A 4W, 56dB GAIN, MICROSTRIP AMPLIFIER AT 15 GHz UTILIZING GaAs FETs AND IMPATT DIODES*

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ABSTRACT

Performance results and design considerations are presented for an all solid-state power amplifier suitable for spacecraft transmitter applications. Design emphasis is placed on high power, high efficiency and high reliability operation, as well as on compact amplifier construction.

Introduction

The use of solid-state devices for efficient amplification of cw microwave signals to power levels exceeding 1 watt in the Ku-band frequency range is now feasible with GaAs IMPATT diodes and to a lesser extent with GaAs FETs. Solid-state amplifiers of this type have obvious application in a wide variety of telecommunication systems both military and commercial, but are especially important for airborne and space applications where high efficiency, high reliability, and small physical size is essential. The purpose of this paper is to present the performance results and corresponding design considerations for an all solid-state 15 GHz, 4 watt, 56dB gain microstrip amplifier utilizing GaAs FETs and GaAs IMPATT diodes. For high power and high efficiency operation GaAs Schottky-Read IMPATTs with low-high-low doping profiles are used in the power stages. The diodes incorporate a titanium/tungsten barrier layer atop a platinum Schottky barrier contact for improved reliability. The realization of this amplifier demonstrates the feasibility of an all solid-state microwave amplifier suitable for spacecraft transmitter applications.

Overall Amplifier Circuit Description

Figure 1 shows a block diagram of the three amplifier chassis; the FET preamplifier, the IMPATT driver amplifier and the IMPATT balanced power stage. The nominal power gain of each stage as well as the dc input power and corresponding rf power output along the chain of amplifiers is also indicated. The amplifier operates from 39V, 6V, and -1V dc power supplies. As specified by the spacecraft transmitter application, the nominal rf input power to the amplifier ranges from threshold (<-30 dBm) to -20 dBm. Below threshold, amplification is no longer required and the driver and power amplifier stages are made idle by removing bias from the IMPATT diodes. This is accomplished automatically by means of a shutdown circuit which is activated by the rectified voltage of a sampling Schottky detector diode situated at the output of the FET preamplifier.

Figure 2 shows a photograph of the integrated amplifier. Because of the high gain of the amplifier, metal partition walls incorporating short sections of 50 Ω transmission line feedthrough separate the three amplifier chassis to suppress potential signal feedback and spurious oscillation in the preamplifier. Also included in the housing are the bias distribution circuits as well as the IMPATT shutdown circuit.

FET Preamplifier

The FET preamplifier is seen as the first chassis on the left in the photo of Figure 2. Figure 3 shows the preamplifier chassis fitted with OSM connectors for testing the first four stages. By changing a gold ribbon bond, the last two stages, or the entire six stage preamplifier can be tested prior to integration with the IMPATT driver and power amplifiers. The circuit design is based on the small signal S-parameters of FETs having 0.5 µm long, electron beam defined gates. The first four stages employ 300 µm gatewidth devices while the last two use two 300 µm devices each. Simple single section λ/4 transformers and bond wire inductance are used to achieve conjugate impedance matching at the design frequency. The FETs are mounted on gold discs and located in holes drilled in the alumina substrate. Figure 4 shows the actual measured gain compression curve for the FET preamplifier. A small signal gain of 44 dB and a 1 dB gain compression point of 100 mW of output power is observed.

GaAs IMPATT Devices and Results of Reliability Testing

The low-high-low GaAs IMPATT structures are grown sequentially in one step by the As $C\ell_3$-Ga-H_2 vapor phase epitaxial process. The epitaxial layers are sulphur doped and consist of a highly doped buffer layer, a lower doped drift layer and a doping spike. To enhance the reliability of the spacecraft transmitter, all of the IMPATTs employed in the amplifier incorporate a high reliability metallization system. The front (junction side) metallization consists of 300Å Pt/2200Å TiW (90% W by weight)/1000Å Pt followed by ∿250 µm thick Au plated heat sink. Because the reaction of a Pt/GaAs interface is known to proceed fairly rapidly thereby degrading the reliability and performance of high-efficiency, Read-type, Schottky barrier GaAs IMPATTs, a thin Pt contact layer followed by a refractory barrier metal is employed.[1,2] The metallization system is serially deposited by sputtering in one pumpdown after a brief sputter etch of the GaAs surface. Au/Ge ohmic back contacts are applied to counteract possible unreliability due to current crowding and thermal runaway.

To confirm the reliability of these devices accelerated life testing was performed. The devices were subjected to three different stress conditions. These were: temperature stress, non-rf bias-temperature (BTS) stress, and rf BTS tests. Results from the temperature stress and non-rf BTS test indicate a mean-time-to-failure (MTTF) of $>10^8$ hours and 1.5×10^7 hours respectively, for a junction temperature, T_j, of 200°C. For the rf BTS tests, ten free-running oscillators having a configuration identical to that utilized for the amplifier were prepared. These units were subjected to consecutive 500-hour stress steps at heat sink temperatures of 25, 50, 75, 100 and 125°C. The most conservative analysis of the data results in a MTTF$>5 \times 10^5$ hours for T_j=200°C, the nominal junction temperature under operating conditions.

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IMPATT Driver and Power Amplifier Stages

Although it is possible to develop high power stable GaAs IMPATT amplifiers (i.e., stable under zero rf drive) using flat doping profile IMPATTs it is not practical to do so with amplifiers employing high efficiency GaAs IMPATTs with low-high-low doping profiles.[3,4,5] This is because for these diodes a large increase in negative resistance accompanies reduced rf drive levels. As a consequence, an amplifier tuned for maximum output power at a high input drive level will oscillate at reduced or zero drive levels.[6] For this reason the high efficiency GaAs IMPATTs are much more appropriate for injection locked oscillator(ILO) operation rather than for stable amplifier operation, provided the dynamic range and bandwidth requirements can be satisfied. Furthermore, this type of power saturated amplifier is suitable for transmission of digital phase modulated signals such as BPSK or QPSK and is directly applicable to the spacecraft transmitter application.[5] Other advantages of the ILO approach include higher amplifier effieiency due to higher gain per stage, a simpler and therefore more cost effective circuit design, and improved overall amplifier gain stability with respect to changes in ambient temperature; this is because the gain variation due to temperature changes is primarily affected by the temperature characteristics of the final ILO stage rather than by the cumulative gain variation of all preceeding stages. Because of the above design considerations, the ILO approach was implemented in both the IMPATT driver and balanced power stages.

The driver amplifier, seen as the middle chassis in Figure 2, consists of two IMPATT stages of circulator coupled reflection amplifiers operating in the ILO mode. Three of the five MIC fabricated circulators serve as isolators at the input and output of the driver and between the two stages. The driver stage design follows closely that used at Texas Instruments for development of similar amplifiers.[3,5] Because the locking bandwidth for a single stage ILO is nominally proportional to the square root of the input power, the critical operating point occurs at the lower drive levels. Consequently, the driver stage is designed to have an output power level of greater than 1W and yet maintain a locking bandwidth, at room temperature, of about 400 MHz at an input level of +10 dBm (-30 dBm input to preamplifier). This ensures at least a 250 MHz locking bandwidth over the entire specified operating temperature range of 0° to 50°C. At an input level of +20 dBm the driver stage has a gain of 11 dB.

The power amplifier consists of two single mesa diodes power combined via a 3 dB interdigitated microstrip coupler fabricated on 0.25 mm thick quartz substrate (seen as the rightmost chassis in Figure 2). Impedance matching circuits are fabricated on 0.25 mm alumina substrates and employ single section $\lambda/4$ transformers to transform from 50 Ω to about 3 Ω. Bonding ribbon inductance is used to resonate the diodes' capacitance. Two way circuit power combining is implemented for two reasons. First, high power multiple mesa operation is difficult to realize in a microstrip configuration at mid Ku-Band frequencies, because of the low impedance levels encountered ($<2\Omega$), and the presence of circuit parasitics which are difficult to control. Second, two way circuit power combining using single mesa diodes is potentially more reliable since a higher probability of optimum efficiency operation from both devices can be achieved. The power amplifier stage provides an output power of 4.1W at 5 dB gain with a power added efficiency (excluding bias network losses) of 15.2%. The locking bandwidth is greater than 1 GHz.

Integrated Amplifier Performance

Figure 5 shows the rf output power of the integrated amplifier over the specified frequency band of 15 GHz ± 125 MHz at three temperatures, 0°, 25°, and 50°C. The output power is seen to vary no more than 0.5 dB for any frequency within the band over the 0 to 50° range. Over the input range of -30 dBm to -20 dBm the output power varies less than 0.2 dB at 15 GHz for all three temperatures measured. No spurious signals were observed in the specified operating bandwidth within 50 dB of the carrier signal. Third order intermodulation measurements, however, revealed third order products within 8 to 10 dB of the two equal magnitude carrier signals (Δf=10 MHz) at a total output power of 4 W. This distortion is primarily due to the large signal, non-linear, operation of the IMPATT stages. The overall dc to rf efficiency including all bias circuit losses is 10.8%. The amplifier weighs 444 grams and occupies a volume of 220 cm^3.

Conclusions

The realization of the 15 GHz, 4 W, 56 dB gain microstrip amplifier using state-of-the-art GaAs FETs and IMPATT diodes demonstrates the feasibility of utilizing both devices in a single amplifier, thereby taking advantage of the unique characteristics of each. The use of high reliability, high efficiency, and high power GaAs IMPATT diodes demonstrates the development of an essentially laboratory experimental device into one that is feasible for use in an important engineering application.

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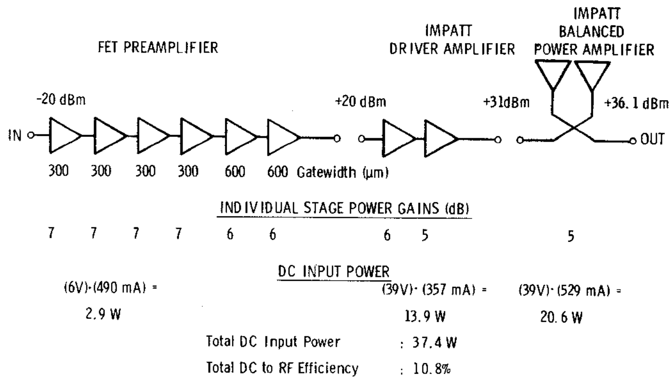

Figure 1. Block diagram of amplifier circuit.

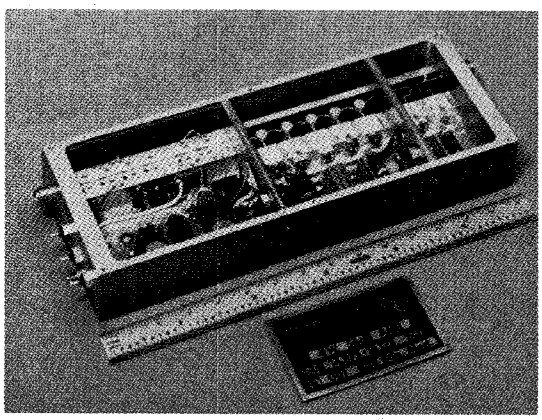

Figure 2. Integrated amplifier and housing.

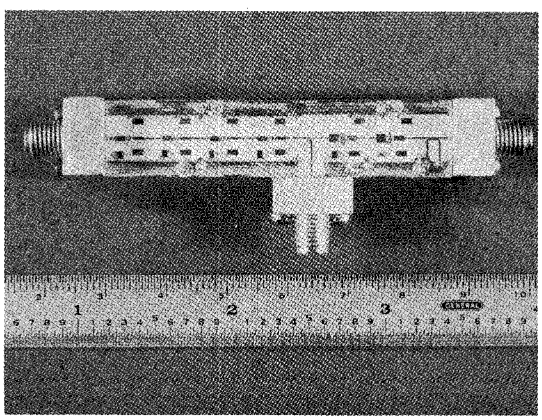

Figure 3. FET preamplifier chassis.

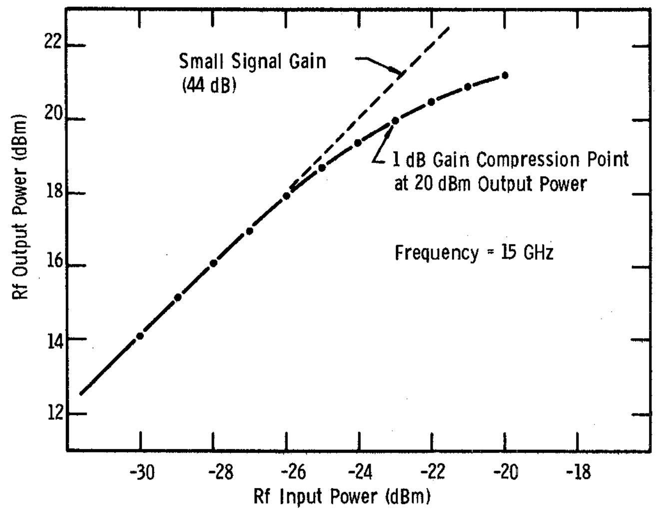

Figure 4. Gain compression curve for 15 GHz six-stage FET preamplifier.

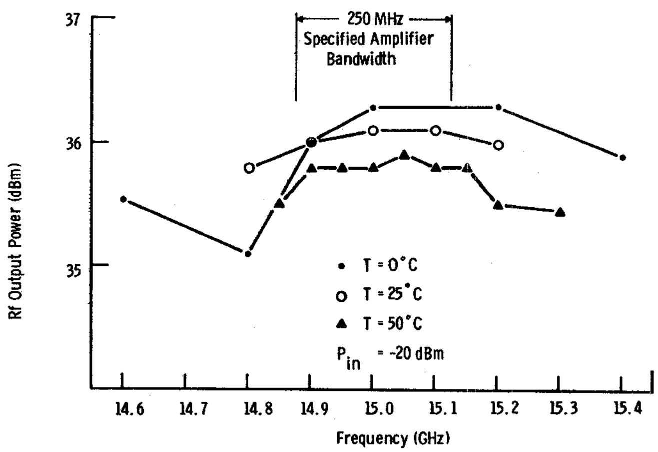

Figure 5. Output power performance over temperature for integrated amplifier.