HIGH PEAK POWER DIELECTRIC RESONATOR OSCILLATOR COMBINER

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ABSTRACT

Traditional approaches to achieving significant amounts of power from a dielectric resonator oscillator (DRO) center using a cascade of amplifier chains cumulating with combined output stage. Described herein is an approach which achieves significant amounts of peak power from an oscillator, dielectrically stabilized, and power combined, in one stage[1]. The active elements used were "stacked" Gunn diodes operating in X- and Ku-bands. Forty watts and one hundred and twelve watts of peak power was measured from a two-diode and four-diode DRO/combiner respectively, operating in X-band (9.3 GHz), and 13.5 watts of peak power was measured from a two-diode DRO/combiner in Ku-band (16.3 GHz).

INTRODUCTION

The circuits described in this paper came about from a need to: 1. reduce the number of stages required to achieve a specified output power goal from solid-state sources (a search for simplicity), 2. improve on the overall DC to RF conversion efficiency of solid-state sources (approaches which use cascaded stages often yield overall DC to RF conversion efficiencies of 1/3 to 1/4 that available from the individual devices which comprise the source).

Attendant with reducing the number of stages required to achieve a stated power goal are: 1. higher MTBFs and lower cost (fewer parts count), 2. smaller size, 3. less weight, and 4. a more reproducible source (simplicity).

These sources were developed to replace the role of magnetrons as used in radar transponders and as such were operated at the duty cycle scenarios typical of radar transponders. That is, a pulse width of 350 nanoSeconds, and with a repetition rate which varies from 100 to 6,000 pulses per second (PPS). As a result of these low duty cycles device junction heating is not a concern.

1. Patent Applied for.

II. DEVICES

The active devices were X- and Ku-band "stacked" pulsed Gunn diodes supplied by MDT, Inc. of Lawrence, MA. These stacked diodes were fabricated by vertically mounting and thermal compression bonding together two or three Gunn Diode die in a microwave pill package. The X-band diodes consisted of both two-stack and three-stack packages. The two die packages generated approximately 20 watts of peak power per package when operated with a pulse bias voltage of 65 volts and 5.5 amperes (5.5% efficiency). The three die packages generated approximately 30 watts of peak power per diode package when operated with a pulse bias voltage of 75 volts at 5.5 amperes (7.2% efficiency). The Ku-band diode packages contained three vertically mounted die and generated approximately 10 watts per diode package when biased with a peak voltage of 60 volts and 5.0 amperes (3.3% efficiency).

Higher peak powers from each diode could have been achieved if the bias voltage were increased. However, one runs the risk of driving the diode past its dielectric breakdown voltage point and causing catastrophic destruction of the diode.

The breakdown voltage of the diode is determined by the dielectric breakdown voltage, operating temperature, and RF power generated by the diode. For example, the DC breakdown voltage is reduced by the RF signal swing at the active junction. In addition, the DC breakdown voltage decreases with decreasing temperature at approximately 0.35 volts per degree Centigrade per die.

III. CIRCUIT REALIZATION AND DEVELOPMENT

It was easily realized that the high-Q reactance slope of a dielectric resonator could be coupled to N active elements by using N-1 Wilkenson in-phase power dividers. The next step was to find a circuit topology which would facilitate coupling the high-Q reactance slopes to the active elements and have the active elements injection phase lock one another.

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The circuit chosen was that as shown in Figure 1. Figure 1 is a modified application of the parallel coupled line bandpass structure of Matthei, Young, and Jones [1]. The equivalent circuit for Figure 1 is given in Figure 2. In Figures 1 and 2 Z1 and Z3 represent the impedances of the active devices, and Z2 is the RF load.

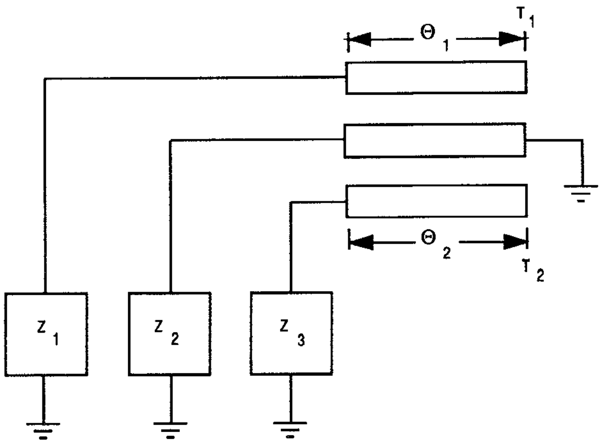

FIGURE 1: PLANAR MICROSTRIP TOPOLOGY FOR THE BASIC COMBINING CIRCUIT, Z1 AND Z3 ARE THE ACTIVE DEVICES, Z2 IS THE LOAD.

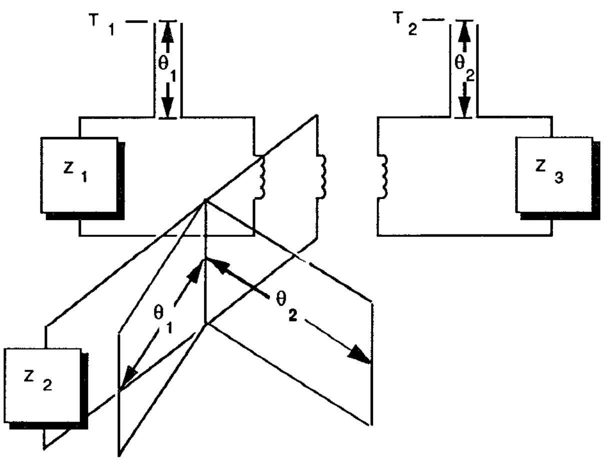

FIGURE 2: OPEN-WIRE LINE REPRESENTATION OF THE CIRCUIT OF FIGURE 1

Figure 1 was analyzed on Touchstone™ using lumped circuit models for the Gunn diodes [2]. The Touchstone model yielded the line widths and length, gap spacings, and the amount of isolation between the two active devices (indicates capability to injection lock).

The interfacing of the dielectric resonator's high-Q reactance slope coupled through a Wilkenson in-phase power divider and the two-device topology of Figure 1 is shown by the planar microstrip topology of Figure 3. The phase angles shown in Figure 3 are such to ensure that the anti-resonant impedance of the dielectric resonator is presented at terminal planes T1 and T2 of Figure 1. The open-wire line circuit representation of Figure 3 is given in Figure 4.

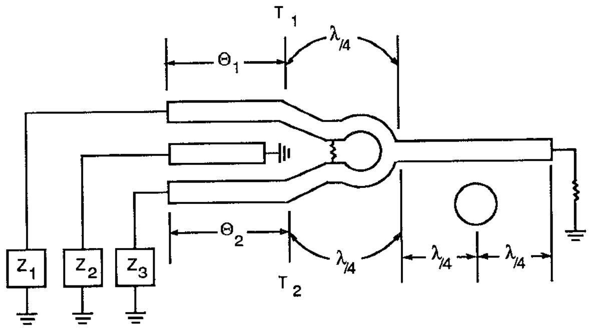

FIGURE 3: THE TWO-DEVICE DRO/COMBINER TOPOLOGY

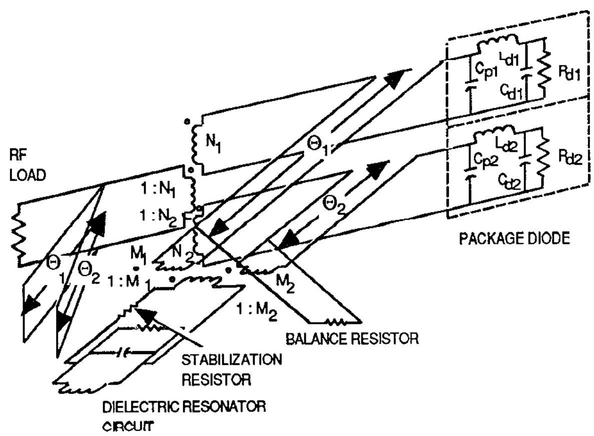

FIGURE 4: OPEN-WIRE LINE EQUIVALENT CIRCUIT OF THE TWO-DEVICE DRO/COMBINER

Touchstone is a registered trademark of EEsof, Inc.

Figure 5 shows the topology of a four-diode DRO/combiner. The extension of the circuit topology of Figure 3 to Figure 5 is obvious.

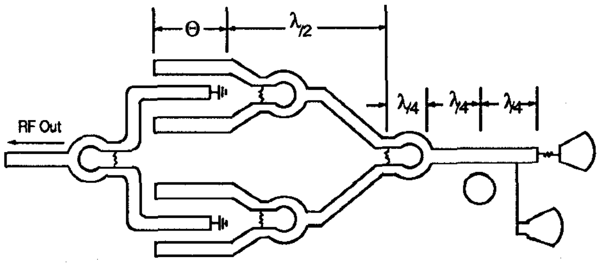

FIGURE 5: FOUR-DIODE DRO/COMBINER TOPOLOGY

IV. MEASURED PERFORMANCE

Two-diode and four-diode DRO/combiners were assembled and tested in X-band and a two-diode circuit was tested in Ku-band.

The measured power and frequency performance of the two-diode X-band circuit is presented in Figure 6. As evidenced by Figure 6 the peak to peak frequency drift for a -10 degree Centigrade to -70 degree Centigrade change was 1.2 MHz, and the peak output power varied from a high of 55 watts to a low of 37 watts. The measured external Q (Qe) for this unit was 350.

The Ku-band unit's measured performance is given by Figure 7. Here the temperature was varied from -31 to +51 degrees Centigrade. Output power and peak to peak frequency drift over this temperature range was a high of 16 watts and a low of 11 watts, and 1.8 MHz. The measured Qe for this unit was 800.

An X-band four-diode DRO/combiner was room temperature tested and generated one hundred and twelve watts of peak output power at 9.3 GHz. The peak operating voltage and current for this unit was 75 volts and 21 amperes (7.1% DC to RF conversion efficiency). The measured Qe was 150, showing the expected Qe reduction as a consequence of four-way circuit loading presented to the dielectric resonator.

Figure 8 presents a photo of the four-diode DRO/combiner.

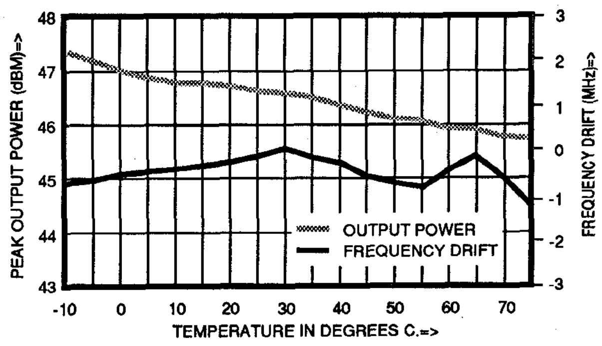

FIGURE 6: X-BAND TWO-DEVICE DRO/COMBINER, POWER AND FREQUENCY DRIFT VERSUS TEMPERATURE

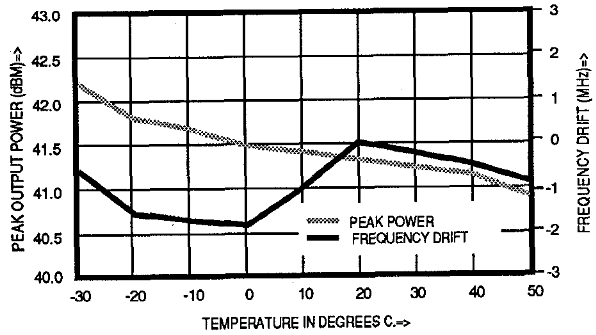

FIGURE 7: Ku-BAND TWO-DEVICE DRO/COMBINER, POWER AND FREQUENCY DRIFT VERSUS TEMPERATURE

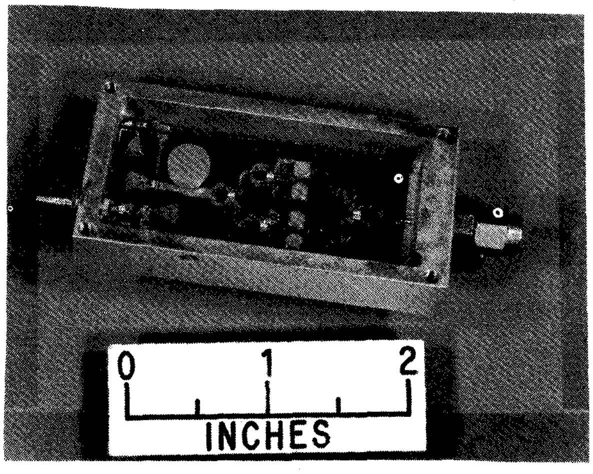

FIGURE 8: PHOTO OF THE X-BAND FOUR-DIODE DRO/COMBINER

V. PREDICTED PEAK POWERS

Ramachadran and Ayyagari [3] predict peak output powers of 15 watts per die in X-band. The number of stacked devices per diode package is limited by reliability considerations, that is, each die has to thermally conduct not only the heat generated in its junction, but the heat of all the die mounted above. If this limitation is three die (as some believe) then a diode which is capable of generating 45 watts per package is predicted. Putting four of these diodes in the four-device combiner could conceivably generate peak powers approaching 180 watts.

VI. CONCLUSIONS

Measured data taken from single stage DRO/combiners has been presented. These DRO/combiners used pulsed Gunn diodes with a multiplicity of stacked die.

The approach presented makes possible the production of sources which contain fewer active devices, and reduces the number of circulators and isolators needed to achieve the same amount of output power (versus the conventional approach of using a low level DRO followed by a cascade of amplifier/power combiner stages).

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REFERENCES

[1] Matthei et al., Microwave Filters, Impedance-Matching Networks, and Coupling Structures, McGraw-hill, 1964, p. 226.

[2] W.J. Getsinger, "The Package and Mounted Diode as a Microwave Circuit", IEEE Trans. Microwave Theory and Technique, Vol. MTT-14, pp. 58-69, February 1966.

[3] Personal communications with M. Ayyagari and T.B. Ramachadran of Microwave Device Technology, Inc., Lawrence, MA.