power. The spacing between the diodes does not seem to be critical when only two diodes are involved, as long as the short position can be adjusted. It appears that power from more than two diodes can be combined by "stacking" more than two modules. The scheme should be applicable to IMPATT devices also.

ACKNOWLEDGMENT

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A Tunable High-Power *V*-Band Gunn Oscillator

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***Abstract*—A method of combining two Gunn devices has been developed in the 50–60-GHz band. A power output of 23.75 dBm with a mechanical tuning range of 6 GHz has been achieved. A varactor-tuned Gunn source with an electronic tuning bandwidth of 200 MHz has also been demonstrated in the *V* band.**

I. INTRODUCTION

IN MANY MILLIMETER-WAVE system applications of solid-state power sources, it is desirable to have 1) high power, 2) a good mechanical tuning range, and 3) some electronic tuning. To obtain high power at millimeter-wave frequencies, a push–pull technique of combining two Gunn devices at 42 GHz has been reported [1]. Although varactor tuning is widely used for Gunn VCO's at frequencies below 50 GHz, tuning methods for Gunn oscillators above 50 GHz have been mostly mechanical [2], [3]. It is the purpose of this paper to report the results of power combining, mechanical and varactor tuning with Gunn devices between 50 and 60 GHz.

II. DEVICES

The Gunn devices used for these experiments were made from vapor phase multiple epitaxial n-type GaAs. The epistructure was similar to that previously described by Tully *et al.* [4]. It consists of a buffer layer of 4 μm with 10^{18} carriers/cm^3, and an active layer of 2.3 μm with 9×10^{15} carrier/cm^3. The nl product for the active layer was approximately 2.1×10^{12}. The Gunn device was bonded with crossed gold-lead ribbons in a ceramic pill package which has been previously discussed by Kramer [5].

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III. TWO-DIODE OSCILLATOR

The circuit used in the two-diode power combining experiments is a reduced-height waveguide circuit as shown in Fig. 1. The impedance matching to the diode was achieved by utilizing two stages of a quarter-wave transformer at the output circuit, a tuning short, and a coaxial spacer. The diameter of the device package is 35 mil, and the diameter for the bias pin is 27 mil, and two aluminum low-pass filter. This circuit configuration has been extensively used in IMPATT oscillator and amplifier applications [6], [7], and has been analyzed recently, to include the effect of a large biasing post and proximity of the waveguide short to the device [8]. In general, the tunability of the source depends on the impedance of the device, the parasitics of the package, and the length of the coaxial spacer. The diameter of the device package is 35 mil, and the diameter for the bias pin is 27 mil, and two devices in direct contact were mounted in the manner as indicated in Fig. 1. Fig. 2 shows the power output and the tuning range for one and two devices, respectively. Device 1 was first soldered in the heat sink, then the circuit and the voltage applied to the device were optimized at 54 GHz. The maximum power output was 20.6 dBm. For comparison, similar power levels were also observed when devices of the same lot were measured in a coaxial cavity with a waveguide iris output. A frequency-tuning bandwidth of 13 GHz was achieved by moving the tuning short. Then device 2 was soldered in, and the circuit and the voltage were again optimized. The maximum power output of 23.75 dBm was achieved, which is approxi-

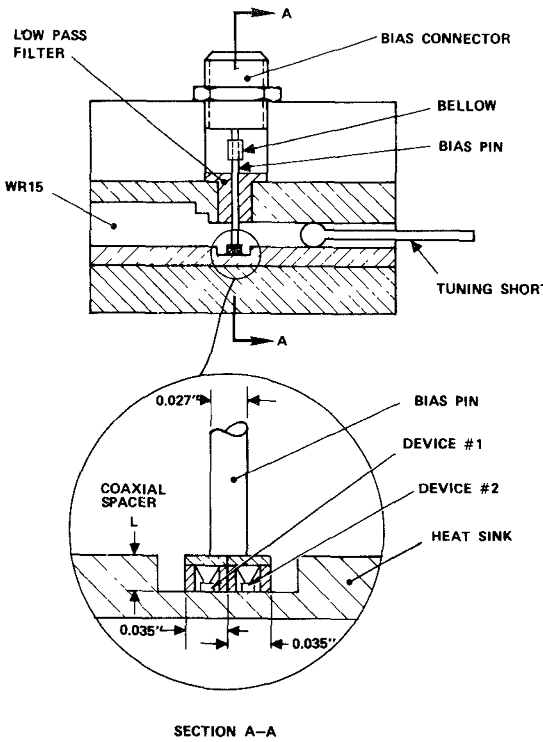

Fig. 1. Cross section of a reduced-height waveguide Gunn oscillator.

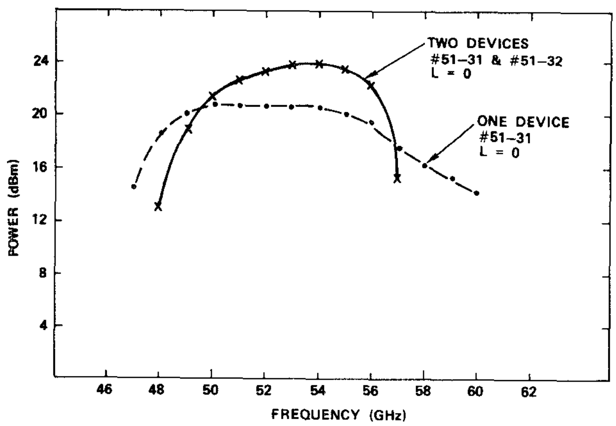

Fig. 2. Power output versus frequency for a single-device and two-devices Gunn oscillators.

mately a 3-dB improvement over that of a single device. The corresponding tuning bandwidth for the two-diode circuit was about 6 GHz. The efficiency for two devices operating at maximum power output was 1.92 percent at an operating voltage of 3.63 V and 3.4 A. Both devices had the same threshold voltage of 1.4 V and threshold current of 1.9 A. The external Q of the oscillator circuit for two devices was measured to be about 27 at 54.5 GHz, by injection-locking experiments.

IV. Varactor-Tuned Oscillator

The arrangement of a varactor-tuned Gunn oscillator is shown in Fig. 3. The circuit [9] is a modification of the circuit shown in Fig. 1, with a tuning varactor placed 60 mil directly behind the single Gunn device. A silicon

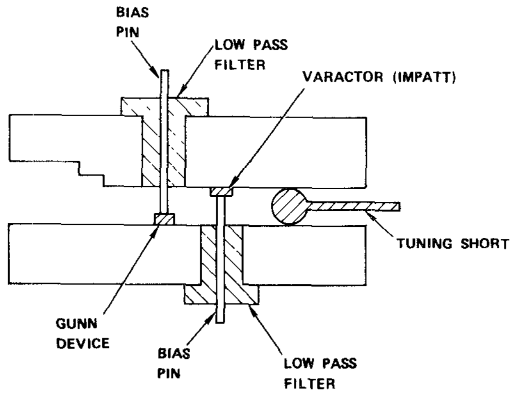

Fig. 3. Cross section of a varactor-tuned Gunn oscillator circuit.

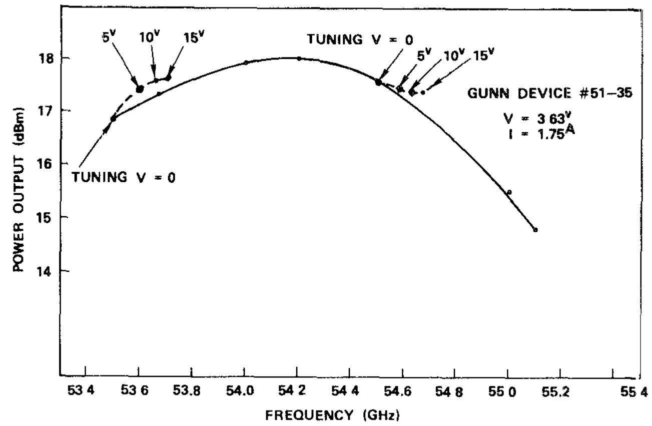

Fig. 4. Power output and tuning range of a varactor-tuned single-device Gunn oscillator.

IMPATT with a breakdown voltage of 17 V, a junction capacitance of 2 pF at 0-V bias, and 0.58 pF at 15 V was used as a tuning varactor. The solid curve in Fig. 4 is the power output of the Gunn device, as the tuning short was moved with zero voltage on the varactor. The power output of the circuit varied from 14.7 to 18 dBm with a tuning range of 1.6 GHz. The dotted curve in Fig. 4 shows the electronic tuning range of 200 MHz at 53.5 GHz, and 170 MHz at 54.5 GHz, when the varactor voltage was varied from 0 to 15 V. No attempt was made to optimize the tuning varactor parameters. For most millimeter-wave phase-locking applications, the power output, the mechanical, and the electronic tuning range of this oscillator are found to be adequate.

V. Conclusions

In conclusion, we have demonstrated the feasibility of power combining, wide mechanical tuning range, and moderate electronic tuning bandwidth with Gunn devices in a reduced-height waveguide circuit in the 50–60-GHz band.

The method of combining described is simple. An increase from two to four diodes is possible with the present circuit configurations, thus even higher power output can be expected for the same arrangement. Furthermore, the concept may be extended to the chip-level combining, where many chips are employed in a single package. The same technique, in principle, can be also applied to the higher frequency range.

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Distributed Bragg Reflector Gunn Oscillators for Dielectric Millimeter-Wave Integrated Circuits

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***Abstract*—A new Gunn oscillator is proposed for microwave and millimeter-wave integrated circuits. The device consists of a Gunn diode placed in a dielectric waveguide in which grating structures are created. The gratings provide frequency-selective feedback to the diode, enabling a stable oscillation. After the design principle is presented, observed oscillation characteristics of prototype oscillators are reported. Some problems as well as future directions for improvement are discussed. Potential applications as multiple-element high-power oscillators are also proposed.**

I. INTRODUCTION

THIS PAPER describes a new Gunn oscillator for dielectric waveguide-type microwave and millimeter-wave integrated circuits and reports some preliminary experimental results. Unlike conventional Gunn or IMPATT oscillators created in a rectangular dielectric cavity, the present structure makes use of the stopband phenomena of the grating structure as a mechanism to provide feedback to the diode. The principle of operation is quite similar to the distributed Bragg reflector (DBR) lasers used in integrated optical circuits. The new device may be potentially useful for developing a multiple-diode high-power oscillator. Before discussing the technical details, some background will be presented.

Dielectric waveguide structures [1]–[3] have been suggested as alternatives to printed-line type millimeter-wave integrated circuits [4], and a number of passive and active components have been created [5]–[7]. A typical solid-state oscillator for dielectric waveguide structures is made of a Gunn or IMPATT diode implemented in a rectangular dielectric waveguide cavity [6]. In such a structure, the oscillation frequency is determined by the cavity dimensions and the diode impedance. The oscillation frequency can be controlled somewhat by varying the bias voltage as well. One drawback of this type of oscillator is that, when the cavity gets longer, there may be more than one longitudinal resonance. Hence, if more than one diode is implanted for the purpose of increasing the output power, coherent oscillations may not be obtained because different diodes can couple with different modes. Another problem is related to fabrication. As the operating frequency gets higher, it becomes increasingly difficult to create a rectangular dielectric cavity in integrated circuits.

The new oscillator structure proposed in this paper may alleviate the problems described in the previous paragraph. The basic structure is shown in Fig. 1(a). A Gunn

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