RF LEAKAGE

Leakage Introduction

This article explores the mechanisms which give rise to signal leakage from cable systems. It discusses the services that leakage could disrupt, and details methods of locating the signal leakage source. Before addressing the complexities of radiation modes, location of leakage sources and troubleshooting in the system, the nature of the services which will be disturbed by an RF leakage problem will be examined. The frequencies carried on the cable which are most apt to cause problems are the marker beacon guard band (74-76 MHz), aircraft navigation and communications (108-136 MHz) V, and 225-400 MHz. Cable systems contain significant energy at many of these critical frequencies. Interference generated in these frequency bands is potentially disastrous. If the shielding system integrity is impaired, these signals can radiate and cause interference to other services. The cable system can leak RF energy in many modes, depending primarily on physical parameters of the cable plant itself. The most important goal is to protect the Aircraft Navigation ILS (Instrument Landing System), and the air traffic control communications system.

The following is a synopsis of several ways RF leakage can be produced by a cable system:

The Cable Subscriber

Many cable subscribers attempt to avoid charges for extra set hookups and the accompanying monthly additions to their bills. Some subscribers decide to extend the system themselves. Radio stores oblige by offering varieties of 300 ohm and 75 ohm splitters, matching transformers and prepared lengths of cable and twinlead. If the perpetrator is sophisticated electronically, 75 ohm parts including splitter(s), matching transformers and coaxial cable will be purchased. Many of the people who attempt to alter a system do not possess this sophistication and, because they have grown accustomed to the 300 ohm flatline world, simply parallel the extra length of 300 ohm extension line to the antenna input screws on the back of their TV receiver. Figure 1 shows the normal cable TV transition to 300 ohms (represented by the matching transformer in 1A), and the extension of that service with hardware store 300 ohm line in 1B.

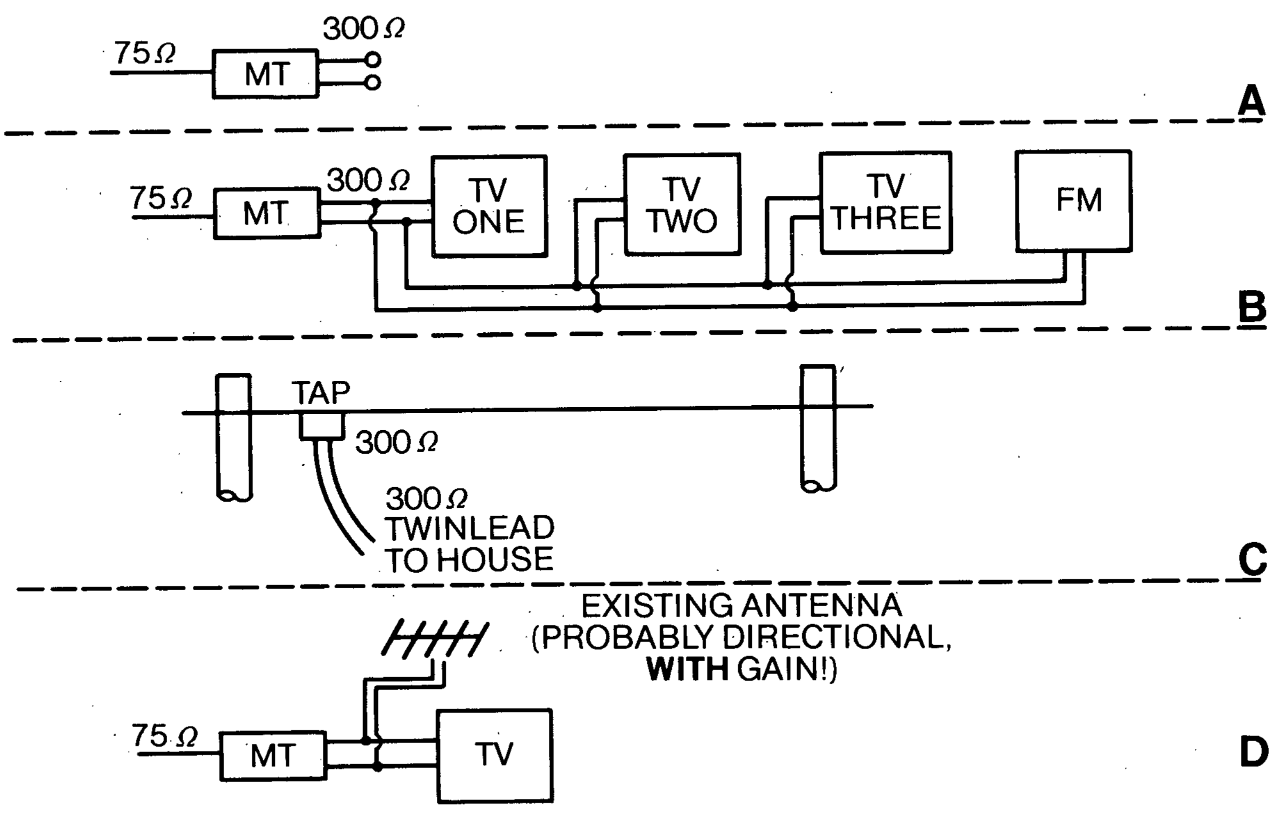

Figure 1: Illegal Hookups.

In a balanced transmission line, the current flow in the conductors sets up equal and opposite magnetic fields. This means there is no RF leakage from balanced line. The balance is maintained as long as the driving or source impedance to the line, and the load of the receiving impedance at the end of the line, equals the impedance of the line itself. The CATV matching transformer is designed to drive a 300 ohm load or the input to the television receiver. However, when two or more 300 ohm loads are connected in parallel, as illustrated in Figure 1B, the impedance of the multiple sets paralleled on the 300 ohm line becomes quite complex and is no longer 300 ohms. An approximation of what happens to the load and impedance seen by the 75/300 ohm matching transformer would look like this:

$$Z_s = \frac{1}{1/Z_1 + 1/Z_2 + 1/Z_3}$$

But this requires that Z_L (which is the TV set, or load) itself be a balanced 300 ohm load. If for some reason Z_l is not a good 300 ohm balanced load, then $Z_S = Z_L/Z_O$ for *odd* quarter wavelengths at any specified frequency, while $Z_S = Z_L$ for *even* quarter wavelengths at any specified frequency. (See Figure 2.)

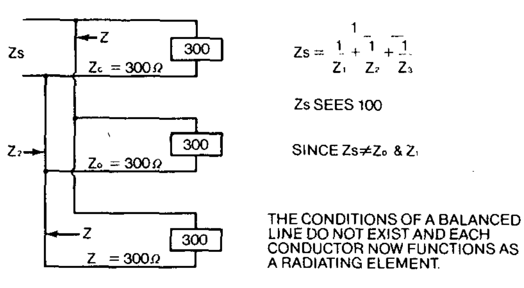

Figure 2: Unbalanced 300 Ohm Load.

Under these conditions, the 300 Ohm extension radiates in an almost unpredictable fashion. Whether it radiates on Channel 2, 11 or any other frequency depends entirely upon its length. The unbalanced twinlead has become an antenna. As an antenna it radiates best when its length is some integral multiple of a quarter wavelength. Since it is impossible to guess the length of the extension lead utilized to hook up extra sets, it is also not possible to predict which frequencies will radiate from the extension lead antenna.

Another type of illegal hookup is shown in Figure 1C. This subscriber sets up the antenna outside his home by connecting the 300 ohm twinlead into a tap. The same conditions of imbalance, and therefore radiation, exist as with the subscriber who does it all inside the home. The physical length of the wire will usually be longer, however, and being suspended on one end at the height of the cable feeder line, the 'flat line antenna' can be more efficient as a radiation source. For a 'drop' of 150 feet, the physical length of the twinlead will be on the order of 10 wavelengths at television Channel 2 (55 MHz) and 40 wavelengths at Channel 13 (213 MHz). When a 'radiator' becomes this long, it tends to become a travelling wave antenna which concentrates the radiation near the plane of the antenna and generally in line with it.

Finally, there is the subscriber who decides to enhance the cable system (Figure 1D). After an installer leaves the premises, the subscriber decides to reconnect his outside antenna to the 300 terminals on the back of his TV receiver. Now the 75 to 300 ohm matching transformer sees a pair of 300 ohm loads; the TV receiver and the 300 ohm antenna. The OdBmV (1000 V) signal now travels (in part) up the antenna lead to the directional outdoor TV antenna. The outdoor antenna has gain so that the radiated power could be as much as 10dB above the level arriving at the outdoor TV antenna terminals from the cable feed. Additionally, some radiation will occur from the TV antenna feeding since it now sees a 300 ohm antenna at one end and two parallel 300 ohm loads on the opposite end, thereby creating mismatch to the line and consequent imbalance.

The Cable System

In the system itself, the coaxial drop line may radiate signal. If the braid covering continuity is damaged, the chance for RF leakage becomes great. The most widely used low cost drop material is RG-59. This cable commonly has a braided and/or foil shield which covers the dielectric. Numerous approaches to shield design are considered to provide the most cost effective shield to keep radiation (engress) and interference (ingress) to a minimum.

The normal braid is usually specified in % coverage of the dielectric by the braid material itself. When new, some cables have shielding in the 30-40dB of isolation region. Double shielded braid is usually restricted to headend jumpers and other locations where high RF signal levels are contained within the cable. Foil shield, with or without braid, is initially an excellent drop cable. There are some reports that aging, flexing and general use can deteriorate the effectiveness of the foil shield. Under certain circumstances, the foil can separate offering a path for RF leakage. It is also true with any drop cable, that RF leakage is likely unless the connectors are properly attached to the cable and properly tightened to the tap, transformer, or other termination point.

A newly constructed and properly installed cable system will easily pass a leakage test. The isolation in solid aluminum sheath cable is very good (on the order of 120dB). The present generation of RFI connectors is excellent, and the latest RFI sealing is generally very effective. Time changes many factors, however, and misuse of the equipment shortens the life span of even the best gear. In time, the shielding integrity will become impaired, and the system may begin to leak. The manner in which this leaking occurs depends on the type of shielding discontinuity. A few of the more common problems with system shielding integrity are discussed below.

Any current carrying element (i.e., the center conductor of coaxial cable) can be turned into an antenna by wrapping the current carrying element in a cover and then cutting an opening in the cover to allow the RF current to radiate. This principle is commonly employed in high band VHF and UHF television transmitting antennas. One form of this slot radiator is found with a CATV amplifier. The RF current is at high levels within the amplifier and if the aluminum housing is ajar, the RF not only has a way to get out, but the open housing reinforces the radiation or RF leakage by acting as a slot radiating antenna (See Figure 3). The case can appear to be physically shut but closed in such a way that the RFI gasket originally supplied is no longer effective. This leaves a small (electrical/RF) opening through which the RF can radiate. The slot radiator is very frequency selective; that is, it acts like a slot when the slot opening is ½ wavelength or more long. Typical amplifier cases are simply not long enough to act as slot radiators below 200 MHz. This characteristic explains why some amplifier-housing radiation problems seem to be limited to the upper end of high band or on super band frequencies.

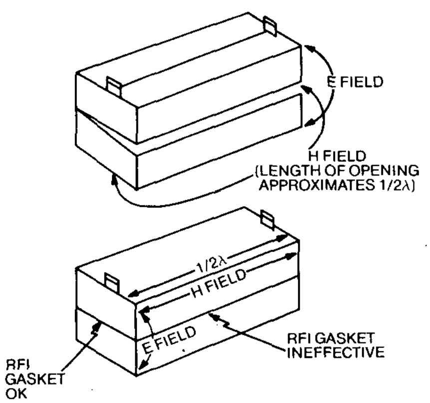

Figure 3: Amplifier Housing As a Cavity-Coupled Slot Radiator.

Another way for a slot to form is on the cable sheath itself. Figure 4 depicts a situation with aluminum jacketed cable; although with certain conditions, it could also happen in flexible cables such as RG-6, 11 and so on. If a tree limb or the messenger rubs on the aluminum sheath or a creature chews on the cable removing a strip of the aluminum jacket, a slot radiator occurs in the feeder or trunk line itself. Maximum radiation will occur when the slot is ½ wavelength long, or multiples of ½ wavelength. Since the cable diameter is a small fraction of a wavelength, the radiation from such a slot would be omni-directional around the cable. Because of the cable height above ground, you may get in-phase reflections from both the ground and nearby cables, strands, down guys etc., which can re-polarize the original horizontal signal into the vertical mode as well as in-between polarization modes.

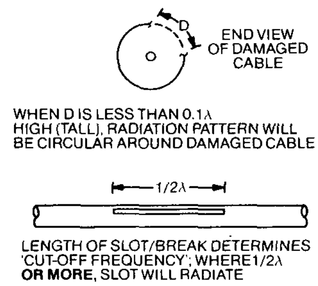

Figure 4: Slot Radiators on an Aluminum Jacketed Cable.

Cable which has been subjected to radial cracking can radiate in either of two manners. In one case, the cable has a single discontinuity at a pole or other location. (See Figure 5). It will radiate as a 'point source'. If the strand happens to be grounded at the pole where the radial break is located, the only radiation likely is a point source. However, if the discontinuity occurs away from a pole or at a pole where there is no ground run, the break in the shield integrity can radiate as both a point source and in the travelling wave mode as well. If energy from a point source couples back onto the cable sheath and/or messenger, it travels along the sheath or messenger and the sheath or messenger becomes a travelling wave antenna that radiates the signal. If the cable happens to be broken in two or more locations, multiple effects occur: point source radiation, non-resonant travelling wave radiation and resonant radiation due to the length of cable between breaks. Radiation maximums in ¼ and ½ wave multiples will occur along the isolated sheath section. Nor is a radial-cracked cable required to produce the combination of point source and travelling wave radiation. Figure 5 also depicts how an improperly installed entry fitting on a cable amplifier housing can create a similar situation.

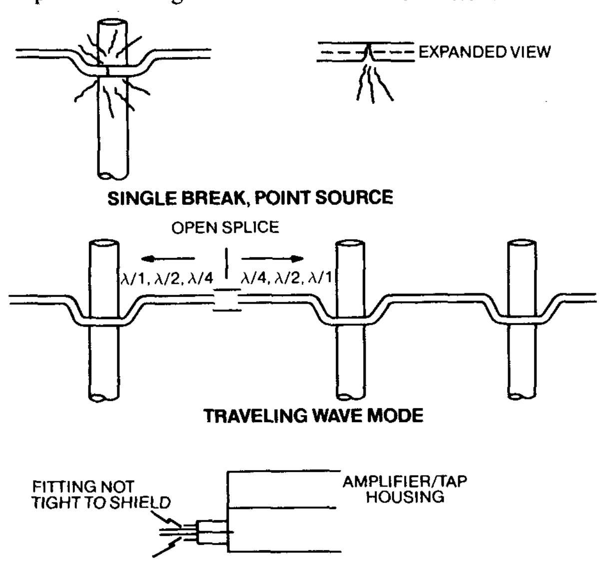

Figure 5: Both Modes — Point Source and Travelling Wave.

The primary problem with RF leakage in a headend facility is the trouble this leakage presents to cable operations. RF leakage might interfere with the operation of other signals on the same or displaced frequencies. Signal levels in the headend are generally as high or higher than at any other location in the system. Not only must we be concerned with radiation at cable carriage frequencies, but also at processor IF (Intermediate Frequencies) and LO (Local Oscillator) frequencies as well.

A list of all radio frequencies present within the headend facility should be compiled and posted. Any headend-created frequencies (such as the IF ranges, LO's from equipment processors or UHF or VHF converters, etc.) should be checked with an RF leakage test set within and immediately outside the headend facility. The use of double-shielded cable for headend wiring is highly recommended because the presence of such extra signals in the headend area may cause reception problems to off-air and locally generated signals as well as to other broadcast services.

Leakage Detection

To this point little has been said regarding reflections and other phenomena which can mislead the radiation investigator. When the RF signal strikes a reflective or partially reflective and partially conductive surface, it may change field polarization as well as direction of travel. After a few bounces, the actual field present, or its original source, is impossible to determine. The cable system which radiates will usually do so at multiple locations. The error in construction or maintenance which allows RF leakage to occur is likely to be repeated in more than one place. In extreme cases of leakage, when the system has no radiation monitoring capability, the first indicator of trouble may be complaints from non-cable customers who report receiving interference from the cable plant. In fringe reception areas where large, tall, home antennas are standard, it may be possible to plot leakage locations by triangulating with rotor equipped home antennas. A TV receiver in the service truck, tuned to a cable channel which is not shared with a locally available off-air channel, is another method of keeping tabs on radiation. As the service truck makes its daily rounds, the presence of a 'unique-to-cable' channel signal will be an instant indicator of problems. There are several dedicated leakage detection systems available in the marketplace. These systems inject a discrete 'test signal' or 'carrier' into the cable system, typically at the headend, and then utilize a remote transportable receiver in the field, tuned to that discrete carrier frequency. One such system utilizes a frequency in, or immediately adjacent to, the FM broadcast band (88-108 MHz) and the receiver used in the field is a portable FM broadcast receiver. By modulating the discrete carrier frequency with a distinctive warbling tone stepped in amplitude, the technician has both a quick identification for the discrete test carrier and a method of determining if one is getting closer to, or farther from, the radiation source.

Another approach provides a choice of frequencies in the midband and/or superband spectrum, as well as FM. The receiver in this system is a dedicated instrument supplied with antennas useful for both general surveillance and specific pinpointing of actual radiation sources.

Assigning radiation or leakage to a single source is difficult. When leakage is first discovered, the operator will have little or no idea as to the source. The monitoring antenna typically has poor directional characteristics, and if they are known in advance, they are typically not predictable under field conditions. This is especially true when the detection antenna is mounted on a vehicle. The presence of the vehicle metal body plus the nearby proximity of numerous other metallic objects (other vehicles, utility lines, buildings, etc.) will distort, and possibly destroy, the ideal directional characteristics of the monitoring antenna. In short, what seems like the front may actually be the back or side!

To determine the true source of radiation, and the direction from the point where the signal is first noticed may well require switching to a directional antenna with relatively stable directional characteristics. A few are shown in Figure 6 with typical 'patterns.' However, when using a loop or dipole antenna for direction finding, calibration should be against the null of the antenna. The null tends to be much more clearly defined than the peak, which tends to be quite broad. However, if utilizing a yagi antenna, the opposite is true; the peak is reasonably sharp and much better defined than the null(s), which tend to be 'multi-pointed' with many minor lobes.

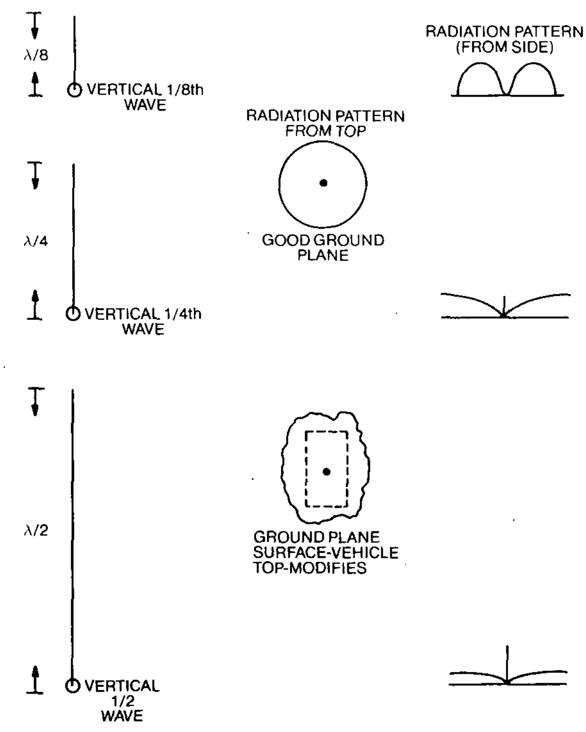

Figure 6: Antenna Patterns, Vertical Antennas.

When the radiation is tracked close to its suspected location, the amount of antenna gain must be reduced, and a small-capture area antenna with a good null indication must be used. This suggests a small, hand held capacitively loaded loop antenna (See Figure 7) for a generalized loop construction technique.

There are two separate and distinct levels of radiation detection: (1) detection of a source which may be harmful to either your system or to other users of the 'ether,' and (2) accurate determination of the absolute radiated signal levels present. To determine the absolute value of a radiated signal requires both precision measurement equipment and precision measurement techniques.

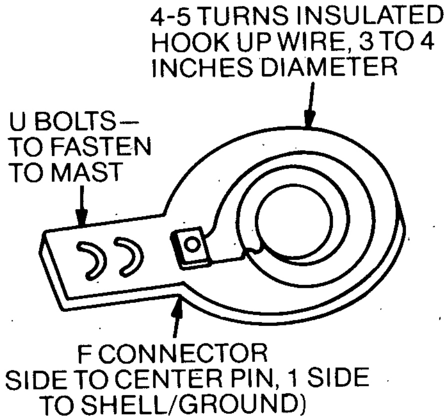

Figure 7: Small Loop Construction.

There are two mistakes commonly made by CATV operations attempting RF field measurement. One is the disregard given to the design and construction of the radiation detection and measurement antenna, and the other is the care in selecting and specifying a preamplifier to be used in the radiation measurement system.

Figure 8 shows three correct methods of designing an antenna that in addition to detecting radiation, will allow accurate measurements of the levels detected. Figure 8A is a folded dipole constructed from twin lead. The dipole is cut to length, and the two ends of the twin lead soldered together to make a loop. Then the bottom side of the loop is split exactly in the middle where a 4:1 balun (matching transformer) is attached (300 ohm side to 300 ohm line). Out of the 75 ohm side comes the 75 ohm (unbalanced) feed. Such a dipole can be built and installed on a piece of 1 x 2 or plastic to hold it rigid.

Figure 8A indicates a practical problem in that the configurations are frequency sensitive. In Figure 8A the twinlead dipole antenna is cut to a fixed frequency. While the 73 ohm balanced dipole in Figure 8B could be adjusted for the frequency changes, the shorting ¼ wave stub would also have to be adjusted. Figure 8C solves this problem by allowing adjustable 73 ohm dipole element lengths to couple to a 75 ohm unbalanced transmission line through a trifilar wound broadband balun.

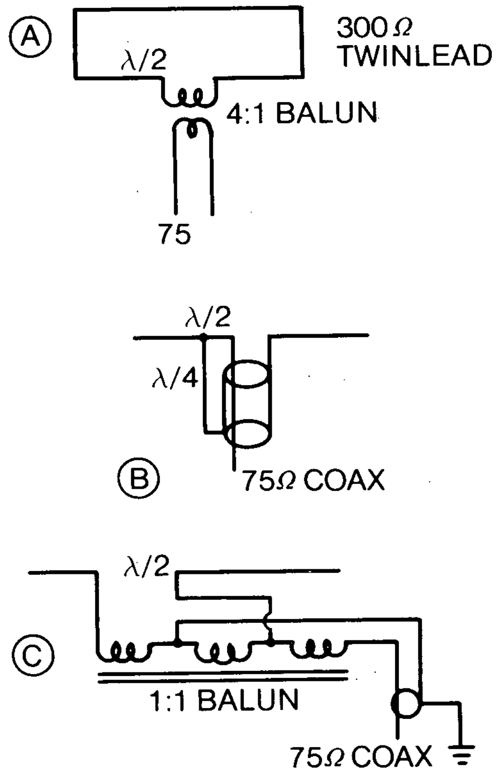

Figure 8: Correct Methods of Designing Antennas.

Another commonly abused portion of the radiation detection and measurement system is the preamplifier. Because signal levels are very low at the permissible radiation level (20 V/m) and the field strength meter/spectrum analyzer has a noise floor at, or several dB above, this permissible level, some pre-amplification is typically necessary. In most locations the pre-amplifier will be expected to perform in an overloaded condition. It should be noted that by definition of the task at hand, the pre-amplifier needs to be broadband (i.e., 50 to ~400 MHz). Any signal reaching the input will be coupled to the pre-amplifier without pre-selection. The optimum situation arises when the dipole antenna rejects frequencies removed from the radiation detection frequency. If one or more strong FM broadcasting stations, TV stations, or two-way radio stations operate in the midband range in a particular area, the pre-amplifier can become a useless piece of instrumentation. When one or more strong signals are present at the input, the pre-amp device goes into compression. This causes intermodulation products (i.e., the pre-amp generates new signals caused by the high input signals). This causes erroneous or highly suspicious readings in the radiation detection system. To solve this problem, either a fixed or variable bandpass filter must be added to the system to act as a pre-selector and restrict the input frequency window to the pre-amplifier (See Figure 9).

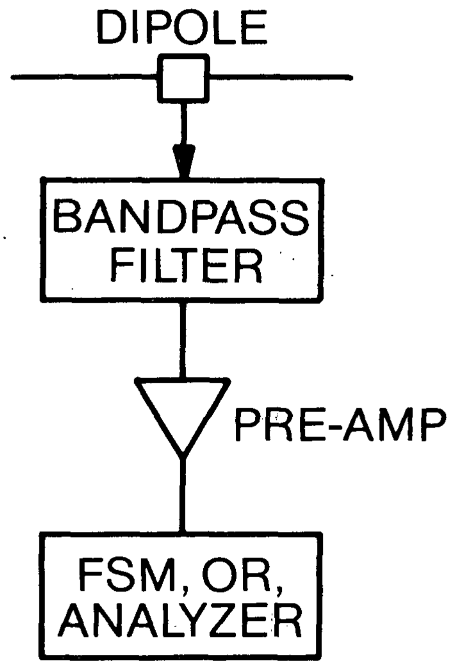

Figure 9: Bandpass Filter Used As a Pre-Selector.

Radiation measurement requires an expert signal to the FSM/SLM or spectrum analyzer that is at least 8 to 10dB greater than the noise floor of the meter/analyzer. For a typical SLM/FSM, this means we must have at least -30dBmV from the pre-amplifier, while with an analyzer the signal must be -40dBmV or more. The following is a table of permissible signal levels per FCC regulations 76.610 subpart K:

Channel/Frequency	dBmV
2	-36dBmV
3	-37dBmV
4	-38dBmV
74 MHz	-39dBmV
5	-39dBmV
6	-40dBmV
100 MHz	-41dBmV
108 MHz	-42dBmV
165 MHz	-46dBmV
7	-46dBmV
8	-46dBmV
9	-47dBmV
10	-47dBmV
11	-48dBmV
12	-48dBmV
13	-49dBmV

Detecting a -49dBmV signal with a test dipole, and adding a 26dB gain pre-amplifier to the system, implies that you will now be able to read the radiation level at the -49dBmV/+26dBg or -13dBmV point on your meter. Unfortunately, this is not quite true. The addition of a 26dB gain pre-amp does not necessarily mean that your system sensitivity goes up 26dB. The noise figure of the pre-amp must also be taken into consideration. If, for example, the pre-amplifier has 26dB gain and a 6dB noise figure, the net increase in system sensitivity is actually 21dB. To this must be added the loss of the downline cable and the bandpass filter.

Figure 10 shows a typical calculation of what the actual signal level is under a specific condition. The meter reads -20dBmV. However, there is a 26dB gain pre-amp in the line (which reduces the indicated level from -20dBmV to -46dBmV), and, two 1dB losses: the downline cable and the bandpass filter. So, rather than -46dBmV, the radiated level detected is 2dB higher than this, or -44 dBmV.

Radiation is never a simple problem. The models of leakage and propagation of the signal source are complex and often confusing. The results of RF leakage can range from minor to disastrous. But this is an issue which will not dissipate. More and more broadcast services are becoming aware of cable TV as an interference source and are focusing much attention on this subject.

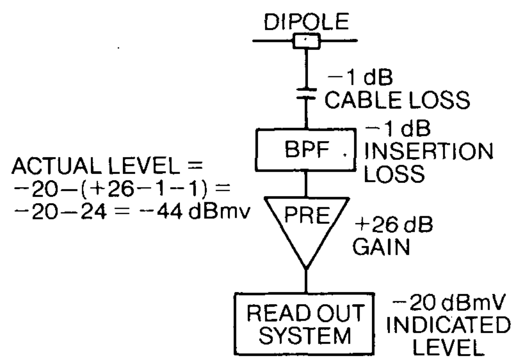

Figure 10: Typical Calculation of an Actual Signal Level.

This article was written for ITEM 84 *by Raleigh B. Stelle III, Vice-President of Marketing, Texscan Corporation, Phoenix, AZ.*