LAB 1

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1. Aim

This experiment aims to investigate amplitude and frequency modulation and demodulation.

2. Methodology

The signals apparatus, has 3 main components, connected by carriers.

The oscilloscope is use to view and measure the signal at given stages in the signals transformation process.

In the modulation sections of a the experiments, a signal is generated in the signal generator,

and it passed though the modulator.

The generated, and modulated signals are observed with the oscilloscope.

In the demodulation section, it is passed onwards through the demodulator,

and that output is also observed.

This is done for both amplitude, and frequency modulation.

3. Results

3.1. Spectrum of AM.

3.1.1. *Generate AM signanl* $\mu = 0.5,\ A_m = 1,\ f_c = 100kHz,\ f_m = 10kHz.$

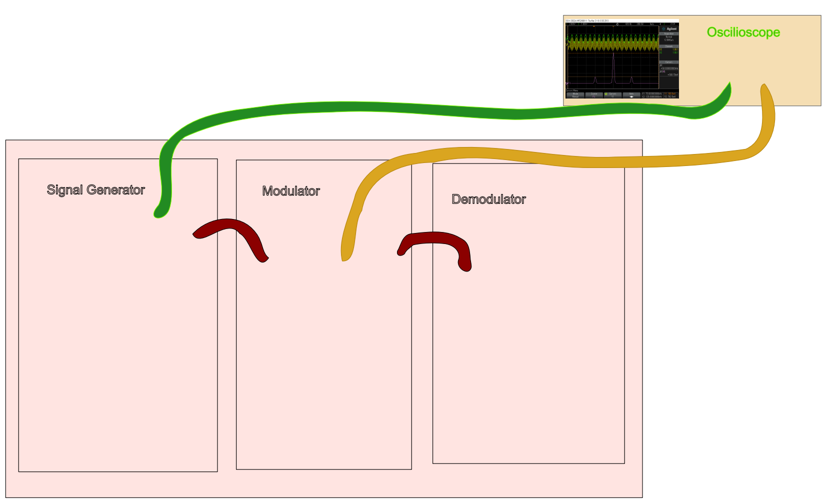

Figure 2.1.

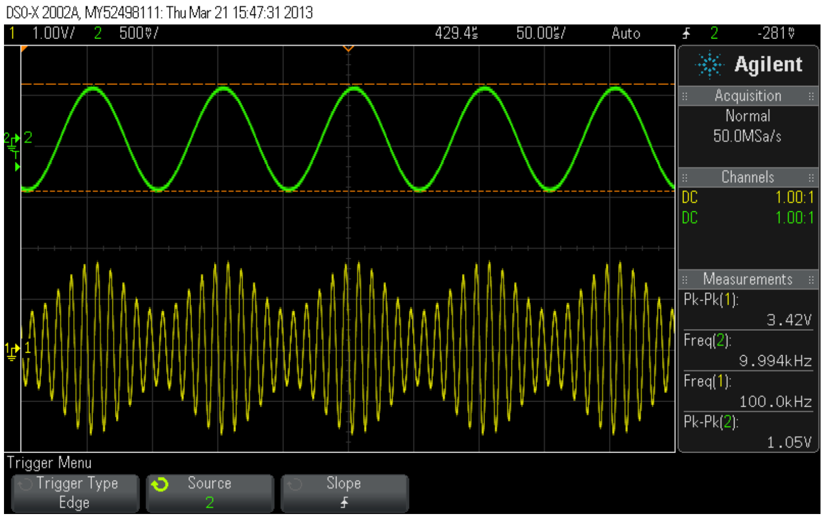

FIGURE 3.1. modulating 10kHz signal (green) Synchronized with charier. Modulated signal (Yellow)

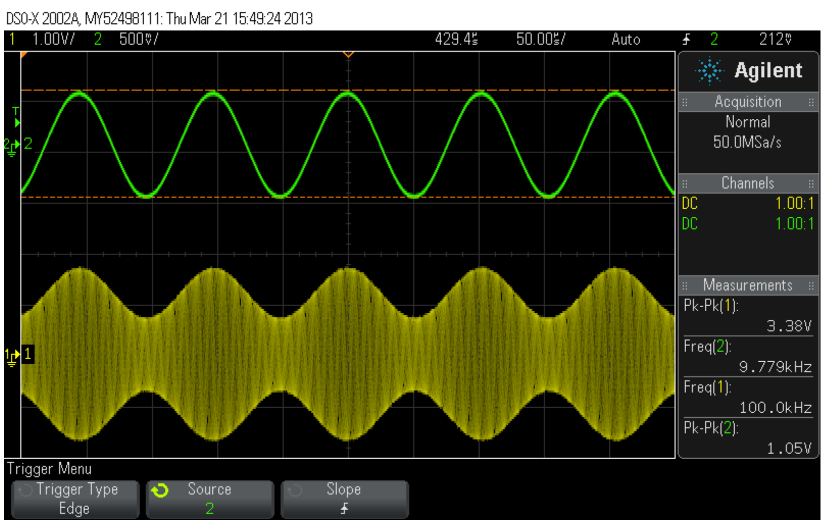

FIGURE 3.2. modulating 10kHz signal (green) unzynchronized with charier. Modulated single (yellow)

Synchronized with carrier

Unsynchronized.

Notice that it is impossible to make the modulated and modualting signal trigger, as they have different phase (they are unsynchronized).

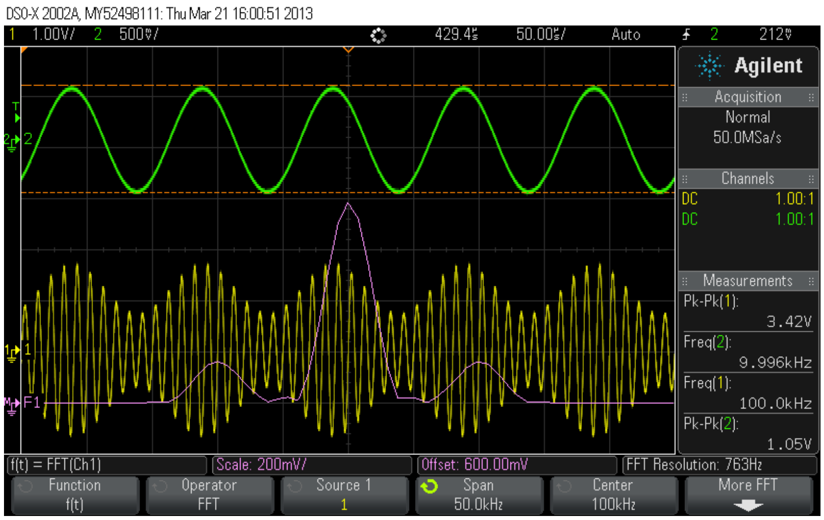

FIGURE 3.3. modulating 10kHz signal (green) Synchronized with charier, modulated signal (Yellow). Frequency Spectum of modulated signal (purple).

What signal should be used to trigger the oscilloscope?

The low frequency source. (Which is the modulating signal)

3.1.2. *B: Estimate Power.*

Estimate carrier power

$P = \frac{A_{C^2}}{2} \times 10^{-6} = 0.5 \times 10^{-6} W$

Estimate side band power power

$P = \frac{\mu^2 A_c^2}{4} = \frac{0.5^2}{4} \times 10^{-6} = 0.625 \times 10^{-7} W$

Estimate percentage of carrier power

$P = \frac{0.5}{0.5 + 2 \times \frac{1}{16}} = 80\%$

These estimates line up with amplitude of the FFT of modulated frequency.

3.1.3. *C: Measure.*

carrier power

$P = \frac{V^2}{R} = \frac{0.7626^2}{10^6} = 0.581 \times 10^{-6} W$

sideband power power

$P = \frac{V^2}{R} = 2 \times \frac{0.1688^2}{10^6} = 0.285 \times 10^{-7} W$

carrier percentage of power

$P = \frac{0.581}{0.581 + 2 \times 0.0285} = 91.2\%$

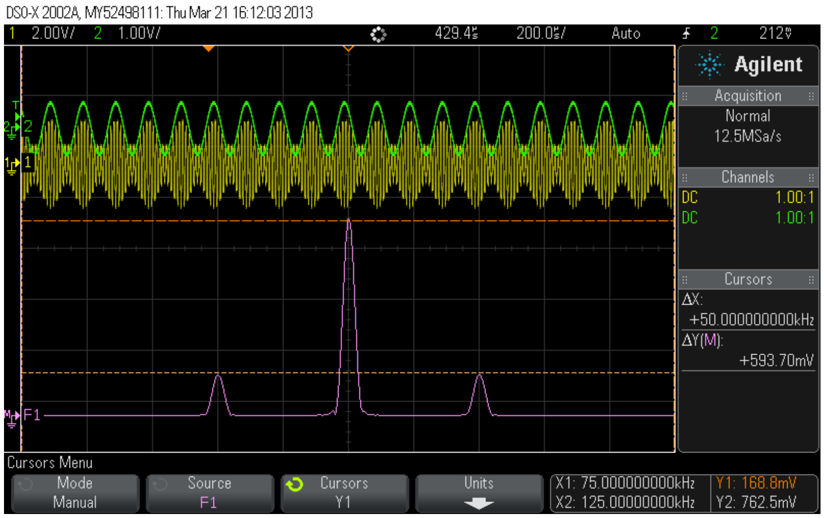

FIGURE 3.4. modulating 10kHz signal (green) Synchronized with charier, modulated signal (Yellow). Frequency Spectum of modulated signal (purple). (As Figure 3.3, but with different span shown) Note Y1 and Y2, are carrier and sideband voltages repectively.

3.1.4. *E) Observe problems.* Bellow are shown modulated signals, at varying modulation factors.

For comparison, all earlier signals were at a 50% modulation factor

$\mu = 1$

Explain the phase reversal

The phase reversal is clearly visible at the 200% modulation in Figure 3.7 (Highlighted in red) and can also be seen in Figure 3.7 (150%).

Let $s(t)$ be the modulated signal.

let $m(t)$be the modulating signal,

let $c(t) = A_c cos(2\pi f_c t)$ be the carrier signal

let $k_a$be the modulating factor

let $e(t)$ be the envelop

$e(t) = 1 + k_a m(t)$

$s(t) = A_c(1 + k_a m(t))cos(2\pi f_c t) = e(t)c(t)$

Since $|m(t)| \leq 1$ for all (t)

$1 - k_a \leq e(t) \leq 1 + k_a$

normally (when $k_a \leq 1$): $0 \leq e(t) \leq 2$. importantly $e(t) \geq 0$

ie the normally the modulated signal is the carrier, with some scaling up ($s(t) = e(t)c(t)$)

but for say modulation factor of $k_a = 1.5$: $-0.5 \leq e(t) \leq 2.5$: importantly sometimes $e(t) < 0$

since $s(t) = e(t)c(t)$, when ,$e(t) < 0$ the instead of merely scaling the carrier signal, it inverts it.

Thus the phase reversal

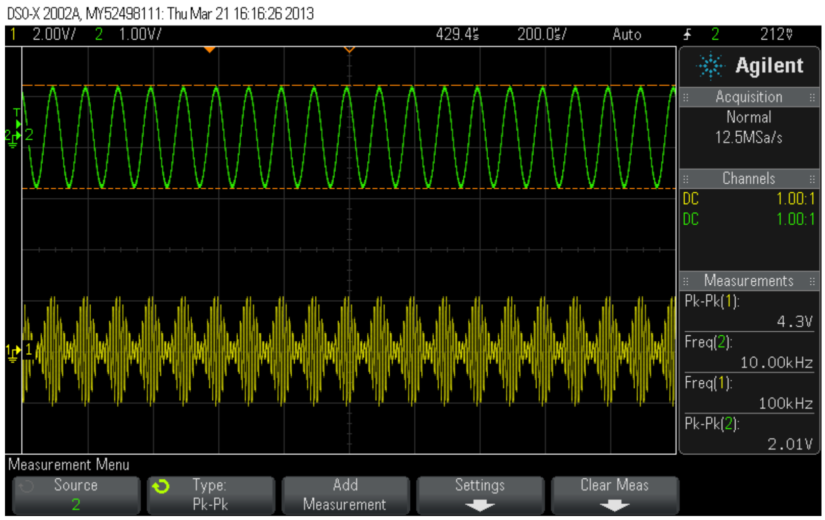

FIGURE 3.5.
modulating 10kHz signal (green) Synchronized with charier, modulated signal (Yellow).
Modulation Factor 100%

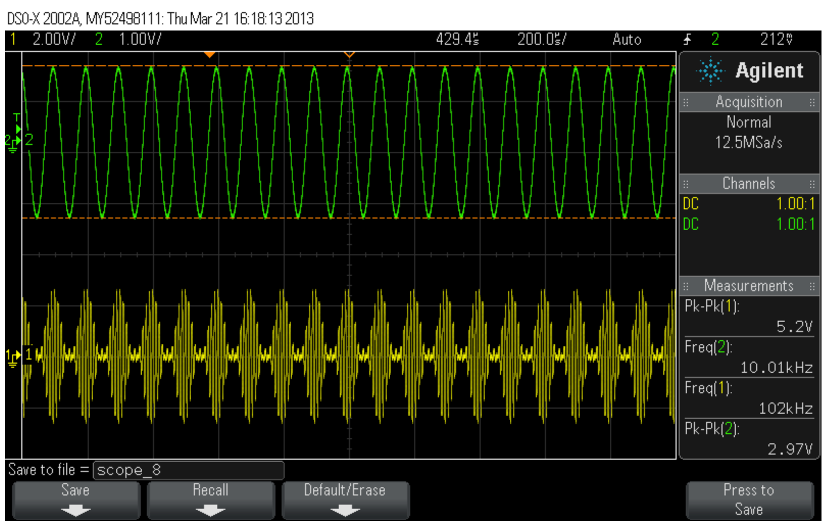

FIGURE 3.6.
modulating 10kHz signal (green) Synchronized with charier, modulated signal (Yellow).
Modulation Factor 150%

Explain why linear relationship between modulating signal and envelop is destroyed when modualtion factor is >100%

Using the above definitions of functions:

$s(t) = e(t)c(t) = A_c(1 + k_a m(t))cos(2\pi f_c t)$

$e(t) = 1 + k_a m(t)$

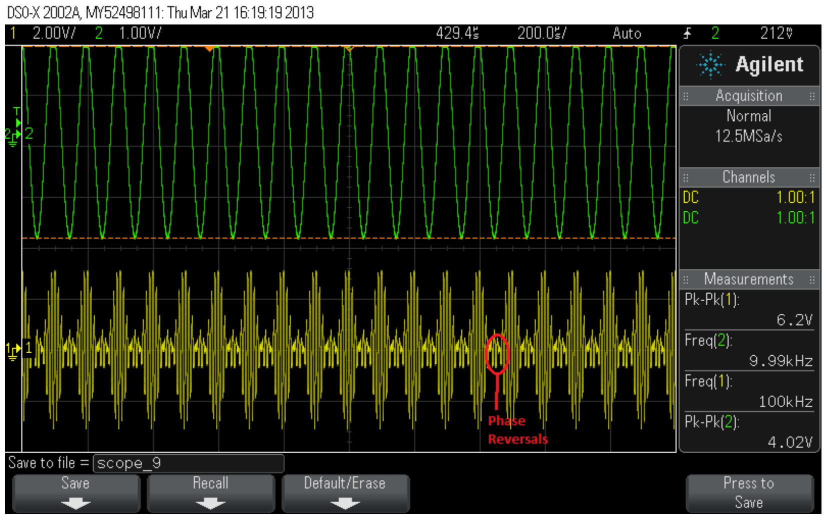

FIGURE 3.7. modulating 10kHz signal (green) Synchronized with charier, modulated signal (Yellow).
Modulation Factor 200%

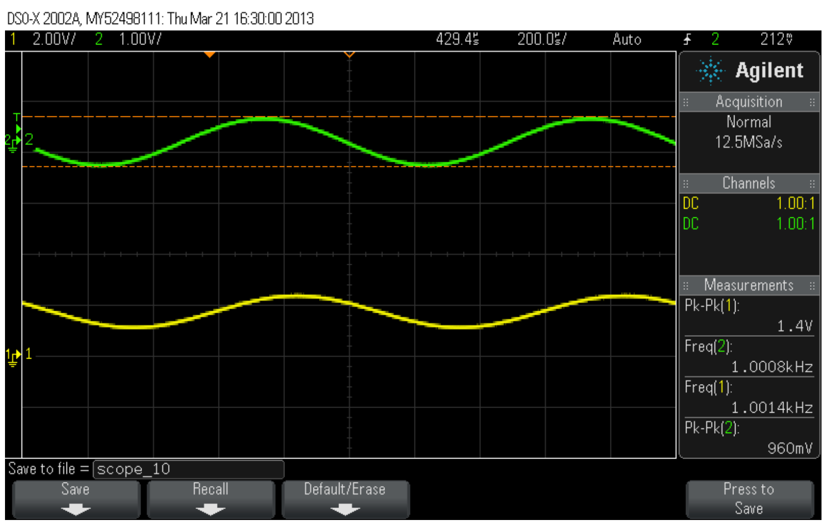

FIGURE 3.8. modulating signal (green), demodulated signal (Yellow).
Modulation Factor 50%

$m(t) = \frac{e(t)-1}{k_a}$

3.2. **Demodulation of AM.**

3.2.1. *a) Observer 1kHz Message over 100kHz carrier.* The signals look identical, which is expected,.

3.2.2. *b) Observe and sketch modulated and modulating signal.*

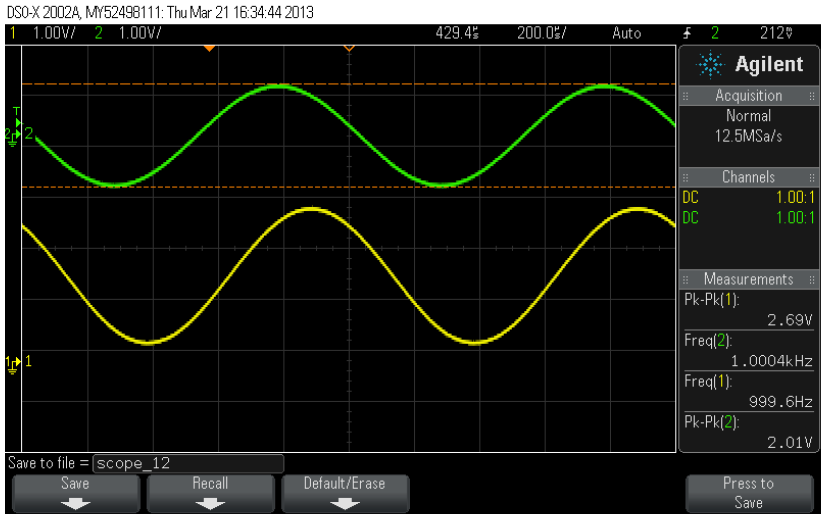

FIGURE 3.9. modulating signal (green), demodulated signal (Yellow). Modulation Factor 100%

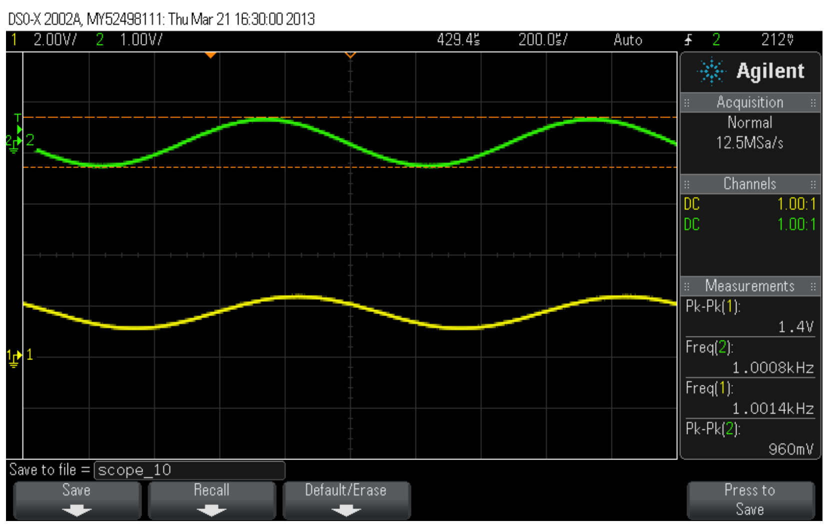

FIGURE 3.10. modulating signal (green), demodulated signal (Yellow). Modulation Factor 150%

Explain how you can demoduilate over modulated signals

Because we are using a Phase Locked Loop (PLL),
rather than a simple Envelop Detector.

3.2.3. *c) observe and sketch modulated 10kHz signal over 100Hz carrier.* It is a requirement that the Carrier Frequency be much greater than the highest frequency companent (W) of the modulated signal.

But in this case: $f_c = 100Hz$, $W = 10,000Hz$, the requirement is not at all met.

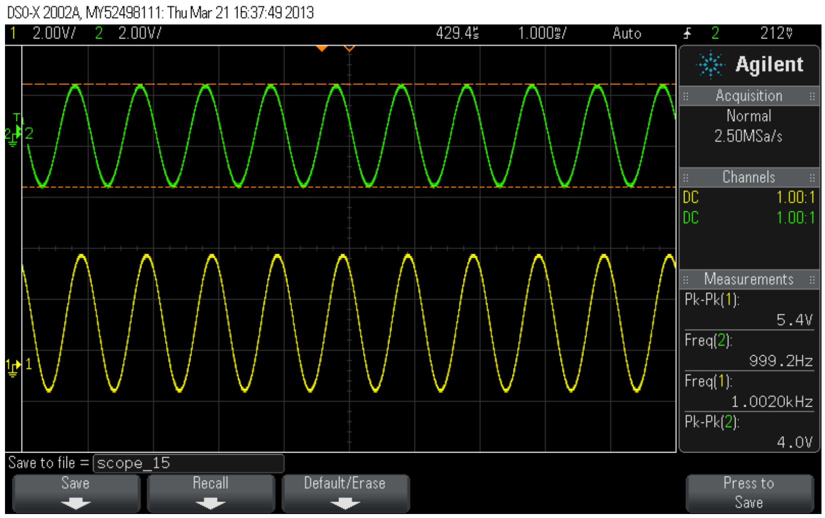

FIGURE 3.11. modulating signal (green), demodulated signal (Yellow). Modulation Factor 200%

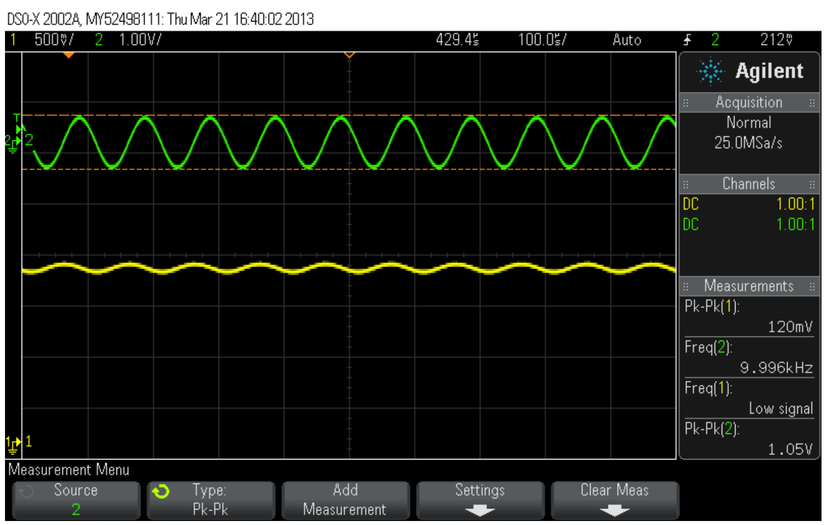

FIGURE 3.12. modulating signal (green), demodulated signal (Yellow). Modulation Factor 50%

$s(t) = e(t)c(t) = A_c(1 + k_a cos(2\pi f_m t))cos(2\pi f_c t)$

When passed though out demodulator, it can't properly tell which signal is the carrier, and which the message.

3.3. FM.

3.3.1. *Measure Frequency scensitivity of the Voltage controlled Oscilator (VCO).* Note that period is too big to see on osciloscop

$f_h = 110kHz$ $V_h = 1$

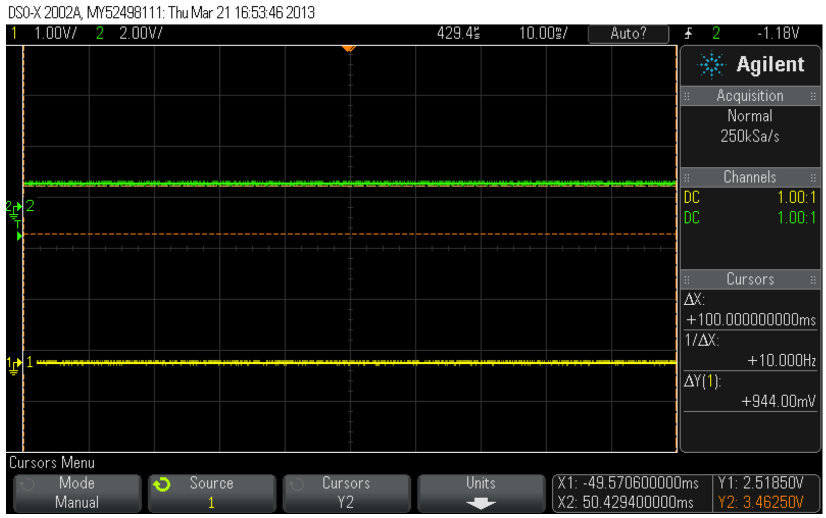

FIGURE 3.13. High

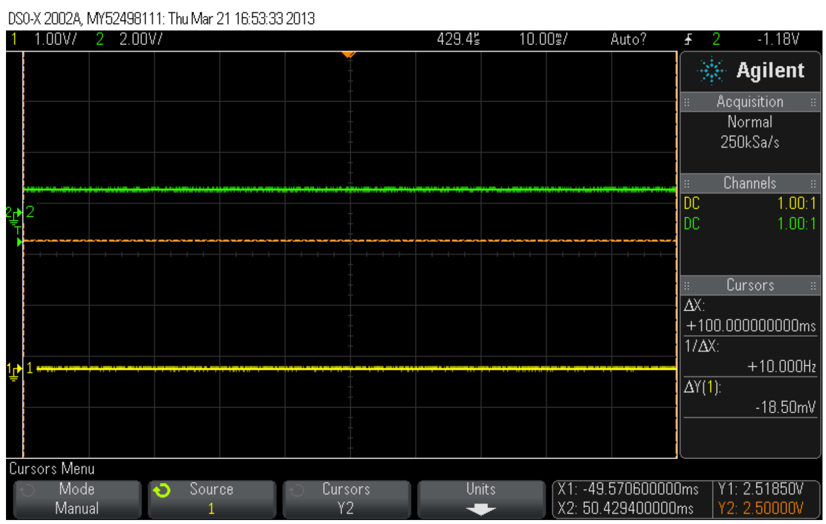

FIGURE 3.14. modulating signal (green), demodulated signal (Yellow). Modulation Factor 50%

$f_l = 90kHz$ $V_l = 0$
$f_c = 100kHz$
$\Delta f = f_c - f_l = 10kHz$
$A_m = 1V$
$k_f = \frac{\Delta f}{A_m} = 10000$

Should the frequency feedback be connected for this? Yes

3.3.2. *b).* $\beta = 2$

$\beta = 2$

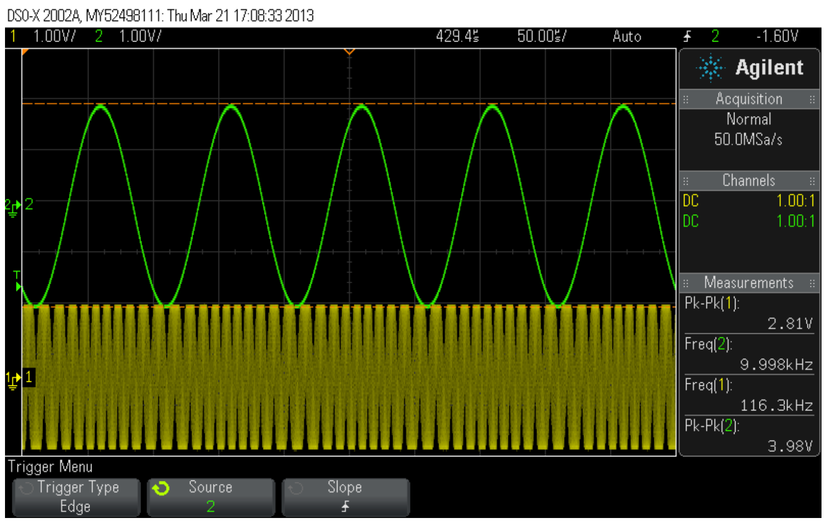

FIGURE 3.15. modulating signal (green), Modulated signal signal (Yellow). Modulation Factor 50%

$f_m = 10kHz$
$A_m = 2$

3.3.3. *c).*

Find Modulating signal, required Vp-p

$k_f = 10,000Hz/v$
$f_m = 10,000Hz$
$\beta = 2$
$A_c = 1$ (since modulated signal has $Vp - p = 2V$)
$\beta = \frac{k_f A_m}{f_m}$
$A_m = \frac{\beta f_m}{k_f} = \frac{2\times 10000}{10000} = 2$
Modulating signal $Vp - p = 4V$

Calculate power of its significant spectral components

$P_{total} = \frac{A_c^2}{2R} = 0.5 \times 10^{-6}W$
$R = 10^6\Omega$ resistance of FFT
Break it up into Spectral companants,
$P_{total} = \sum_{n=-\infty}^{n=+\infty} P_n$
$P_n = \frac{\left(\frac{A_c J_n(\beta)}{2}\right)^2}{2R} = \frac{J_n^2(\beta)}{4} P_{Total}$
$\beta = 2$
Spectral Components:
$P_0 = J_0^2(2) \times \frac{1}{8} \times 10^{-6} = 6.27 \times 10^{-9}W$
$P_1 = J_1^2(2) \times \frac{1}{8} \times 10^{-6} = 4.16 \times 10^{-8}W = P_{-1}$
$P_2 = J_2^2(2) \times \frac{1}{8} \times 10^{-6} = 1.55 \times 10^{-8}W = P_{-2}$

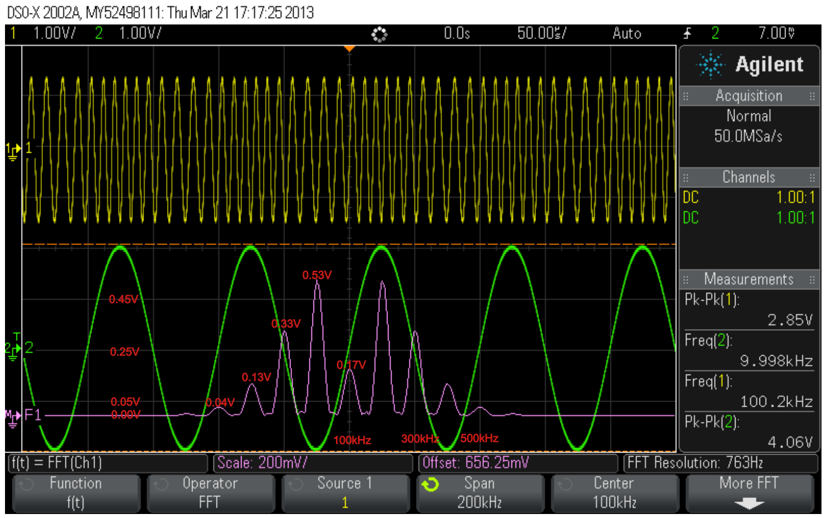

FIGURE 3.16. modulate signal (yellow), demodulated signal (green). Frequency spectum of modulated signal (purple), Frequency Spectrum Axis Values (Red)

$P_3 = J_3^2(2) \times \frac{1}{8} \times 10^{-6} = 2 \times 10^{-9}W = P_{-3}$

3.3.4. *d) Freequncy Specturm.* There are 9 Significant Spectral components

$P = \frac{V^2}{R}$

$P_0 = \frac{0.17^2}{2\times10^6} = 1.45 \times 10^{-8}W$

$P_1 = \frac{0.53^2}{2\times10^6} = 1.40 \times 10^{-7}W = P_{-1}$

$P_2 = \frac{0.33^2}{2\times10^6} = 5.45 \times 10^{-8}W = P_{-2}$

$P_3 = \frac{0.13^2}{2\times10^6} = 8.45 \times 10^{-9}W = P_{-3}$

$P_4 = \frac{0.04^2}{2\times10^6} = 8.00 \times 10^{-10}W = P_{-4}$

Carsons Rule: $B_T \approx 2\Delta f + 2f_m = 2\Delta f(1 + \frac{1}{\beta})$

$f_m = 10kHz$

$\beta = 2 = \frac{\Delta f}{f_m}$

$\Delta f = 10000 \times 2 = 2 \times 10^4 Hz$

$B_T \approx 2\Delta f + 2f_m = 2\Delta f(1 + \frac{1}{\beta})$

$B_T \approx 2 \times (2 \times 10^4 + 1 \times 10^4) = 6 \times 10^4 Hz = 60kHz$

This only covers the central peak, in the frequency spectrum

3.3.5. *e).* $\beta = \frac{\Delta f}{f_m}$

$f_m = 1kHz$

3.3.6. *f) are the bandwidths of two FM signals the modulating signals:* $A_m cos(w_1 t)$ *and* $A_m cos(w_2 t)$ *likely to be the same or different.* They will be the same, as only the amplitude of the modulating signal affected the bandwidth of the modulated signal.

3.4. **Demodulation of FM.**

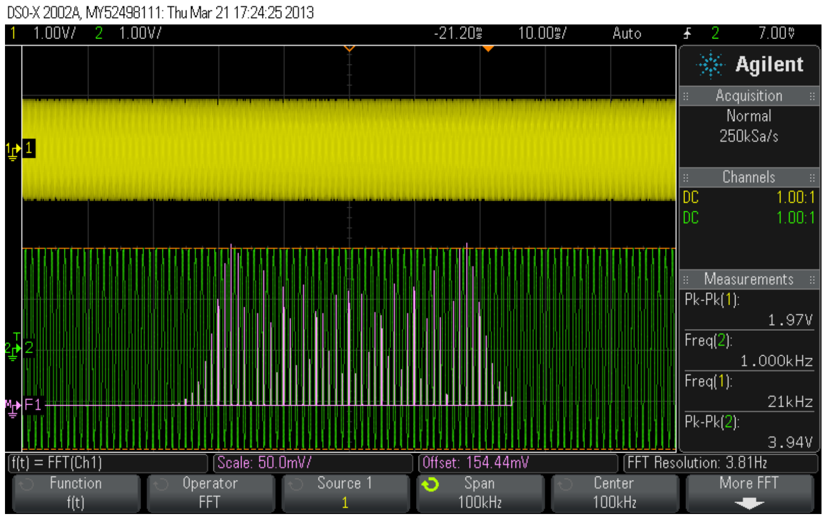

FIGURE 3.17. Frequency Spectum (Purple)
Modulating Signal (Green)
Modulated Signal (Yellow)

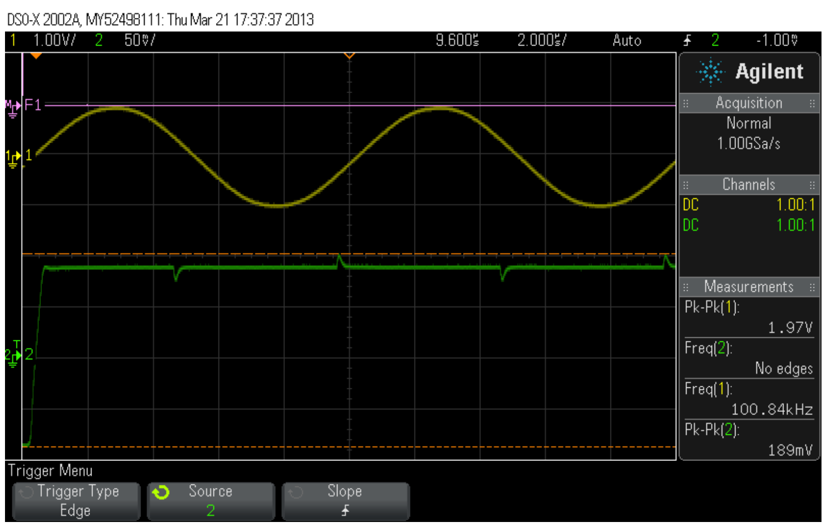

FIGURE 3.18. Modulating Signal (Green) - At High
Modulated Signal (Yellow)

3.4.1. *a).* Notice:
anything above 3.4Khz is lost thus the missshaping of the curve.
What is higher and lowest frequency
$f_h = 101kHz$
$f_l = 99kHz$
Signaling frequencies $= 2kHz$

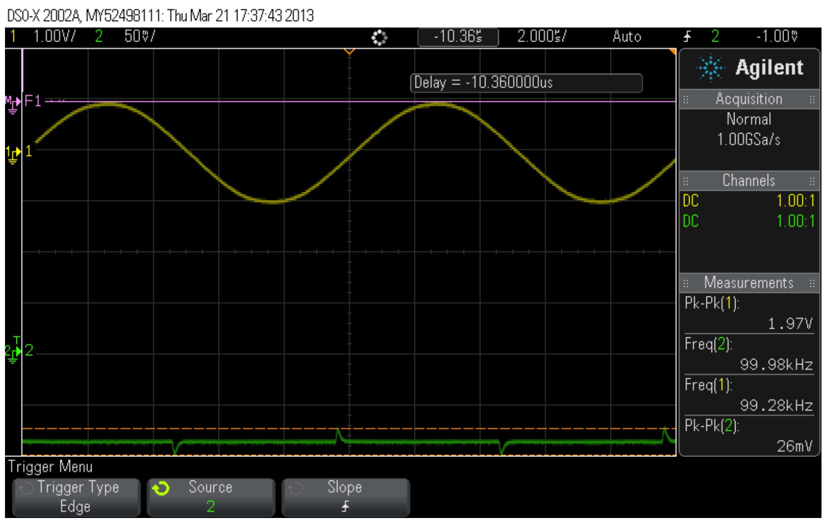

FIGURE 3.19. Modulating Signal (Green) - At Low
Modulated Signal (Yellow)

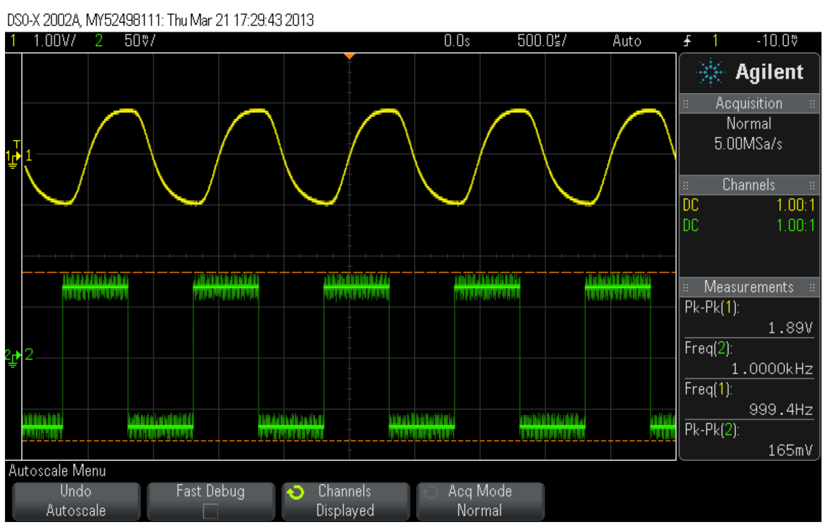

FIGURE 3.20. Modulating Signal (Green)
Demodulated Signal (Yellow)

3.4.2. *b).*

4. Conclusion

This experiment has confirmed the understanding of Amplitude, and Frequency modulation, as it has been covered in lectures.

Amplitude modulation, modifies the amplitude of the carrier frequency in proportion to the instantaious value of the message signal, to product the modulated signal.

Frequency modulation modifies the frequency of the carrier, in proportion to the instantaneous frequency of the message signal, to product the modulated signal.

By using demodulation, we can recover the original signal.