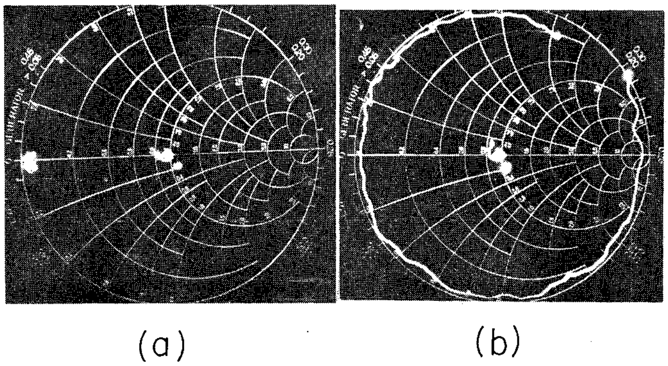

Fig. 2. (a) Impedance locus of the short-ended guide when the reference plane is situated at the shorted point. The impedance locus is concentrated to the $0+j0$-Ω point. The locus is at the center when a matched load is connected. (b) Impedance locus of a short-ended waveguide several centimeters long. The swept frequency is 17.5–19.5 GHz.

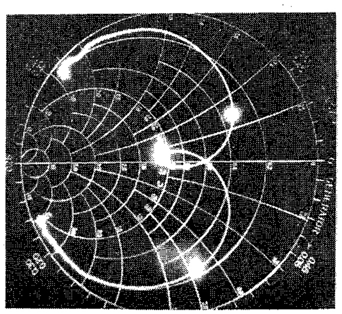

Fig. 3. Impedance locus of the 3-stage Chebyshev waveguide bandpass filter. The swept frequency is 18.0–19.0 GHz. The marker indicates 18.0±0.1 GHz. The reference plane is situated at the first iris of the filter.

lator was used. Due to the frequency limit of the circulator, sweep frequency range is limited to 17.5–19.5 GHz. Fig. 2(a) shows the impedance locus of the short-ended guide when the reference plane is situated at this shorted point. The locus is concentrated to the $0+j0$-Ω point, which shows the correctness of this method. The locus was on the center of the CRT when a matched load was connected as the device under test.

Fig. 2(b) shows the impedance locus of a short-ended waveguide several centimeters long. Fig. 3 shows the impedance locus of the 3-stage Chebyshev waveguide bandpass filter. In this case, the reference plane was located at the first iris of the filter. Simplicity and ease of manufacture in the millimeter waveband are the features of this method.

References

[1] A. L. Samuel, "An oscillographic method of presenting impedances on the reflection-coefficient plane," *Proc. IRE*, vol. 35, pp. 1279–1283, Nov. 1947.
[2] S. B. Cohn, "Impedance measurement by means of a broadband circular-polarization coupler," *Proc. IRE*, vol. 42, pp. 1554–1558, Oct. 1954.
[3] P. I. Somlo, "The locating reflectometer," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 105–112, Feb. 1972.
[4] G. E. Schafer, "Mismatch errors in microwave phase shift measurements," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-8, pp. 617–622, Nov. 1960.

High-Power Frequency Multiplier Using MIS Varactors

F. SCHUMACHER

***Abstract*—The experiment described demonstrates the applicability of MIS varactors in microwave power circuits. A frequency doubler with 55-percent overall efficiency and pulsed output power of 5.5 W at 5.4 GHz with a duty cycle of 50 percent has been built by using two MIS varactors in parallel. The multiplier has a coaxial low-pass filter at the input and a waveguide output, allowing a 3-dB bandwidth of 8 percent.**

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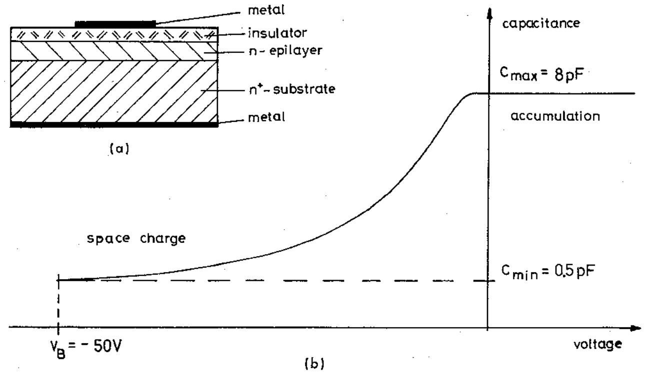

Fig. 1. An MIS varactor. (a) Structure. (b) *CV* characteristic.

TABLE I
MIS Varactor Specifications

Substrate thickness	120 µm
Substrate resistivity	0.011 Ωcm
Epitaxial layer thickness	4 µm
Epitaxial resistivity	0.8 Ωcm
Insulator	100 Å SiO_2 + 800 Å Si_3N_4
Contact diameter	150 µm
Max. capacitance	8 pF
Min. capacitance	0.5 pF
Series resistance	3.2 Ω
Cutoff frequency	94 GHz
Breakdown voltage	50 V
Insulator breakdown voltage	60 V

The application of MIS varactors in frequency multipliers was first described in [1]. Experiments with an upconverter using MIS varactors [2] showed the MIS varactor to be, in many respects, superior to the charge-storage varactor. This short paper describes the application of a MIS varactor in a frequency multiplier at high power levels.

The structure of the MIS varactor is shown in Fig. 1(a). An epitaxial silicon wafer with a highly doped substrate and a thin epitaxial layer is used. Upon this an insulating layer of silicon dioxide and silicon nitride is deposited; a titanium–gold contact is then evaporated by using photoresist techniques.

Fig. 1(b) shows the high-frequency large-signal capacitance–voltage (*CV*) characteristic of the MIS varactors used. With the exception of a finite accumulation capacitance, the *CV* characteristic is similar to that of a charge-storage varactor with constant doping level. The main advantage is that the MIS varactor in this application is a pure majority-carrier device [3]–[5]. No minority-carrier transit time or recombination effects, which would reduce the efficiency and limit the drive level, are present. The MIS varactor therefore allows good efficiencies at higher drive levels, resulting in higher power capability.

The specifications of the MIS varactors are listed in Table I. Since the theoretical resistance of the epitaxial layer is 1.6 Ω, the devices have relatively high parasitic losses. One reason may be the high substrate thickness of 120 µm, which also results in a high thermal resistance. Further progress in technology, e.g., the upside-down technique, and special optimization of varactor parameters for power applications are expected to lead to significantly better devices. A cutoff frequency of 160 GHz and a breakdown voltage of 70 V should be attainable.

Two of these devices have been mounted in parallel in the frequency doubler shown in Fig. 2. This doubler was developed as a simple low-frequency model for further scaling up to the *Ku*-band. 2.7-GHz power is introduced to the varactor diodes from the coaxial input. A transforming low-pass filter within this line bars 5.4-GHz

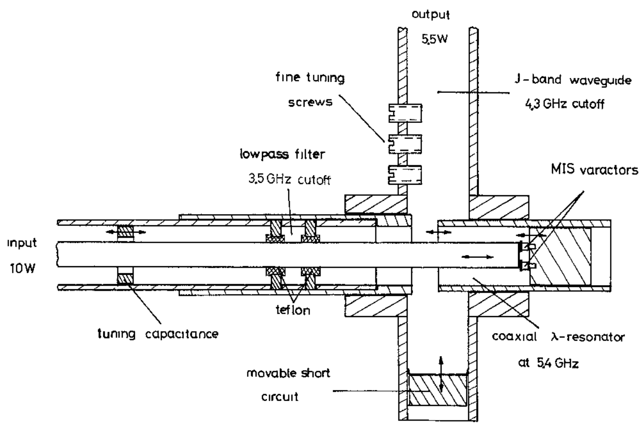

Fig. 2. Frequency doubler from 2.7 to 5.4 GHz.

TABLE II

FREQUENCY DOUBLER PERFORMANCE

Input frequency	2.7 GHz
Input power (2 varactors)	10 W pulsed 50% duty cycle
Output frequency	5.4 GHz
Output power (2 varactors)	5.5 W
Overall efficiency (2 varactors)	55 %
3 dB bandwidth (2 varactors)	8 %
Best efficiency (1 varactor and reduced power)	65 %
Best 3 dB bandwidth (1 varactor and reduced power)	30 %

power from the input. Tuning is possible with a movable capacitive iris and an external stub tuner. The 5.4-GHz currents generated within the coaxial line excite propagating fields in the output waveguide. Tuning of the slot width and position, together with the movable waveguide short, permits output matching over a broad frequency range. For fine tuning of the output, three screws are mounted inside the waveguide. Since the waveguide cutoff frequency is 4.3 GHz, the fundamental does not appear at the output port. The varactors are biased externally through the input circuit.

Detailed data for the multiplier are given in Table II. Because of the relatively low reactive part of the input and output impedances [1], the MIS varactor allows large bandwidths to be attained with simple circuits. With only one varactor the bandwidth increased to 30 percent (due to the higher impedance level), but the attainable power decreased. No instabilities have been observed when sweeping the input frequency, and the output is free of spurious signals within maximum sensitivity of the spectrum analyser, which is 60 dB below the output signal.

An undesirable characteristic of MIS varactors, however, is the shift of the *CV* curve, which is caused by tunneling effects between semiconductor and insulator surface states [5], when the applied voltage exceeds a critical value. This value seems to decrease with temperature, since the *CV* characteristic remained stable at 10-W input power with 50-percent duty cycle but not at 10-W CW. It is possible to compensate the shift by readjusting the bias voltage, but the *CV* characteristic shifts again, and after a short time the device is destroyed by irreversible insulator breakdown. A lower thermal resistance (and therefore a lower insulator temperature) should reduce this problem.

It is concluded that the MIS varactor is suitable for broadband frequency multiplication at high power levels. Therefore, the MIS varactor deserves serious consideration for high-power solid-state applications, e.g., transmitters for microwave relay stations.

REFERENCES

[1] B. Schiek and J. Marquardt, "Optimaler Wirkungsgrad von Frequenzvervielfachern mit MIS-Varaktoren," *Arch. Elek. Übertragung*, vol. 24, pp. 237–243, 1970.
[2] J. Müller, "An upper-sideband upconverter using MIS varactors," *IEEE J. Solid-State Circuits*, vol. SC-7, pp. 43–50, Feb. 1972.
[3] W. G. Pfann and C. G. D. Garret, "Semiconductor varactors using surface space-charge layers," *Proc. IRE* (Corresp.), vol. 47, pp. 2011–2012, Nov. 1959.
[4] R. Lindner, "Semiconductor surface varactor," *Bell Syst. Tech. J.*, vol. 41, pp. 803–831, 1962.
[5] B. Schiek and J. Helmcke, "Untersuchungen an MIS-Varaktoren für Anwendungen als nichtlineare Reaktanzen," *Arch. Elek. Übertragung*, vol. 24, pp. 153–163, 1970.

Metallic Frame Beam Waveguide

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***Abstract*—Experimental tests performed on metallic frame beam waveguides are described. Two types of metallic structures have been considered. The first one constituted by thin annular frames has the same attenuation value as that of an iris beam waveguide (infinite slit) of the same aperture, but presents guiding properties which are polarization sensitive. The second type of a more complex structure is essentially a dielectric frame beam waveguide in which the dielectric of suitable refraction index is simulated by metallic parallel plate waveguide sections.**

Beam waveguides consisting of equispaced dielectric frames, introduced as a by-product of a study on rimmed Fabry–Perot (F.P.) resonators [1], [2], have been extensively described in preceding works [3]–[5].

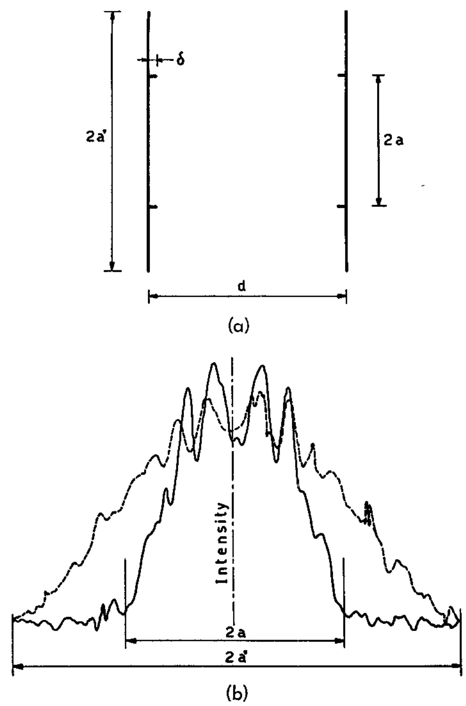

Fig. 1. (a) The Fabry–Perot resonator with thin rims perpendicular to the mirror surfaces. (b) Intensity field patterns across the mirror aperture with and without thin rims.

This short paper is concerned with an experimental investigation performed on another type of the same class of beam waveguides. It consists of a sequence of thin metallic annular frames and constitutes the analogy of an F.P. resonator having end mirrors with thin rims perpendicular to the mirror surfaces [Fig. 1(a)]. Experimental tests performed on an X-band model of such a resonator have shown that the losses oscillate with a quasi-periodical trend as a function of the rim depth with periodicity $\sim\lambda/2$, due to resonances in the current systems over the rims. Hence, for suitable values of the rim depth, the field is confined and the losses decrease. This is

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