The exact location of the cutoff frequencies of these $H$ modes will, of course, depend on $H$ and $W$, and on the sign, magnitude, and frequency dependence of $X_1$ and $X_4$. For the case of a symmetric square waveguide ($H = W$, $X_4 = X_1$), it can be shown that the cutoff frequency of the lowest $H$ mode is *always* below that of the $E_{11}$ mode. At cutoff, $\Gamma = 0$ and $k = k_c = (K_x^2 + K_y^2)^{1/2}$. If $X_4 = X_1$ is positive (inductive reactance) the lowest $H$ mode (for which $K_y = K_x$) is associated with $H_z = H_0 \sin(K_x x) \sin(K_y y) \exp(-\Gamma z)$ and has a normalized cutoff frequency

$$k_c W = 2\sqrt{2} \cot^{-1} (\sqrt{2} X_1/Z_0).$$

The first solution of this equation is always less than $\sqrt{2}\pi$, the value of the normalized cutoff frequency of the $E_{11}$ mode. If $X_4 = X_1$ is negative (capacitive reactance) the lowest $H$ mode ($K_y = K_x$) is associated with $H_z = H_0 \cos(K_x x) \cos(K_y y) \exp(-\Gamma z)$ and has a normalized cutoff frequency

$$k_c W = 2\sqrt{2} \tan^{-1} (-\sqrt{2} X_1/Z_0).$$

Again, the first solution of this equation (recall that $-X_1$ is positive), is always less than $\sqrt{2}\pi$, the value for the $E_{11}$ mode. Thus, based on this model, an $H$ mode will always be the dominant mode of the waveguide, and the $E_{11}$ mode can never be the dominant mode.

In their paper,[1] the authors state that in an experimental study of a square waveguide with longitudinally corrugated walls, they found no evidence of any $H$ modes over a two-to-one frequency range which included the cutoff frequency of the $E_{11}$ mode. They concluded that the $E_{11}$ mode was the dominant mode of the waveguide. The fact that these experimental results conflict with the results of a correct analysis of the wall impedance model suggests that a critical reexamination of the whole problem should be undertaken to resolve this conflict. In view of this conflict, acceptance of the authors' contention that a longitudinally corrugated waveguide always has a dominant $E$ mode appears inadvisable until an independent confirmation of their experimental results is available.

## Comments on "Rectangular Waveguides with Impedance Walls"

M. S. NARASIMHAN AND V. VENKATESWARA RAO

In the above paper,[1] some comments seem to be necessary on the impedance compatibility relation

$$Z_1 Z_3 - Z_2 Z_3 + Z_2 Z_4 = 0 \qquad (1)$$

where $Z_1$, $Z_2$, $Z_3$, and $Z_4$ have been defined.[1] This relation was derived for obtaining a separable modal solution of fields. Though (1) appears to be mathematically correct, controversies arise when it is used for square or rectangular waveguides with all the four walls corrugated transversely to the direction of propagation. Bryant [1] in his analysis used a square corrugated waveguide excited in the TE to $x$ mode of operation and observed that the $H$-plane walls, though corrugated, will act as a conducting surface and will not affect the propagation of TE to $x$ modes. Dybdal *et al.* have pointed out that for this particular geometry (1) is not satisfied and in order to satisfy (1) the $H$-plane walls should be conducting. We would like to point out that it is well known that a separable modal solution of fields in a waveguide with impedance walls may be expressed in terms of

$$\begin{Bmatrix} \text{TE} \\ \text{TM} \end{Bmatrix} \text{ to } x \quad \text{or} \quad \begin{Bmatrix} \text{TE} \\ \text{TM} \end{Bmatrix} \text{ to } y \text{ modes [3].}$$

Hence the impedances which can influence the propagation of these modes will be limited to three only. This can be explained physically also by observing that given the polarization for a desired mode of operation (viz., TE to $x$ or TE to $y$) only one pair of walls will act as an anisotropic surface and the other (with corrugations parallel to the $E$ field) will act only as a conducting surface [4]. This observation has been made by Dybdal *et al.* also.[1] Further considering the modal solution corresponding to the TE to $x$ mode within the corrugated guide of this type one observes that $E_x = 0$ everywhere, $E_y = 0$, and $E_z = 0$ on the $H$ walls [2]. Hence $Z_1 = Z_3 = Z_4 = 0$ and $Z_2 \neq 0$, which satisfy (1). Recently it has been confirmed experimentally [4] that a waveguide with all the four walls corrugated transversely gives satisfactory results when it is excited in TE to $x$ or TE to $y$ mode. This has also been verified by us by constructing a square corrugated guide. Similarly, when the corrugated guide is excited in the TE to $y$ mode $Z_1 = Z_2 = Z_4 = 0$ and $Z_3 \neq 0$. Again (1) is satisfied. For this mode of operation the $E$-plane corrugated surface behaves like a conducting surface and the $H$-plane walls are anisotropic. From the previous discussions it is obvious that the corrugated surface can behave as an anisotropic as well as an isotropic surface, depending upon the choice of the mode of excitation used. From these observations the authors believe that the square corrugated guide may be used most efficiently as a wideband dual polarized device by a judicious choice of the corrugation depth.

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## Surface Acoustic Wave Properties of Tantalum Pentoxide Thin Films on *YX* Quartz

J. F. WELLER AND T. G. GIALLORENZI

***Abstract*—The properties of a Rayleigh surface wave propagating in tantalum oxide thin films on *YX* quartz are presented. Dispersion and acoustic wave loss measurements are made using the optical probe technique.**

The propagation characteristics of surface acoustic waves (SAW) in layered structures differ in several ways from those on a free surface. Rayleigh waves on a free surface are normally dispersionless and have low losses for frequencies less than 300 MHz ($\leq 1$ dB/cm in *YX* quartz). The introduction of a thin film causes velocity dispersion [1] as well as an increase in the losses of the SAW. The film can either mass load the surface which slows the SAW or effectively strengthen the elastic properties of the surface which increases the velocity. In the latter case the wave velocity increases to the point where the wave becomes leaky, i.e., when it has a phase velocity equal to that of the lowest transverse bulk wave; eventually at large film thicknesses, mass loading will again predominate and the wave slows down. Finally, the film introduces more loss due to increased scattering caused by grain boundaries and other surface imperfections [2] and by step discontinuities as recently discussed by Munasinghe and Farnell [3].

The introduction of velocity dispersion resulting from a thin film overlay leads to several applications for SAW devices. Mass loading can be used to produce acoustical waveguiding and provides a means for steering, focusing, or defocusing the SAW [2]. In a few cases where the thin film causes an increase in the phase velocity,

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The authors are with the Optical Sciences Division, Naval Research Laboratory, Washington, D.C. 20375.