Lab 5：SDR FM Recevier

Author:	Name：高荣、曹正阳　　　Student ID: 12110301、12110623

Introduction:

1. Basic principles of FM modulation/demodulation

Basic principles:

FM (Frequency Modulation) is a modulation technique used in communication systems to transmit information by varying the frequency of a carrier signal. In FM modulation, the amplitude of the carrier signal remains constant while the frequency varies in response to the modulating signal.

The modulating signal (which contains the information to be transmitted) is used to vary the frequency of the carrier signal. The amount of frequency deviation is proportional to the amplitude of the modulating signal. This means that as the amplitude of the modulating signal increases, the frequency deviation of the carrier signal also increases.

The equation for FM modulation is as follows: s(t) = Ac * cos(2πfct + 2πk∫[m(t)]dt)

Arctangent demodulation:

Frequency Modulation (FM) arctangent demodulation is a common technique for demodulating FM signals. The FM arctangent demodulation technique involves applying the input FM signal to an arctangent function, which provides a proportional output signal that is proportional to the frequency deviation of the FM signal.

FM receiver :

In the FM receiver, we receive the form of the signal as shown in the below

$$s(t) = a(t)cos[2\pi f_c t + \phi]$$
$$s(t) = a(t)cos(\phi)cos(2\pi f_c t) - a(t)sin(\phi)sin(2\pi f_c t)$$
$$s(t) = S_I(t)cos(2\pi f_c t) - S_Q(t)sin(2\pi f_c t)$$
$$Re[S_L(t) + jS_Q(t)]e^{2\pi f_c t}]$$

We can write the signal as the real part of complex baseband wafter QAM decomposition. At the same time, we put the signal in periodic form. Then we use the "phase unwrapping method", The above formula can be written as follows.

$$s(nT_s) = cos[2\pi f_c t + 2\pi \int K_f m(nT_s)dt]$$

$$s_Q(nT_s) = A_c sin(2\pi \int k_f m(nT_s)dt)$$

$$s_i(nT_s) = A_c cos(2\pi \int k_f m(nT_s)dt)$$

$$s_l(nT_s) = s_i(nT_s) + js_Q(nT_s).$$

We split the signal into two phases, Q and i. Now our goal is to recover the original signal from the received signal m(t). We apply the inverse tangent method to the decomposed phases so that we get a formula about the integral of m(t). We take the derivative of this formula and we get the formula for the original signal m(t).

$$2\pi \int k_f m(nT_s)dt = arctan(\frac{s_Q(nT_s)}{s_I(nT_s)})$$

$$m(nT_s) = \frac{d[arctan(\frac{s_Q(nT_s)]}{s_I(nT_s)})}{dt2\pi k_f}$$

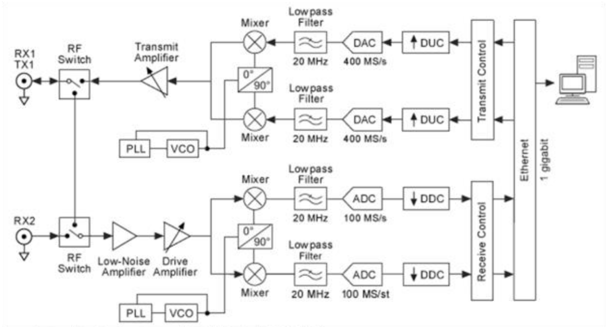
$$\frac{d[A_c 2\pi k_f \int m(nT_S)dt]}{dt} = A_c 2\pi k_f m(nT_S)$$

2.USRP Platform

- **Basic introduction**

  USRP(Universal Software Radio Peripheral). Designed to enable a computer to function like a high bandwidth software radio device, it consists of a USRP master, a daughter board, and some corresponding antennas.

ettus.com/all-products/un210-kit/



researchgate.net/figure/Hardware-structure-of-the-USRP-device_fig18_308277394

- **Function**

  The physical and basic schematic diagram of the USRP is shown above, Essentially, USRP acts as the digital baseband part and the intermediate frequency part of a radio communication system. The master AD sampling rate of USRP adopted in this experiment is 100 megabHz. USRP's daughter board can achieve analog signal modulation and demodulation functions, its master can achieve the transmission process of digital-to-analog conversion and the receiving end of the analog to digital conversion, digital up-conversion and down-conversion, complex baseband signal transmission functions.

3.LabVIEW Express Module:

- **Differentiator Module:**

  The LabVIEW Differentiator Module includes functions such as "Differentiate Signal," which computes the derivative of an input signal, "Differentiate and Filter Signal," which computes the derivative of an input signal and applies a low-pass filter to remove high-frequency noise, and "Transfer Function Differentiation," which computes the derivative of a transfer function.

The module also includes functions for implementing higher-order differentiation, as well as functions for estimating the derivative of non-smooth signals using methods such as finite differences and splines.

Overall, the LabVIEW Differentiator Module provides a comprehensive set of tools for implementing differentiation in LabVIEW, making it a useful tool for signal processing and control applications.

- **Integrator Module:**

  The LabVIEW Integrator Module includes functions such as "Integrate Signal," which computes the integral of an input signal, "Integrate and Filter Signal," which computes the integral of an input signal and applies a low-pass filter to remove high-frequency noise, and "Transfer Function Integration," which computes the integral of a transfer function. The module also includes functions for implementing higher-order integration, as well as functions for estimating the integral of non-smooth signals using methods such as trapezoidal integration and Simpson's rule.

  Overall, the LabVIEW Integrator Module provides a comprehensive set of tools for implementing integration in LabVIEW, making it a useful tool for signal processing and control applications.

- **Arctangent Module:**

  The LabVIEW Arctangent Module is a built-in module that provides tools for implementing arctangent functions in LabVIEW graphical programming language. The module includes a set of functions that can be used to perform mathematical arctangent calculations on input signals.

  The arctangent function, also known as the inverse tangent function, is a mathematical function that maps the values of the tangent function back to their original angle values. It is commonly used in signal processing applications such as phase demodulation and control systems.

  The LabVIEW Arctangent Module includes functions such as "Arctangent," which computes the arctangent of an input signal, and "Arctangent 2," which computes the arctangent of the quotient of two input signals.

Lab results & Analysis:

1.FM modulation/demodulation simulation

Block Diagram:

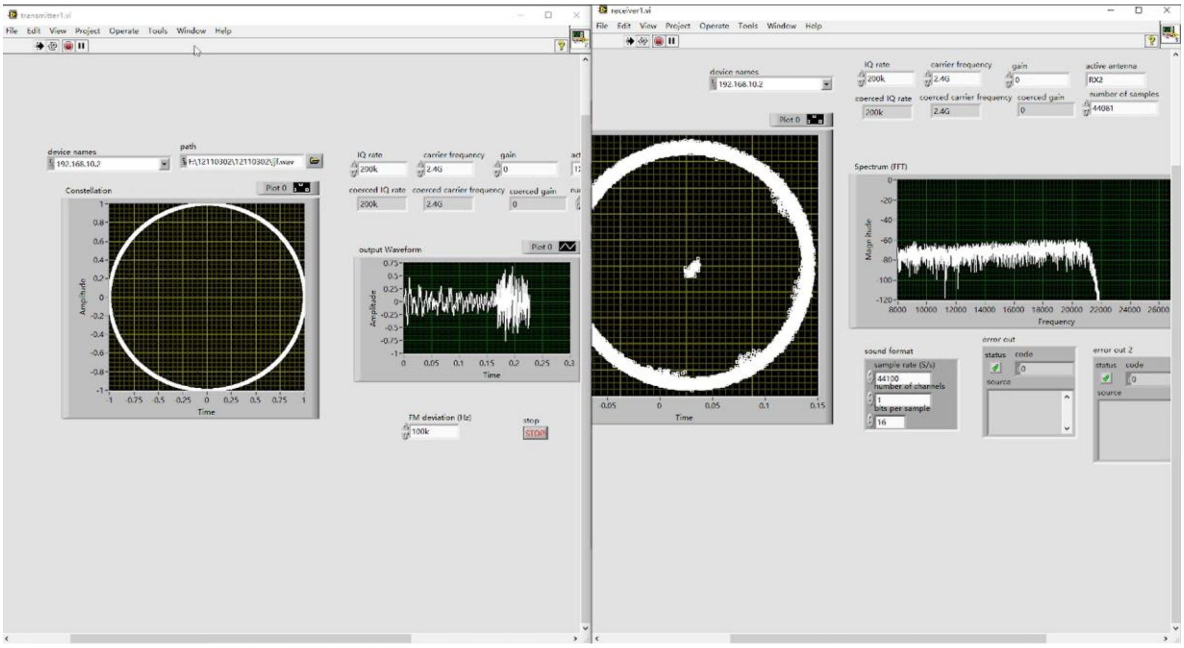
The block diagram of a typical AM modulation and demodulation system is as follows:

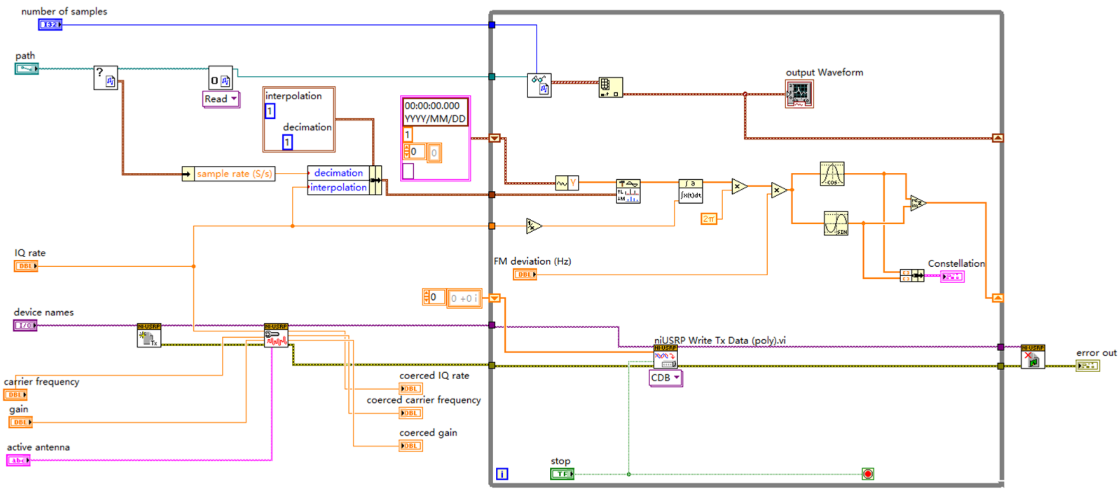
Signal Source --> Signal Modulator --> Modulator --> Amplifier --> Antenna (Channel)

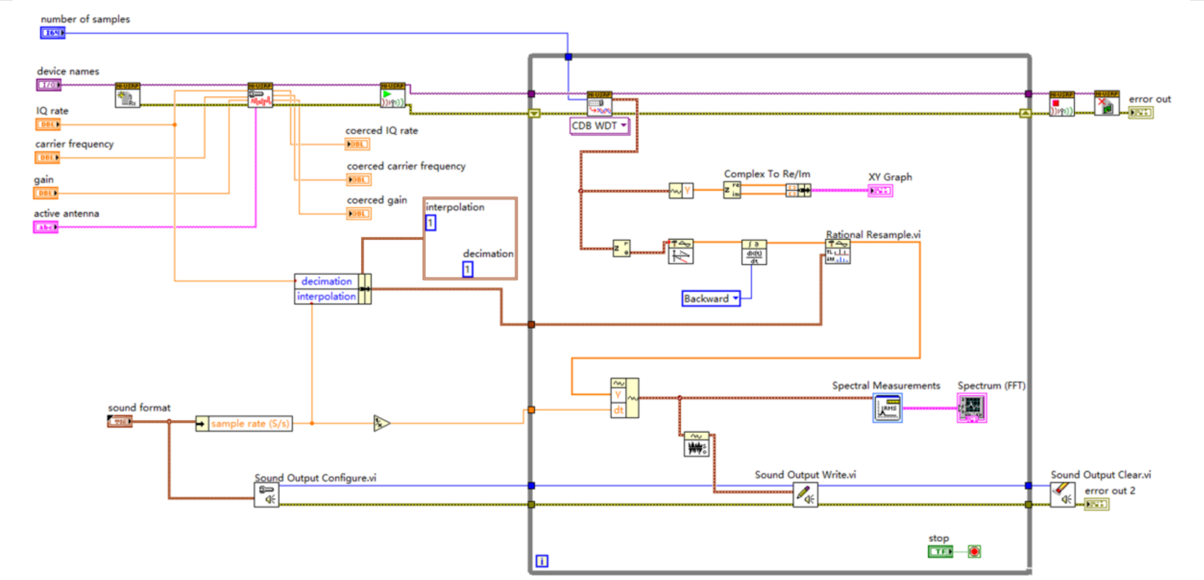
Antenna (channel) --> amplifier --> detector --> arctangent function--> band-pass filter --> speaker or signal output

2.Music Test

After playing the music file provided to us by the teacher, the result of SDR FM Recevier is carried out as shown.







In this experiment, we set the number of samples is 10000 and the IQ rate is 200000. The carrier frequency is 2.4G. Then import the address of the voice file into the block diagram's path in the transmitter. There are some parameter we uesd in recevier: Carrier Freq is 2.4G and the number of samples is 44100. The spectrum is also in line with expectations.

We also can found in the spectrum of this experiment, The spectrum diagram of the receiver roughly restores the spectrum diagram of the transmitter . When we ran the experiment, the first time we ran it on a computer for a long time, we didn't recover the spectrogram. But after a replacement computer, the problem was immediately cleared. This makes us realize that hardware debugging is very important and requires patience.

3. SNR Measurement

Schematic explanation

SNR can be calculate in the formula below:

$$SNR = \frac{P_{signal}}{P_{noise}} = (\frac{A_{signal}}{A_{noise}})^2$$

We can acquire A_{signla}in reciver by reading the original music file and use a Spectrum Analysis VI to read RMS of the music signal.

Suppose the noise in this system is addtive noise, so A_{noise} can be acquired by using $A_{noise} = A_{mixed-singal} - A_{signal}$, $A_{mixed-signal}$ can be also acquire in the signal reciver recived with a Spectrum Analysis VI.

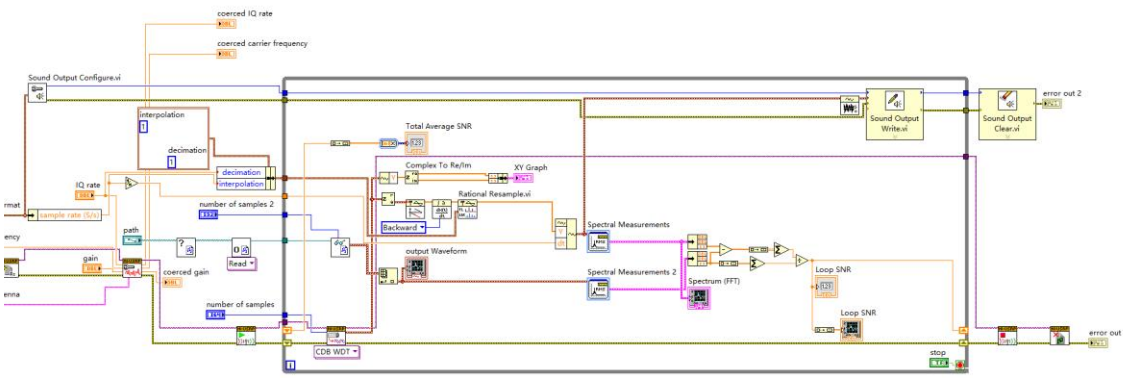
It is important to note that the SNR calculated with a method above is instaneous SNR, which is meaningless in most cases. To gain a valid SNR during a period T, we need do some

Convolution or integration to sum every instaneous SNR into an average SNR.

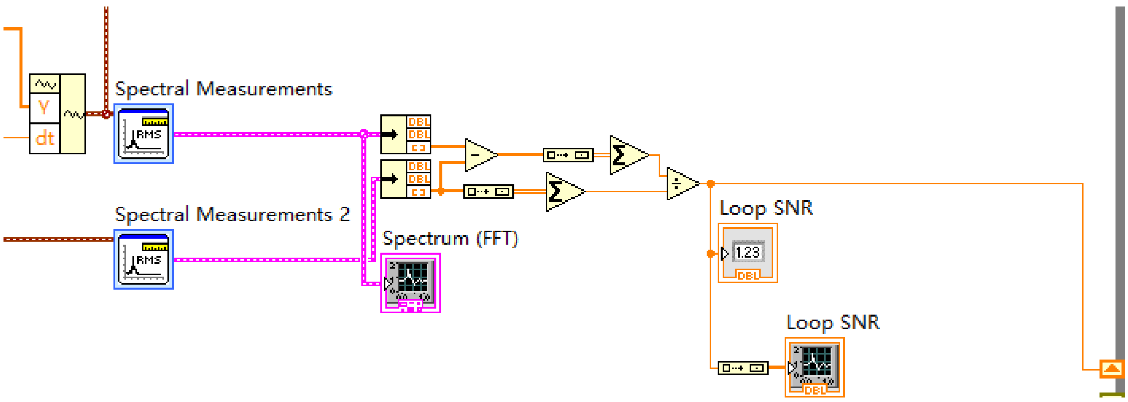
Here we choose array collection to store the instaneous power and uss intergration to sum the power, and passing this array to next loop with shift register.

Program implementation

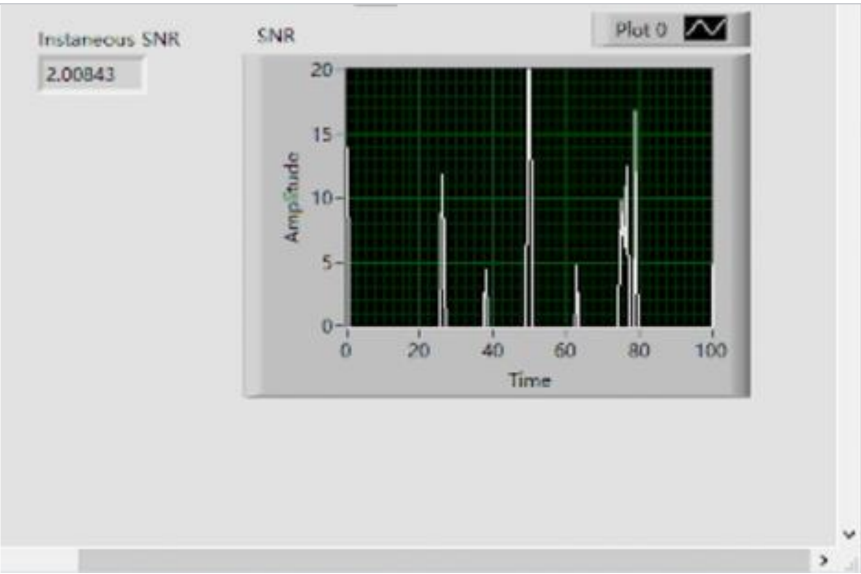
overview:



detail look of SNR measurement:



front panle result:



4.Factors Affecting FM Modulation System

The performance of such an USRP FM modulation system is affected by several factors, some of the main ones are as follows:

- **Maximum frequency deviation:** refers to the maximum allowed difference between the carrier frequency and the band edges of the modulating signal. The higher the maximum frequency deviation, the wider the frequency spectrum occupied by the modulated signal. If the maximum frequency deviation is too low, the modulated signal may not be able to properly transmit all the necessary frequency components of the original signal. This can result in distortion and a loss of some of the original signal's information. On the other hand, if the maximum frequency deviation is too high, it can lead to interference with adjacent radio channels and a reduction in the total number of channels that can be used in a given frequency band.
- **Modulation index:** The modulation index is the ratio of the frequency deviation of the modulating signal to the frequency of the carrier signal. If the modulation index is too high, the FM signal will be overmodulated, resulting in distortion and a loss of signal fidelity. If the modulation index is too low, the FM signal will be undermodulated, resulting in a weak signal that is susceptible to noise and interference.
- **Carson's rule:** Carson's rule affects the result of an FM signal by determining the bandwidth that is required to transmit the signal without any distortion or loss of information. If the bandwidth of the signal is too narrow, then some of the higher-frequency components of the signal will be lost or distorted in BPF, resulting in poor signal quality. On the other hand, if the bandwidth is too wide, then unnecessary frequency components will be transmitted that can cause interference with neighboring channels.
- **Frequency response of the system:** The frequency response of the system, including the transmitter, channel, and receiver, can affect the quality of the modulated signal. Any filtering or

attenuation can impact the amplitude and phase of the modulated signal.

- **Noise:** Noise is a major factor that can affect the performance of an FM modulation system. Noise can be generated from various sources, such as the environment, electronic components, and interference from other radio signals. FM systems can be designed to reduce noise by using techniques such as frequency filtering and amplification.
- **Interference:** Interference can occur from various sources, such as other radio signals or electronic devices. FM systems can be designed with interference rejection capabilities to minimize the impact of interference on signal quality.
- **Bandwidth of the system:** The bandwidth of an FM signal is determined by the frequency deviation of the modulating signal. If the bandwidth is too narrow, it will result in a loss of signal fidelity, while if it is too wide, it can lead to interference and a loss of frequency spectrum.
- **Nonlinear distortion:** Nonlinear distortion can be caused by the nonlinear characteristics of the transmitter, channel, and receiver components. It can cause signal distortion, harmonic generation, and intermodulation.

5.Advantages and Disadvantages of FM Modulation System and Its Value

Advantages:

- **Improved Signal Quality:** FM modulation offers better signal quality compared to other modulation techniques. It is less susceptible to noise and interference, making it ideal for communication in noisy environments.
- **Simple Demodulation:** The demodulation process for FM signals is relatively simple, making it easier to extract the modulating signal from the carrier signal.
- **Low Power Consumption:** FM modulation requires less power to transmit signals comparing to AM and DAB-AM, making it ideal for battery-powered devices such as handheld radios.

Disadvantages:

- **Complex Transmitter Design:** The transmitter design for FM modulation systems can be complex and require high-quality components, making it more expensive than other modulation techniques.
- **Sensitivity to Phase Distortion:** FM modulation is sensitive to phase distortion, which can result in a loss of signal quality.
- **Multipath Fading:** FM signals are susceptible to multipath fading, which occurs when signals reflect off obstacles and arrive at the receiver with different delays. This can result in signal distortion and a loss of signal quality.

Value:

FM modulation has many social applications in various fields. Some of the significant applications are:

Broadcasting: FM modulation is widely used in radio broadcasting for transmitting high-fidelity audio signals over long distances. This has greatly contributed to the dissemination of information, music, and entertainment to the masses.

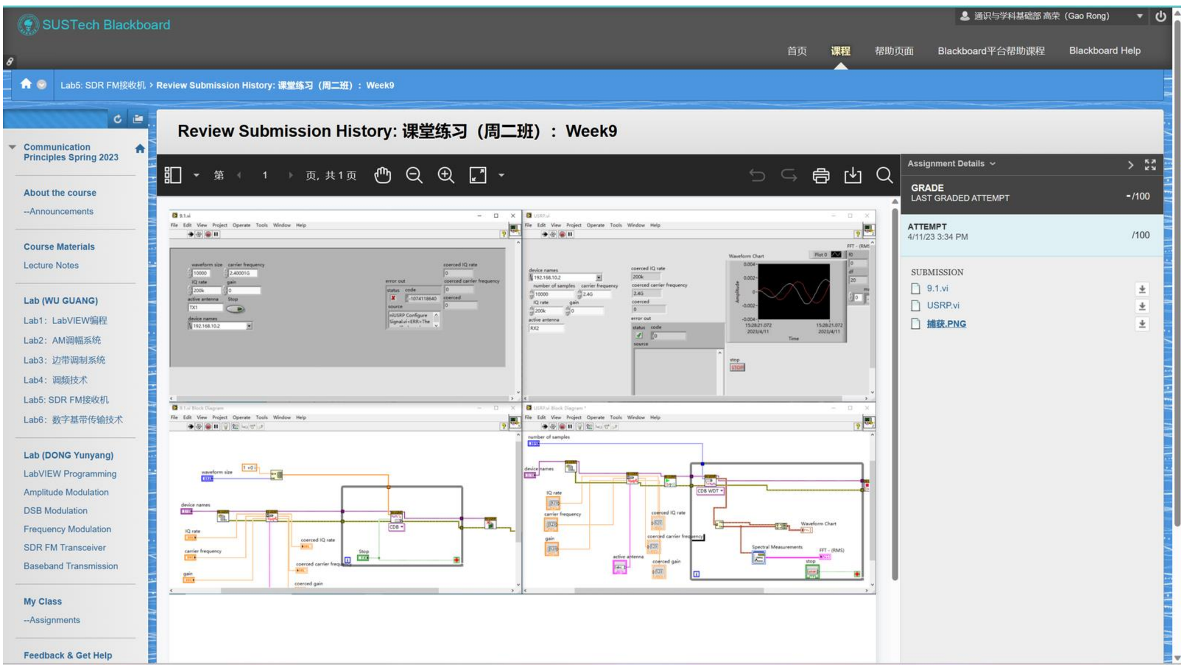
Telecommunications: FM modulation is widely used in telecommunication systems for transmitting data and voice signals. For example, it is used in mobile phone communication, which has revolutionized the way people communicate and stay connected.

Overall, FM modulation has significant social applications that have revolutionized various fields, such as broadcasting, telecommunications, medical applications, navigation systems, and weather forecasting. Its ability to transmit high-fidelity audio signals and data over long distances has greatly contributed to the dissemination of information and improved the quality of life for people around the world.

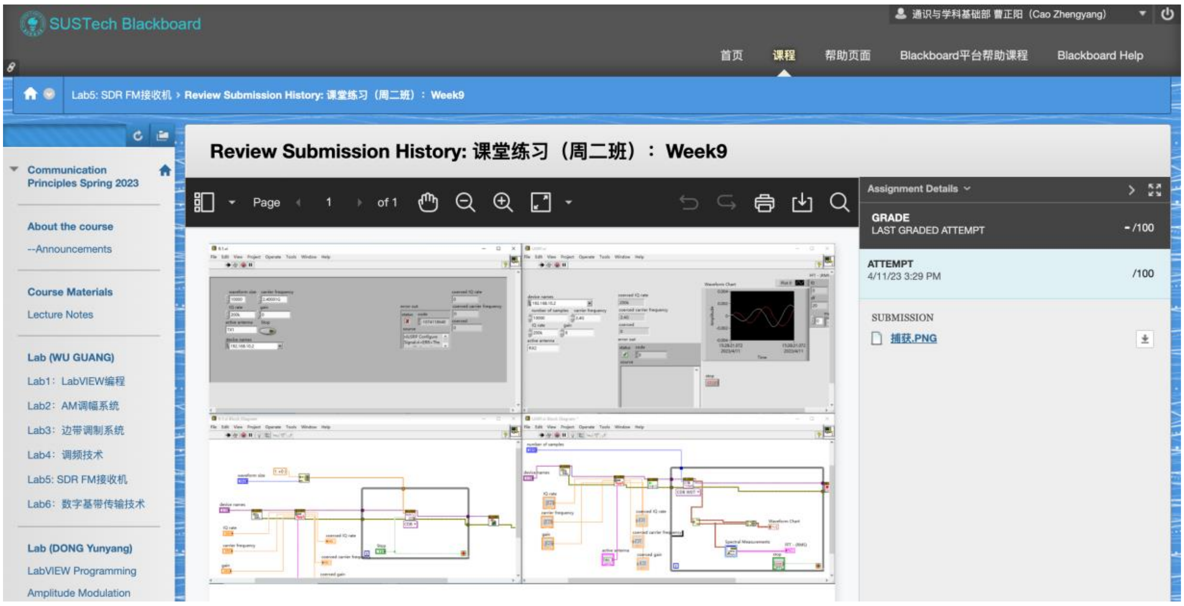
Experience:

Submit shot:

12110301 高荣：



12210623 曹正阳：



Score:	高荣：96　　曹正阳：95