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Design narrow-band frequency amplifier (1.5GHz -1.6GHz) based on InGaP Heterojunction Bipolar Transistor (HBT) and GaAs HBT transistor

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ABSTRACT

The research aims to design a narrow-band frequency drive amplifier (1.5GHz -1.6GHz), which is used to boost the transmitter amplifier's input signal or amplify the GPS, GlONASS signals at the L1 band.

The Power Amplifier printed circuit board (PCB) prototype was designed using InGaP HBT homogeneous technology transistor and GaAs Heterojunction Bipolar Transistor (HBT) transistor. Two models have been compared; one of the models gave 16dB gain, and the other gave 23dB when using an input power signal (-15dBm). The PCB consumes 2.4W of power and has a physical dimension of 11 x 4 cm.

Keywords: Radio Amplifiers, PA, RF Drive Amplifiers, LNA, Low Noise Amplifier.

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تصميم مكبر استطاعة راديوي ضيق المجال (1.5GHz -1.6GHz) بالاعتماد على ترانزستور InGaP ثنائية القطب متغايرة الوصلة HBT وترانزستور GaAs ثنائية القطب متغيرة الوصلة HBT

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الخلاصة

يهدف البحث لتطوير مكبر قيادة ضـيَق المجال الترددي (1.55GHz -1.61GHz) وهو يسـتخدم لتقوية الإشـارة عند مدخل مكبر أجهزة الإرسال أو لتكبير إشارات أنظمة تحديد الموقع GPS، GLONASS عند المجال L1.
تم تصـنيع نموذج أولي للبطاقة المطبوعة للمكبر بالاعتماد على ترانزسـتور تقنية InGaP HBT المتجانسـة وترانزستور ثنائي القطب المتغيرGaAs Heterojunction Bipolar Transistor (HBT)
تم المقارنة بين نموذجين مختلفتين إحدى النماذج يقدم ربح 16dB والنموذج الآخر 23dB وذلك عند اسـتخدام إشـارة دخل باستطاعة (-15dBm) تستهلك البطاقة استطاعة 2.4W وذات أبعاد فيزيائية 4 x 11 سم.

1. INTRODUCTION

Any amplifier with a low Noise Factor (NF) can be used as a Low Noise Amplifier (LNA), which is the first block in high-performance receivers. It also determines the noise limits and receiver sensitivity in addition to signal-to-noise ratio (SNR), so LNA is the most important component in receivers since it determines the quality of the performance of these receivers **(Manjula, et al., 2018) (Kazan, 2018)**.

In a multistage communication system, every stage contributes noise to the entire system, **Fig. 1.** According to Friis' Formula, the total noise factor, which is a scale used to measure the total noise in a circuit, can be calculated as:

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \dots \quad (1)$$

Where F_1, F_2, F_3 are the noise factor for each stage, F_{total} is the total noise factor, and G_1, G_2, G_3 are the power gain factor for each stage.

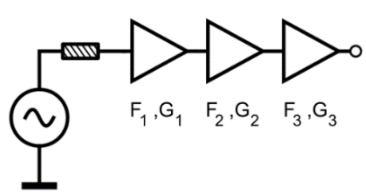


Figure 1. A diagram of a multistage receiver system.

In this equation, the noise factor and gain of the first stage are significant contributions to the total noise factor, and the gain of the first stage reduces the noise factor components of the following stages. A reasonable large gain and a small noise factor for the first stage in a system should be important considerations for good signal processing. Using Friis' Formula for noise and considering that the LNA is typically the first block of the receiver, it is clear that the LNA's noise figure (NF)s a key component for the entire front-end radio receiver circuit **(LIU, 2011)**. **Fig. 2** shows a typical architecture of a radio receiver system.

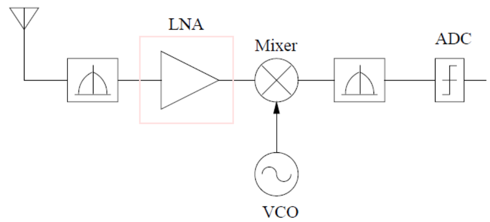


Figure 2. Typical architecture of a radio receiver (LIU, 2011).

The noise in the subsequent stages of the receiver chain is reduced by the gain of the LNA, so Friis' Formula can be expressed as:

$$F_{receiver} = F_{LNA} + \frac{(F_{rest} - 1)}{G_{LNA}} \qquad (2)$$

From equation (2), it is clear that the role of an LNA is an amplification of the input signal without adding too much noise to the whole system.

2. RESEARCH AIM

The design and improvement of a radio power amplifier's performance at the frequency range (1.55GHz -1.61GHz) to increase the signal level at the input of receivers and improve the signal level of the transmitter amplifier input to reach its working point.

3. MATERIALS AND METHODS

3.1.RESEARCH MATERIALS

The amplifier was designed to work at the frequency band 1.55GHz to 1.61GHz. Two stages were used to amplify each stage using a special amplifier in which the monolithic Amplifier ERA-5 was used. It works at the DC-4GHz band providing a power gain of 18.5dB and has a noise figure of 3.5dB. The second stage relied on Medium Power GaAs HBT Amplifier SXA-289 that operates in the frequency band 5-2000MHz, provides a power gain about 15dB, and has a noise figure of about 5.5dB. The research materials and equipment can be summarized as follows:

- FR4 substrate with dielectric thickness 1.6 mm, dielectric constant $\Sigma r = 4.5$, physical dimensions 11 * 4 cm and copper thickness 35µm
- Anritsu MG3692C signal generator up to 20GHz.
- ROHDE & SCHWARZ FSH8 Network & spectrum Analyzer operating in the 100KHz-8GHz frequency range.
- RG188 connection cable operates up to 20GHz.
- ROHDE & SCHWARZ Directional Power Sensor.

- ROHDE & SCHWARZ Power meter.
- 24VDC-5A power supply.

Fig. 3 shows the diagram of the test platform.

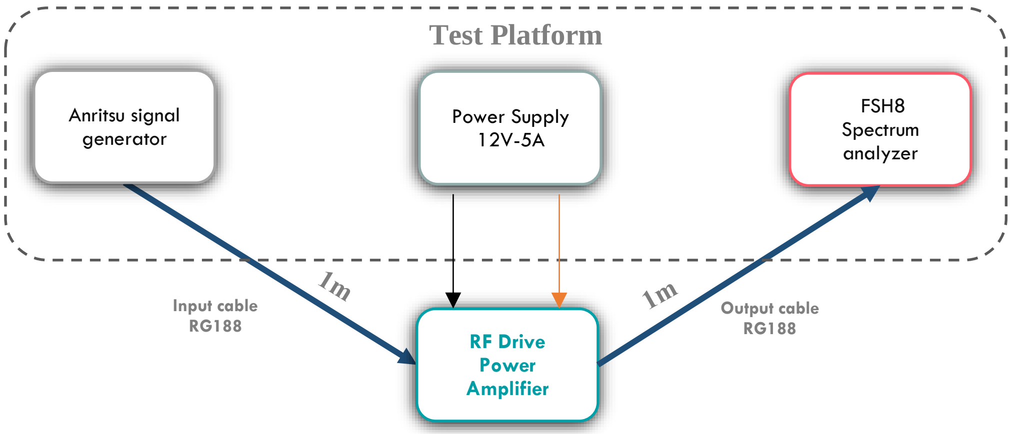


Figure 3. Block diagram of the test platform.

3.2. METHODS

It is based on two different models:

The first model consists of five stages, as shown in **Fig. 4**, as follows:

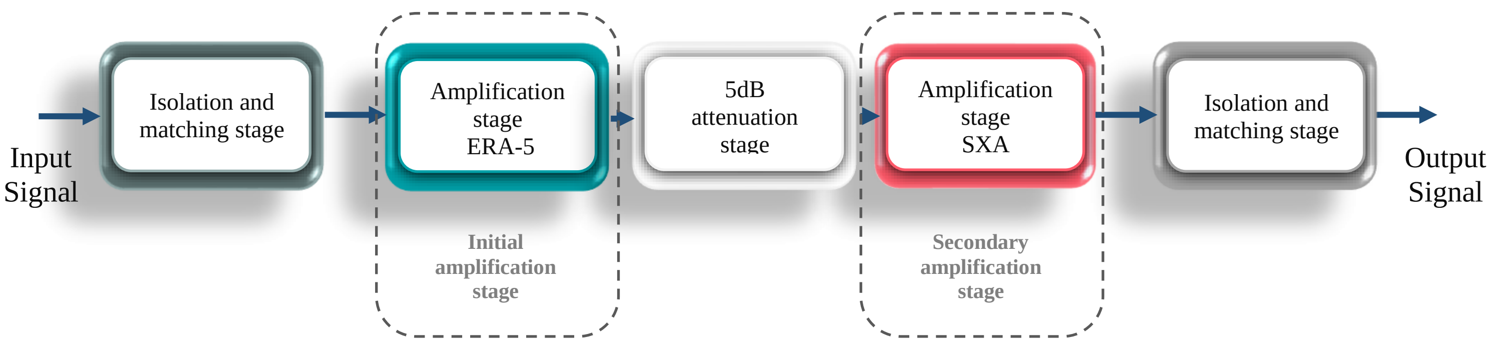


Figure 4. Block diagram of the RF Amplifier according to the first model.

This model is mainly based on five stages. The purpose of the attenuator stage is to reduce the threshold of the subsequent amplification stage's sensitivity.

PCB was designed using CADSTAR v16 as shown in **Fig. 5**, and it was printed on FR4 substrate with dielectric thickness, 1.6 mm, dielectric constant $\Sigma\ r\ =\ 4.5$, physical dimensions 11*4cm, and copper thickness 35µm.

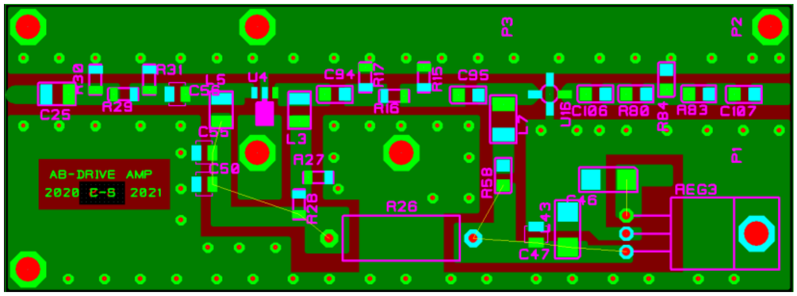


Figure 5. The layout of the RF Amplifier.

Fig. 6 shows a printed circuit board (PCB) before and after assembling the components

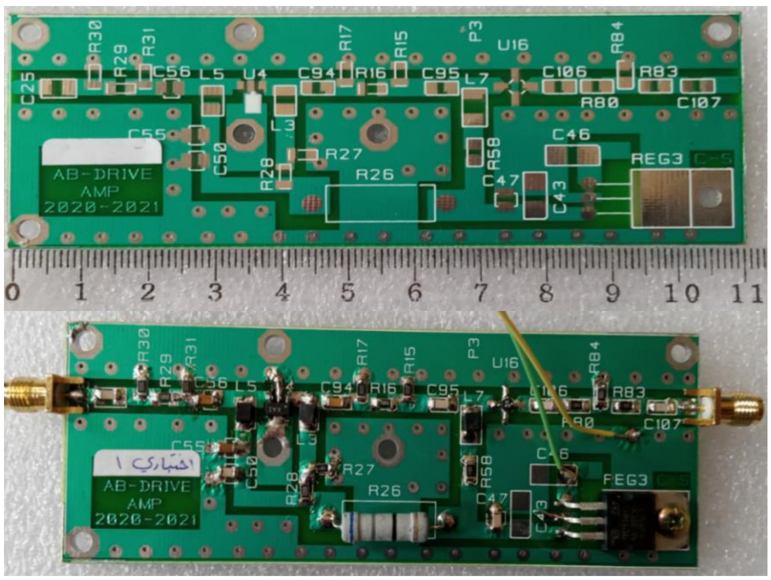


Figure 6. Printed circuit board manufactured according to the first model.

The second model consists of two amplifying stages with an isolation and matching stage between them, as shown in the following **Fig. 7**:

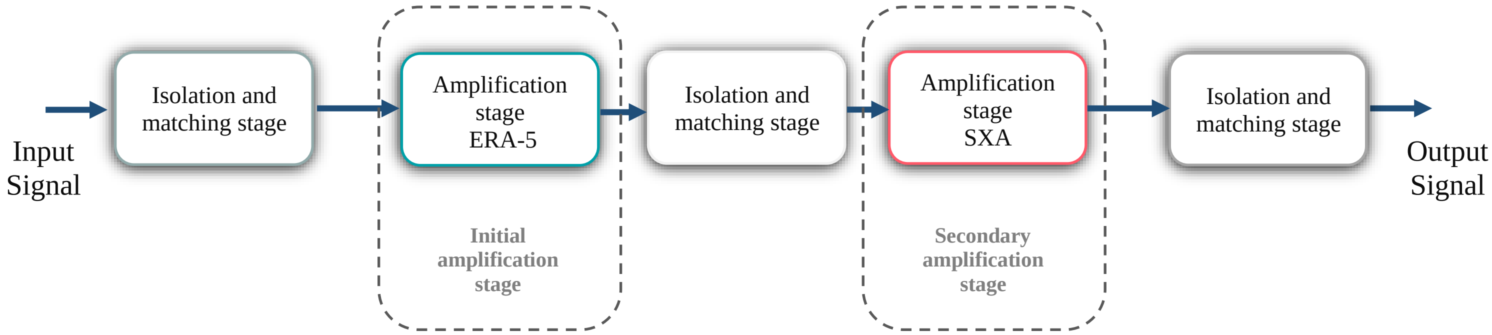


Figure 7. Block diagram of the RF Amplifier according to the second model.

Figure 8. Printed circuit board - second model.

4. RESULTS AND DISCUSSIONS

4.1.RESULTS OF THE FIRST MODEL

The measurements were made using the test platform, as shown in **Fig (3)**. The signal generator was used to generate a virtual receiving signal where its frequency and its level can be controlled in order to increase measurement accuracy and obtain practical results.
A variable frequency signal was generated within the 1.55GHz to 1.61GHz by a 5MHz step and power (-15dBm).

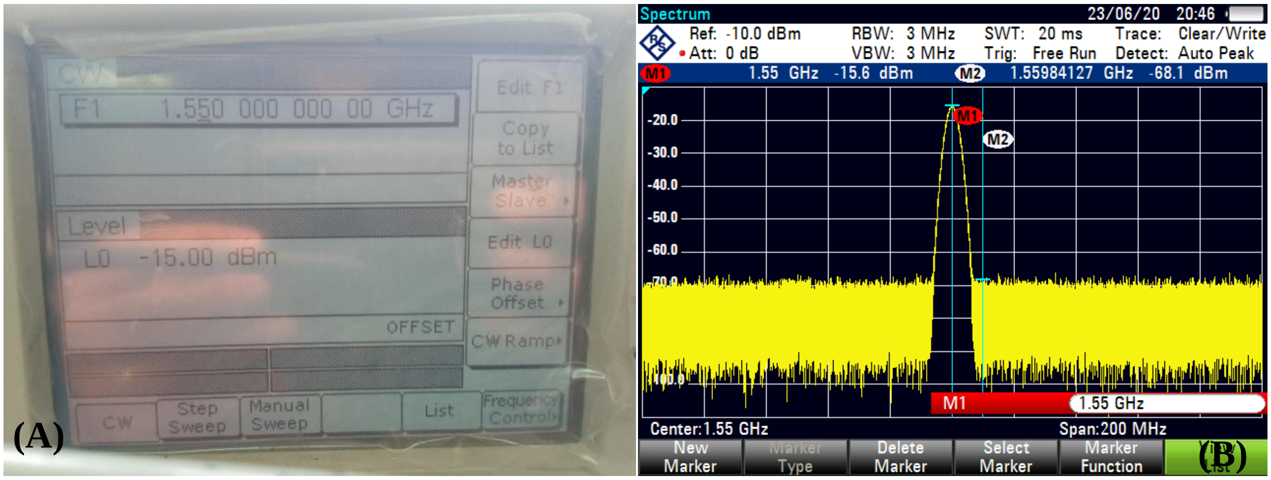


Figure 9. (A) signal generator, (B) the signal spectrum that appears on the spectrum analyzer.

By using Network and spectrum analyzer, the SNR of the input signal was calculated:

$$SNR_{IS}[dB] = 52.5[dB]$$

The test platform was configured before the measurements, and the cable loss resulting from attenuation was calculated for both the input signal and the output signal cables as the following:

- Attenuation of input signal cable (cable with connectors) 1.5dB at 1.55GHz.
- Attenuation of output signal cable (cable with connectors) 1.3dB at 1.55GHz.

The output of PA was connected to the input port of the Network and Spectrum analyzer (ROHDE and SCHWARZ FSH8), so the PA output signal could be viewed, and its parameters were calculated, as shown in **Fig. 9.**

The choice was made to use 1-meter-long cables. Applying a signal at the frequency of 1.55GHz with power (-15dBm), the spectrum analyzer showed the output of the PCB signal with a power (-1.3dBm), as shown in **Fig. 10**. Accordingly, the amplifier gain relationship could be concluded:

$$Gain_{PA}[dB] = Pout[dBm] - Pin[dBm] + InCAB_{loss}[dB] + OutCAB\ _{Loss}[dB] \ldots (3)$$

Where: $Gain_{PA}[dB]$: Gain of RF power amplifier in dB, Pout: output signal power, Pin: input signal power, $InCAB_{loss}$: input cable loss (Attenuation), $OutCAB\ _{Loss}$: output cable loss (Attenuation)

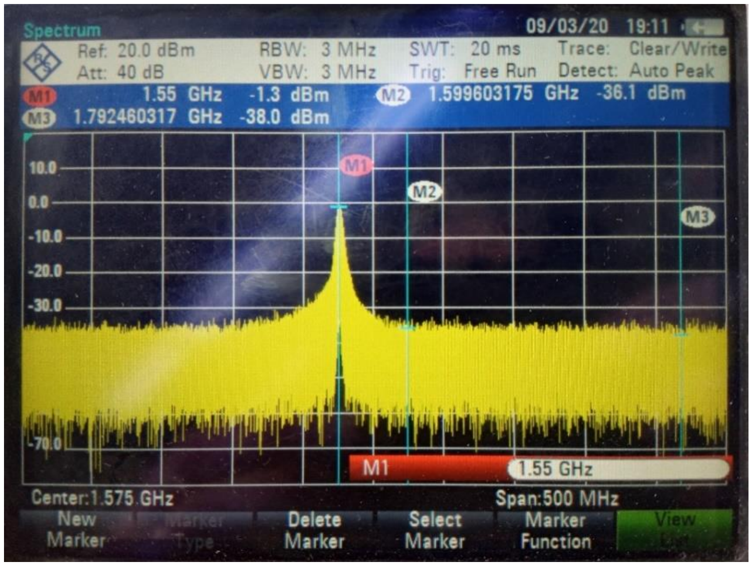


Figure 10. Power amplifier output signal.

By using Eq. 3 and parameters of PA that appeared on Network and spectrum analyzer, RF power amplifier gain can be calculated:

$$Gain_{@1.55GHz}[dB] = 16.5[dB]$$

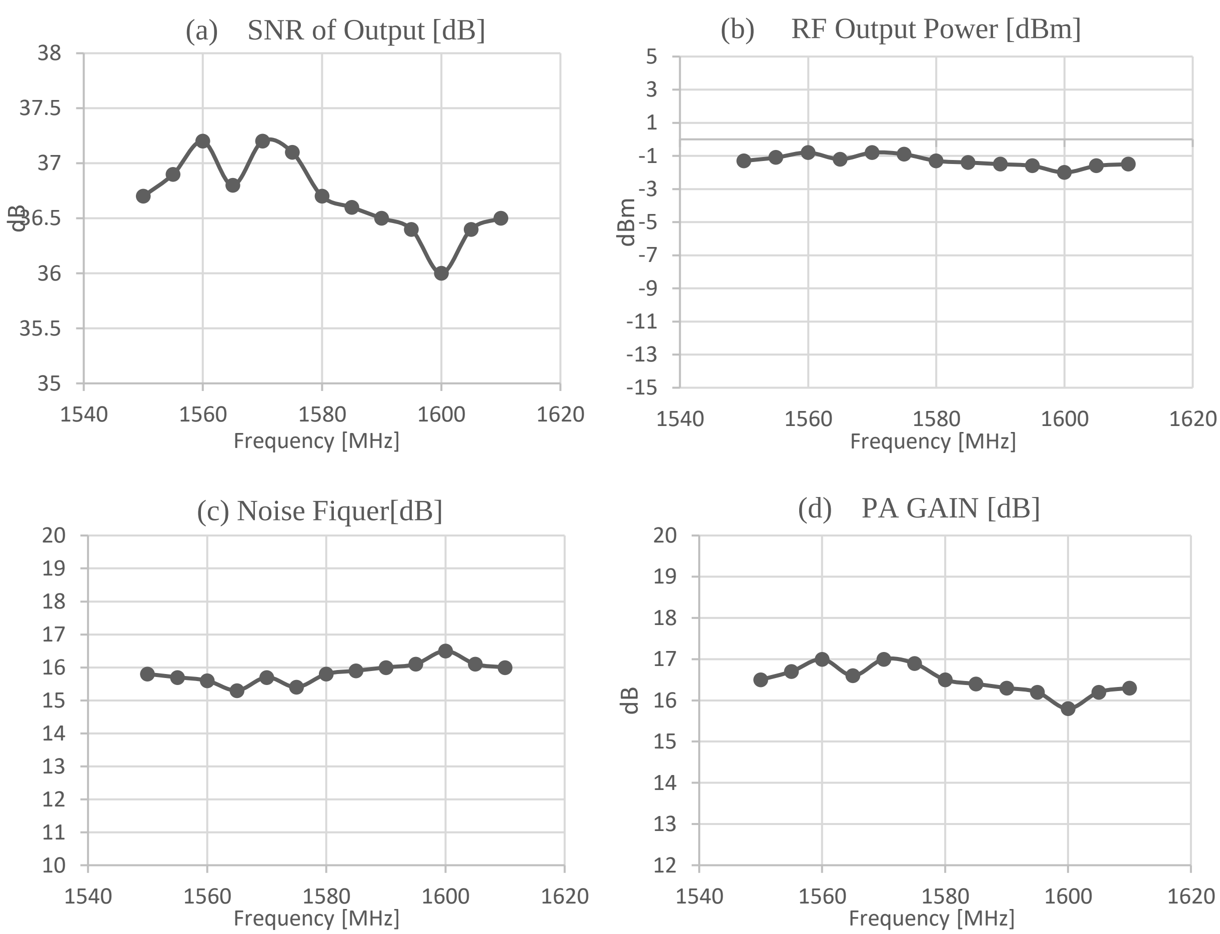
The amplifier at the 1.55GHz frequency band provides a gain of 16.5dB and a signal-to-noise ratio SNR of 36.7dB. These measurements and calculations have been made along the 1.55GHz frequency band to 1.61GHz by a 5MHz step; the results are shown in the following table:

Fig. 9 shows the signal-to-noise ratio, output signal capacity, noise figure, amplifier gain, and Power Added Efficiency vs. frequency.

From the curves, it is noted that the amplifier gain is almost constant along with the frequency band, whereas the NF increases with increasing frequency.

Table 1. Test results of the first model amplifier.

RF Frequency [MHz]	*Output SNR* [dB]	RF output Power [dBm]	F Noise Factor	NF Noise Figure [dB]	PA GAIN [dB]
1550	36.7	-1.3	38	15.8	16.5
1555	36.9	-1.1	37	15.7	16.7
1560	37.2	-0.8	36.3	15.6	17
1565	36.8	-1.2	33.8	15.3	16.6
1570	37.2	-0.8	37	15.7	17
1575	37.1	-0.9	34.6	15.4	16.9
1580	36.7	-1.3	38	15.8	16.5
1585	36.6	-1.4	38.9	15.9	16.4
1590	36.5	-1.5	39.8	16	16.3
1595	36.4	-1.6	40.7	16.1	16.2
1600	36	-2	44.6	16.5	15.8
1605	36.4	-1.6	40.7	16.1	16.2
1610	36.5	-1.5	39.8	16	16.3



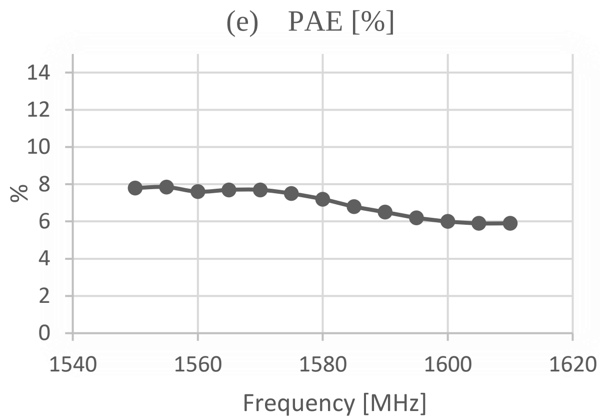


Figure 11. (a) - signal-to-noise ratio, (b) - output signal capacity, (c) - noise figure, (d) - amplifier gain, (e) - Power Added Efficiency vs frequency.

4.2. RESULTS OF THE SECOND MODEL

The same input signal specifications used in the first model were used here and the same connection cables. The results showed that the output signal power at 1.575GHz is 7.4dBm, as shown in **Fig (12).**

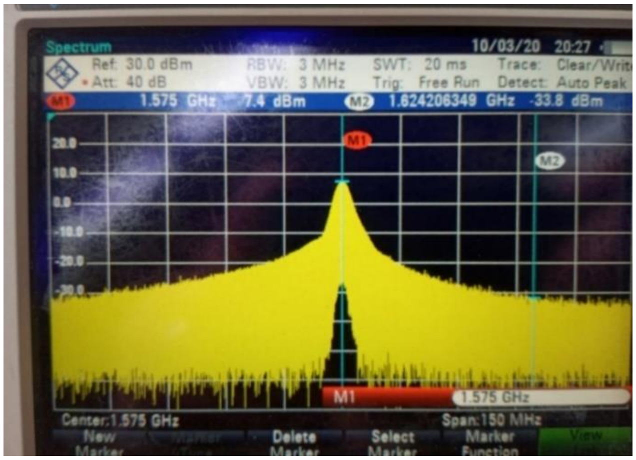


Figure 12. Amplifier output signal.

By using the relationship (5) and parameters of PA that appeared on the network and spectrum analyzer, we can calculate RF power amplifier gain:

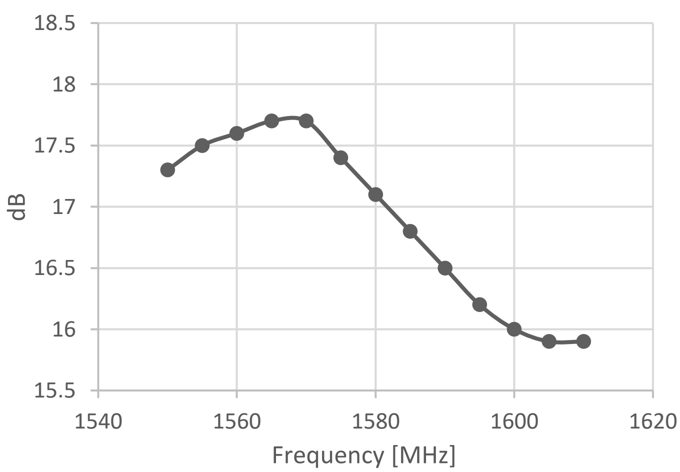
$$Gain_{PA@1.575GHz}[dB] = 25.2\text{dB}$$

The amplifier based on the second model at the 1.575GHz frequency band provided a gain of 25.2dB and a signal-to-noise ratio of 17.4dB. Additionally, these measurements and calculations were made along the 1.55GHz to 1.61GHz frequency band by a 5MHz step; the results are shown in **Table 2. Fig. 13** shows the signal-to-noise ratio, output signal capacity, noise figure, amplifier gain, and Power Added Efficiency vs. frequency

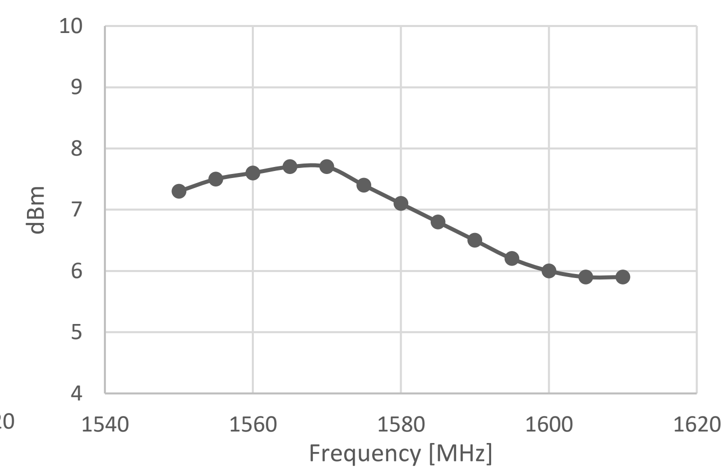
Table 2 Test results of the second model amplifier.

RF Frequency [MHz]	*Output SNR* [dB]	RF output Power [dBm]	NF Noise Figure[dB]	LNA GAIN [dB]
1550	17.3	7.4	35.2	25.1
1555	17.5	7.5	35	25.3
1560	17.6	7.6	34.9	25.4
1565	17.7	7.7	34.8	25.5
1570	17.7	7.7	34.8	25.5
1575	17.4	7.4	35.1	25.2
1580	17.1	7.1	35.4	24.9
1585	16.8	6.8	35.7	24.6
1590	16.5	6.5	36	24.3
1595	16.2	6.2	36.3	24
1600	16	6	36.5	23.8
1605	15.9	5.9	36.6	23.7
1610	15.9	5.9	36.6	23.7

(a) SNR-OS [dB]



(b) RF output power [dBm]



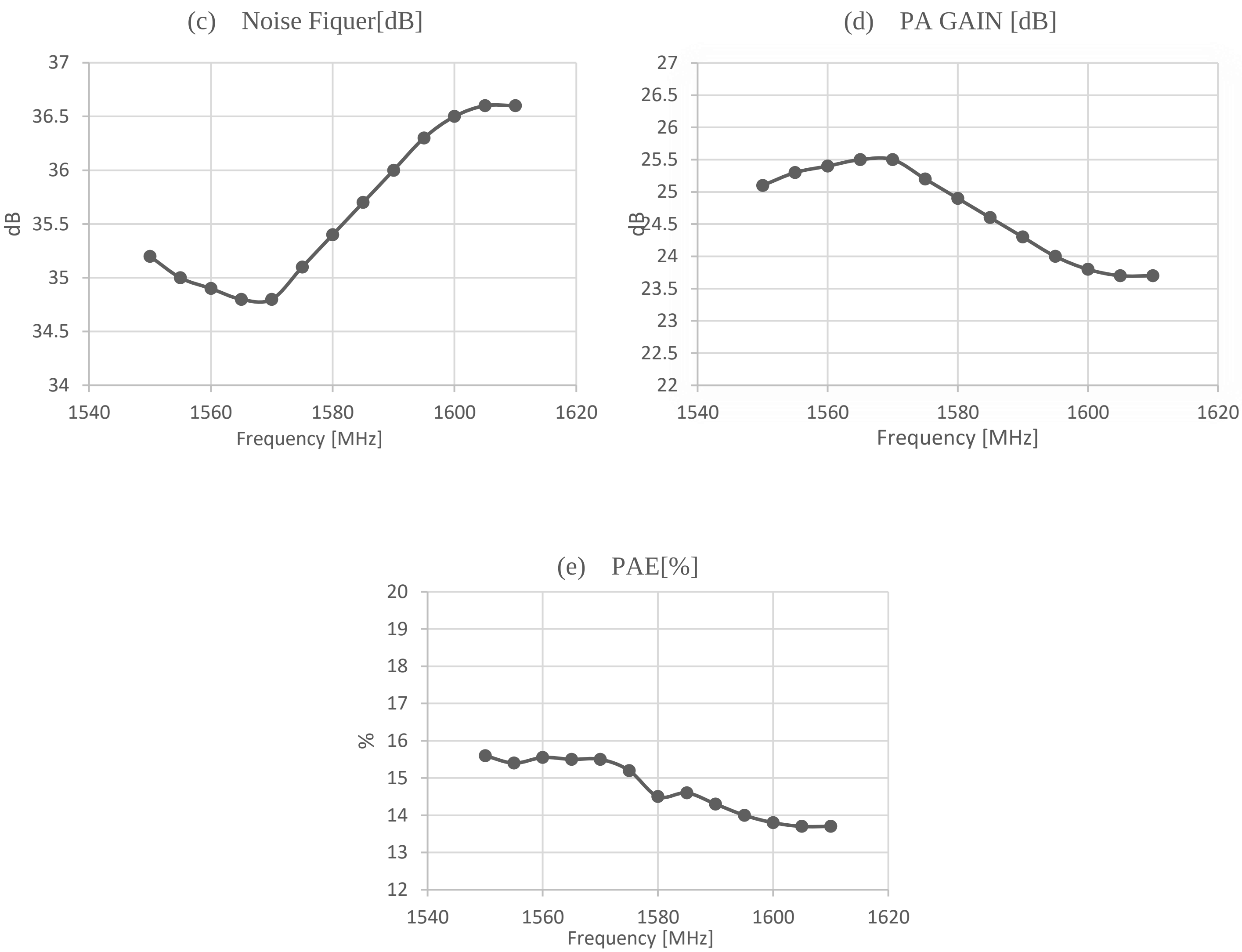


Figure 13. (a) - signal-to-noise ratio, (b) - output signal capacity, (c) - noise figure, (d) - amplifier gain, (e) - Power Added Efficiency vs frequency

A decrease in the gain of the amplifier and an increase in NF with increasing frequency were noticed.

5. CONCLUSIONS AND RECOMMENDATION

From the previous discussion of the results of the two models, the followings can be concluded:

The second model presented a gain of about 25.5dB, which is greater than that obtained in the first model. The first model, on the other hand, only provided a gain of about 16.5dB. However, the second model's gain was not as flat as the gain of the first model, along with the frequency band. Moreover, the high noise figure that was measured in the second model was about 35dB compared to the noise figure of the first model, which was about 15dB.

6. FUTURE RESEARCH PROSPECTS

It is suggested to work on improving the matching of impedance for each of the input and output stages of each amplification stage. Another recommendation is to choose a first-stage amplification transistor with a lower noise figure to improve the amplifier's general noise figure and increase its efficiency.

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