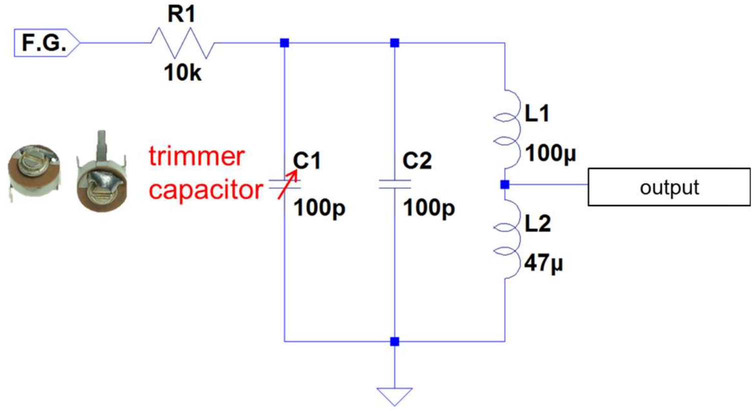
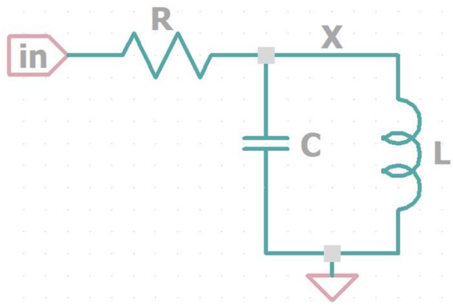
REPORT

Experiment 1: Parallel RLC Tuner Circuit Basic Properties



Circuit Analysis



Simplify the circuit, we have $\begin{cases} R = R1 \\ C = C1 + C2 \\ L = L1 + L2 \end{cases}$

By voltage divider rule,

$$\begin{cases} \boldsymbol{V_x} = \frac{(Z_L||Z_C)}{Z_R+(Z_L||Z_C)}\boldsymbol{V_{in}} = \frac{1}{1+\frac{Z_R}{(Z_L||Z_C)}}\boldsymbol{V_{in}} \\ \boldsymbol{V_{out}} = \frac{Z_{L2}}{Z_L}\boldsymbol{V_x} \end{cases}$$

$$\Rightarrow \boldsymbol{V_{out}} = \frac{j\omega L_2}{j\omega L} \times \frac{1}{1+R\left(\frac{1}{j\omega L}+j\omega C\right)} \boldsymbol{V_{in}}$$

$$\Rightarrow \frac{\boldsymbol{V_{out}}}{\boldsymbol{V_{in}}} = \frac{L_2}{L} \times \frac{1}{1+j\left(\omega RC \quad \frac{R}{\omega L}\right)}$$

Transfer function:

$$\boldsymbol{H}(\omega) = \frac{L_2}{L} \times \frac{1}{1+j\left(\omega RC - \frac{R}{\omega L}\right)}$$

Resonant frequency: $\omega_0 = \sqrt{\frac{1}{LC}}$

Can be quickly obtained by letting the imaginary part of H equals to 0 and solve the equation $\omega_0 RC - \frac{R}{\omega_0 L} = 0$.

$$|\boldsymbol{H}(\omega)|_{max} = \frac{L_2}{L} \times \frac{1}{1+j\times 0} = \frac{L_2}{L}$$

To calculate the half power point, let

$$\frac{|\boldsymbol{H}(\omega)|}{|\boldsymbol{H}(\omega)|_{max}} = \frac{1}{\sqrt{2}} = \frac{1}{1+j\left(\omega RC - \frac{R}{\omega L}\right)}$$

(It's interesting that the ratio between L1, L2 doesn't affect the result.)

$$\Rightarrow \omega RC - \frac{R}{\omega L} = \pm 1 \Rightarrow \omega^2 RC \mp \omega - \frac{R}{L} = 0$$

Use formula of difference of two squares to solve the equation and select positive ω,

$$\Rightarrow \begin{cases} \omega_{high} = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}} \\ \omega_{low} = -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 + \frac{1}{LC}} \end{cases}$$

Bandwidth:

$$\mathrm{B} = \frac{1}{RC}\ rad/s$$

Quality factor:

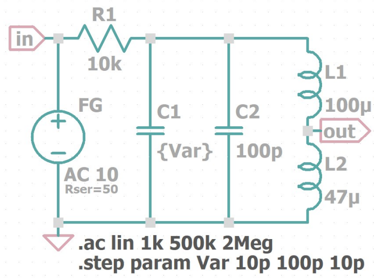
$$\mathrm{Q} = \frac{\omega_0}{B} = R\sqrt{\frac{C}{L}}$$

Through the analysis, we've known that it's a bandpass filter. By adjusting the variable capacitor, we can change the resonant frequency to receive the desired band.

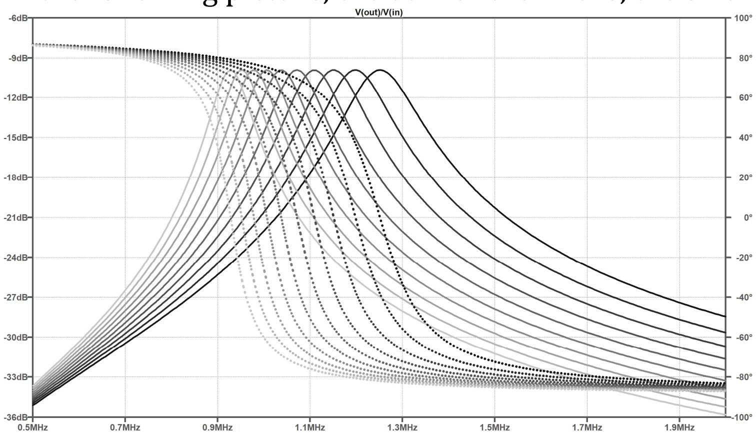
AM ReceiverLab3

LTspice

First, use SPICE command **.step param [Var name] [start] [stop] [step]** to get some samples so that it's easier for us to guess the proper capacitance.

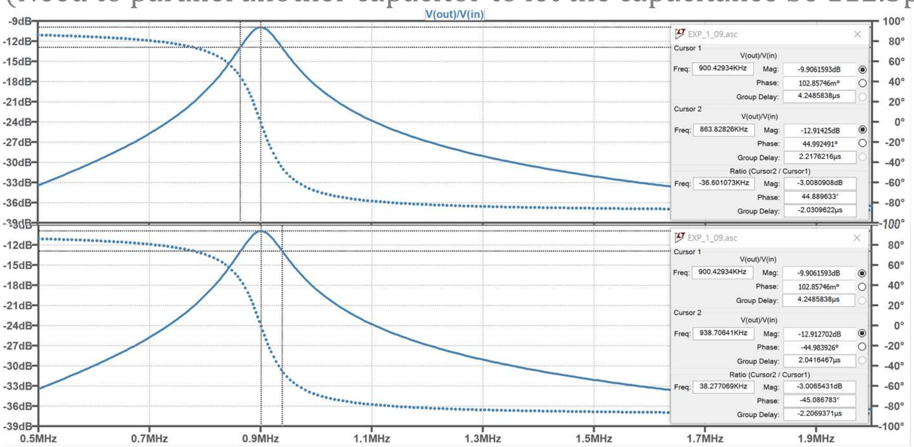


In the following picture, the darker the line is, the smaller the capacitance is.

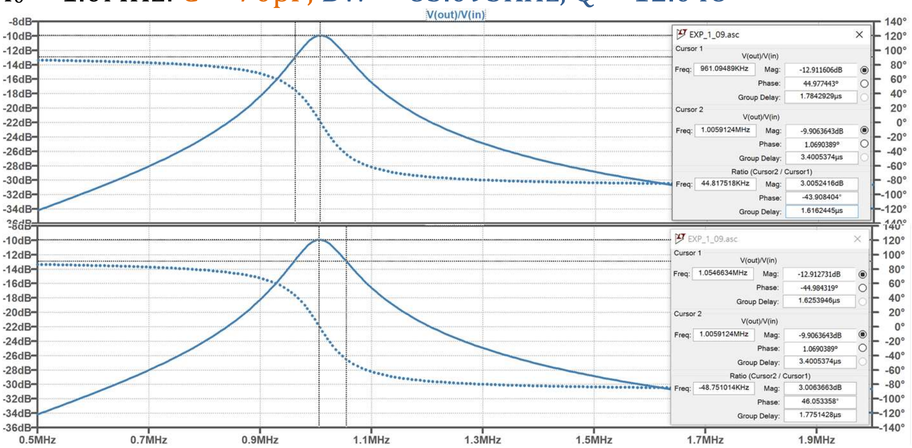


$f_0 = 0.9\text{MHz}$: $C = 112.5\text{pF}$, $BW = 74.878\text{KHz}$, $Q = 12.196$

(Need to parallel another capacitor to let the capacitance be 112.5pF)

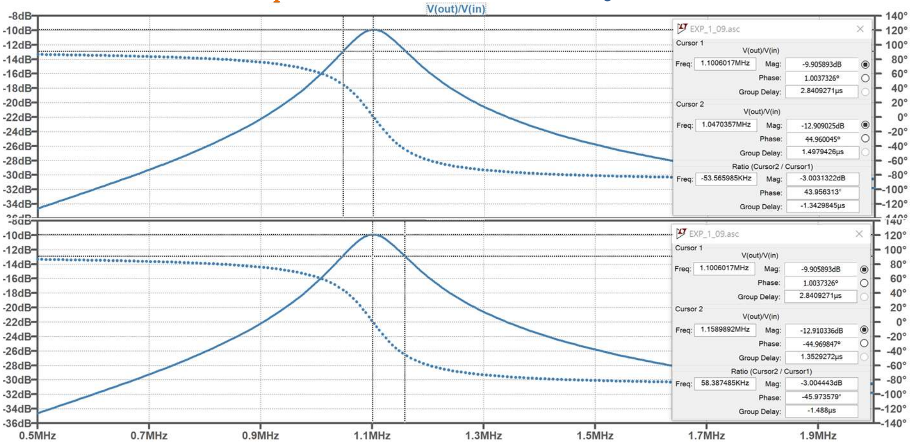


$f_0 = 1.0\text{MHz}$: $C = 70\text{pF}$, $BW = 83.095\text{KHz}$, $Q = 12.048$



AM ReceiverLab3

$f_0 = 1.1MHz$: C = 42pF, BW = 111.953KHz, Q = 9.826

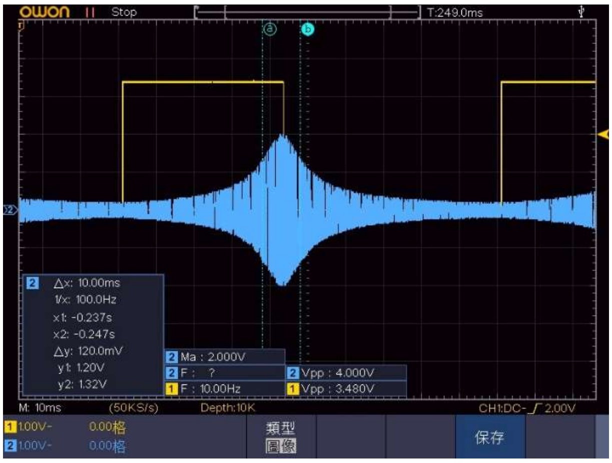


Data

2.

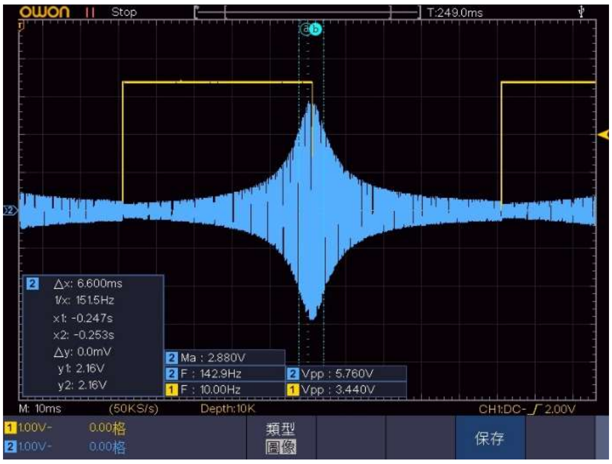
f_{L3dB} (Hz)	f_0 (Hz)	f_{H3dB} (Hz)	BW = f_{H3dB} - f_{L3dB} (Hz)	Q = f_0 / BW
838k	**900k**	**963k**	**125k**	**7.2**

AC SWEEP waveform



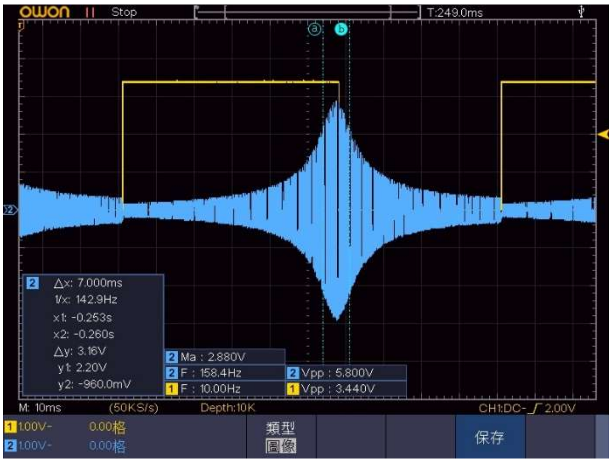
f_{L3dB} (Hz)	f_0 (Hz)	f_{H3dB} (Hz)	BW = f_{H3dB} - f_{L3dB} (Hz)	Q = f_0 / BW
0.960M	**1M**	**1.050M**	**90k**	**11.1**

AC SWEEP waveform



f_{L3dB} (Hz)	f_0 (Hz)	f_{H3dB} (Hz)	BW = f_{H3dB} - f_{L3dB} (Hz)	Q = f_0 / BW
1.045M	**1.1M**	**1.155M**	**110k**	**10.0**

AC SWEEP waveform



Questions

1. How to change the quality factor?

The easiest way is to change the resistor. We can replace the 10kΩ resistor with a **variable** resistor. For example, I use a 50kΩ variable resistor when implementing the experiment. The quality factor is proportional to the resistance, and it's inversely proportional to the bandwidth. Adjusting the bandwidth properly would improve the quality of the signal.

2. Why the amplitude is not constant while adjusting the resistance?

In the circuit analysis part, I didn't consider the parasitic resistances and capacitances. But in reality, these properties might not be negligible.

3. Wrong calculation of deriving half power point.

The definition of half power point is actually $\frac{|\boldsymbol{H}(\boldsymbol{\omega})|}{|\boldsymbol{H}(\boldsymbol{\omega})|_{max}} = \frac{1}{\sqrt{2}}$, rather than $\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{2}}$ in the slides.

The following are the wrong derivation supposing $\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{2}}$.

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{2}} \Rightarrow \frac{L_2}{L} \times \frac{1}{\sqrt{1+\left(\omega RC - \frac{1}{\omega}\frac{R}{L}\right)^2}} = \frac{1}{\sqrt{2}} \Rightarrow \left(\omega RC - \frac{1}{\omega}\frac{R}{L}\right)^2 = \frac{L^2}{{L_2}^2} - 1 \Rightarrow \omega RC - \frac{1}{\omega}\frac{R}{L} = \pm\sqrt{\frac{L^2}{{L_2}^2} - 1}$$

$$\Rightarrow \omega^2 RC \mp \sqrt{\frac{L^2}{{L_2}^2} - 1}\ \omega - \frac{R}{L} = 0$$

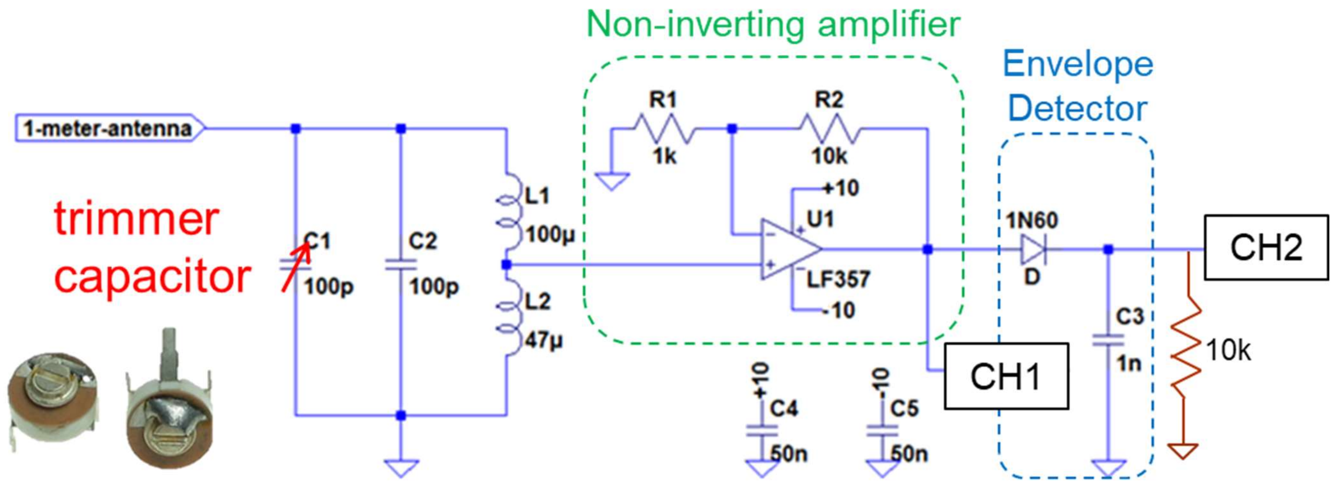
Use formula of difference of two squares to solve the equation and select positive ω,

$$\Rightarrow \omega_{high} = \frac{1}{2RC}\left(\sqrt{\frac{L^2}{{L_2}^2} - 1} + \sqrt{\frac{L^2}{{L_2}^2} - 1 + \frac{4R^2C}{L}}\right), \omega_{low} = \frac{1}{2RC}\left(-\sqrt{\frac{L^2}{{L_2}^2} - 1} + \sqrt{\frac{L^2}{{L_2}^2} - 1 + \frac{4R^2C}{L}}\right)$$

$$\Rightarrow bandwidth = \mathrm{B} = \frac{1}{RC}\sqrt{\frac{L^2}{{L_2}^2} - 1}\ \ rad/s$$

$$\Rightarrow Quality\ factor = \mathrm{Q} = \frac{\omega_0}{B} = \frac{R}{\sqrt{\frac{L}{C}\left(\frac{L^2}{{L_2}^2} - 1\right)}}$$

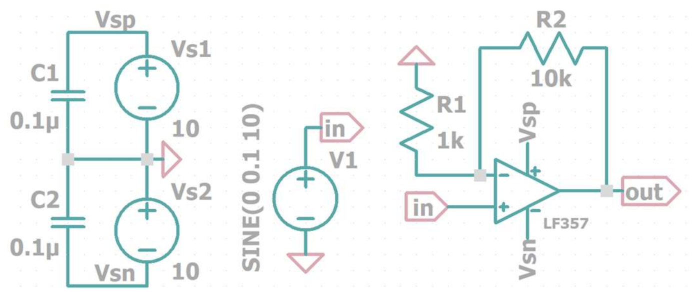
Experiment 2: Parallel RLC Tuner Circuit with the amplifier



NOTICE: Please add decouple capacitor between +10V, -10V, Ground

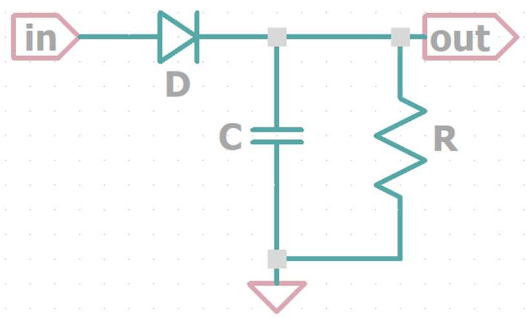
Circuit Analysis

Non-inverting amplifier



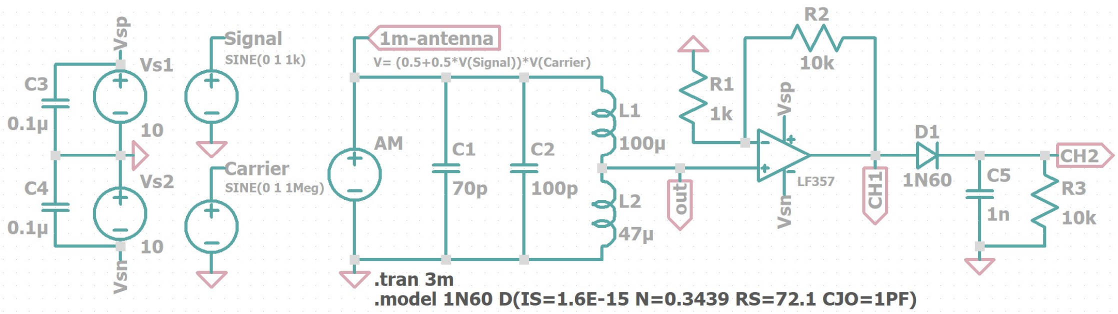
$$V_{out} = \frac{R2}{R1} \times V_{in} = 10V_{in}$$

Envelope detector



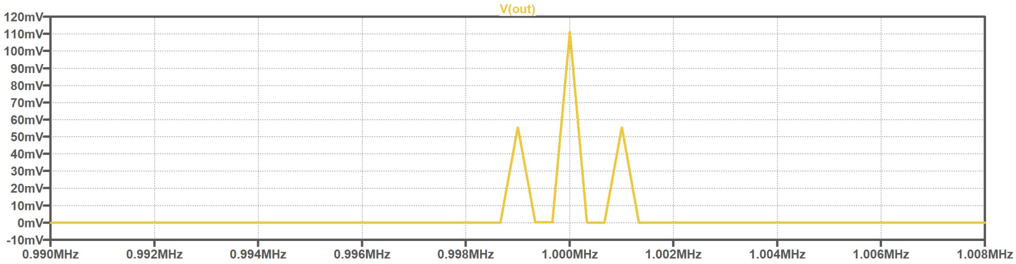
The charging time and discharging time of the capacitor are much slower than the high-frequency signal. Thus, it filtered the high-frequency part and worked as an envelope detector.

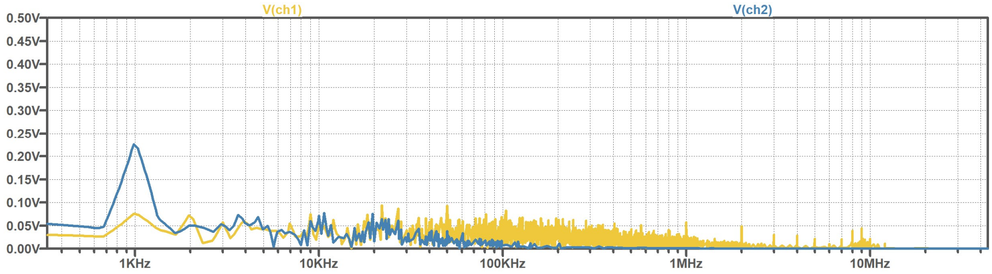
LTspice



AM ReceiverLab3

FFT





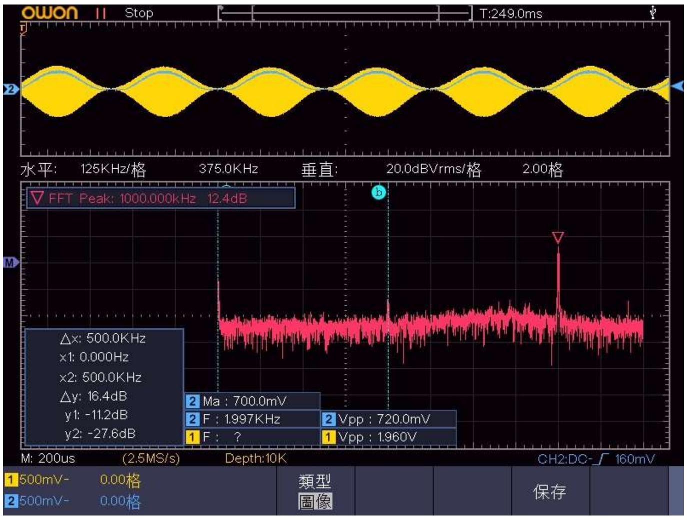
Data

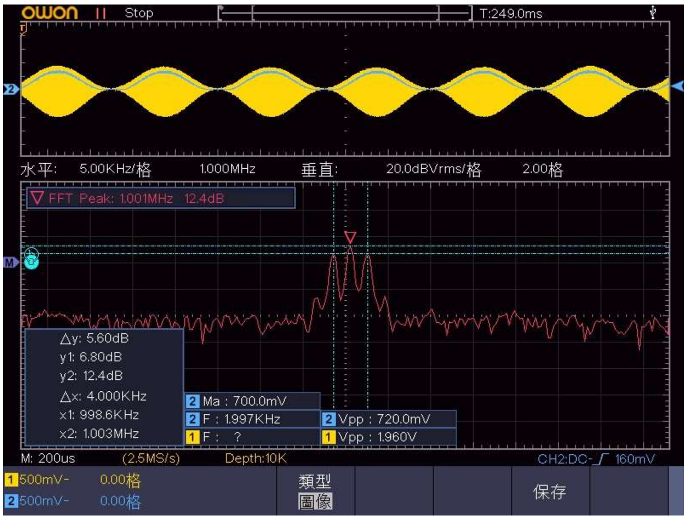
5-1

Waveform of CH1 and CH2 (time-domain) Note: align ground of both channel

5-2

FFT plot of CH1





AM ReceiverLab3

5-3

	Carrier	Lower sideband	Upper sideband
Frequency (Hz)	**1M**	**998.6k**	**1003k**
Magnitude (dB)	**12.4**	**6.8**	**6.8**

5-4

FFT plot of CH2

5-5

	Modulation
Frequency (Hz)	**2k**
Magnitude (dB)	**13.2**

Questions

4. Why does the voltage of LF357 wasn't reaching the saturation voltage but still much smaller than expected?

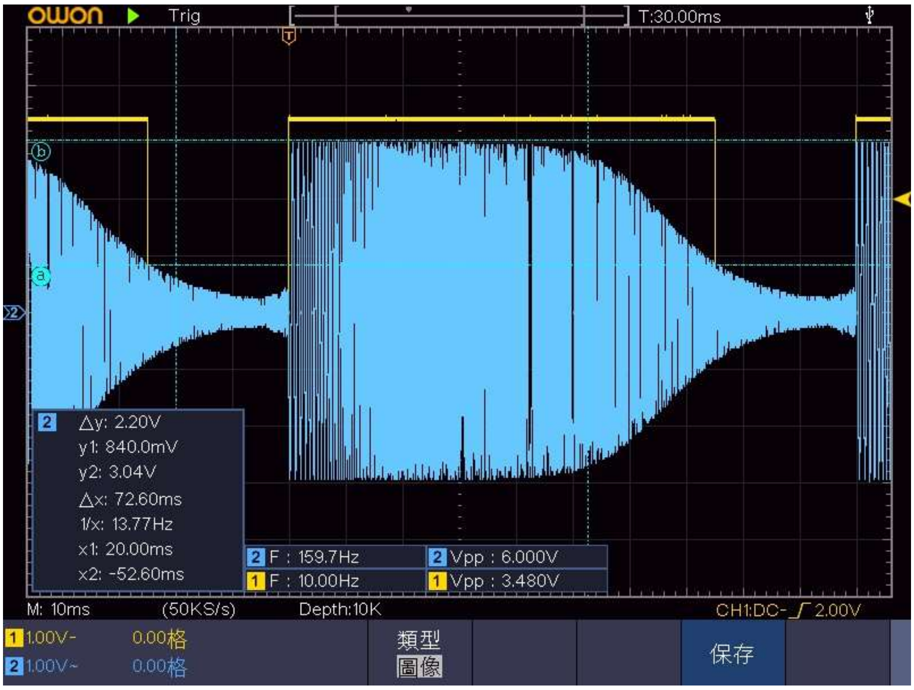
Voltage gain: 3.18

By measuring the frequency response under the condition of the figure of noninverting amplifier in the circuit analysis part. I found that the voltage gain of the circuit at 1MHz is only 2.76.

AM ReceiverLab3

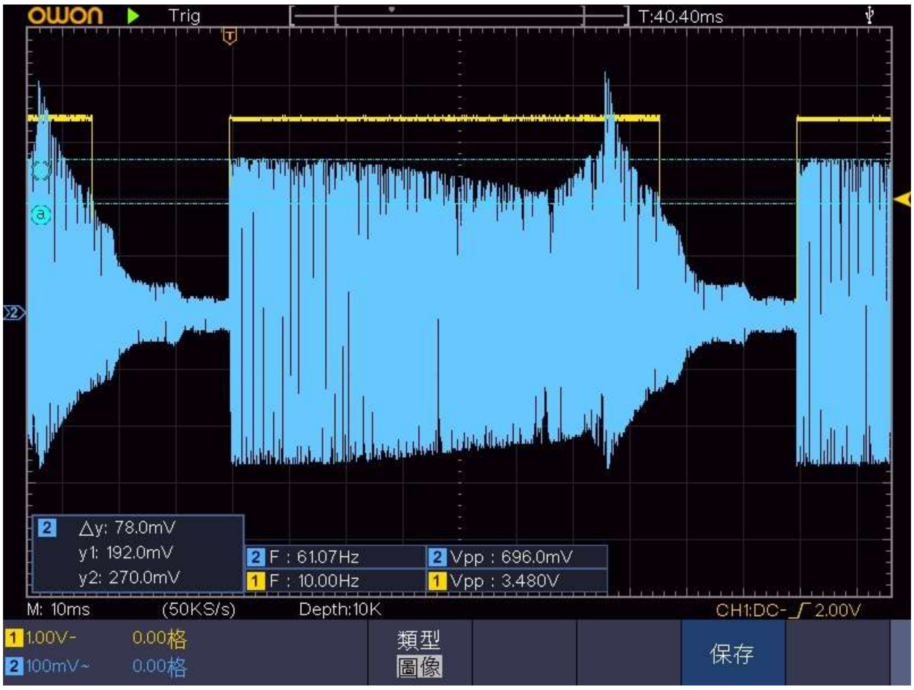
Frequency response (log scale) under the condition of the figure of noninverting amplifier:

The marker pointed out the position of 1MHz signal.



Unit gain(50kHz~40MHz, log scale):

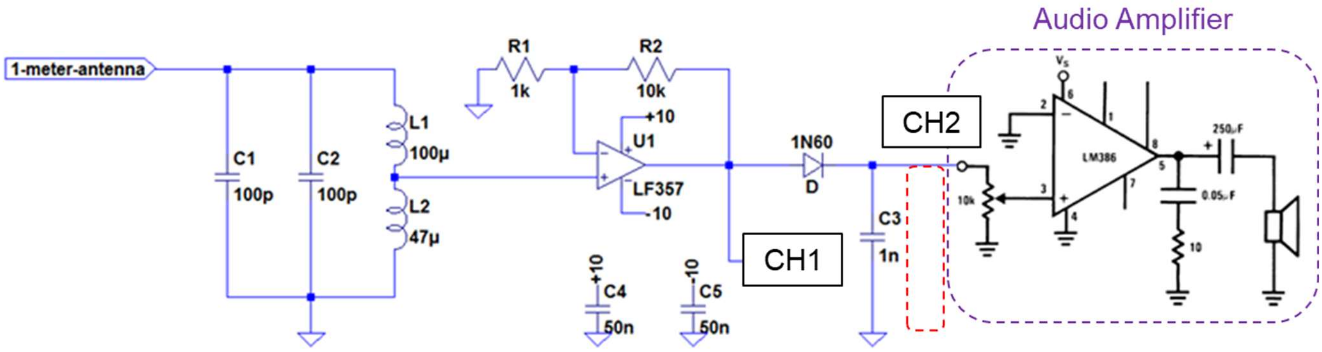
The **unit gain bandwidth** of LF357 is only **13.8MHz**.



5. How does the time constant of the RC circuit in the envelope detector affect the demodulator?

If the time constant is too small, the output signal would not be smooth. If the time constant is too large, the output would be similar to the ripple. They both cause distortion. So it's important to adjust the time constant properly. While implementing the experiment, I replace R3 with a 10k variable resistor, so that it's easier to adjust the time constant and observing the difference.

Experiment 3: AM radio receiver

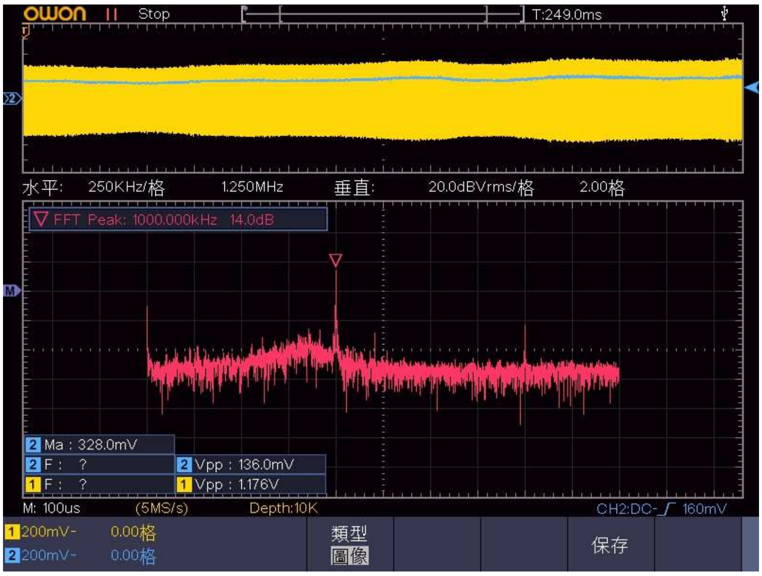


Circuit Analysis

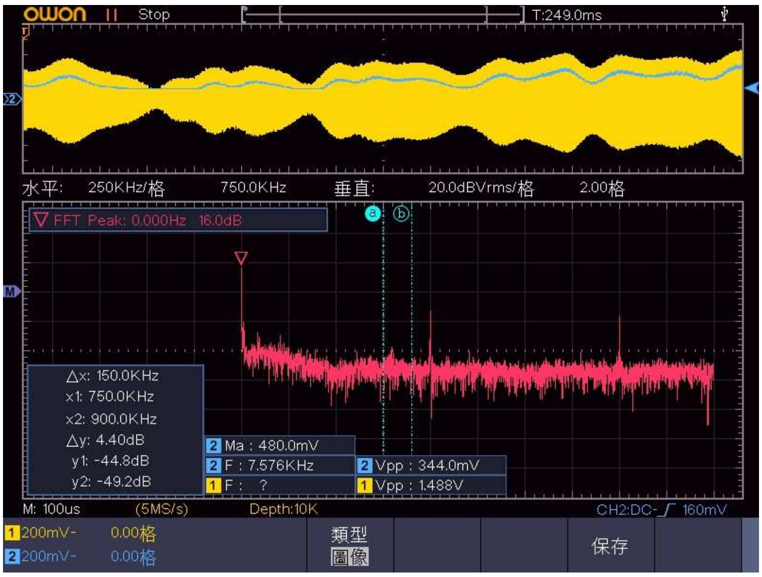
Here we add a speaker circuit at the output so that we could hear the demodulated signal.

Data

Waveform and FFT plot of CH1



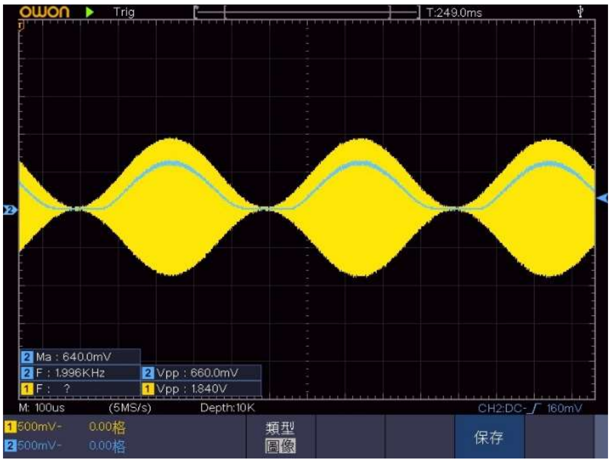
Waveform and FFT plot of CH2



Questions

6. Why the amplitude would be larger if you touched the end of the wire (antenna)?

Untouched



Touched the antenna

Because human body can be the antenna to receive the signal.

7. How does modulation depth affect the signal after LPF?

a. Amplitude

The greater the modulation depth is, the greater the amplitude of the signal at CH2 is. Thus, the sound would be louder, too.

b. Distortion

If the modulation depth is too big, the minimum voltage of the envelope line would be less than the threshold voltage of the diode. Hence, it would ruin part of the signal after rectifying.

Reference

[1] RLC circuit, Wikipedia. https://en.wikipedia.org/wiki/RLC_circuit

[2] AM Demodulation - Envelope Detector Explained (with Simulation), ALL ABOUT ELECTRONICS, YouTube. https://www.youtube.com/watch?v=4JrryefRNFk&ab_channel=ALLABOUTELECTRONICS

[3] Can the human body be used as an antenna for electronics?, Quora. https://www.quora.com/Can-the-human-body-be-used-as-an-antenna-for-electronics

[4] LF357 Datasheet (PDF) – STMicroelectronics, Alldatasheet. https://pdf1.alldatasheet.com/datasheet-pdf/view/22740/STMICROELECTRONICS/LF357.html

心得

這次實驗額外做了不少測量，尤其是有關 LF357 這顆「號稱」unit gain bandwidth 是 20MHz 的 IC 時，發現 datasheet 廣告不實，實測只有宣稱的數據的 6 成多一些，難怪輸出訊號比想像中的小。而且跑 SPICE 時只有 FFT 正常，真是多災多難。

在找有關碰觸天線訊號就會被增幅這個現象時，我換過好幾個關鍵字，找很久才找到答案，還找到什麼把手機放頭上訊號比較好之類的回答。但有趣的是，當我用 “Human body antenna” 作為關鍵字時，居然跑出好幾篇論文。顯然這個現象是有人在研究的，但由於時間不足，我也沒特別去細讀內容，單純覺得酷。