V-BAND HIGH-POWER IMPATT AMPLIFIER

Y. Ma, C. Sun, and E.M. Nakaji
Hughes Aircraft Company
3100 West Lomita Boulevard
Torrance, California 90509

Abstract

A high-power IMPATT combiner/amplifier has been developed at V-band. The amplifier consists of two stages with an overall gain of 50 dB. The maximum output power is 2.5 W at 61 GHz with overall DC to RF conversion efficiency of 3.7 percent.

Introduction

Recently there has been increasing interest in the development of high-power and high-efficiency solid-state amplifiers around 60 GHz for satellite applications. The demand for higher output power has resulted in significant progress both in single-diode[1] and combiner[2] operations in V-band. This paper describes the development of a two-stage high-power V-band IMPATT amplifier. Output power of 2.5 W with amplifier gain of 50 dB has been achieved at 61 GHz. The overall DC to RF conversion efficiency is 3.7 percent. The amplifier is more compact, and potentially more reliable than a TWTA for space applications.

Diode and Circuit Design

The double-drift-region (DDR) IMPATT diode is chosen because of its high-power and high-efficiency capabilities. The diode is designed to have an abrupt p and n doping profile with thicknesses such that the edges of the depletion layer just reach the $n\text{-}n^+$ and $p\text{-}p^+$ interfaces under the normal operating condition. After thinning the substrate to the desired thickness, the doping density in the n^+ substrate is increased by phosphorous diffusion to reduce the series contact resistance which is detrimental to optimum RF performance. The actual profile of V-band diodes has an approximately symmetrical $p^+\text{-}p\text{-}n\text{-}n^+$ structure with a 9.0×10^{16} cm^{-3} doping density and about 1.0 μm total active layer thickness. The diode breakdown voltage is between 21.0 and 22.0 V.

To reduce the thermal resistance, a diamond heatsink is employed. A factor of two improvement in thermal resistance is obtained by using Type IIa diamond against copper heatsink. A small quartz-ring package with cross-strap ribbon is used to minimize the parasitic reactances.

The basic circuit configuration used for the amplifier development is a reduced-height waveguide cavity cross-coupled with a short coaxial line of which one end is terminated by an IMPATT diode, as shown in Figure 1. This circuit configuration provides a wide range of impedance matching and therefore is used for both the driver and output stages. A maximum 1.5 W oscillator output power was achieved from a single diode with about 7 percent efficiency at an elevated junction temperature. At the operating junction temperature of 250°C, 0.8-1.0 W output power has been consistently obtained with minimum efficiency of 5-6 percent in the frequency range between 60 and 63 GHz.

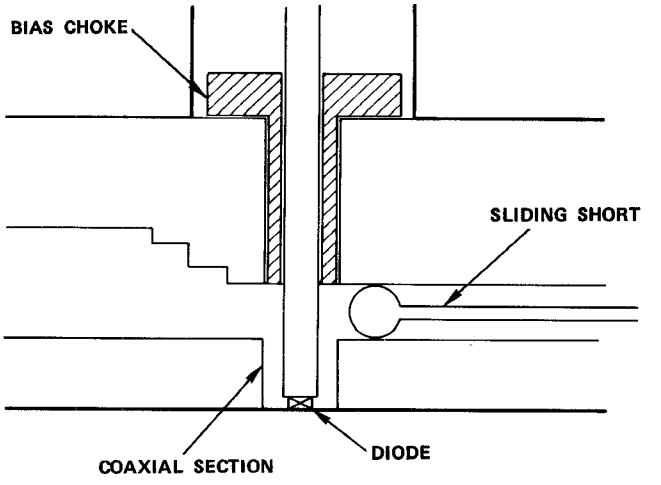

Figure 1 Coaxially coupled waveguide circuit.

Amplifier Development

Figure 2 represents the schematic of the two-stage IMPATT amplifier. The driver stage is a circulator-coupled single-diode amplifier and the output stage is a hybrid-coupled four-diode combiner/amplifier. An isolator is introduced between stages to minimize the interstage effect. Both amplifiers are developed to operate in injection-locking mode.

Driver Stage

The driver stage was developed with the circulator-coupled IMPATT cavity connected to an isolator as an integrated unit. The operating frequency and the output power were adjusted to provide a stable operation for

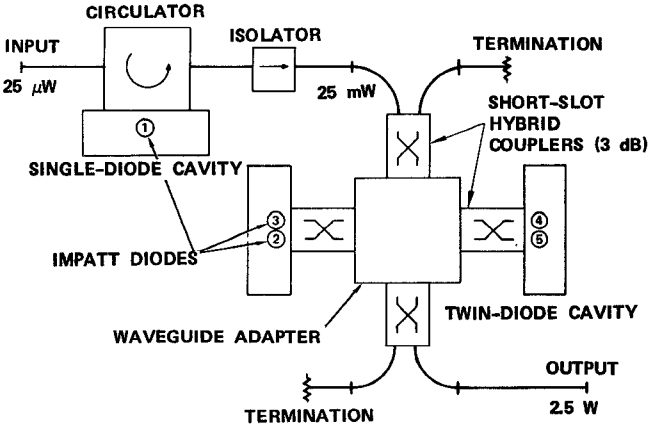

Figure 2 Schematic diagram of two-stage high-power IMPATT amplifier.

the output stage amplifier. Output power of 25 mW with 30 dB gain could easily be obtained at lower IMPATT bias level. About 100 MHz bandwidth was obtained with this gain.

Output Stage (Hybrid-Coupled Combiner/Amplifier)

The hybrid coupler has a wide bandwidth and thus attractive for communication systems where the bandwidth is important. The hybrid coupler also provides high port-to-port isolation, hence the power-impedance limitation and stability problems associated with multi-device operation are minimized. The design approach therefore reduces to that for single-diode operation and the established single-diode circuit design can be directly applicable to a combiner circuit without major modification.

The key design consideration of a hybrid-coupled combiner is the symmetry of the 3 dB hybrid coupler as well as of the sources to be connected over the frequency range of interest. As the number of IMPATT sources increases, it becomes more difficult to operate the diodes at the optimum point with the same operating frequency. Although the number of sources that can be combined is limited to about four in V-band, hybrid-coupled combiners can be used in conjunction with other combining schemes to achieve even higher power output. From a four-diode hybrid-coupled combiner/amplifier, maximum output power of 2.5 W was achieved at 61 GHz with the bandwidth of 50 MHz. The amplifier gain was about 20 dB.

Overall Amplifier Performance

The driver and output stages were then connected to form a two-stage amplifier. Output power of 2.5 W was achieved at the input power of 25 μW with a corresponding gain of 50 dB. The overall DC to RF conversion efficiency was 3.7 percent and the available bandwidth was about 30 MHz. It must be pointed out that the available bandwidth is usually limited by the appearance of strong noisy or spurious signals which is characteristic of large-signal IMPATT operation. The output power was achieved at the IMPATT bias level of 500-550 mA and about 28 V. Since the thermal resistance of this size diode is about 15°C/W, the operating junction temperature is about 250°C. According to our life test results for 40 GHz DDR diodes which shows similar failure distribution with those for the V-band diodes in step-stress tests, the MTTF is expected to be about 1.6×10^5 hours.

The hardware of the two-stage IMPATT amplifier is shown in Figure 3 along with the current regulator circuitry. The output stage four-diode combiner/amplifier unit is assembled by connecting two two-diode hybrid-coupled combiners as well as two additional hybrid couplers to a four-way waveguide adaptor.

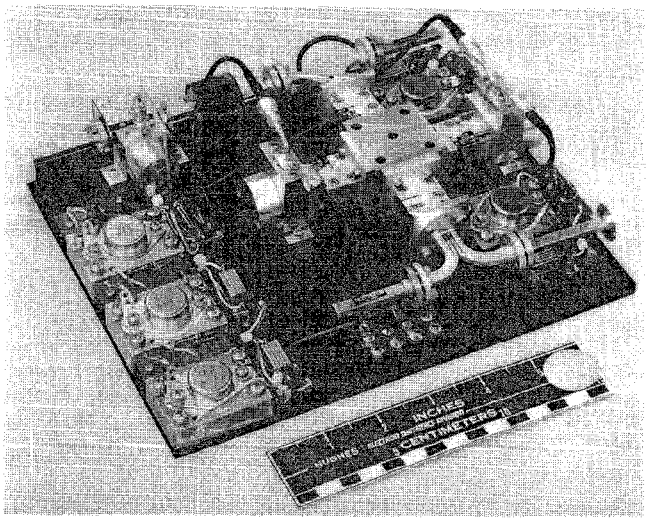

Figure 3 High-power two-stage IMPATT amplifier.

Conclusions

A high-power IMPATT amplifier has been developed at V-band. 2.5 W output power was achieved with 50 dB gain and 3.7 percent conversion efficiency. The operating junction temperature is about 250°C and the MTFF is expected to be over 15 years. These characteristics of a solid-state amplifier are sufficient for many satellite system applications in V-band.

Acknowledgements

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