ward scattering, shadowing effects are also considered in this work.

It is shown that the phase $\phi^{i\gamma}(x)$ in (4.5) is stationary when the local angle of incidence $\theta^{i\gamma}=\theta^{i}-\gamma$ approaches the Brewster angle. However, at this angle, $F^{VV}(\theta_{0s},\theta_{0}^{i})\to 0$. Thus the major contributions to the scattered surface waves H_{s0} do not necessarily come for the neighborhood of the stationary phase points.

The full-wave approach presented here may also be used to determine the coupling of electromagnetic fields into and out of dielectric waveguides with irregular boundaries.

ACKNOWLEDGMENT

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Comparative Testing of Leaky Coaxial Cables for Communications and Guided Radar

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***Abstract*—Leaky coaxial cables are finding increasing use in communications systems involving mines, tunnels, railroads, and highways, and in new obstacle detection, or guided radar, schemes for ground transportation and perimeter surveillance. This paper describes the theory and operation of a new laboratory testing technique for these leaky cables based on a novel form of cavity resonator. The technique yields highly consistent and repeatable results that usefully assist in the prediction of the performance of full-size systems, from a simple test on a small sample of cable in a laboratory setting.**

I. INTRODUCTION

A. Leaky Coaxial Cables

LEAKY COAXIAL cables are generating increasing interest as a means of providing continuous-access guided communications (CAGC) in tunnels and mines, and in guided ground transportation systems [1]–[3]. Many different types are currently being marketed, or tested experimentally, and a selection is shown in Fig. 1, with the designations as used throughout this paper as described in Table I. Also included is conventional twin feeder, Fig. 1(g), to draw attention to the major characteristics shared by all the types illustrated. They are all open electromagnetic waveguides in which the signal energy is guided along a prescribed linear route, with the fields being confined both inside the cable and outside it, within its immediate vicinity, thus enabling signals to be coupled into immediately adjacent mobile communications units.

With the exception of the twin feeder, all these leaky cables are coaxial in form and include a partially open outer conductor.

In all these cases where periodic holes or slots occur, the spacing is very much less than a wavelength and all the cables illustrated act as slow-wave open guiding structures or surface waveguides [4].

B. Guided Radar

A vast amount of work on surface waveguides for railroad communications has been done in Japan and elsewhere over many years and some of the earlier work

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TABLE I
PHYSICAL DESCRIPTION OF LEAKY COAXIAL CABLES

Cable Family and Type	Nominal Characteristic Impedance - Ω	Approximate Outer Conductor diameter-mm	Approximate Outer Conductor Construction Refer to Figure 1 diagrams Dimensions - mm	
A1	50	13.8	Slot: 2.0 slots/cm, length = 6.5 width = 3	
A2	50	13.8	Slot: 2.0 slots/cm, length = 8 width = 3	
A3	50	13.8	Slot: 2.0 slots/cm, length = 12.5 width = 3	
B1	50	13.8	Slot: 2.0 slots/cm, length = 4. width = 2	Low density foam dielectric
B2	50	13.8	Slot: 2.0 slots/cm, length = 6.5 width = 3	
B3	50	13,8	Slot: 2.0 slots/cm, length = 8. width = 3.	
B4	50	13.8	Slot: 2.0 slots/cm, length = 12. width = 3	
C	50	13.7	0.5 holes/cm, hole diameter = 8.3	
D	50	7.8	optical cover = 66%	
*F1	50	7.8	slit width = 9.3, 6 strands, axial separation of strands = 4.2	
*H2	50	13.3	slit width = 12	

* Other types of F and H cables have been tested.

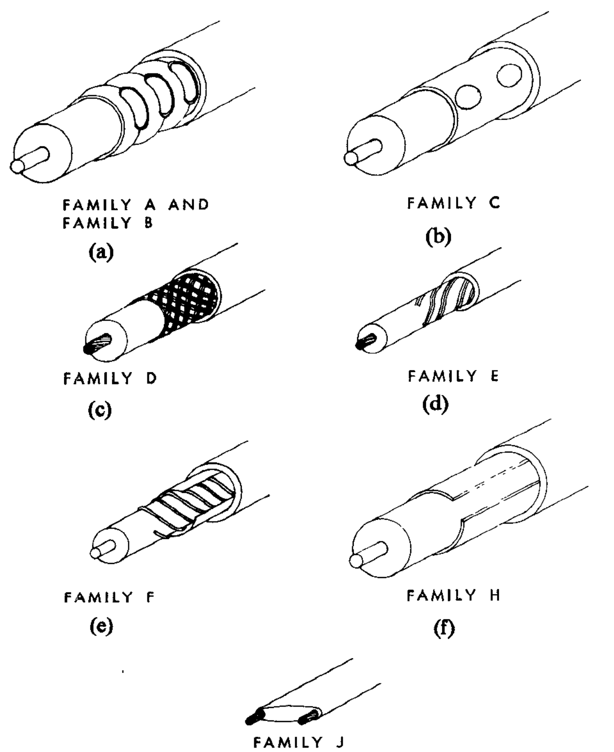


Fig. 1. Leaky coaxial cable constructions and family designations.

included an investigation of their application to obstacle detection [5]. At about the same time Ogilvy in the U.K. also discussed guided radar on the railways [6]. Neither of these papers included the use of leaky coaxial cables for obstacle detection schemes as such cables were not then available.

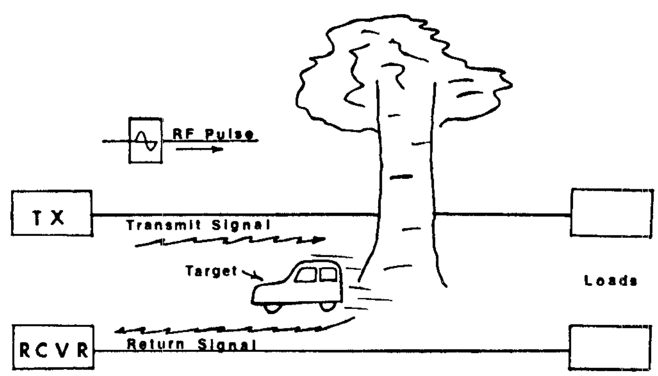


Fig. 2. Guided radar concept.

In the past five years a guided radar system has been developed at Queen's University, in association with the Computing Devices Company (GUIDAR), based on the use of leaky coaxial cables [7]–[9]. The immediate purpose is the provision of perimeter surveillance around secure installations such as penitentiaries, with possible extension to use for obstacle detection on railroad systems, airport runways, and highways. The basic concept of this guided radar system is shown in Fig. 2. Two leaky coaxial cables are mounted in parallel along the specific route to be scanned. These cables may be mounted in air, on the ground, or buried. A simple pulse transmitter is connected to one cable and a receiver with appropriate signal processing is connected to the other.

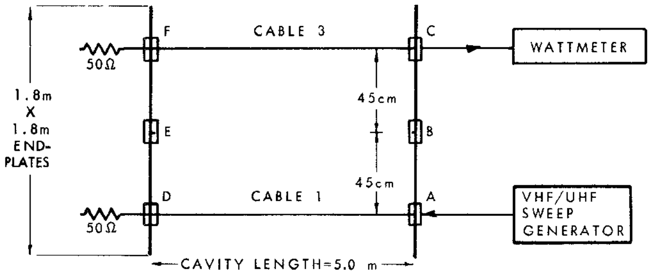


Fig. 3. Two-cable cavity resonator.

C. Performance Parameters of Leaky Coaxial Cables

The two main parameters affecting the performance of leaky coaxial cables in CAGC and guided radar systems are attenuation, which limits the longitudinal range, and "coupling," which determines the overall sensitivity. Attenuation is relatively easy to measure by simple insertion loss techniques although the accurate prediction of losses in an actual working environment is much more difficult. "Coupling" is the measure of the signal accessibility at a given radial distance outside the cable and, being very dependent on the particular installation and environmental aspects, is very difficult to assess. Some attempts have been made to predict it based on waveguide concepts [10] and on transfer impedance concepts [11], [12] but most workers have relied on some simple measurement such as that using a conventional field strength meter. It is obvious that this latter method can not be very reliable as it must be seriously affected by local ground conditions.

This paper describes the theory and operation of a novel testing technique for the "coupling" performance of leaky coaxial cables that has been developed at Queen's University for use in a laboratory, based upon a form of cavity resonator as shown in Fig. 3 and described later.

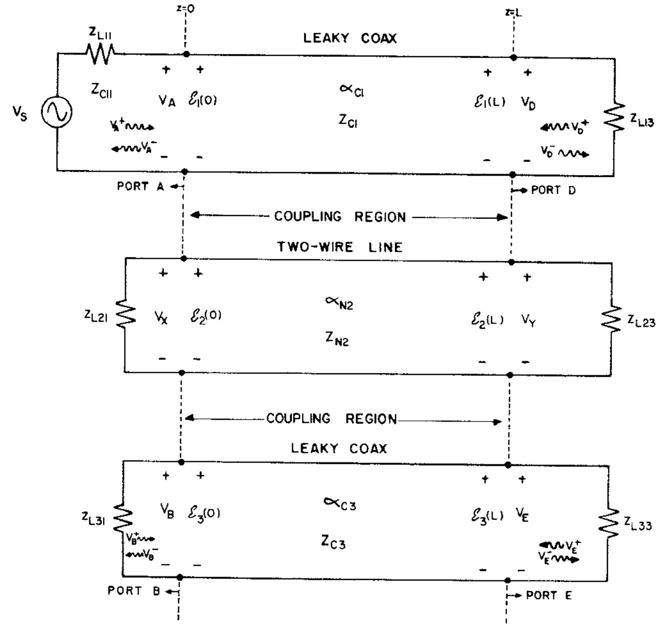
II. Theoretical Model of the Cavity Resonator

A. Coupled Transmission Lines

The two-cable cavity resonator as depicted in Fig. 3 can be analyzed as a system of 3 coupled transmission lines, the circuit equivalent of which is shown in Fig. 4. Cables 1 and 3 are leaky coaxial cables. The outer conductors of cables 1 and 3 then form a two-wire transmission line that becomes the third coupled line.

A single-cable cavity resonator consisting of only two coupled transmission lines can be constructed by the removal, in Fig. 3, of cable 3 and the insertion of a ground plane, for example 90 cm beneath, and parallel to, cable 1. The two-wire line is now formed by the outer conductor of cable 1, and its image in the nearby ground. Two theoretical models, based on coupled mode theory [13]–[15], are outlined below for the single-cable cavity resonator and for the two-cable cavity resonator, respectively.

The analysis extends over a frequency range from dc to 1 GHz. Cable parameters, including phase velocity, attenuation, and characteristic impedance, are assumed to



z = DISTANCE ALONG THE COUPLING REGION
V_s = SOURCE VOLTAGE
V_n = $V_n^+ + V_n^-$, THE TOTAL PORT n VOLTAGE COMPOSED OF INCIDENT AND REFLECTED COMPONENTS
$\mathcal{E}_r(z)$ = THE TOTAL VOLTAGE ON THE r^{th} LINE
Z_{Lrm} = THE IMPEDANCES THAT TERMINATE THE r^{th} LINE
Z_{C11}, Z_{C1}, Z_{N2}, Z_{C3} = CHARACTERISTIC IMPEDANCES
α_{C1}, α_{N2}, α_{C3} = ATTENUATION COEFFICIENTS

Fig. 4. Two-cable cavity resonator transmission line model.

apply here to the leaky coaxial cables as they do to conventional coaxial TEM transmission lines, and can usefully be related to the characteristics of a quasi-TEM mode of propagation [1], [16], [17].

In a system of coupled transmission lines the voltage on each line is composed of weighted voltage contributions from all the lines in the system. If all forward waves are orthogonal to all reverse waves [14], then the transmission line equations that describe the normal modes of propagation are generalized to take the form of [15]

$$j\frac{d\epsilon_r^+(z)}{dz} - \sum_n H_{rn}\epsilon_n^+(z) = 0 \qquad (1)$$

for modes propagating in the ^+z direction, for example, and solutions are sought of the form

$$\epsilon_r^{\pm}(z) = E_r^{\pm} e^{\mp j\gamma_s z} \qquad (2)$$

where

- $\epsilon_r^+(z)$, $\epsilon_r^-(z)$ the forward and reverse voltage waves, respectively, on the rth line;
- $\epsilon_n^{\pm}(z)$ the forward and reverse voltage waves on the n lines that couple to ϵ_r;
- H_{rn} the mutual coupling coefficient between ϵ_r and ϵ_n;
- H_{rr} $\beta + \Delta\beta$, the propagation coefficient on the rth line, which is similar to the free

space propagation coefficient β, but perturbed by an amount $\Delta\beta$ due to the coupling process;

γ_s the propagation coefficient of the sth normal mode on the coupled system.

For two coupled lines, with summation of the forward and reverse voltage waves, the total voltage on line 1, for example, is

$$\epsilon_1(z)=E_{11}^+e^{-j\gamma_1 z}+E_{11}^-e^{+j\gamma_1 z}+E_{12}^+e^{-j\gamma_2 z}+E_{12}^-e^{+j\gamma_2 z} \quad (3)$$

where E_{rs}^+, E_{rs}^- is the sth coupled mode voltage on the rth line in the forward and reverse directions, respectively.

By appropriate substitutions for $\epsilon_1^+(z)$ and $\epsilon_2^+(z)$ in (1), the system of coupled modes is expressed as an eigenvalue problem which in matrix notation becomes

$$\gamma[E]-[H][E]=0. \quad (4)$$

From consideration of the conservation of energy [15], a fundamental relationship is deduced that $H_{rn}=H_{nr}$, which corresponds to power in the n and r lines propagating codirectionally as has been verified experimentally for leaky coaxial cables [18].

B. The Single-Cable Cavity Resonator

The model of the single-cable cavity resonator includes two accessible ports, A and D in Fig. 4. At the reference plane $z=0^-$, just to the left of $z=0$, the time average power passing to the source from the junction at $z=0$, between the ordinary coaxial cable and the leaky coaxial cable, relative to the normalized power input, $|V_A^+|^2$, is expressed as

$$S_{AA}=20\log|V_A^-/V_A^+|\text{dB} \quad (5)$$

and, similarly, that passing to the final load is given by

$$S_{DA}=20\log|V_D^-/V_A^+|\text{dB} \quad (6)$$

where V_A^- and V_D^- are as indicated in Fig. 4. The solution of this eigenvalue problem yields expressions for S_{AA} and S_{DA}.

The coupled mode propagation coefficients for the single-cable model are calculated from the eigenvalue equation derived from (4) by setting the determinant of the coefficient matrix, $[\gamma-H]$, equal to zero, which has solutions given by

$$\gamma_{1,2}=(H_{11}+H_{22})/2\pm\sqrt{[(H_{11}-H_{22})^2/4+H_{12}^2]} \quad (7)$$

with corresponding values for the modes travelling in the $-z$ direction.

Eight eigenvalue relations are deduced by use of (4). For a nontrivial solution only 4 of the relations are useful, for example,

$$E_{21}^+=WE_{11}^+ \qquad E_{21}^-=WE_{11}^- \quad (8a,b)$$

$$E_{22}^+=-E_{12}^+/W \qquad E_{22}^-=-E_{12}^-/W \quad (9a,b)$$

where

$$W=(H_{22}-H_{11})/2H+\sqrt{[(H_{11}-H_{22})^2/4H_{12}^2+1]}\ . \quad (10)$$

To constrain the coupled system fully the four other required relations are determined by the physical boundary conditions defined at each end of each coupled line.

V_A^+ is the source datum, and, typically, $Z_{L_{11}}=Z_{C_1}=50$ Ω. Z_{N_2} is calculated on the basis of an open two-wire line in free space. The choice of the wire diameter is that of the outer diameter of the leaky coaxial cable, and the separation of the wires is twice the distance to the ground plane. $Z_{L_{21}}=Z_{L_{23}}$ is the estimated equivalent impedance of each metallic end-plate shown in Fig. 3 and represents the conduction loss in the metal and, of greater importance, the effect of the field spill-over loss due to the finite size of the plate. Based on previous work elsewhere at super-high frequency (SHF) [19] on unloaded cavity Q factors, an initial value of $Z_{L_{21}}=0.02$ Ω was estimated. It was subsequently found that increasing this by a factor of 5 was not significant.

It remains to provide practical values for the propagation coefficients H_{11}, H_{22} and the mutual coupling coefficient H_{12}. To include loss, H_{11} and H_{22} are of the general form $H=\beta-j\alpha$ where β and α are the phase and attenuation coefficients of the mode of propagation. H_{11} and H_{22} are perturbed slightly from their isolated free space values due to the coupling process. β_{C_1} and α_{C_1} can be set initially from a knowledge of the free space phase velocity and attenuation of the leaky coaxial cable. The model is sensitive to the β_{C_1} value but relatively insensitive to α_{C_1} for practical attenuation values.

H_{22} is estimated from the test of the cable in the cavity. αN_2 is calculated on the basis of an open two-wire line in free space and is found to be less than 0.3 dB/100 m; a value of about 1 dB/100 m was found to be reasonable, to allow for practical imperfections. βN_2 is calculated by measurement of the frequencies (f_r) at which the cavity resonates

$$\beta N_2=\frac{\omega}{\left(2L/n\sum_{i=1}^{n}f_{ri}/i\right)} \quad (11)$$

where i is the order of resonance.

The remaining parameter to be estimated is H_{12}, the coupling coefficient between the coaxial line and the two-wire line, dimensioned as a phase coefficient. The magnitude of the power transfer is directly linked to H_{12} and is apparently characteristic of the particular construction of the leakly coaxial cable. It must be estimated by an iterative process by review of the experimental power transfer magnitude in comparison with that calculated theoretically. With H_{12} normalized to 1 MHz and assumed to vary directly with the frequency, the range of values that is typical of H_{12} is 10^{-5} m^{-1} MHz^{-1} to 10^{-3} m^{-1} MHz^{-1}.

In principle there are 8 $E_{rs}^{\pm}$ voltage components in the single-cable cavity resonator eigenvalue problem. The arithmetic problem is reduced to the inversion of a 4×4 matrix by the elimination of the 4 $E_{rs}^{\pm}$ components of the two-wire line by use of the eigenvalue relations. The problem is summarized thus:

$$\begin{bmatrix} 1+\frac{Z_{L_{11}}}{Z_{c_1}} & 1-\frac{Z_{L_{11}}}{Z_{c_1}} & 1+\frac{Z_{L_{11}}}{Z_{c_1}} & 1-\frac{Z_{L_{11}}}{Z_{c_1}} \\ \rho_{13}e^{-j\gamma_1 L} & -e^{+j\gamma_1 L} & \rho_{13}e^{-j\gamma_2 L} & -e^{+j\gamma_2 L} \\ W & -\rho_{21}W & \frac{-1}{W} & \frac{\rho 21}{W} \\ \rho_{23}We^{-j\gamma_1 L} & -We^{+j\gamma_1 L} & \frac{-\rho_{23}}{W}e^{-j\gamma_2 L} & \frac{e^{+j\gamma_2 L}}{W} \end{bmatrix} \cdot \begin{bmatrix} E_{11}^+ \\ E_{11}^- \\ E_{12}^+ \\ E_{12}^- \end{bmatrix} = \begin{bmatrix} 2_{VA}^+ \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{12}$$

where

$$\rho_{13}=\frac{Z_{L_{13}}-Z_{c_1}}{Z_{L_{13}}+Z_{c_1}} \tag{13}$$

$$\rho_{21}=\rho_{23}=\frac{Z_{L_{23}}-Z_{N_2}}{Z_{L_{23}}+Z_{N_2}}. \tag{14}$$

The relative power S_{AA} (with $Z_{L_{21}}=Z_{L_{23}}$) at port A is then calculated as follows:

$$S_{AA}=20\log|(E_{11}^+ + E_{11}^- + E_{12}^+ + E_{12}^-)/V_A^+ - 1|\text{dB}. \tag{15}$$

For insight the problem can be simplified by the following assumptions. Suppose that ports A and D are matched, that the two-wire line is terminated in perfect short-circuits, and that both lines are loss free. S_{AA} can then be written explicitly

$$S_{AA}=20\log\left|\frac{4W^2\sin^2(\beta_B L)}{2W^2+2\cos(\beta_B L)+(W^4-1)e^{-j2\beta_B L}-(1+W^2)^2e^{j2\beta_A L}}\right|\text{dB} \tag{16}$$

where

$$\beta_A=(2\pi f/V_{PC}+2\pi f/V_{PT})/2,\ \beta_B=\sqrt{((\pi f(1/V_{PC}-1/V_{PT}))^2+H_{12}^2)} \tag{17a,b}$$

where

$$W=(2\pi f/V_{PT}-2\pi f/V_{PC})/2H+\sqrt{((\pi f(1/V_{PC}-1V_{PT})/H_{12})^2+1)}\ . \tag{18}$$

C. The Two-Cable Cavity Resonator

The two-cable model uses a system of 3 coupled transmission lines as shown in Fig. 4. There are now 3 coupled modes and the total voltage on line 1, for example, is

$$\epsilon_1(z)=E_{11}^+e^{-j\gamma_1 z}+E_{11}^-e^{+j\gamma_1 z}+E_{12}^+e^{-j\gamma_2 z}+E_{12}^-e^{+j\gamma_2 z}+E_{13}^+e^{-j\gamma_3 z}+E_{13}^-e^{+j\gamma_3 z} \tag{19}$$

with similar expressions for $\epsilon_2(z)$ and $\epsilon_3(z)$ on the two-wire line (2), and coaxial line (3), respectively.

This problem can be expressed as an eigenvalue problem in the form of (4) involving 18 $E_{rs}^{\pm}$ eigenfunctions on the three coupled lines, and three γ_s coupled mode eigenvalues. As the coupling process is codirectional, it follows that $H_{12}=H_{21}$, $H_{13}=H_{31}$, and $H_{23}=H_{32}$. The numerical values of the H_{rr} propagation coefficients are estimated as described above, with $H_{33}=H_{11}$. Similarly, the value for H_{12} is estimated as described above and by symmetry it is observed that $H_{23}=H_{12}$. H_{13} is assumed to be approximately equal to the product $H_{23}H_{12}$.

The remaining six constraints, after use of the eigenvalue relations, are provided by the boundary conditions. The line 2 constraints are identical to those of the single-cable model except that the characteristic impedance calculation is now based on the separation between the outer conductors of the two leaky coaxial cables.

III. Experimental Tests

The two-cable test cavity in Fig. 3 has two vertical, parallel, aluminum end-plates, each 1.8 m×1.8 m, spaced approximately 5 m apart. Two lengths of leaky cable run parallel to each other between the end-plates at a specified separation (shown as 90 cm; alternative arrangement would give 45-cm spacing). At each end-plate each cable is connected to a conventional feed-through, type N, coaxial connector. On one end of each cable a 50-Ω conventional coaxial load is attached to the feed-through connector immediately on the outside of the end-plate. On the other end of each cable is connected, outside the end-plate via ordinary RG-8 coaxial cable, 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 two cables. The ground conditions can be standardized by use of an aluminum ground plane at floor level. In contrast with other test techniques the cable environment is controlled and repeatable.

It then becomes possible to deduce the coupling behavior between two cables of a particular specified type and how it varies as functions of cable spacing and frequency throughout the VHF and UHF bands. For each pair of cables of a given type, the laboratory cavity test yields a characteristic power versus frequency "signature" for that particular spacing and this signature corresponds to the theoretical relative power described as S_{BA}.

The resonant aspect of the cavity test results from the use of short-circuit end plates to terminate the two-wire transmission line. The sources of loss in the cavity are: the coaxial cable terminations outside the cavity; the two-wire line attenuation; the nonideal short circuits on the two-wire line; and the coaxial cable attenuation.

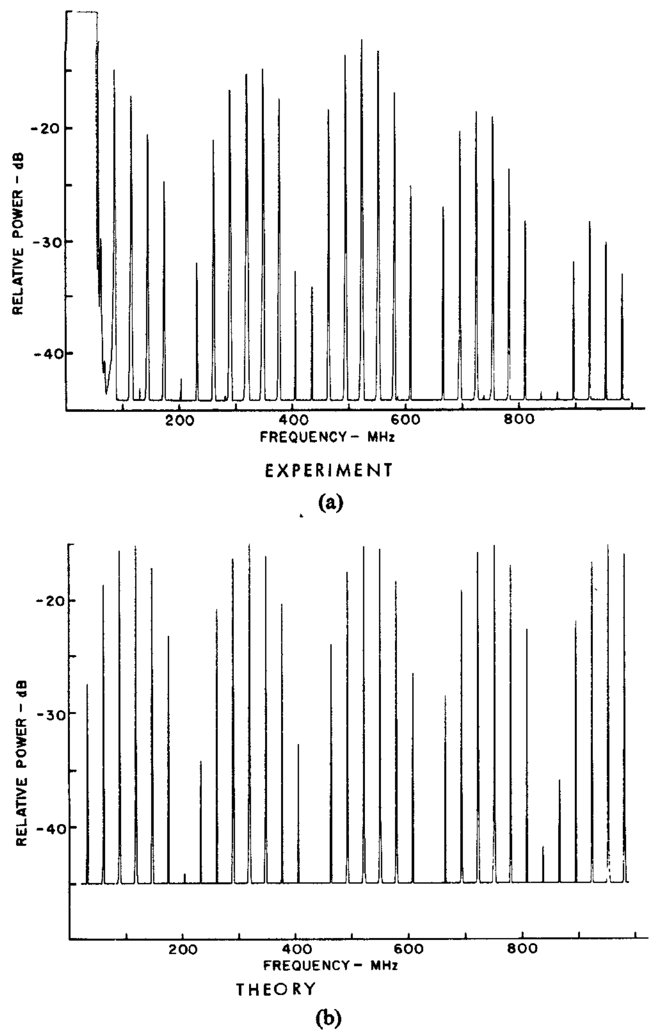


Fig. 5. Type A3 cable evaluation.

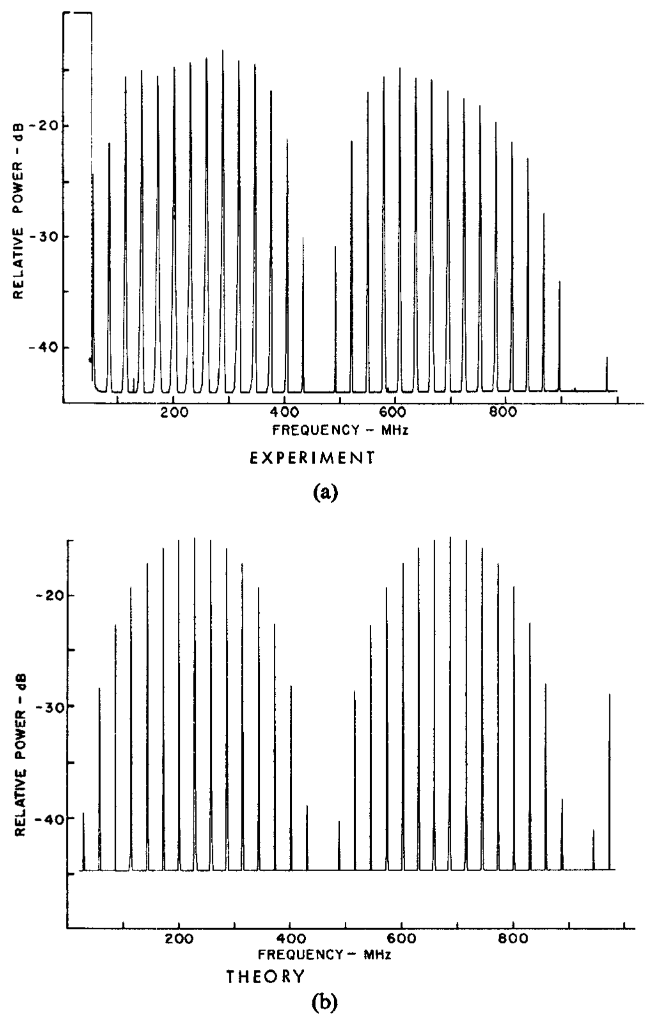


Fig. 6. Type B4 cable evaluation.

A typical example is shown, in Fig. 5(a), for two cables of type A3 spaced 0.9 m apart in the cavity of length = 5 m. The upper graph, Fig. 5(a), is the laboratory test result and the lower graph, Fig. 5(b), is the corresponding computed result from the theoretical model. The solid vertical lines indicate the cavity resonances that occur at regularly spaced intervals of about 29.2 MHz, corresponding to a relative phase velocity V_{PT}, of 0.98 c for the two-wire line. It is at once obvious that these resonances have amplitudes that vary according to an overall "envelope" with minima at approximately every 225 MHz. The spacing between the minima of the imagined overall envelope is strongly linked to the difference in phase velocity between that of the single isolated leaky cable V_{PC} and that of the two-wire line V_{PT}. V_{PC} is estimated to be 0.77 c for Fig. 5, and the coupling coefficient H_{12} is estimated to be about 0.00017 $\mathrm{m}^{-1} \cdot \mathrm{MHz}^{-1}$. Note that in the laboratory test results, the lowest order resonance is lost and the 2nd and 3rd order resonance power values are not reliable, all due to an instrumentation frequency limit of about 100 MHz.

Fig. 6(a) and (b) illustrate the markedly different behavior of cable type B4 having a lower density foam dielectric than the family A cables. V_{PC} is now estimated to be 0.87 c and the mutual coupling coefficient in this case is estimated to be about 0.000078 $\mathrm{m}^{-1} \cdot \mathrm{MHz}^{-1}$.

The slot size is identical for cables A3 and B4 with the apparent result that the coupled power signatures of each have similar envelope maxima values. The slot size of cable A1 is smaller than that of the slots in cables A3 and B4 and a similar test on cable A1 showed greatly reduced envelope maxima values, both experimentally and theoretically.

To determine the effect of attenuation on the experimental and theoretical coupled power signatures, an approximately double length ($L = 10$ m) cavity test was conducted with cable A3 and the results were compared to the 5-m test results of Fig. 5. In both the experimental and theoretical signatures the maxima level was down about 3 dB in the 10-m test as compared with the 5-m test, due predominantly to the attenuation of the two-wire line.

From this brief description of test results it can be seen that the coupling behavior of one type of cable can be deduced relative to that of another. Fig. 7 is a composite graph of the envelopes of the coupled power signatures of 11 different cable types (as designated in Fig. 1 and Table I) tested in the two-cable resonator at 45-cm cable spacings.

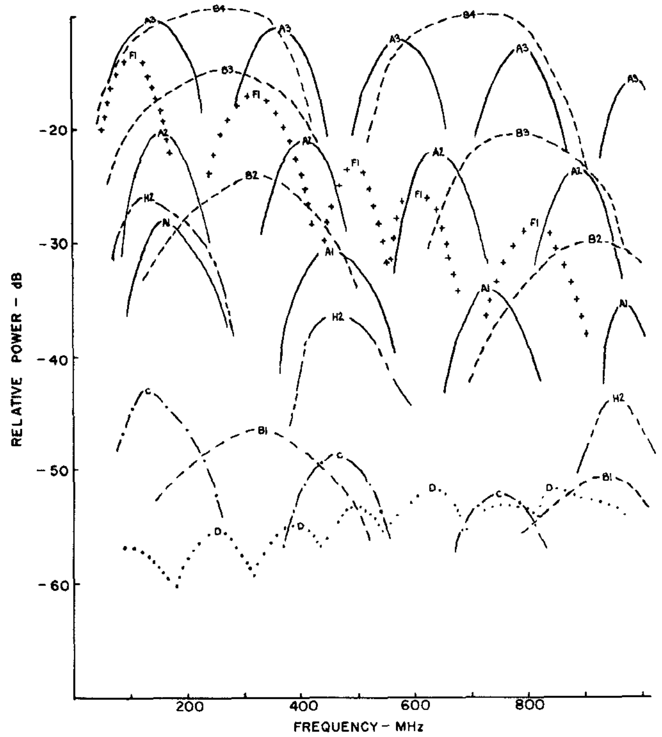


Fig. 7. Coupled power comparison of 11 types of leaky coaxial cable.

Experimental confidence in the two-cable cavity resonator test method has been established by tests on about 20 different types of leaky coaxial cable, some of which have also been used in a full-sized guided radar field-site test.

Five types of leaky coaxial cable were ranked, from the field test results, on the basis of relative human target sensitivity [8]. There was a one-to-one correspondence between the cable ranks based on the field tests and those based on the two-cable cavity resonator and close agreement among the relative levels in decibels [20].

IV. Discussion of Results

A. Curve-Fitting Procedure

The results shown in Figs. 5 and 6 indicate that it is possible to get a very good match, by a process of curve fitting, between the measured performance of the leaky coaxial cables in the test cavity and that predicted by the theoretical model. Ideally, one would have a complete and accurate knowledge of all the cable parameters in advance and then simply apply them to the model. Complete knowledge of the parameters described previously could be found, in principle, from an exact field solution of the Helmholtz equation for the situation treated as an overall waveguide problem, although it would scarcely be worth the effort here in what is intended to be a useful method for the practical testing of leaky cables.

The detailed procedure of curve fitting can be summarized as follows. The major characteristics of each observation, such as that in Fig. 5(a), are: 1) the almost exactly uniform spacing between the individual cavity resonances, which is a simple function of the two-wire line's phase velocity and the cavity length, as discussed above; 2) the overall "envelope" pattern of maxima and minima, having an almost uniform repetition in the frequency domain with, in turn, two main features: a) the overall level in decibels of the maxima of the envelope in the frequency range of interest; b) The spacing between the minima of the envelope.

The dependence of each of these last two features is as shown in Table II.

For all the leaky cables tested except those with the largest effective coupling, (e.g., Types A3 and B4 in Fig. 7), only the "Strong Dependence" parameter was truly significant, which made the process of curve fitting into a very simple two-step procedure for most cases. For cable Types A3 and B4, an iterative process was required.

The effect on the model's behavior of the attenuation coefficient of the individual leaky cables was found to be negligible for all reasonable values. Similarly, the imperfection in the end-plates of the cavity due to their finite size and finite conductivity was found to be of negligible importance compared with the effect of the attenuation of the two-wire line, as was confirmed by comparison of Fig. 5 for a 5-m cavity test with the results for a 10-m cavity test of the same cable type.

B. Limitations of the Cavity Test

Exploratory tests showed that the ground plane only began significantly to affect the observed behavior when the height of the cables above it decreased to about 45 cm or less. Similarly, other tests with a specially introduced large metal object showed that the performance of the cavity test was unaffected by any object that was about 1 m or more distant from the cables.

A feature of almost all the observations is the way that the maxima of each envelope tend to decline as the frequency increases, as shown particularly in Fig. 7. This aspect is not indicated by the model which does not allow for any variation with frequency for the two-wire line parameters, and which includes an assumption that the coupling process is independent of frequency. In practice, as with all open waveguides, the fields around each leaky cable may tend to become more closely confined to the immediate vicinity of the cable itself as the frequency is increased. Extrapolation of these results of the cavity test to field installations with much wider cable spacings would be inadvisable as much remains to be understood on this aspect of leaky cables.

V. Conclusion

A novel two-cable cavity resonator has been introduced for the testing of leaky coaxial cables in relation to their probable performance in continuous-access guided communication (CAGC) and guided radar systems. A detailed theoretical model, based on coupled transmission lines, has been formulated and found to show excellent agreement with the measurements made in the cavity. Comparison with experimental work on a full-size guided radar

TABLE II
ENVELOPE PARAMETER DEPENDENCE

Feature of Test Performance	Dependence: Strong	Moderate	Weak
a) Overall level in dB of envelope maxima	Coupling coefficient H_{12} and H_{23}	Phase velocity of leaky cable V_{PC_1}, V_{PC_3} (relative to that of two-wire line)	Attenuation coefficient of two-wire line αN_2
b) Spacing between envelope minima	Phase velocity of leaky cable V_{PC_1}, V_{PC_3} (relative to that of two-wire line)	Coupling coefficient H_{12} and H_{23}	

system has confirmed the usefulness of this new laboratory technique as a means of categorizing the behaviour of leaky coaxial cable in a way considerably superior to that currently used elsewhere.

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