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THESIS

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by

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ABSTRACT

An investigation of several slot line effects is reported. Various metallizations have been tested and experimental data is presented which shows that surface metal adhesive causes an increase in slot wavelength. End effect in a shorted slot was also studied and experimental data is presented showing the inductive nature of this termination.

LIST OF ILLUSTRATIONS

Figure

ACKNOWLEDGEMENTS

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Thanks also extended to Mr. Sproule of the Microwave Lab and STC-Franklin of the Optical Lab for their assistance.

I. SLOT LINE THEORY

The Slot Line has been proposed by S. B. Cohn and others as an alternative transmission line for application to microwave integrated circuits.

The Slot Line offers a unique combination of a planar type geometry and a TE dominant mode similar to the dominant mode in rectangular waveguide, hence it offers some interesting possibilities for realizing miniature microwave devices such as filters, couplers, ferrite devices and other components as well as complete microwave circuits.

A. ZERO ORDER SOLUTION

Galejs in Ref. [1] in his zero order solution of the integral equation shows that for slots of negligible width the propagation constant along the slot approaches the propagation constant of a thin wire which lies in the interface between the two dielect ics.

The zero order solution of the propagation constant is:

$$\gamma = \sqrt{\frac{\gamma_o^2 + \gamma_1^2}{2}}$$

where γ_o and γ_1 are the propagation constant of the two media.

Cohn in Ref. [2] modified Galejs' expression into a simple formula for relative wavelength:

$$\frac{\lambda'}{\lambda} = \sqrt{\frac{2}{\varepsilon_M+1}}$$

and also obtained expressions for the field components on the air side of the slot as a function of λ, λ' and distance γ from the slot:

$$H_z = AH_o^{(1)}(k_c\gamma) \;; \quad \left[H_n^{(1)}(X) \rightarrow \text{Hankel function first kind}\right]$$

$$k_c = \sqrt{\gamma_3^2 + k^2} = j\,\frac{2\pi}{\lambda}\sqrt{\left(\frac{\lambda}{\lambda'}\right)^2 - 1}\ .$$

$$H_\gamma = -\frac{\gamma_z}{k_c}\frac{\delta H_z}{\delta\gamma} = A\left[1-(\lambda'/\lambda)^2\right]^{-\frac{1}{2}} H_1^{(1)}\ (k_c\gamma).$$

$$E_\phi = \frac{j\omega\mu}{k_c^{\,2}}\frac{\delta H_z}{\delta\gamma} = -\eta\ (\lambda'/\lambda)\ A\left[1-(\lambda'/\lambda)^2\right]^{-\frac{1}{2}} H_1^{(1)}\ (k_c\gamma).$$

Of interest is his expression for the ratio of voltage along a semicircular path of constant radius divided by the voltage directly across the slot:

$$V(\gamma) = \frac{k_c\gamma\ H_1^{(1)}\ (k_c\gamma)}{\lim\limits_{|X|\rightarrow 0}\left[|X|\ H_1^{(1)}\ (j|X|)\right]}$$

$$= \frac{\pi}{2}\ |k_c\gamma|\ \left|H_1^{(1)}\ (k_c\gamma)\right|$$

hence the relaiive wavelength ratio less than unity is a sufficient condition to ensure decay of the slot-mode field with radial distance; for values of ε_r = 10 to 30 the slot-mode wavelength will be much smaller than free space wave-length and the fields will be closely confined near the slot.

B. SECOND ORDER SOLUTION

In the zero order solution the ratio λ'/λ is a function of ε_r only, the more accurate second order solution shows quantitatively how λ'/λ varies with the parameters d, w, ε_r, λ.

An analytical approach for slot line offering high accuracy was made by Cohn. The key for his second order solution is the introduction of boundary walls permitting the slot line configuration to be treated as a rectangular waveguide problem rather than as a problem in cylindrical coordinates. Thus the infinite orthogonal sets of relatively simple rectangular waveguide modes apply rather than sets of cylindrical modes embodying all orders of Hankel functions.

Transformation of the slot line configuration into a rectangular waveguide problem is illustrated in Fig. 1.

We assume that slot waves are traveling in the ±X direction with the same amplitude. The transverse planes are placed in the null positions of the transverse E field and normal H. The distance between these transverse planes is $\lambda'/2$. If two conducting planes of infinite extent are inserted without disturbing the field components between the planes as shown in Fig. 1a, the regions $X < 0$ and $X > a$ may be eliminated. The region between the walls is now in resonance with no loss of energy if the dielectric substrate and the walls are assumed dissipationless.

Now we are going to insert conducting planes at $Y = \pm b/2$ perpendicular to the substrate in order to use rectangular

waveguide mode sets which will simplify the analysis. If the value of b is chosen large enough, the planes at $Y = \pm b/2$ will have negligible effect because the fields are tightly bound to the vicinity of the slot.

Thus the introduction of the wall has created the configuration of a capacitive iris in a rectangular waveguide with air and dielectric regions.

Magnetic walls also may be placed at $Y = \pm b/2$ as shown in Fig. 1b.

Consider now the Fig. 1a. All waveguides must have $\lambda'/2$ variation of the slot wave in the X direction. Also all modes must have a maximum E field at the center of the slot, and the modes satisfying the boundary are $TE_{1,2n}$ for $n = 0,1,2,...,n$ and $TM_{1,2m}$ for $m = 1,2,...,m$.

For $\lambda' < \lambda$ and hence $a < \lambda/2$ the TE_{10} and higher modes are cut off depending on the value of b.

The complete derivation for the total susceptance at the iris plane, characteristic impedance (Z_o) utilizing the total susceptance formula, and relations for the ratio of phase velocity to group velocity is obtained in Ref. [2].

$$\eta Bt = \frac{a}{2b}\left[-J + \mu \tan\left(\frac{\pi d\mu}{ap} - \tan^{-1}\frac{v}{\mu}\right)\right.$$

$$+ \frac{1}{p}\left\{\left(\frac{\varepsilon_M+1}{2} - p^2\right)\ell n\,\frac{2}{\pi^5}\right.$$

$$\left.\left. + \frac{1}{2}\sum_{n=1,2,3...}\left[v^2\left(1-\frac{1}{F_n}\right)+M_n\right]\frac{\sin^2(\pi n\delta)}{n(\pi n\delta)^2}\right\}\right]$$

where $p = \frac{\lambda}{2a}$ (the independent variable)

or $p = \lambda/\lambda'$ for $Bt = 0$

$$\mu = \sqrt{\varepsilon_r - p^2}\ ,\ \nu = \sqrt{p^2-1}$$

$$F_n = 1 + \sqrt{\left(\frac{b}{2an} \cdot \frac{\nu}{p}\right)^2}\ ;\ F_{nl} = \sqrt{1 - \left(\frac{b}{2an} \cdot \frac{\mu}{p}\right)^2}$$

$$\delta = /b$$

$$\eta = 376.7 \text{ ohms per square}$$

For F_{nl} real:

$$M_n = \frac{\varepsilon_r \tan h\ \gamma_n - p^2 F_{nl}^2 \text{ co th } q_n}{\left[1 + \left(\frac{b}{2an}\right)^2\right] F_{nl}} - \mu^2$$

where:

$$\gamma_n = \frac{2\pi nd\ F_{nl}}{b} + \tan h^{-1} \left(\frac{F_{nl}}{\varepsilon_r F_n}\right)$$

$$q_n = \frac{2\pi nd\ F_{nl}}{b} + \text{co th}^{-1} \left(\frac{F_n}{F_{nl}}\right)$$

For F_{nl} imaginary:

$$M_n = \frac{\varepsilon_r \tan \gamma_n' - p^2 |F_{nl}|^2 \cot q_n'}{\left[1 + \left(\frac{b}{2an}\right)^2\right] |F_{nl}|} - \mu^2$$

where:

$$\gamma_n' = \frac{2\pi nd\ |F_{nl}|}{b} + \tan^{-1} \left(\frac{|F_{nl}|}{\varepsilon_r F_n}\right)$$

$$q'_n = \frac{2\pi n d\,|F_{n1}|}{b} + \cot^{-1}\left(\frac{F_n}{|F_{n1}|}\right)$$

For the ratio of phase velocity to group velocity and for the characteristic impedance Z_o we have the following expressions:

$$v/vg = 1 + \frac{f}{(\lambda'/\lambda)} \cdot \frac{-\Delta(\lambda'/\lambda)}{\Delta f}$$

$$Z_o = 376.7\,\frac{v}{vg}\,\frac{\pi}{p} \cdot \frac{\Delta p}{-\Delta\eta B t}\ \text{ohms}$$

Normalized graphs of λ'/λ and Z_o vs d/λ for w/ = .02, .1,.4,.6 and for ε_r = 13,16,20 are given in Ref. [3] and are included as shown in Figs. 2, 3, and 4.

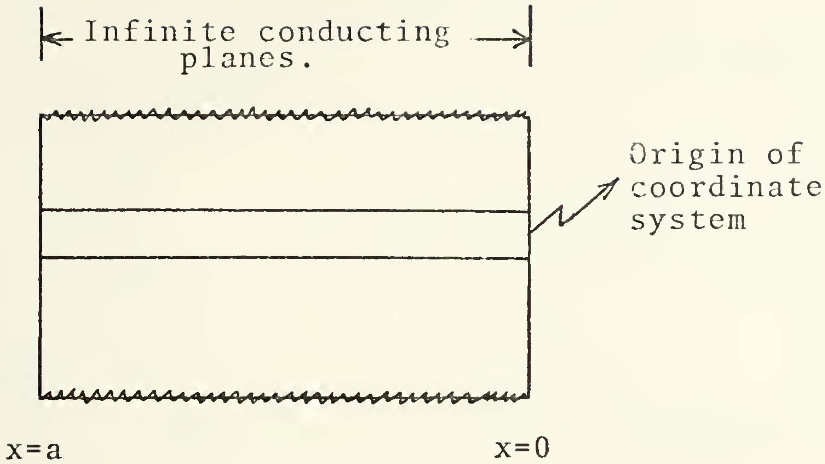


Figure 1a

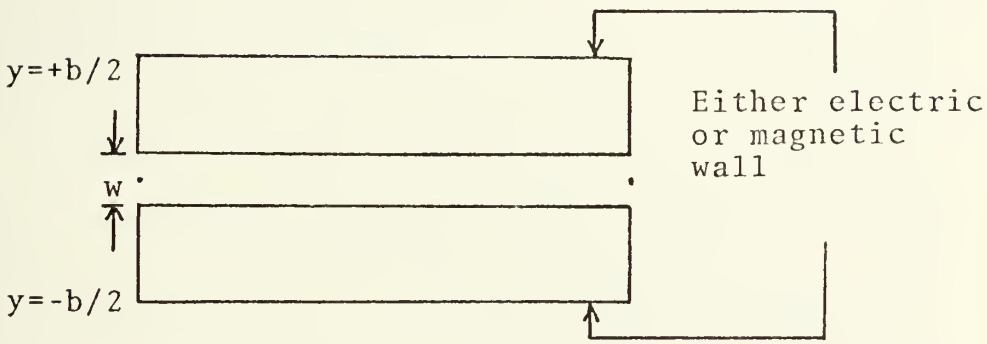


Figure 1b

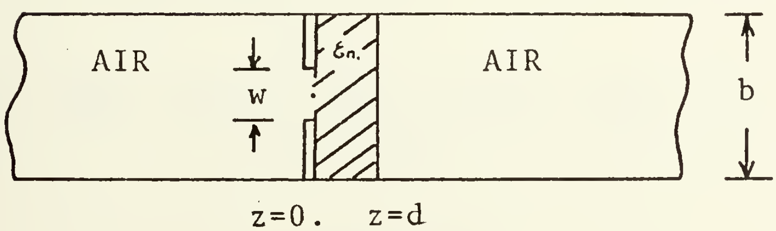


Figure 1c

DEVELOPMENT OF WAVEGUIDE MODELS FOR SLOT LINE

Figure 1

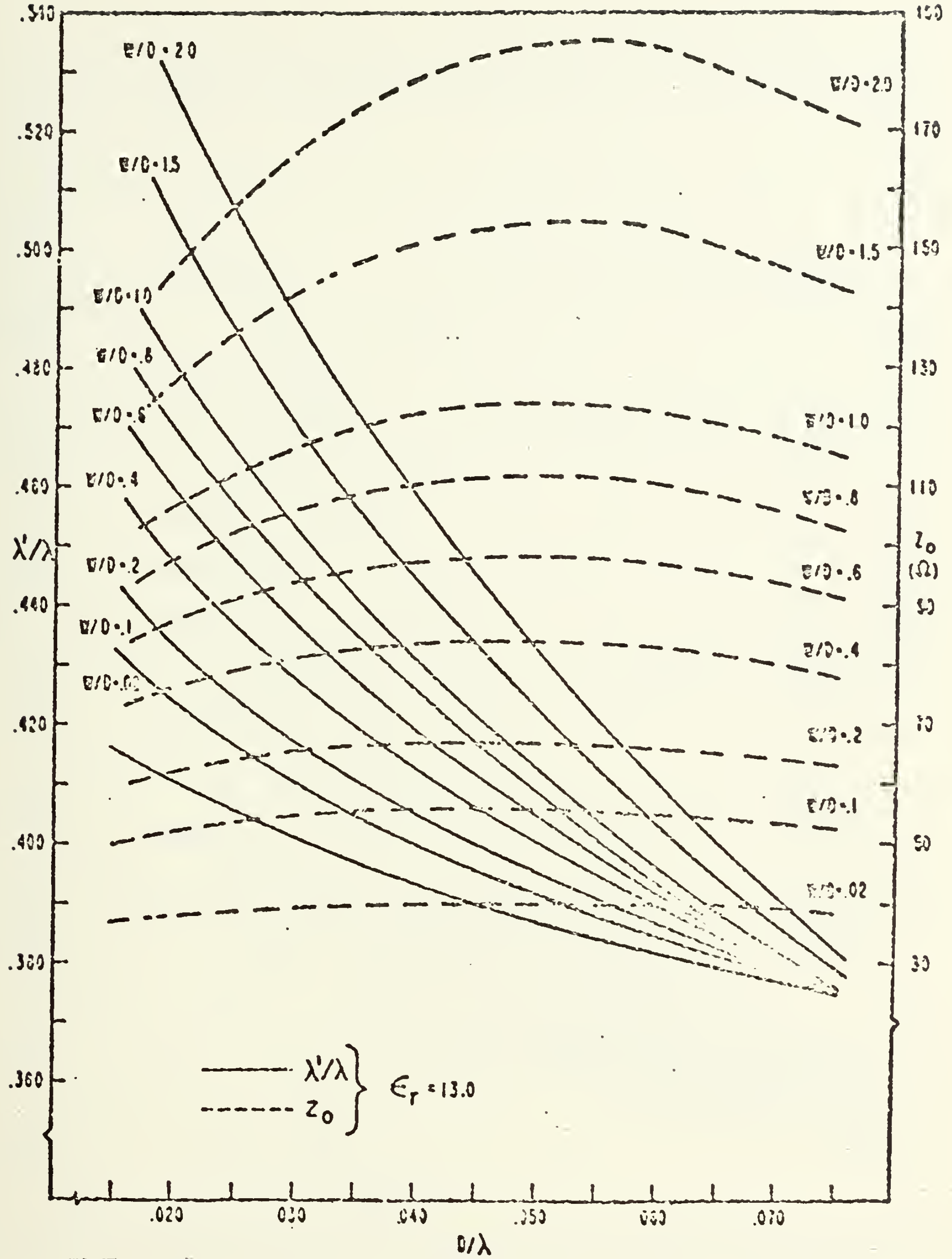
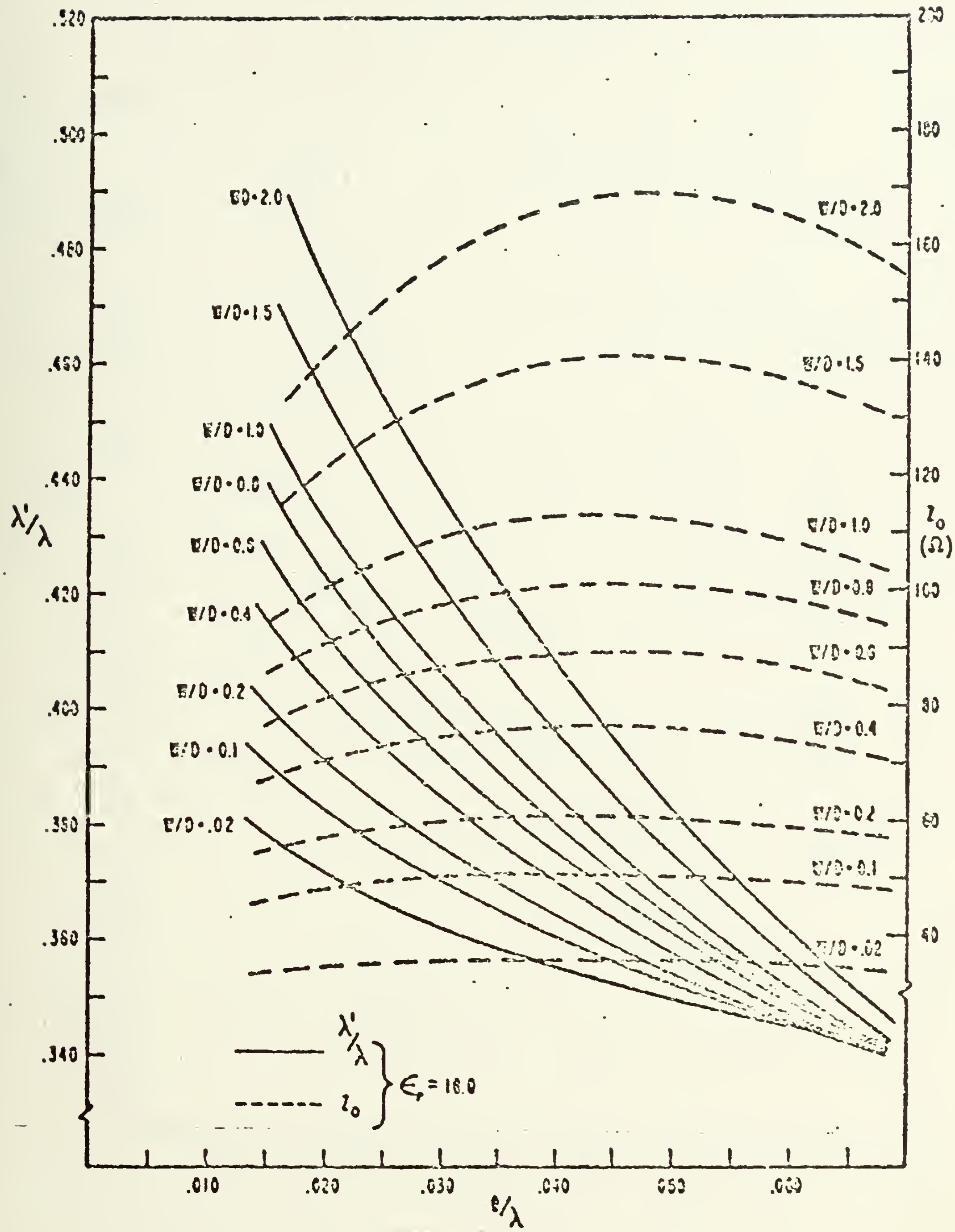


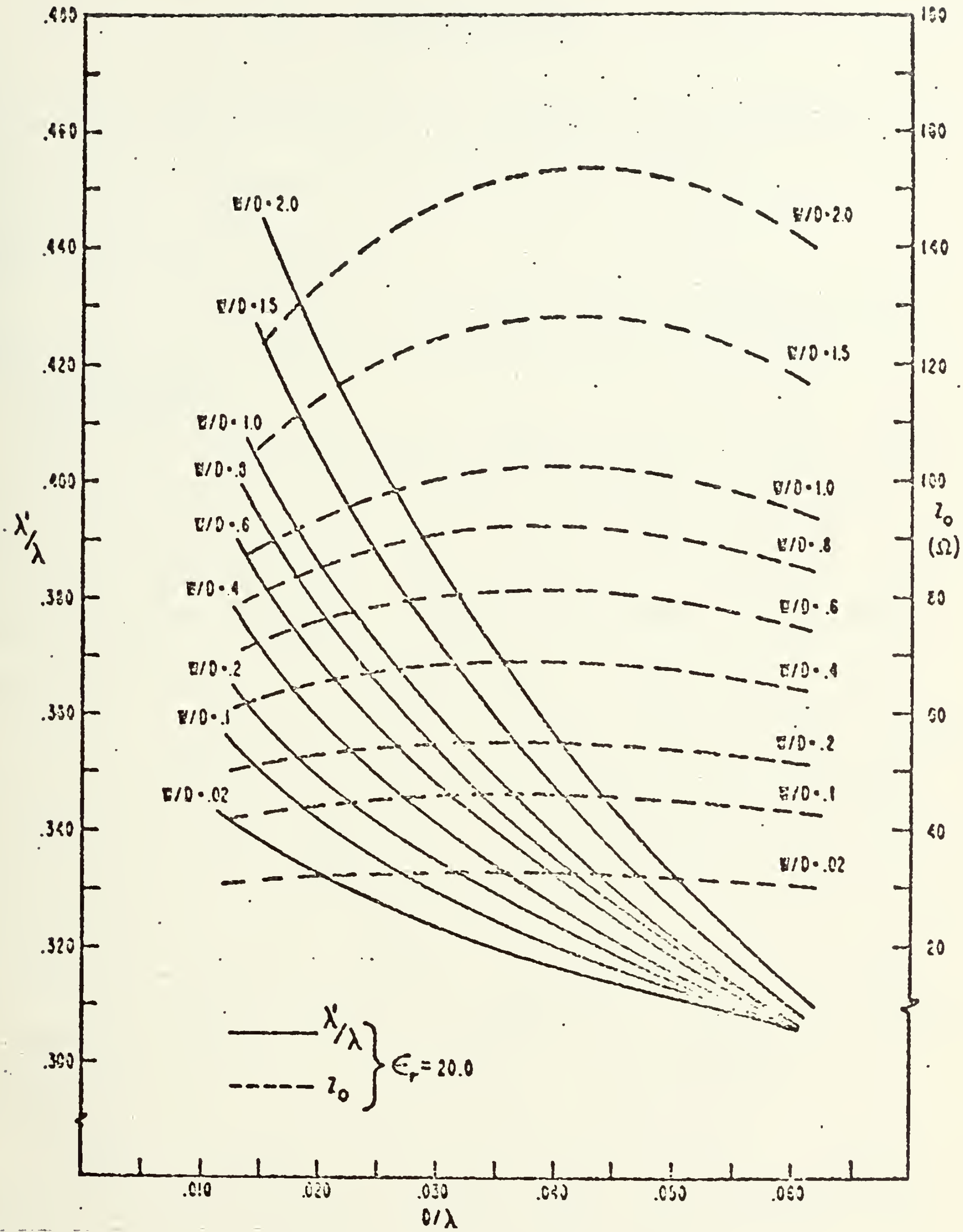
Figure 2

SLOT LINE IMPEDANCE AND NORMALIZED
SLOT LINE WAVELENGTH VERSUS NORMALIZED SUBSTRATE THICKNESS. (FROM REF [3])



SLOT LINE IMPEDANCE AND NORMALIZED SLOT LINE WAVELENGTH VERSUS NORMALIZED SUBSTRATE THICKNESS. (FROM REF [3])

Figure 3



SLOT LINE IMPEDANCE AND NORMALIZED SLOT LINE WAVELENGTH VERSUS NORMALIZED SUBSTRATE THICKNESS. (FROM REF. [3])

Figure 4

II. INVESTIGATION

The experimental work can be divided into two parts: Slot lines construction and metallization effects on λ'/λ and Slot lines and effects.

A. SLOT LINES CONSTRUCTION AND METALIZATION EFFECTS ON λ'/λ

1. Fabrication

The slot fabrication was made by photo-etching technique. Photoresist is first spread uniformly across the surface and allowed to dry. This film is then exposed to ultraviolet light through a photographic mask that permits the light to fall only on those areas in which the copper layer is to be preserved. The unexposed film is next washed away from the surface, leaving a solid film of photoresist in the areas that were exposed. During etching the copper layer is removed in the unprotected areas, but is unaffected under the photoresist. Finally the photoresist is removed with acetone leaving only the copper layer with the shorted slot line printed in the substrate as shown in Fig. 5.

The slot width, (w), was chosen in order to get values of w/d (for fixed d = 1/8") which gave between 80Ω and 50Ω of slot wave characteristic impedance.

The slot line was fed with a transition consisting of a 2½ inch piece of 85 mil semirigid coaxial line, soldered as shown in Fig. 5.

2. Effects of Metallization on λ'/λ

Some difference was observed between experimental and theoretical values of λ'/λ. Experimental values ususlly exceeded theoretical values by approximately +4% in the case of copper clad (as purchased). The same differences were reported by Jenners in Ref. [4]. He also found +16.5% difference between experimental and theoretical values using Circuit Stik Copper Foil with nonconductive adhesive. This discrepancy between theoretical and experimental values was the motivation for further investigation of the effects of metallization on λ'/λ ratio.

It was decided to construct a slot on a piece of 6" x 3" x 1/8" copper clad (as purchased) substrate for w/d = .54, ε_r = 20. Table II-a lists the experimental results. Comparison between experimental and theoretical values is given in the same table. Experimental values of λ'/λ were in agreement with theoretical values by 2.26 to 5.46 percent.

The copper was removed from the substrate and 3M Copper Tape was applied to one side of the substrate. A slot line of w/d ratio of .52 was constructed in the same way as before. Table II-b lists the experimental results. Agreement between experiment and theory is close with 9 to 12 percent difference. We believe that the reason for this increase of difference between theoretical and experimental in the case of Copper Tape metallization is because the effect of the adhesive is to decrease the effective value

of the dielectric constant with a corresponding increase of the λ'/λ ratio.

Using Aluminum Tape we got almost the same disagreement with the theoretical values of λ'/λ as when using Copper Tape, as shown in Table II-c. This result shows once more the effect of the adhesive on the dielectric constant.

In order to confirm the effect of the adhesive in the λ'/λ ratio, copper was vacuum deposited on the same substrate used before. The film was good enough to use photo-etching techniques and a slot of w/d = .516 was constructed. The transition now was soldered with indium because of the thin film of copper.

The values of λ'/λ obtained using the vacuum deposition technique of metallization are 2.5 to 3.5 percent less than theoretical as shown in Table II-d.

As a further convenience the data points given in Tables II-a, b, c, d are reproduced in graph form in Fig. 6.

To conclude, measurements of the copper film was taken for the different kinds of metallization. Also, it was possible to obtain measurements of the thickness of the adhesive. Measurement of the different thicknesses are summarized as follows in Table I.

From the results of Table I we can see that in those cases in which Copper with pressure sensitive adhesive is used, the λ'/λ ratio is always greater than the theoretical value.

TABLE I

Metalization	Thickness of Metal Film	Range Error
1. Copper clad (as purchased)	.00115" ± .00001"	+ 5.46% to 1.63%
2. Copper tape (with adhesive)	.00315" ± .001"	+13.10% to 11.43%
Copper tape (without adhesive)	.00125" ± .00002"	
Adhesive film (copper tape)	.0019"	
3. Aluminum tape (with adhesive)	.00375" ± .0002"	+13.33% to 9.33%
Aluminum tape (without adhesive)	.00195" ± .0001"	
Adhesive film (aluminum tape)	.0018"	
4. Copeer foil Non-conductive (with adhesive)	.00345" ± .0015"	+5.88% to 18.65%
Copper foil Non-conductive (without adhesive)	.00115" ± .00015"	
Adhesive film (copper foil non-conductive)	.0023"	
5. Copper foil "Conductive" (with adhesive)	.00345 ± .0002"	+27.98% to 24.8%
Copper foil "Conductive" (without adhesive)	.00125 ± .0002"	
Adhesive film	.0022"	
6. Evaporated copper film	.00065 ± .00015"	-3.87% to -2.5%

Copper Clad as purchased and evaporated Metallization are the cases which do not use adhesive film and the values of λ'/λ are in close agreement with theoretical, generally about 3 percent or better.

3. Effect of Varying Slot Width (w) on λ'/λ but w/d Held Constant

Cohn's theory shows how λ'/λ ratio varies with w/d. Our interest is to demonstrate experimentally this theory.

On a .125" ± .002 thick substrate, a slot of w = .0676 ± .0009 was constructed. The w/d ratio was .54 and the range of frequency was 1.5 to 5.5 Ghz. The results of λ'/λ are shown in Table III-a; also in the same table we can see the difference with theoretical values. Next, on a substrate of thickness d = .058" ± .002 a slot of w = .0317" ± .0004 was constructed. The w/d ratio was .547 and the frequency range was from 3 to 9 Ghz in order to get similar d/λ ratios. The results appear in Table III-b and also the difference with theoretical. These values have been plotted in Fig. 7 and we can see the close agreement of λ'/λ ratio. The difference may be due to the kind of metallization used; copper clad as purchased in one case and evaporated in the other.

TABLE II-A

Description	f (GHz)	D/λ	λ'/λ (Exp)	λ'/λ (theor)	Error $\frac{0}{100}$
ε_M = 20	1.5	.0158	.3955	.3750	+5.46
Custom High	2.0	.0210	.3660	.3600	+1.67
K-707-20	2.5	.0264	.3560	.3510	+4.26
	3.0	.0317	.3560	.3420	+4.10
w = .0676" ± .002	3.5	.0372	.3480	.3320	+4.80
D = .125" ± .002	4.0	.0422	.3420	.3270	+4.59
$\frac{w}{D}$ = .54	4.5	.0475	.3350	.3200	+4.70
	5.0	.0528	.3320	.3150	+5.39
No adhesive	5.6	.0580	.3170	.3100	+2.26

TABLE II-b

Description	f (GHz)	D/λ	λ'/λ (Exp)	λ'/λ (theor)	Error $\frac{0}{100}$
ε_r = 20	1.5	.0159	.418	.375	+11.46
Copper tape	2.06	.0218	.404	.360	+12.22
w = .0654 .0025	2.50	.0265	.397	.351	+13.10
	3.00	.0317	.386	.342	+12.87
$\frac{w}{D}$ = .52	3.50	.0370	.375	.332	+12.95
Adhesive film .0018"	4.00	.0423	.369	.327	+12.84
	4.50	.0476	.360	.320	+12.50
	5.00	.0529	.351	.315	+11.43

TABLE II-c

Description	f (GHz)	D/λ	λ'/λ (Exp)	λ'/λ (theor)	Error $\frac{0}{100}$
$\varepsilon_r = 20$	1.50	.0159	.410	.375	+9.33
Aluminum tape	2.06	.0218	.408	.360	+13.33
w = .0688" ± .0023	2.50	.0265	.383	.351	+11.96
	3.00	.0317	.382	.342	+.1169
$\frac{w}{D} = .55$	3.50	.0370	.371	.332	+11.75
Adhesive film .0018"	4.00	.0423	.365	.327	+11.62
	4.50	.0476	.361	.320	+12.81
	5.00	.0529	.350	.315	+11.11
	5.50	.0582	.345	.310	+11.29

TABLE II-D

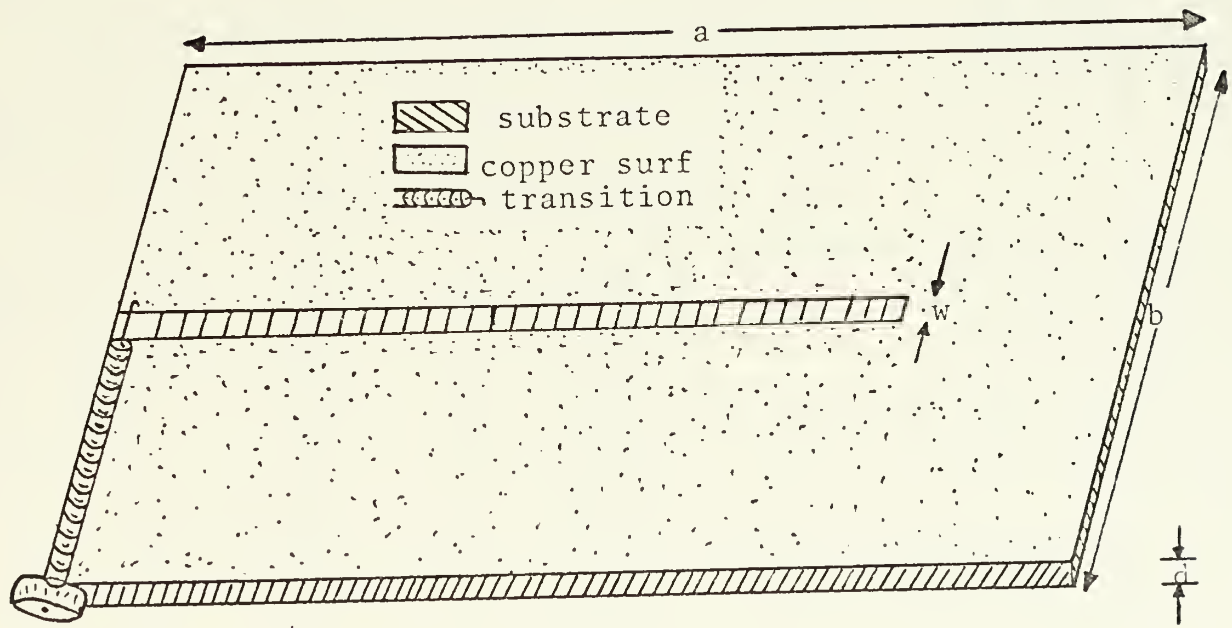
Description	f (GHz)	D/λ	λ'/λ (Exp)	λ'/λ (theor)	Error $\frac{0}{100}$
$\varepsilon_r = 20$	1.5	.0159	.361	.375	-3.7
Evaporated copper	1.993	.0211	.351	.360	-2.5
w = .0644 ± .0045	2.50	.0265	.338	.351	-3.7
	3.00	.0317	.330	.342	-3.5
$\frac{w}{D} = .516$	3.50	.0370	.322	.332	-3.0
No adhesive	4.00	.0423	.318	.327	-2.75
	4.50	.0476	.309	.320	-3.43
	5.00	.0529	.305	.315	-3.17
	5.50	.0582	.298	.310	-3.87

TABLE III-a

Description	f (GHz)	D/λ	λ'/λ (Exp)	λ'/λ (theor)	Percent Difference
$\varepsilon_r = 20$	1.5	.0158	.3955	.3750	+5.46
Custom High -	2.0	.0210	.3660	.3600	+1.67
K-707-20	2.5	.0264	.3660	.3510	+4.26
	3.0	.0317	.3560	.3420	+4.10
w = .0676" ± .0009"	3.5	.0372	.3480	.3320	+4.80
D = .125" ± .002"	4.0	.0422	.3420	.3270	+4.59
$\frac{w}{D}$ = .54"	4.5	.0475	.3350	.3200	+4.70
	5.0	.0528	.3320	.3150	+5.39
a =	5.6	.0580	.3170	.3100	+2.26
b =					

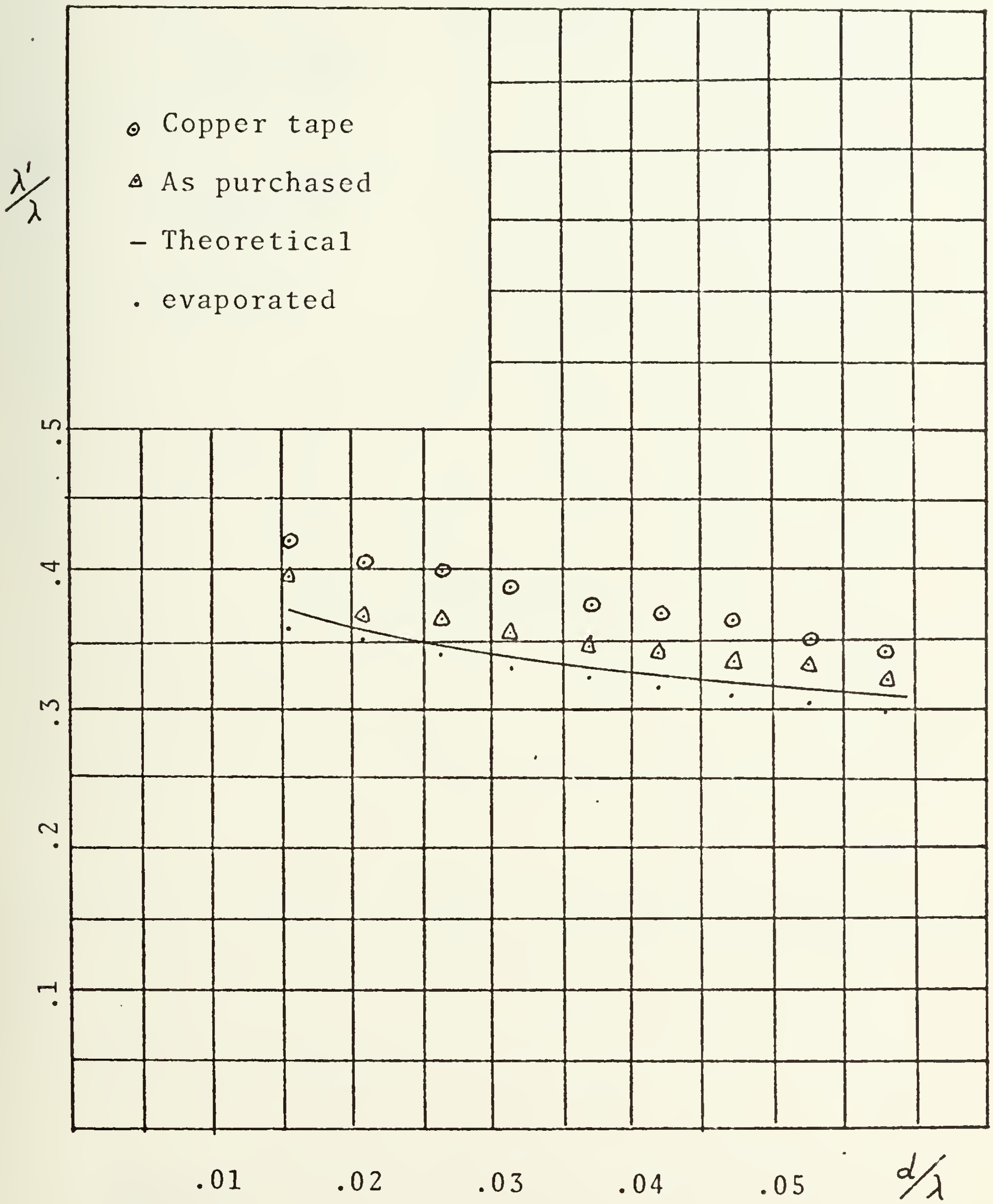
TABLE III-b

Description	f (GHz)	D/λ	λ'/λ (Exp)	λ'/λ (theor)	Percent Difference
$\varepsilon_r = 20$	3	.0147	.358	.378	-5.30
Evaporated	4	.0196	.348	.366	-4.90
w = .0317" ± .0004	5	.0245	.338	.355	-4.79
	6	.0294	.328	.346	-5.20
D = .058" ± .002	7	.0343	.322	.338	-4.73
w/D = .547	7.92	.0387	.307	.331	-7.21
a =	9	.0441	.302	.325	-7.06
b =					



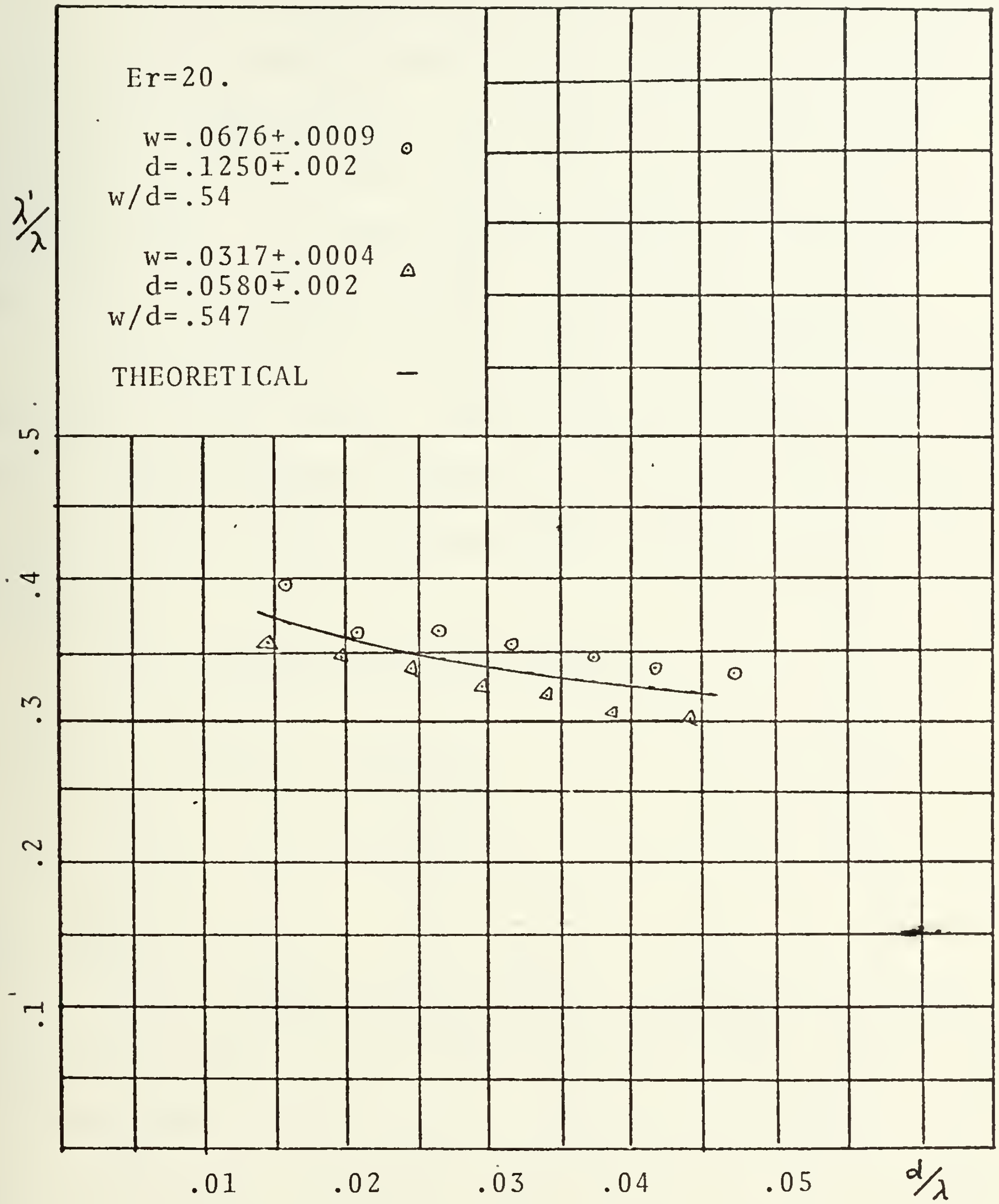
SHORT CIRCUIT SLOT LINE

Figure 5.



METALLIZATION EFFECTS IN SLOT LINES

Figure 6



EFFECT OF VARYING SLOT WIDTH (W) BUT W/D HELD CONSTANT.

Figure 7

B. END EFFECTS

1. Inductive Discontinuity Effect of the Shorted Slot

In ordinary transmission line theory it is possible to study the behavior and characteristics of the short-circuited line without end effects if the short circuit is an image plane. No corresponding freedom is possible in the case of the open-circuited termination.

As a theoretical illustration consider the ordinary line with a short circuit image plane positioned at the null points of the voltage distribution along the line as shown in Fig. 8. The normalized impedance looking either right or left is

From transmission line theory:

$$Z_i/Z_o = j \tan B_z$$

$$= j \tan \frac{2\pi}{\lambda'} z$$

$\frac{Z_i}{Z_o} = 0$ for values of $z = n\lambda'$ for $n = 0, 1/2, 1, \ldots$

In the experimental work we do not have an image plane at the short circuit end--we have a short circuit slot line termination printed on the substrate as shown in Fig. 5, and the effect of this short termination is that the voltage does not go to zero at the position of the end wall, and the distance $\lambda'/2$ taken between two null positions is greater than the distance between the short wall and the first null, as shown in Fig. 8b.

The conclusion is that the short circuit slot line has some inductive shift of minimums, whereas there is no shift in the case of its termination in a conductive image plane. $\frac{Z_i}{Z_o}$ is now:

$$Z_i/Z_o = -j \tan\left\{\frac{2\pi}{\lambda'}\left(\frac{\lambda'}{2} - \Delta Z\right)\right\}$$

$$= +j \tan\frac{\pi\Delta Z}{\lambda'} \simeq +j\ \frac{\pi\Delta Z}{\lambda'} \quad \text{(for small } \Delta Z)$$

2. Experiment

The effect that the voltage does not go to zero at the short wall was proved experimentally for two different frequencies--1 GHz and 4 GHz as shown in Fig. 9.

Obviously the reactances for these two cases are different. The next step was to study how the reactance changed with the frequency for a given value of ε_r and different values of w/d ratio. Readings were observed for $\varepsilon_r = 12$ and 20 with w/d ratios of .221, .56, .892 and .207, .54, .865 respectively. The frequency range was 1.5 GHz to 5.5 GHz. Tables IV-a-f show the experimental values of reactance vs. frequency.

Figures 10 and 11 show the data graphically.

The results of this experiment to show the end effects of a short circuited s t line is that the reactance appears to increase almost linearly with a slight upward curvature with increasing frequency. Also we can see from the graphs that for a given frequency the reactance is greater for larger ε_r and w/d ratio.

TABLE IV-a

Description	freq. GHz	D/λ	$\lambda'/2$ cm	ΔZ	$\Delta Z/\lambda'$	Norm-Reactance $j \tan 2\pi\Delta Z/\lambda'$
$\varepsilon_r = 20$	1.025	.0106	5.81	.10	.0086	.0540
w=.0258"±.0023"	1.50	.0159	3.84	.12	.0156	.0985
d=.125"±.0005	1.918	.0210	2.87	.12	.0209	.132
	2.50	.0265	2.22	.12	.0270	.171
$\frac{w}{D} = .207$	3.00	.0317	1.815	.135	.0372	.238
Custom High -	3.52	.0373	1.53	.12	.0392	.251
K-707-20	4.00	.0422	1.33	.12	.04511	.291
Copper Clad as purchased	4.50	.0475	1.17	.13	.0556	.364
	5.00	.0528	1.03	.13	.0631	.419

TABLE IV-b

Description	freq. GHz	D/λ	$\lambda'/2$ cm	ΔZ	$\Delta Z/\lambda'$	Norm-Reactance $j \tan 2\pi\Delta Z/\lambda'$
$\varepsilon_r = 20$	1.055	.01081	5.6	.14	.0125	.079
w=.0676±±0009	1.50	.0158	3.955	.185	.0234	.148
d=.125 ±.0005	2.00	.021	2.75	.15	.0273	.173
	2.50	.0264	2.15	.15	.0349	.223
$\frac{w}{D} = .54$	3.00	.0317	1.78	.16	.0449	.290
Custom High	3.50	.0372	1.49	.18	.0604	.400
K-707-20	4.00	.0422	1.28	.16	.0625	.414
Copper Clad as purchased	4.50	.0475	1.12	.17	.0759	.517
	5.00	.0528	1.00	.16	.0800	.550
	5.60	.0580	.85	.14	.0824	.570
	6.00	.0640	.78	.15	.0961	.690

TABLE IV-c

Description	freq. GHz	D/λ	$\lambda'/2$ cm	ΔZ	$\Delta Z/\lambda'$	Norm-Reactance $j \tan 2\pi\Delta Z/\lambda'$
$\varepsilon_r = 20$	1.50	.0158	3.980	.23	.0289	.183
w=.108"±.002	1.90	.020	3.045	.185	.0304	.193
D=.125±.0005	2.50	.0264	2.235	.185	.0414	.266
	3.00	.0317	1.815	.195	.0537	.350
$\frac{w}{D} = .865$	3.50	.0372	1.52	.190	.0625	.414
Custom High K-707-20	4.00	.0422	1.29	.190	.0737	.500
	4.50	.0475	1.11	.190	.0856	.596
Copper Clad as purchased	5.00	.0528	.985	.195	.099	.716

TABLE IV-d

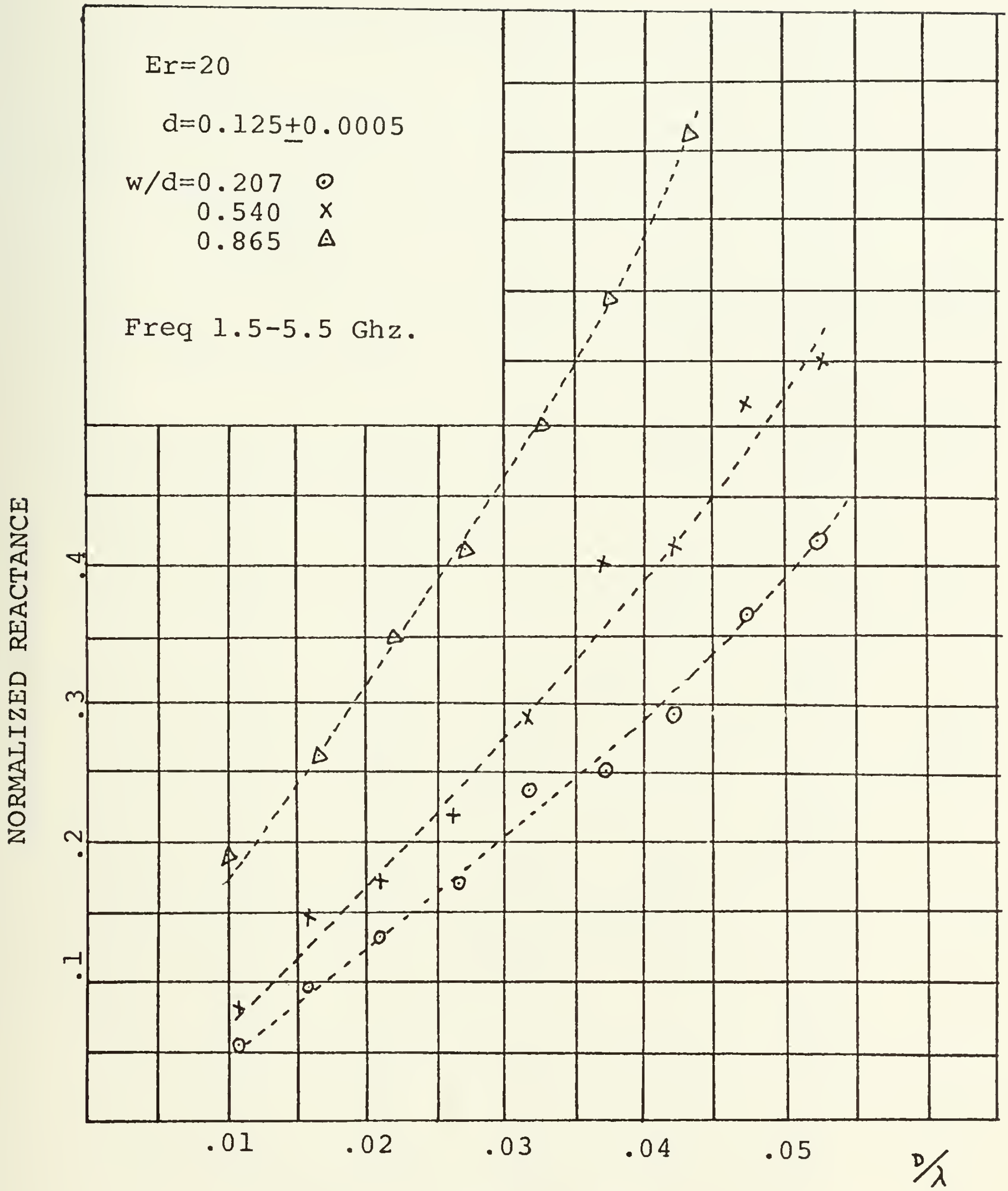
Description	freq. GHz	D/λ	$\lambda'/2$ cm	ΔZ	$\Delta Z/\lambda'$	Norm-Reactance $j \tan 2\pi\Delta Z/\lambda'$
$\varepsilon_r = 12$	2.50	.0256	2.795	.105	.0188	.119
w=.0269±.0028	3.00	.0306	2.285	.095	.0208	.131
	3.50	.0359	1.940	.090	.0232	.147
D=.121"±.001	4.00	.0408	1.680	.100	.0298	.189
$\frac{w}{D} = .221$	4.50	.0460	1.480	.090	.0304	.193
Custom High K-707-12	5.00	.0510	1.300	.090	.0339	.216
	5.50	.0561	1.190	.090	.0378	.242
Copper Clad as purchased	6.00	.0611	1.075	.095	.0442	.285
	6.50	.0671	.97	.090	.0464	.300

TABLE IV-e

Description	freq GHz	D/λ	λ'/2 cm	ΔZ	ΔZ/λ'	Norm-Reactance j tan 2πΔZ/λ'
ε_r = 12	2.50	.0255	2.85	.15	.0263	.166
w=.0679±.003	3.00	.0306	2.31	.14	.0303	.193
	3.50	.0357	1.96	.15	.0383	.242
D=.121±.002	4.00	.0408	1.69	.14	.0404	.266
$\frac{w}{D}$ = .56	4.50	.0460	1.47	.13	.0443	.285
Custom high	5.00	.0510	1.30	.13	.0500	.325
K-707-12	5.50	.0561	1.17	.13	.0555	.364
Copper Clad as purchased	6.00	.0611	1.056	.126	.0600	.395

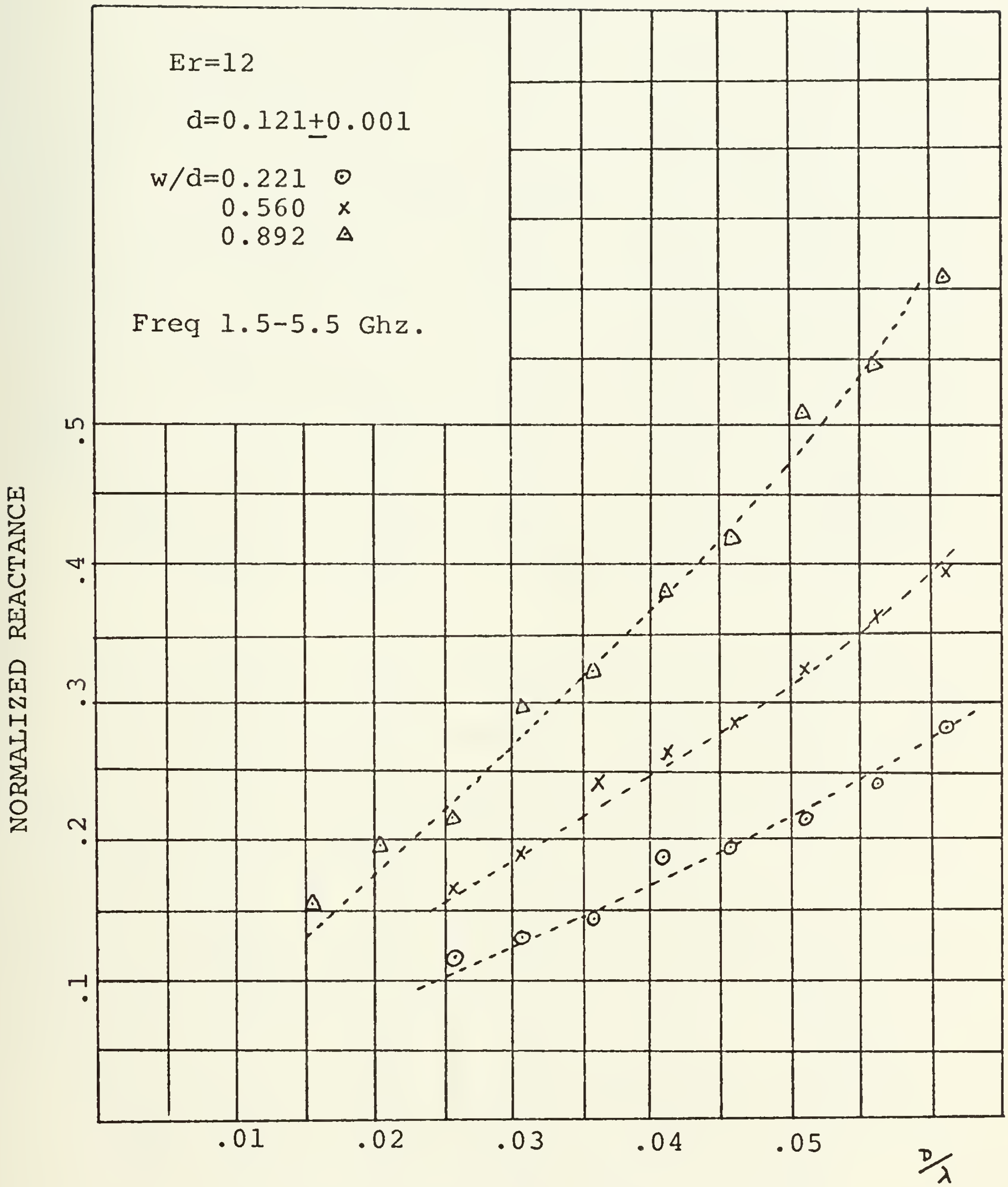
TABLE IV-f

Description	freq GHz	D/λ	λ'/2 cm	ΔZ	ΔZ/λ'	Norm-Reactance j tan 2πΔZ/λ'
ε_r = 12	1.50	0.0153	5.10	.25	.0245	.155
w=.108±.003	2.00	0.0205	3.72	.23	.0309	.197
	2.50	0.0256	2.895	.195	.0337	.215
D=.121±.001	3.00	0.0306	2.38	.22	.0462	.299
$\frac{w}{D}$ = .892	3.50	0.0359	2.00	.200	.0500	.325
Custom high	4.00	0.0408	1.72	.200	.0581	.382
K-707-12	4.50	0.0460	1.50	.190	.0633	.420
Copper Clad as purchased	5.00	0.0510	1.33	.200	.0752	.511
	5.50	0.0561	1.19	.190	.0798	.548
	6.00	0.0611	1.065	.185	.0869	.608



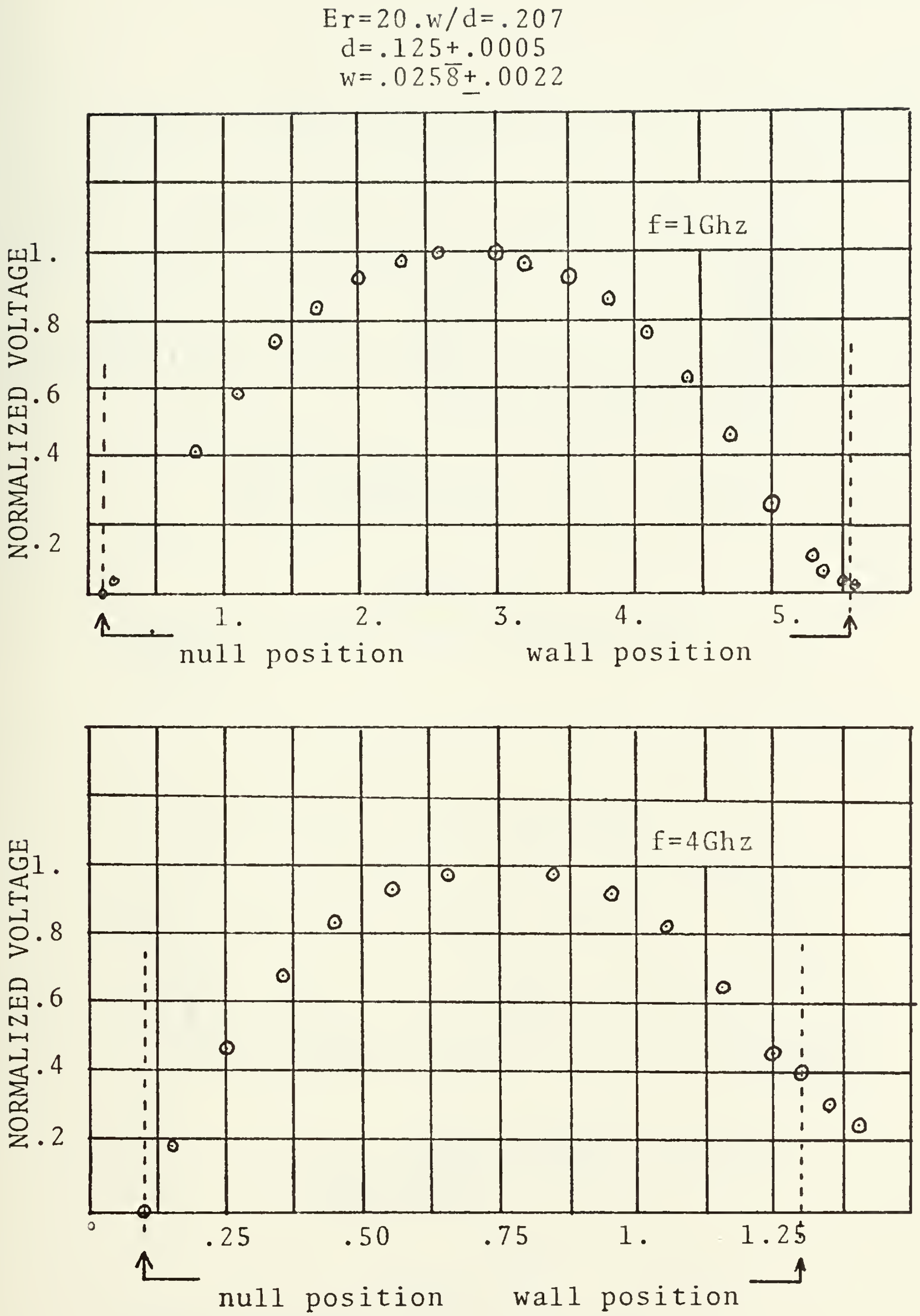
REACTANCE VARIATION WITH W/D RATIO

Figure 11



REACTANCE VARIATION WITH W/D RATIO

Figure 10



EXPERIMENTAL NORMALIZED VOLTAGE DISTRIBUTION

Figure 9

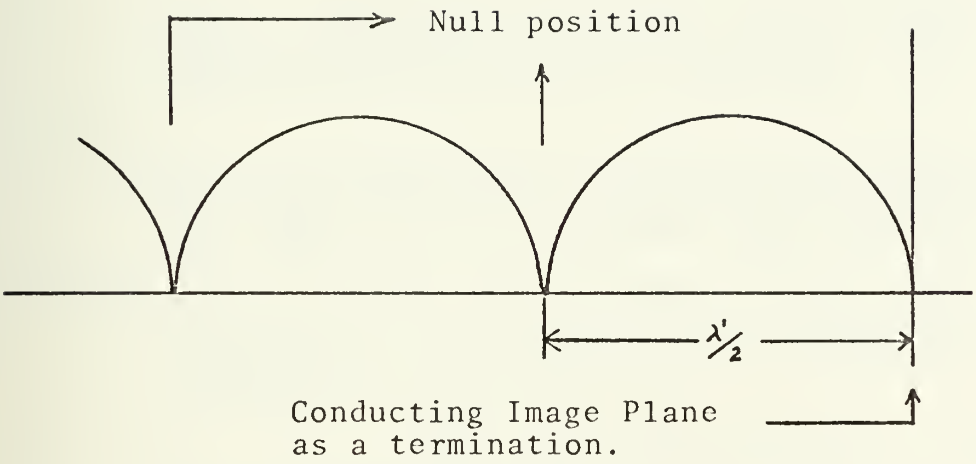


Figure 8a

SHORT CIRCUITED LINE WITHOUT END EFFECTS.

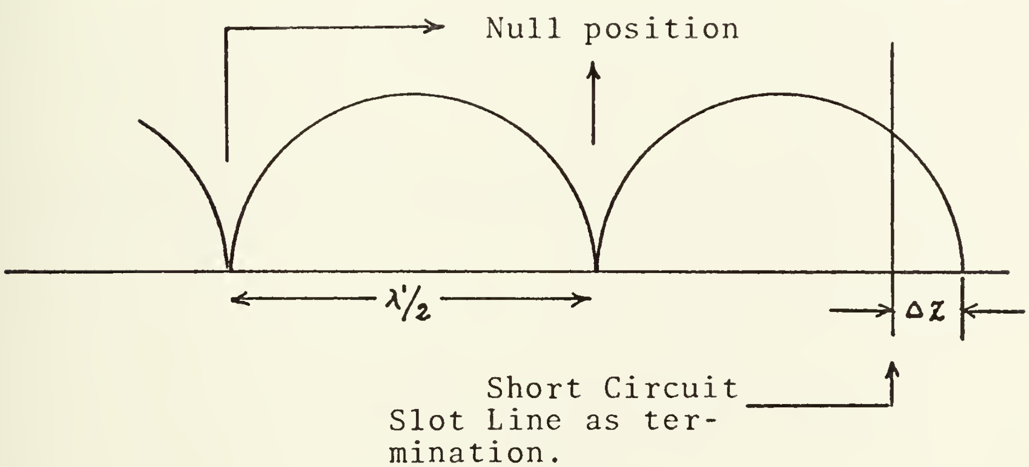


Figure 8b

SHORT CIRCUITED SLOT LINE WITH INDUCTIVE SHIFT.

Figure 8

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13. ABSTRACT

An investigation of several slot line effects is reported. Various metallizations have been tested and experimental data is presented which shows that surface metal adhesive causes an increase in slot wavelength. End effect in a shorted slot was also studied and experimental data is presented showing the inductive nature of this termination.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
SLOT LINE INVESTIGATION						

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