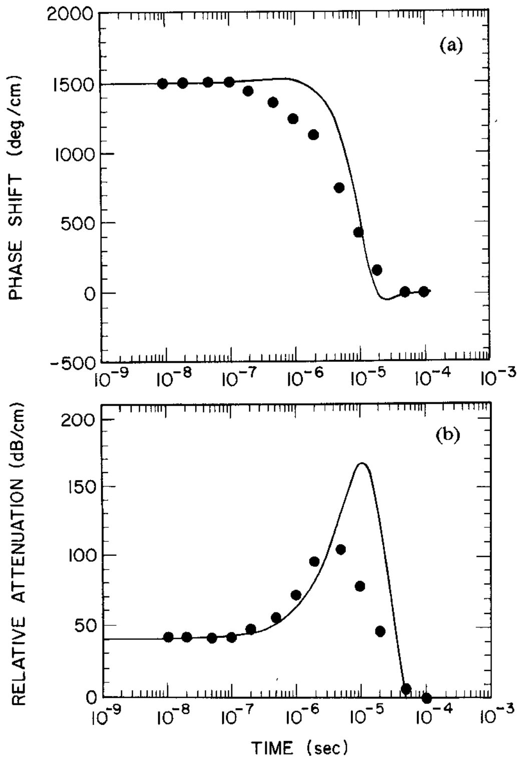

Fig. 8. Comparison of theoretical (solid line) and experimental (data points) results for the situation when the millimeter-wave bridge is illuminated by a single pulse from a frequency doubled mode-locked Nd:YAG laser. The experimental technique is the dynamic bridge method. (a) Phase shift with respect to time. (b) Relative attenuation with respect to time.

semiconductor waveguides. This technique is also applicable to the measurement of the transient behavior of any microwave/millimeter-wave device. The time resolution of this technique can be further improved to the picosecond range if an optoelectronic correlation or an electronic sampling technique is used to map out the temporal variation of the signal [10].

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An X-Band Four-Diode Power Combiner Using Gunn Diodes

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Abstract **—A four-diode X-band Gunn diode combiner is described, and the performance characteristics are presented for combining efficiency, tuning range, pushing figure, frequency drift, external Q, and FM noise.**

I. Introduction

Solid-state microwave sources are advantageous in many applications since the size is small and the required power supplies are simple. The maximum power available from an individual device is, however, limited to 500–750-mW CW for Gunn diodes in the X-band [1]. Although higher power may be obtained from IMPATT diodes, Gunn diodes are often preferred for certain purposes because of their lower noise [2]. Attempts have, therefore, been made for generating higher powers than obtainable from single devices by combining the outputs of several devices [3].

A general scheme for combining multiple diodes in a rectangular cavity was given by Kurokawa and Magalhaes [4]. A cylindrical cavity combiner using the same principles, developed by Harp and Stover [5], is widely used. A variation of this scheme, proposed by Diamond [6], uses modules of diode pairs in push–pull operation and thereby achieves higher packing density and combining efficiency than a regular cylindrical cavity combiner. These types of combiners, however, require precise design and adjustments for realizing the optimum performance. Simple forms of combiners with less stringent design requirements are, therefore, preferred for a small number of diodes. Simple single-resonator two-diode combiners have been reported with different configurations [7], [8].

Single-resonator, four-diode combiners have also been reported in two configurations [9], [10]. In one configuration [9], the diodes are mounted at the four corners of a TE_{101} rectangular cavity. The output is coupled through an iris and the tuning is achieved by a dielectric screw tuner. It is reported that combining efficiencies of 80–90 percent and a tuning bandwidth of 3 GHz at 33 GHz may be realized with these combiners. In the second configuration [10], modules of two-diode combiners are mounted in cascade in an oversized shorted waveguide. The discontinuity at the output end and the short forms the cavity, and tuning is achieved by adjusting the position of the short.

In this paper, a simpler single-resonator, four-diode combiner is described, which is suitable for the X-band. This configuration has been mentioned in a footnote in [11] but the details are not available. The performance characteristics of the combiner using diodes with different power ratings are also presented.

II. The Combiner and Performance Characteristics

The mounting arrangement of the diodes in the combiner is shown schematically in Fig. 1. The diodes are mounted at the opposite ends of two posts, placed symmetrically on the two sides of the central line in a cross-sectional plane of a shorted, rectan-

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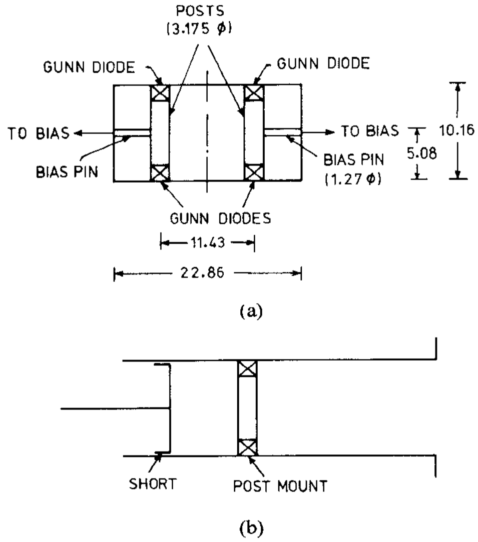

Fig. 1. An X-band four-diode Gunn oscillator in WR-90 waveguide resonator. (a) Schematic arrangement of device mount in transverse plane (all dimensions in mm). (b) Longitudinal section through one post mount.

gular, X-band waveguide. Bias voltage is supplied to the diodes by two pins introduced through the narrow sides of the waveguide. The dimensions of the posts and the pins, and the position of the posts were optimized at 9.5 GHz to obtain maximum power.

The load (the power-detecting head of a power meter) is coupled to the combiner through a sliding-screw tuner. The resonator is formed by the section of the waveguide shorted at one end by the sliding short and terminated at the other end by the post-mounted diodes. The frequency is changed by changing the position of the short, and the load is matched to the combiner by the sliding-screw tuner.

Experiments were done with Microwave Associate diodes (types MA 49156, 49158, 49159, and 49110) having nominal ratings of 25 mW, 100 mW, 250 mW, and 500 mW. Measurements were made to determine the variation of power with frequency, pushing figure (rate of change of frequency with bias voltage), long-term frequency drift, external Q of the oscillator, and FM noise. The frequency was measured by a counter (EIP 578), and the power was measured by a power meter (Marconi-type 6460) with a 3-W thin-film thermoelectric power sensor (Marconi-type 6423). The external Q was obtained by determining the locking range for an injected power in an injection-locking experiment [12]. The FM noise was measured by a variation of the carrier-suppression method [13], described in [8].

The experimental results are presented in Tables I and II. It is seen that significant power is obtained from the combiner over a bandwidth of 2–3 GHz for all the diodes with different power ratings. The combiner is continuously tunable by the back-short over this band, like a single-diode oscillator. The fourth column of Table I gives the combining efficiency η_e, which has been defined as the ratio of the power output of the combiner to the sum of the powers obtained from the individual diodes when working in a single-diode oscillator. The combining efficiency is found to have values between 60 percent and 150 percent. The single-diode oscillator was optimized at 9.5 GHz, and the large values of η_e at frequencies away from 9.5 GHz may be explained as due to nonoptimum operation of the single-diode oscillator and better performance of the diodes in the combiner at these frequencies. However, the values of η_e are also slightly larger than 100 percent at 9.5 GHz for some diodes. These higher values may be explained as a consequence of the increase in the conversion efficiency of the diodes in the presence of the larger RF signal in the combiner. Such higher values of combining efficiency have also been reported by Frank and Crowley [14] for a W-band combiner with half-wavelength-spaced InP Gunn diodes.

It was not possible to optimize the stub dimensions of the present combiner for all frequencies, but it may be expected that when such optimization is done the power output of the combiner will be further increased.

TABLE I
PERFORMANCE CHARACTERISTICS OF THE FOUR-DIODE COMBINER WITH VARIOUS DIODES

Frequency (GHz)	P_{out} (mW)	η (%)	η_e (%)	$\Delta f/\Delta V$ (MHz/V)	$\Delta f/\Delta t$ (kHz/min)	Q_e
a) 25 mW diodes (MA 49156)						
9.0	200	1.85	69	3.4 (-0.8)	-	148 (279)
9.5	320	2.96	90	19.1 (-3.7)	113 (80)	150 (120)
10.0	220	2.04	68	4.5 (-12.7)	161 (210)	73 (147)
10.5	225	2.08	92	1.6	175	83
11.0	275	2.55	147	-7.3	-	-
b) 100 mW diodes (MA 49158)						
8.5	560	2.42	136	17.7	143 (210)	100
9.0	380	1.65	61	29.7 (0.5)	259 (55)	127 (248)
9.5	680	2.94	106	16.1 (0.27)	218 (130)	45 (106)
10.0	300	1.30	56	-0.4 (1.02)	-	-
c) 250 mW diodes (MA 49159)						
8.0	730	1.66	91	-2.3 (0.74)	1.8	-
8.5	660	1.50	69	-2.4 (2.53)	9.0 (19.4)	142 (337)
9.0	900	2.05	79	-6.9 (-3.23)	1.0 (15.4)	138 (237)
9.5	900	2.05	79	-17.6 (-3.65)	29.8 (39.8)	89 (283)
10.0	200	0.45	17	-	-	-
d) 500 mW diodes (MA 49110)						
8.0	1000	2.58	-	-	-	-
8.5	950	2.45	113	-0.8 (1.39)	-	-
9.0	1350	3.48	129	0.9 (1.4)	66 (15.4)	54 (427)
9.5	1300	3.35	106	7.6 (2.0)	100 (25.8)	76 (211)
10.0	1180	3.04	151	2.1 (6.3)	149 (19.6)	71 (78)
10.5	900	2.32	117	-1.3 (1.2)	-	113
11.0	780	2.01	-	-	-	-

η = dc-to-RF conversion efficiency. η_e = combining efficiency. Q_e = external Q.

TABLE II
FM NOISE OF THE FOUR-DIODE COMBINER

Diode Type	Frequency (GHz)	Δf_{rms} in (Hz/$\sqrt{Hz}$) in 1 Hz BW			
		Frequency (KHz) off carrier			
		100	200	500	1000
MA 49156 (25 mW)	9.5	.49(.34)	.32(.35)	.22(.38)	.17(.30)
	9.9	.90(.58)	.70(.53)	.47(.53)	.42(.56)
	10.3	.60(.77)	.50(.71)	.31(.76)	.24(.78)
MA 49158 (100 mW)	9.5	.32(.66)	.27(.6)	.16(.44)	.09(.26)
	9.9	1.15(1.7)	.97(1.6)	.55(1.06)	.36(.57)
	10.3	1.95(3.99)	1.62(3.51)	1.01(2.55)	.60(1.97)
MA 49110 (500 mW)	9.5	.28(0.24)	.23(0.23)	.11(0.13)	.12(0.16)
	9.9	.32(0.37)	.27(0.29)	.13(0.28)	.12(0.24)

The results on pushing figure, frequency drift, external Q, and FM noise of the combiner may be compared with those for single-diode oscillators (given in parentheses). It is seen that the long-term frequency drift is comparable and the pushing figure is of higher value. The external Q, Q_e of the oscillators is lower for the combiner, as was also observed earlier [15].

The FM noise of the combiner is found to be nearly the same or smaller than the individual diode oscillator, although the external Q has lower values for the combiner. The result may be understood considering the theoretical analysis of Kurokawa [16], which indicates that the FM noise in combiners decreases with an increase in the number of combining diodes, although it increases with a decrease in Q_e. Further, the configuration of the diodes in the combiner also affects significantly the FM noise [8].

III. CONCLUSIONS

The detailed experimental study of the four-diode combiner indicates that this configuration may be used at X-band to combine, with 60–150-percent efficiency, the output powers of diodes with nominal outputs of 25, 100, 250, and 500 mW. The performance characteristics show no significant deterioration in comparison to that of single-diode oscillators.

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