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Switch less Bidirectional RF Amplifier for 2.4 GHz Wireless Sensor Networks

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Abstract— ***Bidirectional amplifiers in anti-parallel configuration are designed for 2.4 GHz ISM band applications. These amplifiers are critical for applications where the transceiver module and the antenna element are physically separated to provide possibly better antenna performance. They can also be used as range extenders. One of the designs employs low-insertion loss RF switches and the other has no switches at all. The amplifiers are DC-fed through coaxial cable that connects the antenna to transceiver unit. In switchless design, +/- 3V DC are generated at the amplifier (antenna) side so that negative supply is fed to the unused portion, either PA or LNA. The LNA and PA consume 6 mA and 55 mA of current from the supply, respectively. SiGe RF transistors are used for the design. Amplifiers are built and tested. Their measurements characteristics such as 1 dB compression point, input/output match and stability corroborate with simulation results.***

Index Terms— **RF Amplifier, range extenders, switchless amplifier, low-noise amplifier, power amplifier, wireless sensor network.**

I. INTRODUCTION

Wireless sensor networks (WSN's) at 2.4 GHz frequency band are becoming increasingly popular. There are many off-the-shelf transceiver integrated circuits (IC's) targeted for WSN applications. One major deficiency in the application of WSN's is to maintain reliable communication in harsh environments. Some of these deficiencies can be attributed to inferior antenna location which is usually placed on the same circuit board with the transceiver electronics. WSN applications for security and surveillance of critical buildings and infrastructures present such harsh environments due to visually obscured sensor nodes to prevent a potential damage from intruders. In these applications, units are placed close to earth or over metal fences where human intervention to wireless units is very limited. One can overcome these difficulties by placing antenna element further apart from the transceiver unit. Separating the antenna element for better reception requires coaxial cable attachment to the transceiver unit. However, cable loss increases the noise figure of the unit, thus, degrades reception performance. Instead, low noise amplifier (LNA) and power amplifier (PA) can be housed within the antenna element and this unit can be easily connected to the transceiver unit.

In this study, we present designs, simulations and measurements of two bidirectional amplifiers. Transmit and receive states of amplifiers can be controlled via transmit/receive enable pins existing in all transceiver IC's. These designs differ from earlier studies [1]-[2] in a way that amplifier topologies are different, and negative bias voltages are applied to unused receive/transmit amplifiers. The units are DC-fed through RF coaxial cable.

II. BIDIRECTIONAL AMPLIFIER DESIGN

The most straightforward approach for bidirectional amplifier is to switch LNA and PA through "transmit enable" and "receive enable" pins of the transceiver IC as shown in Fig. 1a. To get rid of switches, the amplifier can be designed in such a way that the unused amplifier presents itself high-impedance to the other amplifier. It is possible to ground the DC supply of unused amplifier. However, when the unused amplifier DC supply is grounded, we observe that parasitic loading of the amplifier affects the other amplifier. To alleviate this problem, we used negative supply for the unused amplifier. The DC supply is fed from the main unit through the coaxial cable. Using bias-tee, DC voltage is separated at the antenna unit and bipolar supply (Linear LTC3260) is used to create positive and small negative DC voltages. Then, a DC switch (Fairchild FSA4157) selects either + 3VDC or -1 VDC for the respective amplifier. The topology of the amplifier and DC supply configurations are illustrated in Figs. 1a and 1b.

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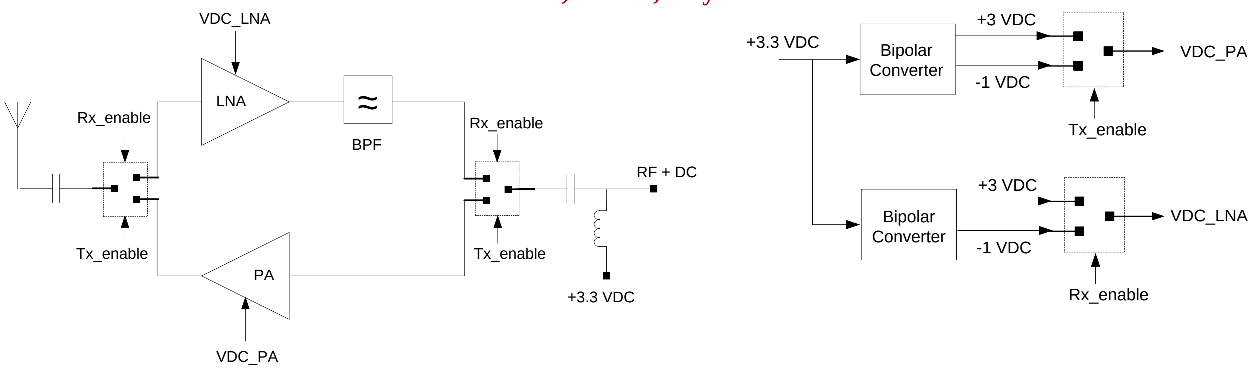

(a) (b)

Fig. 1. Bidirectional amplifier, a) block diagram, b) DC feed configuration for switchless design.

The RF switches in Fig 1a are low-insertion loss single pole double throw (Skyworks AS214-92LF). Second amplifier design completely eliminates RF switches by carefully optimizing transmission lines that connect amplifier units to input and output ports of the unit as shown in Fig. 2. We call this second amplifier *switchless **bidirectional amplifier***.

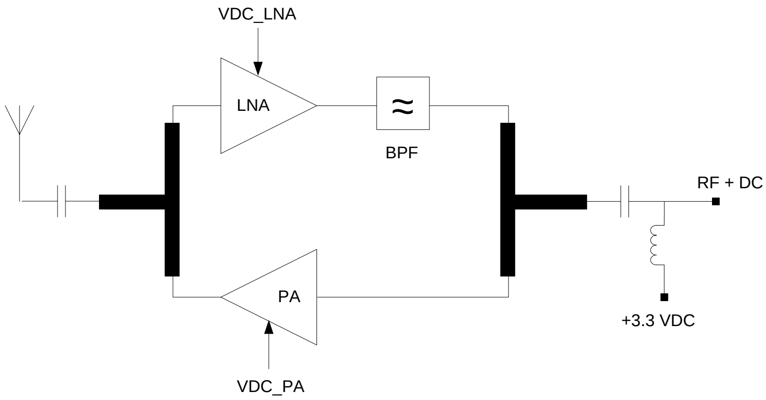

Fig. 2. Switchless bidirectional amplifier.

A. *Design Specifications*

Overview of important design specifications are summarized in Table I. Specifications follow the metrics of standalone LNA or PA designs.

TABLE I Design specifications.

	LNA	PA
DC Power (3V supply)	< 30 mW	< 200 mW
Input Return Loss	< -6 dB	< -10 dB
Output Return Loss	< -10 dB	< -12 dB
Gain	> 14 dB	> 10 dB
Reverse Isolation	< -30 dB	< -30 dB
Noise Figure	< 1 dB	-
Input IP3	> 0 dBm	-
Output IP3	-	> 27 dBm
Input P1dB	> -10 dBm	-
Output P1dB	-	> 24 dBm
P1dB at 433 MHz	> 5 dBm	-
P1dB at 1967 MHz	> 0 dBm	-

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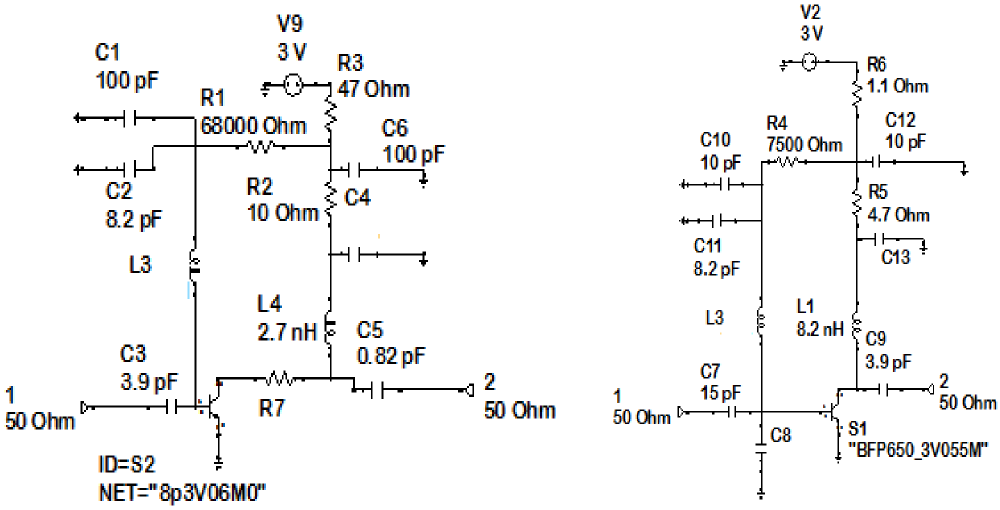
B. *LNA Design*

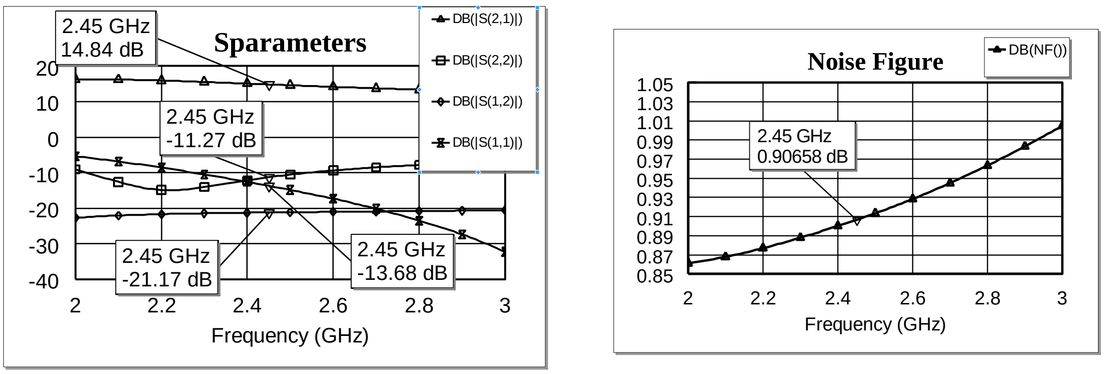
LNA design compromises trade-offs between linearity, stability, noise figure, input/output match, and DC power consumption [3]-[5]. From given design specifications, BFP640 Si-Ge bipolar transistor manufactured by Infineon Technologies is chosen. The transistor has the ability to provide high gain, low noise figure and high IIP3 with low DC power consumption. The transistor is biased at 2.6 V collector-emitter voltage with 6.6 mA of collector current. The design is shown in Fig. 3a. Instead of using a large RF choke for DC decoupling, we used L3 and C3 for input match and large RF impedance together with R1. L4 and C4, on the other hand, decouples output RF from DC path and at the same time helps output match. Since our goal is to use minimum real estate, we combined DC decoupling and input/output match together. Presence of C1 and C6 improve input and output IP3, respectively by filtering out video frequencies. Emitter degeneration by short microstrip lines is also utilized to improve linearity at the expense of slight deterioration in noise figure. Unconditional stability up to 10 GHz is obtained by using a small resistor (R7) at the collector along RF path. C3 and C5 are bypass and impedance match capacitors.



(a) (b)

Fig. 3. Circuit schematics for a) LNA, and b) PA.

Simulation results of the LNA design are shown in Figs. 4 and 5. Stability, OIP3 and 1dB compression values are all within design goals. Stability is analyzed in terms of geometric stability factor for both input and output of the amplifier and the amplifier is unconditionally stable up to 11 GHz.



(a) (b)

Fig. 4. LNA , a) S-parameters simulation, b) Noise Figure simulation.

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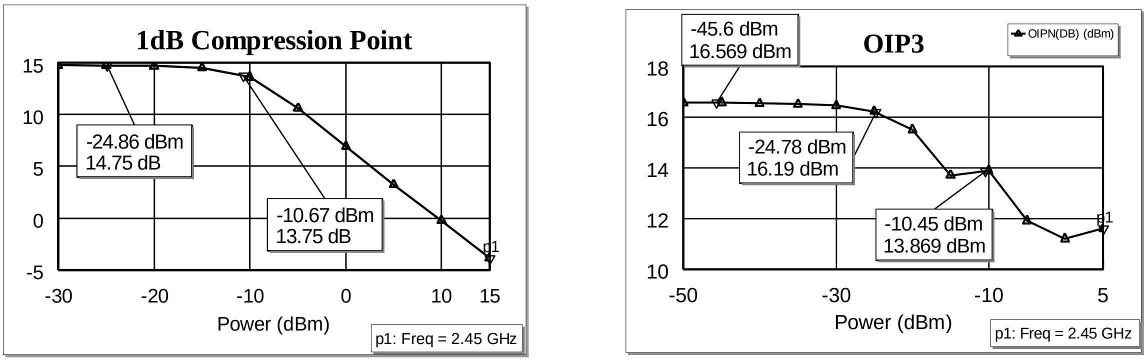
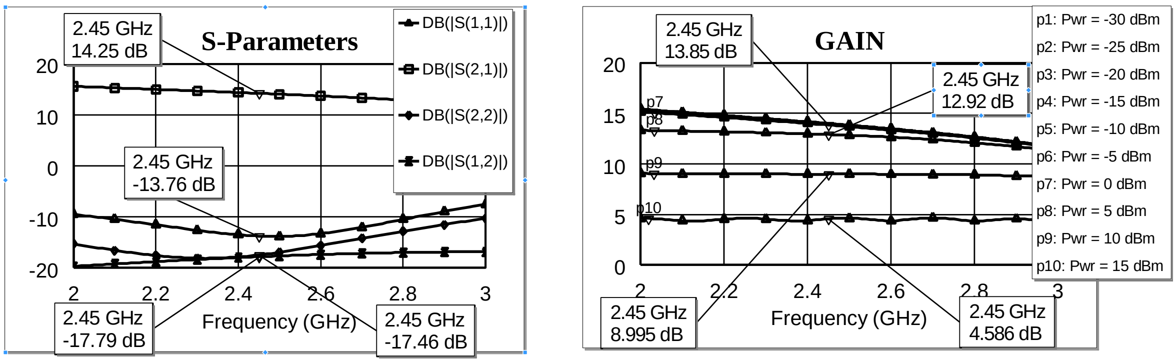


(a) **(b)**

Fig. 5. LNA, a) 1dB compression point, b) Output IP3.

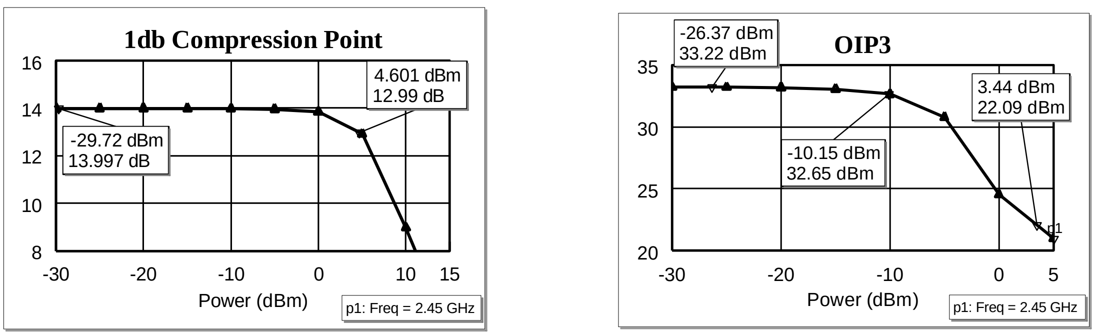
C. *PA Design*

For PA design, BFP 650 manufactured by Infineon is used. The amplifier is Class A and when DC power supply voltage is 3V, the collector current is 55 mA. PA schematic is shown in Fig. 3b. We used similar techniques for IP3 improvement as we did in LNA, but input and output match of this PA is entirely different. Again, we used very few components to meet design specifications. Simulation results of PA are shown in Figs. 6 and 7.



(a) **(b)**

Fig. 6. PA, a) S-parameters simulation, b) gain for different input power levels.



(a) **(b)**

Fig. 7. PA, a) 1-dB compression point, b) OIP3.

D. *Switchless Design*

For switchless design, the PA is disabled, i.e. -3 V is applied at DC supply line and LNA is operated. Hence, matching of LNA to input and output is achieved first. Then, LNA is assumed OFF, i.e. -3V is applied to collector of BFP640 and PA is optimized for performance criteria. Since both designs demand different input and output matching conditions, optimization is run input/output matching for both states. Of course, the final design is not as good as separate, individual designs with switch, but performance was acceptable. The design and its layout are

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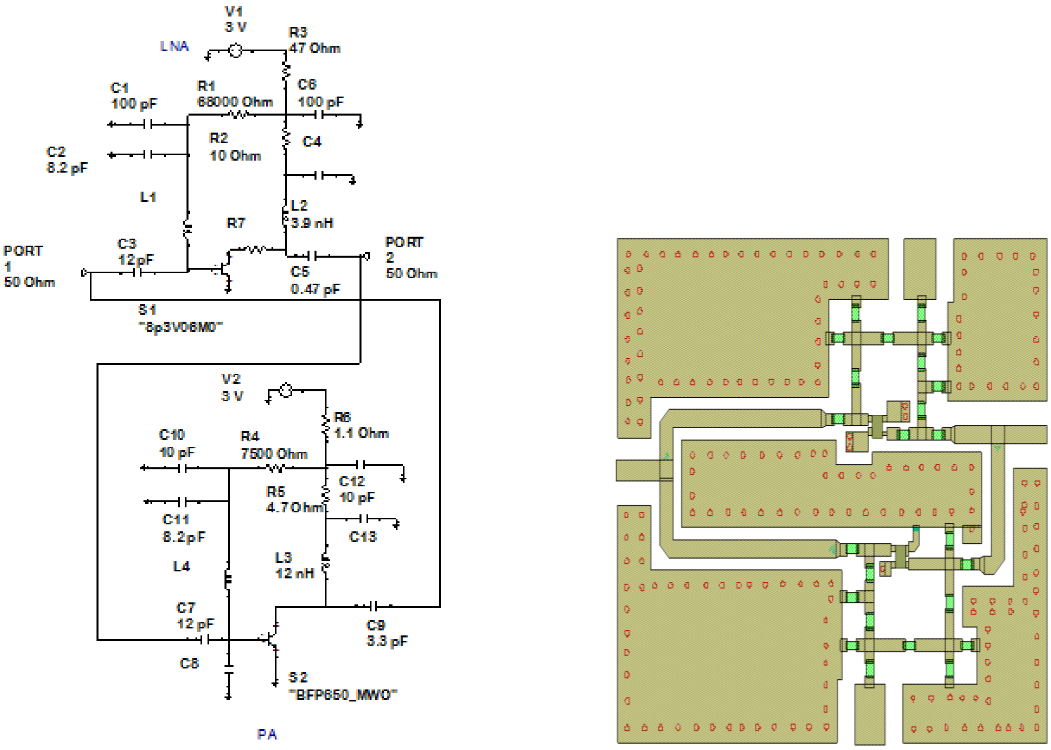
shown in Fig. 8. Comparison of both amplifier designs for LNA and PA are shown in Tables II and III, respectively.



(a) (b)

Fig. 8. Bidirectional design, a) schematic, b) layout.

Table II. LNA simulation of both amplifiers.

	Switchless bidirectional amplifier-LNA	Bidirectional amplifier with switch- LNA
Gain	13.93 dB at 2.45 GHz	14.84 dB at 2.45 GHz
Reverse isolation	22.3 dB at 2.45 GHz	21.17dB at 2.45 GHz
Input return loss	18.86 dB at 2.45 GHz	13.68 dB at 2.45 GHz
Output return loss	10.3 dB at 2.45 GHz	11.27 dB at 2.45 GHz
Noise figure	1.56 dB at 2.45 GHz	0.9 dB at 2.45 GHz
Input 1dB compression point	-8.65 dBm	-10.67 dBm
Output 1dB compression point	4.17 dBm	3.75 dBm
Input 3rd order intercept point	4.5dBm at -15 dBm input power	2.4 dBm at -10 dBm input power
Output 3rd order intercept point	15.5 dBm at -15 dBm input power	13.86 dBm at -10 dBm input power

Table III. PA simulation of amplifiers.

	Switchless bidirectional amplifier-PA	Bidirectional amplifier with switch-PA
Gain	13.4 dB at 2.45 GHz	14.25 dB at 2.45 GHz
Reverse isolation	20.73 dB at 2.45 GHz	17.46 dB at 2.45 GHz
Input return loss	14.14 dB at 2.45 GHz	13.76 dB at 2.45 GHz
Output return loss	10.7 dB at 2.45 GHz	17.79 dB at 2.45 GHz
Noise figure	2.37 dB at 2.45 GHz	1.626 dB at 2.45 GHz
Input 1dB compression point	4.5 dBm	4.5 dBm
Output 1dB compression point	16.5 dBm	17.5 dBm
Input 3rd order intercept point	13 dBm at -1.8 dBm input power	15 dBm at 3.4 dBm input power
Output 3rd order intercept point	28 dBm at -1.8 dBm input power	22 dBm at 3.4 dBm input power

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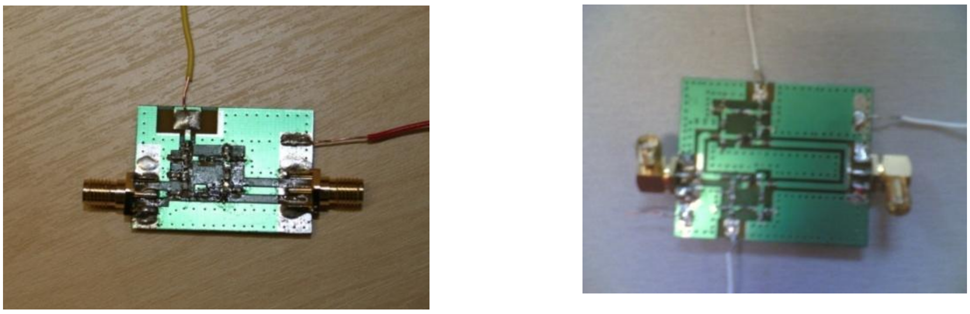
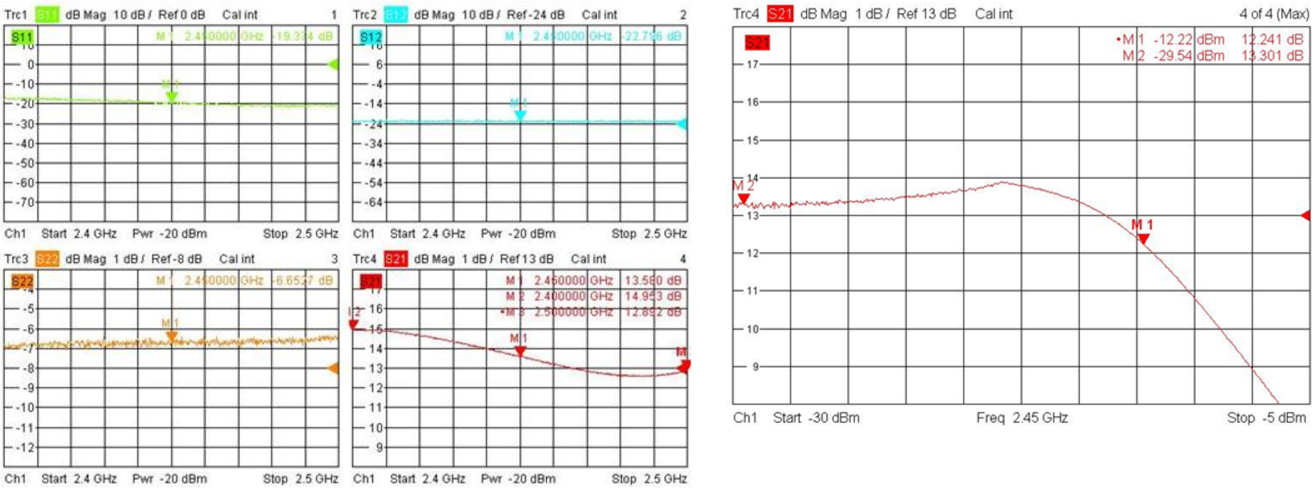
III. PROTOTYPES AND MEASUREMENTS

The circuit boards for both designs are built and measured for corroboration with simulations. Prototype boards are illustrated in Fig. 9. Measurements were performed with Rohde & Schwarz ZVB20 Network Analyzer. Measurement results for LNA and PA are shown in Fig. 10 and 11. Summary of measurement results for PA and LNA, together with their simulated values are presented in Table IV.



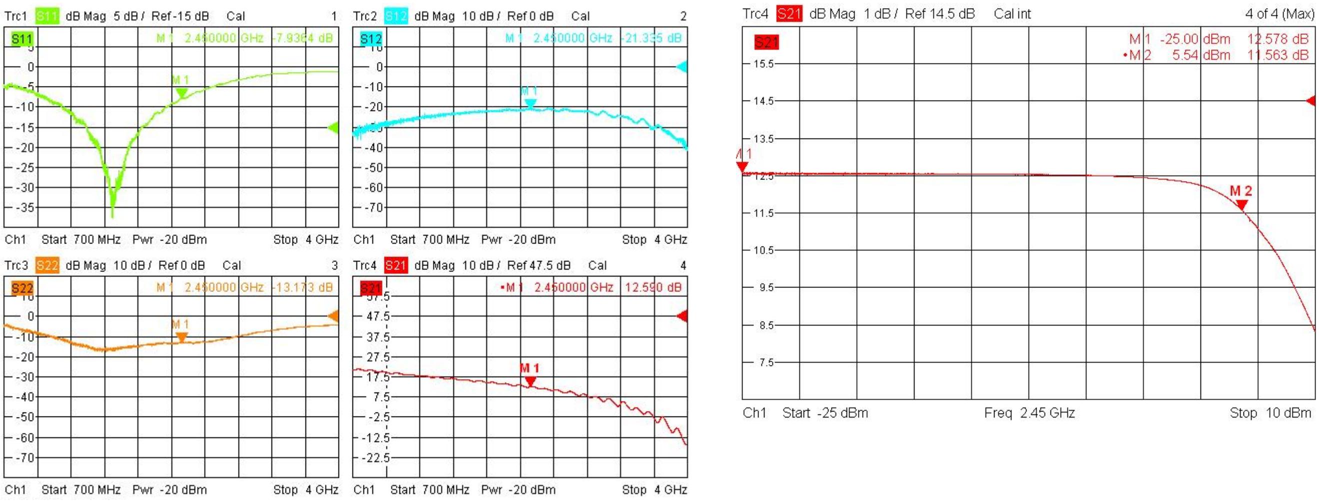
(a) (b)

Fig. 9. Prototype pictures a) with switch, b) switchless amplifier.



(a) (b)

Fig. 10. LNA measurements a) full S-parameters, b) 1-dB compression point.



(a) (b)

Fig. 11. PA measurements a) full S-parameters, b) 1-dB compression point.

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Table IV Comparison of simulated and measured values

	LNA		PA	
	Simulated	Measured	Simulated	Measured
Gain	14.84 dB	13.58 dB	14.25 dB	12.59 dB
Reverse isolation	21.17dB	22.79 dB	17.46 dB	21.33 dB
Input return loss	13.68 dB	19.3 dB	13.76 dB	7.93 dB
Output return loss	11.27dB	6.65 dB	17.79 dB	13.17 dB
Input 1-dB comp. point	-10.67dBm	-12.22 dBm	4.5 dBm	5.54 dBm
Output 1-dB comp. point	3.75 dBm	0.02 dBm	17.5 dBm	17.1 dBm

IV. CONCLUSION

We show that it is possible to design bidirectional amplifier with and without using RF switches. The performance of switchless design is a bit inferior to that of design with switch. Nevertheless, both designs employ minimal number of components to meet design specifications. LNA and PA current draws are 6.5 mA and 55 mA, respectively from a 3 V DC supply. Unlike previous designs, our switchless design employs negative DC bias for the unused amplifier, i.e. either LNA or PA. For both designs, good linearity is achieved. Presented designs offer low-cost implementation of bidirectional amplifiers for separating transceiver units from the antenna element.

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