A 1 Watt, 3.2 VDC, High Efficiency Distributed Power PHEMT Amplifier Fabricated Using LTCC Technology

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Abstract **— A 1 watt distributed PHEMT amplifier, that operates from 800 MHz to 2.1 GHz, with a 3.2 Volt DC supply has been developed using a novel new approach. The amplifier was designed to provide high efficiency operation, targeted for broadband wireless applications. Key to the amplifier's performance, is a novel broadband impedance matching transformer, fabricated using LTCC technology as well as a low loss tapered drain network. The class B design has 50 Ω terminal impedances and built-in bias decoupling.**

I. INTRODUCTION

Distributed amplifiers and mixers have been used extensively for many years in a variety of broadband system applications such as microwave EW receivers, wide band transmitter exciters and low noise oscilloscope preamplifiers [1-3]. By using a new synthesis method [4], distributed amplifiers have been designed to demonstrate high efficiency and high power output performance. This new synthesis method still relies on the use of artificial transmission line structures to form the amplifier's input and output networks, which absorb the parasitic capacitances of each active device in the chain; but, the new load targets vastly improve performance.

For handset cellular applications, 3.2 Volt DC supply is generally used in the phone. This means that for a distributed amplifier used in such applications, the load impedance presented to the amplifier must be fairly low, e.g. 3.3 Ω in order to obtain 1 Watt of output power. In this paper, a distributed amplifier using 3.2 Volt DC supply and a broadband impedance transformer that transforms 3.3 Ω to 50 Ω, with a bandwidth of 800 MHz to 2.1 GHz, is described.

II. CIRCUIT DESIGN

The bandwidth of a single-ended amplifier is limited by device and circuit parasitics. In addition, the ability to realize broadband high order matching networks is also difficult. An alternative approach to tuning out the parasitic reactances, associated with real devices, is to imbed these devices in artificial transmission line structures, yielding a frequency response beyond that of the discrete bandwidth optimized amplifier circuit.

The synthesis method for developing a high efficiency distributed power amplifier has been outlined in [4]. In this section we will describe the main features of this method. The normal constraints used in designing power distributed amplifiers still apply, such as equalizing the phase shift between the input and output transmission line sections, as well as amplitude matching the drive signal at the input of each device. In addition, gate- and drain-line terminations must be provided to enhance gain flatness, and are also used to improve amplifier stability. A typical n-cell distributed amplifier is shown in Figure 1. Unlike an ideal transmission line, with characteristic impedance terminations, a distributed amplifier will have a "virtual impedance" as a result of the injected signals at each device output node.

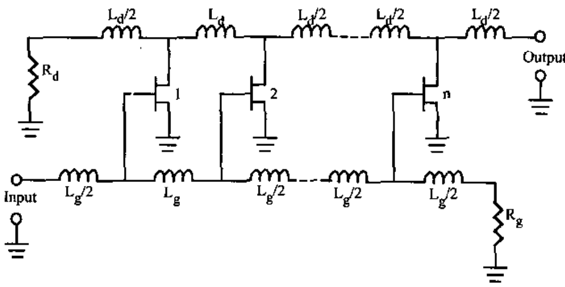

Figure 1 Classic distributed amplifier topology.

For the example shown in Figure 1, each of the current sources are designed for a load impedance of R_L (Ohms). Thus, the output network of Figure 1, neglecting the termination, then becomes the circuit shown in Figure 2. Here, the objective is operate each of the devices with identical conditions, including the load impedance, (shown as R_L in Figure 2); hence, this implies that the last section of transmission line must be designed with a characteristic impedance of $R_L/3$. Similarly, the adjacent node to the left has a virtual impedance of R_L, with a branch impedance of $R_L/2$. By tapering the drain or output line characteristic impedance in this manner, the optimum load for either power output, efficiency, or a combination of the two impedances can be obtained.

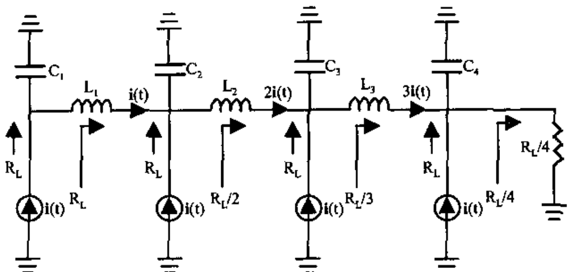

Figure 2 Current combining for a four-cell distributed amplifier.

LTCC (low temperature co-fired ceramic) technology is an excellent choice for fabricating high power amplifiers because it provides high circuit density integration, low RF loss and good thermal dissipation. Discrete semiconductor devices can also be placed directly on top of the 400 μm diameter thermal vias, which are filled with silver. These thermal vias provide good heat dissipation, which is very critical for a power amplifier modules.

III. PHEMT Distributed PA Design

Based on these concepts, a high efficiency, 31 dBm output power distributed amplifier for wireless applications with 3.2 VDC supply was developed. The five-cell design, shown in Figure 3, was realized using an LTCC technology circuit substrate and discrete PHEMT (2.1 mm gate periphery) devices (Figure 4). As with most power distributed amplifier, series gate capacitors were employed to equalize the RF drive signal on each gate, while series gate resistors were used to improve stability. The small signal gain performance for the amplifier is shown in Figure 5.

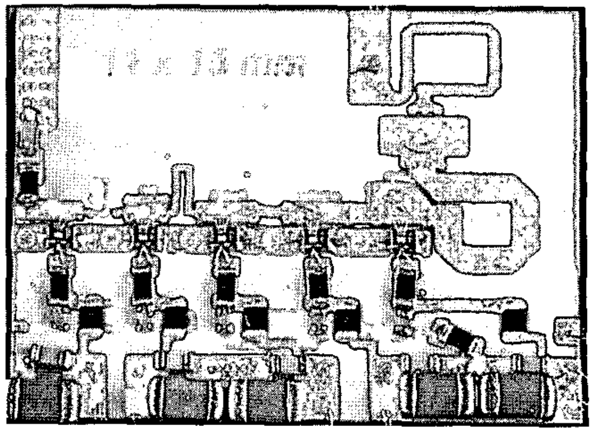

Figure 4 LTCC PHEMT Distributed Power Amplifier.

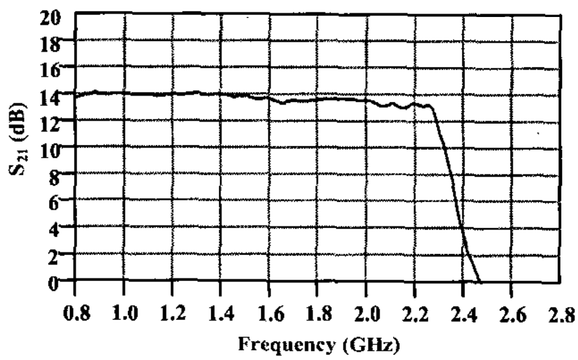

Figure 5 Amplifier Small Signal Gain.

The amplifier employs five 2.1 mm gate periphery devices operated in class B with a 3.2 VDC drain supply. The device size and supply voltage were chosen so that the amplifier output impedance would be about 3.3 Ω and the output power level would be greater than 1 Watt at saturation. The large signal performance of the amplifier

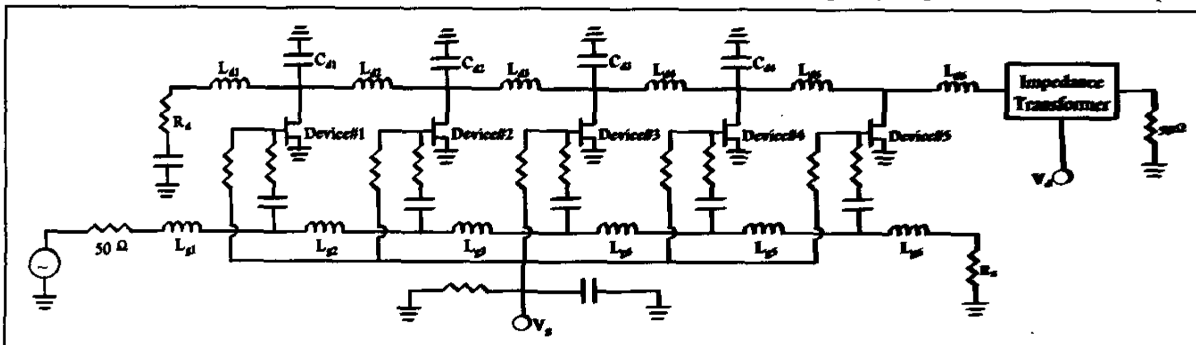

Figure 3 Five Cell Distributed Amplifier Schematic.

is shown in Figure 6. As can be seen, the measured output power and efficiency performance is excellent. The dimensions of the power amplifier, which was constructed with Dupont 951 50 μm and 100 μm tapes, are 11 mm x 15 mm.

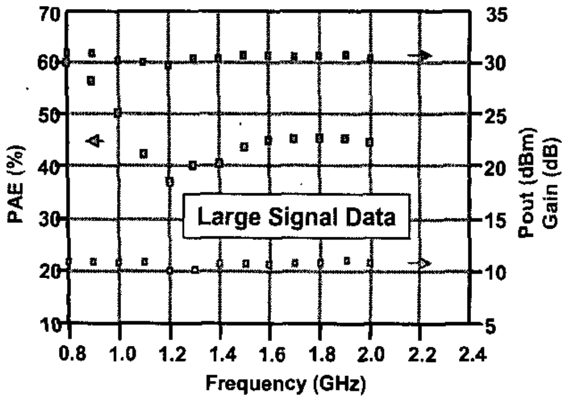

Figure 6 Large-Signal Measured Performance.

The power amplifier described in the last section, required a broadband impedance transformer to transform the 3.3 Ω load impedance to 50 Ω, throughout the band of interest from 800 MHz to 2.1 GHz. The transformer incorporates two 4:1 coupled-coil impedance transformers in series with additional matching elements. The transformer, shown in Figure 7, was realized using LTCC technology. The performance of the transformer, after EM optimization, is shown in Figure 8. The optimization was accomplished using space-mapping techniques with the aid of ADS 2002 and Sonnet EM 8.0 [5,6]. Without EM optimization adequate transformer performance would not be possible, since no simple circuit model exists for the LTCC elements.

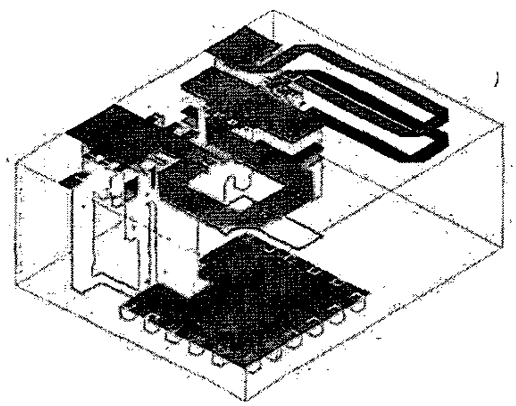

Figure 7a Layer Configuration for LTCC Multi-Section Transformer.

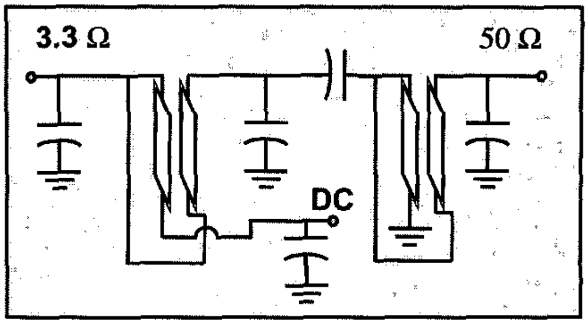

Figure 7b LTCC Multi-Section Transformer Schematic.

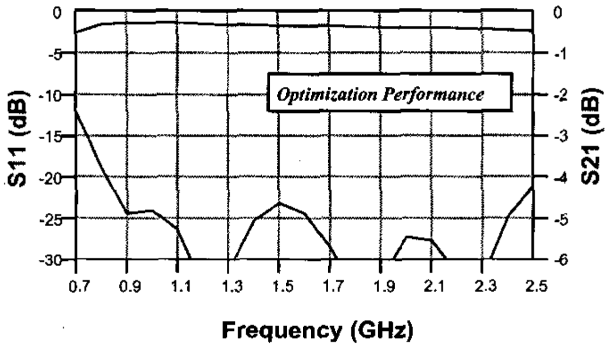

Figure 8 EM-Optimized Transformer Performance.

Constructing power amplifier modules, using an LTCC implementation, allows for the integration of most passive components, formation of thermal heat vias beneath the active devices, and the realization of very low loss transmission lines. The thermal vias exhibit a temperature rise of less than 5° C between the active device and the heatsink since they are solid silver and are larger than the active die area. It should also be noted that the loss in the drain-line structure was measured to be less than 0.5 dB at 2 GHz.

As with any distributed power amplifier, series gate capacitors were employed to equalize the RF drive signal on each gate, while series gate resistors were employed to improve stability. The DC supply to each device is supplied through the drain transmission line. The bias is applied at the hot plate of the bypass capacitor, which is at the base of the first transformer section. This 240 pF capacitor, was fully integrated and was constructed using a dielectric ε_r = 90 paste, (Heraes, Inc.) with a paste thickness of approximately 25 μm.

IV. CONCLUSION

The above designs illustrate the dramatic improvement that can be obtained in power-added efficiency, when the drain transmission line is properly impedance tapered, and the devices are selected for the correct load impedance. This was made possible, because of the low loss broadband performance of the 3.3 Ω to 50 Ω output transformer, which was realized using LTCC technology. The presented distributed amplifier PAE performance, is nearly twice as high as previously reported for a low voltage (3.2 VDC) application. The work presented above, also shows that broadband high efficiency, low voltage amplifiers for wireless communications are clearly realizable. The circuit techniques presented, have made possible the realization of an efficient compact amplifier design that is in the correct form factor commensurate with cellular handset applications, with the addition of an extended frequency coverage of 800 MHz to 2.1 GHz..

ACKNOWLEDGEMENT

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