VANIER COLLEGE – Computer Engineering Technology – Winter 2021

Telecommunications (247-410-VA)

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LABORATORY EXPERIMENT #1

Signals in time and frequency domains

NOTE:
To be completed in one lab session of 3 hrs.
To be submitted using the typical lab format, one week later via Lea – **before the start** of your respective lab session.
This exercise is to be done **individually** except where specified in the procedure. **Each** student must submit a lab report with original observations and conclusions.

OBJECTIVES:

After performing this experiment, the student will be able to:

1. Use a spectrum analyzer.
2. Display different waves in the frequency domain using a spectrum analyzer.

Prelab: Calculate the following signal and hand in before the lab.

1- Convert the following power and voltage to dbm:

a) 1mW b) 10mW c)100mW d) 1000mW e) 2000mW

2- What is the power of the following signal in dBm if it applies to 50 Ohm resistor.

a) $V_{rms} = 5V$ b) Vp=5V c) $V_{rms} = 225mV$

PROCEDURE

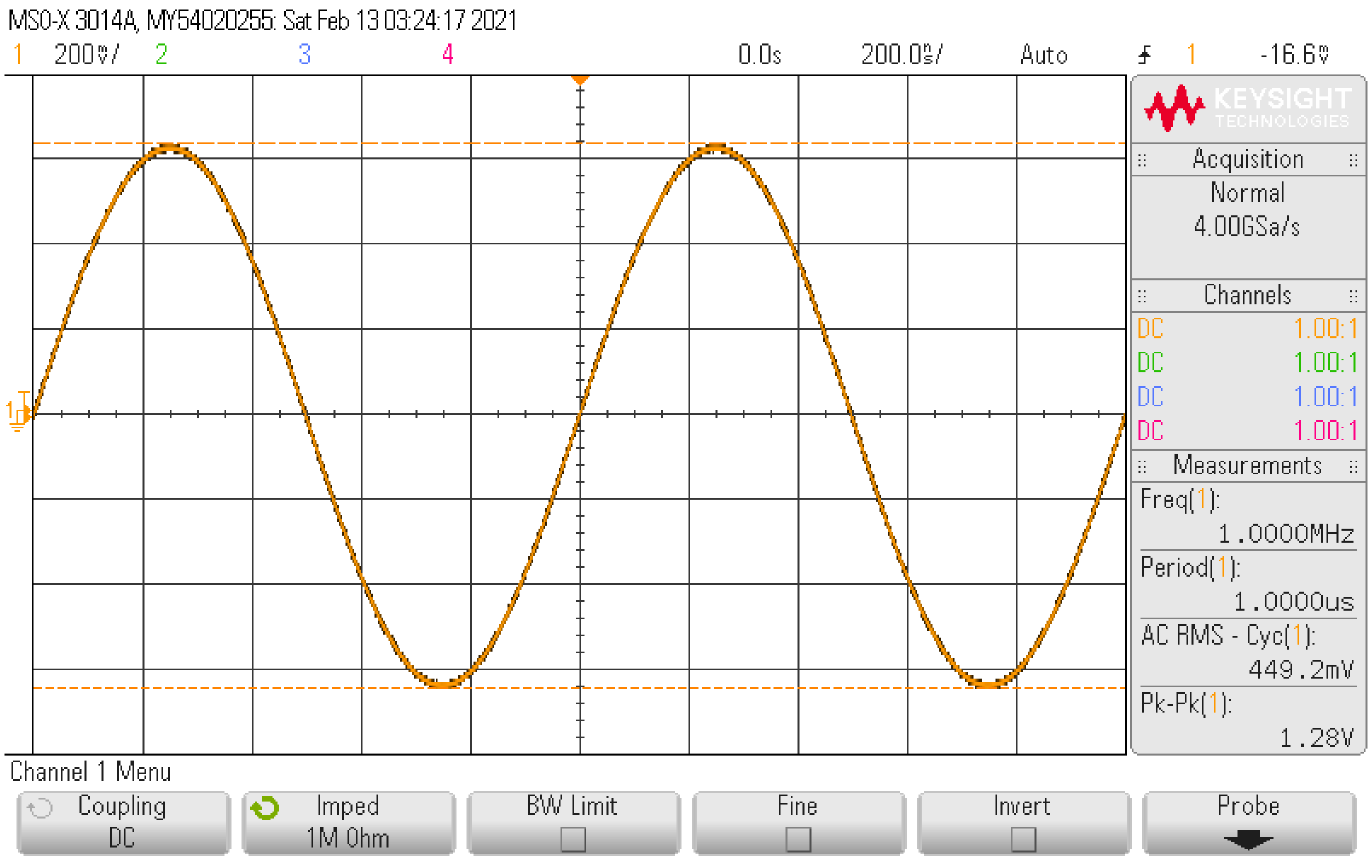
Take screenshot of all your signals on oscilloscope and spectrum analyzer.

Part 1: Time and Frequency Domain of Signals

1) Adjust the waveform generator to produce an un-modulated 1 MHz sine wave signal. Set the amplitude to 225 mVrms without offset or modulation.
2) Use a BNC to BNC connector to connect your function generator to Oscilloscope.
3) Display this signal on the oscilloscope. Set input impedance of oscilloscope to Hi-Z.

a) What is the amplitude in RMS displayed on the oscilloscope? Is this what you expected?

The amplitude displayed on the oscilloscope is not what was expected. The amplitude viewed on the oscilloscope was twice the amount than what was expected. The expected amplitude was 225mV RMS. The observed amplitude was around ~450mV RMS. See screenshot below.



Above screenshot shows the result when impedances don't match. Here, the impedance of the scope is set to HI-Z for channel 1 and the impedance on the waveform generator is set to 50Ω. The result is that the amplitude will be greater than what was expected.

b) What is the default output impedance of the Waveform Generator?

The output impedance of the waveform generator is set to 50Ω by default.

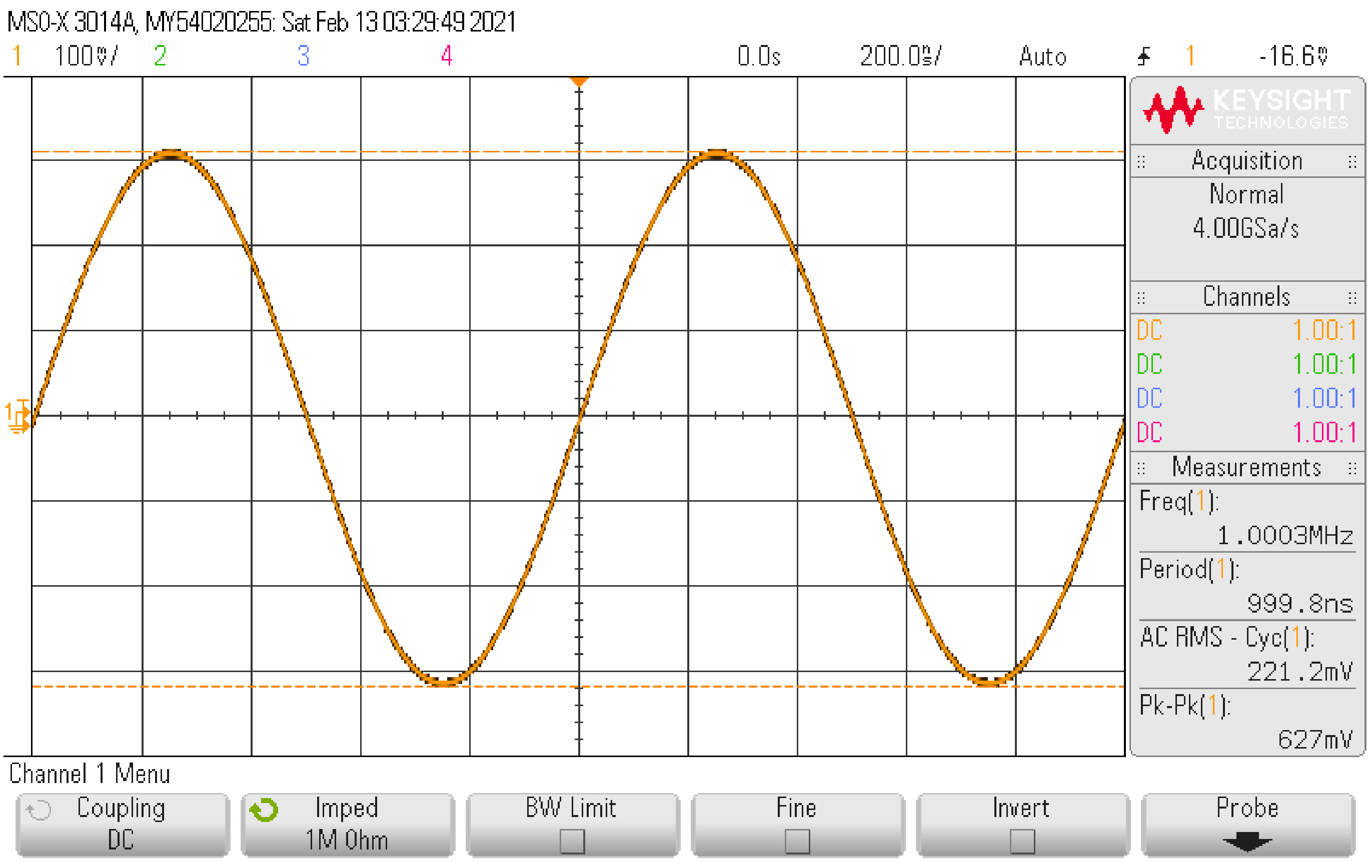
4) Use a BNC T-adaptor to put a 50Ω terminator (internal resistor) on the oscilloscope input together with the coax cable from the waveform generator. If you are not using the BNC T-adaptor, you have to change the oscilloscope's input impedance to 50 Ohms.

a) What is the amplitude displayed on the oscilloscope? Is this what you expected?

The displayed amplitude on the scope is around 225mV RMS. This is the expected result. See screenshot on next page.

b) Does the result make more sense now? In your report, explain what is meant by "output impedance" and "input impedance" of test equipment and why it is important to consider these when making measurements.

The result viewed from the scope makes more sense now than what was shown before when the BNC T-adaptor was not used. Output impedance refers to what type of load the waveform generator (or any other test equipment) will have to drive/support. Input impedance is the opposite of output impedance where the oscilloscope (or any other test equipment) will have to provide the load that will be connected to the waveform generator (or any other test equipment). It is important to ensure that these impedances (on the waveform generator and scope) match so that readings will be accurate/expected. If they are not, then readings will become inaccurate/unexpected as shown before. See screenshot on next page.



Above screenshot shows the result when impedances match. Here, the impedance of the scope is still set to HI-Z for channel 1 but with the addition of the BNC-T adaptor with 50Ω load connected to it and the impedance on the waveform generator is set to 50Ω. The result is that the amplitude will be the expected amplitude produced.

c) Calculate the power of the signal in dBm.

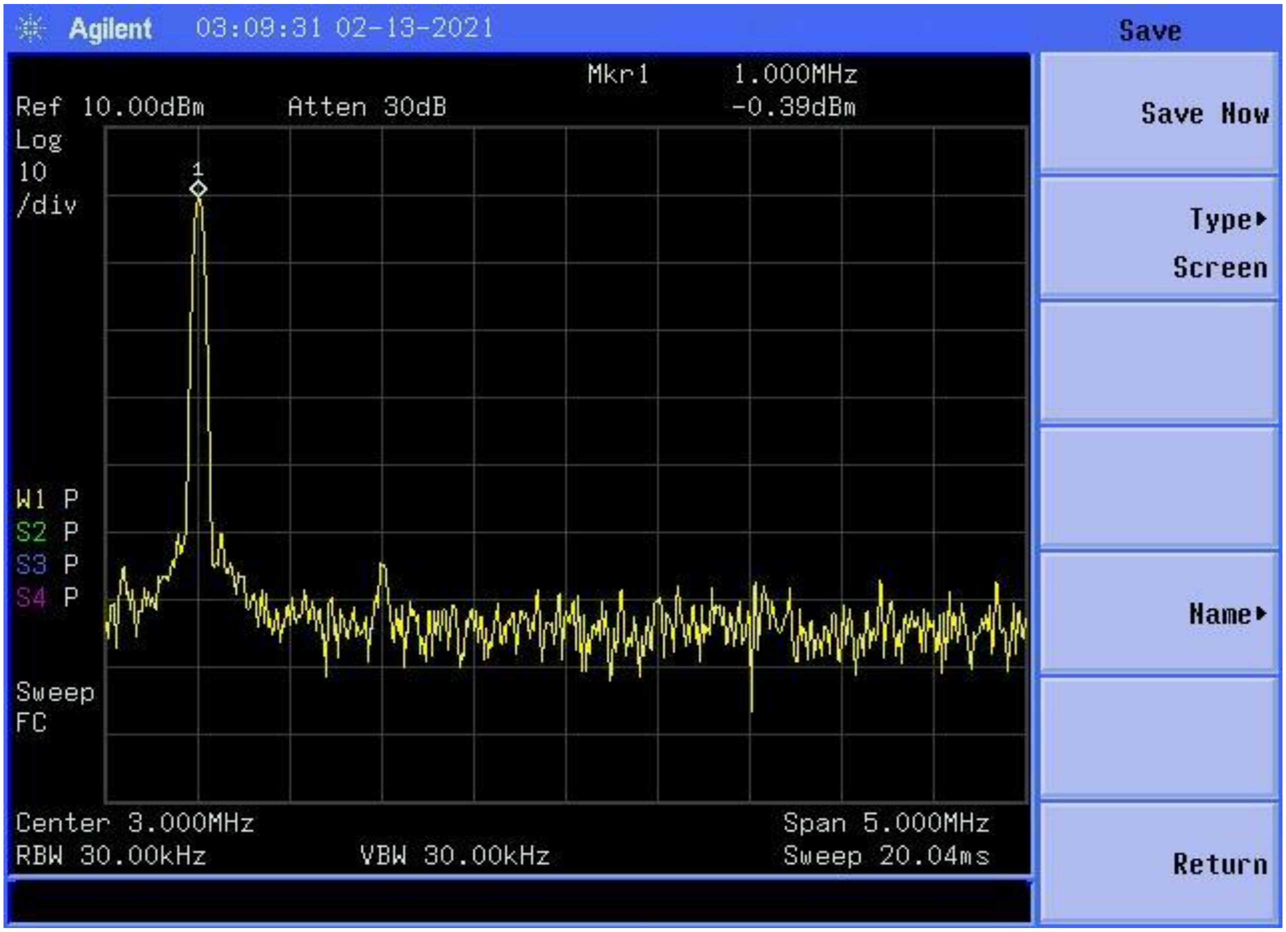
The power of the signal is: $P_W = \frac{V^2}{R} = \frac{225mV^2}{50\Omega} = \sim 1.01mW,\ P_{dBm} = 10log\frac{\sim 1.01mW}{1mW} = \sim 0.0432dBm$

5) Remove the 50Ω terminator from BNC T-adaptor and connect that T-port to the input of spectrum analyzer. **Note**: the output of signal generator is now connected to both oscilloscope and spectrum analyzer at the same time!

6) Set the Spectrum analyzer for the following settings. Access to the related settings via the 2 menu buttons on the front panel.

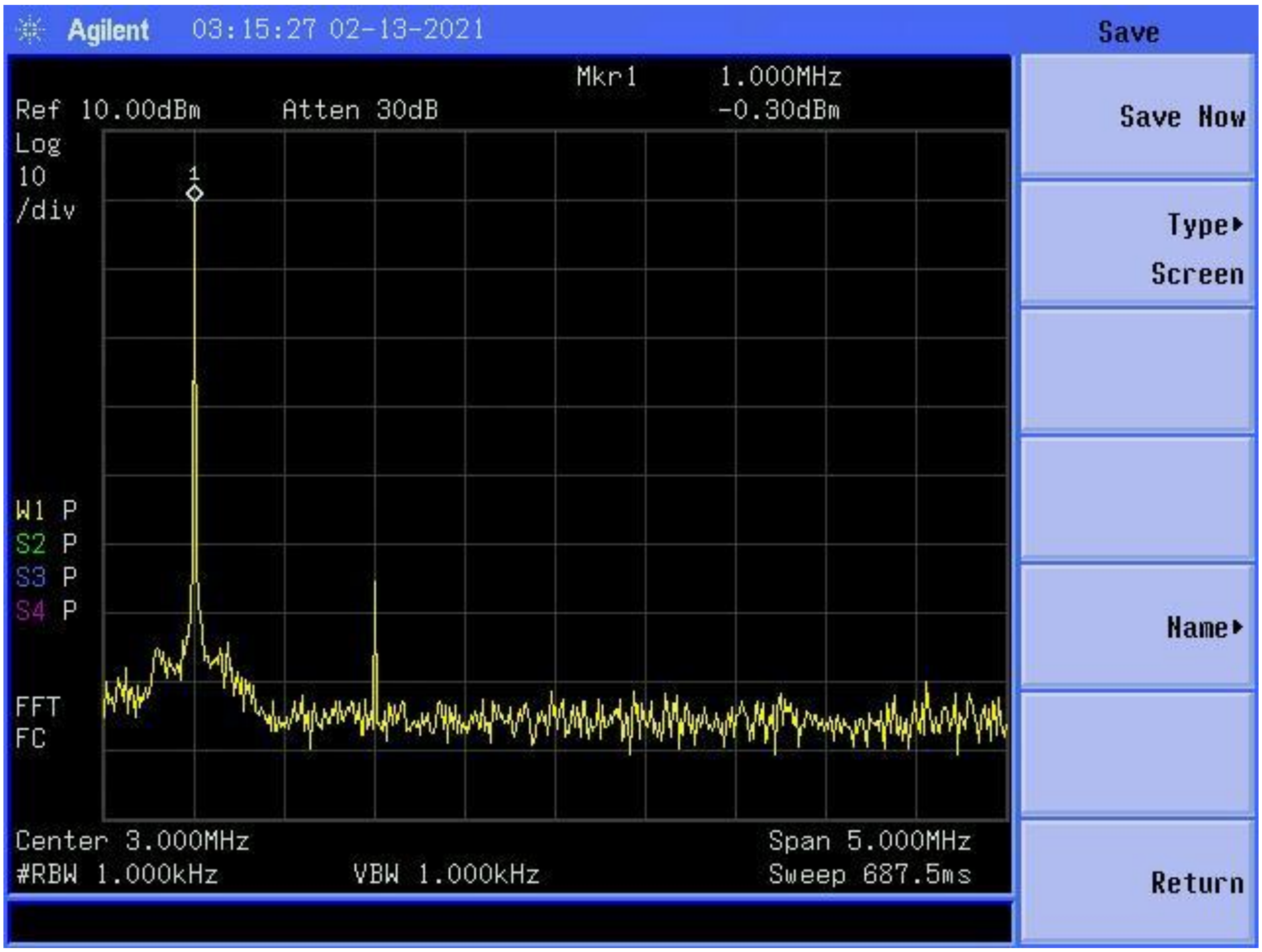
- Ref. Level: +10 dBm
- Stop frequency: 5.5 MHz
- Start frequency: 0.5 MHz

a) Use a marker on the Spectrum Analyzer to measure the peak signal obtained (hint: try "Peak Search"):
   i. Observed signal frequency: *1MHz.*
   ii. Observed signal power: *-0.39dBm (almost 0dBm).*



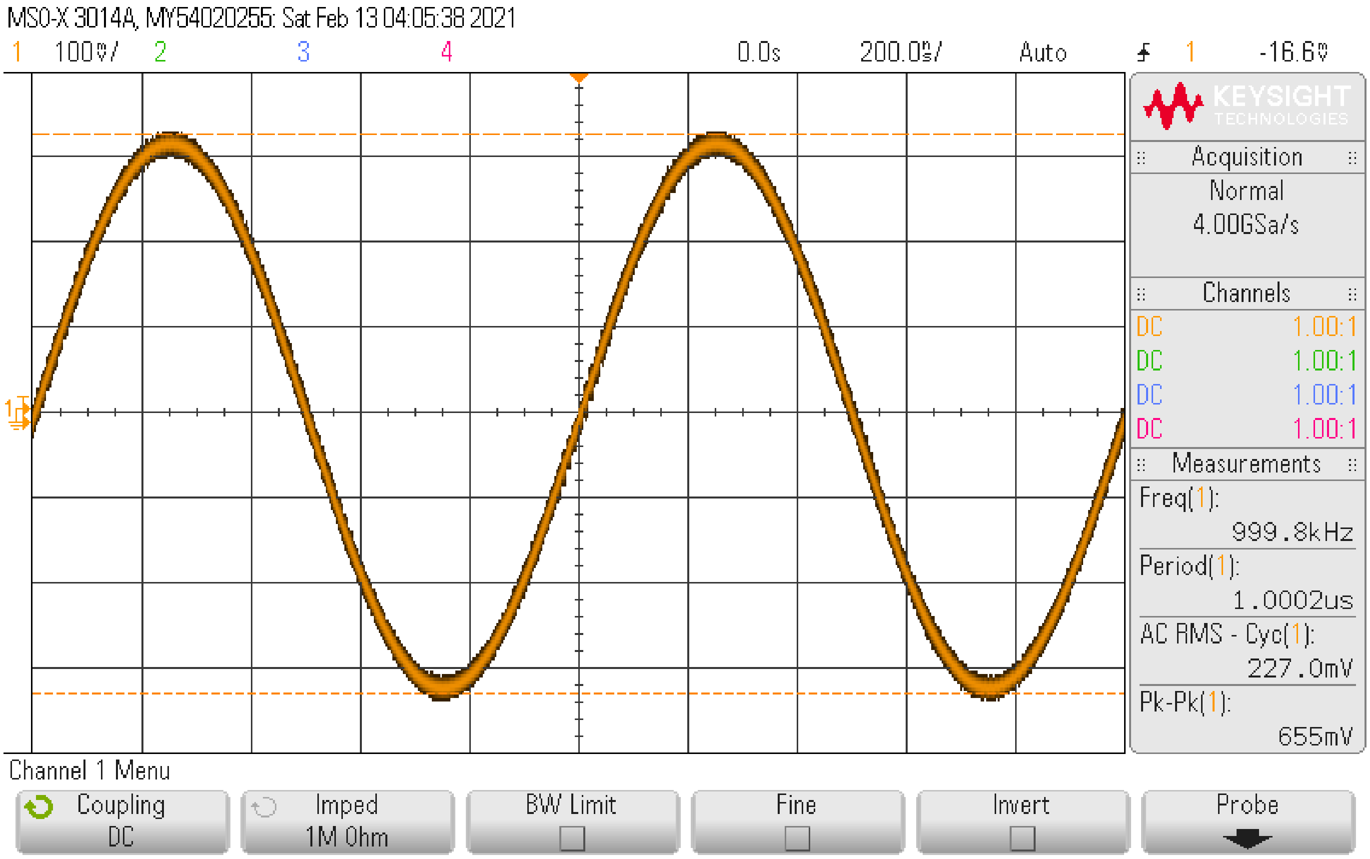
Observed frequency: 1MHz and observed power: -0.39dBm as shown by Mkr1 (at top right).

b) Note the Resolution Bandwidth (RBW) settings on the Spectrum Analyzer. Try to change RBW to smaller bandwidth. Observe and compare the width of the "spike" on the spectrum analyzer display and explain.

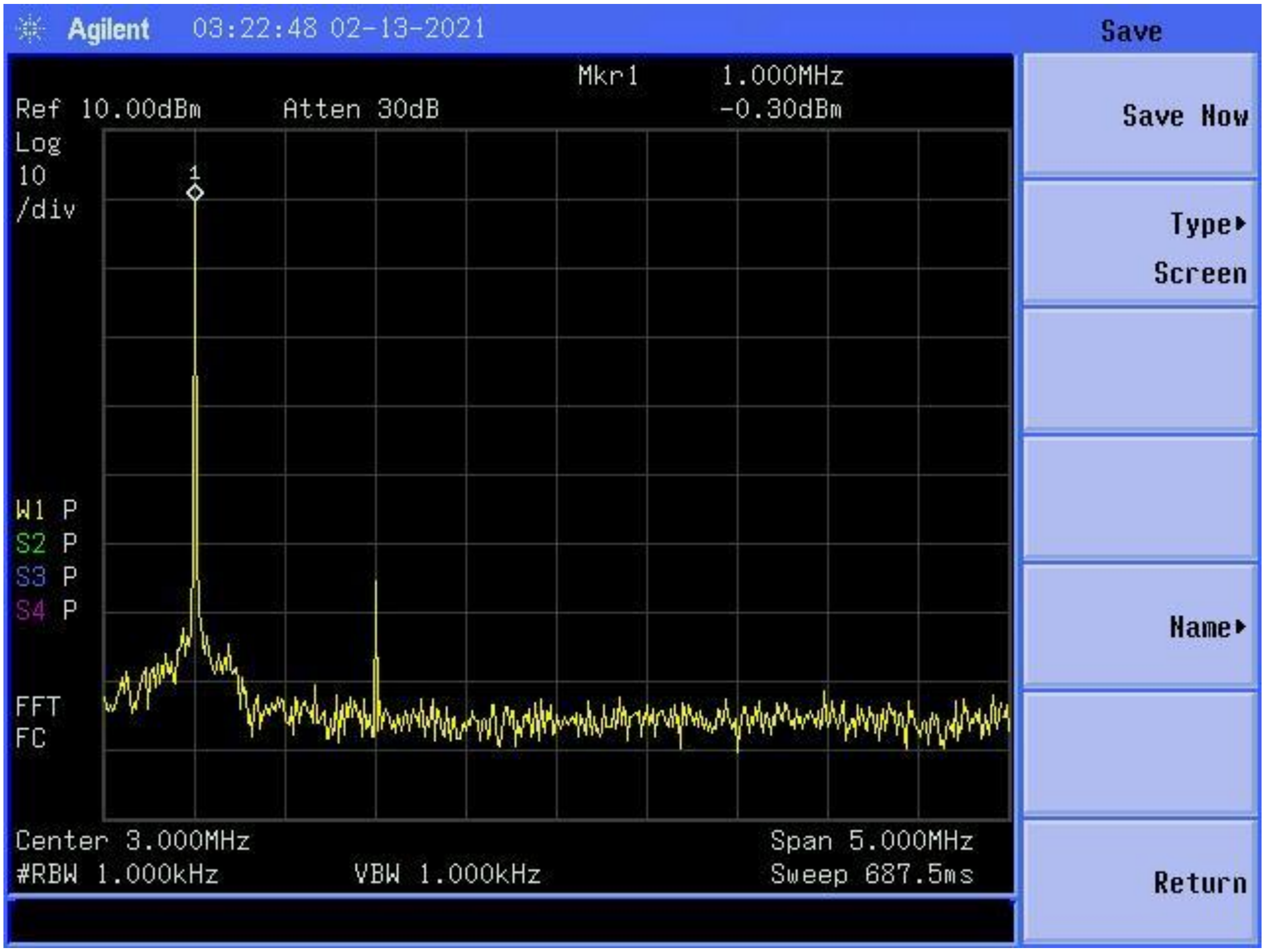


The resolution bandwidth (RBW) has been decreased to 1kHz as shown above. The width of the spike on the spectrum analyzer has become narrower than what was seen when the RBW was set to 30kHz. The fundamental frequency of 1MHz (largest spike) is shown and its marker at the top right. There seems to be another spike (smaller one to the right of the fundamental frequency) that is much more noticeable than before when the RBW was set to 30kHz.

c) Sketch or capture the waveform of the signal in time domain (oscilloscope) and frequency domain (spectrum analyzer).



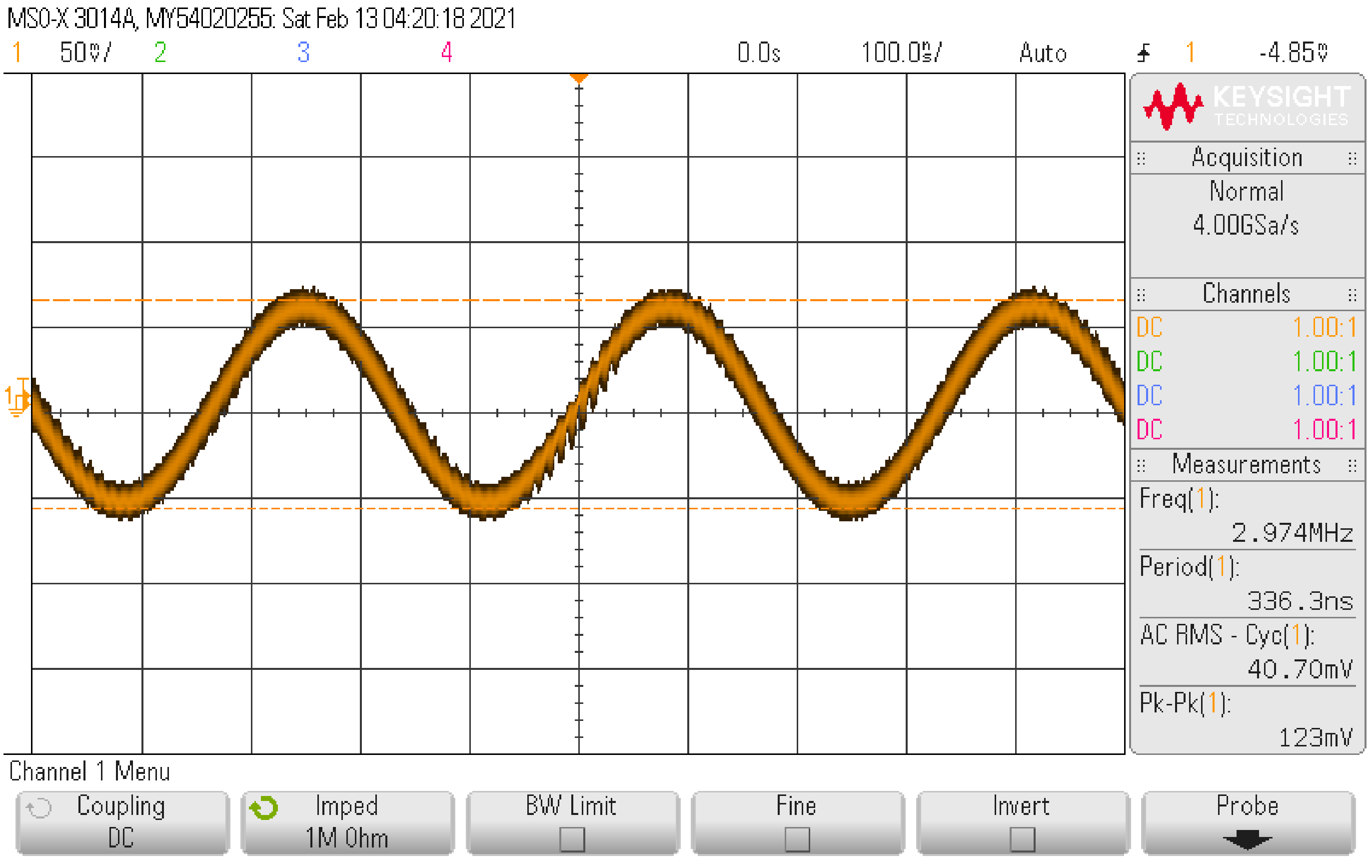
Signal in time domain shown above. Signal in frequency domain showed on next page.



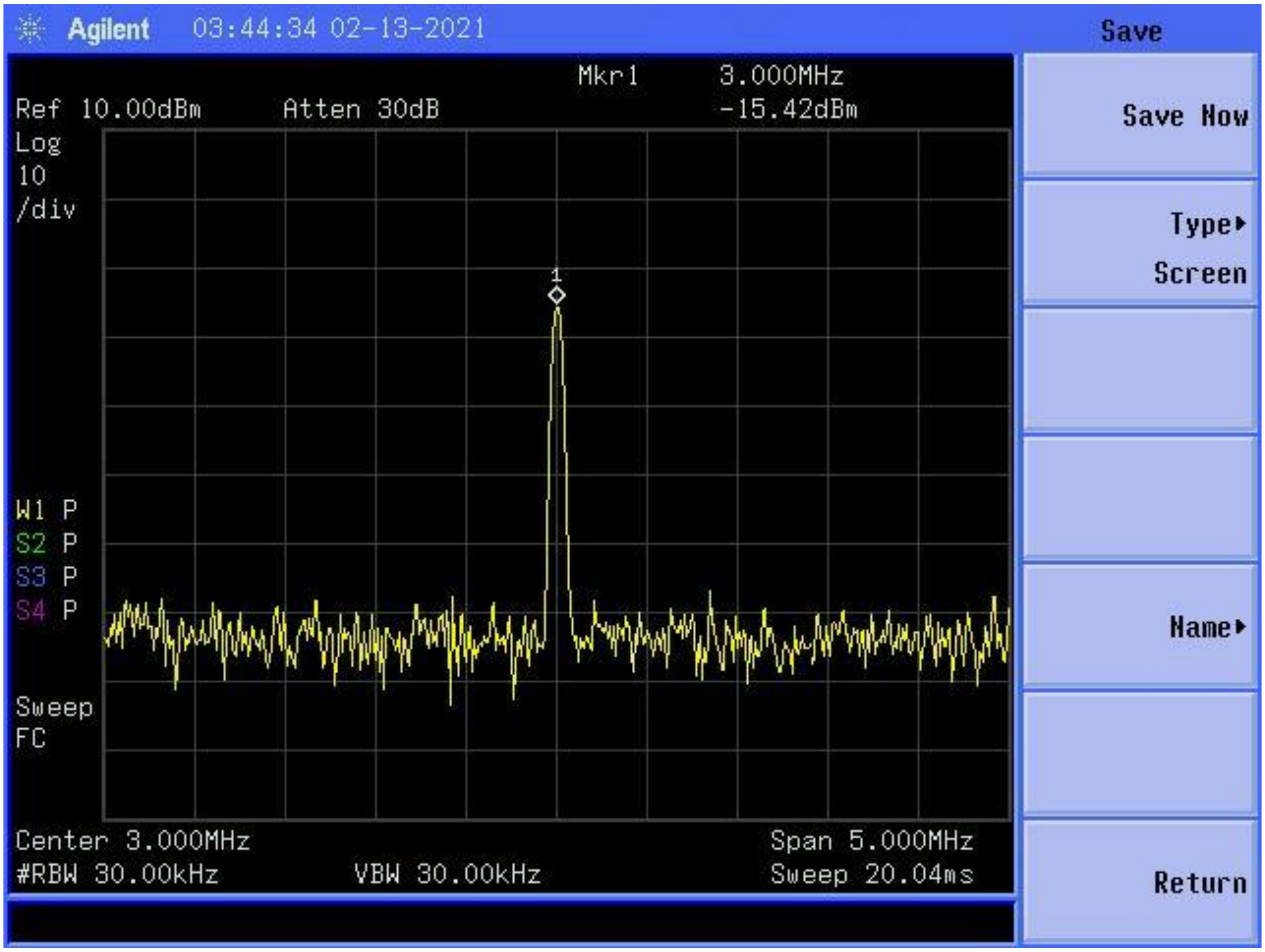
Signal in frequency domain shown above.

d) Set the Resolution Bandwidth (RBW) back to 30 kHz.

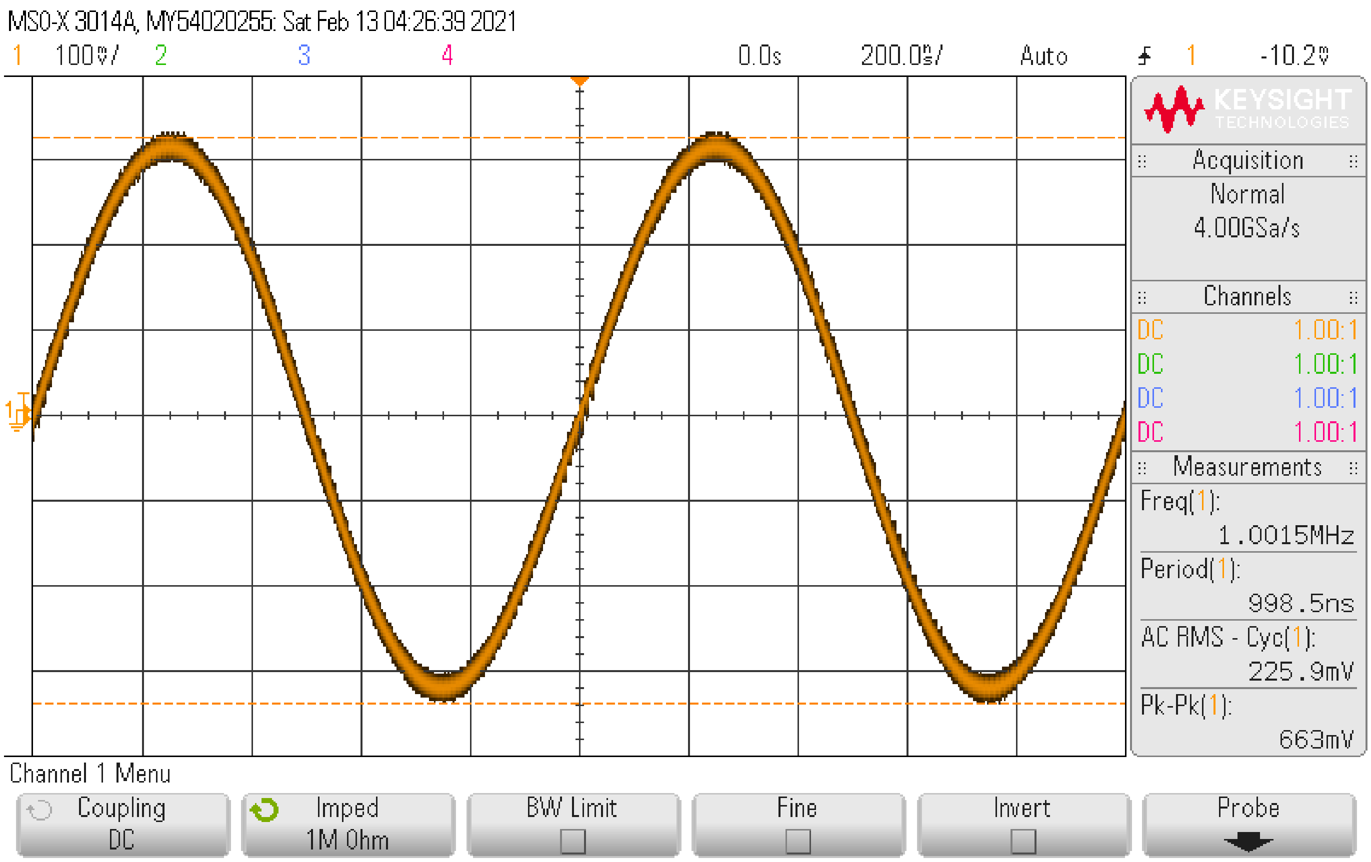
7) Set the waveform generator to a frequency of 3 MHz and signal amplitude (power) of -15 dBm. How did this change the time domain and frequency domain views of the signal? **Set the waveform generator back to 1 MHz and 0 dBm.**



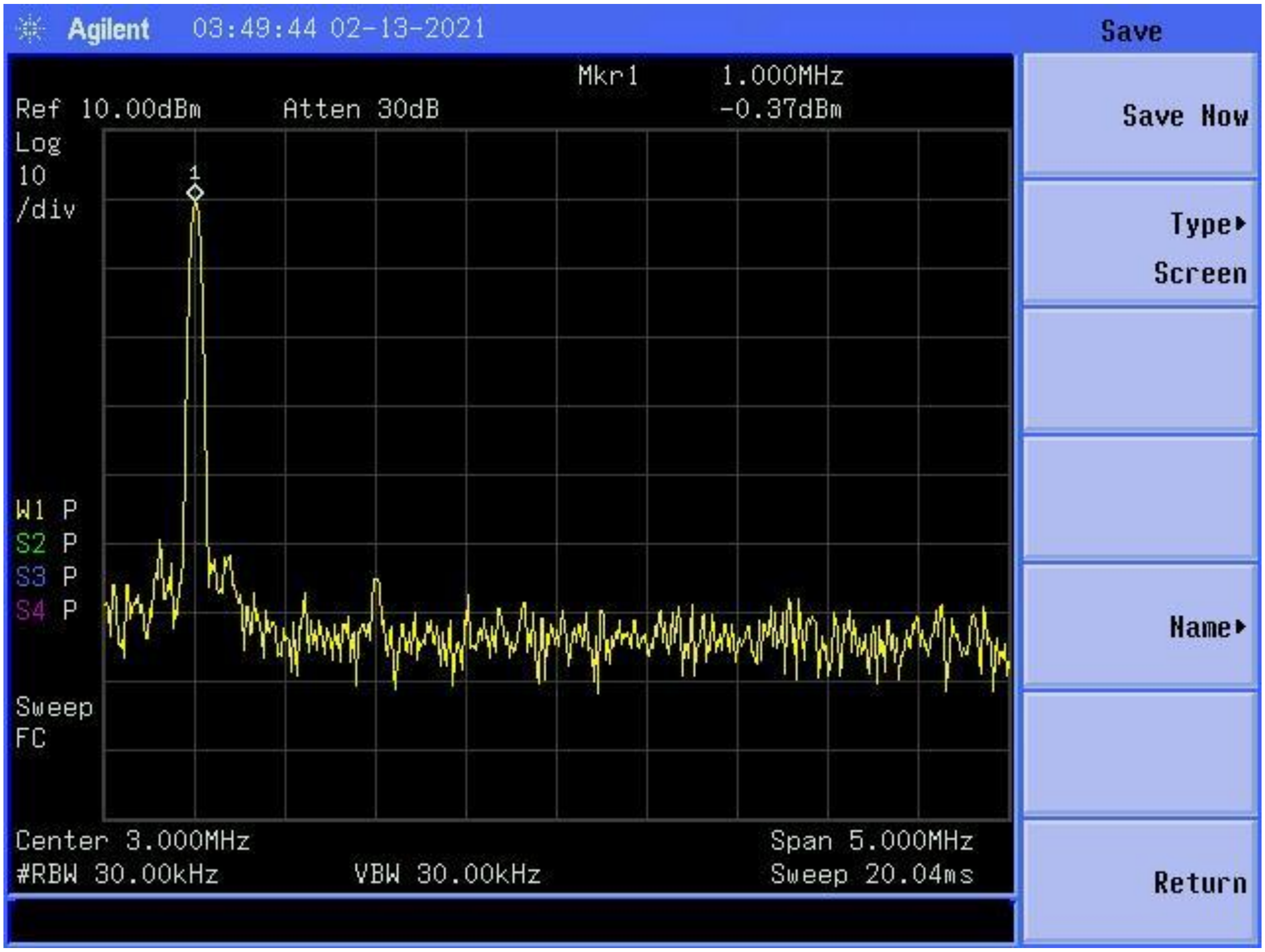
Signal in time domain shown above. With the waveform generator set at 3MHz and -15dBm, the frequency observed has increased (to 3MHz) and the power of the signal has dropped. The observed peak amplitude of the signal is around 60mV.



Signal in frequency domain shown above. The spike of the signal is now located in the center of the screen. The power of the signal has decreased and is close to -15dBm.



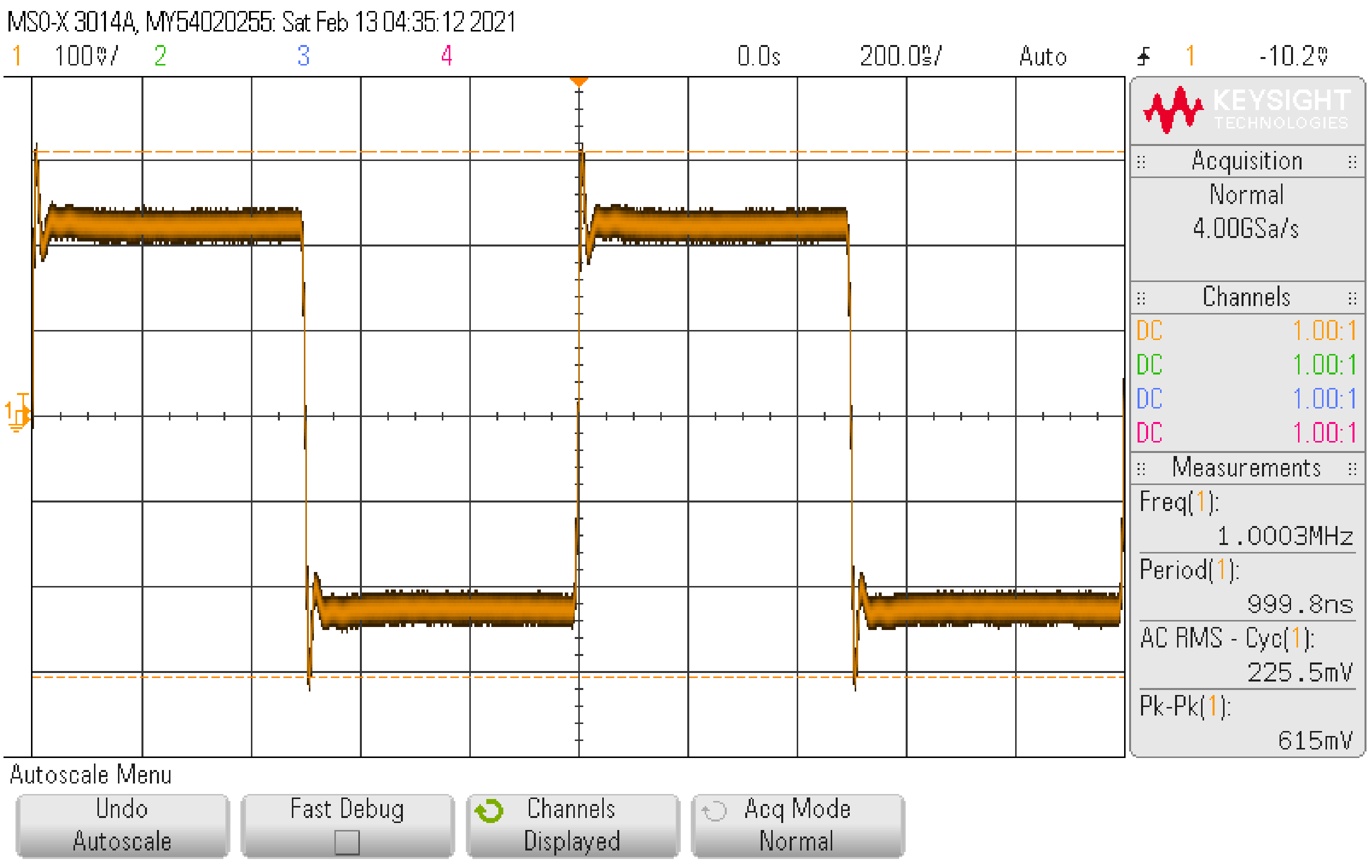
Signal in time domain shown above. With the waveform generator set at 1MHz and -15dBm, the frequency observed has decreased (to 1MHz) and the power of the signal has increased (in contrast to before it was lower). The observed peak amplitude of the signal is around 330mV.



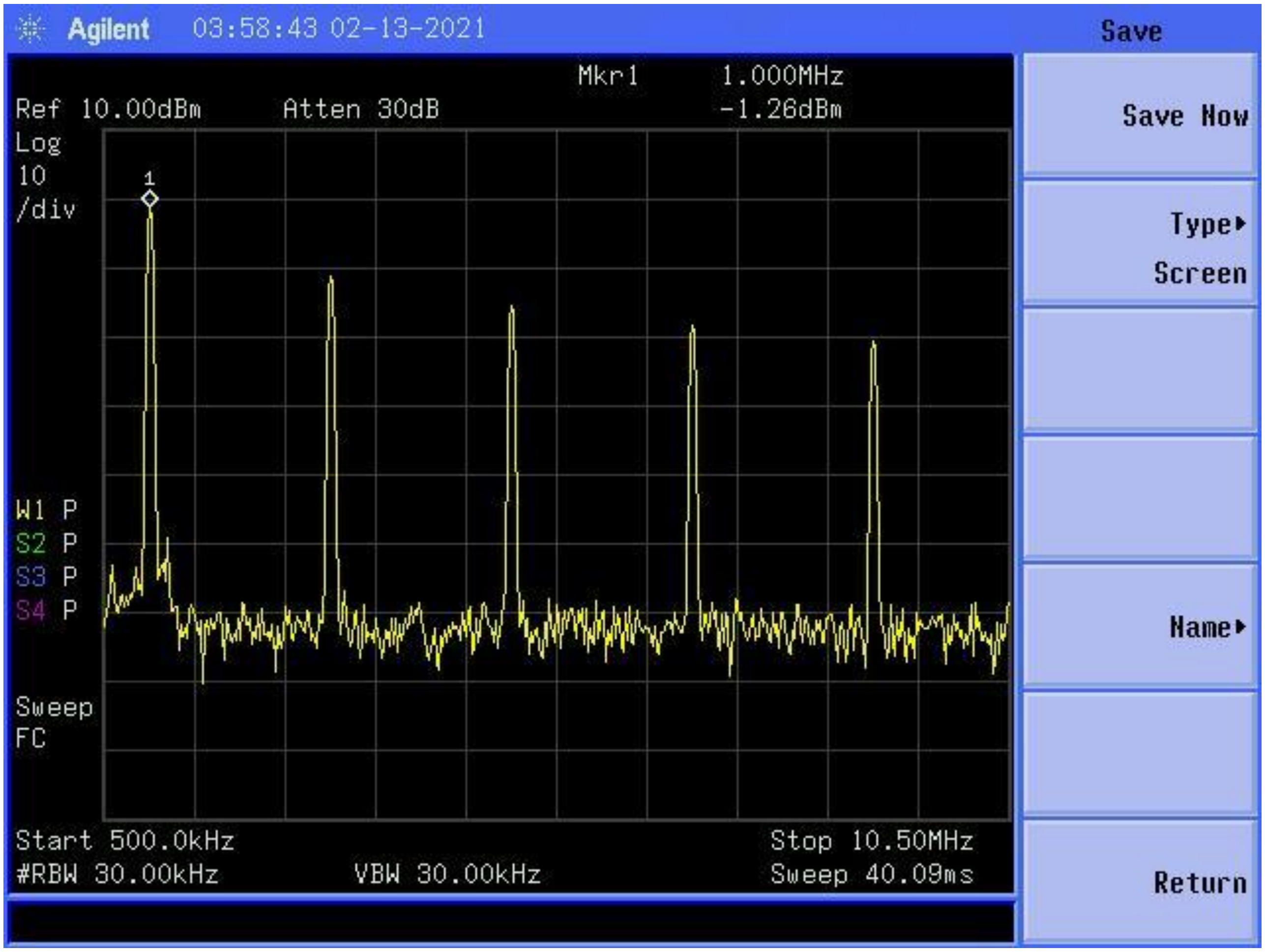
Signal in frequency domain shown above. The spike of the signal is now located to the left of the screen (in contrast to before it was in the center). The power of the signal has increased and is close to 0dBm.

8) Change the waveform generator wave type to square wave.

   a) Change the Stop Frequency on the spectrum analyzer to 10.5 MHz How many frequencies do you see on the spectrum analyzer? Attach a screen shot of both time and frequency domain in your report.



Signal in time domain shown above. Observed frequency is around 1MHz and peak amplitude is around 300mV.



Signal in frequency domain shown above. With the current settings of the spectrum analyzer, there are 5 noticeable frequencies on the display. They are all odd frequencies because the signal from the waveform generator is a square wave. Power of the fundamental frequency is around 0dBm. Refer to table below for a complete list of observed frequencies and powers for the first five harmonics.

b) For each frequency component that you see now (try "Peak Search"), measure and record in a table the:

- Frequency
- Power

Observed Frequency	***Observed Power***
1MHz	-1.25dBm
3MHz	-10.89dBm
5MHz	-15.28dBm
7MHz	-18.23dBm
9MHz	-20.47dBm

c) Compare the frequencies and powers to the Fourier series amplitudes for a square wave as seen below. Show some examples of your calculations.

$$x_{\text{square}}(t)=(4/\pi)(\sin(2\pi ft)+(1/3)\sin(6\pi ft)+(1/5)\sin(10\pi ft)+\cdots)$$

Observed Frequency & Powers	***Calculated Frequency & Powers*** 0dBm = 316.8mV peak
1MHz / -1.25dBm	1MHz / $V_{1MHz} = \frac{4(316.18mV)}{\pi} = \sim 402.57mV$ $P = \frac{402.57mV^2}{2*50} = 1.62mW$ $P_{dBm} = 10log\frac{1.62mW}{1mW} = 2.09dBm$
3MHz / -10.89dBm	3MHz / $V_{3MHz} = \frac{4(316.18mV)}{3\pi} = \sim 134.19mV$ $P = \frac{134.19mV^2}{2*50} = 180uW$ $P_{dBm} = 10log\frac{180uW}{1mW} = -7.44dBm$
5MHz / -15.28dBm	5MHz / $V_{5MHz} = \frac{4(316.18mV)}{5\pi} = \sim 80.51mV$ $P = \frac{80.51mV^2}{2*50} = 64.81uW$ $P_{dBm} = 10log\frac{64.81uW}{1mW} = -11.88dBm$
7MHz / -18.23dBm	7MHz / $V_{7MHz} = \frac{4(316.18mV)}{7\pi} = \sim 57.51mV$ $P = \frac{57.51mV^2}{2*50} = 33.07uW$ $P_{dBm} = 10log\frac{33.07uW}{1mW} = -14.80dBm$
9MHz / -20.47dBm	9MHz / $V_{9MHz} = \frac{4(316.18mV)}{9\pi} = \sim 44.73mV$ $P = \frac{44.73mV^2}{2*50} = 20uW$ $P_{dBm} = 10log\frac{20uW}{1mW} = -16.98dBm$

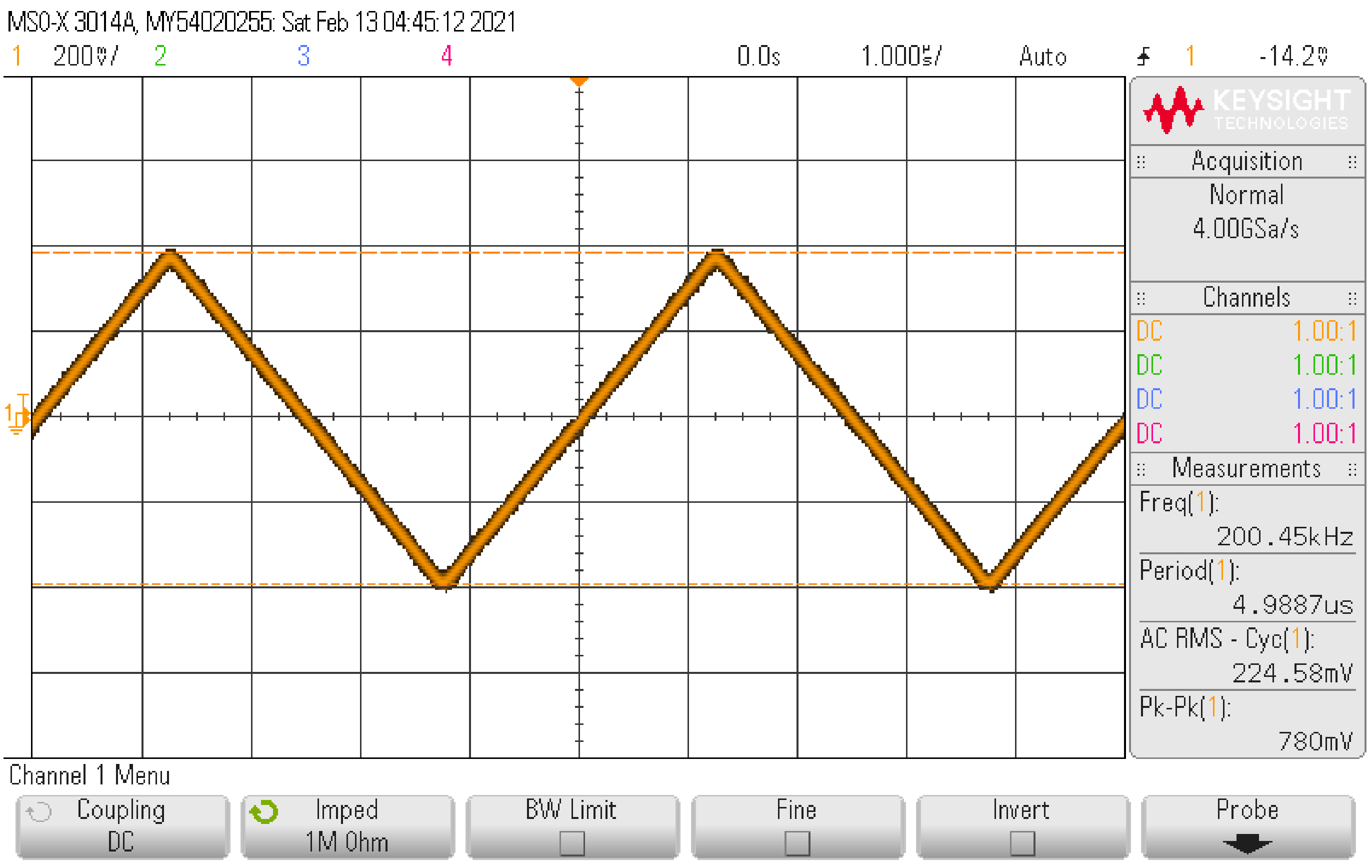
9) Change the waveform generator wave type to triangle wave.

   a) What is the maximum frequency of the waveform that generator could produce?

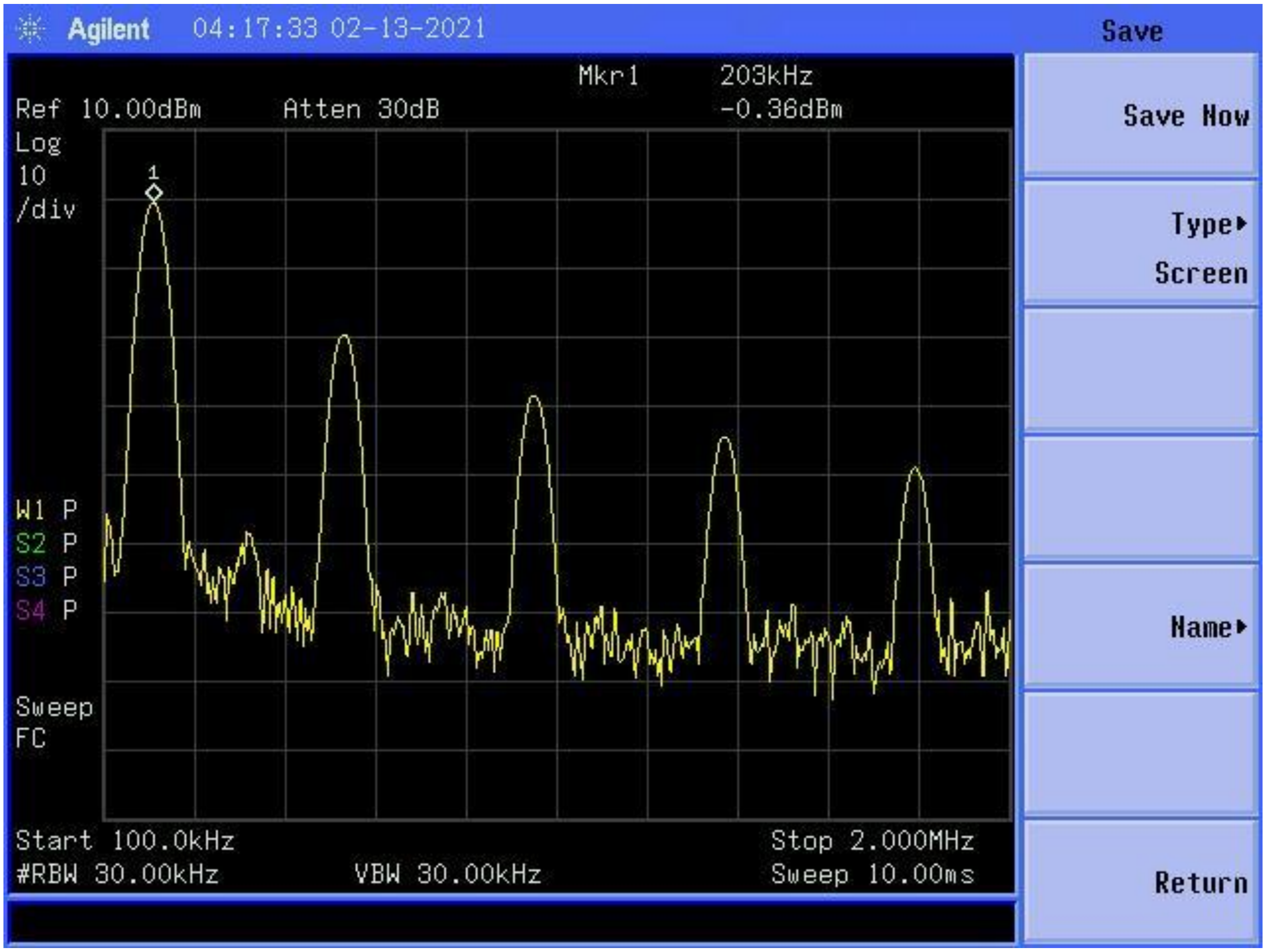
      The maximum frequency the waveform generator can produce for a triangle wave is 200kHz.

   b) Set up your frequency span on that you could observe 5 lowest frequency components. What are the settings? Attach a screen shot of both time and frequency domain in your report.

      The start frequency is 100kHz and the stop frequency is 2MHz. See screenshots below.



Signal in time domain shown above. Observed frequency is around 200kHz and peak amplitude of the signal is around 390mV. Signal in frequency domain is on next page.



Signal in frequency domain shown above. Power of the fundamental frequency is around 0dBm. With the current spectrum analyzer settings, there are 5 noticeable frequencies on the display. Complete list of observed frequencies and powers can be found in the table on the next page.

c) For each frequency component that you see now (try "Peak Search"), measure and record in a table the:

- Frequency
- Power

Observed Frequency	***Observed Power***
203kHz	-0.36dBm
604kHz	-19.41dBm
1.005MHz	-28.24dBm
1.401MHz	-34.29dBm
1.802MHz	-38.66dBm

Part 2: AM modulation

1) Set the signal generator main frequency to 10 MHz.
2) Configure the signal generator to amplitude modulate the 10 MHz carrier using an internally-generated 500 kHz sine wave with a modulation depth of 100% *(note: you can ask the instructor for help)*.
3) Note: If you have trouble triggering the oscilloscope, you can connect the **SYNC** output of the signal generator to the second channel of the oscilloscope. Trigger the oscilloscope from the SYNC signal.
4) Using the oscilloscope display:
   a) What is the Peak Amplitude?

   **Note: 0dBm = 316.180mV Peak*

$$Peak = V_C(1+m) = 316.180mV(1+1) = 632.36mV$$

   b) What is the Minimum Amplitude?

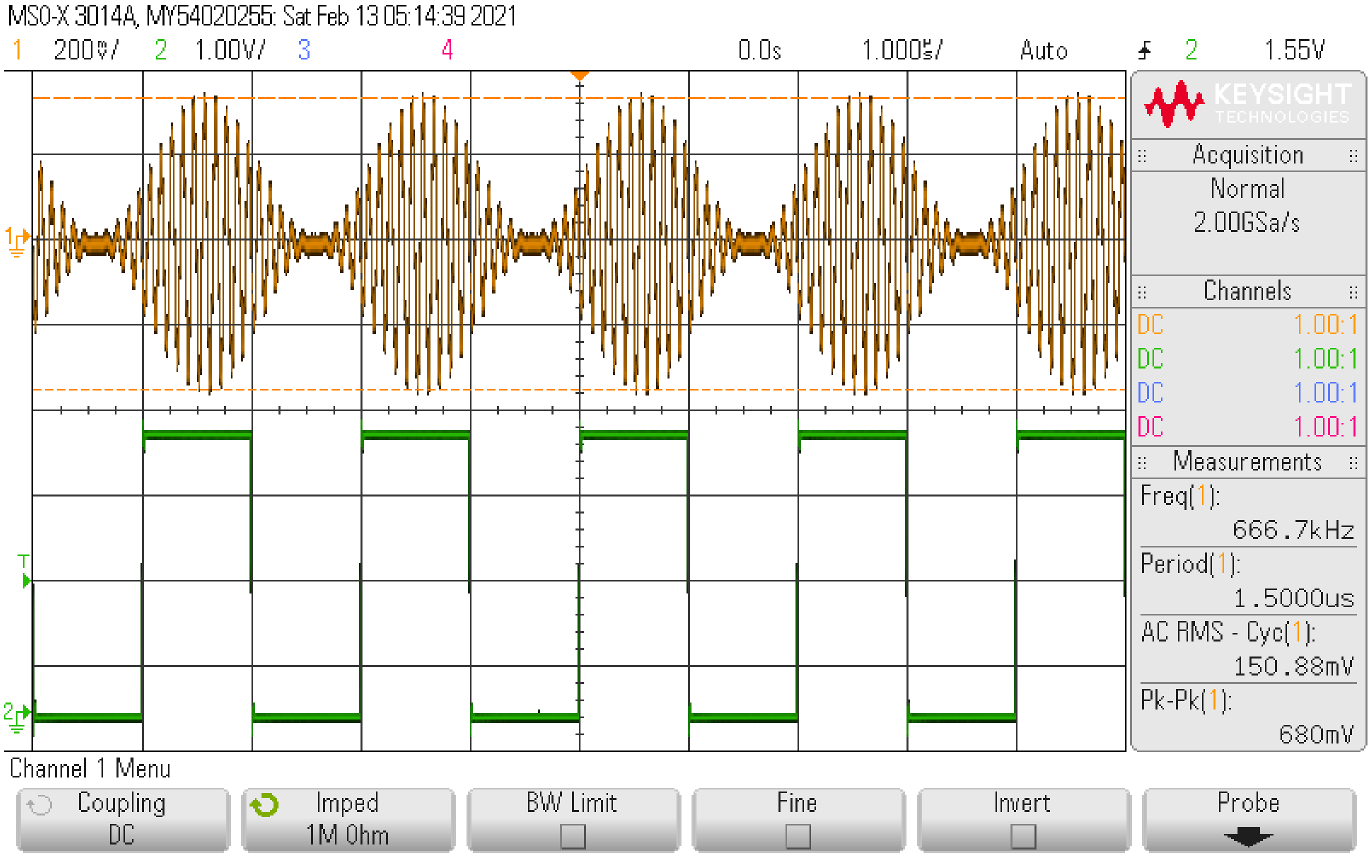
   **Note: 0dBm = 316.180mV Peak*

$$Minimum = V_c(1-m) = 316.180mV(1-1) = 0V$$

   c) Calculate the modulation index using the formula learned in class.

$$Modulation\ index = \frac{Peak - Minimum}{Peak + Minimum} = \frac{632.36mV - 0V}{632.36mV + 0V} = 1\ (100\%)$$

d) Sketch the waveform (or take a screen shot).



Signal in time domain shown above. Modulation index is 100%. Green square wave is SYNC output from the waveform generator.

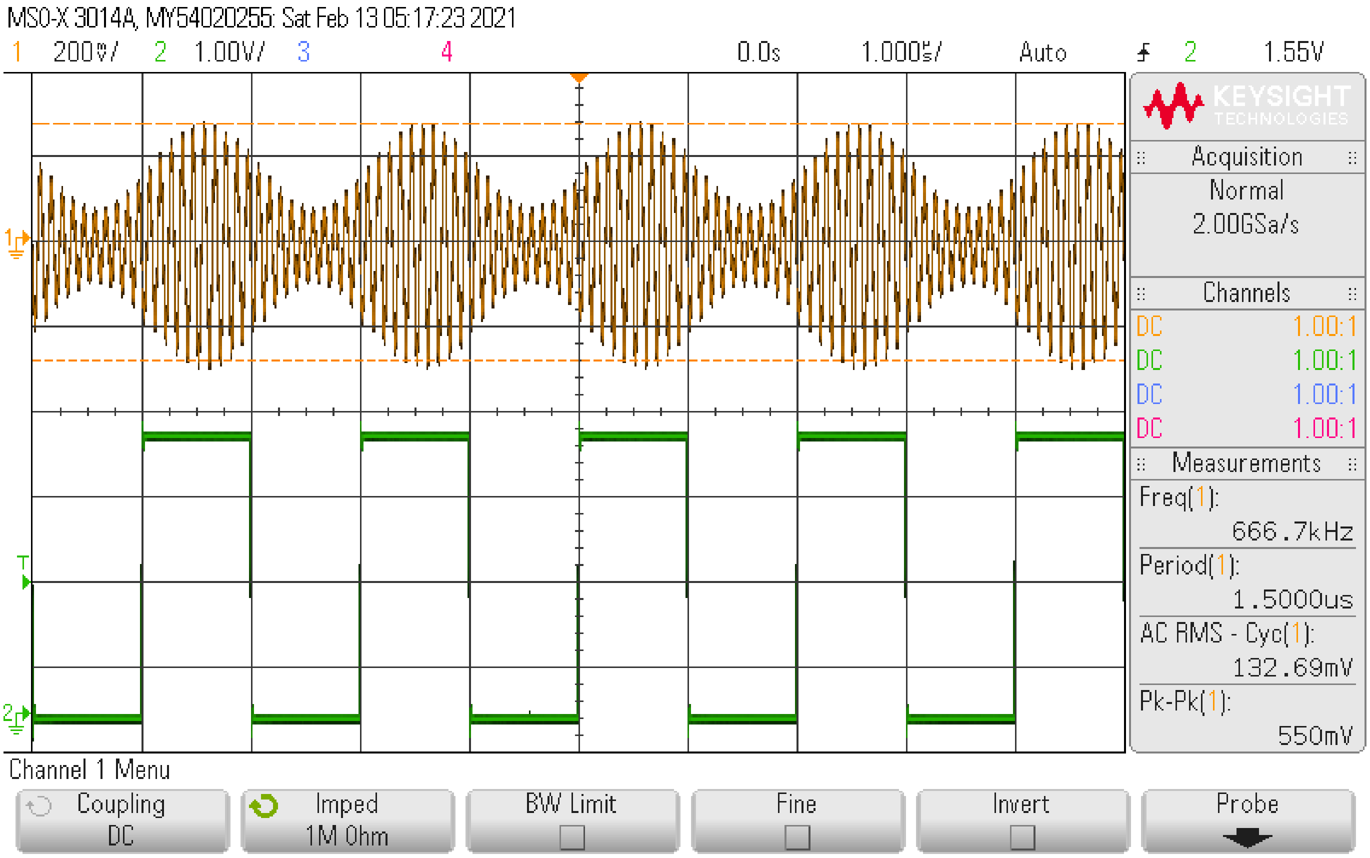
5) Repeat step 4 for modulation depths of 60%

Note: 0dBm = 316.180mV Peak*

$$Peak = V_C(1+m) = 316.180mV(1+0.6) = 505.88mV$$

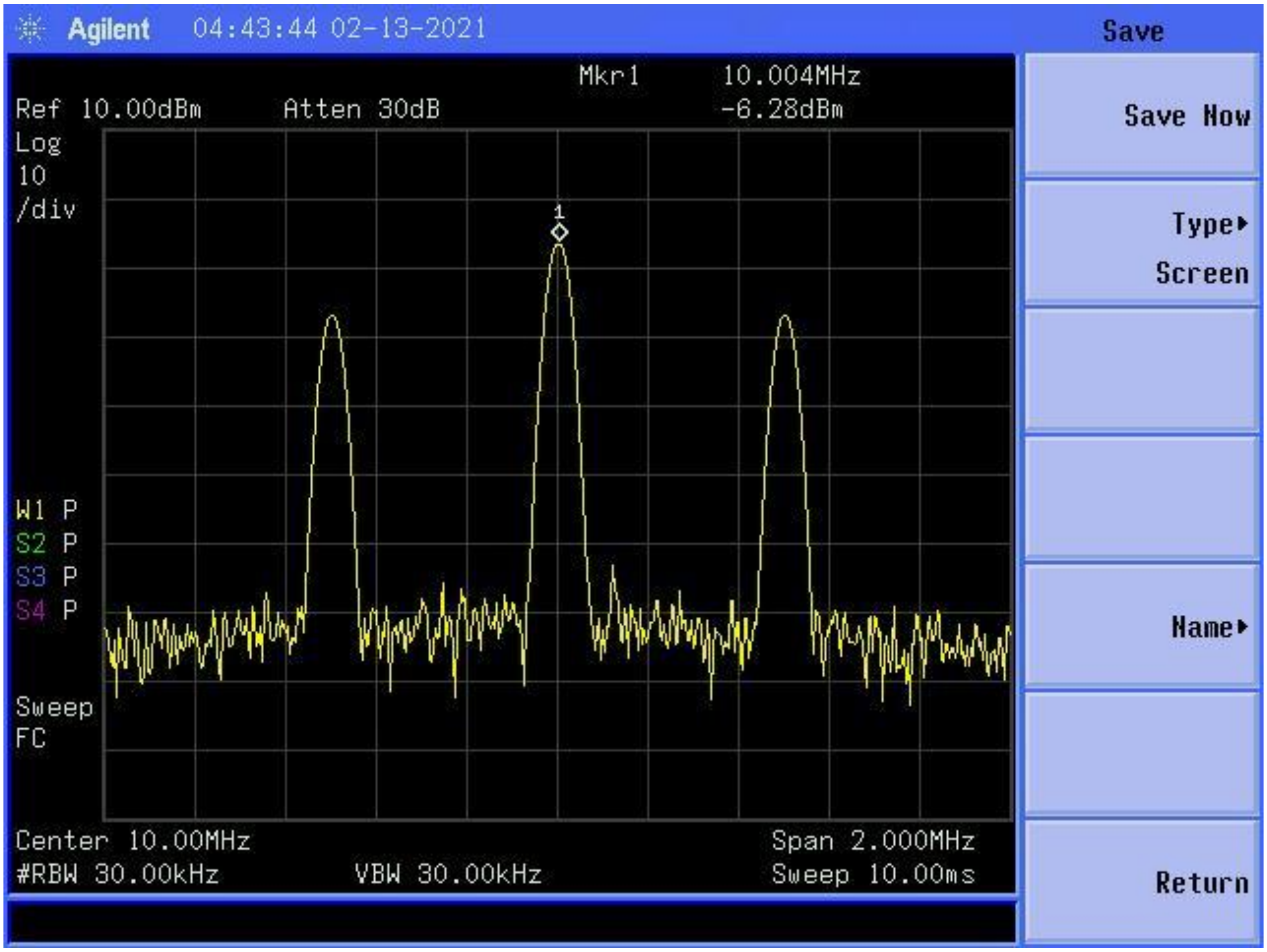
$$Minimum = V_c(1-m) = 316.180mV(1-0.6) = 126.47mV$$

$$Modulation\ index = \frac{Peak - Minimum}{Peak + Minimum} = \frac{505.88mV - 126.47mV}{505.88mV + 126.47mV} = 0.6\ (60\%)$$



Signal in time domain shown above. The shape of the AM signal has changed slightly compared to when the modulation index was 100%. Modulation index of observed signal is 60%. Green square wave is SYNC output from the waveform generator.

6) In the spectrum analyzer, set the center frequency at 10MHz and span 2MHz. Capture the spectrum.



Signal in frequency domain shown above. With current spectrum analyzer settings, the center frequency and sidebands are noticeable on the screen. The observed center frequency is 10MHz, upper sideband frequency is 10.5MHz and lower sideband frequency is 9.5MHz.

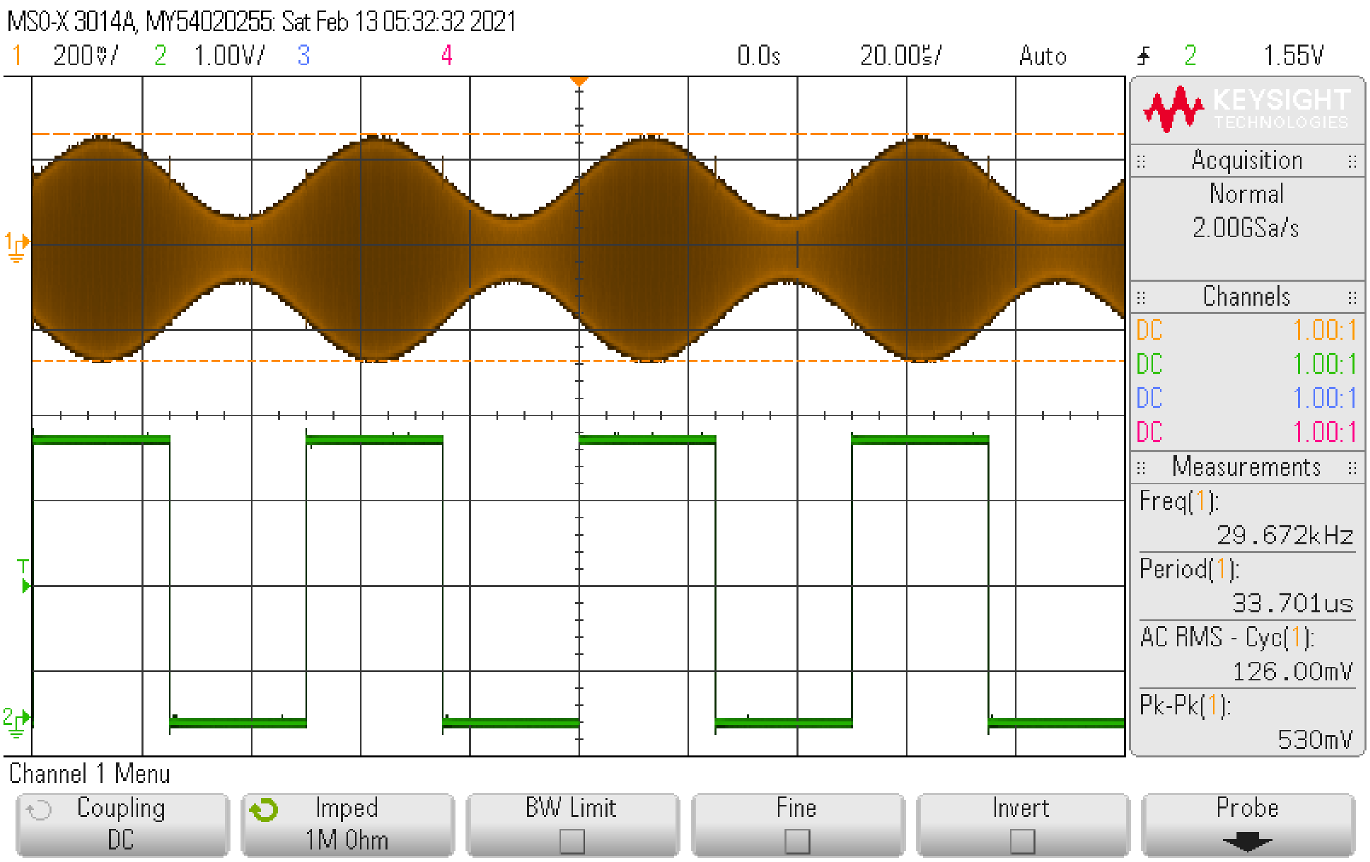
7) Change the modulating signal to 20KHz sin wave and modulation depth of 60%. Repeat step 4

<u>Note</u>: 0dBm = 316.180mV Peak

$$Peak = V_C(1+m) = 316.180mV(1+0.6) = 505.88mV$$

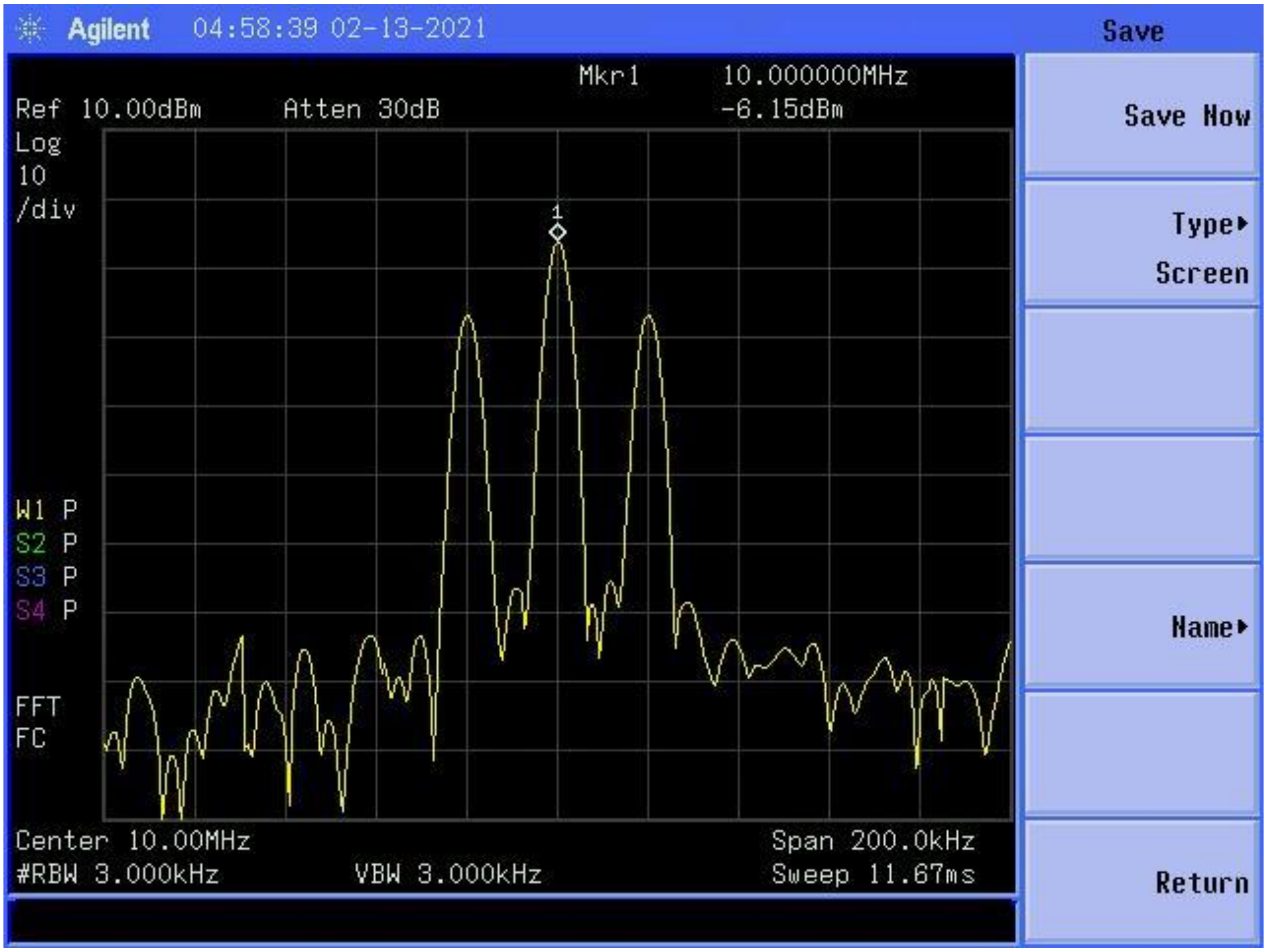
$$Minimum = V_c(1-m) = 316.180mV(1-0.6) = 126.47mV$$

$$Modulation\ index = \frac{Peak - Minimum}{Peak + Minimum} = \frac{505.88mV - 126.47mV}{505.88mV + 126.47mV} = 0.6\ (60\%)$$



Signal in time domain shown above. Modulating signal is now 20kHz and modulation index is now 60%. The overall shape of the signal remains the same with the exception that the number of frequencies has increased in the signal. Green square wave is SYNC output from waveform the generator.

8) Set the Spectrum analyzer to Center Frequency 10 MHz, Span of 200 kHz and RBW of 3 kHz. With the modulation depth still set to 60% from the previous step, capture or sketch the spectrum analyzer display.



Signal in frequency domain shown above. With current spectrum analyzer settings, the center frequency and sidebands are noticeable on the screen. The observed center frequency is 10MHz, upper sideband frequency is 10.02MHz and lower sideband frequency is 9.98MHz.

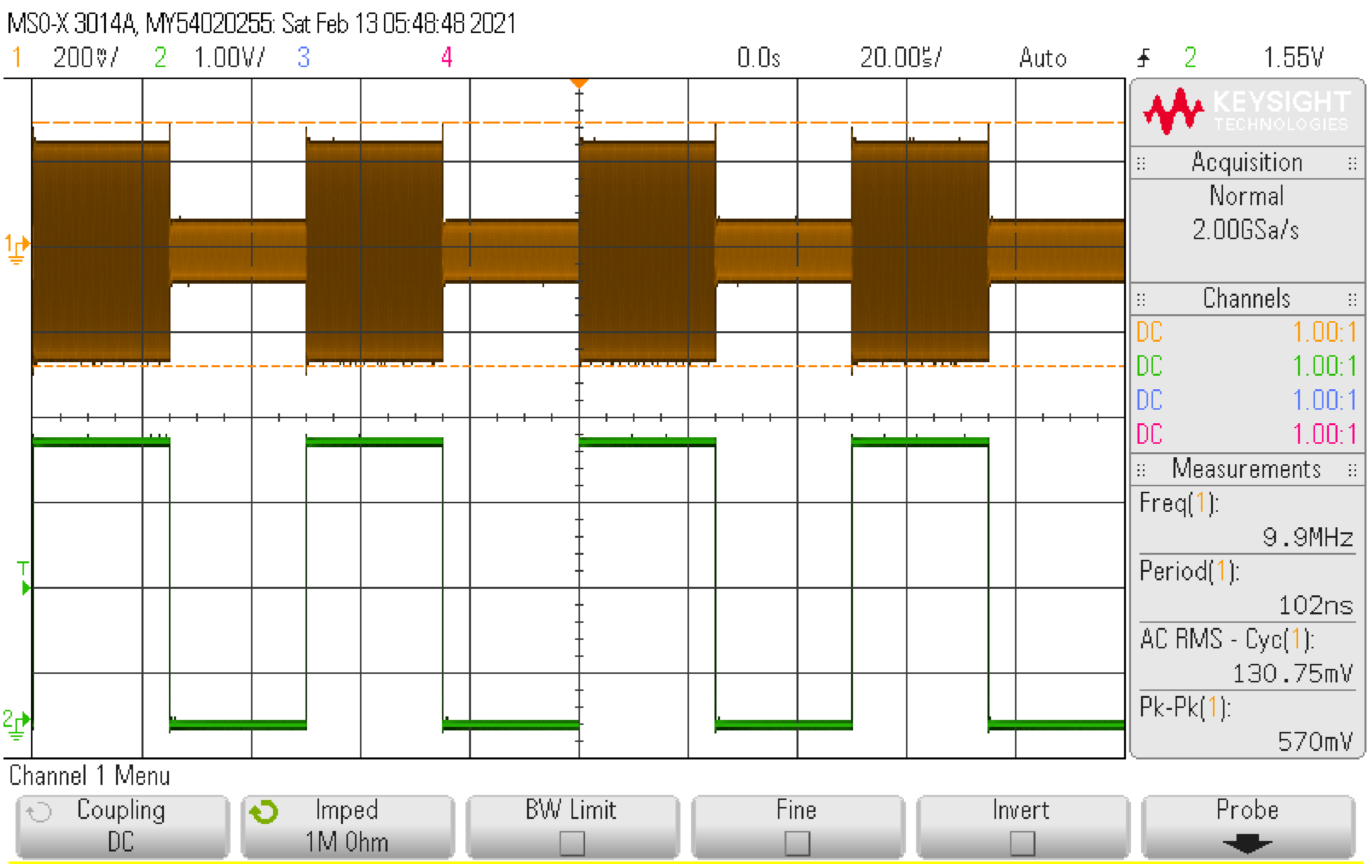
9) Measure the frequency and power of the center carrier and each sideband. Note: the sidebands may be hard to see because only 20 kHz away from the carrier (within the resolution).

Observed Frequency	***Observed Power***
LSB: 9.98MHz	*-16.67dBm*
Carrier: 10MHz	*-6.14dBm*
USB: 10.02MHz	*-16.63dBm*

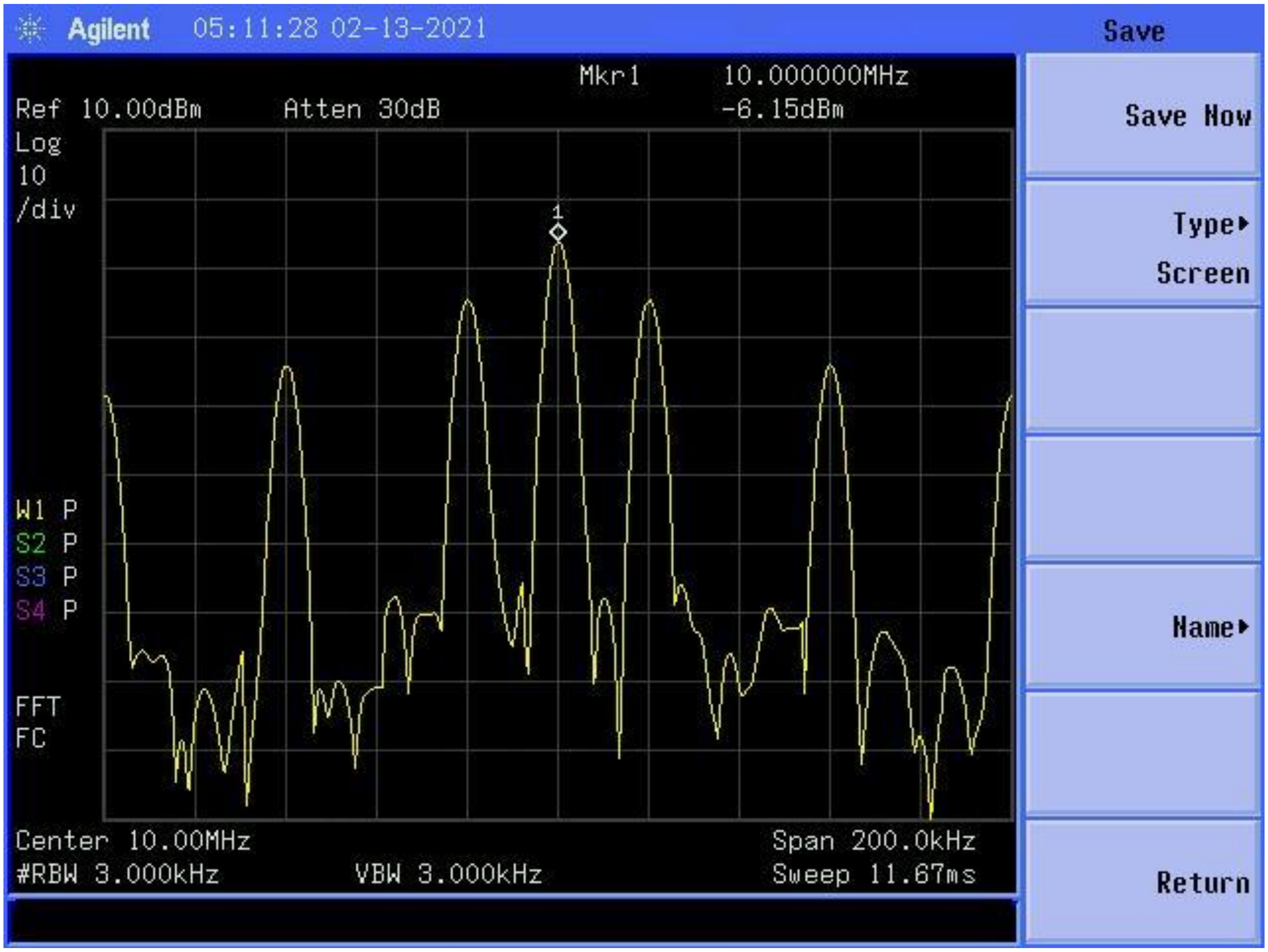
10) Use the formulas presented in the theory section in your previous lab (lab 2) to compare these results with theory.

Calculated Frequency	***Calculated Power***
LSB:	$P_{LSB} = \frac{m^2}{4} * V_c = \frac{0.6^2}{4} * 1mW = 90uW$ $P_{dBm} = 10log\frac{P_{LSB}}{1mW} = 10log\frac{90uW}{1mW} = -10.45dBm$
Carrier:	$P_C = \frac{V_C^2}{2*50} = \frac{316.80mV^2}{2*50} = 1mW$ $P_{dBm} = 10log\frac{P_C}{1mW} = 10log\frac{1mW}{1mW} = 0dBm$
USB:	$P_{USB} = \frac{m^2}{4} * V_c = \frac{0.6^2}{4} * 1mW = 90uW$ $P_{dBm} = 10log\frac{P_{USB}}{1mW} = 10log\frac{90uW}{1mW} = -10.45dBm$

11) Change the shape of the baseband (modulation) signal to square wave. Capture or sketch the oscilloscope and spectrum analyzer displays. Observe and comment on the results.



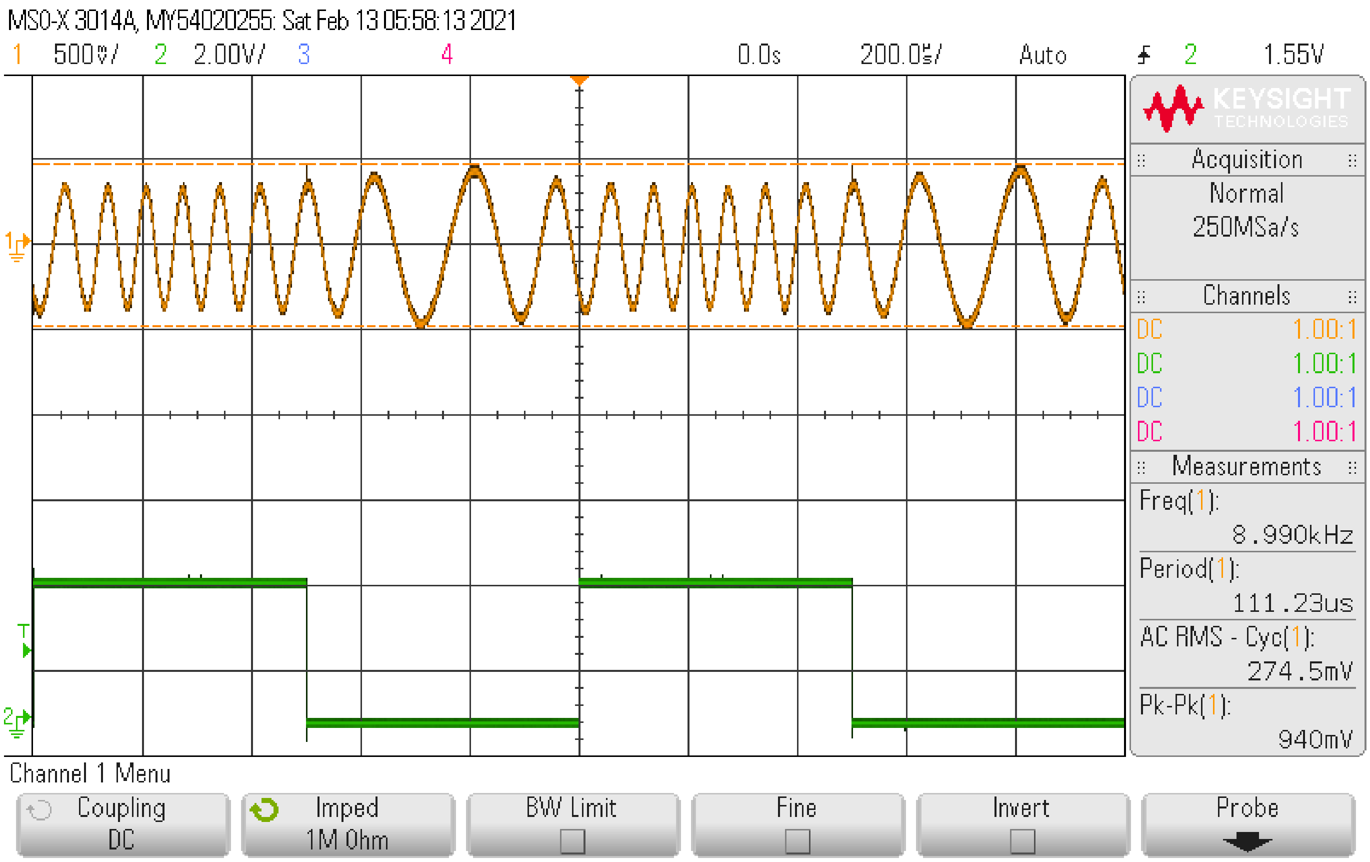
Signal in time domain shown above. Modulation index is 60%. Overall shape of the signal has changed but there is still a high number of frequencies shown. Green square wave is SYNC output from waveform generator.



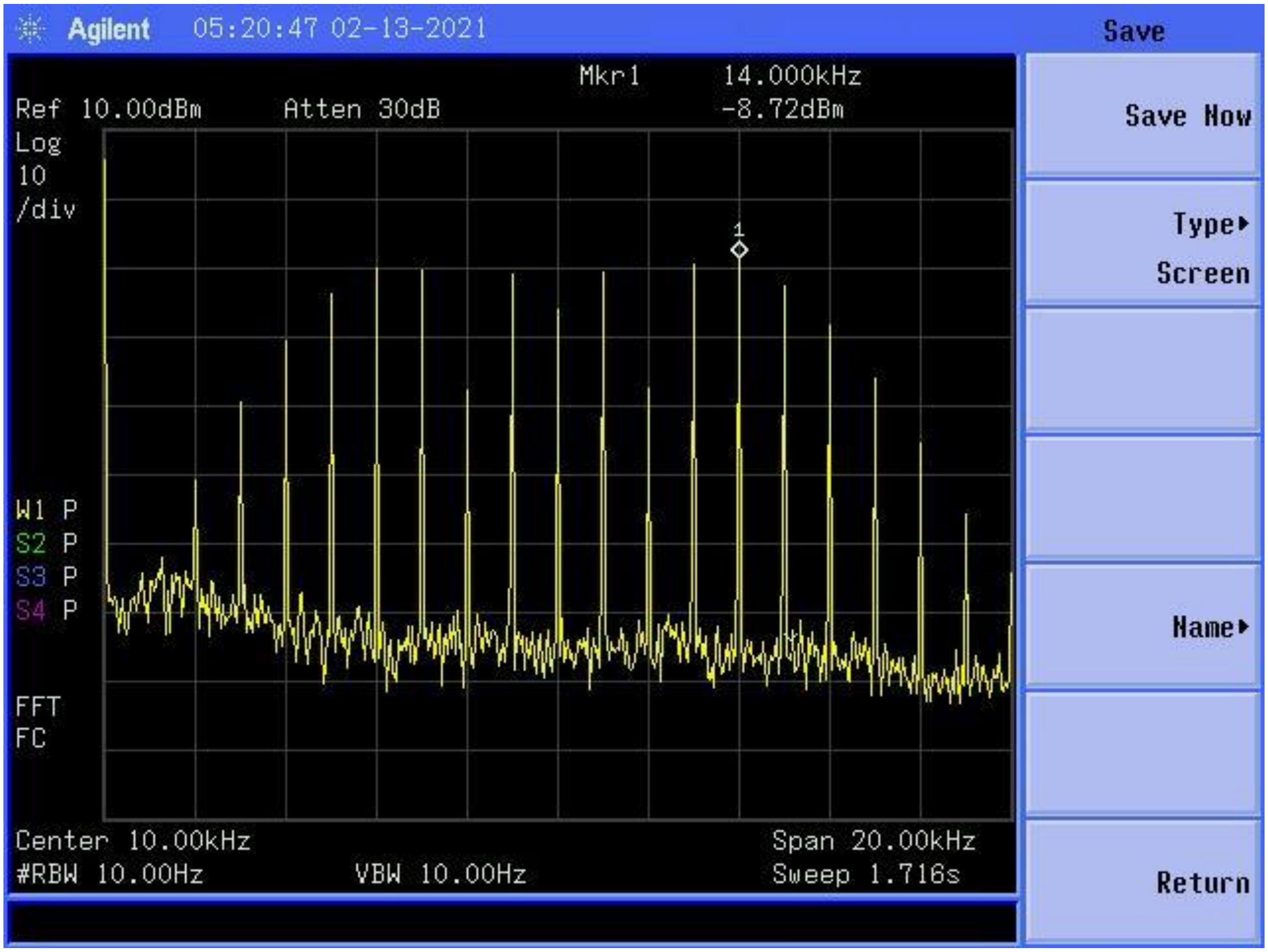
Signal in frequency domain shown above. With the current spectrum analyzer settings, not only are the center and sideband frequencies shown, other spikes (harmonics) are shown as well compared to when the modulated frequency was a sine wave.

Part 2 (Optional):

If you have time try to see a frequency modulated (FM)signal with main frequency of 10KHz, and modulation signal of 1KHz with frequency depth of 1KHz in oscilloscope and spectrum analyzer. (Keep resolution bandwidth low)



FM signal in time domain shown above. What is not shown is that the FM signal is continuously changing in respect to time. Green square wave is SYNC output from waveform generator.



FM signal in frequency domain shown above. In contrast to AM, all the frequencies are shown on the spectrum analyzer display in FM.