High Performance Voltage Controlled Bi-Directional Amplifiers In Support Of Component Reuse For Large Aperture Phase Array

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Abstract- ***The objective of this paper is to provide a novel and innovative solution to reduce the projected high parts count for large aperture phase array (>100,000 elements). Bi-directional amplifiers are ideal for this application since R.F. amplification, in either transmit or receive directions, are controlled through bias thus eliminating the need for lossy switches that degrades the system noise figure performance. In addition, the size, weight, and cost of the transceiver module can be greatly reduced since only one amplifier is required. Two bi-directional amplifiers are presented here in both common-gate and common-source configurations.***

I. INTRODUCTION

The realization of a space-based surveillance system requires large apertures (100 square meters or greater) to achieve the high spatial resolution necessary to support GMTI, AMTI, and SAR. However, current technology and design approaches supporting this large space-borne phased array are impractical and expensive. For instance, a phased array with a square aperture that has side dimension of 10 meters at X-band, taking into account the mutual coupling between adjacent radiation element, can be populated up to 300,000 elements. A typical allocation of 20 kW and 10,000 1bs for the spacecraft would require each element to consume no more than 50-100 mW DC power and weigh less than 10-20 grams. This is not trivial since each element needs to electrically provide transmit and receive functions, and mechanically include radiating and support structure. Hence, the power and weight requirements are severe at the component level. This not only highlights some of the challenges ahead for space-based radar, but also indicates why conventional phased array designs relying on today's technology are unable to meet this challenge.

In this paper, an innovative voltage controlled bi-directional amplifier implementation approach will be introduced to obtain high performance T/R modules with reduced weight and cost. This approach will lead the way to an affordable, high performance, large aperture space-based phased array system.

II. DESIGN AND SIMULATION

In this section, design and simulation results for two bi-directional amplifiers will be presented. Figure 1 shows a summary of key amplifier parameters and the associated design goals. Note here that since there are overwhelming numbers of transceiver elements, output power of each element need not be great.

Figure 1. Summary of Key Amplifier Parameters and Design Goals.

Modes	Parameters	Design Goals
Transmit	Bandwidth	2GHz with Fc=10GHz
	Output Power	>10 mW
	DC Power	<50 mW
Receive	Bandwidth	4GHz with Fc=10GHz
	NF	<2 dB
	Linear Gain	>15dB

There are two main advantages of having a voltage controlled bi-directional amplifier. First, it eliminates extra switches in the RF path to reduce path loss and enhance noise figure performance. Second, the actual dimension of the amplifier will be approximately halved since only one amplifier is required.

Common Gate Topology To realize this design, we have chosen a symmetrical common-gate HEMT device with which we can control the direction of amplification by simply reversing the bias polarity.

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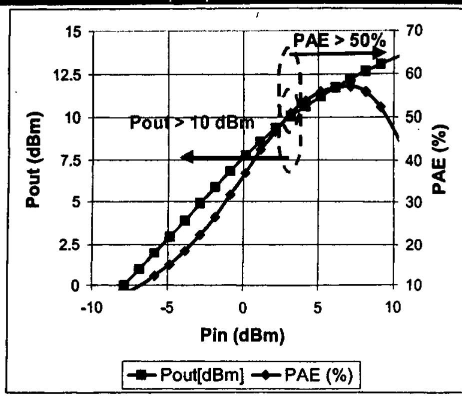
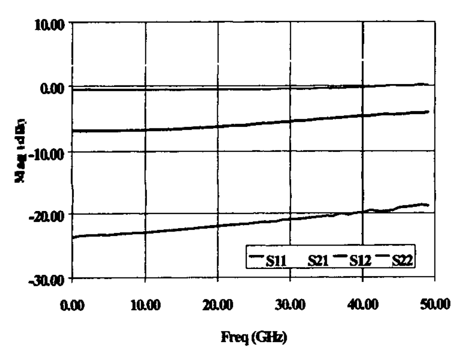
The enabling technology for this bi-directional amplifier is TRW's InP HEMT symmetrical common-gate device. Load-pull measurement shows the device can achieve > 50% PAE. (See Figure 2)

Figure 2. Common-gate InP HEMT Device load pull power performance at X-band. Peak PAE of 50% at 20 mW output power was achieved

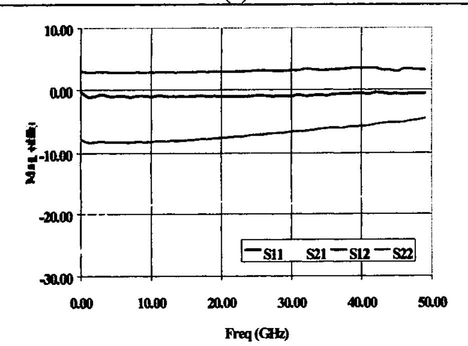


The small signal data for a HEMT common-gate device is shown in Figure 3. By changing the voltage polarity of Vds, the device shows gain in both a forward (Figure 3a) and reverse (Figure 3b) direction up to 50GHz.

Figure 3. Forward (a) and reverse (b) small signal sweep data for a common gate device.



(a)

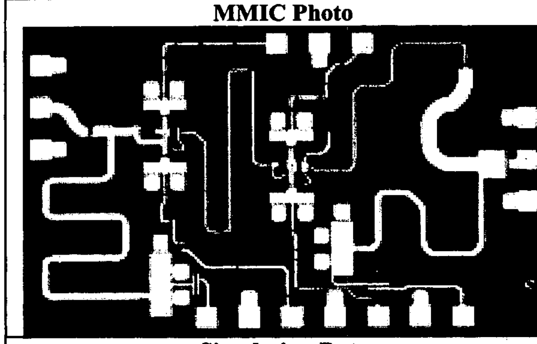


(b)

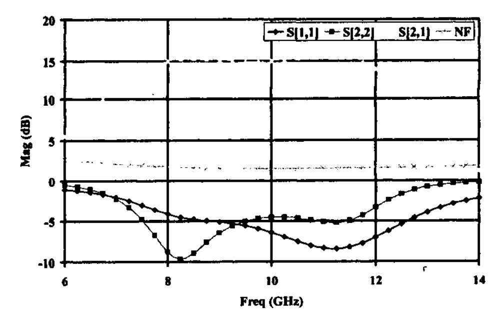
Simulation and layout was completed for a 2-stage bi-directional amplifier design (See Figure 4). Simulation result demonstrates noise performance of the bi-directional amplifier to be comparable to that of the conventional single-direction amplifiers (NF~1.5 dB). This amplifier achieved 15 dB gain at X-band in the receive direction and 11 dB gain in the transmit direction as shown in Figure 4. Note here that the matching networks in the forward and reverse directions are optimized according to the direction of transmitting and receiving. As a result, the input and output matching networks do not look symmetrical. The size of the amplifier chip is compact (<4 mm^2). This is significantly smaller than the size of conventional T/R implementation where switches, LNA and PA MMICs can occupy area greater than 18 mm^2 in the module.

Figure 4. Common Gate Bi-Directional Amplifier

MMIC Photo



Simulation Data



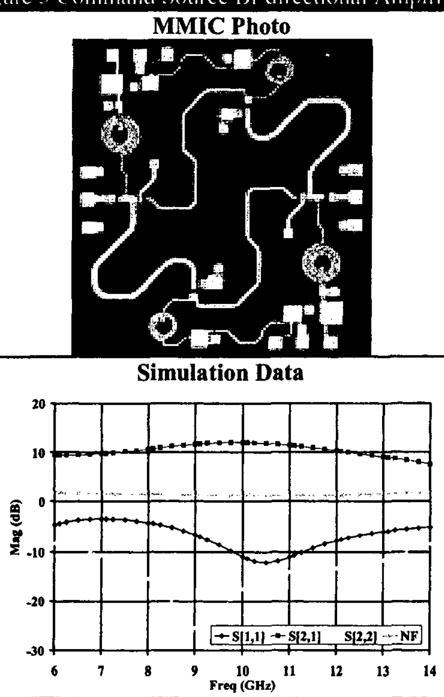
Another attractive feature of this amplifier is its stacked device topology. This topology links the devices in a current sharing fashion, which is advantageous in a system that can provide high voltage but limited current. Hence, additional gain can be instituted with higher operating voltage to reduce the NF contribution of the subsequent components without increasing current consumption.

The two challenges in this novel approach were matching and stability. Optimizing the matching simultaneously for output power and low noise is not a trivial task with a fixed matching structure that serves both as the input match for the LNA and the output match for the PA. However, this may not be as difficult as it appears if the device is already pre-matched close to 50 ohms, which can be accomplished with a common gate configuration.

The second challenge is the topology's potential for instability since stability needs to be obtained for both the transmit and receive mode. We were able to resolve this issue with the present design. We found that the main contributors of unstable feedback in common gate mode are high values of R_g, L_g, and C_{ds}. An attempt to minimize these parameters during device layout can ensure circuit stability. L_g can be reduced by decreasing the distance from the gate fingers to the grounding via. R_g can be minimized by using multi-finger topology. Simulation may need to be conducted to ensure that these modifications will not significantly increase C_{ds}.

Common Source Topology The common source topology is introduced as an alternative approach to the bi-directional amplifier (See Figure 5)

Figure 5 Command Source Bi-directional Amplifier



This amplifier design takes advantage of the microstrip quarter-wave transformer property to direct the RF signal flow. A diode is placed at the end of a quarter-wave stub to control the impedance of the line. When Vd is applied to the device, the diode is simultaneously turned on and RF shorts to ground. This will transform to an RF open at the other end of quarter-wave microstrip line. As a result, RF is forced to flow to the other branch of the junction. The layout and simulation result of the MMIC is shown in Figure 5. At 5 mm^2, this is an extremely compact MMIC. Since it is only a single stage design, the small signal gain is 3 dB less than the common-gate amplifier. However, since this topology is symmetrical, more gain can be obtained by cascading more stages. Note here that the common source topology can potentially achieve better NF over the common-gate topology.

Figure 6 summarizes the simulation results for the two bi-directional amplifier topologies.

Figure 6. Summary of Amplifier Performance.

Mode	Parameter	Common Gate	Common Source
LNA	Bandwidth	4 GHz	4 GHz
	Linear Gain	15 dB	10 dB
	NF	1.5 dB	1.2 dB
	DC PWR	15 mW	10 mW
PA	Bandwidth	2 GHz	2 GHz
	P1dB	10 dBm	12 dBm
	DC PWR	30 mW	50 mW

III. MEASUREMENT AND VALIDATION

Two types of amplifier designs were fabricated to validate the simulation results. For the common gate topology, the test data is shown in Figure 7. In transmit mode, P1dB of the amplifier is about 11.5 dBm with 10 dB of gain. In receive mode, the gain is approximately 15 dB with average noise figure of 1.75 dB. In comparison to the summary of the simulated performance in Figure 6, the common gate bi-directional amplifier measurement demonstrated extremely good correlation with the simulation.

Data for the common source topology is shown in Figure 8. The measured receive gain is very close to the simulated value of 10 dB. However, P1dB for the transmit mode is measured at only about 7.5 dBm with 9.5 dB of gain, which is significantly lower than the simulated value. As a result of low gain, noise figure performance suffers. With the help of a loadpull station, we were able to achieve the expected P1dB by optimizing the load impedance. Thus, we can conclude that the mismatch is the main cause of the degradation of the amplifier performance. This suggests that the desired performance can be achieved through improve matching network design.

Figure 7. Common Gate Amplifier Performance

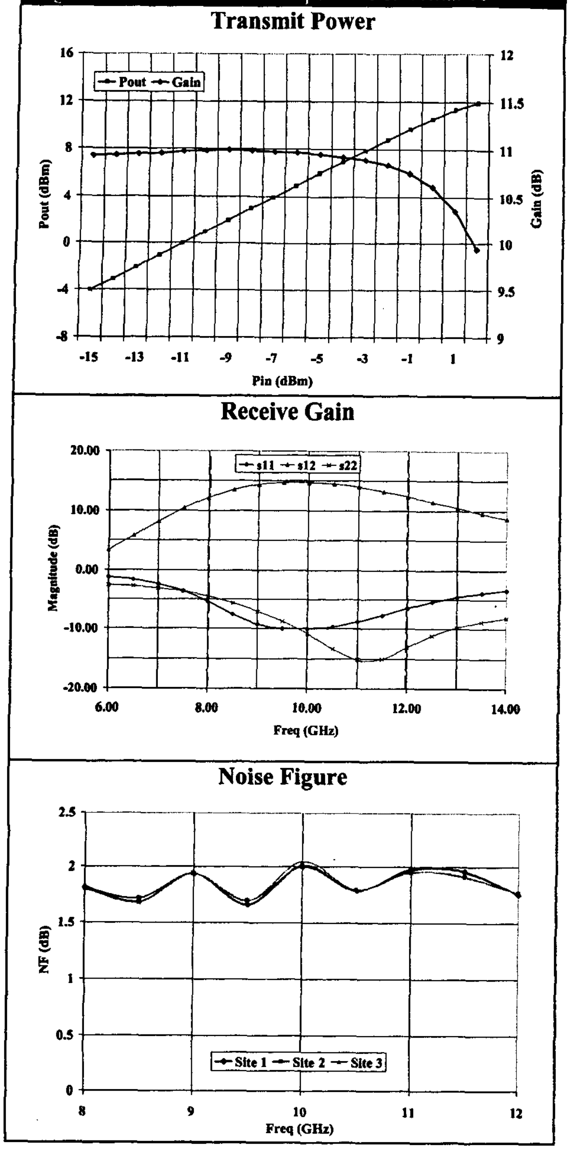
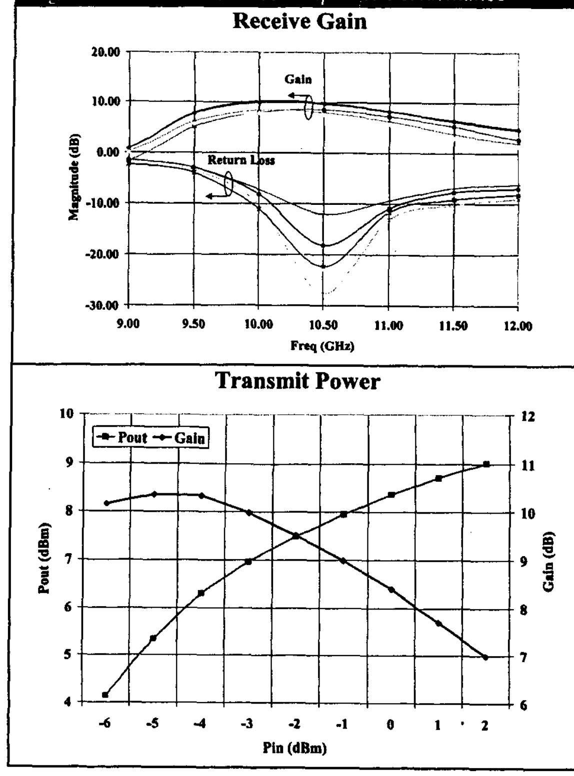


Figure 8. Common Source Amplifier Performance



IV. CONCLUSION

We have demonstrated two novel approaches for implementing the bi-directional amplifier required to realize a future large aperture phase array system. Part counts reduction intended to lower cost, size and weight of the system is achieved through component reuse. We intend to continue to enhance the maturity of these technologies in support of the vision for future space-based surveillance systems.