1-W Millimeter-Wave Gunn Diode Combiner

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***Abstract*—A simple, modular approach for combining many Gunn devices has been developed. By cascading the two-diode wafer modules, output power of 1 W was achieved in the 45-GHz range from eight Gunn devices with combining efficiency greater than 90 percent. The overall dc-to-RF conversion efficiency of the eight-diode combiner was about 2 percent. The circuit adjustment was easy and no spurious oscillations were observed during the experiment.**

I. Introduction

The GUNN-EFFECT device has been widely used for low-noise signal source development at microwave and millimeter-wave frequencies. However, the power generation capability of a single Gunn device is limited and falls below the level required for many potential applications. Combining more than one Gunn diode is a very attractive way to obtain clean high-power signal sources. Recently, several different schemes have been reported for circuit-level power combining in low millimeter-wave frequency range [1]-[3] by combining up to four Gunn diodes. This paper describes a convenient method for combining a large number of Gunn diodes in a rectangular resonator similar to the one first proposed by Kurokawa [4]. A simple two-diode wafer module is developed by mounting two Gunn devices symmetrically in the transverse direction of a rectangular waveguide. Power combining is accomplished by cascading many wafer modules with minimal circuit adjustment. Output power of 1 W was achieved at 45.3 GHz from eight Gunn diodes with combining efficiency greater than 90 percent.

II. Gunn Device

The Gunn devices used were made from vapor-phase-grown multiple-epitaxial n-type gallium arsenide. It consists of a buffer layer of 2.2 μm with approximately 10^{18} carriers/cm^3 and an active layer of 2.7 μm with 10^{16} carriers/cm^3. The ohmic contact on both sides of the diode is a gold–germanium–nickel alloy covered by tungsten and gold. The diode is fabricated in mesa form on a copper-plated integral heatsink and surrounded by a 35-mil diameter ceramic pill-type package with cross-strap gold ribbon configuration. The threshold voltage and current of the diode are 1.3–1.5 V and 1.8–2.0 A, respectively. The diode is designed for the operating frequency of 45 GHz and optimum output power of a single diode around this frequency is between 140 mW and 160 mW. The operating voltage is 4–5 V and the operating current is 1.3–1.6 A.

Manuscript received May 16, 1980; revised August 2, 1980.

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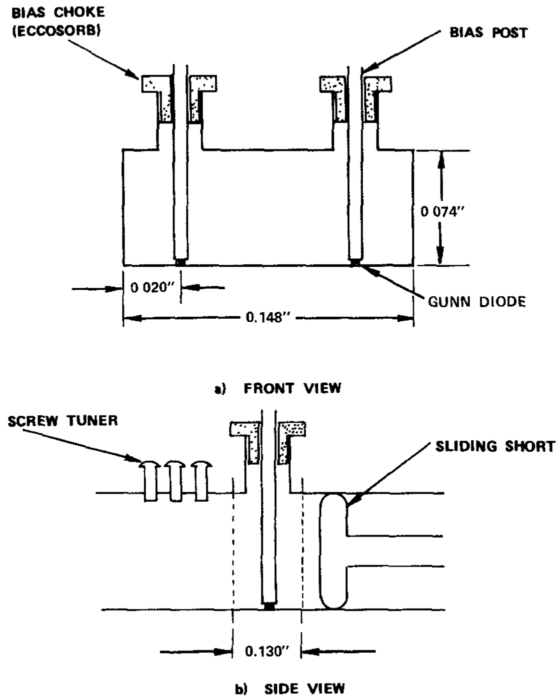

Fig. 1. Circuit configuration of two-diode wafer module. (a) Front view. (b) Side view.

III. Two-Diode Wafer Module

Fig. 1 shows the circuit configuration of a two-diode wafer module developed for convenient power combining. The two Gunn diodes are mounted symetrically in the transverse direction at the bottom wall of a WR-15 full-height waveguide. DC biases are provided through the round posts insulated by Eccosorb chokes. The Eccosorb chokes can be moved up and down for impedance matching as well as for frequency stabilization. Final tuning of the circuit is obtained by adjusting the sliding short at one side of the waveguide. Screw tuners are also employed for additional tuning at the other side. Photographs of assembled and disassembled hardware of a two-diode wafer module are shown in Fig. 2.

The Gunn diodes were selected to have similar threshold voltage and current in dc test, and similar operating voltage and current, power output, and oscillation frequency when tested in a single-diode cavity. Each pair

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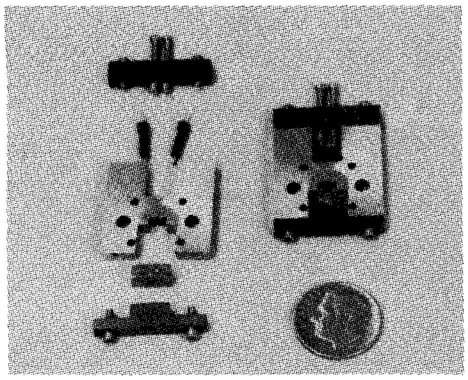

Fig. 2. Assembly photograph of two-diode wafer module.

TABLE I
PERFORMANCE DATA OF TWO-DIODE WAFER MODULES

Wafer No.	1	2	3	4
Oscillation Frequency (GHz)	44.0	43.9	44.4	44.6
Output Power (mW)	324	295	223	270
Efficiency (%)	2.3	2.35	1.6	2.0

of diodes was then simultaneously tuned to realize maximum combined output power. Several different spacings between the two diodes were tried. As the posts were moved toward the center from the side walls of the waveguide by 0.010-in increment, output power increased by about 1 dB. However, beyond a certain point no further power improvement was observed. A 0.108-in spacing was chosen for the convenience of machining. Locking between the two signals was verified by observing the spectrum on a spectrum analyzer.

Optimum power output of 250–300 mW was obtained from a two-diode wafer module in the frequency range between 44 and 48 GHz. The combining efficiency was higher than 95 percent and the dc-to-RF conversion efficiency was about 2 percent. Mechanical tuning range was about 6 GHz and the injection locking bandwidth was about 100 MHz with 20-dB locking gain. Oscillation frequency decreased by 40 MHz as the temperature increased from $-20°C$ to $50°C$. Output power variation over the same temperature range was 0.6 dB. Four wafer modules have been developed for further power combining. The performance data of the modules are shown in Table I.

IV. WAFER COMBINING

Two wafer modules were cascaded together for power combining experiment. Since each wafer module was adjusted individually with a sliding short and screw tuners at each side, readjustment of the circuit is required for optimum operation. Different thicknesses of wafer modules were tried. The spacing between each pair of diodes was varied from $1/4\lambda_g$ to $1\text{-}1/2\lambda_g$ by $1/4\lambda_g$ increment, where λ_g is the guide wavelength. No significant change

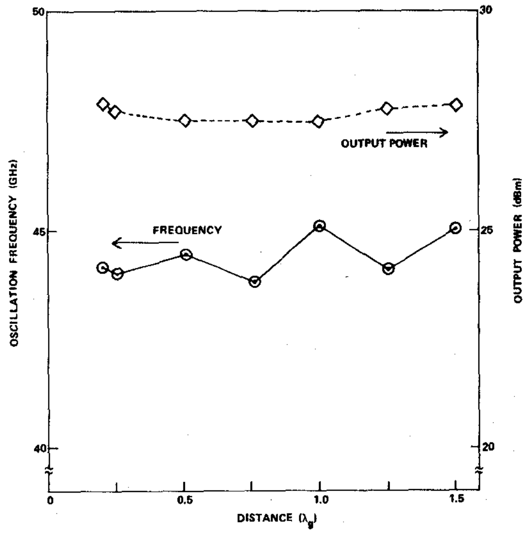

Fig. 3. Power output and frequency versus distance.

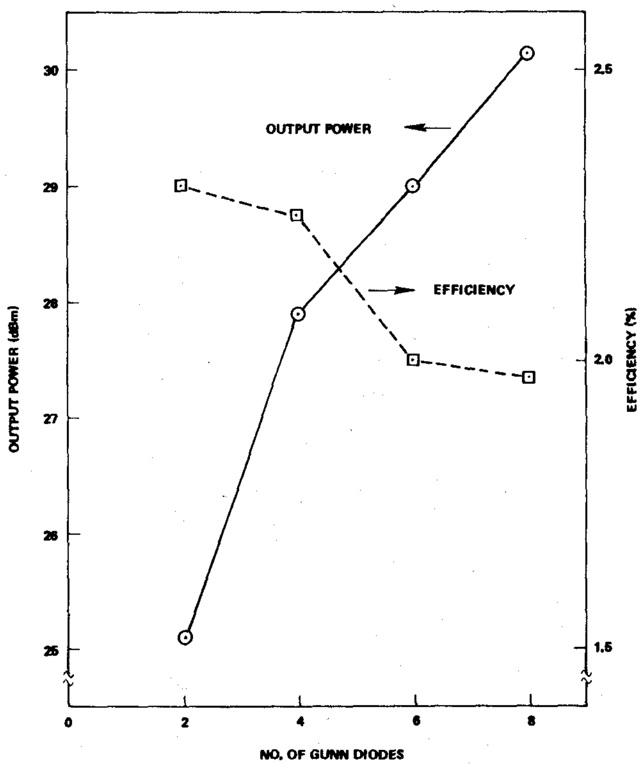

Fig. 4. Power output and efficiency versus number of diodes.

was observed either in output power or in oscillation frequency when the circuit was optimized by adjusting the sliding short and tuning screws. A typical result is shown in Fig. 3.

As more wafer modules were combined, minor circuit readjustment was required only for the two end wafer modules. No further tuning was conducted for the middle wafer modules. Fig. 4 represents the output power and dc-to-RF conversion efficiency of the combiners as a function of the number of combining diodes. Discontinuities associated with six-diode combiner can be attributed to the poor performance of wafer No. 3 as shown in Table I. Output power of 1.03 W was obtained from an eight-

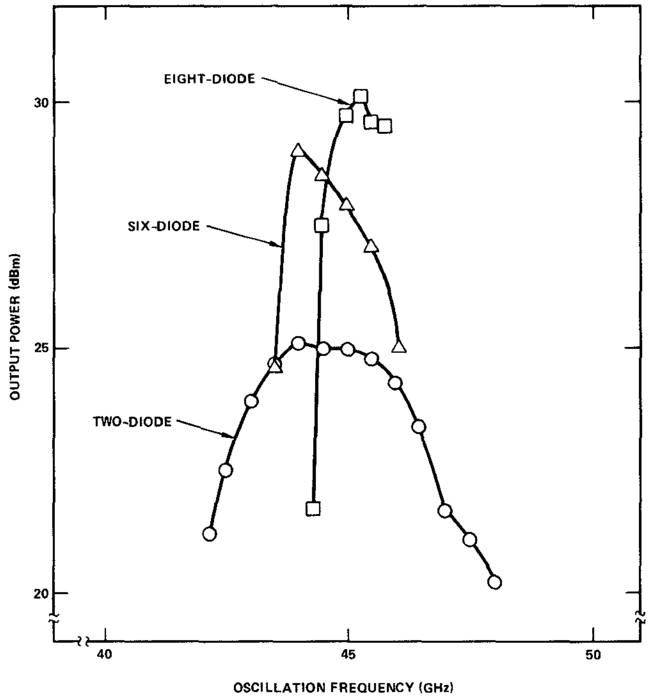

Fig. 5. Mechanical tuning characteristics of the combiners.

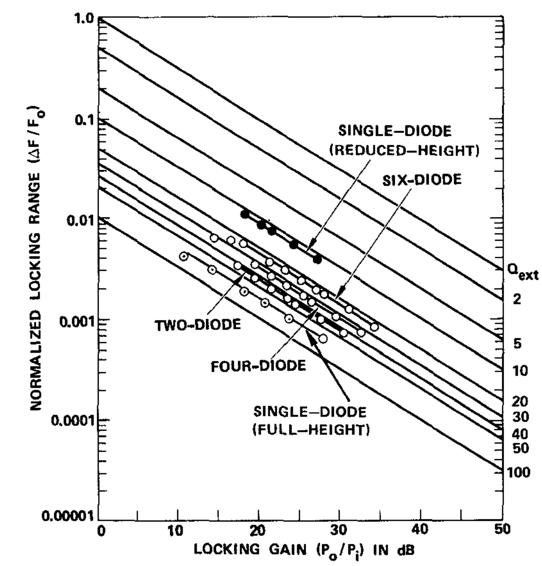

Fig. 6. Injection locking characteristics of the combiners.

diode combiner with 1.97-percent dc-to-RF conversion efficiency. The combining efficiency was 91 percent for this combiner.

Mechanical tuning was conducted by moving the sliding short position and the tuning characteristics are plotted in Fig. 5 with corresponding output power at each frequency. In general, the tuning range decreases with the number of combining diodes. It is difficult to operate a large number of diodes at same operating condition. Consequently, frequency jumps often occur as the sliding short moves, thus limiting the tuning range.

Injection locking characteristics of the combiners are shown in Fig. 6. The locking gain–bandwidth characteristics generally follow very closely to the theoretical curves.

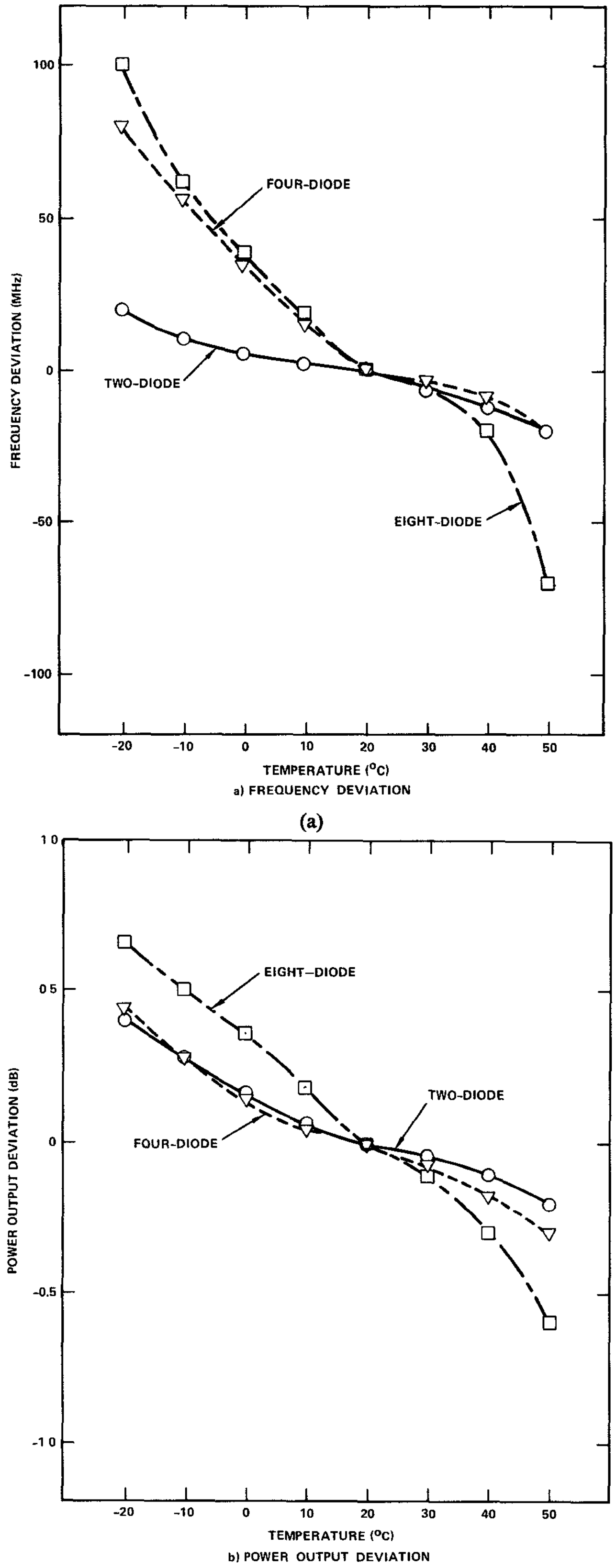

Fig. 7. Temperature characteristics of the combiners. (a) Frequency deviation. (b) Power output deviation.

It is seen that the external Q of the combiner circuit decreases as the number of combining diodes increases. For a six-diode combiner, the locking bandwidth was

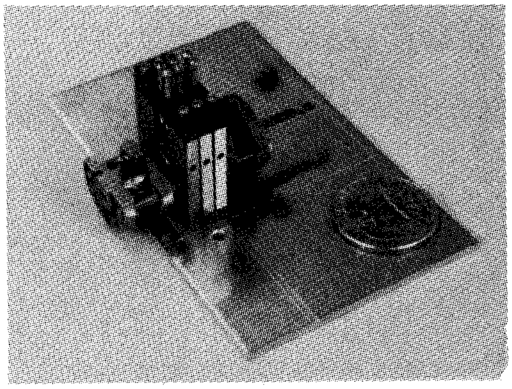

Fig. 8. Hardware of six-diode combiner.

about 200 MHz with 20-dB locking gain and about 50 MHz with 30-dB locking gain, respectively. Locking bandwidth of a reduced-height single-diode cavity (1/3 of full-height waveguide) is also included in the figure for comparison. Obviously the reduced-height waveguide cavity has lower circuit Q than the full-height waveguide resonators.

Fig. 7 represents the RF performance variation of the combiners as a function of temperature. Deviation both in oscillation frequency and in output power increases with the number of combining diodes. The maximum change of oscillation frequency is about 170 MHz while the change of output power is 1.2 dB over the temperature range from $-20°C$ to $50°C$ for a eight-diode combiner. No spurious oscillations were observed during the experiment and the spectrum of the output signal was clean.

The hardware of a six-diode combiner is shown in Fig. 8. It consists of three two-diode wafer modules, a tuning short block, and an output block with screw tuners.

V. Conclusions

A compact two-diode wafer module has been developed and the power combining is accomplished by simply cascading many wafer modules depending on the output power requirement. 1-W output power was achieved around 45 GHz by combining eight Gunn devices in a waveguide resonator. Higher output power was obtained when the two diodes are mounted off the waveguide side walls. The spacing between wafer modules does not seem to be critical on the combiner performance when only two wafer modules are involved, as long as the sliding short and screw tuners are adjusted. This type of combiner should provide sufficient power output for low-noise parametric amplifier, medium power transmitter, and frequency multiplier applications. The same combining approach can also be extended to higher millimeter frequencies.

Acknowledgment

The authors would like to thank Dr. H. J. Kuno for his encouragement and many helpful suggestions. They also wish to thank J. Kung and K. Li for the diode fabrication and M. Quijije for his excellent technical assistance.

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