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A High-Pulsed-Power Frequency Doubler to 190 GHz

D. Porterfield[1], T. Crowe[1], W. Bishop[1], D. Kurtz[1], E. Grossman[2]

[1]Virginia Diodes, Inc., Charlottesville, Virginia, USA
[2]National Institute of Standards and Technology, Boulder CO, USA

Abstract

A high-pulsed-power varactor doubler has been developed to efficiently transfer the power from a pulsed 95 GHZ IMPATT oscillator to the 190 GHz band. The frequency doubler uses waveguide based embedding structures employing high-thermal conductivity circuits and Virginia Diodes, Inc. (VDI) proprietary GaAs Schottky varactor diode technology. The embedding circuitry is based on a balanced doubler topology that delivers state-of-the-art power and fixed-tuned bandwidth at millimeter-wave frequencies. The waveguide structure is modified to provide ample room for the large diode arrays while simultaneously blocking propagation of the unwanted TM modes. Special attention was given to maximizing the heat conduction pathways in the embedding structure to minimize heating of the varactor devices.

Introduction

Researchers at NIST are developing a high frequency imaging system for portal security applications. Terahertz energy has been shown to pass through clothing materials to reveal hidden weapons and explosives. The NIST imaging system has been developed at 95 GHz because of the availability of high pulsed power and compact solid-state sources at this frequency based on IMPATT diodes. However, at this relatively low frequency the image resolution is poor unless an extremely large antenna system is used. By increasing the measurement frequency by a factor of four the same resolution can be achieved with an antenna area sixteen times smaller and a complete system with nearly 1/64th the volume. The goal of the work presented here is to develop cascaded frequency doublers that have sufficient efficiency and pulsed power handling ability to provide ample power for an imaging system near 360-380 GHz.

Circuit Design

VDI's current generation of frequency doublers are capable of producing CW output power of 70 mW at 200 GHz with an input drive signal of approximately 230 mW. These doublers use linear diode arrays in anti-series on a high-thermal-conductivity dielectric circuit situated across a reduced height waveguide [1-3]. The pulsed IMPATT can produce 10 W pulses at 95 GHz with 100 ns pulse widths and a 50 kHz rep rate. The goal is to handle as much of this available peak power as possible. An advantage to pulsed operation is reduced heat in the Schottky diode and a subsequent reduction in the parasitic series resistance. However, the main constraint on power handling comes from the electrical breakdown limits and this limitation is not affected by pulsed operation.

Our basic approach is to increase the number of diodes in the array and lower the epitaxial doping as much as possible without going into velocity saturation [4]. Adding diodes requires increasing the waveguide height under the constraint that the TM_{11} mode remains cut off. The embedding architecture is illustrated in Fig. 1. Reduced-height WR-10 waveguide is used except in a small region near the diodes where a perturbed full-height section is employed. This provides ample room for the diodes while simultaneously blocking propagation of the unwanted TM modes. EM simulations on this structure led to circuit and varactor chip designs with very tightly controlled embedding impedances and large fixed-tuned bandwidth (no mechanical tuners).

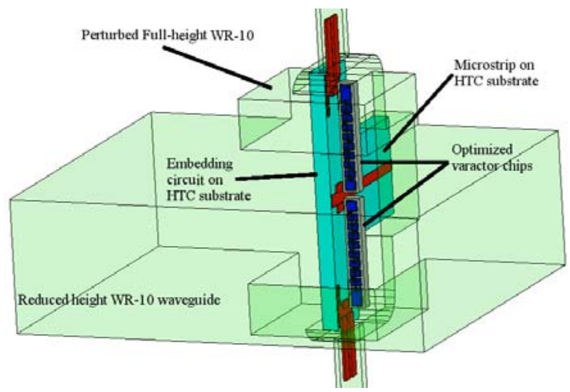

Fig. 1: Sketch of the D190HP frequency doubler.

Design of the varactor chips was an integral part of this effort because the parasitic capacitance and inductance of the chip package have a significant impact on the embedding impedances. A photograph and scanning electron micrograph of the chips are shown below in Fig. 2. Each chip has nine anodes and employs surface channels and air-bridges to minimize the parasitic shunt capacitances of the package. The D190hp frequency doubler employs two of these chips arranged in anti-series in a waveguide housing as illustrated in Fig. 1 and thus power is distributed among eighteen anodes. This arrangement spreads out the heat generation and maximizes the electrical power handling.

Fig. 2: Photograph and scanning electron micrograph of the D190HP Schottky barrier varactor chips.

Test Results

The graph in Fig. 3 shows measured maximum peak output power for five of the frequency doublers. Input power was approximately 10 W peak with a duty cycle of 0.5 %, 100 ns pulse width and a pulse rate of 50 kHz. A peak output power of 630 mW was observed using a 10.5 μm anode diameter.

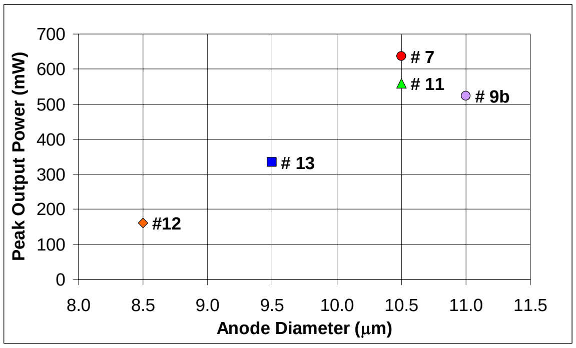

Fig. 3: Measured maximum peak output power for five of the 190 GHz frequency doublers.

The multiplier efficiency tended to peak somewhere in the 0.5-1.5 W range and steadily decrease for higher power levels as shown in the graph in Fig. 4.

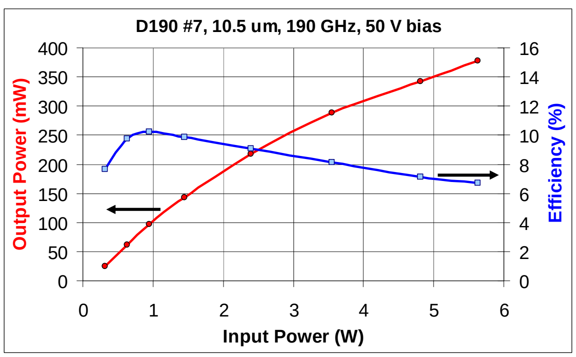

Fig. 4: Measured peak output power and efficiency.

The measured peak efficiencies of 10-11 % are about one half as high as we might reasonably expect for one of our doublers at these frequencies. The graph in Fig. 5 indicates that the IRL is optimal at the 0.5-1 W drive level and decreases to about 3.3 dB at a drive level near 4 W. Thus at the higher drive levels nearly one half of the available input power is reflected back to the source. The input reflection accounts for a factor of two drop in the multiplier efficiency.

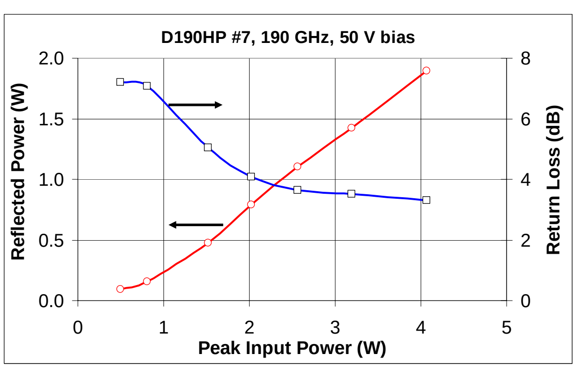

Fig. 5: Measured input return loss of the 190 GHz doubler.

The input and output pulses were also examined using directional couplers attached to the input and output waveguide flanges of the doubler. The measured waveforms are shown below in Fig. 6. The output pulse of the frequency doubler exhibits a slow rise over the entire pulse period and it is unclear if the maximum steady-state value is ever achieved. Peak power was calculated from the measured average power delivered to a calorimeter. If the measured output pulse shown in Fig. 6 is accurate, then the calculated peak output power is the average value of the pulse or roughly half of the peak value of the pulse.

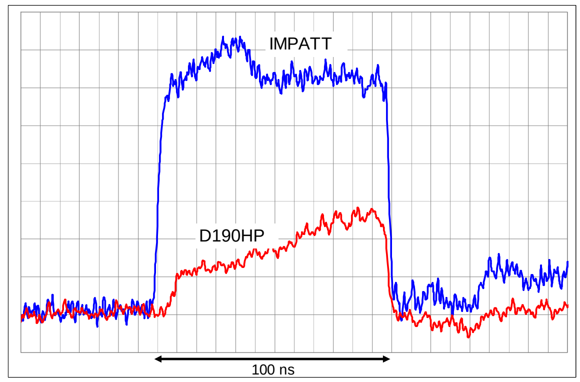

Fig. 6: Measured output pulse waveforms of the IMPATT oscillator and the D190hp. The IMPATT pulse width is 100 ns.

The ramp shape of the measured pulse is probably due to an RC time constant of the embedding circuitry. The diodes are voltage biased for optimum performance. In pulsed operation the rapid onset of input power may cause the voltage across the diodes to shift to non-optimal values. The RC time constant of the Schottky diode capacitance and series resistance is orders of magnitude smaller than the pulse period.

Summary

The prototype 190 GHz frequency doubler has achieved record pulsed power for a compact, solid-state, waveguide mounted frequency doubler at this frequency. This verifies the basic circuit design and indicates that the diodes are capable of handling large pulse power levels. However, analysis of the test data has also indicated that important improvements can be made. Refinements to the embedding and bias circuitry should lead to improved efficiency and output power.

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