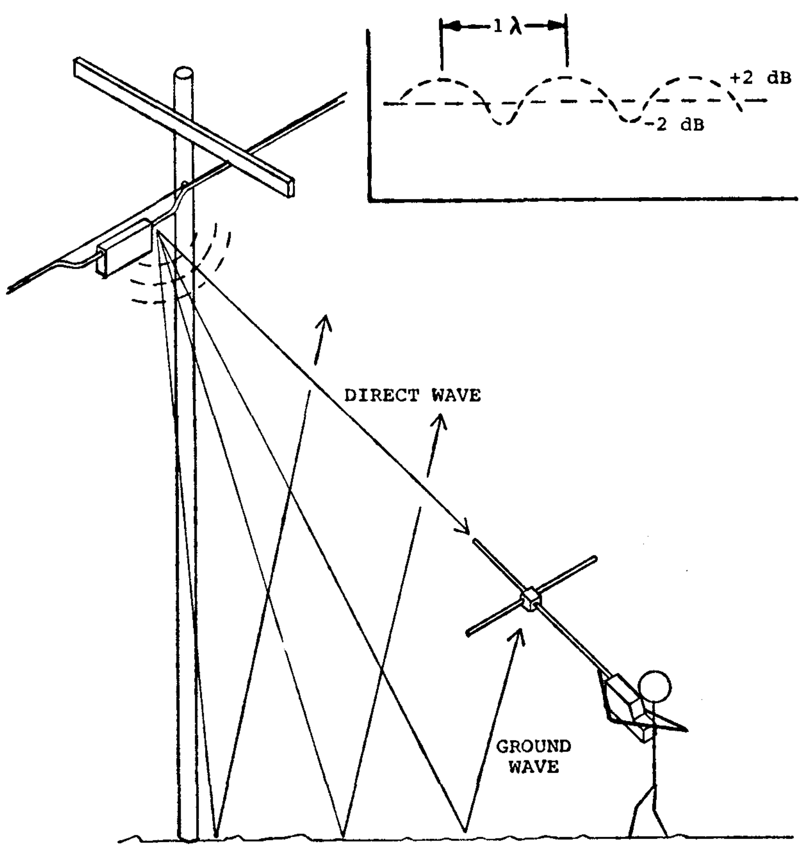

Figure 10 - Illustration showing the ground reflection effect when measuring overhead from the ground.

lowering the test antenna close to the ground, such as squatting to take measurements, will yield low readings.

The final group of field experiences that I will summarize involves common sense issues. Radio waves bounce, bend, and travel in strange but always explainable ways. The Handheld Leakage Locator, because of it's narrow beam-width, will seem to exaggerate problems that would normally be masked by a wide beam-width antenna.

Listed below are some of the more common situations that might be encountered:

- Searching for leaks beside or in front of a vehicle can bend or reflect the leak field. Move at least 15 to 20 feet away from vehicles.

- Guy wires are also a problem. The user should move away from and around the down-guy wires, and take multiple "shots" from a few positions to confirm the probable leak source.

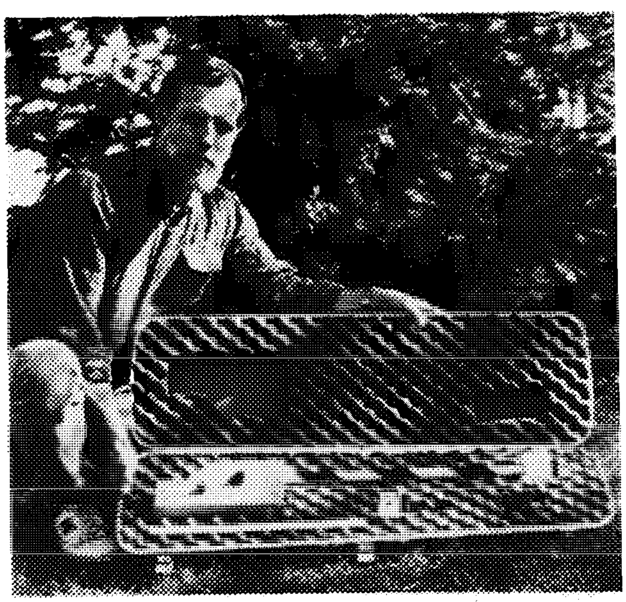

Figure 11 - Photo showing the complete field system which includes the Leakage Locator, Calibrated Leak, AC and Auto chargers, and the carrying case.

- Follow the orientation of the wires, keeping the sense antenna parallel to the wires. If, for example, a power supply is mounted on a pole, rotate the antenna 90 degrees and sweep the vertical section of the coax from the power supply to the power adder.

- The same recommendation applies to "shooting" a house from the street. Rotate the unit 90 degrees and check both the horizontal and vertical fields.

- Multiple leaks, within one wavelength of each other, may appear to give a "phantom" target at some point between the two leaks. A full ring break in a sheath may also have a false peak within a wavelength of the actual break. This is where you apply a near field probe. A wavelength is only seven feet at 130 MHz, so don't panic!

- As you move closer to multiple point source leaks, they will usually begin to resolve into separate leaks that will each peak on the direction finder.

CONCLUSION

The Handheld Leakage Locator has been shown to be a powerful and effective tool to be used in locating leaks in both aerial and underground plants. It is felt that the unit can be part of the cable operator's arsenal of equipment, and will assure a complete and successful Cumulative Leakage compliance program.

A patent application has been prepared for filing on the Handheld Leakage Locator System.