A PRACTICAL APPROACH TO AIRBORNE SIGNAL LEAKAGE TESTING (CLI)

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ABSTRACT

Over the past three years, a development program has been undertaken to design, construct and calibrate an equipment package suitable for airborne signal leakage measurement. The Final Report of the Federal Communications Commission, Advisory Committee on Cable Leakage, issued November 1, 1979, outlined the basic parameters in testing cable television systems for cumulative leakage. The conclusions and recommendations of this report were based on airborne test results primarily from small cable systems. This paper will focus on a practical approach to airborne testing.

At the time of writing, systems ranging in size from 2,000 subscribers in 6 square miles of plant, to 250,000 subscribers in 400 square miles have been tested. In the final development stage, more than 100 hours of flight time was logged in verifying equipment performance, calibration and methodology of airborne testing. A specific calibration method and testing procedure has been documented, to ensure standardization of airborne measurements.

These airborne signal leakage measurement packages are now being used on a regular basis to test cable plant. Test results from selected flyovers will be presented with this paper.

INTRODUCTION

Cumulative signal leakage is a field of radio frequency energy, exhibiting no distinct plane of polarization, existing in the airspace above an active cable television system. The airborne signal leakage specification, as defined by the FCC, requires a maximum leakage criteria of 10 uV/m at 1,500 ft. altitude (450 m) above a cable system. To better understand this test method, visualize thousands of very small leaks from the system, without any specific relationship to each other, and all interacting on the input of an airborne receiver. The requirements for receiving and measuring this type of signal are significantly different than for conventional communications receiving apparatus. While most receiving applications are intended to preselect one specific communication, this system must recognize and collectively measure a multiplicity of signals. The equipment to measure such a group of signal sources must have very precise specifications. While the allowable level of signal leakage at 1,500 ft. above the cable systems is 10 uV/m, one should not assume that this is the threshold level for measurement. The equipment must have a dynamic range substantially above and below this level. Furthermore, any measurement taken within these parameters must be linear. The receiver must also be capable of withstanding severe overload, as may occur should a pilot accidentally transmit on the monitored frequency. The desired signal may, at times, be almost buried in the noise floor of the receiver, so stability and selectively are extremely important design considerations. The ultimate capability of the collection package must accommodate precise calibration repeatability to guarantee the accuracy of testing.

AIRCRAFT CHOICE

After experimenting with different aircraft, it was found necessary to set down selection criteria for the type of aircraft, receiving equipment and antennas. To avoid any compromise on the selection of the aircraft type, the following criteria were established.

1. The aircraft should be a high wing aircraft with good downward visibility.

2. The aircraft must be reliable, readily available and capable of instrument flight as well as visual flight.

3. It should be relatively simple to fly, have a reputation as a well behaved aircraft at low altitude and have excellent gliding characteristics.

4. Operating cost is a consideration.

5. Executive type aircraft should not be used. A "work horse" such as the type of aircraft normally found in flying schools is preferable.

The aircraft which was found to be the most suitable in meeting these criteria is the Cessna 172, a four passenger, high wing, single engine configuration, which is readily available throughout North America. In fact, there are 9,000 such aircraft currently in use. It is easy to fly, performs well in the 90 to 100 knot air speed range, and has six hours of flying time with normal fuel reserves. Similar type aircraft meeting the above criteria could also be used.

AIRCRAFT ANTENNA

The initial approach to airborne leakage measurements was to attempt to use existing navigational or communications mounted antennas which are part of the aircraft electronics package. Early in the development program the existing VOR antenna installation on our test aircraft was used for receiving signal leakage. However, extensive testing using a calibrated discrete leak showed that test results were unreliable and inconsistent. The conventional communications and navigational antennas on aircraft are primarily designed to receive signals from communication points on the horizon. These antennas do not have directivity in the downward direction, partially due to their placement and orientation. Because these antennas also have very poor directional capabilities, they typically are not satisfactory for differentiating signal sources. One of the main problems experienced with the conventional aircraft communication or navigation antenna is the hull effect (or reflective surface effect) of the aircraft, in this special application. This is normally not a problem in airborne communications, but severely curtails the probability of repeatability and calibration accuracy for airborne leakage measurements. Referring to my earlier comments on the literally thousands of leaks which will be within the horizon of the antenna, all being received from different directions, different field strengths, phase relationships, etc., it is inevitable that incorrect readings will be generated as a result of the reflective surfaces of the aircraft bouncing signal into the antenna. In calibration testing, using a discrete leak in accordance with the FCC prescribed test methods, it was found that the hull effect would create nulls and peaks in the signal as the aircraft passed over the signal source. For accurate testing, the received signal should not be influenced by the aircraft itself. Antenna placement and orientation should be such that the aircraft is in a null point of the antenna.

One of the original concepts of the airborne signal leakage tests was to have "a universal mounting" which would allow the test package to be installed on any Cessna 172 aircraft in a matter of minutes, without any structural changes to the aircraft itself. The intent was to be able to easily source an aircraft, mount the antenna and equipment in minutes, with no requirements for recertification or modification of the aircraft. However, since antenna performance is so critical to both sensitivity and geographic definition, it was necessary to develop a special antenna with the proper characteristics. This antenna pattern also must not be disturbed in any way by the aircraft itself. A balanced antenna is also necessary for increased noise rejection. In our search for the best antenna, a spar-mounted, co-axial dipole situated behind the aircraft's tail assembly was chosen. In this configuration the aircraft is on the antenna's insensitive axis and distortion of the antenna's dipole pattern is negligable. At an altitude of 450 m, an area spanning 900 m laterally by 500 m fore and aft is within the -3 dB contour of this antenna.

COLLECTION PACKAGE

The collection package is specifically designed for ease of shipping from point to point in a specialized shipping container, and for ease of mounting in the aircraft. In fact, once the antenna brackets have been permanently installed on the aircraft, the antenna and equipment package can be installed and removed in a matter of minutes. The testing process is designed for operation by the aircraft pilot, without the need for any other personnel in the aircraft, with a few exceptions.

The package consists of two parts: a ground based RF carrier source installed in the headend, and the airborne equipment package. Within the airborne equipment package there are several separate component blocks. It contains a sophisticated LORAN-C navigational unit, a computer and CRT display, a specially designed receiver, disk drive, power supply, etc. To facilitate ease of operation, the right front seat of the aircraft is removed and this "black box" mounts directly in its place. Equipment layout allows the pilot easy access to all equipment controls and CRT screen. A special keypad for function control is mounted on a saddle which is strapped to the pilot's right leg. The LORAN-C receiver is capable of storing a complete grid pattern in its memory, which is sequentially accessed during the audit process. Where LORAN-C navigation can be used, signal leakage testing can be accommodated using only the pilot of the aircraft. In certain areas west of the Mississippi and east of the Rockies, LORAN-C coverage is unreliable or unavailable. In these areas, an observer supplements the LORAN-C information and the aircraft is flown on a ground recognition grid as opposed to an electronic grid.

During airborne testing the aircraft equipped with our test package is flown in a sequence of parallel paths over the cable system being tested. The flight legs are spaced a distance of 900 m apart so that the receive antenna's -3 dB contour just overlaps on each pass. Flight passes are flown in a north-south direction then repeated in an east-west direction. Cable system coverage is complete with this grid pattern.

A cross track error indication from the Loran receiver allows for a very accurate flight path to be flown. At the end of each pass over the cable system, the collected data, along with flight path start-stop co-ordinates, are transferred to floppy disk while the aircraft is being turned around to begin the next sampling run (see Figure 1).

CALIBRATION

As previously mentioned, calibration is a critical factor in airborne signal leakage tests. Part 76.611 of the FCC rules suggests that calibration should be made in the community being tested or within a reasonable time frame to performing the measurements. While this may be quite satisfactory for ground CLI testing, airborne calibration should not be undertaken in close proximity to a cable system, a major airport or aircraft communication facility. Our primary calibration standard uses the recommended methods outlined in associated FCC documentation. Calibration is performed at a significant distance from any major communication facility, cable system or an interfering source. To maintain calibration accuracy we employ a secondary standard of test procedures and equipment, which is carried with the aircraft, and which verifies performance accuracy and calibration before and after the testing process.

COMPUTER AIDED DRAFTING AND PROCESSING

While a preliminary analysis of cable system leakage is available from the collection equipment even before the aircraft has landed, collected data is transferred to a more powerful computer to undergo further processing. Word processing capability is also integrated into the system, to prepare an accompanying written report.

Data files from the collection unit's floppy disk are down loaded to the computer aided drafting system. A map outline of the active plant area is digitized and stored in the computer memory as a map drawing file. A map creation program calculates paths flown by the aircraft from latitude and longitude co-ordinates stored during the airborne data collection process. Signal level information is then processed as follows:

first - accurate positions of measurements along the data collection flight path are established;

second - signal levels are sorted into windows for signal level vs. color identification as well as signal level vs. width of line presentation; and,

third - signal level data collected from outside of the active plant boundary is discarded and signal level files contain only information collected from the cable system's active plant.

The 90th percentile is accurately calculated from these files. A map displaying the cable system plant boundary with received cumulative signal levels, plotted along the calculated aircraft flight path, is generated for a visual presentation of the extent of cable system signal leakage (see Figure 2).

FIGURE 1

AIRBORNE COLLECTION PACKAGE

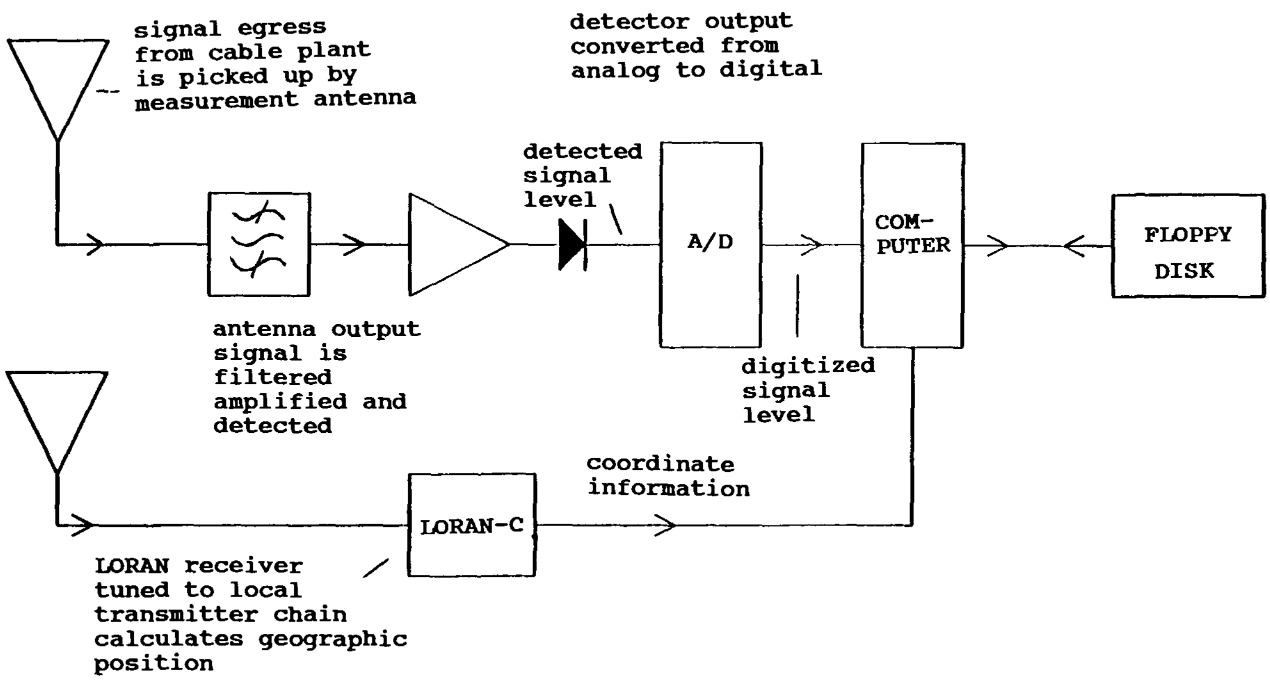
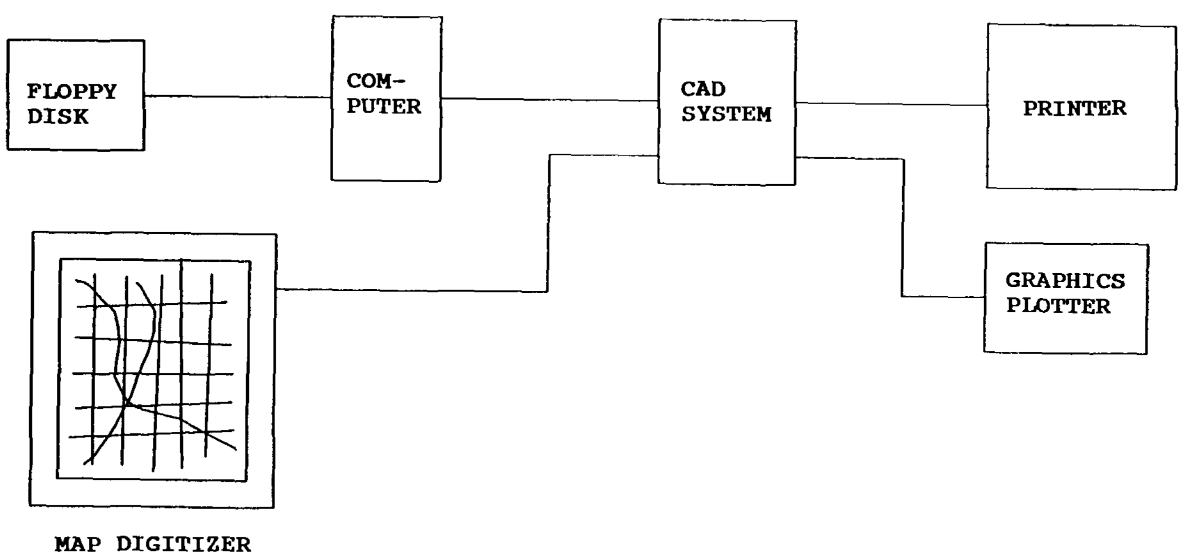


FIGURE 2

CAD PROCESSING/MAPPING PACKAGE



TEST RESULTS

If a cable system has been reasonably well maintained, and regular signal leakage control procedures have been followed, the mapping will give good geographic identification of problem areas. If little or no signal leakage efforts have been undertaken by the system management, then the overall map presentation will show levels of signal leakage totally blanketing the cable area. Level differences can also reflect the integrity of the components used during the various phases of the original construction, and the specific demographics (e.g. multi-units, older building wiring, areas of improperly installed plant etcetera).

In summary, airborne testing provides a cable system operator with a global prospective of cable leakage. In a well maintained plant, specific "hot spots" can be identified readily for increased maintenance attention. In a poorly maintained plant, the magnitude of the problem facing the cable operator in correcting signal leakage will be very apparent. As an example, a three hour long flyover of a 50,000 - 75,000 subscriber system will provide a full understanding and recognition of the depth of the signal leakage problem in the system. A similar analysis of thousands of ground based readings will not provide the conceptional level of understanding that can be achieved during a review of an airborne signal leakage map. The airborne signal leakage map is most valuable in defining signal leakage problems to senior management and corporate executives. It provides an instant recognition of the dimension of the signal leakage, and the relationship to maintenance requirements can be identified though this interpretation. A multiple system operator has the ability, at the Corporate level, to better understand the condition of each cable plant, and the implications for each system of the Cumulative Leakage Index requirements commencing in July, 1990. This allows informed decisions in allocation of resources to meet these requirements.

A GLOBAL PROSPECTIVE

Let us now examine the implications that we face in the next two years in order to meet the 1990 requirements. Many cable system operators are actively performing ground checks to verify whether the ground based measurements of I infinity and I 3,000 can be met with the existing cable plant. In large cable systems, particularly those in metropolitan areas with high rise apartments, multi-units, and very large geographic areas, it is extremely difficult to meet the I infinity method of calculating CLI. The I infinity formula is a theoretical formula, correlated from airborne tests done by the FCC. These tests were performed on relatively small cable systems where the I infinity method may be quite appropriate. However, since the accumulation of leakage measurements in the I infinity formula does not recognize free space attenuation, all signals are deemed to be at the same geographic location, when collected within the formula. From a practical interference point of view, failure to recognize the free space attenuation factors and the slant range implications makes it extremely difficult to meet this CLI test in large geographic areas. In cities more than 10 miles (16 km) in diameter, the inadequacy of the formula becomes quite obvious. Nevertheless, systems have a choice of three methods of meeting CLI. The I infinity method for large systems is, in our point-of-view, inappropriate. The I 3,000 formula, which is better in that it recognizes the implications of free space attenuation, is more applicable, but does not consider all factors and involves many calculations. The airborne method of signal leakage described here records an accurate interference factor in a matter of hours.

We have discussed earlier the implications of airborne signal leakage in terms of ability to measure signal leakage involving large amounts of cable plant in short periods of time. To give this a bit more perspective, based on testing to date and average flying times for systems, a few rules of thumb can be developed. For each hour of actual system flying time (ignoring ferrying time for the aircraft to and from the system) approximately 200 miles of cable plant, 10,000 - 20,000 subscribers, or 25 square miles of geographic area can be tested. Obviously the length of the test is a function of the size of the geographic area, since this determines the number of passes over the system. One Ontario system with 28,000 subscribers and 240 miles of plant was flown in approximately 1 hour and 20 minutes. Another 65,000 subscriber system was flown in 2 hours and 30 minutes.

Let us now look at what might be required to perform airborne signal leakage testing throughout the United States. As mentioned earlier, our approach was to concentrate on the type of aircraft which would be most suitable for the actual measurements, and to give less priority to flight speed during aircraft ferrying time between franchises. A reasonable zone for an aircraft to perform airborne signal leakage testing from one operations base would be approximately a 500 mile radius. This represents a 785,000 square mile area. Given that the United States is approximately 3.6 million square miles, the practical number of aircraft required to do airborne signal leakage tests throughout the U.S. should not be more than 15-20 aircraft. Since the aircraft need only be used on an as-required basis once modified, airborne signal leakage equipment need not be dedicated to an individual aircraft. By examining a total number of cabled households in the United States, the total plant miles, and some extrapolation from the sample of signal leakage tests already conducted by our company, we can draw the rough assumption that there are 8-10 route miles of cable plant per square mile of cabled community. This will vary significantly from community to community; however, on balance it is a safe assumption. Similarly since there is approximately 700,000 miles of cable plant in the U.S., and we can fly 200 cable miles per hour, approximately 3,500 hours of flying would be required to perform airborne signal leakage in all cable systems in the continental United States. If we assume that ferrying time is approximately equal to airborne testing time, then 7000 hours per year of flying time would be required. However, since smaller systems can be grouped and flown sequentially, and some small systems in remote locations may prefer ground-based testing, the estimated total flying time could be approximately 5,000 hours per year. With strategically placed aircraft, this equates to 300-500 hours per aircraft per year.

The equipment is essentially automated, with minimal operational training required. A professional pilot could perform airborne signal leakage testing, and could simply download the data at the end of each day of flying, to a central processing point via telephone line into the CAD system to produce the necessary mapping. Using overnight courier the information could be returned to the system within two to three days. A support person would be required to assist in interfacing with system personnel and headend equipment set up, if it is anticipated that a large number of flyovers would be occurring in an immediate geographic area. Pilots for this type of aircraft are readily available, and can be easily trained to perform airborne leakage testing, due to the highly automated nature of the collection package.

CONCLUSION

The use of airborne signal leakage testing methods is a practical and efficient approach to system certification for signal leakage purposes. While ground patrol, coupled with system maintenance, will always be required to meet system leakage requirements, airborne tests will provide efficient and conclusive annual audit testing for compliance with FCC CLI regulations. It will also assist in identifying signal leakage missed by the ground patrols. The advantages of being able to quickly obtain a signal leakage profile of an operating system and identify geographically "hot spots" is a significant management tool in the operation of cable plant. Irrespective of the regulatory requirements, the signal leakage audit also provides a profile of maintenance effectiveness and system component integrity, which is also valuable to the cable operator.

REFERENCES

Final Report of the Advisory Committee on Cable Leakage to the Chief, Television Bureau, Federal Communications Commission November 1, 1979.