F-BAND* TRAPATT DIODE FUNDAMENTAL MODE AMPLIFIER CIRCUITS

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Abstract

This paper describes some new circuit approaches and corresponding performance breakthroughs for F-Band TRAPATT diode circuits. Power outputs of up to 200 watts have been measured for fundamental mode operation at F-Band using alumina substrate circuits.

Introduction

Considerable effort is presently under way to achieve higher output powers at higher frequencies and higher efficiencies from TRAPATT diode amplifiers. (1) (2) Etched ceramic circuits using MIC technology were used in this work to demonstrate higher RF powers and efficiencies than have been previously achieved to date.

The work reported here is based on fundamental mode extraction rather than harmonic extraction techniques. Fundamental mode power extraction represents the case in which the diode is designed to operate directly at F-band. Harmonic mode extraction circuits use diodes which operate basically at a sub-harmonic of the output frequency. RF power is then typically extracted at the second or third harmonic of this sub-harmonic frequency. Power extraction at the fundamental frequency minimizes circuit size and leads to the highest possible DC to RF power conversion efficiency. Furthermore, all circuits were designed using MIC techniques on high dielectric constant alumina (ε_r = 10) substrates which are directly compatible with solid-state microwave module technology for phased array antenna system applications. All TRAPATT diodes were supplied by the RCA Laboratories in Princeton, New Jersey, and were thoroughly evaluated for operation both as oscillators and amplifiers. In the work reported here, the oscillators were of the free-running type and the amplifiers were true stable amplifiers rather than locked oscillators. The diodes were mounted in several package configurations including a threaded pill box package and a rectangular microstrip package.

A typical circuit incorporating the threaded pill box package is shown in FIG. 1. The circuit size is 1 inch by 5 inches with a substrate thickness of 25 mils. A schematic of this circuit is shown in FIG. 2. The open-circuited stub to the left of the diode determines the frequency of operation, whereas the tuning elements to the right of the diode provide the required impedance match at the fundamental frequency and reflect the harmonic frequencies in the correct phase. The impedance of the transmission line near the diode is 20 ohms, and it is tapered to a 50 ohm level at the output. The pulsed DC bias is applied through the quarter-wavelength high impedance line shown in FIG. 1 and 2. In the case of an amplifier, an external circulator is used to perform the duplexing functions for the input and output ports.

A circuit incorporating the rectangular microstrip package is shown in FIG. 3. The diode chip is soldered to the diode package which is then screwed into the circuit block as shown. This interface forms both the electrical and thermal contact for the diode. A gold ribbon is bonded to the top of the diode and subsequently to the transmission lines of the alumina substrate circuit. In other respects, this circuit is similar to that shown in FIG. 1. Tuning elements are placed over the diode as well as along the transmission line.

Both n-type and p-type TRAPATT diodes were investigated, although most of the results were obtained with n-type diodes.

Circuit Performance

The original tests were performed with diode chips mounted in the threaded pill box package and evaluated in the circuit shown in FIG. 1.

Using this circuit, oscillator output powers of 84 watts with an efficiency of 35 per cent were achieved. Amplifier results of 133 watts output power at F-Band with an efficiency of 17.4 per cent and 8 dB were obtained over a 1.8 per cent bandwidth.

In an attempt to improve bandwidth characteristics of the TRAPATT diode amplifier, the dynamic circuit impedance requirements of the diode were investigated. This was accomplished by first tuning the circuit for maximum power output. The tuning elements were then fixed to the circuit and the diode was replaced by a section of coaxial transmission line. The input impedance of the external circuitry as seen by the diode was then measured at the fundamental, the second, third and fourth harmonic frequencies. Some typical measured input impedance data are shown in FIG. 4. It is noted that the input impedance at the fundamental frequency is the order of (7 - j7) ohms. The input impedance for the second, third, and fourth harmonic frequencies, however, is completely reactive and inductive. It was also noted that the impedance locus moved very rapidly with a small change in frequency. This in turn would tend to explain the rather narrow bandwidth characteristics of this amplifier circuit. This input impedance was then used to design amplifier circuits having improved bandwidth characteristics.

One such design consisted of a coupled-bar circuit shown in FIG. 5 in which one of the coupled arms was short-circuited to ground (3). Near the resonant frequency, the circuit reduces to a simple transformer. With the proper design parameters, an impedance transformation from 50 ohms to 7 ohms can be obtained over a relatively broad frequency band. The reactive impedance varies monotonically with frequency over this frequency range, but can be centered around

* F-Band denotes the new Tri-Service Frequency Code of 3-4 GHz.

(-j7) ohms. Experimentally, it was determined that this variation could be minimized by placing an additional tuning element across the coupled bar circuit. Amplifier results obtained using this coupled bar circuit showed improved efficiency, higher gains, and most importantly, wider bandwidths with no decrease in output power. For example, 132 watts output power was achieved with an efficiency of 17 per cent and 9.5 dB gain over a 2.5 per cent bandwidth. In another test, 3.8 per cent bandwidth was obtained with 103 watts output power at 18 per cent efficiency and 8.6 dB gain.

Further circuit improvements were attained through computer-aided design techniques. One such circuit consisted of a two-section low pass filter on a 10 mil alumina substrate. This circuit resulted in amplifier performance with a 9.5 per cent bandwidth at a somewhat reduced power level of 51 watts and 9 per cent efficiency. At 66 watts output power, 4.1 per cent bandwidth results were obtained at F-Band with 7.1 dB gain.

Significant improvement in amplifier performance capabilities was observed with the rectangular microstrip diode package shown mounted in the circuit of FIG. 3. Typical results include an amplifier with over 150 watts output power with a 3 dB bandwidth of over 8%, 17% efficiency, and a gain of 9 dB. Operating conditions consisted of a 1 μsec pulsewidth and 100 Hz repetition frequency. In another test, 120 watts of output power was generated with a 5 μsec pulsewidth and 1 KHz repetition frequency. In this case, the amplifier was operated with a gain of 8.2 dB and an efficiency of 18.5% over a bandwidth of 2.5%. A third amplifier generated 200 watts of power with a gain of 10 dB, efficiency of 30% and a bandwidth of approximately 6% using a 1 μsec pulsewidth. In all three amplifiers, the tuning elements consisted basically of one large element located directly over the diode.

Conclusions

It has been demonstrated that the Trapatt diode is capable of generating high pulsed microwave powers with high efficiency and wide bandwidths at F-Band. Several circuit design approaches have been investigated and successfully demonstrated. Work is progressing in areas where performance requirements have not yet been met including wider bandwidths, wider pulsewidths, and higher output power levels.

References

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Acknowledgment

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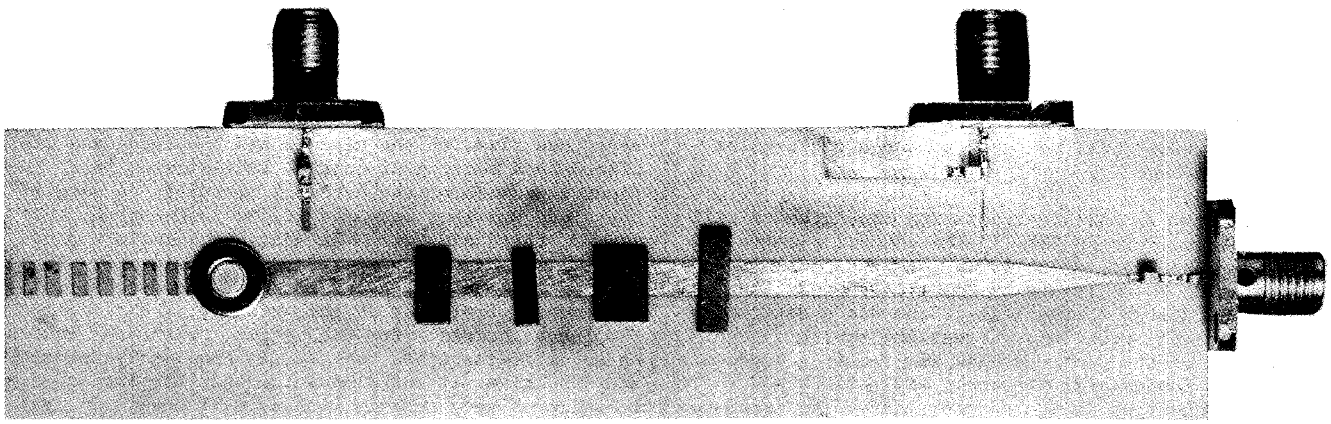

FIG. 1 Photograph of typical alumina substrate circuit designed to use threaded pill box diode package.

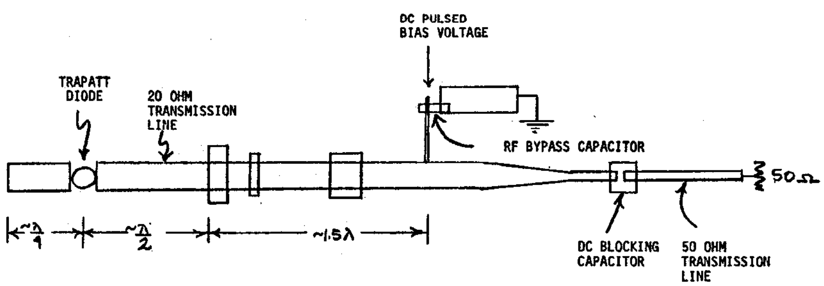

FIG. 2 Fundamental Mode Standard Test Circuit Description

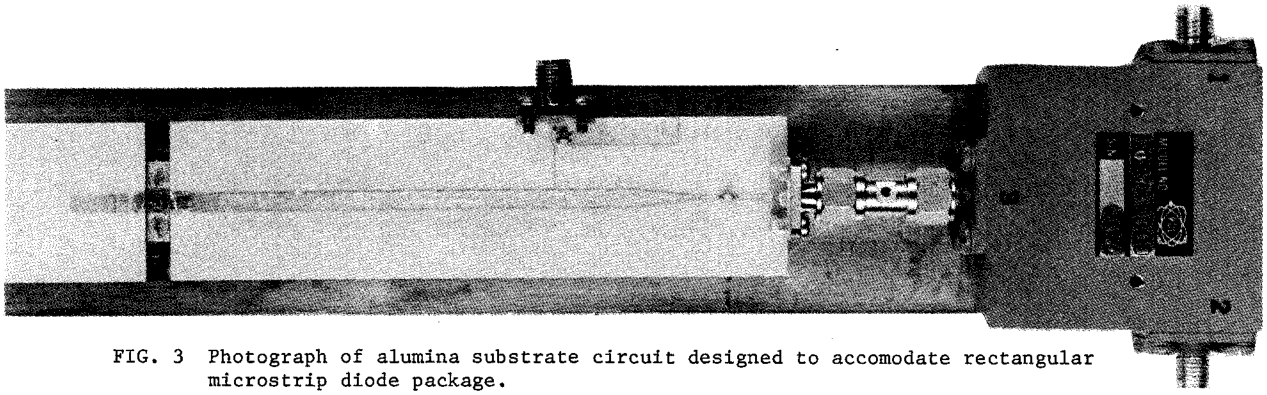

FIG. 3 Photograph of alumina substrate circuit designed to accomodate rectangular microstrip diode package.

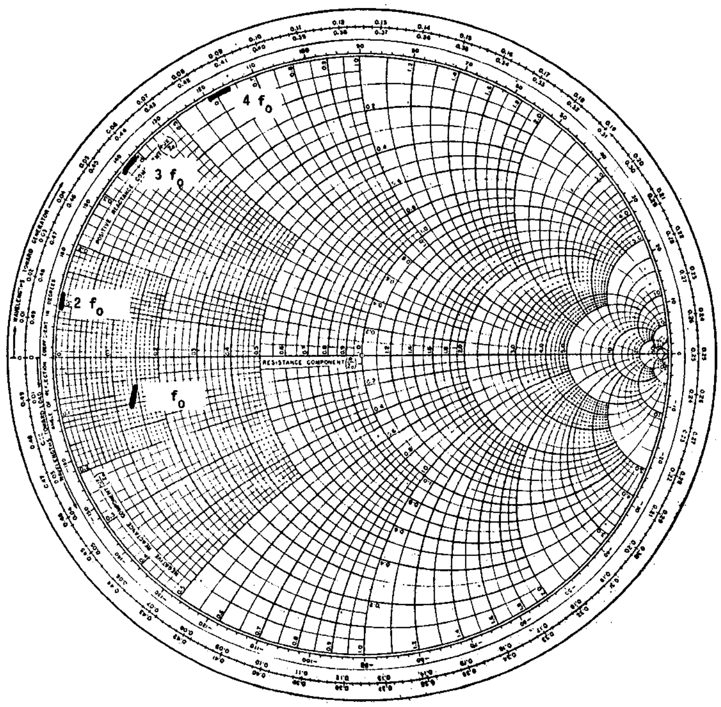

FIG. 4 Circuit Impedance seen by Diode in an Amplifier Circuit

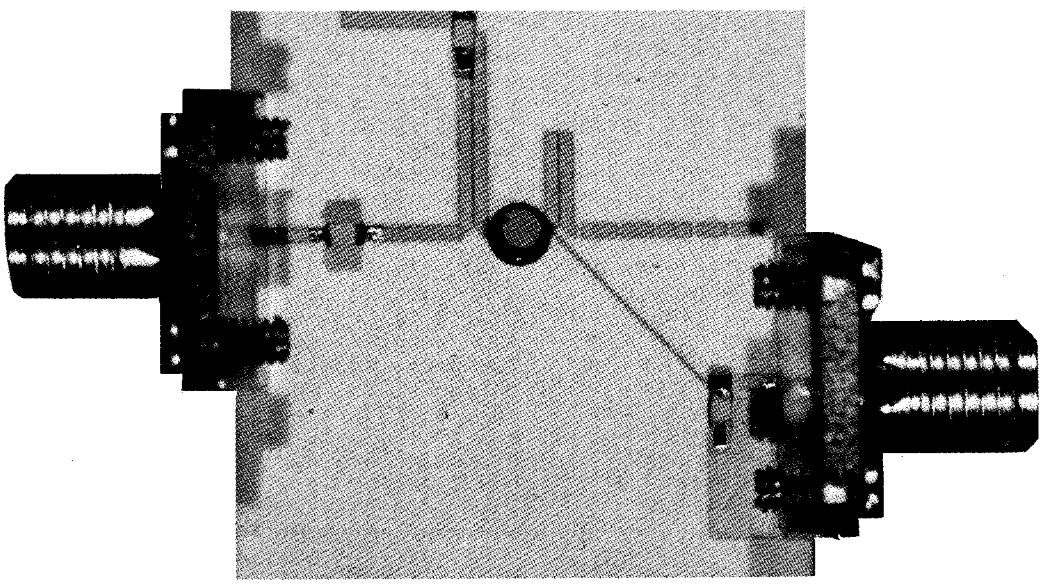

FIG. 5 Fundamental mode coupled-bar amplifier circuit.