MICROWAVE GaAs POWER FET AMPLIFIERS WITH LUMPED-ELEMENT IMPEDANCE MATCHING NETWORKS*

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ABSTRACT

Lumped-element impedance matching has been used successfully for the design of GaAs power FET amplifiers at C- and X bands. It is shown that output powers up to 8W with 1 dB bandwidth of from 1 to 5 GHz can be obtained.

Introduction

Single and multicell FET devices with 1 μm gate lengths(1) (up to a total gate width of 6400 μm) with "internal matching networks" have been used for the design of broadband amplifiers at C- and X bands. There are several reasons for investigating the "internal matching" approach for the FET amplifiers: (1) to reduce the size of the amplifiers (both single and multiple stages) for miniaturization, (2) to study the feasibility of fabricating lumped LC elements on the semi-insulating GaAs substrates for eventual monolithic integration of the amplifiers, and (3) to pursue the "impedance matching on the chip" technique for combining more cells at the chip level while still maintaining a manageable impedance level for matching to the 50 Ω source and load.

Circuit Development and Microwave Performance

Circuit Topology

Figure 1 shows the circuit topology using lumped elements for impedance matching. Depending on the cell size and the desired frequency range of operation, the value of the input shunt capacitance can range from 0.6 to 1.2 pF. The inductances are on the order of 0.3 to 1.5 nH and can be realized with bonding wire inductances. Silicon MOS capacitors are used for impedance matching and rf bypass. For larger unit cell sizes (>1200 μm), the output lumped-element matching circuit can be of the same topology as that of the input, i.e., series L-shunt C-series L type. With increased unit cell sizes, it was found to be easier to use a shunt capacitance for impedance matching at the output because of smaller drain output resistance and larger drain output capacitance. Using simple Smith chart design techniques, bandwidths on the order of 2 to 5 GHz and output powers up to 3 W were achieved at C and X bands. With further computer optimization, even wider operating bandwidths are expected. Microwave performance of some of the "internally matched" amplifiers is summarized below.

Single-Stage Amplifier

With no input/output tuning required (in a 50 Ω system), a band-width of 5 GHz (7 to 12 GHz) can be obtained with gains in excess of 5 dB for a 300 μm gate width FET. When optimized for a narrower band-width (9 to 10 GHz), an output power of 182 mW with 6.6 dB gain and 32.3% power-added efficiency can be achieved at 9.5 GHz. The linear gain is 9.3 dB.

A single-cell device with 1200 μm gatewidth was also used in a single-stage amplifier with internal matching. A gain of 5.5 ± 0.5 dB was obtained from 7 to 10.2 GHz with an rf input of 22 dBm. A power-added efficiency of ∿26% at an output power of ∿630 mW and 6 dB gain was achieved at 9.6 GHz; the linear gain was 7.2 dB.

The microwave performance results of single-stage amplifiers using four-cell (4800 μm-6400 μm gate width) FETs are summarized in Figure 2. It is seen that output powers on the order of 2 to 3 watts with 5 to 6 dB gain can be achieved with a 1 dB band-width of ∿2 GHz over the 7 to 10 GHz frequency range. Power-added efficiencies generally fall into the range of 20-30%.

Single-Stage Amplifiers with Power Combining

To achieve output powers in excess of 4 watts, circuit level power combining can be used. For this purpose, a 3 dB 90° microstrip hybrid of the Lange type was used. Figure 3 shows the results with 2-way and 4-way power combining. Output powers of up to 5 watts with bandwidth of 1 to 2 GHz were achieved with 2-way power combining. Output power as high as 8 watts was achieved at 7.3 GHz with 4 dB gain and 20% power-added efficiency using a four-way combiner. With further reduction in the combiner loss and expected device improvements output power in the range of 10 to 15 watts can be expected at X band with 4-way power combining.

Multistage Amplifiers

With a power amplifier as the output stage, high-power, high gain multistage amplifiers were demonstrated. Figure 4 shows the gain-output power-frequency response of some of these amplifiers. For amplifiers with output powers in excess of 4 watts, a balanced output stage was used. The design and performance of the driver amplifiers with ∿1.5W output were reported in Reference 2. Figure 5 shows a four-stage GaAs power FET amplifier module with a balanced output stage. Both the driver and the output stages were characterized prior to cascading in the amplifier housing. Output powers of 4∿5 watts were obtained with ∿25 dB gain with the amplifier module shown in Figure 5.

Lumped-Element Subminiature GaAs FET Amplifier

A subminiature two-stage GaAs FET amplifier using lumped element matching networks has also been demonstrated. Figure 6 shows the gain-frequency response

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of this two-stage amplifier. The inset in Figure 6 shows a simplified schematic diagram of this two-stage amplifier. A gain of 13.5 dB with 355 mW output was achieved at 9.7 GHz, with a 3 dB bandwidth of 2.5 GHz (8.4 to 10.9 GHz). The linear gain is 14.5 dB. With a slight adjustment of the dc bias, a linear gain of 15 dB with 22 dBm output has been obtained. Figure 7 shows a photograph of the two-stage FET amplifier. The amplifier is only 0.254 cm (0.100 inch) long, excluding the input/output 50 Ω lines. No external tuning is required, since the input and output are already matched to the 50 Ω source and load. In this amplifier a 300 μm and a 1200 μm FET were used in the first and the second stages, respectively. The same approach can be used for cascading FET stages with larger gate-width devices to achieve higher powers and gains.

Conclusions

It is shown that GaAs power FET amplifiers can be designed using lumped element impedance matching at C and X bands. Output powers of these amplifiers range from a few hundred mW to 3W with 1 dB bandwidth from 1 to 5 GHz. With circuit-level power combining output power as high as 8 watts was achieved. The experimental results presented in this paper indicated that it is also feasible to fabricate lumped-element GaAs power FET amplifiers with subminiature dimensions and will eventually lead to the development of monolithic GaAs power FET amplifiers for microwave system applications.

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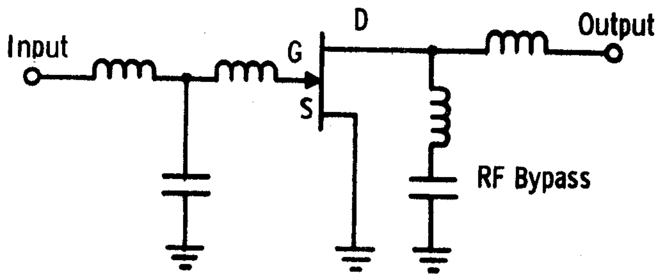

Figure 1. Lumped-Element Impedance Matching Network for GaAs FET Amplifier

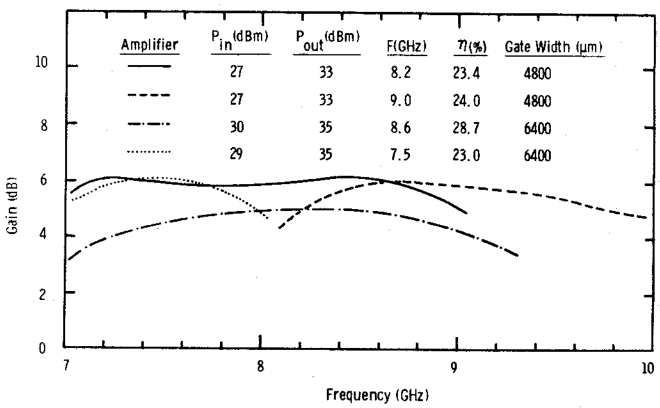

Figure 2. Single-Stage GaAs FET Amplifier Performance

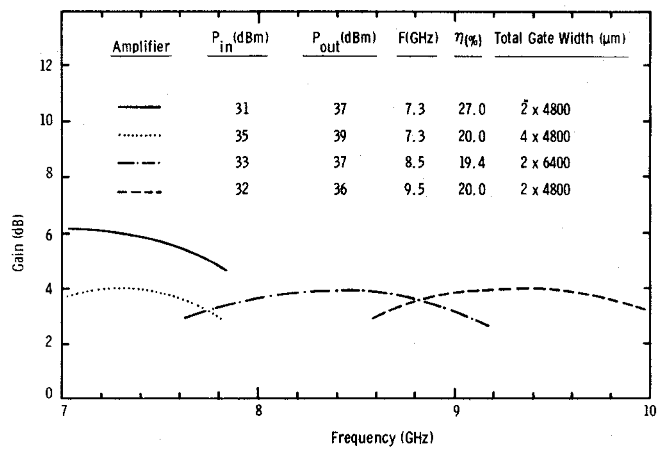

Figure 3. Performance of Single-Stage GaAs FET Amplifiers with 2-Way and 4-Way Power Combining

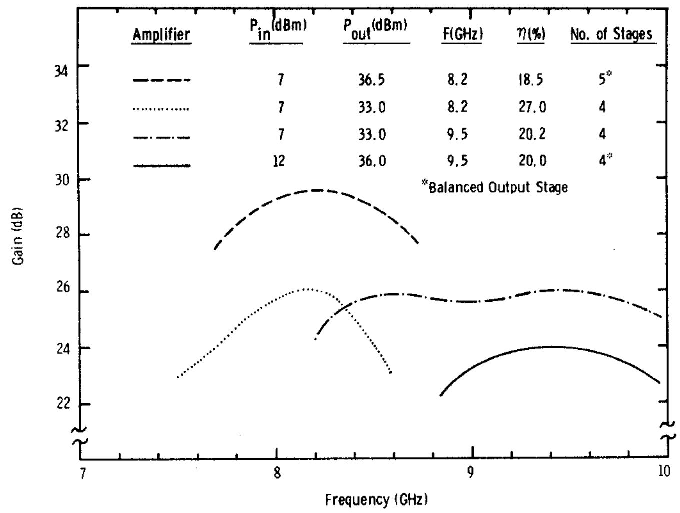

Figure 4. Performance of Multistage GaAs FET Amplifier

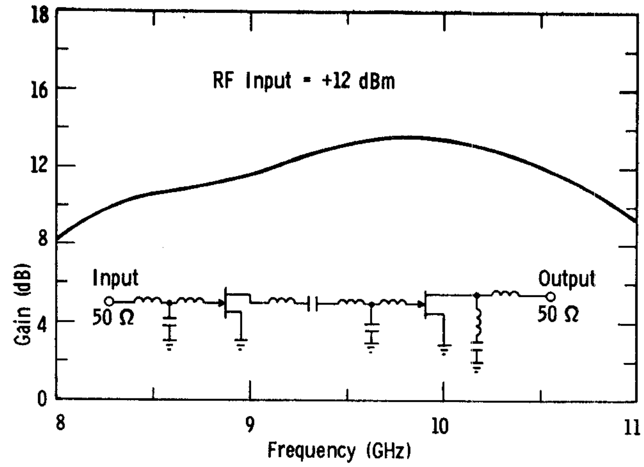

Figure 6. Gain-Frequency Response of a Two-Stage GaAs FET Amplifier Using Lumped-Element Matching Networks

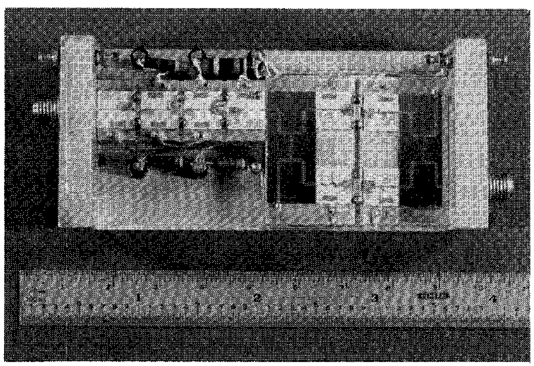

Figure 5. A High Power GaAs FET Amplifier Module

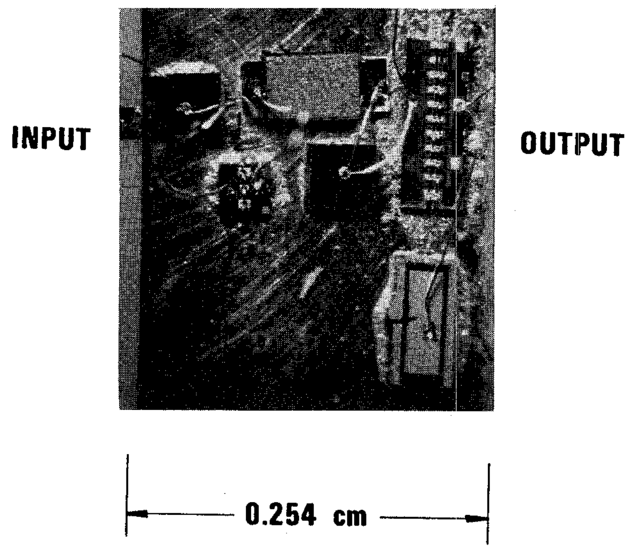

Figure 7. Two-Stage GaAs FET Amplifier with Lumped-Element Impedance Matching Networks