COMPARATIVE TESTING OF LEAKY COAXIAL CABLES BY USE OF A TWO-CABLE CAVITY RESONATOR

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ABSTRACT

This paper presents a two-cable resonant cavity test of leaky coaxial cables to determine coupling effectiveness. The laboratory test is repeatable and is done in a controlled electrical environment and is related to the growing interest in leaky coaxial cables for communications and obstacle detection.

Introduction

Leaky coaxial cables are based on modified forms of coaxial cable in which the outer conductor has a loosely woven braid or a continuous long slot or many small slots. These cables are used to provide continous access guided communication (CAGC) in mines, tunnels, and along transportation routes[1] and, more recently novel obstacle detection systems. The two-cable cavity resonator is in fact related to an experimental obstacle detection scheme (GUIDAR) sometimes referred to as Guided Radar, which uses two parallel leaky coaxial cables for continuous signal coupling[2].

A typical manufacturer's figure of merit is the cable's coupling loss. Often this datum is an averaged value representing the power difference between the in-cable signal and a signal received by a specified antenna at a specified distance from the cable. Unfortunately the coupling loss value is quite sensitive to the test environment.

This paper describes a repeatable laboratory test in a controlled environment capable of providing a relative measure of cable coupling effectiveness. The test facility can be described as a two-cable resonant cavity and is an extension of the well known single-line resonant cavity used to test open waveguide structures such as Goubau lines[3].

Resonant Cavity Test Facility

The two-cable cavity resonator is shown in Figure 1. It has two vertical, parallel, aluminum end-plates, each 1.8m × 1.8m., spaced approximately 5m. apart. Two lengths of leaky coaxial cable are placed spatially parallel between the end-plates. At each end-plate each cable is connected to a conventional feed-through, type N, coaxial connector. On one end of each cable a 50Ω conventional coaxial load is attached to the feed-through connector, external to the end-plate. On the other end of each cable is connected, outside the end-plate via ordinary RG-8 coaxial cables, a wattmeter and a VHF/UHF sweep generator, respectively.

The combined effects of the two metallic end-plates are confined to the space between them, and to that immediately around the cables. The arrangement is now suited for use in a laboratory with negligible interference from nearby objects inside the building.

It then becomes possible to deduce the coupling behaviour between two cables of a particular specified type and how it varies as functions of cable spacing and of frequency throughout the VHF and UHF bands.

Data Interpretation

For each pair of cables of a given type, the laboratory cavity test yields a characteristic 'signature' for the particular test spacing. An example is shown in Figure 2 for two type 'A' cables spaced 0.9m apart. The solid vertical lines indicate the cavity resonances spaced at intervals of about 29 MHz, corresponding to a relative phase velocity of 98% for the two-wire line formed by the outer conductors of the leaky coaxial cables. It is at once obvious that these resonances have amplitudes that vary according to an overall 'envelope' with minima approximately every 450 MHz. The shape of the envelope is strongly linked to the difference in phase velocity between that of the single, isolated, leaky cable and that of the two-wire line formed by the outer conductors of the two cables.

Figure 3 illustrates the markedly different behaviour of type 'B' cable having a higher-density foam dielectric. The resonance spacing is essentially as before being a function of the cavity length and not of the cable construction. The signature envelope shows a reduced minima interval of about 220 MHz. This is associated with a leaky cable phase velocity that is now not as close in value to that of the two-wire line.

In Figure 4, the envelope maxima for the cable 'C' signature are almost 20 dB down from those of both cable A and cable B. The dielectric of cable C is identical to cable B; thus the envelope cycle of 220 MHz is similar also.

All three cables discussed here are of a leaky cable construction using closely spaced periodic slots (spacing << wavelength) in the outer conductor. The slot size is identical for cables A and B with the apparent result that the envelope maxima values are similar for both signatures, and hence the cables have similar coupling behaviour. The slot size of cable C is smaller than that of the slots in cables A and B, and the coupled power signature shows reduced envelope maxima values.

Experimental confidence in the test method has been established by tests on 15 different types of cables many of which have also been tested in a full-size guided radar test[2].

Theoretical Overview

The transfer of energy between the cables in the cavity resonator theoretically can be analysed using a model of three coupled guiding systems. The coupling

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of energy among either leaky cable and the two-wire line formed by the outer conductors is fundamentally co-directional and can be represented by an extension of the usual odd and even mode concept.[4]

The total voltage on one of the coaxial lines in the cavity is:

Coax line (1):

$$E_1(z) = E_{11}^{+} e^{-j\beta_1 z} + E_{11}^{-} e^{+j\beta_1 z} + E_{12}^{+} e^{-j\beta_2 z}$$

$$+ E_{12}^{-} e^{+j\beta_2 z} + E_{13}^{+} e^{-j\beta_3 z} + E_{13}^{-} e^{+j\beta_3 z} \qquad (1)$$

with two similar equations for the two-wire line and the second coaxial cable,

where z = 0 to ℓ, distance along the cables in the cavity.

where E_{rs}^{+} & E_{rs}^{-} = s^{th} coupled mode voltage on the r^{th} line in the forward direction and reverse direction, respectively.

where $\beta_1, \beta_2, \beta_3$ = propagation coefficients for the three coupled modes.

The three propagation coefficients are the roots of the equation formed by taking the determinant of the matrix of the coupling coefficients derived from the usual eigenvalue relations.

The 18 unknown $E_{rs}^{\pm}$ quantities are deduced from 6 cavity boundary conditions and 12 eigenvalue conditions. In specifying these conditions line attenuation loss and cavity end-plate loss are included.

Figures 5 and 6 are plots based on the theoretical model of the two-cable cavity resonator. Figure 5 was derived from this model for the case of the type A cable with parameter values of phase velocity, characteristic impedance and attenuation chosen to yield a plot as nearly as possible identical to that observed experimentally. With the corresponding parameters from the experimental observation of the type B cable, the theoretical cable B signature was produced in Figure 6. As can be seen, it has been possible to obtain a high degree of similarity between Figures 2 and 5, and between Figures 3 and 6. The decline of the envelope magnitude with increasing frequency, as in Figure 3 compared to Figure 6, is probably related to the behaviour of the basic co-directional coupling coefficient. The model assumes a coefficient that varies linearly with frequency.

For insight, the cavity resonator can be analysed by use of a simplified model of two coupled guiding systems. In effect this corresponds to removing one of the coaxial lines from the cavity and introducing a metallic ground plane parallel to and beneath the cable. The coupling of energy can be represented by a transfer between the coaxial line and the two-wire line formed by the cable's outer conductor and its image in the ground plane.

The effective power reflection coefficient as seen in the coaxial line connected to the input port, can be expressed in the general form:

$$P_{RC1} = \frac{P_{C1}^{-}}{P_{C1}^{+}} = \frac{\text{Envelope Factor}}{\text{Cavity Resonance Factor}} \qquad (2)$$

When derived in detail for the loss free case this can be shown to be

$$P_{RC1} = \frac{4W^2 \sin^2(\beta_B \ell)}{2W^2+2\cos(\beta_B \ell)+(W^4-1)e^{-j2\beta_B \ell}-(1+W^2)^2 e^{j2\beta_A \ell}} \qquad (3)$$

where

$$\beta_A = \left(\frac{2\pi f}{V_{PC}} + \frac{2\pi f}{V_{PT}}\right) / 2 \quad ; \quad \beta_B = \sqrt{\left(\frac{\pi f}{C}\right)^2 \left(\frac{C}{V_{PT}} - \frac{C}{V_{PC}}\right)^2 + H^2} \, .$$

where

$$W = \left(\frac{2\pi f}{V_{PC}} + \frac{2\pi f}{V_{PT}}\right) / 2H + \sqrt{\left(\frac{\frac{\pi f}{V_{PC}} - \frac{\pi f}{V_{PT}}}{H}\right)^2 + 1} \, .$$

where ℓ = coupling or cavity length; f = frequency.

C = speed of light in air (3×10^8 m/sec.).

V_{PT} = $2\Delta f \ell$ m/sec - the two-wire line phase velocity where Δf is the frequency increment between cavity resonances.

V_{PC} = phase velocity inside the leaky cable (slightly perturbed) which can be found from the "envelope factor" above.

H = the basic co-directional coupling coefficient.

In comparing the cable signatures, the envelope maxima yield a first indication of the relative coupling effectiveness of the cable types.

Solution of the 18 × 18 matrix equation implied by equation (1) gives rise to similar, but very much more complicated, expressions for the relative power associated with the actual two-cable cavity test.

Conclusions

The two-cable resonant cavity test enables a coupled power cable signature to be obtained for each type of leaky cable. These signatures can then be compared to give an estimate of relative coupling effectiveness. The test is quick and repeatable and is conducted in a small space inside a laboratory.

Acknowledgements

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References

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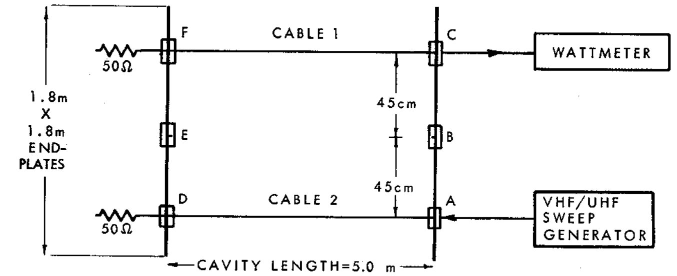

FIGURE 1: TWO-CABLE CAVITY RESONATOR.

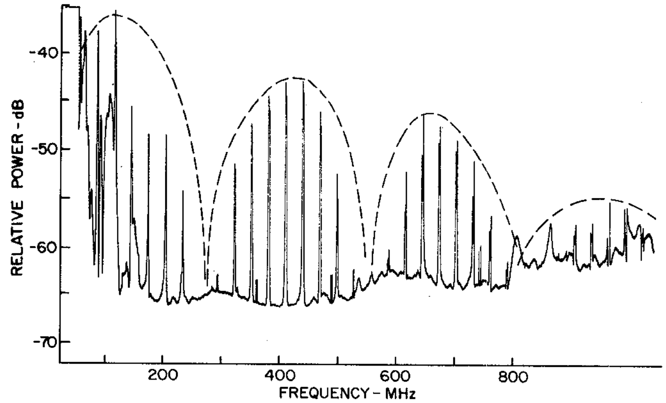

FIGURE 4: CABLE C TEST SIGNATURE
CABLES SPACING: 90 cm.

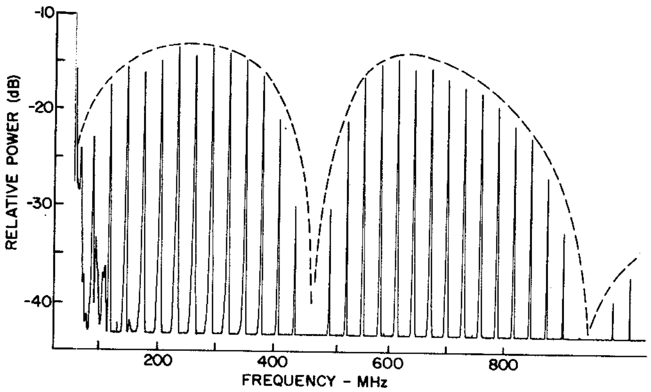

FIGURE 2: CABLE A TEST SIGNATURE
CABLES SPACING: 90 cm.

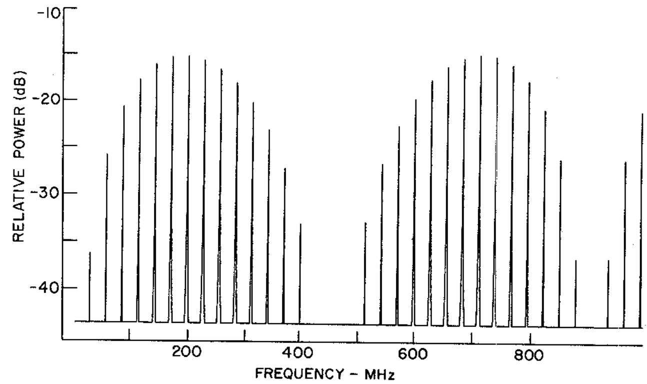

FIGURE 5: CABLE A THEORETICAL
SIGNATURE.

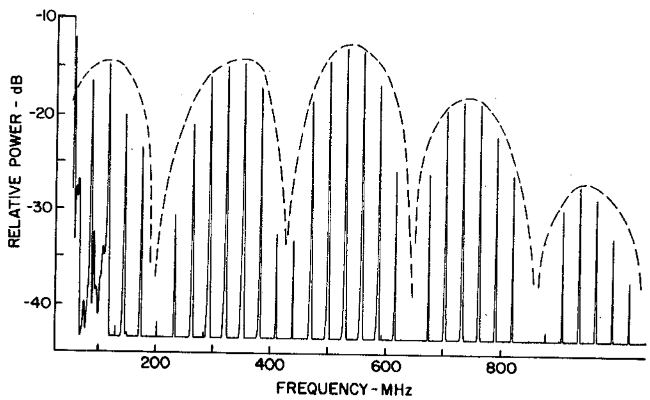

FIGURE 3: CABLE B TEST SIGNATURE
CABLES SPACING: 90 cm.

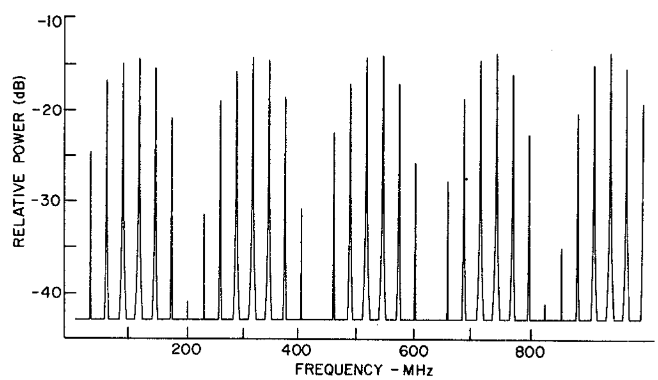

FIGURE 6: CABLE B THEORETICAL
SIGNATURE.