Y-5

A MULTI-DIODE CAVITY POWER COMBINER USING STATE-OF-THE-ART PULSED GUNN DIODES

Bernard E. Sigmon and Murthy Ayyagari

Motorola Government Electronics Group, Tempe, AZ 85282
and
M/A-Com Semiconductor Products, Inc., Burlington, MA 01803

ABSTRACT

Large area mesa pulsed Gunn diodes were developed. These diodes generated 30 to 40 watts per device. By combining multiples of these diodes in a miniature C-band cavity power combiner, 90 watts (3-diode combiner) and 150 watts (5-diode combiner) of peak power was achieved.

INTRODUCTION

This paper reports on the technical accomplishments to date (11-21-86) toward the development of a solid-state source replacement for the magnetrons and triode vacuum tubes presently used as the power generating elements in Radar Transponders.

These older forms of technology (vacuum tubes and magnetrons) exhibit poor MTBF's (less than 1000 hours), require filament power, high voltage modulators, and ancillary component functions such as power management systems. As a result, the life-cycle-cost of the user equipment is relatively high.

PRIOR ART

The previous state-of-the-art in peak power from pulsed Gunn diodes was 10 to 12 watts per device. In the early part of 1986, Motorola GEG, Inc. and M/A-Com, Inc. collaborated on the development of high peak power Gunn diodes. Two types of geometries were investigated: 1) large area mesa chips and 2) multiple chip diodes. In October of 1986 the first batch of large area mesa diodes were tested; 30 to 40 watts of peak power per device was measured.

DEVICE FABRICATION

The Gunn diodes developed for this program were grown using halide based vapor phase epitaxy. The active n-layer is bounded by highly doped n+ layers on both sides and the doping profile of these devices is shown in Figure 1. Gold/Germanium ohmic contact metallization is alloyed into the active layer using photolithographic techniques and the chips are separated by dicing using a diamond tipped saw. Large area devices have been known to produce high peak powers, but in the past the corresponding low impedances of these devices have been difficult to match in a cavity. The diodes were then thermo-compression bonded into a standard M/A-Com 111 package with a 3-48 threaded stud as shown in Figure 2. Gunn diode performance over the temperature range required by military systems was achieved by obtaining a high breakdown voltage for these devices coupled with low thermal resistance.

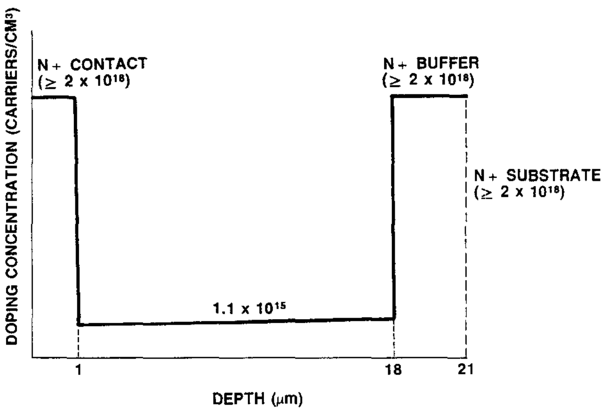

Figure 1.

Doping Profile of the Pulsed Gunn Diode

0149-645X/87/0000-0871$01.00 © 1987 IEEE

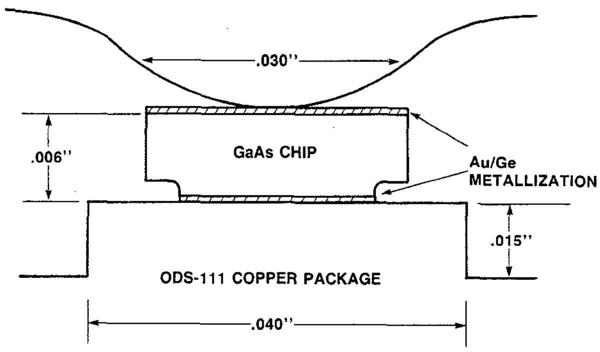

Figure 2.
Schematic of the Chip in the Package

With additional development of the chip and package geometry, peak power of up to 100 watts seems feasible for each packaged device. These devices, with refinements in the combining technique, may permit peak power approaching 500 watts in the near future.

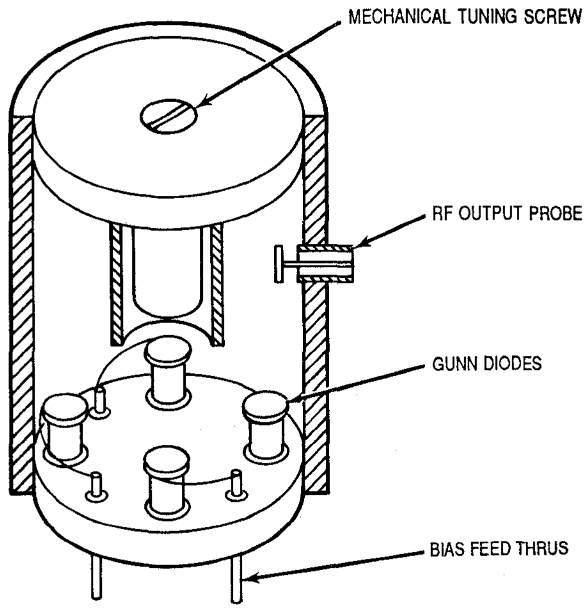

Figure 3.
Cut-Away View of N-Diode Power Combiner

CIRCUIT DESCRIPTION

The original combiner circuit dates back to 1981 and was developed on Motorola IR&D funds. The circuit consisted of two Gunn diodes capacitively coupled to a re-entrant coaxial cavity[1] operated in its dominant TEM mode. Subsequent development and improvement of the combiner achieved N-device combining capability along with an excellent frequency versus temperature stability ($\leq \pm 4$ MHz for a -30°C to a $+70^{\circ}$C temperature range) over its mechanical tuning range of 5.4 to 5.9 GHz. The number of devices combined is limited by the physical size of the diode package and the cavity's diameter set by the boundary conditions for waveguide mode propagation. Typical outside dimensions for the combiner is 5/8 inch^3. Figure 3 is a cutaway view of the N-diode combiner whereas Figures 4, 5, and 6 present, respectively, a production version of the original two diode combiner, a five diode combiner, and a frequency versus temperature plot for a three diode combiner, all operating in C-band.

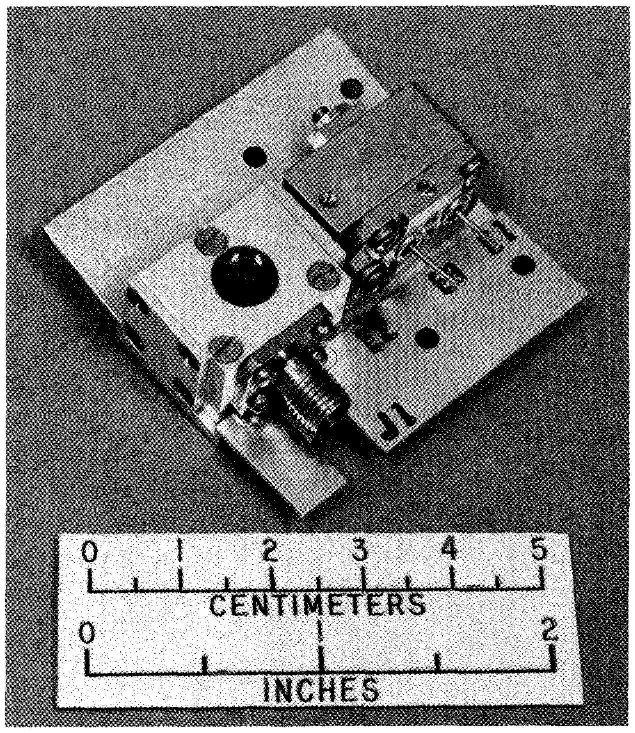

Figure 4.
20 Watt C-Band Combiner

---

1 U.S. Patent No. 4,571,555.

Figure 7 demonstrated one of the reasons that pulsed Gunn diodes are attractive devices for power combining. That is, the voltage pushing of the diodes (Δf/ΔV) is quite small over a wide range of bias voltages. In Figure 7 the power combiner changes one megahertz in frequency for a twenty volt change in pulse bias voltage (50 to 70 volts). This low pushing factor implies that the reactive component of the pulse Gunn diode is relatively insensitive to bias voltage changes. Thus, each device can be fed from a common pulse bias line which simplifies modulator requirements. Another aspect of this low pushing factor is that pulse smearing is quite low resulting in near text book sin(x)/(x) spectrums. Figure 8 presents the sin(x)/(x) response for the 150 watt combiner.

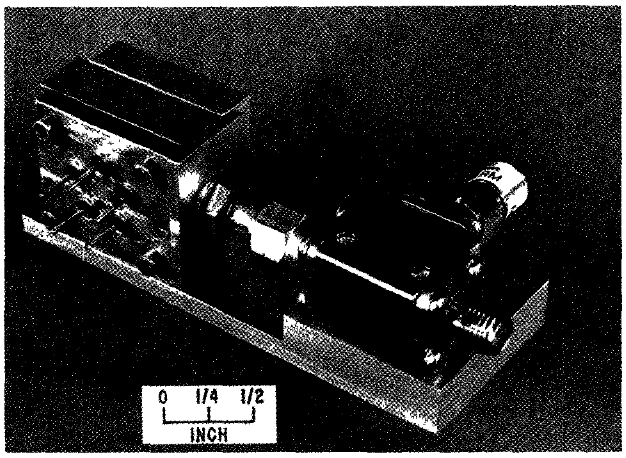

Figure 5.
150 Watt C-Band Combiner

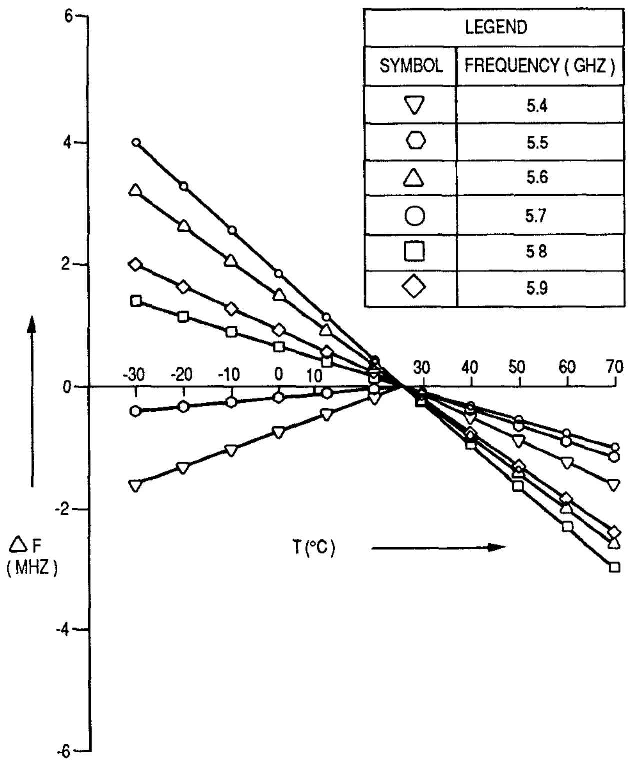

Figure 6.
Frequency Versus Temperature Plot Typical of the N-Diode Cavity Combiner

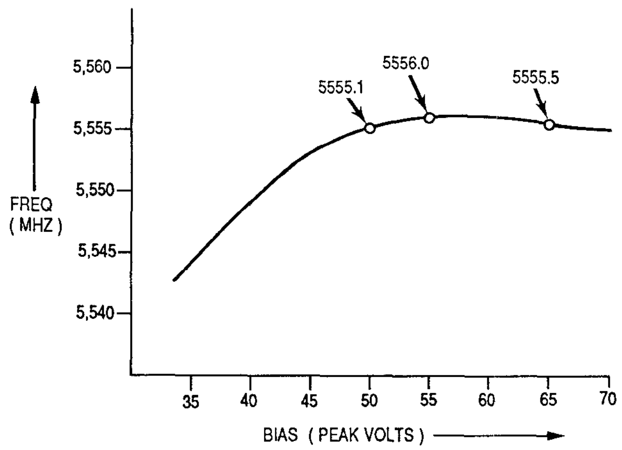

Figure 7.
Voltage Pushing for the Pulsed Gunn Diode Combiner

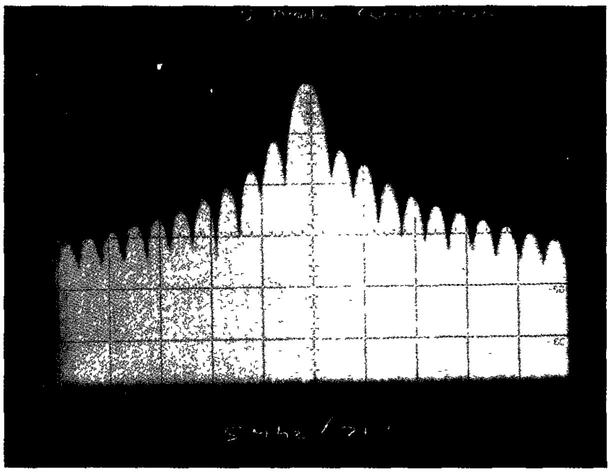

Figure 8.

Sin(x)/(x) RF Spectrum for the 150 Watt Peak Power C-Band Combiner

POWER COMBINING RESULTS

Nine large area mesa diodes were individually tested for their 25°C peak output power. Eight devices produced from 30 to 33 watts per diode. One diode generated 40 watts of peak power. Three of the eight diodes were tested in a combiner circuit and 90 watts of peak power (@ 5.7 GHz) was measured. Next, five of the 30 watt devices were combined and 150 watts of peak output power was measured. An additional test was performed by injection locking the 150 watt source with a 30 watt source. The purpose of this test was to see if the injected power added to the output power. This experiment measured 170 watts of peak output power from the cascade combination. All of these experiments were performed at a 500 nSec pulse width and a 2 KHz repetition frequency, a typical duty cycle scenario for Radar Transponders. Individual diode peak voltage and current was 65 volts and 10 amperes (5% DC to RF conversion efficiency).

The measured power versus temperature performance for the two, three, and five diode combiners is -0.02 dB per degree centigrade. Thus, a combiner producing 150 watts at room temperature will generate approximately 190 watts at -30°C and 120 watts at $+70^{\circ}$C.

SUMMARY AND CONCLUSIONS

Large area mesa pulsed Gunn diodes which generate three to four times the powers of previous Gunn diodes have been developed. These devices when combined in an N-diode coaxial combiner generated the sum of the individual diode powers. For example, five 30 to 33 watt devices generated 150 watts of peak output power.

With additional development of the chip and package geometry coupled with increases in the number of combined device packages per cavity, peak powers approaching 500 watts are predicted.

Since the submission of this paper, a seven diode combiner was room temperature tested and 200 watts of peak power was achieved (at 5.9 GHz).

ACKNOWLEDGEMENTS

Many individuals at both Motorola and M/A-Com have contributed to the success of this program - from those who granted the resources to those who fabricated the devices and circuits - the authors express their thanks.

This work was supported by Motorola Independent Research and Development (IRAD) funds and M/A-Com internal funds.

Murthy Ayyagari is the Business Center Manager for Gunn Diodes, M/A-Com Semiconductor Products, Inc., Burlington, MA. Bernard E. Sigmon is a Technical Staff Engineer with the Motorola Government Electronics Group's Radar Systems Division, Tempe, AZ.