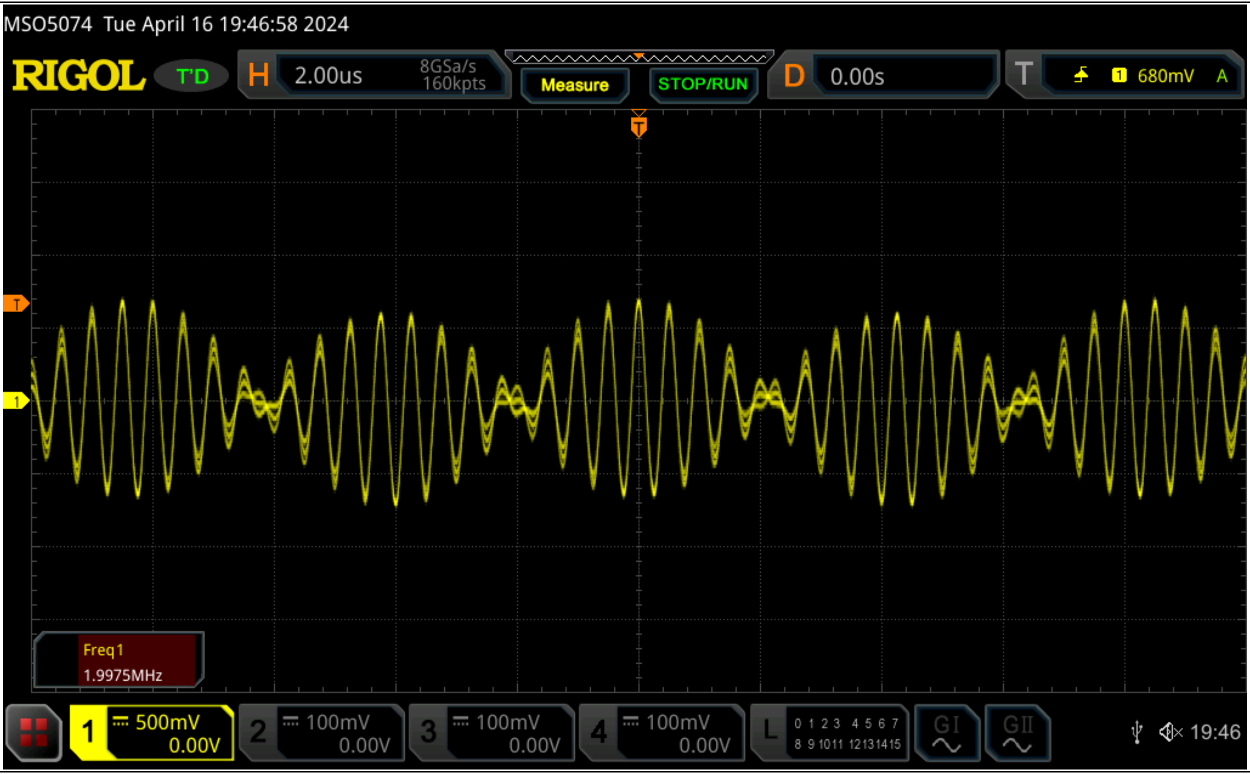
REPORT

Experiment 1: Double Side Band – Suppressed Carrier Modulation and Demodulation

2. & 3.

output waveform in DC coupling

output FFT waveform with data (measured by cursor)


Signal Name	Modulation wave	Lower sideband	Upper sideband
Frequency measured (Hz)	120k	1.88M	2.12M
Magnitude measured (dB)	-32.66	-14	-14

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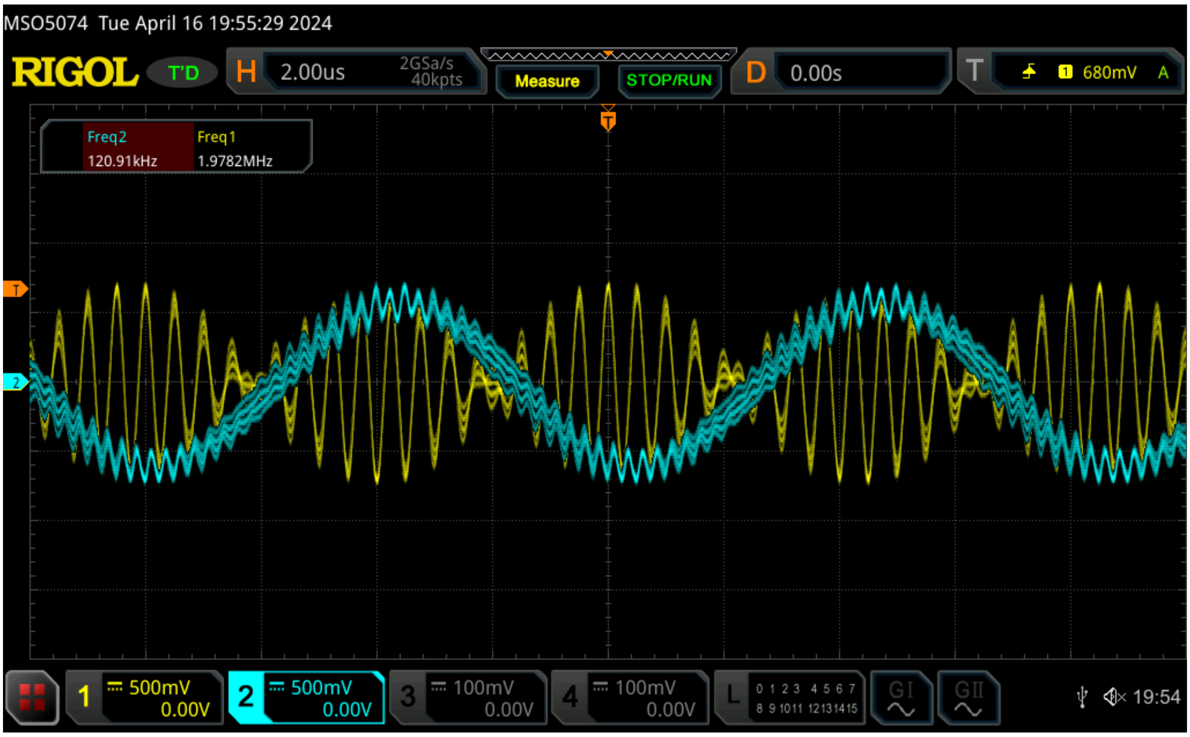
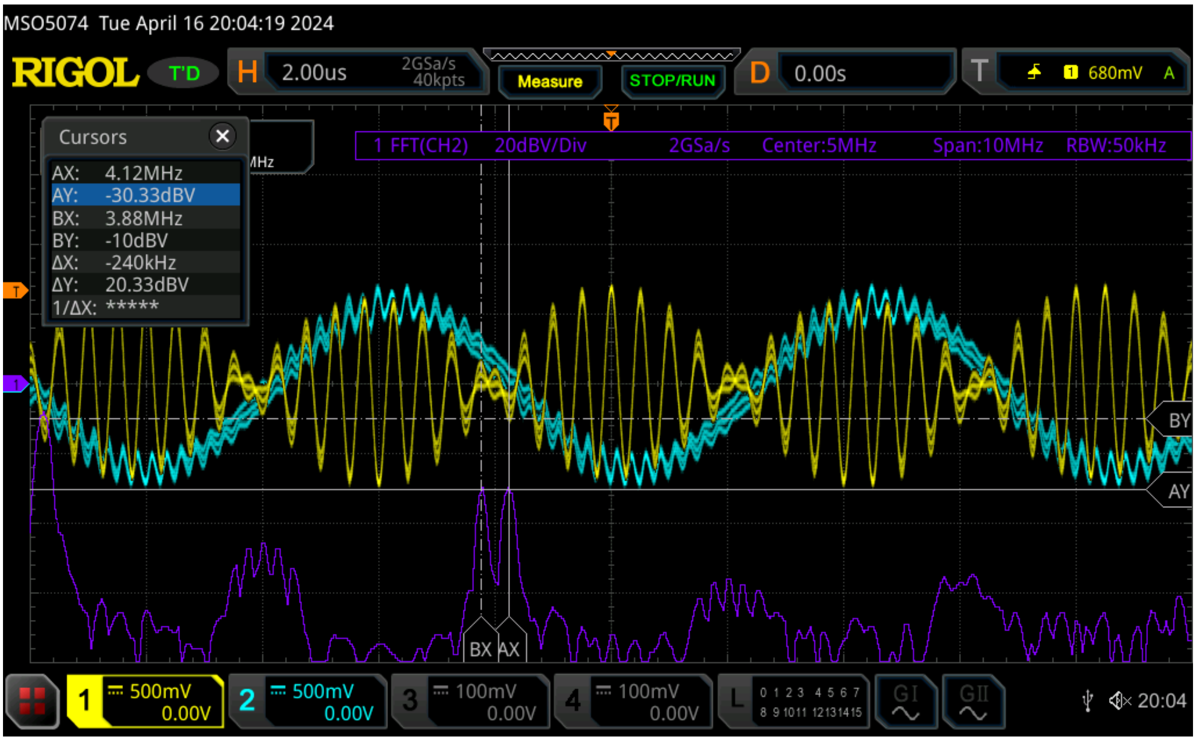
Vout1 and Vout2 waveform in DC coupling

Vout2 FFT waveform with data (measured by cursor)


Signal Name	Modulation wave	Lower sideband	Upper sideband
Frequency measured (Hz)	120k	3.88M	4.12M
Magnitude measured (dB)	-10	-30.33	-30.33

Question:

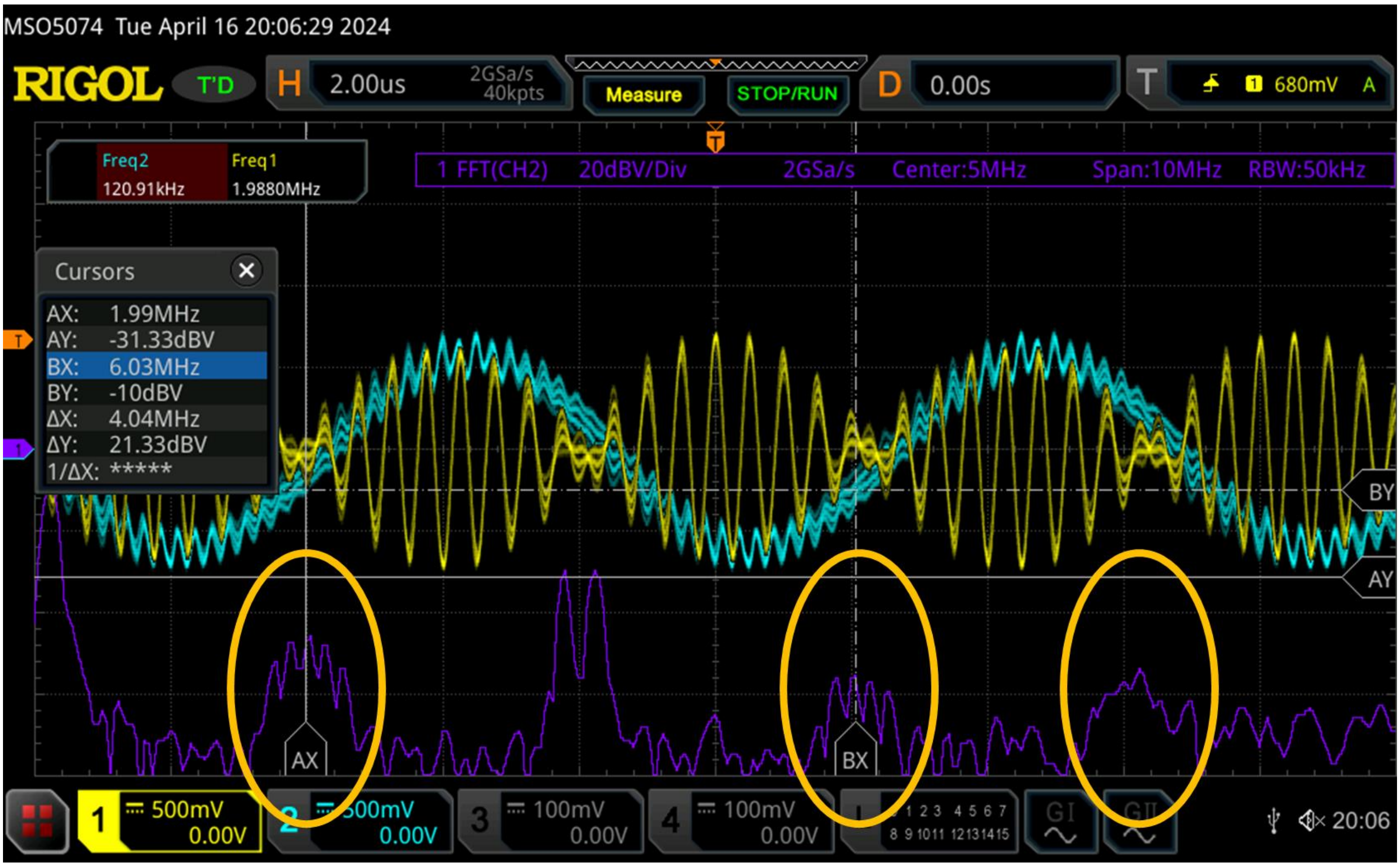
Why the sideband frequencies are 1.88MHz and 2.12MHz?

In amplitude modulation (AM), the modulated signal is the product of the carrier signal and the sum of a constant and the modulating signal. This multiplication in the time domain corresponds to a convolution in the frequency domain, which results in the generation of sidebands on either side of the carrier frequency. We can obtain the sideband frequency using this formula.

$$Carrier\ Freq\ \pm\ Modulation\ Freq\ = Sideband\ Freq$$

In the case of this experiment, Carrier Freq = 2M (Hz) & Modulation Freq = 0.12M (Hz).
We obtain the lower sideband freq = 1.88 M & lower sideband freq = 2.12 M.

Is there any other frequency element observed after demodulation?



According to the FFT waveform, frequencies that are positive integer multiples(harmonics) of 2M can be observed. This is a phenomenon called “spectral regrowth”.

What is spectral regrowth?

When a signal passes through a nonlinear device or system, such as an amplifier or mixer, the nonlinearity causes the generation of additional frequency components that were not present in the original input signal. These new frequency components are called intermodulation products or spectral regrowth components.

Mechanisms behind modulation & demodulation:

At first, I didn't fully understand the mechanisms behind modulation, but after this week's signal and systems lecture, I can now give a step-by-step explanation of how modulation works:

1. Consider a cos wave and its Fourier transform. (We use a cosine wave instead of sine to avoid dealing with complex number.) Notice that cosine's spectrum is simply two impulse functions.

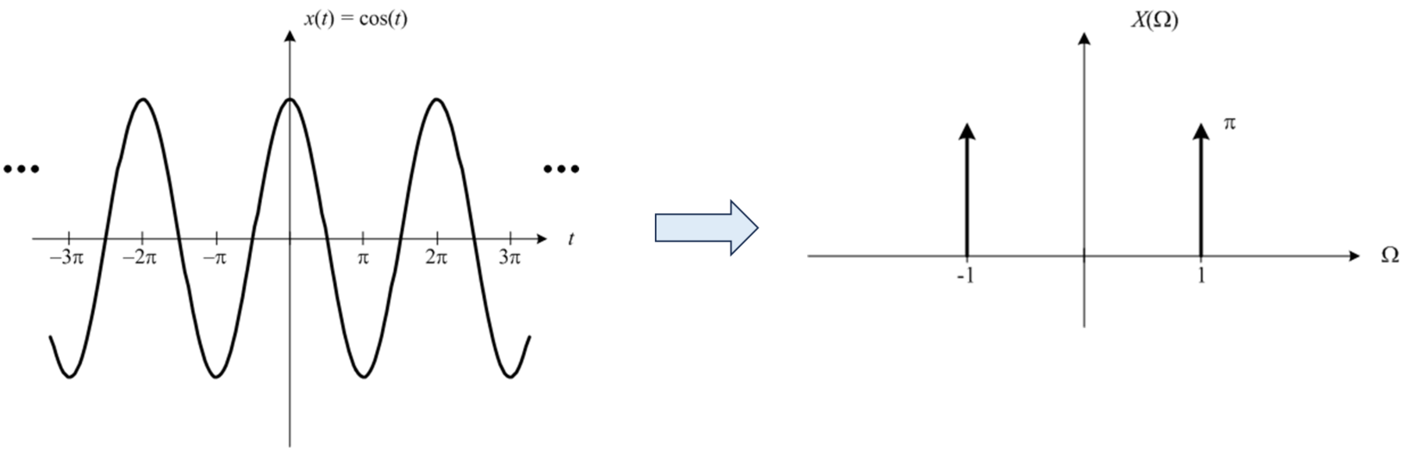


Fig.1 Cosine Wave Time Domain & Frequency Domain
Source: MATLAB Central Blog

2. Modulation is simply multiplication between the carrier and the modulating signal. A fundamental rule in signal in systems states that $A \times B$ in the time domain equals $A * B$ in the frequency domain. Additionally, convolution between any signal and a $\delta(f - f_0)$ is simply that signal shifted by f_0. The result of this is depicted in the following figure.

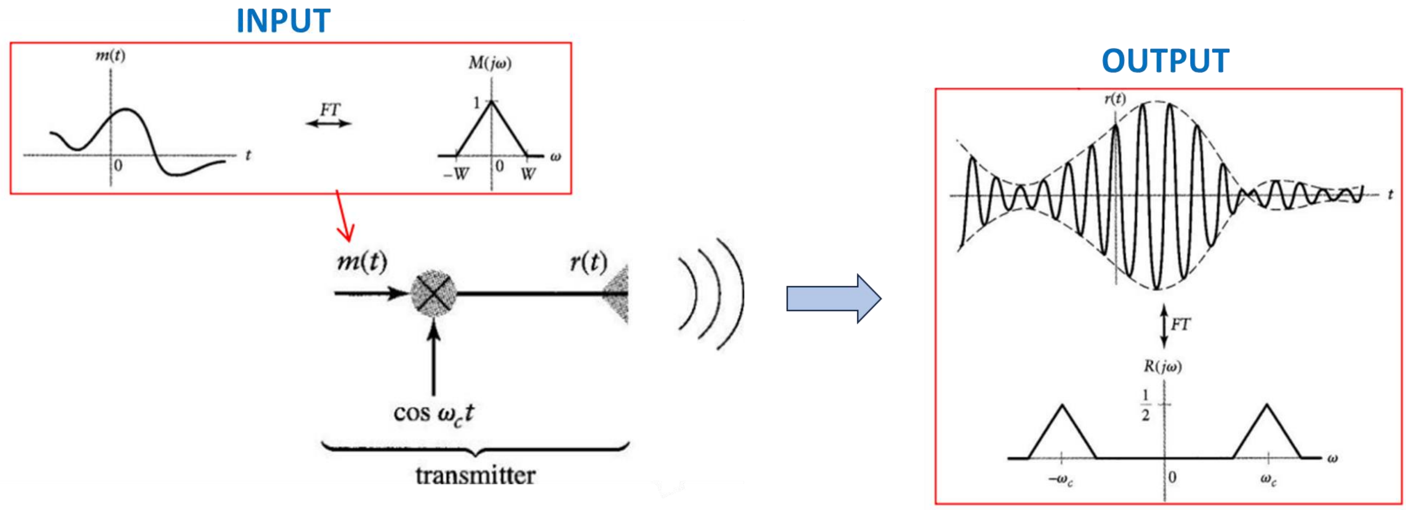


Fig.2 Signal Modulation
Source: *Signals and Systems (Simon Haykin, Barry Van Veen)*

3. If we take the output of the previous stage and multiply it by the same cosine wave yet again. We acquire the following spectrum. Notice that the middle is the same as the original signal's spectrum. We can then remove the undesired higher frequency spectrum by passing this through an LPF. This will allow us to restore the signal.

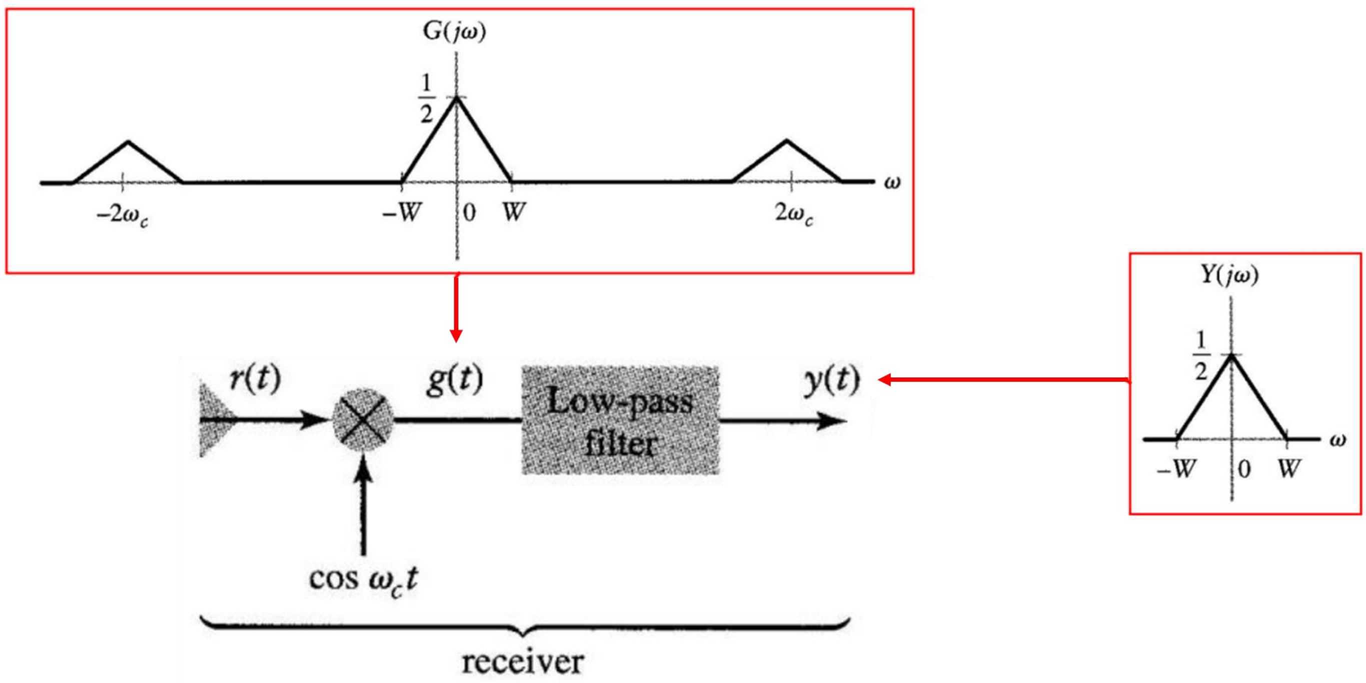


Fig.3 Signal Demodulation
Source: *Signals and Systems (Simon Haykin, Barry Van Veen)*

Experiment 2: The Envelope Detector

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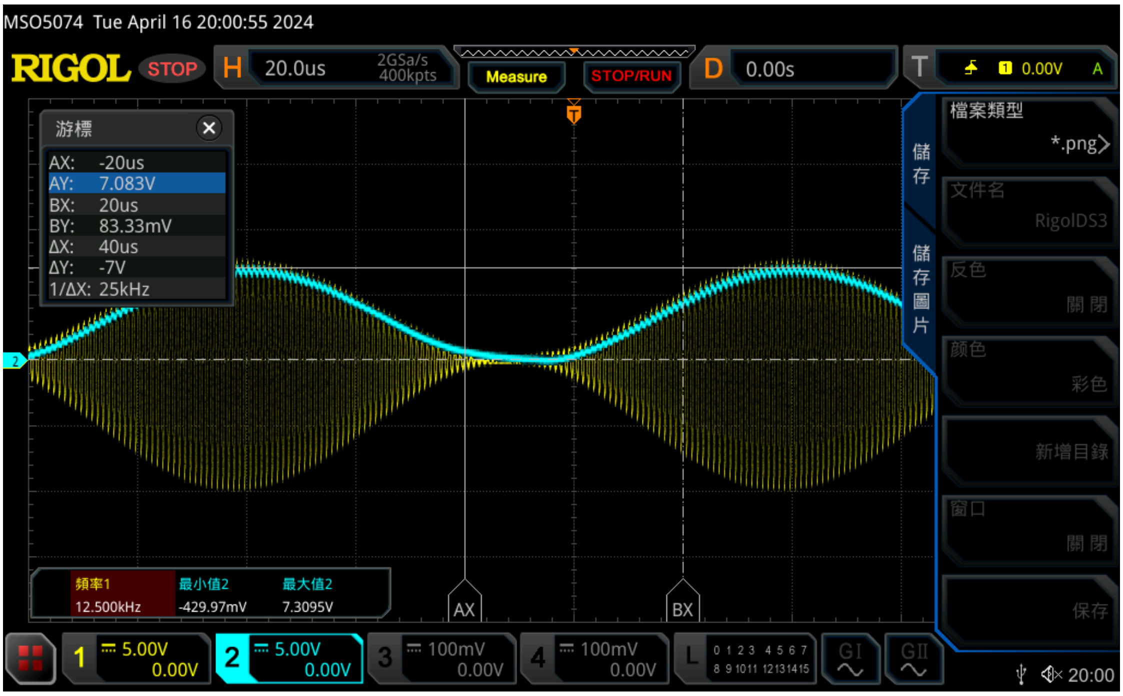
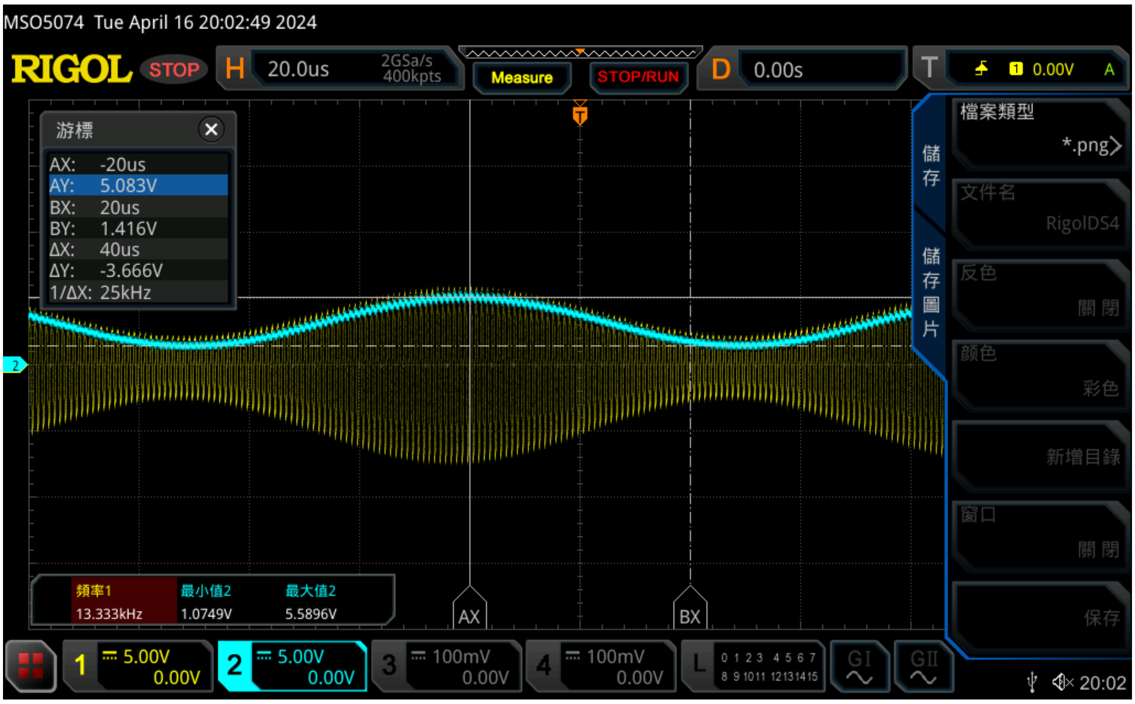
input and output waveforms in DC coupling (AM depth 100%)



input and output waveforms in DC coupling (AM depth 50%)



AM depth in F.G.	Vmax measured (V)	Vmin measured (V)	mod. Index calculated
100%	7.083	83.33m	97.68%
50%	5.083	1.416	56.42%

What is an envelope detector?

An envelope detector is a type of circuit used in radio receivers to recover the modulating signal from an amplitude-modulated (AM) signal. It is also known as an AM demodulator or an envelope demodulator.

The envelope detector works by rectifying the modulated signal and filtering out the high-frequency components, leaving behind the low-frequency modulating signal, which represents the envelope of the modulated waveform.

The basic components of an envelope detector are:

1. Diode rectifier: A diode is used as a rectifier to rectify the modulated signal. This means that it allows only one half of the modulated waveform to pass through, effectively removing the high-frequency carrier component.
2. Filter circuit: A low-pass filter is used to remove any remaining high-frequency components from the rectified signal. This filter passes the low-frequency modulating signal while blocking the higher frequencies.

How does the envelope detector work?

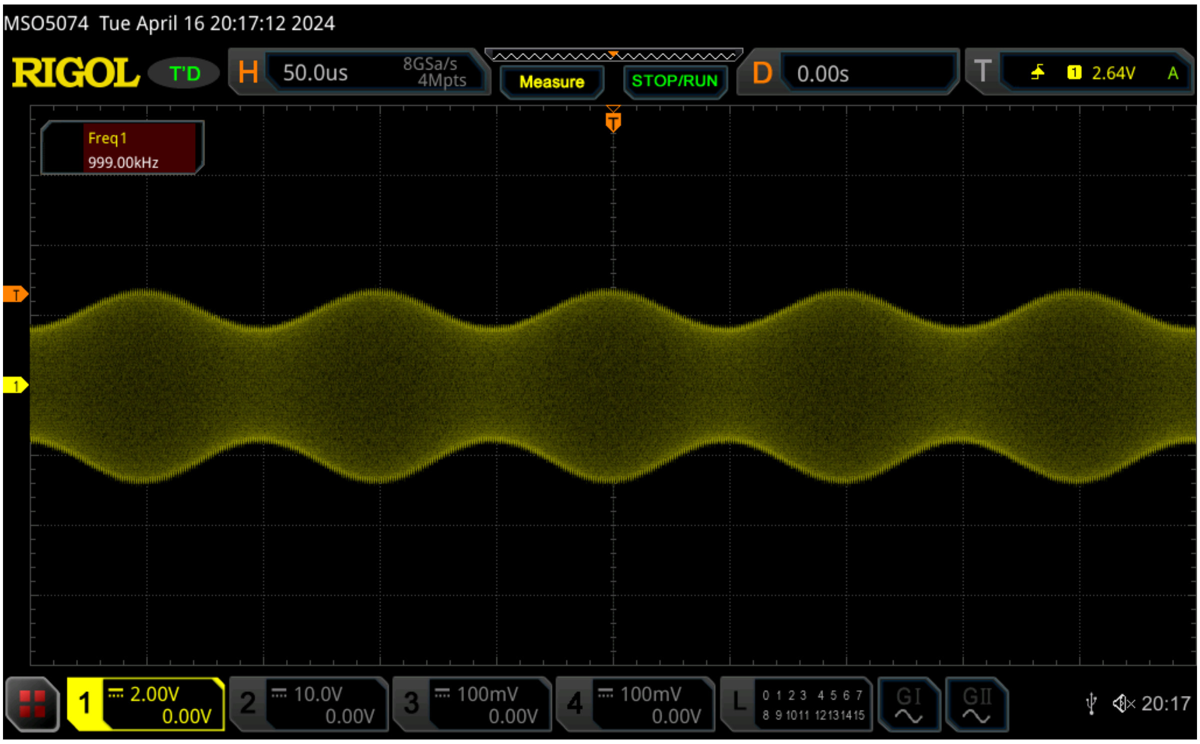
The operation of an envelope detector can be summarized as follows:

1. The modulated AM signal is applied to the diode rectifier.
2. The diode rectifier conducts only during the positive half-cycles of the modulated signal, allowing the positive half-cycles to pass through while blocking the negative half-cycles.
3. The resulting half-wave rectified signal still contains high-frequency components related to the carrier frequency.
4. The low-pass filter removes these high-frequency components, leaving behind the low-frequency modulating signal, which represents the envelope of the modulated waveform.

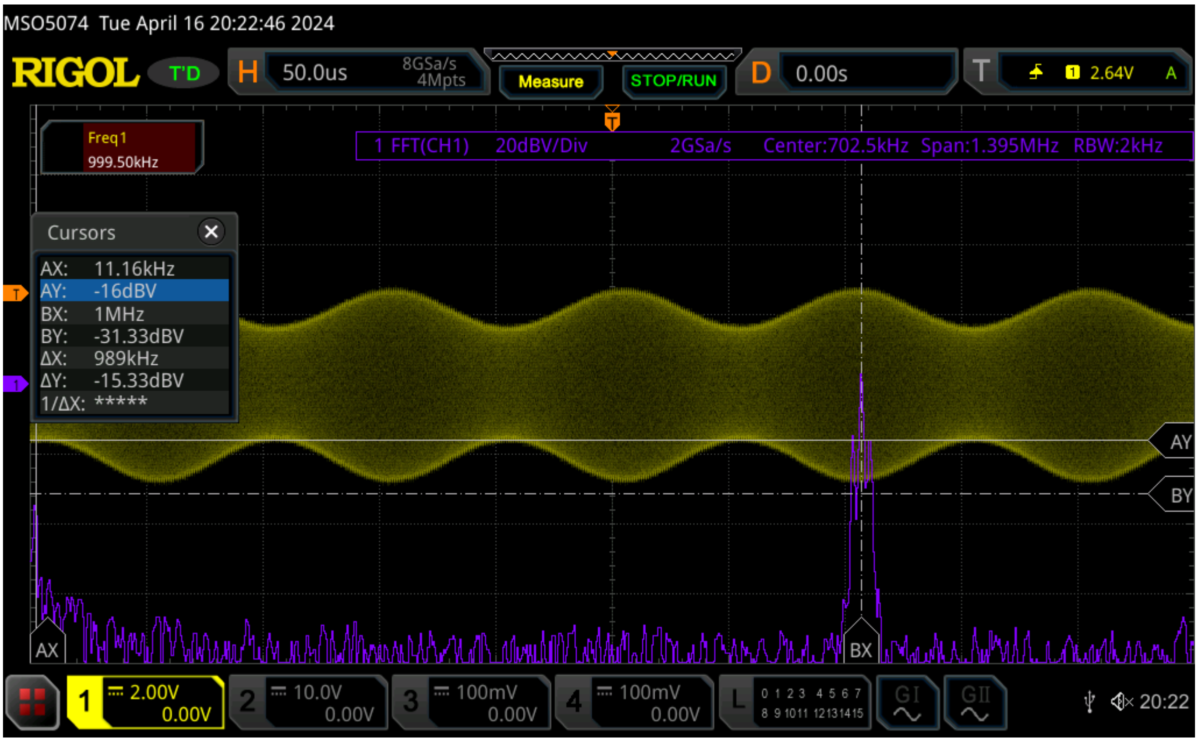
Experiment 3: Linear AM Modulator and Demodulation

2. & 3.

output waveform in DC coupling



output FFT waveform with data (measured by cursor)

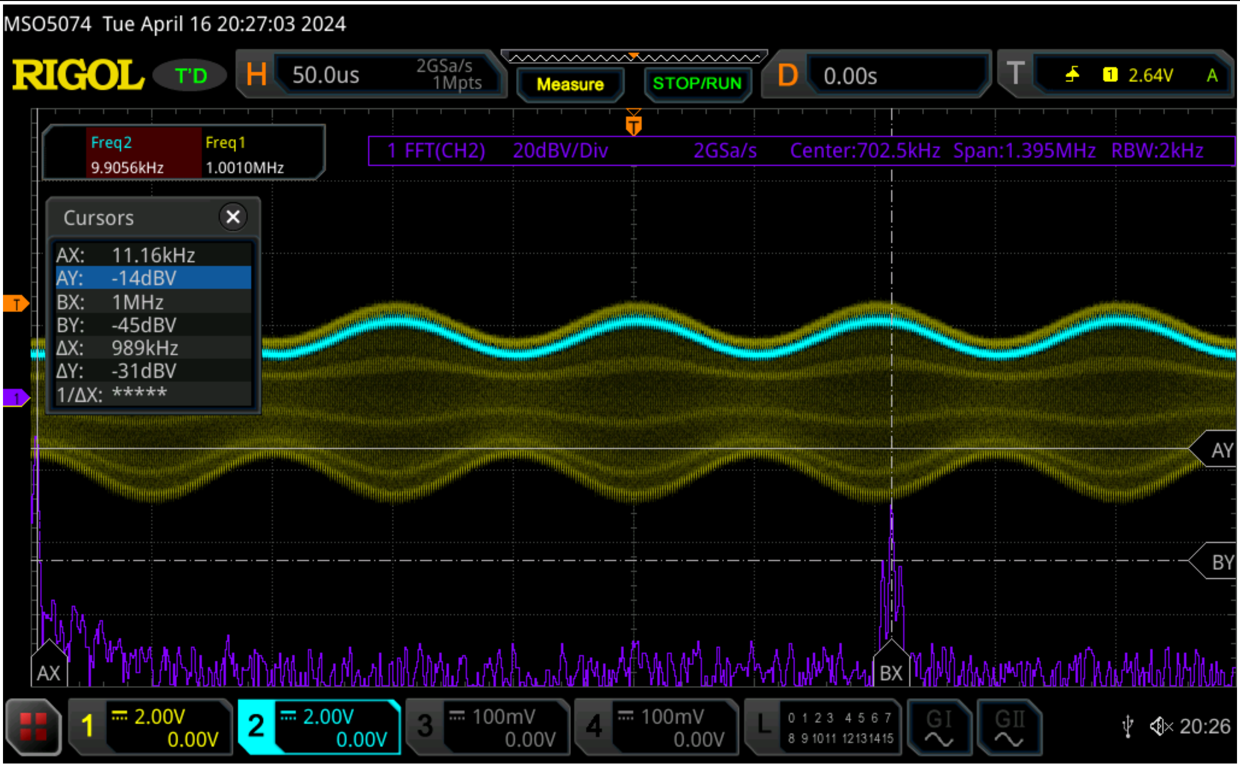


Signal Name	mod. wave	lower sideband	carrier wave	upper sideband
freq. measured (Hz)	10k	0.99M	1M	1.01M
magnitude (dB)	-31.33	-14	1.666	-14

5. & 6.

Vout1 and Vout2 waveform in DC coupling

Vout2 FFT waveform with data (measured by cursor)



Signal Name	mod. wave	carrier wave
freq. measured (Hz)	10k	1M
magnitude (dB)	-14	-29.66

What's the difference between DSB-SC (Double Sideband Suppressed Carrier) and DSB-LC (Double Sideband with Large Carrier)?

Characteristic	**DSB-SC**	**DSB-LC**
Carrier Signal	Suppressed/Removed	Transmitted
Power Efficiency	High, no power wasted on carrier	Lower, power used for carrier
Bandwidth Efficiency	High, no bandwidth used for carrier	Lower, bandwidth used for carrier
Demodulation at Receiver	Requires synchronous demodulation	Allows non-coherent demodulation using carrier
Receiver Complexity	Higher, requires carrier recovery	Lower, carrier available

What's synchronous demodulation?

In synchronous demodulation, the receiver must generate a locally produced carrier signal that is synchronized in frequency and phase with the original carrier used at the transmitter. This locally generated carrier is then used to demodulate the received signal by mixing it with the received sidebands.

References:

1. *Signals and Systems (Simon Haykin, Barry Van Veen)*
2. https://www.geeksforgeeks.org/difference-between-modulation-and-demodulation/
3. https://chchoiw.github.io/posts/2020/06/signals_systems4/