CATV LEAKAGE AERIAL SURVEYS

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Over the past few years the date of July 1990 has been deeply etched on the minds of CATV operators as the date when the FCC will begin to enforce the provisions of Part 76.611 regarding annual qualification of cable systems to the cable leakage standards. Compliance with this section was delayed in the rule making of late 1984 in order to allow cable systems to "clean up their leakage act". When enforcement of this section begins the Commission has threatened severe consequences including forfeitures and cessation of operation for lack of compliance. Not to dwell on this well known area, suffice it to say that the consequences are highly undesirable for the cable operator.

FLYOVER vs. CLI

Qualification under Part 76.611 can be accomplished in either of two ways; 1) compliance with the limits of the Cumulative Leakage Index (CLI), compiled from ground based measurements or 2) flyover measurements in the airspace above the cable system. Ground based measurements, which require the location and measurement of every leak in excess of 50 microvolts per meter (uV/m) in at least 75% of the cable system, are time consuming, tedious, and expensive, consuming weeks, if not months of time. In the process of these measurements, ample time is allowed for new leaks to develop before the measurements are complete. Flyover measurements, on the other hand, are quickly done, usually within a few hours or days, and provide much more of a "snap shot" view of the cable system leakage situation.

Flyover measurements directly address the basic "protection from interference" purpose as established by the FCC. This applies to protection primarily of aeronautical radio services and secondarily, other over-the-air radio services. FCC and industry studies (see Report of Advisory Committee on Cable Signal Leakage - 1977) indicate that leakage fields not exceeding 10 uV/m in the airspace do not present a significant interference hazard to aeronautical communication and navigation radio services. A flyover survey directly measures these leakage fields along the flight path, and compares them to the 10 uV/m threshold. In contrast, the two methods for determining CLI (I of infinity and I of 3000) estimate the total leakage field strength in the airspace by summation of the probable effects of the leaks measured on the ground. In the report of the Advisory Committee on Cable Signal Leakage the CLI thresholds were established by comparison of ground and airspace measurements in but a few systems. The actual mechanism of summation of distributed cable system leaks is quite complex involving not only distances but radiation patterns, polarizations, and phase addition of signals, making precise analytical determination extremely difficult. Flyover measurements are direct and to the point thereby eliminating much estimation.

This paper describes the efforts of Dovetail Systems Corporation to develop hardware and software to automatically gather data in an aircraft and subsequently process that data to produce results which are useful to the cable operator for evaluation and refinement of his monitoring and maintenance procedures and to the FCC for evaluation of system leakage performance.

THE MEASUREMENT PROCESS

Paragraph 76.611 of the FCC Regulations is fairly brief but does specify a threshold of 10 uV/m at 450 meters above the average ground level below which leakage levels are permissible as well as certain requirements and guidelines for calibration and measurement. In consideration of the altitude of the overflight we find that it is exactly 150 times the distance specified for the standard ground based leakage measurement (450 meters (1500 feet) versus 3 meters (10 feet)). On this basis one can say that a single leak which would equal the airspace threshold would measure 150 times 10 uV/m at three meters from the leak. In other words, it requires a single leak of 1500 uV/m at 3 meters to produce the 10 uV/m threshold at 450 meters. This indicates that single leaks in the few hundred uV/m region are not expected to be the problem in failing the flyover measurement test.

Part 76.611 specifies a horizontally polarized antenna on the aircraft but it does not specify any further restrictions. Assuming the practical orientation of a horizontal dipole on an aircraft to be either longitudinal or transverse to the fore and aft axis, two general types of search patterns are indicated. If the antenna is oriented transverse to the fore/aft axis of the aircraft the main dipole lobes are directed fore and aft producing a pattern with nulls to the left and right and maximum response within perhaps + 45 degrees of the flight path. With orientation parallel to the fore/aft axis of the aircraft, the coverage tends to be to the sides and beneath the aircraft thereby producing a main lobe coverage of roughly ± 45 degrees fore and aft of the vertical with a fairly broad pattern to the left and right. In either case the coverage patterns are quite broad and the aircraft antenna accepts maximum energy from ground signals which present horizontally polarized fields to it. A receiving dipole orientation diagram is given in Figure 1. With the receiving antenna oriented parallel to the fore and aft axis of the aircraft, as has been chosen in our configuration, horizontally polarized signals generated to the sides of the aircraft by horizontal radiators parallel to the receiving antenna are readily detected, while those generated by transmitting elements orthogonal to the receiving antenna are not sensed at all. This is shown in Figure 2. In the fore/aft direction the same is true but it is clear that even if all radiating elements are horizontal (parallel to the ground) there will be all variations of coupling to the receiving antenna depending upon the orientation of the radiating elements relative to the receiving antenna rather than their orientation to the ground.

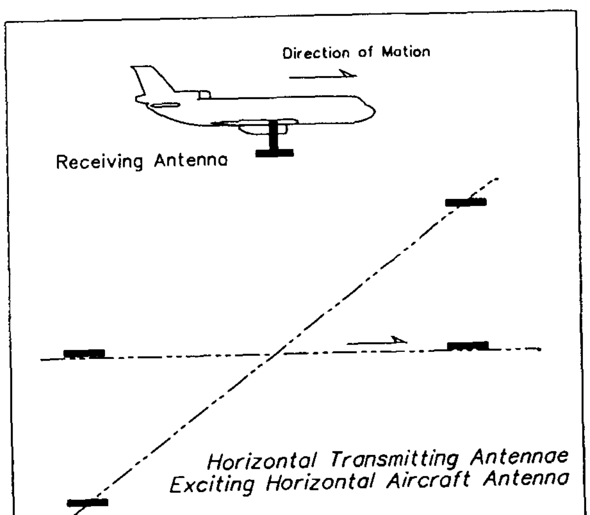

Figure 1

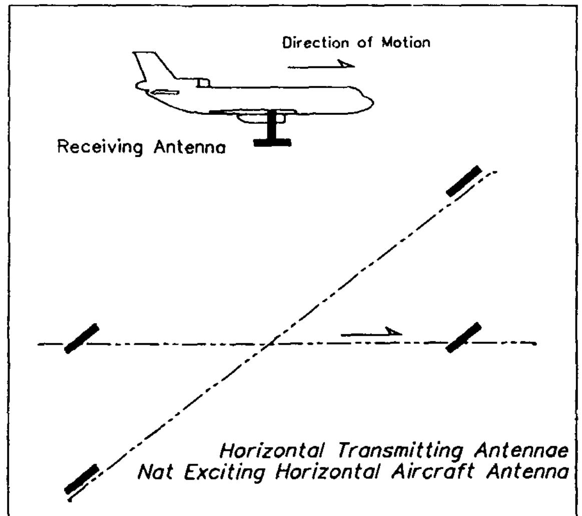

Figure 2

Let us, for a moment, assume that there are also elements in the cable system which produce vertical polarization with respect to the ground. These might be caused by leakage currents flowing on drops, system grounds, etc. In the case chosen in Figure 3, vertical elements to the left and right of the aircraft, will be orthogonal to the receiving antenna on the aircraft and therefore coupling would be minimum. Vertical elements fore and aft of the aircraft will have projections in the plane of the receiving antenna and will be received to the degree that the projections of these elements intercept the receiving antenna on the aircraft. The bottom line is that in three dimensions, specification of polarization as simply "horizontal" or "vertical" does not completely define the energy received by the measurement antenna, particularly when the reception is accomplished by use of a linearly polarized element.

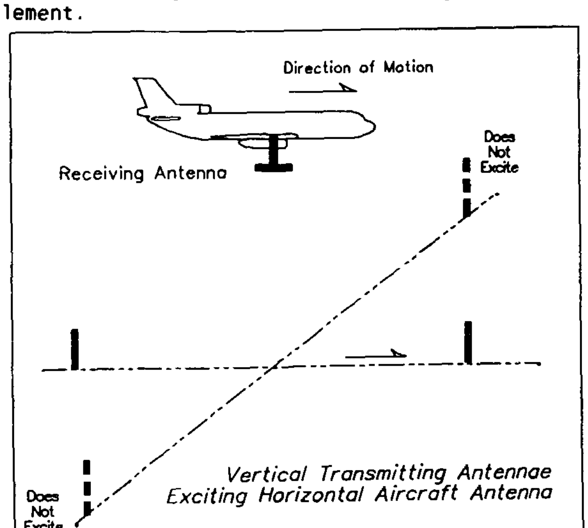

Figure 3

A number of solutions for this dilemma can be conceived. First, if an antenna were given higher gain and its coverage thereby restricted to a smaller angle, it would be possible to restrict the angles of reception and thereby reduce the polarization ambiguities. The problem with this solution is that increase of antenna gain with its commensurate decrease in angle of reception, requires a larger receiving antenna array. A single dipole element is already large relative to the dimensions of a small or even medium sized aircraft so that utilization of an array becomes particularly unwieldy in terms of size and projections from the aircraft structure. It would also be a step forward if a circularly polarized antenna were employed, especially one which maintained its circularity over a wide range of look angles. This also is somewhat impractical due to size.

At this point it makes sense to appeal to the basic reason for making the measurements in the first place. This is to try to quantify the amount of energy which would be received by an aircraft receiving system flying through the airspace. In the scope of all aircraft which might fly in the airspace, any one of a large number of antenna configurations might be employed. Each of these configurations could have a differing response which is further altered by varying aircraft shapes. It would appear that the best which can be said about the leakage survey system is that it attempts to measure field strengths in a way "similar" to a "typical" aircraft receiving system where "typical" seldom corresponds exactly to a specific antenna and its configuration on the aircraft.

Due to the polarization confusion generated in three dimensional space previously described, one might use an antenna which was vertically polarized and which would probably produce an equally valid measurement of the fields in the airspace. Vertically polarized antennas can be conveniently installed and usually produce less impediments to flight and are often used in actual aircraft communications and navigation installations. The program for measurement of signal leakage in the airspace above the cable system, which has been instituted by Dovetail Systems, has made provision for some "research" in these areas. We hope to fly simultaneous horizontal and vertical measuring systems comparing the data. If there is reasonable correlation it will probably prove to be far more practical to use low profile, vertically polarized antennas for reception rather than the somewhat awkward horizontal dipole which now clears the ground by but a few inches on landings and take-offs.

THE MEASUREMENT EQUIPMENT

In the system described a multi-purpose receiver has been employed. This receiver has a bandwidth in the 25 kHz region and can be programmed to receive AM or FM signals. In either case some AGC is used which has the effect of low pass filtering the data and producing an analog measurement. The computer receives the detected analog signal and records the data in successive samples. Many samples are taken each second allowing measurement at speeds in excess of 150 mph. Selection of AM or FM modes on the receiver is largely a function of modulation detection. AM modulation affects the average power in the carrier and therefore requires a correction if such modulation is used for identification. Narrow band FM modulation, on the other hand, as long as it does not at any time move the carrier out of the passband, does not change the average power and requires no correction factor.

Modulation is applied to the test signal to make it audibly identifiable. This is the only area of the data acquisition process which requires operator attention. Whenever the received signal level on the channel is above a certain threshold (well below the 10 uV/m) the distinctive tone(s) can be heard and recognized by the operator. Should a substantial level reading be encountered but the identification not be audible, the data is flagged as being suspect, probably the result of some interference phenomenon. This data is not used in the final analysis since the absence of modulation indicates that the leakage is not the predominant signal being received. In our flight tests we have encountered occasional interference of this type, however, these occurences have been infrequent and have not represented a significant fraction of the total data taken. If such interference were regularly encountered the test frequency should be changed to avoid it.

In addition to the basic receiver selectivity a relatively narrow RF bandpass filter is inserted ahead of the receiver to prevent overloads from out-of-band signals such as television and FM broadcast stations, aircraft transmitters and the like. The receiver with its preselector, is calibrated in the laboratory generating a curve relating microvolts input to the output level indication. In this way the receiver is characterized over the entire range of signal levels encountered in the measurements. A calibration of the measurement system (receiver, bandpass filters and installed receiving antenna) is flown over a "well characterized antenna..." and signal source as specified by Part 76.611. This ties the microvolts input versus output curve of the receiver to the actual 10 uV/m signal threshold in the airspace thus providing an absolute calibration of the entire system. The calibration factor obtained (uV/m in the airspace to microvolts input to the receiver system) is then used to relate the receiver output level indication directly to the field strength in the airspace.

In the DSC system an industrial digital computer is employed. This unit is of rugged construction and high stability and has served very well in our tests to date. It employs both

AC and DC supplies so that it can be run on 24 volts DC in the aircraft and 110 volts AC for calibration in the lab and even for data reduction after the flight. Although the data reduction function may be performed on another similar computer in the laboratory environment. The existing system employs extensive RAM plus a hard disk and a single floppy disk drive. All data recorded is saved. In the process of data reduction (to be covered later) all data points may not be used. Since there are a number of optional routines for data reduction, the original files are preserved and can be reprocessed in the future if a re-run or processing with another algorithm is desired. In the current version of the equipment, a nine inch CRT and a keyboard are also employed. These allow maximum flexibility of configuration and can be of great benefit when "researchy" ideas occur during the flight.

The present equipment is configured to take inputs from multiple receivers so that multi-frequency measurements are possible if the proper antennas to cover the desired frequencies are present. Ground measurements by others have shown occasional heavily frequency dependent results. We are anxious to, over the next few years of measurements, investigate multi-frequency effects whenever possible.

Data in the computer is taken simultaneously with LORAN position indications. The LORAN updates approximately once per second and its data is recorded along with the field strengths. The resolution of LORAN is basically .01 nautical miles or about 60 feet. In the non-precision atmosphere of airborne measurements employing collection of the radiation from numerous leaks simultaneously, it is unnecessary to interpolate these LORAN readings. We occasionally experience intermittent LORAN failures due to either propagation anomalies or actual cessation of transmission from one or more LORAN stations. We have developed procedures for recovery whose efficacy depends primarily on how long the system went without location data.

Flyover paths are preplanned to provide the most efficient flight patterns. It can be seen that a long narrow segment with only a few parallel passes wastes a minimum of time in turnarounds, etc. After establishing a reference path along the edge or through the center of an area, parallel flights are conducted at offsets usually of 0.4 nautical miles (0.4nm equals 0.46 statute miles). This is a convenient method using the LORAN instrumentation. Heading and correction information is fed back from the LORAN, either to the auto-pilot or displayed for the pilot so that the flight paths, although not perfect, approximate parallel traverses one half mile apart. Observation of the latitude/longitude plot, illustrated as part of our report, will show the precision of these passes (or lack thereof). However, it must be remembered that the LORAN at all times gives the actual position whether exactly on the desired flight path or not, therefore the data is accurate in this respect.

It is well to note that flyovers such as this are concerned with coverage of "square miles" of a CATV system and not with "strand miles". The relationship between square miles and strand miles varies greatly between systems and between parts of single systems. In order to properly setup and organize for an overflight the extremities and boundaries of the CATV systems must be located by latitude and longitude. The easiest method to do this is not by use of strand maps nor even Geodetic Survey topographic maps, but simply the use a standard road map which has latitude and longitude information on it. The easiest way for a cable operator to get us started is to simply list these specific points in latitude and longitude and lay out the extremities and boundaries on the road map. From this we construct the optimum flight paths and feed the proper waypoint information into the LORAN system.

Parts of the report which we assemble, are illustrated in Figures 4 through 7. Much of the information is self explanatory. There are tabular and graphic histograms which show the distribution of the data points in order of leakage levels, either as a fraction of the total points within a certain uV/m range (Fig. 4) or the cumulative distribution (Fig. 5) which shows the fraction of the points in and above each particular range. These plots do not provide primary information on the actual leakage conditions but do present a basis for comparison of subsequent flyovers. Similar to a CLI, these presentations can indicate the trends towards (or away from) better leakage control and can thereby be used as a measure of the efficacy of the leakage maintenance program in the particular CATV system.

The latitude and longitude plot of the flight path and the signal intensities (Fig. 6) is very informative. Specific landmarks are indicated on the lat/long chart by the use of alphabetic characters referenced in the accompanying "Position Labels" list (Fig. 7). These may include extremities of the system, headends, hubs, City Hall, major intersections or whatever is of benefit to relate the data to actual landmarks. Over this is plotted the exact flight path of the aircraft as indicated by the recorded lat/long data. In our standard report this plot is in color and various selectable field intensity ranges are indicated by different colors so that it is easy to see at a glance where the areas of maximum leakage are and their extent. This type of presentation was chosen since plotting contours with single line data as is acquired during these runs, is difficult since the resolution along the flight path is very high; so high as to make meaningful interpolation between adjacent flight paths of questionable value. Hence, the representation of the leakage levels received in varying colors has proven to be quite informative. The presentation of this plot in this paper, which can only here be reproduced in black and white, is much more difficult to interpret than the actual color plots in the reports. Figure 7 includes a list of locations where the levels exceeded the 10 uV/m threshold. In addition to this lat/long plot it is possible to present the same data scaled to overlay virtually any map. Such overlays can be provided but require an exact knowledge of the scaling in order to perfectly match the map or chart.

One additional analysis plot can be produced for analysis purposes. In this plot a small section of the lat/long traverse is displayed as a heavy line. An additional plot shows the fine structure of the leakage in that part of the flight path. After some experience is gained in analyzing these plots, it becomes quite easy to pick out responses which are due to interference such as radio transmissions. These detailed plots can be provided when such a problem needs to be resolved.

In the present system data reduction and plotting of the report takes a considerable amount of laboratory analysis time but is deemed to be the most important and necessary part of the survey.

CONCLUSION

In conclusion, we have presented the rationale for and the implementation of an automatic data gathering and analysis project to observe CATV leakage by aerial survey. A good number of systems have been flown to date. We have encountered systems with excessive leakage as well as some with very little. It is our observation that leakage can be controlled, even in large systems, but not without consistent well planned monitoring and repair efforts.

Development of flyover measurement equipment and techniques continues. Not so much in terms of implementation but, in terms of data correlation with actual system parameters and investigation of secondary phenomenon such as multiple frequency and polarization effects. We expect the next several years to be years of development and progress and would not be surprised to find many interesting and perhaps unexpected conclusions as the result of a large volume of flyover and ground measurements plus the evolution of new techniques and instrumentation to achieve more meaningful results.

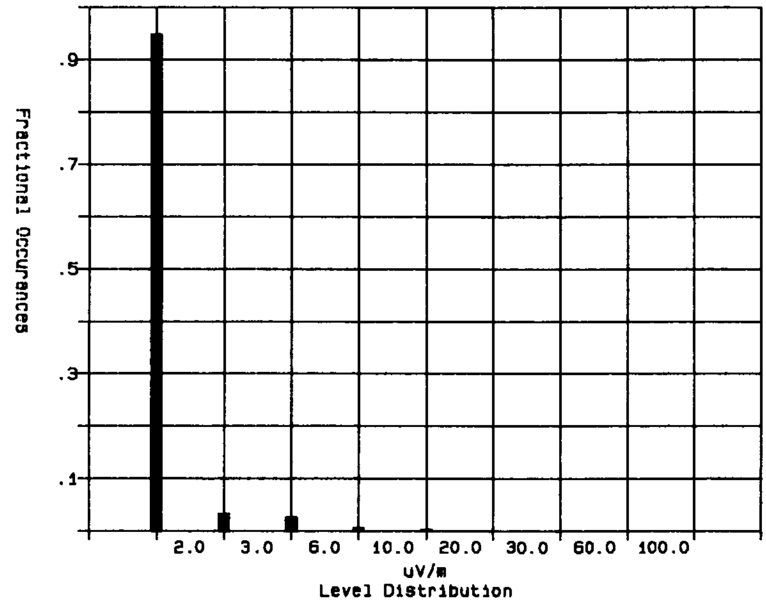

Figure 4

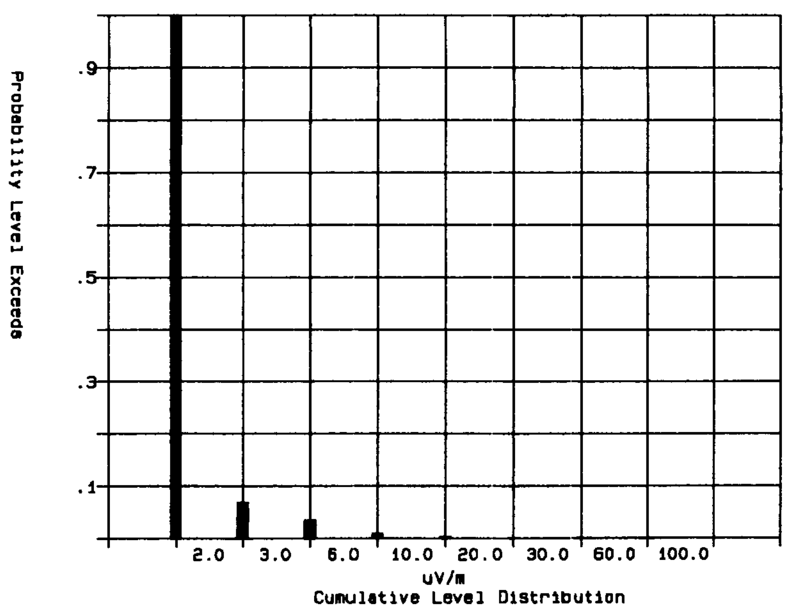

Figure 5

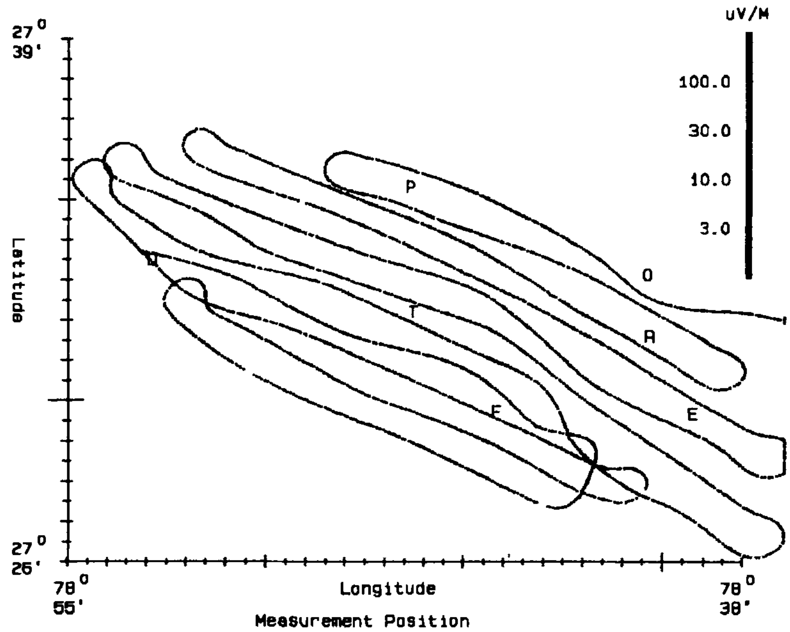

Figure 6

POSITION LABELS

Key	Position		Description
D	N27 33' 16"	W78 53' 21"	WEST HIGHWAY
E	N27 29' 30"	W78 40' 14"	RURAL AIRPORT
F	N27 29' 33"	W78 44' 58"	BEACH SITE
O	N27 32' 54"	W78 41' 18"	TOWER (415 FEET)
P	N27 35' 04"	W78 47' 05"	RAILROAD
R	N27 31' 24"	W78 41' 15"	URBAN AIRPORT
T	N27 32' 00"	W78 47' 00"	DOWNTOWN

LEVELS IN EXCESS OF 10 uV/m

uV/m	Position		Time
15.28	N27 31' 55"	W78 32' 19"	15:30:44
17.19	N27 29' 04"	W78 38' 21"	15:50:36
17.57	N27 29' 22"	W78 40' 43"	15:52:06
16.39	N27 29' 33"	W78 42' 14"	16:02:22
33.42	N27 31' 29"	W78 46' 16"	16:07:54
20.37	N27 29' 53"	W78 45' 46"	16:15:24
12.17	N27 29' 17"	W78 45' 59"	16:18:51
29.29	N27 29' 20"	W78 46' 07"	16:18:54
11.61	N27 30' 32"	W78 45' 23"	16:27:25

Figure 7

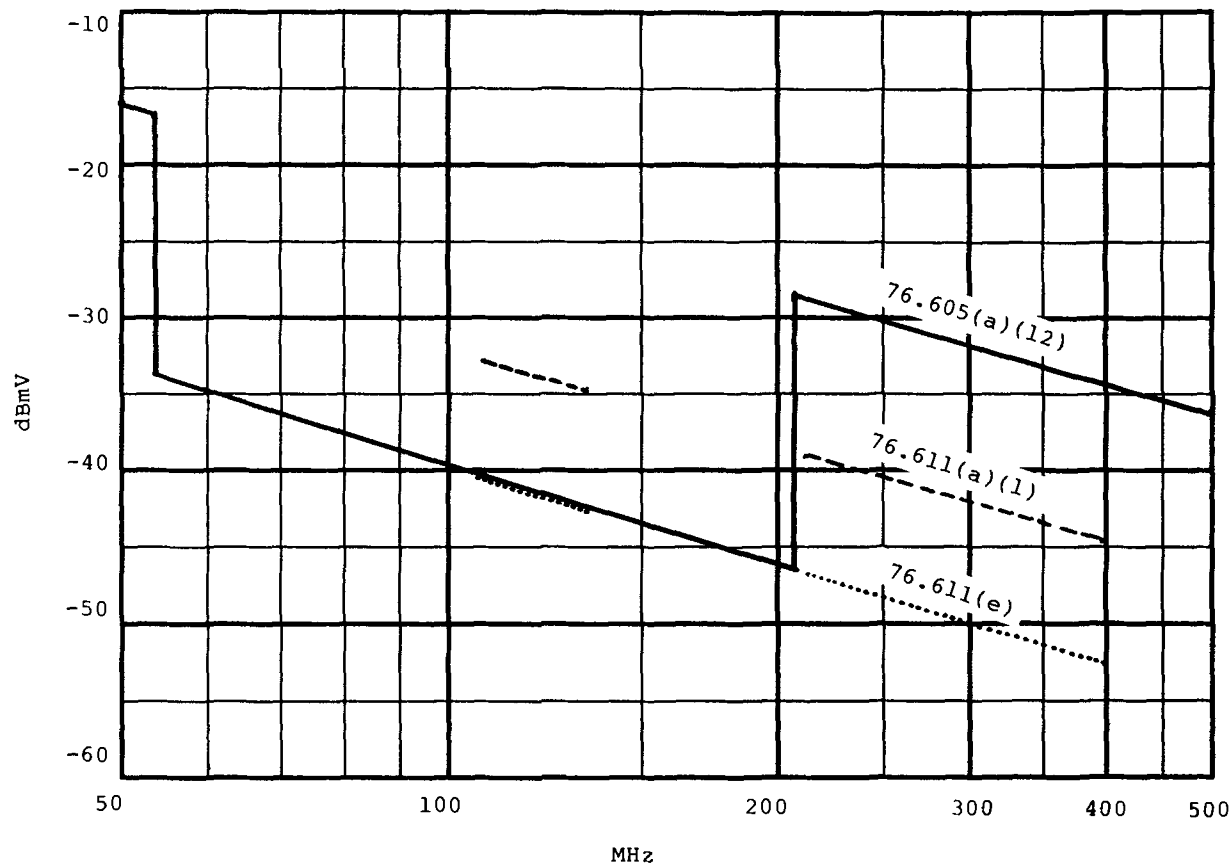

FIGURE 7

FCC Radiation Specifications for CATV
76.605(a)(12) = general system limit
76.611(a)(1) = limit of leaks to be included in CLI requirements
76.611(e) = CLI - limit for new construction

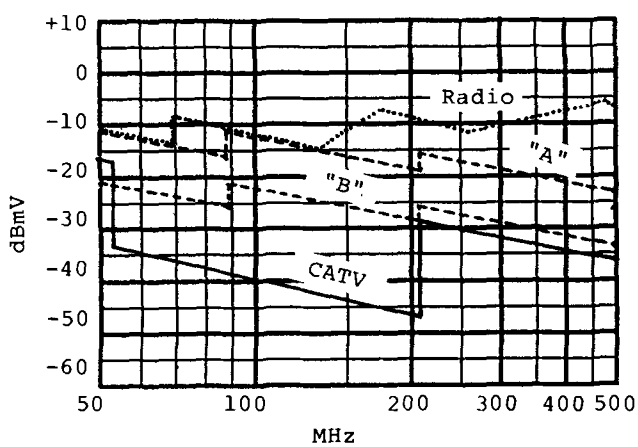

FIGURE 8

FCC Part 15 & Part 76 limits

SOURCES OF ERROR

Following the above steps and arriving at a value for measured radiation level seems deceptively simple, but in an actual situation several factors that are not easily predictable can cause erroneous results. However, if we can analyze the source of the errors and predict their maximum magnitude, we will be able to establish a safety margin for worst case conditions.

Ground reflections

Ground reflections are by far the most prominent factor in altering the measurement results of a free space test site. They affect the readings in two

TABLE I

Sensitivity of Measurement System

Noise Floor, dBmV

Analyzer Bandwidth	Preamplifier Noise Figure 3dB	6dB	9dB	12dB
4 Mhz	- 56	- 53	- 50	- 47
300 KHz	- 67	- 64	- 61	- 58
100 KHz	- 72	- 69	- 66	- 63
30 KHz	- 77	- 74	- 71	- 68
10 KHz	- 82	- 79	- 76	- 73
3 KHz	- 87	- 84	- 81	- 78
1 KHz	- 82	- 89	- 86	- 83

elements. To cover the CATV frequency range of 50 to 450 MHz each element (constituting 1/2 of the dipole, or 1/4 wavelength) should be extendable from about 6.5 to 55 inches. Fig. 1 shows the element length for any resonant frequency

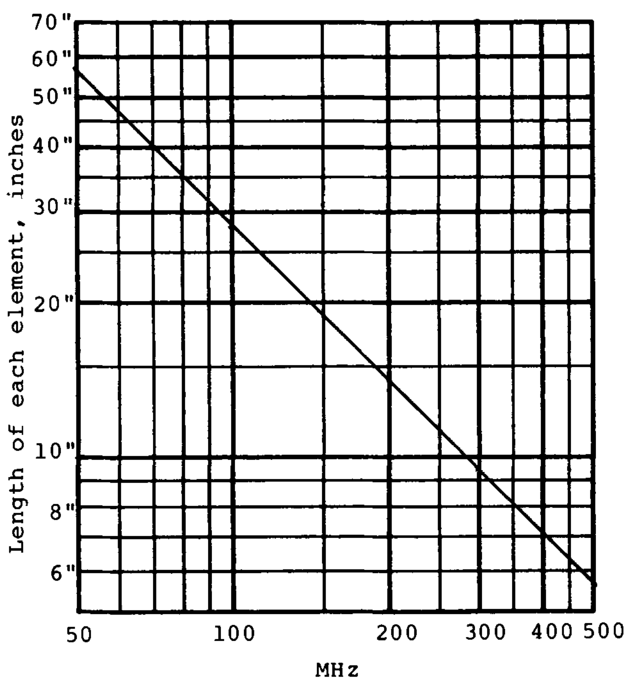

FIGURE 1

Length of each dipole element

(including average corrections for practical element thickness dimensions). But the dipole adjustment for each frequency to be measured need not be too exact, as indicated in Fig. 2, which plots the relative gain of a dipole vs. normalized frequency. In fact, three fixed

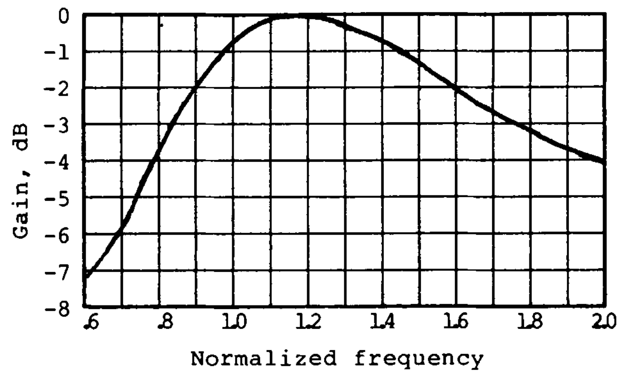

FIGURE 2

Normalized dipole gain

dipoles will cover the frequency range of 54 to 440 MHz to a 3 dB accuracy and six discrete lengths will measure 50 to 550 MHz to within 1 dB (see Table II).

TABLE II

Fixed Dipole Ranges

Element Length Inches	Frequency Range MHz	Gain Flatness dB
43	54 - 109	3
21	109 - 219	3
11	219 - 440	3
49	50 - 75	1
33	75 - 112	1
22	112 - 166	1
15	166 - 247	1
10	247 - 368	1
6½	368 - 550	1

Connections and Calibration

The dipole output impedance is close to 75 ohms, balanced; the preamplifier input is also 75 ohms, but unbalanced. A miniature 75-ohm balanced twinlead (available from several sources), about 15 feet long, should be used as the downlead. At the preamplifier input a balance-to-unbalance transformer (or "elevator coil") is constructed by winding several turns of the 75-ohm twinlead thru a toroidal ferrite core, of the type used in many CATV passives. Placing the transformer at the dipole end and running a 75-ohm coaxial line to the preamplifier is not recommended because of the unpredictable reflections that can occur between the dipole and the grounded ccaxial shield.

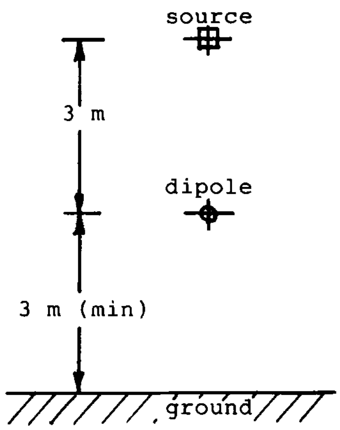

FIGURE 3

Preferred FCC test configuration

After completing the above interconnections, the total system gain from the dipole output to the analyzer input should be measured and recorded at a number of frequencies across the spectrum. These are the calibration values that will have to be subtracted from the analyzer

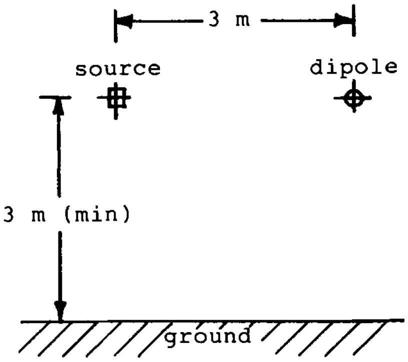

FIGURE 4

Alternate FCC test configuration

reading in order to establish the true voltage levels received by the dipole. If the preamplifier has a variable slope control, it can be set to somewhat equalize the gain vs. frequency characteristic. The downlead loss not only reduces system gain, but adds directly (dB for dB) to the preamplifier noise figure, thus reducing available sensitivity.

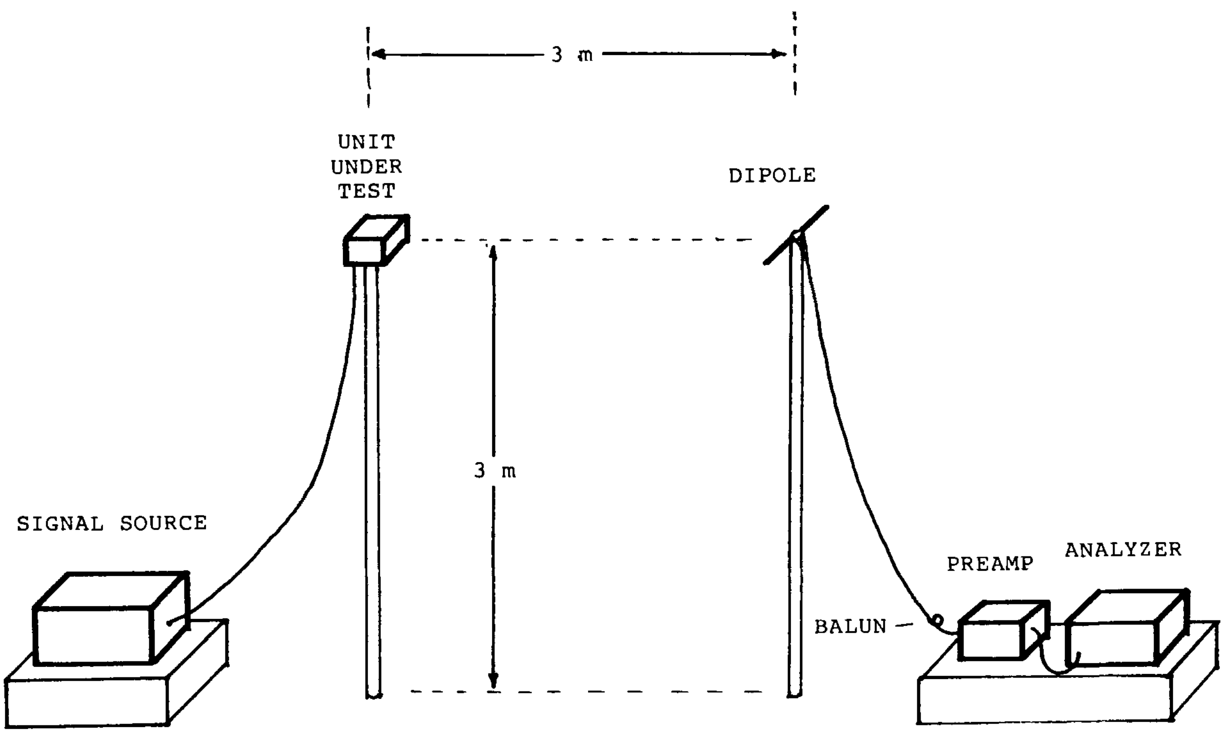

FIGURE 5

Radiation test site - Block Diagram

SET-UP

The FCC procedure outlines both a vertical (preferred) as well as a horizontal (permitted) placement between the dipole and the CATV components to be measured (Fig. 3 & 4). When monitoring an installed system, the placement will be of course predetermined, and only the dipole will have to be positioned. But when setting up a specific measurement site, the horizontal (permitted) placement is more convenient and in this case both the unit under test and the dipole should each be attached to the top of a non-metallic pole (a 3-inch diameter or thicker PVC pipe is suitable), at least 10 feet (or 3 meters) high and exactly 3 meters from each other. The tripod or other structure supporting the poles should also be made from non-metallic material, such as wood. If at all possible, the chosen measurement site should be in the open, far away from all possible interfering signal sources and also remote from structures that could be the cause of unwanted reflections. The ground should be reasonably level (but not mirror-flat or paved) and the drier the topsoil, the better (dry sand is the best). Avoid thick grass or other heavy vegetation.

The coaxial cables carrying signals and perhaps power to the unit under test should be double-shielded and sleeved radiation-proof connectors are a must. If the signal source is an actual CATV feed, route it in the shortest possible manner from the side furthest away from the dipole. If using a signal generator, make sure it is well shielded and located at least 30 feet from the test site.

The signal level reaching the input of the unit to be tested must be adjusted to correspond to the maximum that it would see in an actual installation at the frequency in question.

Fig. 5 is a block diagram of the complete test setup.

MEASURING FIELD STRENGTH

Identify the signal to be measured and received by the dipole on the analyzer display, then rotate the horizontally mounted antenna about the vertical axis (by turning the supporting pole) until the signal reaches a maximum value. Read this level on the analyzer, and using the previously obtained calibration numbers for the appropriate frequency (see "Connections") determine the actual signal level, in dBmV, received by the dipole. Then use this value to calculate the field strength :

$$E = 20.69\ f\ \log^{-1}(e_r/20)$$

where : E = field strength (uV/m)
f = frequency (MHz)
e_r = received signal level by a resonant dipole (dBmV)

Fig. 6 is a graphic plot of the above equation and Appendix A traces its mathematical derivation.

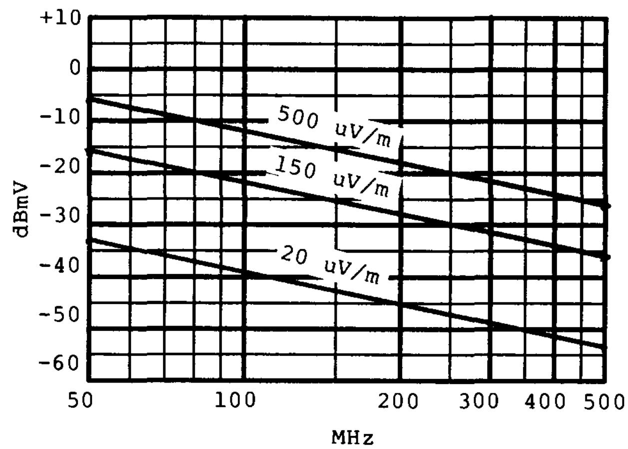

FIGURE 6

uV/m vs. dBmV

FCC Compliance

Having established a method of measuring the received signal level directly in dBmV and calculating the intercepted field strength in uV/m, it is a simple matter to compare the results to the FCC limits.

Fig. 7 shows the radiation limits (normalized to a uniform measurement distance of 3 meters or 10 feet) directly in received dBmV vs. frequency. Any reading above the level of the solid line is in violation.

Other Standards

Just to indicate how stringent the present FCC limits really are, Fig. 8 compares Part 76 (CATV) ceiling to those that are imposed under Part 15 on : (1) Commercial (Class A) Computing Devices, (2) Personal (Class B) Computing Devices and (3) Radio Receivers. FCC General Docket 87-389 which proposes to unify the requirements for all devices under Part 15 (but not CATV), coincides with Class B Computing Device requirements.