A PUSH-PULL IMPATT DIODE AMPLIFIER*

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ABSTRACT

A new circuit approach which connects two IMPATT diode chips in push-pull configuration is presented. The impedance level of the push-pull diode is doubled. The theoretical device maximum output power capability is increased by a factor of four.

Introduction

Methods of serializing[1, 2, 3] or paralleling[4] a number of avalanche diodes for the purpose of increased output power capability have been reported. Parallel connected diodes, besides reducing the overall thermal resistance, lower the impedance level of the device. The maximum achievable power capability still rolls off in a $1/f^2$ fashion. Series connected diodes raise up the impedance level. However, the series connection usually introduces serious parasitic problems, such as the large mounting inductance between the two diodes[3]. The new push-pull circuit to be described here takes advantage of the merits of both methods[5]. In this push-pull circuit the two diodes with opposite polarities are in rf series connection, yet maintaining the dc and thermal paths in parallel. Kawamoto and Liu[6] reported an anti-parallel pair of avalanche diodes which are located half-wavelength apart and opposite in polarity. In their circuit the two diodes also allow for push-pull operation yet the circuit principle is entirely different. In their circuit the two diodes are essentially in parallel while in the present circuit the two diodes are in series. In contrast to their anti-parallel name, the present push-pull diodes should be called an anti-series pair.

Circuit Configuration

FIG. 1(a) shows a basic push-pull configuration. A pair of diodes are dc biased in parallel but function as a series pair in the rf circuit shown in the figure. Each diode is biased at I_o, V_o as the quiescent point and experiences the same rf current "i_o". The polarity of the rf current is the same as the dc bias current in one diode but opposite in the other diode. Thus, the rf current pushes one diode to a high current state, $I_o + i_o$, while it pushes the other diode to a lower current state $I_o - i_o$. In this push-pull circuit the overall impedance of the device is the arithmetic sum of each individual diode. For two identical diodes connected in push-pull, the overall impedance and the power handling capability should be doubled. For the overall device impedance level equal to that of a single diode, individual diodes in the push-pull circuit can have twice the junction area, and, thus raise the overall device power handling capability by a factor of four. Here we assume that there is no serious current crowding effect occurring when the junction area is doubled.

FIG. 1(b) shows a circuit realization of the push-pull configuration. Half-wavelength open circuited stubs with impedances Z_1, Z_2, and Z_3 are used for bias isolations. A quarter-wavelength open circuited stub of impedance Z_4 provides a rf ground while maintaining dc isolation. In this circuit, each diode can be individually biased. This individual bias controllability offers the flexibility of minor adjustments in matching diode characteristics as well as operating points. If the individual biasing is not required, then the two diodes can also be biased together by a common dc source.

Experimental Results

Two GaAs avalanche Schottky-barrier diodes were etched out on a common gold plated heat sink (PHS)[7]. This double dot PHS device was then bonded on a BeO or diamond substrate for dc isolation and better heat sinking. The BeO or diamond substrate with diodes was then embedded into an MIC circuit as outlined by the dotted line in FIG. 1(b). In the experiment, the BeO substrate was used for diode mounting and the MIC circuit was printed on an alumina substrate. A rectangular hole was cut out from the MIC circuit board for the BeO substrate mounting. The photographic picture of the actual push-pull circuit is shown in FIG. 2. In the actual circuit all the biases are connected through two sections of quarter-wavelength high-low impedance line for wide-band bias isolation from rf circuit.

The small signal push-pull device impedance was measured in a network analyzer. The measured result normalized to the 50 ohm system is plotted on the Smith Chart by the solid curve in FIG. 3. A very high diode negative resistance (≃ -18 ohm in the real axis cross-over) was observed in comparison with a similar single junction GaAs Schottky-barrier avalanche diode negative resistance (≃ -7 to -9 ohm) reported earlier[8]. This push-pull circuit was also connected to a circulator and used as a stable reflection type amplifier. Without using any broadbanding techniques, but using just a straight 50 ohm line, the gain was measured and plotted in FIG. 4. A 3 GHz bandwidth for which the gain is 3 dB or above, was measured with a center frequency at 7.75 GHz. Such a high gain and wide bandwidth amplifier has never before been measured for a

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single junction IMPATT diode in a straight 50 ohm circuit.

The device mounting parasitic as well as each individual diode chip impedance were also evaluated separately. After each individual chip and parasitic impedance was obtained, a check was made to determine whether the two diode junction impedances add up in the push-pull mount by directly adding up the two single diode chips and their mounting parasitic impedances. This is also shown in FIG. 3 as indicated by the dotted curve. Comparing the two curves in FIG. 3, it is seen that they are close together except that the actual measured data is rotated clockwise by a small angle. This deviation is believed to be due to the accumulation error of over-simplifying the equivalent circuit in the evaluation of parasitic. We have concluded that the two diode impedances do indeed add up in the push-pull mount.

Conclusion

The impedances of two individual IMPATT diodes can be added up in the push-pull circuit. The maximum theoretically achievable power capability can be increased by a factor of four. The push-pull pair can, in turn, be connected in series or in parallel by using conventional power combining methods. As is always true in all push-pull operations, the even harmonics contents are all suppressed. It is expected to see a higher negative resistance, higher efficiency, higher power handling capability and wide bandwidth of the device operation. The push-pull IMPATT devices can be used as a stable amplifier as well as an oscillator.

Acknowledgment

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References

1. J. G. Josenhans, "Diamond as an Insulating Heat Sink for a Series Combination of IMPATT Diodes", Proc. IEEE, Vol. 56, April 1968, pp. 762-763.

2. F. M. Magalhaes and W. O. Schlosser, "A Series Connection of IMPATT Diodes", Proc. IEEE, Vol. 56, May 1968, pp. 865-866.

3. W. Chen and C. Kim, "Series Connected IMPATT Diodes", Presented at the IEEE Workshop, New York City, February 1972, (to be published).

4. C. B. Swan, T. Misawa, and L. Marinaccio, "Composite Avalanche Diode Structures for Increased Power Capability", IEEE Trans. Electron D-vices, Vol. ED-14, September 1967, pp. 584-589.

5. C. Lee, "X-Band Tunnel Diode for Phased Array Radar", Final Report, BuShip Contract Nobsr-89328, Phase II, 1966.

6. H. Kawamoto and S. G. Liu, "Anti-Parallel Pair of High Efficiency Avalanche Diodes", Proc. IEEE, Vol. 59, March 1971, pp. 427-428.

7. W. G. Matthei and C. K. Kim, "New GaAs IMPATT Diode Results", Proceedings, Biennial Cornell Conference, 1971, "High Frequency Generation and Amplification", Cornell University, Ithaca, New York.

8. W. C. Tsai and C. W. Lee, "A C-Band All Ferrite Integrated Wideband High Power GaAs Avalanche Diode Amplifier", IEEE-GMTT International Microwave Symposium Digest, Chicago, Illinois, May 1972, pp. 179-181.

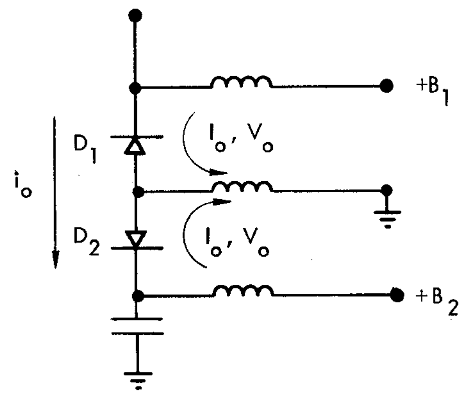

FIG. 1(a) PUSH-PULL CIRCUIT CONFIGURATION

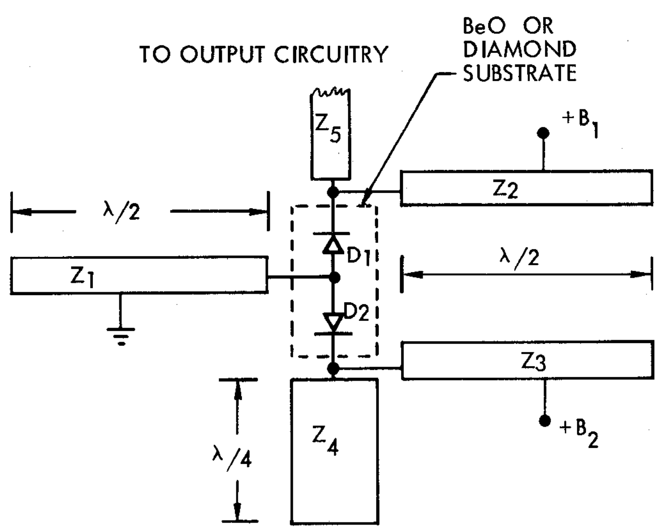

FIG. 1(b) PUSH-PULL CIRCUIT REALIZED ON MIC

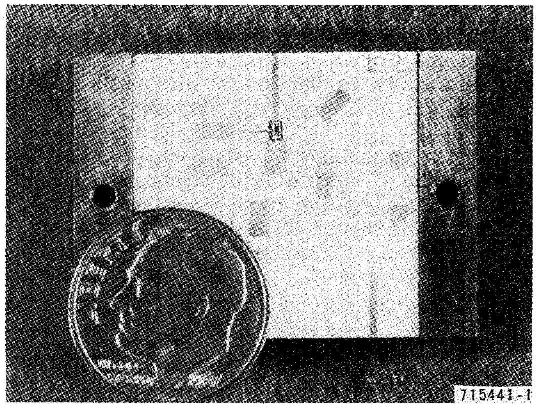

FIG. 2 PICTURE OF PUSH-PULL DEVICE

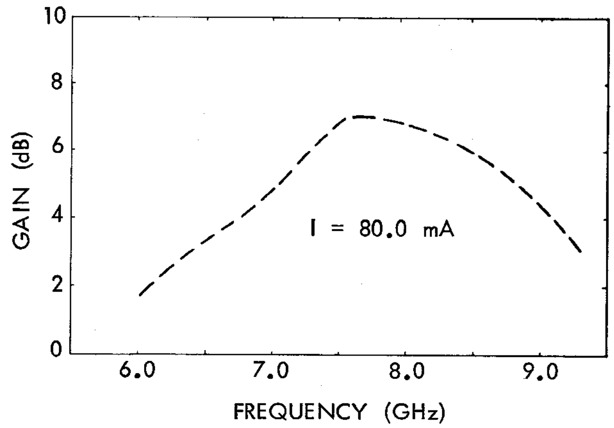

FIG. 4 GAIN AND FREQUENCY RESPONSE OF THE PUSH-PULL IMPATT DEVICE IN STRAIGHT 50 OHM CIRCUIT

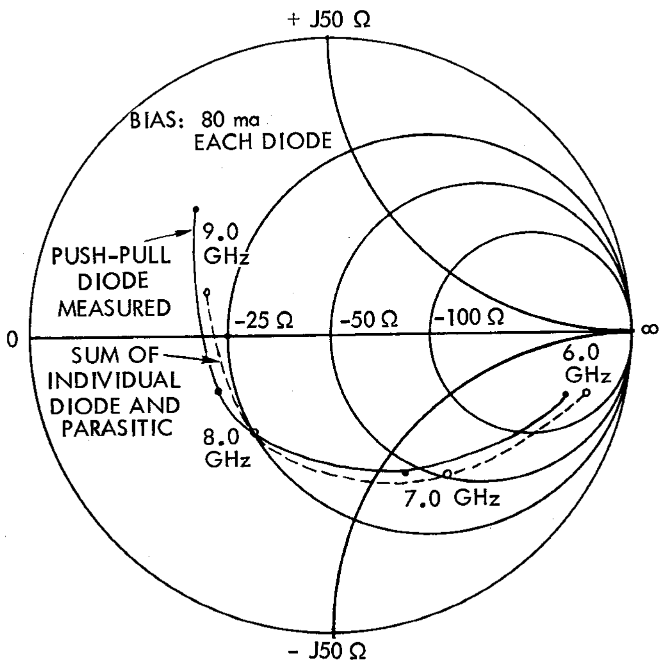

FIG. 3 THE IMPEDANCE PLOT OF PUSH-PULL IMPATT DEVICE