FLYOVER CALIBRATION PROCEDURES

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In qualification of a cable system according to the FCC Leakage rules the flyover is often preferred since it is a direct measurement of the leakage signal strength in the airspace above the cable system. As in any other measurement it is necessary to establish standards against which to compare the actual data taken. In the case of a flyover one must establish the threshold level of 10 microvolts per meter (uV/m) at 450 meters above the average terrain in order that the pass/fail requirements of the regulations may be tested. A rather specific method for producing this reference field is given in part 76.611(a)(2) of the FCC Rules and Regulations. Even this well defined procedure is subjected to certain inherent inaccuracies and some aspects that may be improved upon. This paper deals with these subjects and suggests some possible modifications. Before proceeding with the discussion it must be stated that anything said below which is not consistent with the current Rules and Regulations has NOT BEEN APPROVED by the FCC and therefore cannot be assumed to be acceptable for flyover calibration.

CALIBRATION BASICS

The fundamental concept of flyover calibration must first be understood. In the survey aircraft we have a total measurement system which involves a receiver and antenna in addition to the data gathering, storage, and analysis equipment. The receiver and the other components in the path of the received signal may be conveniently and accurately calibrated in the laboratory. Not so the antenna. Since the antenna pattern is affected by its mounting and its environment (the aircraft) it becomes a very complex system which is extremely difficult to quantify. Measurement of the pattern of an antenna on an aircraft is done only in extremely large, elaborate, and expensive antenna ranges. These procedures are not appropriate or required by cable TV signal leakage measurement demands. Even if detailed calibration was achieved this information would not be of great value since the signal leakage data taken is the composite of the signals received from numerous leaks in the system.. The intent of the leakage measurement rules is to evaluate the threat of interference to aircraft flying through the airspace. These aircraft will also receive simultaneous signals from multiple sources and will doubtlessly have a somewhat different antenna configuration than the measurement aircraft. The program then is to find the measurement system response to a standardized field from a single source and use this as a basis for surveying in the airspace. The results from such a survey will be adequate to assure protection of the aircraft using this airspace and to check the limits established for cable signal leakage.

The Commission has required that sensing of cable signal leakage in the airspace be done with a horizontally polarized antenna. There are points of discussion as to whether horizontal polarization is a necessity or even the best choice, but it is certainly a reasonable choice and it is the law. It is well to note that standard aircraft antenna are seldom purely horizontally polarized even though they exhibit a good deal of structure which is horizontal. They are often, in the frequencies of use, largely vertically polarized with horizontal sections employed as end loading for the vertical element.

Establishment of the 10 uV/m field at 450m for calibration of the horizontally polarized aircraft antenna, is achieved by use of a pair of horizontally polarized dipoles on the ground. The configuration specified in 76.611(a)(2) (the paragraph which covers all aspects peculiar to flyover measurements) consists of two resonant half wave dipoles mounted at right angles to each other, parallel to and one quarter wavelength above a ground screen of at least two meters in diameter. These two dipoles are fed with radio frequency energy equal in amplitude but differing in phase by 90 degrees. For those unfamiliar with antenna theory, in this configuration the resulting electric field vector rotates about the vertical axis producing circular polarization. This will be either righthand or lefthand polarization depending upon which current is leading. For this case the polarization sense is unimportant. Ideally the rotating vector maintains the same amplitude at all angles in the horizontal plane. Practically speaking, this seldom happens since any current inequality or phase error between the dipoles will cause the polarization no longer to be circular but elliptical. Hence the antenna pattern has a property called "ellipticity" or "axial ratio". We will examine the importance of ellipticity further.

Considering a practical flyover calibration maneuver an attempt is made to fly directly over the calibration antenna in order to pass through the maximum field which is preset to a 10 uV/m intensity at 450m above the antenna. In the general case some amount of cross wind can be expected which means that the aircraft, although flying directly over the antenna, will have its longitudinal axis and hence the axis of the sense antenna at an angle to the line of flight. If the antenna on the ground were a single dipole it then would be necessary to ensure a flight path with no cross wind component and hence no crab angle in order that the two antenna elements be parallel so that the maximum field is received. On a practical level this is extremely difficult to achieve. It may be seen, however, that with the circularly polarized field not only can a crab angle be tolerated but the approach can be made from any angle and still achieve the desired results as long as the pass is made directly over the antenna. This is due to the fact that the circularly polarized field appears to be linear and parallel to the receiving dipole at any angle of approach. Hence, the crossed dipole circular polarization scheme required by the Commission is an excellent choice. Practically speaking, such an arrangement can be constructed to produce circular polarization with less than 1 dB ellipticity.

Another aspect of the calibration run is the precision with which the pass is made over the calibration antenna. Even though it sounds simple a high degree of pilotage proficiency is required to fly directly over the antenna at a 450m altitude. This is due to many factors including the ability to visually judge lateral offset from the aircraft. Even with electronic navigation aids errors of a few hundred feet are not uncommon.

Considering the calibration antenna configuration and its sensitivity to misalignment, it should be noted that the 1 dB beamwidth of a simple dipole (which is the equivalent of the circularly polarized antenna as approached from any angle) is in the vicinity of 90 degrees, that is 45 degrees either side of center. At an altitude of 450m altitude the 45 degree angle would allow misalignment up to 450m with only 1 dB of reduction in the calibrating field strength. Assuming a similar drop off in the aircraft receiving antenna pattern this misalignment could result in a - 2 dB total error. The one-half dB beamwidth of a dipole antenna is greater than 80 degrees therefore misalignment of 1200' laterally would result in no more than 1 dB of total error. While other factors do affect the situation this example is given to illustrate that reasonable misalignments will not materially distort the calibration results.

There are other effects which bear on the calibration procedure. The presence of other signals within the bandpass of the measurement receiver may cause erroneous results. A typical situation occurs when attempting to calibrate on a frequency which is also used by a nearby cable system. It is generally true that the calibration generator and the signal from the other cable system will not be exactly the same in frequency, in which case the airborne receiver will see the power addition of the calibration signal and the spurious signal. The presence of a spurious signal 10 dB below the calibration signal will result in an indication in the aircraft receiver which is approximately 1 dB too high. This receiver will then be calibrated to the wrong level. This receiver sensitivity miscalibration will interpret the signal leakage measured in the flyover to be 1 dB lower than actual. The interfering signal might also be noise from the power local system or spurious signals from a host of electronic emitters including large signals at great distances. As a rule any interfering signal within the passband of the receiver should be no greater than -20 dB relative to the calibration signal level.

The same power addition effect exists when there is a cochannel signal during a measurement flight, but with the opposite result. In the case of masking noise such as power line interfence of level equal to the leakage signal, the sum of the two noncoherent signals is 3 dB higher than either therefore the leakage indicated would be 3 dB higher than actual. This is equivalent to 3 points in a ground based CLI calculation and could well fail a passing system if the effect existed over large portions of the area surveyed. The moral to this story is that when overflying systems with substantial spurious cochannel signals and no ability to select a better frequency, constant monitoring to identify the leakage signal must be done to verify that actual signal leakage is present. It might also be well to consider post-flight calcuations to eliminate the weighting effects of the noise. This is not always possible since quantification of the noise signal level in the presence of the cable signal leakage may not be within the capability of the measuring equipment or procedures.

CALIBRATING THE CALIBRATION SETUP

Generally speaking compliance with the specific details of the calibration rules in paragraph 76.611(a)(2) will satisfy the FCC. However, in an effort to have a high degree of confidence in the validity of the test procedure and its results, one must devise some method of verifying the actual field radiated by the calibration system. Indeed this is virtually mandatory since the price for failure to qualify due to flawed data is so high. Basically the radiation can be quantized by using a probe antenna in the field of the calibration antenna and measuring the signal level with a well calibrated receiver. This same setup may be used to check ellipticity as well. There are, however, some sticky problems in doing such measurements. For instance, feed lines to the probe antenna must be routed in such a way as to not affect the pattern of the probe antenna or the calibration system. The probe antenna may be rotated on axis to measure the ellipticity but the same cautions apply. In addition neither the test equipment nor the technician should be close enough to either antenna to distort the radiation pattern(s).

Measurement of the ellipticity of the calibration antenna pattern has been mentioned and the question may arise as to why one would expect significant errors in such a simple system. Briefly stated there are numerous reasons including physical and electrical parameters such as stray capacitance, ground plane irregularities, and probably most importantly, imperfections in the power division and 90 degree phase shifting networks in the crossed dipole antenna. These networks can be rather simple but must be quite extact to maintain the tolerance that is necessary. For instance a 1 dB difference in drive levels can cause a 1 dB difference in ellipticity resulting in an uncertainty of 1 dB in the actual calibration level depending upon angle of approach, crab angle, etc.

In situations where measurements must done at varying frequencies the calibration antenna must be capable of standardizion at each frequency used. It is desirable to have a single unchanging physical and electrical configuration which can be excited with any required frequency. This, however, is very difficult to achieve and presents a challenge to the design engineer.

Another important consideration is the actual calibration site. The qualifications for this site include a flat open area without structures which can affect the pattern of the calibration antenna. For instance, if the calibration antenna where set up near a large reflecting structure, reflections from that structure could affect the energy arriving at the aircraft at altitude while not altering the calibration antenna pattern sensed locally by the probe antenna. This is a difficult situation since even though the calibration antenna itself checked out well the operator would be unaware of the change occuring in the airspace. Any resonant structures or large conducting objects in the field of the antenna can induce such perturbations. Reraditation by a tower, guy cables, or a metal or steel reinforced building near the site could seriously distort the calibration pattern. It is therefore important that a clean, flat, open area be selected for the calibration. All calibrations should be done at the same properly selected site(s) resulting in better and more stable results. Although this suggestion is contrary to the FCC requirement that calibration be done in the area to be flown, it can well be a step toward significant improvement in calibration accuracy.

The calibration antenna ground system is also a matter of some concern. The FCC requires a ground plane of at least two meters in diameter beneath the calibration dipoles. This does a lot towards stabilizing the antenna impedance and the radiation pattern. As a matter of fact, this insures that the field directly above the antenna is fairly well defined since, by tracing rays from the antenna, it can be seen that all of the power that goes vertically toward the ground is reflected upward by the ground screen which is highly conductive. On the other hand the two meter ground screen does not intercept all the near field currents of the antenna. Those which are not intercepted by the ground screen must return through the local earth ground whose conductivity can vary with location. This is a second order effect in terms of ray reflections and does not significantly alter the field directly overhead but does impact upon the exact impedance of the antenna system. Use of the same calibration location will at least stabilize this effect.

Impedance match to the calibration antenna is also an important concern. This involves the return loss of the antenna system. Return loss, as we are aware, is a measure of the amount of power which is reflected back from a device and in this case is not used in the process of radiation. If one is expecting all of the power introduced into the calibrating antenna system to be radiated the resulting field will be reduced when some energy is reflected and cause incorrect calibrations. A return loss of 10 dB results in 1 dB less power delivered. This is a good reason to measure the actual radiation from the antenna system rather than simply calculate the theoretical value. In the same vein, it is well to check the match of the final system for each calibration run to make sure that nothing has changed.

Questions are often asked about the power required to produced a 10 uV/m field at 450m. The method of calculation of that power runs along these lines. The field strength in free space is related to the power density by the following formula:

$E = \text{sq.rt.}(30 \times P_t \times G_t)/A$
where
E = field intensity - uV/m
P_t = power transmitted - watts
G_t = gain of transmitting antenna
A = altitude - meters

Solving this equation for P_t produces the power required to produce the desired field intensity (E) at the desired altitude (A) which is 10uV/m at 450 meters. The calibration antenna using orthogonal dipoles can be thought of as two independent systems. Therefore the computation may be made on the basis of a single dipole with equal power required by the second dipole. It is then necessary to compute the losses in the power dividing and phasing networks, the cables and any other elements introduced into the system. Remember that the power level must be correlated to a secondary standard which can usually to supplied by an organization that does test equipment calibration. The standardized signal generator can also be used to calibrate receiving equipment, signal level meters, spectrum analyzers, and other equipment used in the process.

After we have done a careful job of setting up the calibration system we must consider the accuracy of the calibration achieved by use of the generated field. A careful analysis would have to include the matters such as precision of power generation, loss measurement, antenna gain, etc. not to mention the uncertainties of the aircraft antenna and receiving system plus the aircraft attitude during the calibration and measurement process. It seems likely that the uncertainty of the calibration field could well be plus or minus 2 dB from the desired level even with good engineering practice and careful control. It is doubtful whether a certainty better than plus or minus 1 dB can be claimed with anything but the most elaborate instrumentation and setup. Although not a point for detailed discussion here, it is abundantly clear that the field established by these methods in the airspace is far better controlled than the field used to calibrate ground based CLI measurement equipment. The typical case is the antenna near which you drive your truck to set your 20 uV/m threshold. Here it is clear that there are so many nearby uncontrolled reflecting objects that to expect precision calibration is not realistic.

CONCLUSIONS

It can reasonably be said that aerial calibration and subsequent measurement is plainly the most direct and the most accurate method of surveying cable signal leakage since it is done by direct measurement made in the environment where protection is desired rather than estimation from ground data. Airborne calibration is subject to fewer errors but, all in all, is not a laboratory situation where 0.1 dB precision can be expected nor for that matter is even important. To properly setup for and conduct the necessary calibration requires great care and a system of checks and balances to assure accuracy and repeatability. Good calibrations are necessary to uphold the dedicated efforts of the ground repair teams and assure timely qualification of the cable system.