INVESTIGATION OF FERRITE PHASE-SHIFTERS AT C- AND X-BAND

FINAL REPORT

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ELECTRONICS LABORATORY
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GENERAL ELECTRIC
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INVESTIGATION OF FERRITE PHASE SHIFTERS AT C- AND X-BAND

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This report is subdivided into three parts, each with its own page numbers, references, etc. These parts are:

I. Phase Shifter Development
by Robert Seckelmann

II. Non-Linear Losses in Ferrites
by Edward J. McKinney

II. Propagation of TE Modes in Dielectrically Loaded Rectangular Waveguides
by Robert Seckelmann

Part I. contains data on the experimental work and general acknowledgements.

Part II. and Part III. are theoretical studies.

PART I. PHASE SHIFTER DEVELOPMENT

ABSTRACT

The phase shifters discussed are nonreciprocal. They contain circumferentially magnetized ferrite cylinders, which work at remanence. The differential phase shift is controlled by partial magnetization of the ferrite, achieved by controlled flux transfer. Three problems, common to all such phase shifters are dealt with:

1. The efficiency of flux transfer and the possibility to add flux bits. Experimental data and a theory in agreement with these data are presented.

2. The determination of r-f magnetic threshold fields above which the losses of ferrites increase with field strength. The threshold is calculated from the measured threshold power of guides completely or in part filled with ferrite.

3. The influence of waveguide and ferrite dimensions on the frequency dependence of the differential phase shift, on the proportionality between phase shift and transferred flux, and on the peak power handling capability is investigated experimentally. Slabline and waveguide type devices have been used.

I. PROJECT OUTLINE

The object of the program reported here was to demonstrate the feasability of non-reciprocal multibit latched ferrite phase shifters for frequencies in the 4 - 12 GHz range, capable of handling peak powers of 10 KW and controlled by flux transfer techniques.

Tentative goals were set in contract review conferences during the initial phase of the development as follows:

- Investigate slabline and waveguide type devices
- Switch in four bits (180°, 90°, 45°, 22.5°)
- Achieve at least 360°/dB
- Drive with 500 μjoules or less per switching cycle
- Allow for a switching cycle approximately 5 μsec.
- Understand the trade-offs between the various parameters and formulate design rules

The phase shifter requirements could have been fulfilled by using four ferrite bits of different lengths along the axis of the device and switching them between their largest negative remanent magnetization and some positive remanent magnetization smaller than the largest one by means of controlled flux transfer to secure a phase shift independent of temperature.(1) In review conferences, however, the investigators were encouraged to pursue their idea to achieve several bits of differential phase shift by using only one bit of ferrite along the axis of the device and to control the phase shift by controlling the state of magnetization of this ferrite. Consequently a device very close to an analogue phase shifter has been developed. This second approach requires a much tighter control of the field distribution in the device and imposes more restrictions on the ferrite and guide shape than the first approach would have done.

Flux transfer circuits have been analyzed theoretically and the theory has been found to be in good agreement with experimental data. Circuits have been designed to add phaseshift bits by adding flux bits.

The phase shifters and the systems using them could be considerably simpler, if it were possible to eliminate some of the switching wires. This should be possible by supplying to the phase shifter voltage pulses of constant height (voltage) and variable length (time). Ideas for such circuits - temporarily called "analogue drivers" - have been conceived during the last phase of the contract, but have not yet been tested. An electronic driver of very small volume and steered by a computer could be incorporated in the phase shifter. Whereas now such a computer has to select - in the case of a four bit phase shifter - any of 16 bit combinations, it would then select any of 16 times, during which it would activate the driver. All phase shifters studied use round ferrite cylinders. The devices have too complex a geometry to be directly dealt with mathematically. Rectangular waveguides with dielectric slabs parallel to the narrow guide walls serve as more or less crude analytical models. The propagation of TE modes in these loaded guides has been studied in detail. Numerical results for a large range of parameters are given in Part III of the report. They will also be published as a G.E. TIS Report. The computer program to obtain these data was financed in part by this contract. The slabline type phase shifter performance could be explained nicely in terms of TE modes in dielectrically loaded rectangular waveguides. The computer results were also used to evaluate tests to determine the threshold field strength for the onset of non-linear losses in a rectangular waveguide containing a ferrite slab.

The differential phase shift versus flux dependence led to a model for magnetization of ferrite toroids, which in turn led to a reciprocal TEM phase shifter controlled by partial magnetization. This reciprocal phase shifter has been tested in one of the high power test structures.

The development of high-power ferrites is covered by other contracts. Here the influence of the device geometry on the on-set of non-linear losses was considered. The requirements were met, and results encouraging the development of phase shifters capable to handle higher peak powers, say 50-100 KW were obtained. An effort has been made to understand and predict the onset of non-linear losses in ferrites of arbitrary shape. A theoretical study is given as part II of this report. This treatise includes the results obtained by other workers with more restricted models. At the moment, however, it cannot be used to its full extent because not all parameters could be determined in experiment.

Figures of merit of more than 400°/dB have been obtained throughout the development. Nearly octave bandwidths with only a few percent variation in differential phase shift have been obtained in waveguide type phase shifters. The highest peak power handling capability, the broadest bandwidth and proportionally between differential phase shift and flux transferred have, however, not been obtained simultaneously. Trends have been found for the optimization of each characteristic, but the trade-offs are not fully understood. Nearly all parameters are mutually dependent (e.g. ferrite wall thickness, diameter. waveguide height and width, filling factor).

The project was started with three parallel efforts:

to investigate flux transfer circuits
to study the onset of non-linear losses in ferrites
to develop phase shifters at low powers.

In the second half of the project the flux transfer investigation was replaced by an effort

to develop driver circuits

Finally, the phase shifters were tested with high peak power pulses. The different efforts will now be described in the order given above.

II. CONTROL OF FLUX-TRANSFER

A flux transfer circuit is shown in Figure 1. R is a variable resistor in the circuit. $C_D = C_1, \ldots, C_n$ are n "driver" cores (index D) of various sizes, which are switched from negative to positive saturation magnetization or the corresponding remanent magnetization. C is the "microwave" core (no index), which produces the differential phase shift. For both, the driver and the microwave core the simple BH-loops of Figure 1 are used to analyze the transfer circuit. B is the flux density and H is the magnetic field strength.

In an unmagnetized ferrite core the magnetic dipoles are randomly oriented. There exist domains for any orientation. In a core saturated by sending a strong current pulse through the core the ferrite is circumferentially magnetized. Sending now an increasing current in opposite direction through the core, one reverses gradually the sense of circumferential magnetization. Two models to describe the magnetizing process may be used. In a "many shells" model the ferrite may be looked upon as consisting of many successive, very thin, laminar layers. A magnetizing current will either not change the state of magnetization of a particular shell or drive it to saturation magnetization. According to this model, an increasing d.c. current would at first "switch" the inner ferrite rings, then the outer ones. An a.c. current with decreasing amplitudes would produce a sequence of circumferentially magnetized ferrite shells with alternating directions of magnetization. In a "one shall" model the magnetization would be homogeneous throughout the ferrite wall and can vary from complete spin alignment in one direction to random spin orientation to complete alignment in the other circumferential direction, depending on the driving conditions. An a.c. current pulse with decreasing amplitudes sent through a "switching" wire through the axis of the ferrite core would demagnetize the ferrite, i.e. randomly orient the spins. It is felt that often a super position of a "many shells" and a "one shell" model will offer the best explanation of effects. Assuming for the ferrite a simplified BH loop as shown in Figure 1, the shell thickness would be given approximately by $r_1'/r_2' = H_k/H_s$ where r_1', r_2' are the radii of the layer switched (with $r_1 \le r_1' \le r_2' \le r_2$ and r_1, r_2 the inner and outer core radii).

Dynamic permeabilities $\mu = dB/dH$ are defined by

$$\mu^{(V)} = B_s/(H_s - H_c), \quad \mu_D^{(V)} = B_{Ds}/(H_{Ds} - H_{Dc}) \qquad (1a)$$

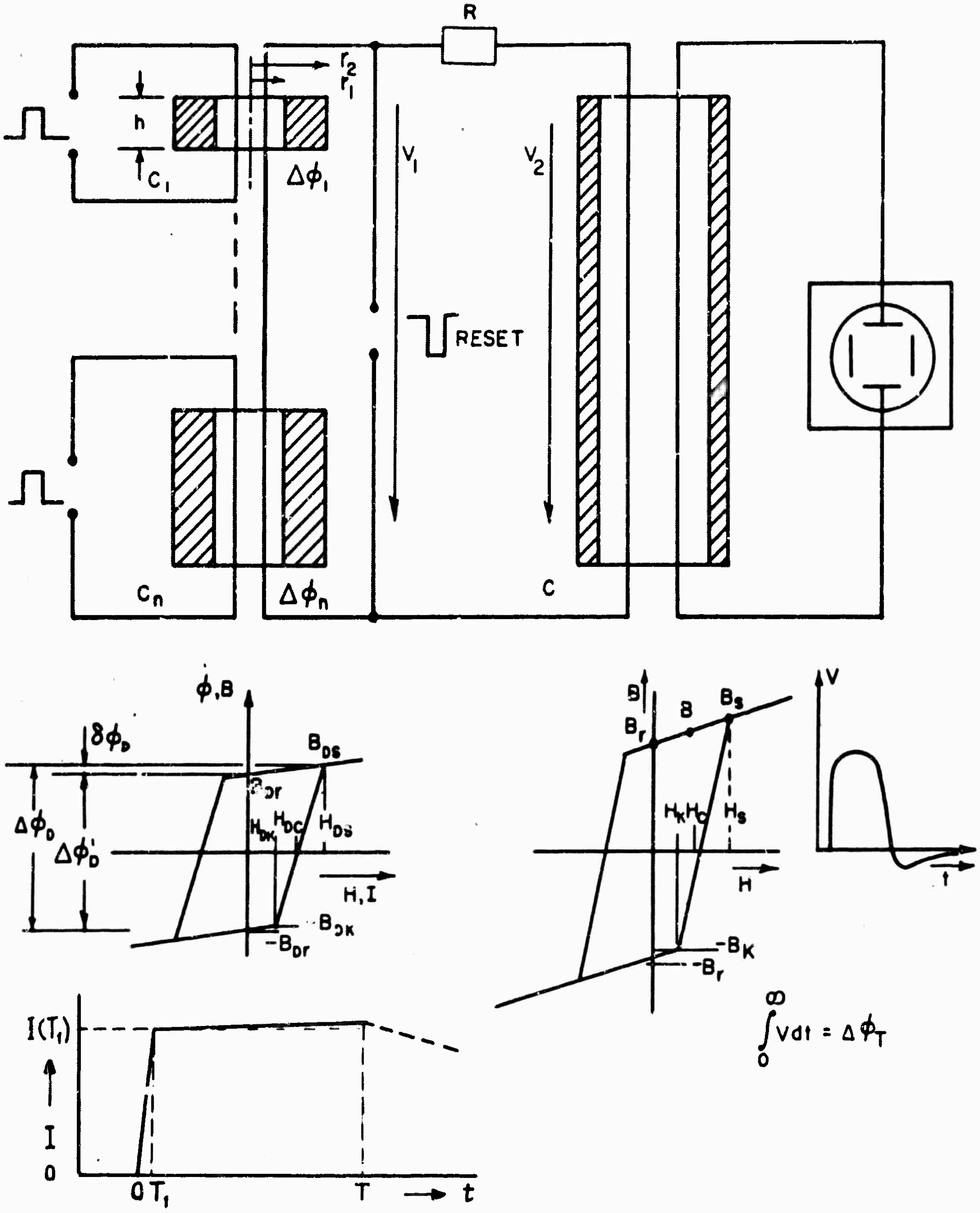
$$\mu^{(H)} = (B_s - B_r)/H_s, \quad \mu_D^{(H)} = (B_{Ds} - B_{Dr})/H_{Ds} \qquad (1b)$$

and dynamic inductances with the core height h by

$$L = d\phi/dI = \mu \; h \; \ln\,(r_2'/r_1')/2\pi \qquad (2)$$

$A' = h(r_2' - r_1')$ is the area of a particular core, in which the flux it changed by

$\Delta\phi = \Delta B \cdot A'$, with $A'_{max} = A$.



FLUX TRANSFER SWITCHING TECHNIQUE

FIGURE 1.

Before a switching cycle begins, a reset pulse drives both the driver and the microwave core to saturation and subsequently to the corresponding remanent state. Let this be the negative state for both cores, $-B_r$ and $-B_{Dr}$, respectively. The driver core is now driven to B_{Ds} and then falls back to $B_{Dr} = B_{Ds} - \delta B_D$, the remanent state. It feeds the transfer circuit with an approximately rectangular voltage pulse of height (voltage) V_1 and length (time) T, followed by a pulse with a relatively small negative peak voltage. T is proportional to the length of the driver core. The available flux is

$$\Delta\phi_D' = 2B_{Br} A = \Delta\phi_D - \delta\phi_D, \quad \Delta\phi_D = \int_0^T V_1(t)dt \approx V_1 T \tag{3}$$

Let $\delta\phi_D << \Delta\phi_D$, (with holding current applied or $\mu_D^{(H)} \approx 0$), so that

$$\Delta\phi_D' \approx \Delta\phi_D \tag{4}$$

The flux transferred is

$$\Delta\phi_t = \int_0^\infty V_2(t)dt = \int_0^T V_2(t)dt - \delta\phi \tag{5}$$

$\delta\phi$ is a relatively small contribution caused by the falling back of the microwave core from a value B_1 to $B_1 - \delta B_1$. With $\mu_D^{(H)} \approx 0$, the time constant for this fall back process is given by $L^{(H)}/R$. Let the microwave core be driven to a value $B < B_s$. The transferred flux is for a lossy circuit:

$$\Delta\phi_t \approx \int_0^\infty V_1(t)dt - \int_0^\infty i(t)\, Rdt \tag{6}$$

$$\Delta\phi_t + \delta\phi = \int_0^T V_1(t)dt - \int_0^T i(t)Rdt = \int_0^T L^{(V)}\frac{di(t)}{dt}\, dt \tag{7}$$

so that

$$i(t) = (1 - \exp(-tR/L(t)))\, V_1/R \approx tV_1/L(t) \text{ with } t \le T << L(t)/R$$

Initially, during $0 \le t \le T_1 << T$, the inductivity of the microwave core is $L^{(H)}$. The current in the transfer circuit rises fast as

$$I(t) = (1 - \exp(-tR/L^{(H)}))\, V_1/R \approx tV_1/L^{(H)} \text{ with } t \le T_1 << T \tag{8a}$$

At $t = T_1$ the inductivity becomes $L^{(V)} >> L^{(H)}$, and the transfer current increases only slowly as

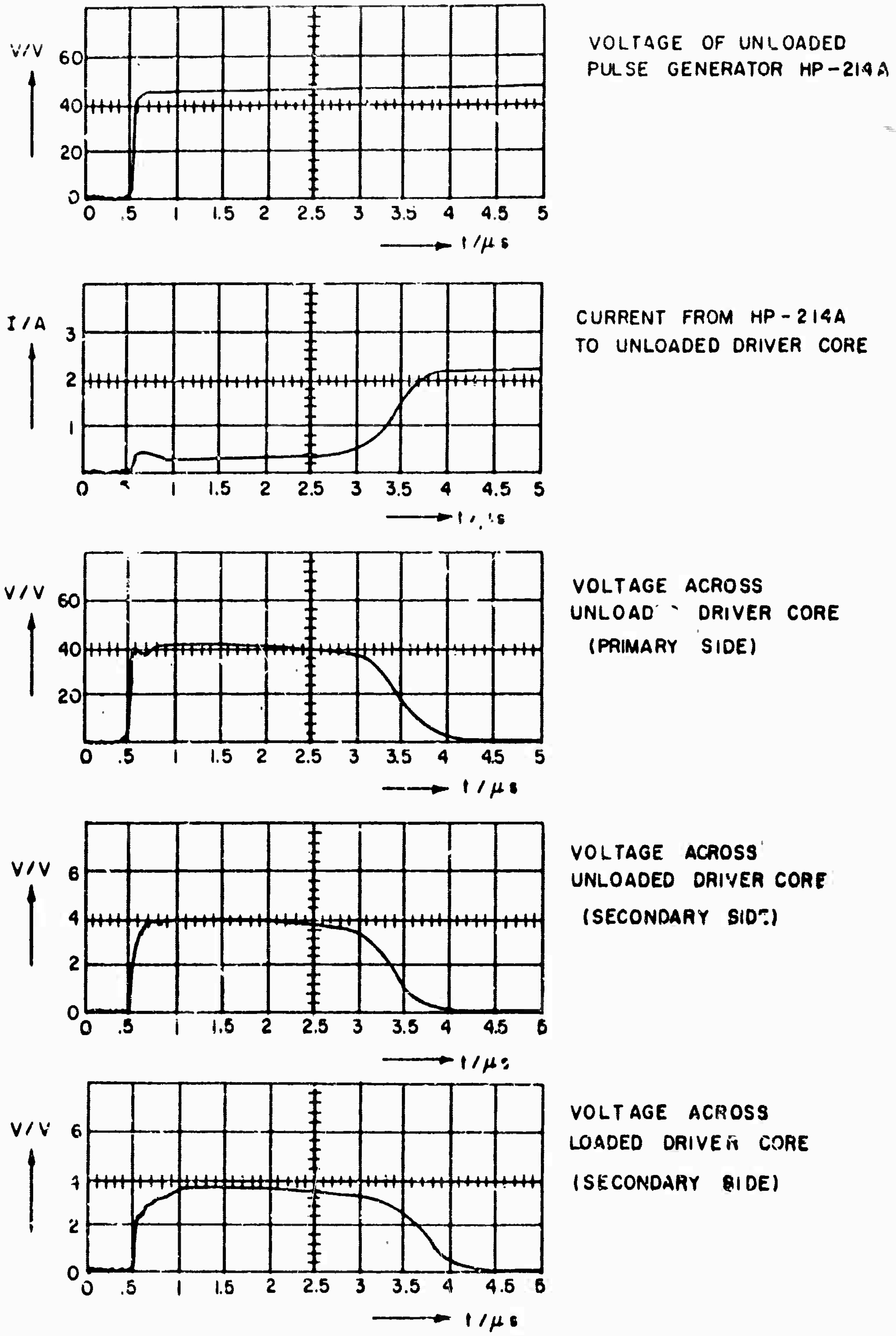
$$\begin{aligned} I(t) &= I(T_1) + (1 - \exp(-(t - T_1)\, R/L^{(V)}))\, (V_1 - I(T_1)R)/R \\ &\approx I(T_1) + (t - T_1)(V_1 - I(T_1)R)/L^{(V)} \approx I(T_1) \\ &\text{with } T_1 \le t \le T << L^{(V)}/R \end{aligned} \tag{8b}$$

A HP 214A pulse generator was used to saturate the driver core. Figure 2 shows the output voltage of the unloaded source, the output voltage of the driver-core-loaded source, the output current of the driver-core-loaded source, the voltage across the secondary side of the driver core (open transfer circuit), the voltage across the secondary side of the driver core (with microwave core applied). One recognizes the fast increase in current (from the source) due to the small inductivity between $-B_{Dr}$ and B_{Dk}, then the slow increase of current due to the large inductivity between $-B_{Dr}$ and B_{Ds} and the fast increase between B_{Ds} and $B > B_{Ds}$. Figure 3 shows the current in the transfer circuit ($R = 0$) and the voltage across the microwave core. The decaying current trail at the end of the current pulse produces a negative voltage across the microwave core, as indicated in Figure 1. In Figure 3 it cannot be seen. It follows the positive voltage pulse and has a very low peak value. Figure 4 shows the voltage V_1 across the driver core for several driver core sizes (with holding current). The driver core supplies an approximately rectangular voltage pulse of height (voltage) V_1 and a width (time interval) T. In Figure 4 V_1 is approximately constant and T proportional to the size of the driver core. It is not necessary to produce the time voltage area V_1T via a driver ferrite. It can also be done electronically. As indicated in Figure 1, the flux loss via ohmic losses during the current rise time T_1 is very small compared with the loss during $T_1 \leq t \leq T$. With this approximation and $T - T_1 \approx T$, the transfer efficiency becomes

$$\eta = (\Delta\phi_t/\Delta\phi_D) \approx 1 - (\delta\phi/\Delta\phi_D) - (RT_1/L^{(V)}) \tag{9a}$$

As long as the microwave core is not saturated $L^{(V)} \sim \Delta\phi_D$. In the "many shells" model this means that only a certain fraction of the total number of laminar layers are switched; in the "one shell" model $L^{(V)}$ is a function of an effective permeability, which increases with driving current.

In Figure 5 the driver and microwave core sizes have been varied by using various numbers (n_D and n_M) of equal ferrite rings for both, the



VOLTAGE OF UNLOADED PULSE GENERATOR HP-214A

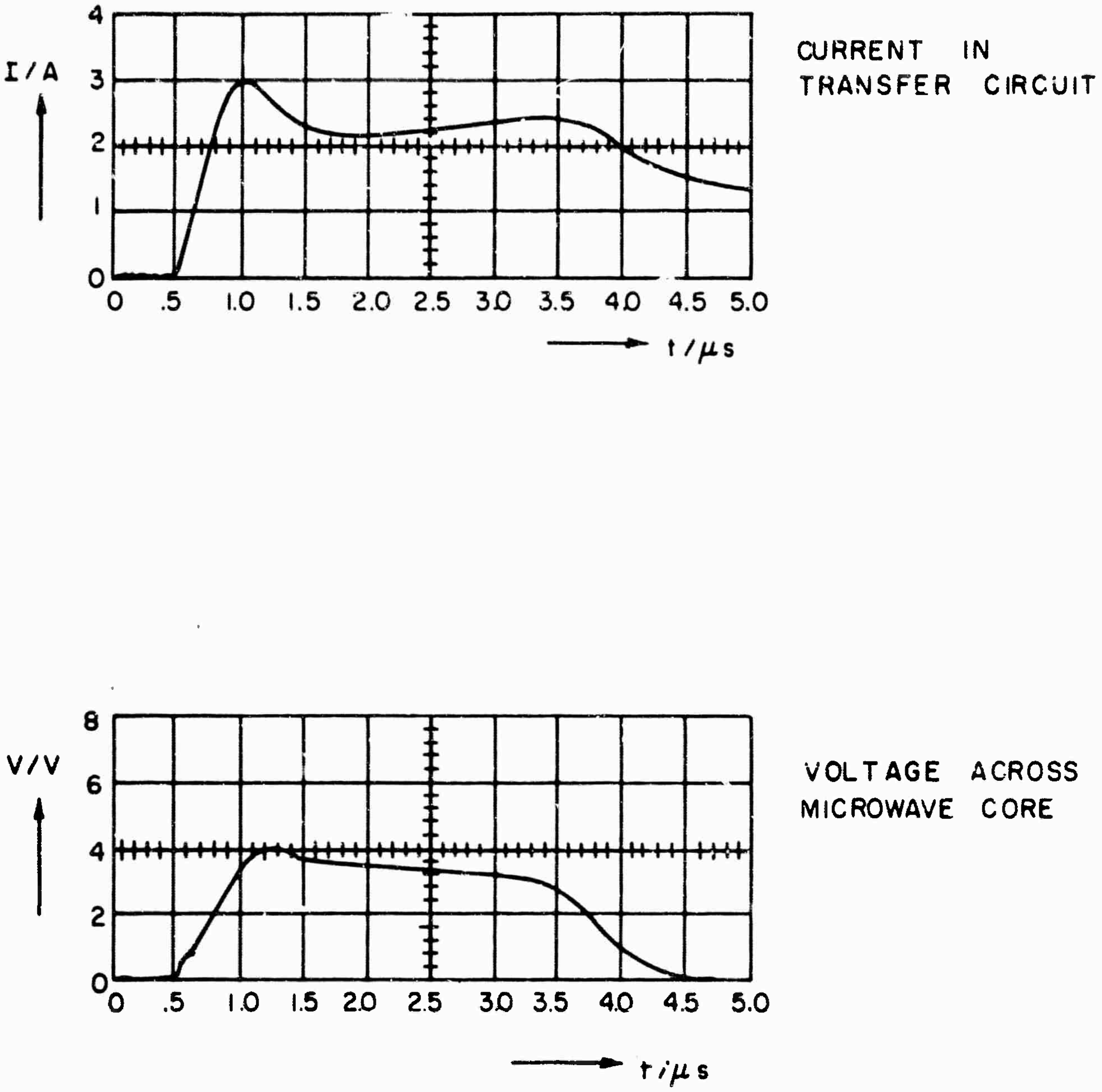
CURRENT FROM HP-214A TO UNLOADED DRIVER CORE

VOLTAGE ACROSS UNLOADED DRIVER CORE (PRIMARY SIDE)

VOLTAGE ACROSS UNLOADED DRIVER CORE (SECONDARY SIDE)

VOLTAGE ACROSS LOADED DRIVER CORE (SECONDARY SIDE)

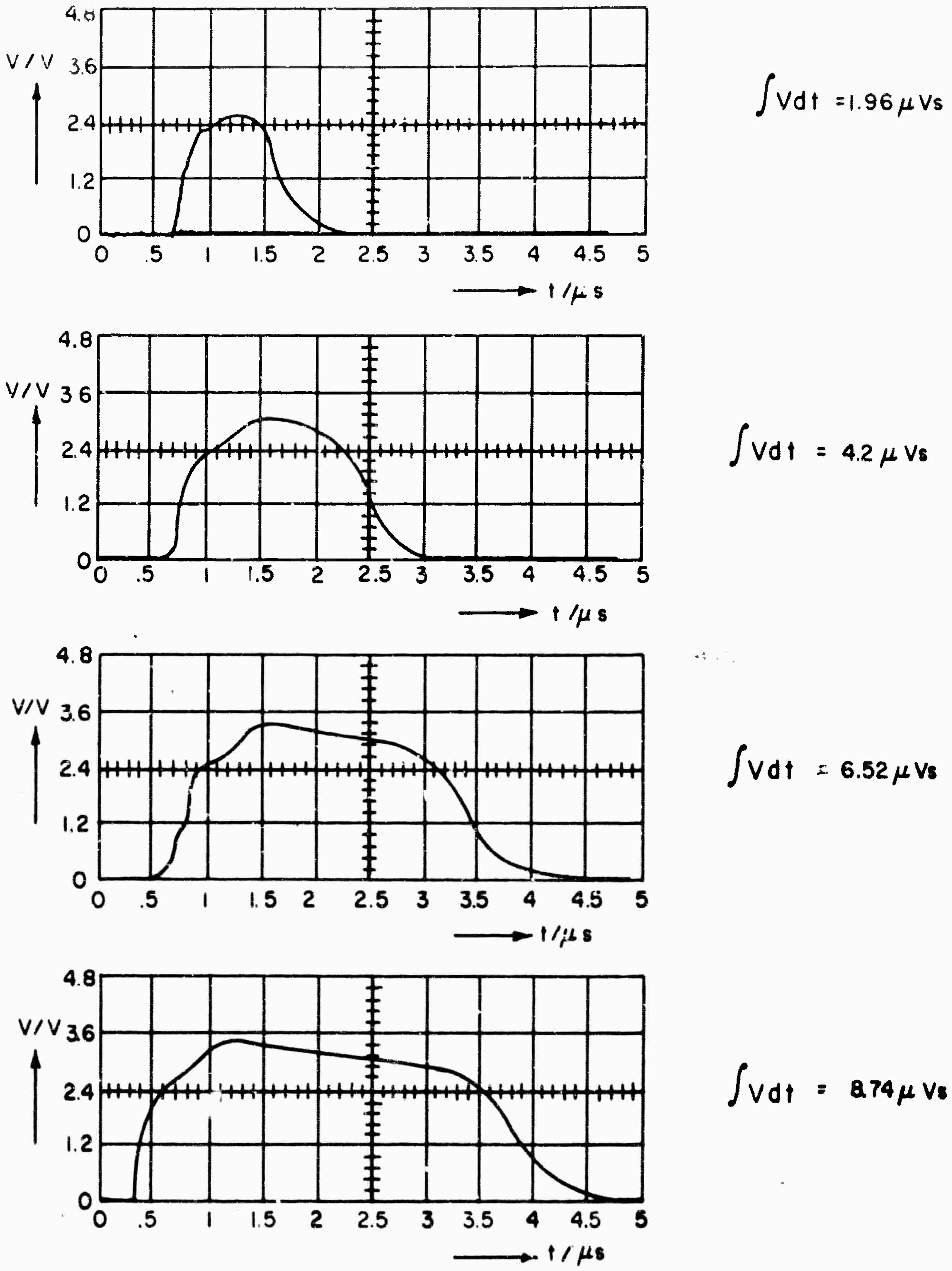
FIG. 2 VOLTAGE AND CURRENT OF DRIVER CORE


CURRENT IN TRANSFER CIRCUIT

VOLTAGE ACROSS MICROWAVE CORE

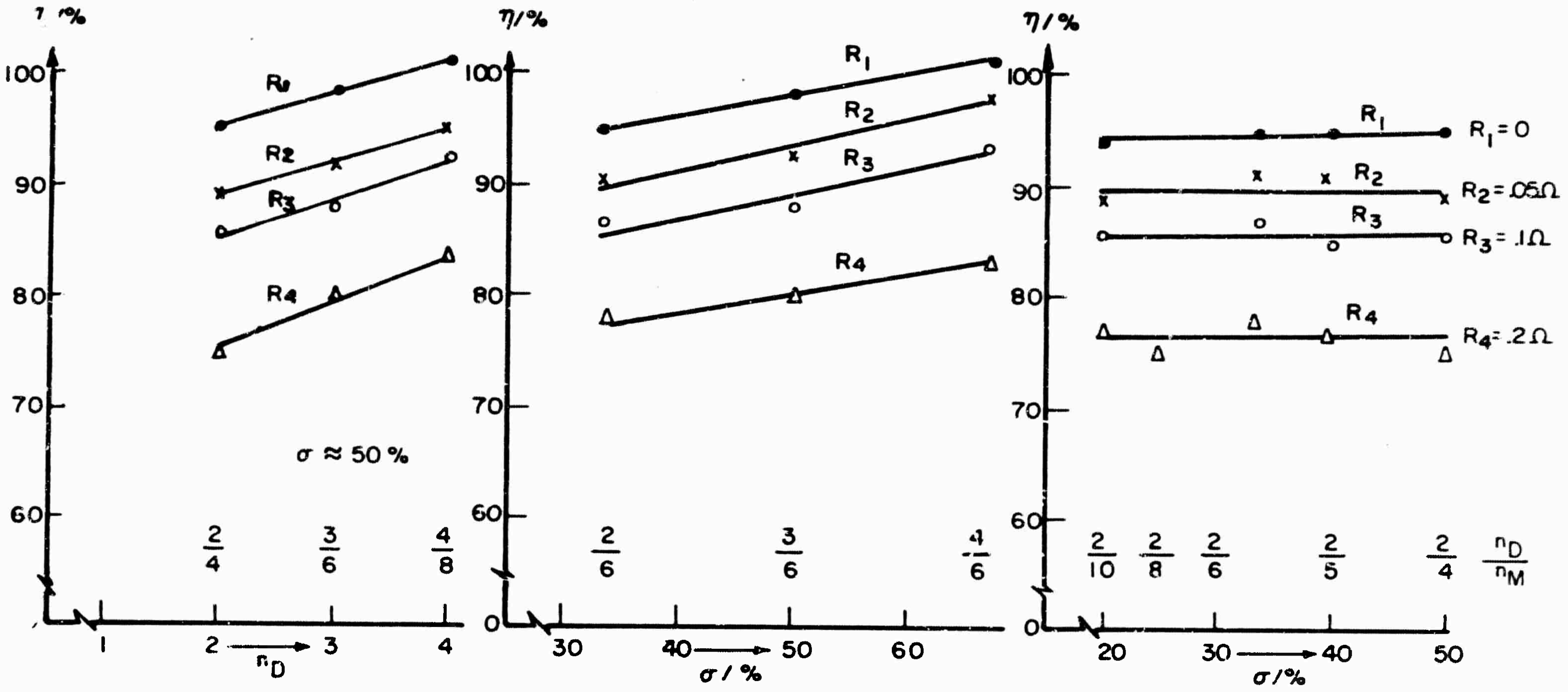
VOLTAGE AND CURRENT OF MICROWAVE CORE

FIGURE 3



DRIVER CORE AS PULSE GENERATOR

FIGURE 4



GE 42L CORES .309" x .550" O.D x .350 i. D. $\int V dt = (2.78 - .12)\,\mu V_s$

EFFICIENCY OF FLUX-TRANSFER UNDER VARIOUS CONDITIONS

FIGURE 5

driver and the ferrite core. Then $\Delta\phi_D \sim n_D$, [illegible] (9) n_M, $\delta\phi \sim n_M$, $r_1 \sim n_M/n_D$ (assumed). With proportionality constants K_1, K_2

$$\eta = 1 - K_1 \frac{n_M}{n_D} - K_2 \frac{n_M/n_D}{n_D} \qquad (9b)$$

Let the ratio "available flux/flux necessary to drive microwave core from $-M_s$ to $+M_s$" be the saturation

$$\sigma = \Delta\phi_D/\Delta\phi_r \quad \text{with} \quad \Delta\phi_r = 2B_rA \qquad (10)$$

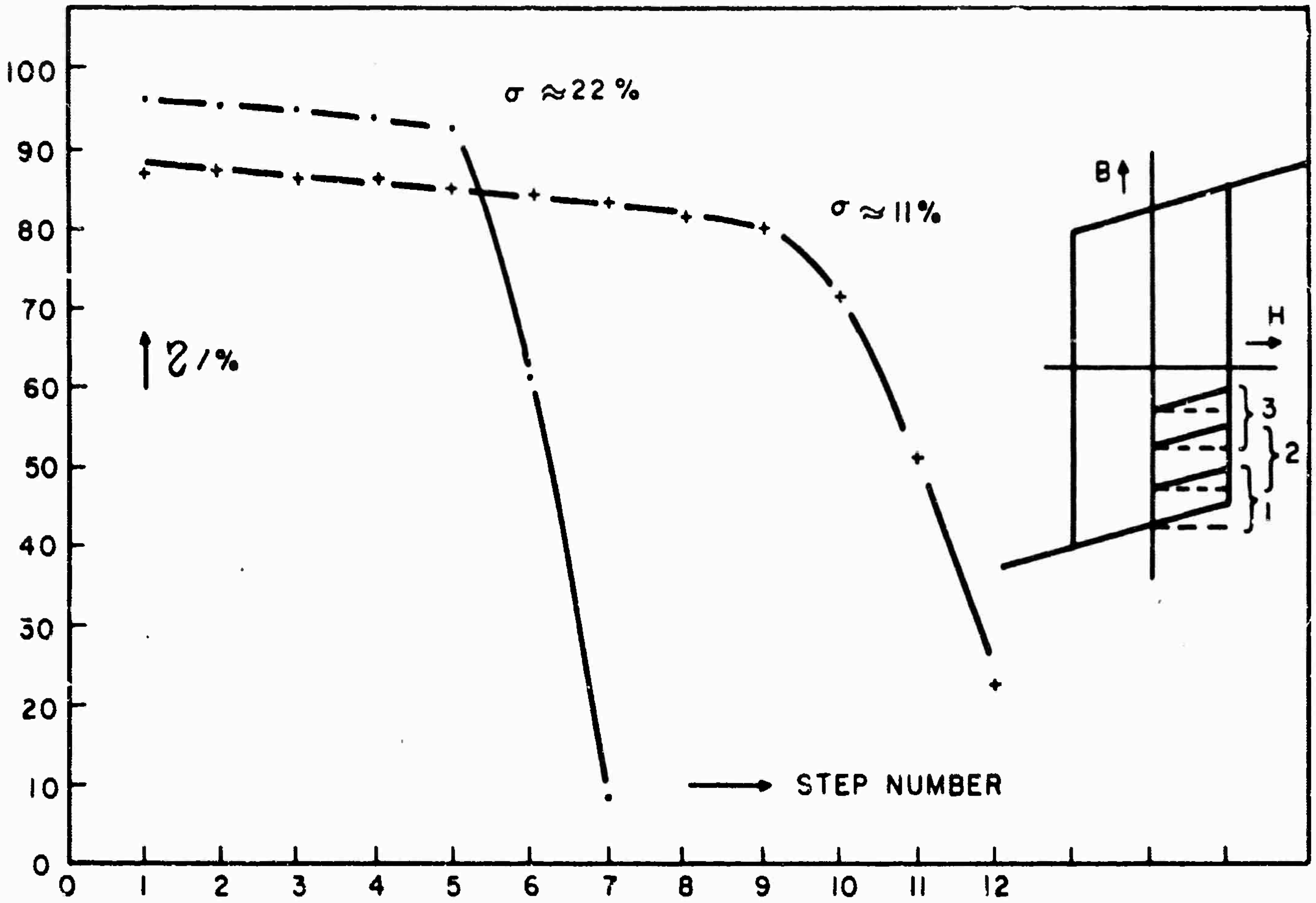
In Figure 5a $\sigma = n_D/n_M$ is kept constant. η increases with n_D. In Figure 5b n_M is kept constant. η increases with n_D. In Figure 5c n_D is kept constant. η decreases with increasing n_M. These results agree with equation (9b).

It is possible to "step-up" the BH loop of the microwave core by adding a constant bit of flux, to whatever state of magnetization has been reached, as long as the core is unsaturated. The transfer efficiency is nearly constant. Figure 6 shows for different driver core sizes and saturation values that the transfer efficiency decreases somewhat with increasing step number. In Figure 7 the fall back flux per step is plotted versus the total flux transferred. The results of Figure 6 indicate that the vertical branch of the BH loop is not parallel to the B-axis. As seen later, this effect can be compensated by an increase in phase shift for a constant flux transferred when stepping up the BH-loop. In a first approximation however, the transfer efficiency can be looked upon as constant until the microwave core is nearly saturated. The transferred flux is then $\Delta\phi_D - \delta\phi$. If two bits $\Delta\phi_1$ and $\Delta\phi_2$ are switched one after the other, the total flux transferred is

$$\Delta\phi_t^{(1+2)} = \Delta\phi_t^{(1)} + \Delta\phi_t^{(2)} = \Delta\phi_1 + \Delta\phi_2 - 2\delta\phi \qquad (11)$$

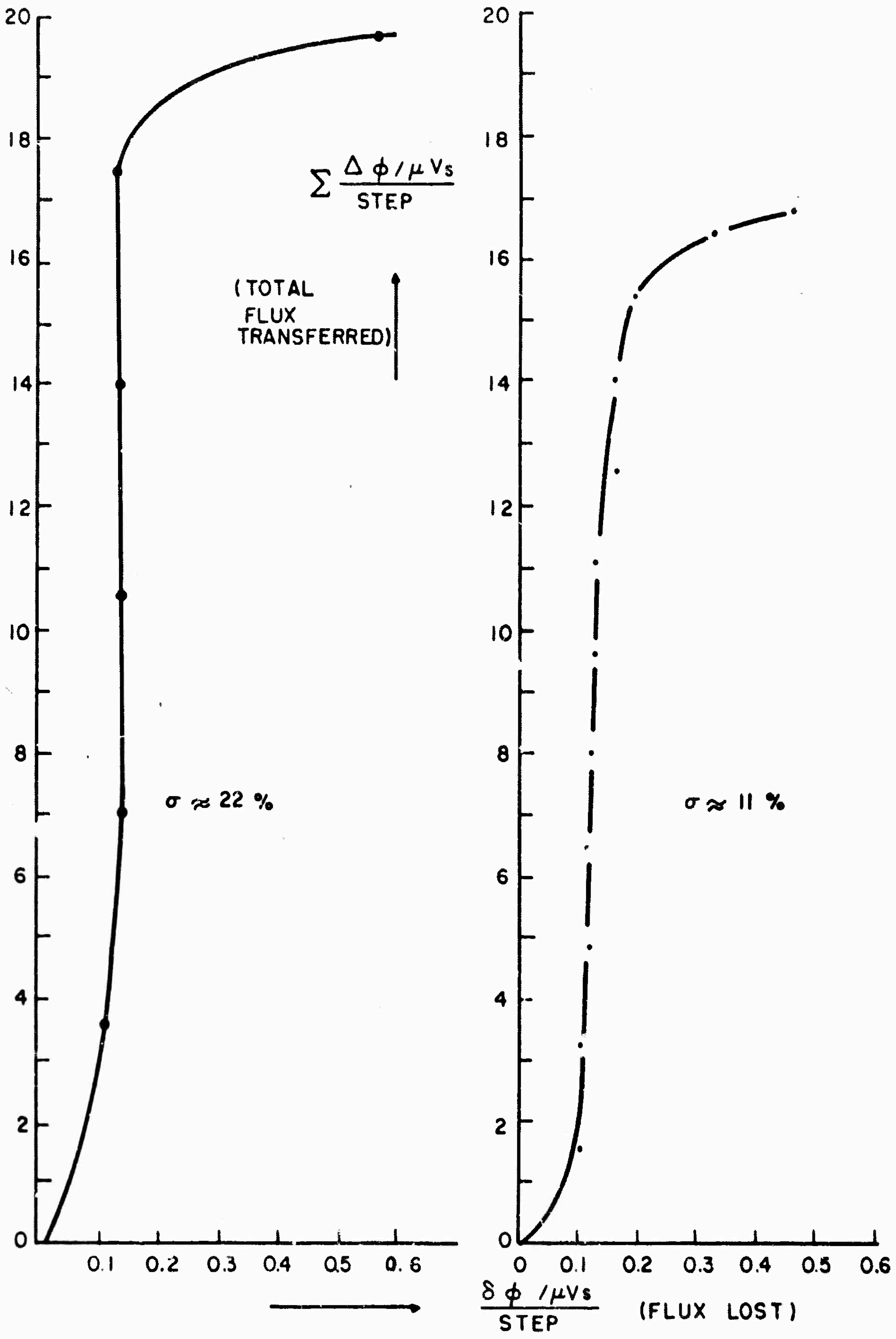
If the two bits are switched at a time, the transferred flux is

$$\Delta\phi_t^{(1,2)} = \Delta\phi_1 + \Delta\phi_2 - \delta\phi \qquad (12)$$



TRANSFER EFFICIENCY WHEN "STEPPING UP" A BH-LOOP

FIGURE 6



FLUX LOST PER STEP WHEN STEPPING UP A BH-LOOP

FIGURE 7

The difference can be overcome by adding to the n different bits a compensation flux bit $\Delta\phi_c = \delta\phi$. Whenever bits are switched, individually or several at a time, the extra bit is switched at the same time. The transferred flux is then

$$\Delta\phi_t^{(n)} = (\Delta\phi_n + \Delta\phi_c) - \delta\phi = \Delta\phi_n \tag{13}$$

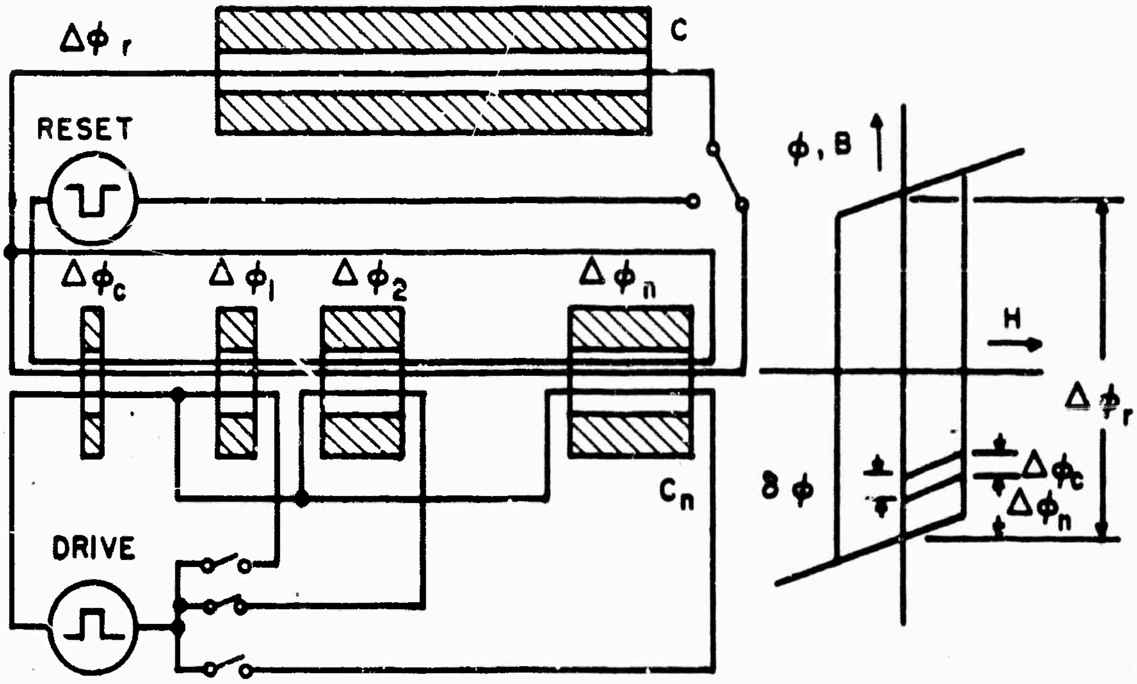
$$\Delta\phi_t^{(1+2)} = (\Delta\phi_1 + \Delta\phi_c) - \delta\phi + (\Delta\phi_2 + \Delta\phi_c) - \delta\phi = \Delta\phi_1 + \Delta\phi_2 \tag{14}$$

$$\Delta\phi_t^{(1,2)} = (\Delta\phi_1 + \Delta\phi_2 + \Delta\phi_c) - \delta\phi = \delta\phi_1 + \delta\phi_2 \tag{15}$$

The transfer circuits of Figure 1 and Figure 8 contain the microwave core, the active driver core to achieve a certain flux transfer, and some idle driver cores. The influence of the idle core on the transfer efficiency has been found to be negligible. In a setup as in Figure 1 different numbers of equal ferrite toroids have been used for microwave, driver and idle cores to establish this result. The idle cores are, of course, reset to negative saturation just as the active driver before flux is transferred. Thus, their inductivity is close to zero. The results are summarized in Table 1. The flux transferred to both the microwave and the idle cores has been measured. The low efficiency for $\sigma = 20\%$ is due to the fact that rather small cores have been used, so that ohmic losses in the transfer circuit represented a considerable fraction of the total losses.

Active cores	F available	Idle cores	Flux Transf.	Microw. cores	Flux transf.	σ	η
2	5.32 μVs	0	0 μVs	5	4.46 μVs	40%	83.7%
2	5.32 "	3	<0.02 "	5	4.45 "	40%	83.6%
1	2.66 "	0	0	5	1.66 "	20%	62.5%
1	2.66 "	4	<0.03 "	5	1.66 "	20%	62.5%

TABLE 1. Influence of Idle Cores on Transfer Efficiency



TRANSFER CIRCUIT FOR ADDING FLUX BITS

FIGURE 8

III. NON-LINEAR LOSSES IN FERRITES

Non-linear losses occur when the rf - magnetic field in the waveguide surpasses a threshold value. Power is then dissipated into the spin wave spectrum. The dominant mechanism is subharmonic generation, where spin-waves of half the frequency of the driving rf-field are excited. This is a "first-order" effect because the spin wave amplitude is proportional to the rf-field amplitude. Via a second mechanism spin-waves can be excited at the frequency of the driving rf field. This effect is of "second order" because the amplitude of these spin waves is proportional to the square of the rf-field amplitude. Whenever the subharmonic generation takes place it occurs at such low rf-field amplitudes that the second order effect may be neglected. Assuming only subharmonic generation, E. McKinney has derived threshold field strengths for ferrites of arbitrary shape at remanence. This treatise is given fully as Part II of this report. It includes the results of other workers. McKinney has to normalize the threshold field strength to a spinwave line width or relaxation time. Were this line width known, it would be possible to predict the threshold field strength for ferrites as a function of frequency, and for devices where the field distribution is known one could also predict the threshold power. So far it was not possible to measure the relaxation time accurately at one frequency only, even less to determine whether the relaxation time is a function of frequency, ferrite shape, driving field strength or other parameters.

By testing ferrites of equal size and shape in equal test devices at 6.5 GHz, relative power handling capabilities could be determined. Two test series were performed: In the first one a coaxial line was completely filled with ferrite. The diameters were chosen so that only TEM modes should propagate. This test device was matched into 50 ohm lines via step transformers at both ends. The VSWR was below 1.5 in all cases, corresponding to a reflection loss < 0.17 dB or a power reflection of less than 4%. In the second series a ferrite slab was placed in the center plane of a rectangular waveguide parallel to the narrow wall and extending over the full height of the guide. The filling factor was five percent. The ferrite was tapered at both ends to secure a VSWR < 1.5. The rf magnetic field amplitude was calculated under the assumption that the relative ferrite permeability $\mu_f = 1$ and the relative ferrite dielectric constant $\epsilon_f = 11, \ldots 16$, as given by the manufacturer. In the coaxial line the strongest rf-magnetic field occurs at the inner conductor. With

$$P = ZI^2 = Z\pi^2 D^2 H^2 \qquad (16)$$

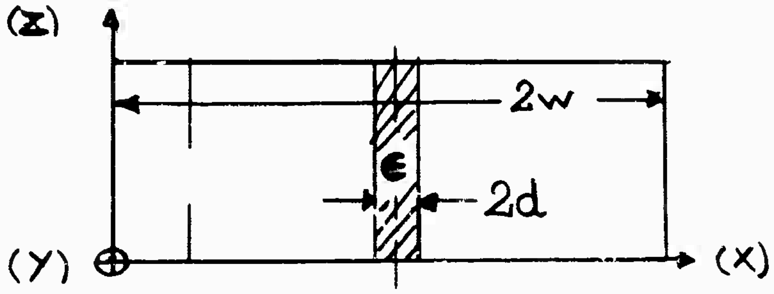
where P = peak power, I = current in inner conductor, D = diameter of inner conductor, Z = line impedance, H = rf-magnetic field. One obtains with $\pi^2 \approx 10$

$$\frac{H}{A/cm} = 10 \, \frac{D}{cm} \sqrt{\frac{P/K\,W}{Z/ohm}} \qquad (17)$$

In the rectangular waveguide (WR 137) at the test frequency of 6.5 GHz the field distribution outside the ferrite slab follows a hyperbolic function and one obtains with the dimensions sketched below

$$P_y = \oint (E_z \times H_x)\, dA = 2b \int_0^w (E_z \times H_x) dx$$

$$\equiv 2wb \, \frac{\omega\mu_o}{k} \, H^2 \left[\int_0^{1-\delta} \frac{sh^2 \, P \varphi}{D^2} \, d\varphi + \int_{1-\delta}^{1} \sin^2 (Q\varphi + \theta) \, d\varphi \right] \qquad (18)$$



where

$k \hat{=}$ longitudinal propagation constant

$P/w \hat{=}$ transverse propagation constant in empty part of guide

$Q/w \hat{=}$ transverse propagation in dielectric

$1/D \hat{=}$ relative amplitude in empty part of guide

$1 \hat{=}$ relative amplitude in dielectric

$\delta = d/W$

$\varphi = x/W$

The full theory is given as Part III of this report. For the given frequency and waveguide (2w = 1.372 inches, b = .622 inches) one obtains finally

$$\frac{H}{A/cm} = N \sqrt{\frac{P}{kW}} \qquad (19)$$

where N is a function of the ferrite dielectric constant

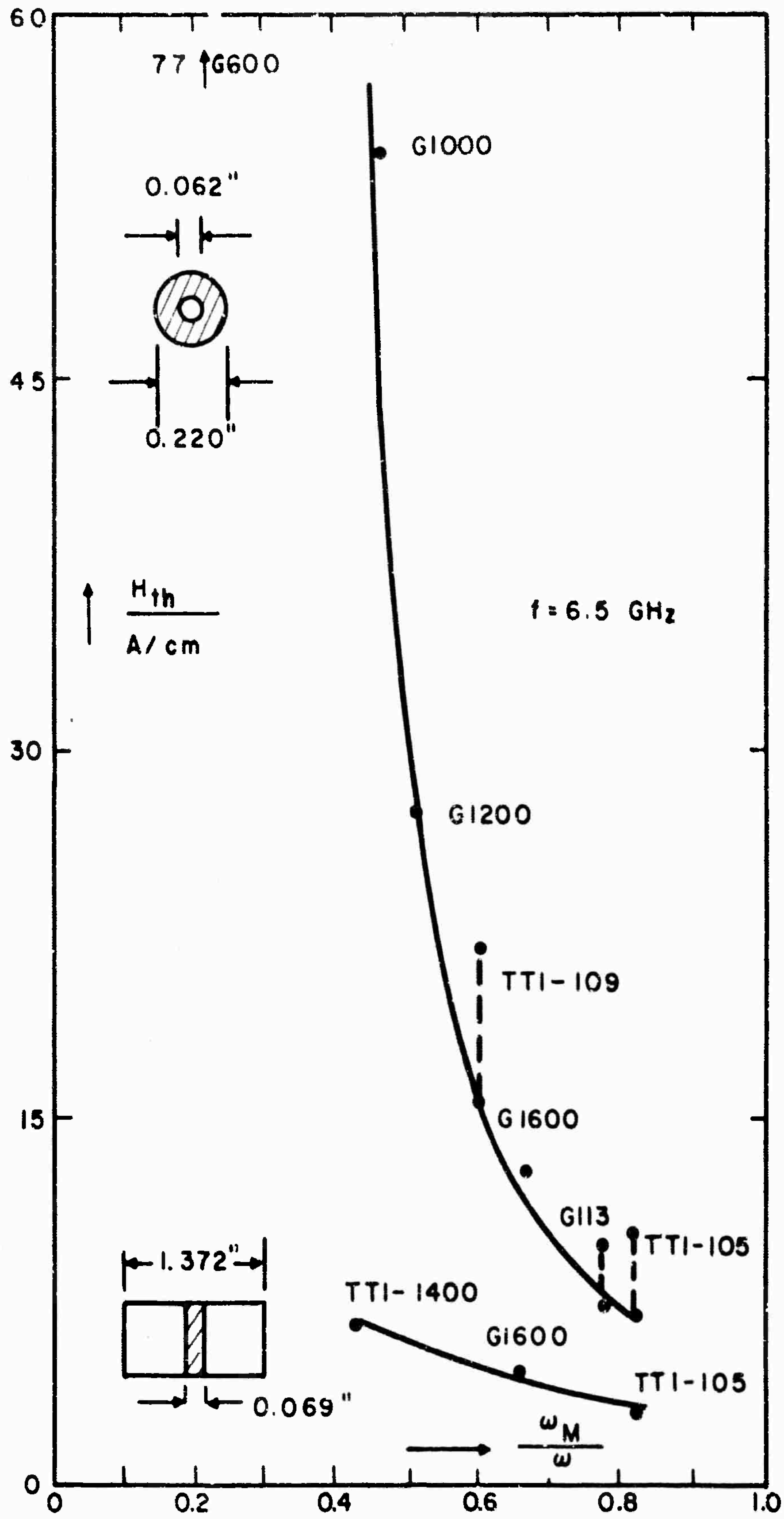
ϵ_f	1	8	[illegible]	12	14	16
N	.925	1.055	1.108	1.130	1.162	1.180

The test results are summarized in Figure 9. The coaxial line test leads to considerably higher values for the threshold field than the wave guide test does. The reason is not yet understood. The spin wave spectra excited in both test series may not be equal. Other possible explanations are for the coaxial line test:

The impedance is other than calculated with ϵ_f

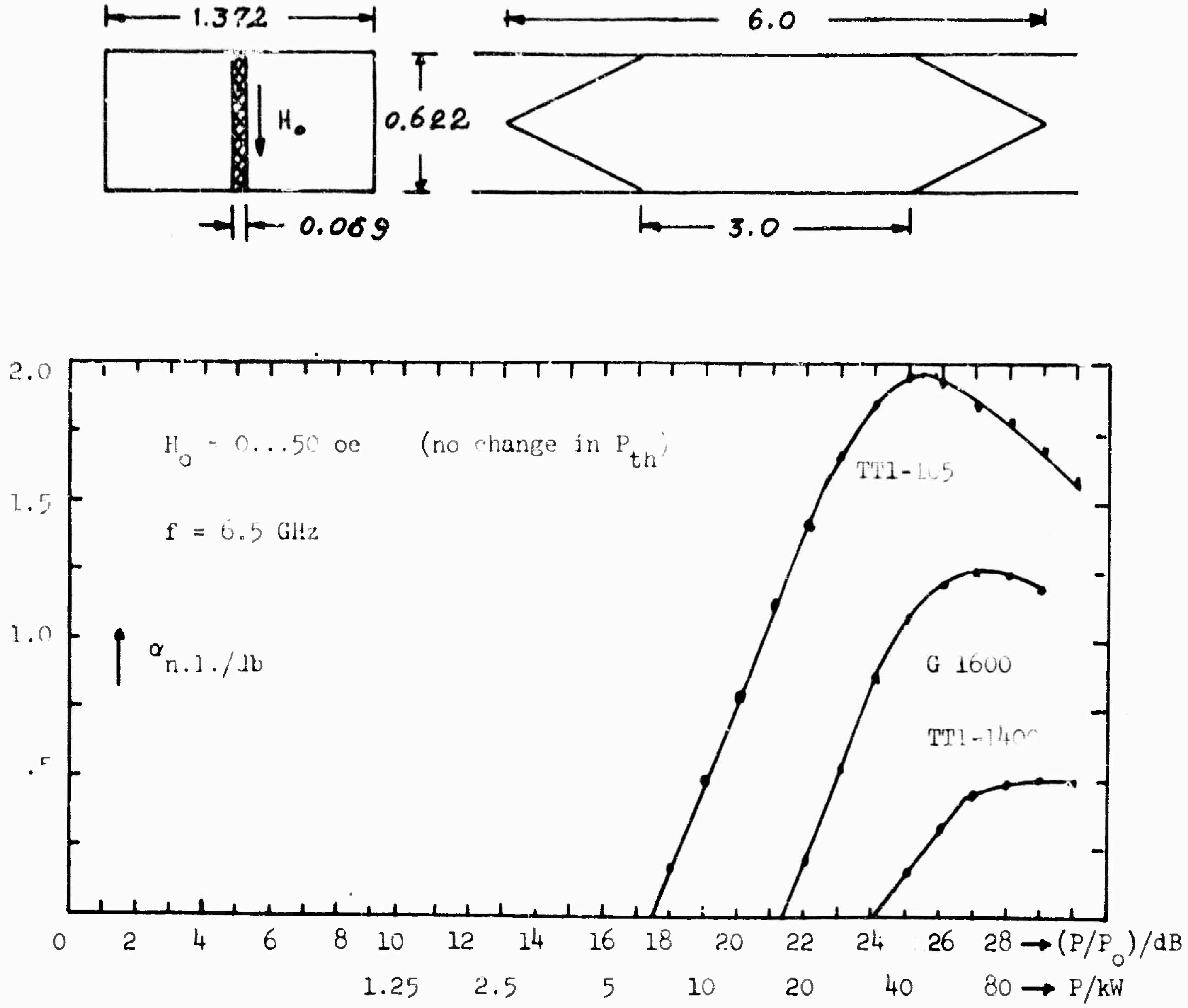
Several modes exist (partly due to air gaps between ferrite and conductors)

The rf-magnetic field strength varies considerably over the ferrite wall thickness.



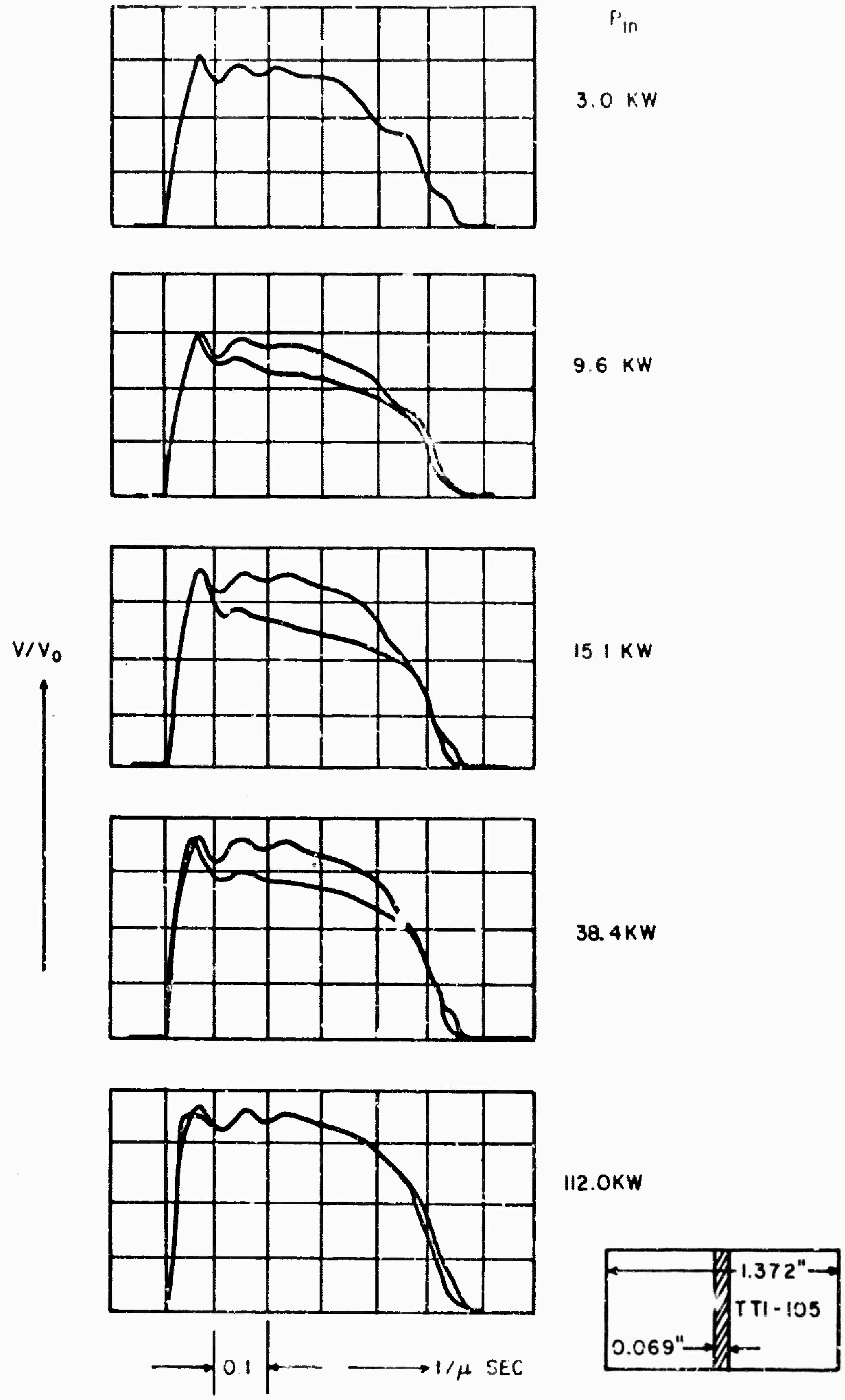
THRESHOLD FIELD STRENGTHS OF VARIOUS FERRITES

FIGURE 9

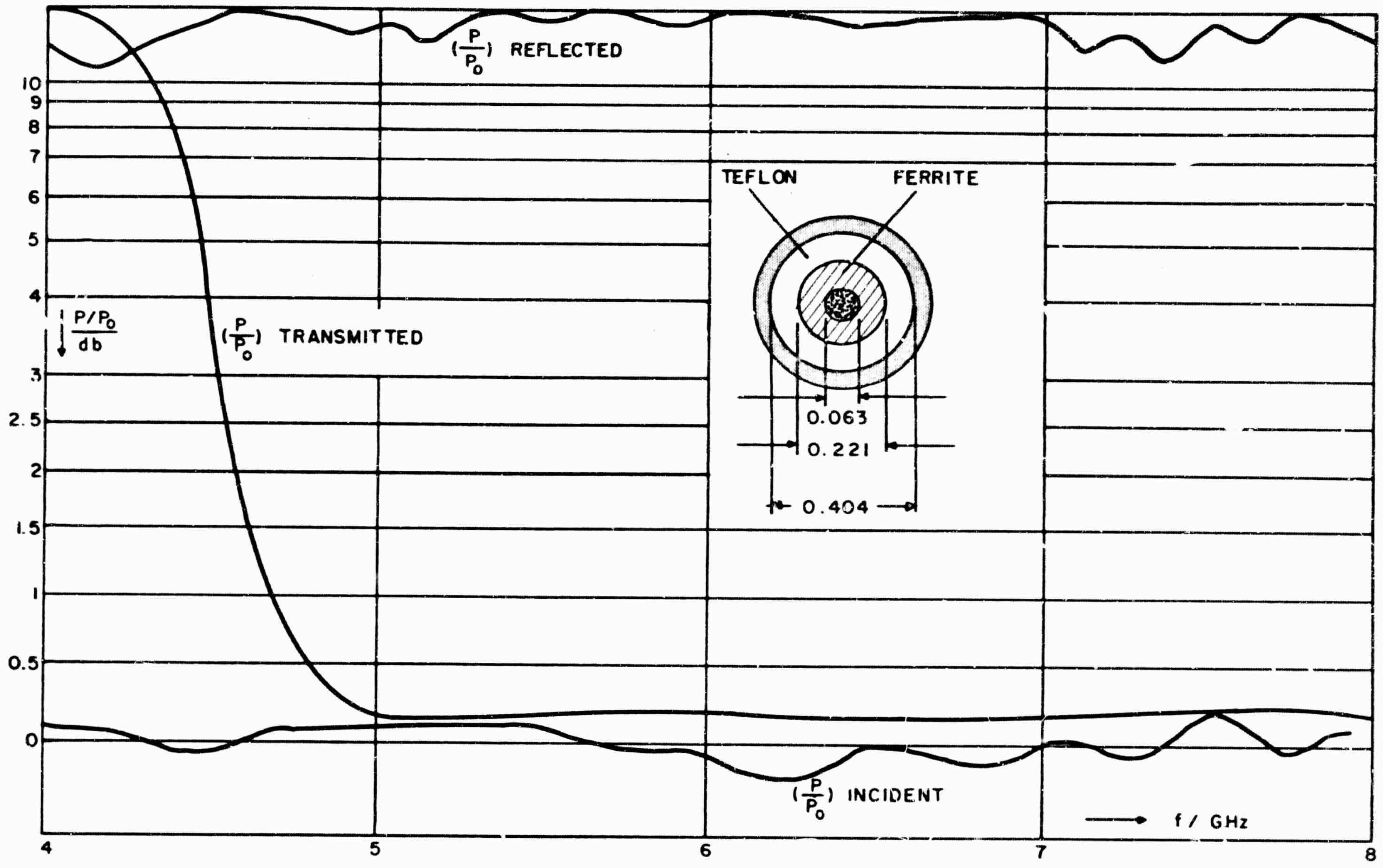


Ferrite (TransTech)	Listed M_s/G	fm/f	P_{th}/kW	
G 600	515	0.22	>125	Voltage breakdown
TT1-414	660	0.28	>125	
TT1-900	(700)	(0.3)	>125	(...) not listed, assumed
TT1-109	860	0.37	>125	
TT1-1400	(1000)	(0.43)	32	(...) not listed, assumed
G1600	1165	0.5	18	
TT1-105	1380	0.58	7	

FIGURE 10. Ferrites at High Peak Powers



DEFORMATION OF RF-PULS BY NON-LINEAR ATTENUATION AT 6.5 GHz
UPPER TRACE; INPUT PULS, LOWER TRACE; OUTPUT PULS



MAIN RESONANCE LOSS IN 50 ohms COAXIAL LINE PARTIALLY LOADED WITH FERRITE (TRANS TECH. G 113)

FIGURE 12

The average threshold power in the waveguide test could be determined accurately, because the non-linear loss/power characteristic is a straight line in a double logarithmic scale as shown in Figure 10. If the ferrite would not warm up, this line would end abruptly at a maximim power-independent loss. Such a maximum loss has been maintained over a large power range when the ferrite was kept cool. Figure 10 shows a peak in loss due to the warming up of the ferrite and the subsequent change in saturation magnetization. The onset of non-linear losses in the coaxial line tests was not as well defined. The losses increased to a small value over a large power range before they followed the straight line. Besides the results were not as reproducible as in the waveguide tests.

Figure 11 shows the input pulse and the deformed output pulse at various power levels. The reduction in loss at high powers shows up clearly. To determine the threshold power it has been assumed that the input pulse is rectangular and 0.42 μsec wide. Assuming an exponential growth of the spin waves it should be possible to find the relaxation time from the decay of the high peak of the output pulse.

With the poor input pulse shape, however, this does not yield accurate results. The spin wave line width appears to be between 0.5 to 2 A/cm.

The resonance frequency has been taken from the manufacturers data or from the onset of losses at lower frequencies in a coaxial line filled with ferrite, as illustrated in Figure 12, or from measuring the flux available from a toroid. In any case the accuracy may be ± 5%. Plotting the threshold fields versus ω_m/ω, as done in Figure 9 and assuming a linewidth of 1 A/cm, one finds that the waveguide test data come closer to the theoretical results than the coaxial line test data do.

In any case the power handling capability increases as the saturation magnetization decreases.

IV. RECIPROCAL TEM MODE PHASE SHIFTER

The "one shell" and the "many shells" model for the magnetization of ferrite toroids - mentioned under "Control of Flux Transfer" - leads to an interesting consequence. The "many shells" model forbids, while the "one shell" model allows a reciprocal, latched ferrite phase shifter using the TEM modes in a coaxial line. According to the "many shells" model an alternating current with decreasing amplitudes applied to the inner conductor of the coaxial line would produce a sequence of circumferentially magnetized ferrite shells with alternating directions of magnetization. In any such sequence no microwave interaction between the ferrite and rf magnetic field of a TEM mode would occur. The effective relative permeability for this mode would always be one. In a "one shell" model the magnetization would be homogeneous throughout the ferrite wall thickness and could vary from complete alignment in one direction to random spin orientation to complete alignment in the other circumferential direction, depending on the driving conditions. This model allows a reciprocal latched coaxial phase shifter. The electrical length of the device depends on the degree of dipole alignment in the ferrite, not on the circumferential direction. In a coaxial line filled with ferrite (TT1-109, L = 4 inches, D_0 = .221 inches, D_i = .063 inches), a differential phase shift has been measured between a) the demagnetized state, achieved by sending an a.c. pulse with decreasing amplitude through the center conductor and, b) the state of partially circumferential magnetization (either direction) achieved by sending a d.c. pulse through the inner conductor.

The reciprocal phase shift could be controlled by the amplitude of the d.c. current pulse or by controlled flux transfer. At about 5 GHz the reciprocal phase shift could be stepped up to approximately 20, 40, 60, and 80 degrees. The coaxial line used in this experiment was built for ferrite tests at high peak powers at 6.5 GHz. The phase shift experiment was only a feasibility demonstration. The demagnetization was done at 60 Hz. The switching properties of nonreciprocal phase shifters - investigated under the present contract— indicate that demagnetization at a few kHz should be possible.

Stepping up the B-H loop from one state of circumferential magnetization to the demagnetized state to the opposite state of magnetization gave a smaller maximum reciprocal phase shift than starting from the a.c. demangetized state.

V. DIFFERENTIAL PHASE SHIFTERS

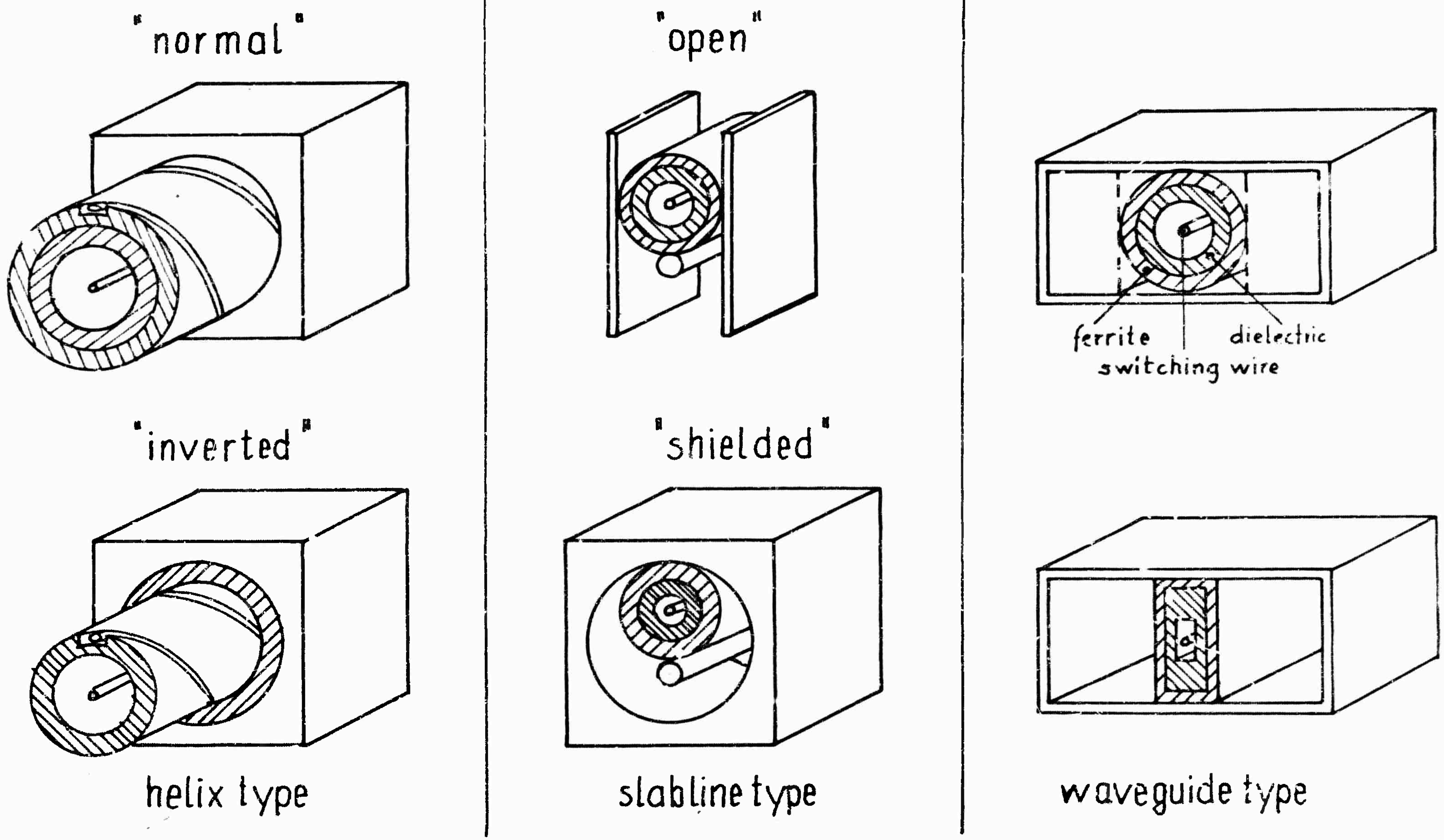
Three types of nonreciprocal phase shifters are shown in Figure 13. All of them use as the nonreciprocal element ferrite toroids, which are circumferentially magnetized and work at remanence. In all of them the phase shift is controlled by partial magnetization, achieved through controlled flux transfer.

The "normal" helix type phase shifter has been developed and described by H. A. Hair.(1) The "inverted" helix type phase shifter has been found less effective(2) than the normal one.

The slabline type phase shifter and the waveguide type phase shifter with ferrite toroids were used in the experiments described further down. Rectangular ferrite tubes were used in the first waveguide type phase shifter by Levey and Silber(3) and the improved versions by Blevins,(4) and Taft and Sweeney.(5)

The direction of magnetization in the phase shifters considered is in a plane transverse to the direction of propagation. Differential phase shift can be obtained when circularly polarized rf fields exist in a plane transverse to the direction of magnetization. Hybrid modes, which do not occur in empty guides, and TE modes, which have counterparts in empty guides, fulfill this condition. The tensor permeability of the ferrite makes the exact computation of the propagation constants in these guides so difficult, that so far no exact solution exists. An analysis has to be based on more or less crude models. In simple configurations exact solutions may be found for dielectrically loaded guides. Perturbation calculations can then take care of thin magnetized ferrites.(6) But even in the complex configurations investigated, the dielectrically loaded waveguide model analyzed in Part III of this report offers good explanations.

In the phase shifters considered here it has been attempted to achieve a proportionality between the differential phase shift and the flux transferred to the phase shifter. The ferrite was driven between its maximum negative remanent state of magnetization and various other remanent states between this one and the maximum positive remanence. All tests were performed with Trans-Tech ferrites.



LATCHED PHASE SHIFTERS

FIGURE 13

V.1 Waveguide Type Phase Shifters

All the phase shifters investigated use round ferrite cylinders. Previous work done in this laboratory indicated, that they should perform at least as well - as far as figure of merit and bandwidth are concerned - as phase shifters using rectangular ferrite cylinders.

The first experiments were done with a TT1-105 ferrite toroid ($M_s \approx 17\ \mu Vs/cm^2$) with .662" outer diameter in a standard WR 137 waveguide. With tapered slabs the guide width was reduced. The final step was to go to a circular guide of the ferrite diameter. The device is shown in Figure 14. Other parameters varied were the ferrite wall thickness and the core dielectric constant. The results are shown in Figures 15, 16, 17, (phase shift versus frequency) and Figure 18 (phase shift when stepping up the B-H loop). The results show that thin wall ferrites with proper dielectric cores can produce phase shift nearly as large as achieved with thick wall ferrites and that the phase shift versus frequency curve is the flatter the wider the guide. The "phase shift per step" characteristic for stepping up a BH-loop could be improved when the guide cross-section was changed as shown in Figure 19. The guide height is reduced to less than the ferrite toroid diameter and the toroid rests in groves in the top and bottom wall of the guide. The threshold power with this device was .8 KW.

Since the threshold field strengths for ferrites generally increases with decreasing magnetization the ferrite TT1-1400 ($M_s \approx 10\ \mu Vs/cm^2$) was chosen for further experiments. Figure 20 shows first results with this ferrite. Reducing the ferrite diameter reduced the slope of the phase shift versus frequency characteristic. Essentially, constant differential phase shift over a bandwidth of 2.5 GHz, centered at 6.2 GHz was achieved with a filling factor of about 31%. With increasing filling factor the slope becomes negative, as seen in the illustrations of this report; with decreasing filling factor the slope becomes positive, as shown for guides with rectangular ferrite toroids by Taft and Sweeney.(5) The optimum filling factor for constant phase shift over a broad band seems to be in the neighborhood of 35%. In Figure 22 it is seen that the guide height has no great

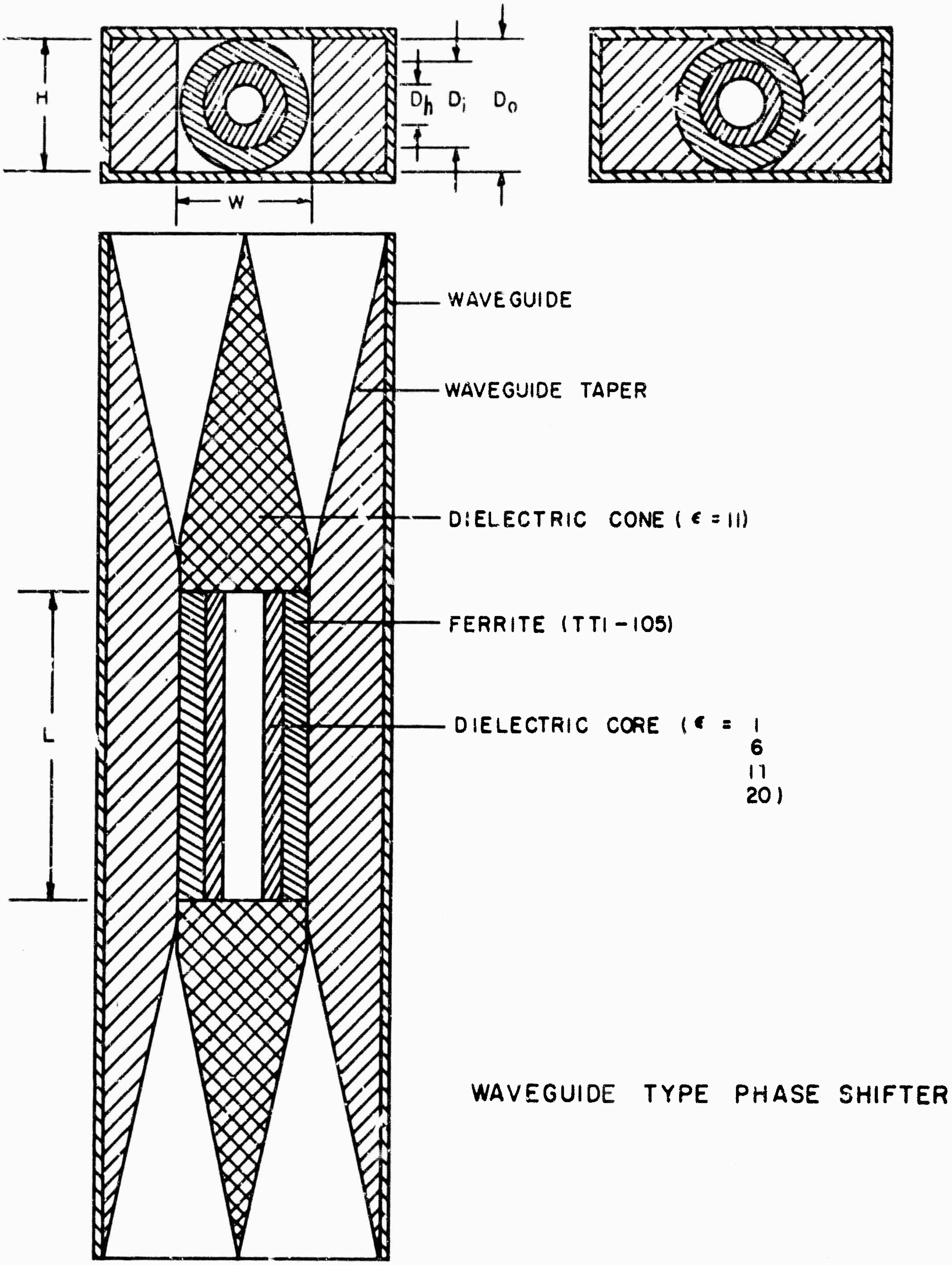
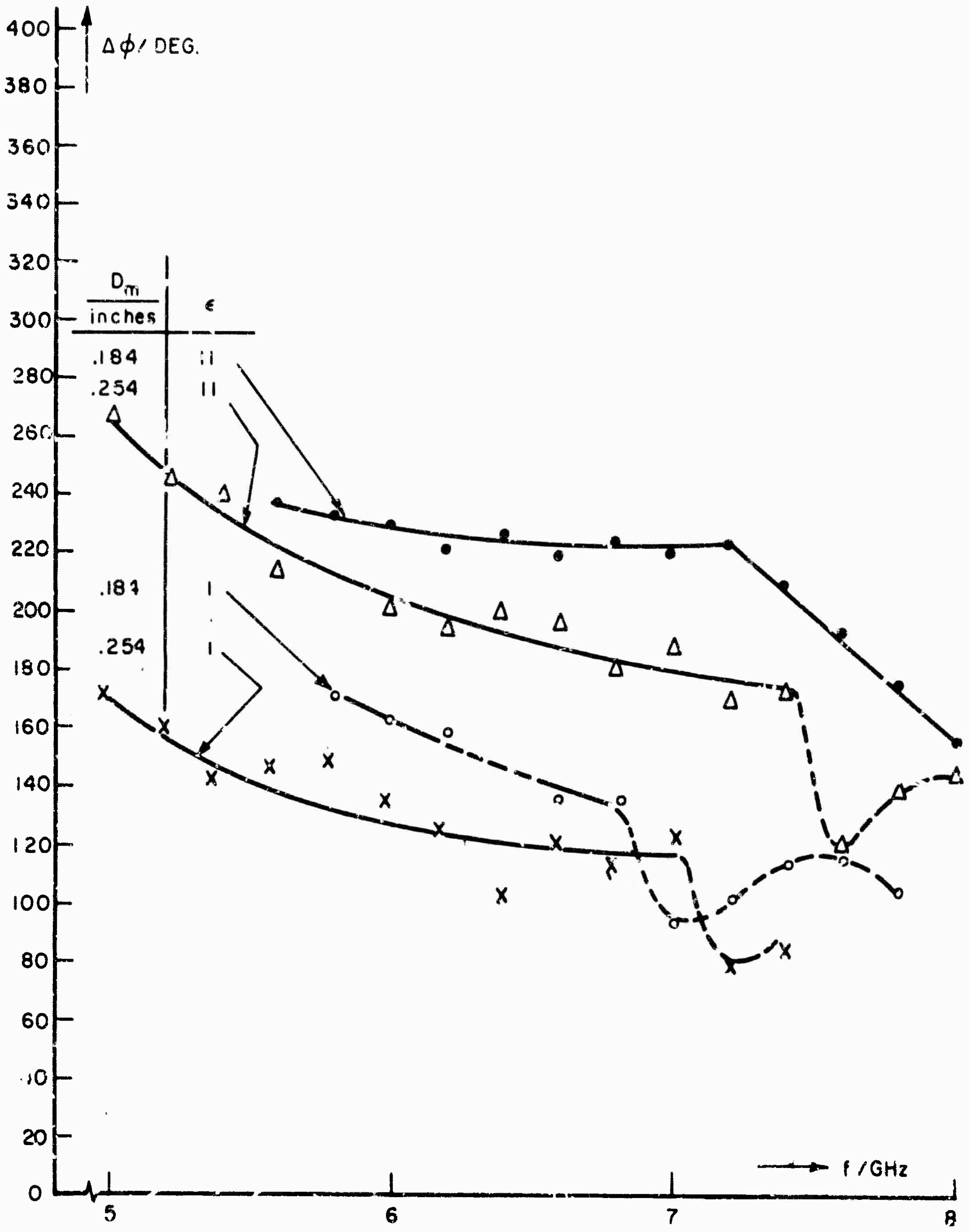
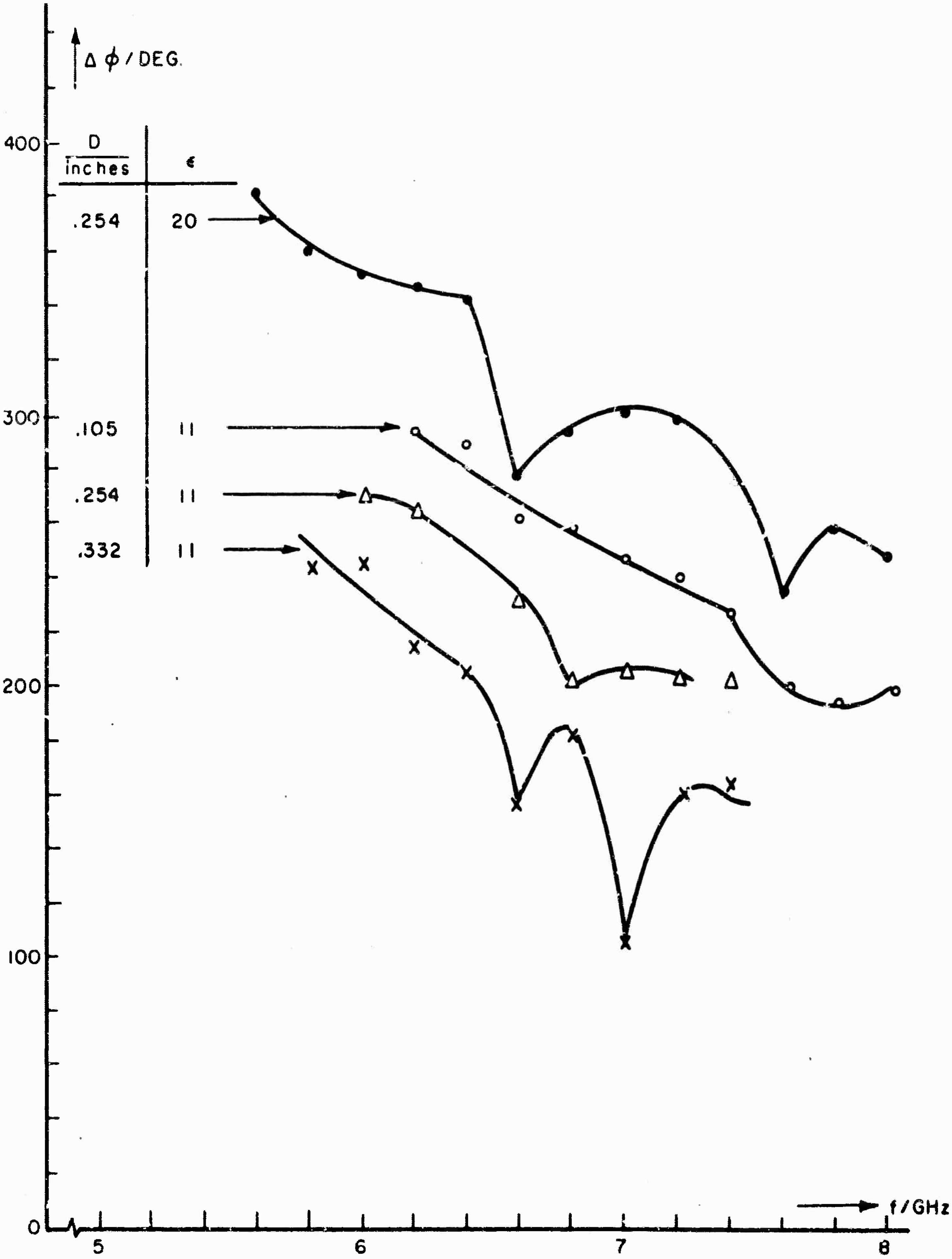

H
W
D_h
D_i
D_o
L
WAVEGUIDE
WAVEGUIDE TAPER
DIELECTRIC CONE (ε = 11)
FERRITE (TTI-105)
DIELECTRIC CORE (ε = 1
6
11
20)
WAVEGUIDE TYPE PHASE SHIFTER

FIGURE 14



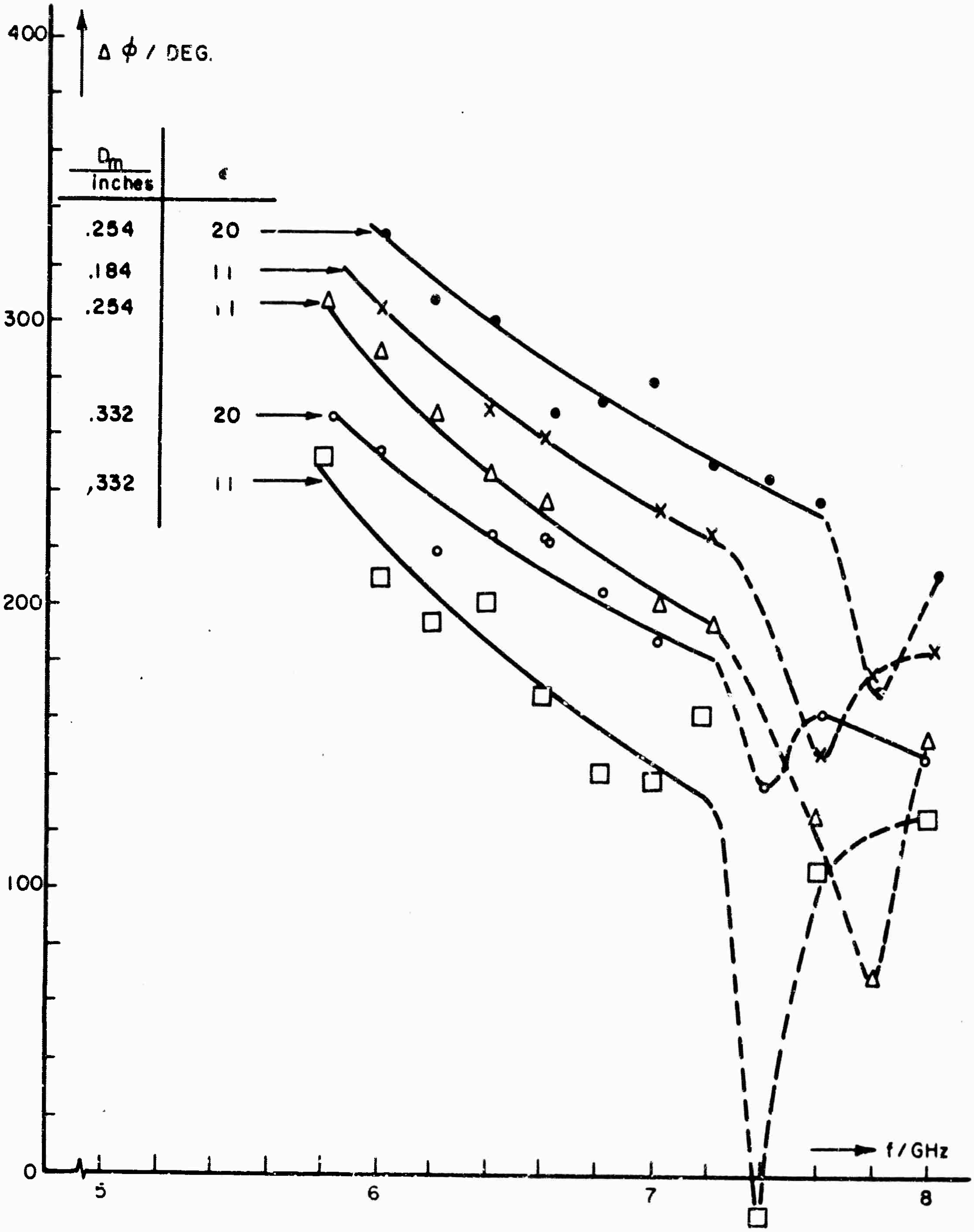
PHASESHIFT IN WAVEGUIDE WITH REDUCED WIDTH (W=.782")

FIGURE 15



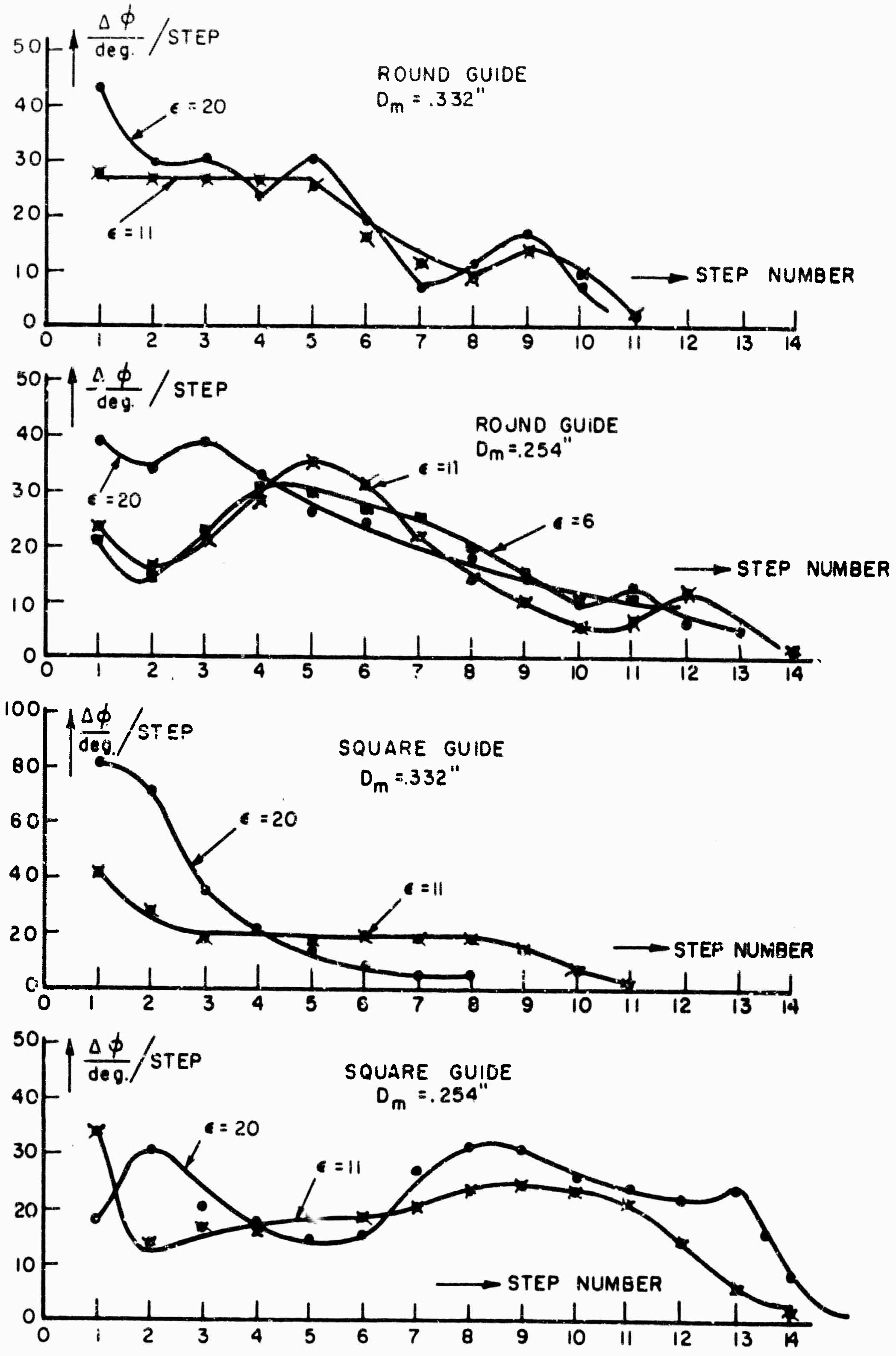
PHASESHIFT IN SQUARE WAVEGUIDE (W =.622")

FIGURE 16



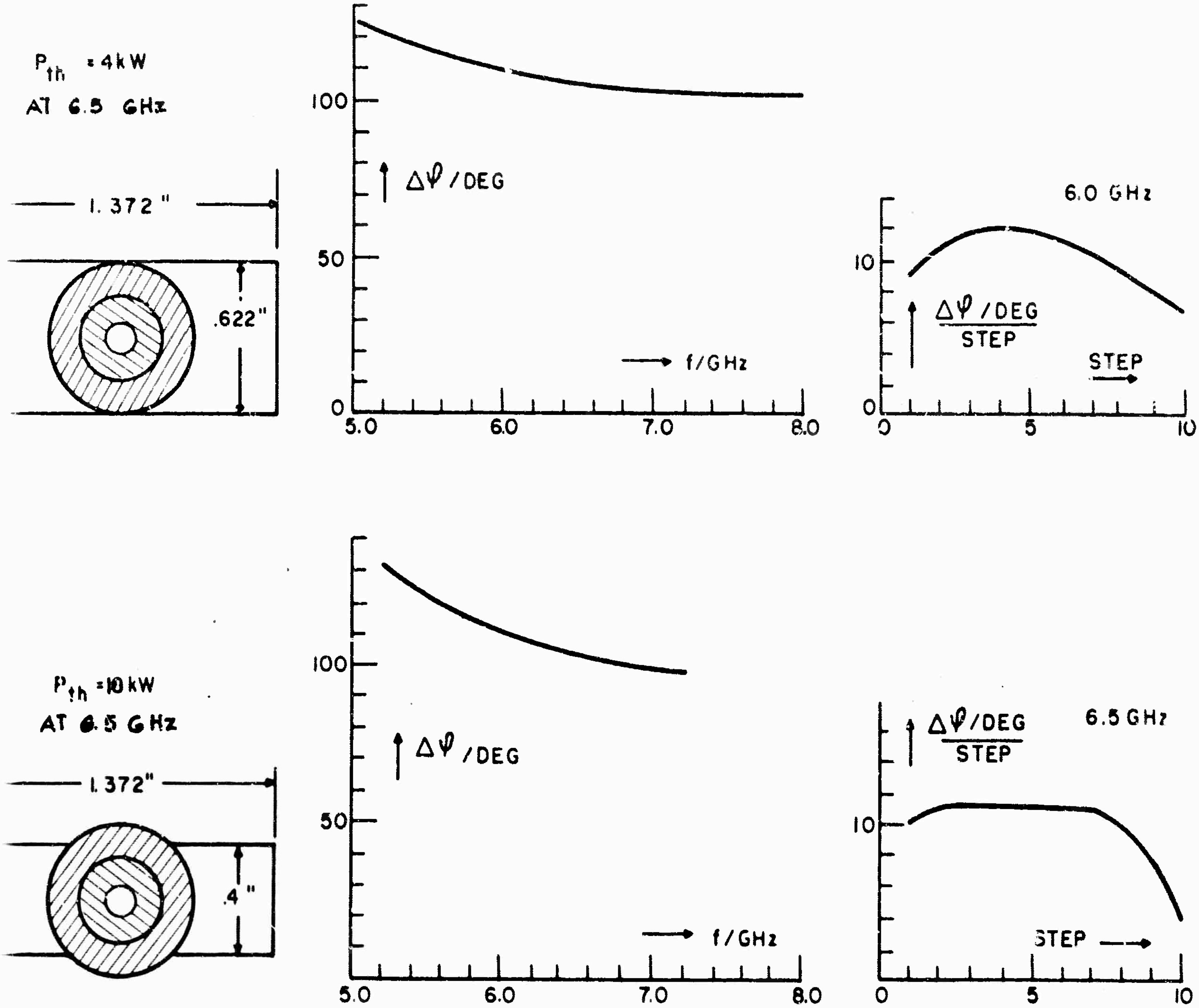
PHASESHIFT IN ROUND WAVEGUIDE (D = .622")

FIGURE 17



PHASESHIFT PER STEP AT 6.4 GHz

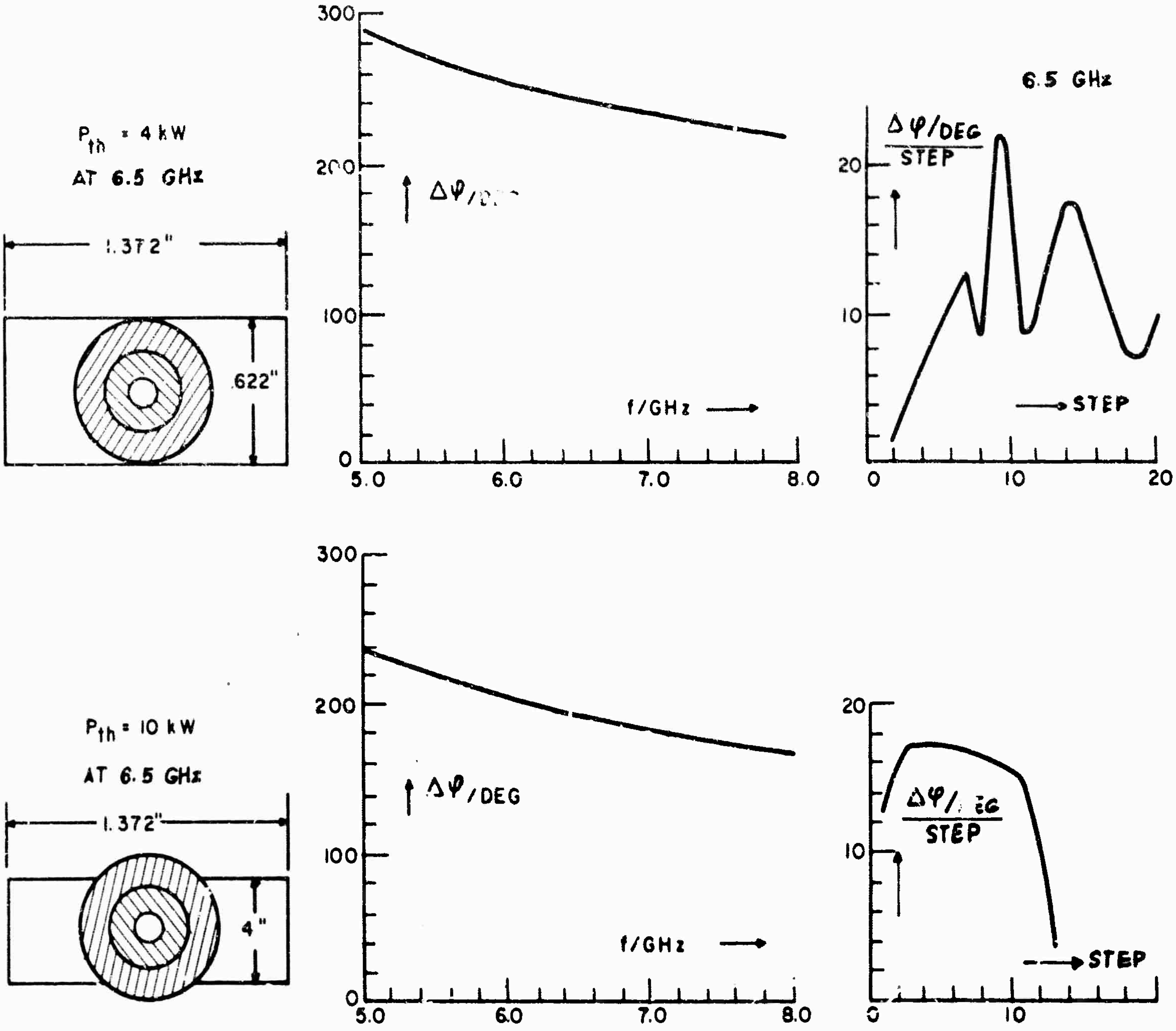
FIGURE 18



FERRITE : TTI-105, D_o = 0.622", D_i = 0.437", l = 1.5" CORE : E = 11

WAVEGUIDE TYPE PHASE SHIFTER

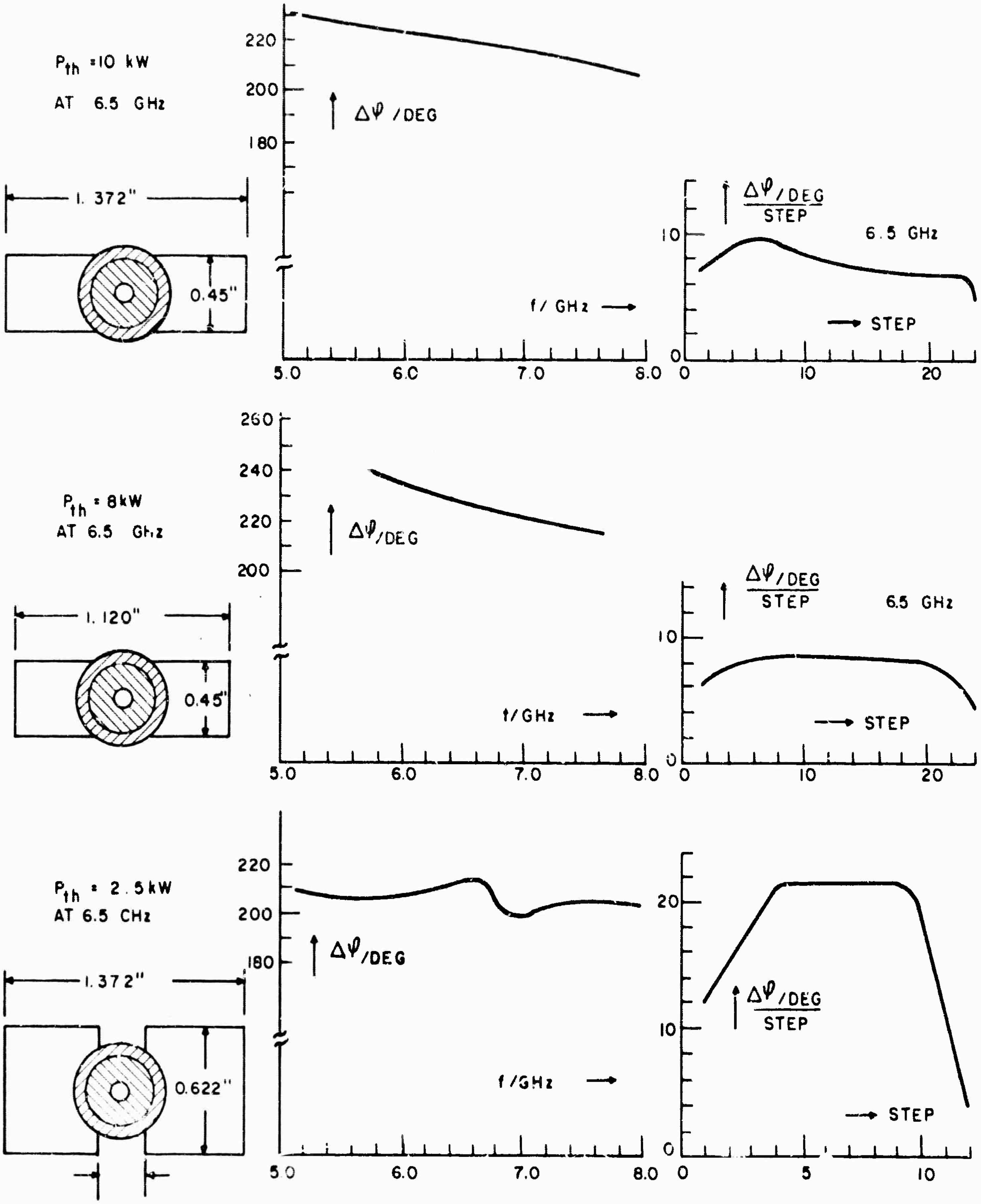
FIGURE 19



FERRITE: TTi-1400, $D_o = 0.622"$, $D_i = 0.380"$, $l = 3.0"$. CORE: $\epsilon = 11$

WAVEGUIDE TYPE PHASE SHIFTER

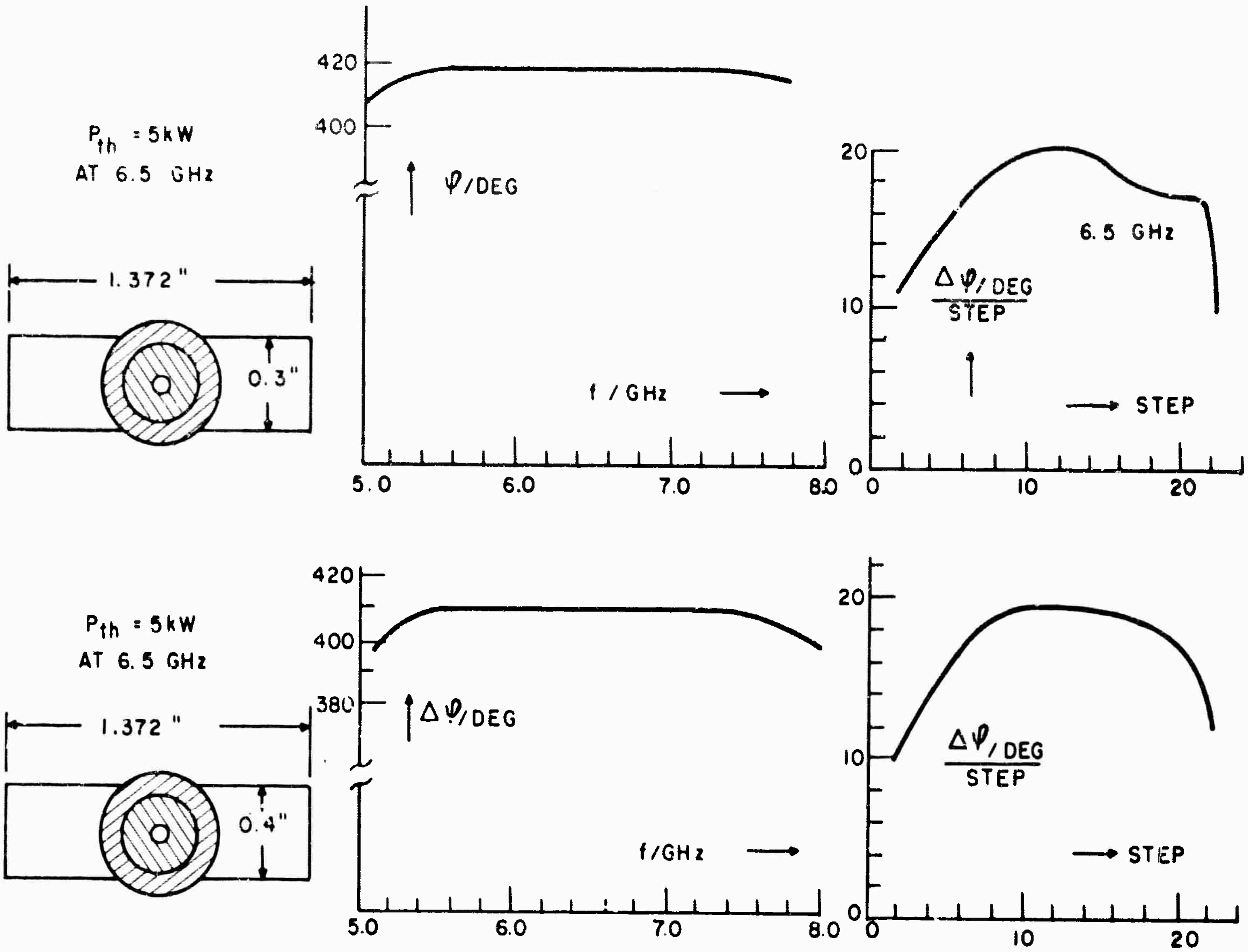
FIGURE 20



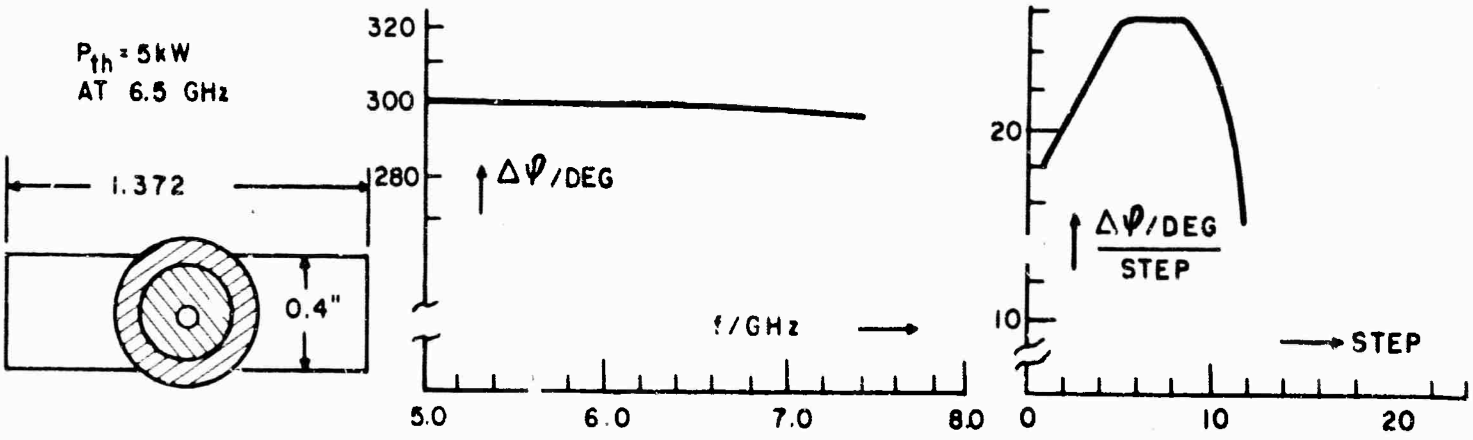
FERRITE : TTI-1400 D_0 = 0.500", D_i = 0.380", l = 5.0", CORE: E = 11

WAVEGUIDE TYPE PHASE SHIFTER

FIGURE 21



FERRITE TTI-1400, D_o = 0.437", D_i = 0.200", l = 5.0", ϵ = 11



FERRITE TTI-1400, D_o = 0.437", D_i = 0.300", l = 5.0", CORE: ϵ = 11

WAVE GUIDE TYPE PHASE SHIFTER

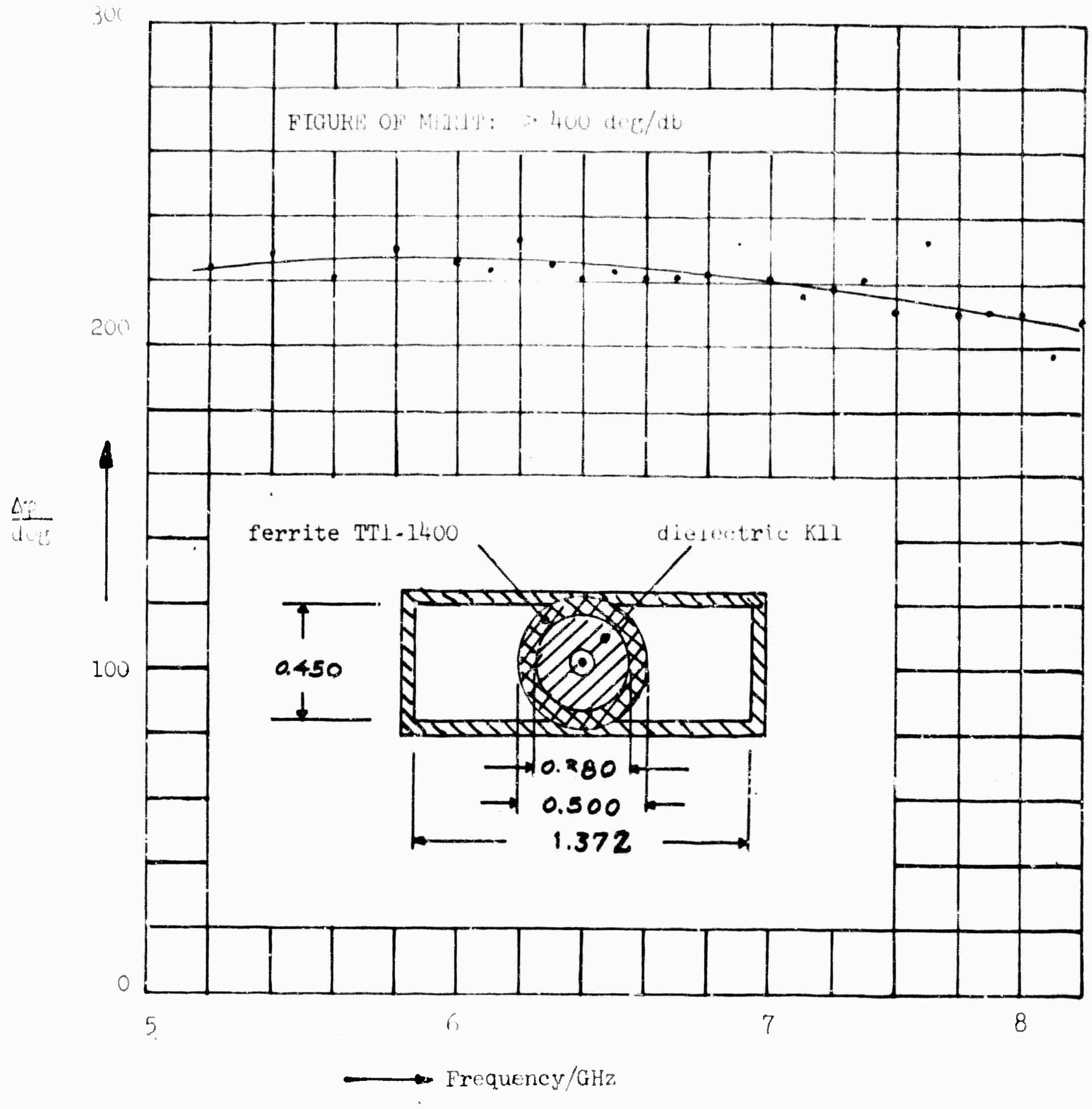
FIGURE 22

influence on the phase shift. Increasing the wall thickness by 80% increased the phase shift by 40%. The threshold power was independent of guide height and ferrite wall thickness.

The flattest phase shift versus transferred flux characteristic at 6.5 GHz was achieved with a filling factor of about 36%, as shown in the center row of Figure 21. The performance of this phase shifter is illustrated in more detail in Figures 23, 24, and 25. The phase shift/flux curve (Fig. 24) indicates that a "one driver bit" phase shifter could be built, if enough time is available to step up the BH-loop. The driver bit would be charged and discharged to the phase shifter as often as necessary to achieve a certain phase shift. The high power properties shown in Figure 25 are typical for all the phase shifters investigated. The ferrite was driven between its maximum remanent states. The differential phase shift stayed constant up to a power 1 to 3 dB above the threshold power. Then it decreased. This decrease is mainly due to the change in insertion length in one state of magnetization, the length in the other state stays approximately constant.

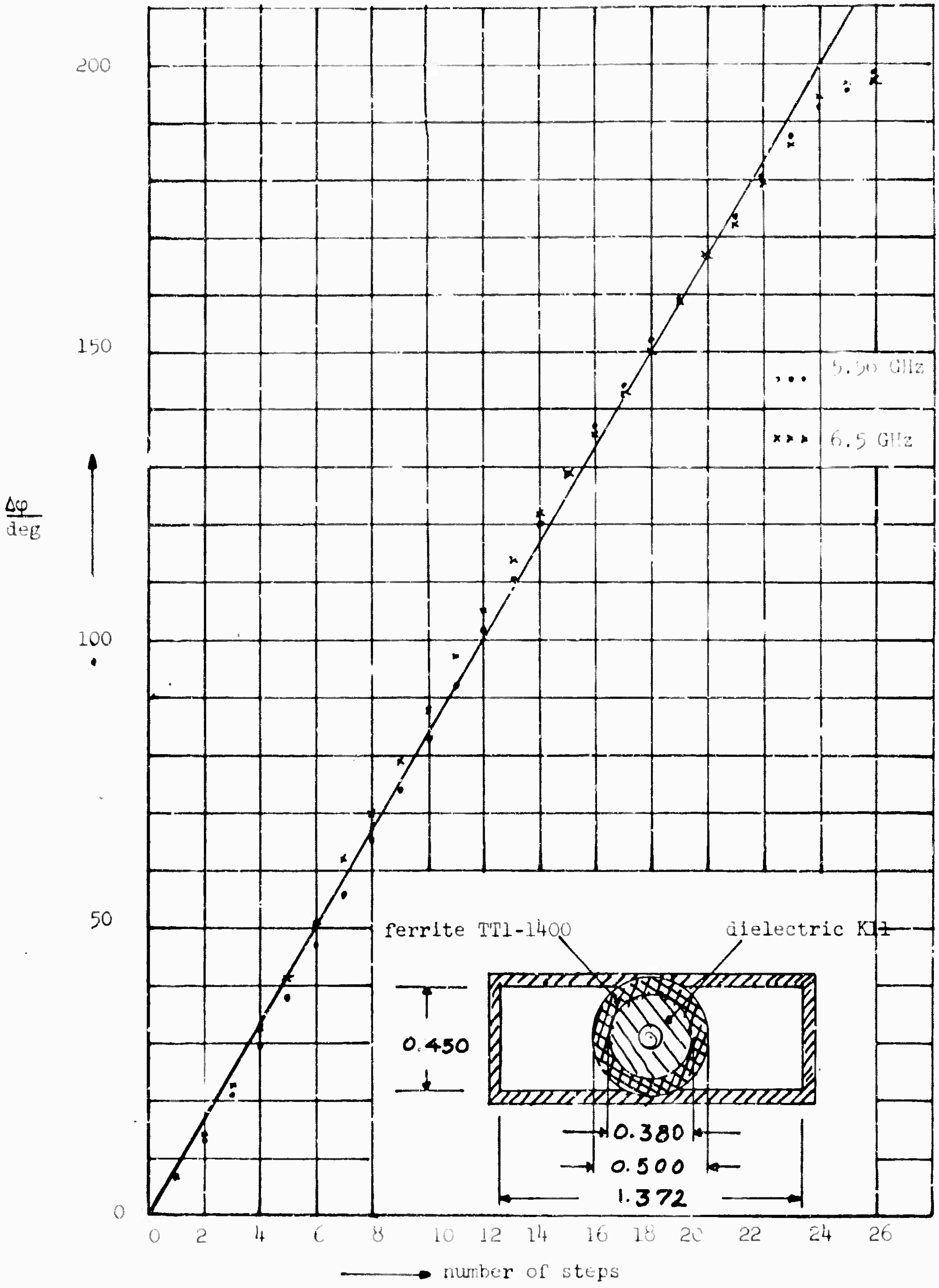
If the ferrite warms up even without non-linear losses, the insertion length and differential phase may vary even then. Methods to prevent this change are a) the use of temperature compensated garnets, b) an effective cooling method, and c) to drive the ferrite between its maximum negative remanent magnetization and a positive magnetization smaller than the maximum. This last method has been demonstrated first by Hair.(1) It is inherent in the flux transfer controlled phase shifters investigated here.

While this report was being written a final test was made with four inches of TT1-900 ferrite ($M_s \approx 7\ \mu Vs/cm^2$). The ferrite was selected because it was found to possess a very high threshold field strength (see Section III). The maximum differential phase shift was 104°. The bandwidth and flux control of phase shift were comparable to the result achieved with TT1-1400 with the same device and ferrite dimensions. The onset of non-linear losses occurred at above 100 KW. At 150 KW the non-linear losses were < 0.5 dB.



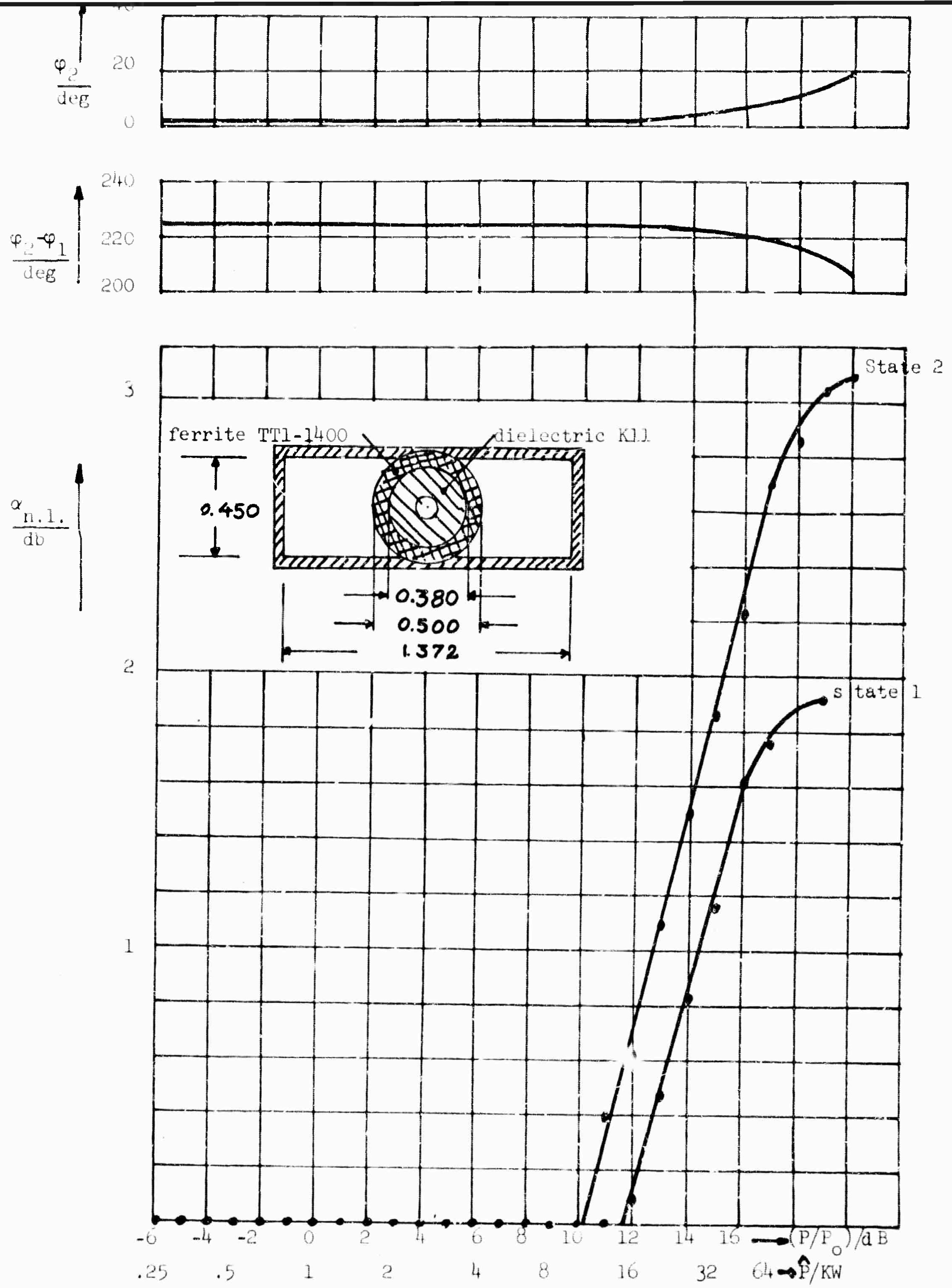
Differential Phase Shift Between States of Maximum Remanent Magnetization

FIGURE 23



Differential Phase Shift when "Stepping Up" a B-H Loop

FIGURE 24



High Power Performance of Differential Phase Shifter at 6.5 GHz

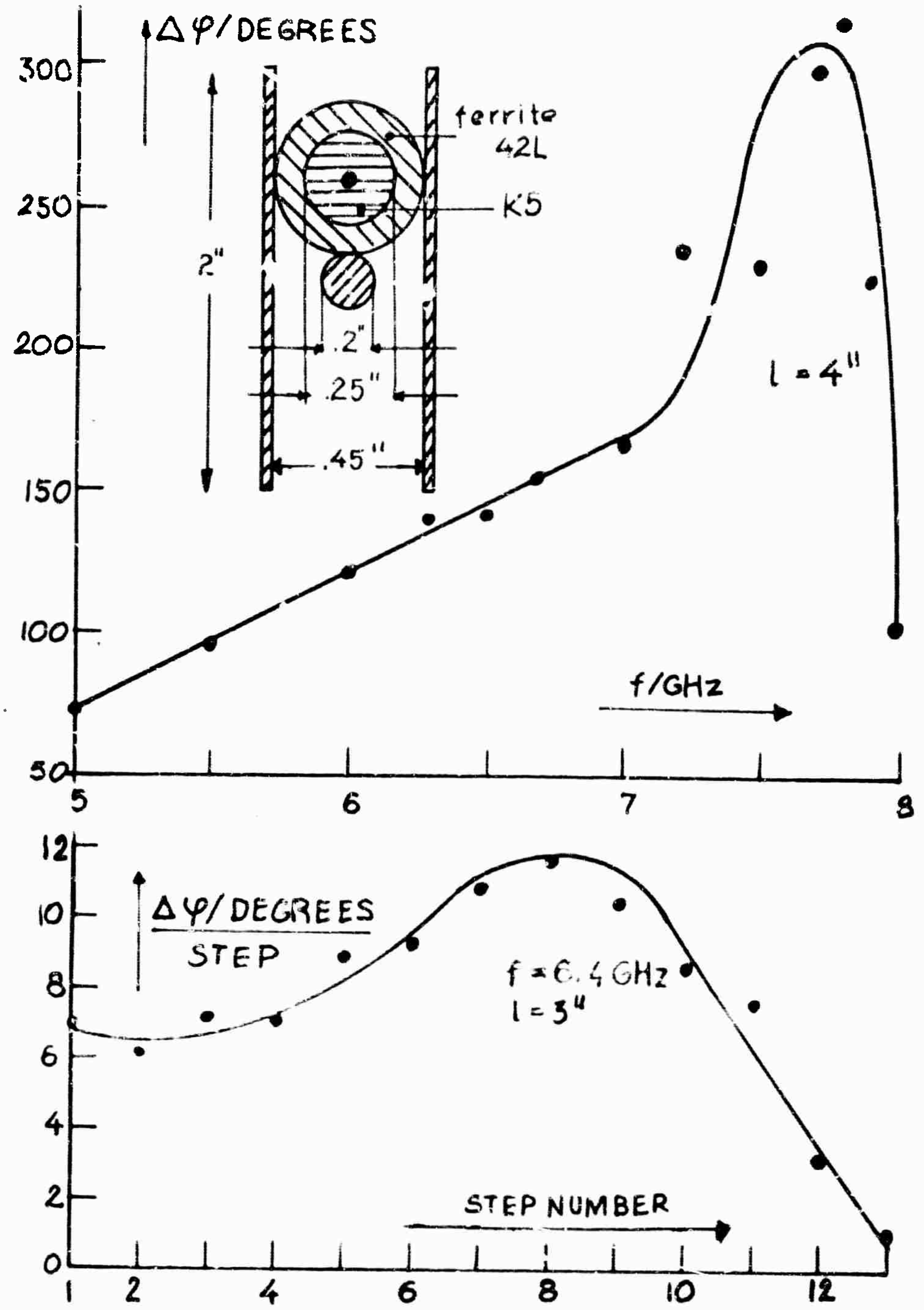
FIGURE 25

V. 2 Slab Line Type Phase Shifters

A typical differential phase shift versus frequency characteristic of a slabline type phase shifter is shown in Figure 26. The phase shift increases gradually with frequency below 7 GHz, shows a high peak at 7.5 GHz and then declines suddenly. The phase shift per step of this phase shifter (with a reduced ferrite length) at 6.4 GHz shows a peak at the eighth step.

With some imagination one may use a rectangular waveguide with dielectric slabs parallel to the narrow walls as a model to analyze the fields in the slab line. This is done in Figure 27. The TE_{10} mode for the centrally loaded guide is the first to appear. With increasing frequency the plane of circular polarization moves from the center of the dielectric towards its outside. In the slabline this is the region of magnetization. A "positive" phase shift increasing with frequency is to be expected. A maximum differential phase shift per step will occur when the plane with circular polarization is magnetized. At high frequencies this is the boundary plane between dielectric and the empty part of the guide, corresponding to the outer ferrite diameter. At these frequencies, however, a TE_{01} mode corresponding to the side wall loaded rectangular guide is possible and at little higher frequencies the TE_{02} mode for either the centrally or sidewall loaded guide may also exist. Both these modes produce close to their respective cutoff-frequencies "negative" phase shift. At higher frequencies negatively as well as positively circularly polarized fields exist in the dielectric. The slabline type phase shifter responds in this frequency range with a rather erratic phase shift versus frequency characteristic. The phase shifter should, therefore, work in the frequency range below the cutoff-frequency corresponding to the sidewall loaded guide.

Figures 28 and 29 show that all the slab line type phase shifters with parallel side walls have the frequency characteristic described above. Increasing, in Figure 29, the wall thickness by 80% increased the phase shift by 50% at 6 GHz. The threshold power doubled from 5 to 10 KW.



Differential Phase Shift Characteristics of Slabline Type Phase Shifter

FIGURE 26

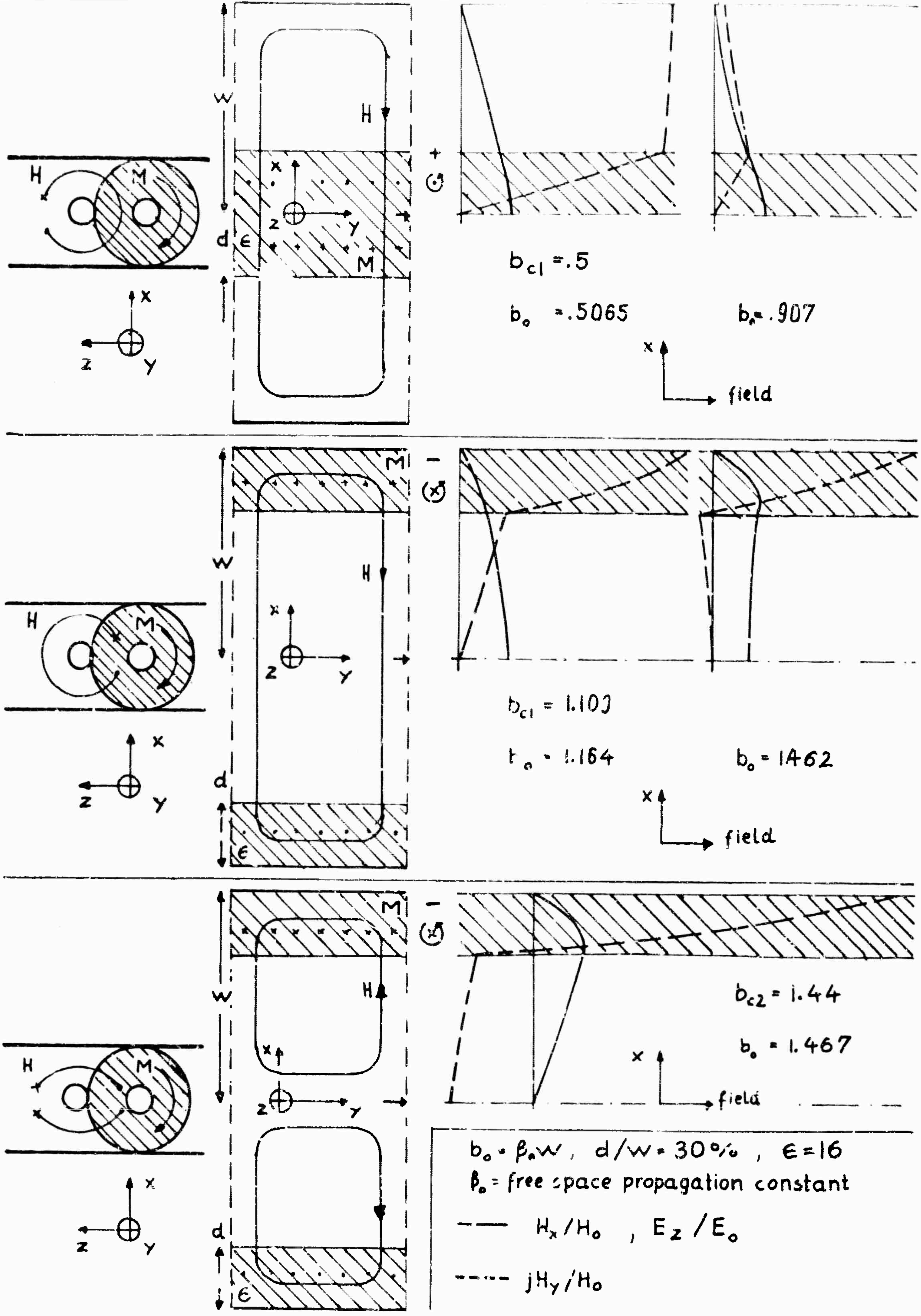
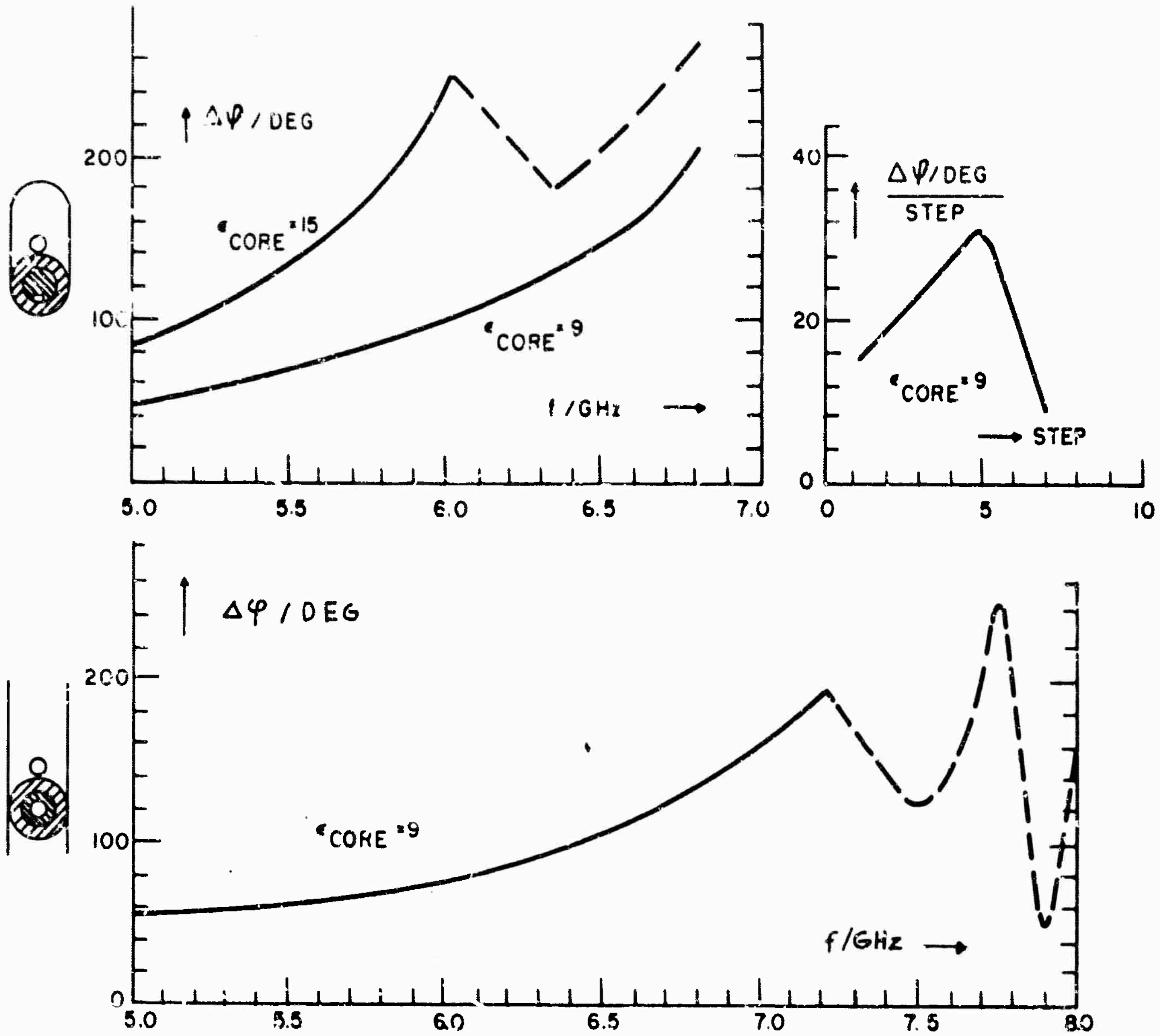
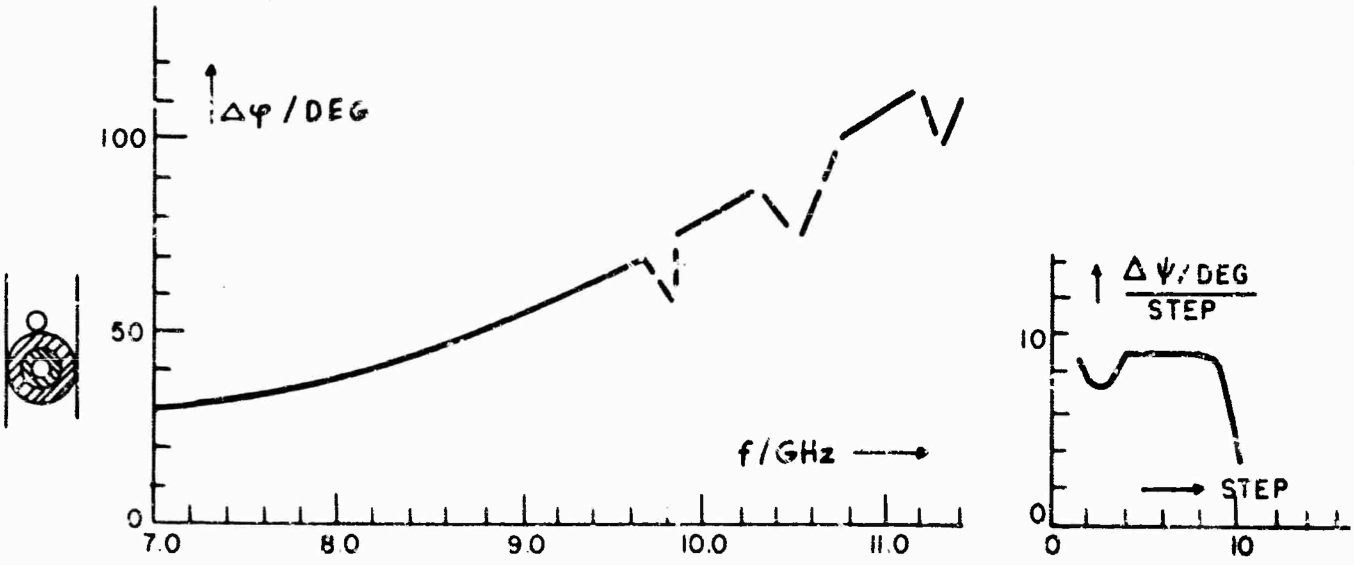


FIGURE 27. Waveguide Model for TE-Modes in Slablines



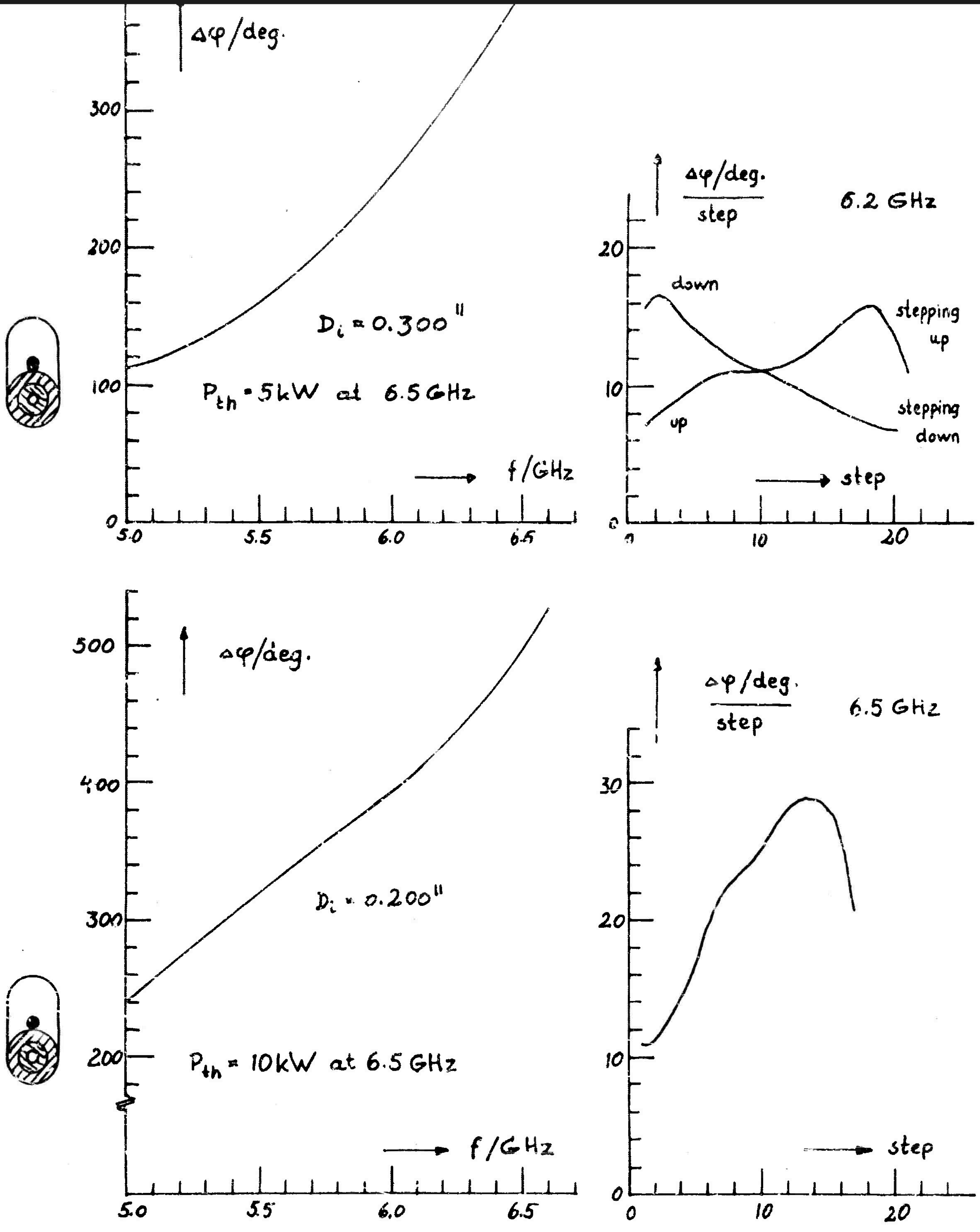
FERRITE TTi-103, $D_0 = 0.437''$, $D_i = 0.29''$, $l = 2.0''$



FERRITE: TTi-103, $D_0 = 0.250''$, $D_i = 0.150''$, $l = 3.0''$, $\epsilon_{CORE} = 9$,

SLABLINE TYPE PHASE SHIFTER

FIGURE 28



Ferrite: TT1-1400, D_o = 0.437", L = 5.0", Core: ε = 10

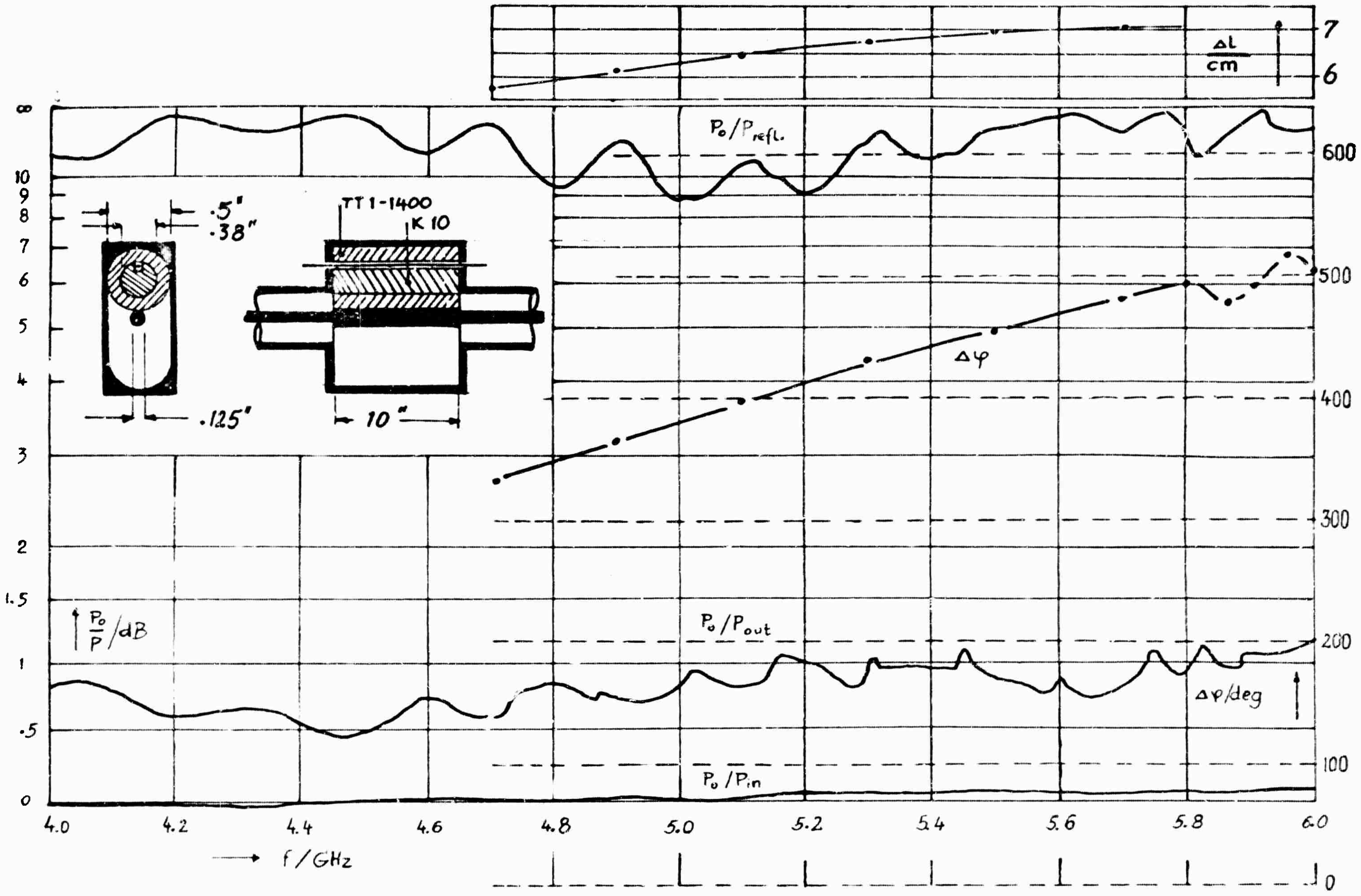
FIGURE 29

The lower value achieved with the thinner wall is somewhat doubtful because moding problems occur at the test frequency. In some other slabline type phase shifters with ferrites with D_6 = .5", D_i = .3" the threshold powers achieved at 6.5 GHz were

6 KW peak with TT1-105 in a shielded slabline
9 KW peak with TT1-105 in an open slabline
15 KW peak with TT1-1400 in an open slabline

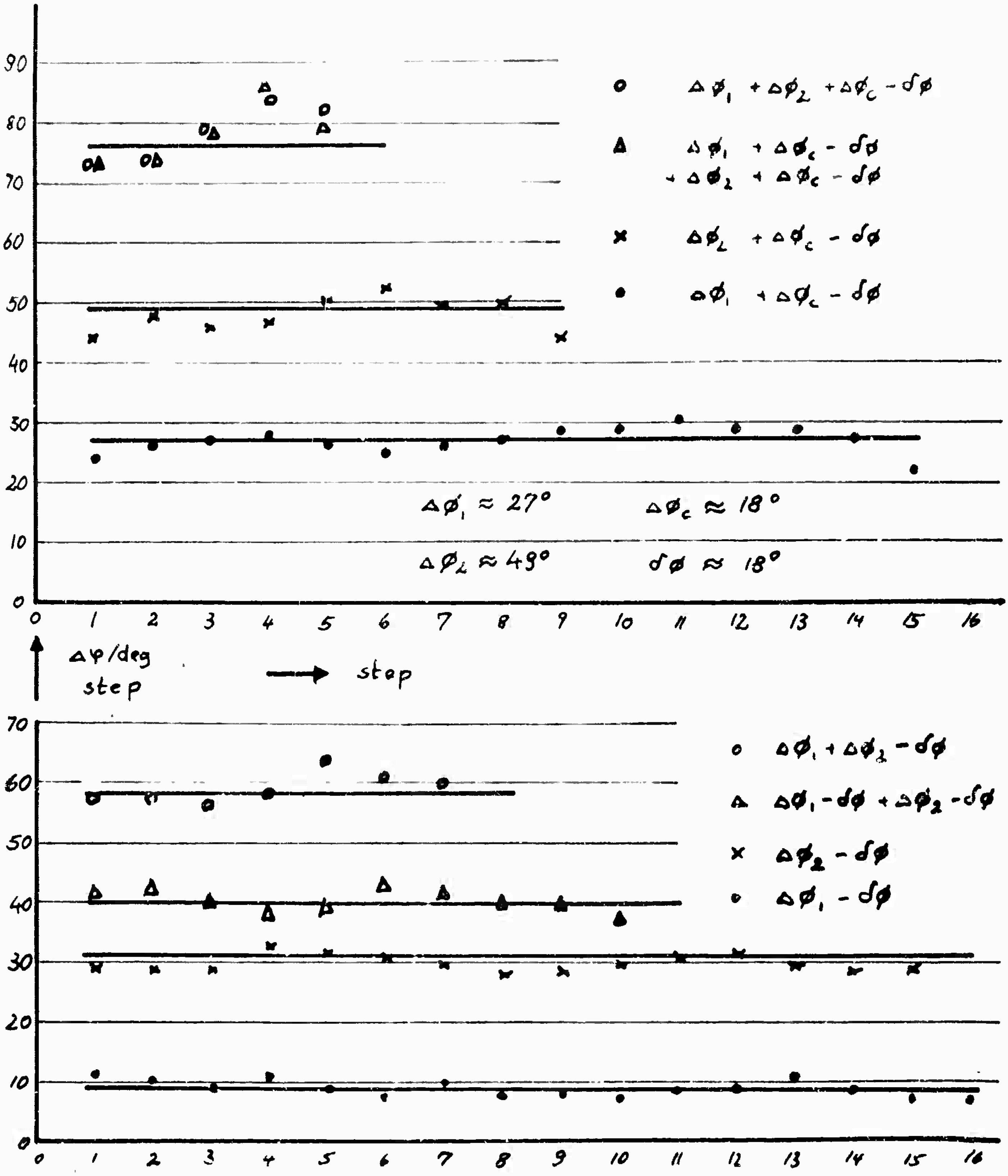
Changing the ferrite and device dimensions led to the phase shifter of Figure 30. The figure of merit is above 400°/dB. Half the ferrite is in contact with the outer conductor. This facilitates heat transfer problems at high average and peak powers. Figure 31 shows the phase shift per step for this device for two different bit sizes and their combinations (switched one after the other and both together) with and without a correction bit. Though the device performance is not yet ideal, the influence of the correction bit is striking. At 5.7 GHz four equal phase shift bits and a correction bit have been added with a transfer circuit as in Figure 8. The results are:

Bit	$\Delta\varphi$/deg(measured)	$\Delta\varphi$/deg(nominal)
1	76	77
2	77	
3	76	
4	76	
1 + 2	151	154
1 + 3	151	
1 + 4	151	
2 + 3	152	
2 + 4	152	
3 + 4	151	
1 + 2 + 3	233	231
1 + 2 + 4	233	
1 + 3 + 4	232	
2 + 3 + 4	233	
1 + 2 + 3 + 4	314	308



Overall Performance of Shielded Slabline Type Phase Shifter

FIGURE 30



Adding Phase Shift Bits by Controlled Flux Transfer (f = 5.6 GHz)

FIGURE 31

Figure 32 shows the results achieved with four different bit sizes and the correction bit. The bits are somewhat too small for a 360° phase shifter. The best approximation is given by the 350° line. With respect to this line the error was within ± 6° and within ± 3%, whatever is smaller. Better results have been achieved but were not reproducible. For good results the switching wire has to be perfectly parallel to the center conductor and center conductor and switching wire have to be perfectly centered. This phase shifter could not be tested at high power, because the available source works at 6.5 GHz, i.e. beyond the phase shifter range.

To enlarge the bandwidth of the slab line type phase shifter a thin slab was inserted into the slab line as shown in Figure 33 to suppress the mode corresponding to the TE_{01} mode in the sidewall loaded rectangular guide. The frequency range has well been extended to higher frequencies. The small remaining erratic phase shift response is ascribed to imperfect adjustment of the switching wire and to the mode corresponding to the TE_{02} mode in the rectangular eielectrically loaded guide. Non-linear losses occurred at about 2.5 KW and voltage breakdown at about 35 KW. The figure of merit is > 300 deg/dB.

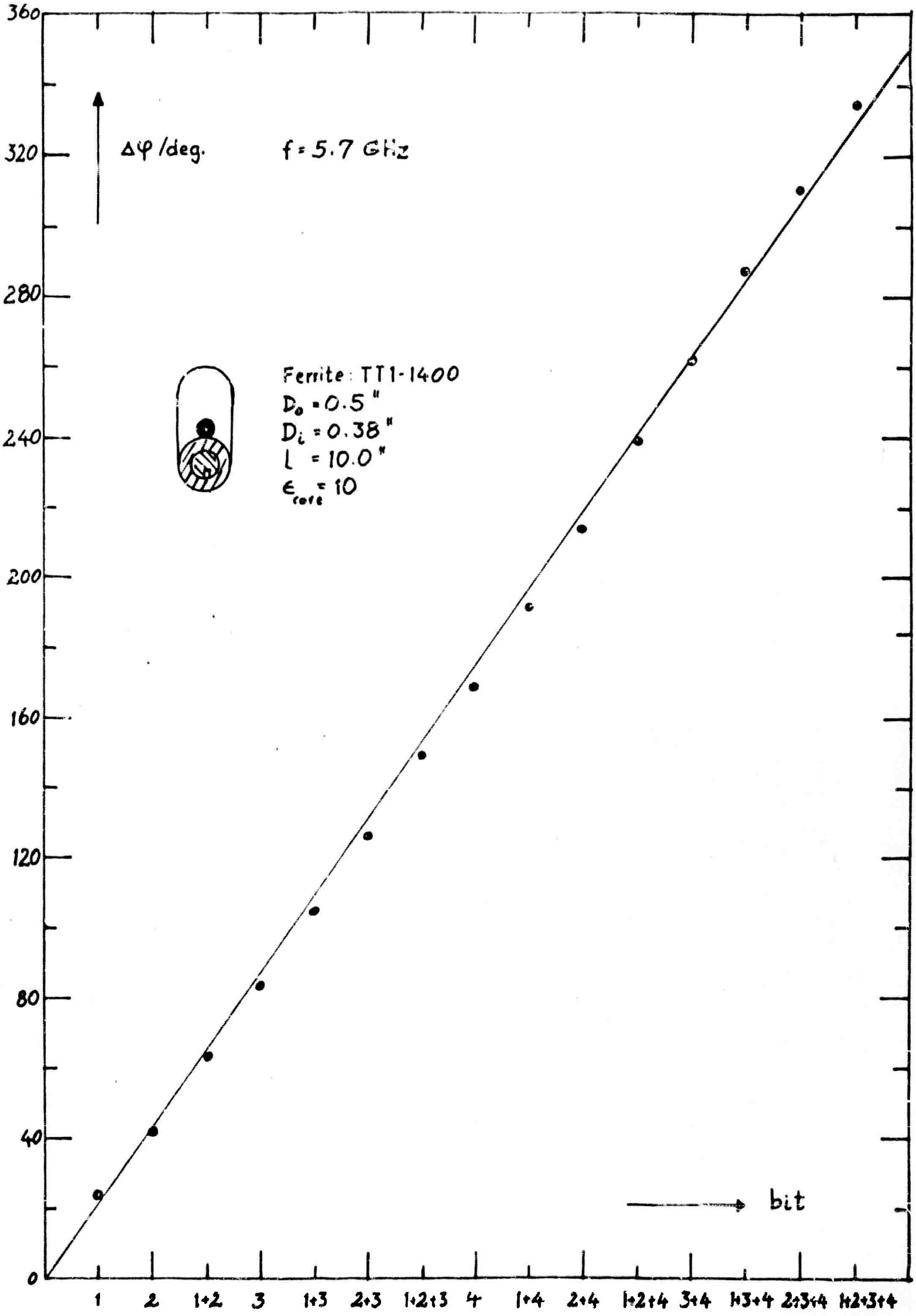


FIGURE 32. Slabline Type Phase Shifter with Flux Controlled Phase Bits

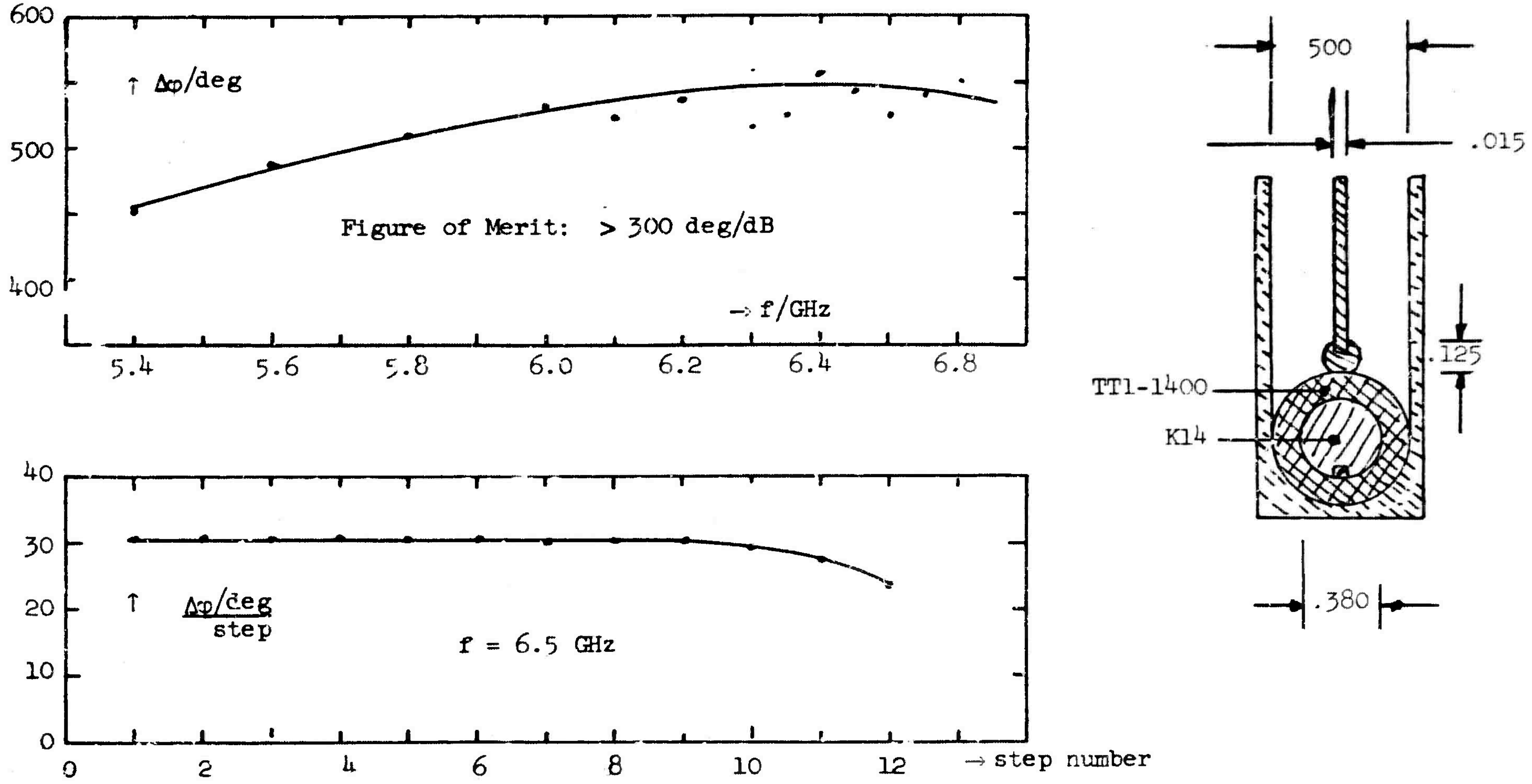


FIGURE 33. Stabline Type Phase Shifter with Mode Suppressor

V.3 General Remarks

The differential line lengths is

$$\Delta L = (\Delta\varphi/\text{rad}) \cdot (\lambda/2\pi)$$

$$\Delta L/\text{cm} = (1/12) \cdot (\Delta\varphi/\text{deg})/(f/\text{GHz})$$

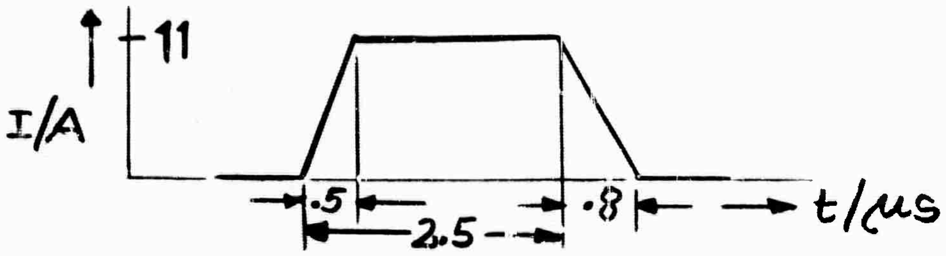
Phase shifters with positive slope $[\partial(\Delta\varphi)/\partial f]$ may thus be useful as delay lines with frequency independent differential line length. All slabline type phase shifters investigated have this positive slope. While the differential phase shift of the phase shifter in Figure 30 increases by 48% between 4.7 and 5.8 GHz, the differential line length increases only by 15%. The waveguide type phase shifter exhibits no slope with a filling factor of about 1/3, positive slope requires a reduced filling factor. A very broad band with constant phase shift has been achieved with this phase shifter. For low power applications the small size of the slab line type phase shifter is an advantage, for high power application voltage breakdown may occur before the ferrite goes unstable because of the small dimensions.

How well a ferrite is used in a phase shifter at a certain frequency may be described in terms of phase shift per flux. Typical for the devices investigated is $10^\circ/\mu$Vs. This value may be constant over a broad band. In helical phase shifters one may obtain $30^\circ/\mu$Vs in the narrow band with maximum phase shift.

Other workers,(7) using rectangular ferrite cylinders in waveguide type phase shifters, found that rounding the edges of the ferrite cylinders increased the differential phase shift and the figure of merit. Under the present contract the "rounding effect" was carried to the extreme.

VI. DRIVING CIRCUITS

Figure 34 shows the basic circuit used in the drivers. It produces an eleven ampere current pulse 2.5 μsec. long with 0.5 μsec. rise time and 0.8 μsec. fall time as sketched below. The power supply voltage was made



as large as possible under the constraints of the 2N1908 transistor.

Initially the reset driver was arranged as in Figure 1. This arrangement did not work well because one of the two parallel inductivities (microwave and driver core) was saturated first and then shorted the other one, so that the other core was not completely reset. Therefore, an arrangement , as indicated in Figure 8, was chosen for the reset circuit. A block diagram for the complete driver circuit is given in Figure 35.

The phase shifter of Figure 30 has a ferrite volume $V \approx 14$ cm^3, a coercive field strength $H_c \approx$ 1A/cm, and a saturation magnetization $M_s \approx$ 10 μVs/cm^2. The required energy per switching cycle is $E_{requ} \approx 4H_cM_sV \approx 560$ μjoules. The drivers have an efficiency of at least 65%. Thus the total switching energy per cycle is 840 μjoules or less. It is believed that for all the phase shifters investigated one needs 0.8 to 1.5 μjoules/degree.

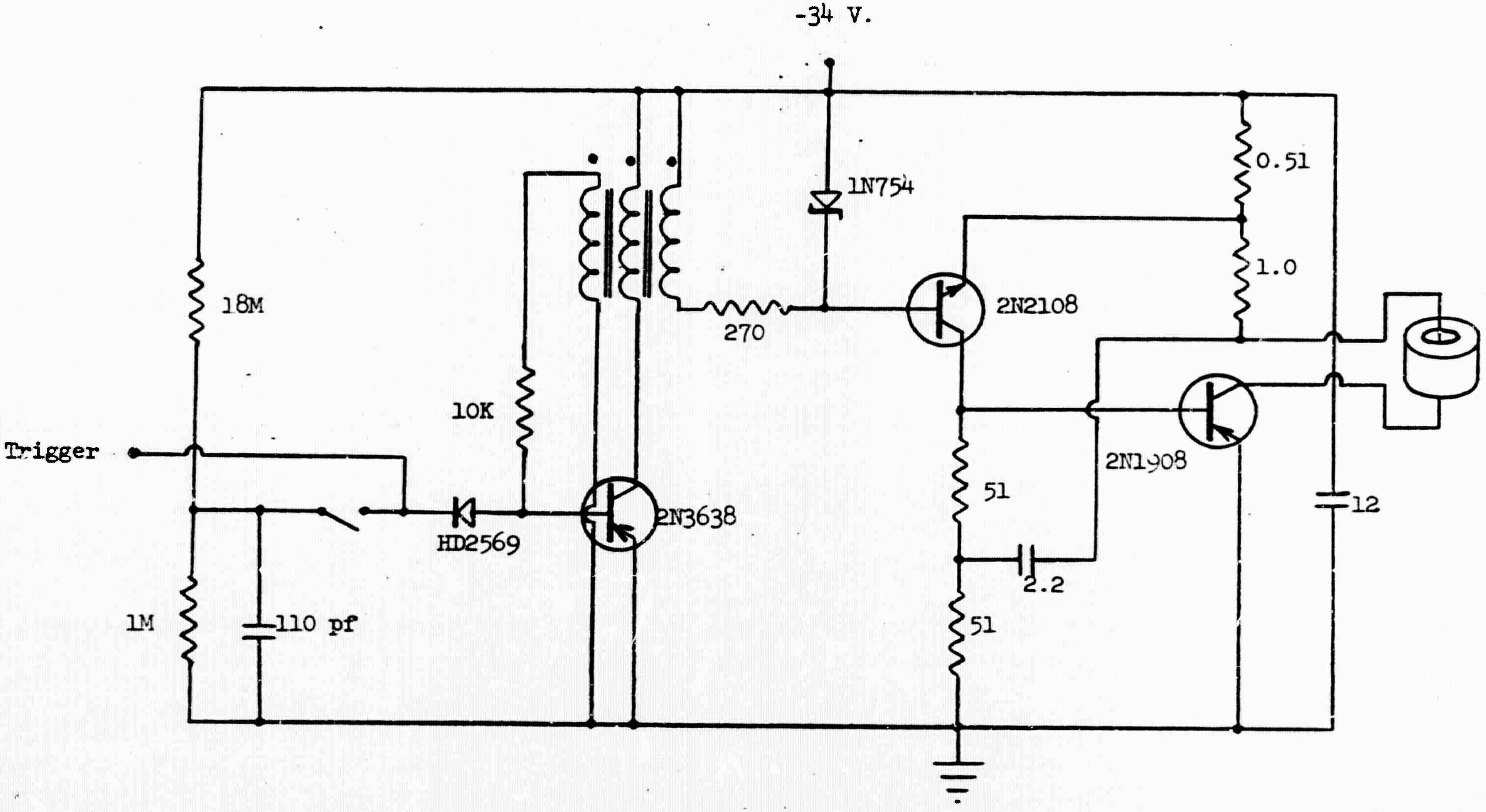
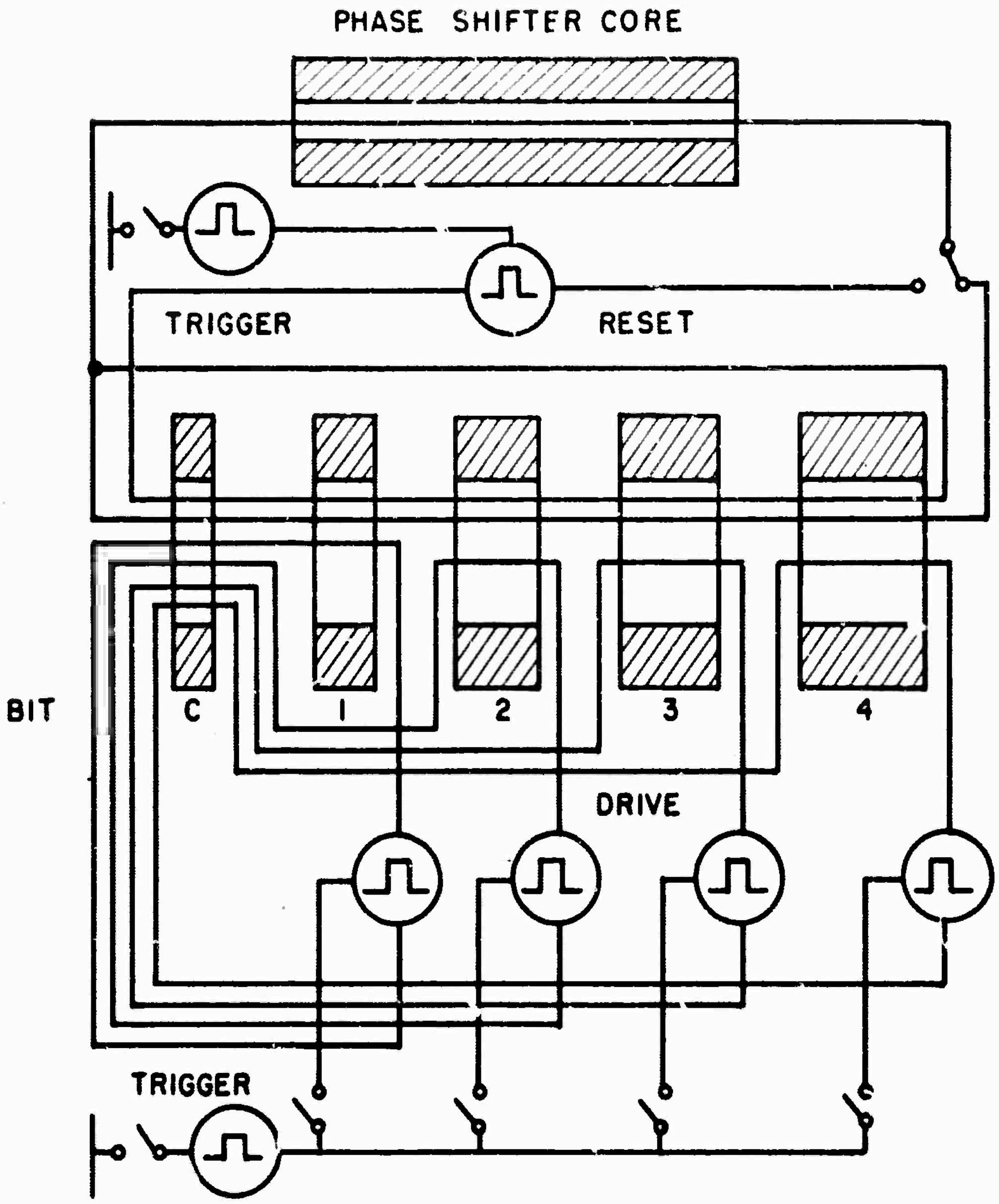


Figure 34. Pulse Driver Circuit



EXPERIMENTAL FOUR BIT DRIVER CIRCUIT

FIGURE 35

ACKNOWLEDGEMENTS

The assistence of Mr. G. T. Roome, who designed and tested the first slabline type phase shifter, and of Mr. E. J. McKinney, who wrote Part II of this report, is highly appreciated. Mr. G. E. Claflin took most of the flux transfer data and designed, together with Mr. T. L. Sly, the driver circuits. Mssrs. E. E. Des Jardins and D. L. Kortz took the bulk of the experimental data. As always, the secretaries, Mrs. I. Maki and Miss L. Jessmore did an excellent job in preparing this report. It is a pleasure to thank all of them.

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PART II. NONLINEAR LOSSES IN FERRITES

ABSTRACT

First and second order solutions for the critical field at which the magnetization in a domain becomes unstable are derived. The domain is assumed to be immersed in a larger sample of ferrite which has a spacial average magnetization equal to the remnant value. It is assumed that the magnetization in the domain of interest is uniform and in the direction of the applied field since this case yields the smallest critical field. The first order solution corresponds to the zero order spin mode for the domain (all spins precessing in unison). The second order solution includes spin waves which exist as traveling waves within the domain. A third order solution would include interactions between spin wave modes, particularly the zero order mode and higher order modes. The spin wave which is excited to unstability by the driving field is shown to have half the frequency of the driving field. It is shown that the critical field increases as the saturation magnetization of the material decreases.

NON-LINEAR LOSSES IN FERRITES

I. INTRODUCTION

The determination of the rf field strength at which nonlinear effects commence in a ferrite has been the object of several investigations. Suhl(1) developed the general theoretical approach and applied it to the configuration in which an rf driving field is applied perpendicular to a dc magnetic biasing field. Schlömann and his associates in various publications(2) have presented the results for a rf driving field which is parallel to and small compared to the dc magnetic biasing field. This investigation considered the special case of a ferrite toroid biased to saturation by means of a pulse of current in a wire coincident with the axis of the toroid. During the time interval of the current pulse, the magnetization throughout the sample is circumferential and has the saturation magnitude, M_s. When the current is removed, it is assumed that domains are formed. In each domain the magnetization is unidirectional, but not necessarily circumferential, and has the saturation magnitude. The magnetization from domain to domain is not unidirectional however, and the average circumferential magnetization throughout the toroid is reduced to the remnant magnitude, M_R.

After the biasing current is removed, a rf driving field $h_1 \cos\omega_1 t$ is applied in the circumferential direction. The purpose of this analysis is to determine the minimum value of h_1 which will cause instability in the toroid. The critical field will be a minimum in a domain in which the dc part of the magnetization is in the same direction as the applied field, so that only this case will be considered. It is assumed that there exists at least one domain within the toroid for which this applies.

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(1) H. Suhl, Proc. IRE, 44, 1270 (1956).

(2) E. Schlomann and R. I. Joseph, Jour. Appl. Phys., 32, 1006 (1961) for example.

II. DEFINITION OF TERMS AND EQUATIONS OF MOTION

Consider a domain in which the dc part of the magnetization is in the same direction as the applied rf field. Assume that the domain is small enough to neglect the curvature of the fields in the circumferential direction of the toroid and let the direction of the applied field be defined as the Z axis of a cartsian coordinate system.

The total magnetization within the domain of interest is assumed to be made up of several components defined as follows:

$\underset{\sim}{\mathcal{M}}$ is the total mangetization vector at a point

$\underset{\sim}{M}$ is the dc component of the magnetization vector

$\underset{\sim}{m}$ is the spacial average of the ac part of the magnetization averaged throughout the sample

$\underset{\sim}{\delta m}$ is the local deviation of the magnetization vector from the spacial average.

Similar definitions will apply to the magnetic field vector terms. The magnetization and field vectors are then expressed in rationalized MKS units by

$$\underset{\sim}{\mathcal{M}} = \underset{\sim}{M} + \underset{\sim}{m} + \underset{\sim}{\delta m} \tag{1}$$

$$\underset{\sim}{\mathcal{H}} = \underset{\sim}{H} + \underset{\sim}{h} + \underset{\sim}{\delta h} = \frac{\underset{\sim}{B}}{\mu_o} - \underset{\sim}{\mathcal{M}} \tag{2}$$

The magnetization is assumed to have a dc component only in the z direction. After the initial biasing magnetic field is removed, it is assumed that no applied dc component of magnetic field exists. Let $\underset{\sim}{x}$, $\underset{\sim}{y}$, and $\underset{\sim}{z}$ be unit vectors in the cartsian coordinate directions and Equation (1) can be written in component form as

$$\underset{\sim}{\mathcal{M}} = (m_x + \delta m_x)\,\underset{\sim}{x} + (m_y + \delta m_y)\,\underset{\sim}{y} + (M_z + m_z + \delta m_z)\,\underset{\sim}{z} \tag{3}$$

The magnetic field inside the domain is made up of four terms, the applied rf field in the z direction, the demagnetizing field resulting from the average ac magnetization throughout the domain, the demangetizing field due to the magnetization in the toroid sample outside the domain of interest, and the demagnetizing field due to local deviations of the magnetization. The demangetizing field due to the average ac magnetization in the domain can be expressed in terms of the demagnetizing factors N_x, N_y and N_z. The local deviations of the magnetization can be expressed in terms of a spin wave spectrum which gives rise to a magnetic field which must satisfy Maxwell's equations. The resultant demagnetizing field can be expressed as(3)

$$\delta \utilde{h} = - \sum_{\utilde{k}} \frac{\utilde{k}(\delta \utilde{m} \cdot \utilde{k})}{k^2} \qquad (4)$$

where $\utilde{k}$ is the spin wave vector.

It will be assumed that the only important local deviations of the magnetization are those which are driven in some way be the applied rf field and that these are restricted, in any particular example, to a narrow region of wave vector $\utilde{k}$. Therefore, Equation (4) can be replaced by the single term in $\utilde{k}$ which dominates. That is

$$\delta \utilde{h} \approx - \frac{\utilde{k}(\delta \utilde{m} \cdot \utilde{k})}{k^2} \qquad (5)$$

The demagneeizing field due to the toroid magnetization outside the sample can be expressed by(4)

$$\utilde{h}_d(\utilde{r}) = \nabla \int \frac{(\nabla' \cdot \utilde{\mathfrak{M}})}{|\utilde{r} - \utilde{r}'|} \, d^3\utilde{r}' \qquad (6)$$

where $\utilde{h}_d(\utilde{r})$ represents the demagnetizing field at the point r inside the sample, ∇ represnets the gradient operator applied at the point $\utilde{r}$ and $\nabla' \cdot \utilde{\mathfrak{M}}$ represents the divergence of $\utilde{\mathfrak{M}}$ at the point $\utilde{r}'$ outside the domain of

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(3) Ronald F. Soohoo, Theory and Application of Ferrites; Prentice-Hall, Inc., 1960, p. 232.

(4) Ernst Schlömann; Advances in Quantum Electronics; Columbia Univ. Press, 1961, p. 450.

interest. Since the magnetization is assumed to be uniform in any domain, Equation (6) would become a surface integral over all the domain boundaries. Since

$$\nabla \left(\frac{1}{|r-r'|}\right) = \frac{\underset{\sim}{r}-\underset{\sim}{r}'}{|r-r'|^{3}} \qquad (7)$$

the integrand in Equation (6) will decrease as one over the square of the distance from the point at which the field is being calculated to the point at which the source of the field is located. Thus, only the magnetization in domains bordering the domain in which instability occurs are important in determining $\underset{\sim}{h}_d(\underset{\sim}{r})$. Obviously $\underset{\sim}{h}_d(\underset{\sim}{r})$ will be a function of position within the domain but also of the location of the domain within the toroidal sample. Since the domain structure throughout the sample cannot be known accurately, it will only be possible to approximate $\underset{\sim}{h}_d(\underset{\sim}{r})$. The simplest approximation is to let it be zero. This is not a bad approximation for points well within the domain of interest (the domain in which instability occurs) because of the one over distance squared dependence mentioned above. A better approximation might be to assume that the magnetization in neighboring domains is nearly z directed and assure a uniform value of $\underset{\sim}{h}_d(\underset{\sim}{r})$ in the z direction of the form $-NM_R$. For most domains this would be a good approximation since the presnece of residual magnetization implies an average non zero z component of magnetization throughout the toroidal sample. There will be domains, however, in which the magnetization is not nearly z directed, and for these the approximation would be poor. In this analysis, it will be assumed that $\underset{\sim}{h}_d(\underset{\sim}{r})$ is zero.

The magnetic field in the domain can then be expressed as

$$\underset{\sim}{H} = \left(-N_x m_x - \frac{k_x}{k^2}\,\delta \underset{\sim}{m}\cdot\underset{\sim}{k}\right)\underset{\sim}{x} + \left(-N_y m_y - \frac{k_y}{k^2}\,\delta \underset{\sim}{m}\cdot\underset{\sim}{k}\right)\underset{\sim}{y} \qquad (8)$$

$$+ \left(h_1 \cos\omega_1 t - N_z M_z - N_z m_z - \frac{k_z}{k^2}\,\delta \underset{\sim}{m}\cdot\underset{\sim}{k}\right)\underset{\sim}{z}$$

The equation of motion for the total magnetization vector contains three terms of interest. These are: the Zeeman term which describes the coupling between the magnetic field and magnetization, the loss term and the exchange term which describes the mutual coupling between spins. Crystalline anisotropy terms are omitted because we are dealing with a polycrystalline material. The equation of motion is given as

$$\dot{\underset{\sim}{m}} = -\gamma(\underset{\sim}{m} \times \underset{\sim}{h}) - \frac{\gamma}{M_s} a^2 H_E \underset{\sim}{m} \times \nabla^2 \underset{\sim}{m} + \text{loss term} \qquad (9)$$

where γ is the gyromagnetic ratio, a^2 the lattice constant and H_E is the effective exchange field. The loss term will be of the Landau-Lifshitz form given by Suhl.(5) The loss term is not stated explicitly in Equation (9) because the loss parameter α will not necessarily be the same for m and for δm. Let α_o represent the loss term associated with the uniform precession terms m and α_k represent the spin wave loss term. Some care is necessary in the choice of sign applied to α_o and α_k to insure that the homogeneous solutions ($h_1 = 0$) result in decaying waves. The following assumption is made regarding the order of magnitude of the magnitization

M_z is a zero order quantity
m_x and m_y are first order quantities
m_z, δm_x and δm_y are second order quantities
δm_z is a third order quantity

Since it has been assumed that the domain is saturated, the magnetization terms can be related by

$$(m_x + \delta m_x)^2 + (m_y + \delta m_y)^2 + (M_z + m_z + \delta m_z)^2 = M_s^2 \qquad (10)$$

Equating terms of equal order of magnitude in Equation (10) gives the approximations

$$\begin{aligned} M_z &\approx M_s \\ m_z &\approx -\frac{1}{2}\,\frac{m_x^2 + m_y^2}{M_s} \qquad (11) \\ \delta m_z &\approx -\frac{1}{M_s}(m_x \delta m_x + m_y \delta m_y) \end{aligned}$$

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(5) H. Suhl, Proc IRE, 44, (1956) p. 1271.

Define ω_s and ω_m by

$$\omega_s \equiv \gamma h_1 \tag{12}$$

$$\omega_M \equiv \gamma M_s \approx \gamma(M_z + m_z) \approx \gamma M_z \tag{13}$$

Let Z_x and Z_y be the x and y components of the Zeeman term in Equation (9). Then from Equations (3) and (8) and the order of magnitudes assumed, Z_x and Z_y can be written to third order as

$$\begin{aligned}
Z_x = & -\left[\omega_s \cos\omega_1 t - \omega_M (N_z - N_y)\right] m_y && \text{First Order} \\
& -\left[\omega_M \frac{k_x k_y}{k^2}\right]\delta m_x - \left[\omega_s \cos\omega_1 t - \omega_M N_z + \omega_M \frac{k_y^2}{k^2}\right]\delta m_y && \text{Second Order} \\
& -\left[\omega_M \frac{k_y k_z}{k^2}\right]\delta m_z + \left[\gamma \frac{k_x k_z}{k^2}\right]\delta m_x m_y + \left[\gamma \frac{k_y k_z}{k^2}\right]\delta m_y m_y && \text{Third Order}
\end{aligned} \tag{14}$$

$$\begin{aligned}
Z_y = & \left[\omega_s \cos\omega_1 t - \omega_M (N_z - N_x)\right] m_x && \text{First Order} \\
& +\left[\omega_M \frac{k_x k_y}{k^2}\right] m_y + \left[\omega_s \cos\omega_1 t - \omega_M N_z + \omega_M \frac{k_y^2}{k^2}\right]\delta m_x && \text{Second Order} \\
& +\left[\omega_M \frac{k_x k_z}{k^2}\right]\delta m_z - \left[\gamma \frac{k_x k_z}{k^2}\right]\delta m_x m_x - \left[\gamma \frac{k_y k_z}{k^2}\right]\delta m_y m_y && \text{Third Order}
\end{aligned} \tag{15}$$

Similarly the components L_x and L_y of the loss term and E_x and E_y of the exchange term can be written

$$L_x \approx \alpha_o \dot{m}_y - \alpha_k \delta\dot{m}_y + \frac{\alpha_o}{M_s} \dot{m}_z m_y \tag{16}$$

$$L_y \approx -\alpha_o \dot{m}_x + \alpha_k \delta\dot{m}_x - \frac{\alpha_o}{M_s} \dot{m}_z m_x \tag{17}$$

where the first term on the right is the first order term, the second the second order term and the third the third order term and

$$E_x = a^2\omega_E\nabla^2\delta m_y = - a^2\omega_E k^2\delta m_y \tag{18}$$

$$E_y = - a^2\omega_E\nabla^2\delta m_x = a^2\omega_E k^2\delta m_x \tag{19}$$

where

$$\omega_E \equiv \gamma H_E \tag{20}$$

The exchange terms E_x and E_y are both of second order. The exchange term contains no first or third order terms.

III. FIRST ORDER SOLUTION

Collecting only the first order terms from Equations (14) through (19) gives

$$\begin{aligned}(1 + i\alpha_o)\dot{m}^+ + iAm^+ + iBm^- &= i\omega_s(\cos\omega_1 t)m^+ \\ (1 - i\alpha_o)\dot{m}^- - iAm^- - iBm^+ &= -i\omega_s(\cos\omega_1 t)m^-\end{aligned} \tag{21}$$

where the terms are defined as follows

$$\begin{aligned}m^{\pm} &= m_x \pm im_y \\ A &= \omega_M(N_z - \tfrac{1}{2}N_x - \tfrac{1}{2}N_y) \\ B &= \tfrac{1}{2}\,\omega_M(N_y - N_x)\end{aligned} \tag{22}$$

The coupled equations of motion of Equation (21) can be decoupled in the homogeneous case by making the change of variables

$$\begin{aligned}m^+ &= an^+ - bn^- \\ m^- &= -b^*n^+ + an^-\end{aligned} \tag{23}$$

where

$$\begin{aligned}\cosh x &= A/\omega o \\ \sinh x &= B/\omega_o \\ a &= \cosh x/2 \\ b &= (1 - i\alpha_o)\sinh x/2 \\ b^* &= (1 + i\alpha_o)\sinh x/2 \\ \omega_o^2 &= A^2 - B^2 = \omega_M^2(N_z - N_x)(N_z - N_y)\end{aligned} \tag{24}$$

Neglecting all terms containing α_o^2, the decoupled equations of motion become

$$\begin{aligned}\dot{n}^+ + (i\omega_o + \alpha_o A)n^+ &= \left(i\frac{\omega_s}{\omega_o}A\cos\omega_1 t\right)n^+ - \left(i\frac{\omega_s}{\omega_o}B\cos\omega_1 t\right)n^- \\ \dot{n}^- - (i\omega_o - \alpha_o A)n^- &= -\left(i\frac{\omega_s}{\omega_o}A\cos\omega_1 t\right)n^- + \left(i\frac{\omega_s}{\omega_o}B\cos\omega_1 t\right)n^+\end{aligned} \tag{25}$$

The homogeneous solution is obtained by equating the right sides of Equations (26) to zero and is given by

$$n^{+} = n_o^{+} e^{-(i\omega_o + \alpha_o A)t}$$
$$n^{-} = n_o^{-} e^{(i\omega_o + \alpha_o A)t} \tag{26}$$

The particular solution is obtained by differentiating Equations (26) with respect to time, with n_o^{+} and n_o^{-} considered time variable, and substituting into Equations (25). The driving terms on the right sides of the resulting equations will contain time variations of the form $\omega_1 \pm \omega_o$ and $-\omega_1 \pm \omega_o$. Only those terms which have time variations nearly equal to the natural frequencies, $\pm \omega_o$, will be effective. Such terms exist only for

$$\omega_1 \approx 2\omega_o \tag{27}$$

Assuming Equation (27) and neglecting off resonant driving terms gives

$$\dot{n}_o^{+} \approx -i\left(\frac{\omega_s}{\omega_o}\right)\left(\frac{B}{2}\right) n_o^{-} e^{-i(\omega_1 - 2\omega_o)t}$$
$$\dot{n}_o^{-} \approx i\left(\frac{\omega_s}{\omega_o}\right)\left(\frac{B}{2}\right) n_o^{+} e^{i(\omega_1 - 2\omega_o)t} \tag{28}$$

Differentiating Equations (28) again with respect to time and rearranging terms gives

$$n_o^{\pm} \pm i(\omega_1 - 2\omega_o)N_o^{\pm} - \left(\frac{B}{2}\right)^2 \left(\frac{\omega_s}{\omega_o}\right) n_o^{\pm} - 0 \tag{29}$$

Assuming a solution of the form

$$n_o^{\pm} = N_o^{\pm} e^{\pm(i\omega \pm \beta)t} \tag{30}$$

where ω is an oscillatory part and β a damping part of the time variation and substituting into Equation (29), gives, by equating real and imaginary terms,

$$\omega = -\left(\frac{\omega_1}{2} - \omega_o\right)$$
$$\beta^2 = \left(\frac{B}{2}\right)^2 \left(\frac{\omega_s}{\omega_o}\right)^2 - \left(\frac{\omega_1}{2} - \omega_o\right)^2 \tag{31}$$

The two solutions for n_o^+ and for n_o^- then consist of a low frequency oscillation with an exponentially increasing amplitude for one and an exponentially decreasing amplitude for the other.

From Equation (25) it is seen that instability will occur if $n_o^{\pm}$ grows more rapidly than the exponential decay terms in $n^{\pm}$. The threshold of instability is given by

$$\beta^2 = (\alpha_o A)^2 \qquad (32)$$

Substituting the value of β^2 from Equation (31) and the value of B form Equation (21) into Equation (32) and solving for ω_s gives

$$\omega^2_{s\,crit} = \frac{16\left(\frac{\omega_o}{\omega_m}\right)^2}{(N_y - N_x)^2} \left[\left(\frac{\omega_1}{2} - \omega_o\right)^2 + (\alpha_o \omega_o)^2 - \alpha_o \left(\frac{\omega_M}{2}\right)^2 (N_y - N_x)^2 \right] \qquad (33)$$

The minimum instability threshold occurs when $\omega_1 = 2\omega_o$. For this case we have

$$\left(\frac{h_1}{\Delta_H}\right)_{crit} = \frac{\left[1 - \left(\frac{\omega_M}{\omega_1}\right)^2 (N_y - N_x)^2\right]^{\frac{1}{2}}}{\left(\frac{\omega_M}{\omega_1}\right)(N_y - N_x)} \qquad (34)$$

where

$$\Delta H \equiv \frac{\alpha_o \omega_o}{\gamma} \qquad (35)$$

is the low power resonance linewidth.

Let $N_x = 0$ and recall that

$$N_x + N_y + N_z = 1 \qquad (36)$$

Then solving for $(N_y - N_x)$ in terms of $\left(\frac{\omega_M}{\omega_1}\right)$, using the definition of ω_o from Equation (24) and the assumption that $\omega_1 = 2\omega_o$, gives the normalized minimum critical field as

$$\left(\frac{h_1}{\Delta H}\right)_{crit} = \frac{4\sqrt{1 - \frac{1}{8}\left(\frac{\omega_1}{\omega_M}\right)^2 \left[5 - 3\sqrt{1 + 2\left(\frac{\omega_1}{\omega_M}\right)^2} + \left(\frac{\omega_1}{\omega_M}\right)^2\right]}}{\left(\frac{\omega_M}{\omega_1}\right)\left[3 - \sqrt{1 + 2\left(\frac{\omega_1}{\omega_M}\right)^2}\right]} \qquad (37)$$

The critical field obtained by this approximation is the field which will cause the entire domain to go unstable simultaneously. In this approximation, the spin system throughout the domain is in synchronism. For this model the critical field approaches infinity as the ratio $\left(\frac{\omega_M}{\omega_1}\right)$ approaches 0.5 and is imaginary for smaller values of (ω_M/ω_1). Since finite critical fields have been measured below $(\omega_M/\omega_1) = 0.5$, this model is obviously too crude to be useful in the range of small (ω_M/ω_1). As the ratio (ω_M/ω_1) becomes larger the critical field given by Equation (37) grows smaller and the approximation is somewhat better. A more accurate approximation of the critical field for all ranges of (ω_M/ω_1) is given by the second order differential equations which are taken up in the next section.

IV. SECOND ORDER SOLUTION

Retaining the definitions of Equation (22) and including first and second order terms from Equations (14) through (19) gives the coupled equations of motion as

$$(1 \pm i\alpha_o)\dot{m}^{\pm} + (1 \mp i\alpha_k)\delta\dot{m}^{\pm} = \pm (i\omega_s \cos\omega_1 t)m^{\pm} \mp iAm^{+} \mp iBm^{\mp}$$

$$\pm (i\omega_s \cos\omega_1 t)\delta m^{\pm} \pm iA_k \delta m^{\pm} \pm iB_k^{\pm} \delta m^{\mp} \tag{38}$$

where

$$A_k = -\omega_M N_z + a^2\omega_x k^2 + \frac{\omega_M}{2}\frac{k^+k^-}{k^2} = -\omega_M N_z + a^2\omega_E k^2 + \frac{\omega_M}{2}\sin^2\theta$$

$$B_k^{\pm} = \frac{\omega_M}{2k^2}(k^{\pm})^2 = \frac{\omega_M}{2} e^{\pm i2\varphi} \sin^2\theta \tag{39}$$

The angle θ is the angle between the z axis of the coordinate system and the direction of the spin wave vector $\underset{\sim}{k}$. The angle φ is the angle between the projection of $\underset{\sim}{k}$ on the xy plane and the x axis. Equation (38) can be solved approximately by applying the technique used in solving the differential equations in Part II. First the homogeneous equations for $m^{\pm}$ and $\delta m^{\pm}$ are solved separately. These solutions are then inserted into the particular equation with the constants from the homogeneous solution allowed to be time variable. Next all driving terms which do not have time variations nearly equal to the resonant frequencies from the homogeneous solution are discarded. The resultant equations can then be decoupled by a transformation similar to the one in Part II and the resulting equations solved directly.

The homogeneous solution for $m^{\pm}$ was obtained in Part II and is given by Equation (26). The homogeneous equations for $\delta m^{\pm}$ are given by

$$(1 \mp i\alpha_k)\delta\dot{m}^{\pm}_k = \pm iA_k \delta m^{\pm} \pm iB_k^{\pm} \delta m^{\mp} \tag{40}$$

Making the transformation of variables

$$\delta m^{+} = a_k\ \delta n^{+} - b_k\ \delta n^{-}$$

$$\delta m^{-} = - b_{-k}\ \delta n^{+} + a_k\ \delta n^{-} \tag{41}$$

gives

$$\delta \dot{n}^{\pm} \mp (i\omega_k \mp \alpha_k A_k)\ \delta n^{\pm} = 0 \tag{42}$$

where

$$\cosh x_k = A_k/\omega_k$$

$$\sinh x_k = B_k\ /\omega_k$$

$$a_k = \cosh x_k/2 \tag{43}$$

$$b_{\pm k} = (1 \pm i\alpha)\ e^{\pm\ i2\varphi} \sinh x_k/2$$

$$\omega_k^{\ 2} = A_k^{\ 2} - B_k^{\ +} B_k^{\ -} = (a^2\omega_x k^2 - N_z\omega_M)(\omega_M \sin^2\theta + a^2\omega_x k^2 - N_z\omega_M)$$

Equation (42) has solutions of the form

$$\delta n^{\pm} = \delta n_o^{\pm}\ e^{\pm(i\omega_k \mp \alpha_k A_k)t} \tag{44}$$

From Equations (23) and (26) it can be seen that m^{+} and m^{-} have frequency components at $+\omega_o$ and at $-\omega_o$. Similarly, from Equations (41) and (44), $\delta m^{\pm}$ have frequency components at $+\omega_k$ and at $-\omega_k$. Assuming that these terms dominate, consider the frequency components of the terms in Equation (38). These are summarized in Table I. The equations of motion are now best solved in approximate form by separtely considering various cases in the frequency relationships.

TABLE I. APPROXIMATE FREQUENCIES OF TERMS IN SECOND ORDER MAGNETIZATION EQUATION

$(1 \pm i\alpha)\dot{m}^{\pm}$	$(1 \mp i\alpha_k)\delta\dot{m}^{\pm}$	$i\omega_s \cos\omega_1 t m^{\pm}$	$iAm^{\pm}$	$iBm^{\mp}$	$i\omega_s \cos\omega_1 t\,\delta m^{\pm}$	$A_k\,\delta m^{\pm}$	$B_k^{\pm}\,\delta m^{\mp}$
ω_0	ω_k	$\omega_1 + \omega_0$	ω_0	$-\omega_0$	$\omega_1 + \omega_k$	ω_k	$-\omega_k$
$-\omega_0$	$-\omega_k$	$\omega_1 - \omega_0$	$-\omega_0$	$+\omega_0$	$\omega_1 - \omega_k$	$-\omega_k$	ω_k
		$-\omega_1 + \omega_0$			$-\omega_1 + \omega_k$		
		$-\omega_1 - \omega_0$			$-\omega_1 - \omega_k$		

A. Case 1: $\omega_1 \neq 2\omega_0$; $\frac{1}{2}\omega_1 \approx \omega_k$; $\omega_0 \neq \omega_k$

From Equation (24) it is seen that ω_0 is a function of the ferrite material through ω_M and a function of the domain shape through the demagnetizing factors N_x, N_y and N_z. For a given domain then, ω_0 is a constant. The driving frequency, ω_1, is controlled so that the first inequality of this case can always be established. Spin waves in the sample can exist over a very broad frequency spectrum. The approximate equality $\omega_k \approx \frac{1}{2}\omega_1$ will always be satisfied for a portion of the spin wave spectrum regardless of the value of ω_1 and will be the dominant term. Other spin waves with frequencies $\omega_k \neq \frac{1}{2}\omega_1$ will not be driven by the applied rf field and can be neglected.

Considering only those terms of Equation (38) which vary at ω_k as determined from Table I gives

$$(1 \mp i\alpha_k)\delta\dot{m}^{\pm} = \pm i\omega_s \cos\omega_1 t\,\delta m^{\pm} \pm iA\,\delta m^{\pm} B_k^{\pm}\,\delta m^{\mp} \qquad (45)$$

Again making the change of variables indicated in Equation (41) and assuming a solution of the form given in Equation (44) with $\delta n_0^{\pm}$ time varying, gives

$$\delta\dot{n}_0^{+} \approx -\frac{i}{2}\left|B_k\right|\frac{\omega_s}{\omega_k}\, e^{i2\varphi}\, e^{i(\omega_1 - 2\omega_k)t}\,\delta n_0^{-}$$

$$\delta\dot{n}_0^{-} \approx \frac{i}{2}\left|B_k\right|\frac{\omega_s}{\omega_k}\, e^{-i2\varphi}\, e^{-(\omega_1 - 2\omega_k)t}\,\delta n_0^{+} \qquad (46)$$

Taking second time derivatives and combining equations gives

$$\left[\frac{\partial^2}{\partial t^2} \mp i(\omega_1 - 2\omega_k) - \left(\frac{\left|B_k\right|}{2}\,\frac{\omega_s}{\omega_k}\right)^2\right]\delta n_0^{\pm} = 0 \qquad (47)$$

Assuming a solution of the form

$$\delta n_0^{\pm} = \delta N_0^{\pm}\, e^{\pm(i\omega \pm \kappa)t} \qquad (48)$$

where ω is the oscillatory and κ the loss parts of the time variation and solving for ω and κ gives

$$\omega = \left(\frac{\omega_1}{2} - \omega_k\right)$$

$$\kappa^2 = \left(\frac{\left|B_k\right|}{2}\,\frac{\omega_s}{\omega_k}\right)^2 - \left(\frac{\omega_1}{2} - \omega_k\right)^2 \qquad (49)$$

The instability threshold for this case occurs when

$$\kappa^2 = \alpha_k^2 A_k^2 \qquad (50)$$

Solving Equation (50) for ω_s^2 gives

$$\omega_s^2\text{crit} = (\gamma h_1)^2_{\text{crit}} = \frac{4\omega_k^2}{\left|B_k\right|^2}\left[\left(\frac{\omega_1}{2} - \omega_k\right)^2 + \alpha_k^2 A_k^2\right] \qquad (51)$$

The minimum critical field occurs when $\omega_1 = 2\omega_k$ which gives

$$\left(\frac{h_1}{\Delta H_k}\right)_{crit} = \frac{\left(\frac{\omega_1}{\omega_M}\right)}{\sin^2\theta} \frac{\left(1 - \frac{1}{2}\frac{\omega_M \sin^2\theta}{a^2\omega_x k^2 - \omega_M N_z}\right)}{\sqrt{1 - \frac{\omega_M \sin^2\theta}{a^2\omega_x k^2 - \omega_M N_z}}} \tag{52}$$

where

$$\Delta H_k \cong \frac{2\alpha_k \omega_k}{\gamma} \tag{53}$$

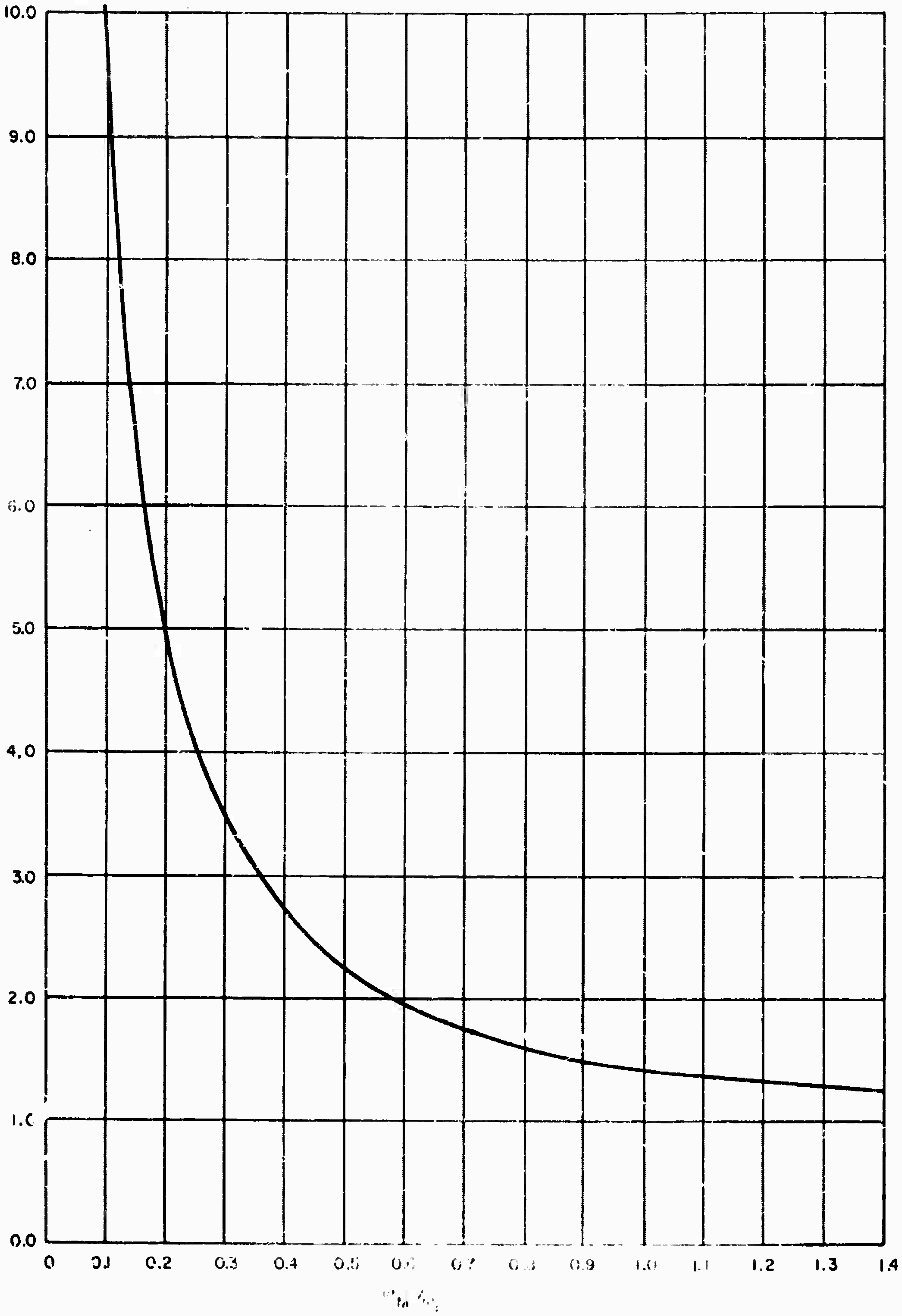
is the spin wave linewidth. Using the definition of ω_k from Equation (43) and the assumption that $\omega_1 = 2\omega_k$, $(a^2\omega_x k^2 - \omega_M N_z)$ can be evaluated and substituting into Equation (42) to obtain the result

$$\left(\frac{h_1}{\Delta H}\right)_{k\ crit} = \frac{\sqrt{1 + \left(\frac{\omega_M}{\omega_1}\right)^2 \sin^4\theta}}{\left(\frac{\omega_M}{\omega_1}\right) \sin^2\theta} \tag{54}$$

Equations (54) is further minimized when $\sin^2\theta = 1$ so that

$$\left(\frac{h_1}{\Delta H_k}\right)_{crit} = \frac{\sqrt{1 + \left(\frac{\omega_M}{\omega_1}\right)^2}}{\left(\frac{\omega_M}{\omega_1}\right)} \tag{55}$$

This expression is plotted in Figure 1.


10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
ω_{1a}/ω_1

Case 2: $\omega_1 - \omega_o \approx \omega_k \neq \omega_o$

The equations of motion for this case are given by

$$(1 \mp \alpha_k)\ \delta\dot{m}^{\pm} \mp iA_k\,\delta m^{\pm} \mp iB_k^{\pm}\ \delta m^{\mp} = \pm\ i\omega_s \cos\omega_1 t\ m^{\pm} \tag{56}$$

which correspond to a coupled pair of lossy harmonic oscillators on the left with a harmonic driving term on the right. The equations can be decoupled by the coordinate transformation of Equation (41), however one need not do so to determine that the solutions of Equations (56) are stable harmonic oscillators as long as the right sides of the equations have constant amplitude, i.e. $m^{\pm}$ constant in amplitude. The critical field for this case would then be given by Equation (37) which is the field required to make $m^{\pm}$ grow exponentially.

Case 3: $\omega_K = \omega_o = \frac{1}{2}\omega_1$

For this case all of the terms from Equation (38) must be retained in part and a direct solution is too complex algabraically to be solved. A reasonable approximation to this case might be given by Equation (55) for low values of ω_M/ω_1 and by the lower of the values from Equations (37) and (55) for large values of ω_M/ω_1.

V. DISCUSSION OF RESULTS AND HIGHER ORDER TERMS

The first and second order solutions both indicated that the normalized critical field increases monotonically as the ratio ω_M/ω_1 decreases. The first order solution does not have a finite critical field for ω_M/ω_1 less than 0.5 and is thus inadequate for low values of ω_M/ω_1. The second order solution has finite values for the normalized dritical field for all non-zero values of ω_M/ω_1. For this reason, and because it considers more of the interacting energy terms, the second order solution is to be preferred.

There are, however, several possibilities for error in the second order solution. One of the most serious problems is the normalizing term ΔH_k which is the spin wave linewidth. This term is related to the spin wave loss or relaxation, and is expected to be a function of frequency and material and possibly even the shape of the sample and domain rather than a constant. Until this term is known more explicitly, Equation (55) and Figure 1 can only be considered as rough approximations.

It was assumed that the demagnetizing field due to spacial average magnetization in the domain could be expressed in terms of the demagnetizing factors N_x, N_y and N_z. These factors apply precisely only for ellipsoidal samples which are small compared to the wavelength of the externally applied fields. For other shapes constant N factors can be assumed throughout the bulk of the domain which will closely approximate the physical situation. However, near the domain boundaries and particularly near sharp edges, the demagnetizing field can be a rapidly varying function of position. This can be accounted for by allowing the demagnetizing factors to be functions of position near the domain boundaries and constant throughout most of the domain. Unfortunately, computation of the functional dependence of the demagnetizing field (or factors) is a prohibitively difficult task for almost all shapes of interest.

The effect of the variation in N_z can be seen from the spin wave dispersion diagram shown in Figure 2. The abscissa scale in Figure 2 is normalized by the factor $\sqrt{\omega_M/a^2\omega_E}$ which depends on the material constants γ, M_s, a^2, and H_E and which makes Figure 2 a general curve applicable to all ferrites.

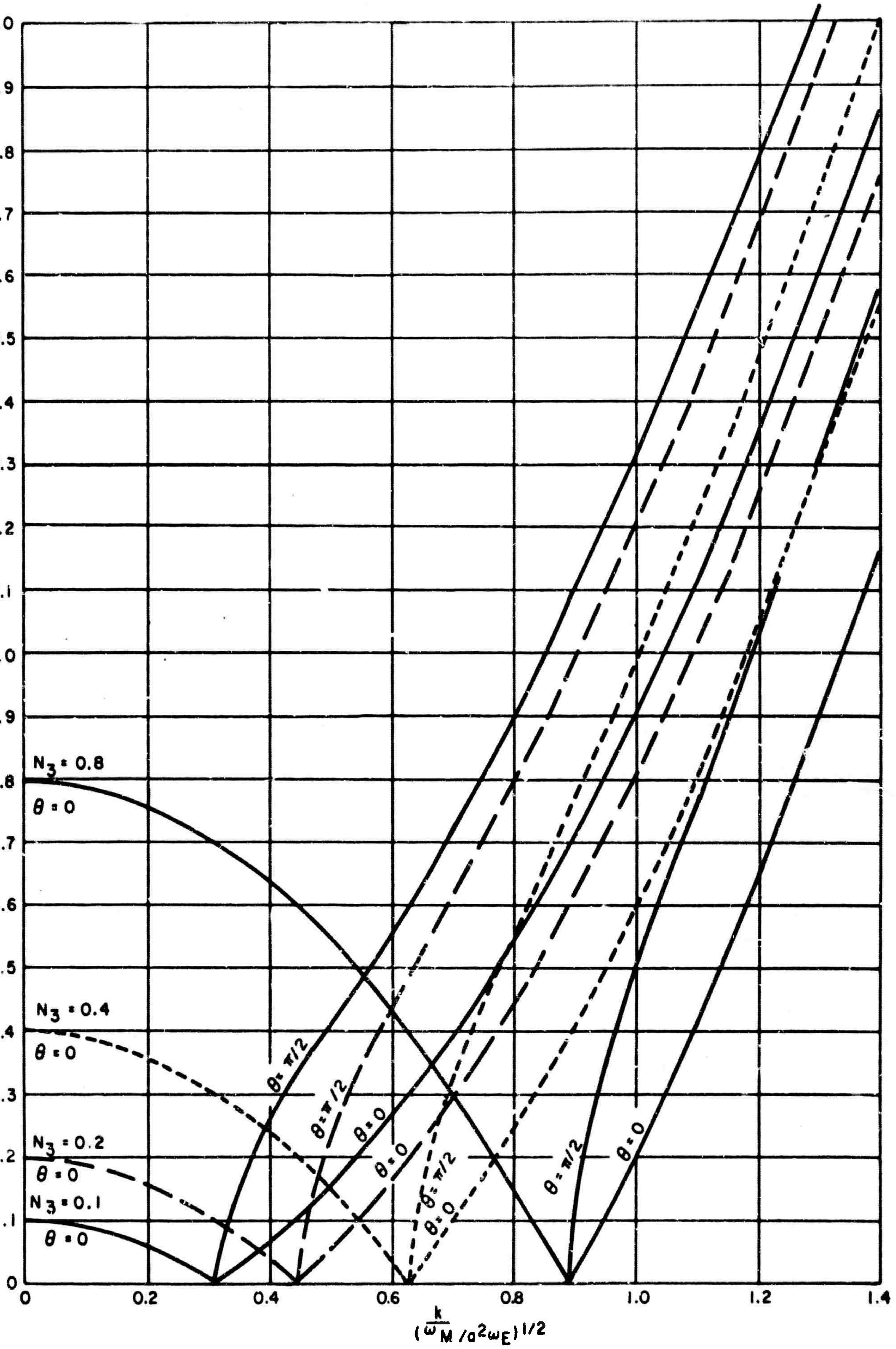


FIGURE 2. Spin Wave Dispersion Diagram with Remnant Magnetization

For a fixed value of ω_k/ω_M (recalling that the applied $\omega_1 = 2\omega_k$) it is seen that for various values of N_z spin waves of various wave numbers or wave lengths can be generated in different regions of the sample. If N_z varies rapidly enough to give interaction between the local demagnetizing fields, $\delta \underset{\sim}{h}$, Equation (5) may no longer be valid. In this case Equation (4) would not be valid either since it represents the case in which a spectrum of spin waves is generated in a given local region. For the case in which spin waves of different wave numbers $\underset{\sim}{k}$ are generated in neighboring regions within the domain Equation (4) should be replaced by a weighted sum in which the weighting terms would be at least a function of the distance between regions. It can also be noted from Figure 2 that for small values of ω_k/ω_M and for some angles θ two spin waves with the same frequency can be generated with different values of wave number k. This is possible for values of θ which satisfy

$$\sin^2\theta < N_z \tag{57}$$

and values of $\frac{\omega_k}{\omega_M}$ which satisfy

$$\frac{\omega_k}{\omega_M} < N_z \tag{58}$$

This situation again makes Equation (5) invalid unless a second term is added to account for the degeneracy. This situation is not too serious however, since it is expected $\omega_k/\omega_M > N_z$ for most practical cases of interest here.

So far only the first and second order solutions to the instability threshold problem have been considered. Some qualitative statements regarding the third order solution can be made. The exchange terms contain no third order quantities and so remain unchanged. The third order loss terms are off frequency and can be neglected. The third order Zeeman terms allow direct coupling from the average magnetization terms to the local deviation terms. Neglecting off frequency terms, the third order equation for the magnetization can be written as

$$(1 - i\alpha_k)\, \delta\dot{m}^+ - iA_k \delta m^+ - iB_k^+\, \delta m^- = i\left[\omega_s \cos\omega_1 t - \frac{k_z}{k^2}(k^- m^+ + k^+ m^-)\right] \delta m^+$$

$$- i\gamma\, \frac{k_z k^+}{k^2}\, m^+ \delta m^- \qquad (59)$$

If the driving term containing ω_s is much larger than the remaining driving terms, Equation (59) reduces to the second order solution. If the term ω_s negligibly small compared to the other driving terms, Equation (59) will reduce to Equation (21) of Suhl's analysis. In general, the local spin system can gain energy from the driving field through the ω_s term or gain energy from or lose energy to the spacial average spin system through the cross product terms. A complete solution should indicate that each driving term will result in one exponentially increasing local spin wave and one exponentially decreasing one above some threshold value. If the wave which grows from the ω_s pumping term corresponds to the decaying wave from the cross product terms, the threshold would be expected to be higher than that computed in the second order solution resulting from the transfer of pump energy from the local spin deviations to the spacial average. This would tend to distribute the total spin energy in the sample more uniformly and thus seem to be a correct evaluation from a thermodynamic approach. Except in the case where $\omega_1 = 2\omega_o$ as well as $\omega_1 = 2\omega_k$, an increase in the spacial average magnetization due to direct pumping is not expected. In this case a noticable increase in the average magnetization due to indirect coupling from locally deviating spin system which is being pumped would not be expected because of the large difference in the number of spins involved in the local variation as compared to the domain as a whole. Therefore, except in the special case of pumping at twice the bulk resonance frequency of the domain ω_o, the normalized critical field can be expected to be somewhat larger than that computed in the second order solution due to the third order Zeeman terms and the instability threshold will be caused by the direct coupling from the applied rf magnetic field to the local spin system.

PART III. PROPAGATION OF TE MODES IN DIELECTRICALLY LOADED WAVEGUIDES

ABSTRACT

The propagation of TE no modes in rectangular waveguides which contain two dielectric slabs parallel to the narrow wall and extending over the full height of the guide is investigated. Waveguide and dielectric are assumed to be lossless and infinitely long. Apart from these restrictions the dielectric slabs may have arbitrary thickness, position and dielectric constant. The analysis is restricted to TE no modes with the E-field parallel to the narrow guidewall. The guide containing only one dielectric slab is covered by this analysis. The even modes $n = 2,4,6,$ of the guide with two slabs correspond to the odd modes $n' = n/2 = 1,2,3,\ldots$ of the guide with one slab and half the width of the guide with two slabs.

For the relative dielectric constants $\epsilon = 2.25, 4, 9, 12.25, 16, 25$ the normalized cutoff frequencies for TE 10, 20, 30, 40, 60 modes have been computed for fifteen slab thicknesses (including 0 and 100% filling factor) and a maximum of eleven slab positions, normalized propagation constants have been computed for five slab thicknesses and a maximum of eight slab positions for TE 10 and TE 20 modes between their respective cutoff frequencies and a frequency slightly above the second and fourth order mode cutoff frequency of the empty guide, respectively. The results are presented graphically and numerically.

These results are discussed. The parametric dependence of field distributions, the ratio of magnetic field components (ellipticity), the ratio of cutoff frequencies (fractional bandwidth), and normalized wave impedances are illustrated.

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PROPAGATION OF TE MODES IN DIELECTRICALLY LOADED WAVEGUIDES

INTRODUCTION

Previous analyses of propagation of TE_{no} modes in rectangular waveguides which contain dielectric slabs have in general been restricted to two cases, where the dielectric slab is placed a) against a waveguide wall (1, 2, 3, 4), or b) in the center plane of the waveguide (2,3,4,5,6). A few more special cases have been considered by workers dealing with ferrite applications in the microwave region (4, 8). For a rather general position of the dielectric slab certain phase shift characteristics of the loaded guide have been calculated (7).

The present analysis deals with a rectangular waveguide which contains two dielectric slabs parallel to the narrow walls and extending over the full height of the guide. The slabs are placed symmetrically with respect to the center E-plane of the guide. Apart from this restriction the slabs have arbitrary position, thickness and dielectric constant. Only TE_{no} -modes with E-fields parallel to the narrow guide wall are considered. The guide and the dielectric are assumed to be lossless and infinitely long. Waveguides containing only one dielectric slab are covered by this analysis.

QUANTITIES AND SYMBOLS

Figure 1 shows the cross-section of a rectangular, dielectrically loaded waveguide in a rectangular coordinate system. The broad dimension of the guide extends along the x-axis, y is the direction of propagation of fields in the guide. a, c, d, w are waveguide dimensions along the x-axis. $\beta = \omega\sqrt{\mu_o\epsilon_o}$ is the free-space propagation constant, k is the propagation constant in the guide in the direction of the guide, p in the empty guide region and q in the dielectric are propagation constants transverse to the direction of the guide and the electric field. Instead of these symbols dimensionless quantities will be used throughout the analysis. These are obtained by either multiplying or dividing the above given quantities by w. Quantities, their dimensions (MKSA-sys and symbols used here are:

Symbol	Unit	Quantity
$\alpha = a/w$	-	waveguide dimensions as shown in Figure 1
$\delta = d/w$	-	
$\gamma = c/w$	-	$\alpha + \delta + \gamma = 1$
x,y,z	m	right hand coordinate system as shown in Fig. 1
$\varphi = x/w$	-	normalized x-coordinate
i_x, i_y, i_z	-	unit vectors
t	s	time
ω	s^{-1}	angular frequency
$B = \beta w$	-	free-space propagation number(frequency parameter)
$B_c = \beta_c w$	-	normalized cutoff frequency
$K = kw$	-	longitudinal propagation number in the guide
$P = pw$	-	transverse propagation number in empty part of guide
$Q = qw$	-	transverse propagation number in the dielectric
$\rho_1, \ldots \rho_6$	radian	electrical widths of waveguide sections
θ	radian	phase angle
C,D	-	relative amplitudes
μ_o	$VsA^{-1}m^{-1}$	free-space permeability
ϵ_o	$AsV^{-1}m^{-1}$	free-space dielectric constant
ϵ or DK	-	relative dielectric constant of dielectric (DK appears in the computer printed tables)
$\vec{E} = i_z E$	Vm^{-1}	electric field
E_o	Vm^{-1}	normalizing electric field
$\vec{H}=i_x H_x + i_y H_y$	Am^{-1}	magnetic field
H_o	AM^{-1}	normalizing magnetic field
Y_W	AV^{-1}	wave admittance of loaded guide
Y_o	AV^{-1}	wave admittance of free space
Ω	-	fractional bandwidth
ELL	-	ellipticity

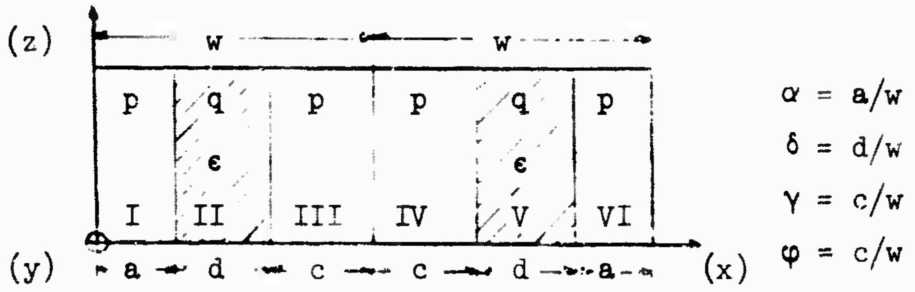


Figure 1. Waveguide with Dielectric Slabs

THEORY

It completely suffices, because of the symmetry of the loaded guide, to consider the regions I, II, III of Figure 1, so that $0 \le x \le w$ or $0 \le \varphi \le 1$. All fields vary as exp $(\omega t - ky)$, so that $\partial/\partial t = j\omega$ and $\partial/\partial y = -jk$. This t and y dependence is omitted in all equations. The relative permeability of the dielectric is assumed to be 1. Maxwell's equations for the problems considered here reduce to

(1) $$\nabla \times \vec{E} = i_x \frac{\partial E}{\partial y} - i_y \frac{\partial E}{\partial x} = - j\omega\mu_o \, (i_x H_x + i_y H_y)$$

(2) $$\nabla \times \vec{H} = i_z\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}\right) = i_z j\omega\epsilon_o \epsilon E$$

(3) $$\nabla \cdot \vec{E} = 0$$

(4) $$\nabla \cdot \vec{H} = 0$$

and from equation (1, 2, 3)

(5) $$\nabla \times \nabla \times \vec{E} = - \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) E = \omega^2 \mu_o \epsilon_o \epsilon E$$

The boundary conditions are

(6) $E_{tang} = E$ is continuous, $H_{tang} = H_y$ is continuous

The fields in the various regions of the guide can be described as in Table 1 with dimensionless quantities:

Field		$H_x/H_o = H_x \omega\mu_o/KE_o$, E/E_o			$jH_y/H_o = jH_y \omega\mu_o/KE_o$		
Region	Modes / Frequencies	$0 \le K/B < 1$	$K/B = 1$	$1 < K/B \le \sqrt{\epsilon}$	$0 \le K/B < 1$	$K/B = 1$	$1 < K/B \le \sqrt{\epsilon}$
$0 \le \varphi \le \alpha$ I	all	$\sin R\varphi$	φ	$\text{sh}\, \lvert P \rvert \varphi$	$\frac{P}{K} \cos R\varphi$	$\frac{1}{K}$	$\frac{\lvert P \rvert}{K} \text{ch}\, \lvert P \rvert \varphi$
II $\alpha \le \varphi \le 1-\gamma$	all	$D \sin(Q\varphi + \theta)$			$D \frac{Q}{K} \cos (Q\varphi + \theta)$		
III $1-\gamma \le \varphi \le 1$	odd	$C \cos P(1-\varphi)$	C	$C\text{ch}\, \lvert P \rvert (1-\varphi)$	$C\frac{P}{K} \sin P(1-\varphi)$	0	$-C \frac{\lvert P \rvert}{K} \text{sh}\, \lvert P \rvert (1-\varphi)$
	even	$C \sin P(1-\varphi)$	$C(1-\varphi)$	$C\text{sh}\, \lvert P \rvert (1-\varphi)$	$-C\frac{P}{K} \cos P(1-\varphi)$	$-C\frac{1}{K}$	$-C \frac{\lvert P \rvert}{K} \text{ch}\, \lvert P \rvert (1-\varphi)$

Table 1. Normalized Field Distribution in Waveguide which Contains Dielectric Slabs

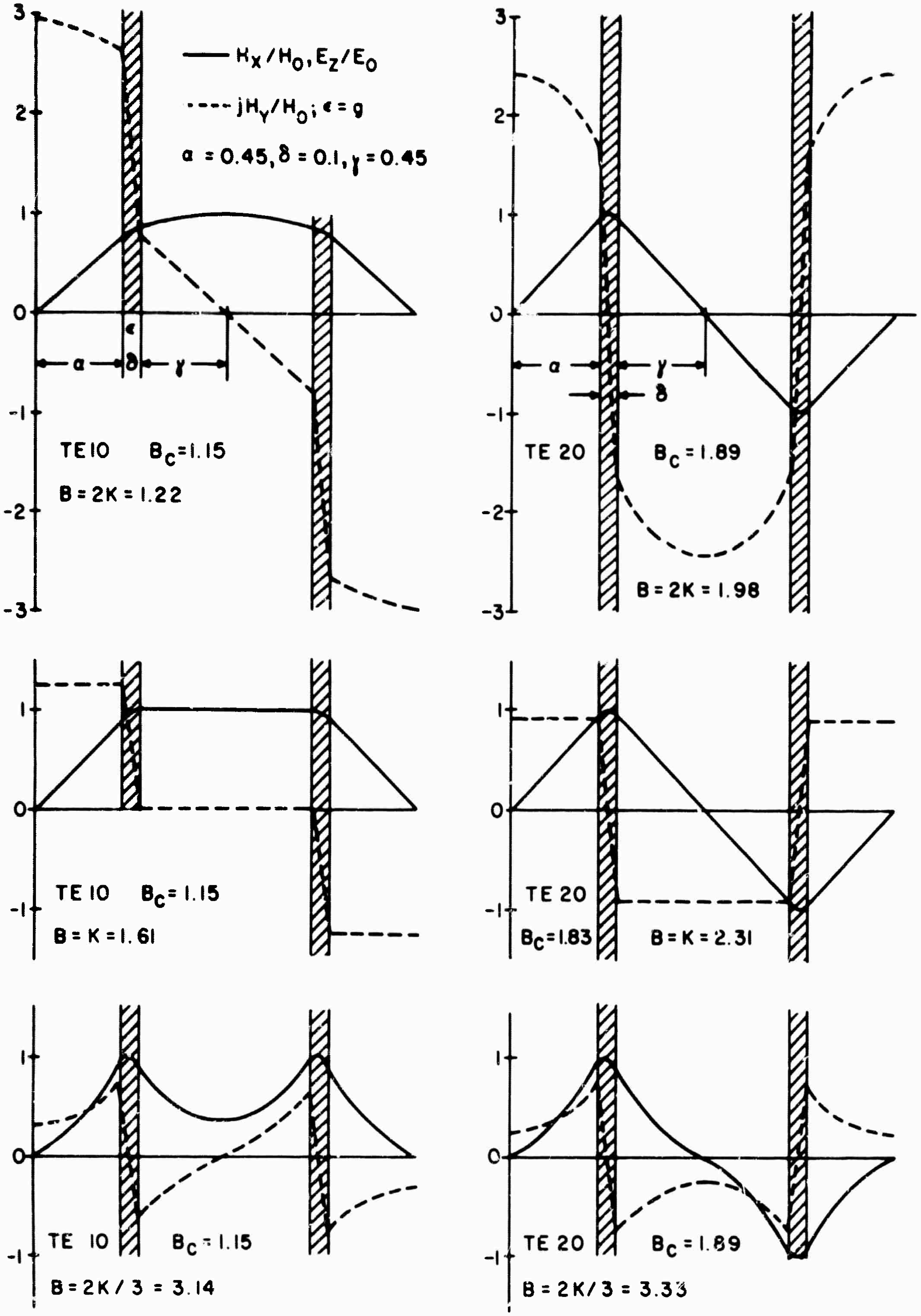


Figure 2. Normalized Field Distribution in Waveguide with Dielectric Slabs

These field distributions are illustrated by Figure 2 for the first odd ($n = 1$) and first even ($n = 2$) mode. The even modes ($n = 2, 4, 6 \ldots.$) of the waveguide under consideration with two symmetrically placed dielectric slabs, where $2w$ is the waveguide width, correspond to the odd and even modes ($n' = n/2 = 1, 2, 3, \ldots.$) of a waveguide with only one dielectric slab, where w is the waveguide width; that is the left half of Figure 1 only.

The fields of Table 1, together with equation (5) give for the propagation constants the relations

(7) $$P^2 = B^2 - K^2$$

(8) $$Q^2 = \epsilon B^2 - K^2$$

(9) $$P^2 = Q^2 - (\epsilon - 1) B^2$$

For any $Q^2 > 0$ there exists a $P^2 \gtrless 0$, the sign depending on $(\epsilon - 1)B^2$. $Q^2 > 0$ describes a sinusoidal field distribution in the dielectric slab, $P^2 > 0$ describes a sinusoidal field distribution in the empty waveguide region. For $P^2 < 0$ the field distributions in the empty waveguide regions are hyperbolic functions which describe a quasi-exponential decay. $P^2 = 0$ gives the intermediate function where E and H_x have a constant slope in the empty part of the guide and where H_y is constant. In this particular case the fields in the empty region are described by functions as $\varphi \exp(R\varphi) = \varphi$, since $P = 0$. When $Q^2 < 0$, also $P^2 < 0$. Then the boundary conditions (6) are violated. H_y is no longer continuous. Therefore, $Q^2 \geq 0$ for all TE_{no} modes. $Q^2 = 0$ is reached at infinitely high frequencies. The assumptions of Table 1 cover only and all allowed field distributions for TE_{no} modes and are thus justified. While the frequency increases from cutoff to infinity, K/B increases from 0 to $\sqrt{\epsilon}$. For $K = B$ the field distribution between the two dielectric slabs represents a pure TEM field for all odd TE_{no} modes in the waveguide considered.

The determinental equations for $B(K)$ - e.g. cutoff frequencies for $K = 0$ - or $K(B)$ - propagation constants for given frequencies - are found by expressing the widths of the empty sections of the guide in equivalent widths of a guide completely filled with the dielectric. The field distribution in the slabs is not changed by this replacement. The total electrical width ($2w_e$) of this equivalent guide is $n\pi$ for a TE_{no} mode.

At the boundary between regions I and II of Figure 1, Table 1 and equation (6) yield for frequencies $0 \leq K/B < 1$ and with $\rho_1 = P\alpha$, $\rho_2 = Q\alpha + \theta$

$$E_o \sin \rho_1 = E_o D \sin \rho_2 \tag{10}$$

$$jE_o P \cos \rho_1/\omega\mu_o = jE_o DQ \cos \rho_2/\omega\mu_o \tag{11}$$

$$\underline{Z}_x(\alpha) = - E_z(\alpha)/jH_y(\alpha) = j\frac{\omega\mu_o}{P} \operatorname{tg} \rho_1 = j \frac{\omega\mu_o}{Q} \operatorname{tg} \rho_2 \tag{12}$$

$\omega\mu_o/P = Z_P$ and $\omega\mu_o/Q = Z_Q$ are the transverse wave-impedances of the empty and loaded waveguide regions, respectively, for waves travelling in ± x direction. $\underline{Z}_x(\alpha)$ is the impedance experienced by a wave travelling into the shorted waveguide of impedance Z_P and length ρ_1 or impedance Z_Q and length ρ_2. From equation (12) follows the equivalent length

$$\rho_2 = \operatorname{arctg}(\frac{Q}{P} \operatorname{tg} \rho_1) \tag{13}$$

Similar considerations for higher frequencies, odd and even modes, and both slab boundaries lead for the various waveguide regions to the actual and equivalent electrical widths of Table 2.

Width \ Frequency			$0 \leq K/B < 1$	$K/B = 1$		$1 < K/B \leq \sqrt{\epsilon}$
	I	ρ_1	$P\alpha$	α		$\lvert P\rvert\alpha$
Equivalent	I	ρ_2	$\operatorname{arctg}(\frac{Q}{P} \operatorname{tg} \rho_1)$	$\operatorname{arctg}(Q\rho_1)$		$\operatorname{arctg}(\frac{Q}{\lvert P\rvert} \operatorname{th}\rho_1)$
	II	ρ_3	$Q\delta$	$Q\delta$		$Q\delta$
	III	φ_4	$P\gamma$	0	γ	$\lvert P\rvert\gamma$
				odd	modes even	
Equivalent	III	ρ_5	$\operatorname{arctg}\left[\left(\frac{Q}{P}\right)^{\left((-1)^n\right)} \operatorname{tg}\rho_4\right]$	0	$\operatorname{arctg}(Q\rho_4)$	$\operatorname{arctg}\left[(-1)^n\left(\frac{Q}{\lvert P\rvert}\right)^{\left((-1)^n\right)} \operatorname{th}\rho_4\right]$
	I + I + III	ρ_6	$\rho_2 + \rho_3 + \rho_5$	$\rho_2 + \rho_3 + \rho_5$		$\rho_2 + \rho_3 + \rho_5$

Table 2. Electrical Widths in Waveguides, which Contain Dielectric Slabs

ρ_5 is defined for $0 \leq K/B < 1$ for odd modes by $1/P\,tg\,\rho_4 = 1/Q\,tg\,\rho_5$ and for even modes by $tg\,\rho_4/P = tg\,\rho_5/Q$ and for other frequencies accordingly. Table 2 is the skeleton for the computer program used to determine the cutoff frequencies $B(K = 0)$ and propagation constants $K(B)$. The determinental equaiton is in both cases

(14) $\rho_6 = n\pi/2$ for TE_{no} -modes

Applying equation (6) to the boundaries of regions I/II and II/III of Figure 1 yields the phase angle θ and the relative amplitudes of Table 1. They are given in Table 3 in terms of the electrical widths defined in Table 2.

Modes \ Frequency		$0 \leq K/B < 1$	$K/B = 1$	$1 < K/B \leq \sqrt{\epsilon}$
θ	all	$\rho_2 - Q\alpha$	$\rho_2 - Q\alpha$	$\rho_2 - Q\alpha$
1/D	all	$\sin\rho_2/\sin\rho_1$	$\sin\rho_2/\rho_1$	$\sin\rho_2/\mathrm{sh}\rho_1$
C/D	odd	$\sin(\rho_2 + \rho_3)/\cos\rho_4$	$\sin(\rho_2 + \rho_3)$	$\sin(\rho_2 + \rho_3)/\mathrm{ch}/\rho_4$
C/D	even	$\sin(\rho_2 + \rho_3)/\sin\rho_4$	$\sin(\rho_2 + \rho_3)/\rho_4$	$\sin(\rho_2 + \rho_3)/\mathrm{sh}\rho_4$

Table 3. Phase Angle and Relative Amplitude of Fields in Waveguides, Which Contain Dielectric Slabs

COMPUTER RESULTS

Normalized cutoff frequencies have been calculated for TE_{no} modes of the guide of Figure 1 with n = 1, 2, 3, 4, 6 for six relative dielectric constants (2.25, 4, 9, 12.25, 16, 25), fifteen slab thicknesses (including 0% and 100% filling factor) and a maximum of eleven positions of the slab in the guide. Normalized propagation constants have been calculated for TE_{10} and TE_{20} modes between their respective cutoff frequency and a frequency somewhat above the second and fourth order mode cutoff frequency of the empty guide, respectively, again for the relative dielectric constants given above,five slab thicknesses (5, 10, 15, 25, 40% filling factor) and a maximum of eight slab positions. The position parameter $\alpha + \delta/2$ gives the distance between the left guidewall and the center plane of the left slab as a fraction of half the guide width. For the odd modes the position is varied between the slabs touching the guide walls ($\alpha + \delta/2 = \delta/2$) and the slabs touching each other in the center of the guide. ($\alpha + \delta/2 = 1 - \delta/2$). For even modes it suffices, because of the symmetry of the field distribution, to vary the position between the slabs touching the wall and moving them half way towards each other ($\alpha + \delta/2 = 0.5$). For even modes the cutoff-frequencies and propagation constants are the same for $\alpha + \delta/2 = \tau$ and $\alpha + \delta/2 = 1 - \tau$. The normalized cutoff-frequencies are given graphically in Figures 8 ... 13 and numerically in Tables 4 ... 9. In these tables the slab thickness (δ) is the horizontal parameter, the position of the slab ($\alpha + \delta/2$) and the order of modes (N) are the vertical parameters.

The normalized propagation constants K are given graphically in Figures 14 ... 43 with one set of curves for every dielectric constant and slab thickness combination and the position as parameter for every curve. They are given numerically in Tables 10 ... 29. The horizontal parameters are position ($\alpha + \delta/2$) and order of mode (TE_{no}). The vertical parameter is the normalized frequency (B). The normalized cutoff frequency (B_c) for each set of parameters is given on top of each column. Propagation constants -0.0 indicate that the frequency for this K is below cutoff.

Examples:

a) Guide WR 137, width 1.372 inches, two slabs each 0.069 inches thick, 0.206 inches between left wall and center of left slab, relative dielectric constant $\epsilon = 9$, $w = \text{width}/2 = 0.686$ inches, $\delta = 0.1$, $\alpha + \delta/2 = 0.3$. Wanted: TE_{10} and TE_{20} cutoff-frequencies and guide wavelengths at 5.46 GHz. One finds: $B_c(TE_{10}) \approx 1.33$, $B_c(TE_{20}) \approx 2.05$. With $\lambda_c = 2\pi w/B_c$ one gets $\lambda_c(TE_{10}) \approx 8.27$cm, $\lambda_c(TE_{20}) \approx 5.35$ cm, $f_c(TE_{10}) \approx 3.63$ GHz $f_c(TE_{20}) \approx 5.6$ GHz. At 5.46 GHz one finds $B = 2$ and $K(TE_{10}) \approx 1.9$, corresponding to $\lambda_g = 2\pi w/K \approx 5.74$ cm, no propagation for the TE_{20} mode.

b) Guide WR 90, width 0.9 inches, one slab with $\epsilon = 12.25$, 0.135 inches thick, 0.18" between wall and center of slab. Wanted: cutoff frequencies of the two lowest order modes, guide wavelength at 10 GHz for the lowest order mode. $w' = \text{width} = 0.9$ inches, $\delta = 0.15$, $\alpha + \delta/2 = 0.2$. $B_c(TE'_{10}) = B_c(TE_{20})$

of guide with two slabs and with 1.8 inches and w = width/2. One finds $B_c(TE'_{10}) \approx 1.83$, $B_c(TE'_{20}) = B_c(TE_{40}) \approx 4.25$; with $\lambda_c = 2\pi w'/B_c$ one gets $\lambda_c(TE'_{10}) \approx 7.85$ cm, $\lambda_c(TE'_{20}) \approx 3.38$ cm and $f_c(TE'_{10}) \approx 3.82$ GHz, $f_c(TE'_{20}) \approx$ 7.83 GHz. At 10 GHz one finds $B = 2\pi w'/\lambda_o \approx 4.8$ and $K \approx 12.71$, yielding $\lambda_g \approx 1.12$ cm.

c) The TE_{20} solutions with $\alpha + \delta/2 = 0.5$ are equivalent to the TE_{10} solutions with the two slabs touching each other, where $\alpha + \delta/2 = 1 - \delta/2$, i.e. $2K\,(TE_{10}, B, \alpha + \delta/2 = 1 - \delta/2) = K\,(TE_{20}, 2B, \alpha + \delta/2 = 0.5)$
$2B_c(TE_{10}, \alpha + \delta/2 = 1 - \delta/2) = B_c(TE_{20}, \alpha + \delta/2 = 0.5)$

DISCUSSION OF RESULTS

The influence of the dielectric slab on the field distribution in the waveguide is to concentrate within the slab with increasing frequency an increasing fraction of the total energy flowing through the guide. The phase velocity approaches asymtotically "$\sqrt{\epsilon}$ times the velocity of light in free space". The parametric dependence of the E field distribution is illustrated by Figure 3.

The influence of a thin slab on the cutoff frequencies is the stronger the closer the slab position is to the lines of maximum electric field strength in the empty guide. With increasing slab thickness the influence is less and less related to the empty guide field distribution. For thick slabs it is weakest when the slabs touch the guide walls; for odd modes it is strongest when the slabs are in the center of the guide and touch each other, for even modes it is strongest when each slab is in center of half a guide width.

At a certain thickness the cutoff frequency is nearly independent of the slab position (see $TE_{30, 40, 60}$). For thinner slabs a similar behavior can be found in the propagation characteristics. Figure 4 shows K versus B curves for the TE_{40} mode with $\epsilon = 9$ and $\delta = 0.2$. At $B \approx 5.42$ the propagation constant is independent of the slab position. Above this crossover frequency the same order of curves is obtained as for cutoff frequencies

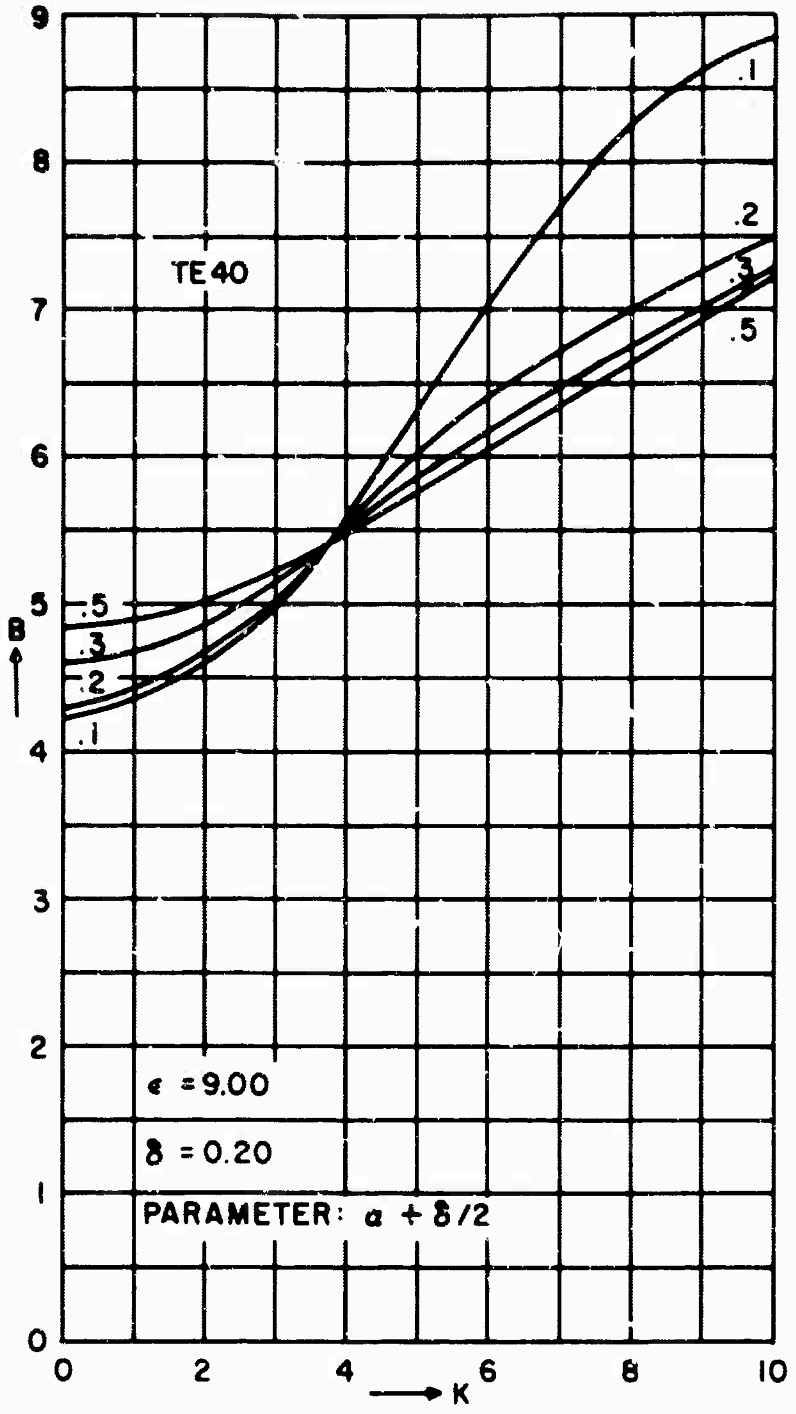


Figure 3. Propagation Characteristics in Waveguide with Dielectric Slabs

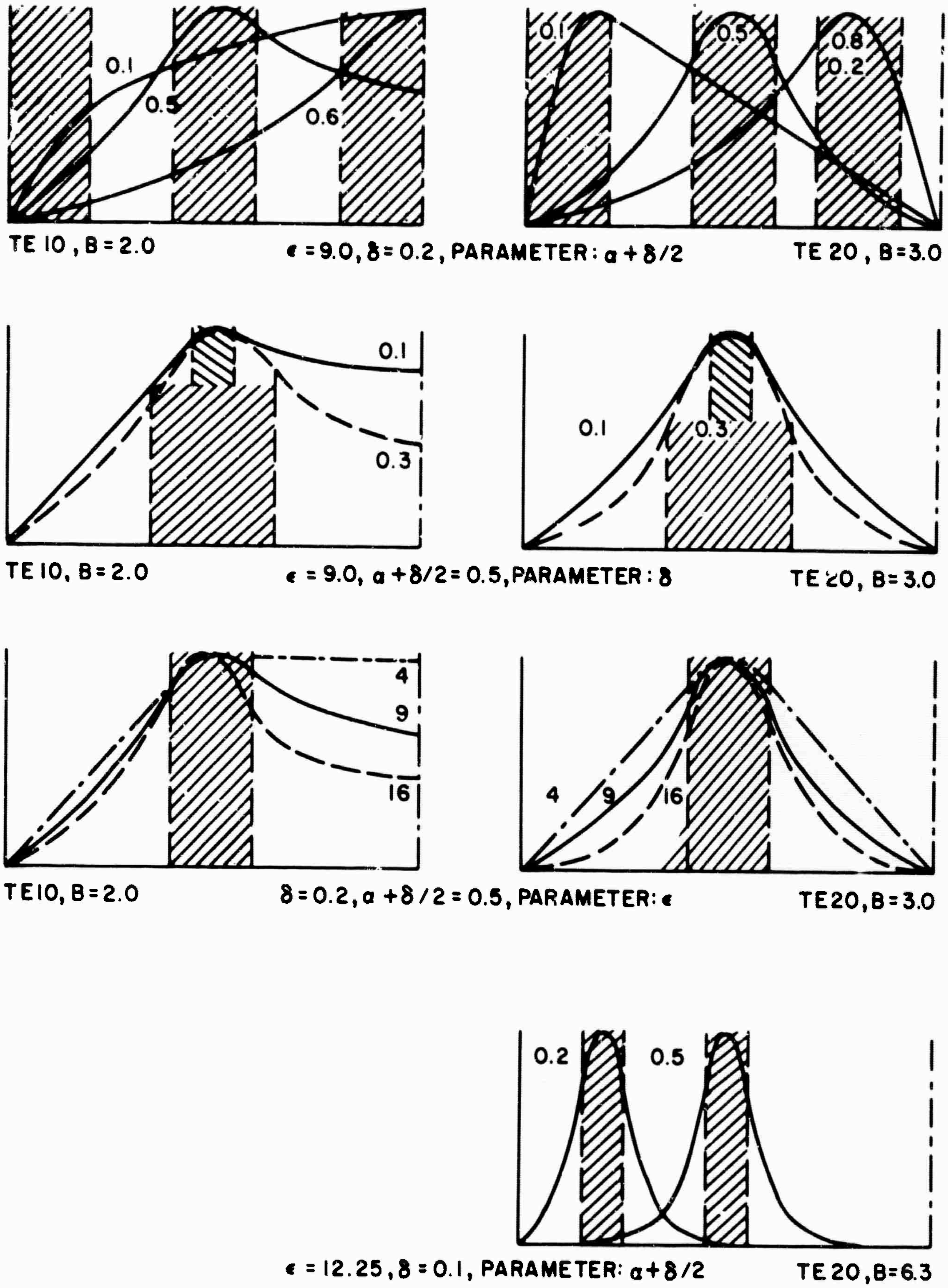


Figure 4. E-Field Distrubition in a Waveguide with Dielectric Slabs

with thick slabs. The propagation characteristics for TE_{20} modes for e.g. $\epsilon = 12.25$ and $\delta = 0.1$ show, however, that this order, too, may change at even higher frequencies. If the empty regions in half the waveguide (I and III, α and γ in Figure 1) are not equal, a wave may treat them at high frequencies as essentially equal with the value of the narrower region. The waveguide shows then a larger, propagation constant and field concentration at a given frequency than a guide with $\alpha = \gamma$ does. An E-field distribution for such a case is shown in the lowest part of Figure 3.

The ratio of the magnetic field components, the ellipticity,

$$\text{ELL}(\varphi) = H_x(\varphi)/jH_y(\varphi) \tag{15}$$

at the slab boundaries I/II and II/III approaches "one" asymtotically, as illustrated in Figure 5 for TE_{10} and TE_{20} modes for various parameters. How the ratios of cutoff frequencies, the fractional bandwidths

$$\Omega_{21} = \frac{B_c(TE_{20})}{B_c(TE_{10})} \quad \text{and} \quad \Omega_{42} = \frac{B_c(TE_{40})}{B_c(TE_{20})} \tag{16}$$

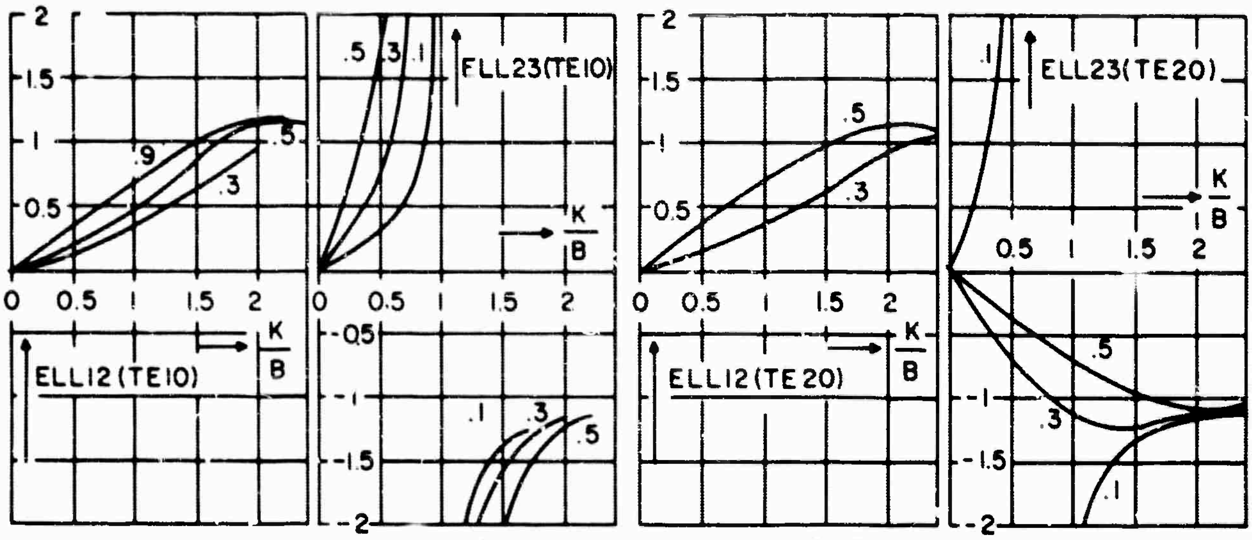
vary with different parameters is shown in Figure 6. Finally, the parametric dependance of the normalized wave admittance

$$Y_w/Y_o = (H_x/E_z)/Y_o = K/B = \lambda_o/\lambda_g \text{ with } Y_o = \sqrt{\epsilon_o/\mu_o} = (377 \text{ ohms})^{-1} \tag{17}$$

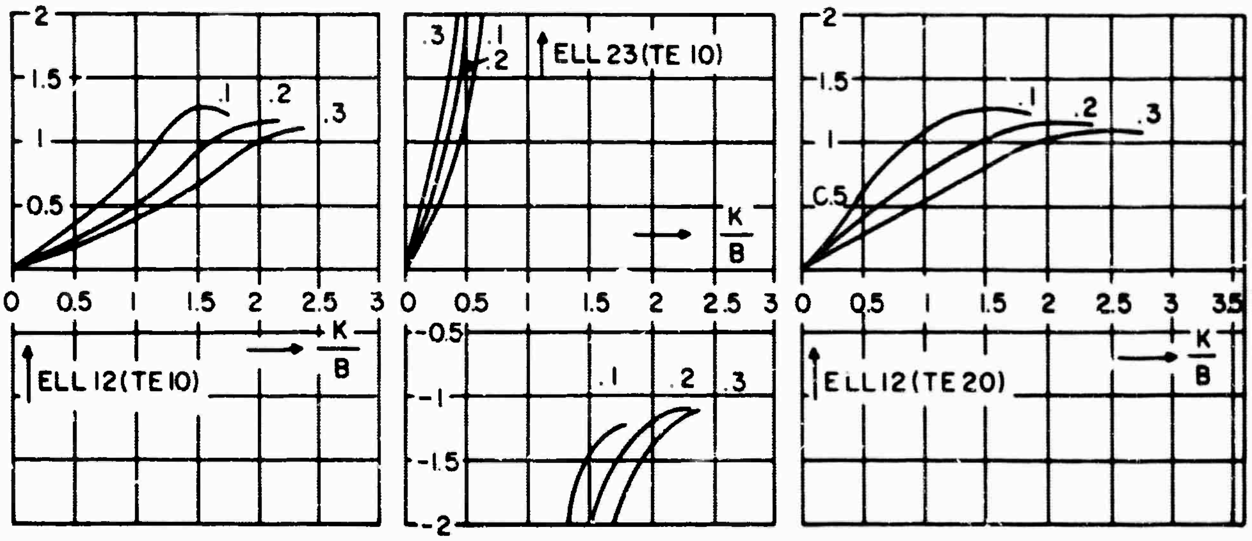
is shown in Figure 7.

ACKNOWLEDGEMENTS

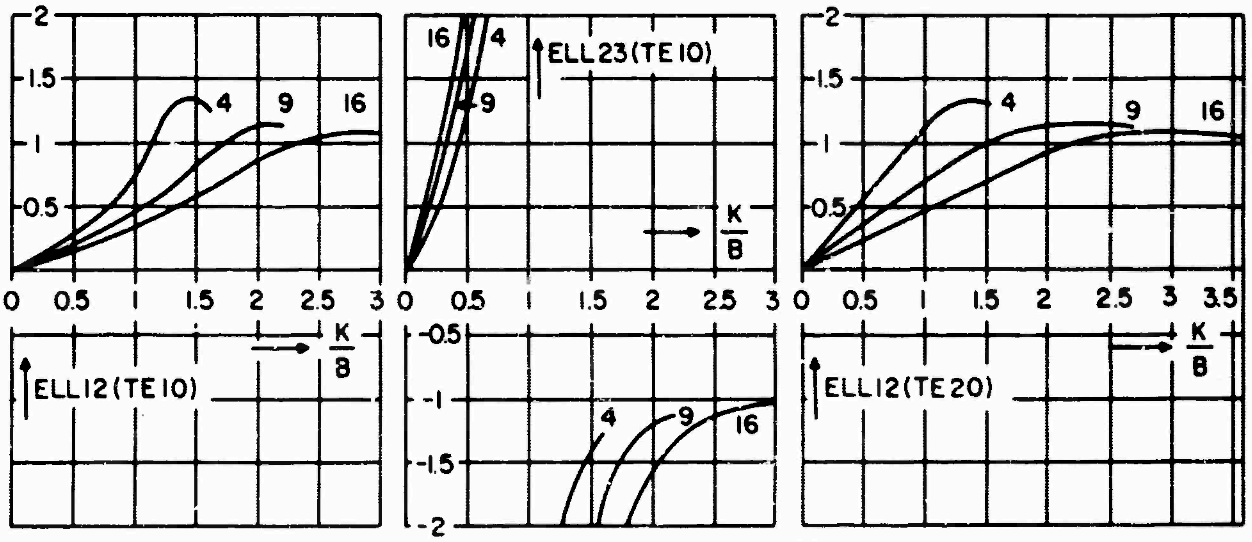
It is a pleasure to thank Mr. W. P. Demkowski for having encouraged and supported this work, and Messrs. H. A. Hair and S. K. Altes for stimulating discussions.



ε = 9.00, δ = 0.2, PARAMETER: a + δ/2

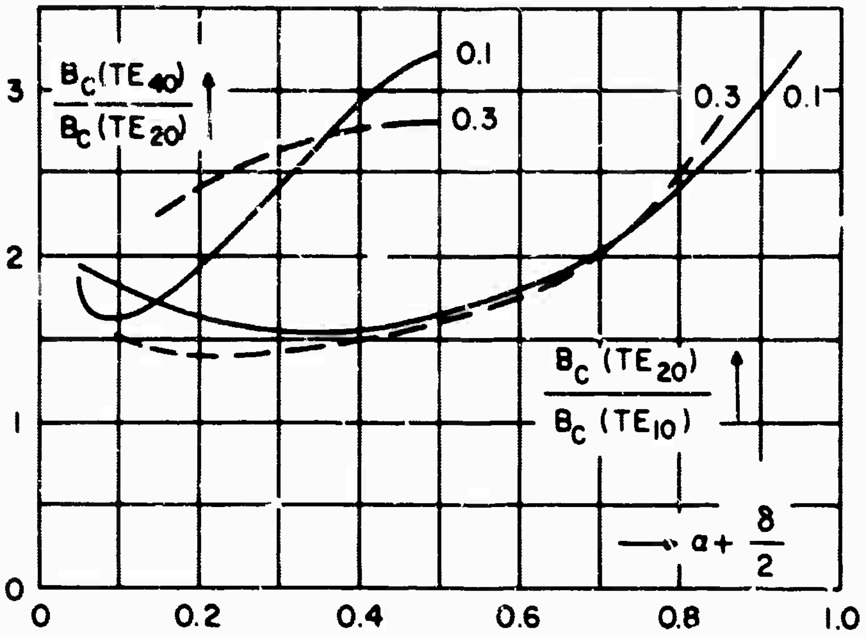


ε = 9.00, a + δ/2 = 0.5, PARAMETER: δ

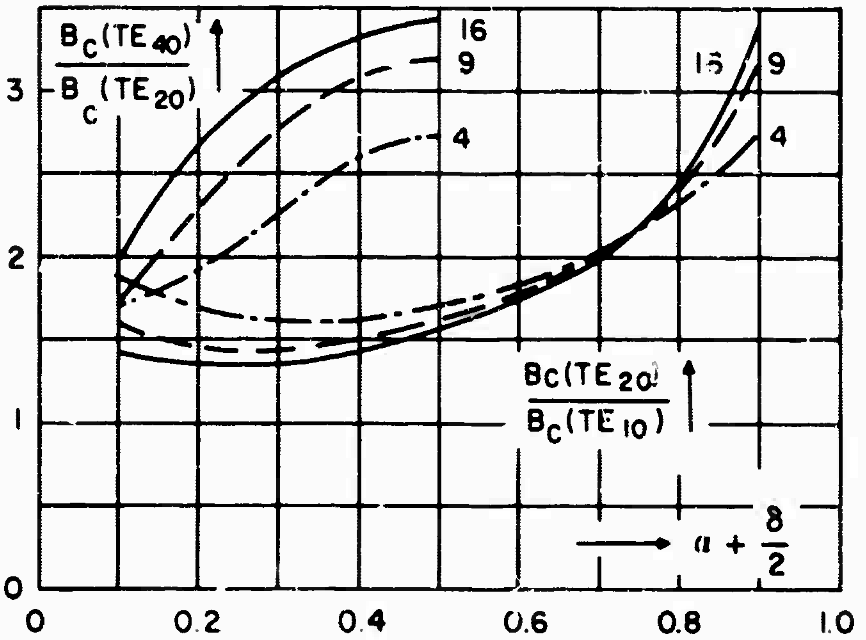


δ = 0.2, a + δ/2 = 0.5, PARAMETER: ε

Figure 5. Ellipticity at Slab Boundaries in Waveguide with Dielectric Slabs

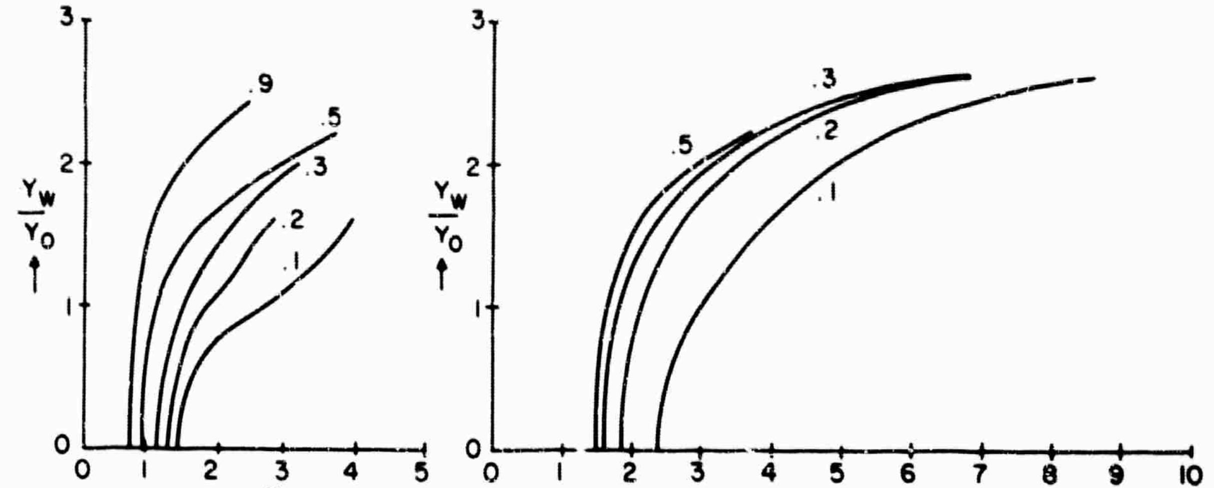


ε = 9.00, PARAMETER: δ

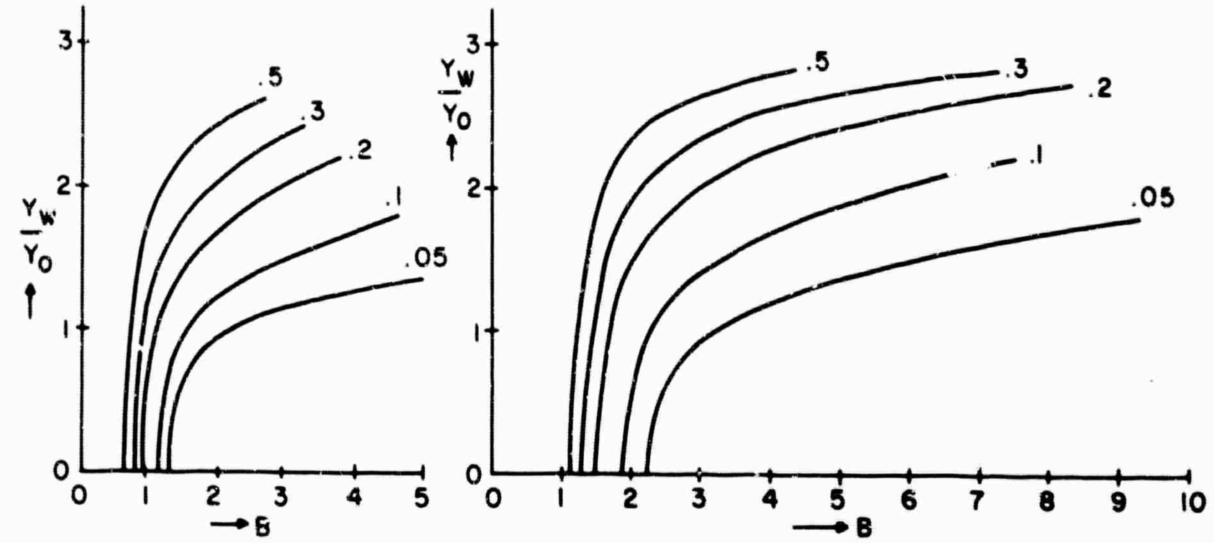


δ = 0.2, PARAMETER: ε

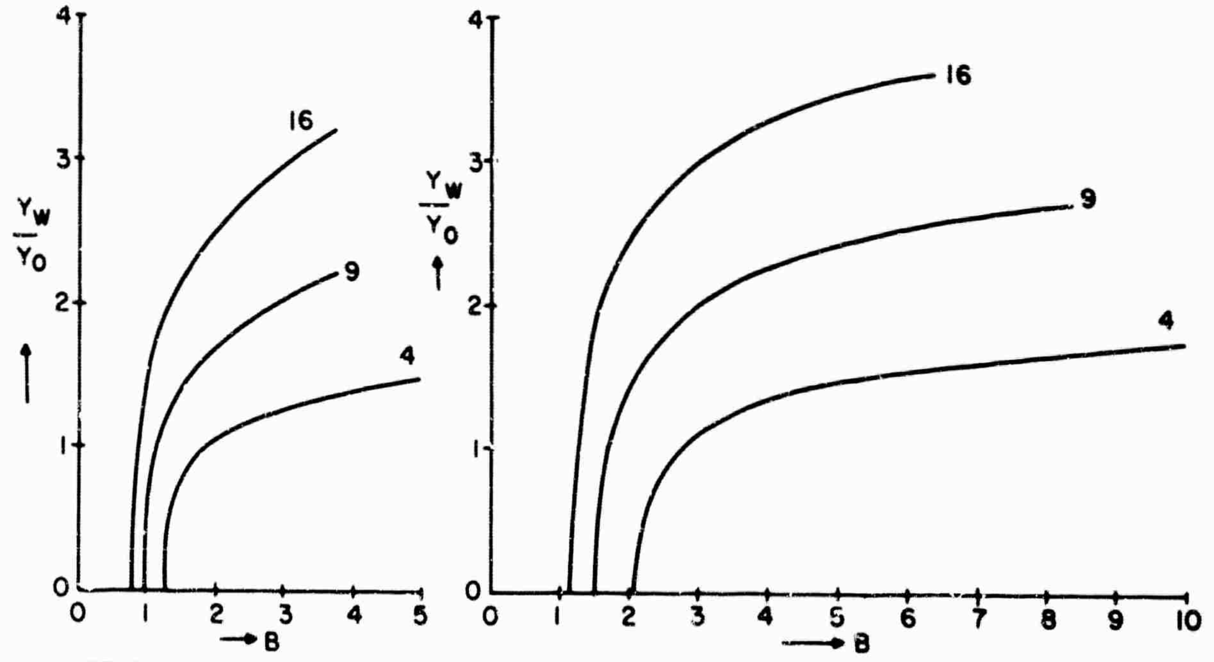
Figure 6. Fractional Bandwidths of Waveguide with Dielectric Slabs



TE10 ε = 9.00, δ = 0.2, PARAMETER: a+δ/2 TE20



TE10 ε = 9.00, a+δ/2 = 0.5, PARAMETER: δ TE20



TE10 δ = 0.2, a+δ/2 = 0.5, PARAMETER: ε TE20

Figure 7. Normalized Wave Admittance of Waveguide with Dielectric Slabs

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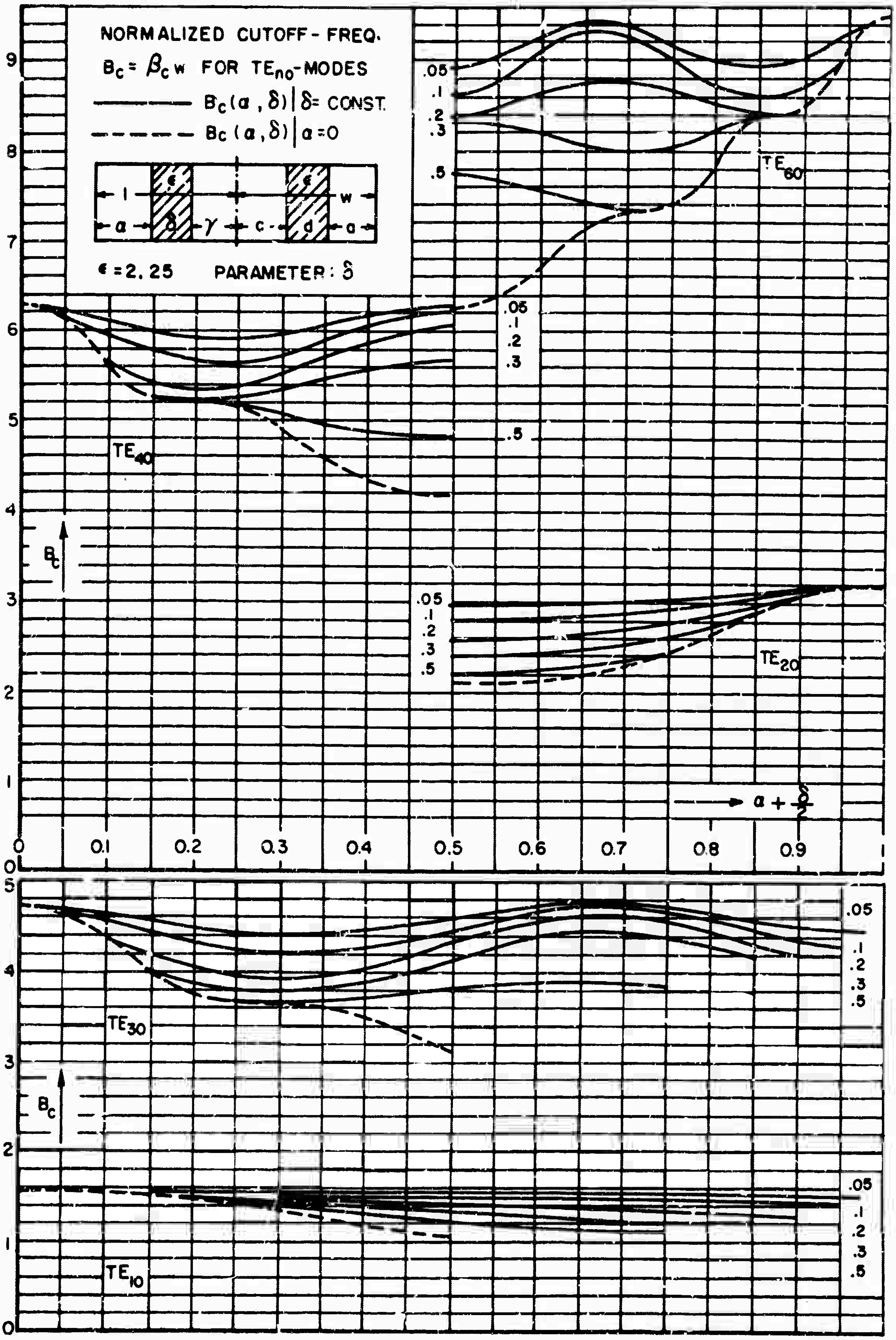
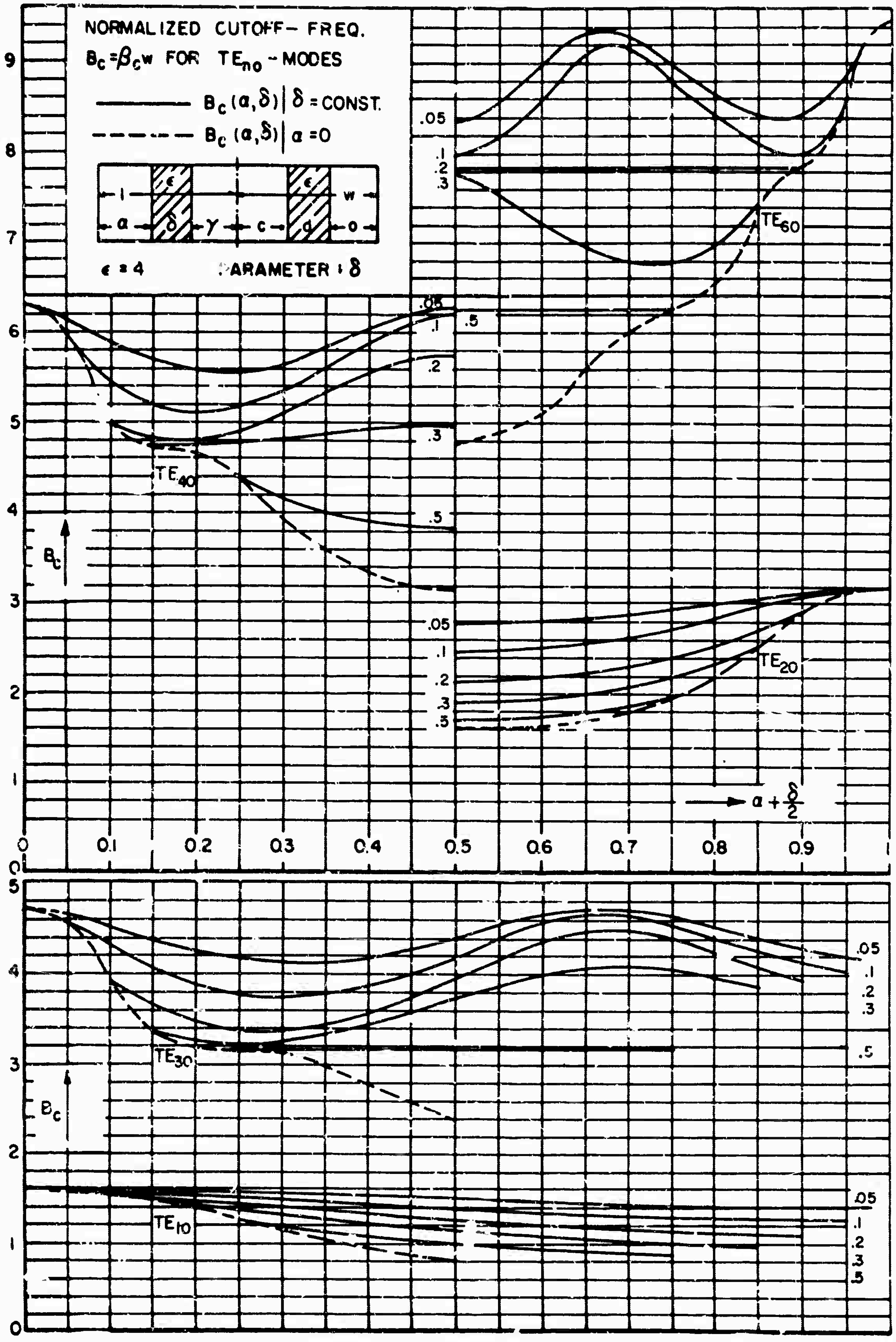
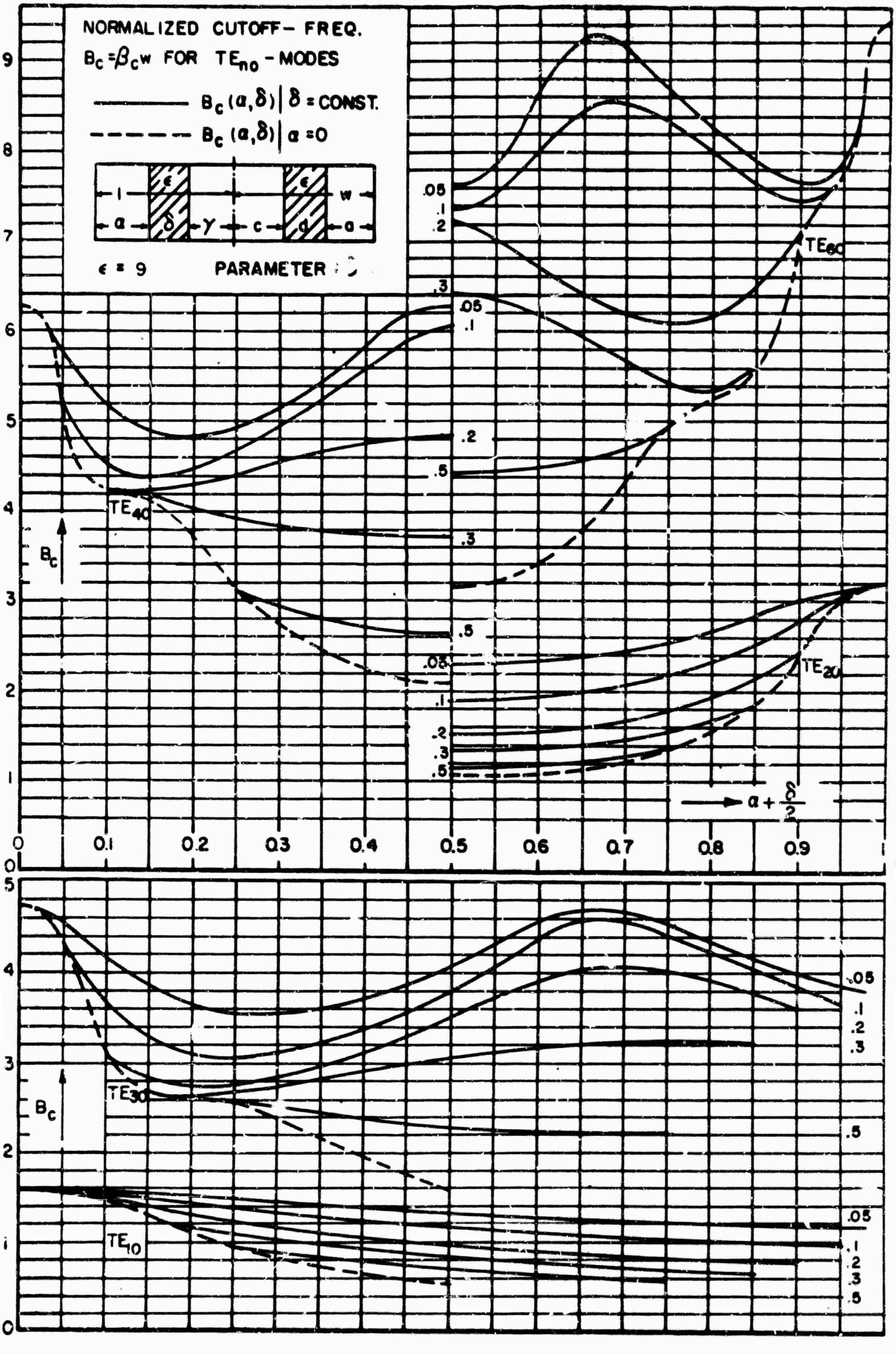
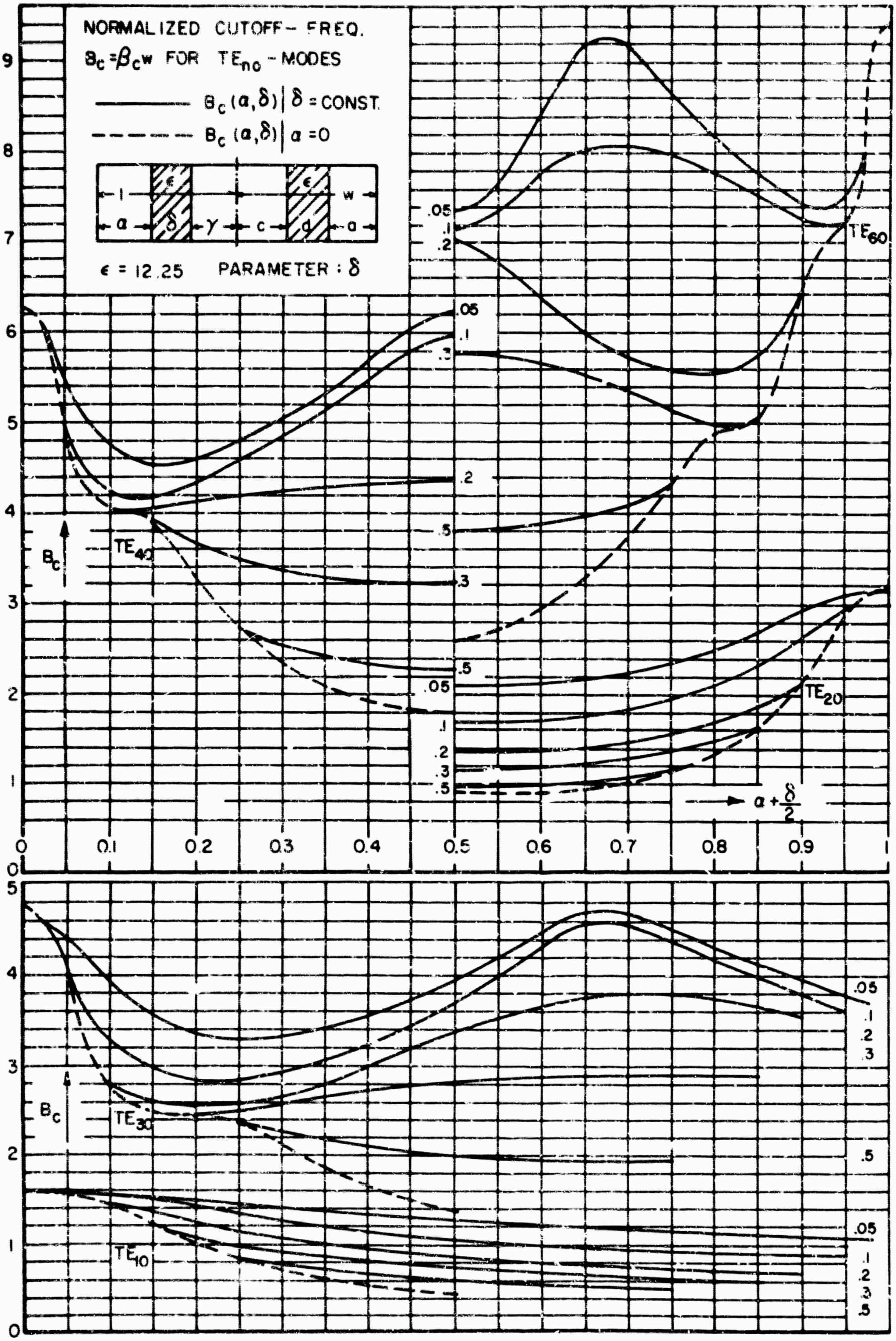

NORMALIZED CUTOFF - FREQ.
$B_c = \beta_c w$ FOR TE_{no}-MODES
$B_c(a, \delta) \mid \delta$ = CONST.
$B_c(a, \delta) \mid a = 0$
l
w
a
ϵ
δ
γ
c
d
ϵ = 2.25
PARAMETER: δ
B_c
$a + \frac{\delta}{2}$
TE_{60}
TE_{40}
TE_{20}
TE_{30}
TE_{10}
.05
.1
.2
.3
.5
0
1
2
3
4
5
6
7
8
9
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


NORMALIZED CUTOFF- FREQ.
$B_c = \beta_c w$ FOR TE_{no} - MODES
$B_c(a,\delta) | \delta$ = CONST.
$B_c(a,\delta) | a = 0$
ϵ
ϵ
1
w
a
δ
γ
c
d
o
$\epsilon = 4$
PARAMETER : δ
TE_{60}
TE_{40}
TE_{20}
TE_{30}
TE_{10}
.05
.1
.2
.3
.5
B_c
$a + \frac{\delta}{2}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9


NORMALIZED CUTOFF- FREQ.
$B_c = \beta_c w$ FOR TE_{n0} - MODES
$B_c(a,\delta) \mid \delta$ = CONST.
$B_c(a,\delta) \mid a = 0$
ε
ε
l
w
a
δ
γ
c
d
a
ε = 9
PARAMETER : δ
B_c
$a + \frac{\delta}{2}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9
TE_{10}
TE_{20}
TE_{30}
TE_{40}
TE_{60}
.05
.1
.2
.3
.5


NORMALIZED CUTOFF- FREQ.
$B_c = \beta_c w$ FOR TE_{no} - MODES
$B_c(a,\delta)\,|\,\delta$ = CONST.
$B_c(a,\delta)\,|\,a = 0$
l
ϵ
ϵ
w
a
δ
γ
c
d
a
ϵ = 12.25
PARAMETER : δ
B_c
$a + \frac{\delta}{2}$
TE40
TE60
TE20
TE30
TE10
.05
.1
.2
.3
.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
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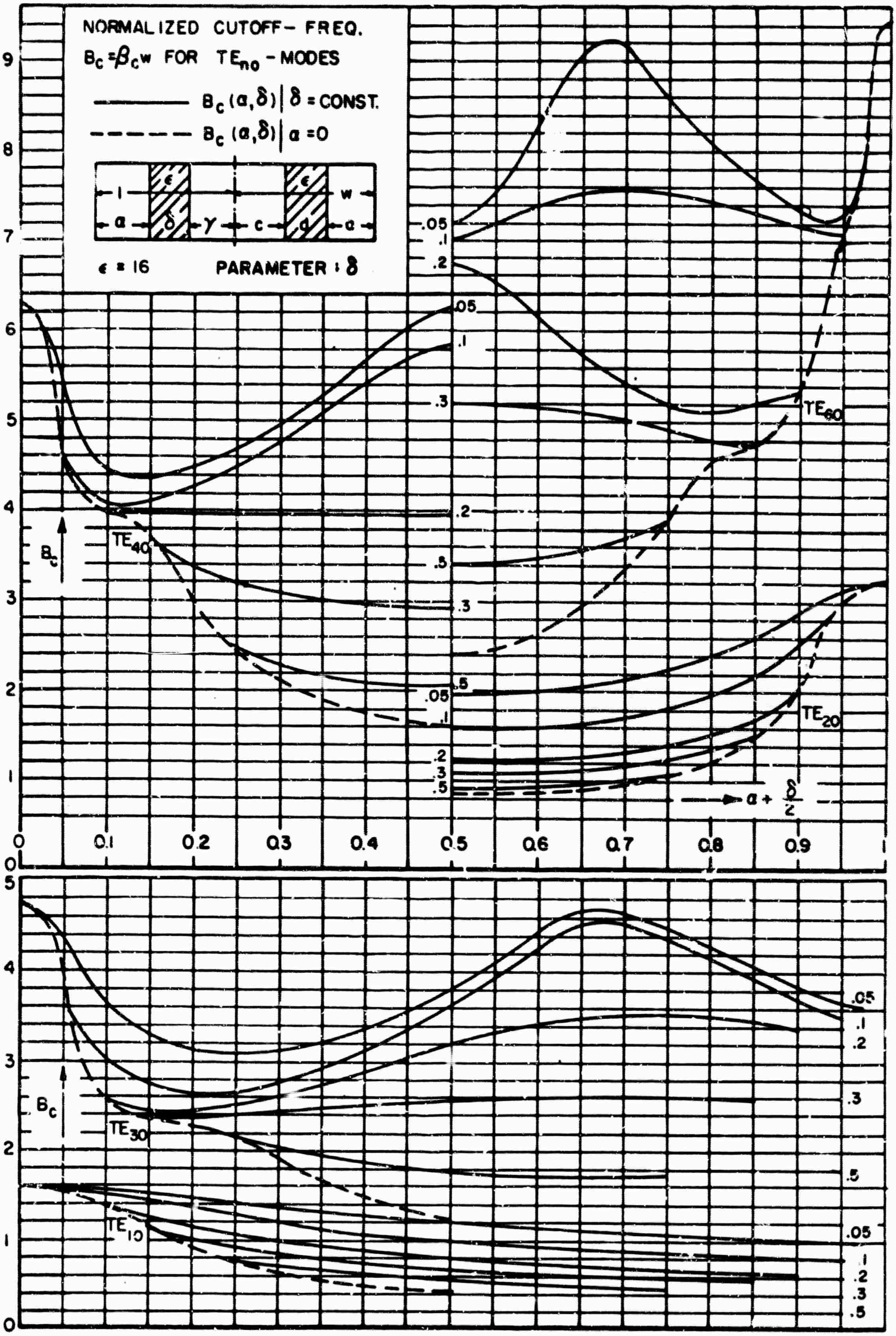
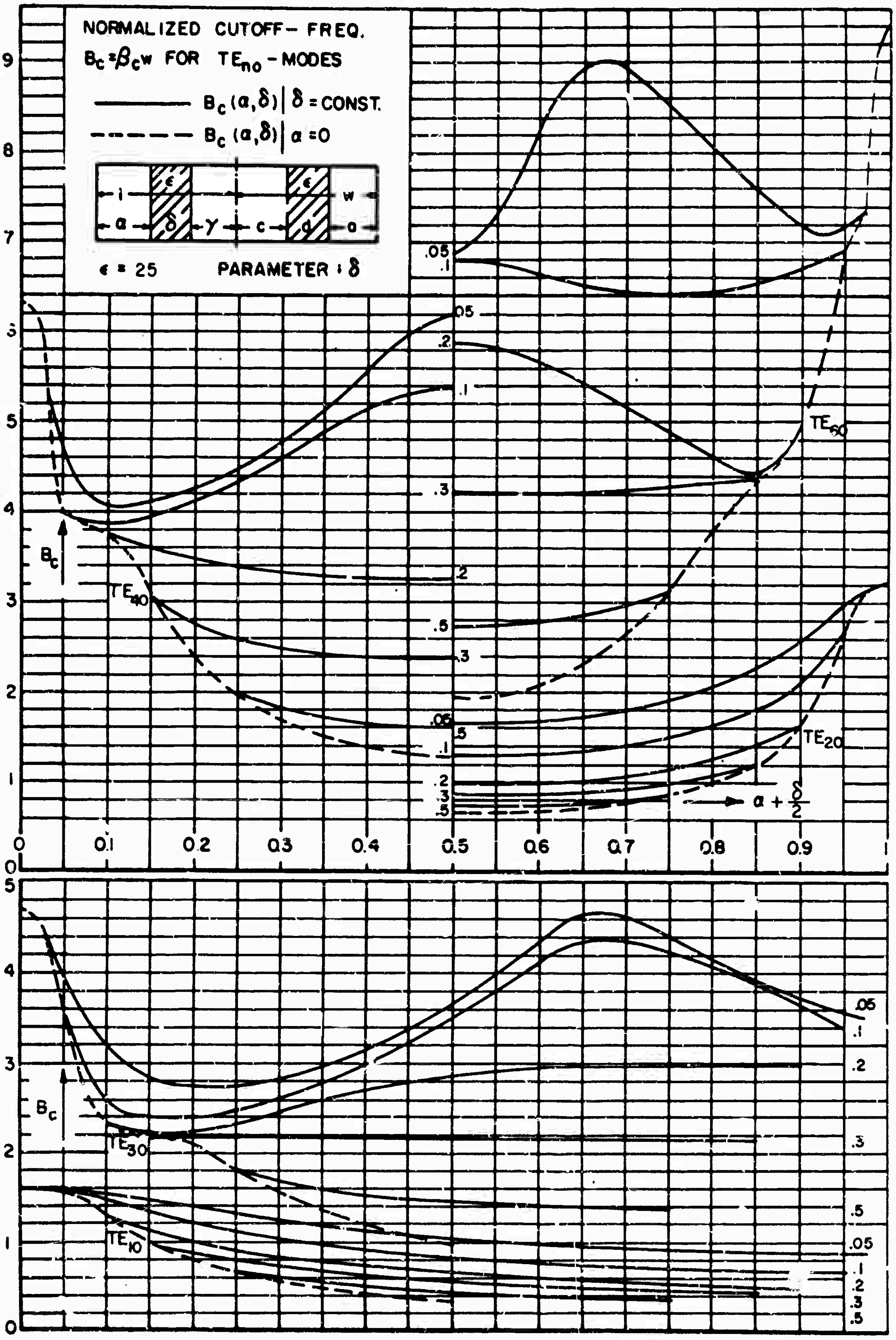
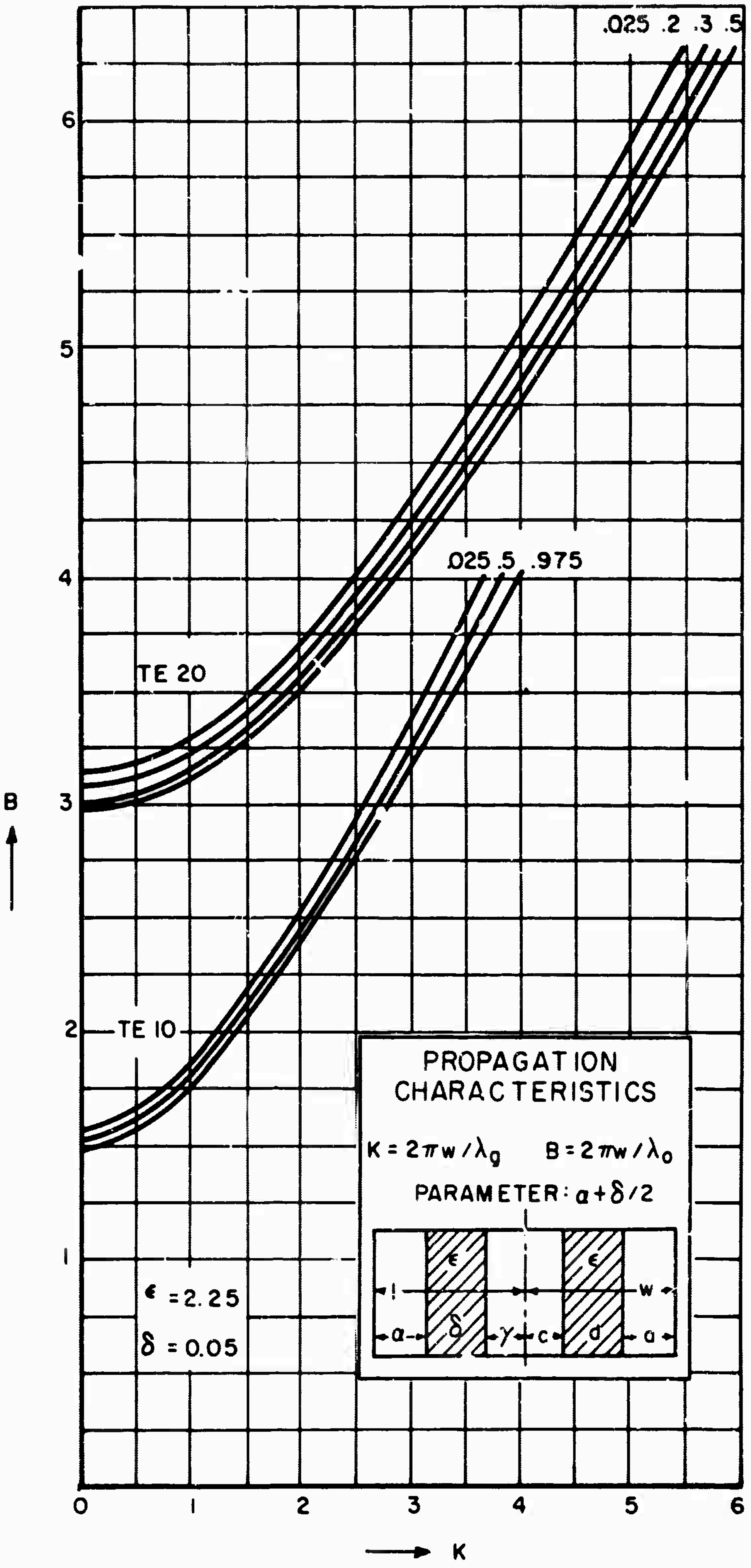

NORMALIZED CUTOFF– FREQ.
$B_c = \beta_c w$ FOR TE_{no} - MODES
$B_c(a,\delta) | \delta$ = CONST.
$B_c(a,\delta) | a = 0$
l
ε
ε
w
a
δ
γ
c
d
a
ε = 16
PARAMETER : δ
9
8
7
6
5
4
3
2
1
0
B_c
TE$_{40}$
TE$_{60}$
TE$_{20}$
.05
.1
.2
.3
.5
$a + \frac{\delta}{2}$
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
4
3
2
1
0
B_c
TE$_{30}$
TE$_{10}$


NORMALIZED CUTOFF- FREQ.
$B_c = \beta_c w$ FOR TE_{n0} - MODES
$B_c(a,\delta)\,|\,\delta$ = CONST.
$B_c(a,\delta)\,|\,a = 0$
ε
i
w
a
δ
γ
c
d
o
ε = 25
PARAMETER : δ
B_c
TE_{60}
TE_{40}
TE_{20}
TE_{30}
TE_{10}
$a + \frac{\delta}{2}$
.05
.1
.2
.3
.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
6
7
8
9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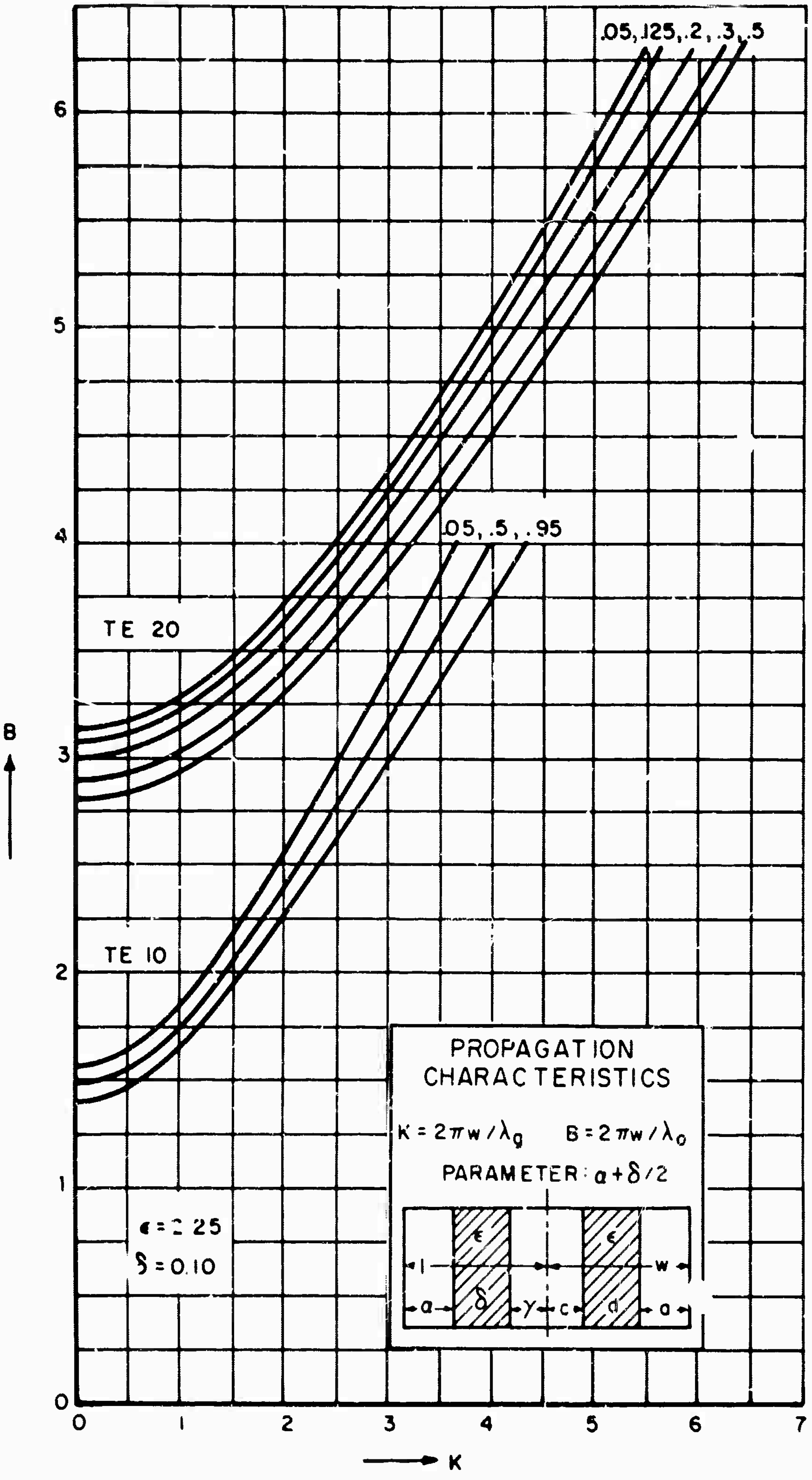
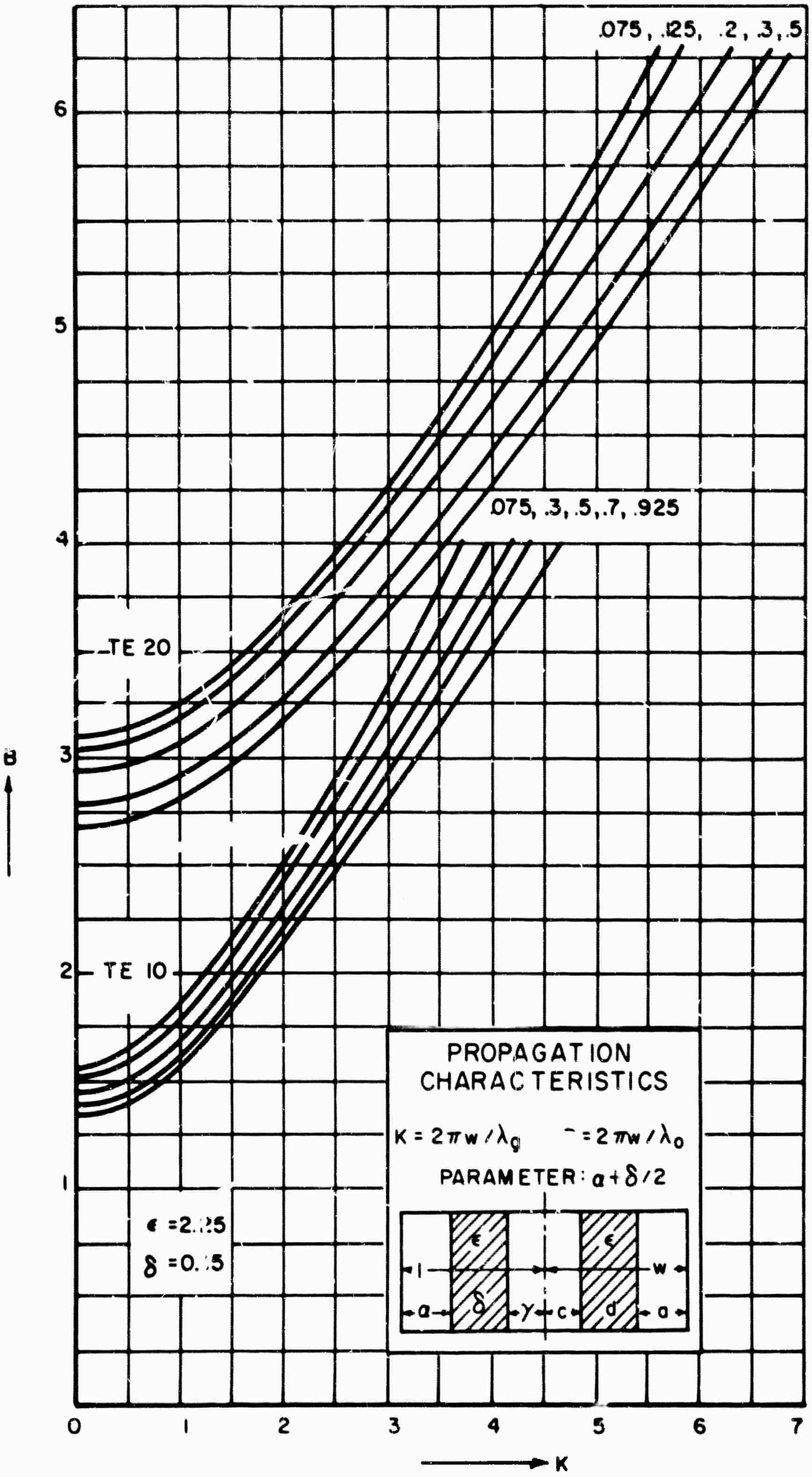
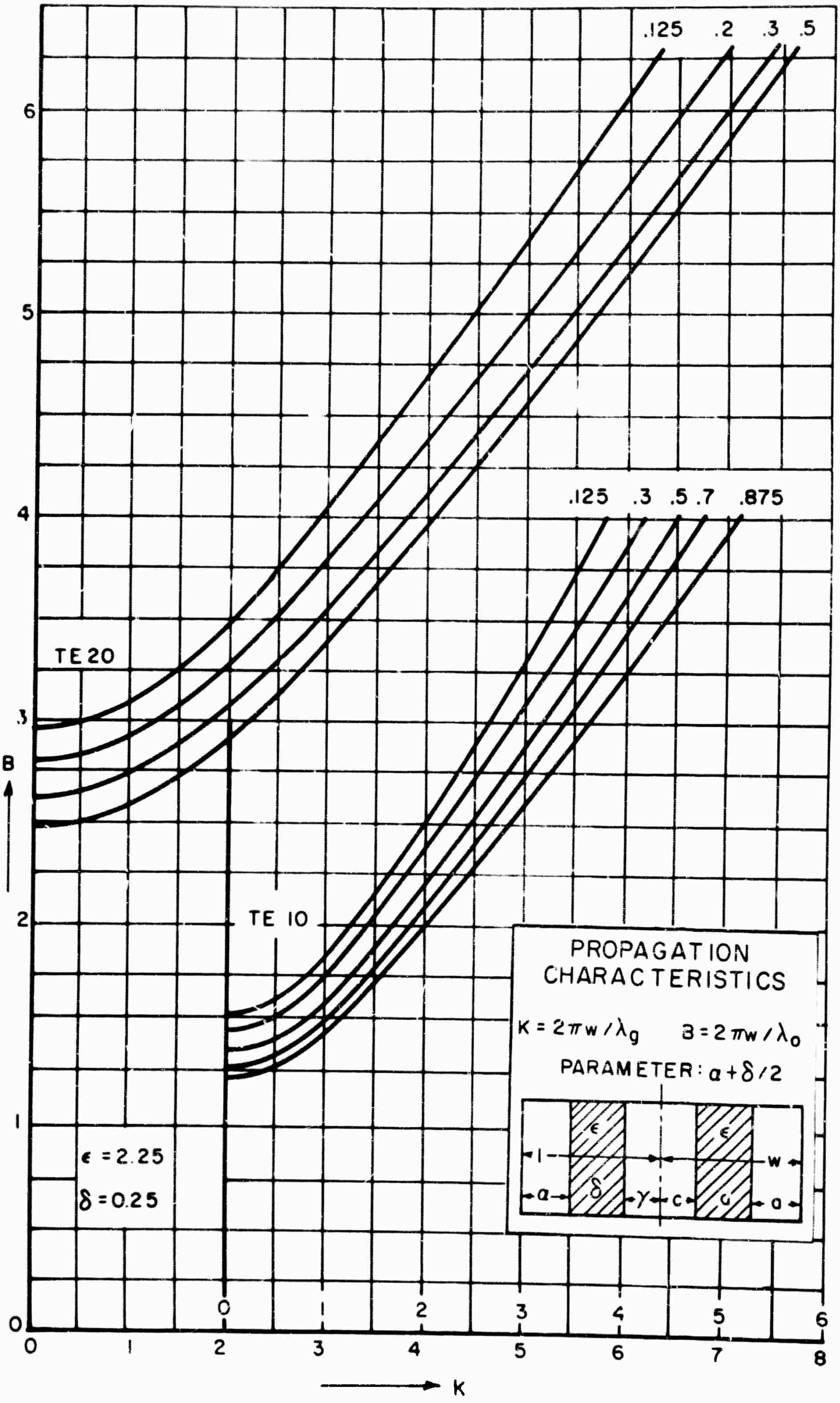
.2
.3
.5
.025
.5
.975
TE 20
TE 10
B
K
0
1
2
3
4
5
6
PROPAGATION CHARACTERISTICS
$K = 2\pi w/\lambda_g$
$B = 2\pi w/\lambda_0$
PARAMETER: $a+\delta/2$
ϵ
ϵ
l
w
a
δ
γ
c
d
a
$\epsilon = 2.25$
$\delta = 0.05$


.05, .125, .2, .3, .5
.05, .5, .95
TE 20
TE 10
B
K
0
1
2
3
4
5
6
7
PROPAGATION CHARACTERISTICS
K = 2πw / λg
B = 2πw / λ0
PARAMETER: a + δ/2
ε = 2.25
δ = 0.10
ε
ε
δ
d
1
w
a
y
c
a


.075, .125, .2, .3, .5
.075, .3, .5, .7, .925
TE 20
TE 10
B
K
0
1
2
3
4
5
6
7
PROPAGATION CHARACTERISTICS
K = 2πw / λg
‾ = 2πw / λo
PARAMETER: a + δ / 2
ε
δ
d
l
w
a
γ
c
ε = 2.25
δ = 0.15


.125
.2
.3
.5
.125
.3
.5
.7
.875
TE20
TE 10
B
K
PROPAGATION
CHARACTERISTICS
K = 2πw/λg
B = 2πw/λo
PARAMETER: a+δ/2
ε
ε
l
w
a
δ
γ
c
c
a
ε = 2.25
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3
4
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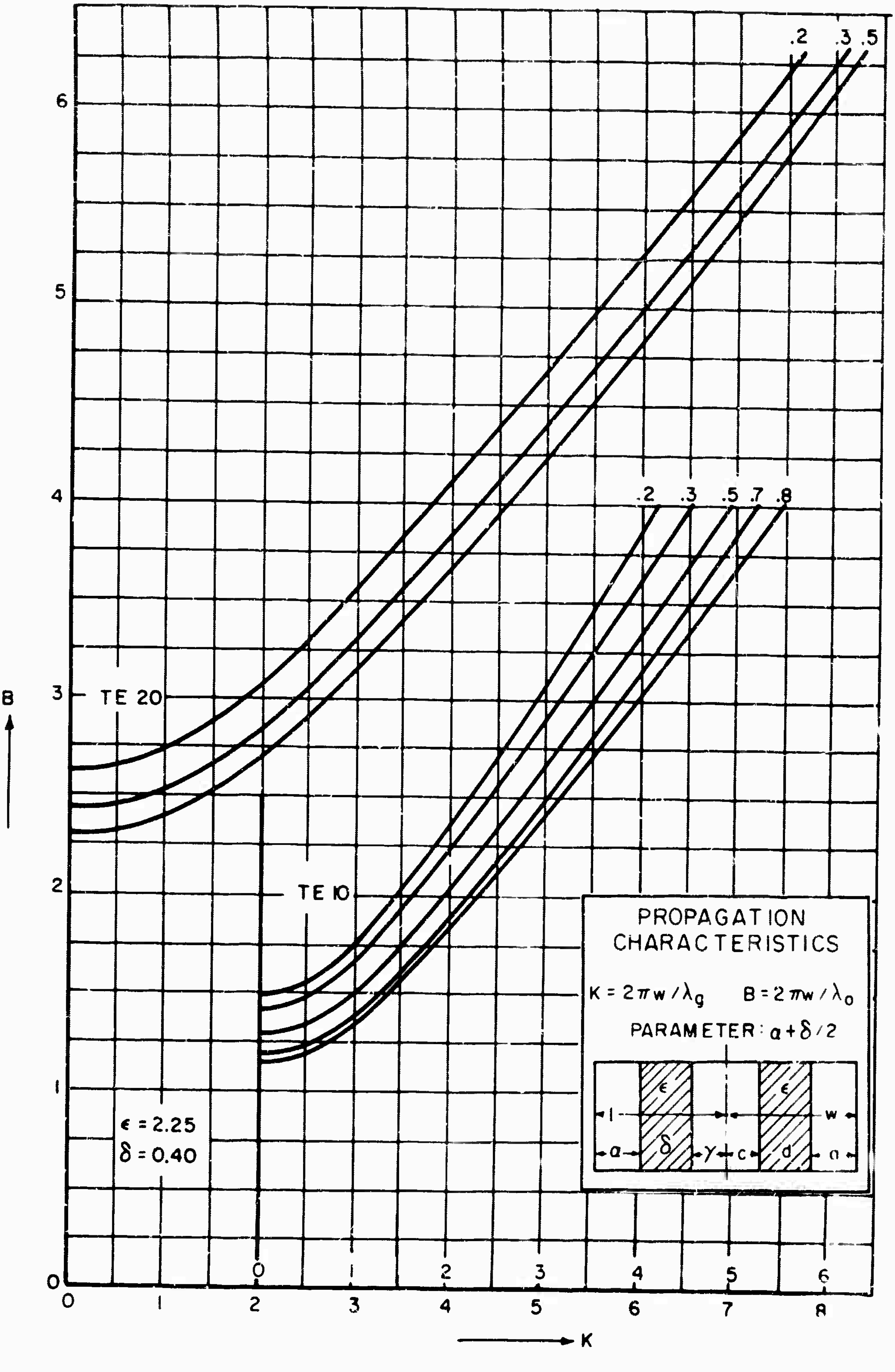
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K = 2πw / λg B = 2πw / λo
PARAMETER: α + δ / 2
ε
ε
l
w
a
δ
γ
c
d
a
TE 20
TE 10
.2
.3
.5
.2
.3
.5
.7
.8
ε = 2.25
δ = 0.40
B
K
0
1
2
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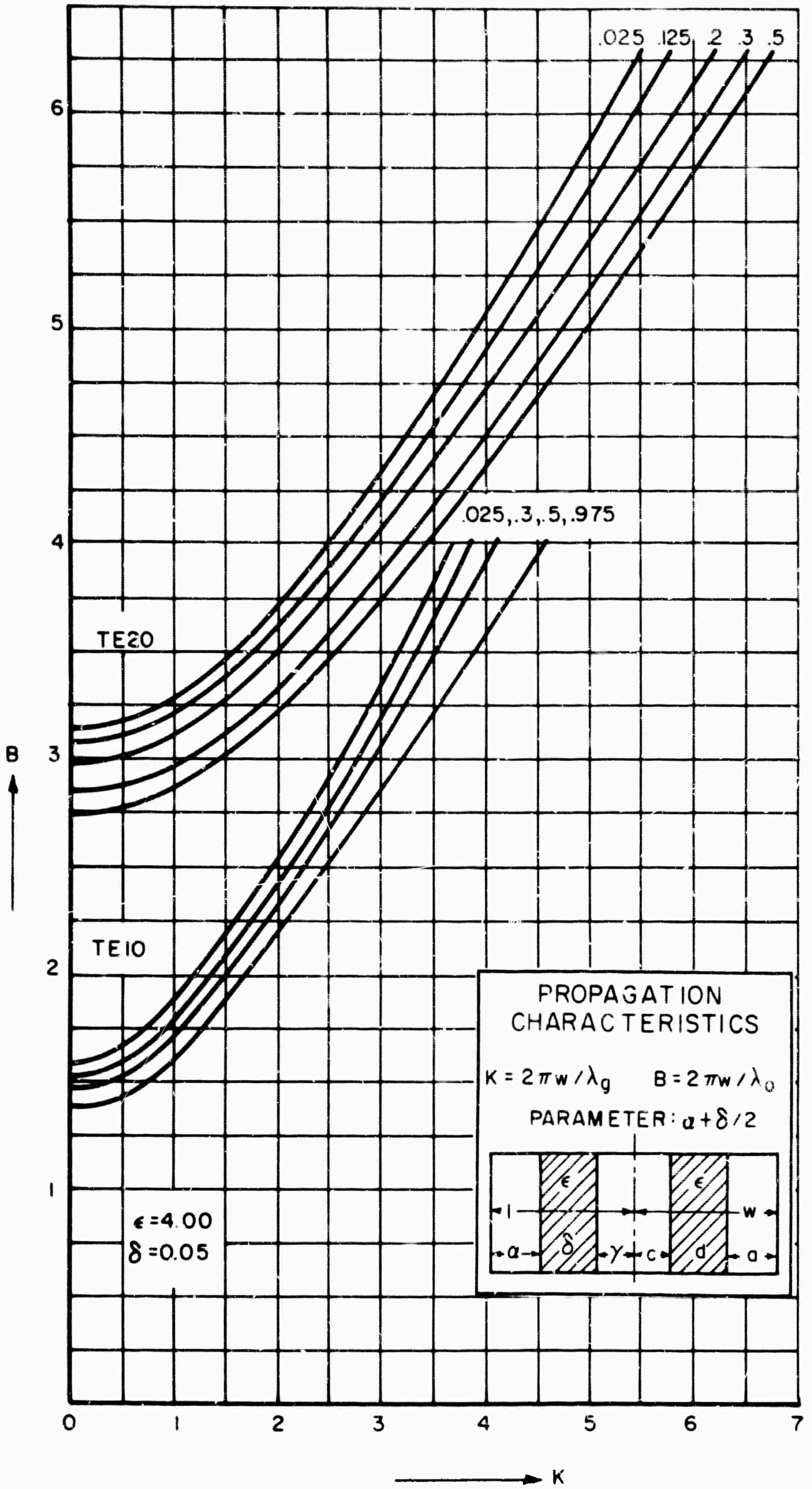
6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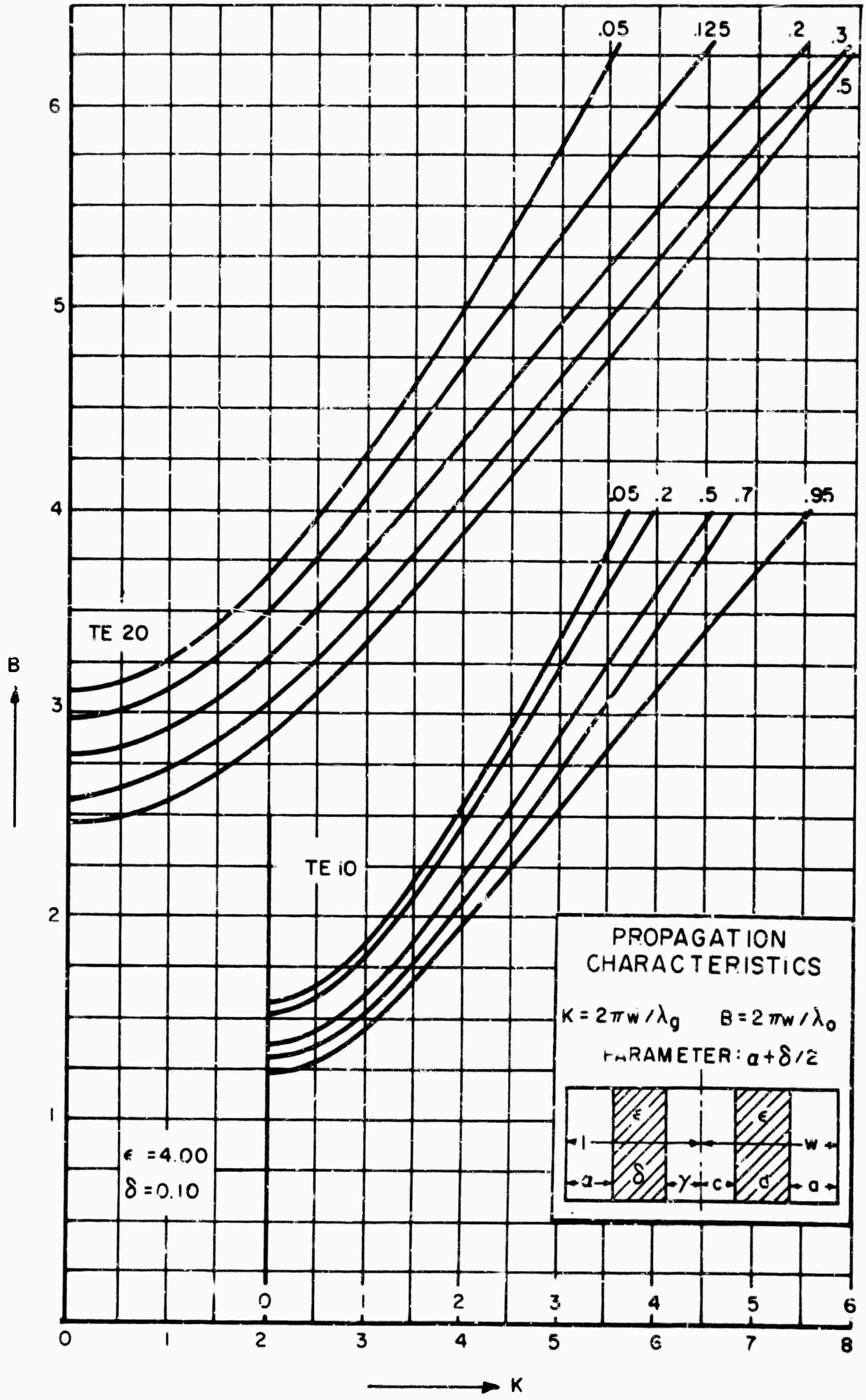
.025,.3,.5,.975
TE20
TE10
B
K
0
1
2
3
4
5
6
7
ε = 4.00
δ = 0.05
PROPAGATION CHARACTERISTICS
K = 2πw/λg   B = 2πw/λ0
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a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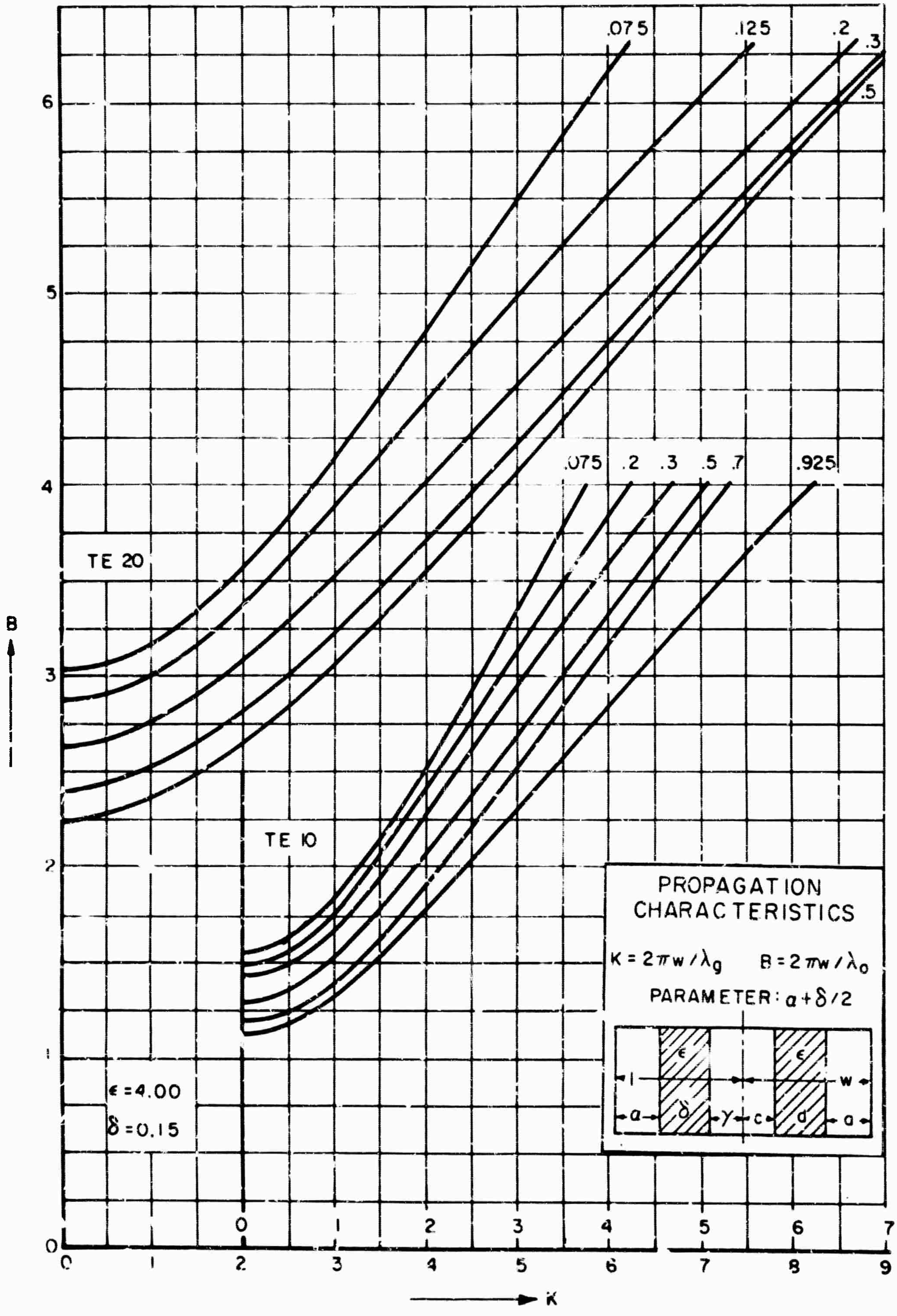
.2
.5
.7
.95
TE 20
TE 10
B
K
0
1
2
3
4
5
6
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
PROPAGATION CHARACTERISTICS
K = 2πw / λg
B = 2πw / λo
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
ε = 4.00
δ = 0.10


PROPAGATION CHARACTERISTICS
K = 2πw / λg
B = 2πw / λ0
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE 20
TE 10
ε = 4.00
δ = 0.15
.075
.125
.2
.3
.5
.075
.2
.3
.5
.7
.925
B
K
0
1
2
3
4
5
6
0
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2
3
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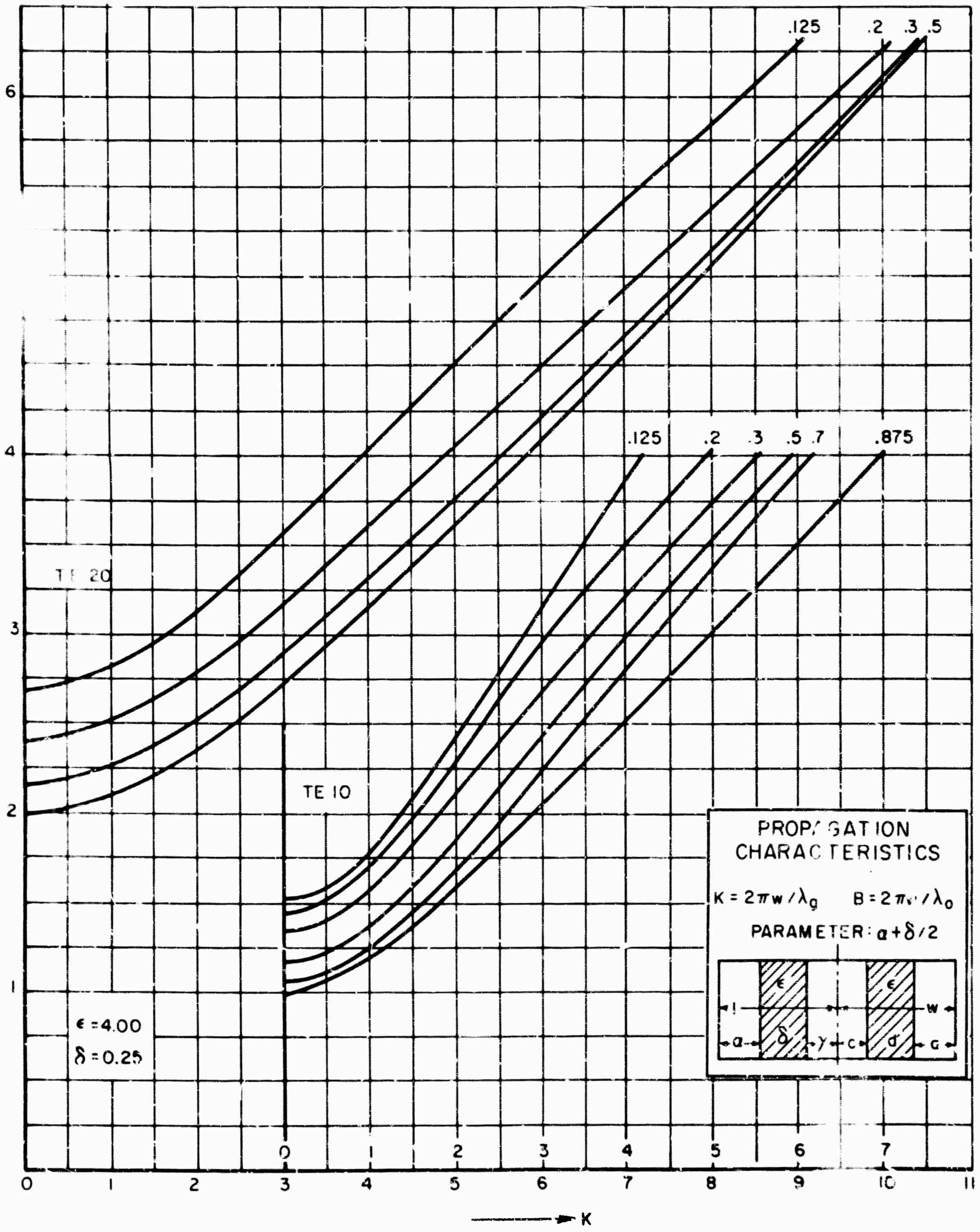
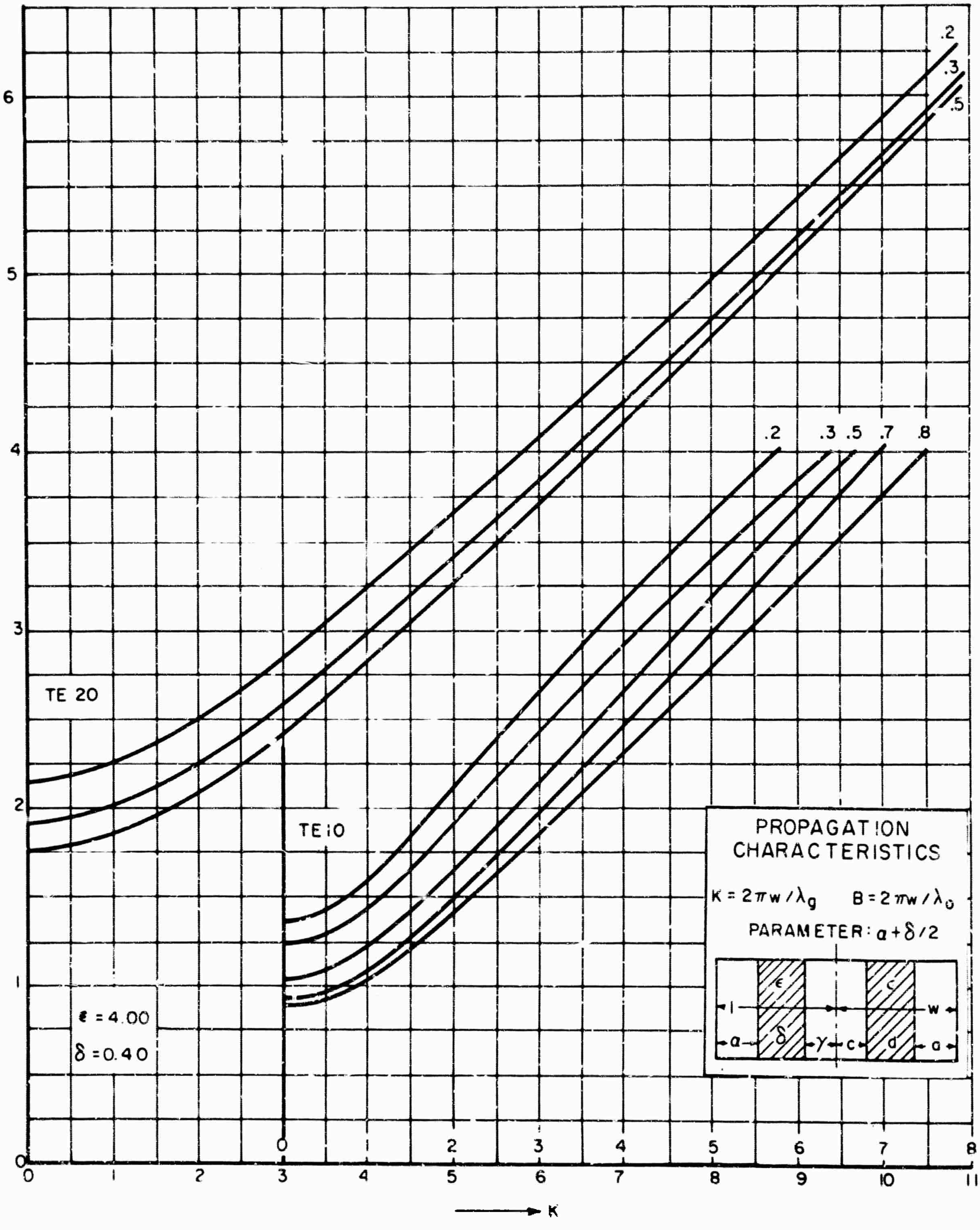
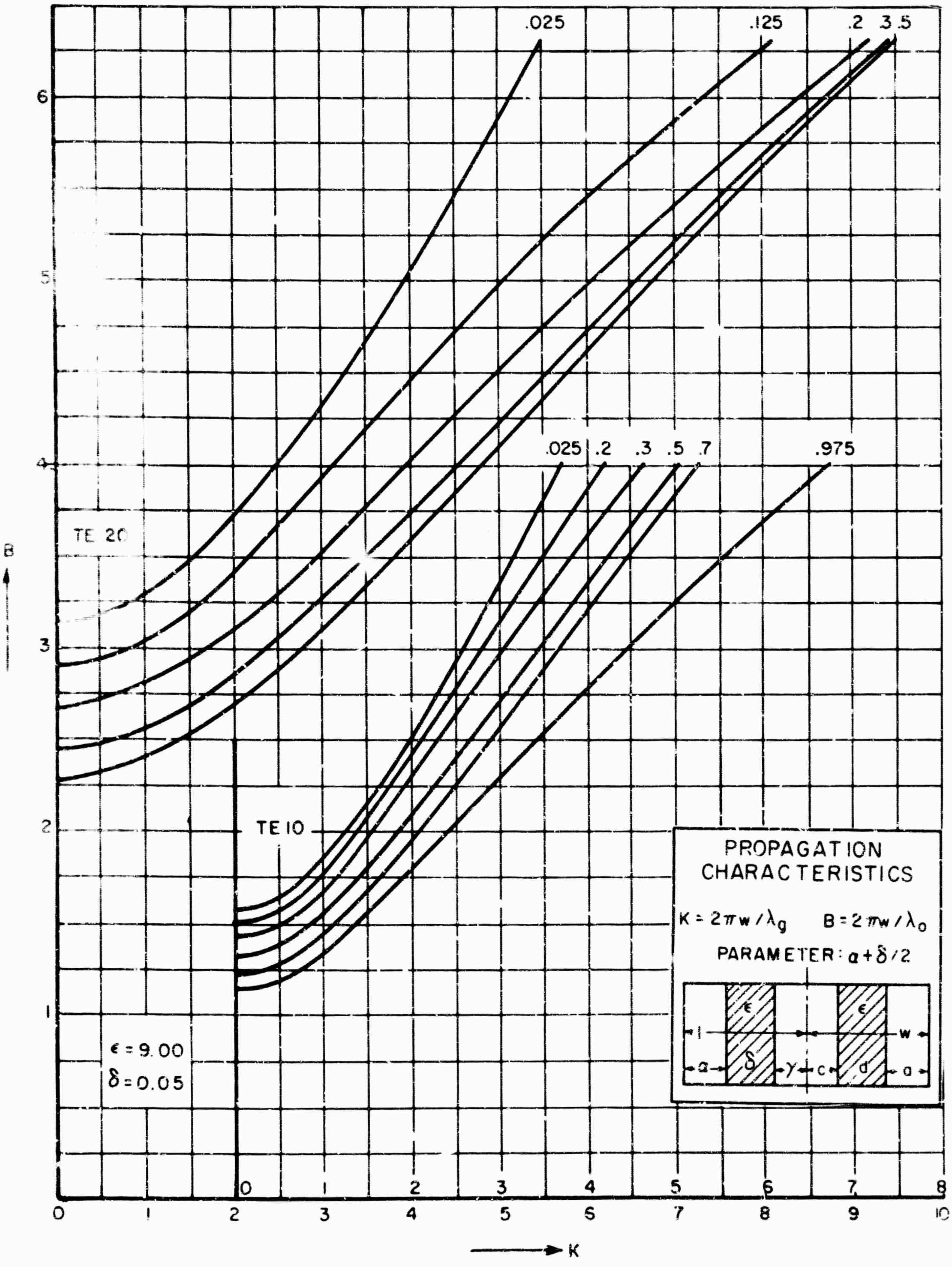
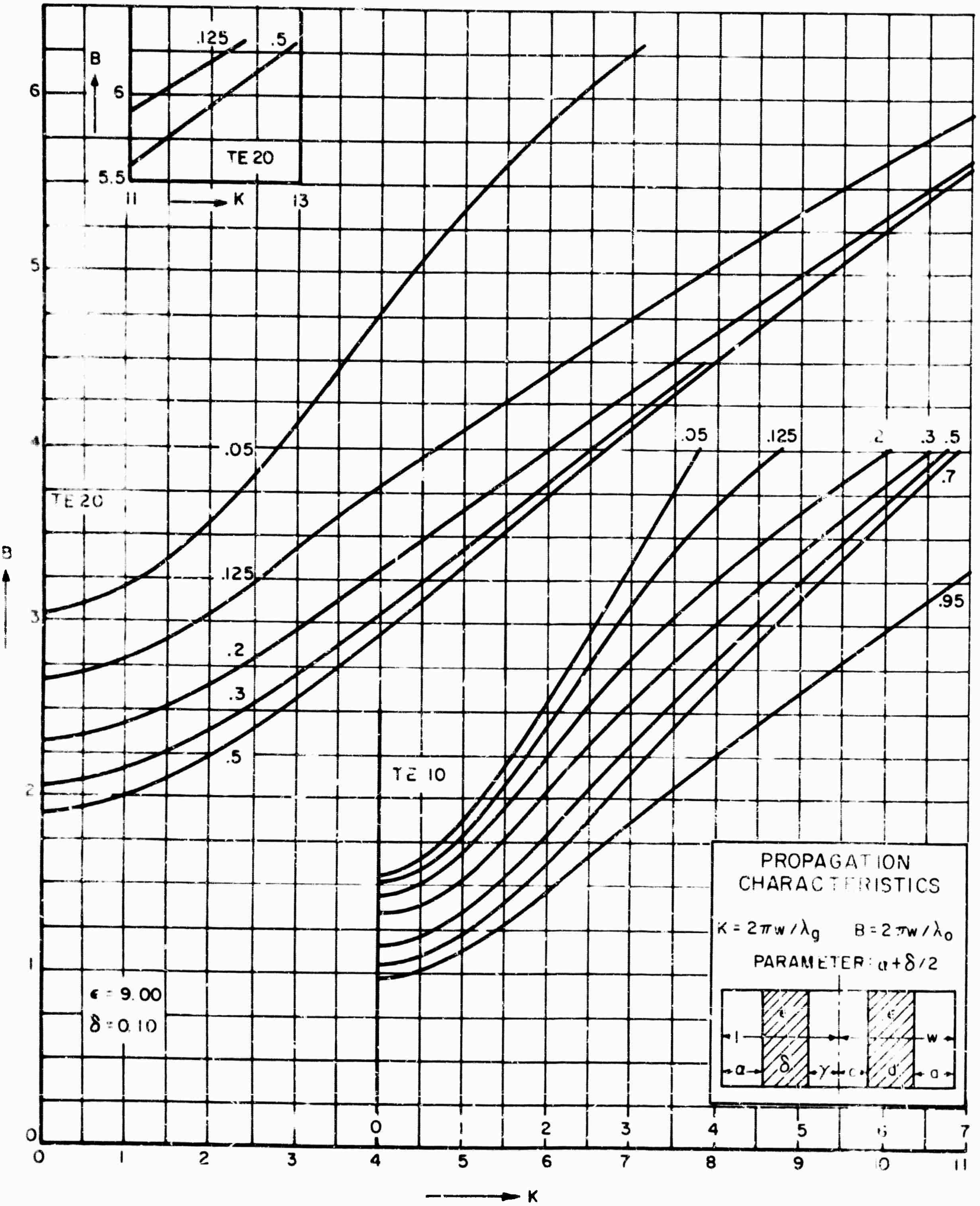
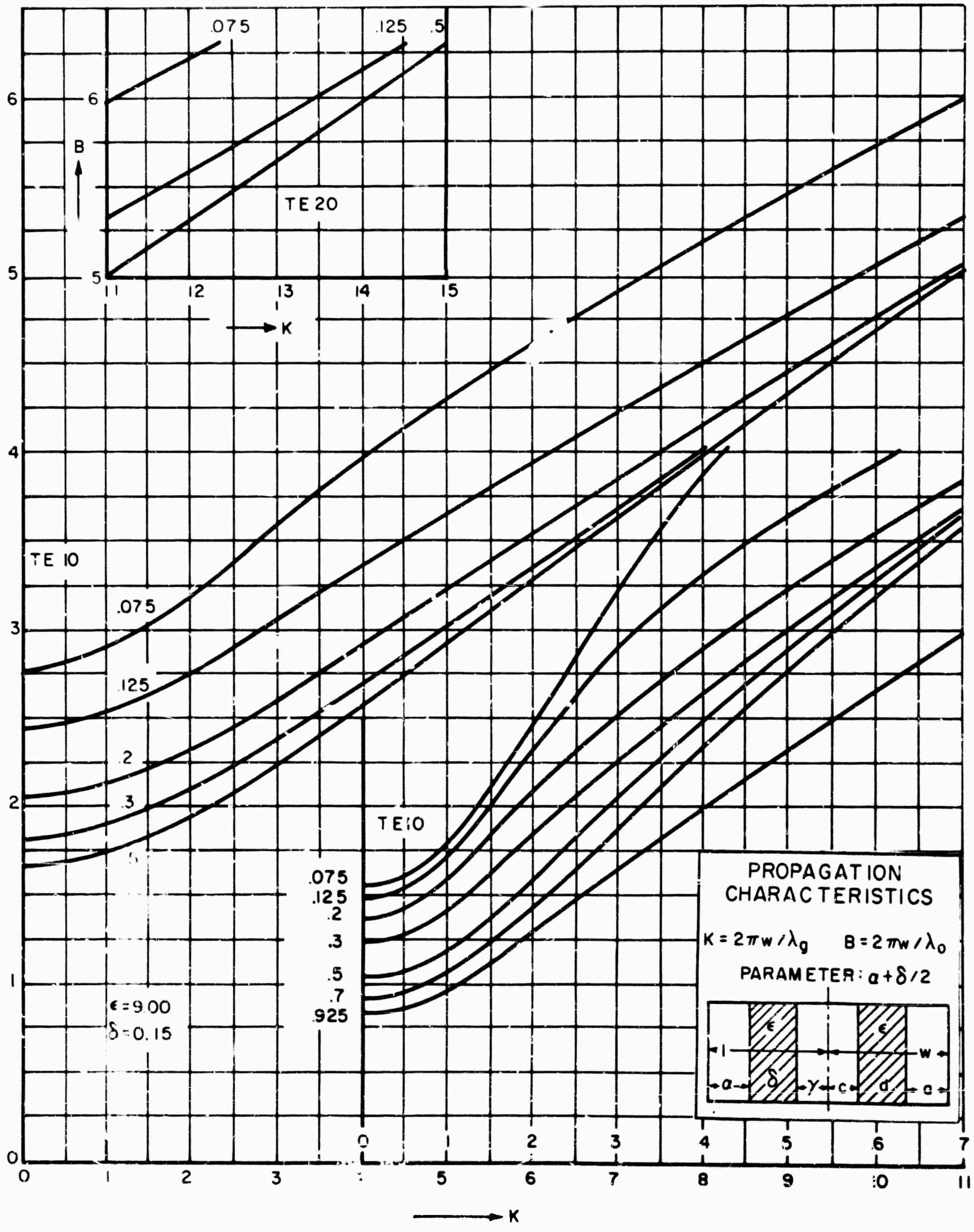
6
7
8
9
0
1
2
3
4
5
6
7

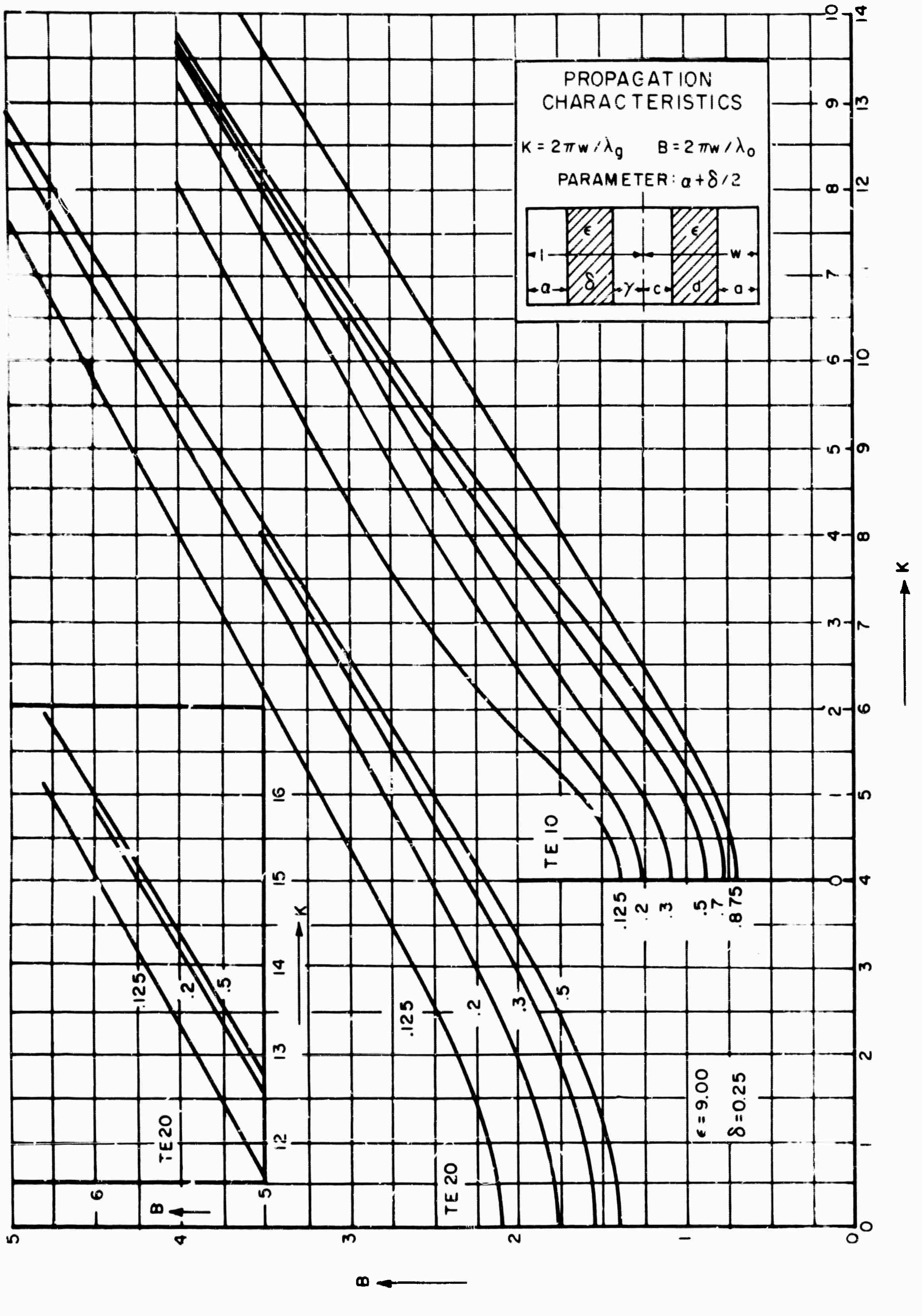

.125
.2
.3
.5
6
4
3
2
1
TE 20
TE 10
.125
.2
.3
.5
.7
.875
PROPAGATION CHARACTERISTICS
K = 2πw / λg
B = 2πw / λo
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
G
ε = 4.00
δ = 0.25
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
8
9
10
11
K

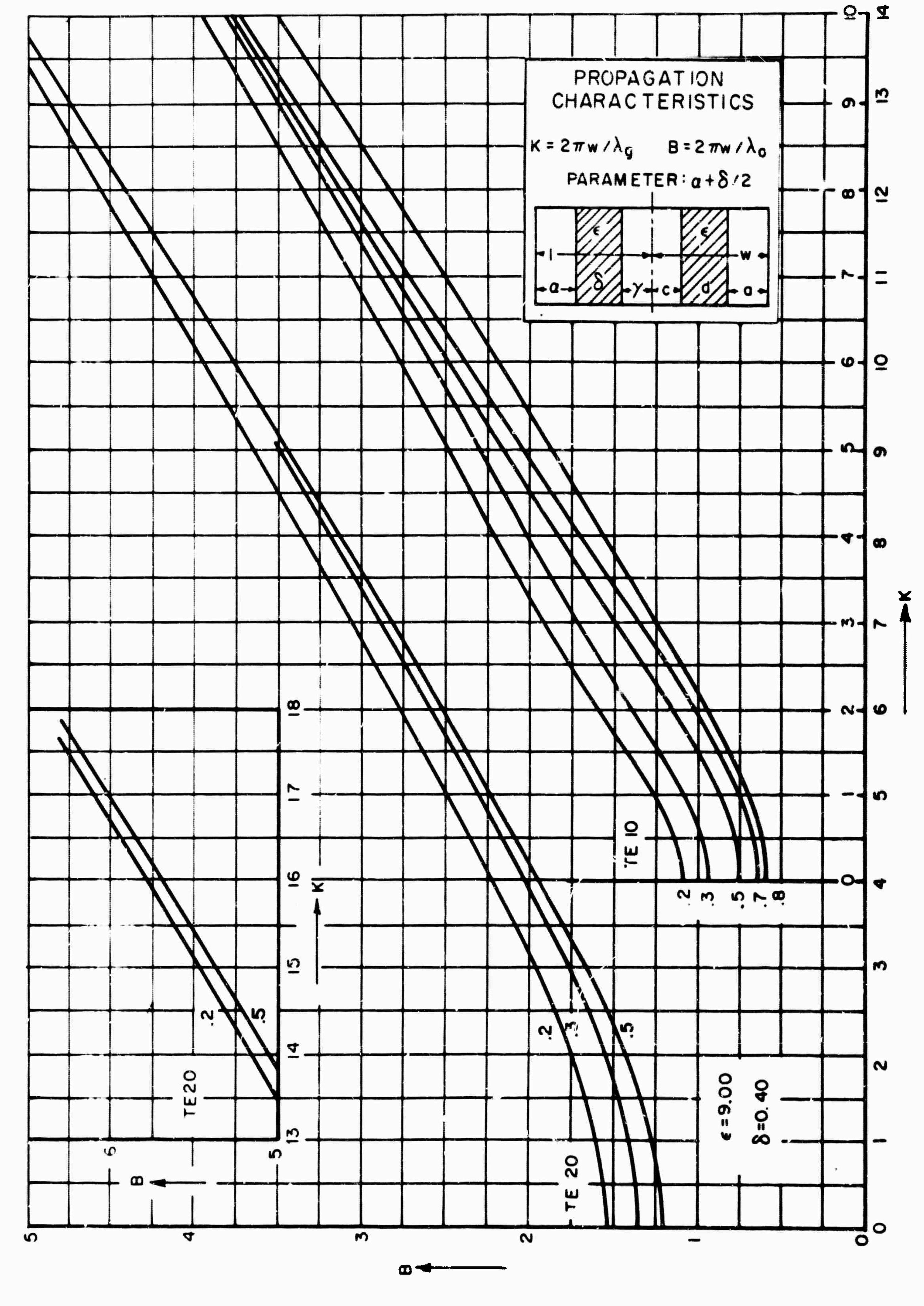

PROPAGATION CHARACTERISTICS
K = 2πw/λg   B = 2πw/λ0
PARAMETER: a+δ/2
ε
δ
l
w
a
γ
c
d
a
ε = 4.00
δ = 0.40
TE 20
TE 10
.2
.3
.5
.2
.3
.5
.7
.8
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
9
10
11
0
1
2
3
4
5
6
7
8
K

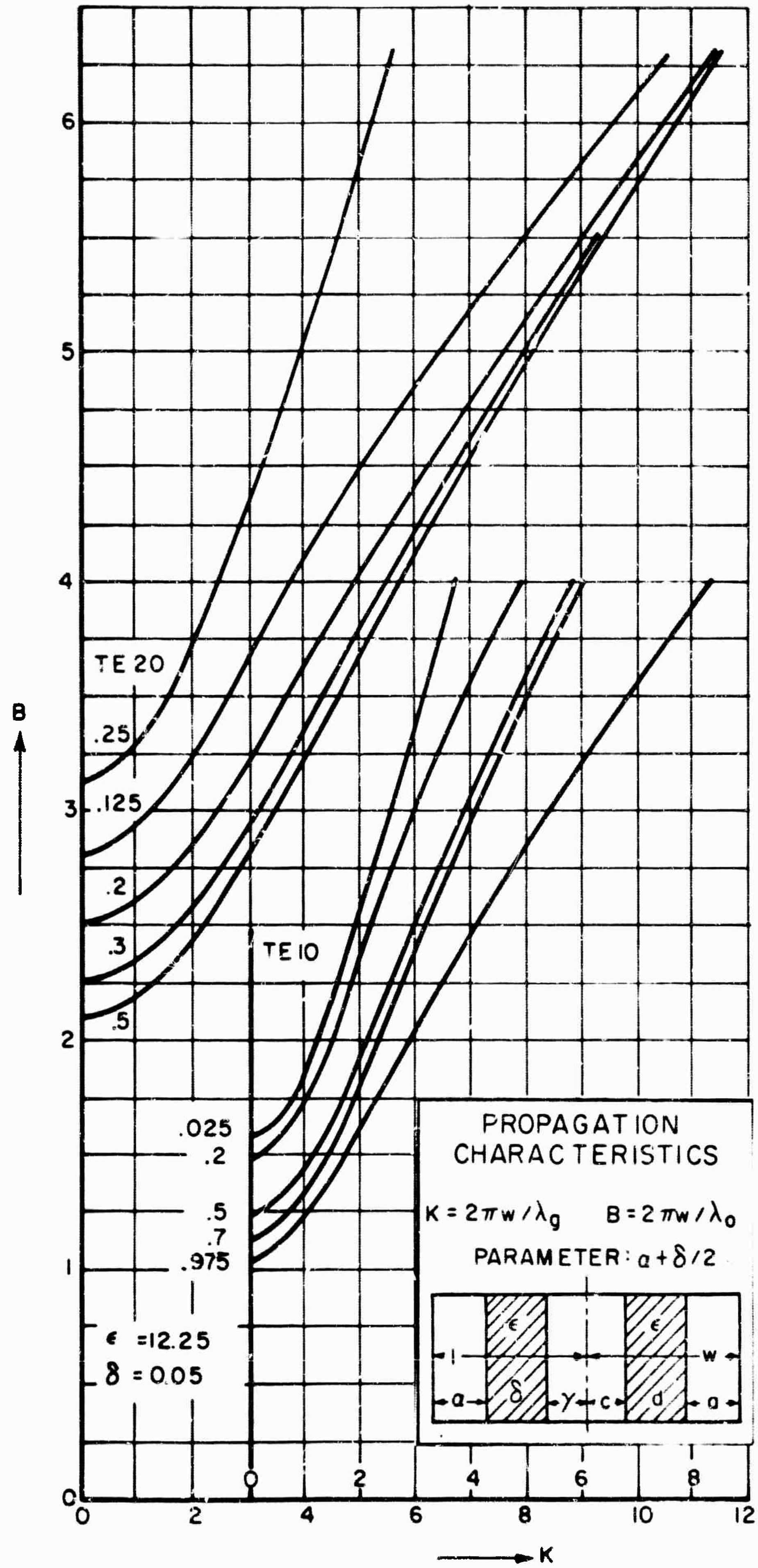

.025
.125
.2
.3
.5
TE 20
TE 10
.025
.2
.3
.5
.7
.975
B
6
5
4
3
2
1
PROPAGATION
CHARACTERISTICS
K = 2πw / λg   B = 2πw / λo
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
ε = 9.00
δ = 0.05
0
1
2
3
4
5
6
7
8
0
1
2
3
4
5
6
7
8
9
10
K


B
6
5.5
.125
.5
TE 20
11
K
13
6
5
4
3
2
1
0
B
.05
.125
.2
.3
.5
TE 20
TE 10
.05
.125
.2
.3
.5
.7
.95
ε = 9.00
δ = 0.10
PROPAGATION CHARACTERISTICS
K = 2πw / λg
B = 2πw / λ0
PARAMETER: α + δ/2
ε
ε
δ
d'
a
γ
c
a
l
w
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7 8 9 10 11
K

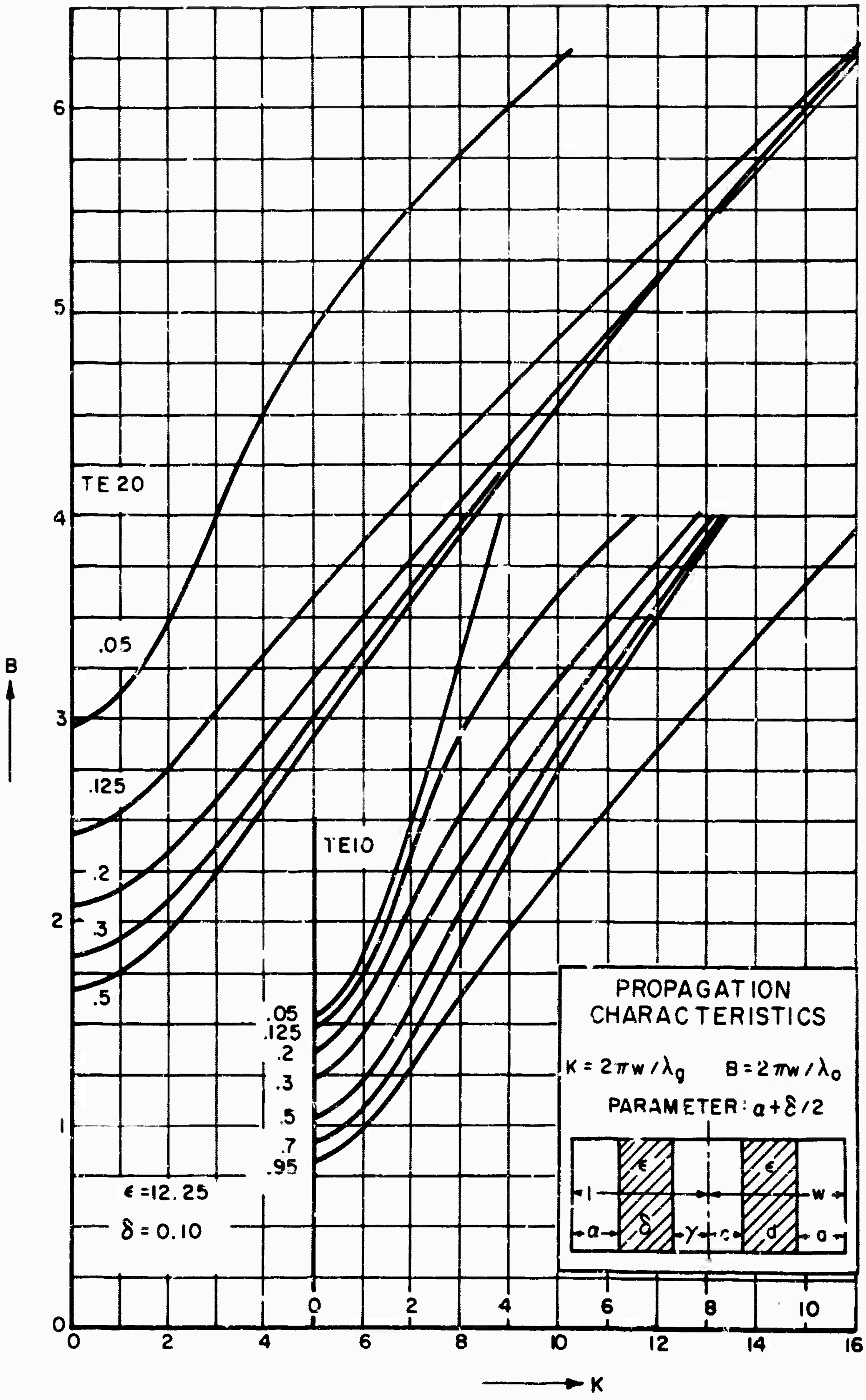

.075
.125
.5
6
B
5
TE 20
11
12
13
14
15
K
6
5
4
3
2
1
0
TE 10
.075
.125
.2
.3
.5
TE10
.075
.125
.2
.3
.5
.7
.925
ε=9.00
δ=0.15
PROPAGATION CHARACTERISTICS
K = 2πw/λg
B = 2πw/λ0
PARAMETER: a+δ/2
ε
ε
l
w
a
δ
γ
c
d
a
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
8
9
10
11
K

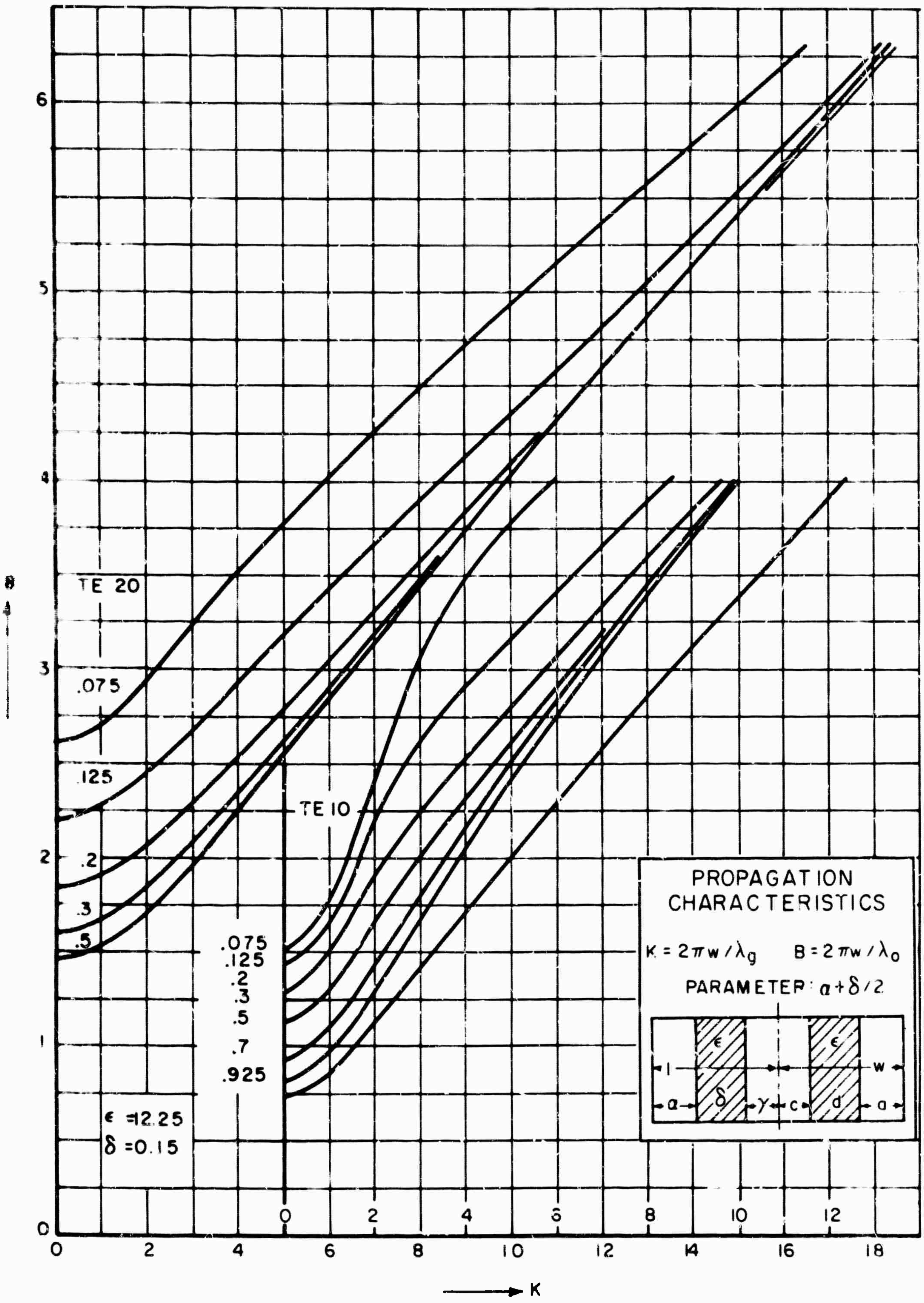

PROPAGATION CHARACTERISTICS
K = 2πw / λg   B = 2πw / λo
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE 10
.125
.2
.3
.5
.7
.875
TE 20
.125
.2
.3
.5
TE 20
.125
.2
.5
ε = 9.00
δ = 0.25
B
K
0
1
2
3
4
5
0
1
2
3
4
5
6
7
8
9
10
4
5
6
7
8
9
10
11
12
13
14
12
13
14
15
16
5
6

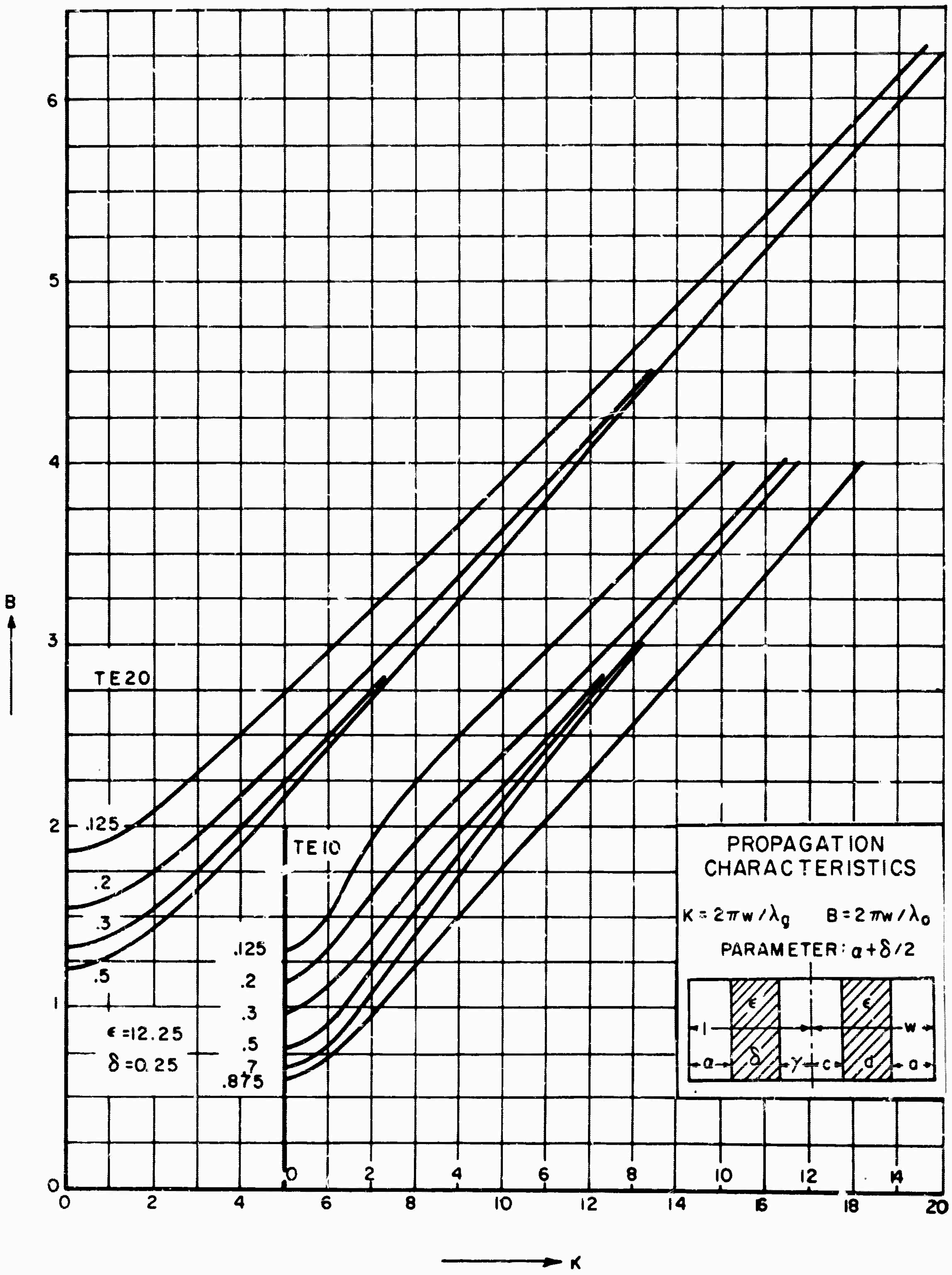

PROPAGATION CHARACTERISTICS
K = 2πw / λ_g
B = 2πw / λ_0
PARAMETER: a+δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE 10
.2
.3
.5
.7
.8
TE 20
.2
.3
.5
ε = 9.00
δ = 0.40
TE20
.2
.5
B
K
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
0
1
2
3
4
5

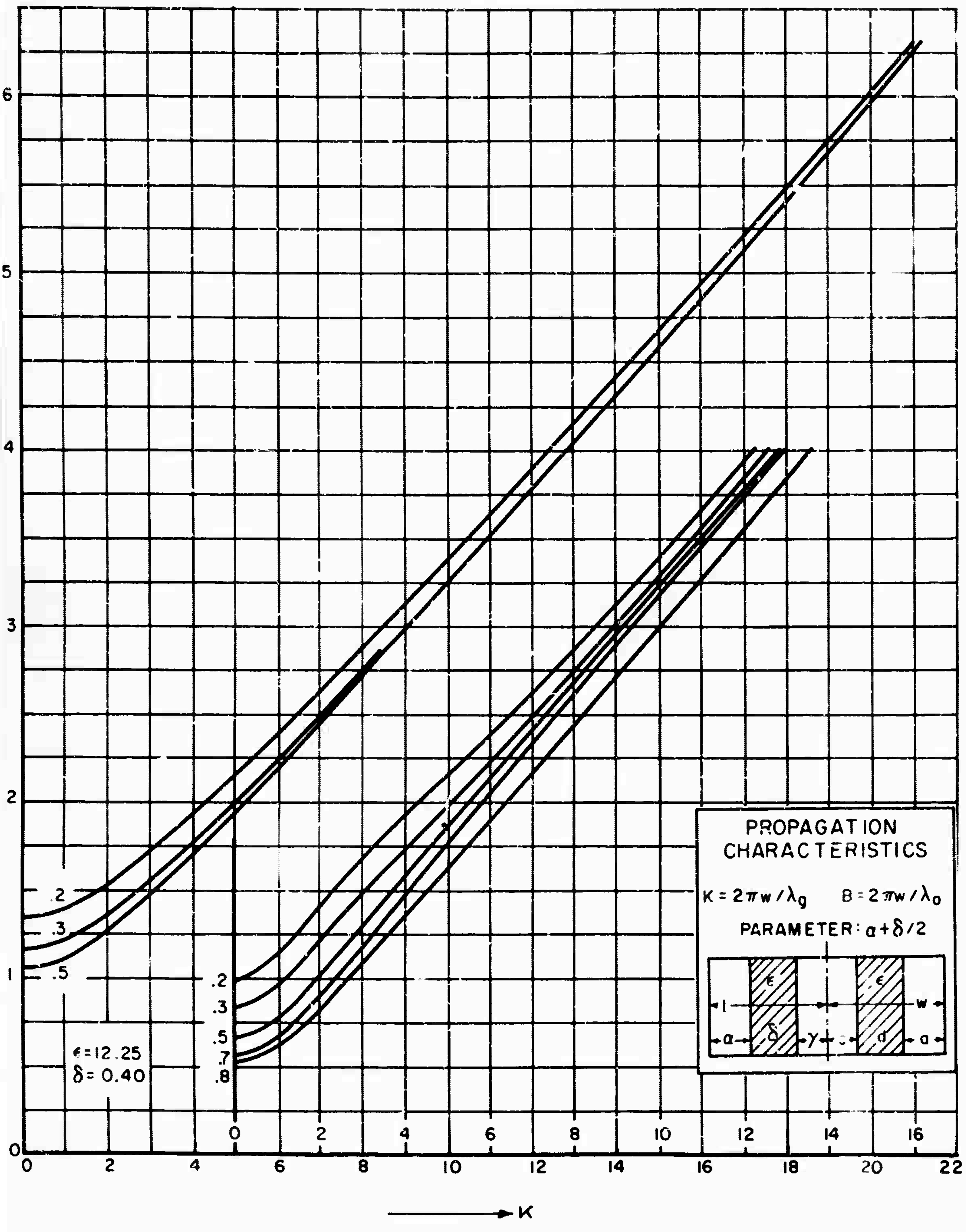


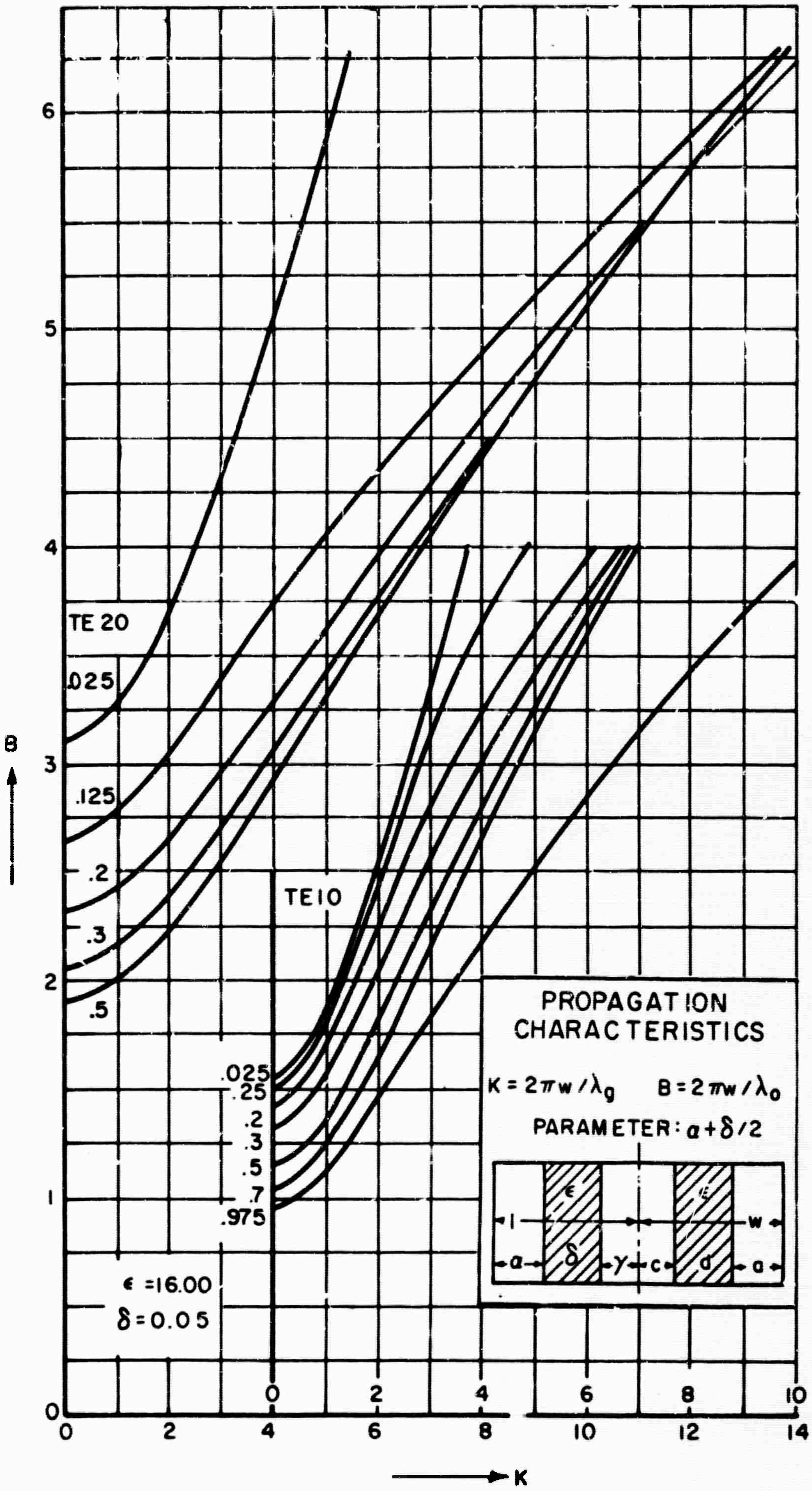
PROPAGATION CHARACTERISTICS
K = 2πw/λg B = 2πw/λo
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE 20
.25
.125
.2
.3
.5
TE 10
.025
.2
.5
.7
.975
ε =12.25
δ = 0.05
B
K
0
1
2
3
4
5
6
0
2
4
6
8
10
12
0
2
4
6
8

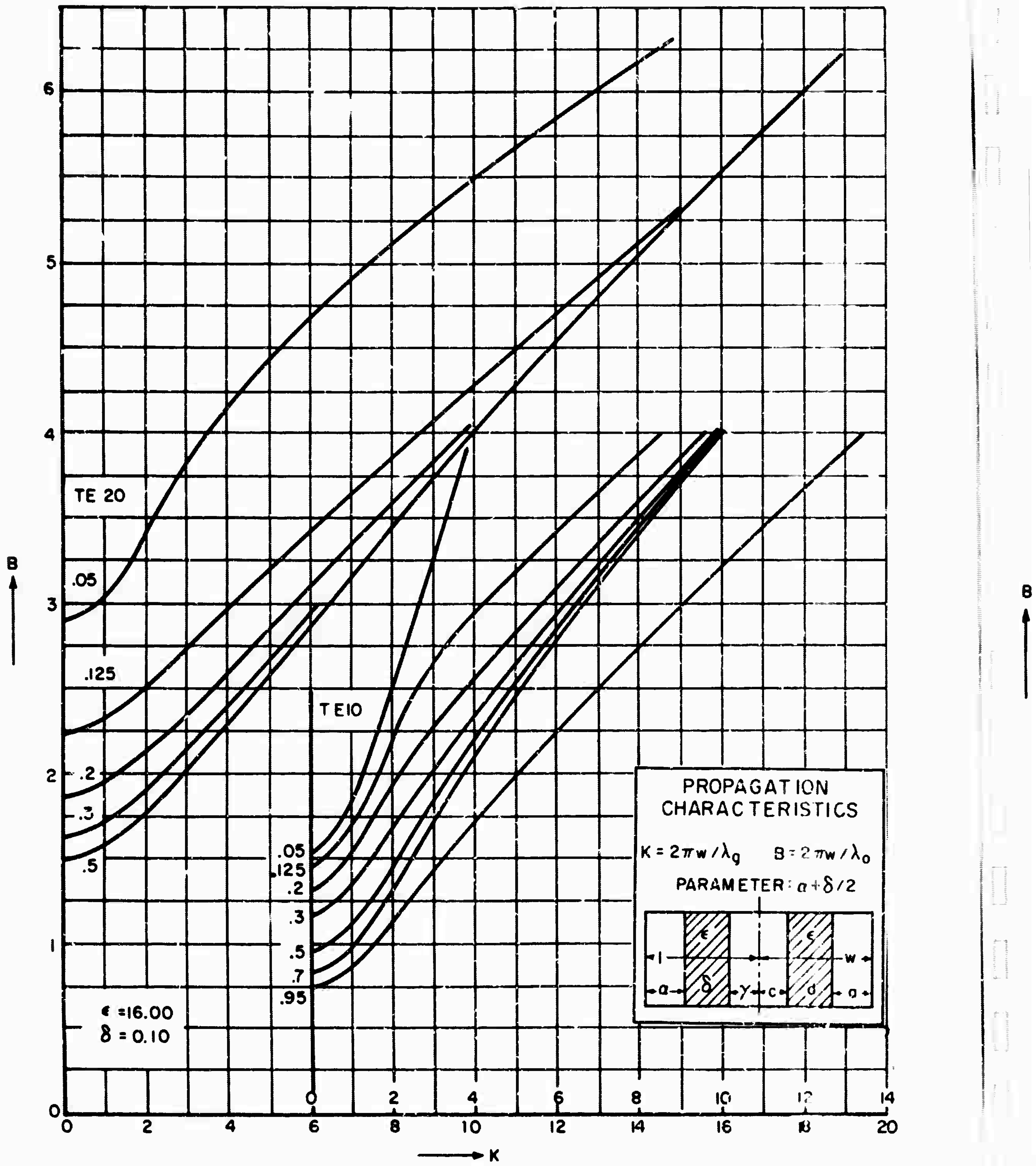

PROPAGATION CHARACTERISTICS
K = 2πw / λg   B = 2πw / λo
PARAMETER: a + δ/2
TE 20
TE10
.05
.125
.2
.3
.5
.7
.95
ε = 12.25
δ = 0.10
ε
δ
d
l
w
a
γ
c
B
K
0
1
2
3
4
5
6
8
10
12
14
16

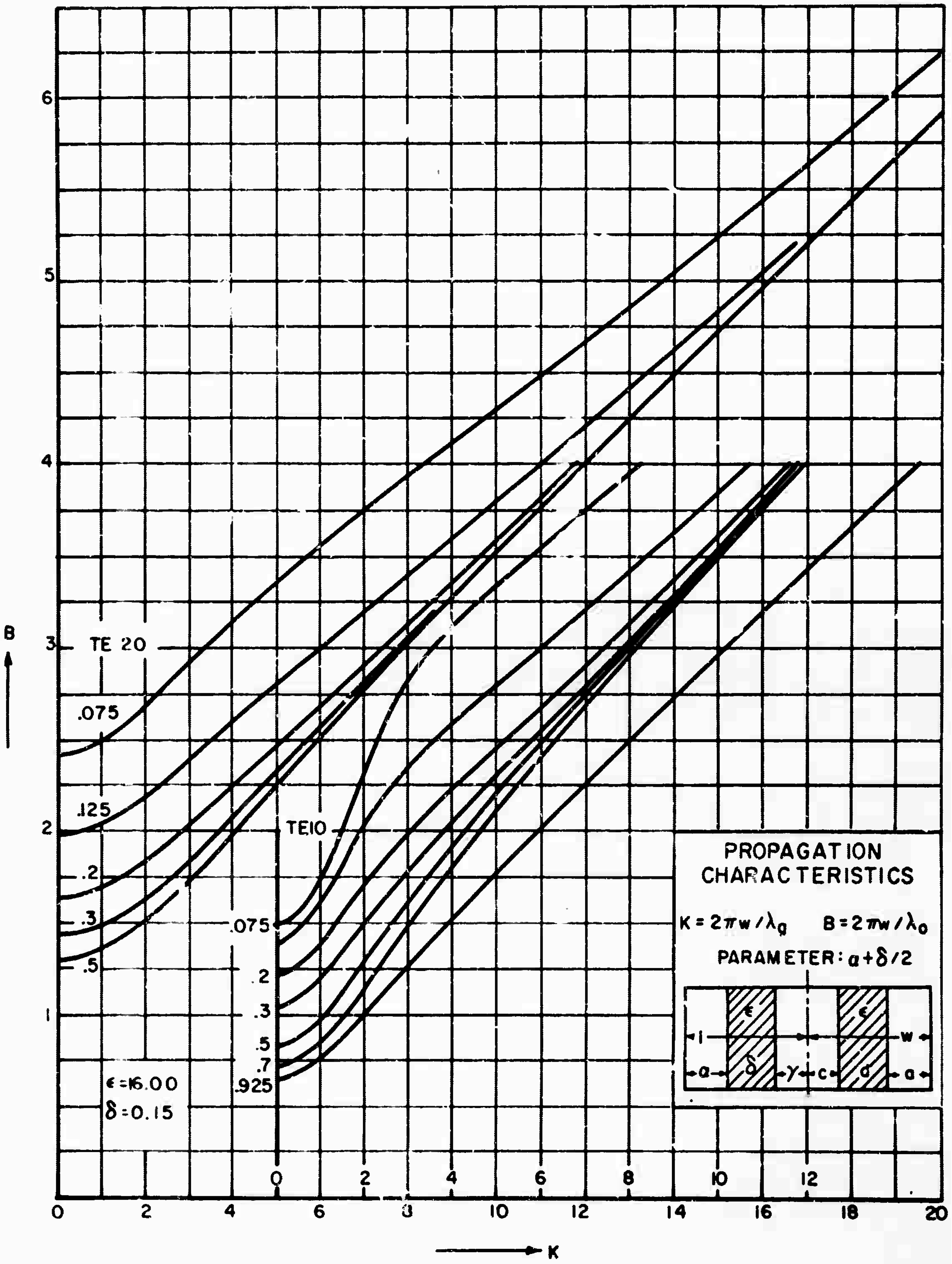

PROPAGATION CHARACTERISTICS
K = 2πw / λg   B = 2πw / λo
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE 20
.075
.125
.2
.3
.5
TE 10
.075
.125
.2
.3
.5
.7
.925
ε = 12.25
δ = 0.15
B
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
0
2
4
6
8
10
12
K


PROPAGATION
CHARACTERISTICS
K = 2πw / λg   B = 2πw / λ0
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE20
.125
.2
.3
.5
TE10
.125
.2
.3
.5
.7
.875
ε = 12.25
δ = 0.25
B
K
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
14

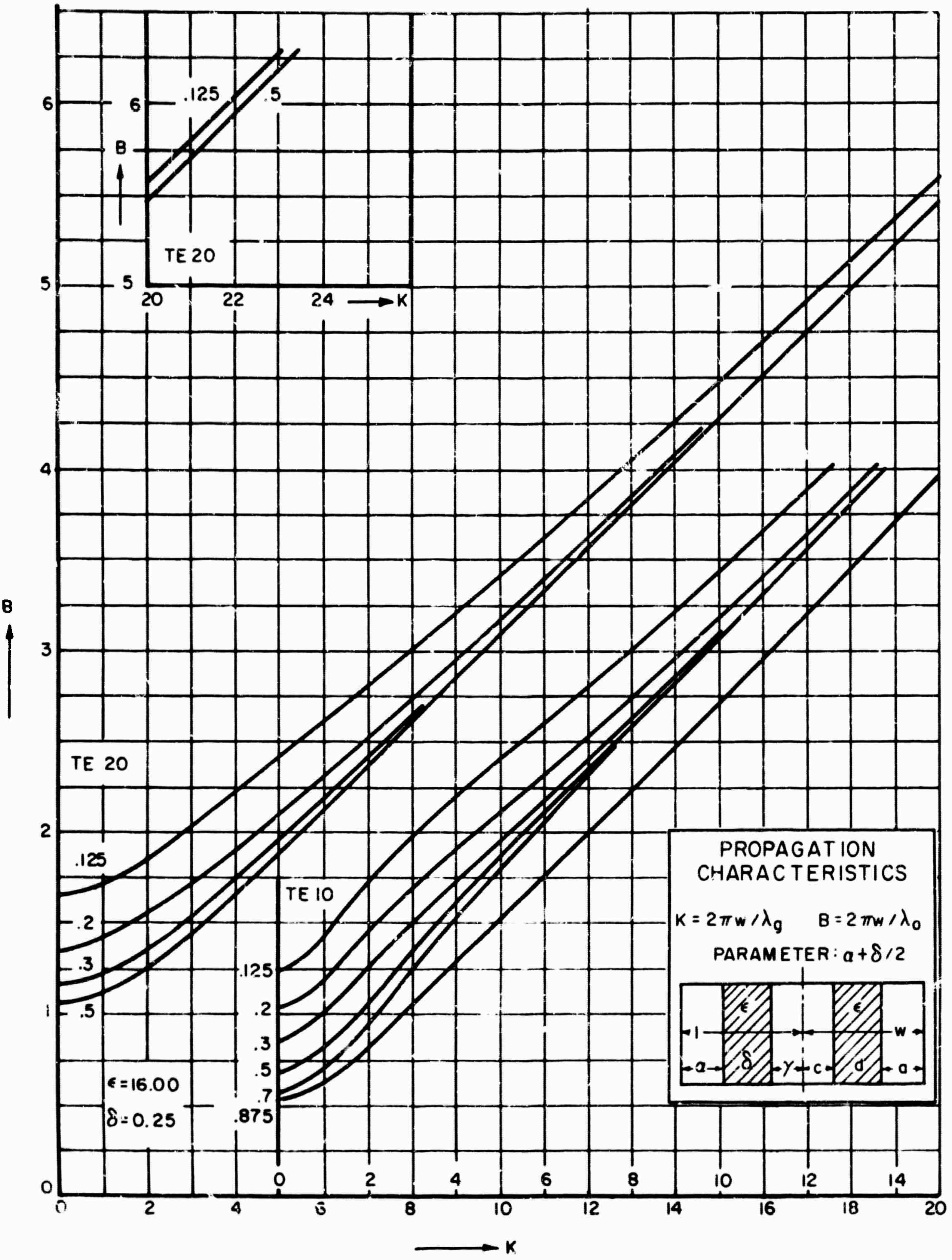

PROPAGATION CHARACTERISTICS
K = 2πw/λg
B = 2πw/λo
PARAMETER: a+δ/2
ε
ε
l
w
a
δ
γ
d
a
ε=12.25
δ= 0.40
.2
.3
.5
.2
.3
.5
.7
.8
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
22
0
2
4
6
8
10
12
14
16
K

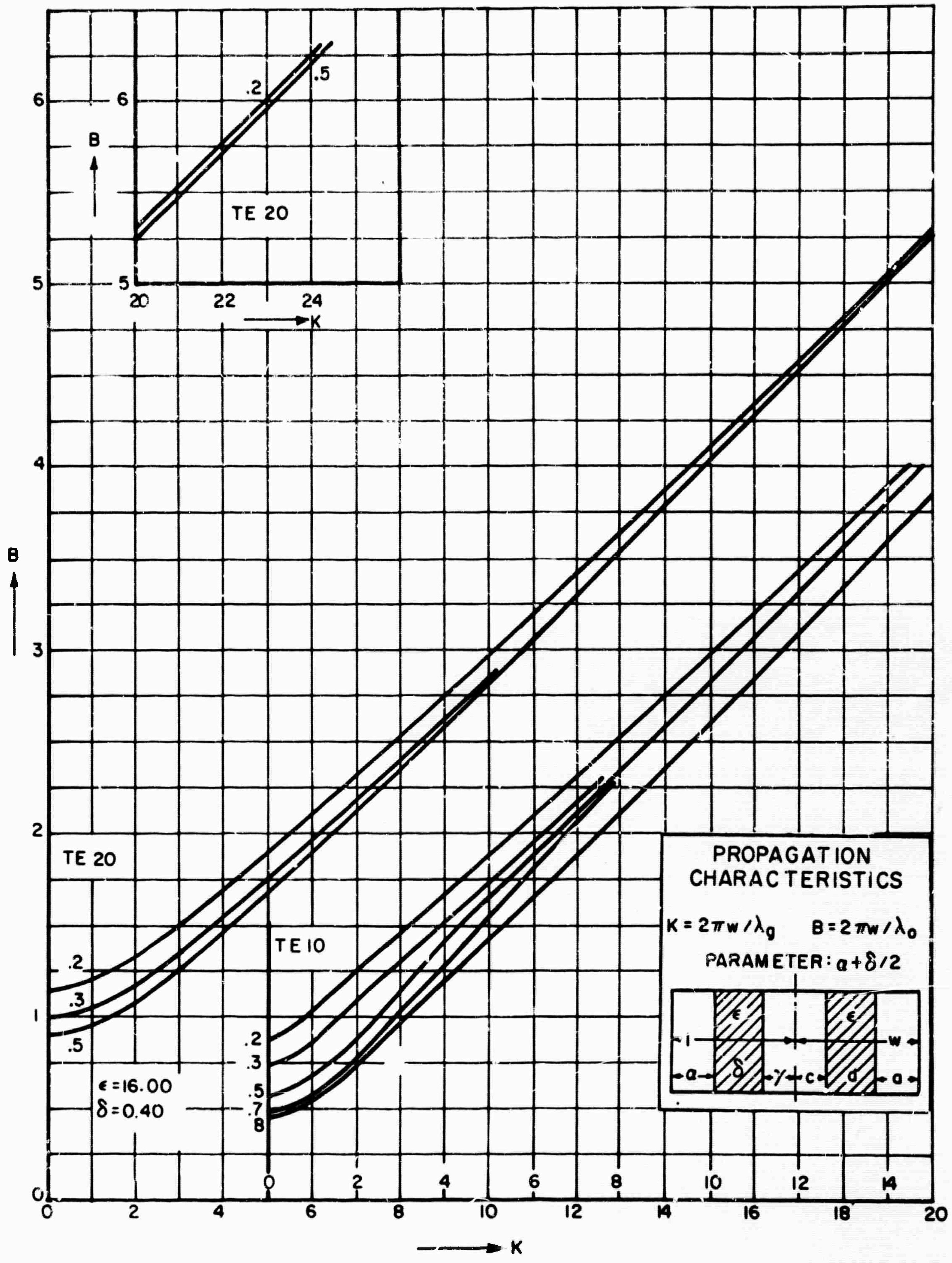

PROPAGATION CHARACTERISTICS
K = 2πw/λg
B = 2πw/λo
PARAMETER: a+δ/2
TE 20
.025
.125
.2
.3
.5
TE10
.025
.25
.2
.3
.5
.7
.975
ε =16.00
δ=0.05
ε
ε
l
w
a
δ
γ
c
d
a
B
0
1
2
3
4
5
6
K
0
2
4
6
8
10
12
14
0
2
4
6
8
10

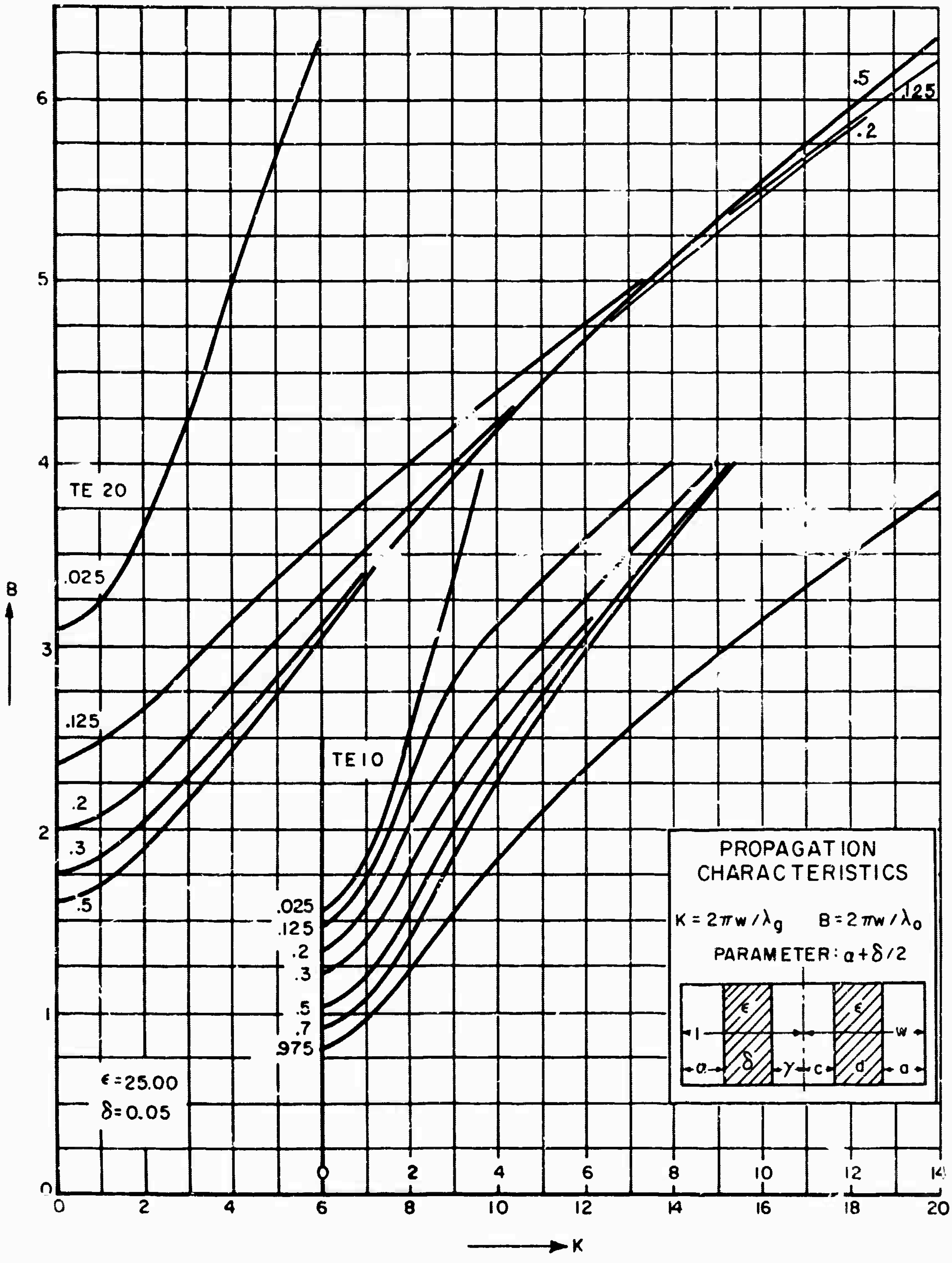

PROPAGATION CHARACTERISTICS
K = 2πw / λg   B = 2πw / λo
PARAMETER: a + δ/2
ε
δ
ε
δ
l
w
a
γ
c
a
TE 20
.05
.125
.2
.3
.5
TE10
.05
.125
.2
.3
.5
.7
.95
ε = 16.00
δ = 0.10
B
B
K
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
14

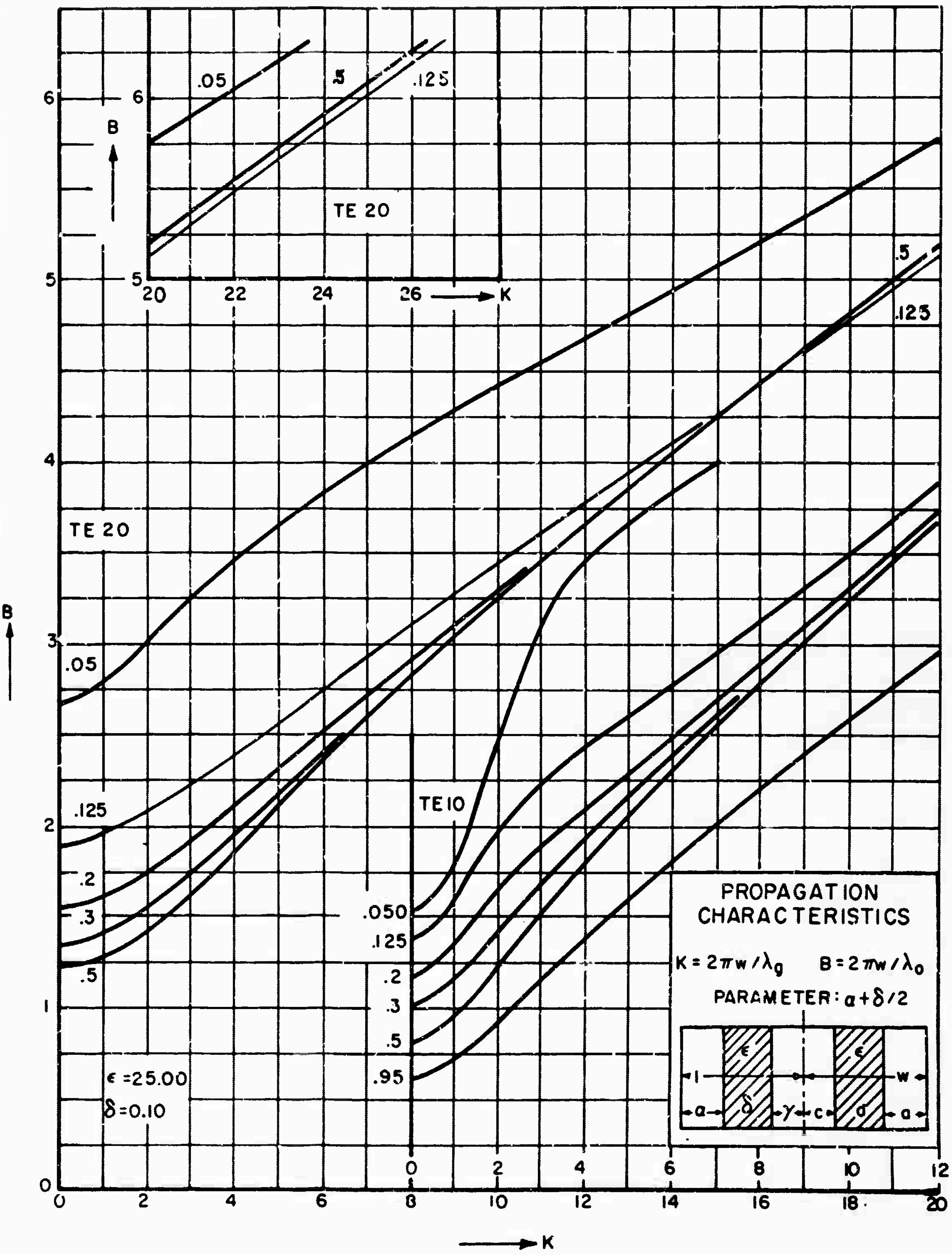


PROPAGATION CHARACTERISTICS
K = 2πw / λg   B = 2πw / λ0
PARAMETER: a + δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE 20
.075
.125
.2
.3
.5
TE10
.075
.2
.3
.5
.7
.925
ε = 16.00
δ = 0.15
B
K
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12

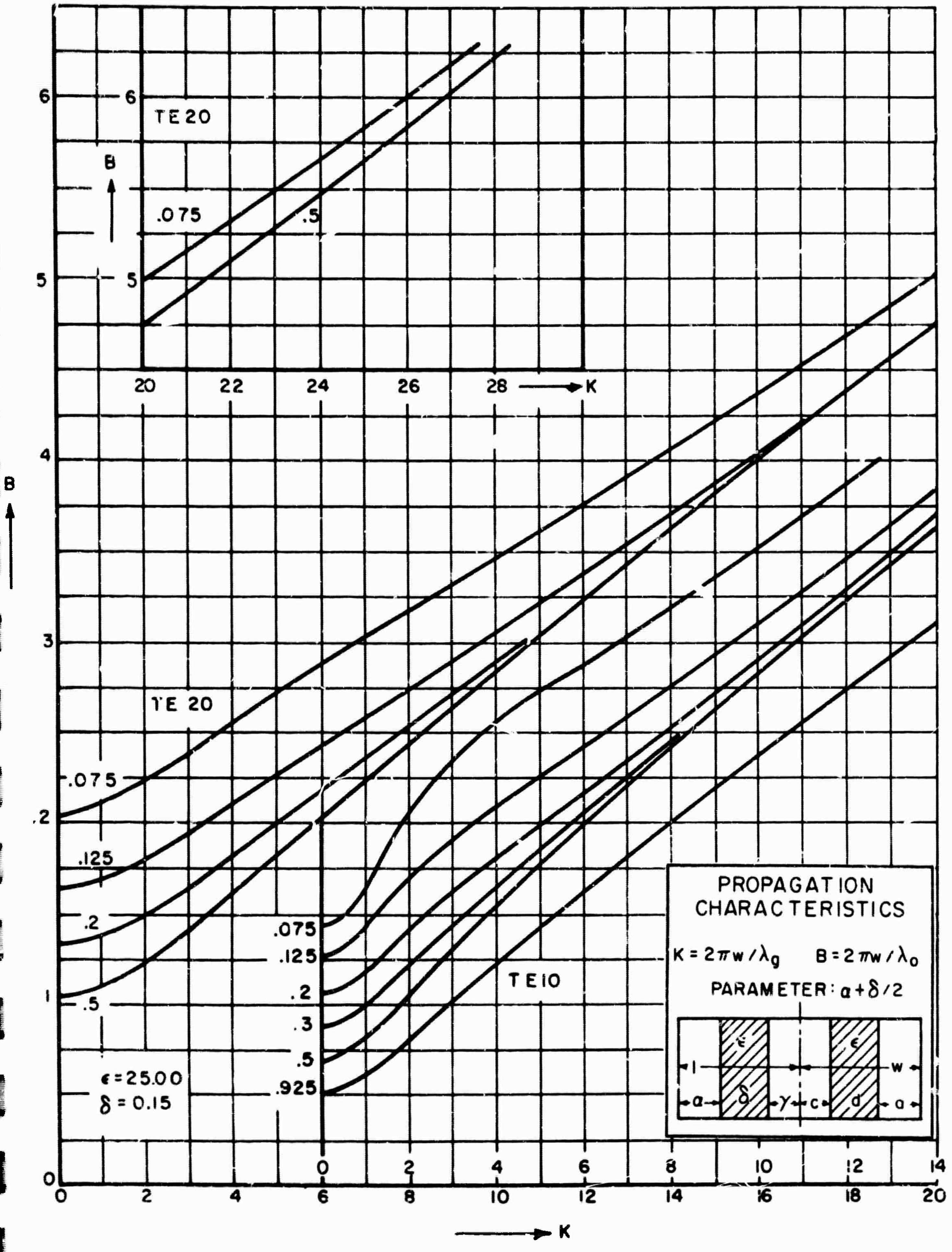

PROPAGATION CHARACTERISTICS
K = 2πw / λ_g
B = 2πw / λ_o
PARAMETER: a + δ/2
ε
ε
δ
l
w
a
γ
c
d
a
TE 20
.125
.2
.3
.5
TE 10
.125
.2
.3
.5
.7
.875
ε = 16.00
δ = 0.25
TE 20
.125
.5
B
6
5
20
22
24
K
B
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
14
K

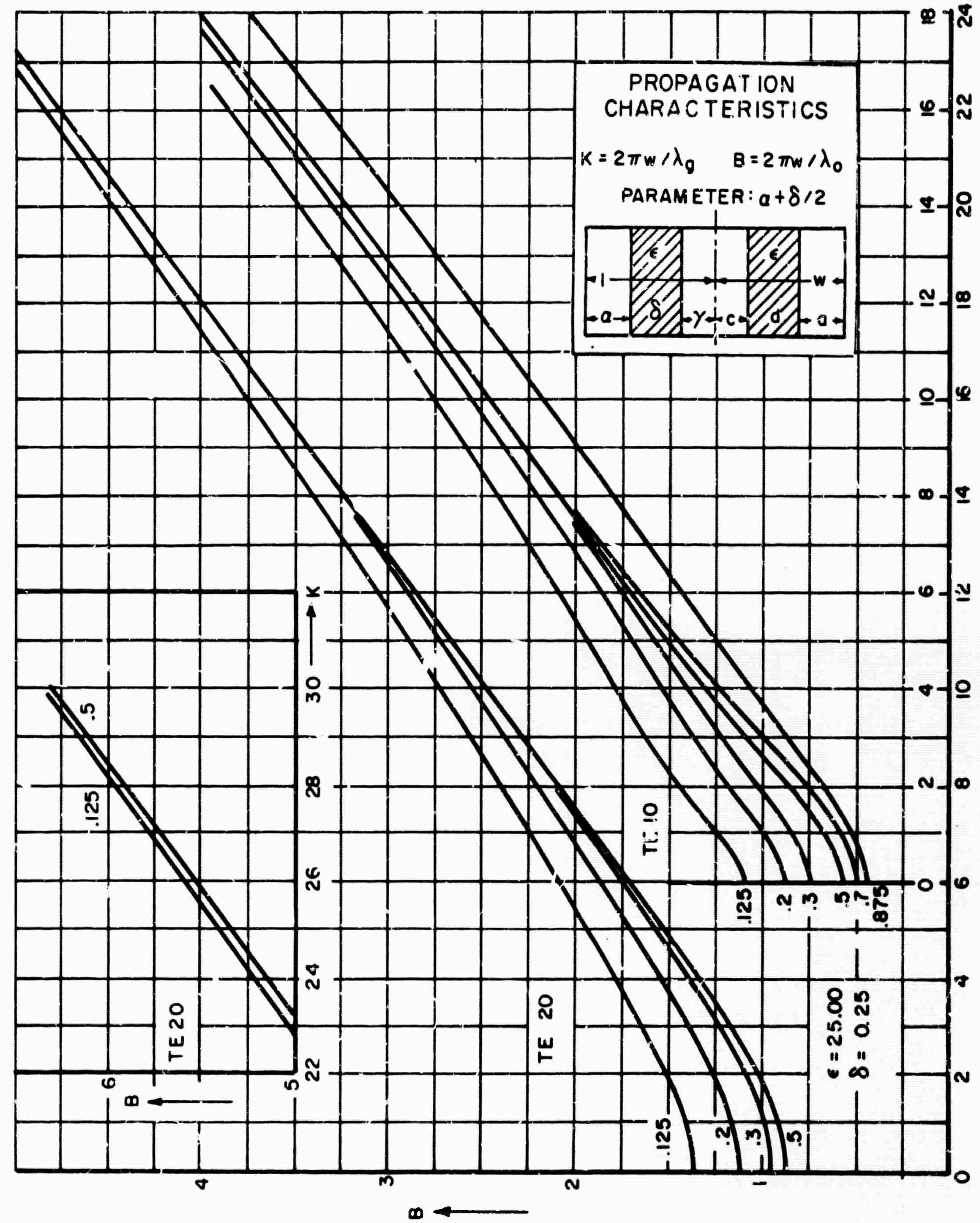

TE 20
B
6
5
20
22
24
K
.2
.5
B
6
5
4
3
2
1
0
TE 20
.2
.3
.5
ε =16.00
δ=0.40
TE 10
.2
.3
.5
.7
8
0
2
4
6
8
10
12
14
0
2
4
6
8
10
12
14
16
18
20
K
PROPAGATION
CHARACTERISTICS
K = 2πw / λg
B = 2πw / λo
PARAMETER: a+δ/2
ε
ε
i
w
a
δ
γ
c
d
a

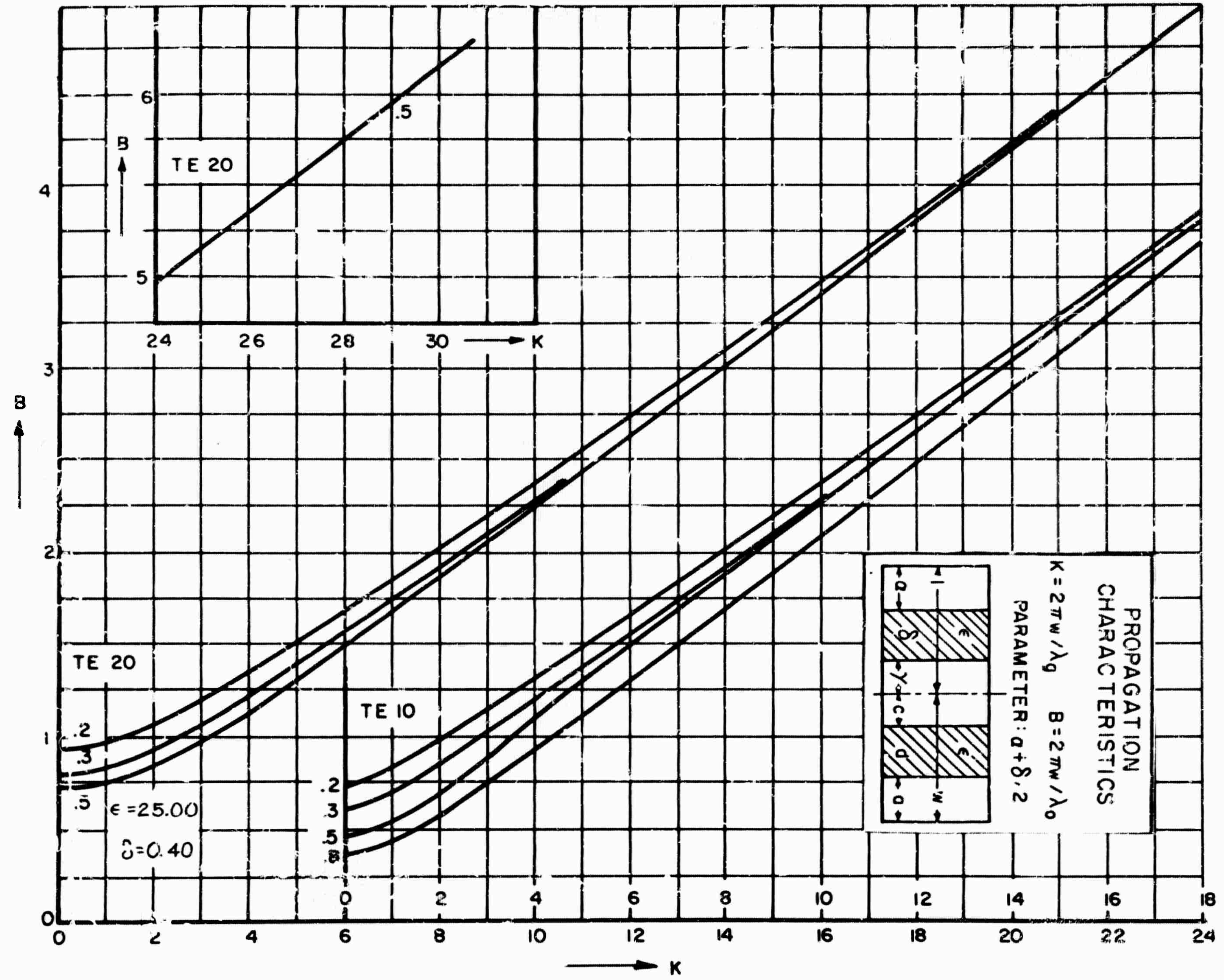

TE 20
.025
.125
.2
.3
.5
TE10
.025
.125
.2
.3
.5
.7
.975
.5
.125
.2
B
K
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
14
ε = 25.00
δ = 0.05
PROPAGATION CHARACTERISTICS
K = 2πw/λg B = 2πw/λ0
PARAMETER: a+δ/2
ε
ε
1
w
a
δ
γ
c
d
a



PROPAGATION CHARACTERISTICS
K = 2πw/λg B = 2πw/λo
PARAMETER: a+δ/2
ϵ
ϵ
l
w
a
δ
γ
c
δ
a
TE 20
TE 10
TE 20
ϵ =25.00
δ=0.10
.05
.125
.2
.3
.5
.050
.125
.2
.3
.5
.95
.5
.125
.05
.5
.125
B
B
K
K
0
1
2
3
4
5
6
0
2
4
6
8
10
12
14
16
18
20
0
2
4
6
8
10
12
5
6
20
22
24
26


PROPAGATION CHARACTERISTICS
K = 2πw/λg
B = 2πw/λo
PARAMETER: α+δ/2
ε
δ
d
l
w
α
γ
c
a
ε = 25.00
δ = 0.15
TE 20
TE10
B
K
.075
.125
.2
.3
.5
.925
0
1
2
3
4
5
6
8
10
12
14
16
18
20
22
24
26
28


PROPAGATION CHARACTERISTICS
K = 2πw/λg   B = 2πw/λ0
PARAMETER: a+δ/2
ε
ε
l
w
a
δ
γ
c
d
a
TE 10
.125
.2
.3
.5
.7
.875
TE 20
.125
.2
.3
.5
ε = 25.00
δ = 0.25
TE 20
.125
.5
B
K
6
5
22
24
26
28
30
0 2 4 6 8 10 12 14 16 18
6 8 10 12 14 16 18 20 22 24
0 2 4 6 8 10 12 14 16 18
1
2
3
4
B
K

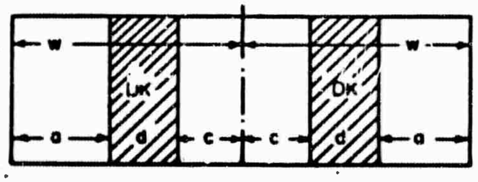


NORMALIZED CUTOFF FREQUENCIES OF A WAVEGUIDE WHICH CONTAINS DIELECTRIC SLABS   DK = 2.25

a+δ/2 N-δ 0.0000 0.0250 0.0500 0.1000 0.1500 0.2000 0.2500 0.3000 0.4000 0.5000 0.6000 0.7000 0.8000 0.9000 1.0000

α+δ/2	N\δ	0.0000	0.0250	0.0500	0.1000	0.1500	0.2000	0.2500	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
δ/2 (α=0)	1	1.5708	1.5708	1.5706	1.5692	1.5653	1.5578	1.5457	1.5282	1.4768	1.4077	1.3299	1.2813	1.1769	1.1087	1.0472
	2	3.1416	3.1414	3.1400	3.1285	3.0972	3.0388	2.9524	2.8457	2.6180	2.4220	2.2762	2.1783	2.1217	2.0981	2.0944
	3	4.7124	4.7117	4.7069	4.6674	4.5630	4.3906	4.1888	4.0037	3.7592	3.6725	3.6647	3.6266	3.5005	3.3231	3.1416
	4	6.2832	6.2816	6.2700	6.1751	5.9462	5.6559	5.4252	5.2939	5.2360	5.1815	4.9298	4.6083	4.3534	4.2156	4.1888
	6	9.4248	9.4192	9.3791	9.0708	8.6215	8.4083	8.3776	8.3475	7.8540	7.3849	7.3266	7.1029	6.6771	6.3817	6.2832
0.0500	1	1.5708	1.5705	1.5701												
	2	3.1416	3.1391	3.1363												
	3	4.7124	4.7040	4.6943												
	4	6.2832	6.2632	6.2398												
	6	9.4248	9.3575	9.2760												
0.1000	1	1.5708	1.5696	1.5683	1.5655	1.5621										
	2	3.1416	3.1320	3.1218	3.0951	3.0719										
	3	4.7124	4.6808	4.6465	4.5703	4.4846										
	4	6.2832	6.2112	6.1322	5.9646	5.8021										
	6	9.4248	9.2188	9.0074	8.6[illegible]10	8.4879										
0.2000	1	1.5708	1.5661	1.5613	1.5514	1.5410	1.5300	1.5181	1.5054							
	2	3.1416	3.1071	3.0718	3.0000	2.9287	2.8698	2.7942	2.7323							
	3	4.7124	4.6145	4.5162	4.3302	4.1707	4.0416	3.9406	3.8830							
	4	6.2832	6.1068	5.9409	5.6574	5.4777	5.3668	5.2863	5.2509							
	6	9.4248	9.1839	8.9[illegible]	8.7707	8.6386	[illegible].5223	8.3776	8.2023							
0.3000	1	1.5708	1.5407	1.5[illegible]05	1.5302	1.5098	1.4896	1.4693	1.4491	1.4092	1.3695					
	2	3.1416	3.0776	3.0149	2.8982	2.7893	2.6953	2.6137	2.5432	2.4297	2.3436					
	3	4.7124	4.5726	4.4432	4.2226	4.0523	3.9250	3.8319	3.7668	3.6919	3.6679					
	4	6.2832	6.1159	5.9719	5.7535	5.6082	5.5096	5.4360	5.3715	5.2360	5.0851					
	6	9.4248	9.3969	9.3684	9.2731	9.0863	8.7700	8.3776	8.0077	7.5214	7.3506					
0.4000	1	1.5708	1.5539	1.5373	1.5050	1.4739	1.4442	1.4169	1.3890	1.3392	1.2939	1.2523	1.2136			
	2	3.1416	3.0550	2.9733	2.8263	2.7012	2.5957	2.5071	2.4328	2.3182	2.2381	2.1828	2.1458			
	3	4.7124	4.5846	4.4690	4.2782	4.1298	4.0202	3.9380	3.8763	3.7846	3.7135	3.6458	3.5761			
	4	6.2832	6.2176	6.1574	6.0624	5.9587	5.8591	5.7376	5.5877	5.2360	4.9049	4.6601	4.4733			
	6	9.4248	9.3226	9.2242	9.0456	8.8605	8.6311	8.3776	8.1639	7.8640	7.5800	7.2274	6.9088			
0.5000	1	1.5708	1.5466	1.5233	1.4790	1.4380	1.4002	1.3663	1.3330	1.2757	1.2261	1.1828	1.1442	1.1093	1.0772	
	2	3.1416	3.0466	2.9584	2.8024	2.6719	2.5632	2.4728	2.3974	2.2824	2.2034	2.1510	2.1188	2.1018	2.0953	
	3	4.7124	4.6402	4.5720	4.4506	4.3497	4.2646	4.1888	4.1167	3.9603	3.7886	3.6177	3.4653	3.3380	3.2328	
	4	6.2832	6.2828	6.27[illegible]9	6.2389	6.1946	6.0776	5.9048	5.6914	5.2360	4.8440	4.5523	4.3565	4.2433	4.1962	
	6	9.4248	9.1451	8.9101	8.5937	8.4398	8.3853	8.3776	8.3700	8.1896	7.7224	7.1813	6.7382	6.4453	6.3071	
0.6000	1	1.5708	1.5395	1.5097	1.4547	1.4063	1.3609	1.3208	1.2845	1.2218	1.1688	1.1240	1.0851	1.0509		
	3	4.7124	4.6982	4.6832	4.6490	4.6047	4.5448	4.4650	4.3641	4.1142	3.845[illegible]	3.5983	3.3904	3.2226		
0.7000	1	1.5708	1.5331	1.4978	1.4337	1.3774	1.3277	1.2836	1.2442	1.1770	1.1218	1.0755				
	3	4.7124	4.7087	4.7041	4.6891	4.6602	4.6106	4.5351	4.4321	4.1627	3.8652	3.5907				
0.8000	1	1.5708	1.5280	1.48[illegible]3	1.4170	1.3562	1.3013	1.2639	1.2120	1.1412						
	3	4.7124	4.6942	4.6211	4.5477	4.4858	4.4274	4.3647	4.2908	4.0948						
1 − δ/2 (γ=0)	1	1.5708	1.5233	1.4792	1.4012	1.3360	1.2816	1.2364	1.1987	1.1412	1.1017	1.0768	1.0594	1.0509	1.0477	1.0472
	3	4.7124	4.5726	4.4561	4.2969	4.2199	4.1926	4.1888	4.1850	4.0948	3.8612	3.5907	3.3691	3.2226	3.1535	3.1416

WAVE GUIDE WIDTH	2w
RELATIVE DIELECTRIC CONSTANT	DK
FREE SPACE PROPAGATION CONSTANT	β
NORMALIZED CUTOFF FREQUENCY	$B = \beta w$
VELOCITY OF LIGHT IN FREE SPACE	v
CUTOFF FREQUENCY	$f = Bv/2\pi w$



$\alpha = a/w$

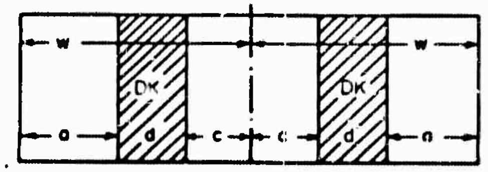
$\delta = d/w$

$\gamma = c/w$

NORMALIZED CUTOFF FREQUENCIES OF A WAVEGUIDE WHICH CONTAINS DIELECTRIC SLABS   DK = 4.00

$\alpha+\delta/2$	$N\backslash\delta$	0.0000	0.0250	0.0500	0.1000	0.1500	0.2000	0.2500	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
$\delta/2$ ($\alpha=0$)	1	1.5708	1.5707	1.5703	1.5669	1.5573	1.5387	1.5087	1.4668	1.3555	1.2310	1.1137	1.0111	0.9235	0.8490	0.7854
	2	3.1416	3.1411	3.1376	3.1084	3.0260	2.8757	2.6801	2.4796	2.1447	1.9106	1.7842	1.6548	1.5981	1.5748	1.5708
	3	4.7124	4.7107	4.6987	4.5921	4.3073	3.9270	3.6031	3.3766	3.1718	3.1416	3.1129	2.9703	2.7587	2.5461	2.3562
	4	6.2832	6.2792	6.2495	5.9775	5.4166	4.9783	4.7748	4.7163	4.6821	4.3726	3.9270	3.5579	3.3026	3.1682	3.1416
	6	9.4248	9.4110	9.2992	8.4608	7.9192	7.8540	7.7919	7.4247	6.4984	6.2632	6.0998	5.5737	5.0953	4.7892	4.7124
0.0500	1	1.5708	1.5701	1.5692												
	2	3.1416	3.1355	3.1285												
	3	4.7124	4.6915	4.6660												
	4	6.2832	6.2322	6.1666												
	6	9.4248	9.2411	8.9887												
0.1000	1	1.5708	1.5679	1.5648	1.5579	1.5494										
	2	3.1416	3.1180	3.0918	3.0315	2.9596										
	3	4.7124	4.6324	4.5392	4.3298	4.1201										
	4	6.2832	6.0970	5.8790	5.4657	5.1710										
	6	9.4248	8.9028	8.4433	7.9923	7.8695										
0.2000	1	1.5708	1.5594	1.5477	1.5233	1.4978	1.4712	1.4437	1.4152							
	2	3.1416	3.0573	2.9696	2.7969	2.6418	2.5090	2.3971	2.3017							
	3	4.7124	4.4747	4.2442	3.8682	3.6095	3.4368	3.3228	3.2481							
	4	6.2832	5.8705	5.5332	5.1108	4.9018	4.7990	4.7490	4.7239							
	6	9.4248	8.9236	8.6538	8.4092	8.2126	7.8540	7.3745	6.9537							
0.3000	1	1.5708	1.5465	1.5221	1.4741	1.4278	1.3839	1.3426	1.3039	1.2337	1.1710					
	2	3.1416	2.9896	2.8468	2.6026	2.4123	2.2649	2.1492	2.0570	1.9205	1.8252					
	3	4.7124	4.3910	4.1268	3.7540	3.5239	3.3792	3.2871	3.2284	3.1682	3.1416					
	4	6.2832	5.9142	5.6552	5.3573	5.2032	5.0946	4.9785	4.8291	4.4692	4.1592					
	6	9.4248	9.3623	9.3026	9.1048	8.6015	7.8540	7.2130	6.7939	6.4358	6.2832					
0.4000	1	1.5708	1.5308	1.4922	1.4206	1.3564	1.2996	1.2492	1.2044	1.1283	1.0657	1.0124	0.9657			
	2	3.1416	2.9410	2.7672	2.4924	2.2913	2.1406	2.0246	1.9336	1.8025	1.7164	1.6594	1.6221			
	3	4.7124	4.4231	4.1948	3.8814	3.6913	3.5693	3.4638	3.4155	3.2859	3.1416	2.9976	2.8710			
	4	6.2832	6.1341	6.0157	5.8481	5.7061	5.5171	5.2468	4.9262	4.3287	3.8942	3.6084	3.4212			
	6	9.4248	9.1838	8.9640	8.6878	8.3244	7.8540	7.4774	7.2509	6.8760	6.2832	5.7248	5.3381			
0.5000	1	1.5708	1.5141	1.4619	1.3699	1.2926	1.2272	1.1714	1.1232	1.0442	0.9818	0.9306	0.8874	0.8497	0.8161	
	2	3.1416	2.9239	2.7404	2.4574	2.2540	2.1027	1.9869	1.8962	1.7664	1.6821	1.6261	1.5954	1.5783	1.5718	
	3	4.7124	4.5446	4.4005	4.1380	4.0392	3.9270	3.8213	3.7047	3.4278	3.1416	2.8560	2.7074	2.5622	2.4497	
	4	6.2832	6.2822	6.2753	6.2169	6.0820	5.7513	5.3602	4.9592	4.2893	3.8213	3.5064	3.3090	3.1961	3.1490	
	6	9.4248	8.8035	8.3878	7.9880	7.5694	7.8540	7.8337	7.7327	7.0972	6.2832	5.6266	5.1629	4.8725	4.7363	
0.6000	1	1.5708	1.4982	1.4330	1.3256	1.2388	1.1678	1.1086	1.0584	0.9779	0.9187	0.8686	0.8244	0.7891		
	3	4.7124	4.6782	4.6430	4.5675	4.4749	4.3476	4.1755	3.9671	3.5252	3.1416	2.8407	2.6109	2.4363		
0.7000	1	1.5708	1.4842	1.4097	1.2887	1.1946	1.1197	1.0582	1.0068	0.9253	0.8633	0.8140				
	3	4.7124	4.7036	4.6933	4.6601	4.5942	4.4746	4.2914	4.0585	3.5636	3.1416	2.8133				
0.8000	1	1.5708	1.4730	1.3905	1.2592	1.1597	1.0814	1.0180	0.9655	0.8832						
	3	4.7124	4.6049	4.5224	4.4067	4.3215	4.2343	4.1191	3.9604	3.5456						
$1-\delta/2$ ($\gamma=0$)	1	1.5708	1.4619	1.3702	1.2287	1.1270	1.0513	0.9934	0.9461	0.8632	0.8411	0.8140	0.7977	0.7891	0.7859	0.7854
	3	4.7124	4.4017	4.1939	3.9940	3.9347	3.9270	3.9194	3.8663	3.5486	3.1416	2.8133	2.5815	2.4363	2.3662	2.3562

WAVE GUIDE WIDTH	2w
RELATIVE DIELECTRIC CONSTANT	DK
FREE SPACE PROPAGATION CONSTANT	β
NORMALIZED CUTOFF FREQUENCY	$B=\beta w$
VELOCITY OF LIGHT IN FREE SPACE	v
CUTOFF FREQUENCY	$f=Bv/2\pi w$



$\alpha = a/w$

$\delta = d/w$

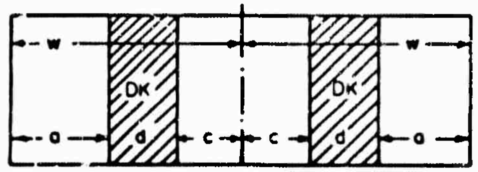
$\gamma = c/w$

NORMALIZED CUTOFF FREQUENCIES OF A WAVEGUIDE WHICH CONTAINS DIELECTRIC SLABS

DK = 12.25

α+δ/2	N\δ	0.0000	0.0250	0.0500	0.1000	0.1500	0.2000	0.2500	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
δ/2 (α=0)	1	1.5708	1.5706	1.5689	1.5551	1.5146	1.4353	1.3235	1.2015	0.9866	0.8264	0.7085	0.6192	0.5497	0.4942	0.4488
	2	3.1416	3.1397	3.1256	2.9832	2.5961	2.1746	1.8845	1.6219	1.3186	1.1377	1.0249	0.9584	0.9165	0.9002	0.8976
	3	4.7124	4.7059	4.6512	4.0459	3.2225	2.7657	2.5581	2.4832	2.4657	2.3501	2.0973	1.8518	1.6482	1.4825	1.3464
	4	6.2832	6.2671	6.1085	4.8132	4.1530	4.0419	4.0338	3.9198	3.2807	2.7271	2.3426	2.0778	1.9043	1.8135	1.7952
	6	9.4248	9.3621	8.5416	7.2048	7.1572	6.5122	5.5765	5.0568	4.9184	4.3739	3.7497	3.2822	2.9491	2.7450	2.6928
0.0500	1	1.5708	1.5679	1.5645												
	2	3.1416	3.1170	3.0847												
	3	4.7124	4.6184	4.4712												
	4	6.2832	6.0202	5.5812												
	6	9.4248	8.3495	7.5340												
0.1000	1	1.5708	1.5594	1.5468	1	1.4803										
	2	3.1415	3.0414	2.9122	2.	.3777										
	3	4.7124	4.3410	3.8956	3.[illegible]	2.9589										
	4	6.2832	5.4329	4.7489	4.2129	4.0725										
	6	9.4248	7.8300	7.4486	7.2764	7 0067										
0.2000	1	1.5708	1.5267	1.4797	1.3840	1.2947	1.2162	1.1481	1.0884							
	2	3.1416	2.8103	2.5025	2.0800	1.8274	1.6613	1.5429	1.4527							
	3	4.7124	3.8697	3.3363	2.8367	2.6312	2.5368	2.4931	2.4750							
	4	6.2832	5.0757	4.6240	4.3515	4.2502	4.1248	3.9091	3.6626							
	6	9.4248	8.3697	8.1746	7.7831	6.4917	5.5413	5.1190	4.98[illegible]2							
0.3000	1	1.5708	1.4798	1.3929	1.2444	1.1303	1.0426	0.9734	0.9172	0.8301	0.7635					
	2	3.1416	2.6191	2.2548	1.8293	1.5916	1.4390	1.3325	1.2539	1.1461	1.0756					
	3	4.7124	3.7558	3.2962	2.9115	2.7615	2.6846	2.6282	2.5673	2.4045	2.2365					
	4	6.2832	5.3361	5.0348	4.8285	4.6457	4.2582	3.7732	3.3677	2.8306	2.5286					
	6	9.4248	9.2503	9.1303	8.0906	6.4698	5.7361	5.5079	5.3415	4.6663	4.0849					
0.4000	1	1.5708	1.4284	1.3094	1.1327	1.0115	0.9236	0.8566	0.8037	0.7242	0.6661	0.6204	0.5826			
	2	3.1416	2.5106	2.1322	1.7144	1.4859	1.3399	1.2382	1.1635	1.0623	0.9994	0.9590	0.9330			
	3	4.7124	3.8826	3.5067	3.1988	3.0696	2.9745	2.8564	2.6968	2.3453	2.06[illegible]5	1.8792	1.7478			
	4	6.2832	5.8560	5.6738	5.4664	5.0313	4.3293	3.7222	3.2687	2.6755	2.3252	2.1137	1.9848			
	6	9.4248	8.7035	8.4228	7.7583	6.7402	6.3707	6.1309	5.6500	4.5868	3.8620	3.3984	3.1156			
0.5000	1	1.5708	1.3796	1.2380	1.0472	0.9248	0.8388	0.7745	0.7242	0.6498	0.5965	0.5555	0.5225	0.4947	0.4704	
	2	3.1416	2.4761	2.0951	1.6805	1.4549	1.3109	1.2107	1.1370	1.0375	[illegible]	0.9376	0.9148	0.9028	0.8983	
	3	4.7124	4.1888	3.9116	3.6635	3.5203	3.3389	3.0785	2.7919	2.3135	1.98[illegible]	1.7609	1.6051	1.4944	1.4125	
	4	6.2832	6.2795	6.2512	5.9664	5.1922	4.3490	3.7091	3.2437	2.6372	2.2755	2.0499	1.9108	1.8329	1.8004	
	6	9.4248	7.8299	7.3772	7.1863	7.1752	7.0150	6.4598	5.7322	4.5705	3.8185	3.3248	3.0005	2.8024	2.7094	
0.6000	1	1.5708	1.3367	1.1793	0.9810	0.8593	0.7755	0.7135	0.6655	0.5949	0.5447	0.5067	0.4765	0.4514		
	3	4.7124	4.5861	4.4786	4.3052	4.0555	3.6583	3.2197	2.8436	2.2971	1.9407	1.6979	1.5260	1.4012		
0.7000	1	1.5708	1.3008	1.1320	0.9291	0.8083	0.7264	0.6664	0.6201	0.5525	0.5048	0.4588				
	3	4.7124	4.6821	4.6523	4.5511	4.2718	3.7777	3.2764	2.8664	2.2887	1.9167	1.6624				
0.8000	1	1.5708	1.2723	1.0943	0.8876	0.7676	0.6873	0.6289	0.5840	0.5187						
	3	4.7124	4.4143	4.2831	4.1558	4.0129	3.7049	3.2707	2.8703	2.2852						
1−δ/2 (γ=0)	1	1.5708	1.2380	1.0476	0.8403	0.7274	0.6555	0.6053	0.5685	0.5187	0.4880	0.4688	0.4574	0.4514	0.4491	0.4488
	3	4.7124	3.3149	3.6886	3.5932	3.5876	3.5075	3.2299	2.8661	2.2852	1.9093	1.6624	1.5003	1.4012	1.3547	1.3464

WAVE GUIDE WIDTH	2w
RELATIVE DIELECTRIC CONSTANT	DK
FREE SPACE PROPAGATION CONSTANT	β
NORMALIZED CUTOFF FREQUENCY	$B = \beta w$
VELOCITY OF LIGHT IN FREE SPACE	v
CUTOFF FREQUENCY	$f = Bv/2\pi w$



$\alpha = a/w$

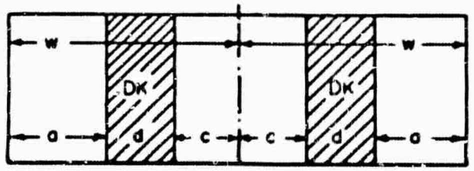
$\delta = d/w$

$\gamma = c/w$

NORMALIZED CUTOFF FREQUENCIES OF A WAVEGUIDE WHICH CONTAINS DIELECTRIC SLABS DK = 9.00

$\alpha+\delta/2$	$n\backslash\delta$	0.0000	0.0250	0.0500	0.1000	0.1500	0.2000	0.2500	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
$\delta/2$ ($\alpha=0$)	1	1.5708	1.5706	1.5695	1.5599	1.5324	1.4782	1.3963	1.2970	1.0984	0.9359	0.8107	0.7136	0.6367	0.5747	0.5236
	2	3.1416	3.1403	3.1306	3.0391	2.7737	2.4111	2.0944	1.8499	1.5196	1.3181	1.1912	1.1126	1.0685	1.0501	1.0472
	3	4.7124	4.7079	4.6719	4.2896	3.5702	3.0661	2.7925	2.6671	2.6180	2.5738	2.3766	2.1285	1.9081	1.7239	1.5708
	4	6.2832	6.2721	6.1745	5.2360	4.4397	4.2147	4.1888	4.1638	3.7164	3.1416	2.7146	2.4155	2.2183	2.1152	2.0944
	6	9.4248	9.3837	8.9186	7.4328	7.3300	7.1013	6.2832	5.5988	5.2360	4.9651	4.3330	3.8117	3.4334	3.2008	3.1416
0.0500	1	1.5708	1.5688	1.5665												
	2	3.1416	3.1247	3.1035												
	3	4.7124	4.6503	4.5617												
	4	6.2832	6.1185	5.9558												
	6	9.4248	8.7456	7.9754												
0.1000	1	1.5708	1.5628	1.5542	1.5341	1.5092										
	2	3.1416	3.0737	2.9903	2.7943	2.5950										
	3	4.7124	4.4673	4.1575	3.6261	3.2882										
	4	6.2832	5.7039	5.1209	4.5075	4.2892										
	6	9.4248	8.1333	7.6372	7.4138	7.3120										
0.2000	1	1.5708	1.5398	1.5071	1.4393	1.3721	1.3086	1.2499	1.1958							
	2	3.1416	2.9085	2.6758	2.3077	2.0610	1.8900	1.7643	1.6668							
	3	4.7124	4.0896	3.6182	3.0912	2.8805	2.7245	2.6601	2.6301							
	4	6.2832	5.3256	4.8468	4.4979	4.3795	4.2989	4.1888	4.0363							
	6	9.4248	8.5071	8.2737	8.0099	7.1717	6.1872	5.6036	5.3361							
0.3000	1	1.5708	1.5059	1.4424	1.3267	1.2297	1.1500	1.0840	1.0286	0.9397	0.8696					
	2	3.1416	2.7549	2.4505	2.0508	1.8089	1.6476	1.5327	1.4467	1.3273	1.2483					
	3	4.7124	3.9666	3.5313	3.1073	2.9214	2.8256	2.7669	2.7203	2.6180	2.4967					
	4	6.2832	5.5074	5.1836	4.9396	4.7959	4.5587	4.1888	3.8102	3.2523	2.9224					
	6	9.4248	9.2863	9.1842	8.5597	7.1421	6.2063	5.8165	5.6559	5.2360	4.6900					
0.4000	1	1.5708	1.4673	1.3756	1.2274	1.1167	1.0319	0.9650	0.9107	0.8271	0.7646	0.7148	0.6731			
	2	3.1416	2.6609	2.3317	1.9291	1.6932	1.5376	1.4272	1.3451	1.2328	1.1622	1.1167	1.0873			
	3	4.7124	4.0589	3.6981	3.3561	3.2031	3.1075	3.0161	2.9028	2.6180	2.3541	2.1577	2.0170			
	4	6.2832	5.9458	5.7664	5.5693	5.2848	4.7572	4.1888	3.7223	3.0817	2.6941	2.4555	2.3097			
	6	9.4248	8.8561	8.5693	8.0890	7.2111	6.6847	6.4664	6.1835	5.2360	4.4574	3.9413	3.6225			
0.5000	1	1.5708	1.4291	1.3150	1.1471	1.0305	0.9448	0.8787	0.8260	0.7464	0.6882	0.6431	0.6063	0.5752	0.5480	
	2	3.1416	2.6302	2.2949	1.8928	1.6591	1.5083	1.3963	1.3152	1.2046	1.1357	1.0924	1.0666	1.0531	1.0480	
	3	4.7124	4.3109	4.0555	3.7915	3.6465	3.5033	3.3100	3.0738	2.6180	2.2749	2.0323	1.8605	1.7372	1.6453	
	4	6.2832	6.2806	6.2611	6.0783	5.5474	4.8223	4.1888	3.6997	3.0391	2.6362	2.3825	2.2252	2.1371	2.1003	
	6	9.4248	8.1162	7.6206	7.3522	7.3303	7.2785	6.9813	6.4061	5.2360	4.4113	3.8575	3.4907	3.2658	3.1603	
0.6000	1	1.5708	1.3945	1.2636	1.0832	0.9641	0.8787	0.8139	0.7627	0.6862	0.6310	0.5837	0.5548	0.5266		
	3	4.7124	4.6217	4.5373	4.3888	4.1999	3.9025	3.5347	3.1791	2.6180	2.2334	1.9653	1.7733	1.6329		
0.7000	1	1.5708	1.3651	1.2213	1.0324	0.9119	0.8271	0.7634	0.7135	0.6395	0.5865	0.5462				
	3	4.7124	4.6902	4.5668	4.5913	4.4082	4.0582	3.6217	3.2226	2.6180	2.2117	1.9288				
0.8000	1	1.5708	1.3418	1.1877	0.9919	0.8703	0.7860	0.7232	0.6743	0.6023						
	3	4.7124	4.4767	4.3455	4.2180	4.1060	3.9085	3.5844	3.2200	2.6180						
$1-\delta/2$ ($\gamma=0$)	1	1.5708	1.3151	1.1475	0.9464	0.8296	0.7527	0.6981	0.6576	0.6023	0.5678	0.5462	0.5333	0.5266	0.5240	0.5236
	3	4.7124	4.0581	3.6103	3.6761	3.6651	3.6393	3.4907	3.2030	2.6180	2.2057	1.9288	1.7453	1.6329	1.3802	1.5708

WAVE GUIDE WIDTH	$2w$
RELATIVE DIELECTRIC CONSTANT	DK
FREE SPACE PROPAGATION CONSTANT	β
NORMALIZED CUTOFF FREQUENCY	$B=\beta w$
VELOCITY OF LIGHT IN FREE SPACE	v
CUTOFF FREQUENCY	$f=Bv/2\pi w$



$\alpha = a/w$

$\delta = d/w$

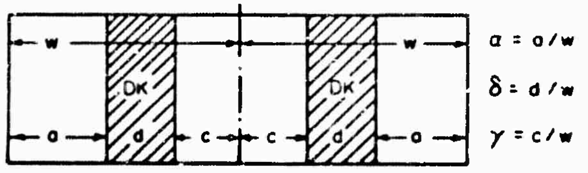
$\gamma = c/w$

NORMALIZED CUTOFF FREQUENCIES OF A WAVEGUIDE WHICH CONTAINS DIELECTRIC SLABS DK = 16.00

NORMALIZED CUTOFF FREQUENCIES OF A WAVEGUIDE WHICH CONTAINS DIELECTRIC SLABS DK = 16.00

$\alpha+\delta/2$	N\δ	0.0000	0.0250	0.0500	0.1000	0.1500	0.2000	0.2500	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
$\delta/2$ ($\alpha=0$)	1	1.5708	1.5705	1.5683	1.5492	1.4922	1.3839	1.2450	1.1085	0.8900	0.7373	0.6278	0.5462	0.4833	0.4333	0.3927
	2	3.1416	3.1391	3.1195	2.9077	2.4055	1.9635	1.6559	1.4395	1.1629	1.0000	0.8990	0.8369	0.8022	0.7877	0.7854
	3	4.7124	4.7036	4.6234	3.7679	2.9311	2.5431	2.3966	2.3586	2.3370	2.1416	4686	1.6356	1.4494	1.2999	1.1781
	4	6.2832	6.2609	6.0096	4.4518	3.9702	3.9270	3.8866	3.6338	2.9169	2.4043	2.0584	1.8222	1.6679	1.5871	1.5708
	6	9.4248	9.3326	8.0794	7.0711	6.9368	5.8905	5.0382	4.7323	4.5732	3.8789	3.2992	2.8801	2.5839	2.4026	2.3562
0.0500	1	1.5708	1.5670	1.5624												
	2	3.1416	3.1076	3.0602												
	3	4.7124	4.5755	4.3427												
	4	6.2832	5.8798	5.2476												
	6	9.4248	7.9353	7.2463												
0.1000	1	1.5708	1.5554	1.5379	1.4960	1.4446										
	2	3.1416	3.0007	2.8132	2.4425	2.1691										
	3	4.7124	4.1839	3.6223	2.9923	2.7003										
	4	6.2832	5.1442	4.4444	4.0215	3.9368										
	6	9.4248	7.6137	7.3328	7.1485	6.5444										
0.2000	1	1.5708	1.5112	1.4474	1.3219	1.2138	1.1253	1.0525	0.9911							
	2	3.1416	2.6994	2.3282	1.8805	1.6338	1.4771	1.3673	1.2846							
	3	4.7124	3.6516	3.0958	2.6440	2.4797	2.4100	2.3786	2.3633							
	4	6.2832	4.8633	4.4664	4.2643	4.1448	3.9270	3.5961	3.3029							
	6	9.4248	8.2687	8.1036	7.4405	5.8838	5.0897	4.8362	4.7571							
0.3000	1	1.5708	1.4500	1.3387	1.1624	1.0381	0.9475	0.8785	0.8238	0.7409	0.6736					
	2	3.1416	2.4793	2.0739	1.6436	1.4166	1.2745	1.1766	1.1061	1.0076	0.9444					
	3	4.7124	3.5607	3.1061	2.7718	2.6512	2.5838	2.5178	2.4289	2.2026	2.0105					
	4	6.2832	5.1939	4.9269	4.7448	4.4782	3.9270	3.3959	2.9996	2.[illegible]996	2.2254					
	6	9.4248	9.2174	9.0757	7.5380	5.9475	5.4519	5.2865	5.0005	4.1618	3.6056					
0.4000	1	1.5708	1.3860	1.2417	1.0448	0.9193	0.8320	0.7673	0.7169	0.6426	0.5890	0.5474	0.5130			
	2	3.1416	2.3620	1.9532	1.5372	1.3205	1.1851	1.0920	1.0241	0.9328	0.8763	0.8402	0.8170			
	3	4.7124	3.7214	3.3534	3.0854	2.9723	2.8646	2.7036	2.4963	2.1098	1.8397	1.6610	1.5400			
	4	6.2832	5.7753	5.6005	5.3669	4.7294	3.9270	3.3289	2.9032	2.3601	2.0449	1.6545	1.7395			
	6	9.4248	8.5724	8.3064	7.3779	6.4040	6.1438	5.7555	5.1148	4.0637	3.4015	2.9847	2.7319			
0.5000	1	1.5708	1.3275	1.1627	0.9582	0.8351	0.7516	0.6904	0.6433	0.574[illegible]	0.5267	0.4886	0.4588	0.4338	0.4121	
	2	3.1416	2.3256	1.9171	1.5059	1.2925	1.1591	1.0674	1.0005	0.9106	0.8555	0.8212	0.8007	0.7901	0.7860	
	3	4.7124	4.0723	3.7922	3.5665	3.4147	3.1754	2.8504	2.5367	2.0641	1.7568	1.5516	1.4104	1.3107	1.2372	
	4	6.2832	6.2782	6.2390	5.8154	4.8109	3.9270	3.3118	2.8789	2.3257	2.0000	1.7980	1.6738	1.6044	1.5754	
	6	9.4248	7.5925	7.1986	7.0692	7.0408	6.6949	5.9108	5.1394	4.0435	3.3618	2.9194	2.6302	2.4538	2.3710	
0.6000	1	1.5708	1.2775	1.0996	0.8924	0.7723	0.6921	0.6339	0.5892	0.5244	0.4789	0.4446	0.4174	0.3950		
	3	4.7124	4.5471	4.4210	4.2273	3.8994	3.4022	2.9317	2.5575	2.0405	1.7133	1.4932	1.3386	1.2269		
0.7000	1	1.5708	1.2364	1.0494	0.8411	0.7236	0.6461	0.5902	0.5476	0.4859	0.4429	0.4106				
	3	4.7124	4.6735	4.6377	4.5048	4.0980	3.4897	2.9659	2.5672	2.0279	1.6888	1.4597				
0.8000	1	1.5708	1.2036	1.0094	0.8002	0.6848	0.6095	0.5555	0.5144	0.4553						
	3	4.7124	4.3584	4.2290	4.1051	3.9075	3.4648	2.9697	2.5702	2.0217						
$1-\delta/2$ ($\gamma=0$)	1	1.5708	1.1628	0.9586	0.7530	0.6462	0.5796	0.5337	0.5002	0.4553	0.4277	0.4106	0.4004	0.3950	0.3930	0.3927
	3	4.7124	3.7962	3.5993	3.5346	3.5204	3.3474	2.9554	2.5697	2.0217	1.6809	1.4597	1.3151	1.2269	1.1855	1.1781

WAVE GUIDE WIDTH	2w
RELATIVE DIELECTRIC CONSTANT	DK
FREE SPACE PROPAGATION CONSTANT	β
NORMALIZED CUTOFF FREQUENCY	$B=\beta w$
VELOCITY OF LIGHT IN FREE SPACE	v
CUTOFF FREQUENCY	$f=Bv/2\pi w$

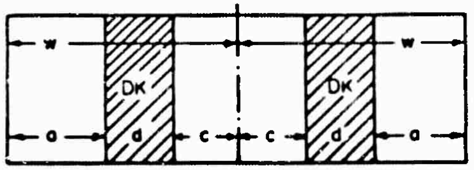


NORMALIZED CUTOFF FREQUENCIES OF A WAVEGUIDE WHICH CONTAINS DIELECTRIC SLABS

DK = 25.00

$\alpha+\delta/2$	N\δ	0.0000	0.0250	0.0500	0.1000	0.1500	0.2000	0.2500	0.3000	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000
$\delta/2$ ($\alpha=0$)	1	1.5708	1.5703	1.5667	1.5338	1.4321	1.2625	1.0888	0.9443	0.7381	0.6035	0.5096	0.4412	0.3888	0.3475	0.3142
	2	3.1416	3.1375	3.1030	2.6921	2.0485	1.6261	1.3552	1.1704	0.9388	0.8042	0.7213	0.6704	0.6421	0.6302	0.6283
	3	4.7124	4.6975	4.5347	3.2352	2.5064	2.2607	2.2031	2.1989	2.0847	1.7874	1.5245	1.3225	1.1662	1.0425	0.9425
	4	6.2832	6.2438	5.6606	3.9666	3.7719	3.7529	3.4994	3.0568	2.3711	1.9395	1.6546	1.4616	1.3359	1.2700	1.2566
	6	9.4248	9.2313	7.3029	6.9095	6.1368	4.9095	4.4315	4.3962	3.8381	3.1416	2.6550	2.3115	2.0703	1.9229	1.8650
0.0500	1	1.5708	1.5645	1.5568												
	2	3.1416	3.0818	2.9872												
	3	4.7124	4.4418	3.9692												
	4	6.2832	5.4560	4.5916												
	6	9.4248	7.3190	6.9656												
0.1000	1	1.5708	1.5453	1.5147	1.4396	1.3530										
	2	3.1416	2.8890	2.5637	2.0913	1.8160										
	3	4.7124	3.8068	3.1284	2.5604	2.3504										
	4	6.2632	4.6186	4.0462	3.8142	3.7767										
	6	9.4248	7.3637	7.2019	6.7200	5.5174										
0.2000	1	1.5708	1.4730	1.3693	1.1889	1.0579	0.9626	0.8897	0.8310							
	2	3.1416	2.4567	2.0085	1.5626	1.3398	1.2035	1.1099	1.0403							
	3	4.7124	3.2583	2.7353	2.3988	2.2972	2.2538	2.2234	2.1880							
	4	6.2832	4.5548	4.2752	4.1291	3.9129	3.4347	3.0078	2.7158							
	6	9.4248	8.1379	8.0001	6.4906	5.0187	4.6302	4.5211	4.3274							
0.3000	1	1.5708	1.3310	1.2235	1.0113	0.8812	0.7933	0.7292	0.6797	0.6067	0.5530					
	2	3.1416	2.2074	1.7662	1.3573	1.1564	1.0342	0.9514	0.8915	0.8106	0.7585					
	3	4.7124	3.2337	2.8363	2.5962	2.5111	2.4352	2.3144	2.1505	1.8503	1.6548					
	4	6.2832	4.9869	4.7882	4.6046	4.0324	3.3059	2.7950	2.4461	2.0200	1.7919					
	6	9.4248	9.1625	8.9391	6.4809	5.3413	5.1330	4.7991	4.2397	3.3874	2.9100					
0.4000	1	1.5708	1.2943	1.1101	0.8940	0.7707	0.6896	0.6313	0.5869	0.5226	0.4772	0.4421	0.4134			
	2	3.1416	2.0856	1.6560	1.2666	1.0762	0.9603	0.8818	0.8250	0.7493	0.7028	0.6731	0.6542			
	3	4.7124	3.4548	3.1365	2.9379	2.8308	2.6557	2.3910	2.1281	1.7400	1.4981	1.3442	1.2420			
	4	6.2832	5.6454	5.4953	5.1213	4.0838	3.2631	2.7276	2.3617	1.9055	1.6447	1.4883	1.3942			
	6	9.4248	8.3760	8.1203	6.6201	6.0265	5.6827	4.9114	4.2189	3.2939	2.7410	2.3978	2.1909			
0.5000	1	1.5708	1.2209	1.0243	0.8114	0.6946	0.6189	0.5649	0.5240	0.4652	0.4242	0.3932	0.3685	0.3479	0.3300	
	2	3.1416	2.0488	1.6235	1.2402	1.0529	0.9389	0.8615	0.8057	0.7312	0.6858	0.6576	0.6409	0.6321	0.6288	
	3	4.7124	3.8702	3.6163	3.4289	3.2173	2.8316	2.4335	2.1172	1.6885	1.4243	1.2515	1.1339	1.0514	0.9910	
	4	6.2832	6.2750	6.2060	5.3842	4.0970	3.2522	2.7104	2.3407	1.8775	1.6083	1.4425	1.3409	1.2841	1.2604	
	6	9.4248	7.2444	6.9653	6.9110	6.7411	5.8889	4.9347	4.2144	3.2743	2.7084	2.3450	2.1086	1.9647	1.8971	
0.6000	1	1.5708	1.1611	0.9584	0.7800	0.6386	0.5671	0.5164	0.4781	0.4233	0.3853	0.3569	0.3345	0.3161		
	3	4.7124	4.4641	4.3183	4.0778	3.5456	2.9267	2.4547	2.1117	1.6613	1.3850	1.2017	1.0741	0.9824		
0.7000	1	1.5708	1.1130	0.9067	0.7024	0.5954	0.5273	0.4791	0.4429	0.3912	0.3554	0.3288				
	3	4.7124	4.6554	4.6093	4.3792	3.6709	2.9653	2.4646	2.1088	1.6459	1.3620	1.1725				
0.8000	1	1.5708	1.0747	0.8655	0.6645	0.5609	0.4955	0.4494	0.4148	0.3656						
	3	4.7124	4.2662	4.1499	4.0171	3.6135	2.9696	2.4661	2.1074	1.6371						
$1-\delta/2$ ($\gamma=0$)	1	1.5708	1.0244	0.8118	0.6201	0.5264	0.4694	0.4308	0.4028	0.3656	0.3429	0.3288	0.3204	0.3161	0.3144	0.3142
	3	4.7124	3.6222	3.4827	3.4555	3.3705	2.9444	2.4674	2.1072	1.6371	1.3842	1.1725	1.0543	0.9824	0.9485	0.9425

WAVE GUIDE WIDTH	2w
RELATIVE DIELECTRIC CONSTANT	DK
FREE SPACE PROPAGATION CONSTANT	β
NORMALIZED CUTOFF FREQUENCY	$B=\beta w$
VELOCITY OF LIGHT IN FREE SPACE	v
CUTOFF FREQUENCY	$f=Bv/2\pi w$



$\alpha = a/w$

$\delta = d/w$

$\gamma = c/w$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 2.25 DELTA = 0.05

$\alpha+\delta/2$	0.025	0.025	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.975
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.57059	3.12997	1.56697	3.11146	1.56129	3.07183	1.55051	3.01490	1.53734	2.97328	1.52329	2.95838	1.49777	1.47919
B														
1.5	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.08583	0.26477
1.6	0.30539	-0.00000	0.32421	-0.00000	0.35200	-0.00000	0.40015	-0.00000	0.45321	-0.00000	0.50498	-0.00000	0.59041	0.64869
1.7	0.65065	-0.00000	0.66087	-0.00000	0.67678	-0.00000	0.70643	-0.00000	0.74180	-0.00000	0.77865	-0.00000	0.84373	0.89130
1.8	0.87945	-0.00000	0.88797	-0.00000	0.90135	-0.00000	0.92658	-0.00000	0.95714	-0.00000	0.98942	-0.00000	1.04761	1.09134
1.9	1.06936	-0.00000	1.07720	-0.00000	1.08955	-0.00000	1.11296	-0.00000	1.14147	-0.00000	1.17176	-0.00000	1.22669	1.26912
2.0	1.23840	-0.00000	1.24592	-0.00000	1.25780	-0.00000	1.28040	-0.00000	1.30799	-0.00000	1.33735	-0.00000	1.39082	1.43297
2.1	1.39418	-0.00000	1.40157	-0.00000	1.41327	-0.00000	1.43555	-0.00000	1.46278	-0.00000	1.4[illegible]178	-0.00000	1.54471	1.58724
2.2	1.54073	-0.00000	1.54809	-0.00000	1.55976	-0.00000	1.58203	-0.00000	1.60924	-0.00000	1.6[illegible]822	-0.00000	1.69116	1.73450
2.3	1.68047	-0.00000	1.68785	-0.00000	1.69962	-0.00000	1.72206	-0.00000	1.74948	-0.00000	1.77866	-0.00000	1.83197	1.87643
2.4	1.81496	-0.00000	1.82244	-0.00000	1.83435	-0.00000	1.85710	-0.00000	1.88488	-0.00000	1.91440	-0.00000	1.96834	2.01417
2.5	1.94531	-0.00000	1.95290	-0.00000	1.96502	-0.00000	1.98818	-0.00000	2.01643	-0.00000	2.04640	-0.00000	2.10114	2.14856
2.6	2.07226	-0.00000	2.08001	-0.00000	2.09238	-0.00000	2.11603	-0.00000	2.14485	-0.00000	2.17535	-0.00000	2.23103	2.28020
2.7	2.19647	-0.00000	2.20436	-0.00000	2.21702	-0.00000	2.24121	-0.00000	2.27066	-0.00000	2.30176	-0.00000	2.35848	2.40956
2.8	2.31832	-0.00000	2.32640	-0.00000	2.33936	-0.00000	2.36415	-0.00000	2.39428	-0.00000	2.42603	-0.00000	2.48387	2.53702
2.9	2.43819	-0.00000	2.44645	-0.00000	2.45975	-0.00000	2.48519	-0.00000	2.51605	-0.00000	2.54848	-0.00000	2.60750	2.66287
3.0	2.55635	-0.00000	2.56481	-0.00000	2.57847	-0.00000	2.60459	-0.00000	2.63622	0.42280	2.66937	0.52954	2.72963	2.78734
3.1	2.67303	-0.00000	2.68171	-0.00000	2.69573	0.42702	2.72257	0.75323	2.75501	0.92856	2.78891	0.98507	2.85043	2.91064
3.2	2.78842	0.61725	2.79731	0.75518	2.81173	0.91828	2.83932	1.12007	2.87259	1.25236	2.90727	1.29738	2.97009	3.03292
3.3	2.90266	1.01572	2.91179	1.11074	2.92661	1.23507	2.95498	1.40142	2.98912	1.51570	3.02459	1.55531	3.08874	3.15434
3.4	3.01589	1.30475	3.02526	1.38481	3.04050	1.49292	3.06963	1.64184	3.10472	1.74617	3.14099	1.78261	3.20649	3.27499
3.5	3.12822	1.54697	3.13783	1.61932	3.15351	1.71858	3.18354	1.85732	3.21949	1.95542	3.25658	1.98982	3.32344	3.39500
3.6	3.23975	1.76178	3.24961	1.82954	3.26574	1.92343	3.29663	2.05571	3.33353	2.14968	3.37145	2.18268	3.43969	3.51443
3.7	3.35055	1.95822	3.36067	2.0[illegible]106	3.37725	2.11352	3.40905	2.24157	3.44691	2.33270	3.48568	2.36470	3.55529	3.63339
3.8	3.46069	2.14136	3.47107	2.20429	3.48815	2.29255	3.52086	2.41780	3.55970	2.50695	3.59932	2.53824	3.67033	3.75192
3.9	3.57023	2.31435	3.58089	2.37604	3.59846	2.46293	3.63212	2.58638	3.67197	2.67415	3.71245	2.70491	3.78485	3.87009
4.0	3.67924	2.47933	3.69017	2.54024	3.70825	2.62635	3.74288	2.74873	3.78376	2.83556	3.82510	2.86594	3.89890	3.98795
4.1		2.63779		2.69828		2.78405		2.90589		2.99212		3.02222		
4.2		2.79085		2.85117		2.93695		3.05868		3.14456		3.17447		
4.3		2.93934		2.99971		3.08677		3.20774		3.29346		3.32325		
4.4		3.08394		3.14452		3.23109		3.35356		3.43929		3.46900		
4.5		3.22515		3.28609		3.37337		3.49656		3.58243		3.61210		
4.6		3.36342		3.42483		3.51297		3.63709		3.72319		3.752[illegible]6		
4.7		3.49908		3.56107		3.65022		3.77542		3.86185		3.89153		
4.8		3.63244		3.69509		3.78537		3.91180		3.99863		4.02834		
4.9		3.76373		3.82713		3.91865		4.04643		4.13371		4.16348		
5.0		3.89317		3.95738		4.05026		4.17950		4.26728		4.29711		
5.1		4.02092		4.08602		4.18035		4.31115		4.39947		4.42938		
5.2		4.14716		4.21320		4.30908		4.44152		4.53040		4.56039		
5.3		4.27201		4.33905		4.43656		4.57072		4.66020		4.69028		
5.4		4.39560		4.46368		4.56291		4.69886		4.78896		4.81912		
5.5		4.51802		4.58721		4.68823		4.82604		4.91676		4.94702		
5.6		4.63936		4.70971		4.81260		4.95234		5.04369		5.07404		
5.7		4.75972		4.83127		4.93611		5.07782		5.16982		5.20026		
5.8		4.87916		4.95196		5.05883		5.20255		5.29521		5.32574		
5.9		4.99775		5.07185		5.18082		5.32663		5.41992		5.45053		
6.0		5.11555		5.19099		5.30213		5.45006		5.54399		5.57468		
6.1		5.23261		5.30944		5.42283		5.57292		5.66749		5.69825		
6.2		5.34898		5.42725		5.54296		5.69524		5.79044		5.82128		
6.3		5.46470		5.54445		5.66257		5.81708		5.91290		5.94380		

2w GUIDE WIDTH

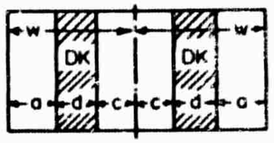
DK RELATIVE DIELECTRIC CONSTANT

λ_0 FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$a=\frac{a}{w}$, $\delta=\frac{d}{w}$, $\gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 2.25 DELTA = 0.10

$\alpha+\delta/2$	0.050	0.050	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.950
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.56917	3.12847	1.56281	3.07807	1.55141	3.00000	1.53016	2.89616	1.50496	2.82633	1.47903	2.80243	1.43373	1.40122
B														
1.5	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.26580	-0.00000	0.48357	0.60256
1.6	0.31288	-0.00000	0.34477	-0.00000	0.39639	-0.00000	0.48050	-0.00000	0.56779	-0.00000	0.64917	-0.00000	0.77901	0.86987
1.7	0.65467	-0.00000	0.67257	-0.00000	0.70413	-0.00000	0.76128	-0.00000	0.82689	-0.00000	0.89169	-0.00000	1.00208	1.08473
1.8	0.88279	-0.00000	0.89782	-0.00000	0.92471	-0.00000	0.97446	-0.00000	1.03261	-0.00000	1.09169	-0.00000	1.19407	1.27404
1.9	1.07243	-0.00000	1.08630	-0.00000	1.11132	-0.00000	1.15802	-0.00000	1.21309	-0.00000	1.26945	-0.00000	1.36815	1.44792
2.0	1.24134	-0.00000	1.25470	-0.00000	1.27891	-0.00000	1.32434	-0.00000	1.37812	-0.00000	1.43329	-0.00000	1.53045	1.61145
2.1	1.39707	-0.00000	1.41023	-0.00000	1.43418	-0.00000	1.47926	-0.00000	1.53271	-0.00000	1.58756	-0.00000	1.68440	1.76757
2.2	1.54360	-0.00000	1.55675	-0.00000	1.58077	-0.00000	1.62608	-0.00000	1.67979	-0.00000	1.73482	-0.00000	1.83213	1.91815
2.3	1.68335	-0.00000	1.69661	-0.00000	1.72090	-0.00000	1.76682	-0.00000	1.82118	-0.00000	1.87575	-0.00000	1.97503	2.06447
2.4	1.81788	-0.00000	1.83133	-0.00000	1.85606	-0.00000	1.90284	-0.00000	1.95814	-0.00000	2.01449	-0.00000	2.11411	2.20744
2.5	1.94827	-0.00000	1.96197	-0.00000	1.98725	-0.00000	2.03512	-0.00000	2.09157	-0.00000	2.14688	-0.00000	2.25009	2.34773
2.6	2.07529	-0.00000	2.08930	-0.00000	2.11523	-0.00000	2.16436	-0.00000	2.22212	-0.00000	2.28052	-0.00000	2.38351	2.48586
2.7	2.19955	-0.00000	2.21389	-0.00000	2.24055	-0.00000	2.29108	-0.00000	2.35030	-0.00000	2.40988	-0.00000	2.51380	2.62224
2.8	2.32147	-0.00000	2.33619	-0.00000	2.36364	-0.00000	2.41571	-0.00000	2.47650	-0.00000	2.53734	-0.00000	2.64428	2.75718
2.9	2.44140	-0.00000	2.45653	-0.00000	2.48485	-0.00000	2.53856	0.16274	2.60102	0.72540	2.66319	0.83934	2.77223	2.89096
3.0	2.55564	-0.00000	2.57520	-0.00000	2.60444	0.00128	2.65990	0.85427	2.72412	1.12383	2.78767	1.20513	2.89885	3.02376
3.1	2.67640	-0.00000	2.69242	0.37640	2.72263	0.82206	2.77996	1.20756	2.84601	1.42330	2.91097	1.49210	3.02433	3.15560
3.2	2.79187	0.67578	2.80836	0.89482	2.83961	1.17248	2.89890	1.48725	2.96686	1.67771	3.03325	1.73974	3.14883	3.28722
3.3	2.90620	1.05471	2.92319	1.21698	2.95553	1.44807	3.01688	1.72946	3.08682	1.90522	3.15467	1.96301	3.27246	3.41316
3.4	3.01952	1.33730	3.03704	1.47741	3.07052	1.68598	3.13403	1.94827	3.20601	2.11456	3.27532	2.16946	3.39633	3.54870
3.5	3.13194	1.57624	3.15001	1.70464	3.18469	1.90043	3.25046	2.15086	3.32454	2.31069	3.39533	2.36353	3.51755	3.67899
3.6	3.24356	1.78911	3.26219	1.91059	3.29813	2.09867	3.36627	2.34148	3.44250	2.49677	3.51477	2.54808	3.63918	3.80908
3.7	3.35446	1.98432	3.37368	2.10152	3.41094	2.28495	3.48154	2.52289	3.55998	2.67491	3.63372	2.72504	3.76030	3.93907
3.8	3.46470	2.16664	3.48452	2.28122	3.52317	2.46201	3.59635	2.69697	3.67705	2.84662	3.75225	2.89584	3.88097	4.06901
3.9	3.57434	2.33910	3.59480	2.45217	3.63489	2.63175	3.71077	2.86509	3.79376	3.01303	3.87042	3.06153	4.00124	4.19898
4.0	3.68345	2.50374	3.70456	2.61611	3.74617	2.79584	3.82486	3.02828	3.91021	3.17499	3.98828	3.22290	4.12117	4.32902
4.1		2.66200		2.77428		2.95439		3.18732		3.33317		3.38060		
4.2		2.81496		2.92783		3.10910		3.34285		3.48811		3.53514		
4.3		2.96345		3.07591		3.26027		3.49535		3.64024		3.68692		
4.4		3.10810		3.22267		3.40842		3.64523		3.78991		3.83630		
4.5		3.24944		3.36540		3.55396		3.79284		3.93744		3.98355		
4.6		3.38787		3.50548		3.69720		3.93847		4.08307		4.12894		
4.7		3.52374		3.64322		3.83847		4.08238		4.22701		4.27268		
4.8		3.65733		3.77890		3.97799		4.22468		4.36946		4.41487		
4.9		3.78889		3.91274		4.11598		4.36566		4.51057		4.55577		
5.0		3.91862		4.04495		4.25262		4.50543		4.65049		4.69546		
5.1		4.04670		4.17568		4.38806		4.64413		4.78933		4.83408		
5.2		4.17329		4.30509		4.52246		4.78188		4.92721		4.97173		
5.3		4.29851		4.43331		4.65594		4.91879		5.06422		5.10850		
5.4		4.42248		4.56046		4.78861		5.05496		5.20046		5.24448		
5.5		4.54530		4.68664		4.92057		5.19046		5.33599		5.37974		
5.6		4.66707		4.81194		5.05192		5.32539		5.47089		5.51436		
5.7		4.78787		4.93646		5.18274		5.45979		5.60622		5.64839		
5.8		4.90777		5.06026		5.31311		5.59378		5.73904		5.78190		
5.9		5.02683		5.18341		5.44310		5.72731		5.87240		5.91492		
6.0		5.14512		5.30599		5.57278		5.86052		6.00536		6.04752		
6.1		5.26269		5.42806		5.70221		5.99344		6.13793		6.17973		
6.2		5.37958		5.54966		5.83148		6.12611		6.27018		6.31160		
6.3		5.49584		5.67056		5.96054		6.25856		6.40215		6.44318		

2w GUIDE WIDTH

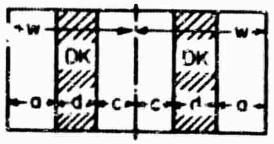
DK RELATIVE DIELECTRIC CONSTANT

λ_0 FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}, \ \delta = \frac{d}{w}, \ \gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 2.25 DELTA = 0.15

$\alpha+\delta/2$	0.075	0.075	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.925
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.56531	3.09723	1.55805	3.04078	1.54101	2.92867	1.50980	2.78926	1.47589	2.70116	1.43804	2.67191	1.37743	1.33596
B														
1.4	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.28594	0.49501
1.5	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.29774	-0.00000	0.46728	-0.00000	0.67841	0.80727
1.6	0.33253	-0.00000	0.36707	-0.00000	0.43920	-0.00000	0.55226	-0.00000	0.66557	-0.00000	0.76851	-0.00000	0.93016	1.04303
1.7	0.66555	-0.00000	0.68586	-0.00000	0.73253	-0.00000	0.81499	-0.00000	0.90597	-0.00000	0.99372	-0.00000	1.13873	1.24660
1.8	0.89191	-0.00000	0.90910	-0.00000	0.94939	-0.00000	1.02259	-0.00000	1.10551	-0.00000	1.18705	-0.00000	1.32471	1.43191
1.9	1.08083	-0.00000	1.09679	-0.00000	1.13453	-0.00000	1.20376	-0.00000	1.28345	-0.00000	1.36220	-0.00000	1.49657	1.60539
2.0	1.24943	-0.00000	1.26486	-0.00000	1.30158	-0.00000	1.36960	-0.00000	1.44783	-0.00000	1.52547	-0.00000	1.65873	1.77064
2.1	1.40503	-0.00000	1.42028	-0.00000	1.45678	-0.00000	1.52469	-0.00000	1.60286	-0.00000	1.68038	-0.00000	1.81382	1.92987
2.2	1.55155	-0.00000	1.56685	-0.00000	1.60361	-0.00000	1.67220	-0.00000	1.75109	-0.00000	1.82910	-0.00000	1.96356	2.08457
2.3	1.69136	-0.00000	1.70684	-0.00000	1.74419	-0.00000	1.81402	-0.00000	1.89415	-0.00000	1.97306	-0.00000	2.10909	2.23577
2.4	1.82600	-0.00000	1.84175	-0.00000	1.87993	-0.00000	1.95142	-0.00000	2.03319	-0.00000	2.11329	-0.00000	2.25127	2.38424
2.5	1.95653	-0.00000	1.97264	-0.00000	2.01185	-0.00000	2.08533	-0.00000	2.16902	-0.00000	2.25052	-0.00000	2.39071	2.53055
2.6	2.08374	-0.00000	2.10027	-0.00000	2.14066	-0.00000	2.21642	-0.00000	2.30227	-0.00000	2.38531	-0.00000	2.52790	2.67515
2.7	2.20819	-0.00000	2.22519	-0.00000	2.26691	-0.00000	2.34519	-0.00000	2.43340	-0.00000	2.51808	0.45920	2.66320	2.81840
2.8	2.33033	-0.00000	2.34785	-0.00000	2.39103	-0.00000	2.47206	0.27876	2.56279	0.56410	2.64920	0.99003	2.79692	2.96057
2.9	2.45051	-0.00000	2.46859	-0.00000	2.51334	-0.00000	2.59734	0.90397	2.69074	1.23737	2.77892	1.33369	2.92930	3.10191
3.0	2.56900	-0.00000	2.58767	-0.00000	2.63413	0.70425	2.72130	1.25896	2.81750	1.53128	2.90748	1.61454	3.06053	3.24260
3.1	2.68603	0.13303	2.70534	0.62560	2.75362	1.10142	2.84417	1.54318	2.94327	1.78552	3.03507	1.86126	3.19078	3.38282
3.2	2.80178	0.81704	2.82176	1.03445	2.87199	1.39856	2.96612	1.79073	3.06823	2.01519	3.16184	2.08605	3.32018	3.52270
3.3	2.91640	1.15685	2.93710	1.33087	2.98939	1.65069	3.08732	2.01525	3.19252	2.22797	3.28793	2.29539	3.44887	3.66235
3.4	3.03003	1.42475	3.05148	1.57952	3.10597	1.87612	3.20790	2.22378	3.31628	2.42833	3.41346	2.49320	3.57694	3.80188
3.5	3.14277	1.65604	3.16501	1.80033	3.22183	2.08359	3.32800	2.42053	3.43962	2.61916	3.53853	2.68208	3.70448	3.94138
3.6	3.25472	1.86440	3.27778	2.00257	3.33709	2.27810	3.44771	2.60823	3.56264	2.80246	3.66323	2.86381	3.83156	4.08091
3.7	3.36595	2.05681	3.38989	2.19141	3.45183	2.46278	3.56713	2.78876	3.68543	2.97964	3.78763	3.03972	3.95825	4.22055
3.8	3.47655	2.23740	3.50140	2.37008	3.56613	2.63976	3.68637	2.96349	3.80807	3.15178	3.91181	3.21078	4.08462	4.36034
3.9	3.58656	2.40884	3.61237	2.54076	3.68007	2.81056	3.80551	3.13344	3.93063	3.31970	4.03583	3.37777	4.21072	4.50033
4.0	3.69604	2.57297	3.72286	2.70499	3.79372	2.97632	3.92461	3.29941	4.05319	3.48403	4.15574	3.54128	4.33659	4.64057
4.1		2.73111		2.86332		3.13789		3.46203		3.64530		3.70181		
4.2		2.88425		3.01840		3.29596		3.62179		3.80393		3.85975		
4.3		3.03316		3.16912		3.45107		3.77911		3.96027		4.01543		
4.4		3.17844		3.31663		3.60369		3.93432		4.11460		4.16914		
4.5		3.32058		3.45136		3.75417		4.08773		4.26718		4.32111		
4.6		3.45997		3.60369		3.90283		4.23956		4.41822		4.47155		
4.7		3.59693		3.74392		4.04994		4.39003		4.56789		4.62062		
4.8		3.73175		3.88231		4.19574		4.53932		4.71637		4.76848		
4.9		3.86465		4.01910		4.34042		4.68758		4.86378		4.91527		
5.0		3.99584		4.15448		4.48417		4.83494		5.01024		5.06111		
5.1		4.12549		4.28862		4.62713		4.98154		5.15586		5.20609		
5.2		4.25374		4.42167		4.76946		5.12747		5.30075		5.35031		
5.3		4.38073		4.55378		4.91128		5.27282		5.44497		5.49385		
5.4		4.50658		4.68507		5.05269		5.41768		5.58862		5.63679		
5.5		4.63139		4.81565		5.19380		5.56212		5.73175		5.77920		
5.6		4.75525		4.94563		5.33471		5.70620		5.87443		5.92114		
5.7		4.87824		5.07510		5.47550		5.84999		6.01671		6.06266		
5.8		5.00045		5.20416		5.61624		5.99353		6.15865		6.20381		
5.9		5.12193		5.33289		5.75700		6.13688		6.30028		6.34465		
6.0		5.24275		5.46138		5.89784		6.28006		6.44166		6.48520		
6.1		5.36297		5.58969		6.03882		6.42312		6.58282		6.62552		
6.2		5.48265		5.71791		6.17998		6.56610		6.72379		6.76564		
6.3		5.60183		5.84611		6.32138		6.70901		6.86460		6.90559		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

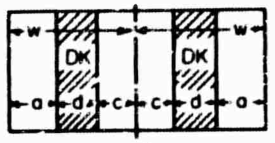
λ_0 FREE SPACE } WAVE LENGTH

λ_g GUIDE

$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha=\frac{a}{w},\ \delta=\frac{d}{w},\ \gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 2.25 DELTA = 0.25

$\alpha+\delta/2$			0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.875
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC			1.54571	2.95240	1.51811	2.79424	1.46926	2.61369	1.41591	2.60711	1.36526	2.47279	1.28359	1.23639
B														
1.3			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.25248	0.51379
1.4			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.35822	-0.00000	0.68562	0.84100
1.5			-0.00000	-0.00000	-0.00000	-0.00000	0.32460	-0.00000	0.55255	-0.00000	0.71961	-0.00000	0.95242	1.08681
1.6			0.42034	-0.00000	0.52414	-0.00000	0.68081	-0.00000	0.83215	-0.00000	0.96561	-0.00000	1.17258	1.30350
1.7			0.71986	-0.00000	0.79386	-0.00000	0.91972	-0.00000	1.05169	-0.00000	1.17327	-0.00000	1.36885	1.49951
1.8			0.93839	-0.00000	1.00389	-0.00000	1.11924	-0.00000	1.24361	-0.00000	1.35984	-0.00000	1.55037	1.68353
1.9			1.12422	-0.00000	1.18642	-0.00000	1.29775	-0.00000	1.41903	-0.00000	1.53312	-0.00000	1.72187	1.85924
2.0			1.29156	-0.00000	1.35267	-0.00000	1.46308	-0.00000	1.58377	-0.00000	1.69729	-0.00000	1.88611	2.02894
2.1			1.44685	-0.00000	1.50809	-0.00000	1.61935	-0.00000	1.74092	-0.00000	1.85483	-0.00000	2.04489	2.19414
2.2			1.59363	-0.00000	1.65577	-0.00000	1.76907	-0.00000	1.89246	-0.00000	2.00740	-0.00000	2.19944	2.35591
2.3			1.73409	-0.00000	1.79766	-0.00000	1.91388	-0.00000	2.03977	-0.00000	2.15614	-0.00000	2.35062	2.51530
2.4			1.86964	-0.00000	1.93610	-0.00000	2.05491	-0.00000	2.18379	-0.00000	2.30186	-0.00000	2.49909	2.67202
2.5			2.00132	-0.00000	2.06902	-0.00000	2.19300	-0.00000	2.32526	-0.00000	2.44519	0.47032	2.64534	2.82739
2.6			2.12986	-0.00000	2.20012	-0.00000	2.32878	-0.00000	2.46471	0.87168	2.58660	1.02758	2.78977	2.98147
2.7			2.25581	-0.00000	2.32893	-0.00000	2.46274	0.82776	2.60259	1.26931	2.72647	1.38750	2.93267	3.13453
2.8			2.37960	-0.00000	2.45587	0.20529	2.59528	1.22917	2.73924	1.58028	2.86511	1.68200	3.07430	3.28681
2.9			2.50156	-0.00000	2.58127	0.88832	2.72673	1.53968	2.87495	1.84891	3.00275	1.94114	3.21486	3.43847
3.0			2.62197	0.57190	2.70542	1.25158	2.85737	1.80703	3.00996	2.09166	3.13961	2.17763	3.35452	3.58968
3.1			2.74106	1.01622	2.82855	1.54100	2.98743	2.04828	3.14446	2.31672	3.27585	2.39822	3.49342	3.74055
3.2			2.85901	1.32804	2.95087	1.79286	3.11711	2.27185	3.27864	2.52890	3.41164	2.60700	3.63170	3.89118
3.3			2.97598	1.58766	3.07255	2.02140	3.24661	2.48263	3.41265	2.73123	3.54708	2.80665	3.76944	4.04166
3.4			3.09210	1.81739	3.19376	2.23391	3.37609	2.68373	3.54661	2.92583	3.68230	2.99903	3.90675	4.19205
3.5			3.20749	2.02776	3.31463	2.43474	3.50571	2.87727	3.68064	3.11413	3.81738	3.18549	4.04370	4.34241
3.6			3.32226	2.22424	3.43530	2.67668	3.63559	3.06476	3.81485	3.29741	3.95241	3.36705	4.18036	4.49278
3.7			3.43648	2.41034	3.55591	2.81168	3.76588	3.24732	3.94931	3.47636	4.08746	3.54451	4.31680	4.64321
3.8			3.55026	2.58836	3.67657	2.99116	3.89669	3.42583	4.08412	3.65171	4.22259	3.71848	4.45306	4.79372
3.9			3.66365	2.75994	3.79741	3.16618	4.02813	3.60095	4.21932	3.82399	4.35787	3.88947	4.58919	4.94432
4.0			3.77674	2.92630	3.91854	3.33764	4.16030	3.77322	4.35499	3.99364	4.49333	4.05788	4.72524	5.09506
4.1				3.08836		3.50591		3.94309		4.16102		4.22406		
4.2				3.24684		3.67181		4.11090		4.32643		4.38828		
4.3				3.40233		3.83567		4.27695		4.49010		4.55080		
4.4				3.55530		3.99785		4.44150		4.65227		4.71181		
4.5				3.70615		4.15865		4.60475		4.81312		4.87150		
4.6				3.85522		4.31833		4.76688		4.97279		5.03001		
4.7				4.00280		4.47711		4.92808		5.13144		5.18748		
4.8				4.14913		4.63517		5.08838		5.28917		5.34403		
4.9				4.29445		4.79267		5.24799		5.44610		5.49976		
5.0				4.43894		4.94977		5.40698		5.60231		5.65477		
5.1				4.58279		5.10656		5.56542		5.75789		5.80914		
5.2				4.72614		5.26317		5.72340		5.91292		5.96293		
5.3				4.86915		5.41966		5.88097		6.06744		6.11622		
5.4				5.01195		5.57612		6.03818		6.22153		6.26906		
5.5				5.15466		5.73262		6.19510		6.37523		6.42151		
5.6				5.29738		5.88919		6.35174		6.52859		6.57361		
5.7				5.44022		6.04588		6.50816		6.68165		6.72541		
5.8				5.58328		6.20273		6.66437		6.83444		6.87695		
5.9				5.72664		6.35976		6.82041		6.98701		7.02825		
6.0				5.87036		6.51697		6.97630		7.13937		7.17936		
6.1				6.01454		6.67443		7.13206		7.29156		7.33030		
6.2				6.15922		6.83208		7.28770		7.44360		7.48110		
6.3				6.30446		6.98996		7.44324		7.59552		7.63178		

2w GUIDE WIDTH

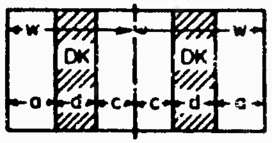
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

6.3 6.30446 6.98996 7.44324 7.59552 7.63178

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 2.25 DELTA = 0.40

$\alpha+\delta/2$					0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.800
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC					1.47680	2.61799	1.40918	2.42967	1.33917	2.31824	1.27565	2.28240	1.17699	1.14120
B														
1.2					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.31266	0.51303
1.3					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.31007	-0.00000	0.73820	0.86156
1.4					-0.00000	-0.00000	-0.00000	-0.00000	0.48281	-0.00000	0.71486	-0.00000	1.01415	1.12308
1.5					0.28089	-0.00000	0.57783	-0.00000	0.80025	-0.00000	0.97891	-0.00000	1.24442	1.34928
1.6					0.65847	-0.00000	0.85288	-0.00000	1.03830	-0.00000	1.19927	-0.00000	1.45097	1.55577
1.7					0.90126	-0.00000	1.07168	-0.00000	1.24362	-0.00000	1.39690	-0.00000	1.64282	1.74963
1.8					1.10237	-0.00000	1.26398	-0.00000	1.43057	-0.00000	1.58048	-0.00000	1.82454	1.93476
1.9					1.28168	-0.00000	1.44061	-0.00000	1.60576	-0.00000	1.75455	-0.00000	1.99923	2.11353
2.0					1.44742	-0.00000	1.60692	-0.00000	1.77284	-0.00000	1.92180	-0.00000	2.16837	2.28752
2.1					1.60391	-0.00000	1.76602	-0.00000	1.93410	-0.00000	2.08400	-0.00000	2.33327	2.45782
2.2					1.75375	-0.00000	1.91989	-0.00000	2.09105	-0.00000	2.24234	-0.00000	2.49482	2.62521
2.3					1.89862	-0.00000	2.06986	-0.00000	2.24476	-0.00000	2.39771	0.39256	2.65366	2.79027
2.4					2.03969	-0.00000	2.21693	-0.00000	2.39601	0.84866	2.55074	1.02606	2.81029	2.95346
2.5					2.17783	-0.00000	2.36182	0.77414	2.54540	1.27952	2.70193	1.41107	2.96509	3.11511
2.6					2.31369	-0.00000	2.50510	1.21849	2.69342	1.61059	2.85167	1.72313	3.11836	3.27552
2.7					2.44776	0.80988	2.64725	1.55230	2.84042	1.89499	3.00028	1.99678	3.27035	3.43488
2.8					2.58052	1.21986	2.78863	1.83699	2.98671	2.15136	3.14799	2.24615	3.42126	3.59338
2.9					2.71226	1.53505	2.92955	2.09282	3.13255	2.38881	3.29503	2.47861	3.57126	3.75117
3.0					2.84330	1.80596	3.07030	2.32943	3.27812	2.61253	3.44156	2.69456	3.72047	3.90836
3.1					2.97389	2.05039	3.21110	2.55226	3.42362	2.82584	3.58772	2.90888	3.86903	4.06505
3.2					3.10426	2.27705	3.35215	2.76473	3.56917	3.03098	3.73363	3.11153	4.01703	4.22132
3.3					3.23463	2.49092	3.49363	2.96915	3.71490	3.22954	3.87940	3.30797	4.16455	4.37723
3.4					3.36519	2.69519	3.63569	3.16715	3.86091	3.42271	4.02510	3.49926	4.31168	4.53285
3.5					3.49613	2.89203	3.77846	3.35993	4.00727	3.61137	4.17081	3.68622	4.45846	4.68622
3.6					3.62761	3.08299	3.92204	3.54842	4.15404	3.79623	4.31660	3.86951	4.60496	4.84337
3.7					3.75980	3.26920	4.06652	3.73331	4.30128	3.97786	4.46250	4.04965	4.75124	4.99834
3.8					3.89285	3.45155	4.21197	3.91517	4.44901	4.15670	4.60957	4.22706	4.89752	5.15316
3.9					4.02691	3.63072	4.35845	4.09446	4.59726	4.33312	4.75482	4.40210	5.04325	5.30785
4.0					4.16211	3.80726	4.50597	4.27153	4.74604	4.50742	4.90130	4.57505	5.18906	5.46242
4.1						3.98161		4.44670		4.67988		4.74616		
4.2						4.15413		4.62021		4.85069		4.91564		
4.3						4.32512		4.79208		5.02006		5.08367		
4.4						4.49483		4.96309		5.18813		5.25042		
4.5						4.66346		5.13279		5.35505		5.41600		
4.6						4.83119		5.30151		5.52094		5.58054		
4.7						4.99817		5.46935		5.68589		5.74415		
4.8						5.16451		5.63642		5.85001		5.90692		
4.9						5.33032		5.80279		6.01337		6.06892		
5.0						5.49569		5.96864		6.17604		6.23023		
5.1						5.66069		6.13372		6.33805		6.39091		
5.2						5.82537		6.29839		6.49957		6.55103		
5.3						5.98980		6.46260		6.66054		6.71063		
5.4						6.15401		6.62638		6.82103		6.86976		
5.5						6.31803		6.78977		6.98108		7.02846		
5.6						6.48190		6.95279		7.14074		7.18676		
5.7						6.64562		7.11548		7.30004		7.34471		
5.8						6.80923		7.27786		7.45899		7.50234		
5.9						6.97273		7.43995		7.61764		7.65966		
6.0						7.13613		7.60177		7.77600		7.81672		
6.1						7.29944		7.76332		7.93409		7.97352		
6.2						7.46267		7.92464		8.09194		8.13009		
6.3						7.62581		8.08572		8.24956		8.28646		

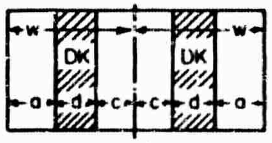
2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE
λ_g GUIDE } LENGTH

$B = 2\pi w/\lambda_o$
NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$
NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 4.00 DELTA = 0.05

$\alpha + \delta/2$	0.025	0.025	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.975
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.57031	3.13763	1.56149	3.06558	1.54768	2.96964	1.52212	2.84684	1.49224	2.76722	1.46188	2.74045	1.40966	1.37022
B														
1.5	0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.16075	-0.00000	0.36182	-0.00000	0.57217	0.704[illegible]
1.6	0.30690	-0.00000	0.35108	-0.00000	0.41219	-0.00000	0.50972	-0.00000	0.60907	-0.00000	0.70046	-0.00000	0.84491	0.95448
1.7	0.65145	-0.00000	0.67629	-0.00000	0.71444	-0.00000	0.78275	-0.00000	0.85954	-0.00000	0.93490	-0.00000	1.06099	1.16390
1.8	0.88012	-0.00000	0.90099	-0.00000	0.93366	-0.00000	0.99364	-0.00000	1.06276	-0.00000	1.13191	-0.00000	1.25016	1.35169
1.9	1.06997	-0.00000	1.08926	-0.00000	1.11975	-0.00000	1.17633	-0.00000	1.24218	-0.00000	1.30854	-0.00000	1.42325	1.52604
2.0	1.23899	-0.00000	1.25757	-0.00000	1.28717	-0.00000	1.34242	-0.00000	1.40697	-0.00000	1.47219	-0.00000	1.58554	1.69124
2.1	1.39476	-0.00000	1.41309	-0.00000	1.44246	-0.00000	1.49746	-0.00000	1.56181	-0.00000	1.62680	-0.00000	1.74007	1.84987
2.2	1.54131	-0.00000	1.55964	-0.00000	1.58916	-0.00000	1.64461	-0.00000	1.70944	-0.00000	1.77478	-0.00000	1.88879	2.00362
2.3	1.68104	-0.00000	1.69955	-0.00000	1.72950	-0.00000	1.78584	-0.00000	1.85162	-0.00000	1.91770	-0.00000	2.03300	2.15365
2.4	1.81555	-0.00000	1.83435	-0.00000	1.86491	-0.00000	1.92250	-0.00000	1.98956	-0.00000	2.05664	-0.00000	2.17361	2.30082
2.5	1.94590	-0.00000	1.96508	-0.00000	1.99642	-0.00000	2.05552	-0.00000	2.12412	-0.00000	2.19240	-0.00000	2.31131	2.44576
2.6	2.07288	-0.00000	2.09252	-0.00000	2.12476	-0.00000	2.18560	-0.00000	2.25594	-0.00000	2.32557	-0.00000	2.44662	2.58897
2.7	2.19709	-0.00000	2.21723	-0.00000	2.25048	-0.00000	2.31326	-0.00000	2.38551	-0.00000	2.45661	-0.00000	2.57993	2.73066
2.8	2.31895	-0.00000	2.33966	-0.00000	2.37402	-0.00000	2.43891	-0.00000	2.51323	0.48858	2.58587	0.66247	2.71157	2.87174
2.9	2.43883	-0.00000	2.46015	-0.00000	2.49570	-0.00000	2.56288	0.61586	2.63939	0.99259	2.71364	1.09457	2.84179	3.01189
3.0	2.55701	-0.00000	2.57897	-0.00000	2.61582	0.45389	2.68544	1.05519	2.76425	1.32653	2.84015	1.40904	2.97080	3.15152
3.1	2.67370	-0.00000	2.69635	0.47357	2.73458	0.94891	2.80680	1.36919	2.88803	1.60069	2.96562	1.67360	3.09878	3.29084
3.2	2.78910	0.62950	2.81248	0.94369	2.85217	1.27254	2.92715	1.63196	3.01098	1.84201	3.09013	1.90916	3.22588	3.43001
3.3	2.90336	1.02370	2.92750	1.25644	2.96876	1.53720	3.04664	1.86535	3.13298	2.06211	3.2[illegible]00	2.12542	3.35222	3.56918
3.4	3.01661	1.31138	3.04155	1.51282	3.08446	1.76562	3.16542	2.07934	3.25444	2.26721	3.33719	2.32781	3.47791	3.70847
3.5	3.12896	1.55291	3.15474	1.73799	3.19939	1.98125	3.28360	2.27946	3.37528	2.46112	3.45985	2.51970	3.60304	3.84801
3.6	3.24051	1.76732	3.26715	1.94285	3.31366	2.17620	3.40129	2.46915	3.49591	2.64636	3.58207	2.70338	3.72769	3.98790
3.7	3.35132	1.96360	3.37884	2.13329	3.42735	2.36420	3.51858	2.65071	3.61610	2.82463	3.70394	2.88044	3.85194	4.12824
3.8	3.46148	2.14647	3.48999	2.31289	3.54054	2.54173	3.63555	2.82576	3.73605	2.99725	3.82553	3.05208	3.97586	4.26910
3.9	3.57105	2.31935	3.60055	2.48403	3.65329	2.71250	3.75230	2.99550	3.85582	3.16519	3.94691	3.21919	4.09949	4.41056
4.0	3.68067	2.48425	3.71061	2.64837	3.76568	2.87777	3.86888	3.16085	3.97549	3.32917	4.06813	3.38248	4.22288	4.55270
4.1		2.64267		2.80713		3.03851		3.32250		3.48951		3.54251		
4.2		2.79570		2.96124		3.19544		3.48104		3.64758		3.69974		
4.3		2.94419		3.11140		3.34918		3.63693		3.80287		3.85455		
4.4		3.08879		3.25819		3.50020		3.79053		3.95602		4.00724		
4.5		3.23003		3.40208		3.64890		3.94219		4.10730		4.15808		
4.6		3.36832		3.54343		3.79562		4.09215		4.25694		4.30730		
4.7		3.50402		3.68258		3.94064		4.24066		4.40516		4.45509		
4.8		3.63742		3.81980		4.08422		4.38792		4.55212		4.60163		
4.9		3.76876		3.95531		4.22657		4.53409		4.69799		4.74706		
5.0		3.89825		4.08932		4.36788		4.67934		4.84288		4.89151		
5.1		4.02607		4.22200		4.50832		4.82379		4.98694		5.03511		
5.2		4.15237		4.35362		4.64804		4.96756		5.13025		5.17795		
5.3		4.27729		4.48400		4.78719		5.11077		5.27293		5.32012		
5.4		4.40095		4.61359		4.92588		5.25351		5.41504		5.46172		
5.5		4.52344		4.74238		5.06423		5.39585		5.55665		5.60282		
5.6		4.64486		4.87080		5.20236		5.53759		5.69792		5.74349		
5.7		4.76530		4.99504		5.34033		5.67969		5.83851		5.88379		
5.8		4.88483		5.12509		5.47627		5.82131		5.97942		6.02378		
5.9		5.00360		5.25174		5.61625		5.96282		6.11979		6.16351		
6.0		5.12139		5.37808		5.75436		6.10426		6.25999		6.30305		
6.1		5.23854		5.50416		5.89264		6.24568		6.40006		6.44242		
6.2		5.35601		5.63012		6.03115		6.38713		6.54004		6.58168		
6.3		5.47083		5.75599		6.17007		6.52366		6.67996		6.72087		

2w GUIDE WIDTH

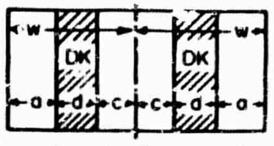
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 4.00 DELTA = 0.10

$\alpha + \delta/2$	0.050	0.050	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.950

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 4.00 DELTA = 0.10

α+δ/2	0.050	0.050	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.950
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.56685	3.10845	1.55135	2.97739	1.52333	2.79685	1.47410	2.60257	1.42056	2.49240	1.38994	2.45744	1.28868	1.22872
B														
1.4	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.33285	-0.00000	0.66358	0.87153
1.5	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.29736	-0.00000	0.53645	-0.00000	0.70538	-0.00000	0.94011	1.12017
1.6	0.32483	-0.00000	0.39763	-0.00000	0.50603	-0.00000	0.66796	-0.00000	0.82080	-0.00000	0.96529	-0.00000	1.16210	1.33768
1.7	0.66123	-0.00000	0.70612	-0.00000	0.78066	-0.00000	0.90877	-0.00000	1.04229	-0.00000	1.16464	-0.00000	1.35564	1.53770
1.8	0.88929	-0.00000	0.92575	-0.00000	0.99239	-0.00000	1.10966	-0.00000	1.23536	-0.00000	1.36229	-0.00000	1.54222	1.72668
1.9	1.07760	-0.00000	1.11247	-0.00000	1.17677	-0.00000	1.28909	-0.00000	1.41187	-0.00000	1.52662	-0.00000	1.71473	1.90823
2.0	1.24623	-0.00000	1.28023	-0.00000	1.34252	-0.00000	1.45514	-0.00000	1.57784	-0.00000	1.69181	-0.00000	1.88000	2.08462
2.1	1.40189	-0.00000	1.43669	-0.00000	1.49826	-0.00000	1.61209	-0.00000	1.73863	-0.00000	1.86043	-0.00000	2.03989	2.25741
2.2	1.54843	-0.00000	1.58261	-0.00000	1.64622	-0.00000	1.76250	-0.00000	1.88619	-0.00000	2.00416	-0.00000	2.19564	2.42766
2.3	1.68822	-0.00000	1.72291	-0.00000	1.78834	-0.00000	1.90836	-0.00000	2.03662	-0.00000	2.16418	-0.00000	2.34816	2.59620
2.4	1.82282	-0.00000	1.85836	-0.00000	1.92600	-0.00000	2.04992	-0.00000	2.18190	-0.00000	2.30134	-0.00000	2.49810	2.76365
2.5	1.95331	-0.00000	1.98999	-0.00000	2.06016	-0.00000	2.18897	-0.00000	2.32480	0.24949	2.44627	0.59466	2.64599	2.93048
2.6	2.08046	-0.00000	2.11828	-0.00000	2.19154	-0.00000	2.32686	-0.00000	2.46588	0.94924	2.58948	1.10042	2.79223	3.09710
2.7	2.20484	-0.00000	2.24400	-0.00000	2.32068	-0.00000	2.46112	0.89007	2.60560	1.33319	2.73136	1.45109	2.93714	3.26362
2.8	2.32691	-0.00000	2.36758	-0.00000	2.44803	0.15285	2.59817	1.28146	2.74436	1.64067	2.87223	1.74306	3.08098	3.43089
2.9	2.44701	-0.00000	2.48932	-0.00000	2.57395	0.88393	2.72637	1.69054	2.88242	1.90914	3.01236	2.00231	3.22398	3.59852
3.0	2.56642	-0.00000	2.60982	0.39259	2.69872	1.25403	2.86104	1.85932	3.02010	2.15339	3.15198	2.24033	3.36632	3.76690
3.1	2.68236	-0.00000	2.72839	0.92280	2.82262	1.54858	2.99346	2.10330	3.15761	2.38100	3.29128	2.46340	3.50815	3.93615
3.2	2.79601	0.76899	2.84613	1.25493	2.94586	1.80815	3.12587	2.33053	3.29517	2.59648	3.43044	2.67636	3.64962	4.10640
3.3	2.91284	1.12121	2.96291	1.52462	3.06867	2.03847	3.25852	2.54569	3.43294	2.80275	3.56959	2.67876	3.79084	4.27772
3.4	3.02807	1.39412	3.07885	1.76092	3.19123	2.25601	3.39161	2.75279	3.57109	3.00182	3.70887	3.07841	3.93192	4.45020
3.5	3.13872	1.62813	3.19409	1.97599	3.31374	2.46220	3.52535	2.95091	3.70977	3.19513	3.84839	3.26660	4.07295	4.62388
3.6	3.25056	1.83616	3.30873	2.17626	3.43638	2.65995	3.65994	3.14463	3.84912	3.38379	3.98826	3.45335	4.21402	4.79880
3.7	3.36169	2.03167	3.42287	2.36563	3.55933	2.85126	3.79658	3.33376	3.98924	3.56864	4.12857	3.63643	4.35521	4.97497
3.8	3.47218	2.21300	3.53661	2.54668	3.68278	3.03760	3.93243	3.51847	4.13024	3.75033	4.26942	3.81645	4.49658	5.15242
3.9	3.58208	2.36494	3.65003	2.72121	3.80694	3.22008	4.07066	3.70234	4.27222	3.92941	4.41066	3.99392	4.63820	5.33114
4.0	3.69146	2.54940	3.76321	2.69066	3.93201	3.39969	4.21044	3.88289	4.41526	4.10631	4.55298	4.16925	4.78014	5.51114
4.1		2.70776		3.05573		3.57681		4.06156		4.28139		4.34278		
4.2		2.86102		3.21756		3.75233		4.23877		4.45496		4.51481		
4.3		3.00998		3.37668		3.92651		4.41476		4.62727		4.68559		
4.4		3.15525		3.53366		4.19007		4.58980		4.79856		4.86532		
4.5		3.29734		3.68897		4.27303		4.76411		4.96900		6.02421		
4.6		3.43664		3.84301		4.44578		4.93787		5.13678		6.19240		
4.7		3.57349		3.99517		4.61867		5.11134		5.30802		6.36006		
4.8		3.70816		4.14877		4.79161		5.28435		5.47687		5.62729		
4.9		3.84393		4.30113		4.96506		5.45730		5.64543		5.69423		
5.0		3.97195		4.45363		5.13908		5.63020		5.81381		5.86097		
5.1		4.10142		4.60626		5.31373		5.80313		5.98208		6.02760		
5.2		4.22949		4.75958		5.48925		5.97616		6.15034		6.19421		
5.3		4.35630		4.91373		5.66556		6.14934		6.31866		6.36066		
5.4		4.48196		5.06897		6.64276		6.32273		6.48709		6.52764		
5.5		4.60659		5.22552		6.02083		6.49636		6.65570		6.69459		
5.6		4.73028		5.38360		6.19993		6.67028		6.82453		6.86178		
5.7		4.85311		5.54341		6.37992		6.84462		6.99364		7.02925		
5.8		4.97516		5.70815		6.56084		7.01910		7.16308		7.19705		
5.9		5.09651		5.86897		6.74267		7.19[illegible]		7.33283		7.36522		
6.0		5.21722		6.03602		6.92538		7.36956		7.50298		7.53380		
6.1		5.33736		6.20341		7.10896		7.54607		7.67355		7.70251		
6.2		5.45696		6.37422		7.29333		7.72119		7.84465		7.87230		
6.3		5.57614		6.54752		7.47856		7.89774		8.01602		8.04229		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

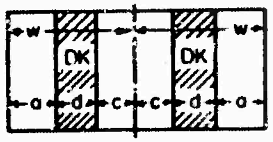
λ_0 FREE SPACE } WAVE LENGTH

λ_g GUIDE

$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT

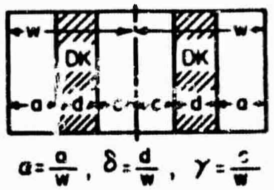


$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 4.00 DELTA = 0.15

$\alpha+\delta/2$	0.075	0.075	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.925
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.55733	3.02599	1.53926	2.88139	1.49781	2.64154	1.42780	2.41232	1.35644	2.29134	1.29261	2.25396	1.19478	1.12698
B														
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.16978	-0.00000	0.67742	0.92107
1.4	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.40614	-0.00000	0.66061	-0.00000	0.96571	1.16519
1.5	-0.00000	-0.00000	-0.00000	-0.00000	0.08535	-0.00000	0.51152	-0.00000	0.75198	-0.00000	0.93647	-0.00000	1.20136	1.41735
1.6	0.37042	-0.00000	0.44644	-0.00000	0.59367	-0.00000	0.80472	-0.00000	0.99852	-0.00000	1.16240	-0.00000	1.41117	1.63211
1.7	0.68800	-0.00000	0.73793	-0.00000	0.84920	-0.00000	1.03024	-0.00000	1.20849	-0.00000	1.36371	-0.00000	1.60542	1.83609
1.8	0.91102	-0.00000	0.95452	-0.00000	1.05532	-0.00000	1.22632	-0.00000	1.39877	-0.00000	1.55026	-0.00000	1.78934	2.03300
1.9	1.09886	-0.00000	1.13979	-0.00000	1.23712	-0.00000	1.40562	-0.00000	1.57682	-0.00000	1.72709	-0.00000	1.96596	2.22517
2.0	1.26875	-0.00000	1.30715	-0.00000	1.40423	-0.00000	1.57419	-0.00000	1.74669	-0.00000	1.89715	-0.00000	2.13722	2.41416
2.1	1.42236	-0.00000	1.46281	-0.00000	1.56152	-0.00000	1.73546	-0.00000	1.91087	-0.00000	2.06235	-0.00000	2.30443	2.60107
2.2	1.58893	-0.00000	1.61021	-0.00000	1.71187	-0.00000	1.89162	-0.00000	2.07104	-0.00000	2.22400	-0.00000	2.46856	2.78670
2.3	1.70906	-0.00000	1.75147	-0.00000	1.85712	-0.00000	2.04418	-0.00000	2.22837	0.27921	2.38305	0.64840	2.63030	2.97165
2.4	1.84414	-0.00000	1.88802	-0.00000	1.99857	-0.00000	2.19423	-0.00000	2.38374	1.00131	2.54021	1.16908	2.79019	3.15637
2.5	1.97821	-0.00000	2.02086	-0.00000	2.13717	-0.00000	2.34264	0.85625	2.63785	1.40489	2.69605	1.53591	2.94857	3.34123
2.6	2.10305	-0.00000	2.15073	-0.00000	2.27367	-0.00000	2.49010	1.31366	2.69124	1.72976	2.85100	1.84334	3.10606	3.52647
2.7	2.22821	-0.00000	2.27818	-0.00000	2.40885	0.69322	2.63718	1.64762	2.84435	2.01460	3.00543	2.11760	3.26265	3.71232
2.8	2.35113	-0.00000	2.40367	-0.00000	2.54263	1.15616	2.78438	1.93742	2.99785	2.27469	3.15963	2.37038	3.41867	3.89891
2.9	2.47216	-0.00000	2.52785	0.36632	2.67605	1.49881	2.93214	2.20092	3.15120	2.51790	3.31385	2.60810	3.57433	4.08636
3.0	2.59150	-0.00000	2.65011	0.93472	2.80931	1.78459	3.08087	2.44692	3.30551	2.74890	3.46831	2.83470	3.72978	4.27475
3.1	2.70960	0.70493	2.77162	1.28260	2.94281	2.04467	3.23092	2.68052	3.46074	2.97069	3.62318	3.05279	3.88518	4.46412
3.2	2.82643	1.09041	2.89228	1.56504	3.07694	2.28837	3.38262	2.90496	3.61707	3.18536	3.77863	3.26423	4.04066	4.65450
3.3	2.94220	1.38023	3.01231	1.81323	3.21207	2.51545	3.53627	3.12246	3.77467	3.39441	3.93479	3.47035	4.19632	4.84590
3.4	3.05707	1.62846	3.13187	2.04003	3.34861	2.73584	3.69211	3.33461	3.93364	3.59895	4.09177	3.67218	4.35227	5.03831
3.5	3.17114	1.84869	3.28116	2.25224	3.48696	2.94909	3.85035	3.54286	4.09411	3.79986	4.24967	3.87053	4.50861	5.23172
3.6	3.28452	2.04942	3.37034	2.45400	3.62785	3.15785	4.01114	3.74721	4.25612	3.99781	4.40857	4.06601	4.66541	5.42611
3.7	3.39729	2.23948	3.48958	2.64805	3.77083	3.36312	4.17460	3.94924	4.41973	4.19334	4.56853	4.25914	4.82274	5.62145
3.8	3.50984	2.41996	3.60908	2.83633	3.91724	3.56589	4.34076	4.14920	4.58495	4.38690	4.72963	4.45035	4.98068	5.81771
3.9	3.62133	2.59294	3.72902	3.02031	4.06721	3.76693	4.50963	4.34753	4.75178	4.57886	4.89189	4.63998	5.13923	6.01485
4.0	3.73273	2.76993	3.84963	3.20113	4.22114	3.96585	4.68112	4.54457	4.92021	4.76981	5.05535	4.82833	5.29862	6.21285
4.1		2.92206		3.37969		4.16611		4.74060		4.95911		5.01565		
4.2		3.08020		3.55679		4.36611		4.93587		5.14785		5.20214		
4.3		3.23805		3.73306		4.56414		5.13055		5.33600		5.38801		
4.4		3.38718		3.90909		4.76341		5.32481		5.52363		5.57340		
4.5		3.53707		4.08538		4.96310		5.51876		5.71091		5.75845		
4.6		3.68513		4.26239		5.16333		5.71252		5.89795		5.94330		
4.7		3.83173		4.44050		5.36418		5.90617		6.08488		6.12803		
4.8		3.97719		4.62008		5.56569		6.09978		6.27171		6.31275		
4.9		4.12181		4.80144		5.76787		6.29340		6.45860		6.49753		
5.0		4.26587		4.98482		5.97074		6.48708		6.64559		6.68245		
5.1		4.40962		5.17045		6.17427		6.68087		6.83272		6.86757		
5.2		4.55332		5.35548		6.37843		6.87479		7.02007		7.05295		
5.3		4.69723		5.54903		6.58319		7.06886		7.20768		7.23862		
5.4		4.84160		5.74214		6.78849		7.26312		7.39553		7.42469		
5.5		4.98667		5.93784		6.99431		7.45757		7.58372		7.61102		
5.6		5.13271		6.13608		7.20059		7.65224		7.77225		7.79782		
5.7		5.27997		6.33680		7.40729		7.84713		7.96114		7.98505		
5.8		5.42872		6.53590		7.61437		8.04226		8.15043		8.17272		
5.9		5.57922		6.74524		7.82180		8.23753		8.34911		8.36087		
6.0		5.73175		6.95269		8.02984		8.43326		8.53021		8.54950		
6.1		5.88657		7.16209		8.23758		8.62915		8.72074		8.73862		
6.2		6.04394		7.37329		8.44587		8.82831		8.91170		8.92524		
6.3		6.20411		7.58414		8.65442		9.02174		9.10311		9.11836		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_0 FREE SPACE } WAVE LENGTH
λ_g GUIDE }
B = $2\pi w/\lambda_0$ NORMALIZED FREQ.
BC CUTOFF-FREQ.
K = $2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha=\frac{a}{w}$, $\delta=\frac{d}{w}$, $\gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 4.00 DELTA = 0.25

$\alpha+\delta/2$ 0.125 0.125 0.200 0.200 0.300 0.300 0.400 0.400 0.500 0.500 0.700 0.875

```
NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN  WAVEGUIDES WHICH CONTAIN  DIELECTRIC SLABS        DK =  4.00        DELTA = 0.25
α.δ/2                             0.125      0.125      0.200      0.200      0.300      0.300      0.400      0.400      0.500      0.500      0.700      0.875
MODE        TF 10      TE 20      TE 10      TE 20      TE 10      TE 20      TE 10      TE 20      TE 10      TE 20      TE 10      TE 20      TE 10      TE 10
BC                              1.50871    2.68008    1.44366    2.39707    1.34258    2.14923    1.24915    2.02463    1.17137    1.96686    1.05823    0.99343
B
1.1                            -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000    0.44825    0.76020
1.2                            -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000    0.35441   -0.00000    0.84566    1.08686
1.3                            -0.00000   -0.00000   -0.00000   -0.00000   -0.00000   -0.00000    0.46212   -0.00000    0.76882   -0.00000    1.12986    1.35858
1.4                            -0.00000   -0.00000   -0.00000   -0.00000    0.47426   -0.00000    0.81423   -0.00000    1.04835   -0.00000    1.37329    1.60406
1.5                            -0.00000   -0.00000    0.44895   -0.00000    0.80230   -0.00000    1.07364   -0.00000    1.28480   -0.00000    1.59493    1.83450
1.6                             0.55766   -0.00000    0.76206   -0.00000    1.04789   -0.00000    1.29788   -0.00000    1.49917   -0.00000    1.80304    2.05544
1.7                             0.82077   -0.00000    0.99401   -0.00000    1.26092   -0.00000    1.50343   -0.00000    1.70026   -0.00000    2.00203    2.27010
1.8                             1.02940   -0.00000    1.19352   -0.00000    1.45545   -0.00000    1.69772   -0.00000    1.89273   -0.00000    2.19458    2.48052
1.9                             1.21215   -0.00000    1.37521   -0.00000    1.64148   -0.00000    1.88484   -0.00000    2.07938   -0.00000    2.38243    2.68807
2.0                             1.37948   -0.00000    1.54581   -0.00000    1.81994   -0.00000    2.06737   -0.00000    2.26205    0.36730    2.56679    2.89370
2.1                             1.53656   -0.00000    1.70911   -0.00000    1.99439   -0.00000    2.24702    0.88551    2.44200    1.09277    2.74852    3.09808
2.2                             1.68643   -0.00000    1.86755   -0.00000    2.16658    0.71661    2.42502    1.36991    2.62017    1.52041    2.92830    3.30168
2.3                             1.83100   -0.00000    2.02282   -0.00000    2.33783    1.25368    2.60230    1.74057    2.79725    1.86770    3.10663    3.50
2.4                             1.97163   -0.00000    2.17622    0.16451    2.50920    1.64116    2.77953    2.06011    2.97378    2.17372    3.28389    3.707
2.5                             2.10928   -0.00000    2.32878    0.98991    2.68150    1.96990    2.95726    2.34972    3.15018    2.45414    3.46043    3.91095
2.6                             2.24472   -0.00000    2.48143    1.41168    2.85543    2.26602    3.13591    2.61957    3.32678    2.71709    3.63649    4.11414
2.7                             2.37856    0.40172    2.63498    1.75181    3.03154    2.54133    3.31576    2.87541    3.50383    2.96733    3.81229    4.31757
2.8                             2.51133    0.99895    2.79019    2.05208    3.21025    2.80228    3.49706    3.12088    3.68155    3.20813    3.98803    4.5212
2.9                             2.64349    1.37116    2.94781    2.32866    3.39188    3.05284    3.67994    3.35842    3.86010    3.44149    4.16383    4.7252
3.0                             2.77547    1.67642    3.10883    2.58979    3.57661    3.29563    3.86450    3.58975    4.03960    3.66900    4.33988    4.92964
3.1                             2.90769    1.94719    3.27303    2.84031    3.76453    3.53247    4.05075    3.81614    4.22014    3.89184    4.51623    5.13432
3.2                             3.04059    2.19594    3.44190    3.08332    3.95558    3.76466    4.23868    4.03855    4.40179    4.11087    4.69302    5.33931
3.3                             3.17460    2.43281    3.61566    3.32096    4.14964    3.99319    4.42825    4.25773    4.58458    4.32680    4.87030    5.54461
3.4                             3.31020    2.65916    3.79468    3.55472    4.34650    4.21878    4.61936    4.47426    4.76855    4.54019    5.04817    5.75019
3.5                             3.44791    2.87888    3.97915    3.78568    4.54590    4.44201    4.81192    4.68861    4.95369    4.75148    5.22667    5.95604
3.6                             3.58830    3.09401    4.16909    4.01464    4.74754    4.66330    5.00583    4.90116    5.14000    4.96104    5.40587    6.16214
3.7                             3.73198    3.30608    4.36431    4.24219    4.95113    4.88302    5.20096    5.11223    5.32746    5.16913    5.58580    6.36846
3.8                             3.87960    3.51624    4.56447    4.46877    5.15635    5.10142    5.39720    5.32206    5.51604    5.37615    5.76651    6.57498
3.9                             4.03184    3.72540    4.76907    4.69468    5.36294    5.31872    5.59444    5.53087    5.70571    5.58216    5.94802    6.78169
4.0                             4.18937    3.93426    4.97757    4.92015    5.57063    5.53511    5.79257    5.73884    5.89643    5.78740    6.13036    6.98857
4.1                                        4.14337               5.14533               5.75071               5.94612               5.99202
4.2                                        4.35316               5.37032               5.96563               6.15284               6.19615
4.3                                        4.56395               5.59519               6.17998               6.35910               6.39990
4.4                                        4.77596               5.81996               6.39382               6.56530               6.60337
4.5                                        4.98933               6.04465               6.60721               6.77061               6.80663
4.6                                        5.20413               6.26926               6.82021               6.97599               7.00975
4.7                                        5.42043               6.49377               7.03286               7.18121               7.21279
4.8                                        5.63815               6.71816               7.24518               7.38630               7.41580
4.9                                        5.85726               6.94242               7.45722               7.59132               7.61883
5.0                                        6.07764               7.16652               7.66900               7.79629               7.82190
5.1                                        6.29923               7.39045               7.88054               8.00124               8.02504
5.2                                        6.52189               7.61419               8.09187               8.20620               8.22829
5.3                                        6.74552               7.83772               8.30299               8.41118               8.43164
5.4                                        6.97000               8.06104               8.51393               8.61620               8.63513
5.5                                        7.19522               8.28412               8.72471               8.82129               8.83876
5.6                                        7.42109               8.50697               8.93534               9.02644               9.04254
5.7                                        7.64751               8.72956               9.14582               9.23167               9.24648
5.8                                        7.87440               8.95198               9.35618               9.43698               9.45059
5.9                                        8.10170               9.17408               9.56642               9.64239               9.65488
6.0                                        8.32933               9.39596               9.77656               9.84789               9.85928
6.1                                        8.55726               9.61760               9.98661              10.05349              10.06388
6.2                                        8.78543               9.83900              10.19657              10.25920              10.26863
6.3                                        9.01381              10.06017              10.40646              10.46500              10.47355
```

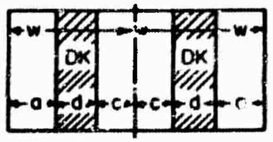
2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT

λ_0 FREE SPACE } WAVE
λ_g GUIDE } LENGTH

$B = 2\pi w/\lambda_0$
NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$
NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}, \quad \delta = \frac{d}{w}, \quad \gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 4.00 DELTA = 0.40

α=δ/2					0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.800
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TF 20	TE 10	TE 10
BC					1.35553	2.14465	1.23369	1.92064	1.12828	1.80253	1.04420	1.76636	0.92533	0.86318
B														
1.0					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.64643	0.84294
1.1					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.52834	-0.00000	1.01491	1.18086
1.2					-0.00000	-0.00000	-0.00000	-0.00000	0.58364	-0.00000	0.90580	-0.00000	1.30496	1.46610
1.3					-0.00000	-0.00000	0.53784	-0.00000	0.92647	-0.00000	1.18990	-0.00000	1.56113	1.72539
1.4					0.41504	-0.00000	0.87299	-0.00000	1.18805	-0.00000	1.43772	-0.00000	1.79313	1.96933
1.5					0.76452	-0.00000	1.13197	-0.00000	1.43271	-0.00000	1.66609	-0.00000	2.02289	2.20333
1.6					1.01617	-0.00000	1.36019	-0.00000	1.65373	-0.00000	1.88261	-0.00000	2.23924	2.43051
1.7					1.23235	-0.00000	1.57222	-0.00000	1.86488	-0.00000	2.09146	-0.00000	2.44957	2.65266
1.8					1.43010	-0.00000	1.77498	-0.00000	2.06998	-0.00000	2.29518	0.62129	2.65545	2.87168
1.9					1.61709	-0.00000	1.97244	-0.00000	2.27144	1.06477	2.49547	1.25679	2.85797	3.08789
2.0					1.79783	-0.00000	2.16716	0.94884	2.47085	1.53829	2.69347	1.68589	3.05792	3.30213
2.1					1.97480	-0.00000	2.36089	1.44641	2.66933	1.91580	2.89004	2.04322	3.25591	3.51489
2.2					2.14965	0.75960	2.55491	1.83212	2.86768	2.24644	3.08578	2.36172	3.45238	3.72650
2.3					2.32481	1.29363	2.75015	2.16801	3.06645	2.54868	3.28115	2.65554	3.64768	3.93723
2.4					2.50088	1.68578	2.94727	2.47418	3.26603	2.83178	3.47649	2.93221	3.84211	4.14727
2.5					2.67858	2.02114	3.14671	2.76082	3.46665	3.10113	3.67205	3.19629	4.03588	4.35677
2.6					2.85946	2.32600	3.34874	3.03372	3.66846	3.36014	3.86801	3.45077	4.22919	4.56583
2.7					3.04389	2.60892	3.55345	3.29648	3.87151	3.61116	4.06451	3.69773	4.42217	4.77454
2.8					3.23240	2.87925	3.76080	3.55153	4.07579	3.85582	4.26162	3.93866	4.61497	4.98296
2.9					3.42532	3.13989	3.97063	3.80085	4.28123	4.09535	4.45940	4.17468	4.80767	5.19117
3.0					3.62280	3.39341	4.18270	4.04473	4.48774	4.33068	4.65789	4.40666	5.00037	5.39908
3.1					3.82478	3.64157	4.39673	4.28512	4.69521	4.56251	4.85708	4.63526	5.19315	5.60665
3.2					4.03104	3.88563	4.61242	4.52226	4.90352	4.79142	5.05696	4.86103	5.38605	5.81445
3.3					4.24125	4.12650	4.82946	4.75674	5.11253	5.01784	5.25751	5.08439	5.57914	6.02190
3.4					4.45490	4.36486	5.04754	4.98897	5.32212	5.24215	5.45871	5.30572	5.77246	6.22921
3.5					4.67153	4.60120	5.26641	5.21927	5.53219	5.46468	5.66052	5.52529	5.96603	6.43637
3.6					4.89062	4.83591	5.48583	5.44793	5.74261	5.68567	5.86290	5.74336	6.15990	6.64341
3.7					5.11168	5.06926	5.70560	5.67513	5.95331	5.90514	6.06580	5.96013	6.35407	6.85032
3.8					5.33427	5.30147	5.92553	5.90106	6.16420	6.12350	6.26920	6.17578	6.54859	7.05711
3.9					5.55800	5.53270	6.14551	6.12584	6.37521	6.34083	6.47303	6.39045	6.74344	7.26378
4.0					5.78254	5.76306	6.36540	6.34961	6.58628	6.55723	6.67728	6.60427	6.93866	7.47034
4.1						5.99264		6.57244		6.77280		6.81735		
4.2						6.22152		6.79443		6.98766		7.02978		
4.3						6.44975		7.01563		7.20185		7.24164		
4.4						6.67735		7.23612		7.41547		7.45301		
4.5						6.90437		7.45593		7.62856		7.66393		
4.6						7.13083		7.67511		7.84118		7.87447		
4.7						7.35675		7.89370		8.05338		8.08466		
4.8						7.58215		8.11173		8.26515		8.29455		
4.9						7.80703		8.32923		8.47659		8.50417		
5.0						8.03143		8.54624		8.68769		8.71354		
5.1						8.25534		8.76277		8.89849		8.92270		
5.2						8.47878		8.97885		9.10902		9.13166		
5.3						8.70177		9.19450		9.31929		9.34045		
5.4						8.92431		9.40974		9.52932		9.54908		
5.5						9.14642		9.62458		9.73912		9.75756		
5.6						9.36811		9.83908		9.94873		9.96591		
5.7						9.58939		10.05317		10.15813		10.17414		
5.8						9.81027		10.26694		10.36736		10.38225		
5.9						10.03076		10.48038		10.57641		10.59025		
6.0						10.25085		10.69351		10.78531		10.79816		
6.1						10.47084		10.90633		10.99405		11.00598		
6.2						10.69004		11.11887		11.20268		11.21370		
6.3						10.90909		11.33113		11.41111		11.42134		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

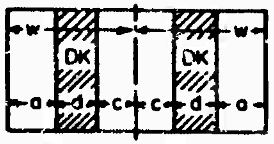
λ_o FREE SPACE } WAVE LENGTH

λ_g GUIDE }

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



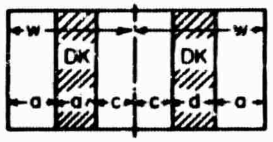
$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 9.00 DELTA = 0.05

$\alpha+\delta/2$	0.025	0.025	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.975
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.56948	3.1[illegible]056	1.54495	2.91276	1.50710	2.67576	1.44244	2.45053	1.37856	2.33167	1.31502	2.29492	1.22134	1.14746
B														
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.57659	0.85922
1.4	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.30086	-0.00000	0.58014	-0.00000	0.88700	1.13293
1.5	-0.00000	0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.45287	-0.00000	0.69233	-0.00000	0.87302	-0.00000	1.13003	1.37118
1.6	0.31127	-0.00000	0.42375	-0.00000	0.56311	-0.00000	0.76313	-0.00000	0.94772	-0.00000	1.10470	-0.00000	1.34295	1.59083
1.7	0.65380	-0.00000	0.72255	-0.00000	0.82507	-0.00000	0.99335	-0.00000	1.16096	-0.00000	1.30839	-0.00000	1.53850	1.79954
1.8	0.88207	-0.00000	0.94113	-0.00000	1.03335	-0.00000	1.19119	-0.00000	1.35247	-0.00000	1.49584	-0.00000	1.72277	2.00153
1.9	1.07177	-0.00000	1.12720	-0.00000	1.21599	-0.00000	1.37101	-0.00000	1.53074	-0.00000	1.67276	-0.00000	1.89922	2.19945
2.0	1.24071	-0.00000	1.29489	-0.00000	1.38332	-0.00000	1.53944	-0.00000	1.70026	-0.00000	1.84247	-0.00000	2.07002	2.39513
2.1	1.39646	-0.00000	1.46062	-0.00000	1.54049	-0.00000	1.70017	-0.00000	1.86373	-0.00000	2.00704	-0.00000	2.23662	2.58985
2.2	1.54300	-0.00000	1.59793	-0.00000	1.69348	-0.00000	1.85551	-0.00000	2.02797	-0.00000	2.16791	-0.00000	2.40007	2.78459
2.3	1.68275	-0.00000	1.73900	-0.00000	1.83522	-0.00000	2.00705	-0.00000	2.17922	-0.00000	2.32610	0.21365	2.56113	2.98014
2.4	1.81727	-0.00000	1.87529	-0.00000	1.97604	-0.00000	2.15896	-0.00000	2.33344	0.78763	2.48239	0.98369	2.72040	3.17709
2.5	1.94766	-0.00000	2.00780	-0.00000	2.11391	-0.00000	2.30312	0.66074	2.48638	1.28220	2.63739	1.39185	2.87834	3.37593
2.6	2.07468	-0.00000	2.13730	-0.00000	2.24960	-0.00000	2.44926	1.16410	2.63861	1.60125	2.79159	1.71843	3.03534	3.57706
2.7	2.19892	-0.00000	2.26435	-0.00000	2.38371	0.44354	2.59500	1.52425	2.79065	1.89988	2.94538	2.00462	3.19171	3.78080
2.8	2.32084	-0.00000	2.38939	-0.00000	2.51677	1.01756	2.74088	1.82839	2.94291	2.16933	3.09911	2.26585	3.34770	3.98740
2.9	2.44077	-0.00000	2.51280	-0.00000	2.64924	1.38550	2.88740	2.10145	3.09578	2.41965	3.25307	2.51018	3.50355	4.19706
3.0	2.55899	-0.00000	2.63487	0.79599	2.78155	1.68869	3.03501	2.35468	3.24951	2.65653	3.40750	2.74236	3.65947	4.40993
3.1	2.67574	-0.00000	2.75586	1.15887	2.91411	1.95813	3.18413	2.59429	3.40447	2.88353	3.56265	2.96548	3.81562	4.62613
3.2	2.79120	0.66855	2.87599	1.47613	3.04736	2.20686	3.33518	2.82414	3.56089	3.10309	3.71871	3.18167	3.97216	4.84574
3.3	2.90553	1.04784	2.99548	1.73285	3.18171	2.44187	3.48854	3.04680	3.71898	3.31693	3.87585	3.39248	4.12925	5.06882
3.4	3.01884	1.33161	3.11450	1.96540	3.31765	2.66741	3.64156	3.26408	3.87893	3.52633	4.03424	3.59907	4.28701	5.29543
3.5	3.13125	1.57119	3.23325	2.18197	3.45566	2.88633	3.80356	3.47732	4.04092	3.73226	4.19402	3.80236	4.44558	5.52562
3.6	3.24287	1.78446	3.35192	2.38736	3.58629	3.10066	3.96580	3.68755	4.20507	3.93552	4.35533	4.00305	4.60506	5.75944
3.7	3.35375	1.97994	3.47070	2.58473	3.74[illegible]13	3.31[illegible]98	4.13150	3.89555	4.37149	4.13670	4.51828	4.20174	4.76557	5.99697
3.8	3.46399	2.16248	3.58980	2.77630	3.88780	3.52117	4.30080	4.10195	4.54025	4.33634	4.68298	4.39891	4.92722	6.23829
3.9	3.57363	2.33509	3.70945	2.96375	4.03994	3.72941	4.47379	4.30725	4.71141	4.53485	4.84951	4.59496	5.09010	6.48350
4.0	3.68273	2.49986	3.82992	3.14842	4.19719	3.93734	4.65046	4.51186	4.88498	4.73258	5.01796	4.79025	5.25430	6.73273
4.1		2.65823		3.33142		4.14853		4.71612		4.92984		4.98507		
4.2		2.81128		3.51370		4.35443		4.92030		5.12690		5.17969		
4.3		2.95985		3.69610		4.56441		5.12463		5.32398		5.37433		
4.4		3.10459		3.87942		4.77573		5.32931		5.52128		5.56919		
4.5		3.24599		4.06438		4.98860		5.53450		5.71898		5.76445		
4.6		3.38449		4.25164		5.20315		5.74031		5.91722		5.96027		
4.7		3.52043		4.44184		5.41947		5.94687		6.11614		6.15681		
4.8		3.65410		4.63554		5.63760		6.15427		6.31587		6.35417		
4.9		3.78573		4.83325		5.857[illegible]		6.36258		6.51652		6.55249		
5.0		3.91854		5.03539		6.07929		6.57188		6.71817		6.75186		
5.1		4.04370		5.24230		6.30279		6.78222		6.92092		6.95237		
5.2		4.17037		5.45420		6.52799		6.99365		7.12484		7.15412		
5.3		4.29868		5.67122		6.75485		7.20623		7.33001		7.35717		
5.4		4.41978		5.89335		6.98332		7.41998		7.53648		7.56160		
5.5		4.54268		6.12080		7.21334		7.63496		7.74432		7.76746		
5.6		4.66456		6.35250		7.44487		7.85119		7.95356		7.97480		
5.7		4.78548		6.58909		7.67789		8.06873		8.16427		8.18369		
5.8		4.90852		6.83001		7.91239		8.28760		8.37648		8.39412		
5.9		5.02473		7.07495		[illegible].14835		8.50786		8.59022		8.60618		
6.0		5.14318		7.32363		[illegible].38579		8.72953		8.80853		8.81987		
6.1		5.26091		7.57577		8.62474		8.95266		9.02245		9.03522		
6.2		5.37799		7.83117		8.86523		9.17731		9.24101		9.25226		
6.3		5.49446		8.08963		9.10732		9.40381		9.46122		9.47100		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_0 FREE SPACE } WAVE
λ_g GUIDE } LENGTH
B = $2\pi w/\lambda_0$
NORMALIZED FREQ.
BC CUTOFF-FREQ.
K = $2\pi w/\lambda_g$
NORMALIZED PROPAGATION CONSTANT

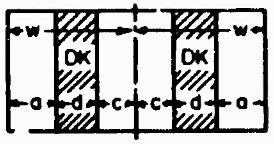


$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 9.00 DELTA = 0.10

$\alpha+\delta/2$	0.050	0.050	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.600	0.700	0.950
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.55988	3.03913	1.51483	2.65034	1.43926	2.30767	1.32674	2.05081	1.22742	1.92908	1.14707	1.89276	1.03239	0.94638
B														
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.58444	0.97011
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.49373	-0.00000	0.94362	1.28670
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.56544	-0.00000	0.86042	-0.00000	1.22170	1.56766
1.4	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.54646	-0.00000	0.89381	-0.00000	1.13394	-0.00000	1.46610	1.83131
1.5	-0.00000	-0.00000	-0.00000	-0.00000	0.47030	-0.00000	0.86044	-0.00000	1.15129	-0.00000	1.37208	-0.00000	1.69195	2.08596
1.6	0.35872	-0.00000	0.53785	-0.00000	0.78060	-0.00000	1.10640	-0.00000	1.37937	-0.00000	1.59166	-0.00000	1.90633	2.33520
1.7	0.68098	-0.00000	0.80656	-0.00000	1.01426	-0.00000	1.32414	-0.00000	1.59190	-0.00000	1.80031	-0.00000	2.11318	2.58486
1.8	0.90510	-0.00000	1.01762	-0.00000	1.21706	-0.00000	1.52714	-0.00000	1.79558	-0.00000	2.00224	-0.00000	2.31498	2.83379
1.9	1.09322	-0.00000	1.20200	-0.00000	1.40330	-0.00000	1.72206	-0.00000	1.99429	-0.00000	2.20012	0.28360	2.51340	3.08424
2.0	1.26155	-0.00000	1.37075	-0.00000	1.57977	-0.00000	1.91286	-0.00000	2.19057	0.69738	2.39574	1.10985	2.70963	3.33707
2.1	1.41718	-0.00000	1.52928	-0.00000	1.75050	-0.00000	2.10230	0.74185	2.38620	1.41679	2.59041	1.56809	2.90456	3.59283
2.2	1.56391	-0.00000	1.68076	-0.00000	1.91821	-0.00000	2.29245	1.31618	2.58252	1.81380	2.78511	1.94022	3.09891	3.85189
2.3	1.70405	-0.00000	1.82725	-0.00000	2.08506	-0.00000	2.48493	1.73284	2.78052	2.15760	2.98060	2.26965	3.29323	4.11444
2.4	1.83912	-0.00000	1.97023	-0.00000	2.25288	0.99661	2.68110	2.08955	2.98100	2.47171	3.17749	2.57341	3.48798	4.38057
2.5	1.97018	-0.00000	2.11081	-0.00000	2.42339	1.46660	2.88205	2.41401	3.18454	2.76639	3.37628	2.86024	3.68356	4.65029
2.6	2.09799	-0.00000	2.24995	-0.00000	2.59831	1.84918	3.08861	2.71867	3.39156	3.04801	3.57736	3.13532	3.88031	4.92356
2.7	2.22312	-0.00000	2.38849	0.66112	2.77939	2.18654	3.30135	3.01033	3.60233	3.32043	3.78104	3.40200	4.07852	5.20032
2.8	2.34802	-0.00000	2.52726	1.17374	2.96636	2.50527	3.52051	3.29313	3.81701	3.58626	3.98758	3.66261	4.27946	5.48048
2.9	2.46704	-0.00000	2.66714	1.54536	3.16888	2.80661	3.74610	3.56981	4.03563	3.84734	4.19715	3.91883	4.48035	5.76398
3.0	2.58845	-0.00000	2.80912	1.86717	3.37633	3.10391	3.97784	3.84225	4.25815	4.10506	4.40990	4.17191	4.68440	6.05075
3.1	2.70448	0.63887	2.95433	2.16173	3.59760	3.39451	4.21527	4.11178	4.48443	4.36043	4.62591	4.42285	4.89081	6.34076
3.2	2.82134	1.04802	3.10420	2.44191	3.83092	3.68259	4.45781	4.37936	4.71432	4.61426	4.84525	4.67240	5.09972	6.63396
3.3	2.93718	1.34862	3.26045	2.71461	4.07579	3.96956	4.70462	4.64577	4.94762	4.86719	5.06792	4.92119	5.31129	6.93034
3.4	3.05213	1.59806	3.42621	2.98430	4.33110	4.25635	4.95570	4.91180	5.18414	5.11973	5.29392	5.16972	5.52565	7.22986
3.5	3.16634	1.82213	3.60102	3.25414	4.59536	4.54357	5.20957	5.17697	5.42366	5.37228	5.52322	5.41840	5.74290	7.53250
3.6	3.27989	2.02808	3.79064	3.52644	4.86695	4.83153	5.46686	5.44281	5.66605	5.62519	5.75576	5.66758	5.96314	7.83822
3.7	3.39290	2.22113	3.99671	3.80282	5.14435	5.12040	5.72626	5.70834	5.91166	5.87872	5.99146	5.91753	6.18644	8.14697
3.8	3.50845	2.40468	4.22116	4.08437	5.42625	5.41027	5.98772	5.97486	6.15862	6.13309	6.23030	6.16848	6.41286	8.45866
3.9	3.61784	2.58067	4.46452	4.37172	5.71155	5.70111	6.25099	6.24183	6.40854	6.38850	6.47213	6.42063	6.64245	8.77319
4.0	3.72984	2.75103	4.72866	4.66507	5.99940	5.99290	6.51586	6.50935	6.66072	6.64508	6.71690	6.67413	6.87523	9.09043
4.1		2.91691		4.96430		6.28556		6.77795		6.90297		6.92911		
4.2		3.07931		5.26904		6.57913		7.04749		7.16226		7.18566		
4.3		3.23906		5.57678		6.87350		7.31605		7.42302		7.44386		
4.4		3.39687		5.89293		7.16869		7.58971		7.68533		7.70378		
4.5		3.55342		6.21091		7.46471		7.86282		7.94923		7.96544		
4.6		3.70931		6.53220		7.76187		8.13686		8.21477		8.22886		
4.7		3.86516		6.85637		8.05932		8.41186		8.48196		8.49411		
4.8		4.02162		7.18309		8.35602		8.68680		8.75083		8.76114		
4.9		4.17933		7.51312		8.65773		8.96653		9.02141		9.02997		
5.0		4.33908		7.84330		8.95862		9.24801		9.29369		9.30058		
5.1		4.50186		8.17686		9.26045		9.52698		9.56769		9.57297		
5.2		4.66779		8.51184		9.56359		9.80949		9.84342		9.84712		
5.3		4.83677		8.84914		9.86601		10.09360		10.12086		10.12302		
5.4		5.01865		9.18846		10.17374		10.37936		10.40006		10.40063		
5.5		5.19969		9.52977		10.48064		10.66677		10.68097		10.67995		
5.6		5.39228		9.87306		10.78933		10.95589		10.96361		10.96095		
5.7		5.59471		10.21628		11.09922		11.24875		11.24798		11.24363		
5.8		5.80835		10.56527		11.41368		11.53936		11.53407		11.52795		
5.9		6.03427		10.91399		11.72321		11.83373		11.82186		11.81392		
6.0		6.27319		11.26427		12.03726		12.12967		12.11140		12.10151		
6.1		6.52846		11.61593		12.35270		12.42776		12.40263		12.39071		
6.2		6.79092		11.96678		12.66940		12.72744		12.69555		12.68152		
6.3		7.06905		12.32263		12.98736		13.02864		12.99017		12.97393		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_o FREE SPACE WAVE LENGTH
λ_g GUIDE WAVE LENGTH
$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.
BC CUTOFF-FREQ.
$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha=\frac{a}{w}$, $\delta=\frac{d}{w}$, $\gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 9.00 DELTA = 0.15

$\alpha + \delta/2$	0.075	0.075	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.925
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.53240	2.77371	1.48006	2.42592	1.37206	2.06103	1.22974	1.80887	1.11671	1.69322	1.03053	1.65910	0.91190	0.82955
B														
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.71684	1.10663
1.1	-0.00000	-0.00000	-0.00000	-0.00000	0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.60486	-0.00000	1.07761	1.44471
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.64694	-0.00000	0.97244	-0.00000	1.37075	1.75121
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.56735	-0.00000	0.98865	-0.00000	1.26165	-0.00000	1.63385	2.04260
1.4	-0.00000	-0.00000	-0.00000	-0.00000	0.33021	-0.00000	0.90939	-0.00000	1.26617	-0.00000	1.51942	-0.00000	1.88028	2.32659
1.5	-0.00000	-0.00000	0.26230	-0.00000	0.72418	-0.00000	1.18030	-0.00000	1.51731	-0.00000	1.76101	-0.00000	2.11657	2.60736
1.6	0.47362	-0.00000	0.65565	-0.00000	0.99098	-0.00000	1.42408	-0.00000	1.75853	-0.00000	1.99366	-0.00000	2.34648	2.88744
1.7	0.75806	-0.00000	0.90464	-0.00000	1.21932	-0.00000	1.65563	-0.00000	1.98753	0.29374	2.22148	0.72550	2.57240	3.16833
1.8	0.97327	-0.00000	1.11158	-0.00000	1.43000	-0.00000	1.88244	-0.00000	2.21725	1.18865	2.44709	1.37186	2.79596	3.45099
1.9	1.15861	-0.00000	1.29740	-0.00000	1.63238	-0.00000	2.10912	1.09610	2.44725	1.68616	2.67227	1.82705	3.01835	3.73594
2.0	1.32678	-0.00000	1.47085	-0.00000	1.83213	-0.00000	.33880	1.62193	2.67928	2.09317	2.89829	2.21327	3.24047	4.02346
2.1	1.48376	-0.00000	1.63670	-0.00000	2.03341	0.69464	2.57373	2.04502	2.91448	2.45600	3.12607	2.56269	3.46302	4.31364
2.2	1.63291	00000	1.79806	-0.00000	2.23972	1.34486	2.81538	2.42118	3.15362	2.79273	3.35630	2.88943	3.68658	4.60646
2.3	1.77637	00000	1.95723	-0.00000	2.45420	1.80851	3.06459	2.77070	3.39709	3.11259	3.58945	3.20111	3.91159	4.90182
2.4	1.91559	.00000	2.11619	-0.00000	2.67968	2.20923	3.32[illegible]	3.10353	3.64505	3.42097	3.82589	3.50241	4.13845	5.19961
2.5	2.05161	0.00000	2.27685	0.89222	2.91844	2.57885	3.58595	3.42532	3.89743	3.72135	4.06582	3.79639	4.36748	5.49969
2.6	2.18533	-0.00000	2.44123	1.40183	3.17192	2.93107	3.85708	3.73959	4.15403	4.01607	4.30937	4.08521	4.59895	5.80193
2.7	2.31736	-0.00000	2.61168	1.80451	3.44036	3.27307	4.13398	4.04865	4.41457	4.30683	4.55659	4.37041	4.83308	6.10620
2.8	2.44832	0.46366	2.79091	2.16474	3.72278	3.60898	4.41566	4.35406	4.67871	4.59485	4.80746	4.65318	5.07006	6.41239
2.9	2.57880	1.03286	2.98216	2.50457	4.01724	3.94125	4.70115	4.65692	4.94611	4.88104	5.06191	4.93438	5.31003	6.72040
3.0	2.70935	1.40613	3.18900	2.83477	4.32133	4.27136	4.98963	4.95802	5.21645	5.16613	5.31986	5.21473	5.55311	7.03014
3.1	2.84060	1.71841	3.41488	3.16147	4.63265	4.60020	5.28040	5.25793	5.48943	5.45064	5.58116	5.49475	5.79939	7.34152
3.2	2.97326	2.00059	3.66239	3.48837	4.94910	4.92827	5.57294	5.55705	5.76481	5.73501	5.84569	5.77487	6.04892	7.65447
3.3	3.10821	2.26618	3.93231	3.81766	5.26902	5.25583	5.86684	5.85572	6.04237	6.01955	6.11329	6.05542	6.30173	7.96888
3.4	3.24653	2.52282	4.22321	4.15049	5.59112	5.58201	6.16179	6.15415	6.32193	6.30453	6.38381	6.33666	6.55783	8.28468
3.5	3.38965	2.77560	4.53197	4.48729	5.91449	5.90988	6.45759	6.45253	6.60333	6.59015	6.65709	6.61880	6.81720	8.60175
3.6	3.53946	3.02829	4.85477	4.82802	6.23346	6.23645	6.75406	6.75105	6.88646	6.87655	6.93298	6.90198	7.07980	8.92000
3.7	3.69845	3.28388	5.18794	5.17232	6.56263	6.56275	7.05111	7.04979	7.17119	7.16387	7.21133	7.18631	7.34558	9.23932
3.8	3.86978	3.54483	5.52842	5.51969	6.88636	6.88879	7.34864	7.34885	7.45744	7.45218	7.49200	7.47189	7.61448	9.55957
3.9	4.05725	3.81312	5.87387	5.86960	7.20970	7.21461	7.64660	7.64334	7.74513	7.74156	7.77484	7.75875	7.88643	9.88066
4.0	4.26480	4.09027	6.22251	6.22156	7.53236	7.54026	7.94494	7.94832	8.03419	8.03205	8.05974	8.04692	8.16133	10.20245
4.1		4.37727		6.57517		7.86579		8.24888		8.32368		8.33644		
4.2		4.67455		6.93011		8.19126		8.55006		8.61647		8.62728		
4.3		4.98204		7.28617		8.51673		8.85193		9.91043		8.91945		
4.4		5.29920		7.64320		8.84228		9.15453		9.20557		9.21292		
4.5		5.62518		8.00111		9.16798		9.45793		9.50188		9.50766		
4.6		5.93897		8.35986		9.49382		9.76215		9.79936		9.80365		
4.7		6.29954		8.71939		9.81991		10.06723		10.09798		10.10085		
4.8		6.64597		9.07968		10.14628		10.37320		10.39775		10.39923		
4.9		6.99746		9.44068		10.47294		10.68008		10.69864		10.69875		
5.0		7.35344		9.80231		10.79990		10.98789		11.00064		10.99939		
5.1		7.71347		10.16448		11.12718		11.29664		11.30372		11.30110		
5.2		8.07730		10.52708		11.45477		11.60633		11.60788		11.60386		
5.3		8.44477		10.88598		11.78264		11.91696		11.91307		11.90764		
5.4		8.81564		11.25304		12.11079		12.22851		12.21929		12.21240		
5.5		9.18594		11.61611		12.43919		12.54097		12.52651		12.51812		
5.6		9.56750		11.97903		12.76779		12.85431		12.83470		12.82478		
5.7		9.94815		12.34165		13.09658		13.16851		13.14384		13.13235		
5.8		10.33166		12.70382		13.42550		13.48354		13.45390		13.44060		
5.9		10.71774		13.06542		13.75454		13.79936		13.76485		13.75012		
6.0		11.10605		13.42633		14.08364		14.11593		14.07666		14.06028		
6.1		11.49621		13.78644		14.41278		14.43321		14.38930		14.37126		
6.2		11.88780		14.14565		14.74191		14.75115		14.70274		14.68305		
6.3		12.28039		14.50389		15.07101		15.06971		15.01695		14.99561		

2w GUIDE WIDTH

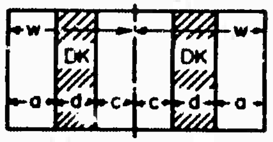
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT

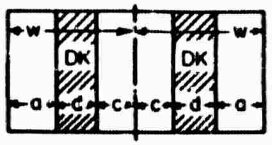


$a = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 9.00 DELTA = 0.25

$\alpha+\delta/2$			0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.875
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC			1.39626	2.09439	1.24990	1.76429	1.08399	1.53267	0.96500	1.42721	0.87874	1.39626	0.76344	0.69813
B														
0.7			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.11768
0.8			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.49744	0.90752
0.9			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.35892	-0.00000	0.99461	1.32976
1.0			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.45039	-0.00000	0.88763	-0.00000	1.35223	1.69019
1.1			-0.00000	-0.00000	-0.00000	-0.00000	0.29009	-0.00000	0.91742	-0.00000	1.24066	-0.00000	1.66392	2.02434
1.2			-0.00000	-0.00000	-0.00000	-0.00000	0.81057	-0.00000	1.25548	-0.00000	1.54599	-0.00000	1.95277	2.34533
1.3			-0.00000	-0.00000	0.48057	-0.00000	1.14903	-0.00000	1.55490	-0.00000	1.82981	-0.00000	2.22856	2.65946
1.4			0.11891	-0.00000	0.85989	-0.00000	1.44528	-0.00000	1.83808	-0.00000	2.10285	0.23577	2.49650	2.97013
1.5			0.64178	-0.00000	1.14911	-0.00000	1.72639	-0.00000	2.11471	1.05746	2.37070	1.26871	2.75969	3.27929
1.6			0.92173	-0.00000	1.41009	-0.00000	2.00379	1.01665	2.38989	1.66482	2.63662	1.81504	3.02018	3.58805
1.7			1.15413	-0.00000	1.66184	-0.00000	2.28361	1.64200	2.66655	2.13664	2.90268	2.26143	3.27937	3.89704
1.8			1.36585	-0.00000	1.91424	0.72089	2.56927	2.12556	2.94631	2.55027	3.17022	2.65953	3.53830	4.20656
1.9			1.56803	-0.00000	2.17379	1.44510	2.86240	2.55072	3.22996	2.93126	3.44006	3.02918	3.79771	4.51676
2.0			1.76723	-0.00000	2.44507	1.95832	3.16334	2.94397	3.51771	3.29167	3.71272	3.38039	4.05818	4.82765
2.1			1.96836	0.26581	2.73096	2.40276	3.47144	3.31751	3.80937	3.63821	3.98847	3.71899	4.32017	5.13920
2.2			2.17575	1.18681	3.03247	2.81337	3.78551	3.67797	4.10457	3.97505	4.26740	4.04869	4.58400	5.45134
2.3			2.39364	1.70442	3.34877	3.20479	4.10414	4.02933	4.40281	4.30492	4.54947	4.37199	4.84993	5.76400
2.4			2.62619	2.13981	3.67786	3.58445	4.42597	4.37411	4.70359	4.62970	4.83457	4.69066	5.11815	6.07709
2.5			2.87711	2.53936	4.01586	3.95645	4.74984	4.71398	5.00643	4.95073	5.12254	5.00598	5.38880	6.39055
2.6			3.14892	2.92089	4.36072	4.32321	5.07483	5.05009	5.31094	5.26900	5.41318	5.31891	5.66197	6.70432
2.7			3.44218	3.29312	4.70983	4.86614	5.40028	5.38325	5.61677	5.58524	5.70628	5.63016	5.93768	7.01833
2.8			3.75518	3.66073	5.08067	5.04609	5.72571	5.71403	5.92367	5.89999	6.00163	5.94026	6.21596	7.33255
2.9			4.08455	4.02626	5.41249	5.40359	6.05081	6.04287	6.23142	6.21366	6.29903	6.24963	6.49679	7.64692
3.0			4.42624	4.39103	5.76416	5.75894	6.37538	6.37008	6.53988	6.52659	6.55829	6.55858	6.78011	7.96142
3.1			4.77652	4.75562	6.11508	6.11237	6.69931	6.69592	6.84891	6.83901	6.89920	6.86735	7.06587	8.27602
3.2			5.13236	5.12021	6.46483	6.46402	7.02254	7.02060	7.15844	7.15110	7.20162	7.17611	7.35398	8.59067
3.3			5.49152	5.48479	6.81318	6.81401	7.34504	7.34427	7.48838	7.46301	7.50539	7.48499	7.64434	8.90536
3.4			5.85238	5.84921	7.15998	7.18244	7.66681	7.66707	7.77870	7.77485	7.81036	7.79408	7.93685	9.22005
3.5			6.21382	6.21334	7.50513	7.50941	7.98788	7.98912	8.08935	8.08669	8.11641	8.10344	8.23140	9.53472
3.6			6.57507	6.57705	7.84859	7.85501	8.30825	8.31053	8.40029	8.39861	8.42342	8.41312	8.52788	9.84935
3.7			6.93554	6.94027	8.19034	8.19933	8.62796	8.63137	8.71149	8.71065	8.73129	8.72314	8.82617	10.16391
3.8			7.29483	7.30293	8.53040	8.54245	8.94705	8.95174	9.02292	9.02283	9.03992	9.03351	9.12615	10.47838
3.9			7.65266	7.66502	8.86878	8.88444	9.26553	9.27169	9.33457	9.33518	9.34923	9.34423	9.42772	10.79272
4.0			8.00880	8.02654	9.20553	9.22538	9.58343	9.59130	9.64640	9.64772	9.65914	9.65529	9.73076	11.10693
4.1				8.38748		9.58533		9.91062		9.96046		9.96869		
4.2				8.74787		9.90435		10.22968		10.27339		10.27839		
4.3				9.10771		10.24248		10.54885		10.58652		10.59040		
4.4				9.46899		10.57977		10.86725		10.89986		10.90268		
4.5				9.82571		10.91625		11.18580		11.21338		11.21521		
4.6				10.18384		11.25195		11.50425		11.52709		11.52799		
4.7				10.54135		11.58690		11.82260		11.84098		11.84099		
4.8				10.89819		11.92111		12.14088		12.15504		12.15418		
4.9				11.25432		12.25460		12.45909		12.46926		12.46758		
5.0				11.60968		12.58739		12.77725		12.78364		12.78110		
5.1				11.96423		12.91948		13.09535		13.09815		13.09480		
5.2				12.31792		13.25089		13.41341		13.41280		13.40864		
5.3				12.67070		13.58163		13.73141		13.72757		13.72259		
5.4				13.02254		13.91171		14.04937		14.04244		14.03666		
5.5				13.37339		14.24113		14.36727		14.35741		14.35083		
5.6				13.72323		14.56991		14.68511		14.67246		14.66509		
5.7				14.07203		14.89806		15.00289		14.98759		14.97943		
5.8				14.41979		15.22558		15.32059		15.30278		15.29385		
5.9				14.76649		15.55249		15.63822		15.61802		15.60832		
6.0				15.11213		15.87880		15.95576		15.93330		15.92285		
6.1				15.45671		16.20452		16.27320		16.24860		16.23742		
6.2				15.80023		16.52966		16.59053		16.56393		16.55203		
6.3				16.14271		16.85423		16.90776		16.87926		16.86667		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE } WAVE LENGTH
B = $2\pi w/\lambda_o$ NORMALIZED FREQ.
BC CUTOFF-FREQ.
K = $2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}, \ \delta = \frac{d}{w}, \ \gamma = \frac{c}{w}$

8.3 16.14271 16.85423 16.90778 16.87926 15.86667

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 9.00 DELTA = 0.40

$\alpha+\delta/2$					0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.800
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC					1.09843	1.51956	0.93966	1.32731	0.82708	1.23275	0.74639	1.20456	0.63950	0.60228
B														
0.7					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.70419	0.94570
0.8					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.62381	-0.00000	1.19143	1.40203
0.9					-0.00000	-0.00000	-0.00000	-0.00000	0.71234	-0.00000	1.09765	-0.00000	1.57326	1.76906
1.0					-0.00000	-0.00000	0.61850	-0.00000	1.14298	-0.00000	1.46441	-0.00000	1.91463	2.14593
1.1					0.09073	-0.00000	1.05245	-0.00000	1.49568	-0.00000	1.79357	-0.00000	2.23486	2.48669
1.2					0.75928	-0.00000	1.40093	-0.00000	1.82049	-0.00000	2.10507	-0.00000	2.54261	2.81600
1.3					1.11468	-0.00000	1.72294	-0.00000	2.13379	1.07808	2.40769	1.29344	2.84252	3.14346
1.4					1.42310	-0.00000	2.03680	1.11510	2.44308	1.73913	2.70611	1.89140	3.13741	3.46514
1.5					1.71744	-0.00000	2.35075	1.76187	2.75216	2.24732	3.00300	2.37480	3.42906	3.79433
1.6					2.01098	1.14611	2.66879	2.26824	3.06296	2.69136	3.29994	2.80407	3.71872	4.10180
1.7					2.31082	1.76380	2.99245	2.71504	3.37620	3.09948	3.59788	3.20150	4.00724	4.41806
1.8					2.62067	2.25848	3.32177	3.12869	3.69201	3.48476	3.89729	3.57812	4.29526	4.73341
1.9					2.94181	2.70047	3.65687	3.52144	4.01009	3.85439	4.19841	3.94026	4.58323	5.04804
2.0					3.27362	3.11369	3.99351	3.90000	4.32998	4.21279	4.50126	4.29186	4.87149	5.36209
2.1					3.61426	3.50894	4.33338	4.26839	4.65114	4.56283	4.80579	4.63562	5.16029	5.67562
2.2					3.96133	3.89353	4.67432	4.62918	4.97312	4.90649	5.11185	4.97339	5.44983	5.98870
2.3					4.31285	4.26786	5.01544	4.98409	5.29649	5.24617	5.41927	5.30652	5.74023	6.30136
2.4					4.66598	4.63707	5.35608	5.33429	5.61793	5.57989	5.72787	5.63601	6.03160	6.61361
2.5					5.02018	5.00154	5.69678	5.68063	5.94022	5.91142	6.03760	6.96261	6.32398	6.92649
2.6					5.37413	5.36216	6.03427	6.02373	6.26217	6.24034	6.34797	6.28691	6.61743	7.23700
2.7					5.72716	5.71964	6.37136	6.36404	6.58366	6.56711	6.65915	6.60935	6.91194	7.54816
2.8					6.07886	6.07411	6.70699	6.70194	6.90464	6.89207	6.97091	6.93028	7.20763	7.85899
2.9					6.42897	6.42618	7.04113	7.03768	7.22506	7.21560	7.28312	7.24997	7.50417	8.16949
3.0					6.77737	6.77699	7.37380	7.37151	7.54488	7.53764	7.59570	7.56865	7.80184	8.47968
3.1					7.12401	7.12372	7.70503	7.70361	7.86414	7.85864	7.90856	7.88648	8.10050	8.78958
3.2					7.46887	7.46956	8.03489	8.03414	8.18283	8.17867	8.22162	8.20360	8.40012	9.09918
3.3					7.81198	7.81361	8.36343	8.36323	8.50097	8.49785	8.53482	8.52012	8.70063	9.40852
3.4					8.15339	8.15601	8.69071	8.69100	8.81869	8.81626	8.84812	8.83612	9.00200	9.71758
3.5					8.49315	8.49688	9.01681	9.01755	9.13570	9.13401	9.16146	9.15166	9.30418	10.02640
3.6					8.83131	8.83630	9.34179	9.34299	9.46234	9.45118	9.47480	9.46681	9.60710	10.33497
3.7					9.16793	9.17437	9.66570	9.66739	9.76852	9.76774	9.78812	9.78161	9.91073	10.64330
3.8					9.50309	9.51117	9.98862	9.99082	10.08427	10.08385	10.10139	10.09608	10.21500	10.95141
3.9					9.83684	9.84677	10.31059	10.31336	10.39961	10.39949	10.41469	10.41027	10.51987	11.26931
4.0					10.16926	10.18124	10.63166	10.63607	10.71457	10.71473	10.72769	10.72418	10.82528	11.56699
4.1						10.61465		10.95600		11.02958		11.03783		
4.2						10.84704		11.27620		11.34407		11.35125		
4.3						11.17648		11.59572		11.65823		11.66444		
4.4						11.50900		11.91461		11.97209		11.97741		
4.6						11.83864		12.23290		12.28666		12.29016		
4.6						12.16745		12.55064		12.59893		12.60272		
4.7						12.49846		12.86784		12.91196		12.91607		
4.8						12.82270		13.18456		13.22473		13.22723		
4.9						13.14919		13.60078		13.53726		13.53920		
5.0						13.47497		13.81657		13.94958		13.85098		
5.1						13.80005		14.13194		14.16167		14.16258		
5.2						14.12447		14.44691		14.47356		14.47400		
5.3						14.44823		14.76150		14.78524		14.78525		
5.4						14.77138		16.07672		15.09674		15.09633		
5.5						15.09391		16.38960		15.40804		15.40724		
5.6						16.41685		15.70314		15.71916		15.71798		
5.7						16.73723		16.01636		16.03011		16.02856		
5.8						16.06805		16.32928		16.34089		16.33896		
5.9						16.37833		16.64191		16.65149		16.64925		
6.0						16.69809		16.95426		16.96194		16.95937		
6.1						17.01734		17.26633		17.27223		17.26933		
6.2						17.33611		17.67814		17.58236		17.67915		
6.3						17.65440		17.88969		17.89234		17.88883		

2w GUIDE WIDTH

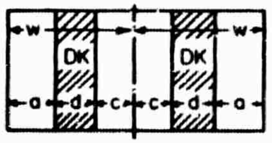
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT

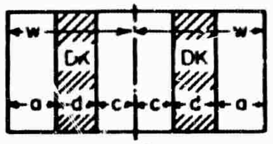


$$\alpha = \frac{a}{w},\ \delta = \frac{d}{w},\ \gamma = \frac{c}{w}$$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 12.25 DELTA = 0.05

$\alpha+\delta/2$	0.025	0.025	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.975
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.56894	3.12561	1.53350	2.80126	1.47967	2.80249	1.39287	2.25480	1.30941	2.13222	1.23795	2.09512	1.13198	1.04756
B														
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.51946
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.55807	0.91173
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.51212	-0.00000	0.89725	1.20730
1.4	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.16201	-0.00000	0.60733	-0.00000	0.84614	-0.00000	1.15844	1.46745
1.5	-0.00000	-0.00000	-0.00000	-0.00000	0.26390	-0.00000	0.64094	-0.00000	0.90016	-0.00000	1.09956	-0.00000	1.38679	1.70995
1.6	0.31413	-0.00000	0.46922	-0.00000	0.65384	-0.00000	0.90949	-0.00000	1.13543	-0.00000	1.32020	-0.00000	1.59678	1.94290
1.7	0.65535	-0.00000	0.75461	-0.00000	0.90065	-0.00000	1.12996	-0.00000	1.34439	-0.00000	1.52289	-0.00000	1.79518	2.170[illegible]
1.8	0.88337	-0.00000	0.96990	-0.00000	1.10516	-0.00000	1.32719	-0.00000	1.53845	-0.00000	1.71451	-0.00000	1.98579	2.39661
1.9	1.07297	-0.00000	1.15507	-0.00000	1.28803	-0.00000	1.51099	-0.00000	1.72332	-0.00000	1.89893	-0.00000	2.17096	2.62219
2.0	1.24187	-0.00000	1.32292	-0.00000	1.45779	-0.00000	1.68647	-0.00000	1.90236	-0.00000	2.07857	-0.00000	2.35229	2.84901
2.1	1.39760	-0.00000	1.47946	-0.00000	1.61898	-0.00000	1.85673	-0.00000	2.07776	-0.00000	2.25507	0.22078	2.53092	3.07811
2.2	1.54414	-0.00000	1.62805	-0.00000	1.77438	-0.00000	2.02391	-0.00000	2.25110	0.82979	2.42965	1.03592	2.70770	3.31030
2.3	1.68391	-0.00000	1.77081	-0.00000	1.92587	-0.00000	2.18959	0.67016	2.42355	1.32533	2.60320	1.47236	2.88330	3.54618
2.4	1.81845	-0.00000	1.90917	-0.00000	2.07489	-0.00000	2.35505	1.22082	2.59603	1.69953	2.77645	1.82346	3.05824	3.78622
2.5	1.94886	-0.00000	2.04415	-0.00000	2.22257	-0.00000	2.52134	1.61243	2.76931	2.02154	2.94997	2.13169	3.23295	4.03074
2.6	2.07591	-0.00000	2.17655	-0.00000	2.36991	0.95890	2.68941	1.94449	2.94401	2.31378	3.12426	2.41460	3.40782	4.27999
2.7	2.20019	-0.00000	2.30699	-0 00000	2.51785	1.38849	2.86011	2.24439	3.12067	2.58687	3.29974	2.68067	3.58316	4.53413
2.8	2.32214	-0.00000	2.43599	-0.00000	2.66731	1.73428	3.03419	2.52435	3.29974	2.84681	3.47675	2.93490	3.75924	4.79328
2.9	2.44211	-0.00000	2.56401	0.88976	2.81925	2.04075	3.21233	2.79105	3.48158	3.09735	3.65561	3.18056	3.93634	5.05753
3.0	2.56038	-0.00000	2.69148	1.28058	2.97470	2.32482	3.39511	3.04861	3.66648	3.34107	3.83659	3.41990	4.11467	5.32698
3.1	2.67718	-0.00000	2.81881	1.59331	3.13474	2.59814	3.58295	3.29977	3.85468	3.57978	4.01991	3.65456	4.29444	5.60172
3.2	2.79269	0.68991	2.94645	1.86884	3.30056	2.85681	3.77617	3.54643	4.04632	3.81484	4.20579	3.88580	4.47586	5.88189
3.3	2.90706	1.06468	3.07487	2.12296	3.47336	3.11317	3.97491	3.79000	4.24150	4.04730	4.39440	4.11457	4.65911	6.16767
3.4	3.02043	1.34590	3.20463	2.36394	3.65428	3.36653	4.17913	4.03151	4.44026	4.27798	4.58586	4.34166	4.84436	6.45928
3.5	3.13291	1.58422	3.33637	2.59686	3.84432	3.61849	4.38868	4.27178	4.64259	4.50753	4.78031	4.56770	5.03178	6.75697
3.6	3.24488	1.79678	3.47089	2.82523	4.04416	3.87028	4.60328	4.51142	4.84843	4.73650	4.97784	4.79321	5.22152	7.06106
3.7	3.35553	1.99185	3.60919	3.05169	4.25407	4.12273	4.82258	4.75092	5.05772	4.96534	5.17852	5.01865	5.41372	7.37188
3.9	3.46583	2.17416	3.75254	3.27834	4.47383	4.37644	5.04619	4.99065	5.27035	5.19442	5.38240	5.24439	5.60852	7.68978
3.9	3.57553	2.34668	3.90249	3.50695	4.70283	4.63183	5.27371	5.23094	5.48622	5.42407	5.58951	5.47075	5.80605	8.01511
4.0	3.68471	2.51143	4.06097	3.73897	4.94013	4.88914	5.50476	5.47202	5.70522	5.65457	5.79988	5.69801	6.00642	8.34816
4.1		2.66986		3.97566		5.1485.		5.71410		5.88614		5.92643		
4.2		2.82303		4.21801		5.41002		5.95734		6.11899		6.15622		
4.3		2.97177		4.46676		5.67364		6.20188		6.35329		6.38755		
4.4		3.11671		4.72240		5.93934		6.44782		6.58920		6.62059		
4.5		3.25836		4.98513		6.20706		6.69528		6.82685		6.85549		
4.6		3.39714		5.25492		6.47676		6.94434		7.06636		7.09236		
4.7		3.53339		5.53150		6.74837		7.19508		7.30783		7 33132		
4.8		3.66740		5.81447		7.02188		7.44759		7.55135		7.57244		
4.9		3.79942		6.10333		7.29728		7.70194		7.79700		7.81581		
5.0		3.92964		6.39754		7.57458		7.95821		8.04484		8.06149		
5.1		4.05824		6.69662		7.85383		8.21648		8.29495		8.30953		
5.2		4.18539		7.00012		8.13510		8.47684		8.54738		8.55998		
5.3		4.31122		7.30772		8.41848		8.73938		8.80218		8.81288		
5.4		4.43584		7.61919		8.70409		9.00418		9.05940		9.06826		
5.5		4.55936		7.93440		8.99204		9.27135		9.31910		9.32615		
5.6		4.68188		8.25334		9.28249		9.54099		9.58132		9.58656		
5.7		4.80349		8.57604		9.57887		9.81320		9.84610		9.84953		
5.8		4.92425		8.90263		9.87143		10.08809		10.11350		10.11507		
5.9		5.04424		9.23325		10.17023		10.36577		10.38356		10.38320		
6.0		5.16353		9.56806		10.47210		10.64638		10.65635		10.65396		
6.1		5.28216		9.90722		10.77718		10.92994		10.93190		10.92735		
6.2		5.40021		10.25086		11.08857		11.21664		11.21028		11.20344		
6.3		5.51771		10.59906		11.39738		11.50656		11.49155		11.48224		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_0 FREE SPACE } WAVE LENGTH
λ_g GUIDE
B = $2\pi w/\lambda_0$ NORMALIZED FREQ.
BC CUTOFF-FREQ.
K = $2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

6.2	5.40021	10.28086	11.08667	11.21664	11.21028	11.20344
6.3	8.61771	10.89906	11.39738	11.50656	11.49155	11.48224

$a=\frac{a}{w}$, $\delta=\frac{d}{w}$, $\gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 12.25 DELTA = 0.10

$\alpha+\delta/2$	0.050	0.050	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.950
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.55507	2.98319	1.48893	2.44914	1.38395	2.08003	1.24438	1.82926	1.13271	1.71444	1.04717	1.68055	0.92907	0.84027
B														
0.9	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.62939
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.63508	1.06917
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.52147	-0.00000	1.01439	1.41553
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.57518	-0.00000	0.91301	-0.00000	1.31287	1.72890
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.49981	-0.00000	0.93420	-0.00000	1.20835	-0.00000	1.57796	2.02766
1.4	-0.00000	-0.00000	-0.00000	-0.00000	0.24838	-0.00000	0.86067	-0.00000	1.21647	-0.00000	1.46838	-0.00000	1.82510	2.32027
1.5	-0.00000	-0.00000	0.19438	-0.00000	0.68431	-0.00000	1.13618	-0.00000	1.46920	-0.00000	1.71078	-0.00000	2.06159	2.61138
1.6	0.38075	-0.00000	0.62747	-0.00000	0.95704	-0.00000	1.38131	-0.00000	1.70778	-0.00000	1.94365	-0.00000	2.29153	2.90375
1.7	0.69468	-0.00000	0.88118	-0.00000	1.18718	-0.00000	1.61295	-0.00000	1.93965	-0.00000	2.17151	0.49831	2.51751	3.19814
1.8	0.91700	-0.00000	1.08965	-0.00000	1.39819	-0.00000	1.83933	-0.00000	2.16916	1.06054	2.39721	1.25879	2.74133	3.49861
1.9	1.10452	-0.00000	1.27588	-0.00000	1.60026	-0.00000	2.06548	0.96402	2.39912	1.59326	2.62273	1.73906	2.96428	3.80278
2.0	1.27274	-0.00000	1.44919	-0.00000	1.79942	-0.00000	2.29488	1.53158	2.63149	2.01598	2.84947	2.13834	3.18735	4.11185
2.1	1.42853	-0.00000	1.61458	-0.00000	2.00013	0.49807	2.53008	1.97221	2.86764	2.38903	3.07850	2.49684	3.41134	4.42599
2.2	1.57559	-0.00000	1.77527	-0.00000	2.20621	1.25315	2.77286	2.35985	3.10848	2.73389	3.31062	2.83106	3.63689	4.74515
2.3	1.71620	-0.00000	1.93366	-0.00000	2.42121	1.74270	3.02432	2.71869	3.35157	3.06108	3.54643	3.14966	3.86484	5.06921
2.4	1.85187	-0.00000	2.09184	-0.00000	2.64847	2.15929	3.28490	3.06014	3.60617	3.37665	3.78637	3.46781	4.09477	5.39806
2.5	1.98364	-0.00000	2.25185	0.74166	2.89087	2.54202	3.55438	3.39053	3.86330	3.68443	4.03076	3.75891	4.32797	5.73159
2.6	2.11228	-0.00000	2.41594	1.31180	3.15034	2.90677	3.83208	3.71375	4.12583	3.98702	4.27980	4.05533	4.56448	6.06972
2.7	2.23336	-0.00000	2.58681	1.73946	3.42746	3.26161	4.11703	4.03233	4.39349	4.28626	4.53361	4.34877	4.80462	6.41238
2.8	2.36234	-0.00000	2.76779	2.11811	3.72123	3.61110	4.40812	4.34799	4.66594	4.58352	4.79221	4.64053	5.04863	6.75954
2.9	2.48459	-0.00000	2.96301	2.47534	4.02940	3.95789	4.70430	4.66192	4.94286	4.87980	5.05560	4.93160	5.29673	7.11115
3.0	2.60540	0.34214	3.17731	2.82401	4.34911	4.30355	5.00464	4.97498	5.22390	5.17589	5.32370	5.22273	5.54910	7.46717
3.1	2.72504	0.91169	3.41562	3.17128	4.67753	4.64895	5.30838	5.28779	5.50877	5.47240	5.59641	5.51453	5.80589	7.82752
3.2	2.84372	1.25562	3.68164	3.52136	5.01221	4.99457	5.61494	5.60080	5.79719	5.76978	5.87359	5.80749	6.06721	8.19209
3.3	2.96166	1.53459	3.97629	3.87659	5.35122	5.34065	5.92385	5.91436	6.08895	6.06842	6.15510	6.10198	6.33312	8.56068
3.4	3.07904	1.77998	4.29716	4.23798	5.69316	5.68730	6.23480	6.22873	6.38384	6.36861	6.44079	6.39828	6.60368	8.93309
3.5	3.19605	2.00478	4.63948	4.60568	6.03698	6.03465	6.54753	6.54413	6.68171	6.67056	6.73048	6.69664	6.87891	9.30902
3.6	3.31290	2.21595	4.95790	4.97923	6.38193	6.38245	6.86188	6.86073	6.98243	6.97447	7.02402	6.99722	7.15678	9.68815
3.7	3.42978	2.41781	5.36768	5.35790	6.72747	6.73105	7.17770	7.17868	7.28586	7.28045	7.32124	7.30014	7.44328	10.07011
3.8	3.54694	2.61341	5.74513	5.74088	7.07318	7.08042	7.49489	7.49813	7.59190	7.58863	7.62197	7.60549	7.73236	10.45433
3.9	3.66466	2.80506	6.12750	6.12743	7.41872	7.43066	7.81335	7.81918	7.90044	7.89906	7.92606	7.91333	8.02596	10.84102
4.0	3.78330	2.99472	6.51274	6.51698	7.76385	7.78189	8.13300	8.14197	8.21140	8.21182	8.23336	8.22369	8.32401	11.22918
4.1		3.18415		6.90914		8.13426		8.46660		8.52694		6.53658		
4.2		3.37510		7.30371		8.48790		8.79318		8.84445		8.85198		
4.3		3.56935		7.70060		8.84296		9.12181		9.16437		9.16990		
4.4		3.76883		8.09983		9.19959		9.45258		9.48672		9.49029		
4.5		3.97568		8.50143		9.55789		9.78558		9.81150		9.81314		
4.6		4.19223		8.90547		9.91796		10.12089		10.13873		10.13841		
4.7		4.42100		9.31195		10.27989		10.45857		10.46839		10.46608		
4.8		4.66452		9.72084		10.64371		10.79868		10.80350		10.79612		
4.9		4.92513		10.13203		11.00945		11.14126		11.13504		11.12849		
5.0		5.20464		10.54533		11.37708		11.48632		11.47202		11.46319		
5.1		5.50403		10.96053		11.74659		11.83388		11.81142		11.80016		
5.2		5.82325		11.37732		12.11790		12.18393		12.15323		12.13943		
5.3		6.16132		11.79539		12.49094		12.53644		12.49744		12.48097		
5.4		6.51663		12.21443		12.86562		12.89137		12.84403		12.82476		
5.5		6.88729		12.63408		13.24162		13.24865		13.19297		13.17079		
5.6		7.27159		13.05405		13.61946		13.60823		13.54423		13.5[illegible]07		
5.7		7.66822		13.47402		13.99837		13.97001		13.89778		13.86958		
5.8		8.07638		13.89375		14.37848		14.33390		14.[illegible]356		14.22230		
5.9		8.49575		14.31299		14.75964		14.69979		14.61155		14.57723		
6.0		8.92637		14.73155		15.14175		15.06759		14.97167		14.93434		
6.1		9.36843		15.14926		15.52469		15.43717		15.33388		15.29363		
6.2		9.82213		15.56600		15.90835		15.80842		15.69811		15.65505		
6.3		10.28749		15.98165		16.29264		16.18122		16.05429		16.01858		

2w GUIDE WIDTH

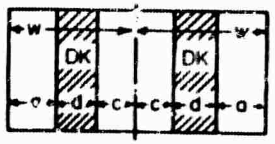
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT

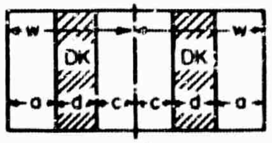


$a=\frac{c}{w}$, $\delta=\frac{d}{w}$, $\gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 12.25 DELTA = 0.15

α-δ/2	0.075	0.075	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.925
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.51450	2.59608	1.43813	2.19157	1.29469	1.82737	1.13032	1.59155	1.01146	1.48586	0.92476	1.45489	0.89[illegible]	0.72745
B														
0.8	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.75140
0.9	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.78272	1.20969
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.67339	-0.00000	1.16911	1.58571
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.71567	-0.00000	1.06325	-0.00000	1.48819	1.93265
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.60554	-0.00000	1.08277	-0.00000	1.37813	-0.00000	1.77787	2.26580
1.3	-0.00000	-0.00000	-0.00000	-0.00000	0.15133	-0.00000	0.98075	-0.00000	1.38919	-0.00000	1.66370	-0.00000	2.05187	2.59480
1.4	-0.00000	-0.00000	-0.00000	-0.00000	0.69541	-0.00000	1.28490	-0.00000	1.67248	-0.00000	1.93538	0.00000	2.31694	2.92319
1.5	-0.00000	-0.00000	0.48013	-0.00000	1.00377	-0.00000	1.56562	-0.00000	1.94642	0.45697	2.20059	0.81976	2.57702	3.25326
1.6	0.54008	-0.00000	0.79438	-0.00000	1.26786	-0.00000	1.83932	0.35412	2.21798	1.32820	2.46360	1.50281	2.83463	3.58523
1.7	0.80938	-0.00000	1.03398	-0.00000	1.51677	-0.00000	2.11442	1.30220	2.49111	1.86090	2.72711	1.99583	3.09154	3.92267
1.8	1.02134	-0.00000	1.24474	-0.00000	1.76359	-0.00000	2.39584	1.85236	2.76820	2.30492	2.99292	2.41939	3.34903	4.26279
1.9	1.20690	-0.00000	1.44160	-0.00000	2.01679	1.04933	2.68646	2.31136	3.05084	2.70570	3.26224	2.80639	3.60809	4.60653
2.0	1.37713	-0.00000	1.63235	-0.00000	2.28282	1.66869	2.98747	2.72748	3.33940	3.08139	3.53588	3.17142	3.86949	4.95374
2.1	1.53756	-0.00000	1.82239	-0.00000	2.56659	2.16328	3.29877	3.11942	3.63408	3.44133	3.81434	3.52237	4.13385	5.30420
2.2	1.69146	-0.00000	2.01646	0.32916	2.87103	2.60880	3.61930	3.49653	3.93461	3.79101	4.09790	3.86410	4.40167	5.65769
2.3	1.84105	-0.00000	2.219[illegible]5	1.21875	3.19647	3.02979	3.94749	3.86441	4.24052	4.13393	4.38665	4.19977	4.67334	6.01401
2.4	1.98802	-0.00000	2.43695	1.74819	3.54071	3.43732	4.28165	4.22542	4.55126	4.47245	4.68056	4.53160	4.94917	6.37299
2.5	2.13383	-0.00000	2.67525	2.20272	3.89987	3.83709	4.62026	4.58257	4.86623	4.80824	4.97950	4.86115	5.22941	6.73446
2.6	2.27984	0.19511	2.94073	2.62782	4.26968	4.23221	4.96207	4.93696	5.18507	5.14250	5.26328	5.18960	5.51421	7.09829
2.7	2.42757	1.02980	3.23819	3.04114	4.64640	4.62436	5.30615	5.28955	5.50719	5.47610	5.59167	5.51779	5.80365	7.46432
2.8	2.57878	1.48087	3.56863	3.45107	5.02717	5.01446	5.65183	5.64101	5.83228	5.80968	5.90440	5.84638	6.09790	7.83242
2.9	2.73575	1.85905	3.92862	3.86172	5.41000	5.40303	5.99667	5.99183	6.16006	6.14374	6.22122	6.17584	6.39684	8.20243
3.0	2.90153	2.20797	4.31131	4.27480	5.79354	5.79034	6.34537	6.34238	6.49029	6.47862	6.54187	6.50652	6.70047	8.57416
3.1	3.08028	2.54568	4.71005	4.69074	6.17691	6.17560	6.69472	6.69294	6.82279	6.81458	6.85606	6.83866	7.00871	8.94749
3.2	3.27759	2.88225	5.11898	5.10927	6.55954	6.56195	7.04360	7.04374	7.15739	7.15182	7.19360	7.17245	7.32146	9.32217
3.3	3.50031	3.22406	5.53391	5.52986	6.94103	6.94654	7.39192	7.39495	7.49398	7.49048	7.52421	7.50799	7.63858	9.69801
3.4	3.75538	3.57523	5.95195	5.95198	7.32113	7.33052	7.74264	7.74676	7.83241	7.83062	7.85769	7.84536	7.95992	10.07481
3.5	4.04719	3.93812	6.37109	6.37519	7.69965	7.71403	8.09269	8.09925	8.17260	8.17236	8.19382	8.18454	8.28532	10.45236
3.6	4.37521	4.31357	6.78990	6.79921	8.07650	8.09724	8.44395	8.45259	8.51443	8.51568	8.53241	8.52558	8.61462	10.83046
3.7	4.73414	4.70122	7.20737	7.22390	8.45156	8.48029	8.79366	8.80586	8.85779	8.86052	8.87328	8.86843	8.94764	11.20898
3.8	5.11662	5.09990	7.62274	7.64920	8.82488	8.86333	9.14451	9.16217	9.20259	9.20719	9.21526	9.21306	9.28421	11.58769
3.9	5.51577	5.50800	8.03548	8.07512	9.19639	9.24646	9.49554	9.51859	9.54372	9.55536	9.56120	9.55943	9.62415	11.96647
4.0	5.92618	5.92395	8.44522	8.50168	9.56614	9.62980	9.84672	9.87615	9.89607	9.90514	9.90794	9.90747	9.93731	12.34518
4.1		6.34637		8.92887		10.0[illegible]40		10.23502		10.26650		10.26715		
4.2		6.77426		9.35664		10.39[illegible]2		10.59511		10.60941		10.60839		
4.3		7.20694		9.78489		10.78157		10.95680		10.96384		10.96118		
4.4		7.64407		10.21347		11.16618		11.31918		11.31977		11.31538		
4.5		8.08548		10.64219		11.55111		11.68316		11.67716		11.67102		
4.6		8.53107		11.07082		11.93633		12.04842		12.03896		12.02803		
4.7		8.98074		11.49913		12.32181		12.41493		12.39615		12.38636		
4.8		9.43430		11.92687		12.70750		12.78264		12.75763		12.74598		
4.9		9.89145		12.35383		13.09335		13.15150		13.12050		13.10665		
5.0		10.35173		12.77978		13.47928		13.52146		13.48486		13.46893		
5.1		10.81459		13.20454		13.86820		13.89245		13.84962		13.83218		
5.2		11.27936		13.62796		14.25113		14.26439		14.21633		14.19657		
5.3		11.74842		14.04992		14.63698		14.63722		14.58372		14.56207		
5.4		12.21201		14.47030		15.02270		15.01085		14.95225		14.92864		
5.5		12.67850		14.88903		15.40824		15.38521		15.32176		15.29624		
5.6		13.14431		15.30607		15.79357		15.76022		15.69216		15.66494		
5.7		13.60891		15.72139		16.17868		16.13581		16.06345		16.03439		
5.8		14.07188		16.13497		16.56344		16.51190		16.43565		16.40486		
5.9		14.53287		16.54682		16.94792		16.88843		16.80838		16.77620		
6.0		14.99160		16.95694		17.33206		17.26532		17.18190		17.14836		
6.1		15.44788		17.36537		17.71584		17.64252		17.55604		17.52131		
6.2		15.90157		17.77213		18.09925		18.01996		17.93076		17.89499		
6.3		16.35258		18.17726		18.48227		18.39760		18.30599		18.26935		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λo FREE SPACE } WAVE LENGTH
λg GUIDE
B = 2πw/λo NORMALIZED FREQ.
BC CUTOFF-FREQ.
K = 2πw/λg NORMALIZED PROPAGATION CONSTANT



$a = \frac{c}{w}$, $\delta = \frac{d}{w}$, $\gamma = c$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 12.25 DELTA = 0.25

α-δ/2			0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.875
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC			1.32353	1.95453	1.14808	1.54290	0.97341	1.33247	0.85664	1.23819	0.77449	1.21068	0.66642	0.60534
B														

MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 12
BC			1.32353	1.95453	1.14808	1.54290	0.97341	1.33247	0.85664	1.23819	0.77449	1.21068	0.66642	0.60534
B														
0.7			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.51145	0.94565
0.8			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.42257	-0.00000	1.06087	1.42115
0.9			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.54174	-0.00000	0.97756	-0.00000	1.45521	1.82901
1.0			-0.00000	-0.00000	-0.00000	-0.00000	0.40565	-0.00000	1.02948	-0.00000	1.36277	-0.00000	1.80355	2.21038
1.1			-0.00000	-0.00000	-0.00000	-0.00000	0.92762	-0.00000	1.40220	-0.00000	1.70346	-0.00000	2.12807	2.57973
1.2			-0.00000	-0.00000	0.53038	-0.00000	1.30289	-0.00000	1.74157	-0.00000	2.02522	-0.00000	2.44038	2.94365
1.3			-0.00000	-0.00000	0.94884	-0.00000	1.64493	-0.00000	2.06947	1.05020	2.33901	1.26806	2.74603	3.30550
1.4			0.58139	-0.00000	1.28203	-0.00000	1.97988	1.10429	2.39531	1.74297	2.65049	1.89131	3.04837	3.66699
1.5			0.91303	-0.00000	1.59580	-0.00000	2.31869	1.78988	2.72372	2.27290	2.96284	2.39405	3.34966	4.02896
1.6			1.18416	-0.00000	1.91184	1.00238	2.66620	2.32629	3.05692	2.73776	3.27795	2.84230	3.65112	4.39173
1.7			1.43617	-0.00000	2.24149	1.71959	3.02375	2.80249	3.39527	3.16754	3.59684	3.26977	3.95409	4.76542
1.8			1.68568	-0.00000	2.59066	2.27446	3.39046	3.24649	3.73889	3.57595	3.92001	3.65802	4.25925	5.11997
1.9			1.94350	0.84619	2.98068	2.76996	3.76429	3.67098	4.08701	3.97044	4.24759	4.04366	4.56716	5.48528
2.0			2.21652	1.56882	3.34903	3.23891	4.14299	4.08274	4.43884	4.35553	4.57950	4.42077	4.87822	5.85122
2.1			2.51825	2.11334	3.75104	3.68505	4.52451	4.48573	4.79359	4.73412	4.91549	4.79208	5.19269	6.21767
2.2			2.84757	2.60023	4.16168	4.12369	4.90731	4.88241	5.15858	5.10819	5.25525	5.16945	5.51074	6.58454
2.3			3.20713	3.06153	4.57685	4.55519	5.29032	5.27437	5.50926	5.47908	5.59843	5.52422	5.83244	6.95172
2.4			3.59298	3.51040	4.99360	4.98142	5.67284	5.66270	5.86922	5.84778	5.94468	5.88731	6.15781	7.31915
2.5			3.99843	3.95299	5.41008	5.40345	6.05449	6.04815	6.23018	6.21497	6.29367	6.24941	6.48679	7.68677
2.6			4.41662	4.39221	5.82513	5.82193	6.43505	6.43126	6.59191	6.58117	6.64508	6.61101	6.81928	8.05451
2.7			4.84211	4.82934	6.23811	6.23730	6.81443	6.81245	6.95426	6.94674	6.99862	6.97245	7.15516	8.42233
2.8			5.27108	5.26486	6.64868	6.64986	7.19261	7.19204	7.31714	7.31196	7.35403	7.33398	7.49425	8.79019
2.9			5.70108	5.69891	7.05664	7.06989	7.56963	7.57029	7.68046	7.67701	7.71109	7.69576	7.83638	9.15803
3.0			6.13055	6.13152	7.46194	7.46759	7.94553	7.94741	8.04416	8.04203	8.06957	8.05789	8.18135	9.52582
3.1			6.55848	6.56269	7.86457	7.87317	8.32037	8.32358	8.40820	8.40714	8.42930	8.42045	8.52898	9.89351
3.2			6.98422	6.99246	8.26458	8.27681	8.69422	8.69896	8.77250	8.77240	8.79012	8.78346	8.87997	10.26107
3.3			7.40735	7.42088	8.66201	8.67867	9.06713	9.07368	9.13712	9.13785	9.15188	9.14692	9.23141	10.62846
3.4			7.82761	7.84805	9.05698	9.07889	9.43917	9.44785	9.50193	9.50353	9.51445	9.51084	9.58583	10.99563
3.5			8.24483	8.27405	9.44956	9.47761	9.81037	9.82159	9.86692	9.86945	9.87772	9.87519	9.94215	11.36257
3.6			8.65897	8.69895	9.83988	9.87493	10.18080	10.19493	10.23205	10.23563	10.24159	10.23994	10.30019	11.72923
3.7			9.07004	9.12280	10.22806	10.27093	10.55050	10.56799	10.59732	10.60206	10.60597	10.60508	10.65980	12.09561
3.8			9.47811	9.54562	10.61423	10.66569	10.91952	10.94081	10.96265	10.96874	10.97078	10.97056	11.02082	12.45167
3.9			9.88330	9.96739	10.99850	11.05927	11.28789	11.31344	11.32803	11.33567	11.33595	11.33636	11.38311	12.82741
4.0			10.28577	10.38808	11.38102	11.45172	11.65565	11.68592	11.69342	11.70282	11.70142	11.70244	11.74653	13.19280
4.1				10.80763		11.84307		12.05826		12.07020		12.06878		
4.2				11.22599		12.23337		12.43050		12.43778		12.43535		
4.3				11.64307		12.62262		12.80265		12.80554		12.80212		
4.4				12.05882		13.01086		13.17470		13.17348		13.16907		
4.5				12.47316		13.39811		13.54667		13.54157		13.53619		
4.6				12.88604		13.78438		13.91864		13.90979		13.90344		
4.7				13.29741		14.16969		14.29032		14.27814		14.27082		
4.8				13.70724		14.55408		14.66200		14.64657		14.63831		
4.9				14.11551		14.93764		15.03355		15.01509		15.00586		
5.0				14.52221		15.32011		15.40498		15.38367		15.37354		
5.1				14.92733		15.70180		15.77628		15.75229		15.74125		
5.2				15.33090		16.06264		16.14741		16.12093		16.10902		
5.3				15.73292		16.46266		16.51839		16.48958		16.47683		
5.4				16.13342		16.84186		16.88918		16.85822		16.84467		
5.5				16.53243		17.22028		17.25979		17.22663		17.21252		
5.6				16.92998		17.59793		17.63020		17.59540		17.58038		
5.7				17.32611		17.97485		18.00040		17.96391		17.94873		
5.8				17.72087		18.35106		18.37038		18.33235		18.31607		
5.9				18.11428		18.72657		18.74013		18.70070		18.68367		
6.0				18.50639		19.10142		19.10965		19.06896		19.05164		
6.1				18.89725		19.47562		19.47894		19.43711		19.41937		
6.2				19.28690		19.84919		19.84797		19.80515		19.78703		
6.3				19.67537		20.22216		20.21676		20.17305		20.15463		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

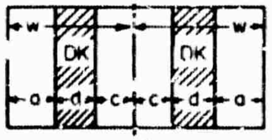
λ_o FREE SPACE } WAVE LENGTH

λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$a = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 12.25 DELTA = 0.40

α+δ/2					0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.800
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC					0.98645	1.31862	0.83013	1.14614	0.72417	1.06234	0.54981	1.03747	0.55280	0.51873
B														
0.6					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.67032	0.92913
0.7					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.65042	-0.00000	1.23457	1.45632
0.8					-0.00000	-0.00000	-0.00000	-0.00000	0.78793	-0.00000	1.17740	-0.00000	1.65665	1.89814
0.9					-0.00000	-0.00000	0.72658	-0.00000	1.26016	-0.00000	1.58797	-0.00000	[illegible]	2.30616
1.0					0.29043	-0.00000	1.19447	-0.00000	1.65714	-0.00000	1.96064	-0.00000	2.41701	2.69727
1.1					0.88478	-0.00000	1.58917	-0.00000	2.02990	0.66599	2.31726	1.12368	2.76830	3.07899
1.2					1.28045	-0.00000	1.96529	1.03502	2.39501	1.70041	2.66703	1.85826	3.11219	3.45518
1.3					1.64196	-0.00000	2.34010	1.80127	2.75950	2.29257	3.01465	2.42043	3.45172	3.82755
1.4					2.00042	1.25872	2.72030	2.3804	3.12635	2.80164	3.36275	2.91265	3.78883	4.19852
1.5					2.36829	1.93595	3.10771	2.88887	3.49644	3.26750	3.71249	3.36646	4.15481	4.56757
1.6					2.75022	2.48840	3.50154	3.35995	3.86957	3.70710	4.06447	3.79627	4.46055	4.93551
1.7					3.14606	2.98720	3.89988	3.30822	4.24503	4.12934	4.41802	4.20996	4.79665	5.30256
1.8					3.55287	3.45714	4.30066	4.24133	4.62201	4.53943	4.77545	4.61233	5.13356	5.66867
1.9					3.96678	3.90952	4.70212	4.66370	4.99977	4.94070	5.13411	5.00648	5.47157	6.03453
2.0					4.38430	4.35022	5.10298	5.07808	5.37769	5.33537	5.49452	5.39464	5.81088	6.39958
2.1					4.80277	4.78257	5.50240	5.48625	5.75536	5.72497	5.85639	5.77801	6.15162	6.76407
2.2					5.22048	5.20356	5.89991	5.88942	6.13246	6.11061	6.21946	6.15797	6.49387	7.12803
2.3					5.63638	5.62944	6.29525	6.28946	6.50882	6.49309	6.58348	6.53522	6.83764	7.49148
2.4					6.04989	6.04602	6.68834	6.68399	6.88435	6.87301	6.94823	6.91035	7.18293	7.85444
2.5					6.46076	6.45897	7.07920	7.07648	7.25901	7.25063	7.31355	7.28380	7.52970	8.21694
2.6					6.86889	6.86842	7.46785	7.46630	7.63278	7.62689	7.67927	7.65590	7.87791	8.57901
2.7					7.27429	7.27301	7.85482	7.85376	8.00570	8.00147	8.04528	8.02692	8.22748	8.94066
2.8					7.67703	7.67890	8.23920	8.23910	8.37780	8.37479	8.41146	8.39704	8.57834	9.30191
2.9					8.07722	8.08033	8.62205	8.62252	8.74913	8.74702	8.77774	8.76641	8.93041	9.66278
3.0					8.47496	8.47961	9.00319	9.00422	9.11972	9.11830	9.14404	9.13514	9.28359	10.02329
3.1					8.87038	8.87650	9.38275	9.38435	9.48962	9.48874	9.51031	9.50332	9.63779	10.38346
3.2					9.28360	9.27177	9.78081	9.76304	9.88888	9.85843	9.87649	9.87101	9.99294	10 74330
3.3					9.68473	9.86516	10.13749	10.14041	10.22754	10.22746	10.24256	10.23827	10.34893	11.10282
3.4					10.04391	10.05869	10.51288	10.51658	10.59563	10.59888	10.60847	10.60512	10.70570	11.46205
3.5					10.43123	10.44707	10.88707	10.89164	10.98318	10.96375	10.97421	10.97161	11.06315	11.82098
3.6					10.81681	10.83480	11.26013	11.26868	11.33023	11.33112	11.33975	11.33775	11.42123	12.17964
3.7					11.20077	11.22316	11.63214	11.63877	11.69680	11.69503	11.70509	11.70356	11.77984	12.53804
3.8					11.58319	11.60924	12.00316	12.01099	12.06291	12.06450	12.07019	12.06906	12.13893	12.89617
3.9					11.96418	11.99409	12.37127	12.38240	12.42859	12.43057	12.43507	12.43426	12.49844	13.25406
4.0					12.34383	12.37779	12.74282	12.75306	12.79388	12.79627	12.79970	12.79917	12.85831	13.61171
4.1						12.76037		13.12303		13.16161		13.16379		
4.2						13.14190		13.49230		13.52861		13.52815		
4.3						13.52241		13.86097		13.89130		13.89223		
4.4						13.90195		14.22907		14.25868		14.26606		
4.5						14.28056		14.59681		14.61978		14.61963		
4.6						14.65827		14.96364		14.98389		14.98298		
4.7						15.03511		15.33018		15.34714		15.34604		
4.8						15.41112		15.69628		15.71043		15.70888		
4.9						15.78632		16.06188		16.07347		16.07150		
5.0						16.18075		16.42709		16.43827		16.43389		
5.1						16.53443		16.79189		16.79884		16.79606		
5.2						16.90739		17.15831		17.16117		17.15802		
5.3						17.27966		17.52037		17.52329		17.51977		
5.4						17.65128		17.88406		17.88519		17.88131		
5.5						18.02222		18.24742		18.24838		18.24266		
5.6						18.39255		18.61045		18.60836		18.60381		
5.7						18.78229		18.97317		18.98964		18.96477		
5.8						19.13145		19.33558		19.33073		19.32555		
5.9						19.50005		19.69770		19.69161		19.68615		
6.0						19.88812		20.05953		20.05231		20.04658		
6.1						20.23567		20.42109		20.41203		20.40883		
6.2						20.60273		20.78239		20.77318		20.76691		
6.3						20.96931		21.14343		21.13331		21.12683		

2w GUIDE WIDTH

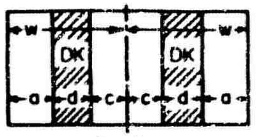
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE }

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}, \ \delta = \frac{d}{w}, \ \gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.05

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.05

$\alpha - \delta/2$	0.025	0.025	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.975
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.56830	3.11952	1.51960	2.66929	1.44737	2.32818	1.33868	2.07388	1.24170	1.95317	1.16269	1.91711	1.04938	0.95855
B														
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.49999	0.92755
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.41039	-0.00000	0.88441	1.25261
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.60206	-0.00000	0.80716	-0.00000	1.16900	1.53935
1.4	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.49603	-0.00000	0.84795	-0.00000	1.08727	-0.00000	1.41588	1.80854
1.5	-0.00000	-0.00000	-0.00000	-0.00000	0.43886	-0.00000	0.82355	-0.00000	1.11000	-0.00000	1.32783	-0.00000	1.64268	2.06944
1.6	0.31746	-0.00000	0.52113	-0.00000	0.76666	-0.00000	1.07297	-0.00000	1.33958	-0.00000	1.54823	-0.00000	1.85730	2.32709
1.7	0.65717	-0.00000	0.79387	-0.00000	0.99293	-0.00000	1.29168	-0.00000	1.55237	-0.00000	1.75696	-0.00000	2.06407	2.58477
1.8	0.88490	-0.00000	1.00617	-0.00000	1.19654	-0.00000	1.49458	-0.00000	1.75569	-0.00000	1.95863	-0.00000	2.26565	2.84464
1.9	1.07439	-0.00000	1.18192	-0.00000	1.38281	-0.00000	1.68883	-0.00000	1.95372	-0.00000	2.15606	-0.00000	2.46385	3.10821
2.0	1.24324	-0.00000	1.35988	-0.00000	1.55889	-0.00000	1.87565	-0.00000	2.14919	0.72582	2.35125	0.97122	2.65995	3.37659
2.1	1.39896	-0.00000	1.51833	-0.00000	1.72895	-0.00000	2.06693	0.53838	2.34402	1.30772	2.54556	1.46699	2.85491	3.65053
2.2	1.54881	-0.00000	1.66961	-0.00000	1.89583	-0.00000	2.25557	1.20592	2.53966	1.72510	2.74008	1.85311	3.04951	3.93058
2.3	1.68529	-0.00000	1.81582	-0.00000	2.06171	-0.00000	2.44725	1.64600	2.73724	2.08044	2.93556	2.19428	3.24436	4.21709
2.4	1.81986	-0.00000	1.95845	-0.00000	2.22852	0.87749	2.64256	2.01510	2.93765	2.40228	3.13300	2.50522	3.44000	4.51029
2.5	1.95031	-0.00000	2.09865	-0.00000	2.39807	1.38687	2.84307	2.34817	3.14161	2.70341	3.33266	2.79807	3.63686	4.81035
2.6	2.07740	-0.00000	2.23740	-0.00000	2.57222	1.78326	3.04982	2.65991	3.34965	2.99085	3.53513	3.07870	3.83535	5.11740
2.7	2.20173	-0.00000	2.37556	0.52273	2.75291	2.13304	3.26356	2.95808	3.56218	3.26594	3.74081	3.35084	4.03582	5.43162
2.8	2.32373	-0.00000	2.51403	1.09937	2.94217	2.45839	3.48475	3.24735	3.77943	3.54055	3.95003	3.61708	4.23560	5.75323
2.9	2.44376	-0.00000	2.65373	1.49020	3.14200	2.76992	3.71355	3.53078	4.00156	3.80781	4.16307	3.87927	4.44400	6.08251
3.0	2.56210	-0.00000	2.79575	1.82204	3.35420	3.07369	3.94978	3.81045	4.22857	4.07216	4.38014	4.13883	4.65228	6.41984
3.1	2.67896	-0.00000	2.94140	2.12565	3.58006	3.37342	4.19304	4.08785	4.46041	4.33479	4.60141	4.39684	4.86370	6.76867
3.2	2.79484	0.71904	3.09237	2.41477	3.82012	3.67155	4.44277	4.36408	4.69697	4.59659	4.82701	4.65418	5.07851	7.12053
3.3	2.90899	1.08536	3.25077	2.69720	4.07398	3.96966	4.69832	4.63994	4.93808	4.85830	5.05701	4.91155	5.29692	7.48494
3.4	3.02244	1.36366	3.41936	2.97810	4.34048	4.26878	4.95903	4.91637	5.18358	5.12080	5.29145	5.16955	5.51913	7.85946
3.5	3.13499	1.60054	3.60152	3.26115	4.61790	4.56954	5.22430	5.19293	5.43329	5.38367	5.53043	5.42865	5.74534	8.24462
3.6	3.24675	1.81234	3.80107	3.54904	4.90440	4.87230	5.49360	5.47089	5.68704	5.64823	5.77385	5.68928	5.97570	8.64048
3.7	3.35780	2.00701	4.02169	3.84369	5.19820	5.17725	5.76650	5.75026	5.94467	5.91449	6.02173	5.95177	6.21038	9.04751
3.8	3.46820	2.18914	4.26591	4.14634	5.49779	5.48444	6.04265	6.03125	6.20606	6.18276	6.27402	6.21642	6.44949	9.46556
3.9	3.57802	2.36164	4.53413	4.45759	5.80196	5.79386	6.32176	6.31408	6.47109	6.45326	6.53067	6.48349	6.69317	9.89432
4.0	3.68730	2.52650	4.82448	4.77752	6.10972	6.10551	6.60362	6.59892	6.73966	6.72619	6.79162	6.75317	6.94150	10.33324
4.1		2.68513		5.10574		6.41937		6.88591		7.00174		7.02565		
4.2		2.83859		5.44162		6.73543		7.17520		7.28005		7.30106		
4.3		2.98768		5.78437		7.05376		7.46694		7.56124		7.57953		
4.4		3.13304		6.13320		7.37445		7.76126		7.84543		7.86116		
4.5		3.27518		6.48747		7.69762		8.05831		8.13271		8.14602		
4.6		3.41451		6.84668		8.02344		8.35824		8.42318		8.43418		
4.7		3.55138		7.21053		8.35211		8.66120		8.71692		8.72568		
4.8		3.68607		7.57892		8.68387		8.96736		9.01401		9.02058		
4.9		3.81883		7.95190		9.01895		9.27687		9.31452		9.31890		
5.0		3.94988		8.32967		9.35761		9.58992		9.61853		9.62069		
5.1		4.07939		8.71248		9.70008		9.90669		9.92613		9.92698		
5.2		4.20752		9.10062		10.04660		10.22734		10.23739		10.23480		
5.3		4.33443		9.49437		10.39740		10.55206		10.55240		10.54721		
5.4		4.46023		9.89395		10.75264		10.88101		10.87125		10.86325		
5.5		4.58805		10.29950		11.11248		11.21435		11.19403		11.18297		
5.6		4.70898		10.71104		11.47704		11.55223		11.52085		11.50645		
5.7		4.83214		11.12848		11.84638		11.89478		11.85179		11.83377		
5.8		4.95460		11.55163		12.22053		12.24211		12.18698		12.16501		
5.9		5.07647		11.95018		12.59948		12.59431		12.52647		12.50027		
6.0		5.19783		12.41372		12.98316		12.95144		12.87040		12.83967		
6.1		5.31878		12.85180		13.37148		13.31355		13.21887		13.18332		
6.2		5.43935		13.29391		13.76430		13.68064		13.57196		13.53134		
6.3		5.55969		13.73954		14.16147		14.05270		13.92976		13.88347		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

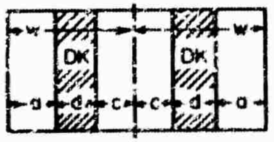
λ_0 FREE SPACE } WAVE LENGTH

λ_g GUIDE } WAVE LENGTH

$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.10

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.10

$\alpha+\delta/2$	0.050	0.050	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.950
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.54921	2.90768	1.45714	2.24925	1.32194	1.88053	1.16242	1.64360	1.04481	1.33716	0.98817	1.50592	0.84112	0.75296
B														
0.8	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.59207
0.9	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.60887	1.09390
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.48789	-0.00000	1.03291	1.48094
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.54882	-0.00000	0.92889	-0.00000	1.36027	1.83254
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.43218	-0.00000	0.95309	-0.00000	1.25368	-0.00000	1.680[illegible]1	2.17054
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.85677	-0.00000	1.26617	-0.00000	1.54027	-0.00000	1.92288	2.50456
1.4	-0.00000	-0.00000	-0.00000	-0.00000	0.58403	-0.00000	1.16796	-0.00000	1.54828	-0.00000	1.80935	-0.00000	2.18447	2.83968
1.5	-0.00000	-0.00000	0.39374	-0.00000	0.91007	-0.00000	1.44634	-0.00000	1.81753	-0.00000	2.07012	-0.00000	2.44030	3.17879
1.6	0.40634	-0.00000	0.73452	-0.00000	1.17533	-0.00000	1.71343	-0.00000	2.08256	0.96416	2.32770	1.18415	2.69330	3.52345
1.7	0.71142	-0.00000	0.97886	-0.00000	1.41946	-0.00000	1.97945	0.91857	2.34825	1.58833	2.58530	1.73875	2.94550	3.87448
1.8	0.93181	-0.00000	1.18939	-0.00000	1.65776	-0.00000	2.25046	1.57033	2.61766	2.06478	2.84507	2.18779	3.19838	4.23218
1.9	1.11881	-0.00000	1.38348	-0.00000	1.89948	0.53183	2.53033	2.06369	2.89271	2.48193	3.10856	2.58844	3.45309	4.59655
2.0	1.28710	-0.00000	1.56951	-0.00000	2.15175	1.35995	2.82128	2.49738	3.17450	2.86740	3.37604	2.96188	3.71056	4.96748
2.1	1.44331	-0.00000	1.75294	-0.00000	2.42058	1.90349	3.12409	2.89991	3.46353	3.22400	3.65066	3.31871	3.97153	5.34479
2.2	1.59105	-0.00000	1.93832	-0.00000	2.71058	2.37211	3.43836	3.28458	3.75982	3.58486	3.93052	3.66509	4.23666	5.72831
2.3	1.73256	-0.00000	2.13030	0.81725	3.02416	2.80748	3.78286	3.65846	4.06311	3.93640	4.21671	4.00498	4.50647	6.11795
2.4	1.86938	-0.00000	2.33427	1.45931	3.36083	3.22611	4.09593	4.02576	4.37294	4.27985	4.50936	4.34107	4.78141	6.51363
2.5	2.00281	-0.00000	2.55689	1.95327	3.71747	3.63603	4.43588	4.38916	4.68879	4.62037	4.80848	4.67531	5.06185	6.91828
2.6	2.13277	-0.00000	2.80604	2.40110	4.08953	4.04144	4.78125	4.75040	5.01018	4.96031	5.11395	5.00911	5.34808	7.32286
2.7	2.26076	-0.00000	3.08961	2.83228	4.47247	4.44463	5.13085	5.11069	5.33653	5.30046	5.42563	5.34353	5.64034	7.73623
2.8	2.38701	-0.00000	3.41271	3.25967	4.86255	4.84679	5.48382	5.47087	5.66754	5.64162	5.74330	5.67937	5.93879	8.15520
2.9	2.51193	-0.00000	3.77465	3.68940	5.28703	5.24857	5.83954	5.83153	6.00285	5.98439	6.06672	6.01723	6.24352	8.57948
3.0	2.63594	0.84216	4.16898	4.12402	5.65404	5.68031	6.19759	6.13313	6.34219	6.32523	6.39565	6.35757	6.55458	9.00868
3.1	2.75942	1.23352	4.58679	4.56410	6.05231	6.05223	6.55768	6.55603	6.68534	6.67648	6.72932	6.70072	6.87198	9.44232
3.2	2.88276	1.54434	5.01996	5.00917	6.45099	6.45464	6.91961	6.92052	7.03210	7.02240	7.06897	7.04690	7.19568	9.87986
3.3	3.00641	1.81835	5.46240	5.45839	6.84946	6.85744	7.28323	7.28584	7.38232	7.37915	7.41285	7.39629	7.52558	10.32068
3.4	3.13090	2.07233	5.90991	5.91094	7.24730	7.26116	7.64840	7.65520	7.73584	7.73490	7.76121	7.74895	7.86161	10.76420
3.5	3.25590	2.31539	6.35957	6.36523	7.64417	7.66898	8.01502	8.02583	8.09250	8.09371	8.11381	8.10496	8.20363	11.20981
3.6	3.38530	2.55360	6.80930	6.82394	8.03981	8.07210	8.38297	8.39889	8.45215	8.45567	8.47041	8.46435	8.55152	11.65695
3.7	3.51736	2.79175	7.25755	7.28402	8.43403	8.47966	8.75214	8.77458	8.81463	8.82082	8.83081	8.82707	8.90514	12.10512
3.8	3.65494	3.03418	7.70316	7.74656	8.82671	8.88948	9.12240	9.15305	9.17979	9.18919	9.19478	9.19310	9.26435	12.55387
3.9	3.80085	3.28514	8.14533	8.21175	9.21777	9.30119	9.49366	9.53444	9.54743	9.56080	9.56213	9.56242	9.62901	13.00280
4.0	3.95945	3.54900	8.58352	8.67974	9.60718	9.71816	9.86578	9.91896	9.91740	9.93556	9.93268	9.93496	9.[illegible]9897	13.45159
4.1		3.83024		9.15061		10.13151		10.30552		10.31376		10.31069		
4.2		4.13306		9.62432		10.55032		10.69739		10.69515		10.68957		
4.3		4.46089		10.10071		10.97161		11.09156		11.07979		11.07156		
4.4		4.81867		10.57947		11.39534		11.48905		11.46767		11.45663		
4.5		5.19742		11.06020		11.82145		11.88987		11.85877		11.84475		
4.6		5.60434		11.54246		12.24981		12.29398		12.25309		12.23890		
4.7		6.03348		12.02573		12.68030		12.70130		12.65058		12.63007		
4.8		6.48169		12.50952		13.11274		13.11175		13.05121		13.02725		
4.9		6.94533		12.99337		13.54696		13.52521		13.45493		13.42742		
5.0		7.42876		13.47687		13.98278		13.94155		13.86167		13.83057		
5.1		7.91928		13.95963		14.42001		14.36059		14.27138		14.23668		
5.2		8.42594		14.44136		14.88848		14.78218		14.68395		14.64572		
5.3		8.94916		14.92181		15.29800		15.20514		15.09931		15.05766		
5.4		9.48528		15.40079		15.73843		15.63229		15.51736		15.47246		
5.5		10.03825		15.87815		16.17961		16.06045		15.93797		15.89006		
5.6		10.80437		16.35382		16.62139		16.49042		16.36105		16.31040		
5.7		11.18319		16.82770		17.06365		16.92205		16.78646		16.73340		
5.8		11.77252		17.29976		17.60627		17.35514		17.21409		17.15896		
5.9		12.37015		17.77001		17.94915		17.78956		17.64379		17.58699		
6.0		12.97310		18.23844		18.39219		18.22513		18.07544		18.01737		
6.1		13.57889		18.70807		18.83532		18.66173		18.50891		18.44996		
6.2		14.18521		19.16995		19.27845		19.09921		18.94408		18.88468		
6.3		14.79017		19.63312		19.72152		19.53746		19.38074		19.32128		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

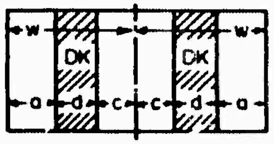
λ_0 FREE SPACE WAVE LENGTH

λ_g GUIDE WAVE LENGTH

$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w},\ \delta = \frac{d}{w},\ \gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.15

$\alpha+\delta/2$	0.075	0.075	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.925

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.15

$\alpha+\delta/2$	0.075	0.075	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.925
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.49218	2.40547	1.38793	1.98135	1.21375	1.63380	1.03806	1.41663	0.91931	1.32050	0.83510	1.29245	0.72363	0.64623
B														
0.7	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.68581
0.8	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.75515	1.21878
0.9	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.66228	-0.00000	1.19082	1.64367
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.72707	-0.00000	1.09809	-0.00000	1.54481	2.03326
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.60980	-0.00000	1.13564	-0.00000	1.44723	-0.00000	1.86620	2.41475
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	1.03230	-0.00000	1.47830	-0.00000	1.76585	-0.00000	2.17141	2.79128
1.3	-0.00000	-0.00000	-0.00000	-0.00000	0.67115	-0.00000	1.37747	-0.00000	1.79916	-0.00000	2.07175	0.35434	2.46830	3.16928
1.4	-0.00000	-0.00000	0.21827	-0.00000	1.03056	-0.00000	1.70255	-0.00000	2.11379	1.17573	2.37334	1.37162	2.76137	3.55093
1.5	0.16355	-0.00000	0.68423	-0.00000	1.34010	-0.00000	2.02646	1.21798	2.42970	1.81356	2.67531	1.95360	3.05352	3.93716
1.6	0.61892	-0.00000	0.96995	-0.00000	1.64048	-0.00000	2.35822	1.86107	2.75087	2.32237	2.98054	2.43757	3.34675	4.32821
1.7	0.87590	-0.00000	1.21524	-0.00000	1.94937	1.08375	2.70210	2.38277	3.07925	2.77618	3.29082	2.87540	3.64262	4.72396
1.8	1.08[illegible]	-0.00000	1.44670	-0.00000	2.27792	1.78121	3.05920	2.85312	3.41650	3.20032	3.60722	3.28734	3.94195	5.12412
1.9	1.27541	-0.00000	1.67763	-0.00000	2.63253	2.33807	3.42840	3.29621	3.75944	3.60689	3.93033	3.68370	4.24589	5.52837
2.0	1.45173	-0.00000	1.91850	0.53941	3.01450	2.84301	3.80743	3.72336	4.11043	4.00268	4.26036	4.07049	4.55501	5.93639
2.1	1.62110	-0.00000	2.17948	1.41793	3.42027	3.32304	4.19376	4.14072	4.46764	4.39189	4.59726	4.45156	4.86979	6.34792
2.2	1.78725	-0.00000	2.47145	2.00853	3.84357	3.78974	4.58514	4.55191	4.83025	4.77724	4.94083	4.82949	5.19059	6.76271
2.3	1.95335	-0.00000	2.80410	2.53223	4.27793	4.24869	4.97986	4.95921	5.19751	5.16062	5.29075	5.20607	5.51765	7.18056
2.4	2.12264	-0.00000	3.18187	3.03176	4.71828	4.70271	5.37675	5.36408	5.56883	5.54330	5.64663	5.58255	5.85108	7.60124
2.5	2.29898	1.09409	3.60085	3.52298	5.16119	5.15330	5.77503	5.76751	5.94375	5.92620	6.00808	5.95984	6.19093	8.02453
2.6	2.48750	1.62952	4.05083	4.01241	5.60451	5.60128	6.17424	6.17020	6.32188	6.30997	6.37467	6.33856	6.53713	8.45016
2.7	2.69534	2.08722	4.52057	4.50239	6.04698	6.04715	6.57411	6.57265	6.70296	6.69506	6.74602	6.71914	6.88956	8.87787
2.8	2.93216	2.52098	5.00130	4.99338	6.48781	6.49130	6.97449	6.97527	7.08675	7.08180	7.12174	7.10186	7.24805	9.30734
2.9	3.20947	2.95168	5.48720	5.48514	6.92657	6.93406	7.37529	7.37837	7.47307	7.47038	7.50146	7.48689	7.61238	9.73826
3.0	3.53678	3.38951	5.97460	5.97727	7.36298	7.37576	7.77644	7.78220	7.86175	7.86094	7.88486	7.87432	7.98229	10.17032
3.1	3.91583	3.83916	6.46112	6.46953	7.79687	7.81669	8.17789	8.18698	8.25262	8.25359	8.27163	8.26417	8.35755	10.60321
3.2	4.33874	4.30178	6.94519	6.96185	8.22816	8.25714	8.57961	8.59291	8.64553	8.64834	8.66148	8.65643	8.73786	11.03664
3.3	4.79311	4.77641	7.42574	7.45431	8.65683	8.69736	8.98154	9.00013	9.04033	9.04823	9.05414	9.05103	9.12296	11.47035
3.4	5.26764	5.26110	7.90207	7.94704	9.08292	9.13757	9.38364	9.40880	9.43685	9.44424	9.44938	9.44793	9.51258	11.90411
3.5	5.75410	5.75381	8.37377	8.44015	9.50651	9.57793	9.78587	9.81901	9.83495	9.84536	9.84697	9.84702	9.90646	12.33773
3.6	6.24683	6.25292	8.84068	8.93370	9.92771	10.01856	10.18819	10.23084	10.23446	10.24856	10.24671	10.24825	10.30435	12.77102
3.7	6.74185	6.75741	9.30282	9.42763	10.34667	10.45954	10.59065	10.64436	10.63523	10.65379	10.64841	10.65151	10.70698	13.20387
3.8	7.23624	7.26682	9.76037	9.92177	10.76365	10.90089	10.99292	11.05958	11.03713	11.06101	11.05189	11.05674	11.11110	13.63615
3.9	7.72790	7.78101	10.21361	10.41587	11.17856	11.34260	11.39530	11.47651	11.44000	11.47017	11.45701	11.46385	11.51949	14.06778
4.0	8.21537	8.30001	10.66288	10.90963	11.59187	11.78464	11.79767	11.89513	11.84373	11.88122	11.86361	11.87278	11.93088	14.49870
4.1		8.82376		11.40269		12.22694		12.31539		12.29409		12.28346		
4.2		9.35202		11.89471		12.66944		12.73721		12.70672		12.69583		
4.3		5.88428		12.38536		13.11203		13.16053		13.12504		13.10984		
4.4		10.41981		12.87435		13.55465		13.58523		13.54296		13.52542		
4.5		10.95768		13.36145		13.99720		14.01122		13.96245		13.94253		
4.6		11.43687		13.84646		14.43961		14.43838		14.38337		14.36111		
4.7		12.03634		14.32924		14.88180		14.86659		14.80565		14.78112		
4.8		12.57514		14.80969		15.32370		15.29573		15.22922		15.20248		
4.9		13.11240		15.28775		15.76526		15.72568		15.65397		15.62516		
5.0		13.64742		15.76341		16.20642		16.15633		16.07981		16.04905		
5.1		14.17965		16.23666		16.64714		16.58757		16.50667		16.47414		
5.2		14.70868		16.70753		17.08738		17.01930		16.93444		16.90033		
5.3		15.23416		17.17606		17.52712		17.45142		17.36304		17.32755		
5.4		15.75597		17.64231		17.96632		17.88384		17.79239		17.75573		
5.5		16.27397		18.10634		18.40498		18.31648		18.22239		18.18480		
5.6		16.78815		18.56822		18.84307		18.74926		18.65297		18.61467		
5.7		17.29852		19.02803		19.28059		19.18211		19.08406		19.04527		
5.8		17.80513		19.48585		19.71753		19.61498		19.51567		19.47652		
5.9		18.30806		19.94175		20.16389		20.04781		19.94745		19.90833		
6.0		18.80744		20.39582		20.58966		20.48056		20.37961		20.34063		
6.1		19.30336		20.84812		21.02485		20.91316		20.81201		20.77335		
6.2		19.79596		21.29873		21.45946		21.34561		21.24459		21.20641		
6.3		20.28536		21.74774		21.89349		21.77785		21.67728		21.63974		

2w GUIDE WIDTH

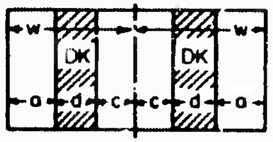
DK RELATIVE DIELECTRIC CONSTANT

λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}, \ \delta = \frac{d}{w}, \ \gamma = \frac{c}{w}$

[redacted] [redacted]ALI[redacted]PRO[redacted]ION[redacted]STAN[redacted]OR [redacted]DES[redacted] WA[redacted]DES[redacted]CH [redacted]IN [redacted]LEC[redacted] SLA[redacted] [redacted] = 1[redacted] [redacted]ELT[redacted]0.2[redacted]

α+δ/2			0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.875
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC			1.24499	1.85591	1.06251	1.38730	0.87852	1.17882	0.78729	1.09199	0.69043	1.06737	0.59024	0.53368
B														
0.6			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.29062	0.83712
0.7			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.27388	-0.00000	1.01958	1.39943
0.8			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.60057	-0.00000	0.97104	-0.00000	1.47091	1.88494
0.9			-0.00000	-0.00000	-0.00000	-0.00000	0.39045	-0.00000	1.06190	-0.00000	1.40690	-0.00000	1.86167	2.29823
1.0			-0.00000	-0.00000	-0.00000	-0.00000	0.98272	-0.00000	1.48160	-0.00000	1.79014	-0.00000	2.22635	2.71857
1.1			-0.00000	-0.00000	0.54831	-0.00000	1.40778	-0.00000	1.86712	0.39822	2.15418	0.80752	2.57826	3.13398
1.2			-0.00000	-0.00000	1.02371	-0.00000	1.80321	0.88718	2.24392	1.50812	2.51197	1.67424	2.92411	3.54806
1.3			0.52552	-0.00000	1.41221	-0.00000	2.19787	1.63208	2.62208	2.15118	2.86980	2.27885	3.26782	3.96251
1.4			0.92274	-0.00000	1.79143	0.81104	2.60215	2.26865	3.00578	2.69224	3.23097	2.79887	3.61189	4.37798
1.5			1.24409	-0.00000	2.18581	1.69928	3.01880	2.81742	3.39619	3.18488	3.59716	3.27880	3.95799	4.79459
1.6			1.55258	-0.00000	2.60504	2.33907	3.44568	3.32417	3.79294	3.64974	3.96905	3.72987	4.30726	5.21228
1.7			1.87259	0.90739	3.04938	2.90456	3.88020	3.80708	4.19496	4.09800	4.34674	4.16800	4.66048	5.63082
1.8			2.22011	1.71197	3.51307	3.43581	4.31891	4.27503	4.60107	4.53548	4.72997	4.59847	5.01818	6.05010
1.9			2.60517	2.32590	3.98850	3.94772	4.75928	4.73303	5.01018	4.96587	5.11829	5.01878	5.38085	6.46993
2.0			3.02980	2.88137	4.46924	4.44803	5.19984	5.18398	5.42146	5.39156	5.51119	5.43715	5.74804	6.89017
2.1			3.48753	3.41189	4.95097	4.94014	5.63899	5.62974	5.83427	5.81415	5.90812	5.85318	6.12036	7.31071
2.2			3.96759	3.93034	5.43118	5.42599	6.07583	6.07152	6.24822	6.23473	6.30856	6.26792	6.49752	7.73147
2.3			4.45998	4.44218	5.90852	5.90669	6.51294	6.51017	6.66304	6.65405	6.71206	6.68206	6.87934	8.15235
2.4			4.95769	4.94964	6.38234	6.38298	6.94729	6.94632	7.07853	7.07284	7.11817	7.09611	7.26580	8.57329
2.5			5.45644	5.45372	6.85238	6.85540	7.37992	7.38043	7.49457	7.49085	7.52654	7.51037	7.65801	8.99422
2.6			5.95376	5.95483	7.31855	7.32438	7.81093	7.81288	7.91108	7.90895	7.93684	7.92503	8.05029	9.41508
2.7			6.44822	6.45322	7.78091	7.79028	8.24044	8.24396	8.32799	8.32709	8.34878	8.34021	8.44813	9.83579
2.8			6.93902	6.94912	8.23957	8.25343	8.66854	8.67394	8.74525	8.74540	8.76211	8.75598	8.84922	10.25630
2.9			7.42568	7.44277	8.69485	8.71411	9.09534	9.10301	9.16279	9.16395	9.17682	9.17228	9.25327	10.67658
3.0			7.90795	7.93440	9.14634	9.17254	9.52094	9.53137	9.58057	9.58279	9.59212	9.58917	9.65998	11.09651
3.1			8.38576	8.42421	9.59482	9.62894	9.94543	9.95914	9.99853	10.00193	10.00844	10.00660	10.06909	11.51610
3.2			8.85913	8.91233	10.04030	10.08347	10.36888	10.38648	10.41683	10.42139	10.42546	10.42453	10.48034	11.93530
3.3			9.32825	9.39884	10.48298	10.53624	10.79137	10.81343	10.83482	10.84116	10.84304	10.84288	10.89348	12.35408
3.4			9.79333	9.88375	10.92307	10.98737	11.21298	11.24011	11.25304	11.26123	11.26107	11.26164	11.30831	12.77241
3.5			10.25464	10.36703	11.36079	11.43693	11.63373	11.66657	11.67124	11.68159	11.67947	11.68078	11.72482	13.19027
3.6			10.71250	10.84861	11.79633	11.88499	12.05373	12.09284	12.08940	12.10222	12.09815	12.10020	12.14221	13.60764
3.7			11.16721	11.32840	12.22990	12.33180	12.47302	12.51897	12.50746	12.52310	12.51705	12.51991	12.56091	14.02452
3.8			11.61909	11.80631	12.66168	12.77679	12.89168	12.94495	12.92539	12.94420	12.93609	12.93985	12.98056	14.44091
3.9			12.06845	12.28225	13.09185	13.22082	13.30971	13.37079	13.34318	13.36550	13.35523	13.36001	13.40101	14.85681
4.0			12.51557	12.75614	13.52057	13.66310	13.72722	13.79650	13.76078	13.78696	13.77443	13.78034	13.82212	15.27221
4.1				13.22791		14.10427		14.22207		14.20857		14.20082		
4.2				13.69754		14.54418		14.64747		14.63028		14.62143		
4.3				14.16499		14.98283		15.07270		15.05208		15.04214		
4.4				14.63028		15.42029		15.49774		15.47394		15.46293		
4.5				15.09342		15.85657		15.92257		15.89583		15.88379		
4.6				15.55444		16.29172		16.34718		16.31771		16.30470		
4.7				16.01338		16.72577		16.77151		16.73957		16.72564		
4.8				16.47029		17.15878		17.19559		17.16139		17.14658		
4.9				16.92523		17.59072		17.61939		17.58313		17.56753		
5.0				17.37827		18.02170		18.04289		18.00478		17.98844		
5.1				17.82948		18.45174		18.46609		18.42631		18.40933		
5.2				18.27887		18.88086		18.88897		18.84771		18.83015		
5.3				18.72685		19.30910		19.31151		19.26896		19.25091		
5.4				19.17265		19.73650		19.73373		19.69004		19.67158		
5.5				19.61715		20.16310		20.15560		20.11094		20.09215		
5.6				20.06014		20.58891		20.57713		20.53165		20.51261		
5.7				20.50168		21.01399		20.99830		20.95216		20.93293		
5.8				20.94185		21.43836		21.41913		21.37245		21.35312		
5.9				21.38069		21.86203		21.83961		21.79252		21.77316		
6.0				21.81827		22.28505		22.25973		22.21235		22.19302		
6.1				22.25464		22.70744		22.67951		22.63195		22.61270		
6.2				22.68985		23.12922		23.09894		23.05131		23.03220		
6.2				23.12395		23.55043		23.51803		23.47042		23.45151		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

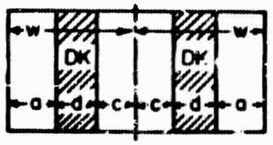
λ_o FREE SPACE} WAVE LENGTH

λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



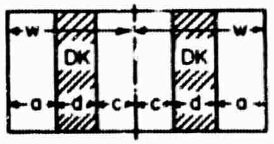
$\alpha=\frac{a}{w}, \ \delta=\frac{d}{w}, \ \gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.40

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 16.00 DELTA = 0.40

x·δ/2					0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.800
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC					0.89002	1.16287	0.74088	1.00765	0.64257	0.93278	0.57444	0.91063	0.48595	0.45532
B														
0.6					-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.49003	-0.00000	1.14938	1.37957
0.7					-0.00000	-0.00000	-0.00000	-0.00000	0.72871	-0.00000	1.14469	-0.00000	1.65122	1.89019
0.8					-0.00000	-0.00000	0.71551	-0.00000	1.27734	-0.00000	1.61402	-0.00000	2.09070	2.35539
0.9					0.26791	-0.00000	1.24976	-0.00000	1.72861	-0.00000	2.03659	-0.00000	2.50260	2.80007
1.0					0.74661	-0.00000	1.70041	-0.00000	2.15395	1.24929	2.44173	1.44955	2.90019	3.23418
1.1					1.39779	-0.00000	2.13548	1.47221	2.57340	2.03065	2.84090	2.17137	3.29003	3.66237
1.2					1.82123	0.89808	2.57365	2.19612	2.99437	2.64245	3.23943	2.75915	3.67579	4.08711
1.3					2.25060	1.79170	3.02019	2.79526	3.41916	3.18527	3.63981	3.28674	4.05974	4.50963
1.4					2.69641	2.44367	3.47465	3.33915	3.84770	3.69067	4.04306	3.78538	4.44332	4.93061
1.5					3.15887	3.01849	3.93397	3.85229	4.27897	4.17299	4.44939	4.25270	4.82747	5.35041
1.6					3.63332	3.55583	4.39542	4.34610	4.71177	4.64000	4.85861	4.71079	5.21282	5.76923
1.7					4.11409	4.07160	4.85657	4.82674	5.14506	5.09631	5.27033	5.15899	5.59978	6.18718
1.8					4.59664	4.57345	5.31589	5.29782	5.57807	5.54488	5.68412	5.60013	5.98860	6.60435
1.9					5.07804	5.06545	5.77254	5.76158	6.01031	5.98765	6.09954	6.03613	6.37943	7.0207
2.0					5.55665	5.54992	6.22613	6.21950	6.44149	6.42599	6.51622	6.46831	6.77230	7.43651
2.1					6.03169	6.02831	6.67657	6.67261	6.87147	6.86086	6.93384	6.89763	7.16721	7.85158
2.2					6.50285	6.50155	7.12391	7.12166	7.30022	7.29295	7.35213	7.32474	7.56410	8.26604
2.3					6.97012	6.97033	7.56831	7.56719	7.72776	7.72278	7.77087	7.75016	7.96288	8.67991
2.4					7.43360	7.43516	8.00995	8.00966	8.15413	8.15076	8.18989	8.17422	8.36345	9.09323
2.5					7.89346	7.89645	8.44903	8.44943	8.57941	8.57717	8.60905	8.59719	8.76566	9.50603
2.6					8.34991	8.35456	8.88574	8.88680	9.00367	9.00224	9.02823	9.01926	9.16938	9.91834
2.7					8.80315	8.80980	9.32028	9.32201	9.42698	9.42617	9.44735	9.44057	9.57449	10.33019
2.8					9.25338	9.26240	9.75280	9.75528	9.84942	9.84909	9.86634	9.86122	9.98083	10.74159
2.9					9.70080	9.71261	10.18348	10.18681	10.27104	10.27113	10.28514	10.28128	10.38828	11.15237
3.0					10.14561	10.16050	10.61246	10.61676	10.69191	10.69237	10.70371	10.70082	10.79671	11.56316
3.1					10.58797	10.60656	11.03987	11.04528	11.11207	11.11291	11.12201	11.11986	11.20600	11.97337
3.2					11.02808	11.05061	11.46582	11.47249	11.53157	11.53280	11.54002	11.53846	11.61604	12.38321
3.3					11.46609	11.49290	11.89043	11.89850	11.95045	11.95210	11.95773	11.95662	12.02673	12.79270
3.4					11.90215	11.93352	12.31381	12.32341	12.36874	12.37085	12.37511	12.37437	12.43796	13.20186
3.5					12.33643	12.37258	12.73603	12.74732	12.78647	12.78909	12.79216	12.79172	12.84966	13.61070
3.6					12.76904	12.81015	13.15720	13.17030	13.20366	13.20687	13.20887	13.20870	13.26173	14.01923
3.7					13.20013	13.24632	13.57738	13.59241	13.62035	13.62419	13.62525	13.62530	13.67412	14.42747
3.8					13.62981	13.68114	13.99666	14.01372	14.03656	14.04110	14.04128	14.04155	14.08675	14.83542
3.9					14.05820	14.11469	14.41509	14.43428	14.45230	14.45762	14.45697	14.45748	14.49957	15.24309
4.0					14.48538	14.54701	14.83274	14.854[illegible]4	14.86760	14.87375	14.87233	14.87301	14.91252	15.65051
4.1						14.97817		15.27334		15.28952		15.28825		
4.2						15.40821		15.69192		15.70495		15.70316		
4.3						15.83717		16.10992		16.12004		16.11777		
4.4						16.26812		16.52736		16.53481		16.53208		
4.5						16.69207		16.94427		16.94927		16.94609		
4.6						17.11609		17.36069		17.36343		17.35982		
4.7						17.54320		17.77662		17.77729		17.77328		
4.8						17.96745		18.19211		18.19088		18.18646		
4.9						18.39087		18.60715		18.60418		18.59939		
5.0						18.81350		19.02178		19.01721		19.01206		
5.1						19.23537		19.43600		19.42999		19.42449		
5.2						19.65651		19.84985		19.84250		19.83668		
5.3						20.07696		20.26332		20.25476		20.24864		
5.4						20.49674		20.67644		20.66678		20.66037		
5.5						20.91588		21.08922		21.07855		21.07188		
5.6						21.33440		21.50166		21.49009		21.48318		
5.7						21.75238		21.91380		21.90140		21.89427		
5.8						22.16973		22.32562		22.31249		22.30515		
5.9						22.58657		22.73711		22.72335		22.71583		
6.0						23.00290		23.14840		23.13400		23.12632		
6.1						23.41874		23.55938		23.54444		23.53662		
6.2						23.83410		23.97009		23.95467		23.94673		
6.3						24.24901		24.38054		24.36470		24.35667		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_o FREE SPACE } WAVE LENGTH
λ_g GUIDE }
$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.
BC CUTOFF-FREQ.
$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$a = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 25.00 DELTA = 0.05

α+δ/2	0.025	0.025	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.975
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.56672	3.10302	1.43338	2.37643	1.36926	2.00851	1.22349	1.76621	1.11008	1.65601	1.02432	1.62362	0.90672	0.81176
B														
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.74830	1.21560
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.63921	-0.00000	1.10831	1.56944
1.2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.68191	-0.00000	1.00428	-0.00000	1.40162	1.90052
1.3	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.60094	-0.00000	1.02314	-0.00000	1.29697	-0.00000	1.66972	2.22396
1.4	-0.00000	-0.00000	-0.00000	-0.00000	0.34985	-0.00000	0.94228	-0.00000	1.30552	-0.00000	1.55066	-0.00000	1.92261	2.54741
1.5	-0.00000	-0.00000	0.23983	-0.00000	0.74097	-0.00000	1.21866	-0.00000	1.56424	-0.00000	1.81009	-0.00000	2.16680	2.87533
1.6	0.32855	-0.00000	0.64787	-0.00000	1.01178	-0.00000	1.47116	-0.00000	1.81246	-0.00000	2.05249	-0.00000	2.40610	3.21050
1.7	0.66162	-0.00000	0.90044	-0.00000	1.24650	-0.00000	1.71484	-0.00000	2.05695	0.77647	2.29209	1.02809	2.64303	3.55468
1.8	0.88872	-0.00000	1.11026	-0.00000	1.46617	-0.00000	1.95669	0.68285	2.30192	1.43636	2.53169	1.59534	2.87937	3.90893
1.9	1.07794	-0.00000	1.29921	-0.00000	1.68086	-0.00000	2.20272	1.39333	2.55018	1.91170	2.77329	2.03969	3.11680	4.27387
2.0	1.24670	-0.00000	1.47655	-0.00000	1.89730	-0.00000	2.45630	1.88890	2.80366	2.32377	3.01837	2.43121	3.35550	4.64990
2.1	1.40240	-0.00000	1.64749	-0.00000	2.12112	1.13615	2.71999	2.31474	3.06371	2.69562	3.26809	2.79375	3.59729	5.03733
2.2	1.54899	-0.00000	1.81573	-0.00000	2.35751	1.69514	2.99535	2.70626	3.33115	3.05052	3.52331	3.13887	3.84264	5.43656
2.3	1.68884	-0.00000	1.98441	-0.00000	2.61133	2.15804	3.28294	3.07857	3.60640	3.39322	3.78472	3.47322	4.09224	5.84817
2.4	1.82352	-0.00000	2.15674	0.52976	2.88657	2.58156	3.58242	3.43969	3.88955	3.72854	4.05280	3.80103	4.34671	6.27292
2.5	1.95408	-0.00000	2.33660	1.28361	3.18847	2.98624	3.89279	3.79437	4.18045	4.05967	4.32791	4.12523	4.60659	6.71180
2.6	2.08132	-0.00000	2.52849	1.74631	3.50778	3.38189	4.21270	4.14566	4.47881	4.38887	4.61027	4.44793	4.87238	7.16589
2.7	2.20580	-0.00000	2.73902	2.18011	3.85088	3.77377	4.54073	4.49559	4.78427	4.71780	4.89999	4.77071	5.14452	7.63631
2.8	2.32798	-0.00000	2.97603	2.59319	4.21077	4.16479	4.87863	4.84558	5.09644	5.04771	5.19711	5.09482	5.42340	8.12397
2.9	2.44821	-0.00000	3.24404	3.00186	4.58332	4.55654	5.21635	5.19664	5.41500	5.37957	5.50160	5.42122	5.70936	8.62947
3.0	2.56675	-0.00000	3.56135	3.41444	4.96499	4.94987	5.56211	5.54952	5.73963	5.71413	5.81338	5.75066	6.00268	9.15289
3.1	2.68385	-0.00000	3.91849	3.83505	5.35311	5.34524	5.91234	5.90479	6.07011	6.05201	6.13232	6.08376	6.30361	9.69367
3.2	2.79988	0.79439	4.30770	4.26518	5.74876	5.74290	6.26662	6.26291	6.40621	6.39367	6.45830	6.42100	6.61234	10.25060
3.3	2.91439	1.14145	4.72868	4.70473	6.14158	6.14310	6.62456	6.62428	6.74779	6.73952	6.79114	6.76277	6.92903	10.82190
3.4	3.02814	1.41292	5.16220	5.15275	6.53958	6.54607	6.98623	6.98926	7.09469	7.08986	7.13067	7.10936	7.25379	11.40535
3.5	3.14101	1.64666	5.61089	5.60808	6.93898	6.95215	7.35118	7.35820	7.44679	7.44496	7.47672	7.46099	7.58673	11.99851
3.6	3.25312	1.85701	6.06613	6.06980	7.33915	7.36173	7.71922	7.73144	7.80394	7.80806	7.82911	7.81785	7.92793	12.59897
3.7	3.36484	2.05123	6.52538	6.53738	7.73958	7.77531	8.09028	8.10932	8.16599	8.17032	8.18766	8.18007	8.27746	13.20445
3.8	3.47635	2.23357	6.98569	7.01078	8.13972	8.19341	8.46404	8.49222	8.53277	8.54095	8.55218	8.54774	8.63541	13.81297
3.9	3.58582	2.40678	7.44497	7.49036	8.53927	8.61660	8.84037	8.88050	8.90409	8.91710	8.92250	8.92096	9.00186	14.42285
4.0	3.69539	2.57277	7.90159	7.97675	8.93790	9.04546	9.21899	9.27454	9.27974	9.29896	9.29843	9.29979	9.37688	15.03277
4.1		2.73290		8.47070		9.48052		9.67472		9.68669		9.68433		
4.2		2.8[illegible]92		8.97293		9.92227		10.08143		10.08047		10.07466		
4.3		3.03950		9.48400		10.37112		10.49501		10.48050		10.47088		
4.4		3.18744		10.00421		10.82738		10.91580		10.88698		10.87313		
4.5		3.33264		10.53354		11.29124		11.34410		11.30010		11.28155		
4.6		3.47827		11.07167		11.76280		11.78013		11.72008		11.69634		
4.7		3.61602		11.61798		12.24200		12.22409		12.14714		12.11769		
4.8		3.75514		12.17162		12.72872		12.67608		12.58146		12.54884		
4.9		3.89297		12.73160		13.22269		13.13615		13.02326		12.98105		
5.0		4.02951		13.29688		13.72360		13.60425		13.47271		13.42359		
5.1		4.16598		13.86645		14.23106		14.08029		13.92997		13.87374		
5.2		4.30181		14.43927		14.74464		14.56405		14.39517		14.33179		
5.3		4.43765		15.01403		15.26388		15.05539		14.86840		14.79799		
5.4		4.57391		15.59148		15.78830		15.55393		15.34973		15.27261		
5.5		4.71108		16.16948		16.31748		16.06937		15.83918		15.75587		
5.6		4.84966		16.74802		16.85086		16.57134		16.33674		16.24794		
5.7		4.99048		17.32670		17.38810		17.08948		16.84234		16.74894		
5.8		5.13436		17.90820		17.92876		17.61339		17.35888		17.25894		
5.9		5.28264		18.48326		18.47248		18.14270		17.87720		17.77792		
6.0		5.43899		19.06073		19.01582		18.67703		18.40610		18.30577		
6.1		5.59977		19.63746		19.56758		19.21602		18.94235		18.84233		
6.2		5.77424		20.21336		20.11834		19.75933		19.48866		19.38733		
6.3		5.96498		20.78837		20.67093		20.30662		20.03878		19.94043		

2w GUIDE WIDTH

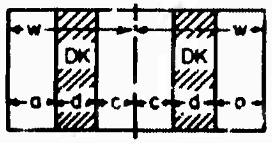
DK RELATIVE DIELECTRIC CONSTANT

λ₀ FREE SPACE } WAVE
λg GUIDE } LENGTH

$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT

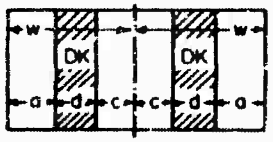


$a=\frac{a}{w}$, $\delta=\frac{d}{w}$, $\gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 25.00 DELTA = 0.10

α+δ/2	0.050	0.050	0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.950
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.53378	2.69208	1.37544	1.89910	1.18887	1.56264	1.01126	1.35727	0.89398	1.26662	0.81142	1.24017	0.70242	0.62008
B														
0.7	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.87775
0.8	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.87846	1.39246
0.9	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.19691	-0.00000	0.79928	-0.00000	1.29979	1.83540
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.66528	-0.00000	1.21675	-0.00000	1.65682	2.25827
1.1	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.76181	-0.00000	1.26437	-0.00000	1.57037	-0.00000	1.98730	2.67849
1.2	-0.00000	-0.00000	-0.00000	-0.00000	0.24083	-0.00000	1.17038	-0.00000	1.61696	-0.00000	1.90128	-0.00000	2.30538	3.10382
1.3	-0.00000	-0.00000	-0.00000	-0.00000	0.79852	-0.00000	1.52949	-0.00000	1.95623	0.77788	2.22459	1.04434	2.61828	3.53793
1.4	-0.00000	-0.00000	0.31664	-0.00000	1.16055	-0.00000	1.88047	0.89460	2.29541	1.60146	2.54791	1.75550	2.93037	3.98229
1.5	-0.00000	-0.00000	0.74179	-0.00000	1.49448	-0.00000	2.23934	1.69118	2.64110	2.18128	2.87571	2.30166	3.24459	4.43727
1.6	0.46948	-0.00000	1.03287	-0.00000	1.83483	0.84675	2.61347	2.28058	2.99661	2.68392	3.21074	2.78492	3.56308	4.90270
1.7	0.75638	-0.00000	1.29337	-0.00000	2.19971	1.69350	3.00510	2.80121	3.36321	3.14962	3.55473	3.23650	3.88750	5.37826
1.8	0.97310	-0.00000	1.55021	-0.00000	2.59905	2.32212	3.41307	3.28927	3.74088	3.59552	3.90862	3.67080	4.21913	5.86368
1.9	1.15991	-0.00000	1.82096	0.12611	3.03433	2.88631	3.83441	3.76016	4.12891	4.03065	4.27287	4.09584	4.55899	6.35882
2.0	1.32975	-0.00000	2.12287	1.40259	3.49944	3.42302	4.26577	4.22179	4.52630	4.46041	4.64751	4.51655	4.90789	6.86355
2.1	1.48876	-0.00000	2.47424	2.08558	3.98488	3.94659	4.70437	4.67864	4.93203	4.88823	5.03235	4.93619	5.26642	7.37774
2.2	1.64047	-0.00000	2.88915	2.69210	4.48207	4.46343	5.14820	5.13345	5.34523	5.31641	5.42699	5.35697	5.63498	7.90108
2.3	1.78718	-0.00000	3.36788	3.27654	4.98506	4.97663	5.59598	5.58797	5.76523	5.74652	5.83097	5.78044	6.01382	8.43304
2.4	1.93063	-0.00000	3.89540	3.85617	5.49027	5.48778	6.04692	6.04337	6.19149	6.17964	6.24377	6.20764	6.40303	8.97283
2.5	2.07223	-0.00000	4.45228	4.43653	5.99562	5.99786	6.50057	6.50052	6.62360	6.61651	6.66484	6.63930	6.80257	9.51942
2.6	2.21377	-0.00000	5.02374	5.01875	6.49988	6.50764	6.95665	6.96007	7.06123	7.05766	7.09365	7.07585	7.21232	10.07164
2.7	2.35584	0.27914	5.60070	5.60263	7.00228	7.01785	7.41496	7.42260	7.50407	7.50343	7.52969	7.51757	7.63205	10.62826
2.8	2.50062	1.06250	6.17777	6.18796	7.50230	7.52918	7.87529	7.88856	7.95182	7.95405	7.97247	7.96458	8.06151	11.18806
2.9	2.65125	1.52640	6.75155	6.77495	7.99959	8.04235	8.33746	8.35839	8.40419	8.40967	8.42151	8.41692	8.50043	11.74991
3.0	2.81147	1.93077	7.31976	7.36419	8.49393	8.55797	8.80127	8.83247	8.86085	8.87038	8.87639	8.87455	8.94849	12.31286
3.1	2.98796	2.32142	7.88098	7.95638	8.98523	9.07560	9.26650	9.31114	9.32145	9.33624	9.33668	9.33740	9.40541	12.87608
3.2	3.19204	2.72102	8.43443	8.55208	9.47351	9.59864	9.73295	9.79468	9.78565	9.80729	9.80201	9.80540	9.87087	13.43892
3.3	3.44229	3.14486	8.97992	9.15158	9.95889	10.12436	10.20041	10.28332	10.25307	10.28354	10.27201	10.27847	10.34456	14.00088
3.4	3.76357	3.60344	9.51767	9.75477	10.44158	10.65387	10.66872	10.77719	10.72338	10.76501	10.74635	10.75652	10.82615	14.56158
3.5	4.17388	4.10187	10.04821	10.36118	10.92184	11.18715	11.13774	11.27638	11.19623	11.25167	11.22472	11.23950	11.31528	15.12075
3.6	4.66708	4.63933	10.57221	10.97005	11.39999	11.72406	11.60736	11.78086	11.67130	11.74351	11.70682	11.72737	11.81157	15.67821
3.7	5.21956	5.21058	11.09048	11.58046	11.87638	12.26435	12.07753	12.29055	12.14832	12.24046	12.19237	12.22009	12.31460	16.23385
3.8	5.80829	5.80897	11.60378	12.19146	12.35133	12.80773	12.54822	12.80526	12.62705	12.74246	12.66114	12.71763	12.82391	16.78761
3.9	6.41667	6.42934	12.11291	12.80213	12.82520	13.35384	13.01943	13.32478	13.10726	13.24942	13.17287	13.21998	13.33903	17.33947
4.0	7.03284	7.06923	12.61858	13.41167	13.29832	13.90232	13.49119	13.84880	13.58887	13.76119	13.66736	13.72710	13.85946	17.88943
4.1		7.72863		14.01943		14.45280		14.37699		14.27764		14.23896		
4.2		8.40874		14.62450		15.00493		14.90901		14.79857		14.75548		
4.3		9.11070		15.22771		15.55839		15.44447		15.32378		15.27659		
4.4		9.83431		15.82764		16.11288		15.98301		15.85305		15.80217		
4.5		10.57751		16.42452		16.66813		16.52425		16.38614		16.33206		
4.6		11.33639		17.01831		17.22389		17.06785		16.92277		16.86608		
4.7		12.10388		17.60900		17.77997		17.61348		17.46270		17.40403		
4.8		12.88064		18.19664		18.33618		18.16083		18.00564		17.94566		
4.9		13.65583		18.78129		18.89238		18.70963		18.55132		18.49069		
5.0		14.42752		19.36306		19.44842		19.25962		19.09946		19.03884		
5.1		15.19287		19.94205		20.00419		19.81058		19.64981		19.58981		
5.2		15.94998		20.51838		20.55961		20.36231		20.20209		20.14329		
5.3		16.69771		21.09218		21.11460		20.91463		20.75606		20.69896		
5.4		17.43552		21.66356		21.66908		21.46739		21.31147		21.25652		
5.5		18.16325		22.23264		22.22300		22.02045		21.86809		21.81567		
5.6		18.88103		22.79954		22.77633		22.57370		22.42570		22.37611		
5.7		19.58912		23.36437		23.32903		23.12703		22.98410		22.93758		
5.8		20.28793		23.92724		23.88106		23.68035		23.54310		23.49983		
5.9		20.97789		24.48824		24.43241		24.23358		24.10251		24.06261		
6.0		21.65946		25.04748		24.98307		24.78665		24.66219		24.62572		
6.1		22.33314		25.60503		25.53301		25.33951		25.22197		25.18896		
6.2		22.99932		26.16099		26.08224		25.89210		25.78173		25.75216		
6.3		23.65849		26.71544		26.63075		26.44437		26.34136		26.31517		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_0 FREE SPACE } WAVE
λ_g GUIDE } LENGTH
$B = 2\pi w/\lambda_0$ NORMALIZED FREQ.
BC CUTOFF-FREQ.
$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT

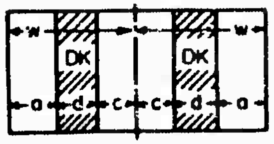


$\alpha = \frac{a}{w}, \ \delta = \frac{d}{w}, \ \gamma = \frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 25.0C DELTA = 0.15

[redacted] α,δ [redacted]	0.[redacted]	0[redacted]	[redacted]5	[redacted]25	[redacted].20[redacted]	0.2[redacted]	0[redacted]	[redacted]0	[redacted]00	[redacted].40[redacted]	0.[redacted]	0[redacted]	[redacted]0	[redacted]26 [redacted]
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC	1.43213	2.04852	1.26887	1.64335	1.05793	1.33981	0.88121	1.15640	0.77071	1.07619	0.69465	1.05288	0.59842	0.52644
B														
0.6	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.19898	0.91088
0.7	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.20567	-0.00000	0.99662	1.48901
0.8	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.47852	-0.00000	0.95978	-0.00000	1.45820	1.98650
0.9	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.37125	-0.00000	1.06338	-0.00000	1.40891	-0.00000	1.85838	2.46268
1.0	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.99398	-0.00000	1.49960	-0.00000	1.80613	-0.00000	2.23428	2.93584
1.1	-0.00000	-0.00000	-0.00000	-0.00000	0.52832	-0.00000	1.44188	-0.00000	1.90488	0.70800	2.18735	0.99874	2.60020	3.41320
1.2	-0.00000	-0.00000	-0.00000	-0.00000	1.03879	-0.00000	1.86642	0.97842	2.30644	1.66934	2.56648	1.82169	2.96381	3.89747
1.3	-0.00000	-0.00000	0.39503	-0.00000	1.46264	-0.00000	2.29831	1.89458	2.71494	2.31944	2.98045	2.43613	3.32866	4.38927
1.4	-0.00000	-0.00000	0.85320	-0.00000	1.89083	1.17707	2.74760	2.49411	3.13447	2.86171	3.34290	2.97802	3.69861	4.88830
1.5	0.51428	-0.00000	1.20165	-0.00000	2.35144	2.01300	3.21503	3.07242	3.56576	3.40348	3.74566	3.48481	4.07544	5.39395
1.6	0.83180	-0.00000	1.54227	-0.00000	2.85168	2.88718	3.69682	3.61723	4.00717	3.90402	4.15940	3.97299	4.46060	5.90562
1.7	1.03299	-0.00000	1.91243	1.11994	3.38449	3.30670	4.18817	4.14417	4.45922	4.39315	4.58404	4.45143	4.85513	6.42277
1.8	1.31232	-0.00000	2.33905	1.97062	3.93704	3.90124	4.68815	4.66107	4.91826	4.87652	5.01910	4.92536	5.25967	6.94495
1.9	1.53753	-0.00000	2.83608	2.66937	4.49837	4.45234	5.18817	5.17222	5.38373	5.35757	5.46384	5.39807	5.67456	7.47173
2.0	1.77191	-0.00000	3.39563	3.32585	5.08165	5.05509	5.68676	5.68018	5.85470	5.83850	5.91745	5.87168	6.09986	8.00266
2.1	2.03036	0.96849	3.99510	3.96771	5.62330	5.62200	6.18916	6.18686	6.33048	6.32069	6.37910	6.34751	6.53548	8.53719
2.2	2.33273	1.75609	4.61347	4.60360	6.18156	8.18458	5.69205	6.69246	6.81061	6.80304	6.84799	6.82640	6.98100	9.07476
2.3	2.70344	2.40373	5.23779	5.23608	6.73861	6.74380	7.19828	7.19869	7.29470	7.29212	7.32336	7.30880	7.43609	9.61471
2.4	3.16051	3.02308	5.86114	5.86588	7.28809	7.30065	7.69880	7.70586	7.78242	7.78225	7.80456	7.79494	7.90020	10.15642
2.5	3.69854	3.64307	6.47977	6.49352	7.82986	7.85587	8.20255	8.21447	8.27348	8.27863	0.29093	8.28487	8.37279	10.69926
2.6	4.29186	4.27160	7.09184	7.11962	8.36993	8.41014	8.70649	8.72490	8.76786	8.77233	8.78194	8.77854	8.85330	11.24267
2.7	4.91479	4.90886	7.69521	7.74485	8.90843	8.96401	9.21086	9.23780	9.26437	9.27238	9.27708	9.27884	9.34116	11.78618
2.8	5.58063	5.55296	8.29028	8.36972	9.43661	9.81787	9.71467	9.75249	9.76389	9.77874	9.77591	9.77660	9.83882	12.32937
2.9	6.18957	6.20240	8.87674	8.99447	9.96377	10.07200	10.21878	10.27008	10.26491	10.28266	10.27802	10.28068	10.33677	12.87192
3.0	6.82852	6.85680	9.45500	9.61903	10.48728	10.62682	10.72282	10.79028	10.76805	10.79216	10.78305	10.78791	10.84348	13.41360
3.1	7.45485	7.51683	10.02573	10.24302	11.00788	11.18147	11.22878	11.31319	11.27271	11.30808	11.29067	11.29814	11.35845	13.95420
3.2	8.07433	8.18212	10.55975	10.86587	11.82800	11.73677	11.73063	11.83878	11.77865	11.82092	11.80089	11.81124	11.87218	14.49362
3.3	8.68385	8.85374	11.14791	11.48694	12.04008	12.29232	12.23441	12.36685	12.28566	12.33963	12.31286	12.32707	12.39319	15.03177
3.4	9.28311	9.53083	11.70107	12.10861	12.85318	12.84797	12.73814	12.89734	12.79384	12.86107	12.82634	12.84883	12.91799	15.56860
3.5	9.87277	10.21212	12.25003	12.72131	13.06469	13.40355	13.24158	13.43002	13.30215	13.36806	13.34173	13.36651	13.44613	16.10409
3.6	10.48385	10.89588	12.79552	13.33360	13.87498	13.98890	13.74870	13.96469	13.81136	13.90149	13.85852	13.88990	13.97716	16.63825
3.7	11.02757	11.58000	13.33817	13.94216	14.08438	14.51385	14.24967	14.50109	14.32110	14.44014	14.37687	14.41858	14.51066	17.17111
3.8	11.89813	12.26268	13.87854	14.54680	14.89316	15.08833	14.75387	15.03900	14.83131	14.97086	14.89573	14.94346	15.04623	17.70263
3.9	12.15769	12.94216	14.41750	15.14741	15.10160	15.62216	15.25839	15.57818	15.34195	15.50345	15.41555	15.47341	15.58350	18.23301
4.0	12.71629	13.61718	14.95428	15.74398	15.60990	16.17526	15.76330	16.11838	15.85303	16.03774	15.93634	16.00531	16.12214	18.76215
4.1		14.28679		16.33655		16.72786		16.65941		16.57384		16.53902		
4.2		14.95037		16.92522		17.27900		17.20105		17.11088		17.07439		
4.3		15.50761		17.81011		17.82953		17.74313		17.54897		17.61127		
4.4		16.25838		18.09137		18.37913		18.28549		18.18826		18.14951		
4.5		16.90267		18.88917		18.92776		18.82797		18.72837		18.68895		
4.6		17.54068		19.24366		19.47543		19.37046		19.26917		19.22942		
4.7		18.17254		19.81501		20.02212		19.91284		19.81050		19.77077		
4.8		18.79857		20.38339		20.56784		20.45503		20.35224		20.31283		
4.9		19.41900		20.94897		21.11260		20.99694		20.89427		20.85546		
5.0		20.03414		21.81189		21.65639		21.53852		21.43648		21.39851		
5.1		20.64424		22.07230		22.19925		22.07970		21.97876		21.94188		
5.2		21.24961		22.63038		22.74117		22.62044		22.52102		22.48534		
5.3		21.85049		23.18616		23.28219		23.16070		23.06318		23.02858		
5.4		22.44715		23.73986		23.82232		23.70046		23.60616		23.57235		
5.5		23.03953		24.29188		24.36157		24.23970		24.14890		24.11567		
5.6		23.62678		24.84141		24.89997		24.77539		24.65834		24.65874		
5.7		24.21413		25.38947		25.43754		25.31653		25.22941		25.20149		
5.8		24.79815		25.93585		25.97429		25.85410		25.77009		25.74385		
5.9		25.37507		26.48063		26.51026		26.39110		26.31033		26.28577		
6.0		25.95095		27.02381		27.04545		26.92783		26.85005		26.82719		
6.1		26.82408		27.56577		27.57990		27.46339		27.38934		27.36509		
6.2		27.09482		28.10627		28.11361		27.99387		27.92806		27.90841		

2w GUIDE WIDTH
DK RELATIVE DIELECTRIC CONSTANT
λ_o FREE SPACE } WAVE
λ_g GUIDE } LENGTH
$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.
BC CUTOFF-FREQ.
$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha=\frac{a}{w}, \delta=\frac{d}{w}, \gamma=\frac{c}{w}$

NORMALIZED PROPAGATION CONSTANTS FOR TE MODES IN WAVEGUIDES WHICH CONTAIN DIELECTRIC SLABS DK = 25.00 DELTA = 0.25

$\alpha+\delta/2$			0.125	0.125	0.200	0.200	0.300	0.300	0.400	0.400	0.500	0.500	0.700	0.875
MODE	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 20	TE 10	TE 10
BC			1.08883	1.35520	0.88973	1.10990	0.72919	0.95141	0.63131	0.88175	0.55490	0.86155	0.47914	0.43077
B														
0.6			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.59267	-0.00000	1.21042	.61400
0.7			-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	0.83355	-0.00000	1.23418	-0.00000	1.72357	2.16949
0.8			-0.00000	-0.00000	-0.00000	-0.00000	0.83148	-0.00000	1.39740	-0.00000	1.72637	-0.00000	2.18257	2.69804
0.9			-0.00000	-0.00000	0.28614	-0.00000	1.39668	-0.00000	1.88756	0.67418	2.18336	0.98231	2.62045	3.21845
1.0			-0.00000	-0.00000	1.01767	-0.00000	1.90732	1.12355	2.36529	1.78060	2.63239	1.93043	3.05047	3.73757
1.1			0.26786	-0.00000	1.53823	-0.00000	2.42137	2.04826	2.84779	2.50724	3.08420	2.62117	3.47944	4.25779
1.2			0.90791	-0.00000	2.05878	1.58811	2.95141	2.75804	3.33980	3.13460	3.54338	3.22800	3.91129	4.77870
1.3			1.35986	-0.00000	2.61202	2.39267	3.49568	3.39458	3.84099	3.71633	4.01152	3.79447	4.34844	5.30318
1.4			1.81622	1.05107	3.19759	3.09911	4.04813	3.99538	4.34928	4.27348	4.48867	4.33898	4.79236	5.82789
1.5			2.31981	1.99735	3.80232	3.75893	4.60331	4.57586	4.86248	4.81844	4.97411	4.87104	5.24386	6.35350
1.6			2.88112	2.74249	4.41349	4.39467	5.15776	5.14354	5.37888	5.35097	5.46682	5.39608	5.70[illegible]32	6.87974
1.7			3.48676	3.42990	5.02332	5.01647	5.70976	5.70254	5.89734	5.88047	5.96573	5.91736	6.17072	7.40639
1.8			4.11550	4.09311	5.62813	5.62557	6.25867	6.25532	6.41718	6.40707	6.48983	6.43690	6.64583	7.93328
1.9			4.75160	4.74341	6.22649	6.22723	6.80438	6.80345	6.93800	6.93207	6.97823	6.95591	7.12819	8.46026
2.0			5.38663	5.38505	6.81802	6.82191	7.34707	7.34802	7.45957	7.45630	7.49018	7.47513	7.61726	8.98720
2.1			6.01661	6.01991	7.40278	7.41067	7.88698	7.88985	7.98175	7.98031	8.00503	7.99496	8.11243	9.51396
2.2			6.63972	6.64911	7.98105	7.99436	8.42439	8.42954	8.50442	8.50440	8.52224	8.51559	8.51307	10.04042
2.3			7.25516	7.27354	8.55320	8.57366	8.95954	8.96760	9.02750	9.02878	9.04134	9.03707	9.11855	10.56647
2.4			7.86267	7.89394	9.11964	9.14914	9.49265	9.50441	9.55088	9.55355	9.56198	9.55941	9.62829	11.09200
2.5			8.46233	8.51066	9.88081	9.72122	10.02392	10.04027	10.07445	10.07877	10.08382	10.08253	10.14174	11.61692
2.6			9.05450	9.12466	10.23717	10.29024	10.55352	10.57543	10.59819	10.60445	10.60660	10.60636	10.65839	12.14117
2.7			9.63970	9.73549	10.78918	10.85846	11.08160	11.11007	11.12193	11.13058	11.13011	11.13080	11.17778	12.66468
2.8			10.21857	10.34336	11.33729	11.42005	11.60830	11.64430	11.64559	11.65713	11.65414	11.65578	11.69949	13.18742
2.9			10.79161	10.94816	11.88193	11.98116	12.13375	12.17821	12.16911	12.18407	12.17856	12.18120	12.22313	13.70937
3.0			11.36012	11.54974	12.42352	12.53989	12.65809	12.71186	12.69241	12.71135	12.70322	12.70700	12.74838	14.23051
3.1			11.92415	12.14795	12.98242	13.09632	13.15144	13.24526	13.21544	13.23393	13.22802	13.23311	13.274[illegible]1	14.75085
3.2			12.48456	12.74267	13.49898	13.65055	13.70390	13.77840	13.73816	13.76675	13.75287	13.75947	13.80245	15.27039
3.3			13.04175	13.33380	14.03348	14.20263	14.22558	14.31127	14.26052	14.29475	14.27769	14.28604	14.33077	15.78915
3.4			13.59634	13.92132	14.56622	14.75266	14.74659	14.54335	14.78253	14.62285	14.80241	14.81277	14.85964	16.30714
3.5			14.14866	14.50524	15.09740	15.30069	15.26701	15.37609	15.30416	15.35109	15.32699	15.33962	15.38886	16.82441
3.6			14.69907	15.08559	15.62724	15.84682	15.78692	15.90796	15.82541	15.87931	15.85139	15.86655	15.91829	17.34096
3.7			15.24784	15.66246	16.15591	16.39111	16.30641	16.43943	16.34630	16.40749	16.37556	16.39353	16.44776	17.85683
3.8			15.79519	16.23600	16.68358	16.93365	16.82552	16.97046	16.86684	16.93560	16.89948	16.92052	16.97717	18.37205
3.9			16.34133	16.80629	17.21029	17.47451	17.34433	17.50101	17.38704	17.46357	17.42314	17.44748	17.50642	18.88665
4.0			16.88632	17.37347	17.73623	18.01378	17.86287	18.03107	17.90693	17.99137	17.94651	17.97439	18.03540	19.40065
4.1				17.93770		18.55154		18.36061		18.51895		18.50121		
4.2				18.49910		19.08785		19.08961		19.04628		19.02791		
4.3				19.05784		19.62279		19.61805		19.57334		19.55447		
4.4				19.61404		20.15644		20.14593		20.10008		20.08084		
4.5				20.16785		20.88885		20.67324		20.62649		20.60701		
4.6				20.71938		21.22010		21.19998		21.15255		21.13294		
4.7				21.26878		21.75023		21.72614		21.67824		21.65861		
4.8				21.81615		22.27931		22.25173		22.20355		22.18400		
4.9				22.36161		22.80740		22.77675		22.72546		22.70908		
5.0				22.90526		23.33454		23.30121		23.25297		23.23385		
5.1				23.44720		23.86079		23.82511		23.77706		23.75827		
5.2				23.98752		24.38617		24.34847		24.30074		24.28234		
5.3				24.52631		24.91075		24.87129		24.82400		24.80604		
5.4				25.06366		25.43456		25.39360		25.34684		25.32936		
5.5				25.59963		25.95763		25.91538		25.86926		25.85230		
5.6				26.13430		26.48000		26.43687		26.39126		26.37485		
5.7				26.66774		27.00170		26.95747		26.91285		26.09699		
5.8				27.20001		27.62277		27.47779		27.43402		27.41874		
5.9				27.73117		28.04323		27.99765		27.95477		27.94008		
6.0				28.26127		28.56311		28.51706		28.47512		28.46102		
6.1				28.79037		29.08244		29.03603		28.99507		28.98156		
6.2				29.31851		29.60124		29.55457		29.51462		29.50169		
6.3				29.84574		30.11953		30.07270		30.03378		30.02143		

2w GUIDE WIDTH

DK RELATIVE DIELECTRIC CONSTANT

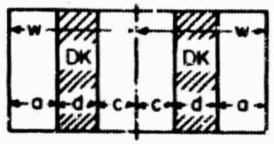
λ_o FREE SPACE } WAVE LENGTH

λ_g GUIDE

$B = 2\pi w/\lambda_o$ NORMALIZED FREQ.

BC CUTOFF-FREQ.

$K = 2\pi w/\lambda_g$ NORMALIZED PROPAGATION CONSTANT



$\alpha = \frac{a}{w}$, $\delta = \frac{d}{w}$, $\gamma = \frac{c}{w}$