smaller, the gain drops. This behavior is to be expected on the basis of the FET drain characteristics; the drain current is independent of V_D when V_D is large, and drops to lower values when V_D is small.

4) The power gain of the frequency doubler increases with increasing input power level at small values of P_{in}, reaches a maximum (about 3 dB at 10-mW input in the present case), and then decreases for further increase in P_{in}. The gain expansion at low power levels can be understood from the fact that the device is nearly linear for small signals; the nonlinearity, and hence the harmonic generation, becomes significant only as the signal level becomes large. For very large signals, the output of the device is saturated so that a gain compression occurs.

IV. Conclusions

The multiplication gain of the FET frequency doubler is strongly dependent upon the choice of dc bias voltages. The gain can be maximized by selecting a gate-to-source voltage near pinchoff, and a drain-to-source voltage of approximately the same magnitude. When the bias has been thus optimized, the multiplication gain shows a maximum with respect to the input signal power level.

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On the Design of Transitions Between a Metal and Inverted Strip Dielectric Waveguide for Millimeter Waves

S. BHOOSHAN AND R. MITTRA

Abstract—**The results of a study of three types of transitions between the rectangular metal waveguide and the inverted strip guide are reported. Reflected power measurements from each type of transition and insertion-loss measurements for configurations involving the three transitions have also been carried out. The procedure of determining the optimum parameters for the transition is quite general, and has the potential for being extended to other dielectric structures.**

I. Introduction

The need for an efficient transition between dielectric and metal waveguides at millimeter-wave frequencies has been recently recognized. The literature on open dielectric structures shows that almost no details of a study of dielectric–metal waveguide transition exist. However, the transitions used to study the effects of such structures could be the basis for investigation [1]. The chief difficulty encountered when studying such transitions is that the wave must pass from an open-waveguiding structure to a closed one, and vice versa, with the field configuration undergoing a complete metamorphosis through the transition region. In this paper, we report the results of an experimental study of several transitions on the basis of the reflected power and insertion loss for these transitions. The dielectric guide used was the homogeneous inverted strip guide, whose cross section is shown in Fig. 1.

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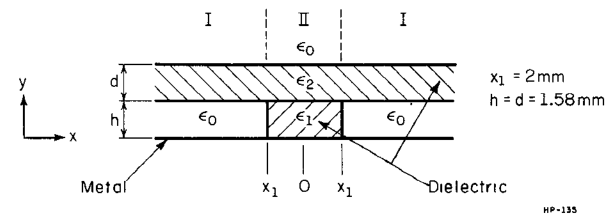

Fig. 1. Cross section of inverted strip guide with typical dimensions.

II. Details of the Study

Two types of transitions were studied: 1) a direct metal to dielectric guide transition, depicted in Fig. 2, and henceforth called transition T-1; and 2) horn-type transitions shown in Figs. 3 and 4, henceforth labeled T-2A and T-2B, respectively.

The study is divided into two parts: a) reflected power measurements from the transition; and b) insertion-loss measurements for a length of dielectric guide introduced between two rectangular metal waveguides which serve as the input and output ports.

A. Reflected Power Measurements

The reflected power measurements for the transition between the metal and dielectric guides were conducted using a length of guide with the transition at its input port. A typical experimental setup consisted of a Y-junction circulator, whose three ports were connected to an RF source, the transition under test, and a power-measuring device. The power from the RF source was incident on the transition, and the power reflected from the same was measured to determine the reflection characteristics. The metal waveguide at the output port of the test setup was terminated by a matched load.

On the basis of these experiments, it was found that the reflection phenomenon in the transition occurs chiefly at two points: (i) at the junction of the metal waveguide and the lower dielectric strip; and (ii) between the lower strip and the top plate of the homogeneous inverted strip guide. The first type of reflection loss can be minimized by inserting an optimum length of taper of the lower strip into the metal waveguide, such that the lower strip is closely matched to the metal guide. The results of the experiments for the determination of the optimum length have been tabulated in Table I, where l_L^* is equal to the optimum value of the inserted length l_L, as shown in Fig. 2. In these measurements, the reflected power was at least 8 dB down as compared to the incident power.

Minimization of the second type of reflection loss can be achieved by using a horn-type feed, as in transitions T-2A and T-2B. Here the tapered top plate was inserted into the horn and the length inserted was adjusted to an optimum value, such that a minimum insertion loss was obtained. A horn-type feed was also instrumental in decreasing considerably the power radiated at the junction by about $\frac{1}{2}$ dB.

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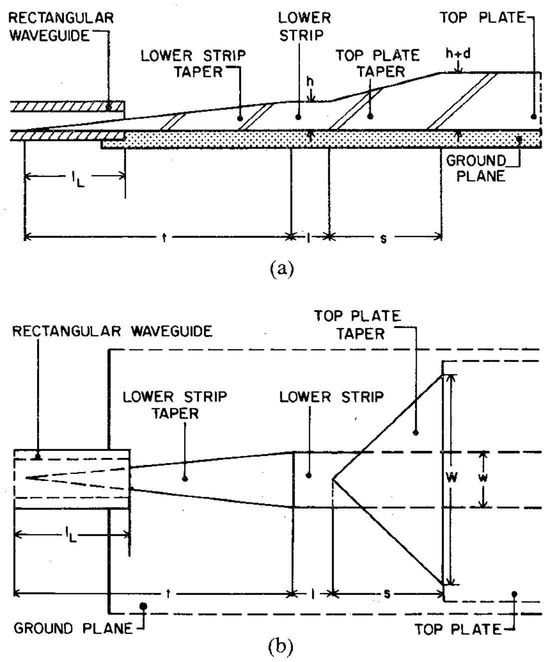

Fig. 2. Transition T-1. (a) Vertical cross section of transition. (b) Top view of transition.

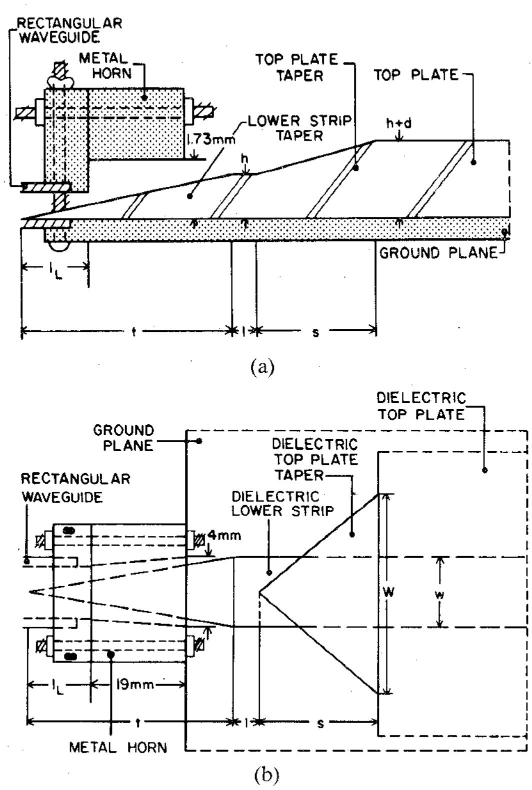

Fig. 3. Transition T-2A. (a) Vertical cross section of transition. (b) Top view of transition.

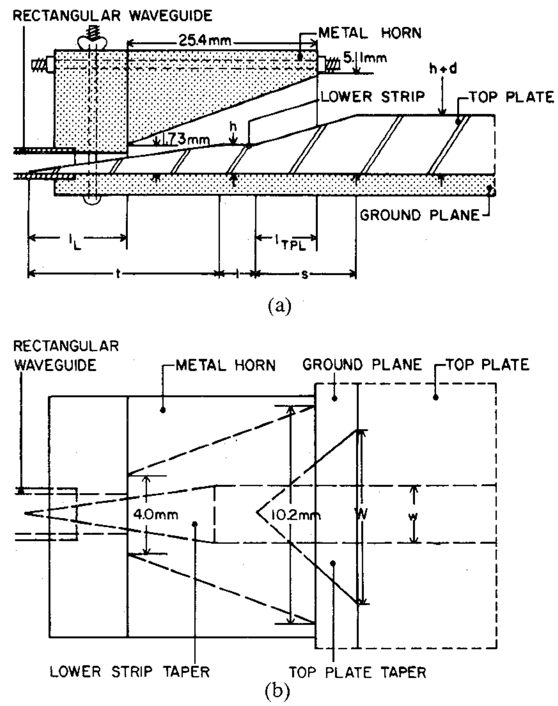

Fig. 4. Transition T-2B. (a) Vertical cross section of transition. (b) Top view of transition.

TABLE I

TAPER DIMENSIONS t (mm)	INSERTED LENGTH FOR MINIMUM REFLECTED POWER I_L^* (mm)
50 mm	15 mm 25 mm 31 mm
45 mm	14.5 mm 24.5 mm 30.0 mm
30 mm	9 mm 13.5 mm 17.0 mm
23 mm	2 mm 9 mm 14.5 mm

I_L^* = optimum I_L for minimum reflected power.

Frequency of operation 80 GHz
Height of lower strip = 1.5875 mm
Width of lower strip = 4.0 mm
Lower strip is tapered in both dimensions

B. Insertion-Loss Measurements

The experimental setup used to measure the insertion loss was similar to the one employed for the reflected power measurements, except that the matched load at the output port was replaced by another power-measuring device. The insertion loss was calculated on the basis of the power available at port 2 of the circulator where the transition under test was connected.

Insertion-loss measurements for various input and output transitions were carried out with the objective of determining a design that minimized the overall loss. Three factors have to be optimized in order to obtain an optimum design: (i) the value of I_L in all the three types of transitions (refer to Figs. 2–4) and an

TABLE II
INSERTION-LOSS MEASUREMENTS

h = d = 1.58mm	w = 4mm		ℓ = 3.5mm	frequency of operation = 80 GHz	
DESIGN NUMBER	TRANSITION TYPE Input End	 Output End	INSERTION LOSS (DB)	INPUT TRANSITION PARAMETERS	OUTPUT TRANSITION PARAMETERS
1.	T-1	T-1	2.5 dB	t = 50 mm I_L^* = 31 mm W = 10 mm s = 18 mm	t = 50 mm I_L^* = 31 mm W = 10 mm s = 18 mm
2. (i) (ii) (iii) (iv)	T-1 T-2B T-1 T-2A	T-1 T-1 T-2B T-1	3.0 dB 2.0 dB 2.25 dB 2.50 dB	t = 50 mm I_L^* = 25 mm W = 8 mm s = 18 mm (I_{TPL}^* ≅ 0.1 mm)	t = 23 mm I_L^* = 9.0 mm W = 10 mm s = 18 mm (I_{TPL}^* = 8 mm)
3. (i) (ii) (iii) (iv)	T-1 T-1 T-2A T-2A	T-1 T-2B T-2B T-1	3.5 dB 2.5 dB 2.0 dB 2.25 dB	t = 50 mm I_L^* = 31 mm W = 8 mm s = 18 mm (I_{TPL}^* = 2 mm)	t = 23 mm I_L^* = 2 mm W = 10 mm s = 18 mm (I_{TPL}^* = 2 mm)

I_{TPL}^*, I_L^* = Optimum [I_{TPL}: I_L] (refer to figures 2, 3, and 4)

approximate value which was obtained from Table I; (ii) the flare of the top-plate taper; and (iii) the type of transition employed at both the input and output ports. The results of optimizing these three factors have been tabulated in Table II.

III. DISCUSSION

An observation of the results given in Table II reveals that the transitions T-2A and T-2B are more effective than the transitions T-1. The best design obtained was for a set of parameters given under entry 3 (iii) in Table II. Referring to Figs. 2–4, we can summarize the various results obtained as follows: 1) there is an optimum value of I_L, I_{TPL}, and W for the best transition; 2) a larger value of I_L^* is more effective in minimizing the reflected power than a smaller value; 3) a horn feed minimizes principally the power lost due to radiation, as well as the reflected power junction between the lower strip and the top plate; 4) the junction between the metal guide and the lower strip exhibits reciprocal properties; 5) a longer lower strip and upper strip taper is more effective in preserving a single mode; and 6) a lower insertion loss is obtained by partially silvering the sides of the top-plate taper (Fig. 5). This may be explained by the fact that the wave remains more confined to the dielectric.

IV. CONCLUSION

An experimental technique to explore the possibility of improving the transition losses between open dielectric structures and closed metal structures has been outlined. Transition losses are mainly due to radiated power, as reflected power losses can be minimized by suitable experiments. Three types of transitions have been studied, and the results show that this approach is suitable to such a problem and can be extended to other open dielectric structures.

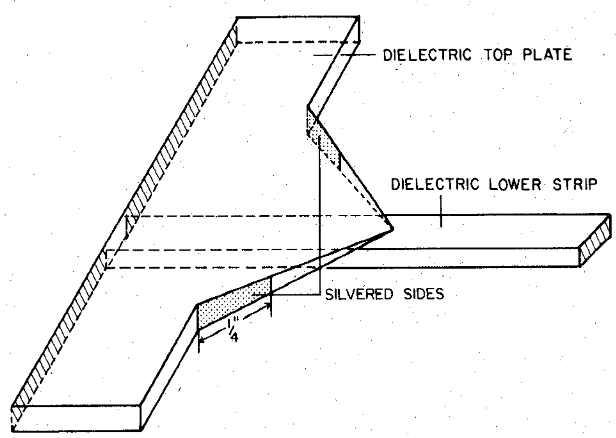

Fig. 5. Top plate taper showing the partial silvering of the sides, for lower reflection losses.

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