A STUDY OF ALUMINUM CABLE-CONNECTOR INTERFACES AND THEIR EFFECT ON CATV SYSTEM RF INGRESS

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The cable-connector interface is dominant in considering long-term system shielding effectiveness. Mechanics of the interface indicate that radial cable stress can reduce contact pressure between cable and clamp; creep is a secondary phenomenon. Internal support sleeves help maintain required contact pressure. Laboratory and field tests show quantitative differences between connectors having internal support sleeves and those without.

The cable-connector interface resistance is explored as a factor in long-term shielding effectiveness; an increase in junction resistance with time is typical.

Field testing with simulated feeder lines is described in detail together with the concept of "effective shielding", the difference between the signal level at a dipole 10' away from the cable and the signal obtained in the cable system, expressed in dB.

A useful approach to the problem of maintaining satisfactory interfaces is presented. Arguments favoring aluminum cable connectors having integral internal sleeves are outlined.

System RF integrity has been a matter of growing concern throughout the CATV industry. The imperatives are self-evident; the need to meet FCC specifications, and the equally compelling requirement to guarantee RF integrity in any part of the spectrum where strong external signals may exist.

The potential routes of RF leakage are well-defined. They exist at the aluminum cable-to-connector and connector-to-housing interfaces, at housing and cover joints, at drop cables and associated fittings, and at the unused multitap connection. While each and every one of these may contribute to the overall problem, we are restricting this discussion primarily to the first of these factors - the cable-connector interface.

The direction of this paper is as follows:

1. To examine the mechanics and measurements of the cable-connector interface, with particular emphasis on finding logical explanations for the typical degradation occuring with time in field use.

2. To discuss the advantages and disadvantages of internal support sleeves.

3. To describe techniques for measuring RF leakage and junction DC resistance in the laboratory; to report on controlled RF shielding tests in the field showing system changes with time as affected by various connector combinations.

4. To present a useful approach to the problem of obtaining and maintaining satisfactory cable-connector interfaces.

1. MECHANICS OF THE CABLE-CONNECTOR INTERFACE

The typical aluminum cable connector contains a compressible ferrule which secures the cable and completes the outer conductor circuit by intimate contact with the outside of the sheath.

Once secured, in typical usage, the connection may be subject to alternate tension and compression, rotational, and both high and low frequency vibrational forces. Both diurnal and seasonal temperature variations contribute to further stresses and strains, while chemical attack from air pollutants, accelerated by varying humidity conditions, may contribute to the gradual deterioration of the vital sheath contact. The effective connector must provide permanent resistance against all these forces.

Some of the mechanical problems are readily overcome by good clamping methods. For example, 1/2" diameter polyethylene foam dielectric aluminum sheath cable will break at 400-450 lbs tensile load near or at the clamp; this is close to the tensile limit of the cable sheath. Such a gripping force will easily overcome normal rotational movements. However, experience has shown that mechanical joint strength alone does not necessarily guarantee satisfactory electrical performance.

The cable jacket is typically extruded 1060 alloy, a soft material having a yield point of 7-10,000 psi, depending on the amount of cold work applied.

Such materials, when stressed, are invariably subject to creep phenomena at normal ambient temperatures which result in strain relief or even in movement in stressed areas as a function of time. The squeezing action of the ferrule described above necessarily imparts compressive stress to the aluminum jacket; hence, a certain amount of creep must be anticipated. In addition there is creep of lesser magnitude in the aluminum alloy connector members, particularly in stressed threads.

2. USE OF INTERNAL SUPPORT SLEEVES

In recent years improvement in connector RF performance seemed evident when rigid support sleeves were placed underneath the cable jacket so that the cable was sandwiched between the compressing clamp as shown in Fig. 1. The obvious benefit from this arrangement is that contact pressure between the sheath and the ferrule is maintained and that jacket creep is limited.

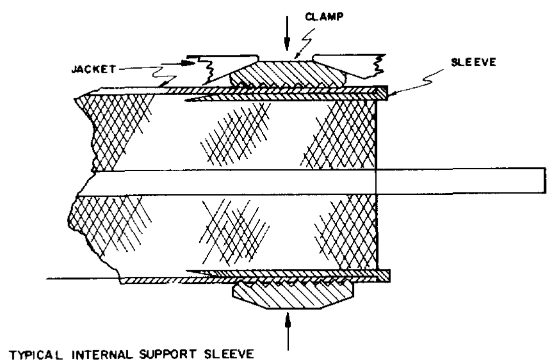


FIG. I

The insertion of a close-fitting, thin wall sleeve is not without problems, however. Both out-of-round cable and ID burrs caused by cable preparation tend to make insertion difficult. If extreme compressive force is applied there is a tendency to reduce the wall thickness of the cable jacket, thus work-hardening and weakening it. The sleeve is a small, loose member, easily dropped, lost, or even discarded by an indifferent technician. Subsequent inspection after connector assembly is virtually impossible. Polyethylene foam dielectric is relatively tough, almost completely restricting the entry of the sleeve unless the dielectric is partially or completely cored out. The cable impedance is changed at the sleeve location. For 1/2" dia. cable, a typical thin-walled sleeve having an inside diameter of .400" inserted with no polystyrene dielectric removed would yield a characteristic impedance of 69.5 ohms. Coring is evidently always desirable and sometimes essential; the operation must be performed with care to avoid damage to the sheath and the center conductor.

3. LABORATORY R.F. LEAKAGE MEASUREMENTS

In order to obtain precise evaluations of the RF shielding capabilities of cables and connectors studied, a reliable and convenient test set-up was essential.

Fig. 2 shows schematically the apparatus used at the Jerrold Laboratory. System measurement capability is 145 dB. This technique compares a reference signal with the maximum picked up by a given tuned high-Q loop antenna, about 5" diameter. Five fixed frequencies, 5, 30, 54, 216 and 295 MHz were used, one antenna for each frequency. The high-level reference signal (about +80 dBmV) is introduced through solid-shield aluminum cable to the unit under test, then brought out of the screen room to a high power, impedance-matching attenuator to provide transition from 75 to 50 ohms and 60 dB attenuation, then back into the screen room at a conveniently lower level through 50 ohm flexible cable to provide a reference signal for comparison with that picked up by the antenna. All cable feed-through fittings are grounded to the screen room ceiling. Power line filters are installed so that there is no leakage through the AC power lines. Signal picked up from the device under test and the attenuated reference signal are fed into a co-axial switcher, thence to a low noise preamp, and to a mixer where the signals are mixed with the output from a fixed oscillator tuned 30 MHz above the test frequency, and fed into a G.R. 1216A 30 MHz IF strip and detector. The detected composite signal is displayed on an oscilloscope. Attenuation is varied until the same level is indicated for each position of the coaxial switch. The amount of leakage is characterized by the total attenuation inserted to match the level at the antenna terminals. This is an extremely reliable and sensitive test set-up. Repeatability of measurement is known to be within plus and minus two dB at the 140 dB shielding level. For any measurement the antenna is manipulated to yield maximum pick-up, usually obtained when its plane is parallel to the axis of connectors.

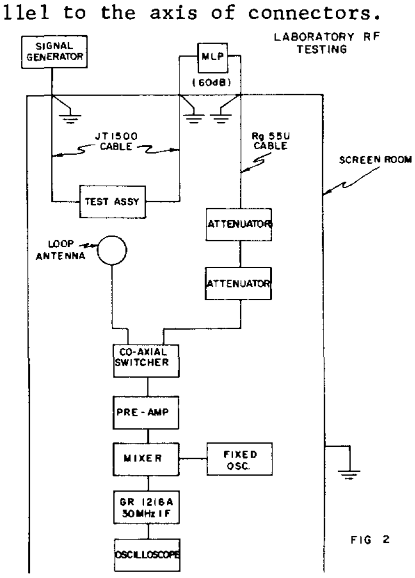


FIG 2

It is necessary to emphasize that the values obtained in this type of testing are relative to each other and are in no sense absolute. Maximum readings always occur close to points of actual leakage in the devices under test.

Using this equipment we have established a hierarchy of shielding numbers for various types of housings, connectors, and cables. Fig. 3 shows RF attenuation obtained with representative CATV hardware. Correlation with a commercial testing laboratory showed that a figure of 60 dB at 295 MHz in tap-connector combinations corresponded to current FCC RF radiation specification limit (15 microvolts/meter at 100 ft).

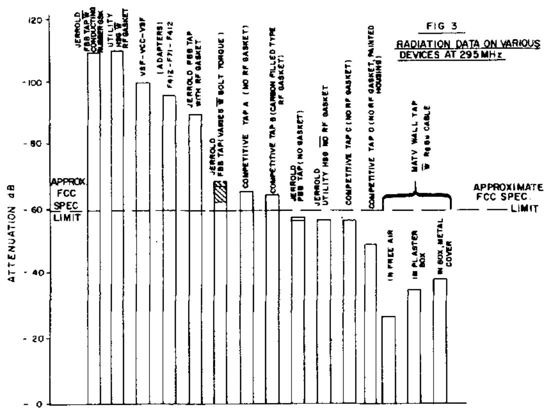
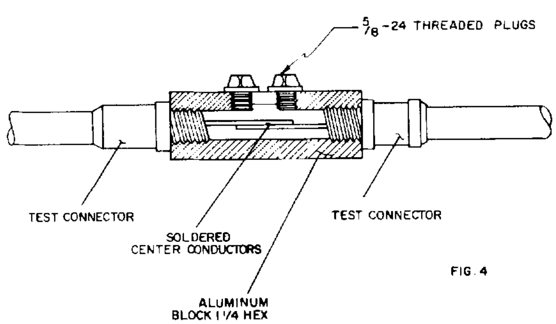


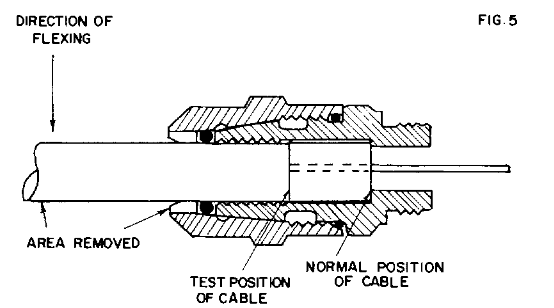
Fig. 4 shows the construction of an aluminum block used for testing cable-connector interfaces. This insures the integrity of the feed-thru device since there is no possible cover leakage. Cable center conductors are soldered together through the threaded port apertures. With the blocks described leakage measurements were initially made using various types of commercial connectors and styrene foam cable without any internal sleeves. As installed, many exceeded system capability - that is, attenuation beyond the 145 dB sensitivity limit. Those which did not invariably exhibited relatively loose cable contact due to insufficient ferrule grip, or due to a sizable gap in the ferrule slot.



TEST BLOCK FOR MEASURING LEAKAGE OF CABLE CONNECTOR INTERFACES

Fitting-cable-tap combinations when first installed generally have shielding effectiveness limited by the housing-cover RF gasket. One such combination, initially checked at -95 dB was heat-cycled between 20 and 60°C for two-hour periods twenty times while in the RF chamber; a 10 dB degradation was observed. This would indicate the degree to which creep may be a contributing cause of signal ingress. Similar combinations left at room temperature for periods in excess of 1000 hours showed little or no change. Evidently creep alone does not account for all the instability which has been reported from the field.

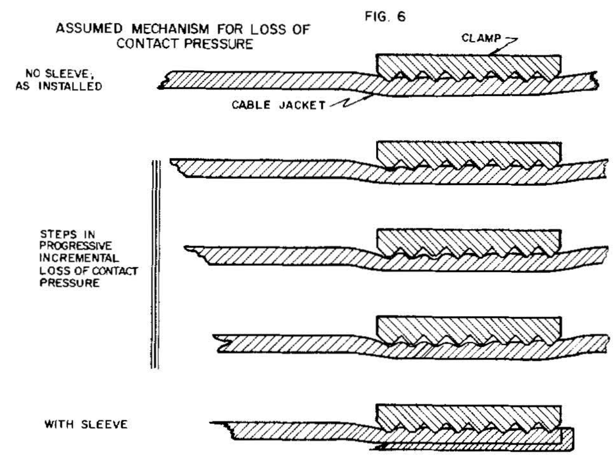
In the attempt to find a more likely source of cable-connector degradation sufficient to account for signal ingress of a magnitude reported from the field, we applied small alternating lateral forces to the cable in the connector block assemblies described above. We used Jerrold VSF-500-D connectors having no internal support sleeves, simulating occasional movements which might occur in aerial field use. Such motion arises from wind, from vibration induced in poles and cable by vehicular traffic, and other sources. In a few minutes the attenuation figure degraded from greater than the 145 dB sensitivity limit to the region of 90-125 dB intermittently. Where possible, tightening the connector nut restored the combination to an attenuation beyond the limit of measurement, following which the process could be repeated. This phenomenon is illustrated even more rapidly and dramatically by performing similar tests relying solely on the clamping mechanism, machining away all the areas of chance contact which normally exist in a connector, as shown in Fig. 5. Similar tests were made with many different connectors with the same results. Those with short clamping ferrules became intermittent rapidly; those with long ferrules took longer to fail.



FLEXING TEST WITH MODIFIED VSF 500D CONNECTORS

These tests would seem to indicate that shielding degradation is largely due to mechanical phenomena which gradually diminish contact pressure and vital contact areas between clamp and cable OD. Creep may well contribute to further degradation of the interface but the drastic ingress noted at field locations where there is high ambient signal strength is more likely caused by the mechanism described.

Similar tests were run using the internal sleeve support. No measurable leakage was observed (i.e. no less than 145 dB shielding) when applying lateral forces to the cable, unless the clamp exerted insufficient pressure to force the cable sheath ID against the sleeve. This would seem to confirm that the primary cause for OD clamp loosening and consequent shielding deterioration is minute, incremental mechanical deformation, and that the internal sleeve helps to prevent it. Fig. 6 shows the assumed contact mechanism prevailing with and without internal support sleeves. Creep is considered to be a secondary effect.



4. INTERFACE RESISTANCE MEASUREMENTS

The actual interface resistance is certain to bear some relationship to RF shielding capability. For example, connectors deliberately hard anodized .001" thick showed very poor shielding (70 dB), as would be expected. This is entirely understandable since large areas of the contact mechanism were virtually insulated. However, there is always some thickness of oxide film on aluminum surfaces. Ragnar Holm cited films 20A thick forming in a few seconds after scraping an aluminum surface.(1) Typical film thickness is given as 50-100A.(2) Contacts having films such as adherent oxides often show markedly erratic behavior, depending on the contact pressure and the applied voltage.(3) Oxide films on aluminum surfaces are omnipresent, tenacious and brittle. Low resistance contacts are made by rupturing the oxide film by shear and tensile forces.(4) We may infer with some certainty that between the extremes represented by the freshly scraped surface and the anodized film cited above, there is an oxide film thickness range which will materially affect contact resistance and shielding effectiveness.

Theoretically, the RF voltage measured across a single leaky interface is that which is developed by current flow across the impedance of that discontinuity. For example, assume that a very high intensity field causes a current of 0.1 amp to flow along the sheath. To limit the magnitude of the leakage signal within the cable to -40 dBmV, or .01 mV, the contact impedance of the joint would have to be less than 100 micro-ohms. Evidently we are looking for very low resistance contacts if we are to maintain low RF leakage paths.

In addition to the normal oxide films, the outside surface of the cable sheath is often stained, discolored and dirty. It is of interest to study the overall effect of all these films on the aluminum cable-connector joint. This was done by measuring D.C. contact resistance for various conditions of surface preparation.

Precise measurements were made using a Kelvin bridge with voltage probes 2" apart on a variety of 1/2" diameter cables with Jerrold VSF-500D and other connectors. Samples were aged outside, hanging from strand in dummy housings. Before each measurement, samples were brought inside and allowed to reach room temperature equilibrium for 24 hours. Typical test set-up is shown in Fig.7. Measurements include the contact resistance and that of 2" of cable plus connector.

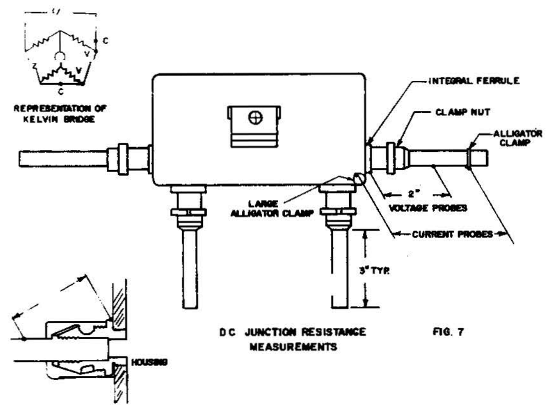


Fig. 8 shows the measured DC resistance of four 1/2" cable-VSF-500D connectors as a function of time. Note the average resistance as installed is about 50 micro-ohms. Resistance of three samples remained nearly constant after 3000 hours outdoor exposure while the fourth rose appreciably after 200 hours and reached 230 micro-ohms at 3000 hours.

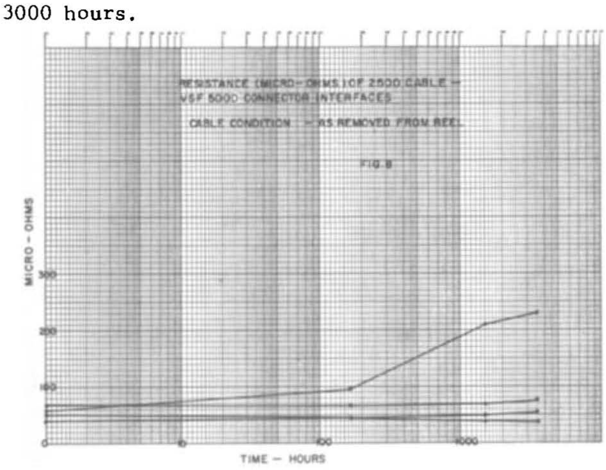


Fig. 9 shows resistances measured on five samples having the cable outer surface polished with steel wool prior to assembly. Initial readings varied from 40 to 130 micro-ohms (average 97). In four cases the resistance increased slightly, averaging 122 after 3500 hours. The fifth sample increased resistance from 55 to 130 in 500 hours and thereafter increased quite rapidly to 800 micro-ohms in 2000 hours. No obvious explanation was found for this erratic behavior. Disassembly of the connector showed the usual clamp indentations uniformly distributed around the circumference.

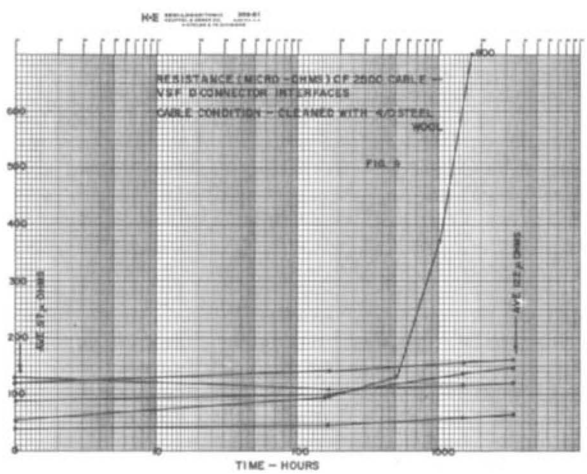


Fig. 10 shows the resistance of four samples having the cables polished as above, but also coated before assembly with a viscous silicone grease. Initial resistance averaged 105 micro-ohms, increasing to 174 after 3000 hours.

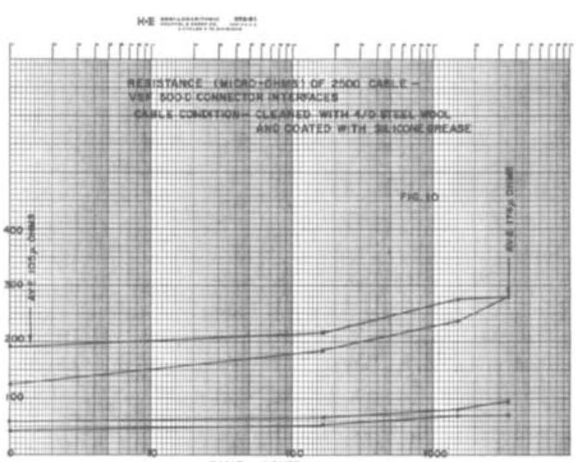
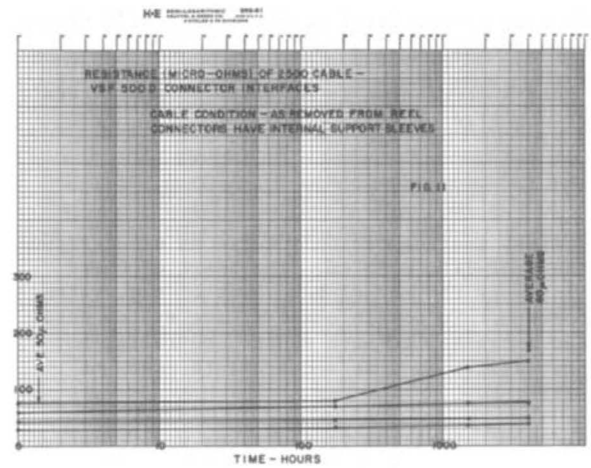


Fig. 11 shows the same test as in Fig. 8, but using internal sleeves. Average of four samples was 50 micro-ohms at the start, 80 after 3000 hours. Naybour and Farrell have demonstrated similar increases in resistance as a function of time when two smooth aluminum surfaces are compression loaded against each other.[5]



Similar tests were made using a connector with a heavy (yellow-green) chromate film; initial resistance was 200 micro-ohms, rising to 580 after 3000 hours. One connector was black anodized; initial reading showed a surprisingly low resistance of 600 micro-ohms. Microscopic examination showed fractured areas of the oxide film resulting from the clamping pressure, but the oxide particles had become embedded in the cable jacket.

One additional test was made following the procedure previously outlined showing how mechanical manipulation of the cable reduces shielding. As installed, with no internal sleeve, cable-connector resistance was measured at 89 micro-ohms. Periodic readings were taken at intervals during the flexing: 148, 144, 243, 299, 230, 121, 201 micro-ohms.

Visual examination of samples (other than the black anodized part) which exhibited definite increase in resistivity as a function of time showed no obvious oxide film formation or anything else significantly different from the more stable samples, within the limits of the optical inspection tools available. The data can be explained only by two mechanisms: (a) gradual reduction of contact pressure through creep reduces activated surface areas which constitute the available paths for current flow, (b) oxide films at contact areas are increasing in thickness thus increasing the contact resistance.

A comprehensive analysis of the chemical and physical phenomena underlying these experiments are beyond the scope of this paper. However, we may draw some tentative conclusions:

1) For 1/2" cable, the cable-connector interface D.C. resistance is typically less than 200 micro-ohms, as installed.

2) There is a tendency for the resistance to increase with time. For some assemblies the increase is abnormally great even though the initial resistance was no greater than in any other sample.

3) Cleaned and polished cable surfaces and protection by grease films do not necessarily prevent this increase.

4) Once a connection is minutely loosened, resistance may rise sharply.

5. SYSTEM TESTING OF CABLES-CONNECTORS-TAPS

Laboratory testing can only serve as a background to the real-life problem. The heart of these questions is the actual behaviour of the system components. To obtain quantitative system data it was necessary to have controlled radiation, an entire passive system, and accurate means of measurement.

Three 1200' simulated feeder lines were constructed on our laboratory property, as shown in Fig. 12, each having 18 Jerrold PBB-20 taps, VSF-500D connectors, and Times 2500 cable. All taps were equipped with RF gaskets, and had terminated tap ports. 8' ground rods were driven at each tap location, but no grounds were connected. One end of each line was terminated and the other introduced into the lab for monitoring purposes. The main test method was as follows: a three watt calibrated C.B. transmitter operating at 26.965 MHz, equipped with a tuned dipole antenna was mounted in a vehicle and moved parallel to the cable along its entire length at a 10' distance and at a velocity of approximately 400' per minute. Every time a pole location was passed, transmission was momentarily shut off. One of the three cables was connected to the input of a spectrum analyzer set at 10 kHz band width, and the output of the analyzer was fed into a strip chart recorder, thus obtaining a permanent record of all tests, including tap locations and measured signal ingress.

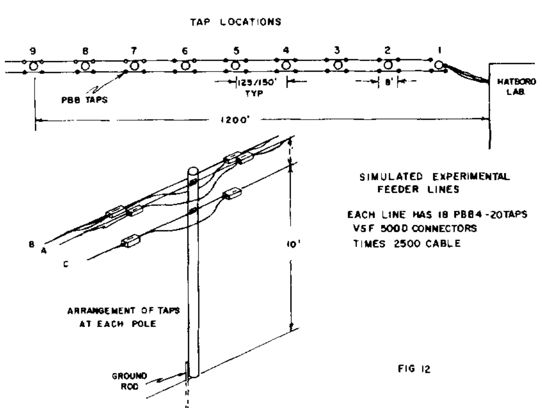
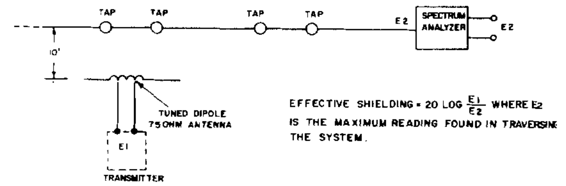


FIG 12

Before presenting data obtained in field system testing, it is necessary to define some measurement terminology which will be used in this discussion. Fig. 13 shows the system schematically. It is considered as a "two port" device, knowing with some certainty only the energy levels obtained at the terminals, and knowing little about radiation patterns or the radiating antenna field.

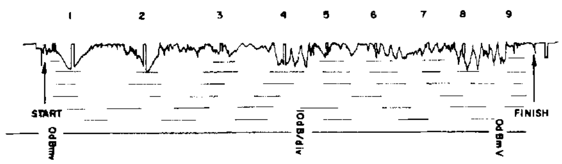


THE SYSTEM AS A "TWO PORT" DEVICE

FIG 13

We shall define "effective shielding" as the dB difference between the signal level at the dipole 10' from the cable, and the resulting signal level obtained in the cable system, for a given frequency of transmission. With the apparatus used the signal level at the dipole terminals was +82 dBmV as derived from 2.1 watts actually fed into a 75 ohm antenna. The effective shielding number is always recorded as the worst reading obtained on a system traverse. Therefore, it is numerically equal to 82 minus the maximum signal level found in the cable. We recognize the possible errors inherent in generalizing such an approach to signal ingress measurements; the presence of multiple cables, and proximate telco and power lines will undoubtedly influence the field intensity in a typical CATV cable system; terrain, moisture, and signal polarization may all affect readings. In these experiments the only variables were climatic conditions and time; the signal levels obtained certainly measure the R.F. integrity of the various arrangements tested.

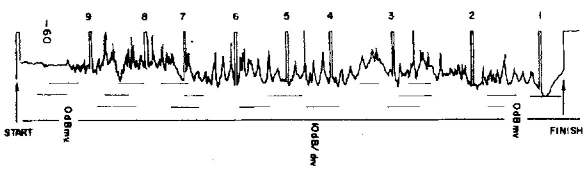
The first set of tests involved two cables. Cable A had internal support sleeves with connectors at locations 2, 4, 6, and 8 only, while cable C had no support sleeves at any location. We hoped to show differences in effective shielding that might occur where internal sleeves were used. Fig. 14 shows the record of ingress into cable A two weeks after installation. The worst reading on the spectrum analyzer was -50 dBmV at location 2, or an effective shielding (E.S.) of 132 dB. Fig. 15 shows the behavior of cable C similarly after two weeks. Note that the readings are definitely worse than in A. Fig. 16 shows the E.S. of both cables as a function of time, for the first seven weeks. Note the gradual deterioration, which is worse with cable C. Fig. 17 shows cable A after 4 weeks. Even though the E.S. has dropped 7 dB, it is not possible to tell any difference in shielding between taps having connectors with internal sleeves and those without, since standing waves completely confuse the issue.



CABLE A

TWO WEEKS AFTER INSTALLATION CONNECTORS HAVE INTERNAL SUPPORT SLEEVES AT LOCATIONS 2, 4, 6, 8

FIG. 14



CABLE C

TWO WEEKS AFTER INSTALLATION NO INTERNAL SLEEVES

FIG. 15

EFFECTIVE SHIELDING IN FEEDER LINES
18 P884 - 20 TAPS, 2500 CABLE, VSF 500D CONNECTORS

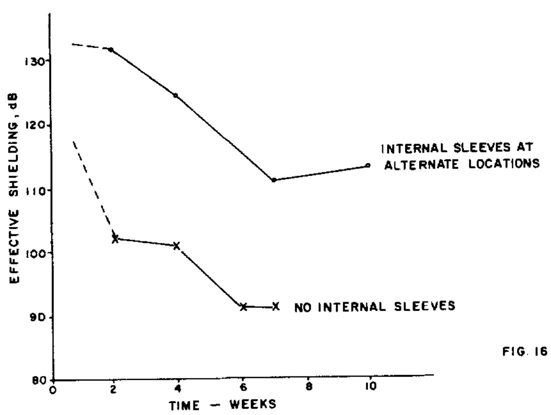
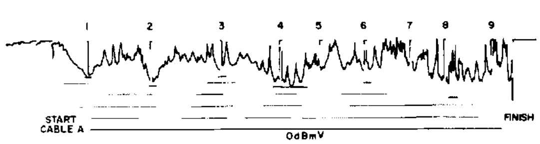


FIG. 16



CABLE A — FOUR WEEKS AFTER INSTALLATION CONNECTORS HAVE INTERNAL SUPPORT SLEEVES AT LOCATIONS 2,4,6,8. NOTE WORST READING AT LOCATION 4 STANDING WAVES OBSCURE "GOOD" AND "BAD" LOCATIONS.

FIG. 17

Fig. 18 shows a running record of cable C. After 8 weeks an experiment was conducted to see if the leakage was actually at the cable-connector interfaces. All 36 were tightly wrapped with steel wool. Note about 30 dB improvement. The following day the steel wool was removed, dropping the E.S. but only to 105 dB. Apparently the movement of the cable during the steel wool wrapping and unwrapping operation markedly improved some contacts in the relatively unstable connector-cable interfaces.

When the feeder lines were installed, no grounds had been connected at any tap location. Fig. 18 also shows the effect of attaching, then disconnecting grounds; no logical conclusion can be drawn since the instability of the connections is overriding.

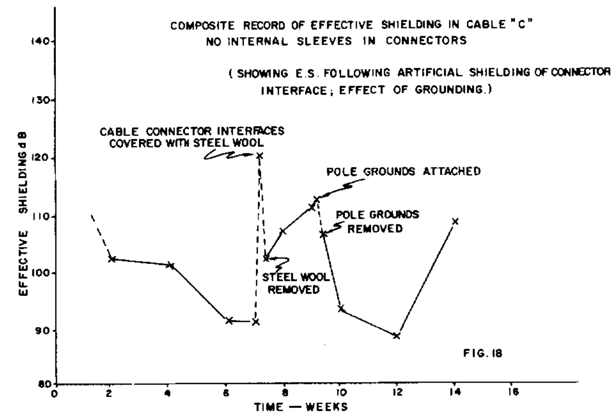


FIG. 18

Cable A was then modified to have all VSF connectors equipped with internal sleeves. Fig. 19 shows the E.S. value over a period of 18 weeks. Note the comparative stability although a degradation of 14 dB was observed. There is a strong inference that the internal sleeve, while providing significant improvement, may not eliminate the tendency for the vital cable-connector interface to deteriorate. Further long-term field testing is being conducted to ascertain the extent of this instability.

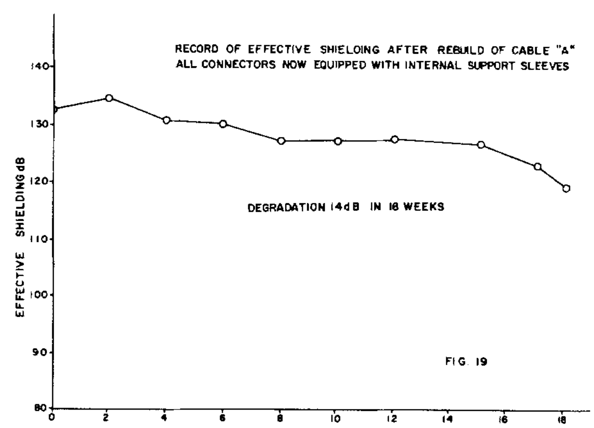


FIG. 19

We have referred to the systems here as "two port" devices. This says that the transmission loss between the cable terminal and the terminal of the test antenna is the same in either direction. Therefore, "effective shielding" is the same for signals radiating from the system or into it. This was easily verified by experiment using the antenna employed in our system measurements. Readings agreed to 2 dB at the 100 E.S. level. An additional test was made at 73.5 MHz introducing a +80 dBmV signal into the cable and using another tuned dipole 10' from the cable with a sensitive 5 kHz bandwidth receiver.

Receiving Antenna at Tap Location	Effective Shielding, dB	
1	128 at 26.965 MHz	129 at 73.5 MHz
2	128	125

The close correlation of results would indicate that the test method is not reflecting any special circumstances at the lower frequency.

6. AN IMPROVED CONCEPT OF CABLE-CONNECTOR INTERFACE

System tests have shown that the internal support sleeve minimizes but may not necessarily eliminate slow degradation of the cable-connector interface. Similarly, tests have indicated gradual increase of junction resistance with time, even with the use of internal sleeves, and that the condition of the cable sheath outside surface may be a factor in the joint resistivity.

These considerations led to the logical conclusion that the support sleeve should be integral with the connector, and that the sheath connection should be made to the inner rather than the outer surface. The advantages of an integral sleeve are manifold. The installer cannot omit it for any reason, since it is no longer a loose part. Current is carried on the inner surface of the sheath and transferred through intimate contact with the sleeve which is now electrically in series with the cable and the housing. The O.D. clamp serves only to secure the connection but not necessarily as a current carrying contact.

Fig. 20 shows the cross section of such a design. The steel sleeve is knurled at both ends. One end serves to make a splined fit with the I.D. of the connector barrel. the other end makes an intimate contact with the inner surface of the cable sheath when it is uniformly squeezed on the sleeve. The slotted fingers are embodied on a captive member which is counterbored at the back to accept an "O" ring for sealing the cable. It is essential to provide true radial squeezing of the cable sheath on the sleeve. Fig. 21 shows a typical portion of the inner surface of the cable jacket after installation. Note the serrations caused by contact with the sleeve knurl.

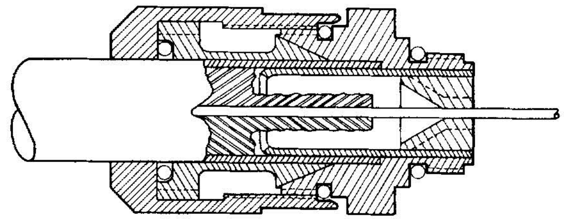


FIG. 20
CONNECTOR HAVING INTEGRAL INTERNAL SLEEVE

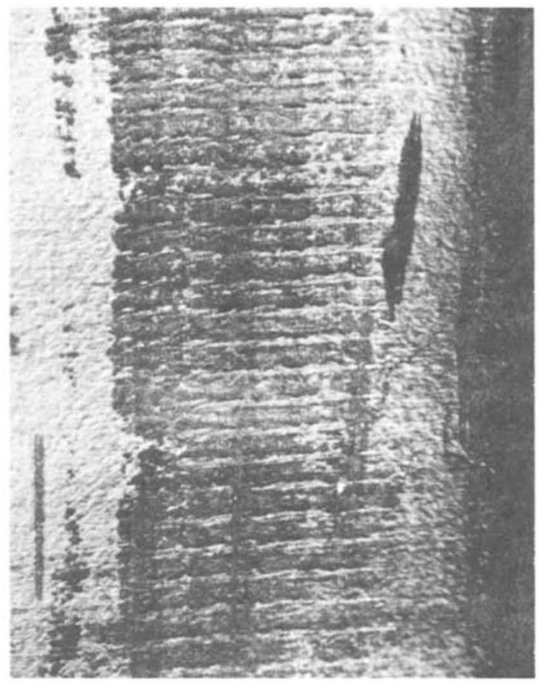
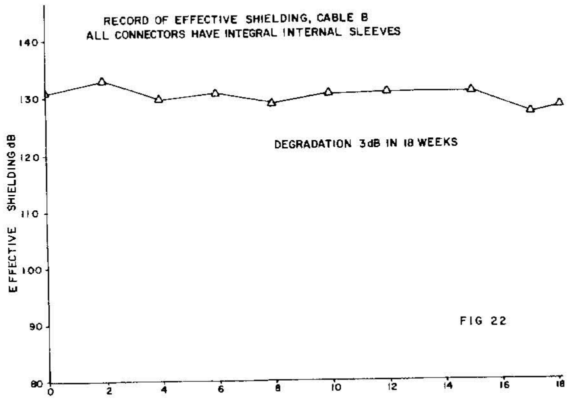
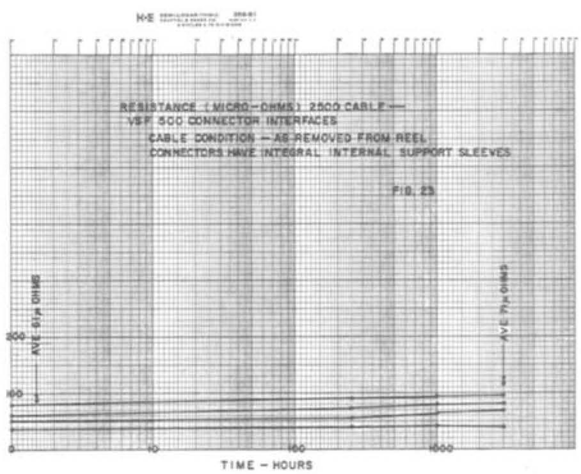


Fig. 21 Typical Contact Inside Cable Sheath After Squeezing on Integral Sleeve

This type of connector passed all R.F. laboratory tests with flying colors. An outside test was run with a feeder line equipped with connectors having integral sleeves in all 18 tap locations. Fig. 22 shows the variation of effective shielding over an 18 week period. Results indicate greater stability of the cable-connector interface; previous test results with connectors having separately installed sleeves are included for comparison. The variation of D.C. resistance with time is shown in Fig. 23. As installed the average resistance of four samples was 61 micro-ohms; after 3000 hours, average rose to 71. These samples show the least rise with time of any combinations tested.





In summary, the integral support sleeve makes and maintains contact with the inner surface of the sheath where all R.F. current flows. The benefits of this approach are revealed in the highest degree of connector-cable interface stability. The integral sleeve design would seem to have considerable merit as a step toward providing the CATV industry with connectors of superior reliability, with consequent minimizing of R.F. leakage problems.

7. CONCLUSION

The ideas presented here have been focussed almost exclusively on the critical cable-connector junction. Experimental evidence seems to show that this is, indeed, a most significant factor in system shielding. However, all of the interfaces as defined in our introduction must be carefully considered, since for maximum shielding capability no R.F. leakage path may be left to chance. Study of each part of the problem will inevitably lead to the most effective and least costly answers.

The author is indebted to Keneth Simons who devised the R.F. test methods, to Richard Kreeger and Donald Rogers for valuable assistance, and to Harry Reichert and Ronald Palmer for painstaking technical services.

REFERENCES

1. Holm, "Electric Contacts Handbook" 3rd ed.p114

2. Binger, Hollingsworth & Sprowls "Resistance to Corrosion and Stress", "Aluminum", Vol 1, p209 seq. Am. Soc. for Metals 1967.

3. Wagar, "The Making of a Good Contact", Bell Labs Record, July 1968.

4. Holm, op. cit. pp27-31 and pp158-159

5. Naybour & Farrell, "Connectors for Aluminum Cables: A Study of the Degradation Mechanisms and Design Criteria for Reliable Connectors", IEEE Transactions, March '73, Vol. PHP-9,No.1

APPENDIX A

The term "effective shielding" is defined in the text as the difference between the signal level, expressed in dB, at a transmitting dipole 10 feet from the cable and parallel to it, and the signal obtained at the output terminal of a cable system at a given frequency. Since theory indicates and tests show, within practical limits, that signal ingress and egress are caused by identical phenomena, we may extend the definition and calculate the equivalent effective shielding required to pass existing F.C.C. radiation specifications. These figures are shown for pertinent frequencies, assuming maximum signal level within the system is +48 dBmV. We postulate that the cable system is transmitting and that a dipole 10 feet from the cable is receiving.

Compare these figures with the shielding required under given conditions of signal ingress. For example: Assume signal ingress must be 50 dB below the typical minimum level in a trunk line (+10 dBmV). Further assume a 3 watt transmitter to be located 10' from the cable. Three watts into 75 ohms impedance, expressed as dBmV is +83.5. Offending signal must be -40 dBmV max. in the cable. The effective shielding required would be 83.5-(-40) or 123.5 dB.

APPENDIX A

FCC RADIATION LIMITS EXPRESSED AS "EFFECTIVE SHIELDING"

Present FCC specification:

0-54 MHz	15uv/m @100'
over 54-216	20uv/m @ 10'
over 216	15uv/m @100'

Signal received by a 75 ohm halfwave dipole in a field:

$$V = 48.3\ E/f^{(1)}$$

where V is microvolts

E is field intensity, microvolts per meter

f is freq. in MHz

Signal limits at 10' (assuming E is inversely proportional to distance)

Freq. MHz	Field uv/m	Level at Dipole output uv	dBmV	Effective Shielding Required* , dB
5	150	1450	+3.2	45
30	150	240	-12.4	60
54	20	18	-35	83
216	20	4.4	-47	95
300	150	24	-32.4	80

*Assuming max. signal in cable is +48dBmV.

These values are found by taking the difference between the dipole output level and the given maximum level inside the system. These numbers are the effective shielding required to comply with FCC requirements.

(1) Simons, "Technical Handbook for CATV Systems" 3rd Ed. p. 103.