Report Title: Experimenting with the AM, FM, and φM modulation capabilities of the SMW200A – signal generator.	
By: Shayma Kulaib Alteneiji	
Description: This is a modified report from the previously submitted report on analog modulation. This report compares the frequency spectrum and the demodulated signal on the IQ analyzer when the LF signal (massage) signal id a train of pulses with periods 100us, and 10us.	
Objective: - *To produce analog modulated signals using the SMW and to view the demodulated signals on the FSW.*	

(Resources: Communication Systems by Simon Haykin, and Signals, Systems, and Transforms by Charles Philips, John Parr, and Eve Riskin.)

Analog Modulations

1. Experimental Setup

In this experimental setup, two power supplies are used. The B1110A pulse-/ pattern generator to provide the LF massage signal, and the SMW to provide the carrier signal. The output (OUTPUT 2) of the pulse generator is connected to the EXT 1 connector of the SMW found on the rear panel, as shown in figure 1. The RF output of the SMW, found on the front panel, is connected to the RF input of the FSW, as shown in figure 2.

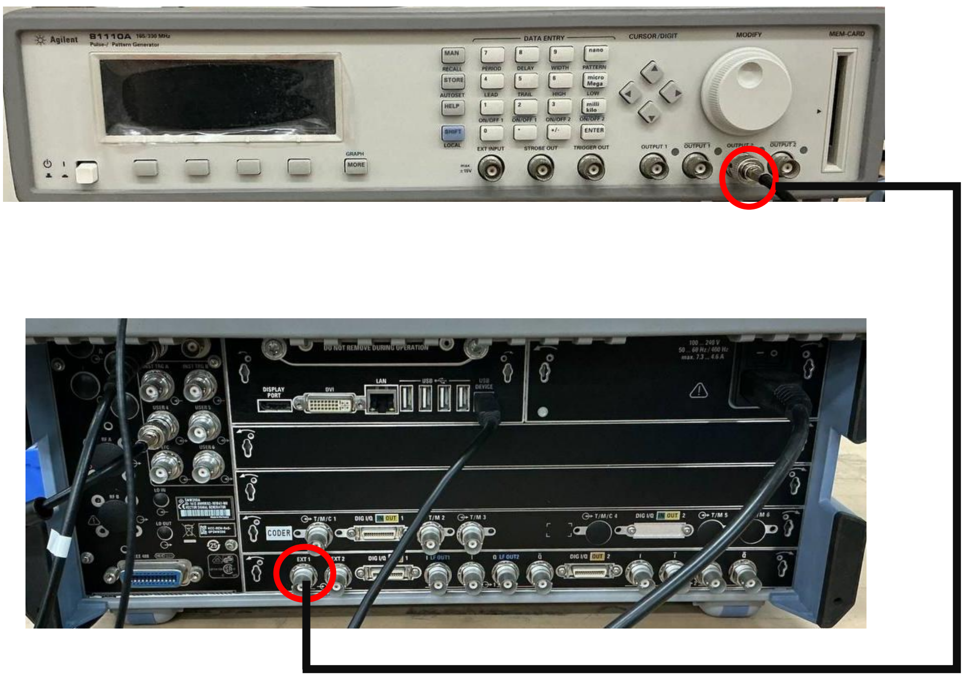

Figure 1. The block diagram showing the connection between the pulse generator and the SMW.

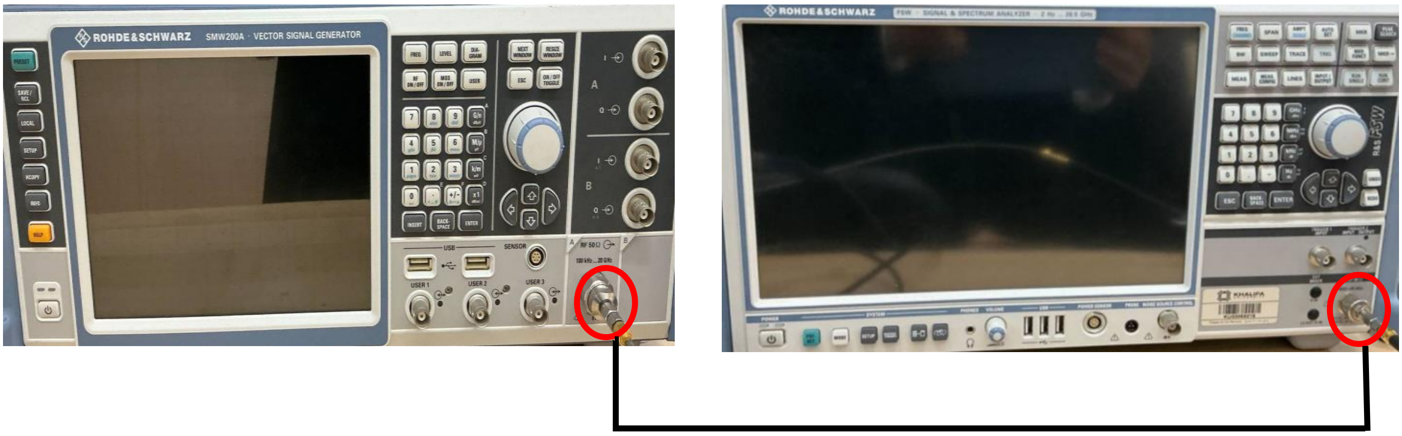

Figure 2. The block diagram showing the connection between the SMW and the FSW.

2. *AM modulation*

This section discusses AM modulation, describes the procedures of producing an AM modulated signal on the SMW, and viewing the demodulated signal on the FSW's IQ analyzer.

Amplitude modulation is a process in which the amplitude of the carrier signal varies by a mean value in accordance with m(t), the massage signal. The equations of the amplitude modulated wave in which the carrier component is not suppressed as a function of time and frequency is given below.

$$s(t) = A[1 + k_a m(t)]\ \sin\,(2\pi f_c t)$$

$$s(f) = \frac{A}{2} \times [\delta(f - f_c) + \delta(f + f_c)] + \frac{A k_a}{2} \times [M(f - f_c) + M(f + f_c)]$$

K_a is in unit of V^{-1}, $k_a \times$ m(t) is called the modulation factor (μ). The modulation factor describes how much the carrier's amplitude varies around its unmodulated level. $\mu \times 100$ is called the *modulation depth* or the percentage modulation.

2.1 Generation of the Modulated Signal on the SMW

To produce an amplitude modulated signal on the SMW; on the home screen, press the "Mod off" box, shown circled in figure 1. In the analog modulation dialog, select the "AM" tab, shown in figure 2. Set the state to "On". Select the modulation depth, herein the modulation depth selected was 100%, finally the select the massage or LF signal generator, whether internal or external. Moreover, the carrier frequency was set to 2.4 GHz, and its power level was set at -10 dBm.

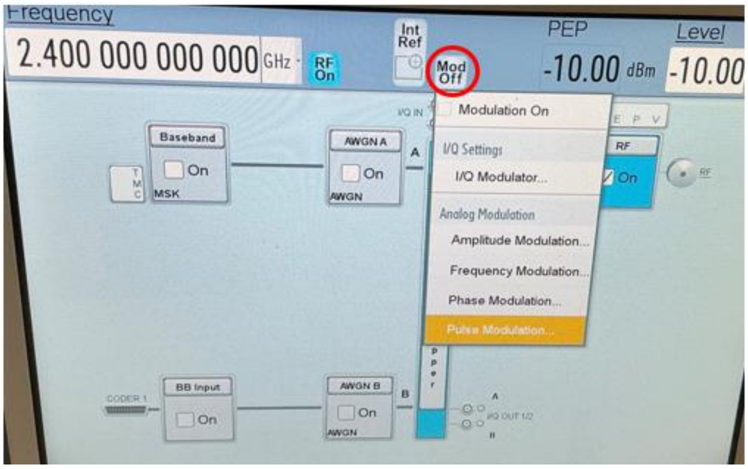

Figure 1. SMW home screen.

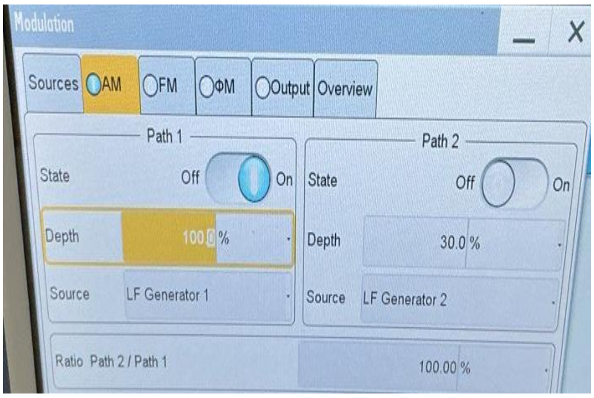

Figure 2. Modulation dialog, AM tab.

The block diagram of a double side band with carrier amplitude modulation (DSB/WC – AM) system is shown in figure 3. c(t) is the carrier signal, and m(t) is the information – bearing signal.

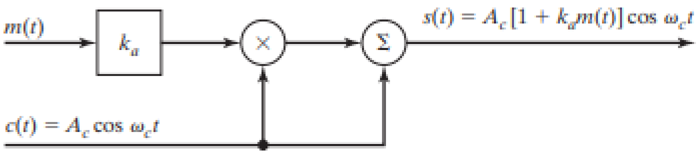

Figure 3. DSB/WC-amplitude modulation system. Taken form the Signal, Systems, and Transforms book.

To select the massage signal waveform on the SMW; in the "Modulation" dialog, select the "Sources" tab. Herein, an amplitude modulated signal was produced with (1) m(t) set as a sine wave with $f = 1$ kHz, as shown in figure 4. (2) m(t) set as a train of pulses with a period of 100 μs, and a pulse width of 1 μs, as shown in figure 5, and (3) using an external pulse generator with the same specifications of the pulses produced by the SMW's internal generator.

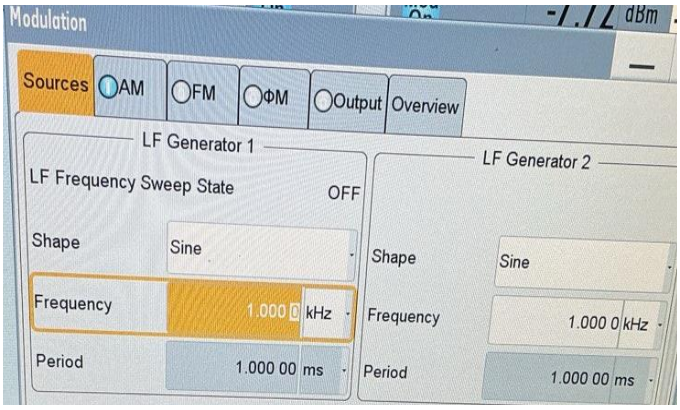

Figure 4. Modulation dialog, sources tab, setting m(t) as a sine wave.

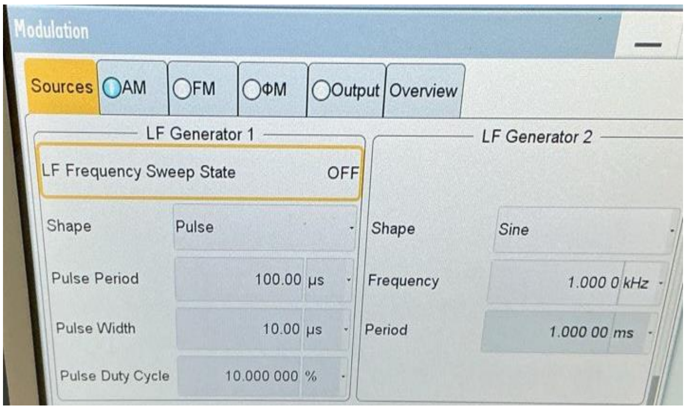

Figure 5. Modulation dialog, sources tab, setting m(t) as a pulses train.

The external source used is the B1110A pulse-/ pattern generator. To configure the generator, press on the first button, "MOD/TRG", the resulting screen is shown in figure 6, change the first option to "Pulses". Press the second button. "TIMING", set the Delay to 2ns, the perioded to 100 μs, and the pulse width to 10 μs. Finally, press the third button, "LEVELS", the resulting screen is shown in figure 7, set the "Offset" to 0V, set the "Amplit" to 1V, and set the impedance to "50 Ω into 50 Ω "when connecting the generator's output to the SMW, and set it to "50 Ω into 1k Ω" when the output is connected to an oscilloscope. The resulting signal could be viewed on the oscilloscope as shown in figure 8. The frequency and amplitude measures on the oscilloscope, shown in figure 8, matched the desired pulses specifications. In the modulation dialog, in the sources tab, configure the characteristics of the external source, "External 1", as given in figure 9.

Figure 6. The pulse generator screen, "MOD/TRIG" tab.

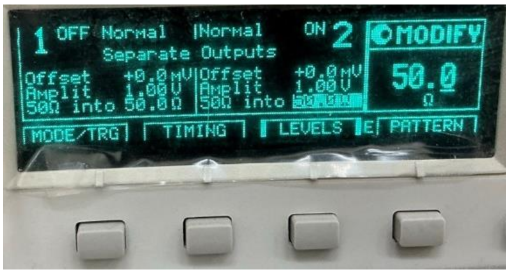

Figure 7. The pulse generator screen, "LEVELS" tab.

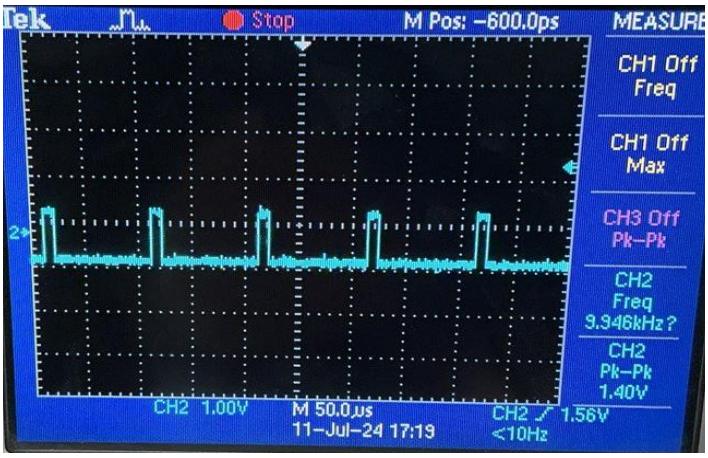

Figure 8. Oscilloscope scree, channel two input is the pulse generator's output. The frequency, and peak -to-peak voltage is shown.

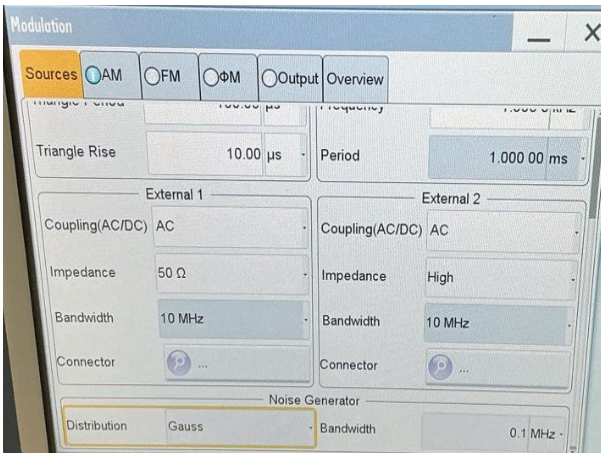

Figure 9. Modulation tab, sources tab. Configuring the external source characteristics.

1.2 Signal demodulation on the FSW

For synchronous demodulation, block diagram shown in figure 10, the carrier frequency (f_c) must be known.

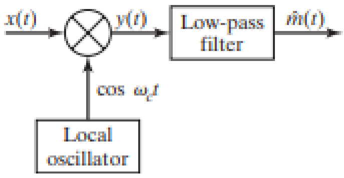

Figure 10. Synchronous demodulator block diagram.

After setting the center frequency on the FSW equal to the carrier frequency, the frequency spectrum of the modulated signal with m(t) set as a sine wave and when m(t) is set as a train of pulses with periods 100us on the FSW are shown in figures 11,12, and 13 respectively. Figures 14, and 15 show the IQ analyzer screen when m(t) is sine wave, and a train of pulses of periods 100us.

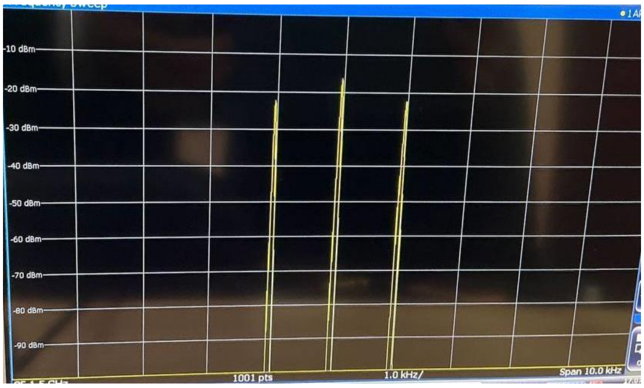

Figure 11. Signal spectrum for an AM modulated signal when m(t) is a sine wave. Span = 10kHz.

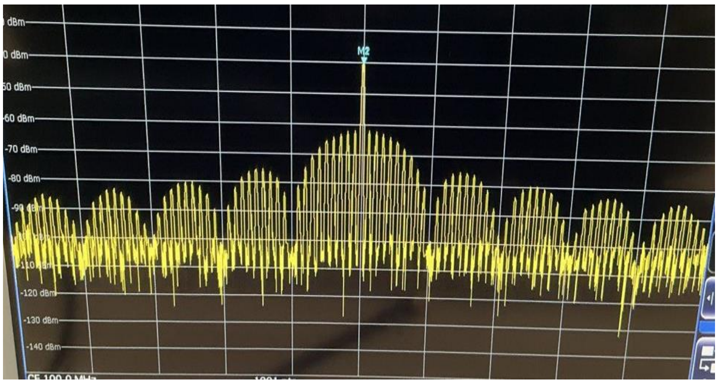

Figure 12. Signal spectrum screen for an AM modulated signal when m(t) is a train of pulses with a period of 100us and a 10% duty cycle. Span = 10MHz.

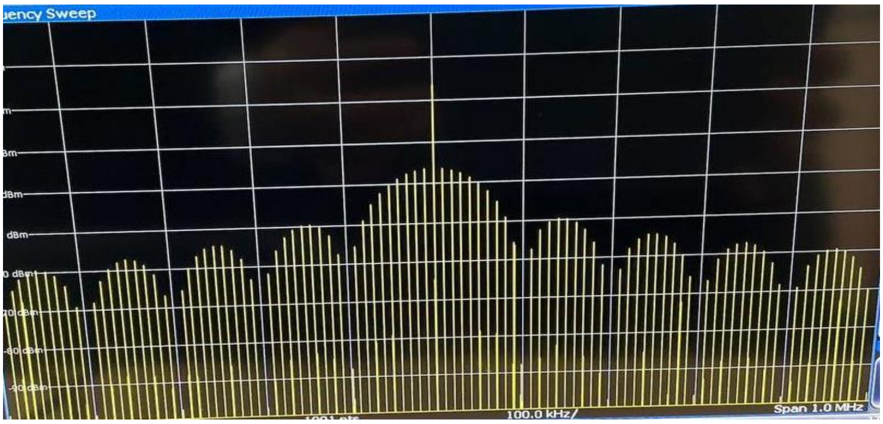

Figure 13. Signal spectrum screen for an AM modulated signal when m(t) is a train of pulses with a period of 100us and a 10% duty cycle. Span = 10MHz.

Figure 14. IQ analyzer screen for a demodulated AM signal when m(t) is a sine wave of a frequency of 1kHz.

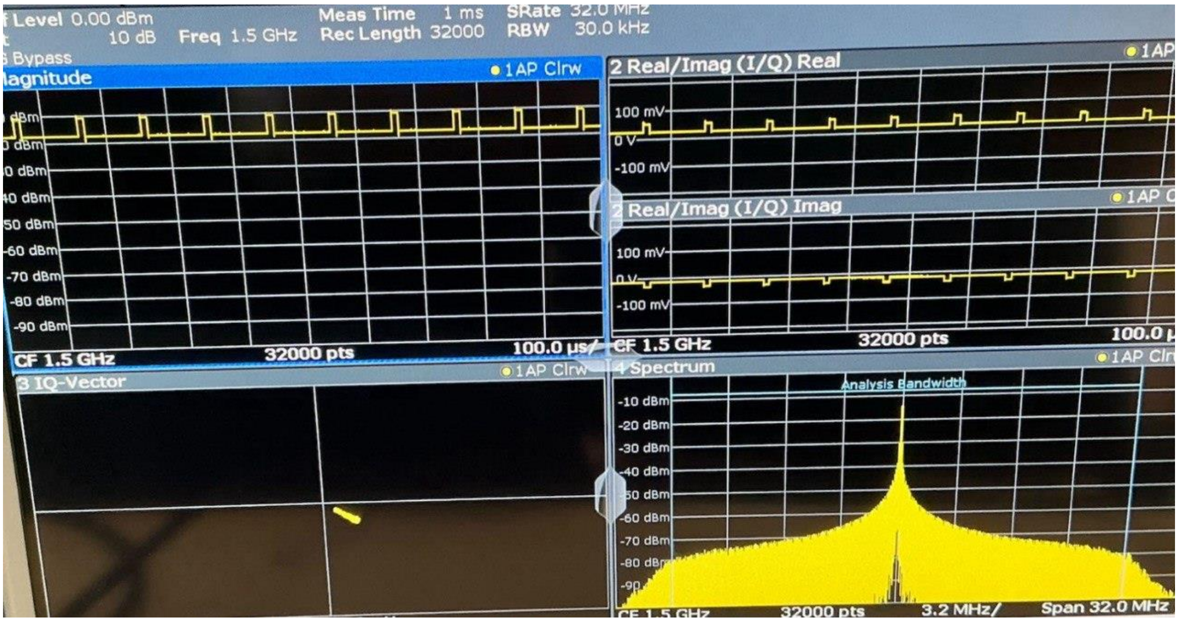

Figure 15. IQ analyzer screen for a demodulated AM signal when m(t) is a train of pulses with a period of 100us and a 10% duty cycle.

1.3 Theoretical analysis of the results

This section discusses the theoretically expected results of the AM modulations carried and compares it to the practical results obtained.

1.3.1 Modulating the carrier signal with a sine wave of 1 kHz frequency

The Fourier transform of the modulated signal is determined below. Ka is 1, considering the case when the modulation depth is 100%.

$$S(f) = FT(A(1+\sin(2000\pi t))\times \sin(3\pi\times 10^2 t))$$

$$|S(f)| = \frac{A}{4}\times\left(\delta(f+1000)+\delta(f-1000)\right) * \left(\delta(f+1.5\times 10^9)+\delta(f-1.5\times 10^9)\right) + \frac{A}{2}\times(\delta(f+1.5\times 10^9) + \delta(f-1.5\times 10^9))$$

$$|S(f)| = \frac{A}{4}\times(\delta(f+1.5\times 10^9+10^3)+\delta(f-10^3+1.5\times 10^9)+\delta(f+1.5\times 10^9+10^3) + \delta(f-10^3+1.5\times 10^9)) + \frac{A}{2}\times(\delta(f+1.5\times 10^9)+\delta(f-1.5\times 10^9))$$

Hence, it is expected to see the Dirac delta function (an impulse) at f = 1.5000001 GHz, 1,499999 GHz, and at 1.5 GHz (as the carrier is not suppressed). Which is what is observed in figure 11. Impulses occurring at negative frequencies are ignored.

1.3.2 Modulating the carrier signal with a train of pulses with a 10% duty cycle, a period of 100 and 10 us.

The m(t) is graphed as shown in figure 16, where T_1 is equal to T/5. The Fourier series of the train of pulses is given below. $2\pi fT = 2\pi$, and $2\pi fT_1 = 2\pi f\left(\frac{T}{5}\right) = \frac{2\pi}{5}$. f = 1/T. The Fourier transform of the modulating signal and the modulated signal is given below.

$$FS(m(t)) = \sum_{k=-\infty}^{\infty}\frac{2\times\sin(k2\pi fT_1)}{k2\pi fT} = \sum_{k=-\infty}^{\infty}\frac{\sin(\frac{2\pi}{5}k)}{k\pi}$$

$$FT(m(t)) = \sum_{k=-\infty}^{\infty} a_k\delta(f-kf) = \sum_{k=-\infty}^{\infty}\frac{\sin(\frac{2\pi}{5}k)}{k\pi}\times\delta(f-kf)$$

$$S(f) = \frac{A}{2}\times\left(\sum_{k=-\infty}^{\infty}\frac{\sin(\frac{2\pi}{5}k)}{k\pi}\times\delta(f-kf)\right) * \left(\delta(f+1.5\times 10^9)+\delta(f-1.5\times 10^9)\right) + \frac{A}{2}\times(\delta(f+1.5\times 10^9) + \delta(f-1.5\times 10^9))$$

$$S(f) = \frac{A}{2}\times\left(\sum_{k=-\infty}^{\infty}\frac{\sin(\frac{2\pi}{5}k)}{k\pi}\times\delta(f-kf+1.5\times 10^9) + \sum_{k=-\infty}^{\infty}\frac{\sin(\frac{2\pi}{5}k)}{k\pi}\times\delta(f-kf-1.5\times 10^9)\right) + \frac{A}{2}\times(\delta(f+1.5\times 10^9)+\delta(f-1.5\times 10^9))$$

Hence, it is expected to observe an impulse at the carrier frequency and a linear combination of the sampled sinc function occurring at f = 1.5 GHz + k(f) with a decreasing amplitude due to the (1/k) factor (where k is not a multiple of 5). When T = 100us, f = 10 kHz, and the sinc functions repeat every 10 kHz, as shown in figure 12. For T = 10 us, the sinc functions repeat every 100 kHz, as shown in figure 13.

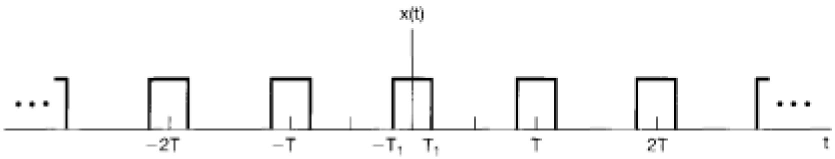

Figure 15. A train of pulses.

1. FM Modulation

This section discusses FM modulation, describes the procedures of producing an FM modulated signal on the SMW, and viewing the demodulated signal on the FSW's IQ analyzer.

Frequency modulation is a form of angle modulation. Let s(t) given below be an angle-modulated wave. The instantaneous phase, $\theta_i(t)$, is related to the instantaneous frequency $f_i(t)$ as given below.

$$s(t) = A \times cos[(\theta_i(t))]$$
$$f_i(t) = \frac{1}{2\pi}\frac{d\theta_i(t)}{dt}$$

For FM modulation, the instantaneous frequency is a linear function of the massage signal as given below. Therefore, solving for $\theta_i(t)$ from the equation given above and substituting it into s(t) results in the equation shown below. Hence, for FM modulation, the modulated signal's frequency is a non-linear function of the massage signal, m(t).

$$f_i(t) = f_c + k_f m(t)$$
$$s(t) = A \times cos\left[(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau\right]$$

k_f is the frequency sensitivity. The frequency deviation (Δf) is equal to $k_f \times A_m$, where A_m is the massage signal's amplitude. The frequency deviation describes maximum departure of the instantaneous frequency from the carrier frequency.

1.1 Generation of the Modulated signal on the SMW

To produce an FM modulated signal, press on the "Mod off" box on the SMW's home screen. In the "Modulation dialog" select the "FM" tab, shown in figure 17. Set the state to "On" and set the frequency deviation as required. A modulated signal was produced for a frequency deviation of 1 kHz, and 10 MHz. The carrier signal frequency was set to 2.4 GHz, and its power level was set to -10 dBm. The procedure followed for setting the modulating signal is described in section 1.1.

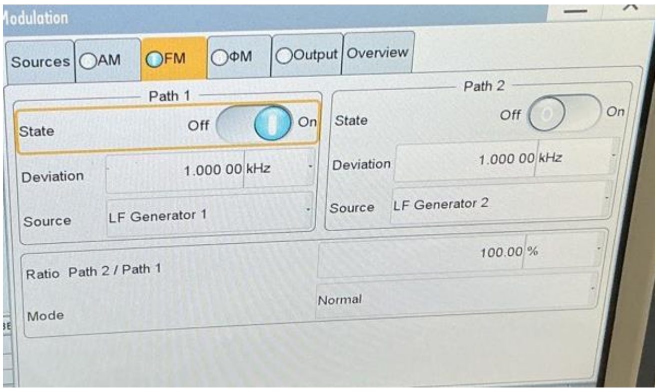

Figure 17. Modulation dialog, FM tab.

1.2 Signal demodulation on the FSW

The frequency spectrums of the FM modulated signal when the massage signal when m(t) is a 1 kHz sine wave, and a train of pulses of 100us, and 10us with $\Delta f = 3$ kHz are shown in figure 18, 19, and 20, and for $\Delta f = 100$ kHz are shown in figures 21, 22, and 23. The IQ analyzer tab screens of the demodulated FM signal when m(t) is a sine wave with $\Delta f = 3$ kHz and with $\Delta f = 100$ kHz are shown in figures 24, and 25, respectively. The IQ analyzer screens when m(t) is a train of pulses with periods of 100 us, and 10 us, for $\Delta f = 3$ kHz are shown in figures 26, and 27, respectively, and for $\Delta f = 100$ kHz, are shown in figure 28, and 29, respectively.

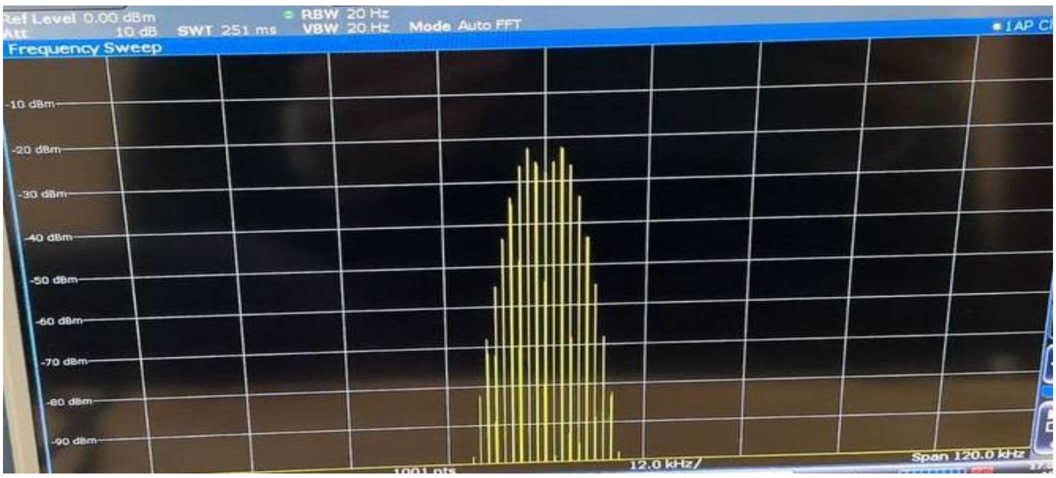

Figure 18. Signal spectrum screen for a FM modulated signal when m(t) is a 1 kHz sine wave. Frequency deviation is 3kHz. Span = 120 kHz.

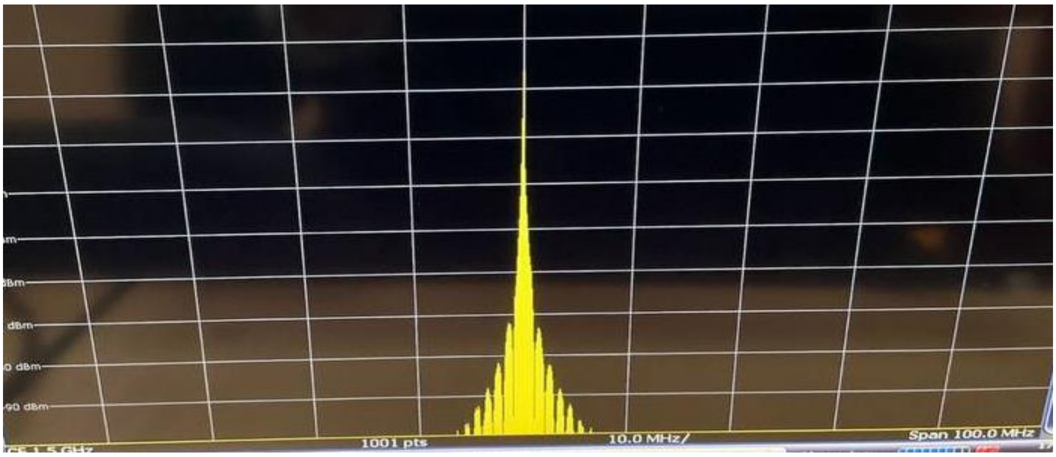

Figure 19. Signal spectrum screen for a FM modulated signal when m(t) is train of pulses of period 100us. Frequency deviation is 3kHz. Span = 100 MHz.

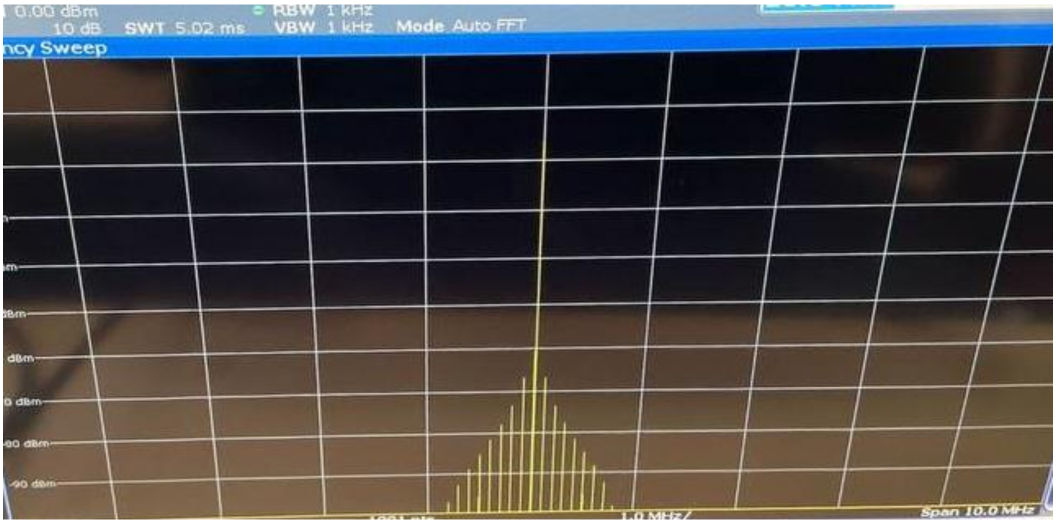

Figure 20. Signal spectrum screen for a FM modulated signal when m(t) is train of pulses of period 10us. Frequency deviation is 3kHz. Span = 100 MHz.

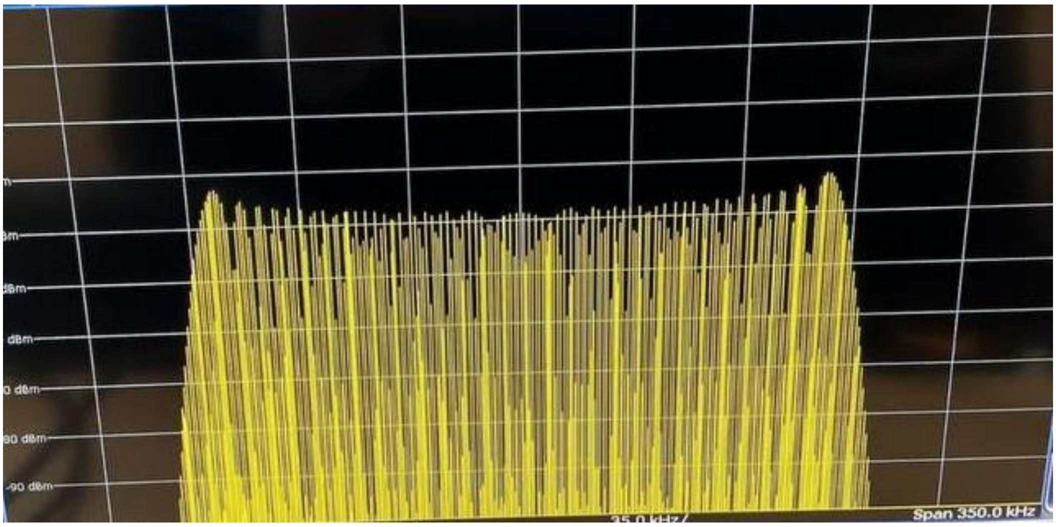

Figure 21. Signal spectrum screen for a FM modulated signal when m(t) is a 1 kHz sine wave. Frequency deviation is 100 kHz. Span = 350 kHz.

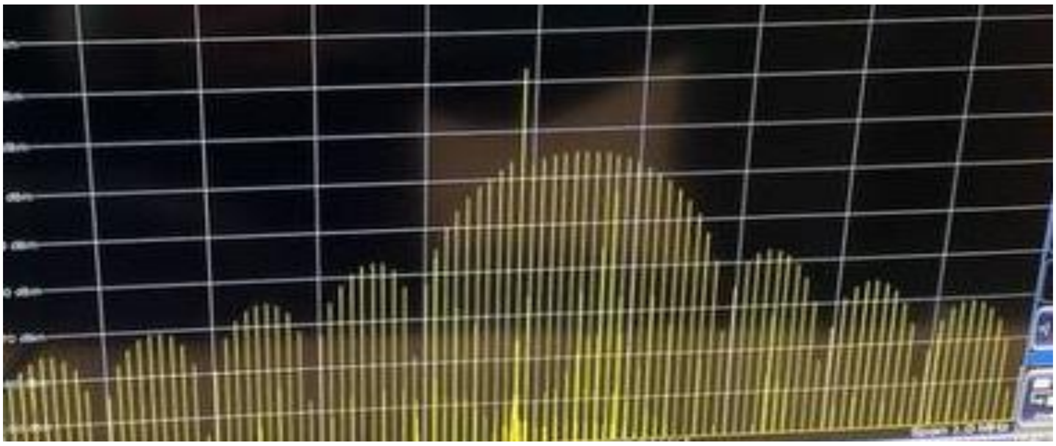

Figure 22. Signal spectrum screen for a FM modulated signal when m(t) is train of pulses of period 100us. Frequency deviation is 100kHz. Span = 1 MHz.

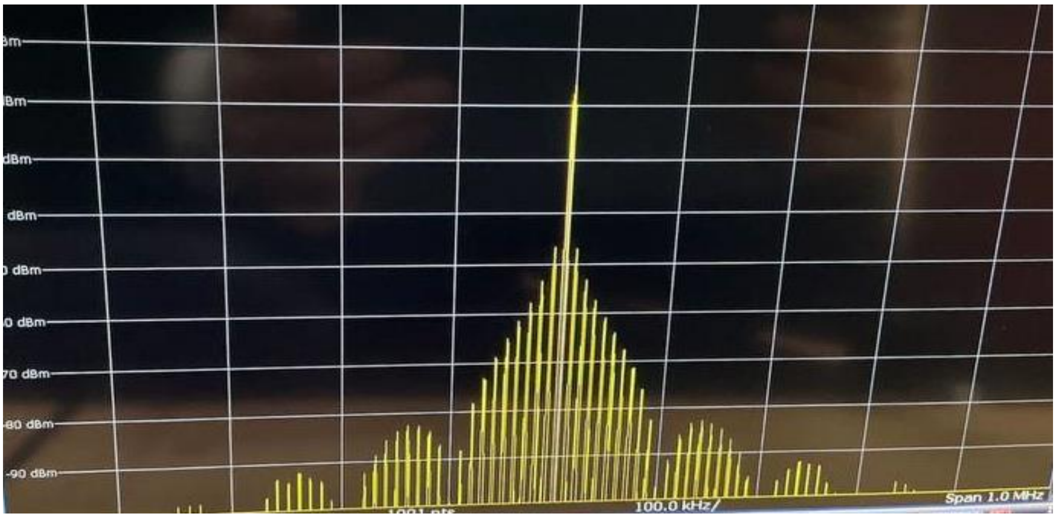

Figure 23. Signal spectrum screen for a FM modulated signal when m(t) is train of pulses of period 100us. Frequency deviation is 100kHz. Span = 1 MHz.

Figure 24. Signal spectrum screen for a FM modulated signal when m(t) is a sine wave. Frequency deviation is 3kHz.

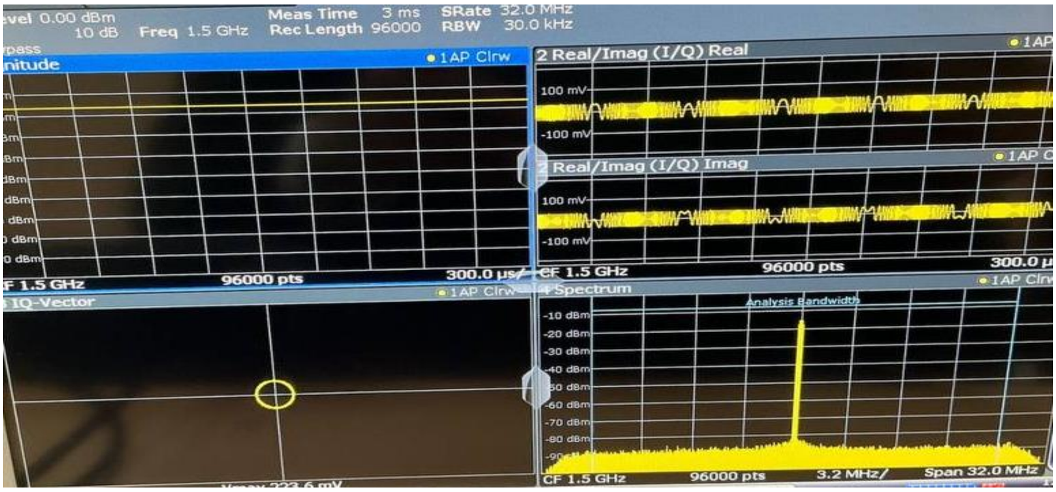

Figure 25. Signal spectrum screen for a FM modulated signal when m(t) is a sine wave. Frequency deviation is 100kHz.

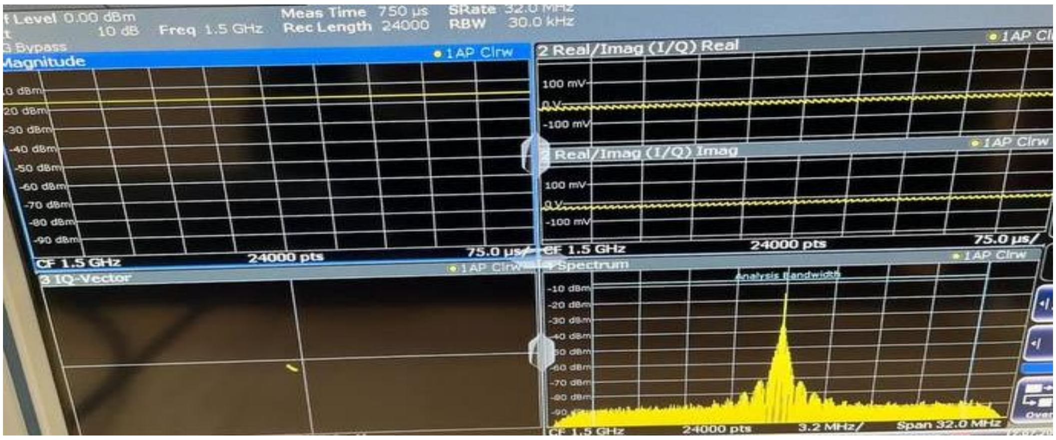

Figure 26. IQ analyzer screen for a demodulated AM signal when m(t) is a train of pulses of period of 100us. Frequency deviation (Δf) is 3 kHz.

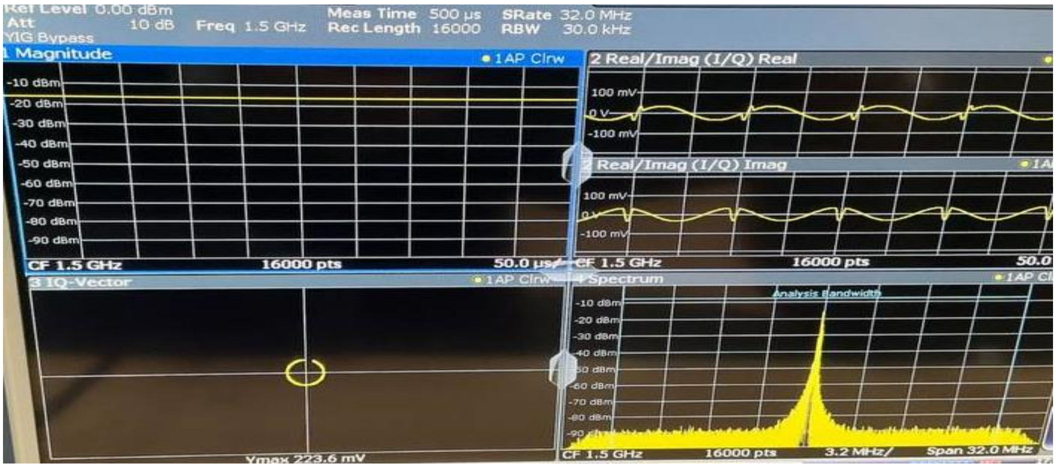

Figure 27. IQ analyzer screen for a demodulated AM signal when m(t) is a train of pulses of period of 100us. Frequency deviation (Δf) is 100 kHz.

Figure 28. IQ analyzer screen for a demodulated AM signal when m(t) is a train of pulses of period of 10us. Frequency deviation (Δf) is 3 kHz.

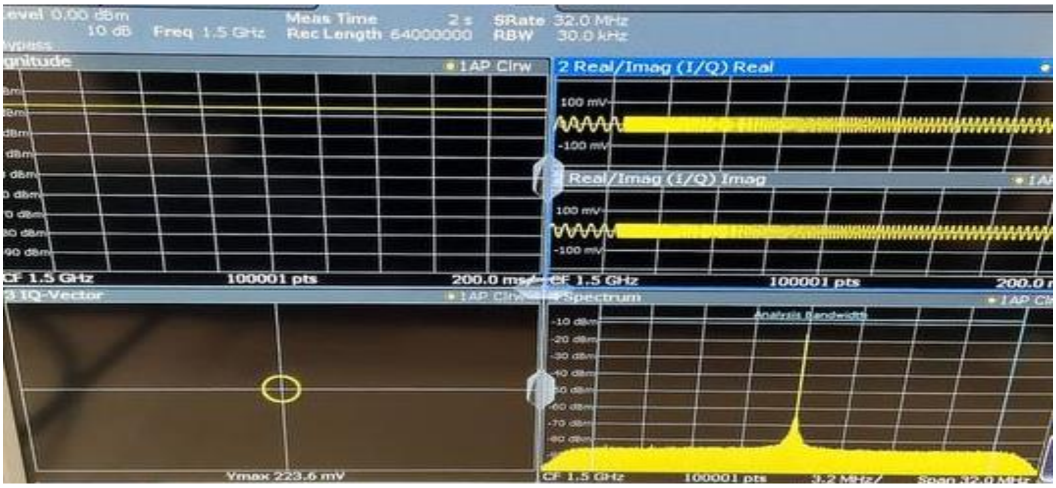

Figure 29. IQ analyzer screen for a demodulated AM signal when m(t) is a train of pulses of period of 10us. Frequency deviation (Δf) is 100 kHz.

2. Phase Modulation

This section discusses phase modulation, describes the procedures of producing a phase modulated signal on the SMW, and viewing the demodulated signal on the FSW's IQ analyzer.

Phase modulation is a form of angular modulation in which the instantaneous phase is varied linearly with the massage signal, as given below. The phase modulated signal is therefore given by the equation shown below.

$$\theta_i(t) = 2\pi f_c t + k_p m(t)$$

$2\pi f_c t$ is the angle of the unmodulated signal (which is zero at t = 0). k_p is the phase sensitivity of the modulating signal in units of V^{-1}. The phase deviation (β) is equal to $\Delta f / f_m$, where f_m is the frequency of the massage signal. The phase deviation describes maximum deviation of the instantaneous phase from the unmodulated carrier phase ($2\pi f_c t$).

2.1 Generation of the Modulated signal on the SMW

To produce a phase modulated signal, press on the "Mod off" box on the SMW's home screen. In the "Modulation dialog" select the "φM" tab, shown in figure 30. Set the state to "On" and set the frequency deviation as required. Herein, a modulated signal was produced for a phase deviation of 0.1 rad, and 10 rad. The carrier signal frequency was set to 2.4 GHz, and its power level was set at -10 dBm.

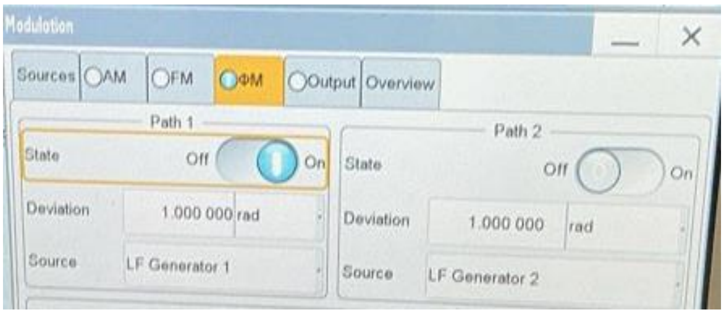

Figure 30. Modulation dialog, φM tab.

2.2 Signal demodulation on the FSW

The frequency spectrum of the phase modulated signal when the massage signal, m(t) is a train of pulses, is shown in figure 31.

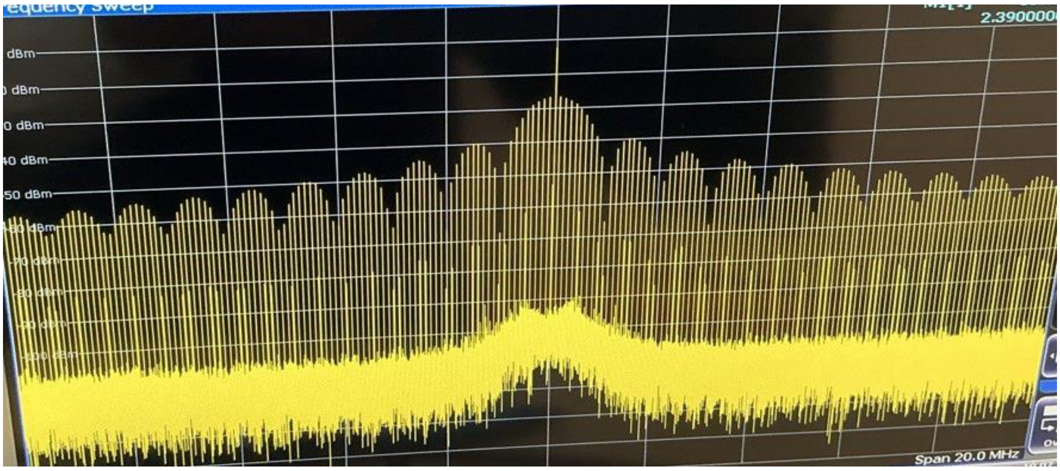

Figure 31. Signal spectrum screen for a phase modulated signal when m(t) is a train of pulses with a period of 100us and a 10% duty cycle.

The IQ analyzer tab screen of the demodulated PhiM signal when m(t) is a train of pulses with $\beta = 1$ rad, is shown in figure 32.

Figure 32. IQ analyzer screen for a demodulated AM signal when m(t) is a train of pulses with a period of 100us and a 10% duty cycle. Frequency deviation (β) is 1 rad.