Locating Analog Cable TV Leaks using Doppler Radio Direction Finding Systems

A Technical Application Note from Doppler Systems

March 15, 1994

1.0 Introduction

Doppler Systems radio direction finding systems have been used to successfully locate cable television (CTV) leaks which exceed the requirements specified in FCC Part 76.605(a)(11). Direction finding of CTV signal leaks is distinguished by the large number of possible signals to use and the relatively low magnitude of the radiating signal. The purpose of this note is to provide guidelines for selecting the signal frequency and to make operational suggestions that will enhance the performance of the direction finding system.

Reflections are always a problem in VHF radio direction finding. Because doppler type direction finding systems provide continuous information on the instantaneous bearing, spatial averaging can be used to advantage. Important clues as to the true direction are found by observing the average bearing and its stability while moving the direction finding vehicle, and noting the surroundings which might be causing reflections (other vehicles, power poles, etc).

2.0 Frequency Selection

Several considerations play a factor in selecting the CTV signal to use with the direction finder. The type of CTV signal modulation is important as well as its relative strength. Interfering over the air signals must be avoided. Range is affected by the effective area of the receiving antenna which depends on frequency. Finally the size of the receiving antenna and especially its ground plane size is frequency related.

2.1 Available Signals

Table 1 lists those CTV frequencies in common use below 216 MHz. The direction finder may also be used at frequencies above 216 MHz, but the allowable leakage level is much higher. Below 216 MHz, the allowable field strength at 10 feet is 20 microvolts per meter while above 216 MHz the allowable field strength is 15 microvolts per meter at 100 ft. This corresponds to 150 microvolts per meter at 10 ft, so the allowable leakage is 7.5 times higher.

2.1 Modulation

The direction finder is intended to be used with a narrow band FM receiver having a bandpass of 15 to 25 KHz. Ideally, the received signal would be an unmodulated carrier. But, either AM or narrow band fm (NBFM) modulated signals can also be used with the direction finder provided that:

- the modulation remains within the bandpass of the receiver,
- the modulation does not contain very much 300 Hz content and,
- the signal is present for at least 150 milliseconds.

All three conditions are met by two types of CTV signals. The video carrier signals are amplitude modulated far in excess of the NBFM bandpass. This would appear to violate condition (1) above; however, the bandwidth of the modulated signal is so much larger than the NBFM bandwidth that the carrier appears very nearly like an unmodulated CW signal when received by a NBFM receiver. The other usable signals are the marker beacons used to detect leakage in the channel 0 or channel 1 frequency bands. These are narrow band amplitude modulated signals which are tone modulated in the 1 to 2 KHz range.

Signals which are not suitable for use with the direction finder are the wide band frequency modulated (WBFM) signals used to carry the TV audio or commercial fm broadcast signals. For this reason, the FM band is shaded on Table 1 and the TV audio carriers are not listed.

2.3 On the Air Signals

TV channels 2 through 6 and 7 through 13 line up with the same CTV channels. Since the on air signals are much stronger than the CTV leakage, these frequencies should not be used. They are also shaded on the table.

2.4 Signal Strength

The video carriers and the marker beacons are the strongest signals present on the cable. In general, a marker beacon has a signal strength equal to or larger than the video carrier, and the distinctive tone modulation used makes it easy to identify. Assuming a spec level leak of 20 microvolts per meter at 10 feet, the signal which would be received by a dipole antenna driving a 50 ohm receiver can be calculated as follows:

$$W := \frac{E^2}{120 \cdot \pi}$$

$$A := \frac{G \cdot \lambda^2}{4 \cdot \pi}$$

$$P_R := W \cdot A$$

$$dBm_R := 10 \cdot \log\left(\frac{P_R}{.001}\right)$$

where **W** is the power density in watts per square meter, **E** is the field strength in volts (rms) per meter, **A** is the effective area of the receiving antenna in square meters, **G** is the antenna gain over an isotropic antenna (and is equal to 1.64 for a thin dipole), λ is the wavelength in meters, $\mathbf{P_R}$ is the received power in watts, and $\mathbf{dBm_R}$ is the received power in decibels over 1 milliwatt.

As frequency increases, the dipole signal strength for a spec level leak decreases about 0.3 to 0.4 dB per CTV channel as indicated on the table. The actual range will depend on the receiver sensitivity as discussed in paragraph 3; however, the signal strengths above channel 22 have been shaded to indicate that higher frequencies will provide reduced range.

2.5 Antenna Size

The direction finder antenna consists of four quarter wave monopole elements spaced in a square pattern on a ground plane (the vehicle's roof). Usually magnetic mounts are used to allow varying the placement to match the received frequency. The actual spacing of the antennas is not critical, but it should be in the range of 1/8 to 1/4 wavelength. Generally, 3/16 wavelength is best. The ground plane itself works best if it extends at least 1/4 wavelength beyond each antenna. Thus, the optimum size ground plane would be 1/4+3/16+1/4 = 11/16 wavelength square. At 169.25 MHz, this works out to a reasonable 48 inches, but at 109.25 MHz, the ground plane (roof) would have to be 74.3 inches. If we require the ground plane to extend only 1/8 wavelength past the elements, and space them 3/16 wavelength apart, the minimum size roof drops to 7/16 wavelength. This is the size indicated in the last column of the table. Sizes at frequencies below 109.25 MHz are shaded to indicate an excessive size. However, it should be remembered that the sizes listed are the minimum recommended, and that a larger ground plane is preferable.

The direction finder works best when the antenna is mounted on a flat ground plane with no other radiating objects in its vicinity (such as other antennas, ladders, etc.)

2.6 Summary

If a marker beacon in the CTV channel 0 or 1 range is available, this would be the first choice. A good alternative is to use a video carrier between CTV channel 14 and 22. An on the air check should be made to first determine which of these frequencies is least subjected to interference from other users.

3.0 Range

The direction finder requires a signal strength approximately equal to the squelch threshold of the receiver for reasonably consistent bearings. On the ICOM R-7000 used for our testing (in the NBFM2 mode), this threshold is about -120 dBm over the frequency range of interest. We will use -114 dBm to allow for the inefficiency between antenna power and receiver input power. The direction finder antenna array actually has some gain over a dipole, but assuming the dipole gain factor of 1.64, the range can be calculated from the equations given in paragraph 2.4. The result is shown in Figure 1 as a function of the field strength at 10 feet for frequencies of 109.275 and 169.250 MHz.

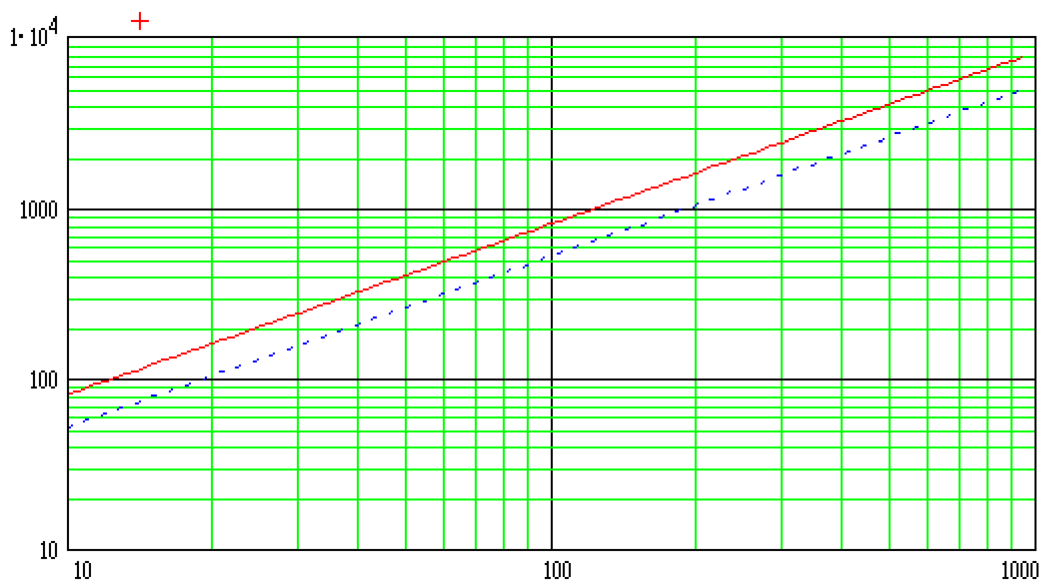

Figure 1

Range in feet for dipole signal of -114 dBm vs field strength in microvolts/meter at 10 feet

Upper trace is 109.275 MHz, lower trace is 169.250 MHz

For a spec level leak of 20 microvolts per meter at 10 ft, the range is between 110 and 160 feet. This increases linearly with the signal leakage strength, so for example the range for a leak equal to ten times the spec is between 1100 and 1600 ft. Everything else being equal, the lower frequency provides the greater range.

4.0 Other Factors

4.1 Receiver Mode

Best bearing stability is obtained when the receiver is used in a narrow band fm mode. It is also possible to use the receiver in the AM mode provided the antenna whips are cut close to resonance. (This should be done for the NBFM mode as well to maximize the range, but in the AM mode, it is necessary to provide an unambiguous bearing.) The direction finder must be recalibrated when switching between AM and NBFM modes, so it is best to standardize on one or the other.

4.2 Polarization

The range calculations assumed vertical polarization of the leak signal, which is unlikely. Since the direction finder is sensitive to the vertically polarized component of the received signal, the range will be reduced and the system will be more susceptable to reflections as the leakage signal becomes more horizontally polarized.

5.0 Operational Notes

Field tests were performed to locate known and unknown leaks of CTV signals. The area tested was suburban with most (but not all) of the cable system underground. No leaks were noted along the overhead cable, but a number were observed coming from the junction boxes mounted just above ground level for subscriber connection. Since these were next to the roadway and could be detected from only about 50 feet, they were probably well within the spec limits.

Several leaks were noted that could be heard (and tracked) from distances up to 500 feet. These were clearly coming from inside houses in the area.

Tests were conducted using a marker beacon on 109.275 and the channel 22 video carrier on 169.250 MHz. Both AM and NBFM modes were tested. As expected, the best range was obtained on 109.275, and the best bearing stability was obtained using the NBFM mode. Since it is hard to distinguish the tone modulation of the marker in the NBFM mode, it was found most convenient to use the receiver in the AM mode to first pick up a leak, then switch to NBFM to locate it.

Table 1 CTV Frequency Selection for Direction Finding

CTV CHANNEL	ICC VIDEO CARRIER (MHZ)	ON AIR SIGNAL	DIPOLE SIGNAL @ 10 FT (dBm)	MIN GROUND PLANE (IN)
2	55.250	TV CHANNEL 2	-83.9	93.5
3	61.250	TV CHANNEL 3	-84.8	84.4
4	67.250	TV CHANNEL 4	-85.6	76.8
5	73.250	TV CHANNEL 5	-86.3	70.5
6	79.250	TV CHANNEL 6	-87.0	65.2
FM	88 TO 108 WBFM	FM BROADCAST	-88.5	60.6
0	109.250 OR MARKER 109.275 TYP	AM	-89.8	47.3
1	115.250 OR MARKER 115.275 TYP	AM	-90.3	44.8
14	121.250	AM	-90.7	42.6
15	127.250	AM	-91.1	40.6
16	133.250	AM	-91.5	38.8
17	139.250	NBFM	-91.9	37.1
18	145.250	NBFM	-92.3	35.6
19	151.250	NBFM	-92.6	34.2
20	157.250	NBFM	-93.0	32.9
21	163.250	NBFM	-93.3	31.7
22	169.250	NBFM	-93.6	30.5
7	175.250	TV CHANNEL 7	-93.9	29.5
8	181.250	TV CHANNEL 8	-94.2	28.5

9	187.250	TV CHANNEL 9	-94.5	27.6
10	193.250	TV CHANNEL 10	-94.8	26.7
11	199.250	TV CHANNEL 11	-95.0	25.9
12	205.250	TV CHANNEL 12	-95.3	25.2
13	211.250	TV CHANNEL 13	-95.5	24.5