HIGH POWER EPITAXIALLY-STACKED VARACTOR DIODE MULTIPLIERS: PERFORMANCE AND APPLICATIONS AT W-BAND

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ABSTRACT - Single diode varactor multipliers capable of providing 260 mW CW and 850 mW pulsed at 94 GHz are described. These new results have application at W-band for systems where high average power, wideband swept linear response, phase coherent transceivers, and inter- and intra-pulse phase stability are required.

INTRODUCTION

Since the early 1960's, the art of varactor frequency multiplication has become standard in solid-state microwave power generation. However, in the case of millimeter wave frequency multipliers, power was previously limited to milliwatt levels, leaving current solid-state mm-wave power generation at power levels above one watt to the IMPATT diode. The development of multilayer epitaxial growth techniques with GaAs material to fabricate multijunction varactor diodes provides a new alternative for millimeter-wave power generation. The epitaxially-stacked varactor (ISIS) can operate at significantly higher power than a single junction device with high conversion efficiencies [1].

Single-diode multi-junction varactor frequency doublers have been designed and developed at frequencies between 22 and 94 GHz. In this paper we present results of single-diode W-band doublers and cascaded doubler-doubler multiplier chains which exhibit state-of-the-art power performance for both CW and pulsed applications.

DIODE DESCRIPTION

The epitaxially grown multi-junction (ISIS) varactor, developed in the early 1980's at M/A-COM [1],[2], consists of a series arrangement of varactor p-n junctions, grown by multiple-layer epitaxy on a single wafer of gallium arsenide. The multi junction varactors are grown with VPE or MOCVD and use standard plated heat sink (PHS) process to remove heat. This construction method provides a low thermal resistance because the active region is adjacent to the heat sink. In most cases, the diode chips are mounted on a metal pedestal (similar to M/A-COM style ODS138) and enclosed with a quartz ring and cap. Gold ribbons are attached from the chip to the top of the quartz ring after which the diode is etched to the desired capacitance. The nominal package capacitance and inductance associated with the assembled package are C_p= 0.1 pF and L_s= 0.12 nH respectively. Two-stack varactor diodes were used for doublers multiplying to 94 GHz and three-stack devices were chosen for the doubler-doubler source used to generate power at 47 GHz The breakdown voltage for typical two-stack and three-stack devices were 50 and 100 V respectively.

The approach used for determining diode parameters is described in the literature [3],[4]. Devices have been measured for their cutoff frequency using both the deLoach [5] and Houlding techniques. These measurements yield results in the 800-1000 GHz range, which predict device conversion efficiencies as high as 40% for W-band doublers.

CIRCUIT DESCRIPTION

The W-band doubler circuit, shown in Fig. 1, used to provide the results described below, combines coaxial and waveguide circuit techniques. The input circuit contains a multi-step waveguide transformer with a transition to coax. Input impedance match to the diode is achieved with a coaxial impedance transformer. Input-output frequency separation is accomplished using a radial line band-reject filter. The output circuit transformation from the packaged diode to full-height waveguide is achieved through a multi-section Chebyshev transformer and appropriate backshort position. A coaxial low-pass filter was designed as a means of biasing the varactor diode and to provide a short-circuited stub to tune the coax transition. Circuit tuning was achieved by adjusting input and output backshort positions and selection of proper bias. For CW operation, a resistor attached to the low-pass filter section of the coaxial center conductor provides the proper self-bias. Alternatively, a fixed DC bias voltage allows fast pulse transition times (<5 nsec)under pulsed conditions.

The W-band multiplier described above was driven with an 11.75-47GHz doubler-doubler chain with power at X-band provided by a high power FET amplifier. Both of these doublers are identical to the W-band doubler conceptually.

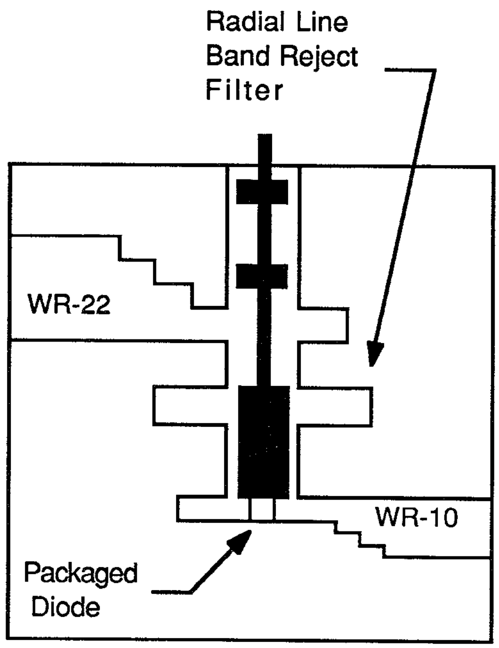

FIG. 1. Single diode W-band circuit.

RESULTS

The dynamic range of the single-diode W-band multiplier at 94 GHz is shown in Fig. 2. Fig. 3 shows the frequency response of this doubler with a nominal input drive of 650 mW. The worst case (circuit) conversion loss was 9.0 dB and the output power was greater than +18 dBm over a 3.0 GHz bandwidth. In this result, output power and conversion loss performance was reduced to obtain the desired bandwidth. For a bandwidth of 250 MHz at 94 GHz, a CW output power of 260 mW at a (circuit) conversion loss of 8.0 dB was achieved.

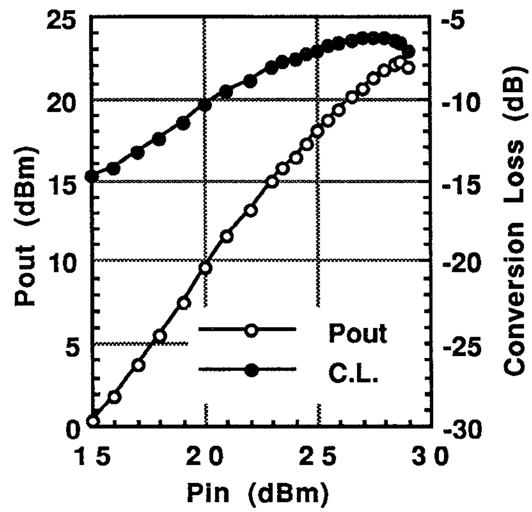

FIG. 2. Dynamic range and efficiency of CW 47-94 GHz doubler at midband.

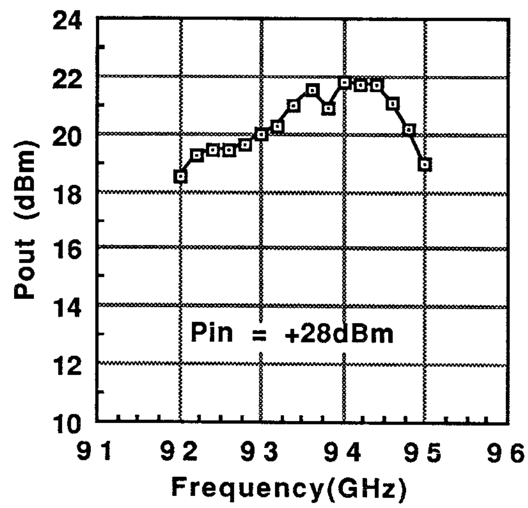

FIG. 3. Frequency response of CW 47-94 GHz doubler.

The power bandwidth characteristic for the X4 doubler-doubler chain used as a power source for the W-band multiplier is shown in Fig. 4. This result includes insertion loss contributions of a coaxial input isolator (0.3dB), an intermediate WR-42 isolator (0.3dB), and a WR-22 output isolator (0.4dB).

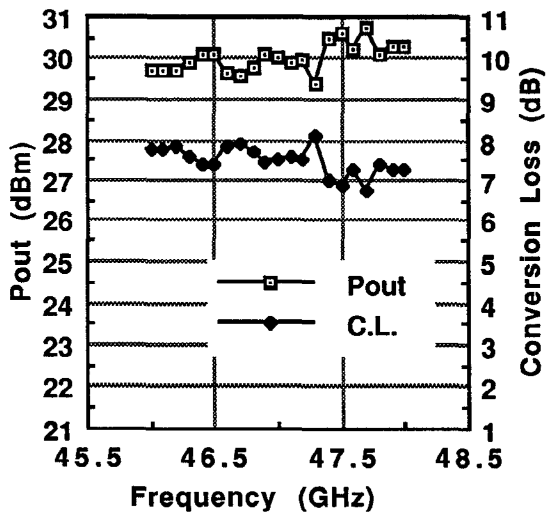

FIG. 4. Frequency response of CW 11.75-47 GHz doubler-doubler chain.

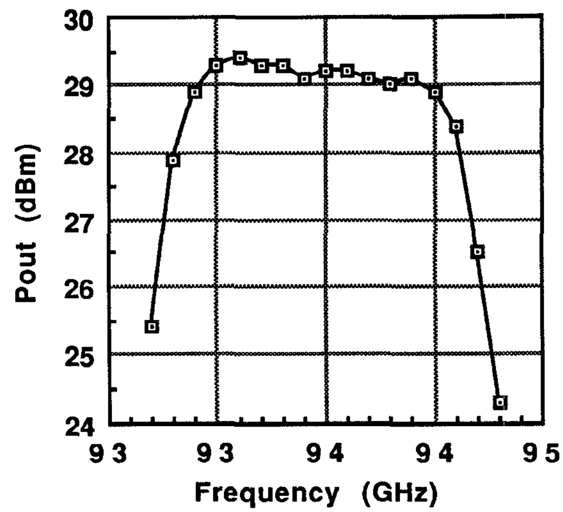

FIG. 6. Frequency response of pulsed 47-94 GHz doubler.

Using a two-junction varactor diode, the W-band frequency multiplier was tested under pulsed conditions. The pulse characteristics in this case were a 2.5 μsec pulsewidth with a 5% duty cycle. Input/output power and bandwidth characteristics for this multiplier are shown in Figs. 5 and 6. Under these conditions, the output pulse rise and fall times were less than 5nsec. Although the intrapulse phase was not observed at W-band, Fig.7 shows a similar measurement made on a 35 GHz unit. The intrapulse phase change across a 15μsec pulse was less than 3 degrees.

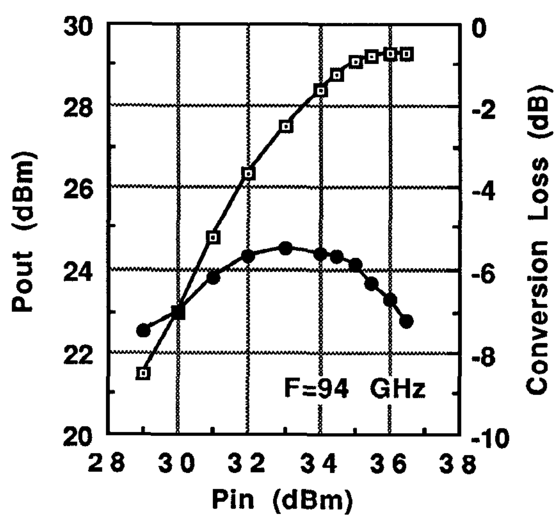

FIG. 5. Dynamic range and efficiency of pulsed 47-94 GHz doubler at midband.

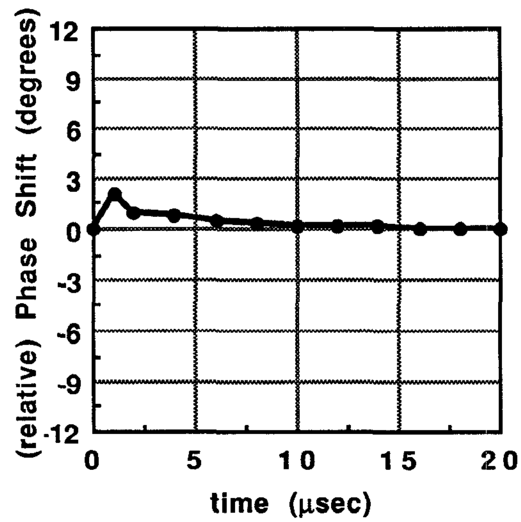

FIG. 7. Intra-pulse phase characteristic measured at 35 GHz

THERMAL RESISTANCE

An effort is underway to determine the thermal properties of the ISIS varactor diode. A theoretical model was used [1],[6] and thermal resistance measurements on devices have been made. Fig. 8 shows reasonable agreement between these measurements and the model.

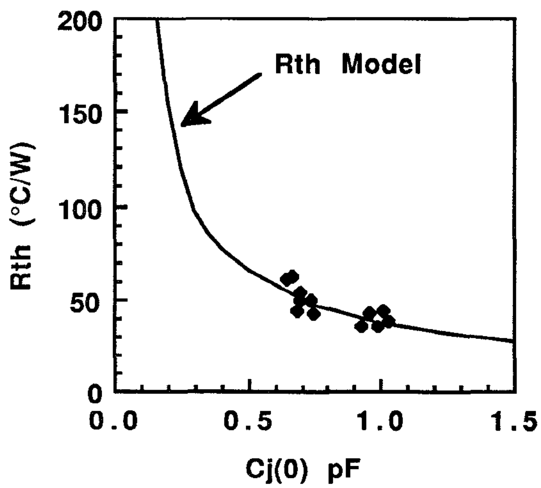

FIG. 8. Measured thermal resistance of stacked varactors versus junction capacitance at zero volts. Solid line is model prediction.

CONCLUSIONS

New results which exhibit improved performance for the generation of millimeter power at W-band have been presented using single-diode doublers and cascaded multiplier chains for both CW and pulsed operation. Frequency multipliers using epitaxially-stacked varactors have given an order-of-magnitude increase in power capability for varactor frequency multiplication. They now provide higher power per device chip than any other millimeter-wave solid-state device.

ACKNOWLEDGEMENTS

Device assembly, characterization and circuit testing efforts of Bob Festa, Stuart Farmer, and My Nguyen are greatly appreciated. In addition, the continued technical support from John Putnam is gratefully acknowledged.

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