Lab 3: Frequency Modulation

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***Abstract*—Frequency modulation is a form of information transmission that manipulates a carrier signal by modulating the carrier signal's frequency, where the carrier signal frequency is encoded with the message signal. The effects of frequency modulation through the use of module circuits was analyzed and displayed with demodulation and FFT transforms.**

I. Introduction and Objectives

Frequency modulation is a subdivision of modulation actions acting on a transmitting signal carrying information. Modulation is done by finding a carrier wave to carry information and manipulating the said signal in some aspect. In this case, frequency modulation modifies the rate of the signal period in a way that translates to the message signal. After demodulation, the signal should represent the message signal closely.

II. Background and Relevant Theory

A. Frequency Modulation

Frequency is a type of modulation represented by Equation 1 where $m(t)$ is the modulating signal of frequency ω_m. The envelop, $g(t)$ represented by Equation 2 where the modulation index of the signal is represented by $\beta = (D_f A_m)/\omega_m$ where D_f is the frequency sensitivity. Additionally, peak frequency deviation is $\Delta_F = (D_f A_m)/2\pi$.

$$m(t) = A_m cos(\omega_m t) \tag{1}$$

$$g(t) = A_c e^{j\theta(t)} \tag{2}$$

B. Bessel Function and Angle Modulation Spectrum

In finding the spectrum, the complex envelope $g(t)$ must be taken as its Fourier series representation shown as a Bessel function of the 'nth' order.

$$S(f) = \frac{1}{2}(G(f - f_c) + G^*(-f - f_c)) \tag{3}$$

The complex envelope $g(t)$ can be represented by Equation 4. Here, the equation displays the spectrum of an angle modulated signal as a function of ΔF, A_c, and ω_m. Manipulated the variables produce the characteristics relating to frequency modulation (FM) and can be explored to relate angle modulation to FM.

$$g(t) = A_c e^{j(\Delta F * 2\pi sin(\omega_m t))/(\omega_m)} \tag{4}$$

To demodulate a frequency modulation signal, two methods can be used a slope detector or a phase locked loop [1]. A slope detector is a simply a circuit that can detect the instantaneous frequency of the input. The reason to detect the instantaneous frequency is because the message is encoded into the frequency of the carrier signal, hence it is called frequency modulation.

III. Procedure

In the first part of the lab, a slope detector was used for demodulating the FM signal. The input low pass filter (LPF) cutoff frequency was equal to the carrier frequency ($f_c = 50$kHz). Here the chosen resistor fell at $R = 1\text{k}\Omega$ and $C = 3.3$nF. The envelope detector used within the slope detector possessed a cutoff frequency LPF that showed the modulation frequency was much less than the cutoff frequency, and more so the carrier. The cutoff frequency ($f_c o$) was set to 5kHz with a resistor of $R_2 = 15\text{k}\Omega$ and capacitor $C_2 = 2.2$nF, chosen arbitrarily to obtain the $f_c o$. The FM signal and spectrum then showed a modulation frequency of 1kHz. Deviation was shown at 50kHz. This process repeated for an incremented modulation frequency of 10, 15, 20, and 50kHz.

As a following procedure, the resistor and capacitor RC was chosen where $\frac{0.33}{RC} = 30$kHz. The value of R and C was respectively chosen at $R = 1000\Omega$ and $C = 10$nF. Values of all resisters in the circuit represented at $1\text{k}\Omega$. These values were used to create a FM circuit using a voltage controlled oscillator. The voltage controlled oscillator what given a modulated signal of 100Hz with the output spectrum observed.

Finally, the FM signal was demodulated using the Phase Locked Loop (PLL). The PLL utilizes the voltage controlled oscillator and requires an R and C_2 to be chosen such that $\frac{0.3}{RC_2} = 30\text{kHz} = f_c$. A value of $4.5\text{k}\Omega$ gave the desired results for R. Following this, a low pass filter was constructed on the output of the PLL. R_3 and C_3 were provided a cutoff frequency of 1061Hz. The demodulated signal and its spectrum was viewed with varied changes to the variables discussed in Section II-B. The effects on the spectrum were viewed and recorded.

IV. Results and Discussion

A. Part 1

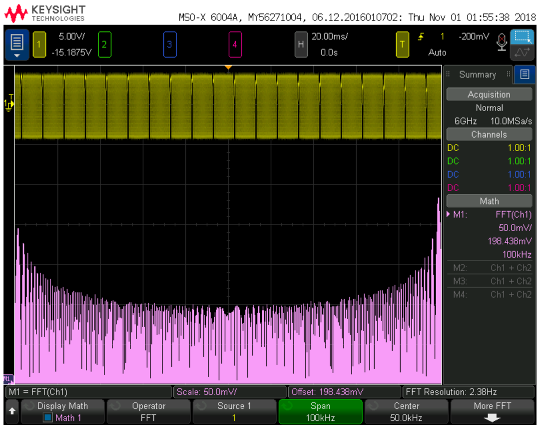

Fig. 1. Frequency modulated signal with $f_c = 50\text{kHz}$, $f_m = 10\text{kHz}$, and $\Delta F = 50\text{kHz}$. Spectrum of the signal is provided below the FM signal.

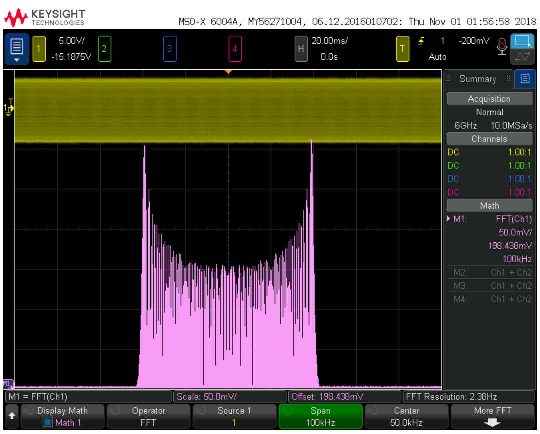

Fig. 2. Frequency modulated signal with $f_c = 50\text{kHz}$, $f_m = 10\text{kHz}$, and $\Delta F = 20\text{kHz}$. Spectrum of the signal is provided below the FM signal.

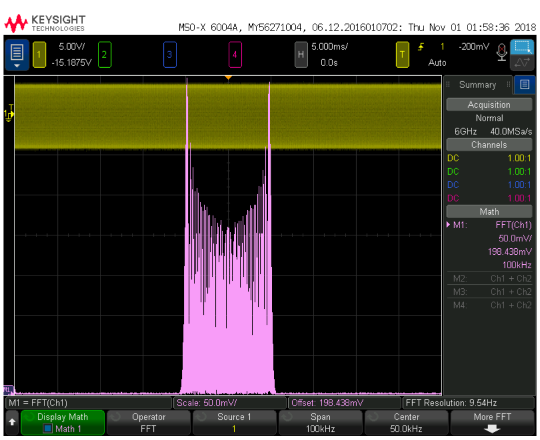

Fig. 3. Frequency modulated signal with $f_c = 50\text{kHz}$, $f_m = 10\text{kHz}$, and $\Delta F = 10\text{kHz}$. Spectrum of the signal is provided below the FM signal.

With decreasing spectrum, the fft of the signal as presented in Figures 1 to 3 display an increase in fft height as the frequency changes.

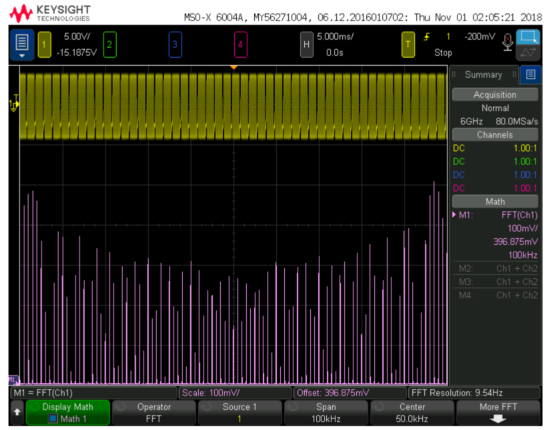

Fig. 4. Frequency modulated signal (top) with $f_c = 50\text{kHz}$, $f_m = 1\text{kHz}$, and $\Delta F = 15\text{kHz}$, spectrum (bottom)

With decreasing modulation frequency, the density of the spectrum and ΔF severely decreased.

B. Part 2

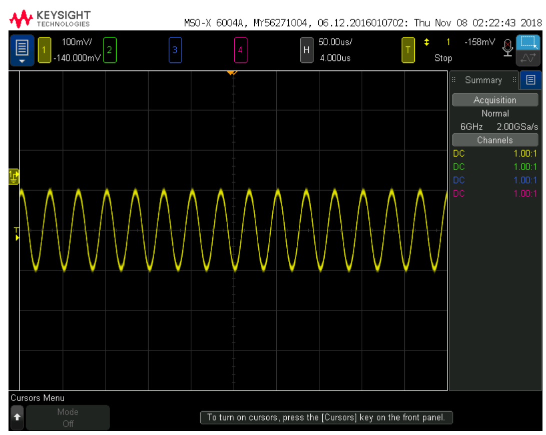

Fig. 5. 30kHz carrier wave

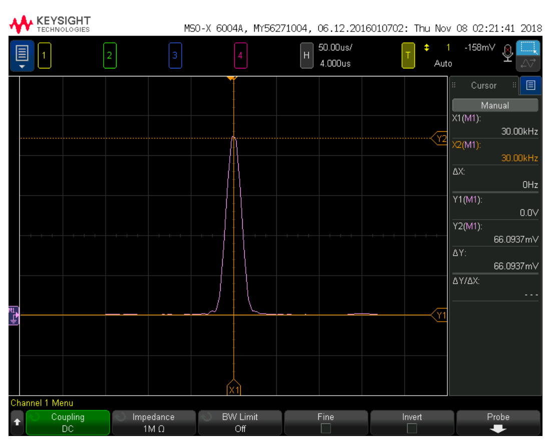

Fig. 6. Spectrum of 30kHz carrier wave

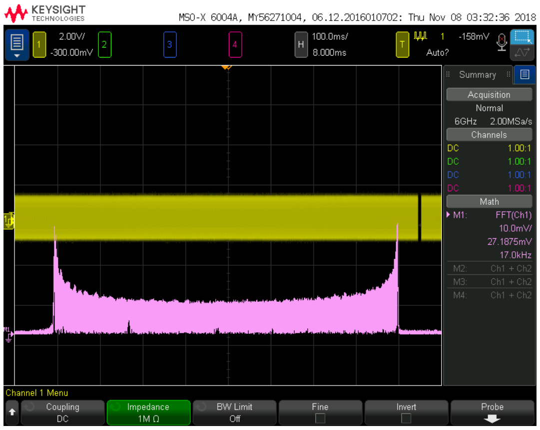

Fig. 7. Modulated signal with $f_c = 30$kHz and $f_m = 1$kHz, with spectrum

C. Part 3

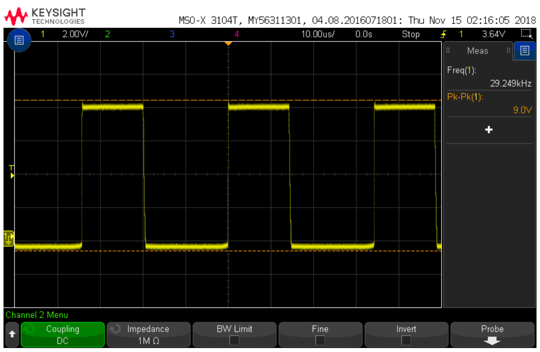

Fig. 8. 30kHz square wave for verifying functionality of of PLL

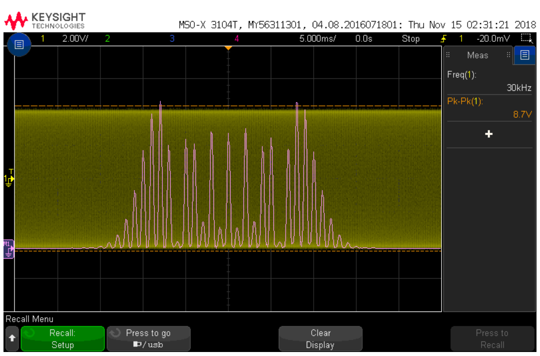

Fig. 9. Fm signal with $f_c = 30$kHz, $f_m = 100$Hz, $A_c = 4V_{pp}$, and $\Delta F = 500$Hz with its spectrum

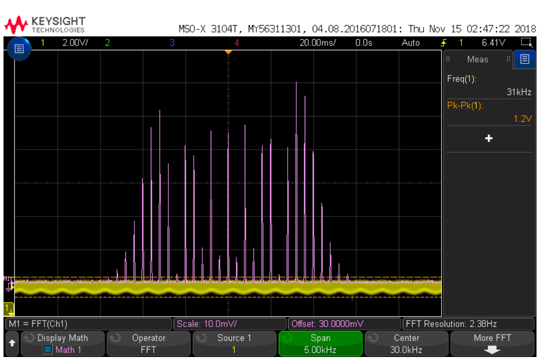

Fig. 10. Spectrum of demodulated FM signal

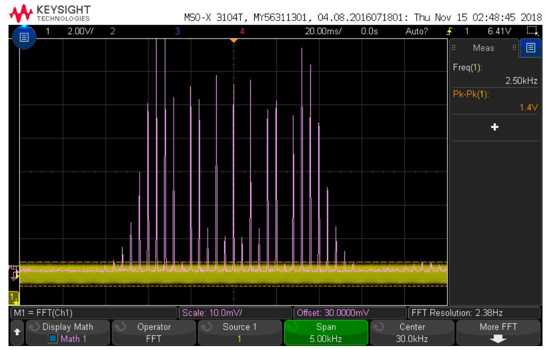

Fig. 11. Spectrum of demodulated FM signal with $A_c = 8V_{pp}$

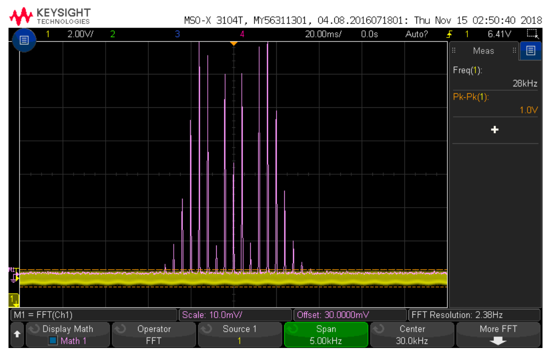

Fig. 12. Spectrum of demodulated FM signal with $\Delta F = 500$Hz

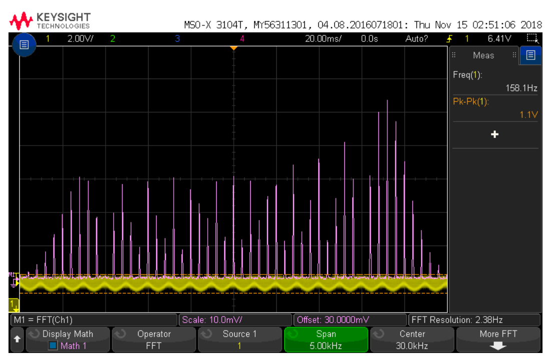

Fig. 13. Spectrum of demodulated FM signal with $\Delta F = 2000$Hz

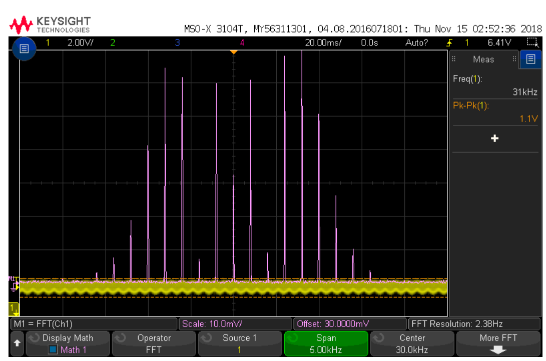

Fig. 14. Spectrum of demodulated FM signal with $f_m = 200$Hz

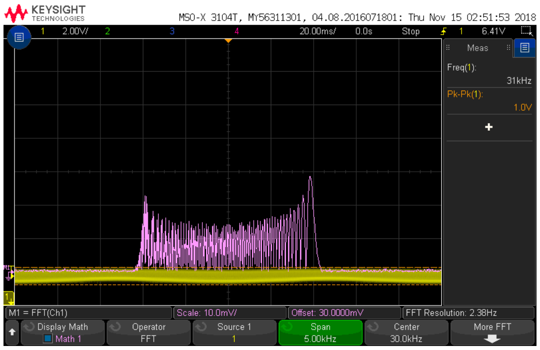

Fig. 15. Spectrum of demodulated FM signal with $f_m = 10$Hz

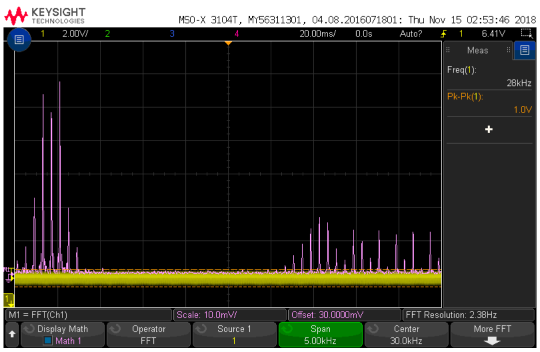

Fig. 16. Spectrum of demodulated FM signal with $f_m = 60$kHz

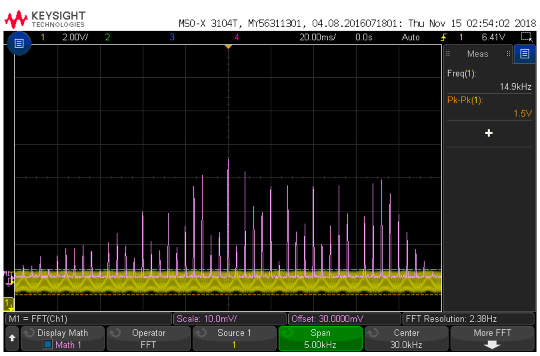

Fig. 17. Spectrum of demodulated FM signal with $f_m = 15$kHz

At the end of Part 3 experiments, several observations of the FM spectrum could be decided. Firstly, as the A_c increases, the spectrum size increases in height represented by Figure 11. With decreasing ΔF, the spectrum becomes narrow and inversely when ΔF increases, the spectrum width increases represented by Figure 12 and 13. Modulation frequency changes the size and scope of the spectrum where decreasing f_m shrinks the field of the spectrum and increasing the f_m changes the demodulated spectrum at different regions represented by Figure 17 and 16.

V. Conclusions

References

[1] L. W. Couch, Digital and analog communication systems, 8th ed. Upper Saddle River, N.J: Prentice Hall, 2013.