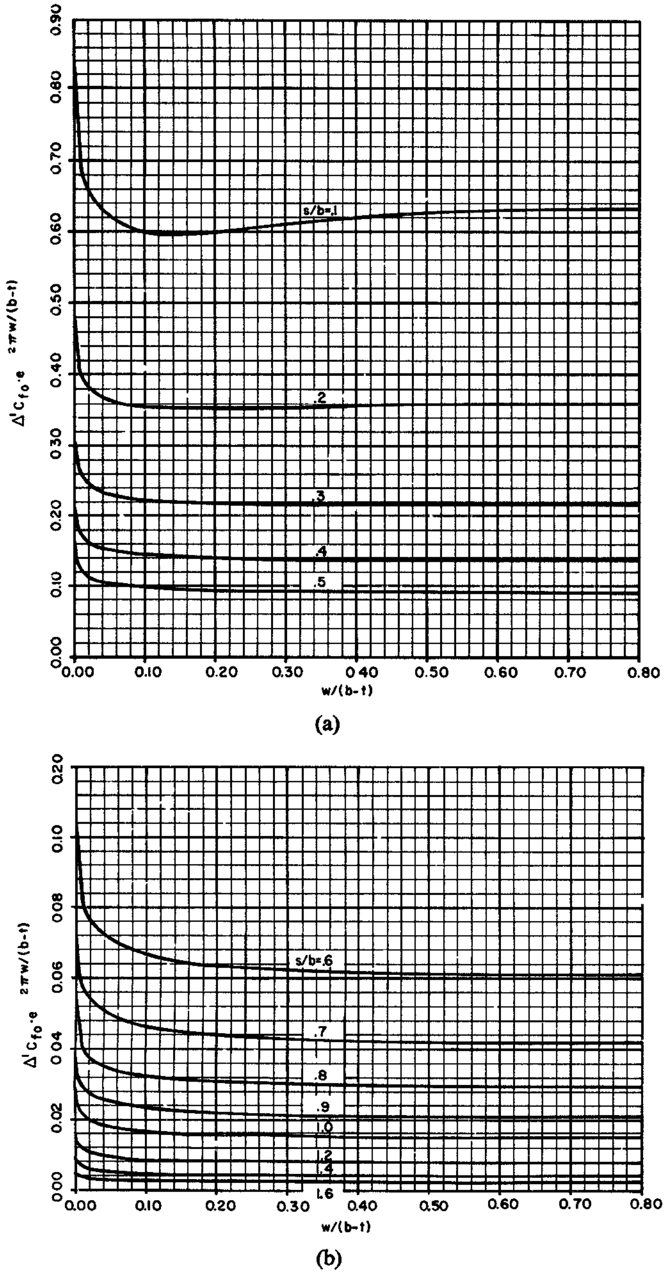

Fig. 2. Curves of $\Delta' C_{f_0} e^{2\pi w/(b-t)}$ for $t/b=0$.

accurate for large values of s/b without regard to the value of $w/(b-t)$. Even if $w/(b-t)$ and s/b are small, it can be very useful, for small values of t/b, when the problem is considered after a rotation of the structure by 90°.

Fig. 2(a) and (b) plot $\Delta' C_{f_0} \exp(+2\pi w/(b-t))$ for a number of values of s/b in the case $t/b=0$. For given values of s/b and $w/(b-t)$, these curves constitute upper limits on the value of $\Delta' C_{f_0}$ for larger values of t/b. Consider the behavior of $\Delta' C_{f_0} = \Delta C_{f_0}(w/(b-t); t/b, s/b) - \Delta C_{f_0}(w/b-t); t/b, \infty)$ for fixed $w/(b-t)$ and s/b. Since both terms on the right approach a common limit as $t/b \to 1$, it follows[1] that their difference, $\Delta' C_{f_0}$ is a decreasing function of t/b. Thus the curves for which $t/b=0$ are upper limits on the other curves for the same value of s/b.

III. Numerical Example

Cruzon and Garver [7, p. 495] have given a series of graphs for determining the characteristic impedance of rectangular coaxial line. They have selected an example which in the notation of this paper has the parameters $w/(b-t)=1$, $t/b=1/3$, and $s/b=4/3$. For this case, the approximate capacitance given by (10) is 7.4541684 with an error which is negative and less in absolute value than $4 \times 0.007 \exp(-2\pi)$, as seen from Fig. 2(b). Then using 376.62 as the characteristic impedance of space, one obtains

$$Z_0 = 50.524750 \begin{matrix} +0.000355 \\ -0.0 \end{matrix} \ \Omega.$$

This value falls well within the range of values given by Cruzon and Garver.

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Plane-Wave Interaction with Structures of Thin Absorbing Films

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***Abstract*—Electromagnetic plane-wave absorption by resistive films of finite dimensions are considered. It is proposed that the effect of edge diffraction from a finite film causes the experimentally observed frequency-dependent sensitivity of thin-film microwave-power monitors. Methods are outlined to prevent such frequency dispersion. It is pointed out that the position of a microwave power source can be determined by 3 pairs of perpendicularly placed thin-film monitors.**

It was shown that plane electromagnetic waves are absorbed independently of frequency by resistive films [1] of thickness much smaller than the wavelength, and that maximum absorption occurs if the film resistance per square is half the wave impedance of the propagation medium. This behavior is strictly only true if the film is of infinite extent, and, therefore, only correctly given for optical or infrared frequencies. When, however, the frequency independence of thin-film absorption is to be exploited for monitoring microwave radiation levels [2], [3], the

[1]Although this argument is certainly valid on the average, the possibility of exceptions over small changes in t/b cannot be excluded. On the other hand, it can be shown to be true when $w/(b-t)=0$ and is probably true in general.

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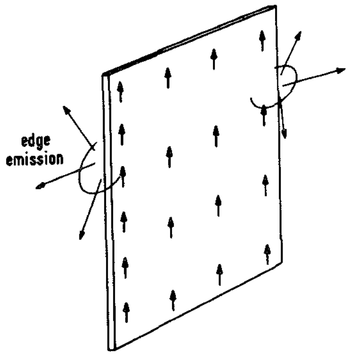

Fig. 1. Finite absorbing film with microwave current arrows and cylindrical emission from film edge where microwave current density thus reduced.

transverse film dimensions would have to be excessively large to be useful for the normal application of a small portable monitor, as otherwise the finite transverse dimensions introduce a nonnegligible frequency dispersion of absorption. However, special precautions can be taken to avoid such difficulties, and these are considered in this paper. The interactions of plane waves with thin absorbing films of finite transverse dimensions are, therefore, the subject of the present contribution. The effects of finite absorbing films have so far only been investigated to a limited extent [2] although it is relevant for an area of growing importance with the development of industrial and consumer microwave power applications. It is also pointed out that 2 finite films, placed perpendicular to each other, can be employed to determine the direction of a plane wave, and that 3 such pairs can normally be used to locate the source of microwave radiation.

The problem concerns the behavior of the film edge in an irradiating plane wave. That part of the plane wave, which illuminates the film, induces for the maximum absorption approaching 50 percent, a current which can be calculated easily from the current–power relation for the absorped power $P=I^2R$ where I is the current per distance transverse to its direction induced in the film and R is the resistance per square of the film for maximum absorption, namely half the impedance of free space. The resulting value for I, in ampere per distance in centimeters, transverse to the current lines, is $0.1\sqrt{P}$, where P is the absorbed power in W per surface area of film. Such a current generates at the film edge (see Fig. 1) a diffraction wave which is inductively produced at the film edge parallel to the current vector, and capacitively for the edge normal to the current vector. This wave propagates in a cylindrical shape away from this edge so that the microwave absorption is reduced near the edge. Such reduced edge absorption modifies also the microwave current density. This current–density modulation can be expected to propagate along the film away from the edge. Assuming that this current–density wave propagation takes place along an equivalent transmission line consisting of the thin film with its loss resistance, and its equivalent inductance and capacitance per length, the complex propagation constant can be estimated. The resistance per length is given by the film resistance per square and is more important than the inductance which can thus be neglected here. The capacitance per length is given by the dielectric constant of free space and the average distance to any earthed conducting plane. (There is of course also a "free-space" wave which originates from the film-edge diffraction and travels along the film surface. It can, however, be shown that this type of wave does not interact with the film and does not, therefore become absorbed.) The current perturbation is then found to vanish relatively quickly within a short distance,

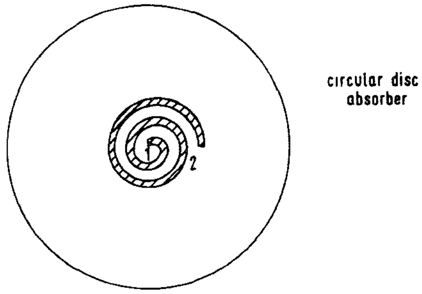

Fig. 2. Thin spiral of removed absorbing material to enable resistance monitoring leads to be placed at positions 1 and 2.

but it is still possible for a standing-wave pattern to occur if the film edges from opposite sides are not too far away from each other. This is particularly pronounced when the film is a circular disc. Such a standing-wave pattern can give a peak on the central point for a circular disc or on the central line for a film band, where the wave originating from opposite corners have traveled the same distance and exhibit therefore, the same phase. Away from this central point occurs first a minimum and then another maximum of absorbed power. If the total absorbed power of the film is measured as an indication of the power density of a plane wave, such a standing-wave behavior on the surface of a film can be expected to give a resonance behavior of sensitivity for changing wave frequency.

This explanation can be considered to be the reason for the frequency-dispersive behavior of sensitivity reported recently [4], when a circular Ge thin film shows a reduction of sensitivity per film area for the film diameter equal approximately half the wavelength. This resonance gives a response variation of about 50 percent.

It is proposed here that such a variation in sensitivity can be minimized by sensing the absorbed power only on the central point of the film. A suitable sensing structure can be etched into the film by photoresist technology so that the resistance change due to an increased film temperature by absorption is measured over a small central area only. Two highly resistive leads can be employed to connect a meter to a meandering or spiralling structure in the film (see, for example, Fig. 2).

Since microwave absorption with planar resistance films does take place for plane waves irradiating the films normally, and the absorption decreases to practically zero by turning the film then by 90°, it is possible to employ perpendicularly positioned pairs of films to determine not only the power level of the microwave radiation but also to locate the position of the radiating source if certain conditions are satisfied. For this purpose it suffices to have 3 such pairs at different positions, each determining the direction of wave propagation. Provided that it can be assumed that the direction opposite to wave propagation points to the source, i.e., provided that there are no large reflectors around, the cross point of the three directions from each of the monitor pairs gives the source position. This can be useful for locating movable parts which are made to carry a cheap microwave source, or for finding microwave power leaks from such systems as microwave ovens.

The example of a microwave bolometer is considered here, but there are of course many other areas of increasing importance such as the use of a suitably resistive film deposited on a conducting surfaces causing 50-percent absorption for normal plane-wave irradiation in the case of the resistive film alone having a resistance of about 100 Ω/□ and the question of biological membranes interacting with microwaves.

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A Fast Low-Loss Low-Drive 14-GHz Microstrip p-i-n Phase Shifter

BERNARD GLANCE

***Abstract*—A 14-GHz 4-bit p-i-n microstrip phase shifter with low RF attenuation, fast switching time, and low switching power requirements is described. The insertion loss for the 16 phase states is 1.4 dB ± 0.1 dB over the 14–14.5-GHz band. This insertion loss, obtained with a forward bias current of 2.5 mA/diode, is the lowest reported for comparable phase shifters. Switching time of each of the 4 cells is 1 ns. Driving power per cell is 15 mW for a switching repetition rate of 1 μs.**

I. Introduction

A communication satellite that uses rapidly scanning spot beams was proposed by Reudink and Yeh in 1977 [1], [2]. One of the key elements of this system are the phase shifters which should provide fast switching, require low driving power and have low RF loss dissipation. A 4-bit p-i-n microstrip phase shifter designed to operate on the 11.7–12.2-GHz range was developed [3], [4] for the transmitter beam fulfilling the system requirements.

This paper describes a phase shifter operating over the 14–14.5-GHz frequency range which was developed for the receiving beam for the same project. Increased RF insertion loss due to the higher frequency of operation was the main problem to resolve in designing this phase shifter. Efforts were directed at minimizing this effect by properly scaling the RF circuit. The RF insertion loss thus obtained is lower than that previously reported for the 12-GHz phase shifter [3] [4].

II. RF Circuit Design

Linear scaling of all the RF circuit dimensions for higher frequency of operation increases the circuit loss by [5], [6].

$$\sqrt{\frac{F_2}{F_1}} \tag{1}$$

where F_1 and F_2 are the low and high frequencies, respectively. This problem can be circumvented if the two frequencies are not too far apart by scaling only the electrical lengths of the circuit. The substrate thickness is kept constant as well as the line widths to conserve the line impedance. The circuit loss then decreased by the factor

$$\sqrt{\frac{F_1}{F_2}}\ . \tag{2}$$

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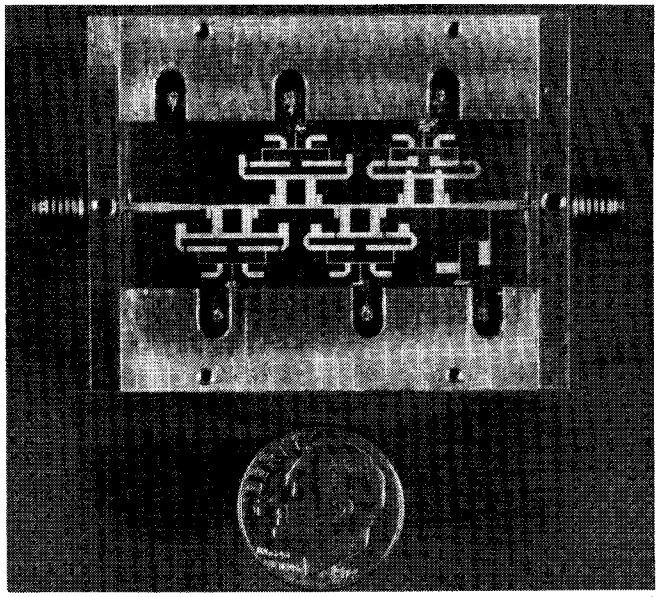

Fig. 1. Photograph of the complete phase shifter.

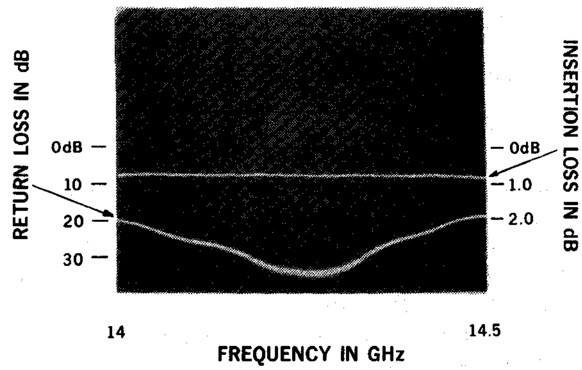

Fig. 2. RF insertion loss and return loss of the microstrip circuit.

The 14-GHz phase-shifter circuit was designed from that of the 12 GHz according to this scheme. The electrical lengths were decreased by the ratio 11.95/14.25, keeping the substrate thickness constant at 0.020 in. The circuit consists of 4 cells designed to provide 180°, 90°, 45°, and 22.5° phase shifts. Each cell is made of a 3-dB hybrid coupler and a biasing circuit. The diodes are shunt-mounted in the gap between the coupler and two identical sections of line whose lengths are selected to give the desired phase shift. The two diodes of a cell are biased in parallel. The circuit is fabricated by evaporation of a chrome layer of 200 Å thick followed by 3 μm of copper on a silica substrate. A photograph of a 14-GHz phase shifter is shown in Fig. 1. The circuit is shielded in a metallic box whose inside dimensions are 1.677 × 0.670 × 0.250 in. The box is dimensioned to avoid excitation of parasitic resonances [7] in the 14–14.5-GHz band. Pins running in the sidewalls contact the biasing circuit to the driver circuit enclosed on the opposite side.

Fig. 2 shows the RF circuit loss which are 0.77 dB over the 14–14.5-GHz band. This is a 0.13-dB improvement over the 12-GHz results in close agreement with (2).

III. Statics Measurements

The p-i-n diodes (HPND 4001) previously used at 12 GHz were also used for the 14-GHz circuit. Return loss degradation

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