of the measured fields, antenna efficiency, antenna lead attenuation, and perhaps still other effects. In any case, the antenna giving the higher results -- the vertical communications antenna -- was used in all other narrow band measurements in this program.

The other polarization test, using a small private aircraft,[10] less sophisticated receiving equipment, and a different technique, showed no significant difference between horizontal polarization and polarization up to at least 60 degrees from horizontal. In this case, the horizontal (navigation) antenna was used, together with the same cable television leak detector (with meter readout) used for some of the ground measurements reported herein. The leak detector transmitter was used to place a signal on a cable system. Then the aircraft, with the leak detector receiver fed by the horizontal antenna, was flown over the cable system and the level of the received signal was noted. The aircraft was then banked very steeply to the left and to the right. No change in signal level was noted.

The polarization sensitivity of this process was checked by flying over a vertical whip which was energized by the leak detector transmitter at 108.625 MHz. A deep null was indeed observed when the aircrft was in a "wings-level" position.

Data reference: Table G.1 and Figures F.81-F.84

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[10] The aircraft was a Piper Cherokee, supplied by Ralph A. Haller.

## 2.2 Single frequency (automated) measurements.

The largest portion of airspace field data was obtained by digitizing and recording on magnetic tape the signal level received by a sensitive narrow band receiver tuned to the frequency of a CW signal placed on the cable system. The equipment onboard the aircraft consisted of the receiver, a microprocessor, the digital tape recorder, and an input/output (I/O) terminal for control of the other equipment. The system was designed and supplied by the Institute for Telecommunication Sciences (ITS), NTIA, Boulder, Colorado. Data reduction was also done by ITS.

The following subsections (2.2.1 - 2.2.3.5) describe in more detail the equipment and the reduction of the data.

### 2.2.1 Specifications and operation of equipment

The aircraft equipment was sensitive to received power on a single frequency. Prior to an overflight of a city, ground personnel placed an RF generator at the head-end of the cable system. The carrier frequency of the generator was set to 117,999,400 Hertz. The peak voltage level of the generator was set to match the peak level of the closest video carrier on the system. Normally, the level of the channel six (6) video carrier was utilized.

The receiver in the aircraft was a MITEQ Model RC-4044,[11] crystal controlled to 117,999,400 Hertz and had a fixed half-power bandwidth of 1,400 Hertz (1 dB bandwidth of 400 Hz). The noise floor of the receiver was -148 dBm. The receiver provided a dc analog output that was calibrated for input levels between -140 dBm and -40 dBm. Power levels less than -139 dBm and greater than -41 dBm were not used in the data processing.

The analog output of the receiver was converted to a digital signal by an analog to digital converter. The digital level was sampled 200 times per second and the data was supplied to the microprocessor. The microprocessor routed the data to magnetic tape for later analysis at Boulder. The raw data were converted to dBm and then collected in 10 dB bins. For real time

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[11] Mention of brand names and model numbers in this report is for identification purposes only, and is not intended as an endorsement by this Committee, the FCC, or any other organization represented on the Committee.

presentation, the number of samples in each bin was printed out after 5,000 samples were recorded. For example, if a given data point corresponded to a level of -126 dBm, it would have appeared as an element in the -120 to -129 dBm column. On the magnetic tapes, however, data were recorded to $\pm 0.01$ dB. A sample of the hard copy printout is attached as Appendix D.

The 200 times per second sampling rate was chosen to obtain six data samples every wavelength of the flight path with an aircraft speed of 150 knots.[12]

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[12] The aircraft, a Convair 580, was owned and supplied by the FAA. It is a twin engine turboprop. The identification number is N49.

### 2.2.2 Receiving antennas.

Aircraft utilize separate antennas for communications and navigation radio equipment. The communications antennas for the range 118-136 MHz are vertically polarized, and the navigation antennas for the range 108-118 MHz are horizontally polarized. Both horizontally and vertically polarized antennas were available for the tests described in this report.

The vertical antenna appeared to indicate slightly higher cable leakage fields, and that antenna was used for all the leakage field observations reported here. It is believed that the difference was due to antenna characteristics such as frequency selectivity rather than to a polarization of the cable leakage fields. See Section 2.1.5 for futher discussion of polarization effects.

Ideally, perhaps, it would have been well to fully calibrate the antenna gain pattern. However, a calibrated gain pattern is useful only if one knows the direction from which the signal being measured is arriving. In our case the signal being observed is the resultant of many small leakage fields, arriving from many different directions simultaneously. Therefore, it would have been impossible to convert a given input power datum into a resultant free space field intensity (or power flux density) in any case except that of a completely isotropic antenna. There are at least three reasons for abandoning an attempt to fully calibrate the gain pattern of the test antenna: (1) the

impossibility of converting a power datum to a field strength measurement where the antenna is not isotropic and the signal is a resultant of many signals from many directions, (2) the fact that power input to the receiver (for example, relative to squelch level) is really the critical parameter for detection of cable signal leakage by aeronautical receiver, and (3) it seems that most aircraft antennas in use today have roughly the same gain, and therefore the ability to detect cable signal leakage will not vary greatly from one aircraft to another. (Indeed, the squelch setting on the receiver and the receiver sensitivity are likely to vary from aircraft to aircraft more than the antenna gain.)

In spite of these circumstances, it was judged desirable to obtain some quantitative characterization of the antennas used for the tests. A calibrating field was obtained by mounting a pair of circularly polarized crossed dipoles one-fourth wavelength above a one-half wavelength ground screen at ground level. The dipoles were each excited by an unmodulated 117.999,400 MHz signal at a level of +1 dBm. Power input to the narrow band receiver was recorded (200 samples per second, approximately 6 samples per wavelength) as the aircraft flew at 450 meters altitude over the crossed dipoles. (For vertical and horizontal antenna data see Figures F.3 and F.4, respectively. Calibration flight paths are shown in Figures E.2 and E.3) The gain relative to isotropic of the entire antenna system, consisting of the receiving antenna and all cables and connectors up to the receiver input, was then calculated for each recorded datum. Gain was calculated from (a) known

aircraft position, (b) calculated field from the crossed dipoles, at the aircraft location, and (c) observed receiver power input. Frequency distribution plots of the observed gain for both vertical and horizontal antennas are given in Figures F.5 and F.6, respectively.

In the case of the vertical antenna (used for all of the narrow band observtions of cable leakage fields) the mean gain was -12.3 dBi[13] and the median was -11.9 dBi. For the horizontal antenna the mean and median were -12.8 dBi and -14.3 dBi, respectively. The 90th percentile gains (gain exceeded by 10% of the data points) were 1.7 dBi and -3.9 dBi for the vertical and horizontal antennas, respectively.[14]

Although the information is not used in the remainder of the discussion it is interesting to calculate a free space field strength which would correspond in some sense to the approximate squelch-opening threshold of about -100 dBm. Since the 90th percentile level of leakage fields will be used as our threshold criterion, let us also use the 90th percentile gain figure of the vertical antenna for the present calculation. We use the formula

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[13] dBi: observed signal level, in decibels relative to the signal available from an ideal isotropic antenna.

[14] Note that because of a change in plans for frequency use, made in early stages of the observations, the horizontal antenna was actually calibrated at 108.05 MHz rather than the usual 118 MHz.

$$P_0 = \frac{E^2}{120\pi} \frac{G\lambda^2}{4\pi} ,$$

where

$P_0$ = available power output from the antenna system (receiver input)

$E$ = electric field intensity at the antenna

$G$ = gain of the antenna system, relative to isotropic, and

$\lambda$ = free space wavelength

For a gain of 1.7 dBi, G=1.48; for frequency 118 MHz, $\lambda^2 = \left(\frac{300}{118}\right)^2$; and -100 dBm = $10^{-13}$ watts. Therefore

$$E^2 = 49.5 \times 10^{-12} \ (V/m)^2$$

and

$$E = 7 \ \mu V/m .$$

### 2.2.3 Reduction of single-frequency airspace data.

During measurement runs the input power level to the 118 MHz receiver, in dBm, was recorded on magnetic tape at the rate of 200 data points per second. All together, data points numbering in the millions were collected. These were reduced by computer at the NTIA laboratories. Reduced data were displayed for futher analysis in several forms; probability distribution plots, cumulative distribution plots, means, ranges, standard deviations, and strip chart displays (See Appendix F). Not all of the data were displayed in every one of these forms.

In general, a data recording "run" consisted of the total data recorded at a given altitude over a given city with a given ground signal configuration (that is, presence or absence of signal on the cable system, and number of artificially introduced leaks). It was not always true, however, that the data for a single "run" were recorded as a single set of data. If for any reason the recording was interrupted during a run, the receiver/recorder equipment was restarted and subsequent data were reduced separately by computer. Percentile levels and other statitistical results were obtained from weighted combinations of the separate subsets of data. Figures F.17 through F.24 are examples of data from interrupted runs.

2.2.3.1 Probability distributions.

Figures such as Figure F.7 are probability distribution plots of data from runs or subsets of runs. The curves are normalized in the usual fashion, so that the area under each curve is unity. Although summary data for further analysis is more easily obtained from the cumulative distribution curves, these probability distributions are useful for indicating whether the signals follow a Rayleigh (log normal) distribution or some other, and whether other signals unrelated to cable leakage are present.

Although none of the distributions exhibit a "perfect" Gaussian shape, it is probably fair to say that generally the distributions are closer to log normal than to normal or other easily analyzed distributions. An important implication of the log normal distribution is that the total received power is the sum of the powers of individual signals at the same frequency arriving with random phases (superposition). Consistent with the results observed from multiple artificial leaks introduced in the Arlington cable system, this observation of approximately log normal distributions indicates that phase addition of cable leakage signals does not occur often enough to be significant.

We have already noted in discussion of aircraft transmitter interference tests (Section 2.1.4) that many or most of the sharp spikes on the probability distribution plots are most likely due to brief use of the aircraft communication transmitter during the data recording runs.

### 2.2.3.2 Cumulative distributions.

Figures such as Figure F.8 are cumulative curves corresponding to the probability distributions. The ordinate value gives the fraction of the data in a given run (or data set) which exceeds the corresponding power level on the abscissa. In further analysis based on these curves, the power level which is exceeded by one tenth of the data (ordinate 0.1) is referred to as the "90th percentile level". Power level data from the cumulative distribution plots are given in Table G.1.

### 2.2.3.3 Strip chart displays.

Figures F.127 through F.129 are samples of strip chart displays of the recorded single frequency airspace data. The strip chart records were obtained directly from the magnetic tape records of signal strength. A voltage proportional to magnetically recorded signal level (in dBm) was generated and used to drive the strip chart recorder. For a closer look at the fine structure of the airspace signal, the rate at which data were fed to the strip chart recorder was slowed down (Figure F.128). The large regularly spaced spikes on the strip chart record were inserted at intervals of 500 data points.

Although numerical analysis was done on the basis of the cumulative distribution plots, the strip chart displays are useful for developing interpretations of the observed data. For example, examination of Figure F.129 enables one to suggest with some confidence that the sudden steady signals at reproducible levels for short periods of time do correspond to use of the on-board communications transmitter. This in turn supports the decision to ignore the corresponding sharp spikes in the probability distribution plots at corresponding signal levels.

The strip chart records are also convincing evidence that detailed geographical mapping of signal leakage over a cable system is not a very useful tool for identifying individual leaks or small "hot spots" of signal leakage (See also Sections 2.1.1 and 3.4.3). The strip chart recording over City B (which had the highest of all airspace signals) at 450 meters altitude is an interesting example. Knowing that the aircraft flight pattern consisted of six short east-west passes and four longer north-south passes, it is easy to pick out the four long and six short humps in the strip chart record and the corresponding dips where the aircraft was beyond the city making its turns. It was even possible to identify those patterns over the central portion of town, which was known to be the oldest and leakiest portion of the cable system. But the differences observed over different portions of town were neither sharp in time (location) nor large in magnitude. Therefore it would seem quite risky to draw many conclusions from maps of signal strength as a function of position without prior knowledge of cable configuration at the various locations.

The fine structure of airspace data on a strip chart display was examined to see whether phase addition was producing significant peaks in the signal (Figure F.128). Data points were fed to the chart recorder sufficiently slowly that individual data points were resolved by the recorder. Examination shows spikes in the downward direction, but no upward spikes other than what

would be expected from the records with less resolution. This is not a surprising result, since the signal is shown on a logarithmic scale. Exact phase addition of two signals, for example, would produce a maximum upward excursion of only 3 dB higher than average power addition, whereas phase cancellation could produce a large downward excursion, limited only by the noise floor of the receiver. Thus, although we cannot conclude from these observations alone that phase addition does not occur, we can at least say that phase addition was not observed. See Section 2.5, however, for more definitive indication of the absence of phase addition.

2.2.3.4 Signals as a function of altitude.

Figures F.130-F.133 show how signal level at three percentile levels varied as a function of altitude over cable systems.[15] All signals were normalized against the observed signal at the percentile level in question which was observed over the same city at 450 meters altitude. Thus the graph shows only altitude dependence at the three percentile levels, and does not represent at all the relative magnitudes of signals over the various cities. Figures F.131-F.133 give the altitude dependence of signals over individual cities, for each of three percentile levels. Figure F.130 shows averages over all cities.

Considerable variation from city to city was observed (F.131-F.133). But the averages (F.130) show a consistent tendency for the highest level signals to decrease as altitude increases (as one would expect) and lower level signals to decrease less rapidly or even to rise with altitude. This increase seems to occur particularly over major metro areas. This effect may be because at any altitude the highest level signals are due to signal sources nearby (below the aircraft) whereas signal sources at larger distances from the ground tend

[15] Cities I, J and M are not included because of lack of analyzed data at the time these figures were prepared.

to contribute more to the lower end of the signal distribution. As the observation point rises one would expect that signals from directly below and nearby locations would decrease in amplitude, while the higher altitude would permit observation of larger numbers of the lower level signals from larger distances.

Such an explanation may be inconsistent with the observation (Section 4.1) that the best correlation between ground and air measurements of cable signal leakage occurs with the 10th and 50th percentile of the airspace measurements. An explanation of the behavior of the lower level (10th and 50th percentile) signals is not vital to this project, however. Our conclusions concerning the possibility of aeronautical interference are based on the higher level 90th percentile) signals in any case.

2.2.3.5 Spatially truncated data sets.

It was originally planned that data points recorded while the aircraft was beyond city boundaries making turns for another pass would be discarded. However, this became difficult in some cases and impossible in others because the Inertial Navigation System (INS) position data as recorded proved to be unreliable. The position of the aircraft was to be recorded along with signal strength data to permit mapping of the data and discarding of data points outside the cities. At times the INS system produced no meaningful position data at all; at other times, the recorded aircraft location would make sudden shifts of latitude or longitude of arbitrary amounts up to one or even ten degrees.

Clearly, keeping data points for analysis that were recorded far away from a cable system might make the cable system appear less leaky than justified. On the other hand, it would be risky to discard strings of low level data on the assumption that the aircraft was at that time beyond city boundaries, since the aircraft may simply have been over a quiet section of the cable system. Therefore, cumulative distribution curves for spatially truncated data sets were plotted for Cities A and G, where good INS data were recorded. For comparison with the full data set, two truncated data sets were plotted: one with the aircraft turns just cut out (Figures F.9 and F.75), and another over a still smaller portion of the center of the city (Figures F.10 and F.76).

Observed signal levels at the 90th percentile were higher by one and three decibels, respectively, than in the full set. At the 50th percentile, signals were higher by 2 and 5 dB, respectively. At the 10th percentile, signals were higher by 3 and 8 dB. The stronger effects at the lower percentiles are expected, of course, since the points discarded were generally low level points.

Even though the effects of truncation seemed to be significant, at least at the lower percentile levels, it was decided to keep full data sets for analysis. In the first place, discarding points in the absence of INS data just because the points were low level would be risky, as discussed earlier in this subsection. Furthermore, truncation would be somewhat arbitrary even if valid INS data were available. Examination of strip chart records did not reveal long flat strings of low level data, which would be expected over rural areas far removed from cable leakage effects. Therefore, it must be that even during aircraft turns the receiver was still detecting signals due to cable leakage. Analyzing the full data sets for all cities was at least as realistic as analyzing only arbitrarily truncated data sets.

## 2.3 Broadband measurements.

This section and its subsections describe airspace measurements made with a broadband receiver. The object was to compare the cable leakage signal with noise and other signals on nearby frequencies. All related tables and figures are collected in Appendix J.

### 2.3.1 Broadband flight test data collection.

Broadband measurements were recorded during all flights using the Digital Processing Oscilloscope (DPO) with the exception of those made over Arlington, Virginia. The Arlington data were not recorded due to equipment failure from vibration. Three types of data were recorded using the DPO in which a 7L13 Tektronix Spectrum Analyzer was employed in the mainframe of the DPO oscilloscope. Firstly, the image of the spectrum analyzer was recorded after every 77 maximum signal recordings. Secondly, recordings were made of aircraft Inertial Navigation System latitude and longitude. Finally, analog data such as receiver AGC and altimeter voltage which were processed by an analog to digital converter and stored. The desired frequency or frequencies to be sampled for maximum signal level were entered via the DPO terminal. During flight data collection the reference frequency of the spectrum analyzer was corrected for drift periodically through use of the tracking generator which was provided a center frequency accuracy with 10 Hz.

2.3.1.1 Broadband data processing analysis.

The maximum signal level data recorded for each plot was to show sequential variation in signal level. It was also treated statistically. The plotting of data was done to allow a geographic comparison of runs to determine if non-linear addition of a signal was occurring. The scales of these plots with the exception of the dBm scale have no relation to the data other than to assist in the plotting. Signal levels were corrected for a 10 dB loss between antenna and analyzer.

An analysis of variance was conducted on many of the data.[16] Where possible, a mean value for each run is computed, and a reference distribution was determined for the runs listed in the tables for 95% probability. Also computed was the pooled variance and the F ratio. The grand mean may be calculated as G/N from table data. Limitations of software sometimes prohibited complete treatment of all runs, but the omissions are not critical due to the large data sample.

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[16] Statistics for Experimenters, G. E. Box, W. G. Hunter, and J. S. Hunter, John Wiley & Sons, 1978.

2.3.1.2 Equipment.

Broadband measurments were made using a Tektronix, Inc., Digital Processing Oscilloscope (DPO) system which was connected to horizontally polarized antenna (6 dB down from vertically polarized) in the same enclosure as the vertically polarized antenna which was used for single frequency measurements. The signal was received through a 7 dB loss splitter (Locus, Inc., MC 211 B) and experienced an additional 3 dB cable loss between the antenna and system impact point.

The DPO system consists of the following several parts:

1. Acquisition Unit - A7704
2. Processor - P7001
3. Spectrum Analyzer - 7L13
4. Tracker Generator and Counter - TR502 and DC-502 Opt. 7
5. Controller - CP4165
6. Terminal - 4010
7. Floppy Disk - CP112
8. Analog to Digital Interface - ADV-11A.

A controller program written in a Tektronix version of BASIC controlled the sequency of data. The program sequenced collection of data from the spectrum analyzer and several analog signal sources, such as receiver AGC and altimeter. Another data source, also controlled by the CP4165, was the INS system which supplied binary position data.

Maximum sensitivity of the spectrum analyzer under optimum conditions is -128 dBm. The dynamic range of the analyzer as used was 70 dB. Data was collected with the spectrum analyzer setting as follows:

Resolution - 30 kHz

Frequency Span - 50 kHz

Time/Div - 5 msec.

Phase Lock - On

Input Attenuation - 0 dB

Ref. Signal Level - -60 dBm

Vertical Amplifier - 10 dB/Div.

2.3.1.3 Discussion of broadband data.

The images for all CATV sites monitored with the spectrum analyzer did not produce distinguishable signals above noise level with the exception of City B and City H.

Both the City B and City H cable systems have been in operation for more than 15 years, as compared to other systems of the mid-west which have been operating only 3 to 5 years. The City B system is in the process of being replaced. The following discussion will be limited to data on City H, City B, City K and City C. The City C system produced an audio signal interference due to a heterodyne with a signal from a VOR station about 90 kilometers away. (See also Section 2.6.)

City H Data: In Figure J.1, runs 1, 3, 5, and 7 plotted from flying course #1, while runs 2, 4, and 6 contain data from course #2. Start of data plot is on the right. Geographically the end (left side) of odd numbered runs correspond with the start of even numbered runs at the right of Figures J.1 through J.3. The even numbered runs exhibit significant change in level in the first half of the data and are at a lower level. The reverse is true for the odd numbered runs.

Representative images of the spectrum analyzer are included in Figures J.4 and J.5. As may be seen in these figures, the CATV radiated signal at 117.9994 MHz is strongly above the noise level.

The statistical treatment of data is made for each altitude. The estimated mean is computed for each run (single pass across the city) and the data tested for significant difference in the means by the reference distribution and the F test. The single surprise of the data was that the data in Table J.1 for Run #1 gave the highest mean even though the flight path for the run was not over the city but along the beachfront. The grand mean (G/N) for the 1500 foot data is -76.13 dBm.

Only one run was made at 5,000 and 10,000 feet and a comparison between the two runs is shown in Tables J.2 and J.3. As shown, significant difference exists between the two means. Run 8 was made at 5,000 feet while Run 9 was at 10,000 feet. An appropriate decline in signal level was measured which would indicate that the level of signal from other source was low.