SIGNAL LEAKAGE FROM CABLE SYSTEMS AND POTENTIAL INTERFERENCE TO RADIO SERVICES[1]

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ABSTRACT

Due to the possible hazard to air navigation that might be presented by leakage from cable television systems utilizing aviation frequencies, the Federal Communications Commission formed a committee to investigate how best to prevent a problem. Numerous airspace and ground based measurements were conducted in an attempt to correlate air and ground leakage fields. The methods employed for these tests and preliminary conclusions of the authors are contained in this paper.

1.1 Background

In 1977 the Federal Communications Commission adopted interim rules designed to prevent interference to aeronautical radio services by signal leakage from cable television systems. The rules require that cable operations be offset in frequency from any aeronautical radio service operating in the neighborhood of the cable television system.[2] Shortly thereafter, a cooperative research program was initiated to determine the conditions, if any, under which cable television systems could safely operate on the same frequencies as nearby aeronautical radio services. Participants in the program include the Commission, the Federal Aviation Administration, the National Telecommunications and Information Administration, and representatives of the cable television industry and private aviation interests. Initial results of that research program are presented in this paper.

1 Opinions and conclusions expressed in this paper are those of the authors and do not necessarily represent the views of the National Telecommunications and Information Administration, the Federal Communications Commission, or its Advisory Committee on Cable Signal Leakage.

2 Report and Order, 65 FCC 2d 813 (1977).

The susceptibility of navigation receivers to cable signal interference was addressed in studies performed by the U.S. Department of Commerce Office of Telecommunications.[3] Results were given in terms of signal to interference ratios, where the interfering signal had to be offset from the navigation signal by very precise frequency differences.

In the case of existing communications receivers, a convenient reference point is the power level at which the squelch control is set to open, although this level is not necessarily the only criterion for interference. The most sensitive of todays receivers may have squelch set at -97 to -101 dBm[4] input to the receiver. Most receivers are less sensitive, and probably have squelch set at a level higher than -97 dBm.

It is not possible to say exactly what the interference susceptibility of tomorrows receivers will be. It is reasonable to assume that many will be digital, and therefore probably less sensitive to interference. But of course, one must not make plans for cable leakage limits on such an assumption. Therefore, no assumptions about interference susceptibility of future receivers are made here.

1.2 Objective

The principal objective of the research was to determine how to predict fields in the airspace from measurements made at ground level. Three methods of ground measurement were used, and several parameters of the airspace fields were considered. Rank order correlation coefficients between the ground measurements and the airspace measurements were used to determine whether or not the objective was achieved.

3 Electromagnetic Compatibility of Simulated CATV Signals and Aircraft Navigation Receivers, OT Report 74-39 (Tom Harr, Jr., et al., 1974); Flight Test Measuring Compatibility of Simulated CATV and VOR Signals, OT Report 75-75, (John R. Juroshek and Tom Harr, Jr., 1975); and Radiating Aerial Coaxial Cable Measurements, OT Report 75-73, (Tom Harr, Jr., et al., 1975). Available from the National Technical Information Service, Springfield, VA 22151.

4 dBm: decibels relative to one milliwatt.

1.3 Assumptions and Conditions

Two principal assumptions were made in order to simplify the research program to manageable proportions:

(a) For a given leakage source, the power radiated is reasonably independent of frequency; and

(b) The effect of radiation patterns of individual leakage sources can be neglected.

The first assumption is reasonable on theoretical grounds, since the physical size of cable leaks (millimeter dimensions) is small compared to wavelengths at the frequencies in question (108 - 400 MHz). The second assumption is reasonable in cases where the number of leaks in the cable system is large (the only case of real concern), since in that case an average of whatever radiation pattern exists, would be observed both on the ground and in the airspace.

It was desired to examine cable systems of a range of sizes, ages, and types of construction. A total of 12 cable systems were chosen for the measurement program.[5]

A pilot signal at 118 MHz was imposed on the cable system for all airspace measurements reported here. The convention of setting the power level of that signal equal to whatever peak power level the cable operator normally used for the visual carrier closest in frequency to 118 MHz was adopted. Since the test signal was unmodulated, its rms power would have been around 4 or 5 decibels higher than that of a visual carrier having the same peak power. Thus the test signal would have been 4 to 5 decibels higher in rms power level than a typical visual carrier which might be carried in the VHF aeronautical radio band (108 - 136 MHz). On the other hand, signals at the higher frequencies are carried on cable systems at levels perhaps seven decibels higher than corresponding signals in the 100 MHz range. Thus, our signal may have been as much as three db or more below the rms power level used in the aeronautical radio band 225 - 400 MHz.

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5 The twelve cities were: Atlantic City, NJ, Arlington, VA, Bridgeton, NJ, Coatesville, PA, Hagerstown, MD, Harrisburg, PA, Independence, MO, Leavenworth, KS, Pottsville, PA, Raytown, MO, St. Joseph, MO, Salisbury, MD. Further reference to individual cities will generally be by letter code only, since our objective was not to publicize characteristics of individual systems but to correlate measurement techniques over a wide range of systems.

2. AIRSPACE MEASUREMENTS AND ANALYSIS

2.1 Single Frequency Measurements

The airspace data reported here were collected on magnetic tape at the rate of 200 power level measurements per sencond as the aircraft flew a predetermined grid pattern at a given altitude. Average speed was about 275 kilometers per hour, giving several samples per wavelength.[6] Altitudes flown were approximately 450, 1500, and 3000 meters above average terrain of the city. The receiver used had a half-power bandwidth of about 400 Hz, operating at the same frequency as the test signal on the cable television system. A spectrum analyzer display centered on 118 MHz served to constantly confirm the presence of the cable leakage signal. Tests were made using both horizontal (navigation) and vertical (communication) receiving antennas. The antenna giving the higher level response -- the vertical antenna -- was used to obtain the data reported here. A separate test indicated that cable radiation appears to exhibit no particular polarization.

An inertial navigation system was used to determine aircraft location at any given instant, anticipating detailed mapping of the signal level in the airspace. However, analysis of strip chart displays of data shows that only rather crude maps could be made. Signal levels generally rise reasonably smoothly to a maximum over the city, then fall of as the aircraft leaves the cabled area.

2.2 Data Analysis

Reduction of the data -- points numbering in the millions -- was done in four ways: (a) frequency distribution plots, (b) cumulative distribution plots, (c) calculated means and standard deviations (in a few cases) and (d) strip chart recorder plots (in a few cases) for visual inspection.

The frequency distribution plots were most useful for differentiating among signal characteristics which were common to all or most runs and therefore most likely due to cable systems, and characteristics which occurred only occasionally and therefore were likely due to signals from other sources.

Cumulative plots were most useful for correlating ground measurements with airspace measurements, since median signal levels as well as 10th and 90th percentile levels were readily obtained from these plots.

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6 The aircraft was a Convair 580 twin engine turboprop.

3. GROUND MEASUREMENTS AND ANALYSIS

3.1 Measurements

Ground-based measurements were made by three different methods: (a) a dipole antenna and a Field Intensity Meter (tunable voltmeter) were used to measure field intensity approximately 3 meters from the cable at all discovered locations where field strength was over 50 microvolts per meter; (b) meter scale readings of a commercially available "leak detector" designed for cable television use were recorded whenever a relative maximum was observed as a vehicle was driven past the cable; and (c) the same equipment used in the airspace measurements was used to record power input to the receiver every 240 millimeters[7] as the vehicle followed cable lines. All three measurement methods utilized a pilot carrier on the cable, in the same manner as the airspace measurements. A vertical whip antenna was used for methods (b) and (c). The commercial leak detector was reset to the same sensitivity for each run by means of an internal calibrator.

System-wide results from the field intensity meter and the leak detector correlated surprisingly well, even though the leak detector scale is highly non-linear near the top end. Therefore, an "absolute calibration" of the leak detector was made by comparison of leak detector meter indications with field intensity meter results. Then the two sets of data were combined for some of the correlation analysis presented in Table I.

3.2 Analysis

In order to identify a single parameter of the ground measurements for correlation with airspace measurements, various "leakage indices" were calculated from the ground data. Given the electric field strength E_i for all leaks i measured 3 meters from the leak; R_i, the slant height from leak i to a point H meters above central point in the cable system, and ϕ, the fraction of the cable system actually covered by the ground crew; a leakage index I_H may be calculated:

$$I_H = \frac{1}{\phi} \sum_i \frac{E_i^2}{R_i^2} \quad .$$

Obviously, the estimation of ϕ could be a significant source of error.

If I_H is calculated for low altitudes it is possible that the arbitrary choice of the "central point" over which the index is calculated might be fairly critical. The index would be rather heavily weighted toward the situation directly under the point chosen. Therefore, the index calculated at an assumed height of 3000 meters was preferred for our analysis.

7 The distance information was provided by an accurately calibrated "fifth wheel" attached on the vehicle.

Calculation of the R_i from maps is tedious. In order to see whether a simpler calculation would be acceptable for routine cable operator use, an index I_∞ was calculated without the use of slant height:

$$I_\infty = \frac{1}{\phi} \sum_i E_i^2 \quad .$$

These indices I_∞ correlated with airspace measurements just as well as the more "intuitively correct" I_{3000} .

In the case of the automated ground data, recorded with the narrow band airspace receiver modified for ground use, the logarithmic mean (mean of the power received, expressed in dBm) was used as the leakage index I_{avg}.

4. RESULTS

Rank order correlation between airspace and ground data was calculated using the following expression[8]:

$$r_s = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{n\left(n^2 - 1\right)} ,$$

where d_i is the difference between the rank of cable system i when ranked according to one measure of leakage and the rank of the same system when ordered according to the second leakage measure being compared, and n is the number of cable systems in each of the lists being compared. The correlation coefficient r_s can assume values between -1 and +1, where +1 indicates perfect correlation.

Table I summarizes these correlation results. We see that the three methods for ground measurement correlate with each other remarkably well, given the many possible sources of error in all three types of measurement. Of course, in cases where only 3 or 4 data sets are available the correlation coefficient could change significantly with additional data.

The correlation of airspace data at 450 meters with airspace data at 3000 meters is high, but definitely not perfect. This probably reflects the detection of more non-cable sources of noise and interference at the higher altitudes.

8 Statistical Methods, G.W. Snedecor and W.G. Cochran, 6th ed., The Iowa State University Press, Ames, Iowa (1967).

The real test comes, however, in the correlation of any one of the ground measurements with any one of the airspace indications of cable system leakage. The highest correlation with ground measurements is obtained from the median (50th percentile) or the 10th percentile of the airspace measurements made at the lowest altitude -- 450 meters. It is not at all surprising that best correlation should be obtained at the lowest altitude, because of the potentially higher noise fields and interference sources detectable at higher altitudes, especially over major metropolitan areas. The frequency distribution plots probably give the best clue as to why the correlation with the 90th percentile level is not so high. Those plots show significant numbers of rather sharp (narrow spread along the power axis) peaks. These peaks are apparently unrelated to cable leakage, since they are not consistently present from one run to another. They are probably other interference sources. They distort the cumulative distribution curves near the 90th percentile level more than at other percentile levels, because they appear more often at or above the highest levels of the distribution of cable signal leakage power.

Correlation coefficients are given both for data sets including and not including City F. City F was dramatically and consistently worse in terms of ground/air correlation than any other city in our set. Typically, City F would appear 10th in the ranking (decreasing order of signal) according to airspace measurements, but around 4th in the ranking by ground measurements. This anomaly is unexplained. But at least it can be said that if the ground measurements are in error, they erred on the "safe" side by giving City F a higher leakage rating than it apparently deserved on the basis of actual airspace measurements. The improvement in correlation coefficient when City F is not considered is given in the far right column of Table I.

Finally, we note that the correlation among all leakage measures was quite high in the case of the city with the highest airspace signals. That city was the only one in which both of the following conditions held: (a) both airspace and ground measurements were available for correlation, and (b) airspace signals at the 90th percentile level would clearly have opened squelch circuits on a modern communications receiver. That city appeared at the top of the list (highest leakage index) in every case -- all airspace measurements at any altitude and any percentile measure, and all ground leakage indices which were calculated.

5. CONCLUSIONS

At the time of this writing, the formal committee report has not been released and no Commission action has been taken; however, there are several possible conclusions. Some of those conclusions may be:

1) To accept the current frequency offset requirements as being the most reliable solution;
2) To adopt the position that ground measurements are sufficient to assure that no air hazards are presented;
3) To require airspace measurements;
4) To prohibit use of midband or superband frequencies by cable systems; or
5) To relax current standards.

The adopted procedure will undoubtedly not be a clear-cut solution, but will either be some combination of the above or some yet undefined conclusions.

6. ACKNOWLEDGEMENTS

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TABLE I

RANK ORDER CORRELATIONS

Rank Order Set 1			Rank Order Set 2			Correlation Coefficient		Number of Items in Rank Order Sets		Correlation Improvement when City F is Removed
Space	Percentile	Altitude (meters)	Space	Percentile	Altitude (meters)	with City F	without City F	with City F	without City F	
				AIR-GROUND						
Air	90th	450		I_∞		.56	.67	10	9	.11
Air	50	450		I_∞		.67	.90	10	9	.23
Air	10	450		I_∞		.62	.83	10	9	.21
Air	90	3000		I_∞		.26	.42	8	7	.16
Air	50	3000		I_∞		.38	.60	9	8	.22
Air	10	3000		I_∞		.40	.59	9	8	.19
				AIR-AIR						
Air	90	450	Air	90	3000	.79		10		
Air	50	450	Air	50	3000	.83		11		
Air	10	450	Air	10	3000	.71		11		
				GROUND-GROUND						
I_{3000} (Field Intensity Meter)			I_{3000} (leak detector)			1.00		3		
I_∞ (Combined FIM & leak detector data)			I_{3000} (Combined FIM & leak detector data)			.99		10		
I_∞ (Combined data)			Automated ground data			.80		4		