WIDEBAND BIDIRECTIONAL MMIC AMPLIFIERS FOR NEW GENERATION T/R MODULE

805-967-5511

T. Tsukii, S.G. Houng
Raytheon Company
Electromagnetic Systems Division
Goleta, CA 93117

M.J. Schindler
Raytheon Research Division
Lexington, MA 02173

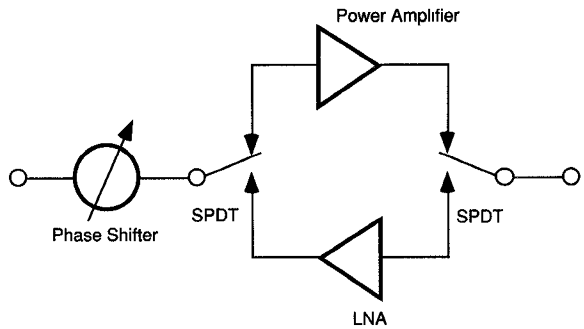
ABSTRACT

Two novel bidirectional amplifier approaches have been conceived and demonstrated with MMICs. These amplifiers are needed in bidirectional transmit/receive (T/R) modules, where close gain and phase tracking are critical. Excellent gain and phase tracking are inherent in the presented bidirectional amplifier approaches, since the same gain elements are used in both the transmit and receive modes.

The Bidirectional Distributed Amplifier (BDA) has exhibited better than ±0.4 dB in gain tracking and ±2.5 degrees in phase tracking between the transmit and receive modes over a 2 to 18 GHz band.

The Bidirectional Balanced Amplifier (BBA) has shown better than ±0.4 dB in gain tracking and ±1.5 degrees in phase tracking over a 6 to 18 GHz band.

1A. Conventional T/R Module



1B. Bidirectional T/R Module

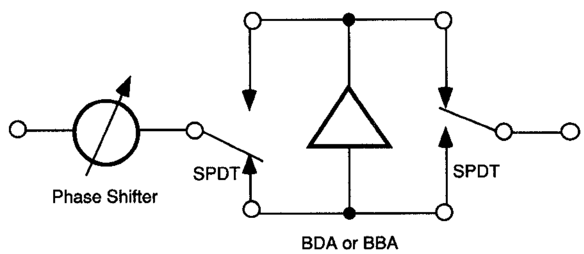


Figure 1. T/R Modules

INTRODUCTION

Conventional Transmit/Receive (T/R) modules as shown in Figure 1A, developed for multifunction phase array applications (either a narrow-band[1] or wide-band[2]) have no requirements for phase and gain trackings between transmit and receive modes. However, recent systems require the T/R module to operate over a wide bandwidth and have minimum phase and gain differences between the transmit and receive modes. The conventional T/R module has two independent signal paths for the transmit and the receive chains. It is therefore very difficult and costly to achieve wideband phase and gain tracking. To meet the phase and gain tracking requirements, two wideband bidirectional MMIC amplifiers, namely Bidirectional Distributed Amplifier (BDA) and Bidirectional Balanced Amplifier (BBA), have been designed, fabricatèd, and demonstrated. Both amplifiers achieved excellent phase and gain tracking characteristics, since the same gain elements are shared by both transmitting and receiving paths (see Figure 1B). The BDAs are designated for small signal gain stages and the BBAs are suited for medium and high-power gain stages. By cascading BDAs and BBAs, a high gain and high power bidirectional amplifier is realized.

This paper will discuss the concepts, design, fabrication, and demonstrated performance of the two types of bidirectional amplifiers.

BIDIRECTIONAL DISTRIBUTED AMPLIFIER (BDA)

The BDA is a 4-port symmetrical distributed amplifier with the network topology as shown in Figure 2A. Here, port "1" and port "2" are input ports, and port "3" and port "4" are output ports.

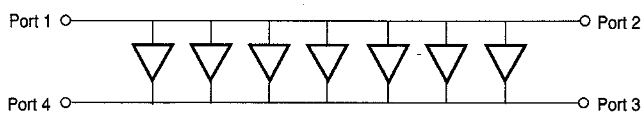
The symmetrical, distributed amplifier is composed of an input artificial transmission line connected between port "1" and port "2," and an output artificial transmission line connected between port "3" and port "4." Both input and output artificial transmission lines have an identical signal phase velocity. In addition, N Field-Effect Transistors (FETs) are used to couple the two artificial transmission lines such that when the signal is applied to port "1," the BDA will produce the maximum signal amplification at port "3." Similarly, due to the symmetric network design, an input signal presented at port "2" will be amplified via the BDA and the maximum signal will appear at the output port "4." Thus, two distinct signal paths can be identified as path from port "1" to port "3," and path from port "2" to port "4." Since both signal paths share the same N FET symmetrical amplifier, the signal phase and gain will be identical in both signal paths.

The design of the BDA is quite similar to that of a conventional distributed amplifier.[3] Gate capacitance is incorporated into the input artificial transmission line. Drain capacitance is also incorporated into the output artificial transmission line. Drain coupling inductors are used to equalize phase velocities. Biasing is accomplished through resistors to each gate electrode when gates are capacitively coupled. Drain bias is usually applied at the drain termination. Since this is not feasible with the BDA design, the drain bias is applied through a quarter-wave transformer connected near the center of the output line.

The BDA MMIC chip is shown in Figure 2B, and the measured data are given in Figure 3.

A slight gain deviation in low frequencies between two signal paths is caused by the slight asymmetry in drain biasing. Nonetheless, the BDA achieves gain tracking better than ±0.4 dB, and phase tracking better than ±2.5 degrees between two signal paths over 2 to 18 GHz frequency band.

2A. Topology



(a) Topology

2B. MMIC Chip (Size 60 x 85 mils)

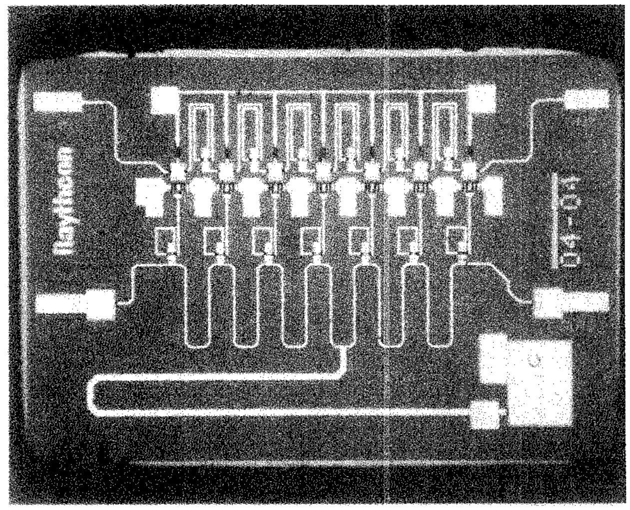


Figure 2. Bidirectional Distributed Amplifier (BDA)

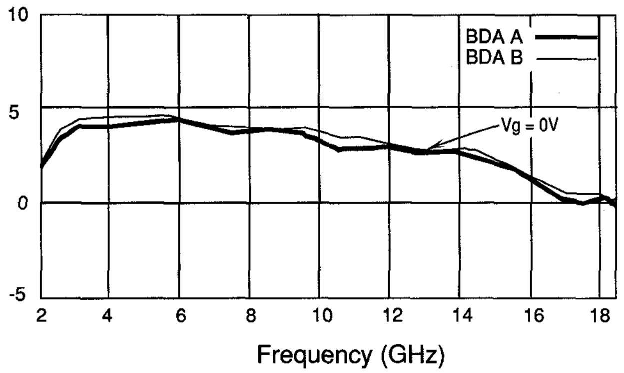
BIDIRECTIONAL BALANCED AMPLIFIER (BBA)

The BBA is a 4-port device which consists of two identical MMIC amplifiers and two quadrature couplers as shown in Figure 4A, where the bidirectional characteristics are provided a 4-port balanced amplifier configuration.

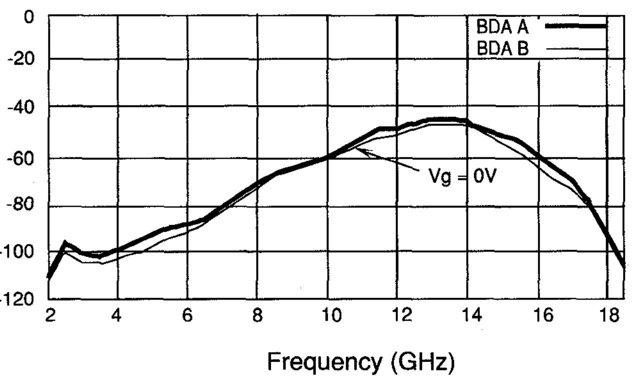
A signal applied to port "1" will emerge at port "3." Similarly, a signal applied to port "2" will appear at port "4." Therefore, two distinct signal paths have been established, one for the path from port "1" to port "3," and the other for the path from port "2" to port "4." Since the two signal paths share the same couplers and amplifiers, both signals have identical phase and gain data.

The design of BBA is identical to that of a conventional balanced amplifier[4], except that the BBA is used as a 4-port device, and the conventional balanced amplifier is used as a 2-port device with terminations at two isolated ports. For this demonstration, we used two standard Raytheon 6 to 18 GHz reactively matched, unidirectional MMIC power amplifier chips. Figure 4B shows an assembled BBA which consists of two MMIC amplifiers and two quadrature couplers fabricated on alumina substrates. The gold ribbons are used for interconnections at the chip-coupler and coupler-transmission line interfaces. These bonding ribbons will cause additional phase and gain tracking degradation. Even with this added uncertainty (with 5 bonding interfaces in each signal path), the measured data in Figure 5 shows excellent bidirectional characteristics. Measured phase tracking is better than ±1.5 degrees, and gain tracking is better than±0.4 dB over the 6 to 18 GHz frequency band.

3A.Gain (dB)



3B. Phase (deg)



3C. Input Return Loss (dB)

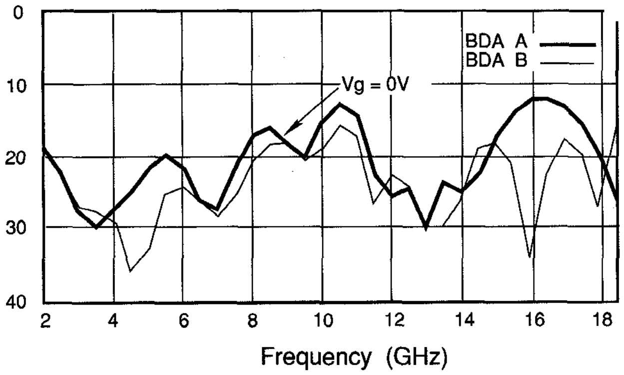
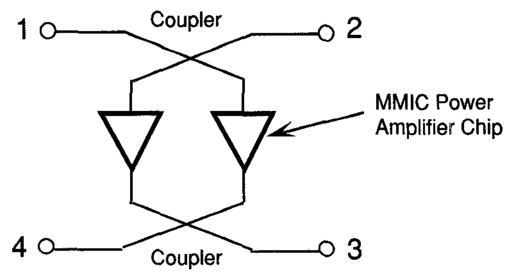


Figure 3. Measured Bidirectional Distributed Amplifier Gain, Phase, and Return Loss Trackings.

4A. Topology



(a) Topology

4B. Assembled MMIC Power Amplifier Stage
(Size 300 x 330 mils)

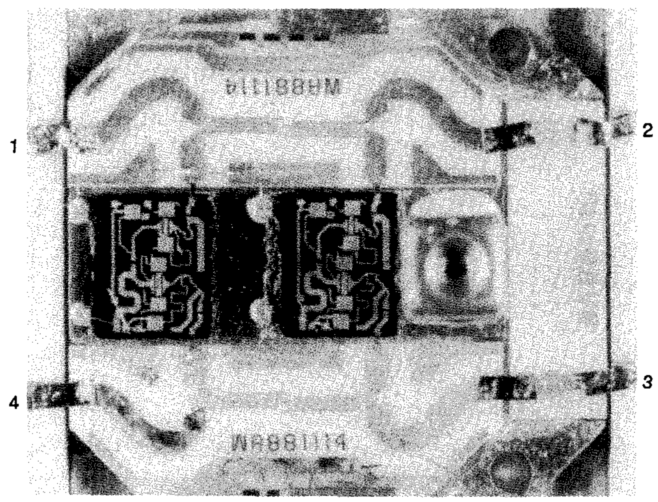
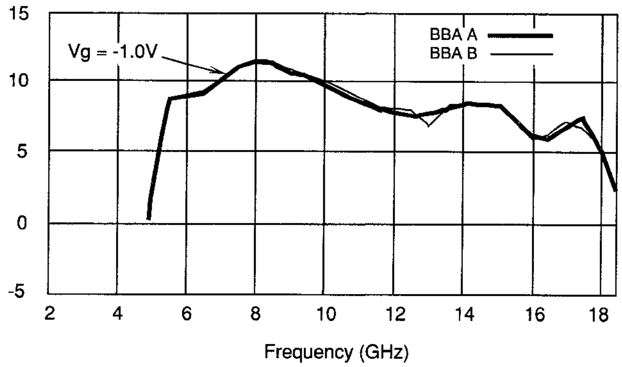
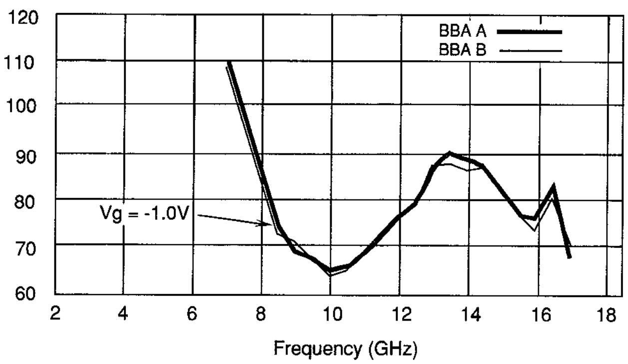


Figure 4. Bidirectional Balanced Amplifier (BBA)

5A. Gain (dB)



5B. Phase (deg)



5C. Input Return Loss (dB)

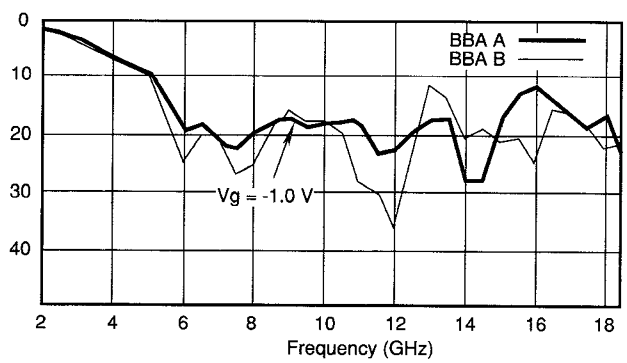


Figure 5. Measured Bidirectional Balanced Amplifier Gain, Phase, Trackings and Return Loss.

FABRICATION

The BDA MMICs were made with a standard Raytheon process. The FETs have 0.5 μm gates and were ion implanted to a doping on $3X10^{17}$ CM^{-3}. A 2000Å Si_3N_4 layer is used as a passivation and a capacitor dielectric. TaN is used for low-value resistors. GaAs mesa is used for large resistor values. The wafer was thinned to 4 mils, and 20x100 mm via holes were etched.

The BBA was made with standard Raytheon 6-18 GHz power amplifier MMICs from an earlier production run. The FETs on these MMICs use 0.5 μm gates and were ion implanted to a doping of $2X10^{17}$ CM^{-3}. A 3000Å silicon nitride thickness was used for passivation and capacitor dielectrics. Resistors were made with TiPt and GaAs mesa. Final wafer thickness was 4 mils, and 100x100 mm via holes were used.

CONCLUSIONS

We have demonstrated two novel approaches for achieving bidirectional amplifiers to be used in bidirectional T/R modules. The first approach (the BDA) takes advantage of the distributed amplifier topology. A single distributed amplifier design having two inputs and two outputs has been demonstrated. Excellent gain and phase trackings have been shown. The second approach (the BBA) makes use of standard unidirectional MMIC amplifiers and Lange couplers. Once again, excellent gain and phase trackings have been demonstrated.

In both novel approaches, good gain and phase trackings are inherent in the design, since the same gain elements are used in both transmitting and receiving modes.

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