DEVELOPMENT OF A PULSED IMPATT DIODE AMPLIFIER

Bernard E. Sigmon and Thomas W. Van Alstyne

Motorola Government Electronics Group,
Radar Operations, Tempe, AZ 85282

ABSTRACT

The impedance transformation properties of parallel coupled lines have been used to develop broadband reflection amplifiers operating in X-band. These amplifiers have demonstrated peak powers of 40 watts (single IMPATT diode), 63 watts (two diode combiner), and 110 watts (four diode combiner). 3 dB bandwidths of 1.4 to 3 GHz (14 to 30%) have been attained.

INTRODUCTION

This paper reports on the progress to date (9-20-85) toward the development of an X-band, 600 watt peak power combiner/amplifier.

Individual GaAs IMPATT diodes have become available which produce peak X-band microwave power in excess of 30 watts. Circuit design procedures have been published (3,5) which allow stable design of high power saturation amplifier/oscillators. The current impetus in amplifier design is to produce multiple arrays of diodes which will operate in phase to achieve reasonable combining efficiencies. Numerous examples of these amplifiers have been described in the literature (1,6,7,8). These results have been primarily achieved using high Q cavity combiners which generate power by active combining of the diodes, i.e., the individual diodes are not isolated from one another by the linear circuit. These circuits generally achieve less than 5% bandwidth and as a result are limited in application.

An alternate approach for broader band applications would be passive combination of individual amplifier modules. This paper presents results achieved by such an approach using microstrip. For this amplifier, the duty cycle used was 0.1% with a 500 nS pulse width and a 2 KHz PRF. Advanced design GaAs IMPATT diodes were used which required no preheating. Modulator rise and fall times were less than 80 nS.

DIODE FABRICATION

The diodes which were used for this work came from a wafer with a hybrid double drift (HDD) doping profile. A vapor phase epitaxial system was used to generate the wafer. The wafer was processed into single mesa, gold plated heat sink devices. The final diode was mounted in a M/A-Com, Inc. 275 package using gold ribbons in a cross strap configuration.

CIRCUIT SELECTION

The most common circuits for power combining take the form of either a Kurokawa (6) structure or a derivative of the Harp and Stover (7) combiner. These combiners exhibit 1 dB bandwidths of 3 to 5% which is characteristic of high Q cavity circuits. An exception to this is the Harp and Russel Ridge Mount Amplifier (8) which exhibits 20% 1 dB bandwidths.

The first task was to choose the circuit medium. Cavity combiners were avoided due to their bandwidth limitations. Microstrip, specifically parallel coupled lines in microstrip, was then considered. Figure 1 shows the parallel coupled line approach. The diode is mounted at terminal plane T-T, indicated by the dashed line. In normal operation, RF power is injected into the 50 ohm end of the coupled line, and reflected, amplifier power is recovered from this same port. Zc, shown in the figure, represents the circuit impedance seen looking into terminal plane T-T with the diode removed.

Analysis of the parallel coupled line topology of Figure 1 showed that the 50:1 impedance transformation needed to match the negative impedance of a packaged IMPATT diode to 50 ohms

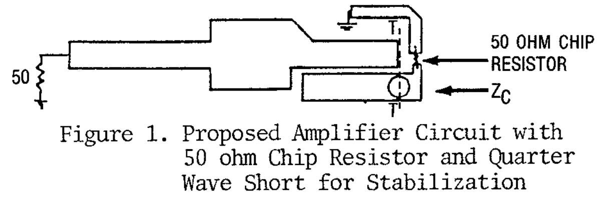

Figure 1. Proposed Amplifier Circuit with 50 ohm Chip Resistor and Quarter Wave Short for Stabilization

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could easily be done using soft substrate with reasonable etching tolerances. This assumed gap spacings on the order of 10 mils.

The circuit of Figure 1 was analyzed and the circuit impedance $Zc(\omega)$ plotted on the Smith Chart (Figure 2). The packaged diode impedance of Figure 3, $Zd(\omega)$, is also shown by Figure 2. This plot is for $Zd(\omega) = |-R| + jXd(\omega)$ which allows the locus to fall within the Smith Chart. The frequency where the circuit curve intersects with the conjugate of the diode curve corresponds to the onset of oscillation. Diode non-linearities then come into play and the oscillator will adjust to a stable power and frequency point (9). The circuit includes a 25 ohm quarter wave impedance transformer between the 50 ohm load and the beginning of the coupled lines. At approximately 10 GHz $Zc(\omega)$ has moved toward the center of the Smith Chart and thus presents an overcoupled load to the diodes circuit impedance. Broadband amplification is predicted by the cusp occurring in $Zc(\omega)$ around the 10 GHz region.

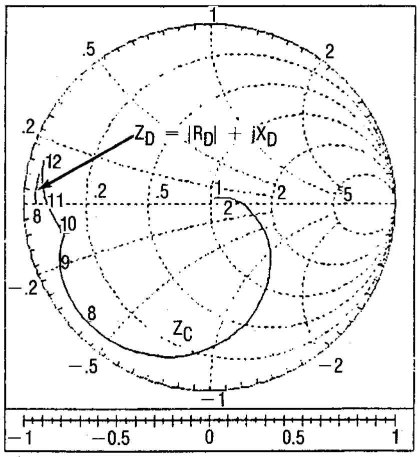

Figure 2. Impedance Locus for Circuit of Figure 1.

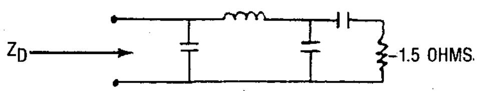

Figure 3. Diode Model and Impedance Locus using the Absolute Value of the Negative Resistance.

AMPLIFIER PERFORMANCE RESULTS

Early program progress was hindered by diode burn out induced by bias circuit oscillations. This problem is theoretically addressed in a paper by Brackett (2). The practical solution presently used is a bias stabilization resistor connected at the diode to a quarter wave shorted stub (Figure 1). The circuit locus with the stabilization network in place is presented in Figure 2. The modulator is terminated in a 50 ohm load from DC to 1 GHz. The high impedance which the shorted stub presents at the resistor effectively masks it from the circuit in the 8 to 12 GHz band. The penalty paid for this stabilization approach is a lowering of overall DC to RF conversion efficiency due to the I^2R losses in the resistor. The 50 ohm value was later raised to 100 ohms without any noticeable change in effectiveness.

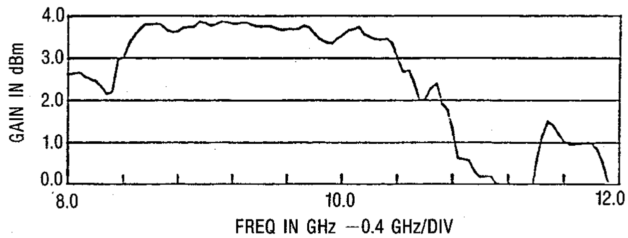

Figure 4. Gain Plot for First Amplifier Circuit.

The initial amplifier produced the gain frequency response of Figure 4. These plots were all taken on an automated system and show the characteristic "jumps" of discretized data. The output power is approximately at the 16 watt level. The 1 dB bandwidth is 2 GHz and the 3 dB bandwidth extends to 3 GHz. Single drift IMPATTs were used here.

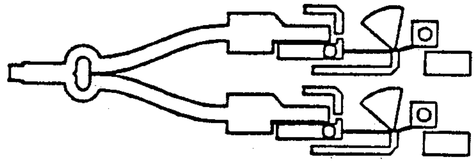

Figure 5. Topology for two, single Amplifiers combined through a Single Wilkinson Combiner.

Figures 5 and 6 present the amplifier topology and the power frequency response of the two single diode amplifiers passively combined through a Wilkinson power adder. These are double drift diodes driven from a 15 watt TWT. The two plots correspond to different bias current levels.

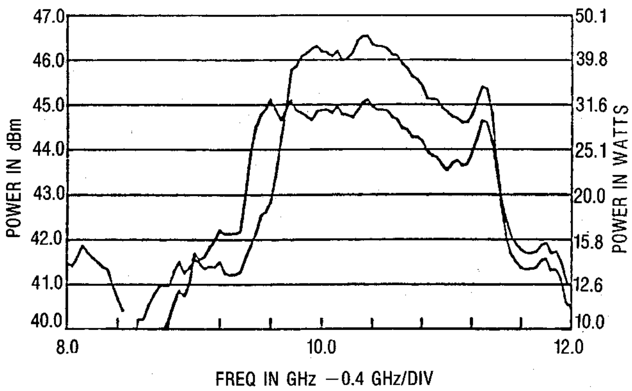

Figure 6. Power Versus Frequency Plots for Circuit of Figure 5. These correspond to two different DC drive levels.

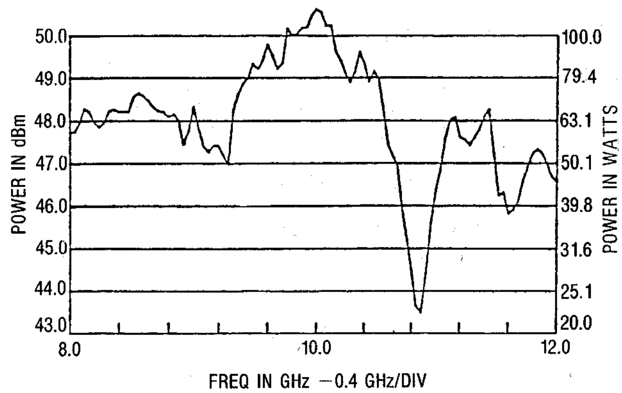

Figure 8. Current Results from 100 watt Amplifier.

The present status of the power combining work is pictorially presented by Figures 7 and 8. Figure 7 shows a photograph of the amplifier. GaAs double drift IMPATTs were employed in this cascade of three amplifiers. Isolators were not used between the amplifiers' respective circulators. This circuit has been carefully packaged to reduce path losses. The power-gain data plot for this amplifier is shown in Figure 8. The packaged circuit has given 112 watts peak power output and greater than 100 watts over a 400 MHz 1 dB bandwidth.

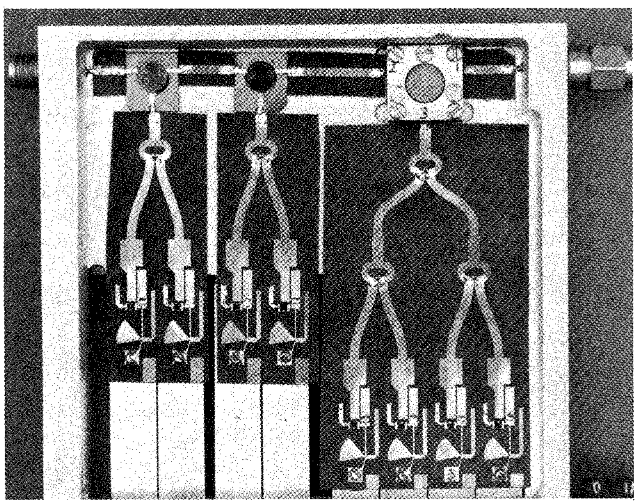

Figure 7. Photo of Circuit which Produced 112 watts.

A NEW COMBINING STRUCTURE

Two diode amplifiers were also built. Each diode was coupled to a common output line (Figure 9). However, these amplifiers suffered from reproducability problems due to diode burn-out (low frequency bias circuit oscillations were induced by the diodes interacting).

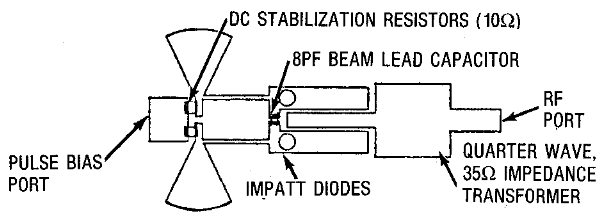

Figure 9. Two Diode Amplifier Topology.

A modification was added by splitting the common coupled line between the two diodes and placing a 100 ohm balance resistor at the diode end of the split. Figure 10 shows the topology. The circuit was modeled on Super Compact™ and Touchstone™. Both predicted greater than 30 dB

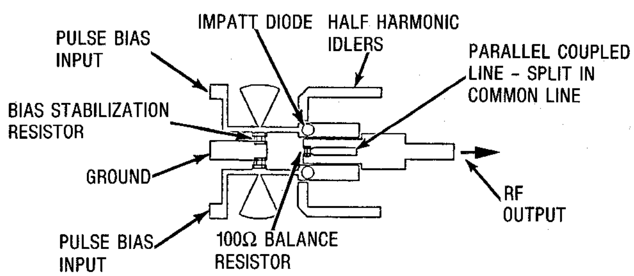

Figure 10. Schematic for Two Diode Amplifier.

of isolation between the diode ports. The circuit was built and tested using two double drift IMPATTs. Preliminary results yielded nearly 60 watts of output power driven from a 15 watt TWT. Subsequent circuit improvements and modifications led the plot in Figure 11. It was evident that the diodes were sufficiently isolated from one another since no catastrophic failure due to low frequency oscillations occurred. A patent disclosure has been initiated for this circuit.

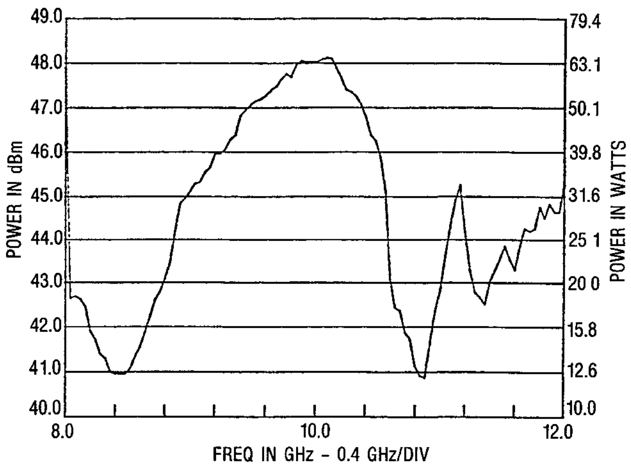

Figure 11. Power/Gain Plot for the Amplifier schematically represented by Figure 10.

SUMMARY AND CONCLUSIONS

This paper reports on preliminary stages of development leading to the realization of a 600 watt peak power low duty cycle, X-band, IMPATT amplifier/combiner.

The design technique of employing parallel coupled lines for single diode and double diode amplifiers has been presented. These amplifiers are passively power combined through Wilkinson power adders to realize wideband, high power amplifiers. Single diode amplifier modules have exhibited bandwidths up to 3 GHz (30%). Peak power of over 100 watts has been realized from a 4 diode output stage.

A new combining technique which gives the isolation of a Wilkinson power adder, but does not exhibit the path loss associated with the physical length of a Wilkinson has been presented.

Since the submission of this paper, an 8 diode combiner using the two diode topology of Figure 10 has produced 200 watts of peak output power.

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