A 1.5 WATT 9 GHz SILICON TRANSISTOR POWER AMPLIFIER

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ABSTRACT

A 9 GHz power amplifier using the newly developed 2 watt X-band silicon power transistor is reported. The amplifier has 1.5 watts saturated output power at 9.0 GHz. The power gain at saturation is 5 dB with 1 dB bandwidth exceeding 600 MHz.

Introduction

Solid-state power amplifiers which are capable of operating in X-band have been the subject of intensive development for some time. To make the power amplifier suitable for system application, it must have adequate output power in the order of 1 to 5 watts. The amplifier is also required to have high efficiency and adequate power gain. And finally, the amplifier should have the potential of being manufactured in large quantities at reasonable cost. Silicon power transistors were not contenders for such applications until recently. Their potential has become revitalized because of technological advancement. This paper reports the performance of a 9 GHz power amplifier designed using one of the new generation of microwave silicon power transistors.

Transistor Model

The difficulties of designing a transistor power amplifier operating in common base class-C mode were reviewed by several previous authors.[1,2] Namely, the role of impedance matching under such circumstance is not just limited to maximizing the gain and bandwidth. The saturated output power and collector efficiency of the transistor depend upon the proper impedance matching also. Since the latter two considerations are nonlinear in nature, transistor models based on single frequency are not sufficient for designing a power amplifier. But to include the harmonic components makes the task of transistor modeling prohibitively difficult. Experimental procedure which can be used to determine transistor impedances at lower frequencies is also difficult at frequencies as high as X-band. Therefore, the circuit design must rely on some simple transistor model which is obtained mostly by empirical knowledge.

The power transistor used in this amplifier, designated as ML-500, was reported recently.[3] It is a transistor fabricated by electron beam direct slice writing and ion implantation. Figure 1 shows a photomicrograph of ML-500. The transistor has a bar size of 0.5 x 1 mm^2. It consists of four 27.5 x 75 μm^2 active cells. The measured f_t and f_{max} of the transistor are 8 GHz and 30 GHz, respectively. To establish a simple device model for preliminary circuit design, the transistor is represented by a single resistance at the input and a parallel combination of resistance and capacitance at the output. The simple device model is shown in Figure 2. The value of the input resistance was chosen to be the same as the series base resistance of the transistor. This is normally valid if the transistor operates close to f_t and under saturated output power conditions. The value of the output capacitance is simply the total collector base capacitance including the contribution from bonding pads and package. The value of the output resistance is more difficult to determine. It depends upon collector saturation voltage, saturation current and the collector bias voltage. However, the value can be determined to within a factor of two by carefully analyzing the transistor physical structures.

Circuit Design

With the knowledge of approximate input and output impedance of the ML-500 transistor, the task of designing the impedance matching circuits can proceed in a straightforward manner. Low pass filter type of matching networks were used in both input and output. Because of the extremely low input resistance of the transistor, two section matching was used for the input. However, for the output, a single section was thought to be sufficient. The calculated values of the components required for matching networks are included in Figure 2 also. The real matching circuits were implemented by using the bonding wires for the inductances. Large value capacitance was provided by a specially fabricated silicon MOS capacitor while the small value capacitance was generated as an integral part of the input and output microstrip circuits. Figure 3 is an enlarged picture of the matching circuits in the vicinity of the ML-500 transistor.

The performance of the 9 GHz amplifier is shown in Figure 4. The data were obtained after some fine tuning made by gold foils on the microstrip circuits. The fine tuning was centered at 9 GHz to make the input reflection better than -20 dB and to maximize the output power into 50 ohms load. After the tuning, the output power was measured from 8.5 GHz to 9.5 GHz with fixed 0.5 watt input drive. Under such conditions, the output power declined at both higher and lower frequencies. At lower frequency, the power decline was caused by increasing collector current which presumably resulted in higher junction temperature. At higher frequency, the decline simply followed the gain decline of the transistor.

Conclusion

The advancement of microwave silicon power transistors was demonstrated by using one of the new generation transistors in a power amplifier design. The amplifier has 1.5 watt saturated output power at 9 GHz with 5 dB gain and better than 600 MHz, 1 dB bandwidth.

Acknowledgements

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References

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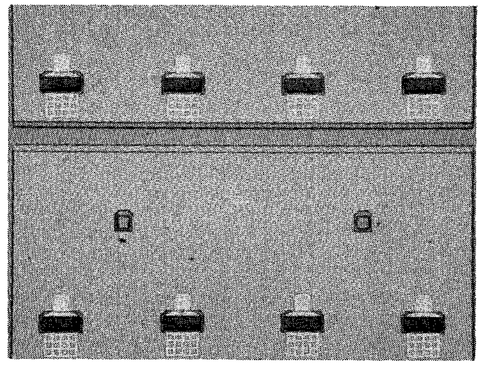

Figure 1. A photomicrograph of ML-500 silicon power transistor.

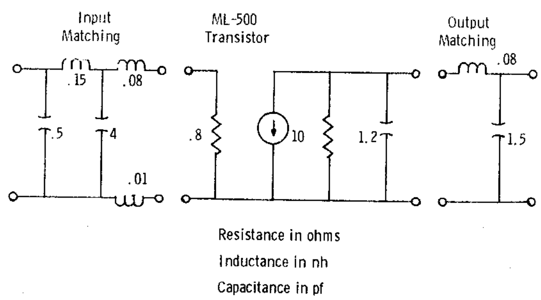

Figure 2. The simple device model and the scheme for input and output impedance matching.

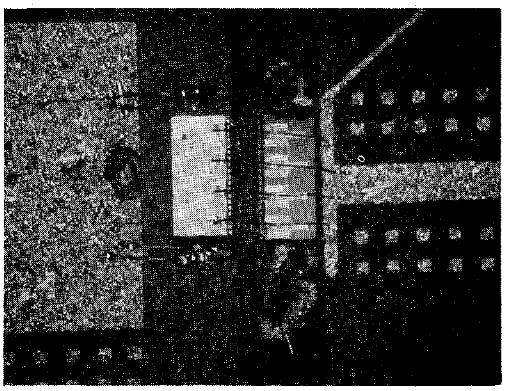

Figure 3. An enlarged picture of the amplifier near the transistor.

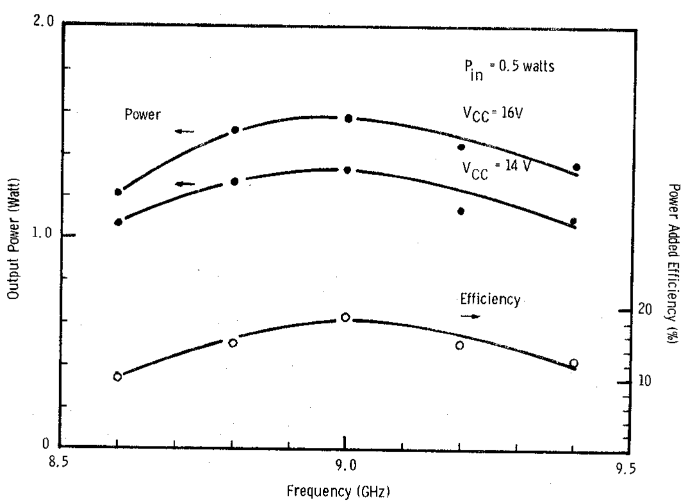

Figure 4. The performance of the power amplifier.