Repeater design based on mixer and re-modulation scheme

by

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Bachelor of Communication Engineering, Henan Normal University, 2020

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in the Department of Electrical and Computer Engineering

University of Victoria

Supervisory Committee

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Abstract

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Half-duplex frequency modulation radios have different communication distances in different application scenarios, due to environmental factors, human factors, etc. In order to deal with the negative environmental impact factors, we propose a solution of a removable mini repeater. In the report, we investigate the performance of the proposed solution using ADS RF simulation software. The simulation results show that the repeater can enhance the received power of the radio signal and the communication range.

List of abbreviations

FM: Frequency Modulation
RF: Radio Frequency
VCO: Voltage Controlled Oscillator
PLL: Phase Locked Loop
LOS: Line-of-Sight
NLOS: Non- Line-of-Sight
DC: Direct Current

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Acknowledgements

This project would not have been possible without the support of many people. First of all, I would like to express my deepest gratitude to Dr. Cai for her invaluable insights leading to the writing of this thesis and her patient instructions. It is an honour to take the master's program with Dr. Cai as my supervisor. Also, I am grateful for my family’s unconditional love and support and my friends’ warm care.

Introduction

With the rapid development of communication technology, especially wireless, a variety of communication equipment have emerged and used in various fields. Half-duplex FM wireless intercom has been widely used in daily life. A half-duplex intercom system has many advantages, such as simple to use, infrastructure-free and low cost, so it has a wide range of applications. However, the radio transmission distance is very limited and affected by several aspects. Therefore, we want to design a mobile mini repeater that can be easily carried. The mini repeater achieves the purpose of extending the transmission range. The mobile mini repeater is lightweight, small size, and full functional. It can enhance the intercom distance and is convenient.

In this thesis, we study the various problems of existing wireless communication devices. Based on the theoretical knowledge of the propagation of wireless signals, we conceived a set of basic circuit construction. The circuits such as VCO, PLL and Repeater are designed in detail on ADS RF simulation software. The ideal devices available in the ADS RF simulation software library, such as amplifiers, filters and other components are also used. The transmit and receive links of the intercom, as well as the repeater link, are constructed. We conclude from the specific simulation results that the designed elements meet our design. After the signal passes through the repeater, the power amplification and the frequency conversion are achieved.

The rest of the thesis is organized as follows. Chapter 1 explains the background of the problem under study. Chapter 2 describes the specific ways in which the studied project can improve the existing problem. Chapter 3 explains the principal architecture of the studied project based on the existing theory. Chapter 4 details the observations obtained through a specific circuit and visualized simulation software. Chapter 5 presents the results of the study and future work.

Chapter 1: Background

1.1 The application of walkie-talkie

A walkie-talkie is a widely used wireless communication tool. Radio walkie-talkies first appeared in the 1930s. After nearly a century of development, in the 21st century, the application of walkie-talkies has become very common. Walkie-talkies have successfully transformed from the professional field to common consumption for both military and civilian usage. Without the need of any infrastructure, walkie-talkies allow users to easily communicate in any places. In addition, walkie-talkies can also support one-to-one and one-to-many calls. The extremely simple operation of walkie-talkies allows people to communicate freely, especially in cases of emergency dispatch and collective, collaborative work.

Because of the many advantages of the walkie-talkie, it has been widely used in various life scenarios.

(1) Indoor scenarios where frequent communication is required. In restaurants, hotels, banks and other environments, staff need to keep in touch to ensure service quality and staff safety. For instance, in a hotel, the walkie-talkie can be used to connect the lobby, front desk, kitchen, security and other venues to maintain timely intercom and rapid response.

(2) Warehouse, factory, field and other large work areas, such as logging, mining and other work, need to keep in touch with colleagues to ensure progress and safety. Walkie-talkies can not only maintain real-time contact but also meet the requirements of waterproof and dustproof.

We interviewed some of the local staff, and from them we learned about the important role of walkie-talkies. “Radios are used as a primary communication device while out on the fire line. Utilizing Simplex channels, they support safety and operations through regular check-ins, confirming locations, relaying information to dispatch, and coordinating personnel movements.” The fire team will head back if the walkie-talkie does not work. If there is a technology that can extend the communication range, the team can go further.

1.2 Existing problems of walkie-talkie

1.2.1 Obstacle influence

The communication of a walkie-talkie is affected by obstacles, including mountains, woods, tall buildings, etc. In the open environment, the communication distance of a 5W walkie-talkie can reach 2.5 km. In a city with tall buildings, the communication distance is reduced to 1 km. When standing in a high place when using the walkie-talkie, the communication distance is much farther because there are fewer obstacles. However, in real life, we can only reach a limited height.

1.2.2 Electromagnetic environment impact

Electromagnetic environment refers to "the sum of all electromagnetic phenomena that exist in a given place." Nowadays, along with the development of electronic technology, electronic products have gradually become essential for people's lives. The popularity of electronic products leads to a more and more electromagnetic severe environment. In the electromagnetic environment, electromagnetic phenomena will produce serious interference to the signal of the walkie-talkie, so the communication distance and quality will be affected. In addition, different weather conditions can also interfere with the use of walkie-talkies.

1.3 Existing solutions

1.3.1 Building infrastructure

The signal base station, i.e. public mobile communication base station, is a form of the radio station, which is a radio transceiver station that transmits information between cell phone terminals in a specific radio coverage area through a mobile communication exchange center. The main function of a base station is to provide wireless coverage, i.e., to realize wireless signal transmission between wired communication networks and wireless terminals. Simply put, the base station is used to ensure that our cell phone can receive a signal anytime anywhere in its coverage even with high mobility.

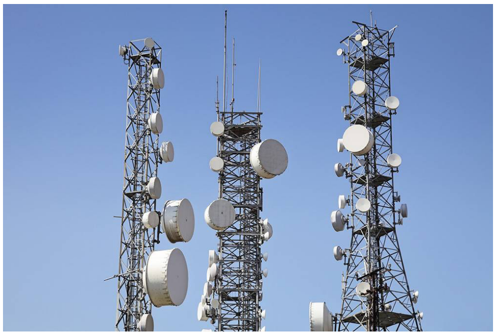

Figure 1: Large signal base stations[1]

The base station signals are sent and received through the antennas. Usually, a base station has three sets of directional antennas, each covering a 120-degree sector. The

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[1] Image from Google Scholar

two small boxes next to the upper antenna are RF amplifiers used to amplify the base station signals.

Although base stations can expand the range of wireless communication, building base stations is expensive.

1.3.2 Increase the transmit power

The main factors affecting the communication distance are the power of wireless products, the receiving sensitivity of wireless products, the selectivity of wireless products, the signal modulation mode of wireless products, the working frequency band, the power supply system, the height of the antenna, the type of antenna, the length and diameter of the feed line, the spectrum distribution of radio interference in the area, the relative position of tall buildings or metal objects and antennas, topography and other environmental factors.

$$Los = 32.45 + 20\log(d) + 20\log(f)$$ [2]

This is the formula for free space transmission, ideal propagation conditions, where Los is the transmission loss in dB; d is the transmission distance in km; f is the operating frequency in MHz. It can be seen from the above formula that the attenuation of radio waves in free space is only related to the operating frequency f and the propagation distance d. When the operating frequency is constant, for every 6dB increase in loss in space, the radio transmission distance will be reduced by twice. From this, we can know that the factors affecting the transmission distance d are transmission loss Los and operating frequency f. Therefore, when the operating frequency of wireless products is fixed, increasing in the wireless transmission distance can be achieved by increasing the transmitting power.

However, increasing the transmit power does not necessarily increase the transmission distance of the wireless product when other conditions remain unchanged. In the actual technical embodiment, increasing the transmit power may also affect the quality of the modulated signal. If the increase in power leads to an increase in EVM (EVM characterizes the modulation accuracy. Its value is used to indicate the quality of the signal. The smaller the value, the better the quality of the signal. This will lead to counterproductive.

In practice, we cannot infinitely increase the transmitting power. For example, in the power supply system, the increase in power of wireless products is accompanied by an increase in power consumption of the entire system. In addition, the legal regulations also clearly state that the act of increasing the transmitting power without authorization is illegal.

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[2] Formula from: https://www.electronics-notes.com/articles/antennas-propagation/propagation-overview/free-space-path-loss.php

1.3.3 Increase the antenna height

Raising the height of the antenna can extend the communication range. Some people can lift the walkie-talkie or climb up to a higher place when there is no signal. But because of the limited height that can be reached within the safety range, the extension to the communication range is also limited.

1.4 Other existing wireless communication technologies

1.4.1 Mobile phone

For most people, cell phones are an integral part of their lives. The cell phone we are currently using is a "digital communication." In other words, the voice signal (continuous analog signal) of our speech is first converted into a digital signal, which is stored in the form of multiple 0s and 1s, and then converted into an electromagnetic wave (analog signal carrying a digital signal) through digital modulation, and finally emitted through an antenna.

Electromagnetic waves transmit 0s and 1s by changing wave characteristics, such as phase, frequency, amplitude, or a combination of these characteristics. For example, the frequency characteristics: low and high frequencies are represented by 0 and 1, respectively. However, electromagnetic waves cannot be transmitted over long distances. Electromagnetic waves are affected by terrain, electrical equipment, obstacles, and many other aspects so that the signal will be continuously attenuated during transmission. To solve this problem, scientists have invented cellular towers using cellular technology. In cellular technology, the geographical area is divided into hexagonal cells, each with its cell tower. These towers are usually connected by fibre optic cables, usually laid underground or in the sea, as a way to connect communications between countries or internationally.

When the signal tower receives the electromagnetic waves emitted by the cell phone, it converts them into high-frequency light pulses. These light pulses are transmitted to the base transceiver at the bottom of the tower for further signal processing. After the processing is completed, the signal will continue to be sent to the other nearby tower via fibre optic cable. After receiving the light pulses, the destination tower will radiate outward in the form of electromagnetic waves. When the other party's cell phone receives the electromagnetic waves, after reverse processing, it can obtain the voice signal. Countless such towers then constitute the cellular network we know.

Although the phone is powerful and portable, the phone signal will be affected by many factors. The antenna that comes with the phone can affect the quality of the signal. The signal can also be affected in more enclosed places such as elevators and tunnels. When there is substantial radio wave interference, there are often dropped lines. When located in a more remote area, mountainous areas or at sea and other places without signal base stations, the signal cannot be covered, and the phone will usually have no signal.

1.4.2 Bluetooth

Bluetooth wireless communication technology is a short-range radio technology. Bluetooth technology can realize wireless communication between terminal devices such as computers, cell phones, tablet PCs, home appliances, and even car systems in a small area. Bluetooth technology can support data transmission between terminal devices, supporting a transmission distance ranging from a few meters to several hundred meters.

The working principle of Bluetooth technology is also straightforward. When devices want to communicate with each other, i.e. to exchange data, they need to be paired. When the network environment is created successfully, one of the devices acts as the controller device and the other acts as the agent device. And the data to be transmitted is split into packets, and the packets are transmitted separately through the channels specified by the Bluetooth technology.

The essential features of Bluetooth technology are its ubiquity, low power consumption, and low application cost. With the development of technology, almost any device has Bluetooth technology; people can easily connect to the stereo, car, home appliances, etc., through Bluetooth. The power consumption of Bluetooth technology is also deficient. Developers even developed only a tiny button battery that can run for months or even years of small sensors. In addition, Bluetooth technology is also straightforward to use; consumers only need to turn on the Bluetooth and other devices to pair can.

But despite the many advantages of Bluetooth technology, we still can not ignore its limitations of Bluetooth technology. Bluetooth technology transmission distance is extremely limited; the current civilian version of the Bluetooth transmission distance of 8-30m. But because of the reality of many wireless signal interference and wall blocking, the actual transmission distance is generally about 10m. Bluetooth technology is also very limited transmission rate, some places show the Bluetooth standard transmission speed of 1Mbps, but the actual application speed is about 700KB/s. In addition, the actual application of Bluetooth technology is also very limited due to the compatibility of the device and other factors.

1.4.3 Satellite Communication

Satellite communication is to launch a satellite into a geostationary orbit about 36,000km above the equator and use the communication transponder on the satellite to receive signals from ground stations and then send them to other ground stations after processing. In short, artificial earth satellites are used as relay stations to relay radio waves, thus enabling communication between two or more earth stations. It can be said that the primary purpose of satellite communication is to achieve "seamless" coverage of the ground.

The main feature of satellite communication is its extensive communication range and high reliability, which is not easily affected by land disasters. Satellite communications can be received in multiple places at the same time and can achieve broadcast, multi-access communications. The same channel can be used for communications in different directions or between different zones. The circuit setup is also very flexible and can readily disperse the overly concentrated traffic. For global communications, only three geostationary satellites are needed to provide communications between any two points except the North and South Poles.

The main advantage of satellite communication systems over cellular communication systems is their comprehensive coverage. Even a low-orbiting satellite at an altitude of 400km can achieve coverage within a radius of several tens of kilometres. The super high coverage makes the satellite phone achieve many tasks that cannot be done by ordinary cell phones and walkie-talkies, such as ocean-going, exploration, field trips and even disaster relief; the satellite phone can guarantee smooth communication. However, ordinary people do not use satellite communications except for special industries or special needs. The terminal equipment still limits satellite communication. Satellite phones are larger and heavier than ordinary cell phones and are not convenient to carry. And the price of satellite phone equipment and telephone tariffs are costly, and the cost of use is extremely high.

Chapter 2: Communication range extension solution

Given the existing equipment and signal transmission problems mentioned above, we envision whether we can design and implement a lightweight repeater, small in size, light in weight and very convenient to carry around. It can even be taken into the air by UAV technology to transmit signals over longer distances. A typical repeater consists of a high-sensitivity receiver and a high-power transmitter; the repeater receives the intercom signal on one frequency, processes it, and then transmits it on another frequency using a high-power transmitter. In other words, the receiving frequency and the transmitting frequency are different. Generally speaking, the transmitting frequency is higher than the receiving frequency. Thus, it achieves the effect of increasing the communication distance, improving the signal power and avoiding the formation of self-interference. The repeater can improve the signal transmission quality from the following aspects.

2.1 Changing the signal channel

We usually divide the propagation of wireless systems into two environments: line-of-sight (LOS) and non-line-of-sight (NLOS) propagation. In the line-of-sight propagation case, the wireless signal can be propagated in a "straight line" between the transmitter and the receiver without obstruction. The diagram below shows the different propagation paths.

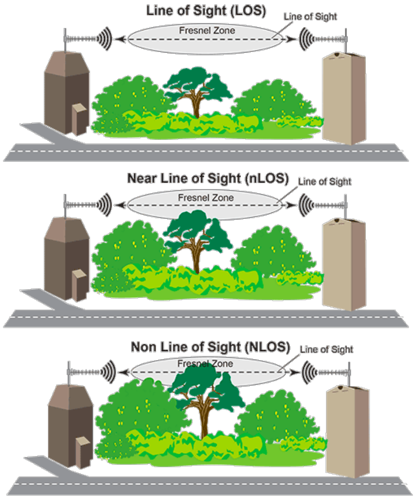

Figure 2: LOS and NLOS[3]

In the case of non-line-of-sight propagation (NLOS), the wireless signal can only reach the receiving end by reflection, diffraction and scattering. In addition to fading, the multipath effect may be accompanied by other effects, such as delay asynchrony, link instability, inter-subcarrier interference, and a series of other problems. The figure 3 shows the non-visual propagation path.

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[3] Image from: https://www.l-com.com/resource/blog/wireless-los-terminology

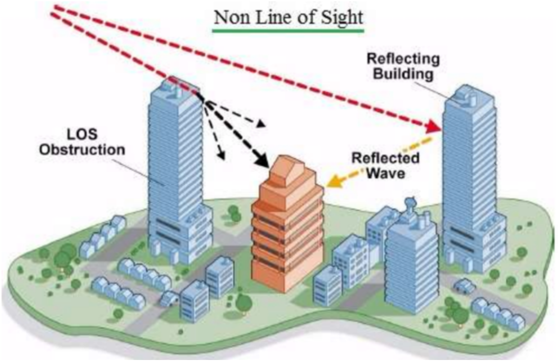

Figure 3: Example of LOS and NLOS[4]

Radio can transmit longer in the line of sight (LOS) case, but this cannot be guaranteed in practice. To prevent the emitted radio waves from being blocked by other objects, the most common method is to raise the height at which the antenna is located. It is built at a high place to avoid buildings so that the signal can be received directly. The signal will be diffracted and reflected when passing through obstacles such as buildings, and the signal will become weaker. Therefore, when the antenna is on the ground, the signal will encounter many obstacles when it is propagated horizontally, and the signal coverage will be small. On the contrary, if the antenna is high, it can avoid the obstacles and propagate far. Therefore increasing the height at which the antenna is located by drones/balloons can effectively extend the LOS range.

We can estimate the LOS range by the rule of thumb as follows.

$$3.57\left(\sqrt{kh_1}+\sqrt{kh_2}\right)$$ [5]

We can obtain this formula from the information about calculating the line-of-sight propagation limit distance for radio communication. Where k is the refraction factor and approximately equal to 1.33, h_1 and h_2 are the antenna heights of repeater and receiver, respectively.

We assume that the receiving end of the walkie-talkie is located at ground level. When the height of the repeater changes, we can obtain the following table.

Table1: Relationship between repeater height above the surrounding area and radio rang

Repeater height above the surrounding area	Radio range
0 foot	6.6 Miles
1 foot	6.8 Miles
2 feet	7.1 Miles
3 feet	7.3 Miles
5 feet	7.7 Miles
10 feet	8.7 Miles

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[4] Image from: https://www.researchgate.net/figure/Example-of-LoS-and-NLoS-links_fig1_320058665

[5] Formula from: https://blog.csdn.net/qingguideng/article/details/125980416

20 feet	10.1 Miles
30 feet	11.3 Miles
50 feet	13.3 Miles
100 feet	17.1 Miles
200 feet	22.5 Miles
500 feet	33.5 Miles
1000 feet	45.8 Miles
2000 feet	63.4 Miles

From the above table, we can conclude that when the repeater is higher, the possibility of obtaining LOS is higher to reach a higher radio range.

2.2 Boosting the signal transmission power

Since there is attenuation in the transmission of wireless signals, an appropriate boost in signal power can increase the communication distance. Repeaters often use high-powered transmitters to regenerate and send signals received with them; Thus increasing the power of signal transmission can giving a boost to wireless signals so that they can be transmitted farther. The repeater can receive a wireless signal from the one. After the power amplification process it can re-send the wireless signal to the other end, playing the role of a signal relay.

2.3 Channel conversion

Since the repeater we designed has a single-channel half-duplex operating mechanism, the simplest way to avoid self-interference between the transmit and receive signals of the repeater is to adopt frequency conversion for improvement, i.e., transmitting and receiving heterodyne frequencies. The repeater uses two separate frequencies for receiving and transmitting, more precisely, input and output frequencies. We can set the differential frequency value in the repeater. Usually, the transmit frequency is higher than the receive frequency. In this experiment, we use two signals with a different frequency of 10 MHz for transmission for the sake of observation. In future designs, we can use two frequencies closer to each other.

Chapter 3: Technical details on repeater design

3.1 Mixer based solution

The ideal repeater should have the functions of amplifying signal power and switching signal channels. Based on these two functions, we propose a repeater design scheme based on a mixer. The mixer has the function of frequency conversion. The signal power amplification can be achieved by adding multiple amplifiers appropriately in the overall repeater link. The usual repeater output power is 10W~20W. In this project, assuming that the signal power input to the repeater is 0dBm, we use two amplifiers with 20dBm gain inside the repeater to achieve an output power of 40dBm, i.e. 10W.

3.1.1 Circuit diagram overview

The circuit diagram of the repeater designed based on the mixer is shown in the figure.

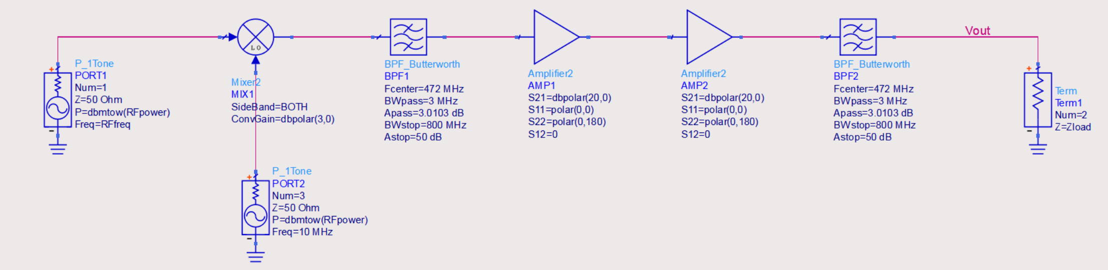

Figure 4: Repeater based on the mixer circuit

The mixer has three ports, two inputs and one output. PORT1 input is the 462MHz RF signal, and PORT2 input is the 10MHz signal to be mixed. These two signals are mixed by the mixer and output as a 452MHz downconverted signal and a 472MHz upconverted signal. After filtering by a Butterworth filter, the 472MHz signal is filtered out, and the 452MHz signal is removed. The signal is amplified and filtered again by the two-stage amplifier to obtain a cleaner upconverted signal. Thus, the signal is converted from 462 MHz to 472 MHz.

3.1.2 Mixer Details

The output signal frequency of a mixer is equal to the sum of the two input signal frequencies. Mixer can be two different frequencies of the signal by multiplying the way so as to produce the original two frequencies and the difference of the new signal. Thus, a mixer can be used to mix the original two frequencies, f_1 and f_2, so as to filter out the signal of the other frequency.

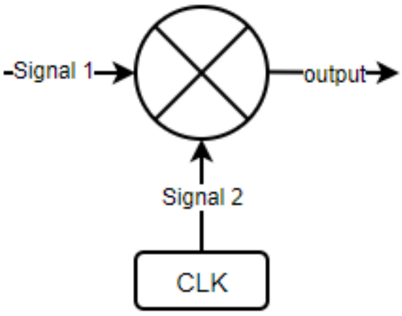

Figure 5: Example of mixer

$$signal1 = cos(\omega_1 t + \theta_1)$$
$$signal2 = cos(\omega_2 t + \theta_2)$$

Step 1: After the mixer, the two waveforms are multiplied together.

$$signal1 \times signal2 = cos(\omega_1 t + \theta_1) \times cos(\omega_2 t + \theta_2)$$
$$= \frac{1}{2}(\, cos(\omega_1 t + \omega_2 t + \theta_1 + \theta_2) - cos(\omega_1 t - \omega_2 t + \theta_1 - \theta_2))$$
$$= \frac{1}{2}\, cos(\omega_1 t + \omega_2 t + \theta_1 + \theta_2) + \frac{1}{2}\, cos(\omega_1 t - \omega_2 t + \theta_1 - \theta_2)$$

Step 2: This generates two frequency signals.

Up-conversion signal.

$$\frac{1}{2}\, cos(\omega_1 t + \omega_2 t + \theta_1 + \theta_2)$$

Down-conversion signal.

$$\frac{1}{2}\, cos(\omega_1 t - \omega_2 t + \theta_1 - \theta_2)$$

Step 3: Since there is a difference between the two frequencies, the upconverted signal can be filtered out. For example, use a bandpass filter to filter out the upconverted signal.

Through the above steps, we mix the original 462MHz signal with the 10MHz signal, get the 472MHz signal and 452MHz signal through the mixer, and then filter out the down-converted signal through the Butterworth bandpass filter to get the 472MHz signal we want.

3.1.3 Filter Details

A filter is a circuit consisting of a capacitor, inductor and resistor. A filter can filter specific frequencies or effectively filter frequencies other than a specific frequency point. A filter is a frequency-selective device that allows specific frequency components of a signal to pass, while others are greatly attenuated. Filters are simply divided into four types, low-pass filters, high-pass filters, band-pass filters and band-stop filters. As the name implies, low-pass filters allow only signals below a certain frequency point to pass, while high-pass filters allow only signals above a certain frequency point to pass. A bandpass filter allows signals within a certain range to pass, while a bandstop filter allows signals outside a certain range to pass.

This circuit design uses a Butterworth bandpass filter with a center frequency of 472 MHz and a bandwidth of 3 MHz. A simple active bandpass filter can be implemented by connecting a passive high-pass filter and a passive low-pass filter to an operational amplifier.

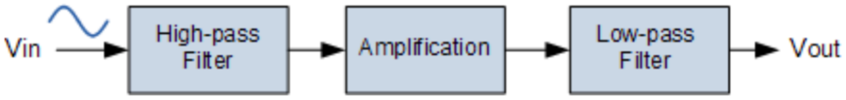

Figure 6: Band pass filter block diagram[6]

The cutoff frequency of the low-pass filter (LPF) needs to be higher than the cutoff frequency of the high-pass filter (HPF). The difference in frequency of the -3dB points will determine the bandwidth of the filter while attenuating any signal beyond these points.

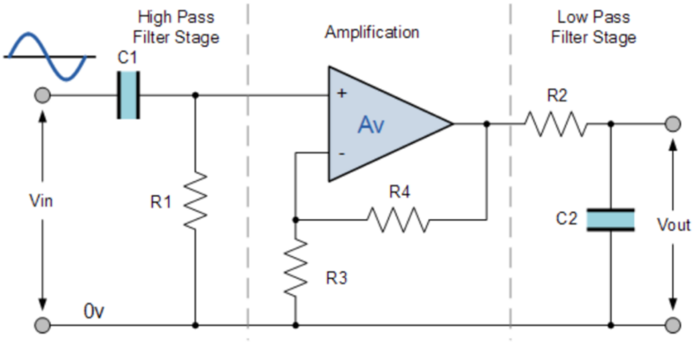

Figure 7: Band pass filter circuit diagram[7]

This cascaded circuit of a separate passive low-pass filter and high-pass filter has the advantage of a wide passband and low Q-factor. The first stage of the bandpass filter is the high-pass stage, which uses capacitors to block any DC bias from the previous stage. The advantage of this design is the ability to produce a relatively flat asymmetric passband frequency response, with half of the low-pass response and half of the high-pass response.

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[6] Image from: https://www.electronics-tutorials.ws/filter/filter_7.html

[7] Image from: https://www.electronics-tutorials.ws/filter/filter_7.html

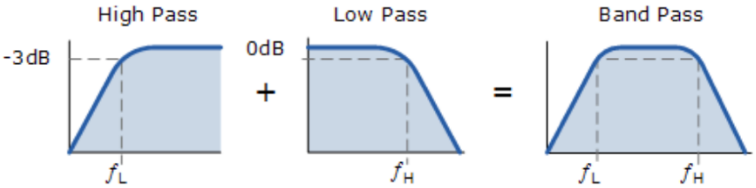

Figure 8: Band pass filter frequency response diagram[8]

The amplifier serves to reasonably isolate the two cutoff points to prevent any interaction between the low-pass and high-pass stages. At the same time, the amplifier defines the overall voltage gain of the circuit. The bandwidth of the filter refers to the difference between these upper and lower -3dB.

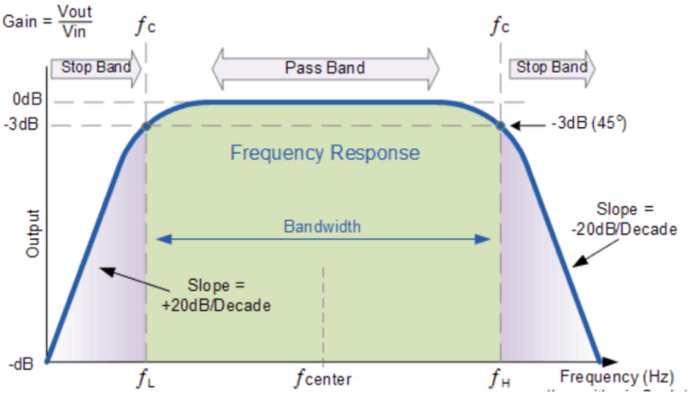

Figure 9: Band pass filter frequency response diagram[9]

The Butterworth filter used in this design is one of the electronic filters. The most important feature of the Butterworth filter is the smoothest frequency response curve in the passband. This filter was first proposed by Stephen Butterworth, a British engineer, in a paper published in the British journal Radio Engineering in 1930, hence the name Butterworth filter. The Butterworth filter has the flattest frequency response curve compared to other filters, and there is no undulation. In addition, the higher the filter order, the better the amplitude and frequency characteristics and the higher the signal fidelity. The Butterworth filter has the advantage of balanced characteristics in terms of linear phase, decay slope, etc., and is simple to design. It is also easy to produce and achieve the design performance because of its low Q value for the components that make up the filter. Therefore, in practical use, Butterworth filters are preferred.

3.1.4 Amplifiers Explained

Amplifiers are commonly used in electronic devices because they can amplify a smaller input signal into a larger output signal. Amplifiers work by using electronic components

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[8] Image from: https://www.electronics-tutorials.ws/filter/filter_7.html

[9] Image from: https://www.electronics-tutorials.ws/filter/filter_7.html

with amplification characteristics, such as triodes, which, when coupled with an operating voltage, can cause a small change in current at the input to cause a larger change in current at the output, with the change at the output being several to several hundred times larger than the change at the input. Thus an amplifier can increase the amplitude or power of a signal. Transistor amplifiers are often used for voltage amplification and current amplification of signals. In addition, they are often used for impedance matching, isolation, current-to-voltage conversion and the use of amplifiers to achieve a certain function between output and input (e.g. operational amplifiers).

The ideal signal amplifier would have three main attributes: input resistance or R_{IN}, output resistance or R_{OUT}, and gain or A amplification. No matter how complex the amplifier circuit is, it is still possible to use a generic amplifier model to show the relationship between these three attributes. The ideal amplifier model is shown in the figure below. The difference in amplification between the input signal and the output signal is called the gain of the amplifier. The gain is a measure of the amplifier's ability to amplify the input signal. For example, if a 1V input signal is amplified by an amplifier and becomes a 30V output signal, the gain of this amplifier is 30.

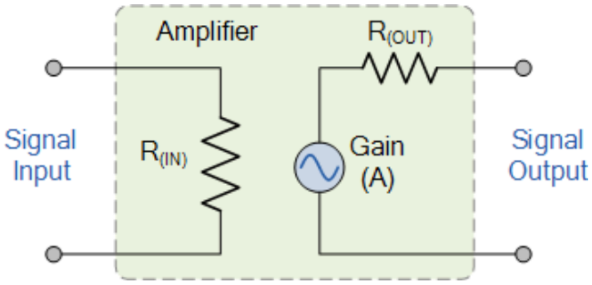

Figure 10: Amplifier block diagram[10]

Amplifier gain is the relationship that exists between the signal at the output and the signal at the input. Three different types of amplifier gain can be measured. They are voltage gain (A_V), current gain (A_I) and power gain (A_P).

Voltage amplifier gain：$voltage\ gain(A_v) = \frac{output\ voltage}{input\ voltage} = \frac{V_{out}}{V_{in}}$

Current amplifier gain：$current\ gain(A_i) = \frac{output\ current}{input\ current} = \frac{I_{out}}{I_{in}}$

Power amplifier gain：$power\ gain(A_p) = A_v \times A_i$

The amplifiers we involve in this design are power amplifiers, operational amplifiers, etc. We take the NPN common-emitter basic amplification circuit as an example and describe the amplification principle of the amplifier in detail.

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[10] Image from: https://www.electronics-tutorials.ws/amplifier/amp_2.html

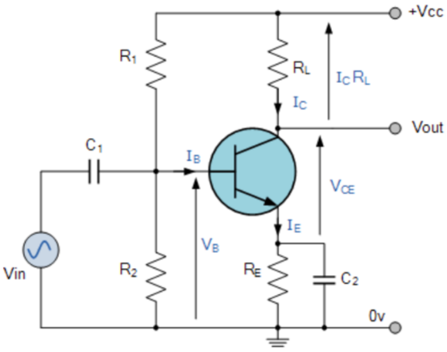

Figure 11: Amplifier circuit diagram[11]

First of all, there are two types of transistors, NPN and PNP, and the above figure shows an NPN transistor. From the diagram, we can see that the input and output are connected together with the ground of the emitter, so it is called a common emitter amplifier circuit. As shown above, we call the current flowing from the base B to the emitter E the base current I_B; the current flowing from the collector C to the emitter E is called the collector current I_C. Both currents flow in the direction of the emitter, so the emitter E with an arrow indicates the direction of the current.

The amplification of the transistor is the collector current is controlled by the base current, and a small change in the base current will cause a large change in the collector current. The change meets a certain proportional relationship. The change in collector current is β times the change in base current, that is, the change in current is amplified β times, so we call β the amplification of the transistor (β is generally much greater than 1, such as tens, hundreds). If we add a small change in signal between the base and the emitter, this will cause a change in the base current I_B, and the change in I_B is amplified, resulting in a large change in I_C. If the collector current I_C is flowing through a resistor R, then according to the voltage formula U=R*I, we can calculate that the voltage on this resistor will change a lot. We take out the voltage on this resistor, and we get the amplified voltage signal.

The triode also requires the addition of a suitable bias circuit when used in an actual amplifier circuit. The first is that due to the nonlinearity of the BE junction of the triode (equivalent to a diode), the base current must be generated only after the input voltage is large enough (for silicon tubes, it is often taken as 0.7V). When the voltage between the base and emitter is less than 0.7V, the base current can be considered to be 0. But in practice, the signal to be amplified is often much smaller than 0.7V, and such a small signal is not enough to cause a change in the base current if no bias is added (because the base current is 0 when it is less than 0.7V). If we add a suitable current to the base of the triode beforehand, then when a small signal is superimposed with this bias current, the small-signal will cause a change in the base current, which will be amplified and

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[11] Image from: https://www.electronics-tutorials.ws/amplifier/amp_2.html

output at the collector. Another reason is the output signal range requirement. If no bias is added, then only those signals that increase are amplified, and those that decrease are not effective (because the collector current is 0 without bias and cannot be decreased any further). When the input base current becomes small, the collector current can be reduced; when the input base current increases, the collector current increases. This way, the reduced signal and the increased signal can be amplified. The bias circuit in the above figure is VCC to R1 to R2 to ground, that is, with R1 and R2 series circuit voltage divider, so that the triode base B voltage exists. Due to the triode base B and the triode emitter E exist positive conduction voltage, so that the triode work.

The coupling capacitor C1 at the input is 10μF because the capacitor has the function of isolating through the crossover, so the input is isolated from the DC input, and sometimes capacitors are added at the output to isolate the DC output. C1 and the input impedance will form a high-frequency filter, which means that only high-frequency pulses can be fed into the circuit. When C1 chooses a very small capacitance value, it is difficult to pass low frequency, so usually choose 10μF. C2 in the figure is the decoupling capacitor, also called the bypass capacitor. Where small capacity C2 is a ceramic capacitor that has no polarity. C2 can be removed in the low-frequency circuit, but in the high-frequency circuit, C2 is essential and can play a role in reducing the capacitive resistance of the power supply to the ground.

We can construct an output characteristic curve based on the collector current I_C versus the collector/emitter voltage Vce, with different values of the base current I_B, for our simple common emitter amplifier circuit. The output characteristic curve shows how the transistor operates within its dynamic range.

When the transistor is "off," Vce is equal to the supply voltage Vcc, which is the "B" point on the line. Similarly, when the transistor is full "on" and saturated, the collector current is determined by the load resistance R L, which is point "A" on the line. We can calculate from the DC gain of the transistor that the base current required for the average position of the transistor is marked on the load line as Q point, which represents the quiescent point or Q point of the amplifier.

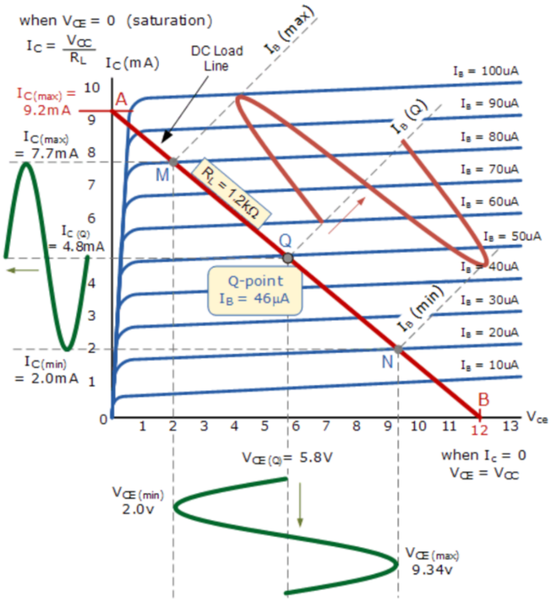

Figure 12: Output Characteristics Curves[12]

3.2 Re-modulation based solution

As mentioned before, the repeater should have the function of frequency conversion. In addition to the mixer for this purpose, demodulation and then modulation of the received signal can also achieve the conversion of the signal frequency. The modulation of the signal is achieved by the VCO, and the tuning voltage of the VCO in the repeater link can be adjusted appropriately to produce modulated signals of different frequencies. Similarly, by adding multiple amplifiers to the link, signal power amplification can be achieved.

3.2.1 Circuit diagram overview

In this design, we not only try to use a mixer for channel conversion but also try to use demodulation and modulation for signal frequency conversion. As the name suggests, the repeater in this way works as follows: when the repeater receives the transmitted signal, it first demodulates the signal to restore the baseband signal, then generates a carrier signal of different frequencies to modulate the baseband signal through VCO, generates a modulated signal of different frequencies and sends it out.

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[12] Image from: https://www.electronics-tutorials.ws/amplifier/amp_2.html

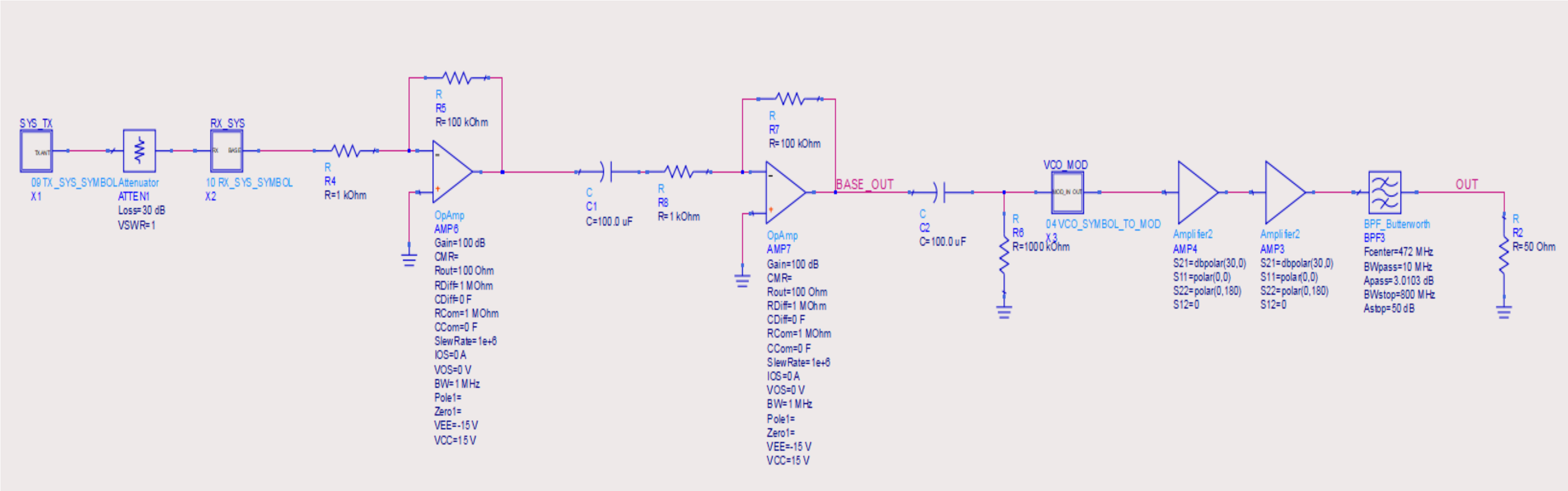

Figure 13: Repeater based on re-modulation circuit

First is a transmitting system, which is attenuated over the air and then passes through a receiving system, which has an FM demodulator to obtain a baseband signal. The baseband signal is amplified by two amplifiers. After the baseband signal is amplified, the baseband signal is again modulated with VCOs. Unlike the VCO modulation in the transmitter system, the VCO modulation in the repeater is done externally, and the tuning voltage of the VCO is controlled at 5.48V when the VCO oscillates at 472MHz, and then amplified and filtered before transmitting.

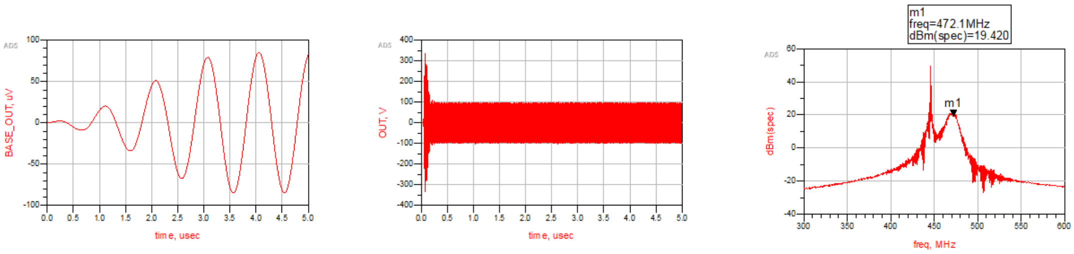

Figure 14: Output of repeater

As can be seen from the above figure, the demodulated baseband signal is modulated by the VCO and finally transmitted at a frequency of about 472 MHz.

3.2.2 Demodulator (core part PLL)

There are many types of FM demodulators, including slope detectors, phase shift detectors, ratio detectors, and PLL (phase-locked loop) FM demodulators. PLL is a very useful RF building block in today's electronics. PLL can be used in many applications such as frequency synthesizers, FM demodulators and signal reconstruction. PLL FM demodulator is considered a relatively high-performance FM demodulator or detector and therefore it is widely used in FM receivers. Since the PLL FM demodulator contains many equations defined by mostly integrated circuits at present, in this design, we focus on the phase-locked loop for design and experiments only.

A phase-locked loop is a feedback control circuit, and this circuit has good tracking performance. The phase-locked loop is characterized by the use of an external input reference signal to control the frequency and phase of the oscillating signal inside the loop. Because the phase-locked loop can achieve automatic tracking of the output signal frequency to the input signal frequency. The phase-locked loop consists of a phase discriminator, a loop filter, and a voltage-controlled oscillator.

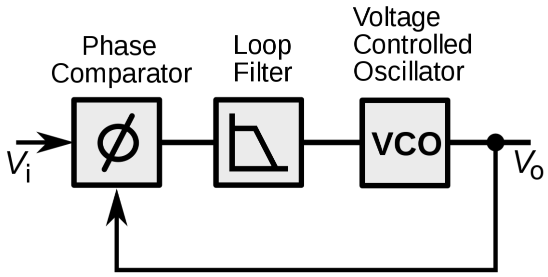

Figure 15: PLL block diagram[13]

In the basic PLL, the voltage-controlled oscillator (VCO) generates a signal that goes to the phase detector. The phase detector is used to compare the phase of the signal from the VCO with the input reference signal.

A phase discriminator is also called a phase comparator. The function of a phase discriminator is to indicate the phase difference between the input signal and the feedback signal through a voltage when this difference is found. The input signal and the feedback signal are two sine signals. The sum and difference of these two sine signals are added to the detector diode, and the potential difference of the detector diode is the output voltage of the discriminator.

After passing through the phase detector, the output is two frequencies, one is the sum of the reference and VCO voltages, and the other is the difference between the reference and VCO voltages. The latter is called the resulting difference or error voltage. This error voltage corresponds to the phase difference between the two signals. The signal from the phase detector is passed through a low pass filter that controls many of the characteristics of the loop and removes any high-frequency elements from the signal, i.e., only the error voltage is retained. Once through the filter, the error signal is applied to the control side of the VCO as its tuning voltage. The significance of any change in this voltage is that it attempts to reduce the phase difference and thus the frequency difference between the two signals. Eventually, the error voltage will pull the frequency of the VCO toward the reference frequency until it is impossible to reduce the error further and lock the loop. The fact that a stable error voltage exists means that the phase difference between the reference signal and the VCO does not change. Since the phase between these two signals does not change, this means that the two signals have exactly the same frequency.

The following diagram shows the PLL circuit.

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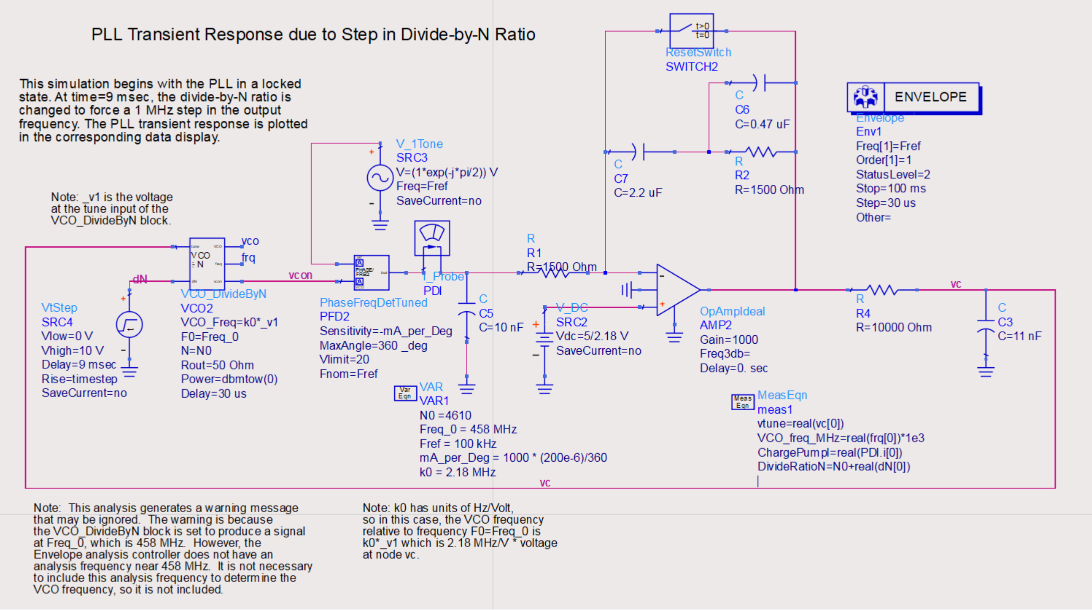
[13] Image from: https://en.wikipedia.org/wiki/Phase-locked_loop


PLL Transient Response due to Step in Divide-by-N Ratio

This simulation begins with the PLL in a locked state. At time=9 msec, the divide-by-N ratio is changed to force a 1 MHz step in the output frequency. The PLL transient response is plotted in the corresponding data display.

Note: _v1 is the voltage at the tune input of the VCO_DivideByN block.

VtStep
SRC4
Vlow=0 V
Vhigh=10 V
Delay=9 msec
Rise=timestep
SaveCurrent=no

VCO_DivideByN
VCO2
VCO_Freq=k0*_v1
F0=Freq_0
N=N0
Rout=50 Ohm
Power=dbmtow(0)
Delay=30 us

V_1Tone
SRC3
V=(1*exp(-j*pi/2)) V
Freq=Fref
SaveCurrent=no

PhaseFreqDetTuned
PFD2
Sensitivity=-mA_per_Deg
MaxAngle=360 _deg
Vlimit=20
Fnom=Fref

I_Probe
PDI

C
C5
C=10 nF

VAR
VAR1
N0 =4610
Freq_0 = 458 MHz
Fref = 100 kHz
mA_per_Deg = 1000 * (200e-6)/360
k0 = 2.18 MHz

R
R1
R=1500 Ohm

V_DC
SRC2
Vdc=5/2.18 V
SaveCurrent=no

ResetSwitch
SWITCH2

C
C7
C=2.2 uF

C
C6
C=0.47 uF

R
R2
R=1500 Ohm

OpAmpIdeal
AMP2
Gain=1000
Freq3db=
Delay=0. sec

Envelope
Env1
Freq[1]=Fref
Order[1]=1
StatusLevel=2
Stop=100 ms
Step=30 us
Other=

R
R4
R=10000 Ohm

C
C3
C=11 nF

MeasEqn
meas1
vtune=real(vc[0])
VCO_freq_MHz=real(frq[0])*1e3
ChargePumpI=real(PDI.i[0])
DivideRatioN=N0+real(dN[0])

Note: This analysis generates a warning message that may be ignored. The warning is because the VCO_DivideByN block is set to produce a signal at Freq_0, which is 458 MHz. However, the Envelope analysis controller does not have an analysis frequency near 458 MHz. It is not necessary to include this analysis frequency to determine the VCO frequency, so it is not included.

Note: k0 has units of Hz/Volt, so in this case, the VCO frequency relative to frequency F0=Freq_0 is k0*_v1 which is 2.18 MHz/V * voltage at node vc.

Figure 16: PLL circuit diagram

The frequency of the discriminator is low, usually around 100kHz, so the 462MHz frequency generated by the VCO needs to be crossed over. The crossover based on the N-division of the VCO enters the discriminator, and the discriminator output is a current output, professionally known as a charge bar. The charge bar passes through the active low-pass filter on the right side, i.e. the loop filter (the figure above shows a fifth-order low-pass filter composed of C3, C6, C7, R2, R4), and the output voltage is Vc. Vc controls the tuning voltage of VCO, which in turn regulates the oscillation frequency of VCO. VCO N=4610 frequency division, the frequency after the division is about 100kHz, this frequency is the discriminator frequency, the discriminator will VCO from the frequency and the reference frequency (usually crystal) for comparison, here the reference frequency is set to 100kHz. Through the discriminator, the frequency difference is converted to phase difference, the output is a charge bar, after active After passing through the discriminator, the frequency difference is converted into a phase difference, and the output is a charge bar, which is returned to VCO again after passing through an active low-pass filter to reverse the tuning voltage.

The following figure shows the simulation results of PLL.

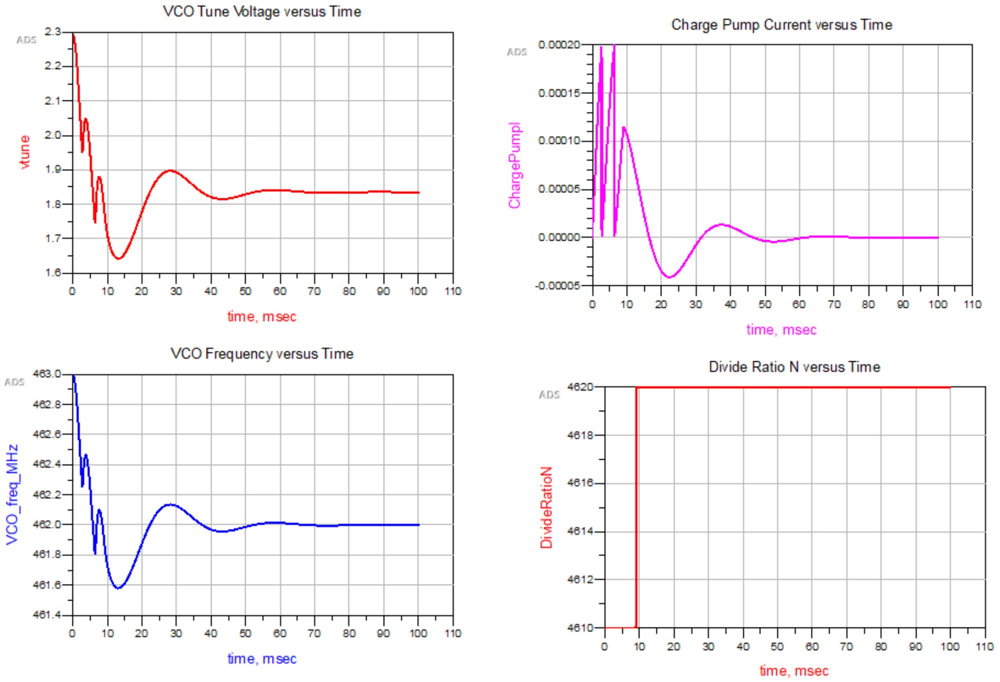


Figure 17: Output of PLL

From the results obtained in the above figure, it is clear that the tuning voltage of the VCO keeps changing until 70 ms. The purpose of the tuning voltage change is precisely to gradually reduce the phase difference with the reference frequency by adjusting the VCO oscillation frequency. When the Vt voltage is fixed after 70 ms, it means that the phase-locked loop has achieved locking. The current of the charge bar is synchronized with the Vt voltage change. Vt voltage is actually the integration of the charge bar. Before 70 ms, the current jumps more. When the phase-locked loop is locked, the current also tends to stabilize. VCO RF frequency change amplitude is also consistent. When it first starts, the frequency is controlled by the vt voltage, and when the Vt voltage drops, the oscillation frequency drops simultaneously. When the Vt voltage is locked, the oscillation frequency is also locked. The crossover frequency ratio is fixed at 4620 after a short period of time from 4610 at first.

3.2.3 VCO detailed explanation

VCO is voltage controlled oscillator. A voltage-controlled oscillator is an oscillation circuit in which the output frequency corresponds to the input control voltage. The three basic modules of an oscillator are 1. transistor 2. resonant circuit (which determines the operating frequency of the oscillator) and 3. energy feedback module (amplifier). VCO can be divided into two types according to its composition principle: feedback type and negative resistance type, but the one we are using is the feedback type, so only the principle and characteristics of the feedback type VCO circuit are discussed here.

In this design, we use an LC feedback type voltage-controlled oscillator, which is generated by inserting a voltage-controlled variable reactance element into the LC oscillation circuit. The feedback type VCO includes both amplification and feedback circuits. To ensure the purity of its output spectrum, there must be a frequency selection network in the oscillation loop, i.e., an LC resonant circuit. In the next section, we will discuss the principle of the LC oscillation circuit.

Also known as resonant circuits, the simplest LC resonant circuit consists of an inductor and a capacitor. LC circuits are used both to generate signals of a specific frequency and to separate signals of a specific frequency from more complex signals. They are key components in many electronic devices, especially radio equipment, and are used in circuits such as oscillators, filters, tuners, and mixers. An oscillator converts a DC input (supply voltage) into an AC output (waveform). Output waveforms can have different frequencies and different shapes, depending on the application.

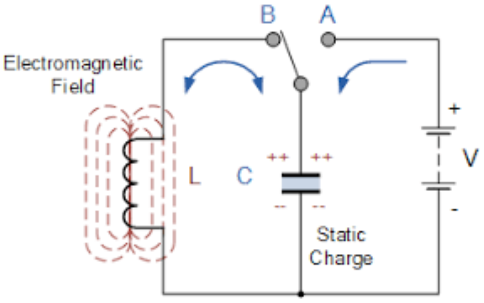


Figure 11: LC oscillator block diagram[14]

The capacitor has the characteristics of charging and discharging, the inductor has the characteristics of obstructing the change of current, and the inductor has the characteristics of converting electric and magnetic fields into each other. The inductor and capacitor are connected together in parallel. When the capacitor discharges to produce current, the inductor will obstruct the passage of current, converting the electric field into a magnetic field and storing it; after the capacitor discharges, the inductor will obstruct the disappearance of current, converting the magnetic field into the inductor into an electric field, and the resulting current charges the other electrode of the capacitor; after the charging is completed, the capacitor starts to discharge in the reverse direction again, forming the energy for oscillation. This process forms the basis of the resonant circuit of the LC oscillator, and in theory, this back-and-forth cycle will continue indefinitely. However, the actual application is not ideal, and each time energy is transferred from capacitor C to inductor L and from L back to C, it is accompanied by energy losses that decay the oscillation to zero over time. In a real LC circuit, the amplitude of the oscillation voltage decreases every half oscillation period and eventually disappears to zero. We call this oscillation "damped oscillation," and the amount of damping is determined by the mass or Q factor of the circuit.

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[14] Image from: https://www.electronics-tutorials.ws/oscillator/oscillators.html

Capacitance and inductance are composed in the LC oscillation circuit, the time to complete an oscillation is called the period, and the frequency refers to the number of times the energy oscillates per second in the circuit. The frequency of the oscillation voltage depends on the value of the inductor and the value of the capacitor in the LC resonant circuit. The oscillation frequency can be calculated from the formula.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

To ensure that the VCO can start and output a stable oscillation signal, the phase and amplitude of A($j\omega$) and F($j\omega$) need to meet certain conditions. Where A($j\omega$) and F($j\omega$) represent the amplifier gain and feedback coefficient without feedback, respectively. Because the amplitude and phase conditions of the feedback RF VCO need to be satisfied are described in detail in many references, they are not demonstrated here.

Phase conditions: $\varphi_{A(j\omega)} + \varphi_{F(j\omega)} = 2n\pi(n = 0,1,2,\cdots)$
The phase condition ensures that Vf is in phase with Vi and satisfies the positive feedback.
Amplitude condition: At the start of vibration: $|A_{(j\omega)}||F_{(j\omega)}| > 1$
After equilibrium: $|A_{(j\omega)}||F_{(j\omega)}| = 1$

The amplitude starting condition of the VCO ensures that the amplitude keeps growing, but then limits its growth to bring the oscillator to the equilibrium condition. The stabilization condition ensures that the oscillator in oscillatory equilibrium automatically returns to its original equilibrium state after a disturbance in amplitude or phase.

The initial circuit used for the LC voltage-controlled oscillator in this design is shown below. The triodes, diodes, and capacitor-resistor devices in the figure can be found in the component library of ADS. The circuit diagram is shown as follows.

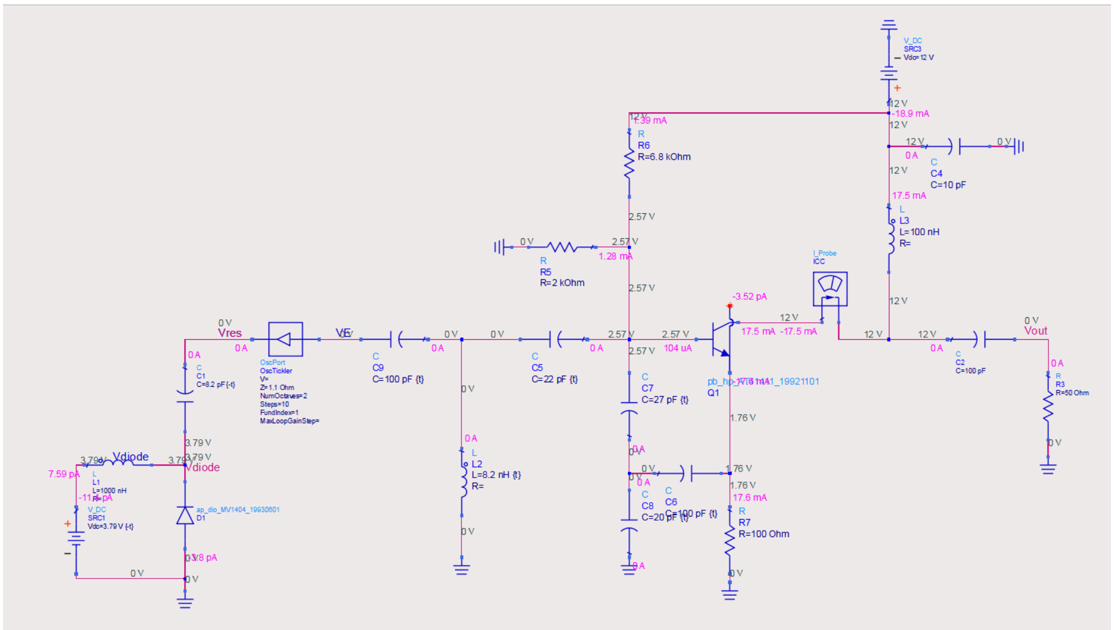


Figure 19: VCO circuit diagram

This voltage-controlled oscillator is designed based on an LC oscillation circuit with a 12V power supply, a tapped LC resonant network composed of C_1, C_5, C_7, C_8, L_2 and varactor diode D_1, amplified and compensated by Q_1 amplifier (BJT triode), the bias voltage of the amplifier is provided by R_5, R_6, divided to 2.57V. C_4 is the bypass capacitor. While D_1 is a voltage-controlled varactor diode, which can change the capacitance value according to the change of input voltage, the higher the voltage the smaller the capacitance, the smaller the voltage the higher the capacitance, the whole varactor diode is also part of the resonant network, so it can change the resonant frequency point. R_7 is the feedback resistor, and C_2 is the output coupling capacitor.

As mentioned earlier, there is energy loss during oscillation in the actual circuit. In order to maintain the oscillation in the LC resonant circuit, we must compensate for all the energy lost during each oscillation, thus keeping the amplitude of the oscillation at a constant level. Therefore, the compensated energy must be equal to the energy lost during each oscillation. If too much energy is compensated, the amplitude of the oscillation increases until power rail clipping occurs; if too little energy is compensated, the amplitude of the oscillation eventually decays over time until the oscillation stops. The easiest way to compensate for energy is to take some of the output from the LC resonant circuit, amplify it, and then feed it back into the LC circuit again. This process can be achieved using an amplifier, and a bipolar transistor is used as its active device in this design.

Based on the fixed voltage in the above figure, the fixed voltage is changed to a variable that becomes the tuning voltage, which can be adjusted by Vtune to adjust the voltage and thus the oscillation frequency of VCO.

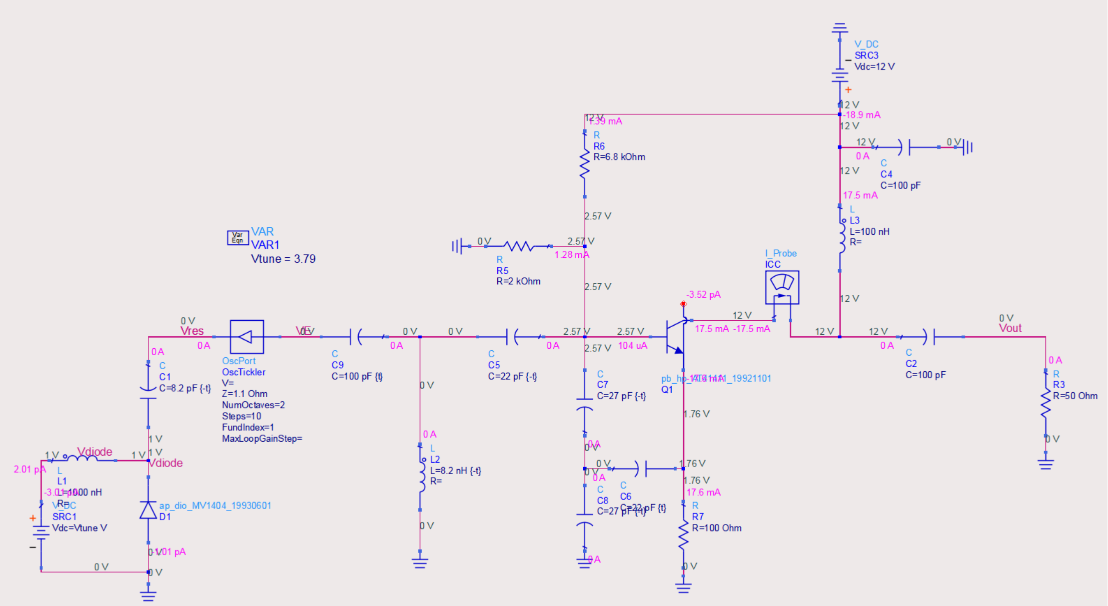


Figure 20: VCO with voltage tune circuit diagram

Since VCO will be affected by the load circuit, we add an isolation amplifier circuit to avoid affecting the normal operation of VCO. The circuit diagram after adding the isolation amplifier circuit is shown in Fig.

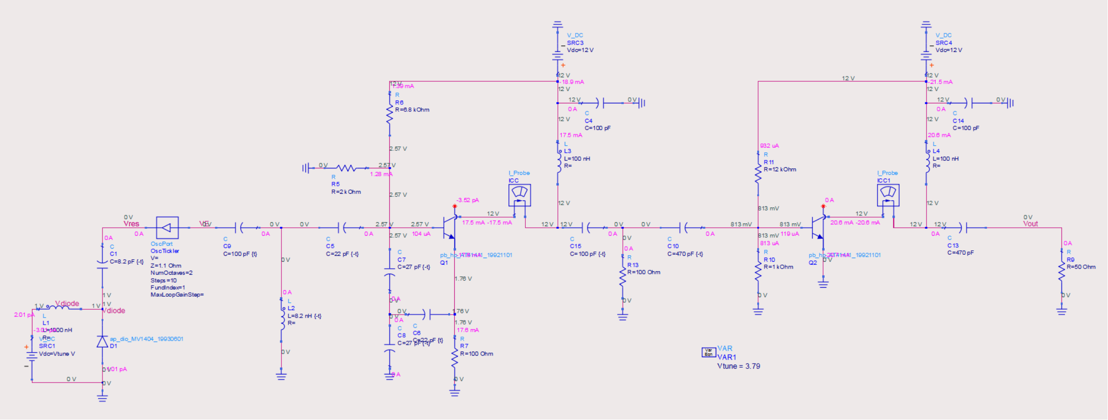


Figure 21: VCO with isolated amplifier circuit diagram

The left VCO circuit remains unchanged, while the right side is an isolated amplifier circuit, where R13 is the analog load.

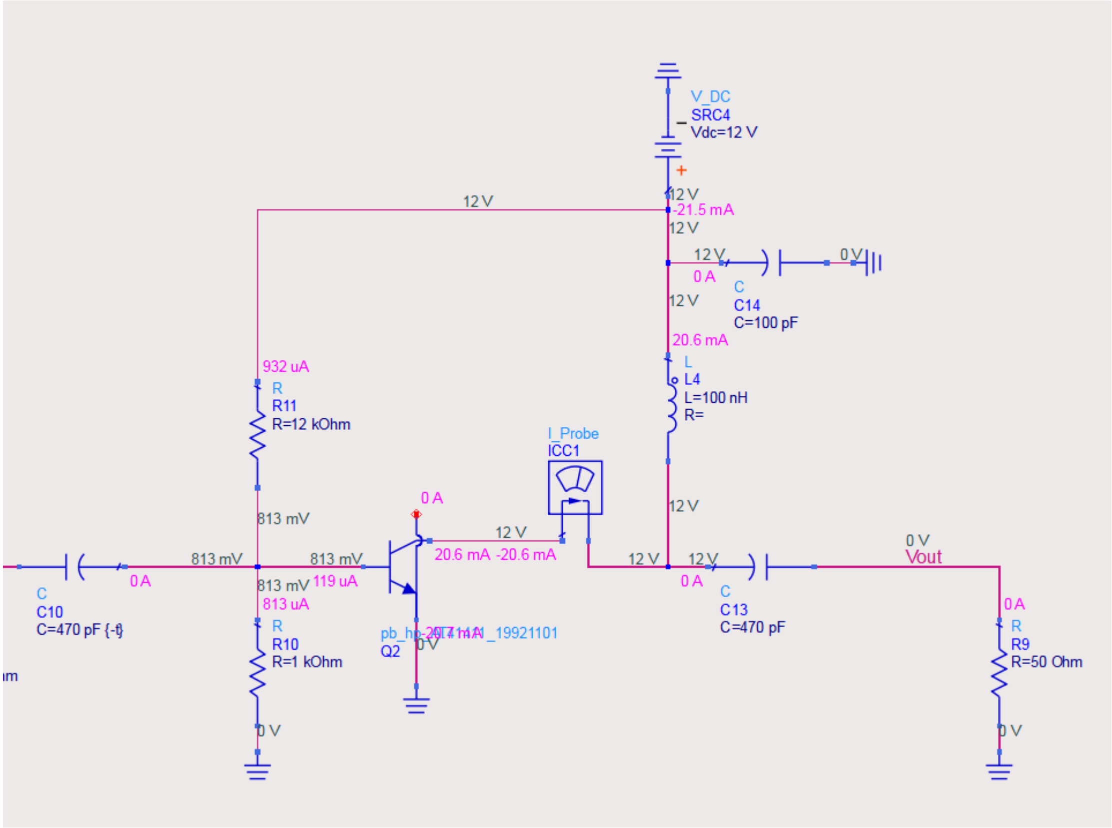


Figure 22: Isolated amplifier circuit diagram

An isolation amplifier circuit is also essential in the circuit to electrically isolate the input and output of the signal. It minimizes the noise and ripple in the output signal and provides a good excitation source for the post-stage application circuit. The original signal is amplified without directly affecting the original signal.

Chapter 4: Overall design and simulation results

4.1 Transmitting System

In the transmitting system part, the VCO generates a carrier signal with an oscillation frequency of 462MHz, and the 1000kHz baseband signal enters the VCO module internally for modulation to generate a 462MHz carrier signal. After the filtering process by a two-stage filter and power amplification by a two-stage amplifier, it is sent out through the antenna.

The circuit diagram for the modulation of the baseband signal inside the VCO with a frequency of 1000 kHz is shown below.

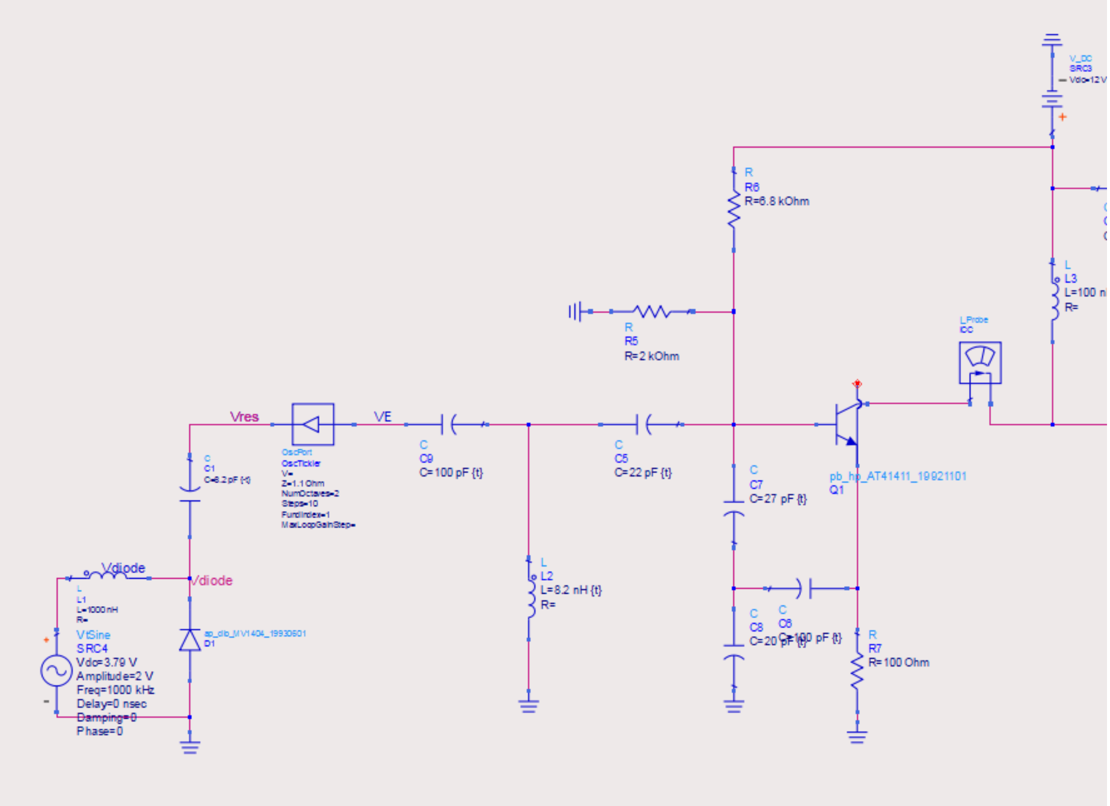


Figure 23: VCO modulation circuit diagram

At this time, the control voltage of VCO is 3.79V, and the oscillation frequency is 462MHz. The results obtained after the simulation is shown in Fig.

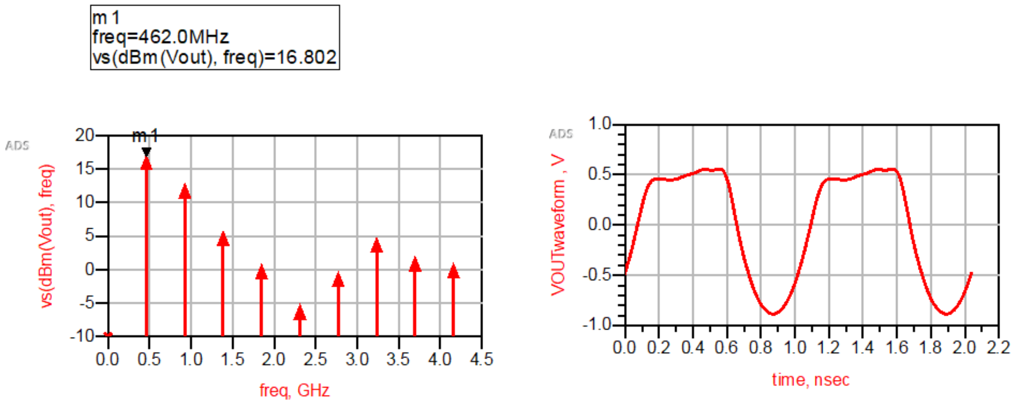


Figure 24: Output of VCO

The oscillation frequency of the VCO is 462 MHz, as can be seen in the left graph. The right graph of Fig.24 shows the oscillation waveform. Distortion is caused by the oscillator oscillation will produce the 2nd, 3rd or even 5th harmonic. The fundamental signal plus the high harmonic signal will lead to distortion. By adding a filter behind the VCO, the higher harmonics can be properly filtered but only slightly reduce the distortion.

The VCO module is encapsulated and then processed with an ideal Butterworth filter and an amplifier with a gain of 20dB before transmitting the signal through the antenna. The circuit diagram is shown below.

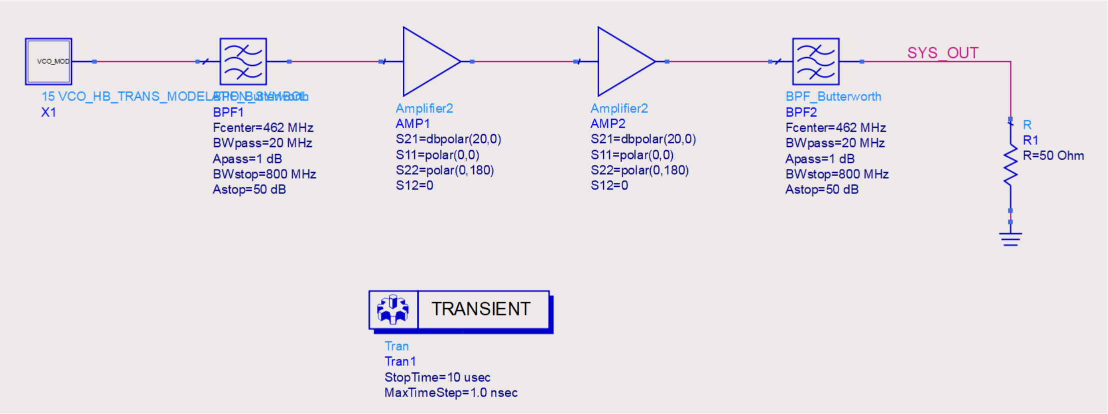


Figure 25: Transmitter circuit diagram

The results obtained after running the simulation are shown in Fig.

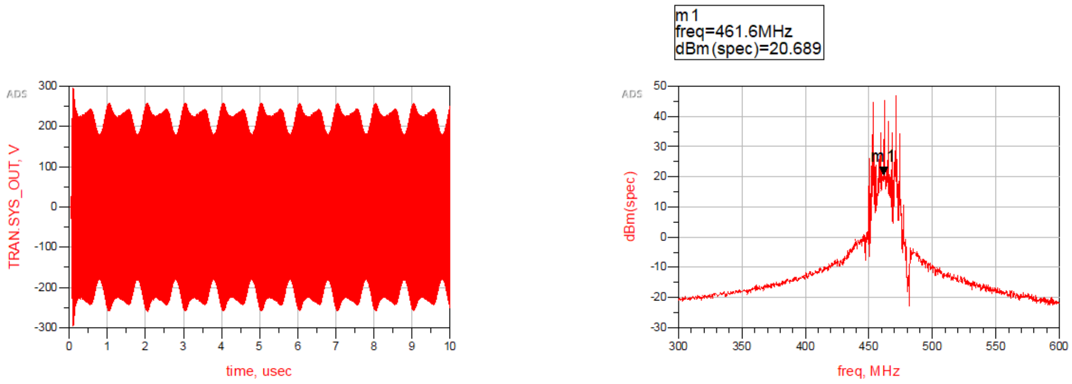


Figure 26: Output of transmitter circuit diagram

The modulated carrier with a frequency of 462 MHz after modulation is shown in the left graph, and the spectrum of the transmitted signal is shown on the right. If the amplitude of the baseband signal inside the VCO is 0V, the spectrum has only an unmodulated signal without a certain bandwidth.

4.2 Receiver

The receiver part consists of an antenna, front-end filter, amplifier and FM demodulator. After the signal emitted by the transmitter is attenuated in the air and mixed with noise, it enters the receiver through the antenna and first passes through the first stage filter to filter out clutter and noise. As the signal attenuation causes the signal to become small, so the signal is amplified by a two-stage amplifier for power. The noise is also amplified during the amplification process, so the signal is filtered again. At this point, the purer signal enters the FM demodulator and is reduced to a baseband signal. The impurities are filtered out again before being converted to the audio again.

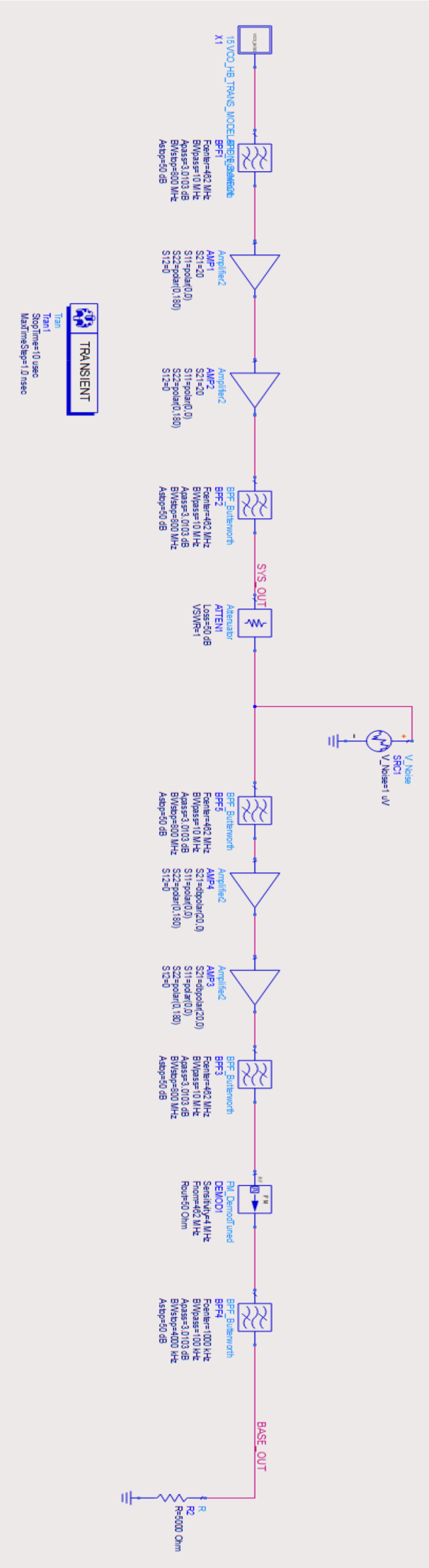


Figure 27: Receiver circuit diagram

The results obtained after running the simulation are shown as Fig.

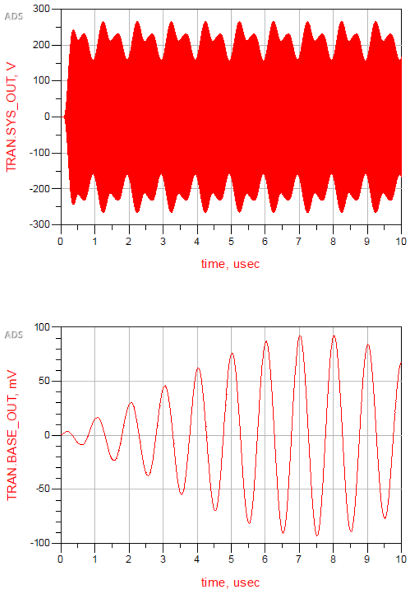


Figure 28: Output of receiver circuit diagram

The top figure shows the modulated signal from the transmitter with a frequency of 462 MHz, and the bottom figure shows the baseband signal after the FM demodulator.

4.3 Transmit-Repeater-Receiver Link

Based on the transmit-receive link, we try to add two types of repeaters designed above and connect the two repeaters into the transmit-receive link after encapsulating them. The following figure shows.

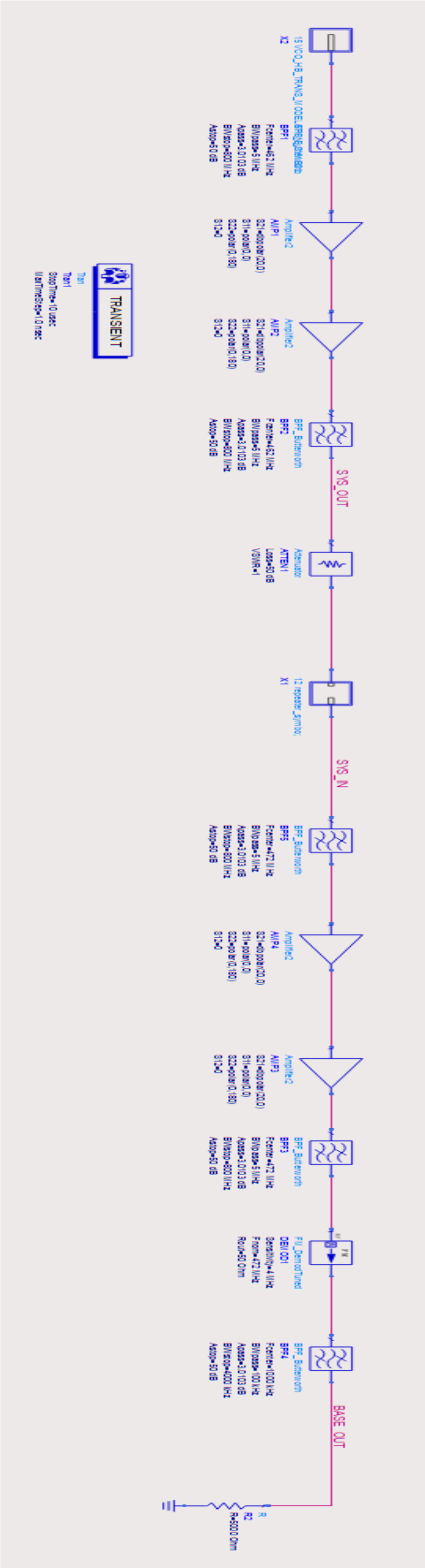


Figure 29: Transmitter and receiver circuit diagram

The results obtained after running the simulation are:

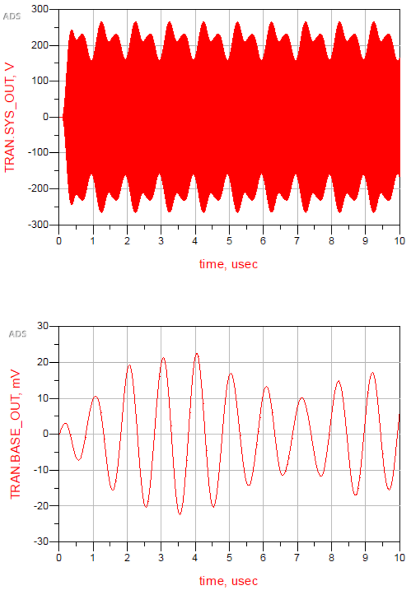


Figure 30: Output of mixer-based repeater

The above figure shows the results obtained from the mixer-based repeater.

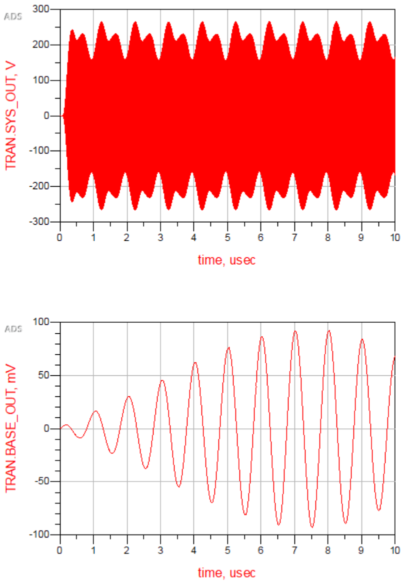


Figure 31: Output of re-modulation based repeater

The above figure shows the results obtained from the repeater based on re-modulation.

Usually, the signal power received by the repeater is extremely small. In this experiment, we assume that the signal power entering the repeater is 0 dBm. by simulating the amplification power of the repeater, we can get the following results.

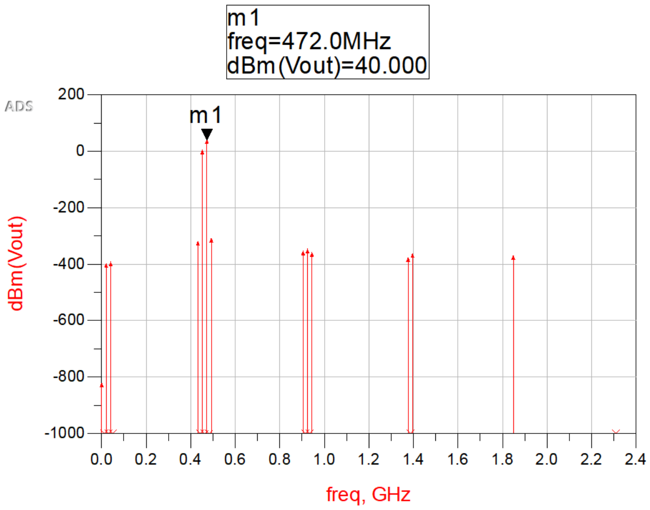
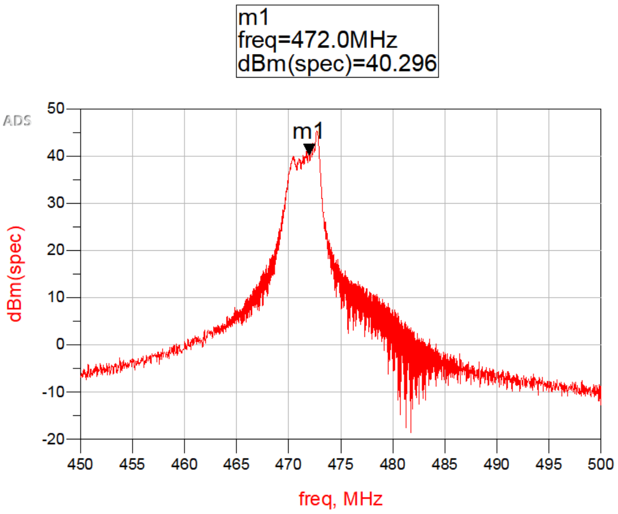


Figure 32: Output power of repeater

From the figure, we can observe that the signal power is boosted to 40dBm, i.e. 10W, by the amplification of the amplifier in the repeater.



Eqn spec=fs(SYS_OUT,450M,500M,2000)

Figure 33: Output spectrum of repeater

It is also obvious from the spectrum graph of the repeater output signal that the signal power at 472MHz is 40dBm, i.e. 10W.

From the above results, it can be seen that the demodulated signal basically restores the input sinusoidal signal. It also means that if we input a speech signal, the demodulated signal can basically restore the speech segment.

4.4 Transmit-repeater-receiver link with different input signal

We tried to use a signal closer to the human voice as the input signal. To do this we need to make some adjustments to the VCO. The voice signal is a broadband signal, and the voice made by humans varies according to age, gender, etc. Therefore we simulate an input signal consisting of a signal with a fundamental frequency of 5 kHz and a mixture of its second and third harmonics. To avoid the influence of post-stage components on the oscillation of the VCO, we add buffer amplifiers to it, which can isolate it to some extent. An additional variable capacitor D3 is used in addition to the original VCO. The purpose is to achieve deep modulation for the receiver's FM demodulator. In addition, it allows the FM demodulator to demodulate more easily. At the very end of the VCO is a low-pass filter, which is designed to filter out the high harmonics generated by the oscillation and reduce the distortion of the oscillation waveform. The specific circuit diagram is shown in the following figure.

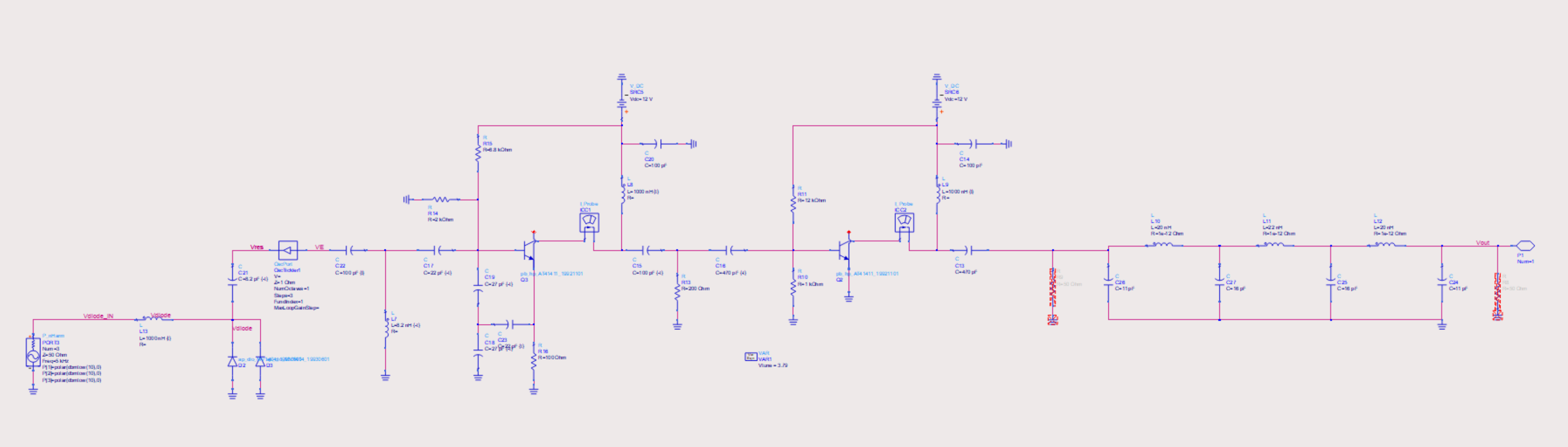


Figure 34: VCO circuit overview

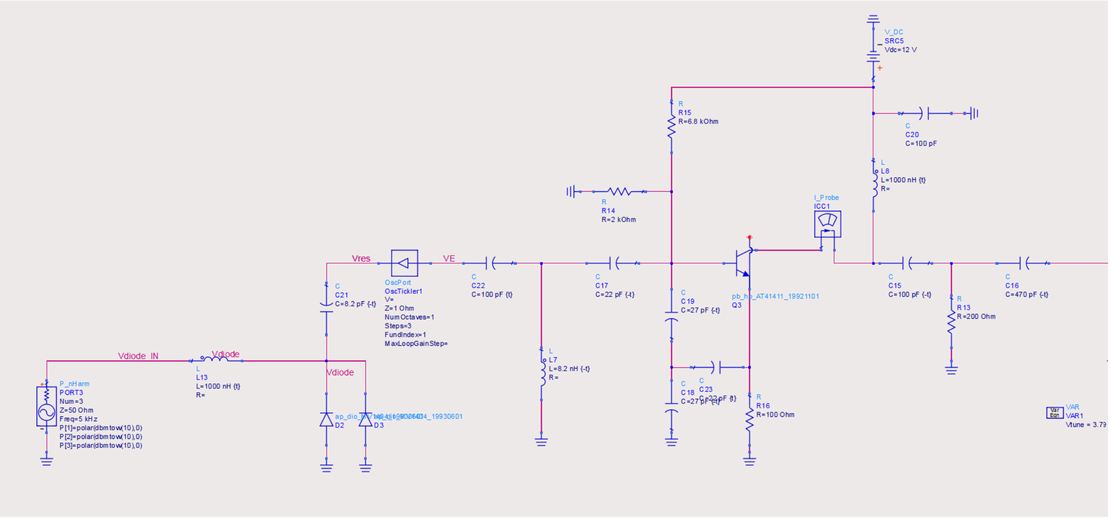


Figure 35: VCO vibration circuit part

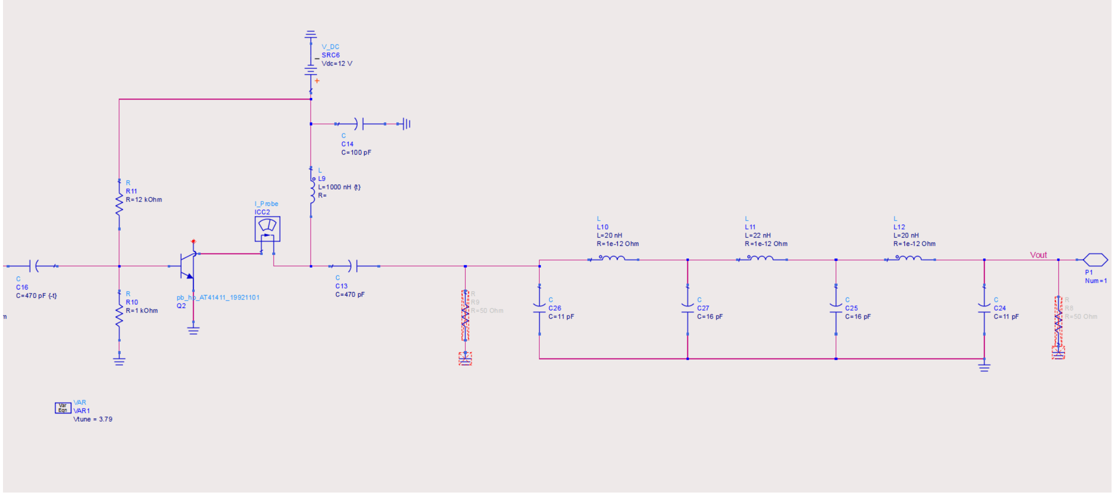


Figure 36: VCO buffer amplifier and low pass filter part

In the new transmitter circuit, not many changes were made. Since the maximum frequency of the input signal is 15 kHz, the filter was changed to a 15 kHz low pass filter. The purpose of adding a 470mF capacitor is to avoid any changes that would cause the transmitter parameters to change and to ensure stable transmitter operation.

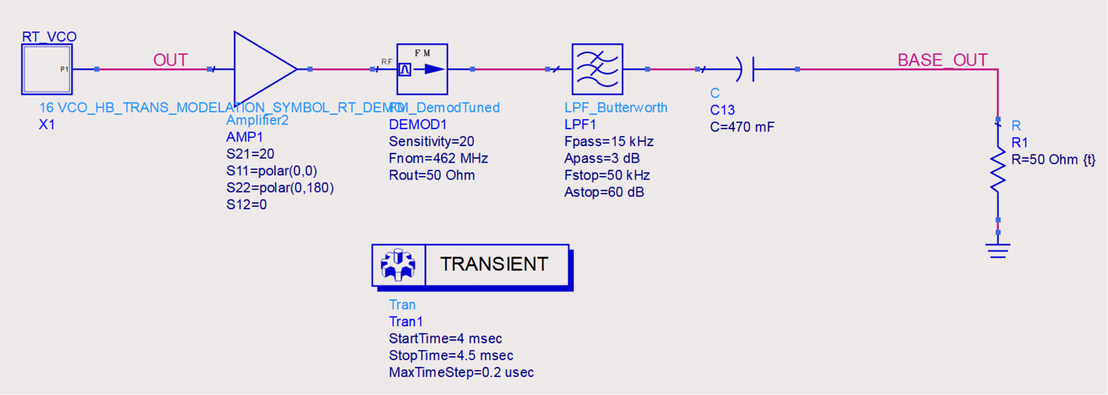


Figure 37: New transmitter circuit diagram

The overall circuit design of the new receiver is the same as the previous one. Apart from the internal changes to the VCO, the only change is to the filter parameters. The specific circuit is shown in the figure below.

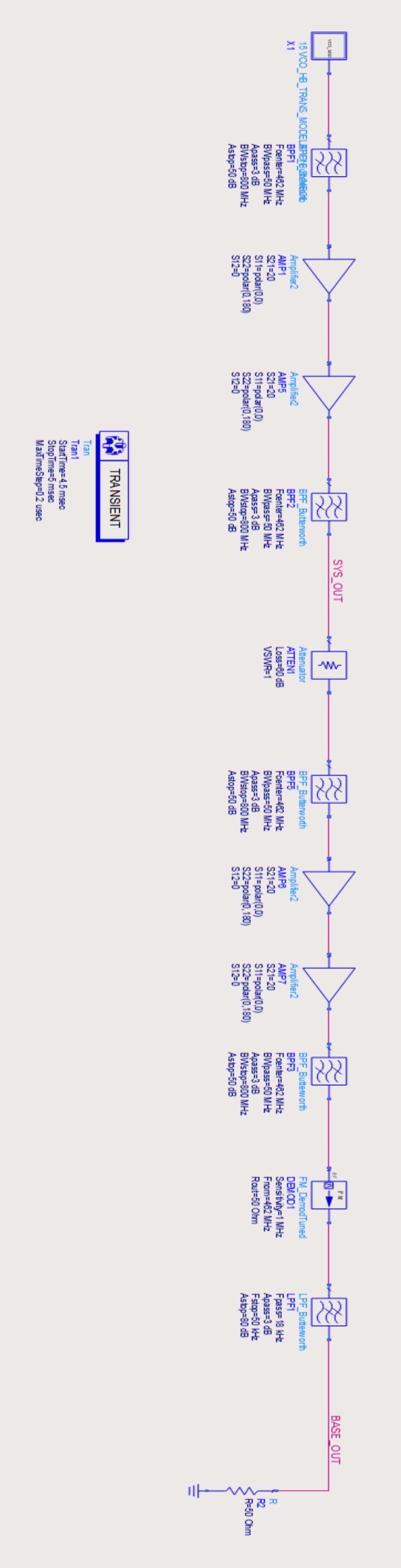


Figure 38: New receiver circuit diagram

The simulation results obtained after running the transmit-receive link designed according to the new VCO are shown in the figure below.

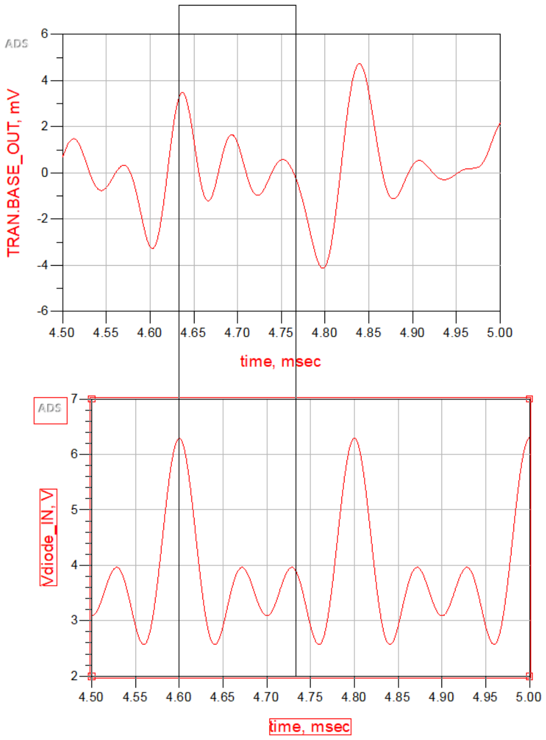


Figure 39: Output of receiver circuit diagram

The top graph of the simulation result shows the demodulated signal after the FM demodulator, and the bottom graph shows the input raw signal. Comparing the two graphs, we can see that the FM demodulator basically restores the original input signal. The demodulated signal is roughly the same as the original input signal, and can basically restore the waveform of the baseband signal, but there is a certain amount of amplitude distortion.

Chapter 5: Conclusion

5.1 Summary

In this study, we have used two different schemes to achieve the purpose of power amplification, signal relaying and frequency conversion of wireless signals. Both plans obtained similar simulation results, implying that both can achieve what we want. In the third part of the study, we use a specific transmitter-repeater-receiver link to restore the actual transmitter and receiver signalling achieved through a repeater. The two repeaters use different frequency conversion methods, respectively, but both can retain signal realism better. Both repeater designs have a two-stage amplification system, both can achieve power amplification of the signal and provide greater transmit power for the call to expand the communication range. However, compared to the components involved in the circuits of both amplifiers, the mixer-based repeater has an advantage over the demodulation-modulation-based repeater. The mixer-based repeater uses fewer components, so the actual device may be lighter in weight, making it easier for UAVs to take it into the air.

5.2 Future work

This thesis has only presented repeater designs based on two different schemes. There may be better design options we do not explore due to the limitations of the ADS software platform and the fact that the components used are mostly ideal components. The simulation results are based on a perfect environment without interference factors such as real-life terrain obstacles and electromagnetic devices. Therefore, the results obtained in the simulation do not fully represent the actual application and can only provide some theoretical reference for our design. In future research, we can improve the repeater design in more aspects, such as repeater signal power improvement, signal quality optimization, equipment cost and weight. Analog noise and other interference factors from the external environment will also be added to the analog circuit. In addition, the frequency conversion range of the repeater scheme designed in this project is very limited. A wider frequency range cannot be covered. Therefore further improvement and enhancement of the frequency coverage of the repeater are needed.

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