A RELIABLE AND REPRODUCIBLE TECHNIQUE FOR EVALUATING THE SHIELDING EFFECTIVENESS OF CATV APPARATUS

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ABSTRACT

The CATV industry has long needed a reliable and reproducible technique for evaluating the shielding effectiveness of CATV apparatus. The author will describe an operational system capable of swept frequency integrity measurements in excess of 150 dB, over a frequency range of 5-300 MHz, which technique does not require a screen room. Results of data obtained will be presented.

Long term CATV system shielding integrity has recently received substantially increased attention due to the FAA/FCC inquiry concerning CATV system radiation. Strict enforcement of the FCC radiation rules, Sub Part K, 76.605, is certain and destined to become of increasing concern for system operators.

The additional factors involving security of service on certain channels, coupled with reverse system signal requirement, all demand close attention to the selection of system components which assure long term shielding integrity.

In the face of this requirement, current experience with available rf integrity measurement methodologies [1,2,3] show substantial deficiences such as:

A) Method difficult to implement.
B) Measurements available at discrete frequencies only.
C) Measurement data influence by environmental factors not easily subject to control

The ideal measurement technology permits system component integrity measurements on an "in situ" environmental condition, and further would permit continuous integrity evaluation over a frequency spectrum of 5-300 MHz, with a continuum of measurements over the spectrum as opposed to spot frequency integrity measurements.

A major connector manufacturing firm, LRC of Horseheads, NY, commissioned the author's R & D firm to study the available technology and following on, develop measurement techniques adequate to fulfill all the desired goals.

ComSonics®, Inc. retained as co-consultants, Sachs & Freeman Associates, Inc., the eminent EMI specialists of Hyattsville, Maryland. After preliminary study it was determined that a new field detection aperature patterned after the one developed by ComSonics® for near field measurement in the Sniffer cable leakage detection system would be designed for this task.

Although the FCC radiation criteria are stated in microvolts per meter, this is a far (Fraunhofer) field intensity specification which is a function of the actual power coupled from the interior of the cable through a shield integrity fault to an external radiation element, composed of an essentially uncontrolled environment. In most cases the statistical nature of the effective aperature "A" and its directivity in this external environment preclude the precision desired for reproducible leakage measurements. Therefore, such measurements should be made in the near field, ie., $\ll 1 \lambda$, (the near field or Fresnel zone) from the radiation source to exclude those variable which are not strictly a part of the connector shielding effectiveness.

Several advantages are realized. Since this type of measurement is dependent only on the magnetic and electrostatic flux lines surrounding the sheath of the cable at the shielding flaw, the total path loss is significantly reduced, substantially improving the system's flaw detection capability. By its inherent characteristics,

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1- 1973 NCTA Transcripts, "A Study of Aluminum Cable Connector Interfaces and Their Effect on CATV System RF Ingress", Eric Winston.

2- Transfer impedance method.

3- Sniffer System.

a "near field" aperature is physically and electrically small[4] to a Fraunhofer (far field) aperature, significantly reducing the interference from external communications transmissions such as FM and TV broadcast facilities. The resultant data is far more reproducible and relevant to actual connector's shielding efficiency.

Far field approximations of field intensity may then be estimated from the known near field flux density.

Unfortunately, no wide band near field aperatures were available to meet this measurement requirement, therefore a major R & D program was implemented to develop such a device. Upon completion of this task, the system possessed the following capability:

* Measurement frequency range - Continuous from 5-300 MHz
* Shielding integrity sensitivity = $>$160 dB
* Reproducibility variation $\cong \pm 2$ dB

METHODOLOGY AND MEASUREMENT SYSTEM DESCRIPTION

A block diagram of the completed measurement system is shown in Fig. 1 comprised of (a) transmission equipment and cable span distribution, (b) leakage detector probe, and (c) reception and signal processing equipment. The inside lab layout is illustrated pictorially in Fig. 2 through Fig. 4, while the outside cable spans and detector probe housing are shown in Fig. 5 through Fig. 8. A list of equipment utilized is shown in Table 1.

The system functions in a continuous sweep/reception mode covering a frequency band from 5 MHz to 300 MHz. The sweep source is provided by a tracking generator whose output frequency versus time is locked to the swept/tuned reception of the spectrum analyzer used as the received signal measurement and processing apparatus. This allows the precise simultaneous transmission and reception of a given frequency as the system continuously sweeps the entire band from 5-300 MHz. To achieve the necessary high signal level injection into the cable, the tracking generator output level is amplified to a level of 4.5 watts of power into the desired cable span under test. The high output levels utilized and high sensitivity of the receiving equipment is close proximity to the R.F. power amplifier, necessitated special isolation construction and procedures in the lab setup. By example, the 50 ohm coaxial interconnection cable from tracking generator to the R.F. power amp assembly enclosure had to be run through a section of solid copper conduit to adequately isolate this cable to avoid regenerative effects in the system. This conduit was soldered completely around the circumference of each connector, thus comprising a solid shield for interconnection. The opposite end of the pipe was inserted through an aperature in the wall of the high power transmitting enclosure and also soldered. The R.F. amplifier shielding housing was constructed of a metal enclosure large enough to house the R.F. amplifier, wideband matching transformer, additional AC power line filters, and connection cables. Two bulkhead mount feed thru type power line filters were mounted in the enclosure wall to adequately shield and filter the power lines to the R.F. power amp. An additional RFI power line filter was mounted on the inside of the enclosure to provide additional power line RFI filtering required to eliminate any externally radiated fields. Four bulkhead mounting type connectors were mounted in the enclosure shield wall to provide the outputs to the four transmitting cables feeding four cable/connector spans. The cable span being used at any time internally selected by connecting the R.F. power amp output to any one of the bulkhead connectors via a jumper cable. These construction precautions provided the necessary high degree of isolation between transmitting and receiving equipment, and precluded the necessity of special shielding techniques in the receiving apparatus apart from usual construction procedures.

As stated previously the transmitting enclosure provides four outputs to the outside cable spans interconnected by four sections of 0.5" cable which were run through the exterior wall of the testing laboratory. The cables are run underground through a section of plastic conduit, providing a protective jacketing for the cables, to one end of each of the 200' aerial cable spans. Two parallel spans were hung on cross arms with a horizontal spacing of 4' with the other two parallel spans hung 4' below the first two. (See Fig. 5) Each of the cable spans is identical in construction to the other three, consisting of a splice block interconnecting the feed cable and the 0.5" cable/connector section. Each cable section between splice blocks measures 18', with each cable span consisting of 11 such sections, interconnecting 10 splice blocks of 2 connectors each. Thus each cable span contains 20 connectors excluding the first splice block. Each

[4] - Compared to a dipole.

cable span is terminated after the 11th cable section by an appropriate 75 ohm terminator. These construction details are illustrated pictorially in Fig. 5 and Fig. 8.

Two receiving cables were mounted under the four main cable spans, each extending aerially halfway between one end of the cable spans and the center, back to the center of the span itself. At this midpoint in the cable span the two cables meet and are fed through an underground plastic conduit returning to an aperature in the exterior wall of the testing facility as was done for the four transmitting cables. These details are illustrated in the block diagram of Fig. 1 and pictorially in Fig. 8.

This construction allows detection probe access to the receiving cable point over the shortest possible distance from one end of the system to the center of the spans. Thus, signal reception is achieved via the receiving cable located under the system portion in which the measurements are being made. The two receiving cables, A and B, are run inside the testing facility in close proximity to the receiving equipment, where the appropriate interconnection is made via a short section of cable. This interconnects the chosen receiving cable/DC power inserter[5] through a wideband matching transformer converting the 75 ohm characteristic impedance of the cable system to the 50 ohm input impedance of a 20 dB low noise wideband post amp. The output of this post amplifier is then connected to the 50 ohm R.F. input to the Tektronix 7L12 spectrum analyzer, which provides the required signal processing and spectrum display. The spectrum analyzer incorporates selectable IF bandwidth, which is operated in the 300 Hz resolution mode providing the lowest system measurement noise. As the analyzer sweeps across the 5-300 MHz band, the tracking generator output is simultaneously produced, and the resulting connector leakage is monitored by the detector probes connected to the spectrum analyzer and displayed on the analyzer CRT.

A separate regulated power supply was constructed to provide +12.5 VDC and +20.0 VDC supply voltages to the detector probes and the 20 dB post amp. This supply insures fixed and reliable gain for reception calibration. The probe powering supply output is switchable allowing power to be interrupted when outside receiving cable disconnection/connection is being made.

RF LEAKAGE DETECTION PROBES AND HOUSING

Connector leakage detection is accomplished by precise physical placement of two near field flux probes located in close to the connector under test. Fig. 7 illustrates construcion of the probe housing and interconnections. Circular notches are cut in two sides to allow the housing to be hung easily on each cable/strand assembly from the ground, as illustrated in Fig. 6. Physical location of support bearing and lateral mounting of the two probes are tightly controlled to facilitate measurement of each connector within narrow limits of distance to each end of the two probe housings. With the spacing thus controlled, the housing can then be moved along each strand to assure that each connector is directly under the probe at time of measurement.

Since there are many connectors mounted on the same energized cable span, leakage from any one connector will be launched along the cable sheath, propagating to other connector locations, combining with leakage measurements being made at a particular connector. The shielding integrity of any connector can potentially degrade sufficiently over time to cause significant signal contributions at other connector test locations and thus introduce errors which result in false spectral signatures in the measurements. It was, therefore, necessary to develop a method to isolate the leakage of a particular splice block from other splice blocks in the cable span. It was determined that an antenna probe housing was needed providing at least a semi-enclosed, R.F. shielded environment for the two leakage detection probes. Fig. 6 and 7 pictorially illustrate the constructed housing. A lightweight metal frame was covered with a fine mesh metal screen, which covered the top, back and two side frame panels, and is physically connected on each side to a multi-layer RFI shielding mesh lining the circular support notches. This mesh provides an electrical contact from the housing to the cable span sheath achieving excellent reproducibility. In early measurements it was also determined that the antenna probe circuit ground must be electrically referenced to the cable sheath very close to the point of radiation. This effectively desensitized the probes to radiation other than leakage produced by the connector under test, and effectively eliminates effects of external signals induced via the receiving cable sheath. Probe referencing connection is provided by two stainless steel rods, as illustrated

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5 - Used to feed the DC supply to the external detection probe/preamplifier.

in Fig. 7, each connected to one probe mounting bracket in such a way as to be under tension against the cable sheath or splice block as the housing rests on the cable at the two support locations.

One antenna probe operates from 5-100 MHz and the other from 100-300 MHz. A combiner/filter module was constructed to connect the two probes to a common output cable, while maintining a high degree of electrical isolation between the individual probe outputs. The highband probe filter input allows only those signals from 100-300 MHz to pass to the common output, while the low band input passes signals only from 5-100 MHz, thus allowing completely independent operation of the two probes. DC power for the probe/preamplifier combination is supplied via the receiving cable. Both probes are small aperature/near field flux/sensing devices, arranged to perform their function in an essentially frequency independent mode. This technology allows the discrete analysis of a small radiating aperature area, such as a single connector in a splice block.

The pick-up loop output in connected to the input of a low noise MOSFET preamplifier stage. This stage provides the requisite match for the antenna sections, also achieving the low input noise floor required for high leakage detection sensitivity. A broadband transformer was constructed for impedance transformation and signal coupling the FET output to the 75 ohm cable input. This transformer also provides DC power connection from the probe output port to the preamplifier stage.

SPECTRUM PHOTOGRAPHS INTERPRETATIONS

Several leakage spectrum photographs are labeled here for comparison. Each photograph contains necessary quantitative information on the spectrum analyzer calibration/display mode settings. The alphanumeric readout on each photograph indicates the signal level vertical display, scaling at 10 dB per main horizontal graticule division, a full scale (top graticule line) reference level of -84 dBm, and a bandwidth or resolution setting of 300 Hz. The lower right hand display of <50 MHz indicates a horizontal frequency scale calibration of less than 50 MHz per division. This is due to the frequency scale calibration of 30 MHz per vertical graticule division, 0[6] Hz is on the extreme left hand vertical scale line and 300 MHz is on the extreme right hand vertical scale line, displaying the total spectrum of 0-300 MHz over the entire CRT display. Since there are 10 main vetical divisions viewing from left to right, each division of change equals 30 MHz. The exact center of the display then represents 5 divisions of 150 MHz.

As was stated, the full scale or top horizontal line indicates a received signal strength of -84 dBm or 84 dB below one milliwatt at the detector probe antenna output terminals. The lowest calibrated full scale reference of the spectrum analyzer is -60 dBm, measured at the analyzer's input port. The broadband gain of the detector probes is 4 dB, and that of the preamp immediately preceeding the analyzer is 20 dB, for a total of 24 dB broadband gain. Therefore, -60 dBm -24 dB = -84 dBm true full scale reference level as indicated in the photograph display. As stated, each vertical divsion equals a 10 dB change in signal level. The midscale graticule in the photographs then represents a -124 dBm level.

The photograph labeled "Noise Floor" represents total receiving system detected spectrum with no signal input to the cable spans and with the energized detector probe assembly hanging outside on one of the cable spans. The display then represents total receiving system noise output and detected pickup of any remote sources of radiation present at the outside measurement site. Therefore, this spectrum representation is defined as the measurement system noise floor or lowest detectable signal levels possible in the measurement system. A reduction in spectrum analyzer resolution reduces the undesired received noise power that would mask any desired signal to be displayed. The analyzer is, therefore, operated with its lowest obtainable bandwidth or resolution of 300 Hz as represented on the spectrum photographs. The system noise floor level, excluding the individual carriers present in the display, ranges from about -134 dBm out to 150 MHz, to about -140 dBm to 300 MHz. The 4.5 watt output level maintained into any of the cable spans converts to +36.5 dBm, resulting then in a total system measurement dynamic range of 36.5 + 134 = 170.5 dB minimum. Thus the receiving apparatus can display detected leakage signals at the antenna probe head output terminals (preceeding the first probe preamp) that are 170 dB reduced from the level present in the cable span, less any cable losses.

Referring to the noise floor photograph, several individual spectrum lines can be seen at levels significantly above that of the -134 dBm noise floor. These represent extraneous signals present at the measurement site, consisting in part of

[6] - Lowest actual measurement frequency is 5 MHz.

VHF television band channels, FM radio broadcast signals, and other business communication signals. The two highest levels seen at 90.7 MHz and 100.7 MHz are being received from two local FM broadcast stations.

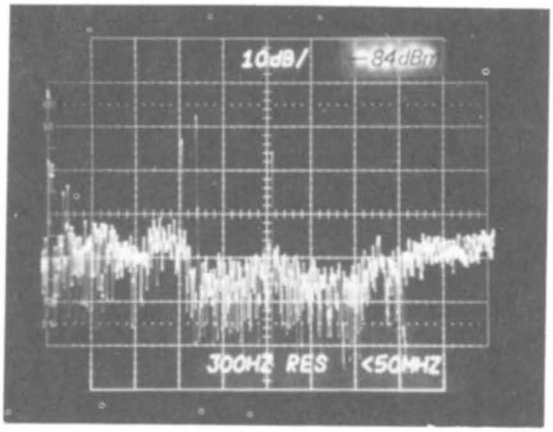
SUMMARY

Test results indicate a reproducible and reliable individual component integrity measurement system, permitting continuous evaluation over a frequency spectrum of 5-300 MHz. Utilizing near field detection methodology and isolation properties of the developed detection probes housing, it is possible to obtain individual components spectral signatures in a multi-component system, thus permitting a more meaningful and relevant analysis of a variety of system components on a statistical basis. This then allows a "typical" performance pattern definition on a particular component group, as well as relative group comparisons. Test results also indicate the capability of more accurate location of the component leakage point, thus facilitating accurate definitions of integrity failure mechanisms.

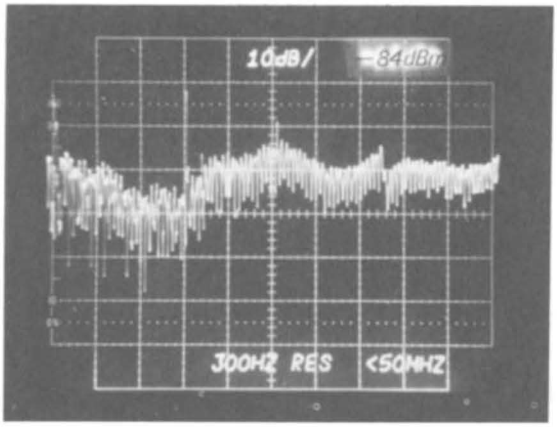
Spectrum pattern data obtained for several different connector types have shown easily detectable spectrum signatures of non-integral mandrel connectors and a variety of integral mandrel types. Cyclical pattern variations due to temperature fluctuations, frequency selective integrity degradations, and general shielding integrity deficiencies over certain selective portions of the measurement band have been identified as a result of the 5-300 MHz spectrum measurement methodology. Such results would obviously not be possible from single connector, spot frequency measurements.

This same measurement system methodology will be utilized by ComSonics®, Inc. in the near future for flexible coaxial cable connectors. However, several characteristics unique to this type of cable require further development for successful measurement implementation. Shielding effectiveness of flexible cable itself is significantly less than the measurement system sensitivity. Unless the integrity of the connector/cable interface is lower than the cable integrity, additional isolation techniques will be needed for relevant measurements. As for hardline connectors, signal levels at a particular connector can be influenced by degrading connectors at other points in the cable span. Present solutions to this problem by special detection probe housing construction will be difficult to implement due to the nonconductive outer jacket of flexible cable to be used for connector point connection. Methodology and apparatus developed for hardline connector measurements will be expanded further to provide reliable testing for this special case.

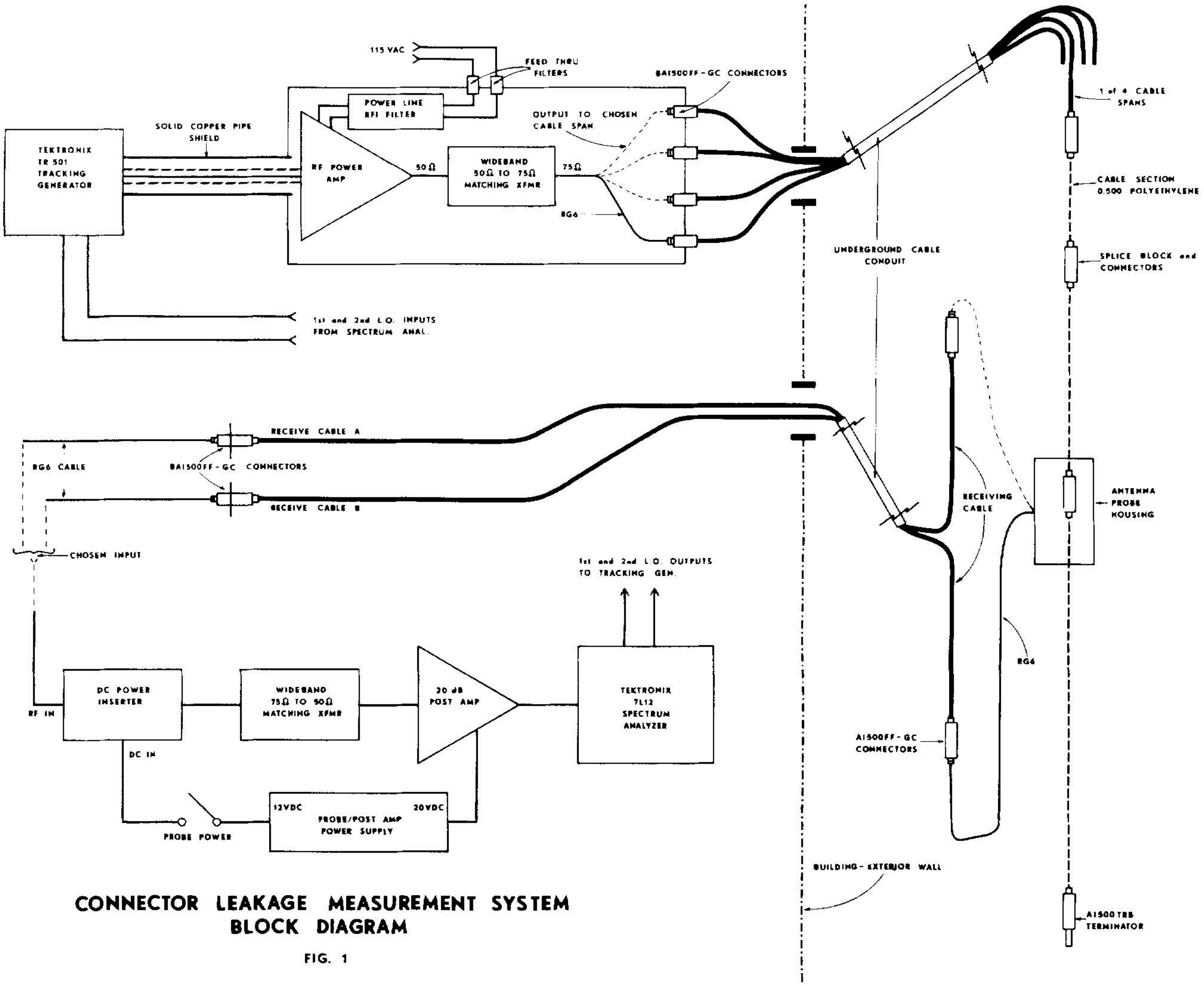
The author wishes to thank Richard Shimp, Director of Research and Development, and Glen K. Shomo, III, P.E., Assistant Director of Research and Development at ComSonics®. Both of these engineers worked diligently and brilliantly, solving some very difficult, state-of-the-art problems.



INTEGRAL MANDREL



NON-INTEGRAL MANDREL



CONNECTOR LEAKAGE MEASUREMENT SYSTEM BLOCK DIAGRAM

FIG. 1

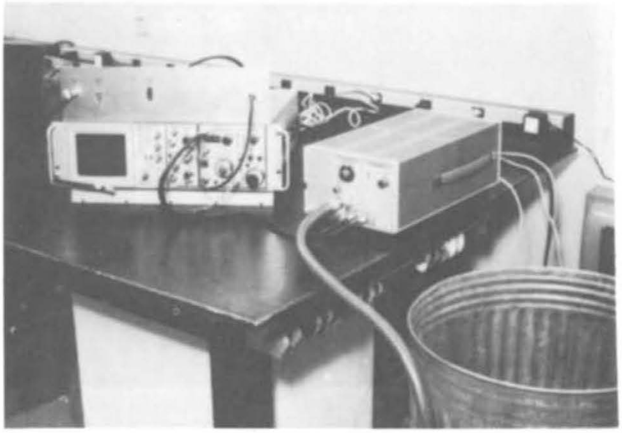


FIG. 2 - Measurement System Apparatus

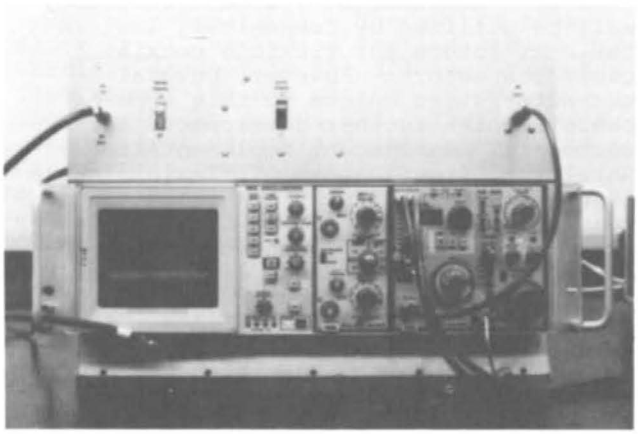


FIG. 3 - Receiving & Processing Apparatus

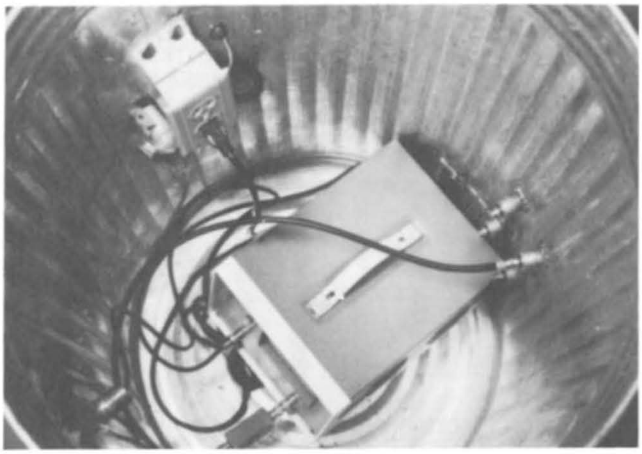


FIG. 4 - Power Amp Assembly Enclosure

FIG. 5 - Cable Spans Feed Points

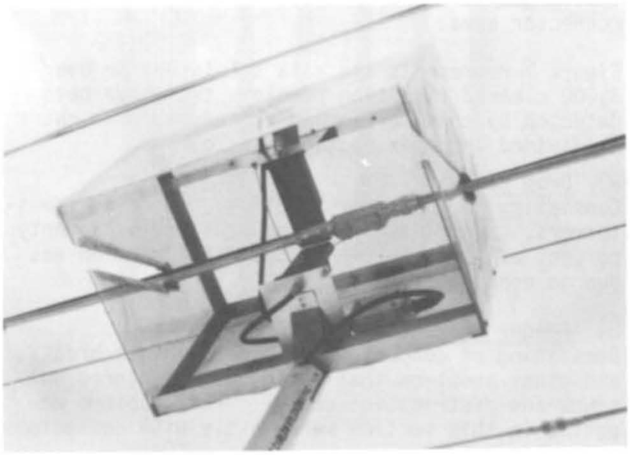


FIG. 6 - Detection Housing - Operational Placement

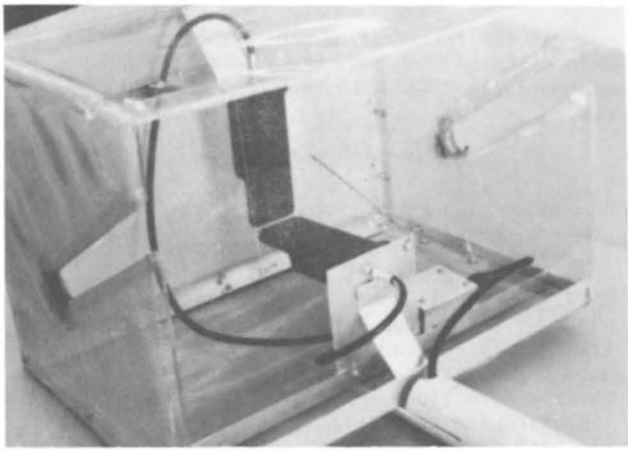


FIG. 7 - Detection Probes & Housing

FIG. 8 - Cable/Connectors Construction