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Design a Broad-band High Flatness Gain Low Noise Amplifier for radar applications

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ABSTRACT

The improvement of Low Noise Amplifier (LNA) of radar systems was a necessity especially for military processes. LNA is the first step of any Radio frequency (RF) Receiver construction in wireless system. The LNA has more effect on any RF receiver performance. The purpose of this paper is to design a broadband LNA based on compensated matching network technique, in order to get high stable gain, low noise figure (NF) for radar systems applications at centre frequency 1.8 GHz with band width 800 MHZ. By using the Advance Design System (ADS), the design and simulation can be performed. The design has been executed using Low noise transistor BFU 730F With the usage of NF of 0.74-0.84 dB with class A bias circuit, Collector current is calculated to be 10.1mA, base current is 35.2μA with supply voltage of 2.25V. The new design is used to achieve high stable amplifier gain 20.4 dB. To enhance the LNA's stability, we used micro strip lines and compensated matching network technique to achieve accurate results.

1. Main text

No doubt that Rader is considered to be one of the most important contrivances in the new world of technology. Radar has been described with various utilizations, and it occurs in all forms and physical dimensions and there huge scale shield systems to remote sensing navigation, imaging, commercial air traffic control, vehicle collision prevention systems; ocean surveillance systems, observe exoteric space, convergence of weather forecasting system; medical purposes, altitude measurement, follow and pursuit the birds; land piercing sonar and the list goes on. Broad-band LNA is essential in multi band radar receiver. Briefly, the definition of LNA, it is a reception system able to receive poor signals and enhance it, in order to achieve the acceptable level for continuity of the comparison of device transceiver to the conventional narrow-band LNA.

The wide-band LNA has a unique design that allows it to overcome a variety of challenges, such as matching Broadband (BB) at the input to reduce reflection coefficient, high gain, low (NF) and high linearity [1].

There are three techniques to design broad band LNA (compensated matching network[2], balanced amplifier[3] and negative feedback[4]. Some references about LNA design have been published, such as proposed the utilization of dual- wide band for Wi MAX with (2-4GHz and 5- 6GHz) LNA in [5]

Over the band of interest , Noise figure (NF) differ from 3-3.7dB , this situation does not support the LNA designs for 3G/4G applications. For this band, the design of LNA with a NF of 0.588 dB,

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unconditionally stable and the gain of 12.85 dB which has been published in [6].

In this paper a broadband LNA is designed by compensated matching network technique at 1.8 GHz to produce high flatness gain and low NF for radar system. The collector current is measured to be 10.1mA. The implementation and simulation are executed by using (ADS) [7].

The second section illustrates the LNA circuit design methods, and the analysis, design steps and simulations using ADS has been discussed in the third section. Finally the conclusion has been explained.

2. LNA Circuits Design Methods

The key and challenge to realize broadband LNA design is to achieve high gain and ensure stability in the whole band.

The broadband LNA techniques are [8]:

- Compensated matching network
- Balanced amplifier
- Negative feedback amplifier

The Compensated matching network design is fundamental to obtain gain flatness and NF by two techniques:

- Stepped impedance matching (quarter wave transmission line)
- Single short stub

Stepped impedance matching circuit (quarter wave transmission line) helps the design to reduce the load and source reflection coefficient (Γ) by making many steps ƛ/4 T.L

Input impedance for T.L characteristic impedance (Z_0) is $Z_{in} = Z_0^2/Z_L$, $Z_{in} = Z_0^2/Z_S$.

Single short stub is also considered matching circuit at source and load, to decrease the load and source reflection coefficient which shows imaginary value to recompense the load or source imaginary value and conclude the matching between T.L characteristic resistance and load, or source resistance, but in impedance mis-matching that can clearly decrease the input and output reflection coefficient. But by using (stepped impedance matching and single short stub), the reflection coefficient (Γ) is clearly enhanced.

Balanced amplifier is practical method of implementation a broad band amplifier that has flat gain and good input and outputs. using two (3-dB) hybrid couplers of a balanced amplifier is considered the most popular arrangement .

To provide a flat gain response and to decrease input and output VSWR, Negative feedback can be used in broad band amplifiers. It also controls the amplifier’s performance according to the variations in the S-parameters from transistor to another.

Negative feedback has two forms, shunt and series. When designed accordingly to negative feedback, it can:

- Preserve flatness- gain
- Reduce affected of thecomponent temperature
- Enhance DC and RF stability
- Reduce distortion (depending on where the distortion is generated) [9].

Overall As a rule, the lower RF frequencies can alone preserve the stability at shunt feedback, but in case of the higher frequencies, the shunt feedback can’t preserve the stability [10].

Series feedback is not favored for RF applications because the parallel feedback is better than it at the stability.

By comparison, this technique isn’t the best way to obtain high stability, even though compensated matching network amplifier can make enhancement at the stability, but with trade off the (NF) marginally, so in our design, compensated matching network amplifier is adopted, to get stable and flatness gain all over the band

3. Circuit Analysis and Design Steps

In this section, the design analysis of the LNA for Radar applications is presented. The proposed design steps are simulated using ADS software [11].

3.1. Device Choosing and Design Parameters

In comparison with other low noise amplifiers , we favored NPN SIGE RF transistor BFU-730F since at high frequency, it has good (NF) all over the band along with high gain, the biased at $V_{cc} = 2.25V$, $I_c = 10.1mA$, the BFU-730F amplifier provides 0.74-0.84 dB (NF) with a maximum gain 20.4 dB.

Table 1. shows a listed of LNA parameters.

Table 1. LNA design parameters

Parameter	Value
Center Frequency (f_c)	1.8 GHz
Sweep Bandwidth (BW)	800 MHz
Max Gain	20.4 dB
Noise Figure	0.74-0.84 dB
Stability	Unconditionally Stable
Supply Voltage	2.25 V

3.2. Bias Configuration

Most microwave bipolar junction transistor (BJT) is made of silicon in the NPN type. Below 4GHZ, silicon BJTs provide a re-liable and low- cost solution to many electronic designs. The transistor dimensions are tiny to allow operations at microwave frequencies. One of the applications where silicon BJTS are used at microwave frequencies in low noise amplifiers.

The impedance matching networks and, the biasing can control The transistor gain, to get suitable results .so In order to get the highest achievable gain at frequency 1.8 GHz, the operating point of BFU-730F was set at V_{CE} = 1.9v, I_C = 10.1mA.

To get lower NF and highest gain, the design must operate at A class (Q-point) at I_C= 10.1 mA, I_{BB}=35.2µA and V_{CE}=1.9v, so the design technique (Collector feedback and fixed base biasing a transistor) by DC source voltage 2.25V, I_{CC} = 10.1mA to get the requirements.

Of course, the higher current generates higher noise. But there is tradeoff between gain and NF to get greatest gain, the NF will become lower. To immediate to supply and easy to adjust, the BFU-730Fis biased through self-biasing incorporating Compensated matching network.

The device is designed to work at the region where V_{CE} = 1.9 v, I_C = 10.1mA and I_{BB} =35.2µA.

I versusV characteristics of BFU-730F as (Figure 1).

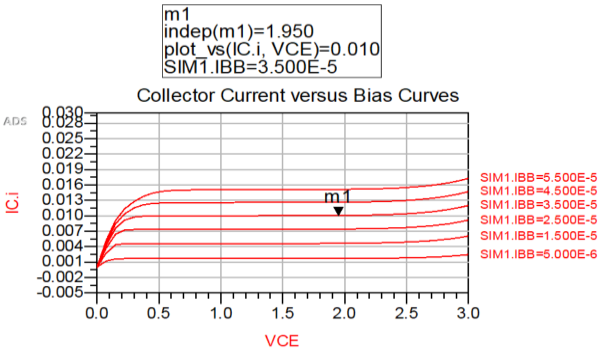

Fig. 1. IC versus V_{CE} characteristics

3.3. Stability Analysis

The stability of any amplifier is a very important consideration , and it can be determined from the device S-parameters, for unconditional stability:

$$|\Gamma_S| < 1 \qquad (1)$$

$$|\Gamma_L| < 1 \qquad (2)$$

$$|\Gamma_{IN}| = |S_{11} + \frac{S12\ S21\ \Gamma L}{1 - S22\ \Gamma S}| < 1 \qquad (3)$$

$$|\Gamma_{out}| = |S_{22} + \frac{S12\ S21\ \Gamma L}{1\text{-}S11\ \Gamma S}| < 1 \qquad (4)$$

Which, Γ_S is source reflection coefficient and Γ_L is load reflection coefficient

Briefly, the value of stability factor (k) means the circuit is stable or unstable. By the S-parameters of the two-Port circuit the stability factor can be calculated.

The condition of unconditional stability can be realized from:

$$K = \frac{1 - |S11|\hat{}2 - |S22|\hat{}2 + |\Delta|\hat{}2}{2|S12\ S21|} > 1 \qquad (5)$$

$$\Delta = S11 \times S22 - S12 \times S21 \quad < 1 \qquad (6)$$

So, |S11| and |S22| must be < 1 to achieve the unconditional stability , in order to reach the entire frequency range we have to use stabilizing branches.

At the outset, the lower stability will be achieved by accommodate the biasing circuit to make the stability factor as high as achievable , determine the stability factor of BFU-730F in the static bias. After continuous simulation and optimization , Compensated matching network circuit are used together to enhance the stability.

3.4. Broadband Matching Network Design

Biasing network is consist of two by pass capacitors (to eliminate the ripples from dc source bias), two RF shock coils (to prevent the interaction between DC source voltage and RF signals) and quarter wavelength transmission line (λ\4 T.L) (to keep the design matching at needed B.W, keep the impedance high at RF signals and keep the impedance low at DC source voltage) which there are three varieties of transmission lines [the two-wire of transmission line, the coaxial transmission line and the micro strip transmission line.

The micro strip transmission line is the most proper for the construction of microwave amplifiers. to get best NF and lower reflection coefficient at the input network, capacitors C1 (DC block), micro strip line matched (Stepped impedance matching Technique)-T, shunt inductor L1 (equivalent for shunt single short stub to make so small size) are used at the design. The output matching network consists of a shunt inductor L2 (equivalent for shunt single short stub) and capacitors C2 (DC block).

4. Simulation Results

The proposed LNA is designed according to a computer-based method. The scattering parameters are obtained by using the ADS software for the NPN SIGE RF transistor BFU-730F device as Figure 2**.** The designed elements values are given in Table 2.

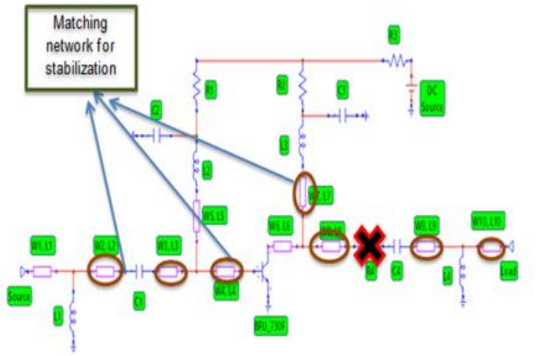

Fig. 2. Idealized circuit schematic of broadband LNA

Where lumped components are listed in Table 2

Table 2. Transmission lines and lumped components Values [12]

Symbols	W_1, l_1 (mm)	W_2, l_2 (mm)	W_3, l_3 (mm)	W_4, l_4 (mm)	W_5, l_5 (mm)	W_6, l_6 (mm)
Values	0.962, 3.14	0.83, 3.35	0.55 ,2.16	0.55, 3.67	0.83, 2.52	0.55, 1.72
Symbols	W_7, l_7 (mm)	W_8, l_8 (mm)	W_9, l_9 (mm)	W_{10}, l_{10} (mm)	DC source	R_1
Values	0.83, 2.52	0.55, 1.11	0.55, 3.35	0.55, 3.14	2.2V	35 KΩ
Symbols	R_2	R_3	R_4	L_1	L_2	L_3
Values	15 Ω	20 Ω	0 Ω	7 nH	3.3 nH	8 nH
Symbols	L_4	C_1	C_2	C_3	C_4	R_2
Values	7 nH	1 pF	68 pF	0.5 pF	2.4 pF	15 Ω

For Radar applications, the LNA circuit designed to operate at broad band frequencies from 1.4 GHZ to 2.2 GHz by using stepped impedance matching network technique and shunt short single stub technique to achieve high flatness gain (20.4dB) and minimum input reflection coefficient (S_{11}) for all the band as (Figure 3) which illustrates the variation of the gain (S_{21}) and the input return loss (S_{11}) over the proposed bandwidth

We observed that the parameter S_{11} varied between (-7.9) dB and (-18.4) dB and observed that the gain (S_{21}) varied between 20.4 dB and 17.9 dB as shown in figure (4), these values indicate a good matching, and high gain over the proposed bandwidth.

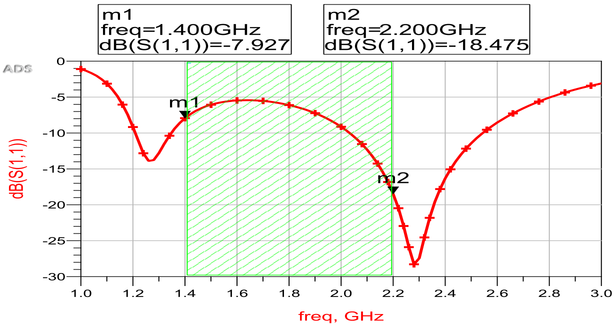

Fig. 3. Plot of the input reflection coefficient (S11) versus frequency

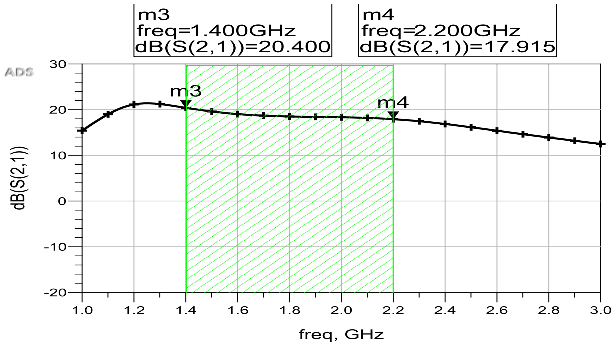

Fig. 4. Plot of the gain (S21) versus frequency

As (Figure 5) the NF achieved a good result (0.74dB-0.84dB) over operating band 1.4GHz-2.3GHz. This value indicates that the amount of noise added to the overall system is very low.

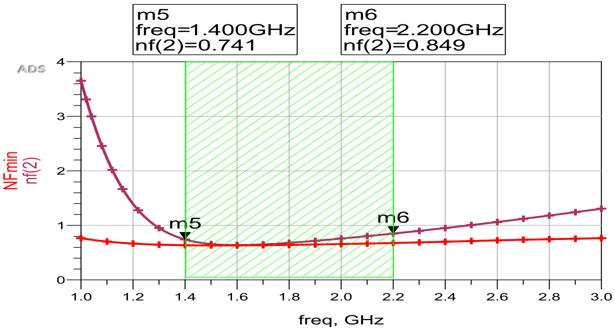

Fig. 5. Plot of the noise figure versus frequency

It can be realized from (Figure 6) that stability factor (K) >1 over the operating band. as follows, the circumstances for unconditional stability are confirmed on the working frequency band. Accordingly, there is no exposure to get oscillations.

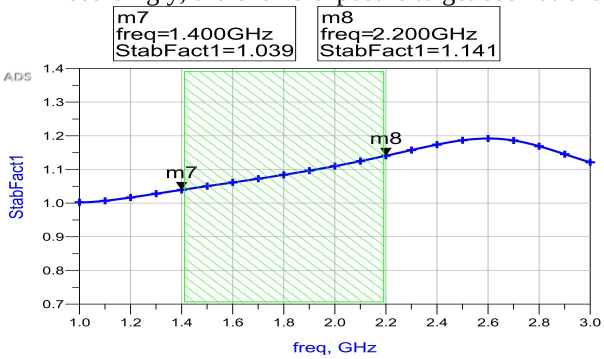

Fig. 6. Plot of the stability factor (K) versus frequency

Presented to test the transistors stability, One of them is called Rollet K stability factor. To estimate the (K) with the s-parameters, firstly delta (Δ) must be calculated by the equation (6) after that estimating Rollet K stability factor according to equation (5) and also by determining the stability circles.
delta (Δ) must be lower than 1 but stability factor (K) must be larger than 1 to obtain system with un conditionally stable

5. Figure of merit (FOM)

A figure of merit is a quantity used to characterize the performance of a device. Figure of merit can be given as a list of specifications that include properties such as gain, bandwidth, noise and linearity. Figure of merit is important for determining the suitability of a particular amplifier for an intended use.

$$F = \frac{S12\, S21\, \Gamma S\, \Gamma L}{(1-S11\Gamma S)(1-S22\Gamma L)} \qquad (7)$$

The value of F varies with frequency because of its dependence on S-parameters and reflection coefficient according to the equation 8. [4]
If F > 1 then the design is said to be much efficient
If F < 1 then the design is adding more noise
The value of figure of merit (F) at the band frequency from 1.4 – 2.2 GHZ is greater than 1 so; the design performance of the low noise amplifier is much efficient

6. Previous Work Comparison

Table 3 shows comparison between suggested broadband LNA and some other developed LNA circuits. The comparison shows that the suggested broadband LNA is achieving the leverage of the gain, small size, with relatively better price, in addition to that, very low noise figure.

Table 3. Previous Work Comparison

Ref.	Technology	Frequency GHZ	NF (dB)	Gain(dB)
This Work	**BFU-730F SIGE**	**1.4-2.2**	**0.74-0.84**	**17.9 -20.4**
[12]	BFU-730F SIGE	1.7 – 2.3	0.62-0.69	16.5-17.8
[13]	SIGE Bipolar	1.8	1.3	17
[14]	AT-41410 Si-BJT	1.75 - 2.15	N/A	10 - 11.8
[15]	ATF-54143	2.3	0.46	13.8
[16]	PHEMT ATF-54143	0.5 to 6	3.5	18
[17]	BFP720	2.3	1.15	34
[18]	SIGE HBT	1.6 – 2.4	1.5	18
[19]	SIGE HBT	1 – 2	1	13

7. Conclusion

With the assist of the Advance Design System (ADS), the Compensated matching network technique and broadband matching theory, the LNA designed to improve and correct the scattering parameters and enhance all other parameters. The simulation was executed by the design and the result proved that the proposed broadband LNA has succeeded to provide gain by 20.4dB and noise-outline by 0.74 dB.

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