MILLIMETER-WAVE POWER
AMPLIFIER AND COMBINER*

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Abstract

The development of a millimeter-wave IMPATT power amplifier/combiner capable of 1 W CW output power with 22 dB small signal gain and 6 GHz bandwidth in the 60 GHz range is described.

Introduction

Applications of IMPATT diodes in millimeter-wave systems have become of great interest and importance in recent years. It has been demonstrated that IMPATT oscillators and amplifiers can be used effectively for millimeter-wave power generation and amplification.[1-5] It is of great interest to combine a number of diodes to achieve high output power.[6-7] In this paper, we describe the development of a millimeter-wave power amplifier/combiner. With a two stage amplifier/combiner, CW output power of 1 W, small signal gain of 22dB and bandwidth of 6 GHz were achieved in the V-band (50-75 GHz) range.

Amplifier/Combiner Configuration

The power amplifier/combiner consists of two stages of hybrid coupled silicon IMPATT amplifiers. The first stage combines two amplifiers and the second stage combines four amplifiers as shown in Figure 1. This power combining technique offers the following advantages over other approaches:

1. The power impedance limitation of multi-device operation in a single cavity is removed.

2. Since the hybrid coupler provides isolation between individual amplifiers, instability problems associated with multi-device operation in a single cavity are minimized.

3. Hybrid coupler operation does not require ferrite circulators.

4. Since hybrid couplers provide broadband characteristics (~8 GHz), a relatively broad amplifier bandwidth can be achieved. (Although an IMPATT diode provides the negative resistance over a broad bandwidth, achievable circulator bandwidth is presently limited to 1-3 GHz in the 60 GHz range.)

5. Since each amplifier can be tuned individually, the amplifiers can be well matched.

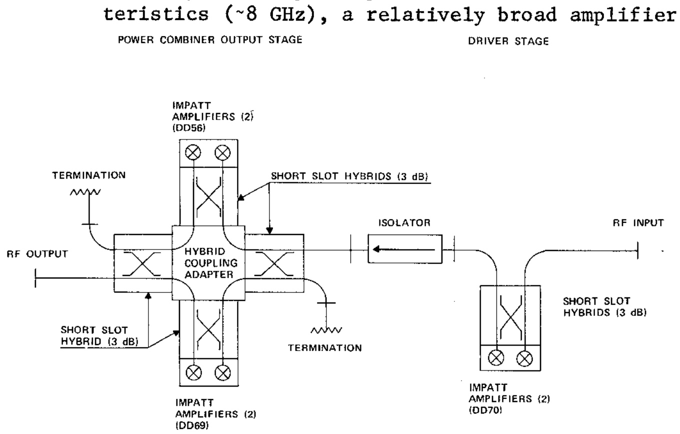

Figure 1 Block diagram of millimeter-wave IMPATT power amplifier/combiner.

Shown in Figure 2 is a photograph of the two stage amplifier/combiner unit developed. A broadband isolator was used for interstage isolation as shown in the figure.

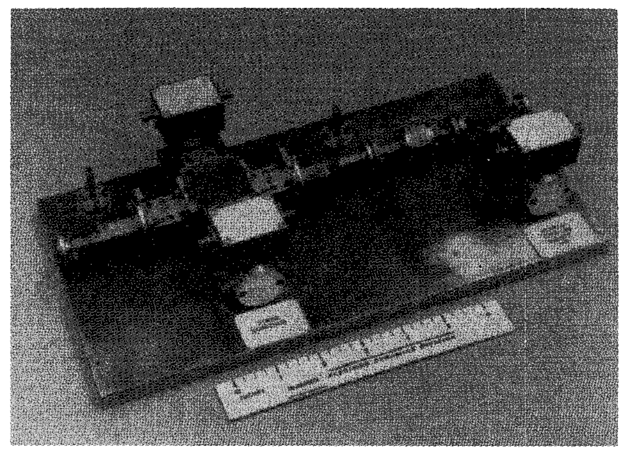

Figure 2 Two stage millimeter-wave IMPATT power amplifier/combiner.

Amplifier Design

Figure 3 shows a cross-sectional view and a simplified equivalent circuit of the amplifier circuit. This circuit possesses a unique feature of providing two degrees of tuning freedom by means of the series and parallel tuning elements provided by the adjustable coaxial section and the moveable short as shown in the figure. In this way a broad range of tuning conditions can be provided to optimize the amplifier performance. The diode is encapsulated in a miniature package for diode junction protection. The package, designed to operate up to the 100 GHz range, has extremely small parasitics. In addition to the electrical characteristics of the circuit, it is also important to provide a good thermal path to remove heat generated in the diode so that the junction temperature can be kept as low as possible for the device reliability. Details of the diode mounting scheme are illustrated in Figure 3. The diode is T.C. bonded onto an OFHC copper disk which consistutes the package base with the junction side very close to the heat sink (<1 μm). In this way, thermal resistance measured between the diode junction and the outside surface of the amplifier circuit ranges between 35 and 45°C/W for diodes operated in the 60 GHz

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range depending on the junction size.

Amplifier/Combiner Performance

The amplifiers were first tuned individually to balance the gain, then assembled into the combiner unit. The performance of the two stage amplifier/combiner was extensively evaluated. The measured output vs. input power transfer characteristics and small signal bandpass characteristics of the unit are shown in Figures 4 and 5 respectively. Small signal gain of 22 dB with a bandwidth of 6 GHz and a saturated CW output power of 1 watt with 9 dB gain have been achieved in the 60 GHz range as shown in the figures. The reflected power at the input port of each stage was typically 16 to 20 dB below the transmitted power level. Non linear characteristics including gain and phase linearities and intermodulation product characteristics of single diode amplifiers as well as those of power amplifier/combiners have been evaluated extensively. It was found that nonlinear characteristics of individual diodes are so similar that stabilities or combiners efficiencies were not affected by the nonlinear characteristics of the diodes at large signal levels.

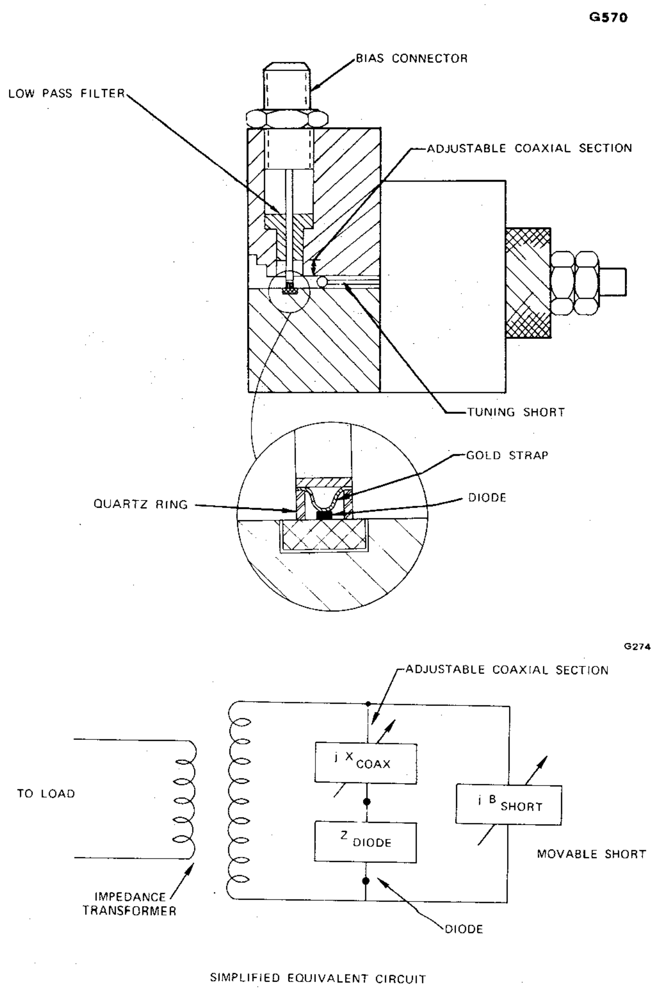

Figure 3 Cross-sectional view and simplified equivalent circuit of IMPATT and amplifier circuit.

Conclusions

The amplifier/combiner has demonstrated the feasibility of efficiently combining a number of devices to achieve high output power at millimeter-wave frequencies. The experiment was performed with the conventional

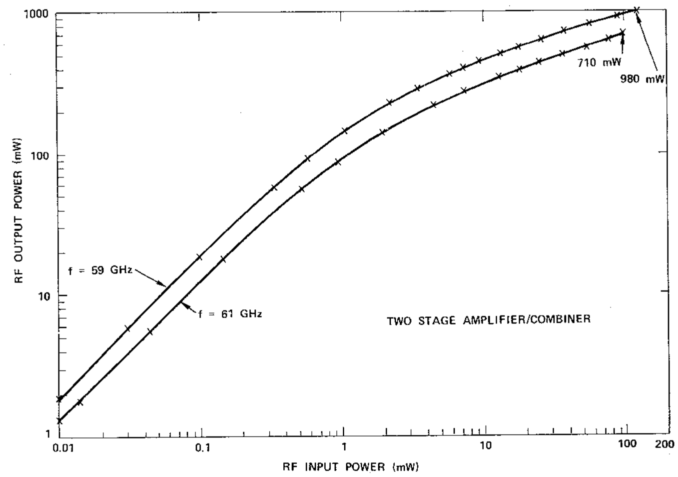

Figure 4 Output vs. input power transfer characteristics of two-stage millimeter-wave IMPATT amplifier/combiner.

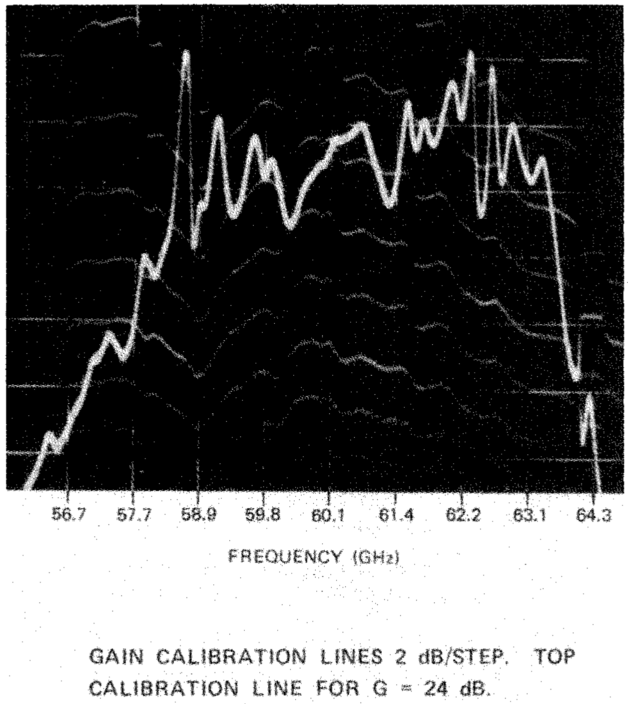

Figure 5 Small signal bandbapp characteristics of the complete 2-stage IMPATT amplifier/combiner.

p^+-n-n^+ type silicon single drift diodes. With the recently developed double drift diodes, higher output power can be expected.

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