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Design of a Front-End for Satellite Receiver

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ABSTRACT

This paper focuses on the design and implementation of a front-end for a Vinasat satellite receiver with auto-searching mechanism and auto-tracking satellite. The front-end consists of a C-band low-noise block down-converter and a L-band receiver. The receiver is designed to meet the requirements about wide-band, high sensitivity, large dynamic range, low noise figure. To reduce noise figure and increase bandwidth, the C-band low-noise amplifier is designed using T-type of matching network with negative feedback and the L-band LNA is designed using cascoded techniques. The local oscillator uses a voltage controlled oscillator combine phase locked loop to reduce the phase noise and select channels. The front-end has successfully been designed and fabricated with parameters: Input frequency is C-band; sensitivity is greater than -130 dBm for C-band receiver and is greater than -110dBm for L-band receiver; output signals are AM/FM demodulation, I/Q demodulation, baseband signals.

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1. INTRODUCTION

The front-end has to be able to process very small signals at C-band in a noisy environment, unwanted signals. Due to these operation conditions, receiver front-ends are much more complex than the transmitter front-ends. They are dominated by analog and digital circuits such as low noise amplifier, mixers, local oscillator, filters, digital signal processing. There are some principal receiver architectures such as direct-conversion (homodyne, zero-IF) and dual-conversion (heterodyne) topologies. These architectures reflect hardware solutions to process the down-conversion of the modulated signals. The dual-conversion receiver architecture is one of the most popular architectures for today's receiver in wireless communication systems. The receiver architecture using heterodyne topology is shown in Figure 1.

The LNA amplifies the weak signal which is further filtered by a band-pass filter (BPF). In the following first mixer (Mixer 1), the C-band signal is mixed with the local oscillator (LO) signal to convert to a lower intermediate frequency (L-Band). The second mixer converts signals from L-Band to IF_2 (70-140MHz). After demodulation, I and Q baseband signals are filtered with a band-pass filter and amplified by variable-gain amplifiers (VGA) to receive an optimal amplitude to provide the output. In addition, to get the average signal provides antenna control system, the receiver is designed to demodulate AM/FM.

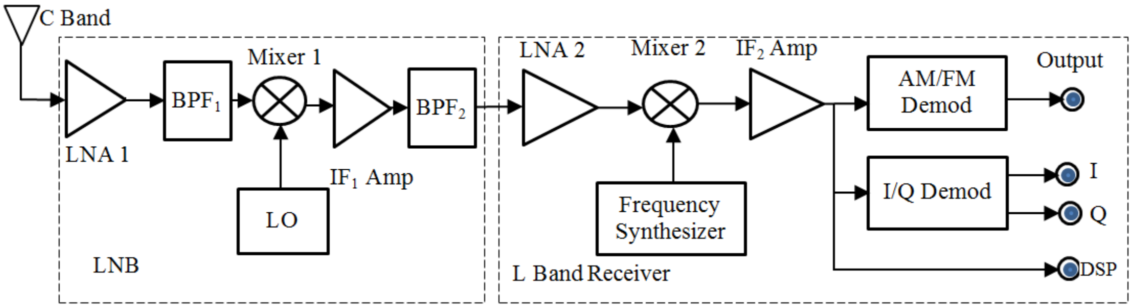


Figure 1. Dual-conversion receiver architecture

To design a receiver front-end with the best characteristic in the entire system, we have to solve those major challenges remain. The first of them is to achieve a low-noise figure (NF), higher sensitivity and sufficient bandwidth, dynamic range, low phase noise. Some results were publicated to optimize noise figure, overall gain, dynamic range and a local oscillator [1]-[5]. In the proposed design, a two-stage cascade LNA using discrete pHEMT amplifier can accomplish this goal. The first-stage amplifier was designed using negative feedback with T-type of matching network to reduce noise figure and increase bandwidth. The second stage is designed for high gain and wide band. To increase bandwidth of L-band LNA, the circuit is designed using cascaded and cascoded techniques. The second challenge is to achieve a low phase noise, spurious free signal with a sufficient power level of voltage controlled oscillator (VCO) [4],[7]. Therefore, the local oscillator use voltage controlled oscillator combine phase locked loop frequency synthesizer.

Under these conditions, the paper is organized as follows. Section 2 describes the design and simulation. Section 3 presents the fabrication and experimental results. Section 4 summarizes the conclusions of the presented work.

2. DESIGN AND SIMULATION

2.1. Design of Bandpass filters

At the input reveiver, the first bandpass filter (BPF1) has a center frequency of 3.8 GHz with passband from 3.4 GHz to 4.2 GHz or fractional bandwidth of 21%. The second bandpass filter (BPF2) passes the frequency from 0.95GHz to 1.75GHz, so it has a center frequency of 1.35GHz and fractional bandwidth of 60% [8].

There are some method designs of bandpass filters such as: End-coupled, parallel-coupled, hairpin, interdigital and stub bandpass filters... However, the hairpin bandpass filter was chosen, because it has open-circuited ends and compact configuration. The Chebyshev filter and FR4 substrate was chosen with parameters: five-pole and ripple of 0.1dB, substrate height 1.5 mm, loss tangent is 0.001 and dielectric constant is 4.34. A procedure of the design can be found in [8], the simulated results is shown in the Figure 2.

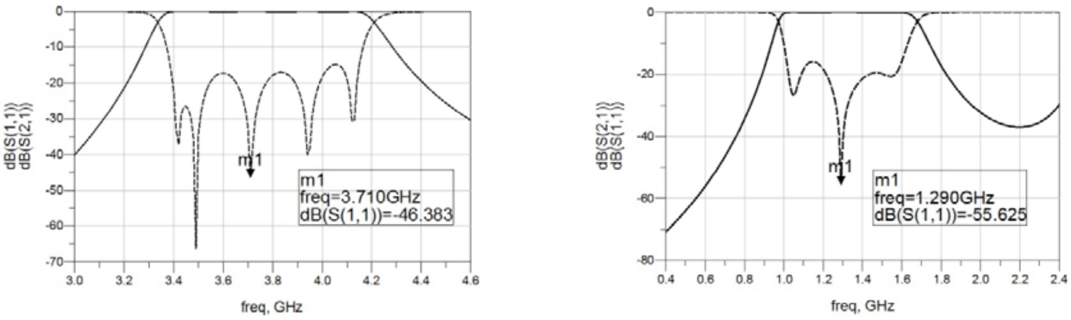


Figure 2. Simulated results of S_{21} and S_{11} at 3.8 GHz and 1.35 GHz

2.2. Design of a C-band low noise amplifier

In order to achieve bandwidth 800 MHz and high gain, we suppose the design of the LNA has two-stage cascade amplifier based on the design of single-stage one. The center frequency in the first stage is 3.7 GHz and the second stage is 3.9 GHz.

This two-stage amplifier was designed using T-type of matching network at the input and output terminal. However, the negative feedback can be used in broadband amplifiers to create a linear, flat gain response and lower input and output VSWR [9]. Thus, the first stage used negative feedback circuit to degrade the noise figure and increase stable, bandwidth. The most common methods of negative feedback technique are the shunt and series resistor configuration. The negative feedback technique proposed by Gozalez was selected for this work [9].

The SPF-3043 transistor with low noise figure and high associated gain was chosen for the amplifier design. The S-parameter is used for the design of the input and output matching networks using Smith chart [2]. To obtain the minimum noise figure in the first stage, the reflection coefficient Γ_S look into the source is equal to Γ_{opt}, where Γ_{in} is set to be the conjugate of Γ_S and Γ_{out} is set to be the conjugate of Γ_L.

In the second stage, it will be designed to obtain the maximum gain. In order to transfer the maximum power from the input matching networks to the transistor will occur when $\Gamma_S = \Gamma^*_{in} = S^*_{11}$ and the maximum power transfer from the transistor to the output matching network will occur when $\Gamma_L = \Gamma^*_{out} = S^*_{22}$. The completed LNA with two stages is shown in Figure 3. To meet the high IIP3 (third-order input intercept point), the transistor will be biased at I_{DS} = 30mA, V_{DD} =5V and V_{GS} = -0.3V.

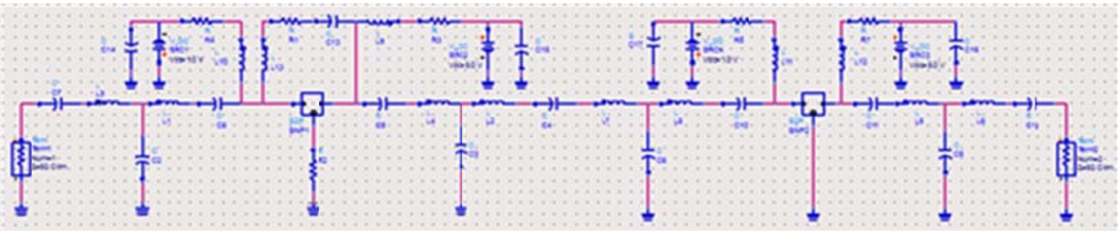


Figure 3. Schematic of the two-stage cascade LNA

The initial simulations to test the LNA performance were done with the S-parameter file of the transistor with ADS software.

The Figure 4 displays the S_{21} parameter which has been achieved: overall gain is greater than 32.5 dB from 3.4 GHz to 4.2 GHz and the value of input and output impedance matching is quite good. The noise figure is less than 1.110dB in a work band.

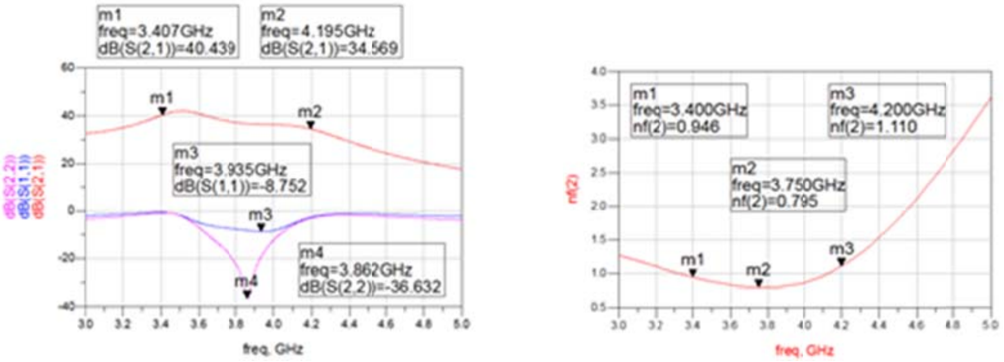


Figure 4. S-parameter simulated results of the LNA and the noise figure of the amplifier

2.3. Design of a L-band low noise amplifier

There are two types of amplifier topology used for LNA, these are the cascaded and cascoded techniques. The cascoded topology is the most famous since this technique introduces a wideband, while cascaded topology is used to increase the gain of the amplifier. To reach wideband and high gain, the L-band LNA is designed using a single cascoded LNA and single stage LNA. The first stage LNA is designed using cascoded topology to achieve a minimum noise figure and bandwidth. The second stage will be designed with the T-type matching networks at center frequency 1.5 GHz to obtain the maximum gain available and bandwidth. The completed L-band LNA with two stages is shown in Figure 5.

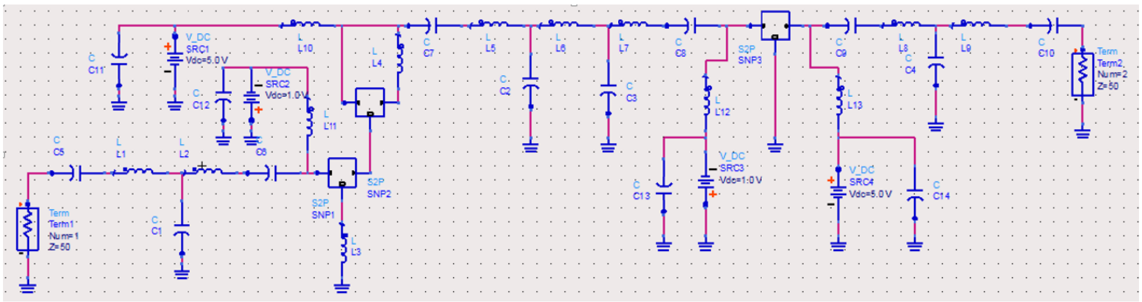


Figure 5. Schematic of the two-stage cascade LNA

The simulated results of the L-band LNA is shown in Figure 6. The gain is greater than 45 dB from 0.8GHz to 2.1 GHz and the value of input and output impedance matching is quite good. The noise figure is less than 1.35dB in a work band.

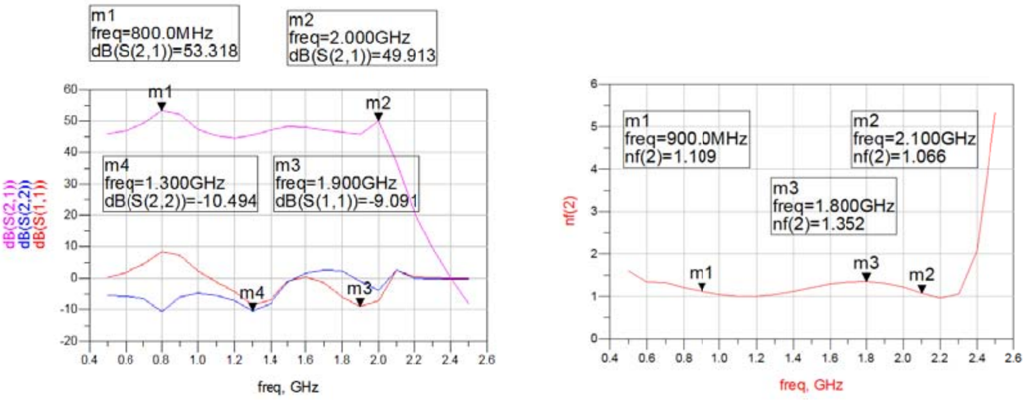


Figure 6. S-parameter simulated results of the LNA and the noise figure of the amplifier

2.4. Design of the local oscillator, frequency synthesizer and IF amplifier

The local oscillator (LO) produces a fixed output frequency and must have extremely high stability as well as satisfying amplitude (in dBm). The design specification of the LO operates at 2.45 GHz to convert from C-band to L-band (950MHz to 1750MHz). A structure of the LO is shown in Figure 7.

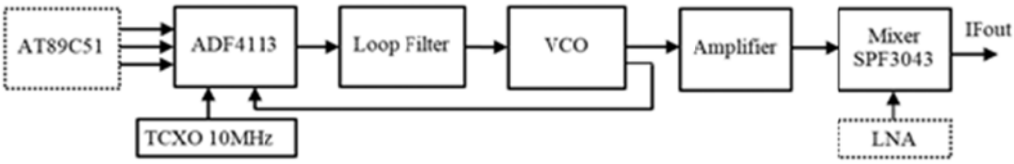


Figure 7. The architecture of the frequency synthesizer

In order to stable oscillator frequency, our solution uses monolithic integrated synthesizer ADF4113 from Analog Devices. It includes a low-noise digital phase frequency detector, a precision charged pump, a programmable reference divider, a dual modulus prescaler and two programmable counters. Data are transferred into the synthesizer by a three-wire serial interface. The loop filter was designed for a RF output of 2.45GHz, a PFD frequency of 1 MHz, a prescaler value of 16/17. The lock detector indicates the lock state of the PLL. The VCO CVCO33BE-2400-2500 from Crystek Corporation is selected. Supply voltage and tuning voltage of the VCO is 5VDC, which is the same supply voltage of ADF4113. The schematic of LO using VCO with PLL is shown in Figure 8.

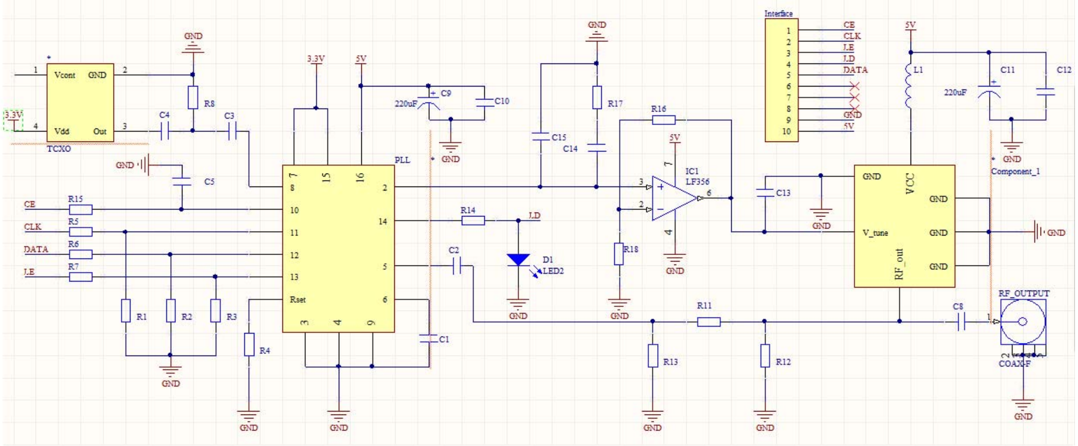


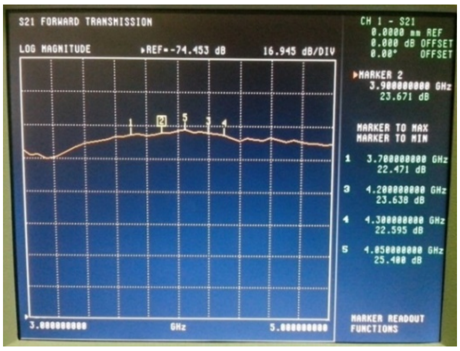
Figure 8. The schematic of the frequency synthesizer

The frequency synthesizer uses a VCO CVCO55BE-1000-2000 from Crystek Corporation. The supply voltage of the VCO is 10VDC and tuning voltage is from 1 to 20VDC. IC ADF4113 is connected to microcontroller ATMEL AT89C51 to change receiver channels. The microcontroller is programmed to recognize the pressed switch to change the oscillator frequency of VCO.

To expand the dynamic range, the IF amplifier is designed with automatic gain control and using a digital attenuator at the input of module before L-band LNA. This is one of the biggest advantages of this design which can improve the upper saturation limit.

3. EXPERIMENTAL RESULTS

The front-end was successfully fabricated in laboratory with the aid of the softwares and equipments. The C-band LNB has been tested, and the consequent measurements on the Network Analyzer 37369D have confirmed the designed parameters. The Figure 9 determines the maximum gain of LNA is 25.4 dB at 4.05 GHz and circuit amplifies wide band from 3.4 to 4.2 GHz with gain is greater than 22 dB.



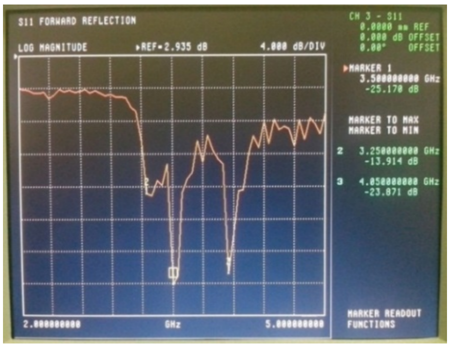


Figure 9. The gain of the LNA

Figure 10. The input reflection coefficient S11

Looking into the results in Figure 9, we can see that, the measured S_{11} resonates at 3.5 GHz and 4.05 GHz, compared to 3.862 GHz of the simulation. However, the measured results is better than simulation. The magnitude of S_{22} clearly illustrates the quite good output impedance matching. Although the measured results have impedance matching to be larger than simulation, but they both display S_{22} value are acceptable and satisfy the requirement set. Figure 12 shows the noise figure measurement, the noise figure is less than 1 dB from 3.4 GHz to 4.2 GHz.

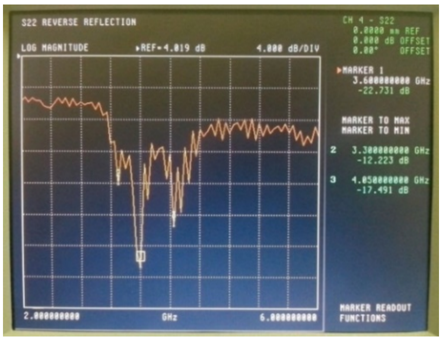


Figure 11. The output reflection coefficient S22

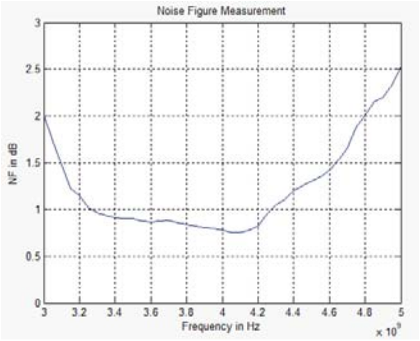


Figure 12. Noise Figure Measurement

Similarly, L-band LNA has been tested on the Network Analyzer with maximum gain is 33.769 dB at 1.191 GHz and circuit amplifies wide band from 0.7 to 2.25 GHz with gain is greater than 30dB. Due to matching networks are designed to obtain a maximum gain.

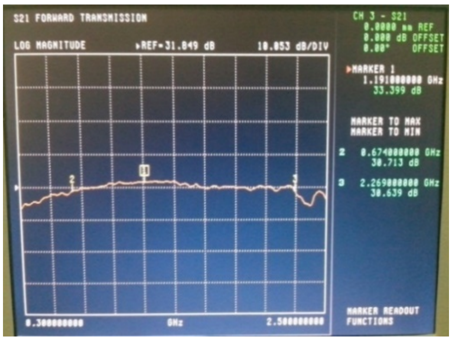


Figure 13. The gain of the IF amplifier

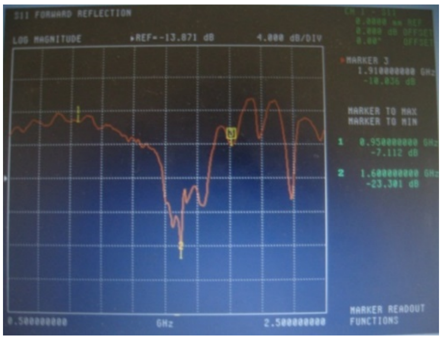


Figure 14. The input reflection coefficient

Both measured input and output reflection coefficient are better than the simulated results. The noise figure is less than 1.5 dB from 0.9 GHz to 2.15 GHz.

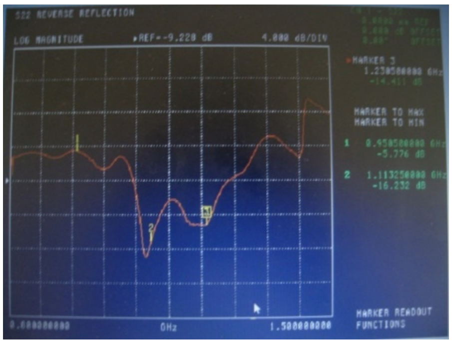


Figure 15. The output reflection coefficient

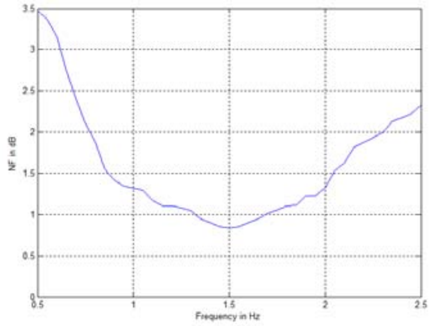


Figure 16. Noise Figure Measurement

The achieved results of the local oscillator are all performed using spectrum analyzer NS-265 from 9 KHz to 26.5 GHz meeting the requested command about stability and amplitude. Figure 17, 18 have shown that the power of the local oscillator is -3.33 dBm at 2.45 GHz and the phase noise reaches -107.55 dBc/Hz at 50KHz. This value is better than the VCO using discrete elements in paper [4].

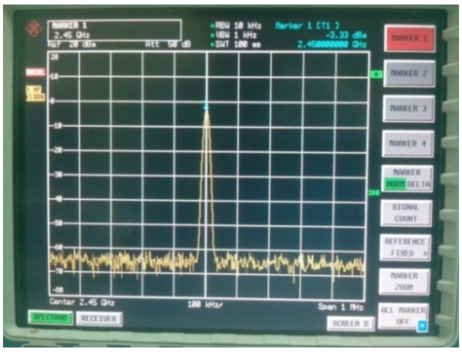


Figure 17. The result on the spectrum analyzer

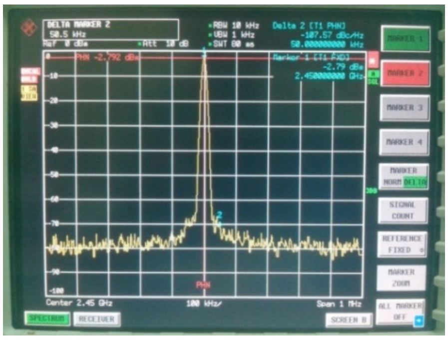


Figure 18. The phase noise at 50KHz

The completed structrure and the front of L-band receiver are shown in Figure 19.

Figure 19. Completed structrure of L-band receiver

The L-band receiver has been tested in a laboratory with equipments: Function generator FG7002C creates square pulses, which is connected to signal generator 8648C. The signal generator 8648C performs amplitude (or frequency) modulation with local oscillator signal to generate a L-band signal. Output signal from SG8648C is connected to L-band receiver to amplify and demodulate to reconstruct the original signal. This signal is put into the oscilloscope DL1720E.

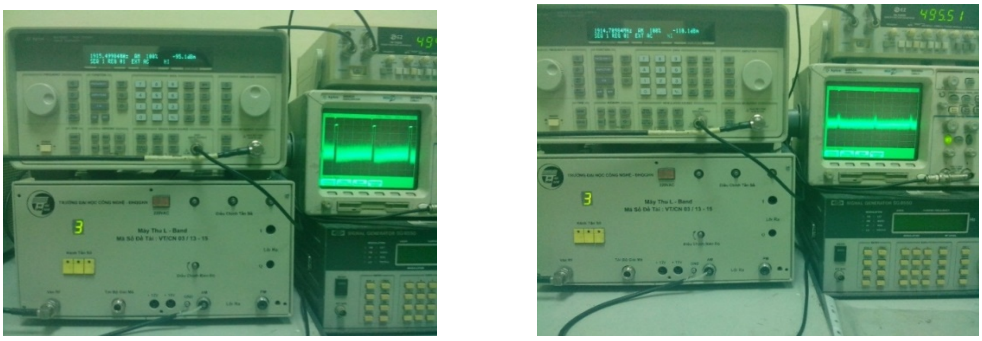


Figure 20. Modulated signal at 1915 MHz frequency, power level from -30 dBm to -110dBm

Square pulse signal at 495Hz from the signal generator FG7002C is passed through the Agilent 8648C signal generator, where the audio signal is modulated AM at 1915 MHz with the power level from -30dBm to -110dBm. From the Figure 20, we can see that the output signal enables to identify the sensitivity of the receiver is -110dBm. If L-band receiver is connected with C-band LNB, receiver sensitivity can be greater than -130 dBm. Due to receiver using automatic gain control and a digital attenuator, recceiver dynamic range can obtain 80dB.

Table 1 has shown comparison results of recently front-ends. The proposed method provides available wide-band, high sensitivity, and large dynamic range.

Table 1. Comparison of recently front-ends

Parameters	Ref. [4]	Ref. [5]	This work
Input frequency	1.26GHz – 1.268 GHz	C band	C band
Output signal	IF - 247MHz	IF – 1.2GHz	I/Q, AM/FM
Sensitivity	(Gain) 37dB	-83dBm	-130 dBm
Dynamic range		91dB	80 dB
Phase noise	-103.3dBc/Hz at 50KHz		-107.57dBc/Hz at 50KHz

4. CONCLUSION

This research presented design and fabrication a frond-end for a satellite receiver. The paper also proposed methods to increase gain, bandwidth and decrease noise figure by using negative feedback circuit and using cascaded and cascoded techniques with T-type matching networks. Besides, the local oscillator circuit used PLL frequency synthesizer to degrade the phase noise and to select receiver channels. The results show that the receiver had better performances in high sensitivity, wide-band and large dynamic range. This receiver has an open-configure due to using three demodulated methods, therefore it can be used for satellite communications, radar and microwave receivers. This receiver was using in the Vinasat satellite receivers with auto-search mechanism and auto-tracking satellite [10].

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