4-W IMPATT AMPLIFIERS
FOR
6 ~ 8 GHz 1800CH FM RADIO SYSTEMS

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Abstract

A 4-W, 10 dB gain, IMPATT amplifier has been developed by utilizing two Si DDR 2.5W IMPATT diodes in two cascaded stages. This paper describes the analysis of power combining in cascade connection, the construction, the measured results, and the thermal noise evaluation method of this amplifier.

Introduction

The development of an all solid-state microwave multiplex communication equipment depends on the realization of an all solid-state transmitter power amplifier. Until now, the development of a high-power amplifier by the direct amplification of a Si bipolar transistor or GaAs FET in the 6 ~ 8 GHz frequency range has been very difficult to achieve, taking into consideration the output power and reliability requirements. At present, Si IMPATT is considered the most promising solid-state device for obtaining both high output power and high reliability. A 4-W IMPATT amplifier with 10 dB gain has been developed by utilizing two Si DDR IMPATT diodes (1ST20), with a 2.5-W oscillation output power ($\triangle Tj \leq 155^{o}C$), in two cascaded stages for use as an all solid-state power amplifier of the 1800 channel radio transmission equipment in the 6 ~ 8 GHz frequency range. This paper describes the construction, the measured input vs. output power characteristics, the thermal noise characteristics, and the AM-PM conversion coefficient of the amplifier. The paper also describes the theoretical analysis of power combining obtained by cascade connection of the amplifier and the evaluation method of thermal noise caused when an IMPATT amplifier is used as the transmitter power amplifier of an FM transmitter-receiver.

Design Considerations

Junction Temperature

Since the reliability of an IMPATT diode depends on the junction temperature (Tj) in operating condition, heat sink of the amplifier should be designed so that Tj becomes as low as possible. In designing the amplifier, we have designed that failure rate of the IMPATT is below 1000 FIT even at the maximum ambient temperature.[1] So, Tj is set to be $Tj \leq 180^{o}C$ (corresponding to 100 FIT) for a standard ambient temperature of $25^{o}C$. The oscillation output obtained when $Tj \leq 180^{o}C$ is 2.5W as show in the oscillation characteristic of Fig. 1. Therefore, the available power, consistent with reliable operation, of the 1ST20 is 2.5W.

Output Power

In designing an amplifier, it is necessary to know what kind of input vs. output power characteristics, output levels and amplitude characteristics will be obtained when a diode of a certain available power is used. This paper only describes the outline of the calculations as the detailed calculations are given in the reference.[2] Assuming a linear or parabolic relationship between the negative conductance variation and the RF voltage amplitude, applied to the diode, we can calculate the input vs. output power characteristics and the amplitude characteristics using a fundamental equation on an amplitude. The output power obtained from power combining is determined by the following equation.

$$\text{Output power} = \text{RF input power} + \text{available power of a diode} \quad (1)$$

This means that 4-W transmitting power required for 1800 channels can be obtained when an RF input power of 2W is applied to an amplifier which uses a diode with a 2-W oscillation output. However, in an IMPATT amplifier, the noise figure normally deteriorates abruptly near the maximum output power obtained from power combining as in Equation (1). So, a negative-resistance amplifier with a 4-W output and 3 dB gain has been designed by utilizing an IMPATT of a 2.5-W oscillation output power, and satisfies the required noise figure and the conditions for power combining.

Construction

The construction of this amplifier, designed for easy electrical adjustment, flexibility in gain setting, etc., is shown in Fig. 2(a). The tuning frequency of the amplifier can be varied easily by varying L. The gain of the amplifier can be varied from high gain to low gain by adjusting ℓ_1 and ℓ_2. By connecting the two amplifiers in two cascaded stages with circulators and isolators as shown in Fig. 2 (b), an amplifier of a 4-W output power can be constructed.

Results

1. Fig. 3 (a) shows the amplitude characteristics of the amplifier and Fig. 3 (b) the output vs. input power characteristics. An output power of 4W is obtained when the RF input of the final stage is 2W and the available power of the IMPATT diode is 2.5W.

2. The measured output power vs. noise figure of this amplifier is shown in Fig. 4. At an output power of 4W the noise figure is about 50 dB, which corresponds to 3.5 pWop. The noise figure of the IMPATT amplifier largely depends on the output power as shown in Fig. 4 and tends to deteriorate abruptly at higher output power, so that the due consideration should be given to the noise behavior as discussed later.

3. The result of the AM-PM conversion obtained by calculation through measurement of the DG variation is shown in Fig. 5.[3] The AM-PM conversion coefficient is about 2 ~ 3°/dB at the required input level, which is nearly equal to that of a TWT.

Thermal-noise Evaluation of IMPATT Amplifier[4]

Although the relation between the output power and noise figure of the amplifier was mentioned previously, the thermal noise evaluation should cover the entire microwave communication system. Because, the output, gain, and noise figure are correlated in the IMPATT amplifier which is used in an FM transmitter.

Let us now consider the thermal noise evaluation of an IMPATT amplifier, using a chart in which the abscissa shows the sum of the gain and noise figure of the IMPATT amplifier and the ordinate the output power of the amplifier. Assuming a system loss of 64 dB and a receiver noise figure of 4.5 dB, the contours of constant system thermal noise (sum of thermal noise of a receiver and that of an IMPATT amplifier) are shown in Fig. 6 by a solid line. The measured values of the output power vs. gain plus noise figure of the IMPATT amplifier are plotted by a thick line on the evaluation chart Fig. 6. If the measured value of the output power vs. gain plus noise figure is above the solid line, the thermal noise requirement of the microwave communication system is satisfied.

The optimum operating point can be easily found using the evaluation chart and the operating margin against thermal noise can be easily estimated. The output power of 4W (Pin = +26 dBm), and 3.5 pWop in thermal noise as shown in Fig. 6 are sufficient requirement for an amplifier which is to be used for the transmission of 1800 channels.

It is worthy to be noted that in an IMPATT amplifier the thermal noise deteriorates when the output power is increased by raising the input power level, and therefore an optimum operating point exists.

Conclusion

A 4-W IMPATT amplifier with a 10 dB gain has been developed using two Si DDR IMPATT diodes (1ST20) each having a 2.5-W oscillation output ($\Delta T_j \leq 155^{\circ}C$) in two cascaded stages. This amplifier has been shown to have satisfactory performance characteristics for a 6 ~ 8 GHz 1800-channel transmitter power amplifier. The use of this amplifier has facilitated the introduction of a high-reliability transmitter-receiver for the transmission of 1800 channels in the 6 ~ 8 GHz range. This evaluation chart is used for the thermal noise evaluation of IMPATT amplifiers in the communication system.

Acknowledgment

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References

1. H. NAGAO et al, "High-Power 6 ~ 30 GHz Si DDR IMPATT Diode," IECE, Japan, ED75 - 74, 1976.

2. T. HAYASAKA et al, "A Study of Injection-Locking and Negative-Resistance Amplifiers," NEC R&D, No. 40, January, 1976.

3. IEC, 12E (Central Office) 40, "METHODS OF MEASUREMENT FOR EQUIPMENT USED IN TERRESTRIAL RADIO-RELAY SYSTEMS."

4. J.W. GEWARTOWSKI et al, "A 1-Watt, 6-Gigahertz IMPATT Amplifier for Short-Haul Radio Applications." The Bell System Technical Journal, Vol. 54, No. 4, April, 1975.

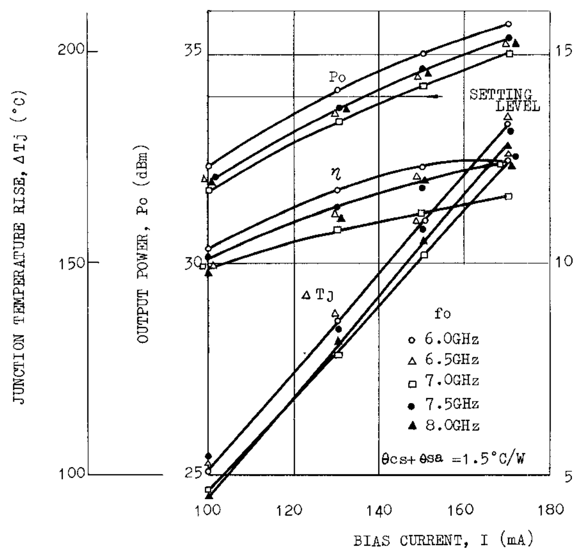

Fig. 1 Oscillation Output Power Characteristics of Si DDR IMPATT, 1ST20

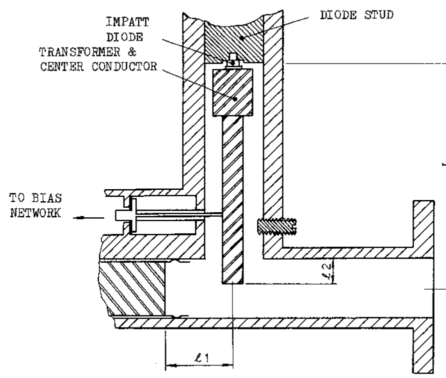

Fig. 2 (a) Cross-sectional View of Amplifier Circuit

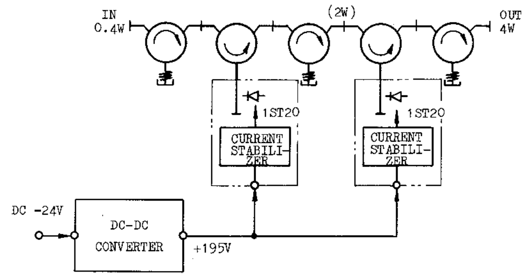

Fig. 2 (b) Block Diagram of 4W IMPATT Amplifier

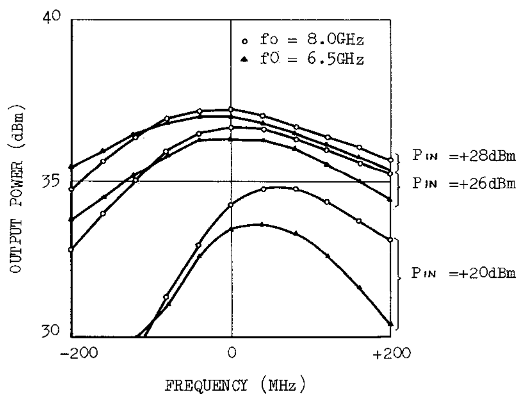

Fig. 3 (a) Output Characteristics of 4W IMPATT Amplifier (Amplitude Characteristics)

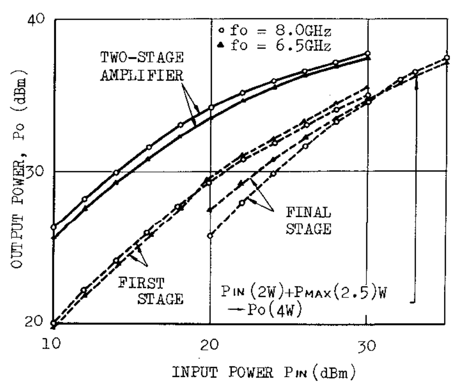

Fig. 3 (b) Output Characteristics of 4W IMPATT Amplifier (Output vs. Input Power)

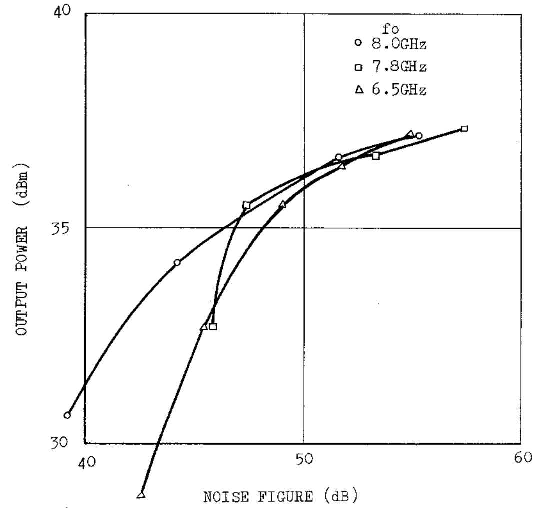

Fig. 4 Output Power vs. Noise Figure Characteristics of 4W Amplifier

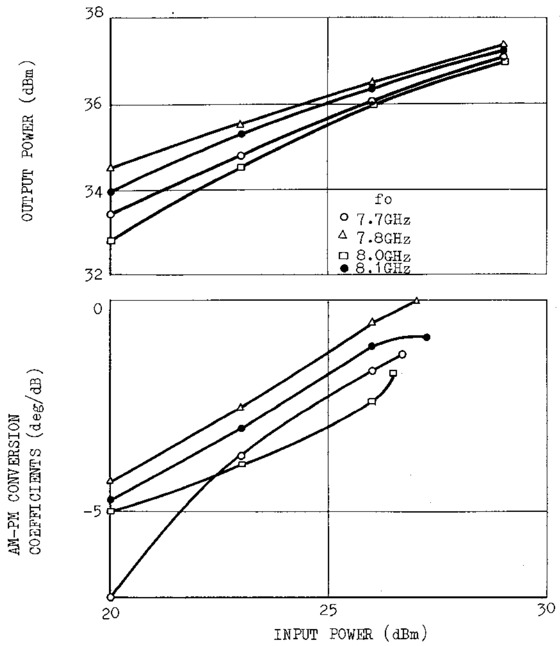

Fig. 5 AM-PM Conversion Coefficients of 4W IMPATT Amplifier (measured by dynamic method)

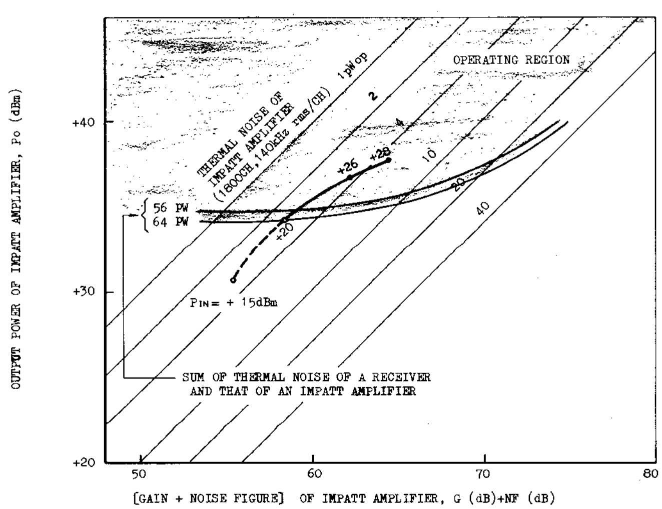

Fig. 6 Evaluation Chart (in the case of 8GHz, 1800CH)