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DESIGN AND FABRICATION TECHNIQUES FOR LUMPED-ELEMENT GaAs MESFET POWER AMPLIFIERS USING AUTOMATED ASSEMBLY PROCEDURES

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Abstract

This paper describes the development and fabrication of lumped-element GaAs MESFET power amplifiers. The amplifiers manufactured were designed for both narrow-band and wideband (6-11 GHz) operation. Emphasis is directed toward performance trimming and automated assembly.

Introduction

The state-of-the-art has now reached a stage where fabrication of lumped-element amplifiers can be carried out using automated assembly equipment by personnel without the special skills of a design group. Techniques for the development of single-chip and dual-chip GaAs MESFET amplifiers have been demonstrated using an on-carrier lumped-element construction technique in which the periphery of the package serves as the surface for mounting matching elements.[1] In addition, the use of lumped-matching components lends itself nicely to automated assembly.

We have recently constructed and tested wideband (6-11 GHz) GaAs MESFET power amplifiers using an automatic wire bonder to realize the inductor elements. With the use of a computer program, the task of trimming performance was reduced to a simple "add a parallel wire-connect a pad" decision process where very little microwave experience is required. Over twenty amplifiers were constructed with each unit exceeding our minimum performance goals of:

Frequency: 6-11 GHz	Power Gain: 3 dB
Output Power: 27.8 dBm	Efficiency: 10%

Bond-wire inductance was evaluated in a test fixture that closely matched the amplifier configuration. Design curves for estimating bond-wire inductance were generated.[2] The S-parameters of 30 GaAs MESFETs were reduced to a standard set of parameters on which the circuit design was based. Before assembly begins the individual circuit elements are adjusted to accommodate the selected device. In this manner each amplifier is partially optimized before rf testing begins.

Design

The circuit transformation network must be capable of matching the upper-band-edge frequency to the 50 ohm system impedance. Secondly, provisions for introducing bias voltages must be addressed. A number of circuit configurations are suitable for this task, however, the realization will be difficult for some. We used the low-pass circuit shown in Figure 1 because it meets a number of requirements for our program; namely, 1) bias can be applied through circuit elements, 2) wire bonds make up the tuning elements, 3) a wire bonder can be programmed to fabricate the inductor elements, and 4) the circuit will match the upper band edge frequencies to 50 ohms.

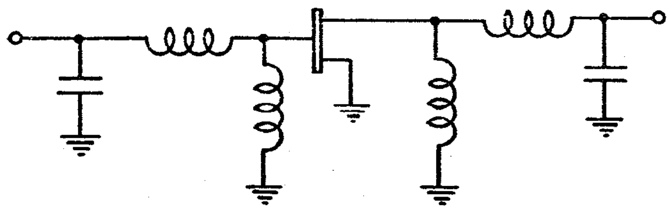

Figure 1. Low-Pass Circuit.

The devices used in this study are MSC 88104, 2400 μm gate width design. The transistor package of this device offers substantial real estate in which to attach lumped-element components. Utilizing this space we construct the complete matching network for both gate and drain elements.

The S-parameters were tabulated and ordered to yield a standard FET on which the design was based. In Figure 2 we show the standard FET data. The associated statistical data for the frequency end points are listed in Table 1. The relative variation measure allows the comparison of the standard deviation of both magnitude and phase angle.

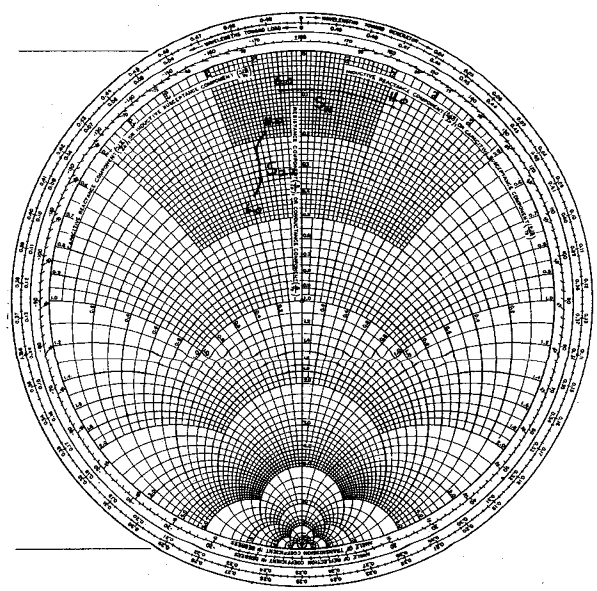

Figure 2. Standard FET Data.

Table 1

Statistical Data from Measured S-Parameters

6 GHz	Variance (σ)	Standard Deviation (σ)	Mean	Mean Deviation	Coeficient of Variation
S_{11} mag	.0003	.0175	.8403	.014	2.0%
S_{11} ang	5.8	2.4	-177 0	2.07	1.4%
S_{22} mag	0.0001	0.0111	.4662	0.009	2.4%
S_{22} ang	21.1	4.59	-155 5	3.9	3.0%
11 GHz					
S_{11} mag	0.0009	0.0308	.8628	0.027	3.6%
S_{11} ang	9.7	3.11	159.2	2.6	2.0%
S_{22} mag	0.0004	0.0199	.6728	0.015	3.0%
S_{22} ang	23.1	4.8	-165.6	3.9	3.0%

The range of inductor values needed to match all the devices are 0.093 nH for S_{11} and 0.1086 for S_{22}. The wire length changes required are 6 mils and 4.8 mils, respectively.

We employed porcelain-type capacitors because they meet the small size requirements necessary for the program. Additionally, these capacitors have a very high Q which is helpful in increasing the efficiency of high-current, low-impedance power amplifiers.

Circuit Simulation

Synthesis of the circuit was made by modeling the known component values into a computer program such as COMPACT. A sensitivity analysis was then performed with each component varied around its design value while listing gain prediction. The tests showed a tight allowable range into which both capacitors must fall for proper circuit performance. The capacitor value used in the actual circuit must be measured before assembly, since changing these components is not practical.

Wire Inductance

The inductance of a very short length of wire is extremely difficult to measure and is also greatly influenced by its environment. We found it was better to measure it in a fixture that matches, as closely as possible, the geometry of the actual amplifier in order to account for the high stray parasitic inductance and capacitances. A test fixture connected to a bypass capacitor that is the same as that used in the circuit was constructed utilizing a 50 ohm microstrip line of the same length as that used on the actual amplifier carrier and terminated by the inductor under test. Since the structure is very much like the amplifier, the inductance values should be near the actual inductor with its parasitics.

Our tests were in agreement with the well-known equations found in the literature.[2] Our tests showed there is virtually no operational differences between parallel straight and looped wires.

Twenty amplifiers were fabricated during the course of this program and each module performed above our minimum of 3 dB power gain at 25 dBm input.

Inspections

Microwave fabrication requires that tight assembly schedules be maintained. We found that the two most important inspections are of incoming devices and capacitors. The GaAs MESFETs undergo the most intense acceptance testing because of the many parameters inherent in its design. A visual inspection is used to confirm both proper chip placement and correct alignment of standoffs. DC characterization is performed with special emphasis on gate reverse breakdown and I_{DSS}. Small-signal rf testing is performed on every FET used in the program.

Capacitors are visually inspected for proper size and quality of the thin-film metallization. Poor metallization will cause weak wire bonds.

Amplifier Optimization

To learn more about the problems of computer optimization, we developed a simple computer program to analyze our circuit and suggest corrective measures to restore performance. The operator enters either S_{11} or S_{22} into the computer where the program will, be de-embedding sections of the circuit, recompute the design. A comparison is made of the measured capacitance and inductance to the design values using the original device S-parameters. From this information, a course of action is chosen that will improve the module performance. Three options are available: 1) should a wire be greatly oversized, replacement is the only alternative, 2) within the range of inductance that can be adjusted by a parallel wire, this will be printed out, and 3) if the capacitor is at fault because of too low a value, the connection of tuning pads on the 50 ohm line will be suggested. The amplifier module is remeasured after the changes have been made and the program is again used to evaluate performance. When further improvement is no longer feasible, "no tuning needed" is printed out.

Bonding

The automatic wire bonding process used in this study combines both thermocompression and ultrasonic energy in what is called thermosonic bonding. Initially, a ball bond is formed at the first programmed wire position, with an optional fine position adjustment by the operator. The second programmed connection is a wedge bond. The wire is "cut" at the weakened section of the wedge by the machine as it pulls on the wire, creating a so-called tailless bond. This automatic system allows an unassisted wire-bonding operation. With the automatic wire bonder, we were able to precisely control the looping and the programmed wire lengths of both the input and output wire inductors to custom-tune each transistor.

Performance

In Figure 3, we show the power function and power conversion efficiency of a typical amplifier at 11 GHz--the upper band edge. Figure 4 is a photograph of the lumped-element stage. In Figure 5 we summarize the performance across the band of two typical amplifiers. The differences in gain are due to the I_{DSS} capability of the two MESFETs. The amplifiers will be combined through couplers to form high-power amplifier units.

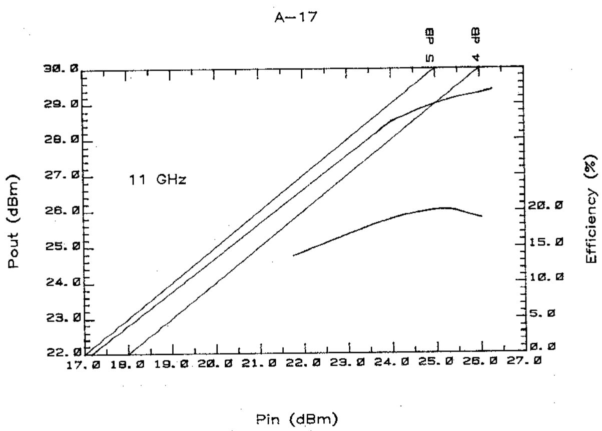

Figure 3. Power Function and Efficiency.

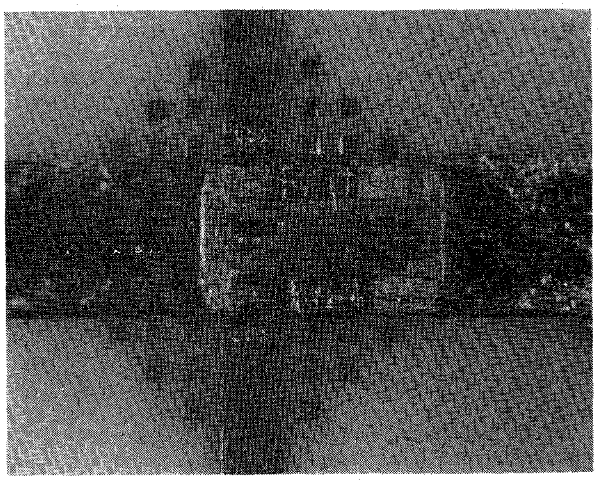

Figure 4. Photograph of Amplifier.

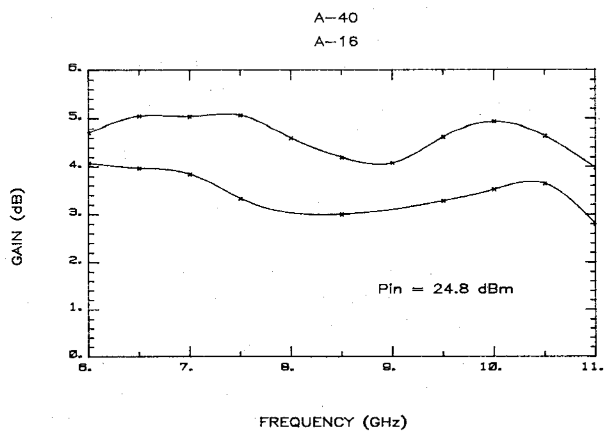

Figure 5. Amplifier Performance.

Conclusion

We have shown the feasibility of using wire bonds as inductors in a lumped-element power amplifier configuration. With wire bonding and automatic wire bonder construction, time is greatly reduced, and inductor-to-inductor uniformity is maintained.

Techniques for trimming amplifier performance were developed and implemented with CAD and manual procedures. This very important trimming operation is greatly reduced and, in many amplifiers, eliminated altogether.

References

1. R.L. Camisa, J.B. Klatskin, and A. Mikelsons, "Broadband Lumped-Element GaAs FET Power Amplifiers," IEEE MTT-S International Microwave Symp. Digest, Los Angeles, CA, June '81.

2. F.E. Terman, Radio Engineer's Handbook, McGraw-Hill Publishing Co., New York, NY, 1943.