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THEORY AND EXPERIMENT PREDICTING THE CUTOFF FREQUENCIES FOR A RECTANGULAR STRIPLINE

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ABSTRACT

The frequency at which the first higher order mode propagates fixes the upper limit of the useful frequency range of a rectangular stripline. In this paper, the results of two disparate analytical techniques used in predicting this cutoff frequency are presented and compared to other published results. Furthermore, a novel experiment was devised and performed. Agreement between the experimental results and the analytical predictions is close.

INTRODUCTION

Rectangular striplines, sometimes called TEM transmission cells (1) or Crawford cells (2), are widely used in biological studies involving nonionizing radiation. For reference, Figure 1 gives an example of the cross section of a rectangular stripline. A basic assumption in these biological studies is that the TEM mode is the only propagating mode.

Estimates of the cutoff frequencies of the first higher order modes have been obtained by several methods. Among these are employing a Fourier expansion of the fields in subregions of the guide (3), applying a rectangular waveguide model (1), (4), and determining the cutoffs by experimentation (2), (5). None of the results obtained have been widely accepted as conclusive; the cutoff frequency of the first higher order mode is a point of contention among experimentalists (2). Specifically, debate has centered on whether the TE10 rectangular waveguide mode or the elliptic coax TE11 odd-type mode of the rectangular stripline has the lowest cutoff frequency.

In this paper, two analytical techniques are applied to obtain the cutoff frequency of the first higher order mode for a range of strip widths. Experimental results are also presented in order to verify the analytical predictions.

THE METHOD OF MOMENTS SOLUTION

Following the general procedure outlined in another paper by the authors (6), an electric field integral equation is solved by the method of moments. The Poisson summation formula is used to accelerate the convergence of the periodic Green's function of the EFIE. The resulting expression can be summed in closed form with respect to one index of summation. Kummer's transformation is then applied to accelerate the convergence of the remaining series for the other index of summation. This solution of the EFIE is thus made both accurate and numerically efficient.

THE TRANSVERSE RESONANCE SOLUTION

The cutoff frequency of the first higher order mode of a ridged waveguide can be found by a transverse resonance technique (7). In this technique, the resonant frequency of an equivalent capacitively loaded transmission line is sought. This susceptance is found from a one term approximation for the variational solution of a thin capacitive window in a parallel plate waveguide (8). This transverse resonance approach gives an accurate, closed form approximation for the cutoff frequency.

THE EXPERIMENT

As in the case of the transverse resonance solution, an E-wall bisecting the rectangular stripline is inserted to create an equivalent guide. This guide encloses a quarter of the cross section of the rectangular stripline by placing perfect electric conducting (PEC) walls on the strip, on the outer walls, and on the E-wall bisecting the strip.

At cutoff, the modal fields of this guide are z independent, and are TE. It is observed that the dual of these fields corresponds to the TM fields of a microstrip patch which is electrically thin in the z direction. In this dual structure, the PEC boundaries of the guide correspond to PMC boundaries of the microstrip patch, and the PMC wall in the gap between the centered strip and the outer wall of the guide corresponds to an electrically shorted wall. By duality, the lowest resonant frequency of this microstrip patch corresponds exactly to the cutoff frequency of the first higher order mode of the rectangular stripline.

RESULTS AND DISCUSSION

Values of normalized cutoff frequencies for the lowest order TE mode for rectangular striplines with different strip widths are presented in Table 1. Figure 2 gives the normalized cutoff frequency for a range of strip widths. Table 1 shows that the cutoff frequencies obtained by the authors are all in close agreement. Furthermore, these results agree well with the cutoff frequencies found by expanding the fields in subregions by a Fourier expansion (3).

The authors agree with Crawford (1) that rectangular waveguide modes which satisfy the boundary conditions of the rectangular stripline are possible modes of this problem. However, these modes have zero total current on the strip. It is the class of elliptic coax-type modes which have current on the strip that the techniques presented in this paper are designed to find. The authors find that the cutoff of the first elliptic coax-type mode is always lower in frequency than the rectangular waveguide TE10 mode for a rectangular stripline of square cross section.

The method of moments procedure was also applied to stripline geometry with no side walls. The normalized cutoff frequency of the lowest order TE mode is plotted in Figure 3. Figure 4 presents a plot of the E_y component of the field for this mode.

CONCLUSION

Two disparate analytical techniques for predicting the cutoff frequency of the first higher order mode of a rectangular stripline and a stripline are presented. A novel experimental procedure for verifying the predictions of the analytical techniques is developed and the experimental and theoretical results are shown to agree.

ACKNOWLEDGEMENT

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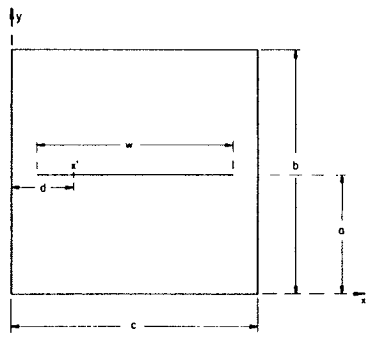

Figure 1. An example of the cross section of a rectangular stripline.

Table 1
Comparison of cutoff frequencies for the first higher order mode in a rectangular stripline

w/c for c=b a=b/2	λ_c/c method of moments	transverse resonance	Fourier expansion [3]	experiment
.20	2.065	2.07	2.062	2.06
.40	2.278	2.26	2.275	2.26
.60	2.665	2.64	2.666	2.63
.80	3.311	3.30	3.311	3.22

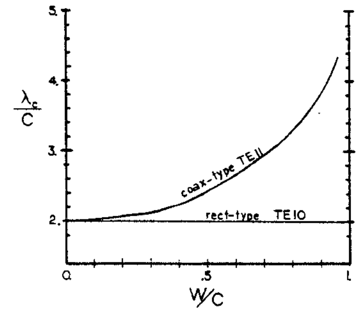

Figure 2. Cutoff frequencies for the first two lowest order modes in a rectangular stripline with b/c=1, b/a=2.

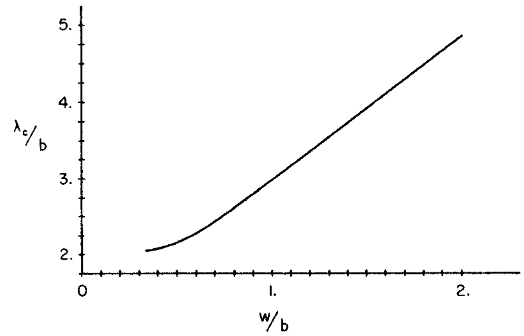

Figure 3. Cutoff frequency vs. stripwidth for the elliptic coax-type TE01 odd mode.

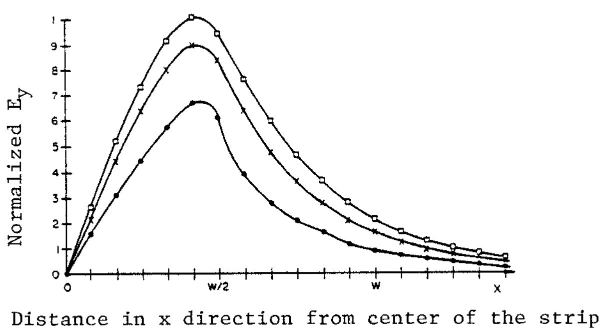

Figure 4. Field plots for the E_y component of the elliptic coax-type TE01 odd mode. The strip is centered at (x=0,y=a), and has width w.
• corresponds to y = 3a/4
x corresponds to y = a/2
□ corresponds to y = a/4