ANALYSIS AND MEASUREMENT OF CATV DROP CABLE RF LEAKAGE

KENNETH L. SMITH

TIMES WIRE AND CABLE
WALLINGFORD, CONNECTICUT

ABSTRACT

The coupling of electromagnetic fields through CATV drop cables can be measured using a Radiometer. The theoretical analysis of this coupling, which began in 1934, is reviewed and the measurements agree with the predictions. Accordingly engineers can theoretically analyze and design coaxial cables. The measurements show that the different types of drop cables in use result in a large variation in coupling. The flexure measurements show that some cables would be expected to have 10 times longer flexure life than other types.

INTRODUCTION

The theoretical development of electromagnetic field coupling through the shields of coaxial cable began many years ago. The general theory was presented in an article by Schelkunoff in 1934 (1). He represented the coupling by a transfer impedance and developed formulae for calculating the characteristics of solid shields. He also analyzed multiple-layer shields. Since 1934 numerous people have analyzed the coupling mechanisms and methods of measuring the coupling.

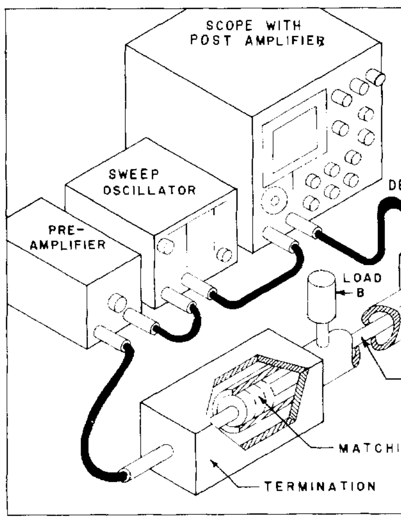
This paper will reference the following: Vance's article (2) presented in 1975, which develops the transfer impedance and transfer admittance of braided-wire shields based on the theory of coupling through electrically small-irises developed by Kaden (3) and Marcuvitz (4). In 1974 the International Electrotechnical Commission's Working Group 1 (Screening Efficiency) accepted a United Kingdom proposal presented by Fowler (5), to express the transfer admittance by a capacitive impedance quantity which the IEC called "Capacitive Coupling Impedance". At the Aneheim, California, NCTA Convention in 1973 Ken Simons gave a presentation titled "A Shielding Effectiveness Measuring Jig for CATV Cables". He also presented a paper (6) to the IEC sub-committee 46A (Radio-Frequency Cables) titled "The Terminated Triaxial Test Fixture". Ken describes a test fixture and test method for measuring transfer impedance and capacitive coupling impedance. Ken's work was an extension of Zorzy's work (7) presented in 1961. Early work was performed on this triaxial test method by Ochem in 1936 and is described in an historical summary by Bourseau and Sandjivy (8). In 1978 Times Wire and Cable developed and started marketing an instrument called a Radiometer for measuring the transfer impedance and capacitive coupling impedance which uses the triaxial test method.

The purpose of this paper is to show the transfer impedance and capacitive coupling impedance of different types of CATV drop cables. The theory of electromagnetic field coupling and method of measurement will be reviewed. The measurement data on different types of drop cables will be given and the change resulting from flexure of the cable will be shown.

MEASUREMENT

The Radiometer measures the absolute value of the transfer impedance and capacitive coupling impedance of the coaxial shield.

An artist sketch of the test set-up is given in Figure 1. The coaxial cable is coaxially supported by a dielectric in the test chamber creating a triaxial transmission system. The inner coaxial transmission system is inside the test specimen. The outer coaxial transmission system's center conductor is the specimen's shield and its outer conductor is the test chamber. The specimen is terminated in its characteristic impedance by load A and the combination of the sweep oscillator and preamplifier. Load B and the detector are



TEST EQUIPMENT ARRANGEMENT FIGURE 1

connected to the outer system by coaxial terminals. The rectangular termination on the ends of the chamber have ferrite toroids surrounding the test sample. These toroids minimize current flow along the shield of the test specimen to the end of the rectangular termination where the shield of the specimen is grounded. These rectangular terminations form "baluns" creating a high impedance allowing the load B and detector to match the impedance of the chamber. Errors are not introduced by leaky connectors; the shield of the specimen is unbroken through the entire length of the fixture. The connectors on the sample are connected to the ends of the rectangular terminations and are not critical since the "baluns" isolate the connector's leakage from the signal in the test chamber.

When the equipment is set up as shown in Figure 1, an analysis, neglecting attenuation and assuming the cable shield is uniform, shows that the magnitude of the output voltage in the triaxial transmission system is:

$$|V_f| = \left| \frac{(Z_t - Z_f)\, V_i \, \text{Sin}\,[(\beta_s - \beta_c)\, L/2]}{Z_s\,(\beta_s - \beta_c)} \right|$$

Where V_f = The detector voltage with set up of Figure 1
V_i = The specimen input voltage
Z_t = The transfer impedance in ohms per meter
Z_f = The capacitive coupling impedance in ohms per meter
L = The distance between the coaxial terminals of the test chamber in meters
Z_s = The specimen characteristic impedance in ohms
β_s = The specimen phase constant in radians per meter
β_c = The test chamber phase constant in radians per meter

An analysis of the output voltage with Load B and detector exchanged shows:

$$|V_R| = \left| \frac{(Z_t + Z_f)\, V_i \, \text{Sin}\,[(\beta_s + \beta_c)\, L/2]}{Z_s\,(\beta_s + \beta_c)} \right|$$

Where V_R = The detector voltage with Load B and detector swapped

Z_t and Z_f may be calculated, since the ratios V_f/V_i, V_R/V_i, β_s, β_c, L, and Z_s can be measured. The test procedure provided with the Radiometer includes tables which can be used to convert the voltage ratios measured in decibels to transfer impedance and capacitive coupling impedance. The minimal specimen attentuation is neglected but the chamber attentuation is accounted for. The tables were obtained from the following equations:

$$Z_t = \frac{1}{L} \sqrt{Z_s Z_c} \left(\left|\frac{\phi}{\text{Sin}\,\phi}\right| e^x + \left|\frac{\theta}{\text{Sin}\,\theta}\right| e^y \right)$$

$$Z_f = \frac{1}{L} \sqrt{Z_s Z_c} \left(\left|\frac{\phi}{\text{Sin}\,\phi}\right| e^x - \left|\frac{\theta}{\text{Sin}\,\theta}\right| e^y \right)$$

Where Z_t = The transfer impedance in ohms per meter
Z_f = Capacitive coupling impedance in ohms per meter
Z_s = The specimen characteristic impedance in ohms
L = Chamber length in meters
$\phi = (\beta_s + \beta_c)\, L/2$ in Radians
$\theta = (\beta_s - \beta_c)\, L/2$ in Radians
Z_c = The chamber characteristic impedance in ohms
β_s = Specimen phase constant in radians per meter
β_c = Chamber phase constant in radians per meter

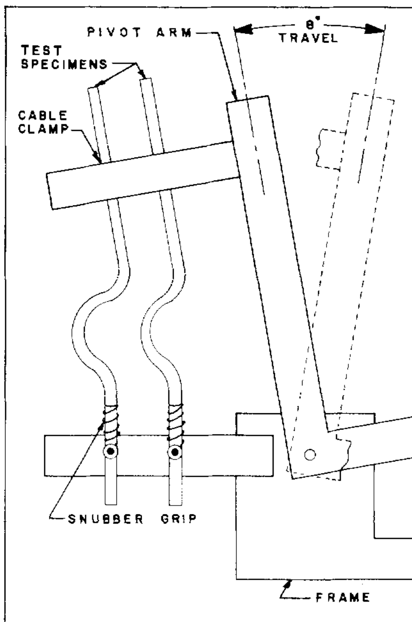
$$x = \frac{DB_R - \alpha_c/2}{8.68} = \ln V_R/V_i$$

$$y = \frac{DB_F - \alpha_c/2}{8.68} = \ln V_F/V_i$$

α_c = Chamber attentuation
Note: X, Y, DB_R, DB_F and α_c are negative quantities.

TEST RESULTS

The transfer impedance and capacitive coupling impedance of the shields can degrade in service as a result of flexure. A test similar to the following is commonly performed, throughout the industry, to evaluate the flexure characteristics: Initial transfer impedance and capacitive coupling impedance is measured. Then the samples are wrapped 360 degrees around a mandrel whose diameter is five (5) times the outer diameter of the cable. The two ends of the specimen are held while the mandrel is moved down the cable length then returned to the starting point. This flexure is repeated five times, then the cable is reverse bent 360 degrees around the mandrel and the flexure repeated. After this flexure it is found that the transfer characteristics from some cables which have a dry foil with a braid over it, increase 40 times. By contrast, a cable with sealed foil - 60% braid - foil - 40% braid shield shows a comparatively small change in transfer characteristics when subjected to the same test. In general, before flexure, the sealed foil constructions have higher transfer characteristics than dry foils. However, after flexure the sealed foils have lower transfer characteristics than dry foils.

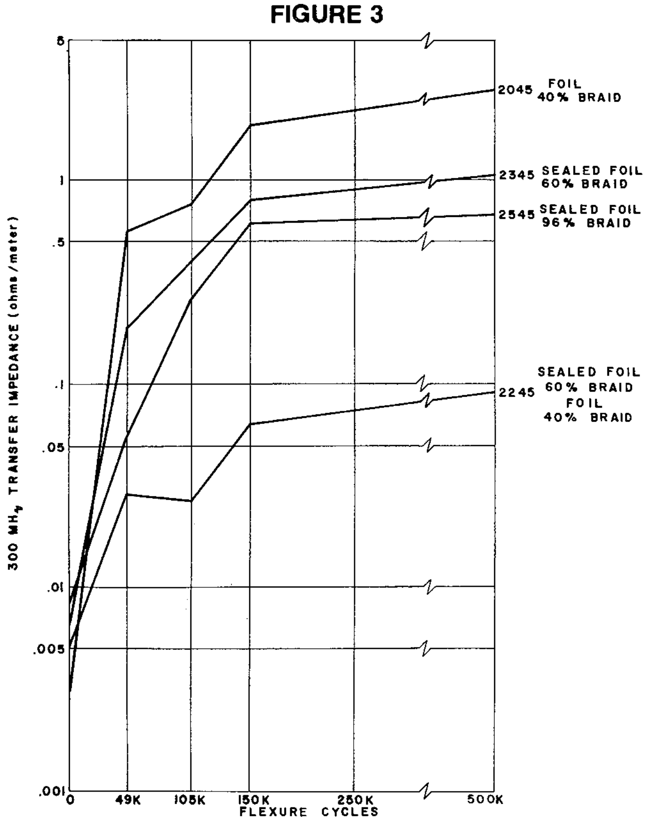


FLEXURE TEST EQUIPMENT FIGURE 2

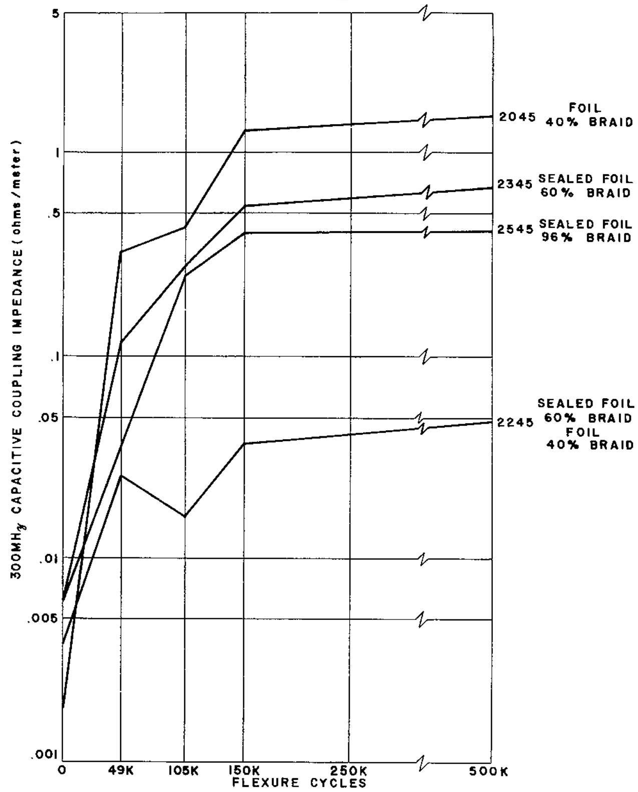
These flexure results are very meaningful but the flexure does not represent the flexure in service. New flexure data was taken using the equipment illustrated in Figure 2. The cables are flexed at a rate of 40 cycles per minute. One flexure cycle is plus and minus 8 degrees travel. The transfer characteristics were measured initially then after different flexure cycles. The highest increase in transfer characteristics occurred at 300 MHz, therefore, this data is plotted versus flexure cycles in Figures 3 and 4. Only limited data has been taken, one sample for each type cable shown. The data confirms that after flexure the sealed foils have lower transfer characteristics than dry foils. As would be expected, the sealed foil - 60% braid - foil - 40% braid type does eventually degrade but it has far longer life than the other constructions. It appears that the flexure life of this cable is 10 times that of all other cable types tested.

The average transfer impedance and capacitive coupling impedance test data, measured on random samples of cable manufactured by Times Wire and Cable, is plotted in Figures 5 thru 10. Except for Times Wire and Cable MI-2245, measurements have been performed to confirm that the cable performance is typical for the same type of cable manufactured in general by industry. To my knowledge Times Wire and Cable is the only company manufacturing a cable with the construction of MI-2245 which has a sealed foil - 60% braid - foil - 40% braid shield.

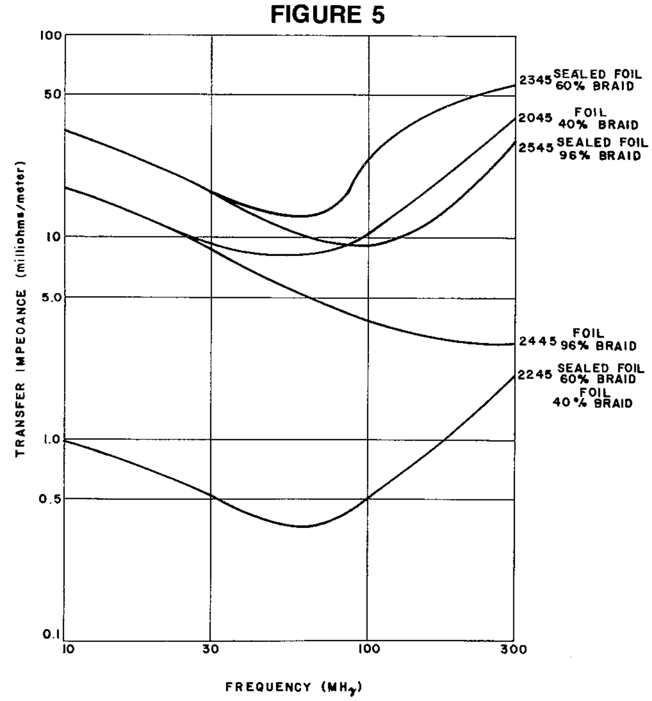
RG-59/U TYPE
300 MHz TRANSFER IMPEDANCE
VERSUS FLEXURE CYCLES
FIGURE 3



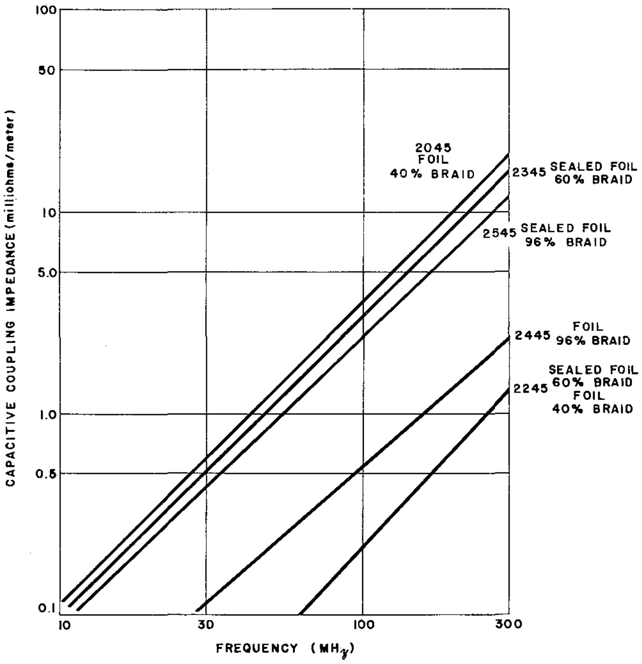
RG-59/U TYPE
300MHz CAPACITIVE COUPLING IMPEDANCE
VERSUS FLEXURE CYCLES
FIGURE 4



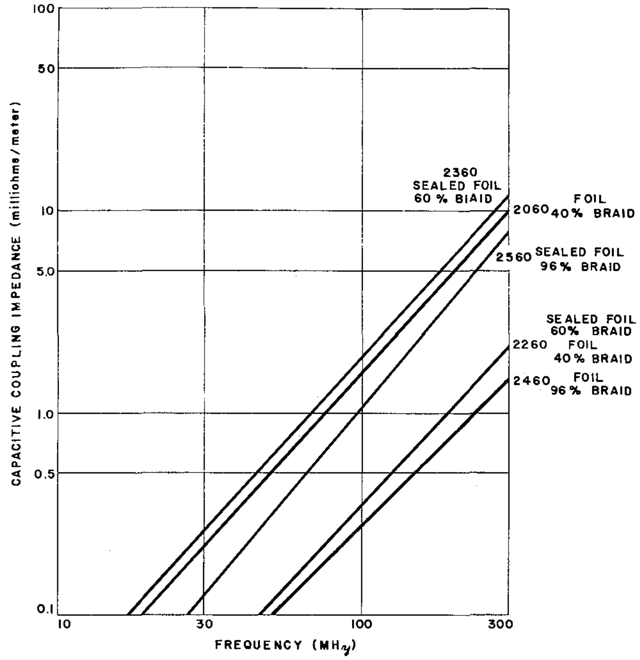
RG-59/U TYPE
TRANSFER IMPEDANCE
VERSUS FREQUENCY
FIGURE 5



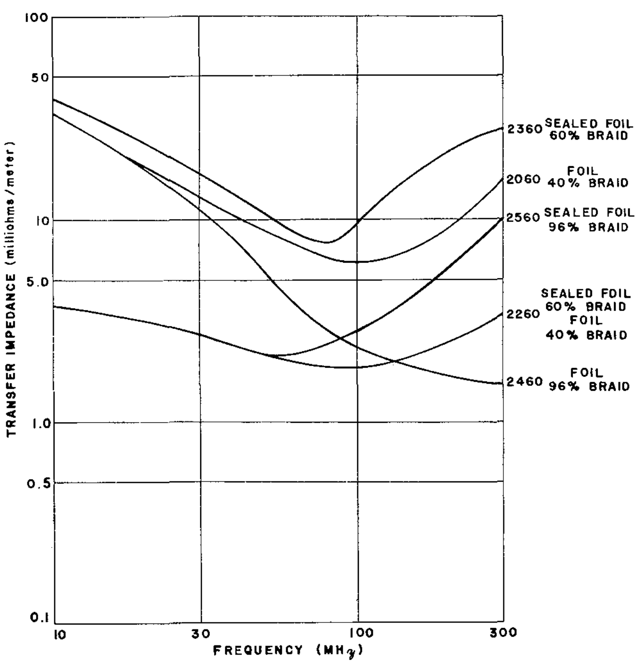
RG-59/U TYPE
CAPACITIVE COUPLING IMPEDANCE
VERSUS FREQUENCY
FIGURE 6



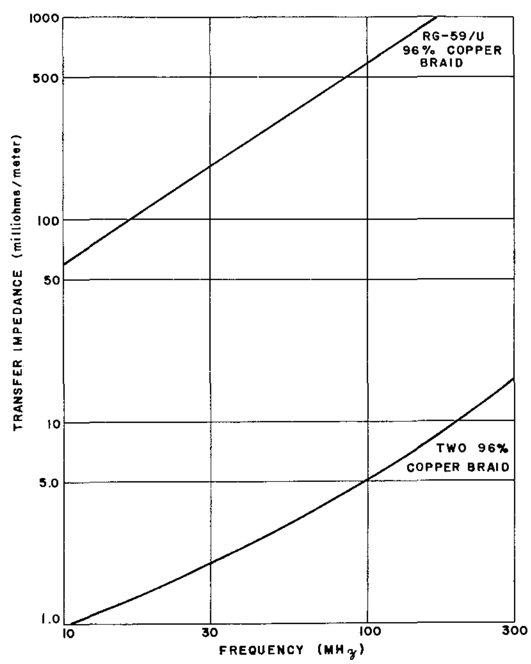
RG-6/U TYPE
CAPACITIVE COUPLING IMPEDANCE
VERSUS FREQUENCY
FIGURE 8



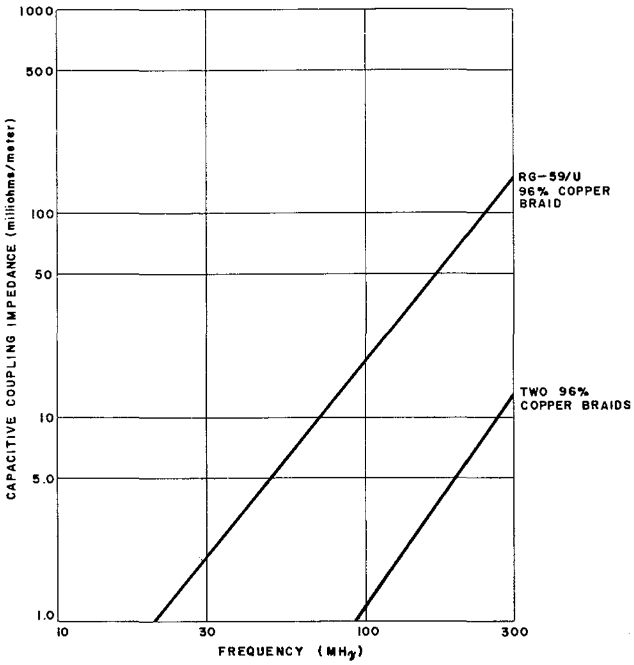
RG-6/U TYPE
TRANSFER IMPEDANCE
VERSUS FREQUENCY
FIGURE 7



BRAIDED SHIELDS
TRANSFER IMPEDANCE
VERSUS FREQUENCY
FIGURE 9



**BRAIDED SHIELDS
CAPACITIVE COUPLING IMPEDANCE
VERSUS FREQUENCY
FIGURE 10**



DISCUSSION AND ANALYSIS OF TRANSFER IMPEDANCE TEST RESULTS

Transfer impedance is defined in an elementary length of coaxial cable as the ratio of the potential gradient (voltage) in the disturbed circuit to the current flowing in the interfering circuit. When the cable is acting as a transmitting antenna (egressive signals) the disturbed circuit is the environment around the cable. When the cable is acting as a receiving antenna (ingressive signals) the disturbed circuit is within the cable and the interfering circuit is the environment around the cable. A lower transfer impedance reduces the electromagnetic coupling (radiation).

The transfer impedance of a braided shield has two components; a diffusion component caused by current diffusing through the metal and a mutual-coupling component caused by penetration of the magnetic field through the openings in the braid. The mutual-coupling component can be represented by a mutual inductance.

The transfer impedance is the vector sum of these two complex quantities and its magnitude is:

$$|Z_t| = \sqrt{(|Z_d| \cos\phi)^2 + (|Z_d| \sin\phi + |Z_m|)^2}$$

Where ϕ = .785 − $\tan^{-1}$ (coth d/δ Tan d/δ)
Z_d = The diffusion component of Z_t in ohms per meter
Z_m = The mutual-coupling component of Z_t in ohms per meter
d = The diameter of braid wire in meters
δ = The skin depth in meters

The approximate diffusion component and mutual-coupling component for braided cable is obtained from an extension of Vance's equation (2) and Schelkunoff's (1):

The diffusion component is:

$$|Z_d| = R_{dc} \frac{(\sqrt{2})\, d/\delta}{\sqrt{\sinh^2(d/\delta) + \sin^2(d/\delta)}}$$

$$\delta = \sqrt{\frac{\rho}{\pi f \mu'}}$$

The mutual coupling is:

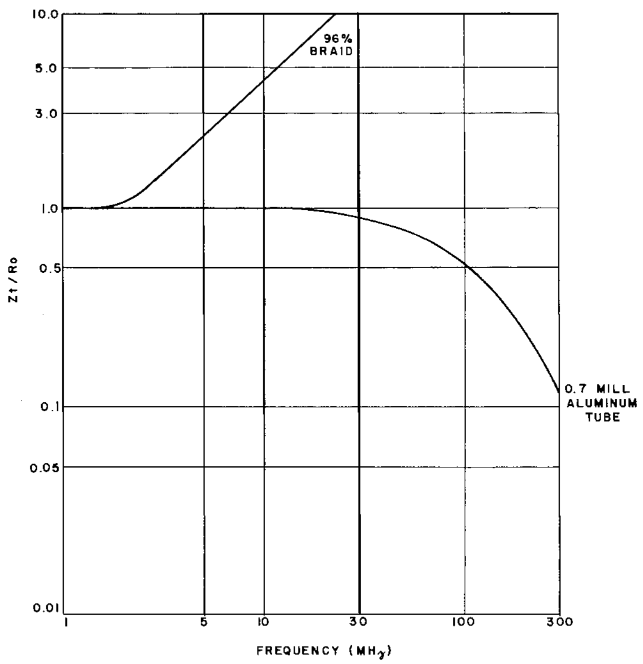
$$|Z_m| = \frac{\omega v \mu m}{\pi^2 D^2}$$

Where ρ = The resistivity of the shield in ohm-meters
f = The frequency in hertz
μ' = The absolute magnetic permeability of the shield in henries per meter
d = The diameter of braid wire in meters
R_{dc} = The dc resistance of the shield in ohms per meter
ω = The angular frequency in radians per second = $2\pi f$
v = The number of holes per meter in the braided shield
μ = The absolute magnetic permeability of the insulation between the conductors in henries per meter
D = The mean inside diameter of the shield in meters
m = The magnetic polarizability of the holes in the braid (2)
Z_m = Mutual-coupling component in ohms per meter
Z_d = Diffusion component in ohms per meter
δ = Skin depth in meters

The magnetic and electric polarizability of holes in a braid can be determined experimentally using electrolytic-tank techniques (7). Vance obtained the polarizability of the diamond-shaped hole by calculating the polarizability of an equivalent elliptical hole (2).

The only fields that transfer through solid shields are those that diffuse through the metal. The preceding equation for the diffusion component is the equation for the transfer impedance of solid shields when "d" is equal to the shield thickness. The theoretical transfer impedance divided by the dc resistance of braided and solid shields versus frequency is plotted in Figure 11.

COAXIAL CABLE
TRANSFER IMPEDANCE (Zt) DIVIDED BY SHIELD D.C. RESISTANCE (Ro) VERSUS FREQUENCY
FIGURE 11



Comparing the test data plotted in Figure 9 with the theoretical curves of Figure 11 shows the RG-59/U cable with a braided shield performed as predicted by the theory for a braid. The constructions of Figures 5 and 7 have shields which are layers of foils and braids. Since the foil completely surrounds the dielectric it might be expected that there would be no openings in the shield allowing mutual-coupling. Therefore, the cable would perform like a tube. The cables do show the tube characteristics except at the higher frequencies where the transfer impedance begins to increase. The cause of this increase is that there are openings at the foil overlap and some mutual-coupling does exist.

The test data presented is for foam polyethylene dielectrics, data on solid polyethylene dielectrics show somewhat lower transfer characteristics. This would be expected since the dielectric is harder and more pressure may be applied by the braid shorting out the overlap.

The sealed foil-60% braid-foil-40% braid construction has the lowest initial transfer characteristics as would be predicted, since the shield has a sealed foil on the dielectric then a dry foil sandwiched between two braids. The braid on both sides of the foil shorts out the foil overlap far better than a braid on only one side. The large amount of metal in the shield results in low transfer characteristics at low frequency caused by low shield resistance and low diffusion of current through the shield. The sealed foil constructions have adhesive on the foil overlap; therefore it causes higher initial transfer characteristics than obtained with foils which have no adhesive.

Flexure causes an increase in the opening at the foil overlap and/or fractures the foil, increasing the mutual-coupling (transfer impedance). The sealed foil constructions adhere the foil to the dielectric and the foil to foil overlap, minimizing the flexure effect on the foil. Flexure has the least effect on the sealed foil-60% braid - foil - 40% braid construction due to the braid on both sides of the foil shorting out the opening at the tape overlap, and it also has two layers of foils and braids.

ANALYSIS OF CAPACITIVE COUPLING IMPEDANCE TEST RESULTS

The openings in the shield also allow the electric field to penetrate creating electric coupling. This coupling can be represented by a capacitive coupling between the center conductor of the coaxial cable and the return path external to the cable.

The capacitive coupling impedance is derived from the definition accepted by the International Electrotechnical Commission Working Group 1 (Screening Efficiency) (5) and Vance's equation for transfer admittance (2).

$$Z_f = \frac{p}{m} Z_m \sqrt{\epsilon_{re}/\epsilon_{ri}}$$

Where Z_f = The capacitive coupling impedance in ohms per meter
p = The electric polarizability of the holes in the braid (2)
m = The magnetic polarizability of the holes in the braid (2)
Z_m = The mutual-coupling component of Z_t in ohms per meter
ϵ_{re} = The relative dielectric constant of the insulation in the external circuit
ϵ_{ri} = The relative dielectric constant of the insulation within the cable

The capacitive coupling impedance will be zero if there are no openings in the shield. If there are openings, then the capacitive coupling impedance should vary directly with frequency. The test data plotted in Figures 6, 8 and 10 follows this characteristic reasonably well.

CONCLUSIONS

The transfer impedance and capacitive coupling impedance of coaxial shields can be measured and the results agree with the theoretical equations. Since the theory of transfer of energy through shields is known, an engineer can theoretically analyze and design coaxial cable.

The different types of drop cables in use today results in a large variation in the coupling of electromagnetic fields through the shields. The RG-59/U drop cable, with a 96% braid, has a transfer impedance at 300 MHz, 1000 times higher than a sealed foil - 60% braid - foil - 40% braid cable. It also has a capacitive coupling impedance at 300 MHz, 400 times higher. The sealed foil - 60% braid - foil - 40% braid cable was the only cable type tested that had a low 5 MHz transfer impedance (.001 ohm per meter), yet all constructions have negligible 5 MHz capacitive coupling impedance.

The type of cable to be used can not be chosen based only on cable performance before installed in a system. The performance after flexure must be considered; flexure life is a very important consideration. It appears that the flexure life of the sealed foil - 60% braid - foil - 40% braid is 10 times that of all other cable types tested.

REFERENCES

(1) S.A. Shelkunoff "The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields", Bell System Technical Journal, Volume 13, Oct. 1934.

(2) Edward F. Vance "Shielding Effectiveness of Braided Wire Shields", IEEE Transactions of Electromagnetic Compatibility, Vol. EMC-17, No. 2, May 1975.

(3) H. Kaden, "Wirbelstrome und Schirmung in der Nachrichtentechnik", Springer-Verlag, Berlin, 1959.

(4) N. Marcuvitz, "Waveguide Handbook", MIT Rad. Lab. Ser., Vol. 10, McGraw-Hill, New York, 1951.

(5) E.P. Fowler, "Observations on the use of Zt(c) for Comparing the Breakthrough Capacitance of Cable Braids", IEC paper SC46A/WG1 (Fowler) 3, Nov. 1973.

(6) Keneth A. Simons, "The Terminated Triaxial Test Fixture", IEC paper SC46A/WG1 (Simons) 2, Oct. 1973.

(7) John Zorzy, "RF Leakage Characteristics of Popular Coaxial Cables and Connectors, 500 MC to 7.5 GC", Microwave Journal, Nov. 1961.

(8) J. Bourseau and H. Sanjiviy, "Mesure de L'impedance de couplage et application a l'etude des ecrans", Cables et Transmission, 10 (1), p. 11, January 1956.