Planar Circuit Mounted in Waveguide Used as a Downconverter

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Abstract—**This paper describes the equivalent network constants of several patterns of the planar circuit mounted in a waveguide, which was proposed by this author [1]–[3]. As an example of the application of the circuit, a planar circuit is designed for a 12-GHz band downconverter by using the equivalent network constants.**

I. Introduction

RECENTLY there has been a demand for a low-noise and low-cost SHF converter applicable to receivers for satellite and terrestrial SHF broadcasting.

In order to meet the demands, the cost of products must be kept low by mass production, and yet their characteristics are required to be better than ever. We have proposed new microwave components with a planar circuit mounted in a waveguide to meet the above requirements [1]–[4]. In this circuit, a planar circuit with the proper patterns to meet the functional requirements is sandwiched in the E plane of a waveguide as shown in Fig. 1. The circuit pattern is formed by one metal sheet. The planar circuit on a dielectric sheet is also used in millimeter-wave components [5], [6]. In our device, however, the all-metal planar circuit was shown to realize a low-noise converter which requires the high-Q (2500~3000) circuits. The planar circuits can be made by an etching technology or by punching with an accuracy better than 20 μm, which is satisfactory for the intended application. To design the patterns of the planar circuit, a powerful approach was applied, based on the equivalent network constants of the patterns. The network constants were obtained by theoretical [2], [7] or empirical methods, and were utilized to design the pattern for the subject downconverter.

In this paper, the values of network constants already obtained and the design method of a converter will be described together with the performance of a converter which we developed.

II. Equivalent Network Constants of a Planar Circuit Mounted in Waveguide

Equivalent network constants of an inductive strip and capacitive strip have been reported in [2] and [3]. The network constants of a ridge guide circuit have also been theoretically obtained [7], [8], and the results have been confirmed by measurements.

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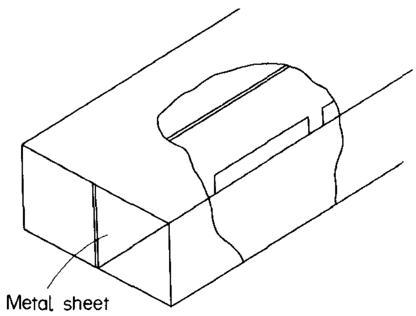
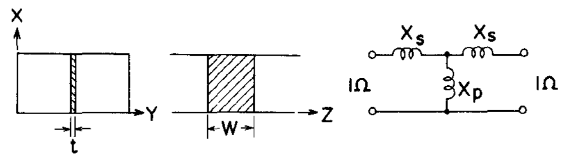


Fig. 1. Construction of planar circuit mounted in waveguide.



(a) (b)

Fig. 2. Inductive strip.

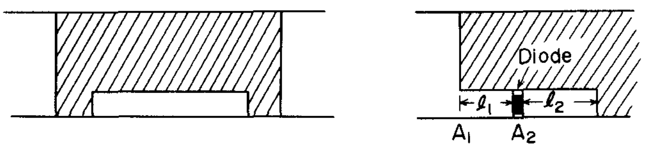


Fig. 3. Example of ridge-guide circuit with planar circuit mounted in waveguide.

The coupling circuit (see Fig. 6) between a ridge guide and a waveguide, and the opened-end circuit (see Fig. 7) between a ridge guide and a waveguide were obtained by empirical methods. The narrow band-stop filter was developed using a physical concept mentioned in Section II-F.

A. Inductive Strip

The equivalent network of an inductive strip shown in Fig. 2(a) can be expressed by the T-network as shown in Fig. 2(b), and the values of constants are shown in [2]. The series impedance becomes smaller and the parallel impedance becomes larger for a narrower width of a strip. A bandpass filter can be made by properly spacing several inductive strips [2].

B. Ridge-Guide Circuits

A ridge guide made by a planar circuit mounted in a waveguide is used for a resonator of a bandpass filter as

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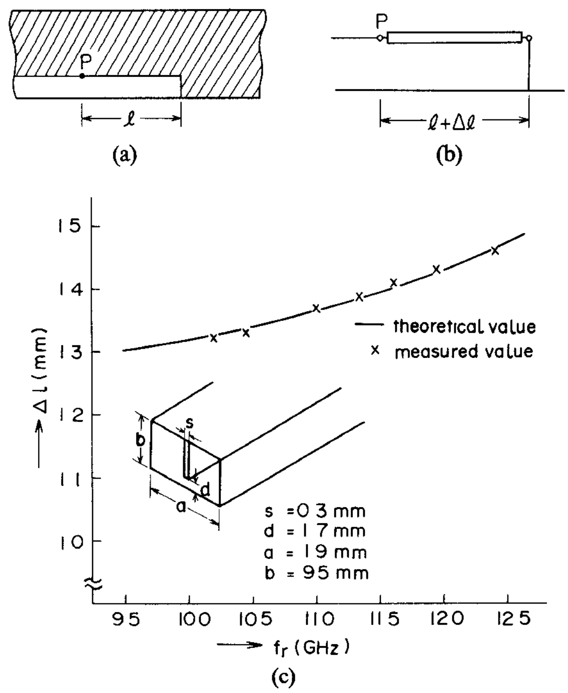


Fig. 4. Shorted-end ridge guide and the equivalent network.

shown in Fig. 3(a) and a matching circuit of a mixer diode as shown in Fig. 3(b).

The shorted-end effect of a ridge guide, which is important in the design of the circuit, was obtained theoretically [8].

Generally, the effective length l_{eff} between an arbitrary point P and the short-circuit point of a guide is larger than the actual length l with the relation of (1) [7].

$$l_{\mathrm{eff}} = l + \Delta l. \tag{1}$$

The applicable equivalent circuit and values of Δl are shown in Fig. 4.

By using the shorted-end effect, the resonant frequency of a resonator can be easily obtained. In the case of a multipole bandpass filter, the coupling coefficient must be also obtained.

The coupling coefficients between two ridge-guide resonators have also been theoretically obtained, and the results are shown in Fig. 5.

C. *Coupling Between a Ridge Guide and a Waveguide*

The coupling circuit between a ridge guide and a waveguide is shown in Fig. 6(a). The equivalent network is shown in Fig. 6(b). The values of constants were obtained by measurements. The results are shown in Figs. 6(c) and (d).

D. *Discontinuity Between Ridge Guide and Waveguide*

The structure and the equivalent network of this discontinuity are shown in Figs. 7(a) and (b). The circuits constants, which were obtained by measurement, are shown in Figs. 7(c) and (d).

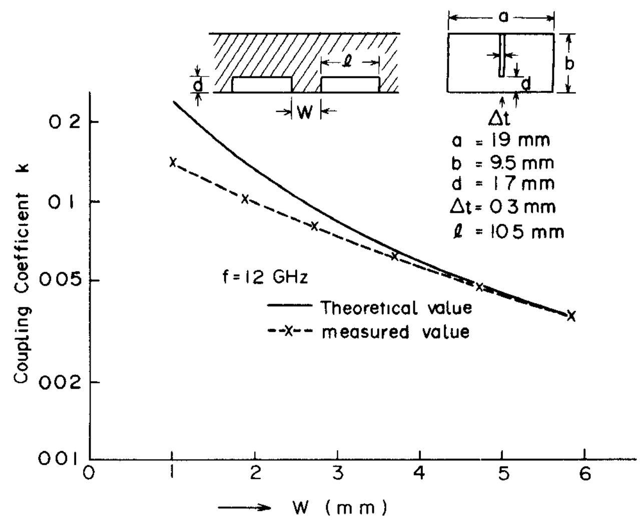


Fig. 5. Coupling coefficient of ridge-guide resonators.

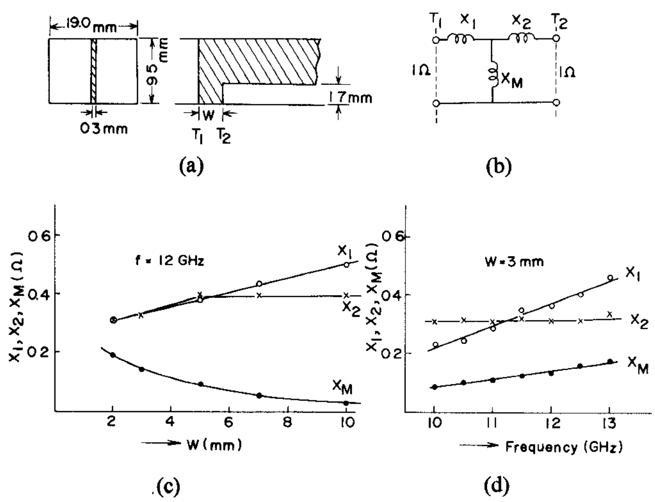


Fig. 6. Coupling circuit between ridge guide and waveguide.

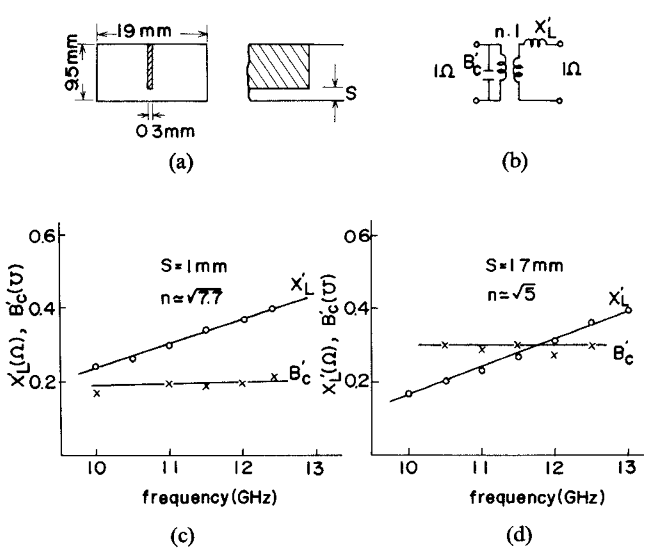


Fig. 7. Open-ended ridge-guide circuit.

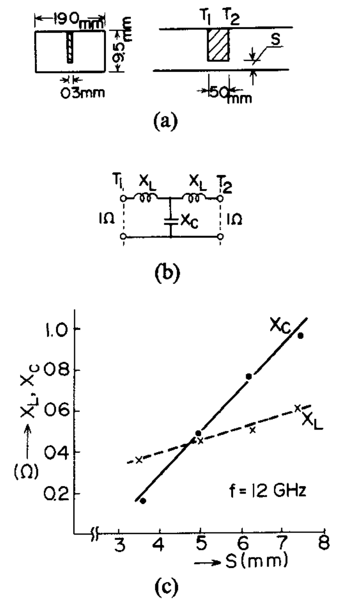
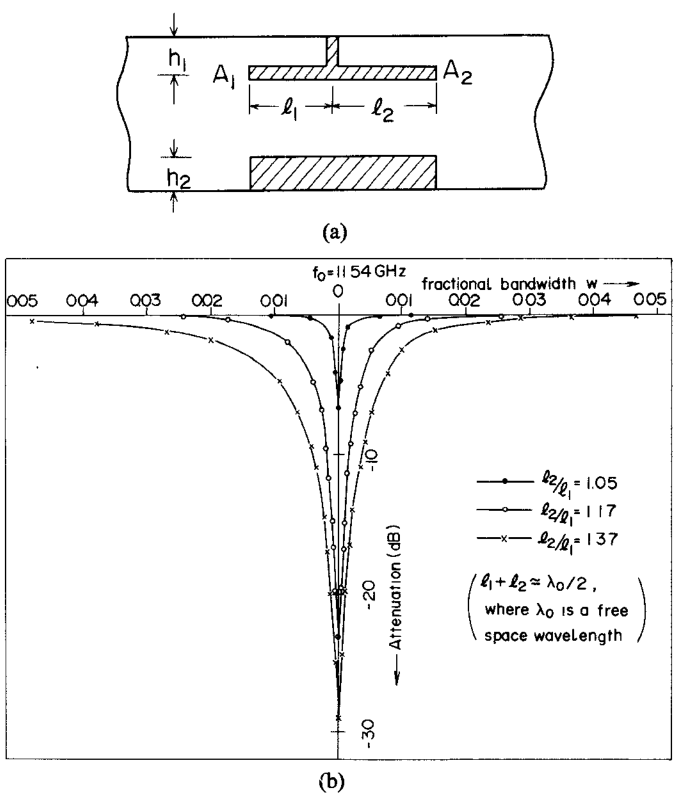


Fig. 8. Capacitive strip.



(b)

Fig. 9. Narrow band-stop planar filter.

E. Capacitive Strip

The capacitive strip and the equivalent network are shown in Figs. 8(a) and (b). The measured values of the constants are shown in Fig. 8(c). The values of the network constants are reported in [3].

F. Narrow Band-Stop Filter

The narrow band-stop filter can be obtained by the pattern as shown in Fig. 9(a). The length between A_1 and A_2 in Fig. 9(a) should be about a half-wave to realize a resonator. This resonator couples to the waveguide through the line length of h_1 in Fig. 9(a). If the coupling line is at the center of the resonator, there is no coupling between the waveguide and the resonator, because the center is at zero potential in the resonant mode.

By the reason mentioned above, the bandwidth of the filter can be adjusted to be narrower by decreasing the length h_1 and the difference between l_1 and l_2. By this technique, we can design a band-reject filter with an unloaded Q of about 1600. The part located opposite the resonator is used for a matching. By adjusting the height of h_2, we can remove the higher mode reactance caused by the resonator, that is, keep a standing-wave ratio of less than 1.05 outside the stopband of the filter. The performances of this narrow band-stop filter, which were obtained by measurements, are shown in Fig. 9(b).

III. Design Example: Planar Circuit for 12-GHz Downconverter

An example of the design of a planar circuit used for matching a mixer diode will be shown. The admittance of the mixer diode at the signal frequency is calculated and it is plotted at point A on the Smith chart shown in Fig. 10. The diode is connected in the planar circuit as shown in Fig. 3(b). The distance between the diode and the short end l_2 was designed as satisfying the image short condition [7]. Therefore, l_2 should take the values of (2):

$$l_2+\Delta l=\lambda_{gm}/2 \tag{2}$$

where λ_{gm} is a ridge-guide wavelength at the image frequency. Since $\lambda_{gs}<\lambda_{gm}$ (where λ_{gs} is a ridge-guide wavelength at the signal frequency), the ridge-guide admittance viewing rightward at the point A_2 becomes inductive. The total admittance including the diode and shorted-end ridge-guide admittance, therefore, moves to point B from point A as shown in Fig. 10. When we design the length l_1 to satisfy the condition of $l_1 \simeq \lambda_{gs}/4$, the admittance viewing right at point A_1 of Fig. 3(b) is shown by point C in Fig. 10. The equivalent network and their constants of the discontinuity at point A_1 in Fig. 3(b), however, is shown in Figs. 7(b) and (c). The admittance at the point C in Fig. 10 moves to the point D by the effect of B_c' of Fig. 7(b) and then moves to the point E by the transformer shown in Fig. 7(b). The inductive reactance X_L' shown in Fig. 7(b) causes point E to move to F. And for canceling this inductive reactance, the capacitive strip shown in Fig. 8 is inserted at the proper position A as shown in Fig. 11.

First, point F moves to G corresponding to the distance between A and A' shown in Fig. 11. And then, by using the equivalent circuit of the capacitive strip shown in Fig. 8, point G moves to H by the effect of series inductance X_L, to I from H by the effect of shunt capacitance X_c and finally to J from I by X_L. This results in a match with the waveguide.

Other patterns for the local oscillator (LO) source and the coupling circuit between the mixer circuit and the LO

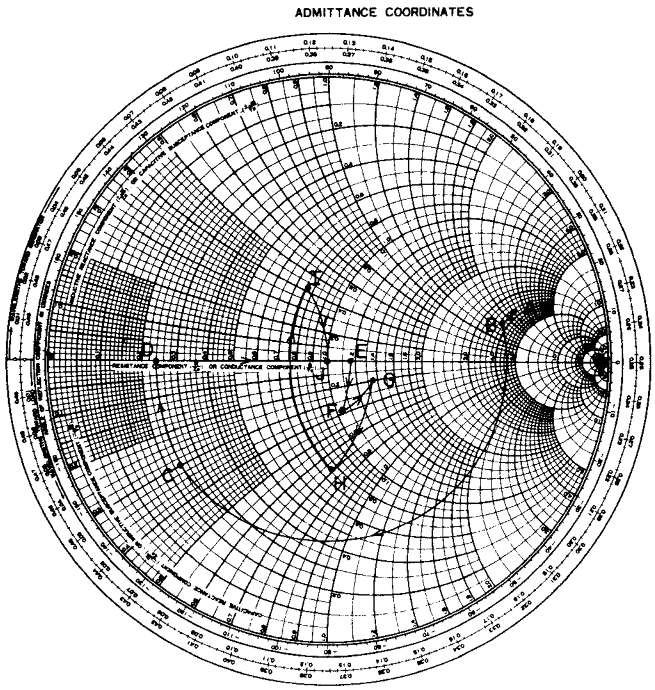


Fig. 10. Design of mixer matching circuit (signal frequency $f_s = 12$ GHz, image frequency $f_m = 9.5$ GHz).

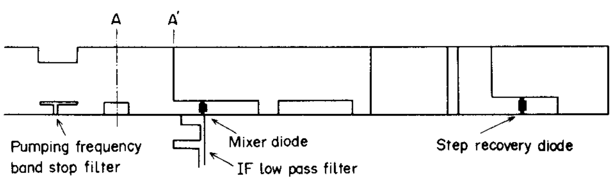


Fig. 11. Pattern of downconverter.

source can be also designed from the network constants described above. An example of the total pattern, which we use for an SHF converter, is shown in Fig. 11. Using this pattern and a mixer diode with the series resistance of 3 Ω at X band and a Schottky contact diameter of 8 μm, we obtain a conversion loss of 3 dB. The bandwidths are 180 and 500 MHz for an IF center frequency of 400 MHz and 1.25 GHz, respectively. The total SSB noise temperature of 500 K was obtained by using an IF amplifier with a 120 K noise temperature at the 12-GHz signal frequency band.

In our final assembly, the entire SHF converter is housed in one aluminum diecast mount. A part of this mounting case is used for mounting the planar circuit, and another compartment is used for the IF amplifier and local oscillator. The converter is shown in Fig. 12.

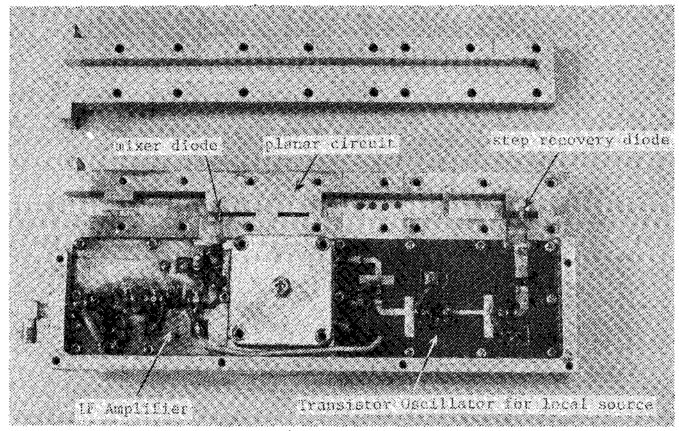


Fig. 12. SHF downconverter with planar circuit mounted in waveguide.

IV. Conclusion

The planar equivalent network and the circuit constants, which have been obtained by theoretical methods or experimental measurements, have been described. As an application example, the pattern for an SHF downconverter and the design procedure were described.

In the future, the theoretical approach will be applied to refine the network constants of the planar circuit. Furthermore, the application to millimeter-wave components will also be important.

References

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