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| HA NOI UNIVERSITY OF SCIENCE AND TECHNOLOGY  **SCHOOL OF ELECTRICAL**  **AND ELECTRONIC ENGINEERING**  logo_128  PROJECT  **ELECTRONIC DESIGN II**  **TOPIC:**  **MIXER DESIGN FOR GSM-900**  **Instructor**: DR. NGUYEN NAM PHONG  **Students**: NGUYEN LE TRUNG 20186076  VU HOANG LONG 20182926  PHAM HUY HOANG 20182544  DANG ANH TU 20182938  NGUYEN VO PHUONG THAO 20182936  Ha Noi, 12-2021 |

**PREFACE**

Tài liệu này được Viện Điện tử - Viễn thông, trường Đại học Bách Khoa Hà Nội soạn thảo và ban hành nhằm mục đích hướng dẫn sinh viên trình bày đồ án tốt nghiệp một cách khoa học và thống nhất. Bản thân tài liệu này được biên soạn phù hợp với các quy định về trình bày một đồ án tốt nghiệp. Vì vậy, sinh viên có thể sử dụng trực tiếp mẫu này như một template khi viết quyển đồ án của mình. Sinh viên cũng được khuyến khích tham khảo hoặc sử dụng mẫu này khi viết báo cáo thực tập, báo cáo kết quả nghiên cứu, và các đồ án môn học khác.

Chi tiết về nội dung của phần Lời nói đầu được trình bày trong Mục 1.3.3.

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# ABBREVIATIONS

|  |  |
| --- | --- |
| **AC**  **BJT**  **DC**  **FDD**  **FDMA**  **FET**  **GSM**  **HB**  **IF**  **LO**  **LPF**  **NF**  **RF**  **SNR**  **TDMA**  **TOI/IP3** | Alternating Current  Bipolar Junction Transistor  Direct Current  Frequency Division Duplex  Frequency Division Multiple Access  Field-Effect Transistor  Global System for Mobile Communications  Harmonic Balance  Intermediate Frequency  Local Oscillator  Low Pass Filter  Noise Figure  Radio Frequency  Signal-to-Noise Ratio  Time Division Multiple Access  Third Order Intercept Point |

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# ABSTRACT

Tóm tắt đồ án, có độ dài 1-2 trang, được trình bày tại đây. Chi tiết xem Mục 1.3.9

# INTRODUCTION

## What is a mixer

* One of the most useful radio frequency processes is mixing, which is performed by a RF mixer. Unlike a conventional audio mixer where sounds are simply added together to create an interesting sound effects, RF mixing refers to a different process. Where signals are multiplied together to create a new signal with a different frequency.
* RF mixers are used in virtually every cellphones and many other devices like radios, spectrum analyzers. It can change signal’s frequencies for different purposes. For example, with mixers a signal can be undertaken on a lower frequency where it is easier to perform signal processing. On contrary, the can also be increased to a higher frequency for transmitting.
* In electronic, a mixer, or frequency mixer, is a nonlinear electrical circuit that creates new frequencies from two signals applied to it. In its most common application, two signals are applied to a mixer, and it produces new signals at the sum and difference of the original frequencies. Other frequency components may also be produced in a practical frequency mixer.
* Mixers are widely used to shift signals from one frequency range to another, a process known as heterodyning, for convenience in transmission or further signal processing. For example, a key component of a superheterodyne receiver is a mixer used to move received signals to a common intermediate frequency. Frequency mixers are also used to modulate a carrier signal in radio transmitters.
* As the heart of the superheterodyne transceivers, mixer play an important role of selecting channels, where changing the local oscillator frequency would result in selecting different radio channel but still maintain the same intermediate frequency. Thus it can be used with same filters and signal processing method for different channels or frequencies.

Shape

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*Figure 1‑1: Mixer*

* A mixer contains 3 ports: Input signal, local oscillator and output signal:

If the output signal has frequency lower than the input signal’s, then the mixer will perform a down conversion transform, else it will perform an up conversion transform.

* There are 2 main type of mixer:
  + **Passive mixers**: Passive mixers typically use passive components in the form of diodes as the switching element within the RF circuit. As a result they cannot exhibit any gain, but many forms can provide excellent levels of performance.

Passive mixers mainly use Schottky diodes because of their low turn-on voltage, but they require the use of a balun / RF transformer if they are to be used in a balanced or double balanced mixer. This can limit the frequency response.

* + **Active mixers**: As the name of the Active RF mixer contains active electronic components like a bipolar transistor, FET or even a vacuum tube / thermionic valve. These types of RF mixer are able to provide gain as well as proving the multiplication or RF mixer capability.
* Mixers are also looked at by whether they are balanced or not. Balancing them requires baluns - balanced to unbalanced transformers - but this provides improvements in performance:
  + Unbalanced mixer
  + Single balanced mixer
  + Double balanced mixer
  + Triple balanced mixer

## Operating Principle

To lower the center frequency, the signal is multiplied by a sinusoid , which is generated by a local oscillator (LO). Since multiplication in the time domain corresponds to convolution in the frequency domain, we observe from Fig. 4.7(b) that the impulses at ± shift the desired channel to ±( ± ). The components at ±( ± ) are not of interest and are removed by the low-pass filter (LPF) in Fig. 4.7(a), leaving the signal at a center frequency of  - . This operation is called “downconversion mixing” or simply “downconversion.” Due to its high noise, the downconversion mixer is preceded by a low-noise amplifier [Fig. 4.7(c)].

Diagram

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*Figure 1‑2: (a) Downconversion by mixing, (b) resulting spectra, (c) use of LNA to reduce noise*

Called the intermediate frequency (IF), the center of the downconverted channel, - , plays a critical role in the performance. “Heterodyne” receivers employ an LO frequency unequal to and hence a nonzero IF.

How does a heterodyne receiver cover a given frequency band? For an N-channel band, we can envision two possibilities. The LO frequency is constant and each RF channel is downconverted to a different IF channel [Fig. 4.8(a)], i.e., . The LO frequency is variable so that all RF channels within the band of interest are translated to a single value of IF [Fig. 4.8(b)], i.e., . The latter case is more common as it simplifies the design of the IF path; e.g., it does not require a filter with a variable center frequency to select the IF channel of interest and reject the others. However, this approach demands a feedback loop that precisely defines the LO frequency steps, i.e., a “frequency synthesizer”.

Diagram, schematic

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*Figure 1‑3: (a) Constant-LO and (b) constant-IF downconversion mixing*

Problem of Image Heterodyne receivers suffer from an effect called the “image.” To understand this phenomenon, let us assume a sinusoidal input and express the IF component as

That is, whether is positive or negative, it yields the same intermediate frequency. Thus, whether lies above or below , it is translated to the same IF. Figure 4.9 depicts a more general case, revealing that two spectra located symmetrically around are downconverted to the IF. Due to this symmetry, the component at is called the image of the desired signal. Note that .

A picture containing text, clock

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*Figure 1‑4: Problem of image in heterodyne downconversion*.

What creates the image? The numerous users in all standards (from police to WLAN bands) that transmit signals produce many interferers. If one interferer happens to fall at , then it corrupts the desired signal after downconversion.

While each wireless standard imposes constraints upon the emissions by its own users, it may have no control over the signals in other bands. The image power can therefore be much higher than that of the desired signal, requiring proper “image rejection.”

## What is GSM 900?

* GSM900 is a version of Global System for Mobile Communications, a popular second generation cellular system, which offer full-duplex voice communication service and operate at 900 MHz band
* The 900 MHz band defined in the ETSI standard includes the primary GSM band (GSM-P), the extension (see E-GSM) and the part of the 900 MHz band that is reserved for railways (R-GSM).
* The total GSM900 band defined in the standard ranges from 876 - 915 MHz paired with 921 - 960 MHz. Mobiles transmit in the lower band and base stations transmit in the upper band.
* In daily life, the term GSM900 band is used for the parts of the band that are used by the GSM operators to offer public services, which exludes the R-GSM band. This part of the band that remains ranges from 880 - 915 MHz paired with 925 - 960 MHz band.
* The system adopts FDD scheme with duplexing distance of 45 MHz. The multiple access scheme is a combination of FDMA and TDMA, where the spectrum for each transmission irection is divided into frequency subband of 200 kHz and each of the subband carries 8 voice channels in a time division.
* Diagram

  Description automatically generated

*Figure 1‑5: GSM900 System*

## Important Parameters of a Mixer.

### Conversion loss

***The conversion loss*** of a mixer is the ratio of the desired IF output (voltage or power) to the RF input signal value (voltage or power), corresponding to each level of the LO.

If the input impedance and the load impedance of the mixer are both equal to the source impedance, then the voltage conversion gain and the power conversion gain of the mixer will be the same in dB’s.

The Conversion Loss of the RF Mixer measured in dBm is given by:

* For Lower Sideband:
* For Upper Sideband:
* Generally:

Diagram

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*Figure 1‑6: High-side and Low-side Injection*

The typical ***conversion gain*** of an Active Mixer is approximately +10dB, when the ***conversion loss*** of a typical Diode Mixer is approximately -6dB.

### Noise Figure

Noise Figure is the ratio between the Signal to noise ratio (SNR) at the input and at the output.

### High-side and Low-side Injection:

* If FLO > FRF: High-side injection. The LO will be called as high-side LO (HSLO).
* If LO < FRF: Low-side injection. The LO will be called as low-side LO (LSLO).

### Third Order Intercept Point (IP3 or TOI)

***IP3*** is an important parameter to consider the linearity of the mixer. It is the fictional value defined by the extrapolated intersection of the primary IF response with the two-tone 3rd intermodulation IF product that results when two RF signals are applied to the RF port.

Diagram

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*Figure 1‑7: Third order Intercept Point*

Denote the local oscillator’s frequency as FLO­ then the IP3 products are (2F­1 ± F2) ± F­LO and (2F­2 ± F1)± F­LO. For the downconversion case, the significant noise products are (2F­1 - F2) - F­LO and (2F­2 - F1) - F­LO since they are near around the Intermediate Frequency (IF).

A screenshot of a video game

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*Figure 1‑8: 2-Tone Downconversion Spectrum*

### 1-dB Compression Point

Within the small input signal level, the output power increases linearly with the input one. If the input power continuously increases, the conversion loss will start to increase. The 1-dB Compression Point is where it gains 1-dB compared to the linear one. Mixer must be designed under this point to avoid the unexpected outputs (such as third or higher order products).

Diagram

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*Figure 1‑9: 1-dB Compression Point*

### Isolation

***Isolation*** is the amount of LO power that leaks into either the IF or the RF ports, usually in dB. This is one of the most significant drawback when designing a transceiver system.

There are multiple types of isolation: LO-to-RF, LO-to-IF and RF-to-IF isolation.

### Linearity

The linearity of a mixer is the ability of controlling the signal level. The higher linearity a mixer gains, the upper its IP3 is.

### Image Frequency

Diagram

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*Figure 1‑10: Image Frequency*

As mentioned above, , hence there are several options for fRF. As the above figure, if we choose fRF > fLO (LSLO case), then aside, fIF we also obtain another unexpected signal at frequency fLO – fIF and so on. Those frequencies are called ***Image Frequency*** and we have to choose an appropriate filter to eliminate them out.

# DC – AC ANALYSIS

As mention in the previous part, GSM900 is the technology that usually be used on mobile devices, especially, cellphones, which battery lifetime is critical. Therefore, the mixer also needs to be power efficient, comparing between 2 kind of mixers, the active mixer having huge advantage over power consumption, which makes it suitable for implementing in the GSM900 devices.

***Mixer specification:***

* **Down conversion** mixer
* RF frequency: **900 MHz**
* IF frequency: **45 MHz**
* **10 dB** conversion gain
* Operating voltage and current: **1 VDC @ 600 μA**

**2.1. Single-ended active mixer**

The single ended mixer is one of the simplest active mixers. The mixing performed by the mixing is performed by modulating the transconductance of the driver stage with the LO signals. Because of architecture simplicity, single ended mixers have lowest noise figure within active mixers

Diagram, schematic

Description automatically generated

*Figure 2‑1 single ended active mixer example*

Some parameters would be considered in mixer design (mentioned in previous chapter):

* Conversion loss
* Noise figure
* Isolation
* Linearity

**2.2. Design a single-ended mixer**

***2.2.1. Selecting devices***

The purposed design consists of a transistor, resistors, capacitors. For the transistor, the purposed candidate is the MMBR941 bipolar junction transistor from Motorola. It doesn’t have as good mixing properties as RF field-effect transistor, it’s very low cost and has accurate simulation model available with a reasonable performance. This BJT model is available with Keysight Advance Design System, where it can be verified and also evaluated the design.

For resistors and capacitors, they are just generic passive devices in the simulation.

***2.2.2. DC curve verification***

In order to verify the device under DC parameters, the I-V Curve of the transistor is needed. So as to plotting the I-V Curve of the transistor, the sweeping parameters function of ADS is used. Therefore, the device can be tested how it would behave under different value range and DC configuration. The parameters are tested in this part are Collector – Emitter Voltage and Base current of the transistor

Simulation sweeping setup:

|  |  |
| --- | --- |
| * Parameter: **VCE**   + Start value: 0V   + Sweeping step: 0.1V   + Stop value: 6V | * Parameter: **IBB**   + Start value: 50uA   + Sweeping step: 75uA   + Stop value: 350uA |

Diagram

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*Figure 2‑2 DC curve verification simulation*

Since the DC controller can only sweep one value, the Parameter sweep will be used for sweeping IBB. Both parameters are set as variable for sweeping controller. The current probe is for measuring the change of Collector current for reference in the I-V Curve plot.

The simulation result:

Chart, line chart

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*Figure 2‑3: Comparison of Measured (blue) and Simulated (red) DC I-V Curve*

There are not much different between simulated and measured result, the curve show that at the specified operating point of VCE = 1V, ICE < 0.6mA the device will operate at low current region.

***2.2.3. DC bias network***

This part will help to select device operation point calculating the base and collector resistors. Therefore, the base current needs to be determined, as the collector voltage and current are already specified.

In this setup VCC will be fixed at 1V and IBB will be swept:

* Parameter: **IBB**
  + Start value: 1uA
  + Sweeping step: 0.5uA
  + Stop value: 10uA

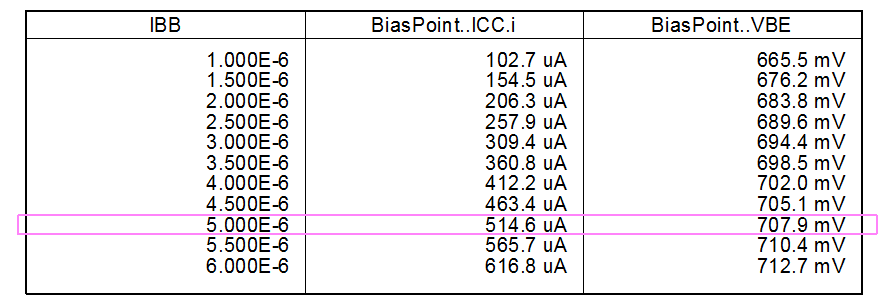
Diagram, schematic

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*Figure 2‑4 bias network schematic*

To mimic the real setup, the bias tee components (the DC\_Feed and DC\_Block components) and 50 Ω terminations are added. The bias point current is lower than the specified final value, because the device will have to work with large LO signal, which cause a shift in the DC component of the collector current.

Table 2‑1: VBE vs IBB, given VCC = 1V



The table 2-1 shows that IBB need to be 5uA to have ICC= 514.6uA with corresponding VBE of 707.9V which is well below the specification

Table 2‑2: Calculated Rb and Rc

Table

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To calculate Rb and Rc, the collector-emitter voltage of 0.75 V, at the point of IBB = 5uA, the correspond Rb and Rc are 8424.296 Ω and 481.125 Ω.

The next step will confirm this bias operation using these standard values of Rb and Rc and then verify the S-parameters of the model against measured value.

***2.2.4. DC bias network verification***

In this part, the bias configuration obtained from 2.1.3 will be verified. The schematic incluse bias tee components (DC feeds and blocks) to make sure the performance of RF

This simulation will run with both values of the exact resistor values and nearest standard values (Rc = 470 Ω, Rb = 8.2 kΩ) to verify the RF performance

Diagram, schematic

Description automatically generated

*Figure 2‑5: schematic of DC bias network*

The S-parameters controller will run the frequency sweep to see the circuit’s frequency response and and displayed, together with measured.

Chart, line chart

Description automatically generated

*Figure 2‑6: simulation result of DC bias network*

There is a great alignment between values obtained here verifies the small-signal RF performance. The device compression point will be simulated next to confirm large-signal operation.

***2.2.4. Large-Signal Verification (gain compression)***

The output compression at frequency of 900MHZ will be calculated in this step. The first method to calculate is using Harmonic Balance controller, by sweeping the input power level from low to high values until the output power compresses (the ratio Pout/Pin starts to fall off from its small-signal value. The input power variable, “PwrIn” is swept from -45 to -5 dBm and a Measurement Equation component is used to define the output power at 900 MHz, in dBm.

The dBm function assumes the power is being delivered to a 50 Ω load. The argument “HB.Vout[1]”, specifies the fundamental frequency.

The second method is more direct and does not require graphs or sweeping variables. The Gain Compression controller “XDB” performs a harmonic balance analysis that correctly calculates and outputs the input and output power levels at the specified compression point. the output from this method: the input and output power levels at 1dB compression are listed in dBm.

Graphical user interface

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*Figure 2‑7: schematic gain compression*

Chart, line chart

Description automatically generated

*Figure 2‑8: result of gain compression*

The result graphs show both calculate method of the simulation agreed with the measured data.

# S-PARAMETER SIMULATIONS

# MATCHING

# MIXER CONVERSION GAIN SIMULATION

In this chapter, we will try to simulate conversion gain of the mixer.

## Mixer conversion gain versus LO drive level

In this part, we will try to simulate conversion gain for the mixer and determine the effect of LO drive level on gain and DC bias.

The RF and LO frequencies and the LO power level have been defined as variables.

The RF drive level is specified at -50 dBm, while the harmonic balance controller is set up to sweep the LO drive level from -30 to -5 dBm. A simulation measurement equation defines the output power, in dBm, at the IF:

Graphical user interface, text, application

Description automatically generated with medium confidence

*Figure 5‑1: Measure equation for P\_IF*

This measurement equation defines it here instead of the data display page makes it possible to optimize for output IF power, if needed. The “**mix**” function will return the component of the Vout spectrum defined by {-1, 1}, meaning {-Freq[1] + Freq[2]} or -LO + RF = IF (45 MHz). The “**P\_IF**” equation calculates the dBm value of the mix function.

Diagram, schematic

Description automatically generated

*Figure 5‑2: LO Drive Level and RF/IF Matching*

Since the conversion gain is the difference between P\_IF and the RF, and the RF power is fixed at -50 dBm, the conversion gain can be calculated with a simple expression.

Logo

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Note that the default dataset, **LODrive**, contains results for a 4.7 kΩ load resistor, and the conversion gain for this simulation is calculated by the equation “**ConvGain**”.

Chart

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*Figure 5‑3: Conversion Gain vs LO Power*

The conversion gain for a -10 dBm LO drive is 17 dB, which is unacceptably high. A second simulation was run with the load resistor reduced 1.5 kΩ, which creates a lossy mismatch on the output. The results for that simulation were output to dataset LOdrive15, and equation “**ConvGain\_Rl5kOhm**” shows the conversion gain is reduced to 13.7 dB. This is still higher than the specification of 10 dB but will be left at this value for now since conversion gain can be expected to decrease further when non-ideal surface mount components replace the ideal components.

The graph below shown illustrates the effect of the LO drive level on DC bias. Increasing the LO signal at the base drives the output swing on the collector harder, shifting the DC component higher (see Figure 19). In practice, a 5 to 15 percent shift in collector bias current typically gives good performance for a mixer of this type.

Chart, line chart

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*Figure 5‑4: ICE vs LO Power*

## Mixer conversion gain versus RF signal level

The set-up for measuring mixer compression is very similar to LOdrive, except that the LO power level is now held constant at -10 dBm, while the RF power is swept from -50 to 0 dBm.

Diagram, schematic

Description automatically generated

*Figure 5‑5 Compression Point Simulation Configuration*

As the results in Figure below show, the mixer’s conversion gain reaches 1 dB compression at an input signal level of -27 dBm.

Chart

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*Figure 5‑6: Gain vs RF Power*

Chart

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*Figure 5‑7: 1-dB Compression Point*

# THIRD-ORDER INTERCEPT POINT AND NOISE FIGURE SIMULATION

In this chapter, we will perform the simulations and related results of ***Third-order Intercept Point*** (TOI or IP3) and ***Noise Figure*** (NF).

## Third-order Intercept Point

In this section, we use the module Hamonic Balance Controller to figure out the value and characteristics of TOI based on our pre-fixed input power of LO and RF, also the chosen frequencies as mentioned in the INTRODUCTION chapter (fLO = 855 MHz, fRF = 900 MHz).

Initially, we define some required parameters by selecting out the module VAR. This VAR will initialize the values needed for the IP3 or TOI (third order intercept) simulation. The variable ***f\_spacing*** is used to separate the 2 RF tones:

Text

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*Figure 6‑1: TOI simulation parameter*

We also modify the source as above, note that we use the ***f\_spacing / 2*** to give 10 KHz offset spacing from the RF, so the actual spacing is 20 KHz.

For the Hamonic Balance Controller, we use Krylov solver to shorten the simulation time. We also allow the RF\_pwr variable to be sent to the dataset.

Text

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*Figure 6‑2: Harmonic Balance Configuration for TOI simulation*

Finally, we set up the IP3out measurement equation (TOI).

Graphical user interface, application, Teams

Description automatically generated

*Figure 6‑3: TOI Equations*

Where hi\_toi represents the higher spaced tone (RF\_freq + spacing/2), and lo\_toi is the remained one.

Running simulation, we obtain the following result:

Table 6‑1 Two-tone IP3 values at the output

Table

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Trying to plot out the spectrum of Vout (denoted in the schematic), we will see the inter-modulation products (max order) generated by the two-tone simulation.

Chart

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*Figure 6‑4: Vout Spectrum*

It is hard to see the separation of m1 and m2, where m1 marks out lo\_toi and m2 marks out hi\_toi. Try to zoom in to see what happens:

Chart, line chart

Description automatically generated

*Figure 6‑5: Vout spectrum (zoom in)*

## Noise Figure

The ***Noise Figure*** (NF) measurement calculates the noise contributed by circuit for the given input frequency (RF) of the designed mixer. To perform it, we have to modify the HB controller and replace our last two-tone RF source with a single tone one.

Text

Description automatically generatedDiagram

Description automatically generated

*Figure 6‑6: NF Simulation Configuration*

Running simulation, we obtain the following result:

Chart, line chart

Description automatically generated

*Figure 6‑7: NF vs LO Power*

As you can see, The Noise Figure is acceptable as specification.

# CONCLUSION

## Kết luận chung

Xem Mục 1.3.12

## Hướng phát triển

(Nếu có)

## Kiến nghị và đề xuất

(Nếu có)

# CONTRIBUTION

1. **Theoretical Concepts and Plans:** Team
2. **Simulation:**

* ***DC – AC Analysis:*** Dang Anh Tu
* ***S – Parameters Analysis:*** Pham Huy Hoang
* ***Matching:*** Nguyen Vo Phuong Thao
* ***Conversion Gain:*** Nguyen Le Trung
* ***IP3 and NF:*** Vu Hoang Long

1. **Report and Proofreading:** Team

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# APPENDIX

## Phụ lục 1. Mẫu trang bìa chính của đồ án

(Xem trang sau)

***Cho thêm schematic, thông số bjt, v.v vào đây***