HIGH EFFICIENCY L-BAND VARIABLE OUTPUT POWER AMPLIFIERS FOR USE IN COMMUNICATION SYSTEMS

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ABSTRACT

A pair of high efficiency low distortion L-band power amplifiers operating over variable drain voltages with a fixed gate voltage were developed. High efficiency and low distortion are maintained for drain voltages over the range of 2-8 Volts, while providing 12dB of output power variation. The two amplifiers are single stage reactively matched hybrids that utilize discrete 0.5μm PHEMT devices consisting of 4.8mm and 17.6mm peripheries. These amplifiers are ideally suited for L-band transmitters in Communication Systems.

INTRODUCTION

The recent growth in Satellite Communication Systems (Iridium, Globalstar, Odyssey) over the past few years has created a demand for L-band and S-band transmitters. The complexity of these systems however, has also imposed high performance specifications on the transmitters, specifically the power amplifiers. The amplifiers are required to maintain high efficiency and low distortion over variable output power levels. In addition, DC power consumption under full drive and backed-off conditions is typically a primary concern. Such stringent requirements mandate that the amplifiers operate over variable drain voltages at low drain quiescent currents in order to meet these specifications. A recent publication[1] demonstrated S-band power amplifiers that meet these requirements.

This paper describes two newly developed L-band power amplifiers that operate over drain voltages of 2-8 Volts, with a fixed gate voltage. The two amplifiers are single stage hybrids that utilize a 4.8mm and 17.6mm discrete 0.5μm PHEMT device. The amplifiers provide 12dB of output power variation (Via the drain voltage) while maintaining high efficiency and low distortion. The amplifiers were measured for small signal and large signal performances. Large signal measurements were performed under single-tone, two-tone, and noise-loaded excitations. Two-tone and noise-loaded measurements were used to measure the amplifiers distortion characteristics.

DEVICE CHARACTERISTICS

The characteristics of our PHEMT devices enable us to operate our amplifiers over variable drain voltages at low drain quiescent currents, with a fixed gate bias. Small signal lumped element models were extracted from measurements performed on our 0.5μm 4.8mm PHEMT devices. Figure 1 shows the intrinsic device model parameters as a function of drain voltage for a fixed gate voltage at Ids=74mA. All the device parameters change less than 2.2:1 over drain voltages ranging from 2-8 Volts. This uniformity in the device intrinsic parameters provide the broadband characteristics needed to operate over a wide range of drain voltages. The small signal performance of the amplifiers is shown in Figures 3 and 7.

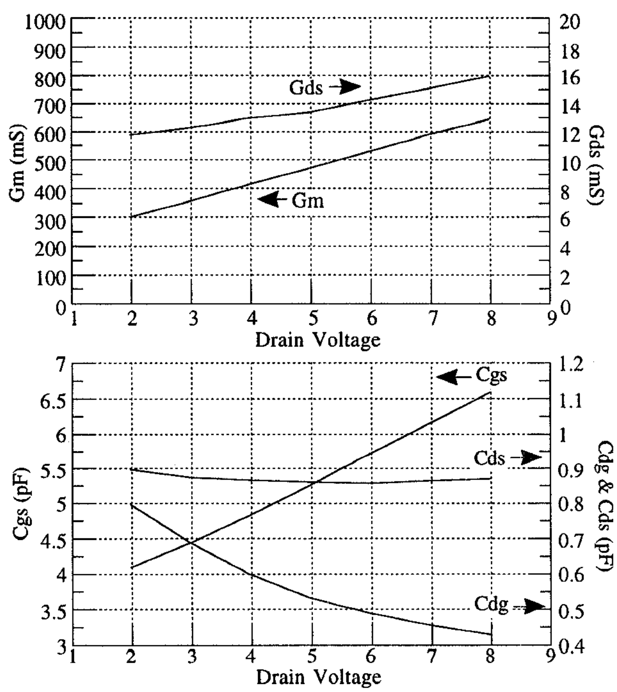

Figure 1. Intrinsic Device Model Parameters Versus Vds of a 0.5μm 4.8mm PHEMT Device for Ids=74mA.

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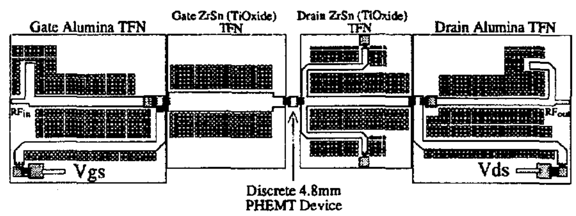
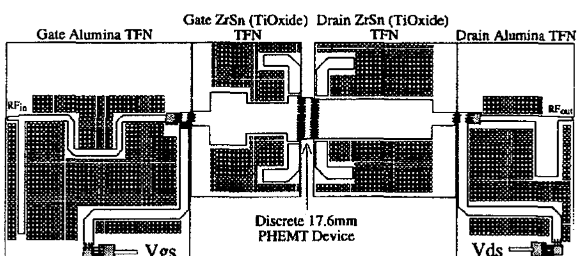
The small gain variations and good return losses over drain voltages are a result of these device characteristics. Our devices also provide high gain at low drain currents enabling us to bias close to pinchoff and reduce DC power consumption at low drive levels.

AMPLIFIERS DESIGN

The Amplifiers utilize discrete 0.5μm PHEMTs for the active components and 15mil thick Thin Film Networks (TFNs) for the passive matching circuits. The matching circuits are composed of two different dielectric materials, Alumina (ε_r=9.8) and (ZrSn)Ti Oxide (ε_r=38). The matching requirements of devices were determined empirically through loadpull and other laboratory measurements. The output matching network presents a parallel RC match of 50Ωmm and -0.4pF/mm. The input is matched for a good return loss and employs resistive loading for stability considerations. Figure 2 shows layouts of the 4.8mm and 17.6mm power amplifiers.



(a)



(b)

Figure 2. (a) 4.8m Amplifier (b) 17.6mm Amplifier.

The two amplifier designs use slightly different topologies. The 4.8mm amplifier transforms the gate and drain impedances to a real 20Ω using λ/4 transformers on the high dielectric TFNs. Symmetrical λ/4 shorted stubs are provided on the drain TFN for harmonic tuning. The 17.6mm amplifier transforms the gate and drain impedances to a real 15Ω (smaller transformation for improved bandwidth) using transformers on the high dielectric TFNs. Unconnected gate and drain λ/8 open stubs are included on the TFNs to provide maximum tuning flexibility. However, the drain stubs did not improve the performance of the amplifiers and were therefore not used. The Alumina TFN's complete the match to 50Ω using a distributed series L shunt C topology. The gate and drain bias circuitry are also provided on the Alumina TFNs via λ/4 shorted stubs. The amplifiers' hardware was designed to provide break-apart fixtures, allowing de-embedded measurements of the input and output matching networks.

4.8mm AMPLIFIER PERFORMANCE

All measurements on the amplifiers were performed for drain voltages of Vds=2,5,7, and 8 Volts with the gate voltage remaining fixed. The amplifiers performed quite well as assembled and required very little additional tuning. Typically, the tuning increased output powers by 0.25dB and efficiencies by 3-4 percentage points. Figure 3 shows the small signal response for a typical 4.8mm amplifier. The small signal gains vary only 3dB while maintaining better than a 10dB return loss over all voltages. Figure 4 shows the single tone power performance at 1.6GHz. At Vds=8V, the amplifier delivers over 3W of saturated output power at 16dB gain with 70% PAE. Over 2-8 Volts, the amplifier provides 12dB of power variation at better than 66% PAE and 12.5dB gain.

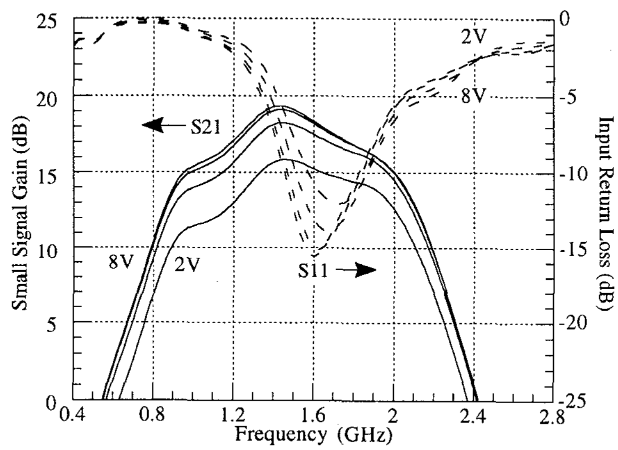


Figure 3. Small Signal Performance of the 4.8mm Amplifier for Vds=2,5,7,8V and Vgs=-0.8V.

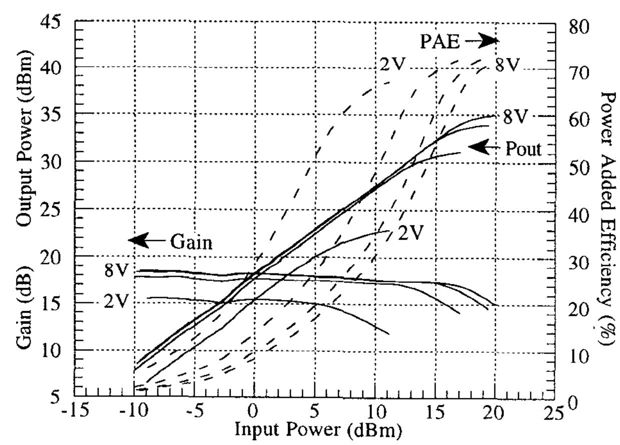


Figure 4. Single Tone 1.6GHz Power Performance of the 4.8mm Amplifier for Vds=2,5,7,8V and Vgs=-0.8V.

Distortion characteristics and nonlinearities of amplifiers are measured in many different ways in the industry. Depending on the type of system and modulation scheme, these can include adjacent-channel, noise-loaded Noise Power Ratio (NPR) , and two-tone measurements. The nonlinearity behavior of our amplifiers was measured utilizing the latter two methods. The noise measurements were performed using the HP Frequency Agile Signal Simulator (FASS). The noise band is simulated using 2565 single tone frequencies over a 10.5MHz bandwidth. A notch of 168KHz centered at 1.6GHz is inserted in the signal. The two-tone measurements were performed with 1.6GHz +/- 12.5KHz signals.

Figure 5 shows the noise power performance of the 4.8mm amplifier. The measured performances of the amplifier under single-tone, two-tone, and noise-loaded excitations at Vds=8V are shown in Figure 6. Total powers and efficiencies, along with noise intermodulation products and third order products are plotted.

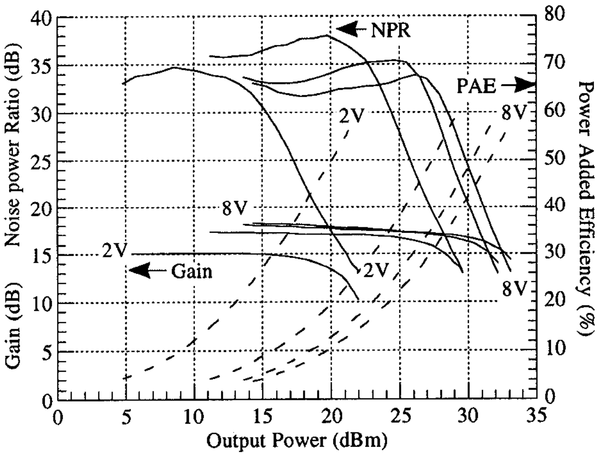


Figure 5. Noise Power Performance of the 4.8mm Amplifier for Vds=2,5,7,8V and Vgs=-0.80V.

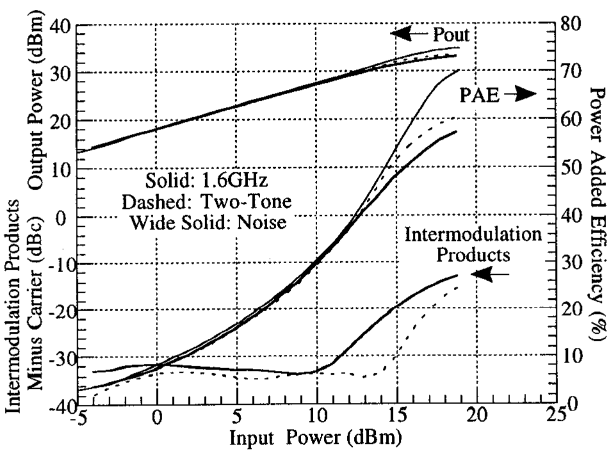


Figure 6. Single-Tone, Two-Tone, and Noise-Loaded Performance of the 4.8mm Amplifier for Vds=8V and Vgs=-0.80V.

Table 1 summarizes the output power, gain, and power added efficiency for all three excitations, along with their corresponding intermodulation products. The table lists these parameters for two input drive levels corresponding to noise power ratios of 17dB and 13dB. The table reveals that as the number of tones increases, the nonlinearity of the amplifier increases and saturated power and power added efficiency decrease, as expected.

Signal	Pout(dBm)	Gain(dB)	PAE(%)	IMP(dBc)
1.6GHz	33.5	17.2	61.0	-----
2-Tone	32.6	16.3	55.8	-23.0
Noise	32.0	15.7	52.0	-17.0
1.6GHz	34.8	15.8	70.2	-----
2-Tone	33.5	14.5	60.5	-15.5
Noise	33.2	14.2	57.7	-13.0

Table 1. Summary of Single-Tone, Two-Tone, and Noise- Loaded Performance of the 4.8mm Amplifier for Vds=8V, Vgs=-0.80V for Pin=16.3dBm and 19.0dBm.

17.6mm AMPLIFIER PERFORMANCE

The same set of small signal and large signal measurements were performed on the 17.6mm amplifier with the gate and drain open stubs unconnected. Typical results are shown in Figures 7-10 and are in the same sequential order as the 4.8mm measurement set. Noteworthy attributes include the extremely flat small signal gain characteristics (over 200MHz), minimal gain variation (only 2dB), and good return loss over all drain voltages. These attributes provide good amplitude and phase tracking over variable output powers (drain voltage). This is extremely important for transmit modules not utilizing phase shifters and variable attenuators. The modules are matched for amplitude and phase at some power level and then are required to track over variable drain voltages. Our amplifier designs and PHEMT devices provide the means for such modules.

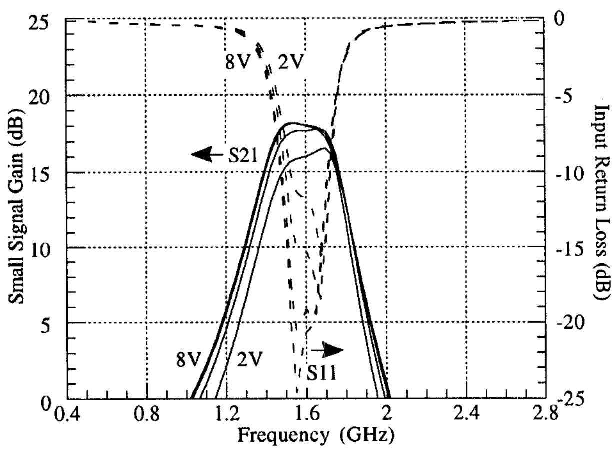


Figure 7. Small Signal Performance of the 17.6mm Amplifier for Vds=2,5,7,8V and Vgs=-0.80V.

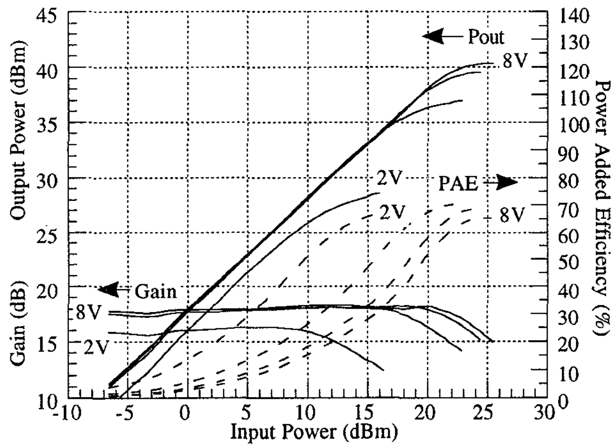


Figure 8. 1.6GHz Single Tone Power Performance of the 17.6mm Amplifier for Vds=2,5,7,8V and Vgs=-0.80V.

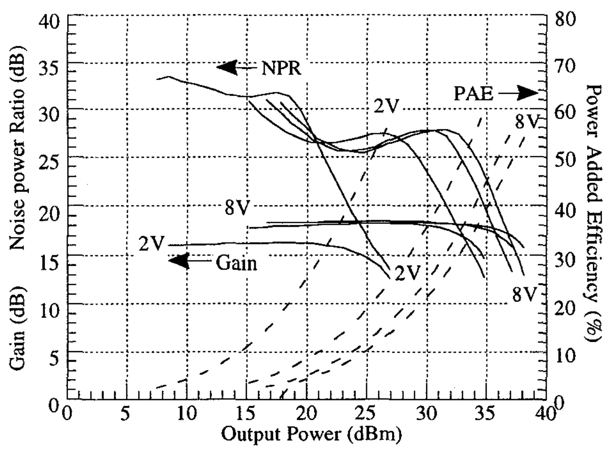


Figure 9. Noise Power Performance of the 17.6mm Amplifier for Vds=2,5,7,8V and Vgs=-0.8V.

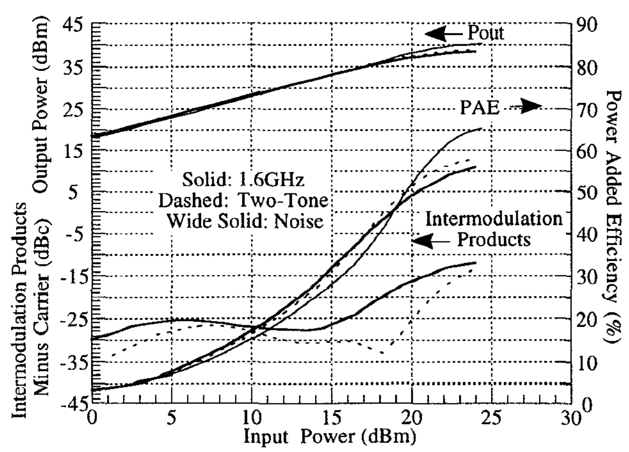


Figure 10. Single-Tone, Two-Tone, and Noise Power Performance of the 17.6mm Amplifier for Vds=8V and Vgs=-0.80V.

At Vds=8V, the amplifier delivers 11W of saturated output power at 15.5dB gain with 65% PAE at 1.6GHz as shown in Figure 8. Table 2 summarizes the output power, gain, and power added efficiency for all three excitations, along with their corresponding intermodulation products.

Signal	Pout(dBm)	Gain (dB)	PAE (%)	IMP (dBc)
1.6GHz	37.7	18.1	50.5	------
2-Tone	37.3	17.7	50.5	-26.5
Noise	36.8	17.2	48.0	-17.0
1.6GHz	39.7	17.3	62.0	-----
2-Tone	38.6	16.2	56.6	-17.0
Noise	38.1	15.7	54.0	-13.0

Table 2. Summary of Single-Tone, Two-Tone, and Noise- Loaded Performance of the 17.6mm Amplifier for Vds=8V, Vgs=-0.80V for Pin=19.6dBm and 22.4dBm.

Other 17.6mm amplifiers were tuned and measured at Vds=8V with the gate open stubs connected. Before the gate stubs were connected, these amplifiers performed similarly to the amplifier described above. Table 3 summarizes the results of a 17.6mm amplifier tuned in this manner. Significant increases in power for all three excitations resulted. The interesting outcome of the experiment was that most of the increase in power resulted from connecting the gate stubs and tuning the input matching network, not the output. The tradeoffs of the tuning were a reduction in bandwidth and gain, with significantly different compression characteristics.

Signal	Pout(dBm)	Gain (dB)	PAE (%)	IMP (dBc)
1.6GHz	39.1	16.8	53.6	-----
2-Tone	38.1	15.8	51.4	-28.0
Noise	37.6	15.3	47.7	-17.0
1.6GHz	40.9	16.1	65.3	-----
2-Tone	39.2	14.4	56.6	-18.0
Noise	38.9	14.1	54.5	-13.0

Table 3. Summary of Single-Tone, Two-Tone, and Noise-Loaded Performance of the 17.6mm Amplifier for Vds=8V, Vgs=-0.96V for Pin=22.3dBm and 24.8dBm.

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[1] A. Platzker, S. Bouthillette, "Variable Output, High Efficiency-Low Distortion S-Band Power Amplifiers and Their Performances Under Single Tone and Noise Excitations", IEEE MTT-S Digest, 1995, pp.441-444.