The Designs of Transmit/Receive Module for X-Band Navigation System

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Abstract – **This paper is concerned with some versions and measurements of the X–Band Transmit/Receive (T/R) module that is a key unit of the active phased array antenna (APAA). In the first version (V1), the transmit chain (TX) is primarily composed of a medium power amplifier and a two-watt-output power amplifier, and the Receive chain (RX) includes a low noise amplifier (LNA), and an attenuator (AT). In the second version (V2), an analog phase shifter is added to the transmit chain (TX), along with a medium power amplifier, as well as temperature controlling circuits. In the Receive chain (RX) a phase shifter (PS) and a LNA with voltage gain amplifier (VGA) are added, but the AT is removed. Thanks to this improvement, the T/R module achieved 31dBm minimum P1dBc with 30 dB linear gain in TX, 32 dB linear gain and with 5.1 dB noise figure in RX, with dynamic range of at least 95 dB. With both versions, the focus of mechanical designing is to reduce effects from noise and rising temperature.**

Keywords – Module Transmit/Receive; X-Band; phase array antenna;

I. Introduction

T/R module with high power amplifier is one of the essential sub-circuits used to transfer the modulated signal of ranging from mobile communication to radar system [1]. In the design of a high frequency T/R module, the goal is to achieve sufficient power gain and output power, as well as high power-added efficiency (PAE) in the TX part; low noise figure and high gain in the RX part. However, to achieve optimum electrical performance of a T/R module, there are a great number of considerations that need to be taken care of such as output power, gain, phase, temperature, current parameters of the T/R module. Nowadays, thanks to the rapid evolution of the semiconductor technology, more and more components (SOC, RFIC, MMIC, etc.) for radio frequency (RF) have been designed to meet the increasingly high demands of target applications [2, 3].

One of the first T/R models for small tracking system in X-Band had been developed by Le Quy Don Technical University in 2009 [4]. Nevertheless, this model has some limitations, namely low gain of RX chain, lack of phase and temperature control. That brought about the demands for a new T/R design with higher performance.

This paper will show some designs and results of T/R modules. The specifications are summarized in Table 1.

TABLE 1
ELECTRICAL FEATURES OF THE T/R MODULE V1

Item	Features	
Classification	TX	RX
RF frequency band	9.3–9.7 GHz	9.3–9.7 GHz
Return loss	13dB (min)	13dB (min)
Insertion loss	13dB (min)	13dB (min)
Linear gain	30dB (min)	22dB (min)
P1dB	31dBm	–
T/R Isolation	–	20dB
Noise Figure	–	4.0dB

TABLE 2
ELECTRICAL FEATURES OF THE T/R MODULE V2

Item	Features	
Classification	TX	RX
RF frequency band	9.3–9.7 GHz	9.3–9.7 GHz
Return loss	13dB (min)	13dB (min)
Insertion loss	13dB (min)	13dB (min)
Linear gain	30dB (min)	32dB (min)
Phase control step	–	–
P1dB	31dBm	–
T/R Isolation	–	20dB
Noise Figure	–	5.1dB

II. T/R MODULE DESIGNS

The primary function of the transmit channel is to provide a highly stable phase and amplitude adjusted pulse of microwave energy to the antenna radiating elements [4, 5]. Its maximum output power depends on using manufacturing technology, technical layout, etc. Two T/R modules based on fixed components [9] will be illustrated in this paper. The first architecture of the T/R module shown in Fig.1 is of simple type, while the second version shown in Fig. 4 has some advantages such as high gain in RX chain, phase control in TX and RX chains, rising temperature control. The first version in Fig. 1, 2, 3, which was designed in 2009, is simple. At the input, the circulator C1 has three ports in which a microwave signal at any port is transmitted to the next port in clockwise rotation. This circulator has a maximum insertion loss of 0.4 dB, a minimum isolation of 20 dB, average power of 10 W, and voltage standing wave ratio of 1.25 from 9.2 GHz to 9.9 GHz. The input power will be around 0 to 5 dBm for transmission, the necessary gain to produce an output power of 30 dBm is provided by the medium power amplifier (14 dB) and the power amplifier (20 dB). The other circulator, C2, is necessary at the output of the power amplifier, to help transmit signal from T/R module to a radiation element (e.g. antenna) or vice versa. The role of low noise amplifiers LNA is to provide high gain approximately 24dB and a low noise figure of 2.3 dB. The attenuator, which operates from DC to 14 GHz and controlled via single voltage attenuator control from 0 to -3 V, provides a continuously variable attenuation range of 30 dB. The block diagram, Microwave office (MWO) [10] schematics and layout for this transceiver are shown in Fig. 1, 2, and 3, respectively.

In the second design, phase shifter and medium power amplifier are added to the transmit part. The phase shifter is one of the most important components in T/R module. It must provide at least 360 degree of accurate phase control across the operating frequency band while providing low insertion loss, low VSWR, high intercept point, and fast switching time. In fact, each T/R module has different phase input and output signals.

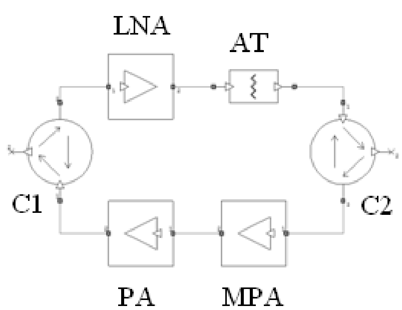


Fig. 1 Block diagram of the first version T/R

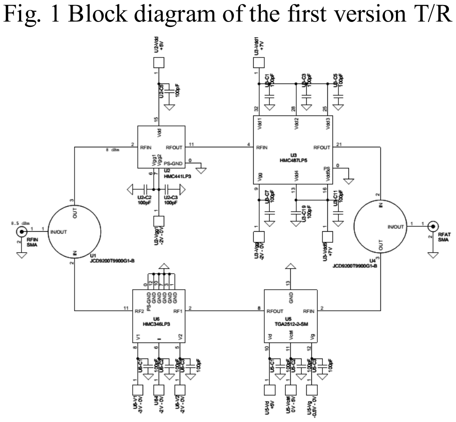


Fig. 2 Schematic of the T/R module of first version

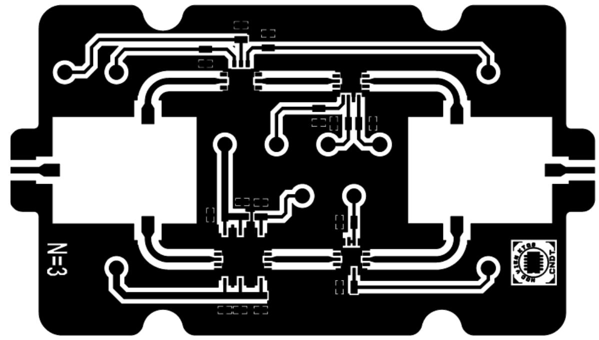


Fig. 3 Photograph of assembled first version T/R

Thus, in order to control all T/R modules phase, phase shifters need to be added in TX and RX chains. This phase shifter operates in wide bandwidth from 6 to 15 GHz, provides a continuously variable phase shift from 0 to 700 degree at 10 GHz with normal insertion loss (input and output) of 8 dB. This insertion loss, in turn, is totally compensated by an additional medium power amplifier located next to the phase shifter. This change comes from the addition of phase shifter to both transmit and receive chains of the T/R module, which allows their phase to be controlled flexibly for different purposes such as radiating beam forming, etc. Besides, with additional low noise amplifier and phase shifter, the RX part could provide higher gain of around 32 dB and control phase in RX part. Apart from that, in this version, two low noise amplifiers LNA1, LNA2 are also installed to provide high gain, but the order of LNAs needs to be considered to provide optimum noise figure. The LNA1 has noise figure and gain of NF_1 and G_1, respectively, while the LNA2 has noise figure and gain of NF_2 and G_2, respectively. Between the LNA1 and its neighbor, LNA2, is a RF loss, namely phase shifter PS2 in the T/R module. The module receiver's noise figure NF includes all contributions beyond that point. The system noise figure is given as [8]:

$$NF = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1.G_2} + \ldots + \frac{NF_n - 1}{G_1.G_2 \ldots G_{n-1}} \qquad (1)$$

Where NF_i, G_i are noise figures and gain of ith component in the RX chain.

According to the datasheets [9], these values might be:

NF_1 = 2.3 dB, G_1 = 20 dB, (LNA1)

NF_2 = 2.3 dB, G_2 = 20 dB, (LNA2)

NF_3 = 8.0 dB, G_3 = 0.125 dB, (PS2)

thus, in the first case when the two LNAs are located next to each other (LN1, LNA2, PS2):

$NF =$ 2.38 dB;

in the second case when the phase shifter is located between two LNAs (LNA1, PS2, LNA2):

$NF =$ 3.17 dB;

Therefore, NF in the first case is smaller than in the second one.

From the above considerations, the schematic in Fig. 4 will be used.

Another change comes from the addition of temperature control circuit to regulate the operation of T/R module in different ranges of temperature. Specifically as shown in Fig. 5, temperature data of T/R module is updated every 4 ms and sent to a microcontroller (MCU) through the I2C interface (SDA and SCL in Fig. 5). Basing on the comparison between the updated value and the preset one, a signal tr_en will be created to allow or prohibit the T/R module's working. The preset-table value might be set in the microcontroller by designers or users (for example: the designer might set the operation condition of the T/R module of below 50^{o}C, then this value must be compared with the continuing updated temperature values). Using the temperature controller circuit could help T/R module avoid hazardous effects which may damage it.

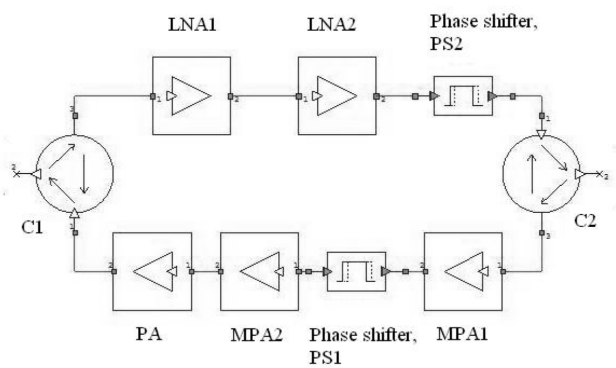


Fig. 4 Block diagram of the second version T/R.

The schematics and layout for this transceiver are shown in Fig. 6 and 7, respectively.

The control part of the module is located in its other side. This part will provide power supply, control pulses to enable or disable the module. Apart from this, there are also some sensors to control parameters such as temperature and current, thus improving the efficiency of the module.

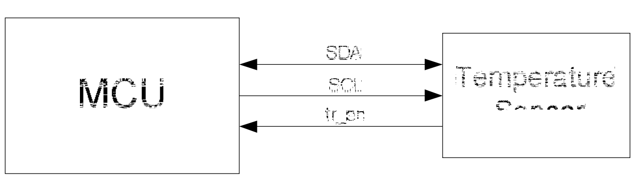


Fig. 5 Block diagram of the temperature controller circuit

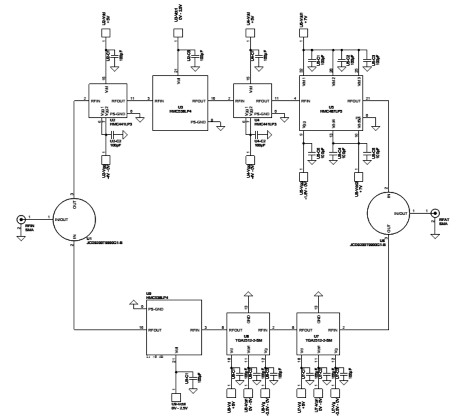


Fig. 6 Schematic of the second version T/R.

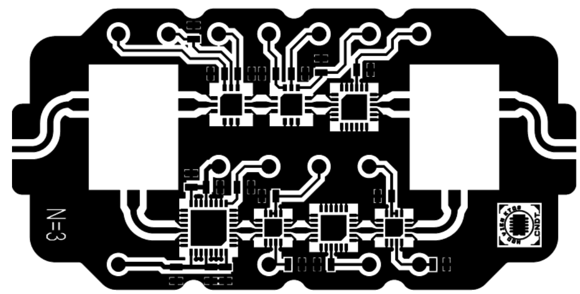
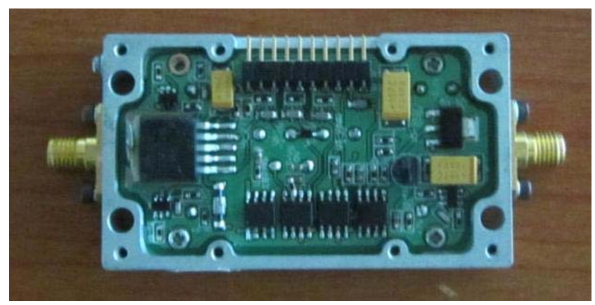


Fig. 7 Photograph of assembled second version T/R module.

III. EXPERIMENTAL RESULTS

In order to develop the T/R module, the RF boards are fabricated on a 10 mil–thick substrate, Roger4350B laminate. By the consideration of mechanic box design for the isolation between TX and RX channels, minimum 20 dB of isolation is achieved.



(a) Control side of first version.

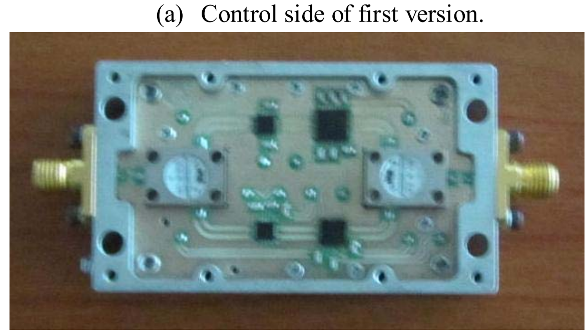
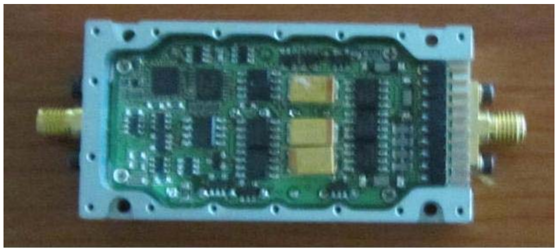


Fig. 8 (b) RF side of first version.



(a) Control side of second version.

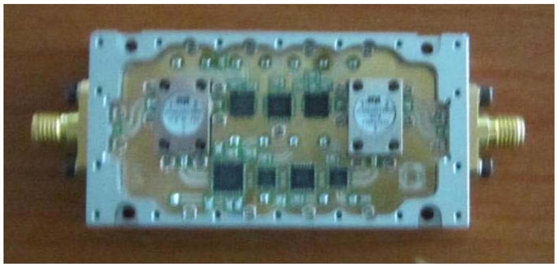


Fig. 9 (b) RF side of second version.

To test for these modules, some aspects were measured such as electrical connection, output powers, phase between inputs and outputs, module handling, electrical connection, measurement, data analysis, and data storage. The capabilities of the test station include PNA Network Analyzer E8362C, R&S NRP Power Meter, Spectrum Analyzer FSL 9 kHz – 18 GHz, oscilloscope TDS2014B, and programmable power supply RS–232C.

The measurement results as have been depicted in Fig. 10 show output powers at some frequencies. The minimum value of output power was 28.6 dBm at 9.3GHz and the maximum value was 31.4 dBm at 9.5 GHz. The Fig. 11 shows the minimum gain of RX chain, which is 1.43 dB at marker 2, obtained using a 30 dB external attenuator and a cable with insertion loss approximately 0.8 dB at 9.7 GHz. The noise figure measured is around 5.1 dB (Fig. 12).

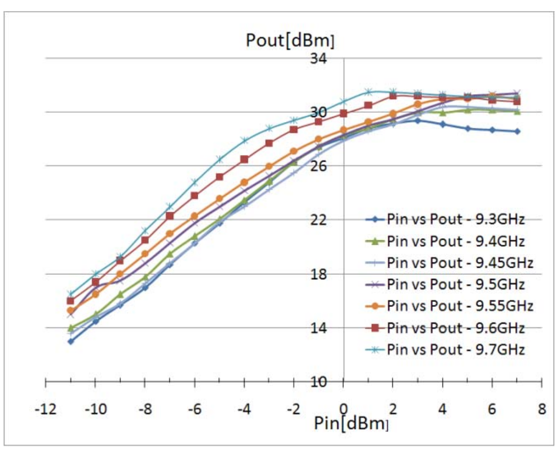


Fig. 10 Depending between output powers and input power of second version T/R module at power supply voltage Vcc = 7 V and current Icc = 1100 mA.

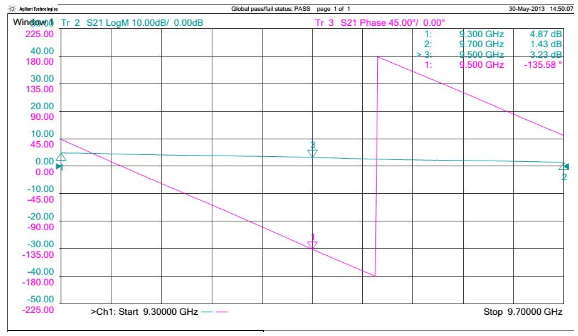


Fig. 11 Gain of RX chain of second version T/R module

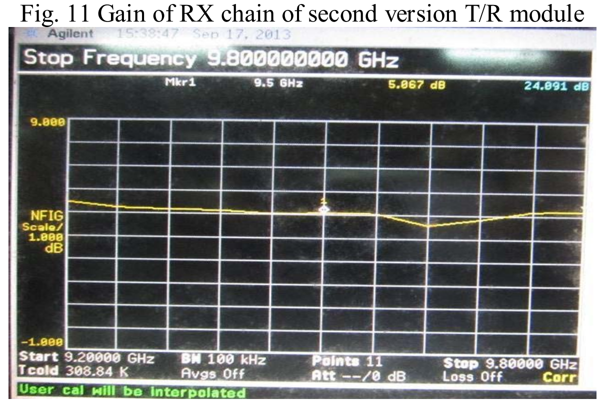


Fig. 12 Noise figure of RX chain of second version T/R module

IV. SUMMARY AND CONCLUSION

The design and measurement results of two T/R module versions have been discussed. Although the module has some limitations regarding heat sinking, isolation between TX and RX, its performance levels achieved are fully applied in navigation systems in Vietnam [4].

In the future, a great number of T/R modules will be produced with higher power amplifier such as 8 or 15 Watt each module and the above limitations will be phased out.

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