Lab #3

FM Modulation and Demodulation

Lab Group #20

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Table of Contents

Introduction

- To use a voltage control oscillator as an FM modulator.
- Use a phase lock loop to demodulate the FM modulated signal.

Section 1 - FM Modulation:

Section 1.1 - Simulink model

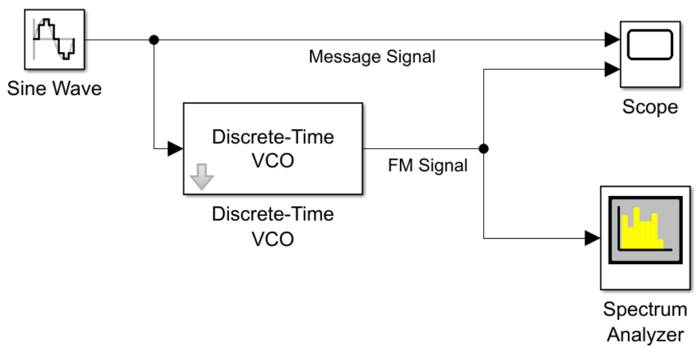
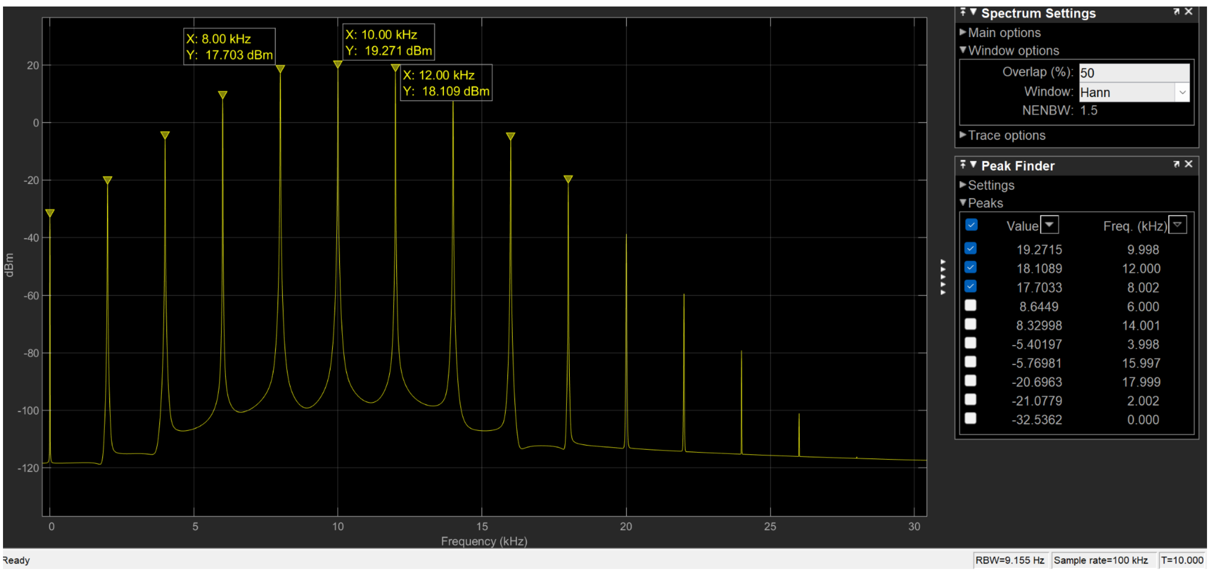


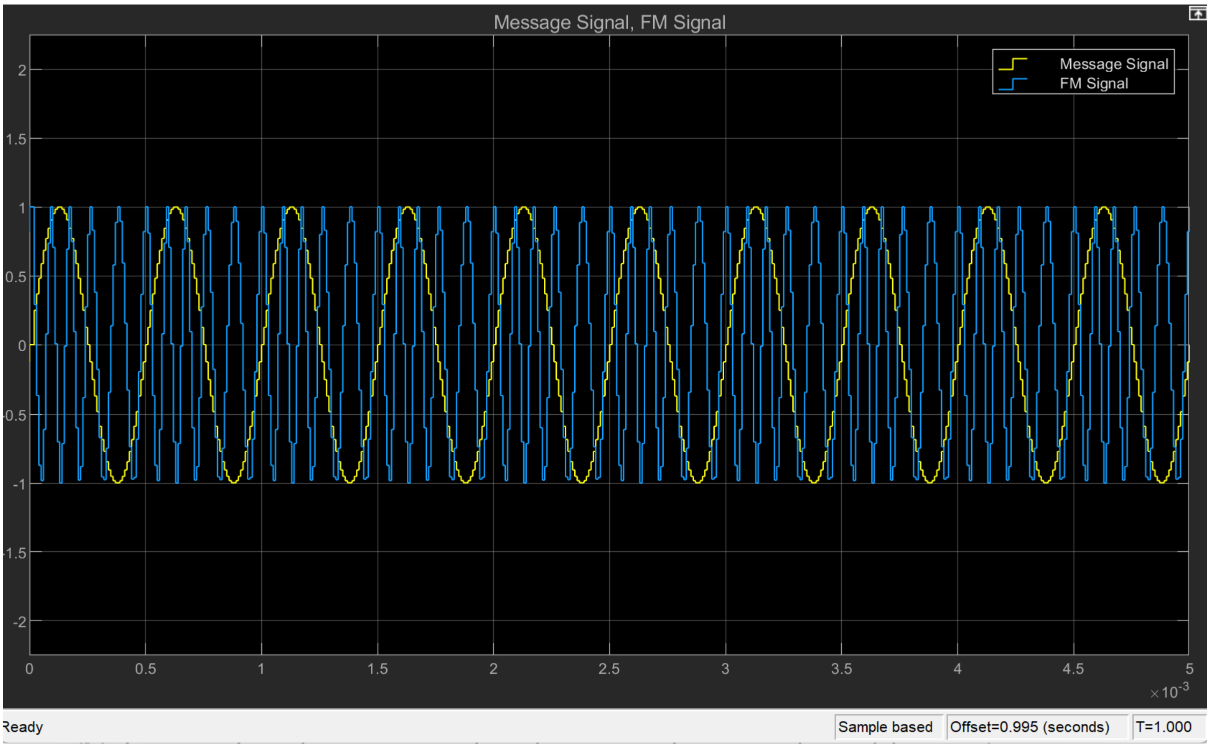
Figure 1.1 - Simulink Model

Section 1.2 - Message Signal 2 Vpp & k_f 2.5kHz

AM = 1 (2 Vpp)
k_f = 2.5 kHz/V

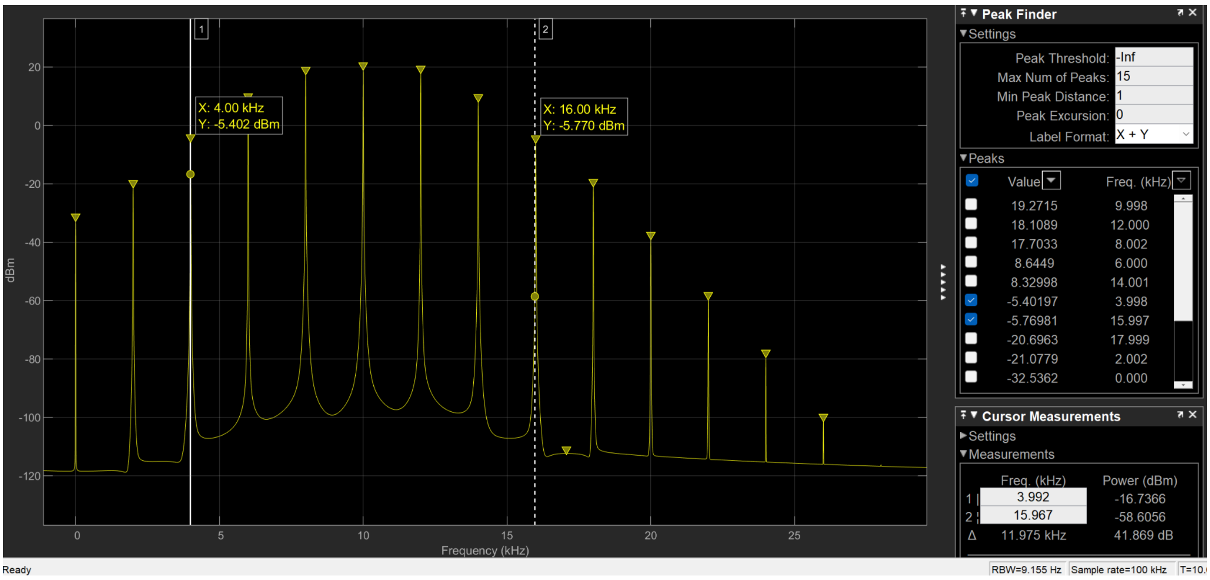


Plot 1.2.1 - Spectrum Analyzer Screenshot



Plot 1.2.2 - Scope Screenshot Zoomed (5 ms)

To find the bandwidth of the signal: **BW= F max - Fmin**
Highest component is **19.27 dB** at **10.00 kHz**
30 dB or more below the highest (ignore anything below **-10 dB**)
Based on the figure below **BW = Δf = 11.975 kHz**



Plot 1.2.3 - Spectrum Analyzer Screenshot for Bandwidth

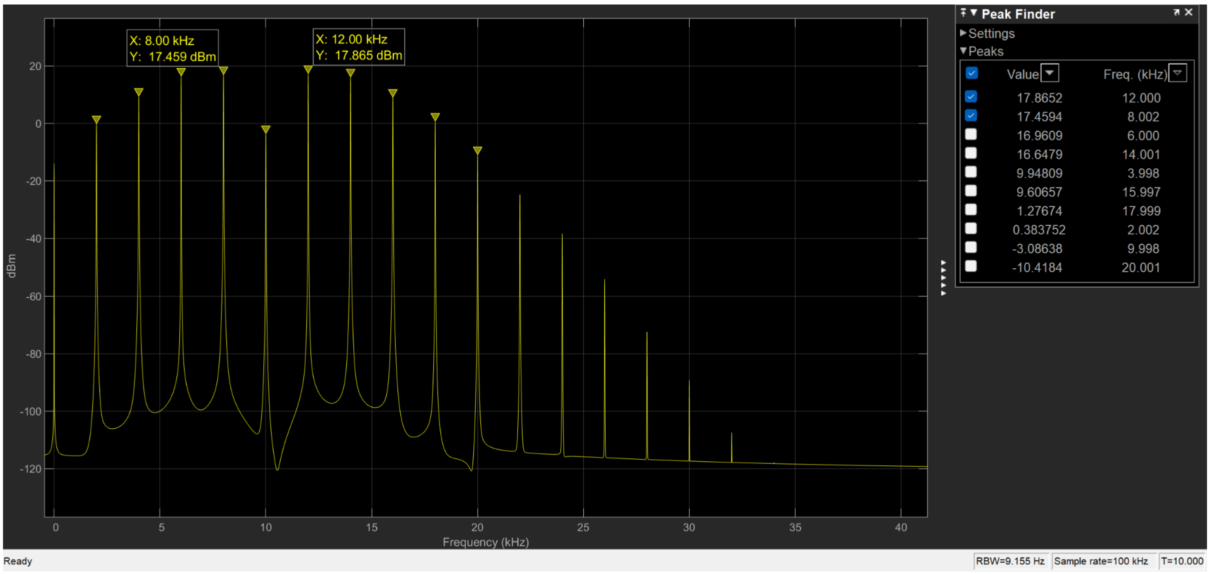
Carson's rule:

$$\Delta f = A_m k_f$$
$$BW(Carson) = 2(\Delta f + f_m)$$
$$f_m = 2kHz$$

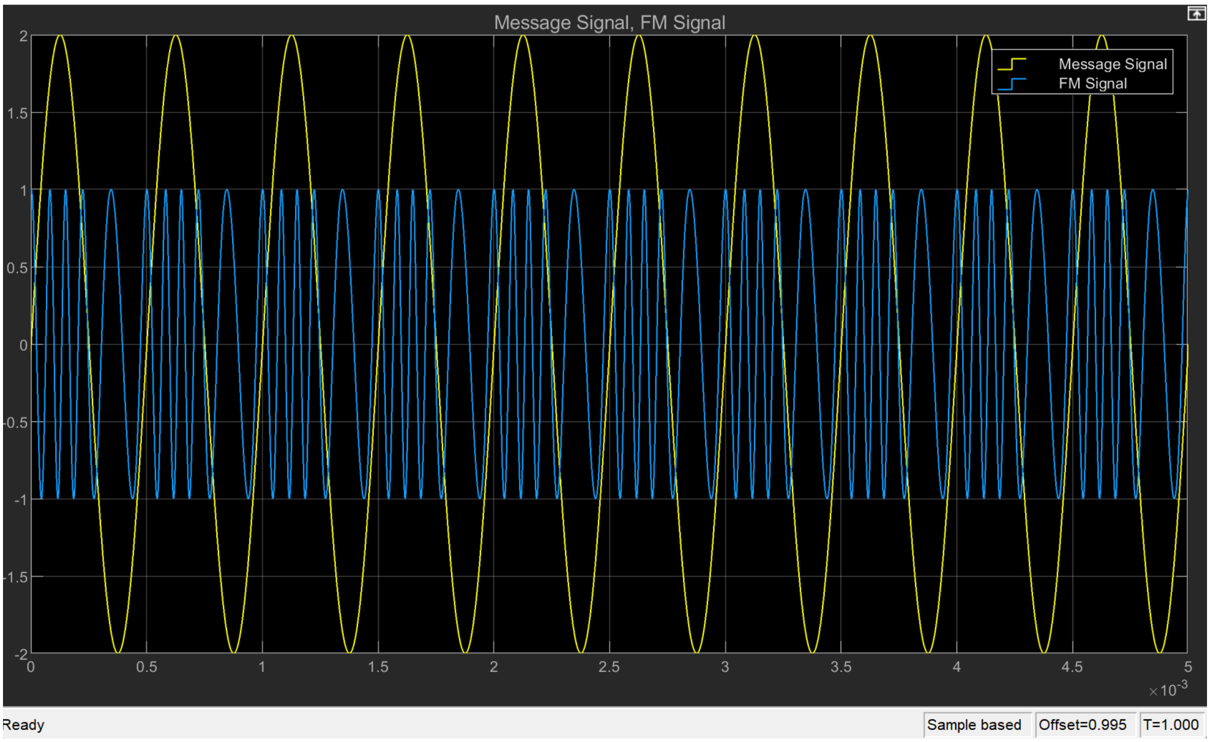
Δf = 1 * 2500 = 2500
BW = 2(2500+2000) = 9 kHz

Section 1.3 - Message Signal 4 Vpp & k_f 2.5kHz

AM= 2V (4 Vpp)
k_f = 2.5 kHz/V

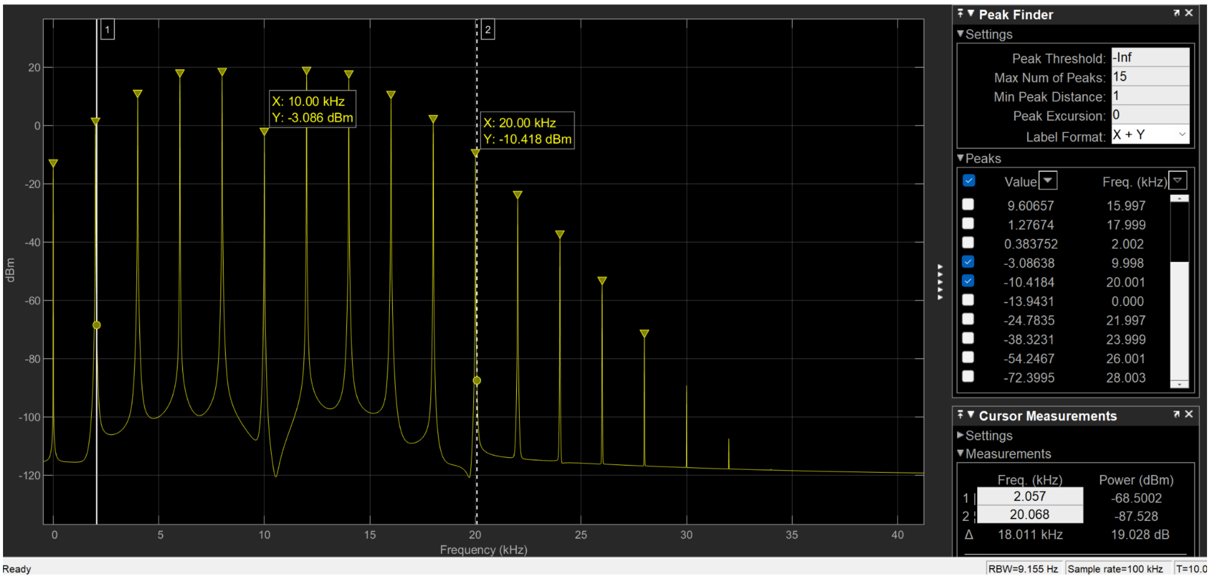


Plot 1.3.1 - Spectrum Analyzer Screenshot



Plot 1.3.2 - Scope Screenshot Zoomed (5 ms)

To find the bandwidth of the signal: **BW= F max - Fmin**
Highest component is **17.87 dB** at **12.00 kHz**
30 dB or more below the highest (ignore anything below **-12.13 dB**)
Based on the figure below **BW = Δf = 18.011 kHz**

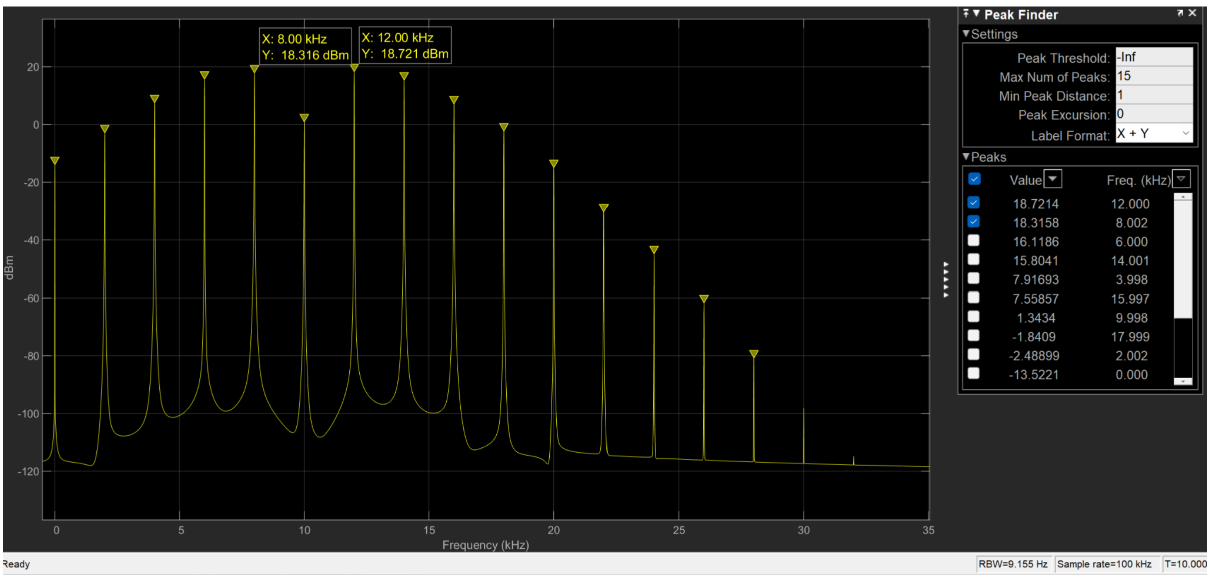


Plot 1.3.3 - Spectrum Analyzer Screenshot for Bandwidth

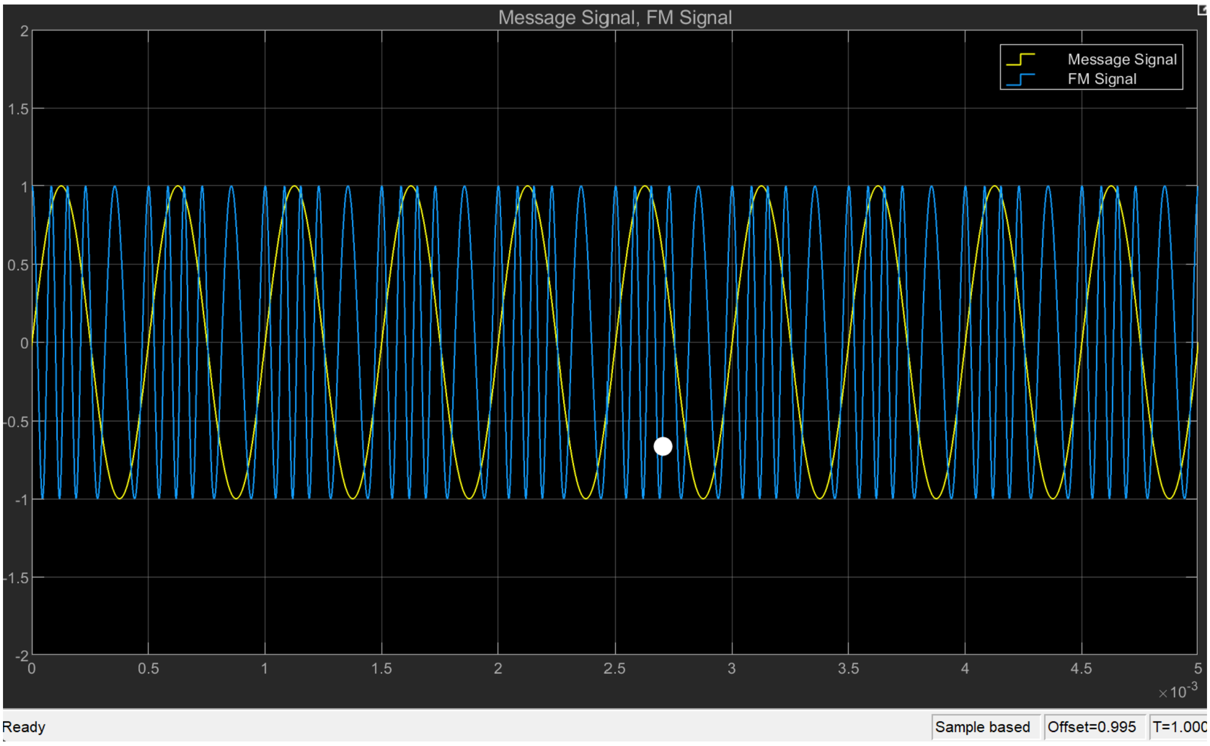
Δf = 2 * 2500 = 5000
BW = 2(5000+2000) = 14 kHz

Section 1.4 - Message Signal 2 Vpp & k_f 4.5kHz

AM= 1V (2 Vpp)
k_f = 4.5 kHz

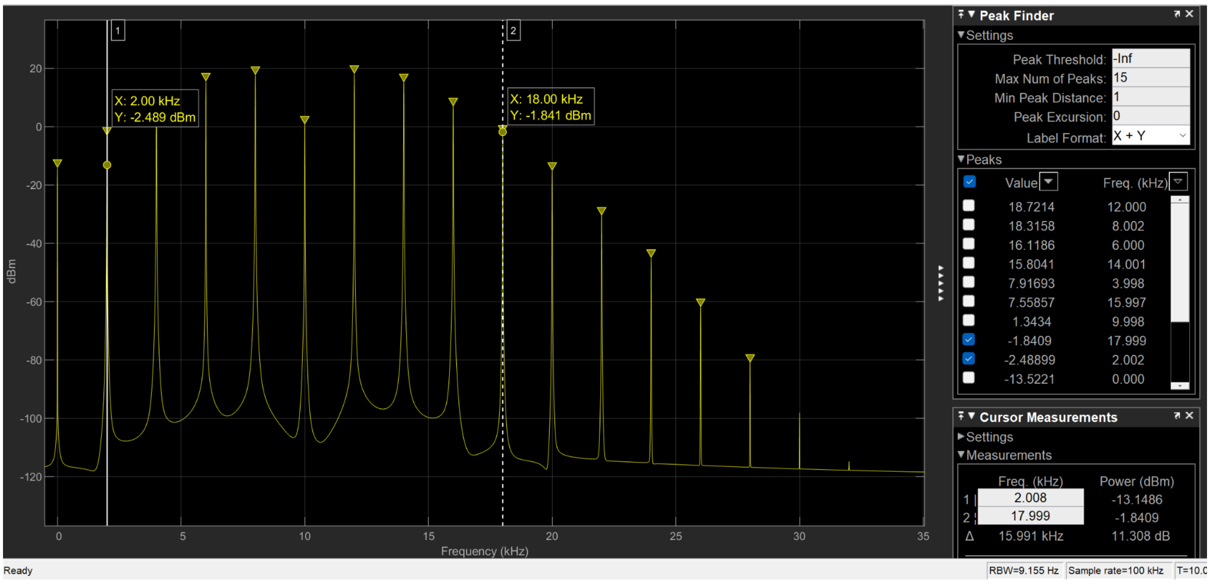


Plot 1.4.1 - Spectrum Analyzer Screenshot



Plot 1.4.2 - Scope Screenshot Zoomed (5 ms)

To find the bandwidth of the signal: **BW= F max - Fmin**
Highest component is **18.721 dB** at **12.00 kHz**
30 dB or more below the highest (ignore anything below **-11.28 dB**)
Based on the figure below **BW = Δf = 15.991 kHz**

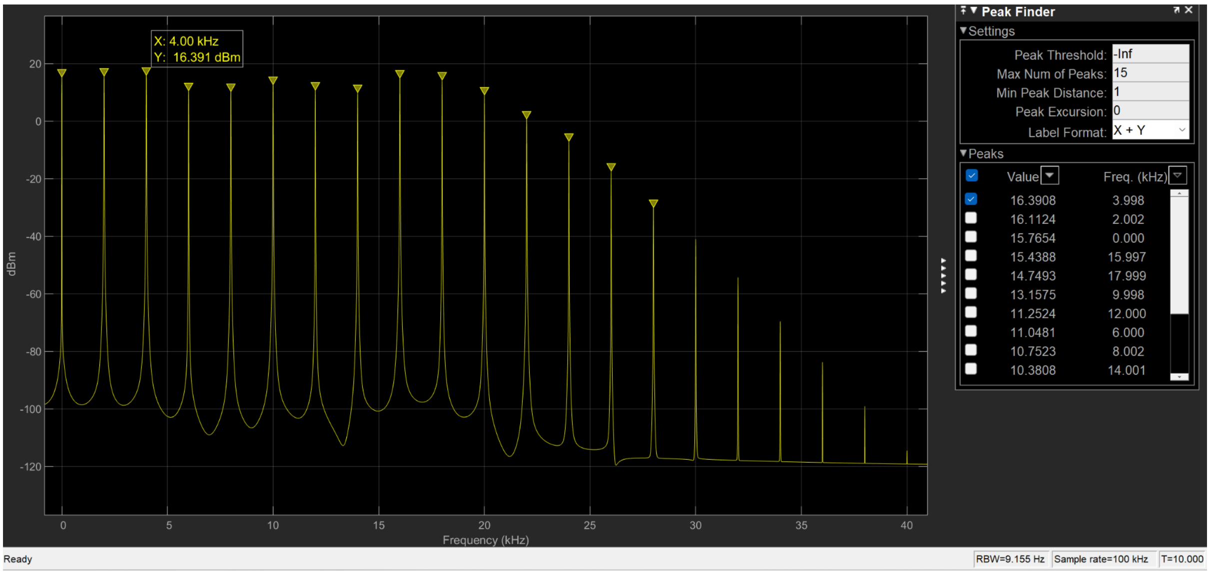


Plot 1.4.3 - Spectrum Analyzer Screenshot for Bandwidth

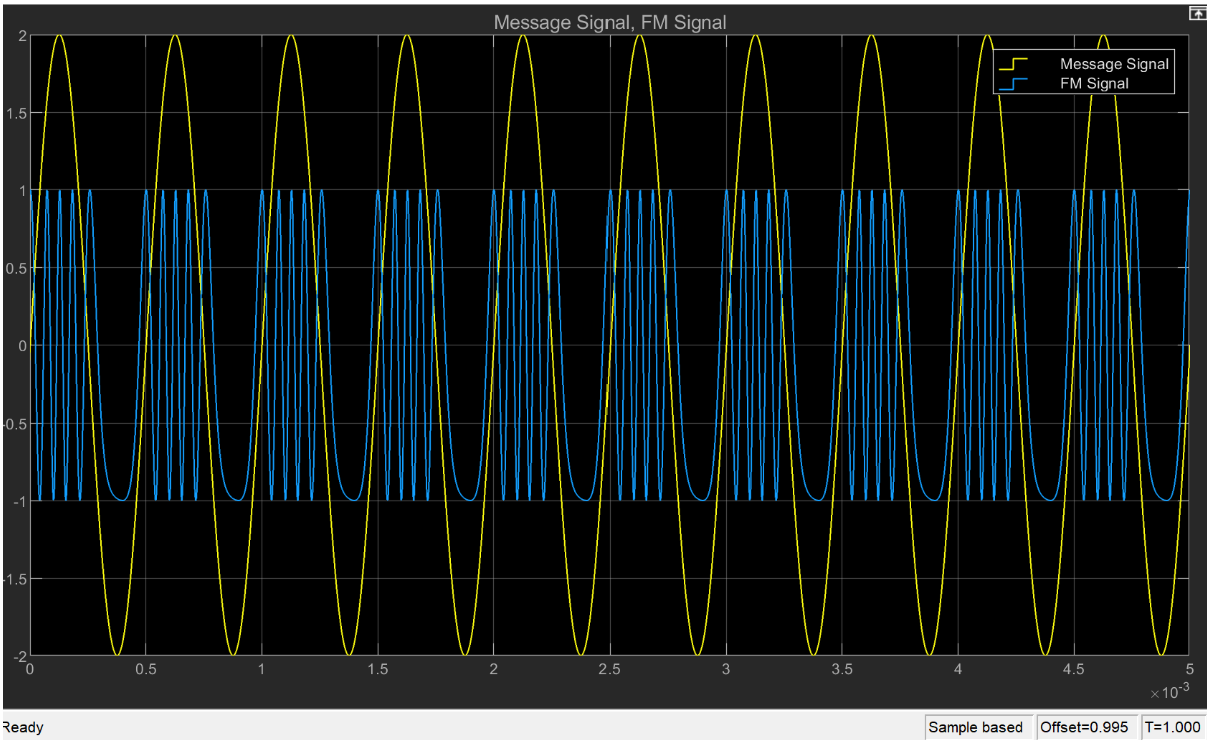
Δf = 1 * 4500 = 4500
BW = 2(4500+2000) = 13 kHz

Section 1.5 - Message Signal 4 Vpp & k_f 4.5kHz

AM= 2V (4 Vpp)
k_f = 4.5 kHz

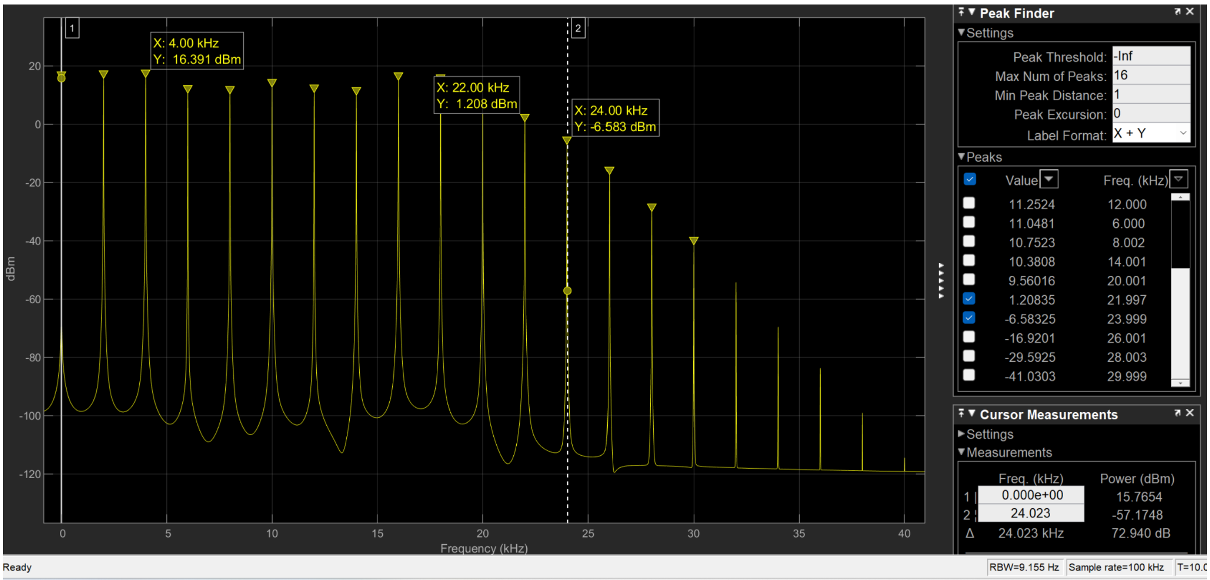


Plot 1.5.1 - Spectrum Analyzer Screenshot



Plot 1.5.2 - Scope Screenshot Zoomed (5 ms)

To find the bandwidth of the signal: **BW= F max - Fmin**
Highest component is **16.39 dB** at **3.998kHz**
30 dB or more below the highest (ignore anything below **-13.61 dB**)
Based on the figure below **BW = Δf = 24.023 kHz**



Plot 1.5.3 - Spectrum Analyzer Screenshot for Bandwidth

Δf = 2 * 4500 = 9000
BW = 2(9000+2000) = 2 kHz

Section 1.6 - Bandwidth & Power Calculations with Comparison

K_f (kHz/V)	A_m (V)	Δf (kHz)	Estimated Bandwidth (kHz)	Measured Bandwidth (kHz)
2.5	1	2.5	9	11.975
2.5	2	5	14	18.011
4.5	1	4.5	13	15.991
4.5	2	9	22	24.023

Table 1.6.1 - Bandwidth Estimated and Measured

Formulae Used:

$$\Delta f = A_m k_f$$
$$BW(Carson) = 2(\Delta f + f_m)$$
$$f_m = 2kHz$$

β Calculated using Bessel Function online calculator

n\\β	1.25	2.5	2.25	4.5
0	0.6459	-0.0483	0.08274	-0.3205
3	0.0368	0.2166	0.17108	0.42470

Table 1.6.2 - Bessel Function Calculations

Calculation for theoretical power:
$S=J_n(\beta)$ from the above table where n is either **0** or **3**
Power (mW) =1000 x $(S/2)^2$
Power (dB) = 10 log (1000 x $(S/2)^2$)
****difference between power when n=0 and n=3**

K_f (kHz/V)	A_m (V)	Δf (kHz)	β	Theoretical Center Band (dBm)	Theoretical 3rd Band (dBm)	Measured Center Band (dBm) **Power at 10 kHz**	Measured 3rd Band (dBm) **Power at 16 kHz**
2.5	1	2.5	1.25	20.1827	-4.6875	19.271	-5.769
2.5	2	5	2.5	-2.3266	10.6925	-3.086	9.607
4.5	1	4.5	2.25	2.3347	8.6439	1.343	7.558
4.5	2	9	4.5	14.0971	16.5411	13.158	15.439

Table 1.6.3 - Power Estimated and Measured

Formulae Used:

$$\beta = \Delta f / f_m$$
$$f_m = 2k\ (Hz)$$
$$A_c = 1\ (V)$$

Explanation:
Bandwidth comparison

- The theoretical bandwidth and the experimental value are relatively close to each other. However, we can see that the difference between the measured BW and the theoretical BW is greater than the difference between powers. The measured value is always greater than the theoretical value. This might be because we dismiss the components that are 30 or more dB below the highest component, we cannot accurately find the point where the bandwidth starts and stops.

Power comparison

- The theoretical power for both n=0 and n=3 closely matches the experimental value. There is some percentage of error due to rounding of the values and the beta generated using the bessel function calculator.

Section 2 - FM Demodulation

Section 2.1 - Simulink model

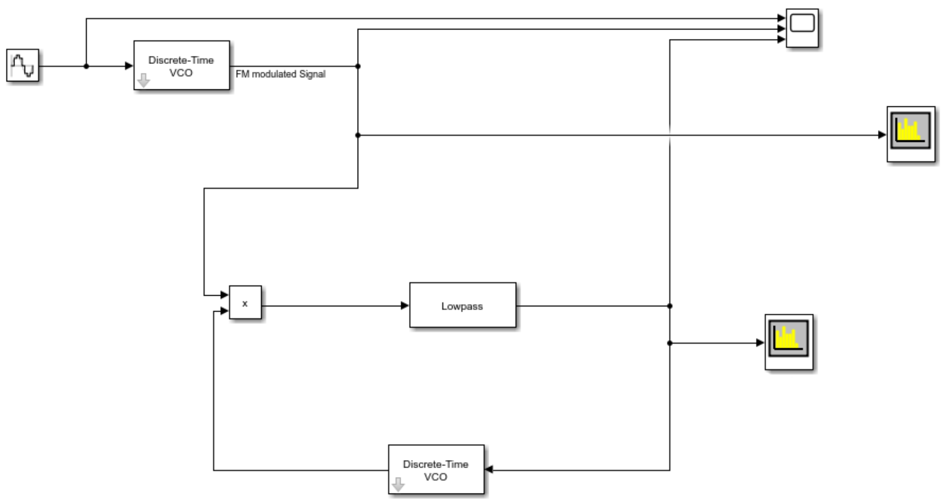
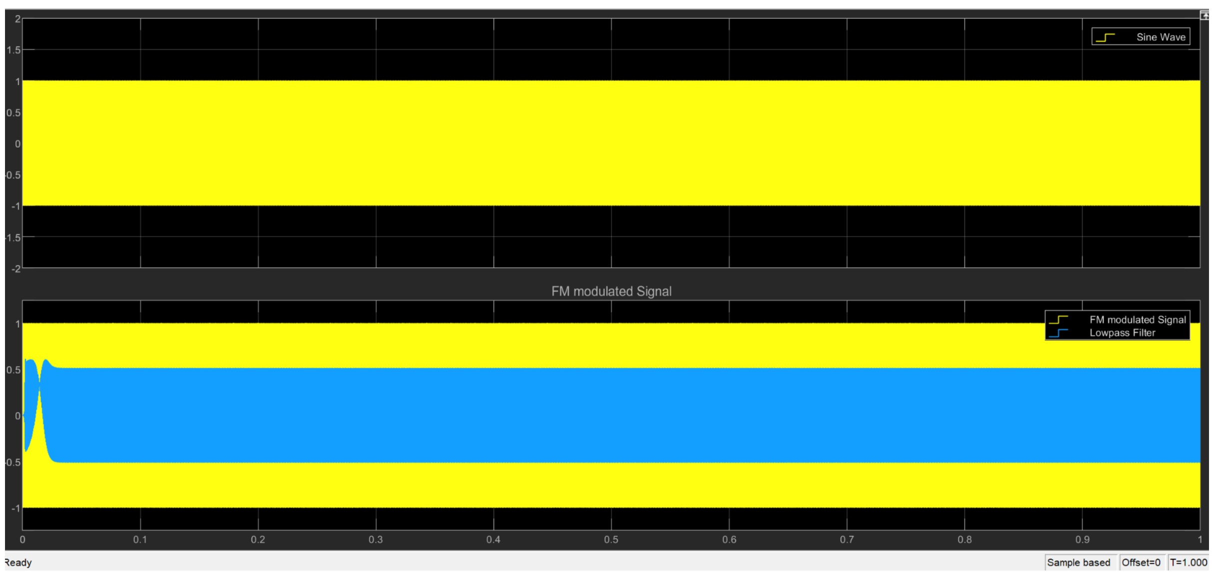
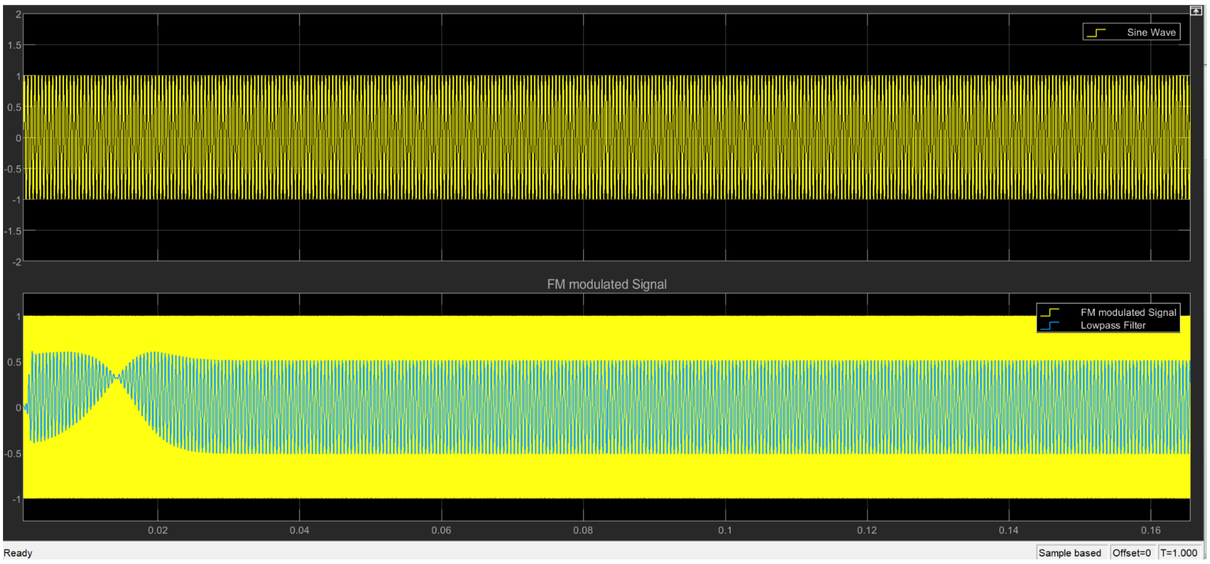


Figure 2.1 - Simulink Model

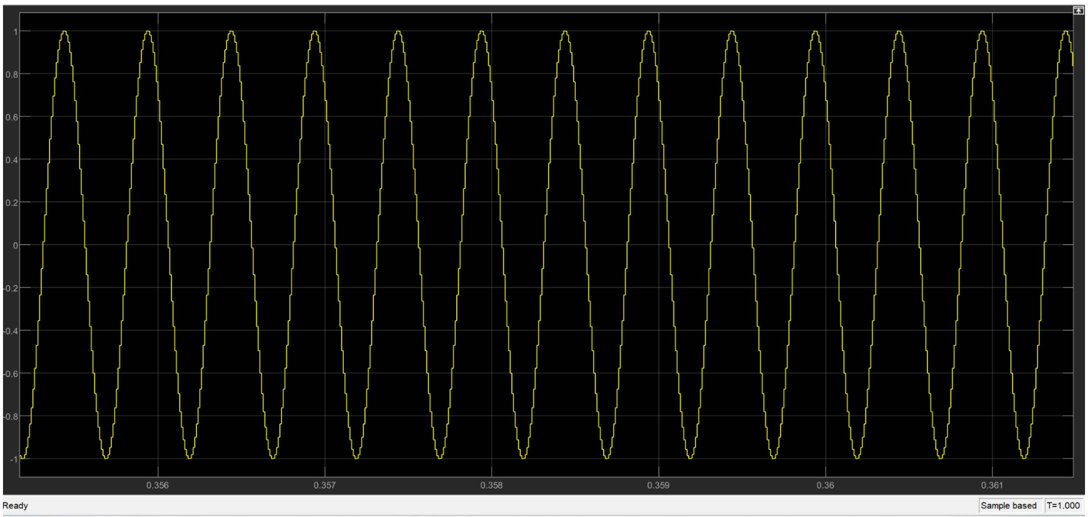
Section 2.2 - FM Demodulation Results



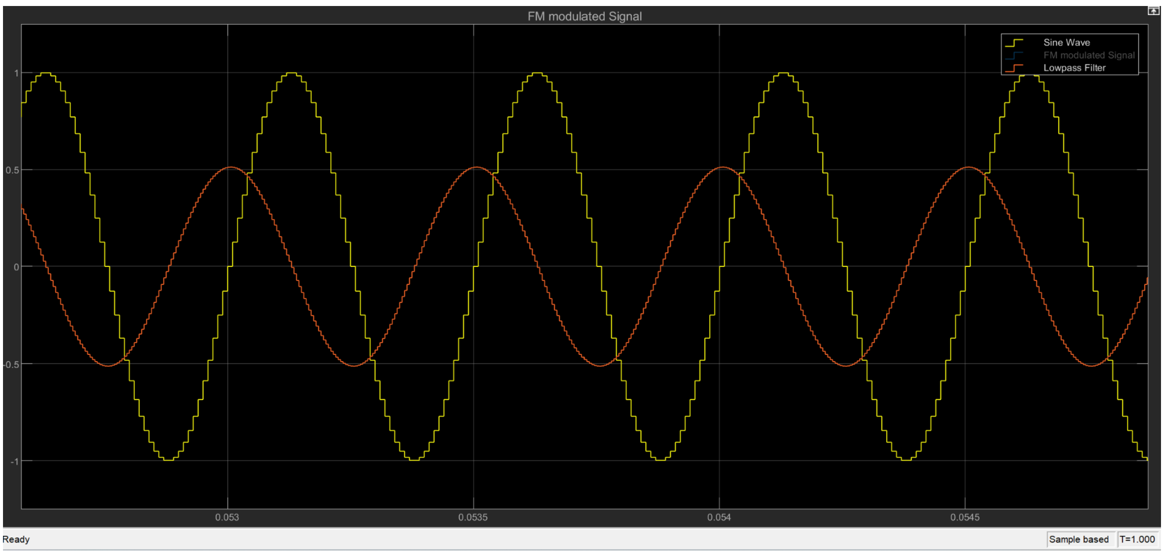
Plot 2.1 - FM Modulated and Demodulated Signals Scope Screenshot
[yellow: Modulated signal; blue: Demodulated signal]



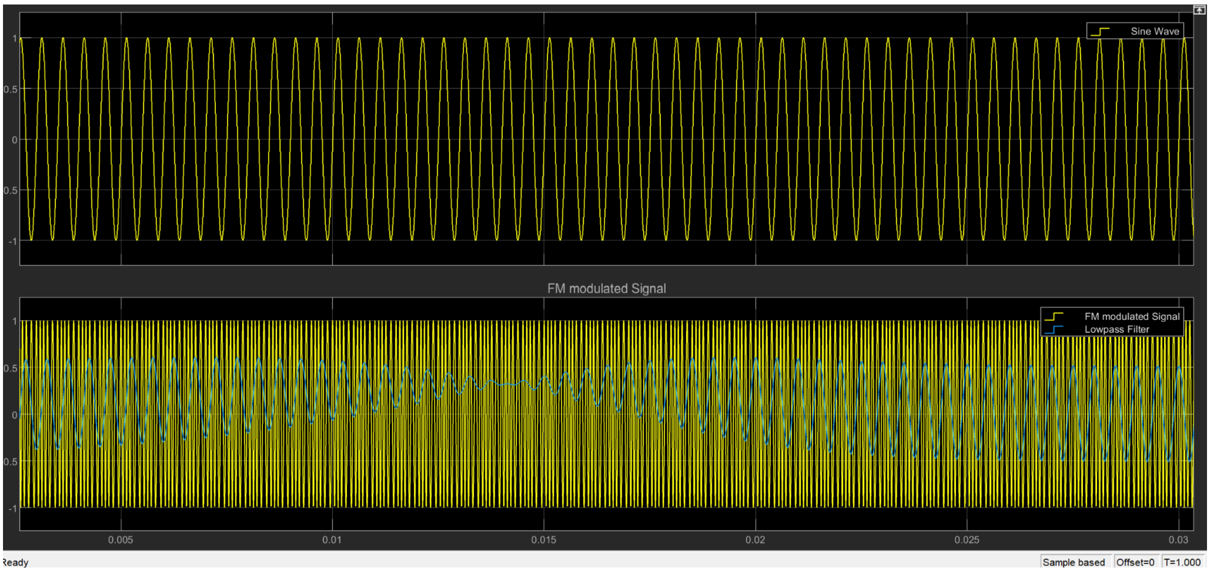
Plot 2.2 - FM Modulated and Demodulated Signals Scope Screenshot Zoomed
[yellow: Modulated signal; blue: Demodulated signal]



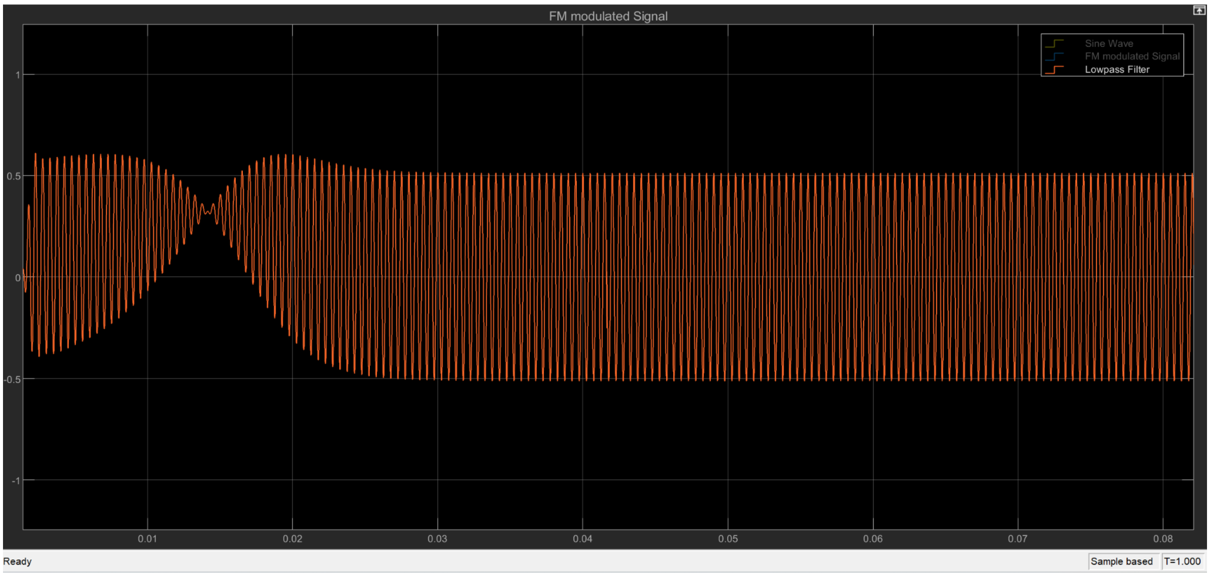
Plot 2.3 - FM Demodulated Signal Scope Screenshot Zoomed (~10 periods shown)



Plot 2.3.1 - The Original Message Signal (yellow) and The Demodulated Signal (red)



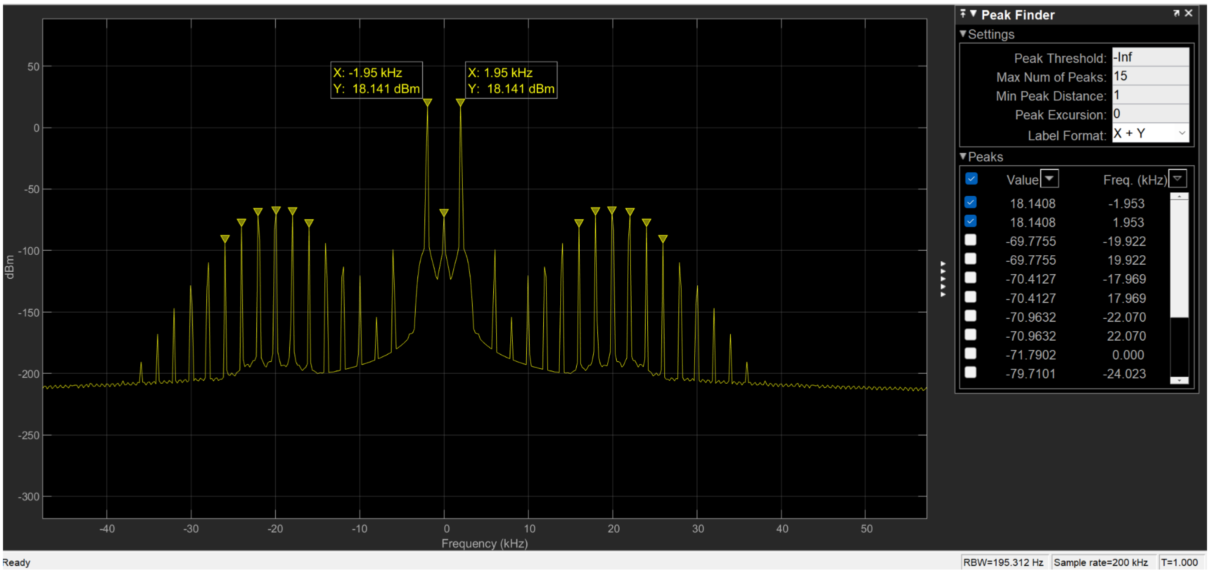
Plot 2.4 - Scope Screenshot FM Demodulated Signal PLL Lock Time



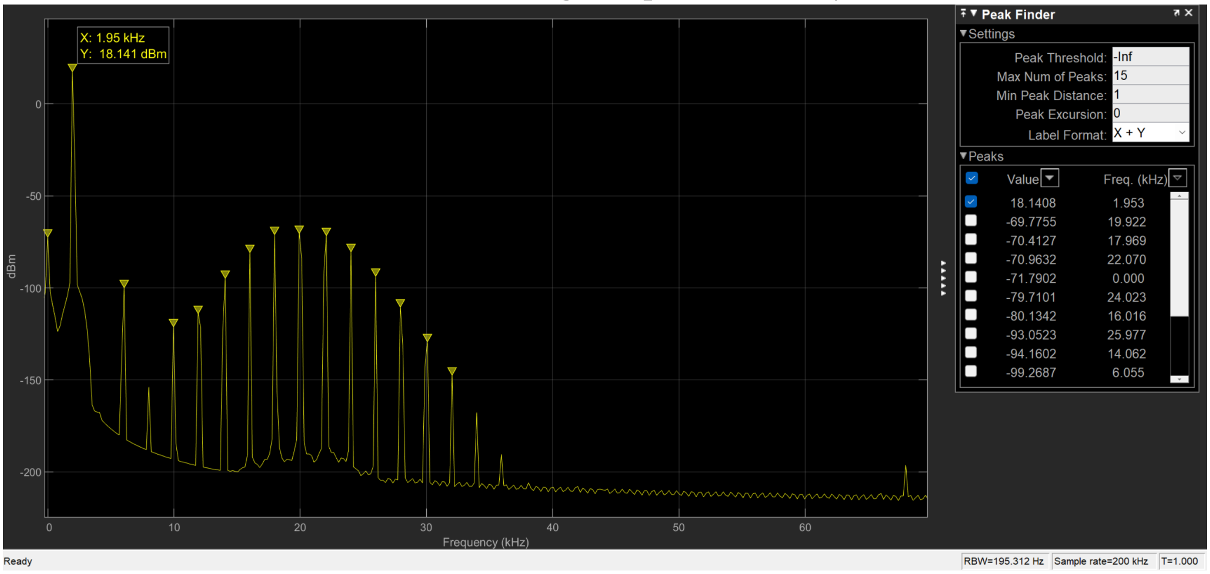
Plot 2.5 - FM Demodulated Signal Scope Screenshot PLL Lock Time Zoomed

How long does it take for the PLL to lock and Why?

According to the plots (Plot 2.4 & Plot 2.5) of the demodulated signal, the amplitude fluctuates up to approximately **30** where it cannot be differentiated from the original signal. Therefore, the PLL takes approximately 30 ms to lock, as this is the point where the two signals are synchronised and stabilized.



Plot 2.6 - FM Demodulated Signal Spectrum Analyzer Screenshot



Plot 2.7 - FM Demodulated Signal Spectrum Analyzer Screenshot Zoomed