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A Power Optimized Power Low-Noise High Linearity Rf Amplifier For Iot Applications

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A POWER OPTIMIZED POWER LOW-NOISE HIGH LINEARITY RF AMPLIFIER FOR IOT APPLICATIONS

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ELECTRICAL AND COMPUTER ENGINEERING

ABSTRACT

Recently, Ultra-Wide Band (UWB) technology has gradually become the focus of research in the wireless communication field. It is regarded as one of the key technologies of the next generation wireless communication system. FCC passed the UWB commercialization specification on February 14, 2002, the world's first, allowing the use of low-power UWB systems in the 3.1 GHz to 10.6 GHz frequency band. UWB has more bandwidth than other wireless technologies that can be used, and at the same time it won't seriously interfere with other wireless communication systems located in the same frequency band. In terms of transmission speed, UWB transmission speed exceeds 100Mbps, even up to 480Mbps, covering a distance of about 10 meters, which is quite suitable for high-end audiovisual multimedia transmission applications.

The ultra-wideband wireless communication system operates on a very wide frequency band, which is a considerable test for the design of radio frequency integrated circuits. Roughly speaking, the operation of radio frequency integrated circuits can be divided into transmission and reception aspects. For radio frequency integrated circuits, transceivers, there are mainly several key sub-circuits including low noise amplifiers, mixers, power amplifiers, and phase lock-in loops. With the advancement of CMOS process technology, CMOS can already meet the requirements of high-frequency electrical components, but to achieve broadband characteristics and system specifications at the same time, that is the main challenge of the current design. This article will focus on the ultra-wideband low-noise amplifier part, and make an in-depth discussion on broadband and other characteristics

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CHAPTER 1
INTRODUCTION

This article is divided into four chapters. Chapter 1: Introduction to this article. Chapter 2: Introduce the advantages and disadvantages of several receiver architectures. Chapter 3: Discuss the characteristics of commonly used amplifiers. Chapter 4: Describe the specifications of the ultra-wideband low-noise amplifier and specify the design circuit to achieve the original broadband characteristics, as well as the results of measurement and simulation.

Chapter 2
Receiver system architecture introduction

In wireless communication, the received radio signals (all analog signals) must be converted into digital signals and then processed by specific signals before they can become useful information. The block that converts analog signals into digital signals is called an analog-to-digital converter (ADC). Because of the limitation of sampling rate and dynamic range, the existing actual ADC cannot directly process the weak high-frequency electric wave signal received by the antenna, so it must pass through the radio frequency receiver. When designing a receiver, different receiver architectures have their own characteristics and application ranges, depending on the designer's consideration. The general considerations focus on the cost, power consumption, number of additional components, and complexity of the receiver. This chapter will briefly describe and analyze several common receiver architectures[1][2].

2-1. Superheterodyne Receiver

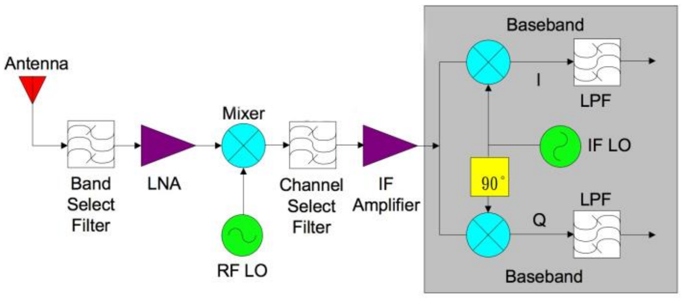


Figure 2.1 Structure of Superheterodyne Receiver

In 1918, after the superheterodyne receiver architecture was proposed by Armstrong, this receiver architecture has far-reaching impact on system designers. There are still many changes and applications in this architecture today, whether it is in the industry or in academic areas. It is suitable for the realization of receivers with multiple communication protocols. It has good signal selectivity and sensitivity as its main advantages. Its basic structure is shown in Figure 2.1. The working principle of this receiver architecture is to mix the high frequency (RF) signal received from the outside world with the local oscillation (LO) signal through a mixer, and convert the original high frequency (RF) signal to a lower frequency[3]. The signal is usually called an intermediate frequency (IF) signal. The center frequency of the IF signal is critical to the receiver, and it usually needs to be adjusted appropriately with the performance of other aspects of the receiver to achieve the expected performance. But the disadvantage is that it requires more components with additional chips, so the cost is relatively higher.

2-1-1. Image Frequency

The generation of image signal interference is mainly due to the fact that the down conversion mixer used will be symmetrical to the output frequency of the local oscillator on the both side and one IF away from the signal, with the same conversion response lower to IF. As shown in Figure 2.2, suppose the desired channel frequency is ω RF = ω LO − ω IF, and the local oscillation frequency (ωLO) enters the mixer, it will produce intermediate frequency ω IF, but suppose there is a frequency ω LO + ω IF also enters the mixer at the same time, and it also mixes with the local oscillator (LO) to produce the intermediate frequency , but this is not the intermediate frequency of the desired channel frequency , so ωLO + ωIF is called the image frequency.

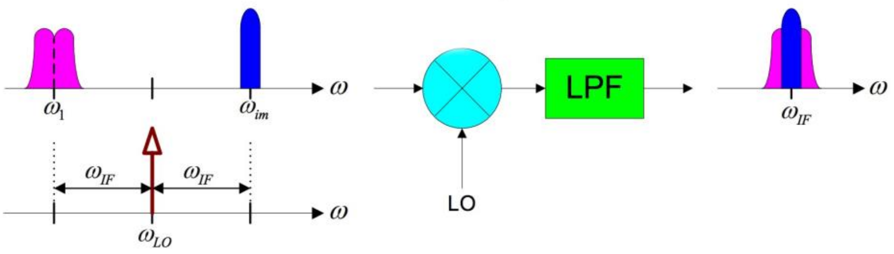


Figure 2.2 Image Frequency

As shown in Figure 2.3, a wave filter can be added in front of the mixer. This wave filter is called Image Reject Filter, which suppresses the interference at the image frequency; and when the selected intermediate frequency is higher, the farther the channel required by the mirror frequency, the better the effect of removing the mirror frequency.

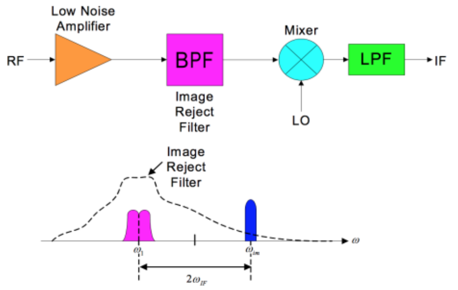


Figure 2.3 An Image reject filter to lower image frequency

2-1-2. Selection of IF

The adjacent channel interference will pass the desired signal through the mixer down to the intermediate frequency, and form interference near the intermediate frequency. As shown in Figure 2.4, therefore, a Channel Select Filter is added after the mixer to remove the interference near the intermediate frequency. Because it is necessary to remove the interference near the intermediate frequency, a very high Q filter is required, that is with a higher skirt factor. Generally, a surface acoustic wave filter (SAW filter) is used as the channel selection wave device.

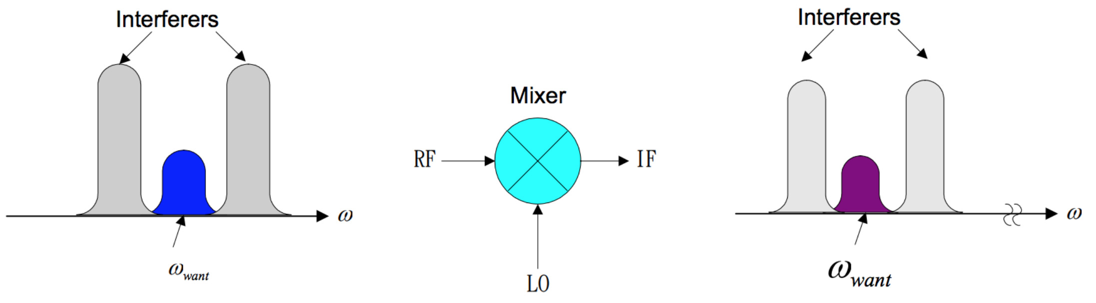


Figure 2.4 The adjacent channel interference

However, the Q value of the wave device of the same architecture decreases as the frequency increases. Therefore, to have a better selectivity, it is the best to choose a lower intermediate frequency. However, when considering eliminating the image frequency, choose a higher value is better which is contradictory. As shown in Figure 2.5, it is the influence of the different intermediate frequency on the mirror image wave device and channel selection wave device. From Figure 2.5(a), it can be seen that selecting higher intermediate frequency can suppress more image frequencies, so that the amount of image frequency can reach intermediate frequency is small, but the effect of suppressing neighboring interference is relatively poor; on the contrary, Figure 2.5(b) selects lower intermediate frequency, which has a better suppression of neighboring interference. However, the effect of suppressing the mirror image frequency is poor. Therefore, the IF frequency must be carefully selected.

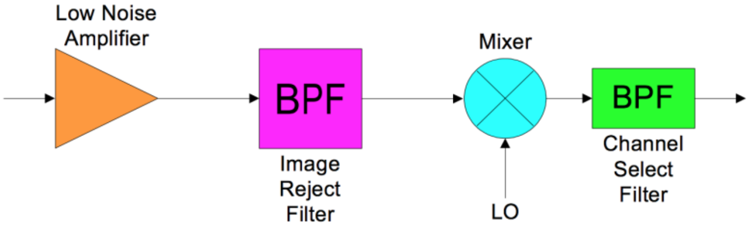


Fig 2.5 Image Reject Filter and Channel Select Filter

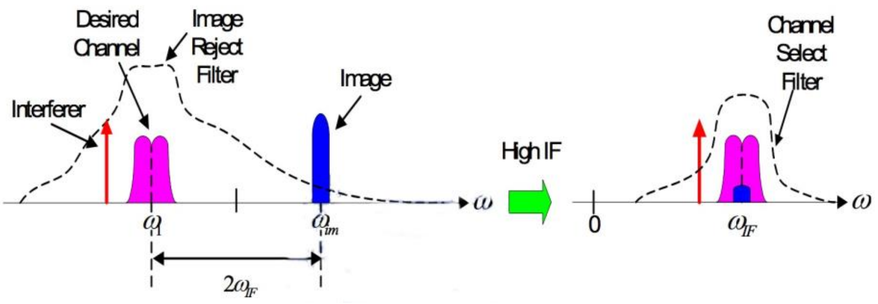


Fig 2.5(a) Higher IF

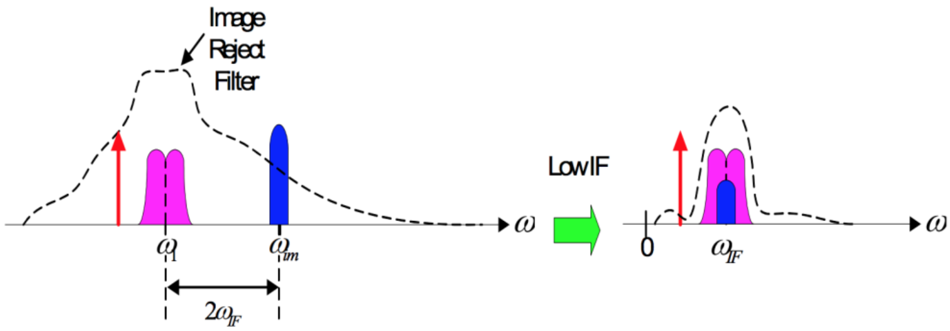


Fig 2.5(b) Lower IF

In addition, the influence of the phase noise of the local oscillator signal on the system is also very important. During the mixing process, the phase noise will be transferred to the intermediate frequency, so the lower phase noise is better. As shown in Figure 2.6, when a strong adjacent channel interference and a very weak received signal appear at the same time, the excess phase noise will cross-modulate to the intermediate frequency with the strong interference, making the weak IF signal getting interfered. As for the selection of the local oscillation frequency, there are two ways, one is that the frequency is lower than the center frequency of the communication channel, and the other is higher than the center frequency of the communication channel. It is recommended to use the first type, because the voltage-controlled oscillator (VCO) is relatively easy to design and the local oscillation frequency is low, and the phase noise will be better.

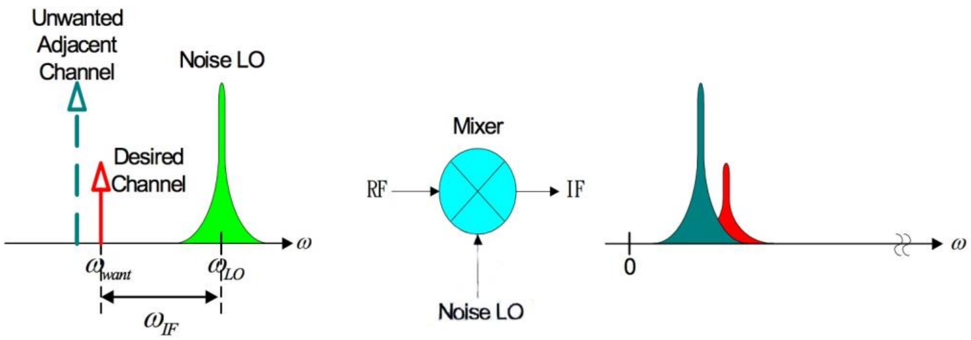


Fig 2.6 Phase noise affects the sensitivity and selectivity of the receiver

2-1-3. Effects of half IF

As shown in Figure 2.7, assuming that the interference frequency is (ωin + ω LO)/2, the second harmonic distortion produced by the low-noise amplifier is mixed with the second harmonic term of the local oscillation to become |(ω in +ωLO) - 2ωLO| = ω IF, this will cause interference to the intermediate frequency. In addition, the interference frequency (ωin + ω LO)/2 is mixed with the local oscillation (ωLO) to become one-half of the intermediate frequency signal (ωin + ω LO)/2= ω IF/2, and this signal passes through the amplifier and the second harmonic distortion generated after the mixer will also cause interference at the intermediate frequency. For the impact of the low half-IF on the system, the RF and IF active components should be as low as possible with low second harmonic distortion.

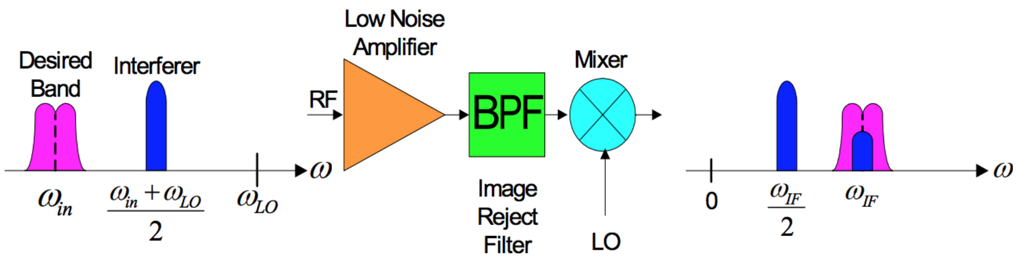


Fig 2.7 The effect of half IF to IF

2-2. Direct-Conversion Receiver

Since the local oscillation frequency of the direct conversion architecture is different to the RF frequency, there is no problem with the image frequency. Therefore, there is no need for an image wave device to be added before the mixer. Because there is no intermediate frequency, it is not necessary to add a channel selection wave device and an intermediate frequency amplifier after the mixer, instead, a low-pass filter is added. Therefore, the direct conversion architecture requires fewer components than the superheterodyne architecture, and it is easier to integrate the entire receiver into a single chip. The receiving architecture is shown in Figure 2.8. Although the direct frequency receiver has the above advantages and simple structure, it has not been widely used in the past for the following reasons below.

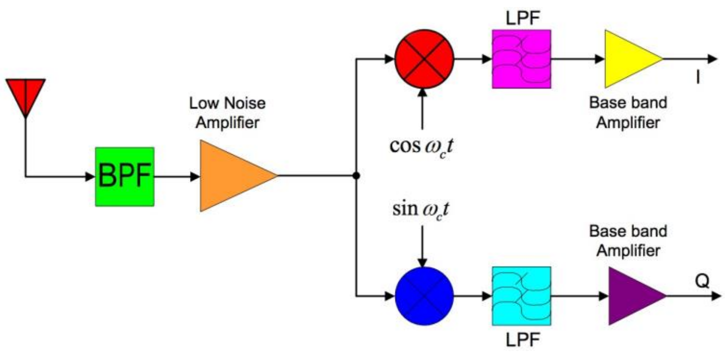


Fig 2.8 The structure of Direct-Conversion Receiver

2-2-1. DC Offset

As shown in Figure 2.9, because the RF-LO separation of the mixer is limited, the leakage of the local oscillation signal is caused by the coupling between the capacitor and the substrate and the bonding wire effect. When the local oscillation signal leaks to point A and point B, the leaked signal is reflected back and mixed with the local oscillation again and become the DC signal at point C; there is another situation when a larger interference signal overflows from point B to the local oscillation (Interferer Leakage) , then mixed with the same frequency interference signal, it will also become DC signal at point C. These phenomena are called self-mixing. However, this situation may interfere with the desired signal.

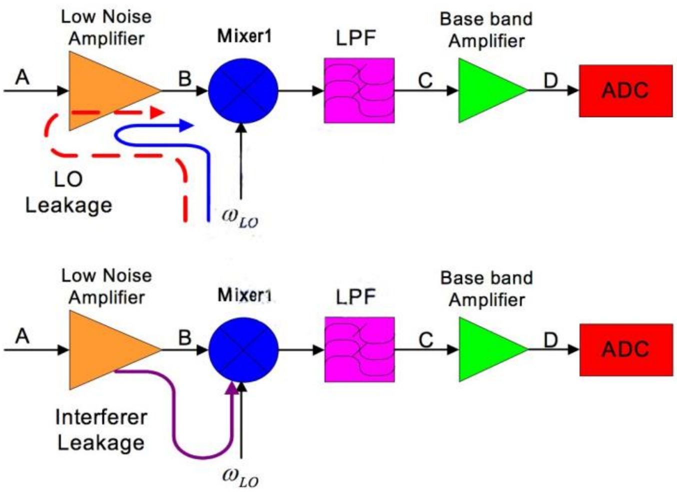


Fig 2.9 DC Offset

2-2-2. Even-Order Distortion

As shown in Figure 2.10, when there are two interference signals $A_1\cos\omega_1$t and $A_1\cos\omega_1$, which are very close to the desired signal, after the nonlinear effect of the low noise amplifier, the second-order modulation derivative signal generated. If they are very close to the DC signal, when the RF-IF interval of the mixer is not large enough, and then pass through the output of the mixer leaked from the mixer, which causes interference to the received fundamental frequency signal. This is called even order distortion. In fact, the mixer of the superheterodyne receiver also has this problem, so a low-noise amplifier and mixer with high linearity are required to prevent even-order distortion.

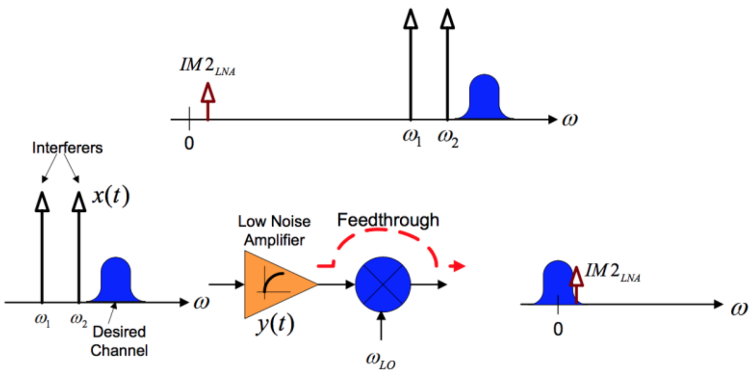


Fig 2.10 Even-Order Distortion in LAN and mixer.

2-2-3. Flicker Noise

The flicker noise of the transistor is low-frequency noise, and the power spectral density and is inversely proportional to the frequency (1/f). Therefore, generally the gain of the low noise, the amplifiers (LNA) and mixers have been increased to reduce the impact of flicker noise, such as using active mixers instead of passive mixers.

2-2-4 I/Q Mismatch

As shown in Figure 2.11, in the perfect condition, the I/Q mismatch should not appear, but in fact, the electrical circuit will not be able to do so. When the I/Q signal passes through the phase or the gain mismatch electrical circuit, the constellation of the I/Q signal will be distorted and bit errors will increase. Figure 2.12 is the distortion constellation generated when the QPSK signal undergoes phase and the gain mismatch electrical circuit. In the superheterodyne receiving architecture, because the I/Q signal is formed by the underclocking from the intermediate frequency, the frequency of the underclocking is lower than the frequency of the underclocking from RF in the direct conversion receiver. The electricity used is less after the I/Q signal is separated than in the direct conversion receiver, so there is relatively no I/Q mismatching situation.

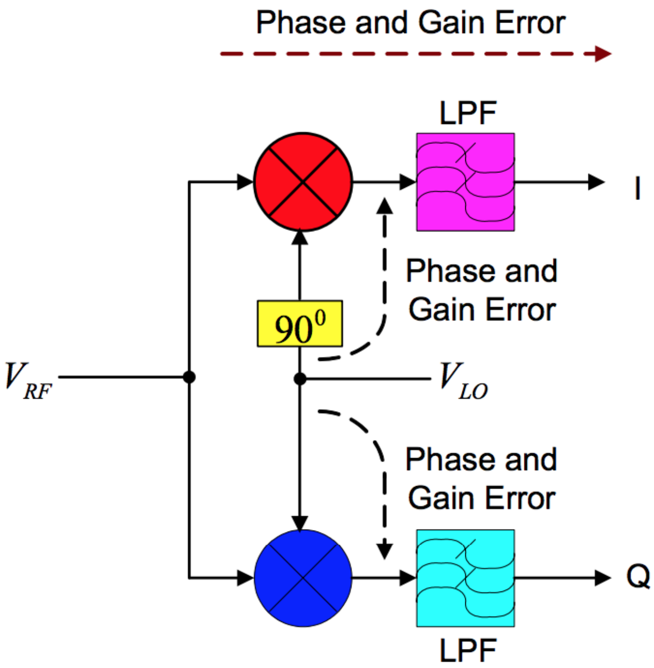


Fig 2.11 Distribution of I/Q mismatch

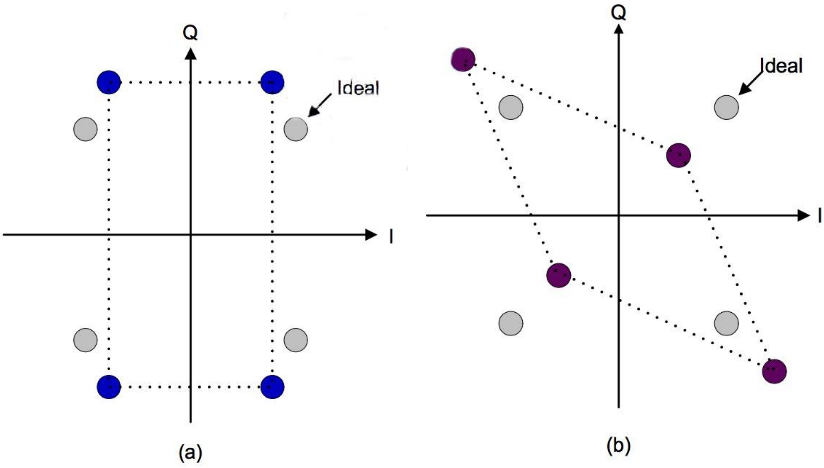


Fig 2.12 the constellation of the I/Q signal, (a) Gain error, (b) Phase error

2-3. Image-Rejection Receiver

Another way to remove the image signal is to use an image rejection receiver. This type of receiver can omit the image rejection filter which is required in the superheterodyne receiver. Generally speaking, there are two kinds of image rejection receiver: Hartley architecture receiver and Weaver architecture receiver.

2-3-1. Hartley architecture receiver

As shown in Figure 2.13, it is mainly composed of two mixers with a phase difference of 90 degrees, because the local oscillator source of the mixer is generated by two signals with a phase difference of 90 degrees as input. As for the phenomenon of image rejection, it uses a mixer and a 90 degree phase shifter to create a 180 degree phase shift for the image signal of the I and Q path, and finally uses a synthesizer to synthesize the signal so that the image signal is eliminated.

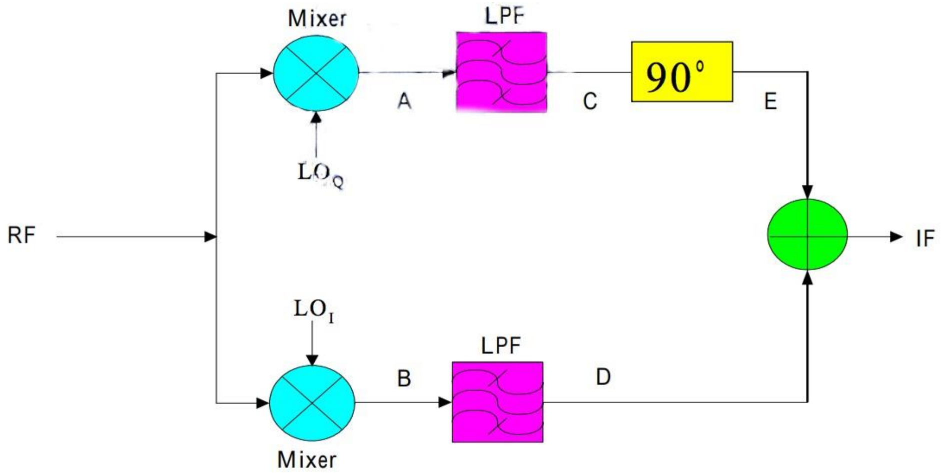


Fig 2.13 Diagram of Hartley architecture receiver

Chapter 3
Introduction to commonly used amplifier architectures

3-1. Low Noise Amplifier Introduction

In the increasingly vigorous wireless communication applications, the Low Noise Amplifier is an indispensable part of the receiving end, because the low noise amplifier is the front end of the RF transceiver circuit, and its main purpose is providing the gain needed to receive the weak RF signal from the antenna. In a system with several amplifiers connected in series, the noise figure is almost determined by the first-stage amplifier. Since the low-noise amplifier (LNA) is the front-end part of the receiving end, the noise figure is good or bad will be determined by the noise figure of the low noise amplifier. For the design of low-noise amplifiers, although sufficient gain is required to minimize the noise figure of the series connection, the gain should not be too high to avoid over-amplification of the signal, which exceeds the operation of the next-stage mixer. Generally speaking, the gain of the low-noise amplifier is about 10dB~20dB. The architecture of several receivers has been introduced in the previous section. Figure 3.1 shows the necessary components of the basic receiver. Generally, the filter will be designed with 50Ω. Matching is designed to pass the signal and reduce interference. In order to achieve good power transmission, the low-noise amplifier also needs to achieve good input matching (relative to 50Ω), and often the choice of the first-stage transistor size affects the quality of the matching and the noise figure. The noise figure also determine the power reduction and gain, so it is unlikely that there will be very small noise and extremely high gain at the same time. It is necessary to make a compromise between each characteristic. Therefore, how to effectively reduce the noise figure of the amplifier to improve the performance of the circuit and meet the system specifications is also an important issue for the overall transceiver design.

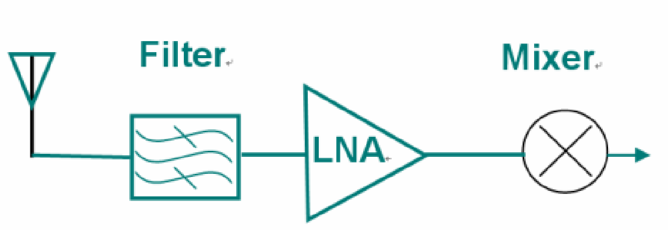


Fig 3.1 Basic receiver architecture

3-2. Transistor Noise Model

(1). Channel thermal noise

This noise source is generated by the thermal movement of electrons, so it can be known that its value is related to the absolute temperature T. In fact, thermal noise is directly proportional to T, which is generally equivalent to outputting a parallel noise current source, and its power spectral density is:

$$(\overline{i_d^2}/\Delta f) = 4kT\gamma g_{d0}$$

(2). distributed gate resistance noise

In the gate layout of the transistor, a polysilicon layer must be used, so there is a gate polysilicon resistor, and the noise generated by it can be regarded as general resistive thermal noise. The resistance is:

$$R_g = R_H W / 3n^2 L$$

(3). induced gate current noise

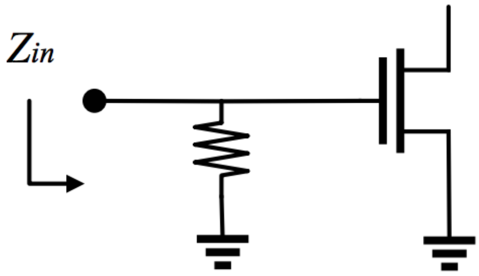
When the transistor is biased and the channel is reversed, the perturbed charge in the channel will be coupled to the gate through the capacitor to generate an induced noise current. The noise power spectral density is

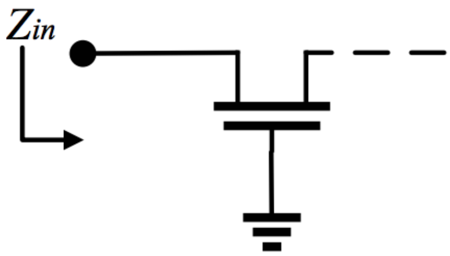
$$(\overline{i_g^2}/\Delta f) = 4kT\delta g_g$$

(4). flicker noise

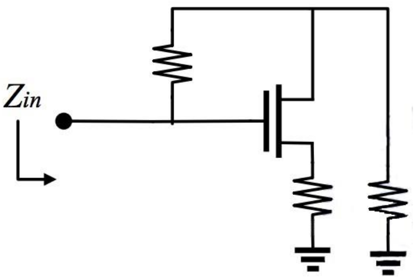
When the transistor is at low frequency, the main noise present is tremor noise. Since its noise spectral density is proportional to 1/f, it is also called 1/f noise. The reason for this is that there is a phenomenon in the interface between the gate oxide layer of the transistor and the silicon substrate, that is, there are many discontinuous dangling bonds at the junction.

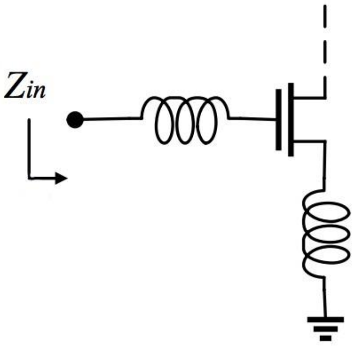
3-3. Introduction to commonly used amplifier architectures[4]





(a) Resistive Termination (b) 1/gm Termination





(c) Shunt-series feedback (d) Source inductive degeneration

Fig 3.2 Commonly used amplifier architectures

Generally speaking, amplifiers have four common architectures: Resistive Termination, 1/gm termination, shunt-series feedback, and source inductive degeneration. The following will analyze these four architectures

3-3-1. Resistive Termination

As shown in Figure 3-2(a), since the gate terminal looks high impedance, it is easy to match the input terminal by connecting a resistor in parallel in the front. Generally speaking, the better the input matching, the better the power that the LNA can absorb, but the use of this matching resistor will consume a lot of power, so even if the input matching is good, the LNA can absorb only a little power. In addition, the resistor will also generate a lot of channel thermal noise, this architecture will make the noise figure of the entire LNA too high.

Characteristic:

(i) Suitable for broadband matching

(ii) High noise figure

(iii) The connected matching resistor attenuates the signal

3-3-2. 1/gm Termination

From an intuitive point of view, the signal of this architecture will go from the source level to the sink level. Therefore, generally speaking, the noise of the 1/gm matched amplifier architecture is usually higher, but the current common source-level stacking architecture is used. Most of them are more suitable for narrow frequency applications. To achieve wide frequency, it is often necessary to add inductance and capacitance matching circuits, which must account for more layout area, so the noise figure of 1/gm matched amplifier architecture will be slightly higher, but it is convenient for broadband matching, but for some communication systems, it is not conducive to use. The 1/gm matched amplifier architecture is used as the first stage, and its gain is usually very low. Therefore, amplifiers must be connected in series to increase the overall gain. Therefore, 1/gm termination architecture is used, and amplifiers of more than two stages are usually connected in series.

Characteristic:

(i) The gm value of the transistor is not affected by the frequency in a certain range

(ii) Good characteristics in broadband impedance matching

(iii) Because this structure has no Miller effect, it allows its own impedance and gain to have broadband performance.

3-3-3. Shunt-series feedback

This kind of architecture involves a resistor feedback circuit, so be careful when designing, otherwise it will easily cause oscillation.

Characteristic:

(i) Consider stability issues in design

(ii) Noise Figure is not the smallest

(iii) Good broadband performance

3-3-4. Source inductive degeneration

The source of the name Source inductive degeneration is that an inductor is connected to the source terminal. The resistance of the inductor itself will reduce the g_m of the transistor.

Characteristic:

(i) Noise Figure can reach a very good ideal value

(ii) Excellent impedance matching can be achieved on narrowband application systems

(iii) Design Lg to achieve the resonant frequency

(iv) Ls can be selected to achieve impedance matching purpose

Chapter 4
Introduction to Ultra Wideband Low Noise Amplifier Architecture

4-1. Considerations for actual measurement added to analog circuits

RF PAD Effect

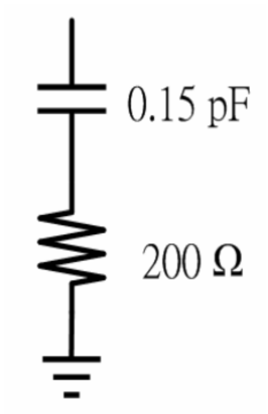


Fig 4.1 RF Pad value

Bondwire Effect

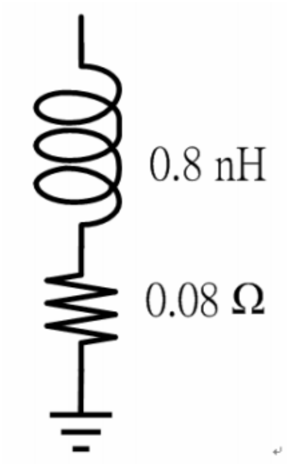


Fig 4.2 Bondwire value

4-2. Cascode Low-Noise Amplifier

In the receiver architecture, the first stage after the bandpass filter is usually a low noise amplifier, so that the noise figure of the low noise amplifier dominates the noise figure in the overall receiver chain. Therefore, the design of the low noise amplifier focuses on the noise figure. In addition, the external components of the front end of the RF transceiver, such as filters, T/R switches, and duplexers, are generally based on 50Ω. In order not to affect the frequency response of the filter, CMOS LNAs in RFIC are all based on 50Ω input impedance. In the design of low noise amplifiers, transistor noise models are often used to design and manufacture important parameters such as power elimination, input matching, noise figure, and gain.

As shown in Figure 4.3, it is a traditional common-source stacked low-noise amplifier architecture, in which a transistor M1 and a resistor provide the bias voltage; the resistor is generally a large resistor, mainly to avoid RF signal leakage and affect the bias voltage. The biggest advantage of the stacked structure is to reduce the Miller effect, which will improve the high-frequency response of the circuit. The architecture can also make the isolation between the input and output ends better. Therefore, the input and output impedances can more easily achieve impedance matching with the signal and load impedance. As for the operation principle of this circuit and the important specifications of the circuit, we will continue to discuss further

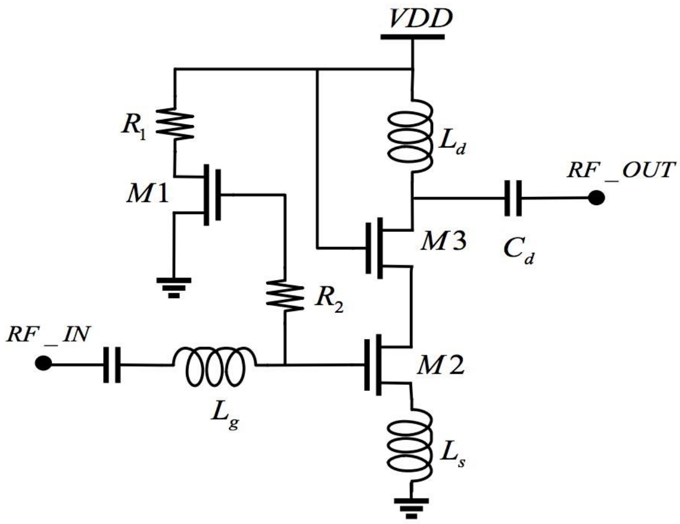


Fig 4.3 Traditional Common Source Cascode Low Noise Amplifier

4-2-1. Input matching

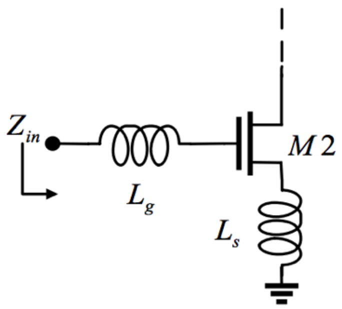


Fig 4.4 Cascode Low-Noise Amplifier input impedance

Using the small signal model of the transistor and the KVL calculation, the input impedance can be obtained as

$$Z_{in} = \frac{V_{in}}{I_{in}} = j\omega\left(L_g + L_g\right) + \frac{1}{j\omega C_{gs}} + \frac{g_m L_s}{C_{gs}}$$

Generally, the input impedance is usually matched to 50Ω, that is, Z_{in} = 50Ω, so it can be known $w = \sqrt{\frac{1}{(L_s+L_g)*C_{gs}}}$ and $L_s = \frac{50C_{gs}}{g_m}$. That is, the inductance L_s is used to match the real part of the input impedance to 50Ω, and the imaginary part of the input impedance is eliminated by appropriately setting the inductance value L_g.

4-2-2. Output matching

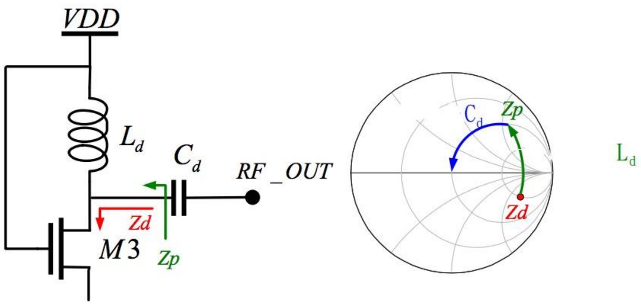


Fig 4.5 Smith chart of output impedance

According to Smith chart analysis, as shown in Figure 4.5, the output can be matched to 50Ω by selecting the appropriate inductance Ld and capacitance Cd.

4-2-3. Gain

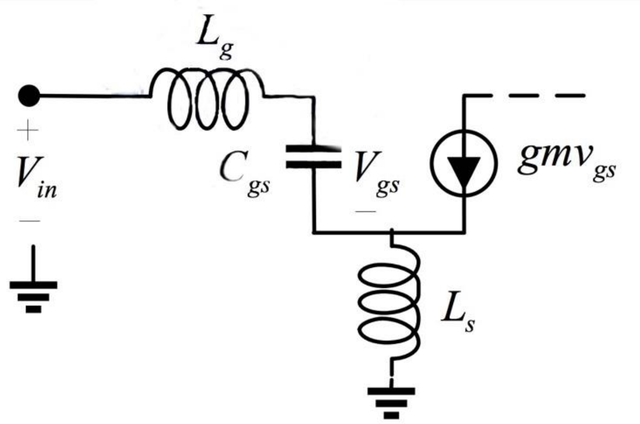


Fig 4.6 Equivalent small signal model

As shown in Figure 4.6: $G_m = \frac{g_m V_{gs}}{V_{in}} = \frac{g_m}{Z_{in} jwC_{gs}}$. Assuming that the input impedance has been matched to 50Ω (representing Z_{in} = 50Ω). We can get $G_m = \frac{1}{jwL_s}$. Therefore, the gain $A_V \approx G_m(\text{jw}L_d) = \frac{L_d}{L_s}$.

4-3. Design of ultra-wideband low-noise amplifier with repulsion characteristics with suppressing external gain of bandwidth

In the UWB system specification, the most important feature of the low-noise amplifier is broadband. Ultra-wideband and low noise are listed below

(i) Broadband input and output are matched to 50Ω impedance (bandwidth range is usually defined by -10dB)

(ii) The flatness of the gain required within the UWB bandwidth (generally within 3dB)

(iii) The lowest possible noise figure value

(iv) Low power consumption

(v) Due to the low transmission power regulated by the UWB system, the linearity requirements are relatively low

4-3-1. Principle of resonant input matching

Figure 4.7 The part surrounded by the dashed line can be regarded as the analysis of a single-band common source stacking (Cascode) low-noise amplifier. The small signal model of the transistor can be used and the KVL operation can be used to obtain the input impedance as equation 4-2.

$$Z_{in} = \frac{V_{in}}{I_{in}} = j\omega(L_g + L_s) + \frac{1}{j\omega C_{gs}} + \frac{g_m L_s}{C_{gs}}$$ …….. equation 4-2

In the equation 4-2, the input impedance can be regarded as an RLC series electric circuit, although the real part of the input impedance can be matched to 50Ω with the inductance Ls, the imaginary part of the input impedance is eliminated by appropriately giving the inductance value Lg. But this is a narrow-band design. Figure 4.6 applies LC resonance matching to meet the requirements of wide-band. The description is as follows: Figure 4.8 shows the equivalent RLC series electric circuit of the input impedance of a single-band common-source stacking (Cascode) low-noise amplifier. Appropriate design R to be around 50Ω. For this load, make a sweep curve on the Smith Chart. The direction of arrow represents the curve, which goes clockwise from low frequency to high frequency. This load is capacitive to inductive from low frequency to high frequency. The trend on Z chart is shown in Figure 4.9(a), and the symmetrical relationship shows that the trend on Y chart is shown in Figure 4.9 (b). Now we add a parallel resonant cavity, and its parallel resonant cavity Y parameter impedance is shown in Figure 4.10. The overall broadband input matching is shown in Figure 4.17. Design the values of L1 and C1 appropriately, we can use Y = $-j\beta$ for $\omega < \omega_0$ and Y = $j\beta$ for $\omega > \omega_0$ to eliminate Figure 4.9(a) Load Y parameter in order to make two more resonance points before and after the resonance frequency $\omega_0$on the Smith Chart. On the above situation, the possible trend on the Y chart is shown in Figure 4.12(a), the design of the S11 circle path is within the UWB specification bandwidth and the distance from the Smith Chart center point <0.316 (S11<-10dB), and finally the S11 sweep chart is shown in the Figure 4.12(b).

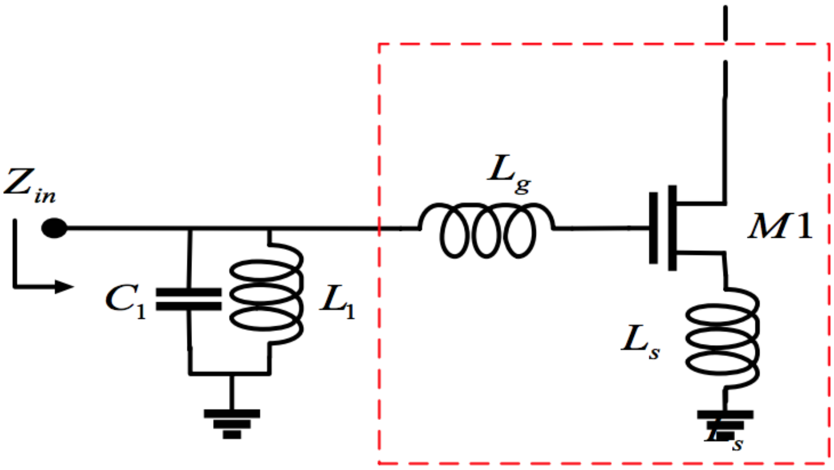


Fig.4.7 Circuit of LC resonant input matching

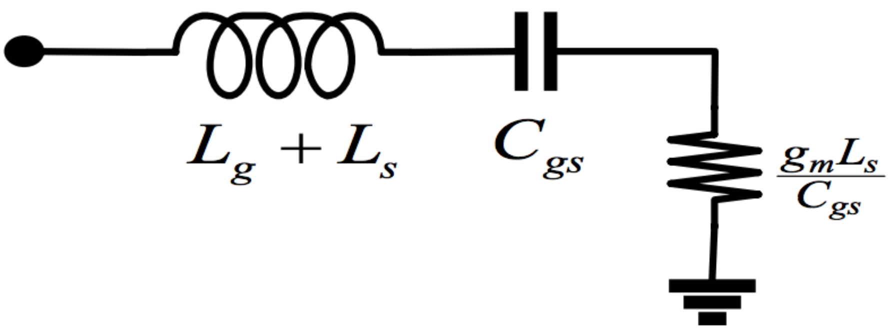
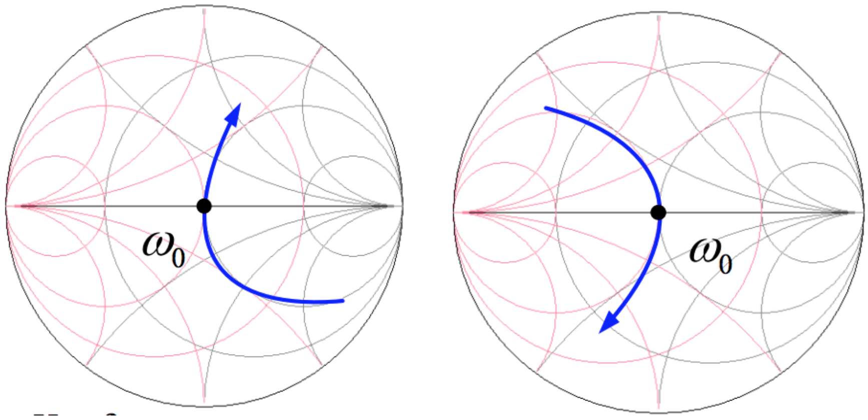


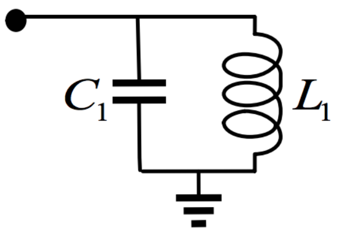
Fig.4.8 Equivalent series RLC circuit of input impedance

Z = -jX for $\omega > \omega_0$ inductive   Y = jβ for $\omega < \omega_0$ capacitive



Z = -jX for $\omega < \omega_0$ capacitive   Y = jβ for $\omega > \omega_0$ inductive

Fig.4.9 Smith chart of input loading



$$Y = j\omega C1 + \frac{1}{j\omega L1} = j(\omega C1 - \frac{1}{\omega L1})$$

$$Y = 0 \quad at \quad \omega = \omega_0$$

$$Y = -jB \quad \text{for} \quad \omega < \omega_0$$

$$Y = +jB \quad \text{for} \quad \omega > \omega_0$$

Fig.4.10 Parallel resonant cavity Y parameter loading

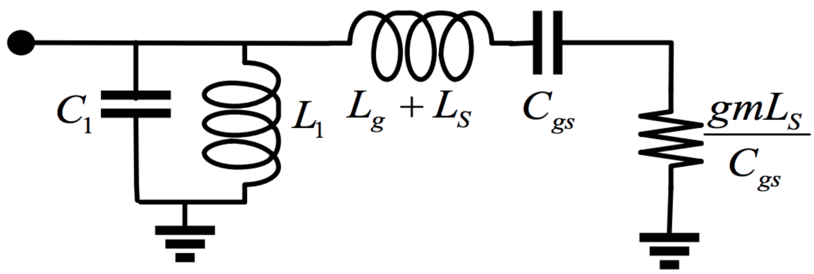
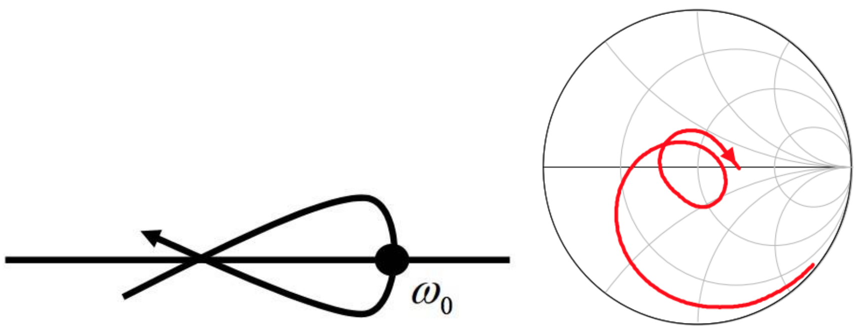


Fig.4.11 Broadband input matching circuit diagram



(a) (b)

Fig.4.12 Broadband matches the possible trend of Y chart and Smith Chart sweep

4-3-2. Discussion on Broadband Increase

In microwave power transmission, power transmission to the load often causes loss due to matching problems. In order to achieve the maximum power transmission, it must be designed as conjugate matching. As Fig.4.13, assume

$Z_S = R_S + X_S$, and $Z_L = R_L + X_L$, we get the equation 4-3

$$P = \frac{1}{2}\mathrm{Re}\{V_{in}I_{in}^*\} = \frac{1}{2}|V_{in}|^2\,\mathrm{Re}\{\frac{1}{Z_{in}}\} = \frac{1}{2}|V_g^2|\frac{R_L}{(R_L+R_S)^2+(X_L+X_S)^2}$$ …….. equation 4-3

In Figure 4.14(a), the low noise amplifier using Cascode architecture, add a set of inductors and capacitors in the middle part, the purpose is to achieve the intermediate stage conjugate matching. As can be seen from Figure 4.14(b), after conjugate matching, the gain of the amplifier increases by 5dB. The above is used for single-frequency intermediate stage matching, while in UWB system, low noise amplifiers focus on broadband. Now if we change to the high frequency (about 9 to 10GHz), do intermediate matching between the second stage, so that the high frequency gain increase, the overall effect is to increase the bandwidth, so in the Fig.4.15, between the Cascode architecture of the first stage and the voltage follower of the second stage, in order to have the maximum power transmission, an inductance Lseries is added to design the intermediate stage to be close to conjugate matching. Whether the inductance Lseries is added or not, the change of the increase in bandwidth is shown in Figure 4.16.

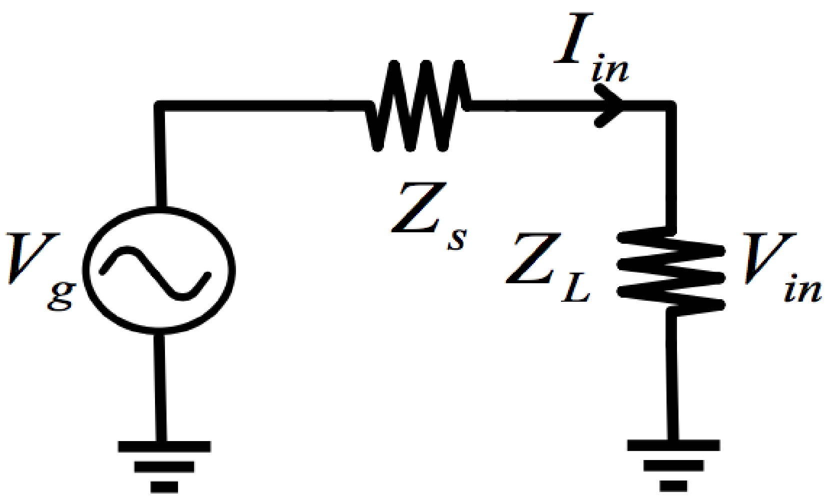


Fig.4.13 Conjugate matching for maximum power transmission

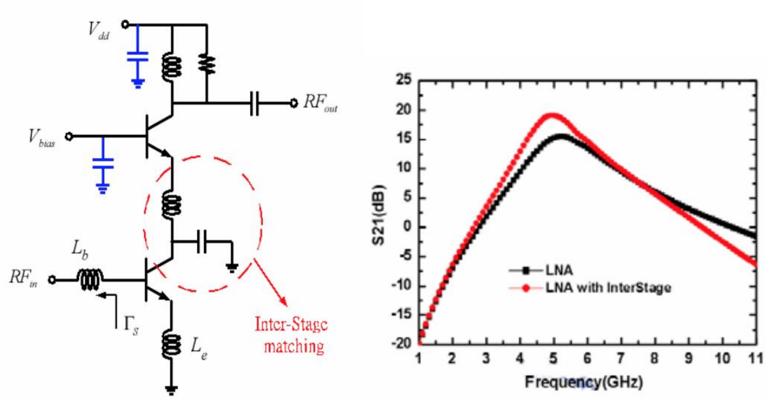


Fig.4.14 Inter-Stage conjugate matching LNA and gain comparison diagram

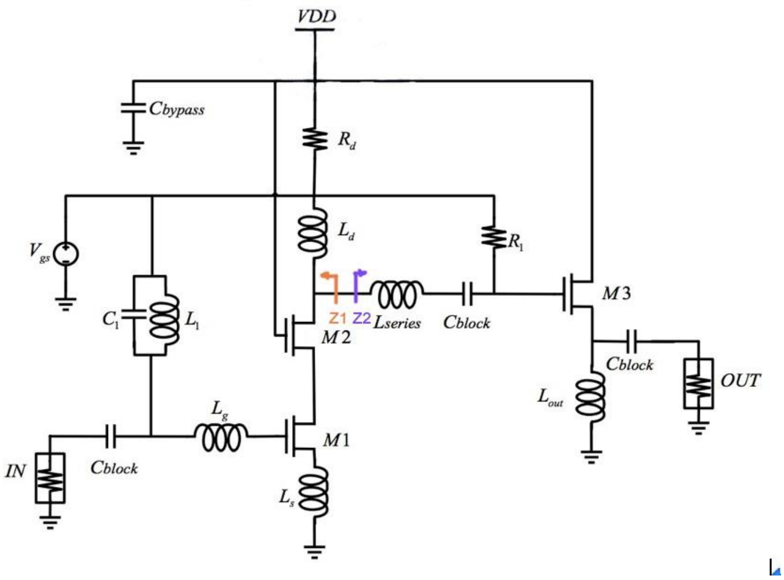


Fig.4.15 Add inductance L’series

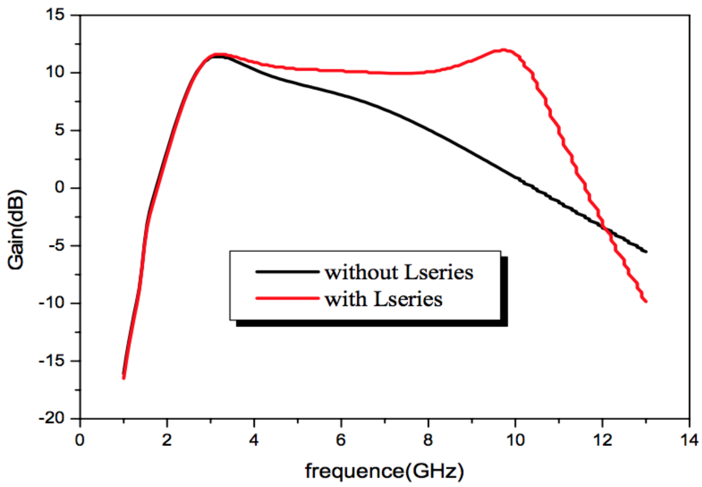


Fig.4.16 Gain difference with or without L’series

4-3-3. LNA Design

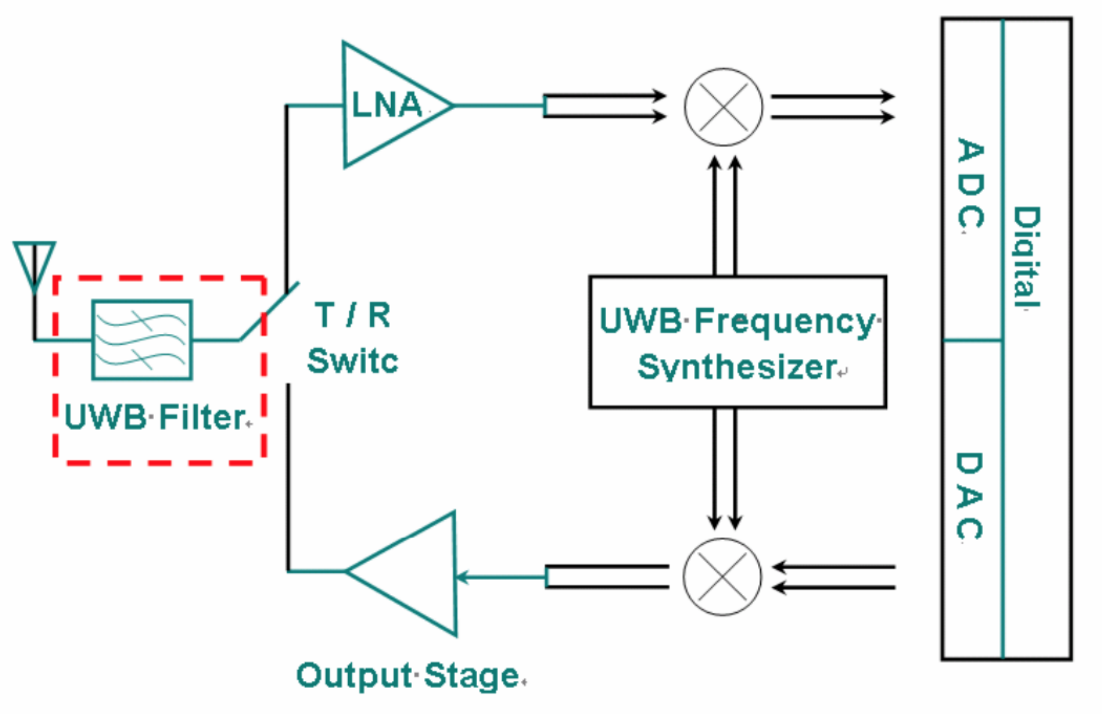


Fig.4.17 Basic MB-OFDM UWB system transceiver architecture

In the vicinity of the frequency band used by the UWB system, there is currently a GSM wireless communication system in the 1.8/1.9GHz band, and a Bluetooth wireless communication system at 2.4GHz. The power emitted by the GSM wireless communication system is comparable large to UWB system. Due to the design, these are a kind of interference signal to the UWB system. As shown in Figure 4.17, in the receiver part of the UWB system, when the signal is received from the antenna, it will first pass through a UWB filter to reduce the interference outside the bandwidth. In the previous section, the concept of the LC resonant matching circuit is similar to f the filter design. Here I will add two suppression capacitors based on the structure of the previous section. The locations of the two capacitors are shown in Figure 4.18. It shows that just adding two capacitors Cs and Co to the LC resonance broadband matching circuit can cut down the gain outside the UWB bandwidth. Figure 4.19 shows the comparison of the simulation results before and after the suppression capacitor is added to the LC resonance matching ultra-wideband low noise amplifier circuit.

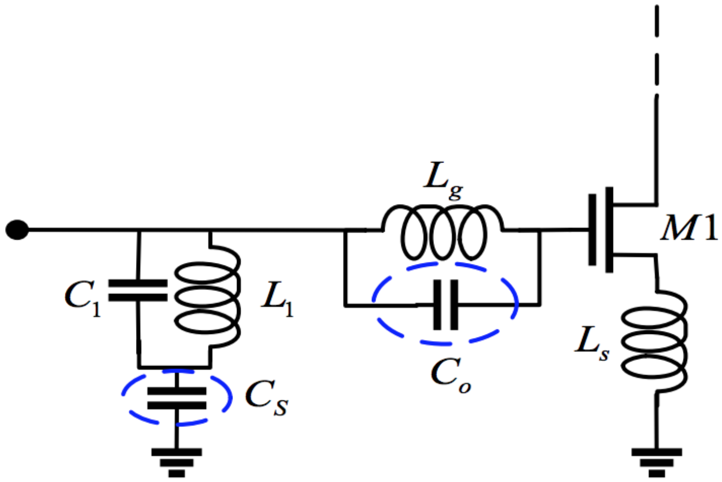


Fig.4.18 Adding two capacitors Cs and Co

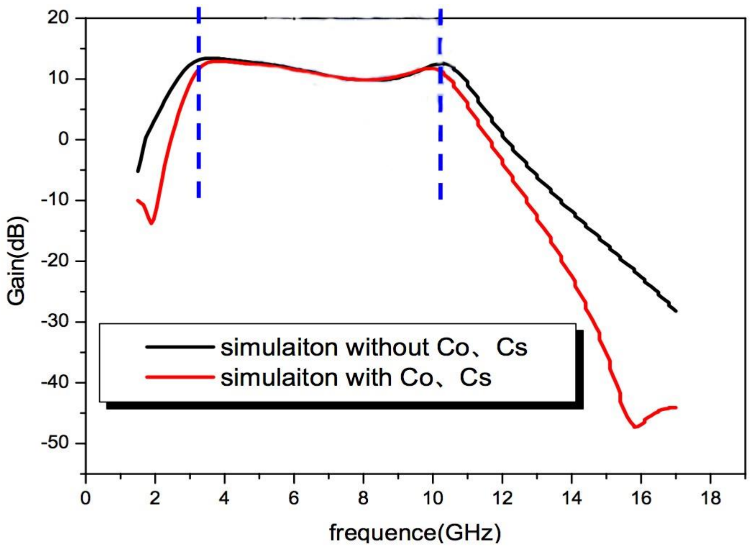


Fig.4.19 Simulation of gain adding Cs and Co

In Figure 4.20, when the operating frequency is lower than L1, C1 parallel the resonance frequency, L1 and C1 parallel will be inductive. Using its inductance to series a capacitor Cs can create a gain suppression in low frequency. When operating at low frequency, L1 and C1 parallel are inductive and with capacitive Cs can be regarded as series resonance. Properly designing the Cs value can bring the signal to the ground near 1.8GHz, so that the gain in the GSM system frequency band can be quickly dropped , Figure 4.19 shows that the increase of Cs is about 15dB different from the original without capacitor.

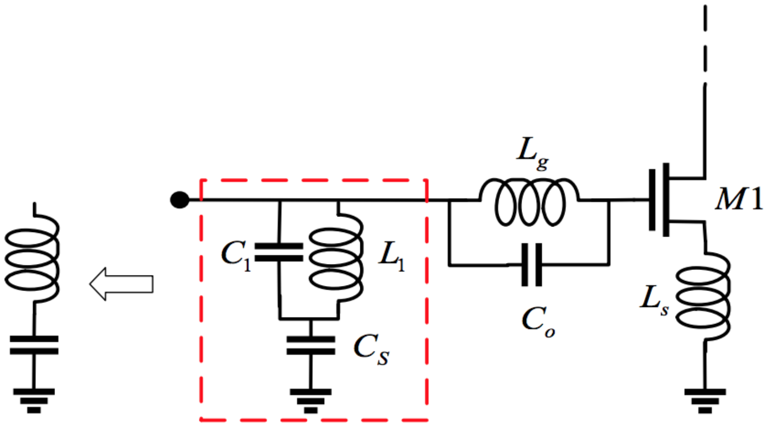


Fig.4.20 Adding capacitor Cs

It can be seen from Figure 4.21 that the suppression of high-frequency gain is mainly due to the addition of capacitor Co to make Lg and Co in parallel, and design Lg and Co to parallel resonate at high frequency, and the signal can bounce back and fail to pass at resonance. This also has the effect of suppressing the high frequency gain outside the bandwidth.

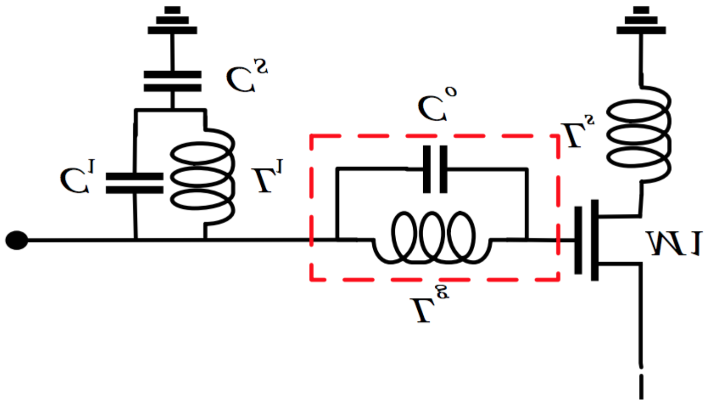


Fig.4.21 Adding capacitor Co

4-3-4. Cs Discussion

The capacitor Cs added to suppress the gain outside the bandwidth is basically a large capacitance value. Because the capacitor Cs mainly contributes to series resonance to suppress the gain at low frequency, and the operating frequency needs a larger capacitance value at low frequency. In addition, in the UWB operating band frequency, after the inductive series resonance frequency is provided by the capacitor Cs and the inductor L1 and the capacitor C1, the impedance of the capacitor Cs will show a small resistance value. In the UWB frequency band, the resistance value of the capacitor Cs can be basically ignored to be grounding, so it can be inferred that the effect of adding capacitor Cs to the broadband matching circuit on the original matching will not be too serious, and a good matching can be achieved after proper fine-tuning of the circuit. The difference between the addition of capacitor Cs in the broadband matching circuit is shown in Figure 4.322

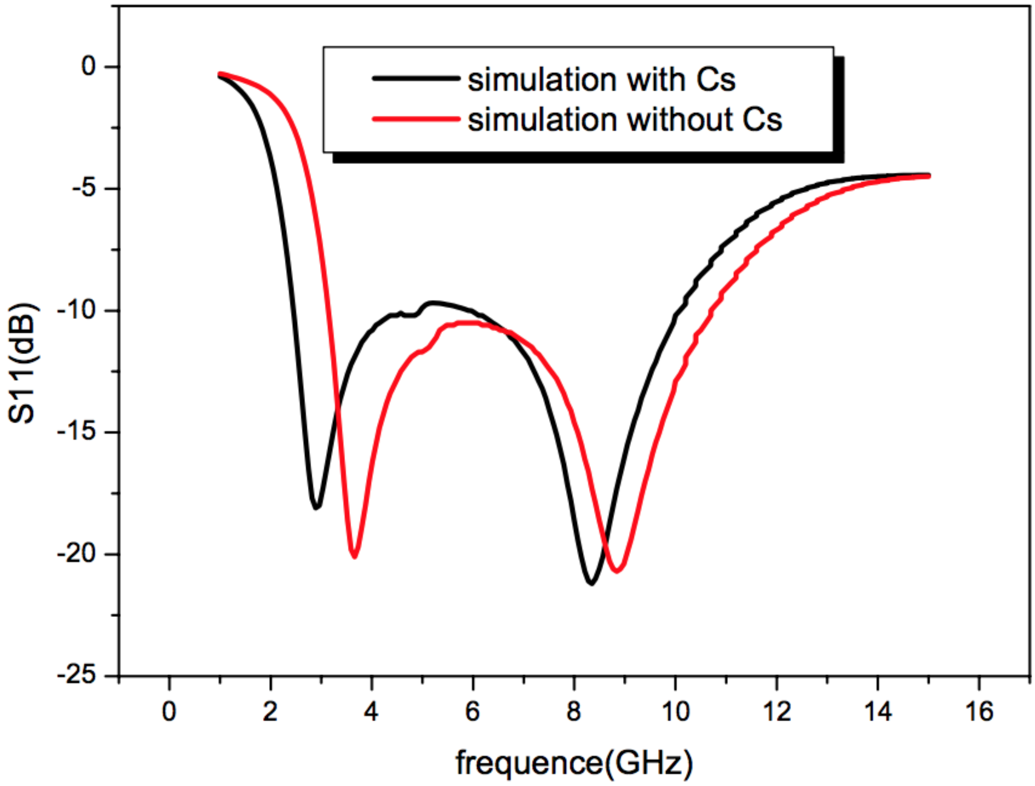


Fig.4.22 Simulation of adding Cs

4-3-5. Co Discussion

Exploring the characteristics of parallel resonance from Figure 4.23, when L = 1nH, C = 1pF, its resonance frequency is at 5.033 GHz, which is inductive and the inductance far away from the resonance frequency is close to the original inductance value before the resonance frequency, and in the high frequency, it is capacitance, and the capacitance far away the resonance frequency is close the original capacitance. In the matching circuit, the resonance frequency for suppressing the high frequency gain is about 16 GHz, and the designed resonance frequency is far away from the UWB operation coupling, so it can be inferred that the addition of the capacitor Co will not affect the original matching too much.

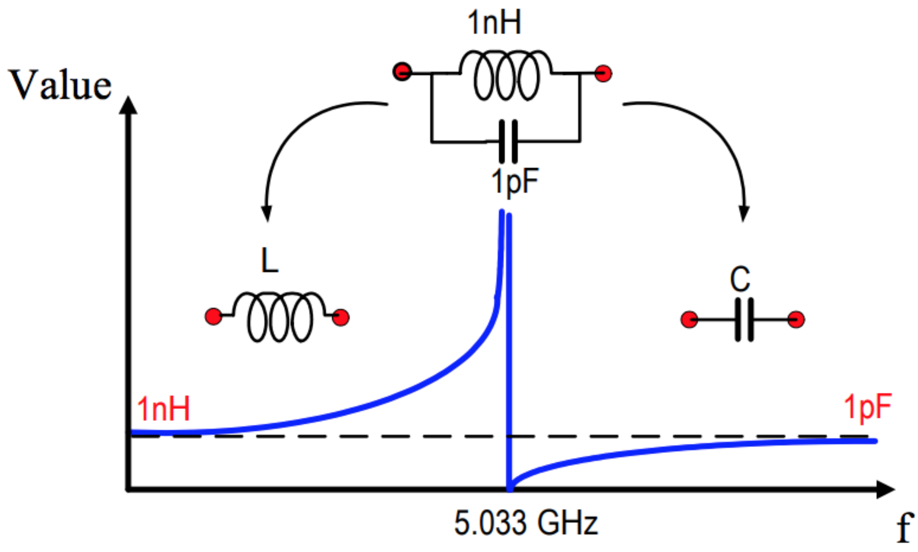


Fig.4.23 The effect of capacity Co

4-4. Final Circuit Design and Simulation Result

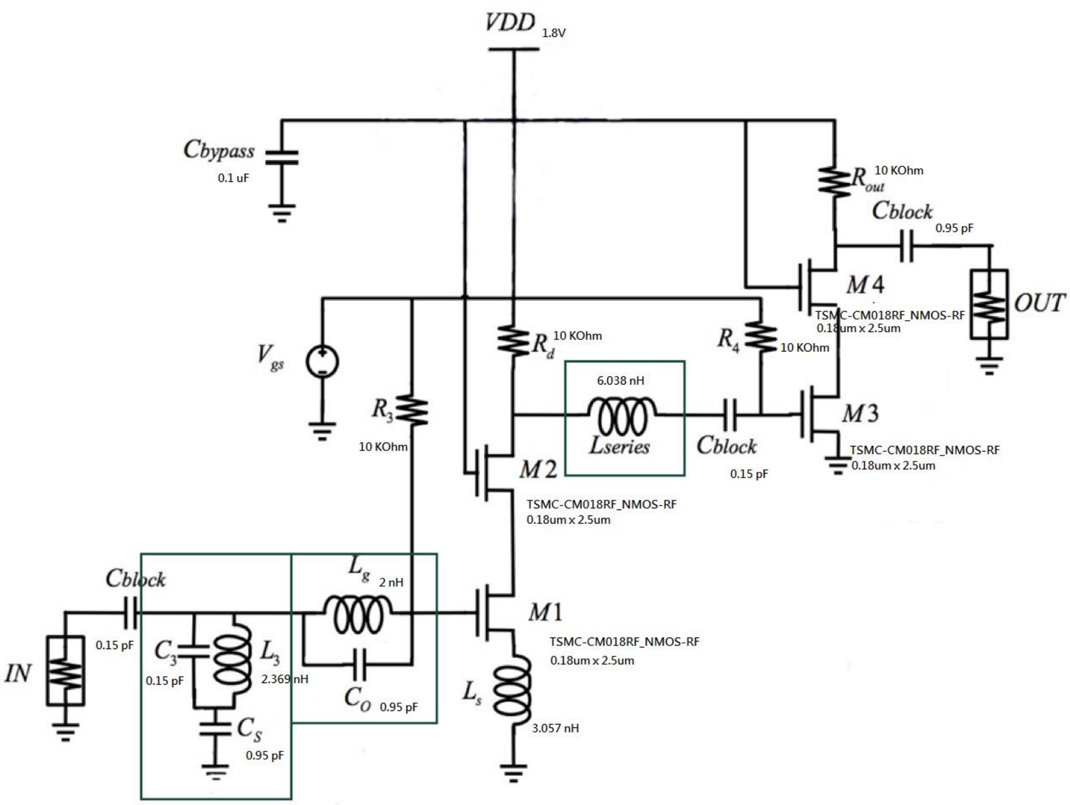


Fig.4.24 LNA circuit design

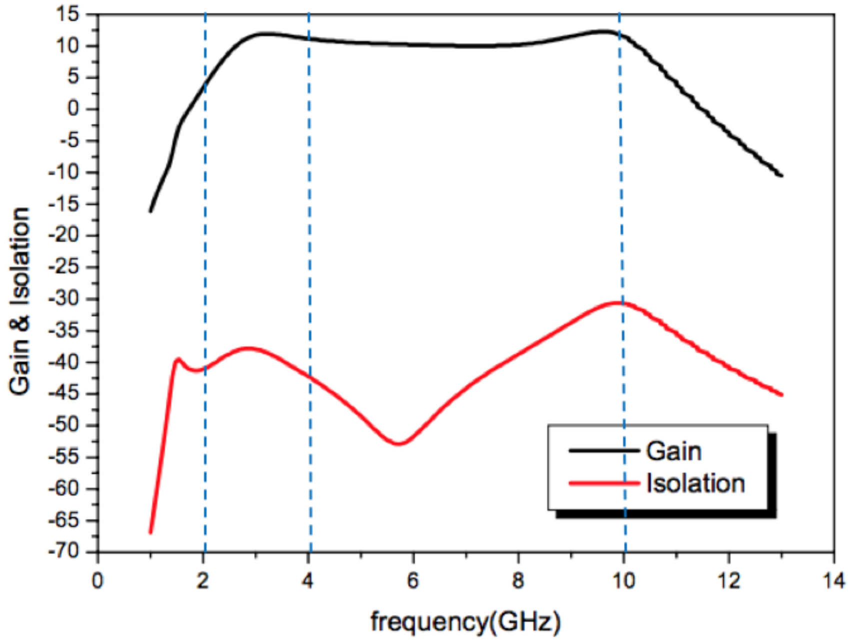


Fig.4.25 Simulation of gain and isolation

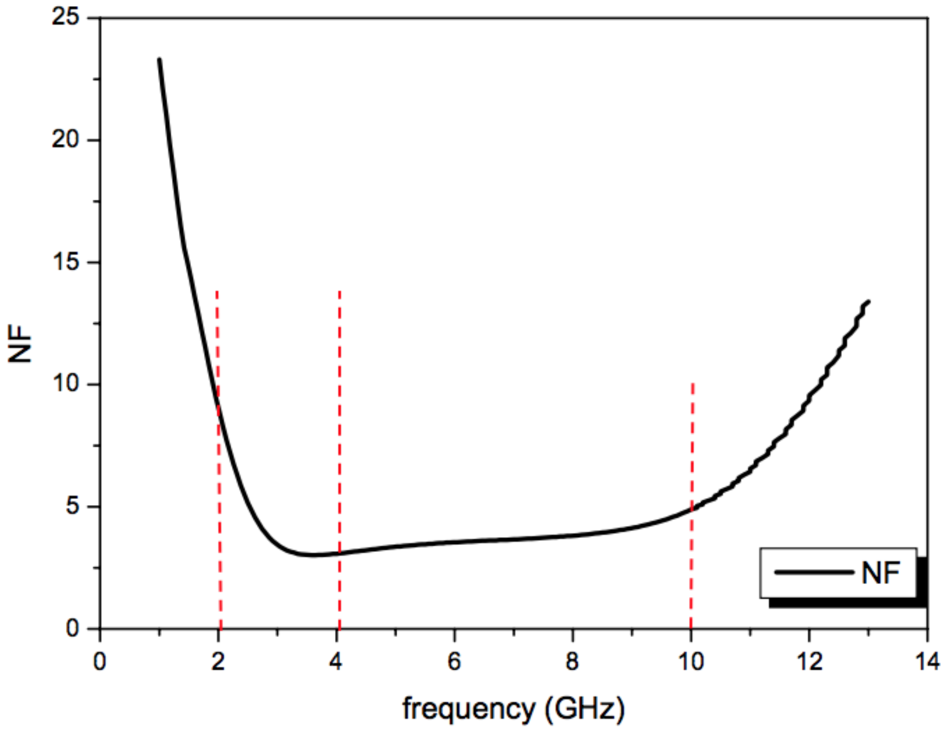


Fig.4.26 Simulation of noise figure

4-5 Comparison with exist LNA

Parameter	LNA(Vdd=1.8V)	MAX2611	MAX2630
Gain (dB)	11 ± 1	18.5	13.4
Noise (dB)	3.34 ~ 5	3.5	3.8

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