Title: Double Sideband Modulation Using IQ Mixer
Objective: To perform double sideband (DSB) modulation using an IQ mixer and evaluate the up-conversion of a low-frequency signal to a higher frequency.
Equipment: - R&S Vector Signal Generator SMW200A, 100kHz - 20 GHz - R&S Signal and Spectrum analyzer FSW, 2Hz - 26.5 GHz - Function Generator - Power Splitter - IQ Mixer - Wideband load - Oscilloscope - RF Cables
Remarks: - Never connect a DC coupled source or an active device directly to the SA or to the source unless you are sure it is AC-coupled. When in doubt, use a DC-BLOCK. - Use short cables, account for the insertion loss. - Use Torque wrench

Description:

In this experiment, the spectrum of an up-converted signal will be measured using the SMW200A spectrum analyzer. The procedures are described below.

1. The function generator was set to produce a 1 MHz sine wave with 225 mVrms voltage level.
2. The signal generator (SMW) was configured to generate the local oscillator (LO) signal with an amplitude of 13 dBm at 6 GHz.
3. Using the IQ mixer pinout shown in figure 1, the low-frequency (IF) signal from the function generator was connected to pin number 1, and pin 3 was grounded.
4. The high-frequency LO signal was inputted into the LO port of the IQ mixer.
5. The RF port of the IQ mixer was connected to the spectrum analyzer to observe the up-converted RF signal.
6. The RBW and VBW were set to 500kHz, and the center frequency was set to 6 GHz.
7. The results on the spectrum analyzer were recorded.
8. The function generator of the IF signal was configured to produce a square wave, results obtained on the spectrum analyzer were recorded.
9. Finally, the RBW and VBW were varied to 1kHz, 10kHz, 100 kHz, 1MHz, 10MHz, and observation of results were recorded.

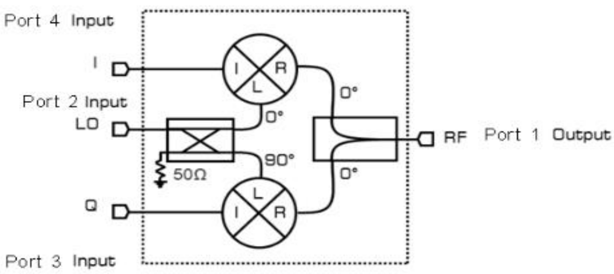

Figure 1. IQ mixer pinout.

Analysis:

Theoretical analysis:

For a sine wave as a baseband signal:

I(t) = Q(t) $= 225 \times \sin(2\pi f_{int} t)$ mV$_{rms}$, $f_{int} = 1MHz$

Carrier Signal (in-phase): C1(t) = $1000 \times \cos(2\pi f_c t)$ mV$_{rms}$, $f_c = 6\ GHz$

Carrier Signal (90 degrees out of phase): C2(t) = $1000 \times \sin(2\pi f_c t)$ mV$_{rms}$, $f_c = 6\ GHz$

$$I(f) = Q(f) = \frac{225}{2} \times \left(\delta(f + f_{int}) + \delta(f - f_{int})\right),$$

$$C1(f) = \frac{1000}{2} \times \left(\delta(f + f_c) + \delta(f - f_c)\right)$$

$C2(f) = \left|\frac{1000}{2} \times \left(\delta(f + f_{int}) - \delta(f - f_{int})\right)\right| = \frac{1000}{2}\ |\delta(f + f_{int})| + \frac{1000}{2}\ \left|e^{j\pi} \times \delta(f - f_{int})\right|$, Therefore,

$$C1(f) = C2(f) = \frac{1000}{2} \times \left(\delta(f + f_c) + \delta(f - f_c)\right)$$

$$\left|F\left(\mathrm{I(t)} \times \mathrm{C1(t)}\right)\right| = \left|F\left(\mathrm{Q(t)} \times \mathrm{C2(t)}\right)\right| = I(f) * C1(f) = Q(f) * C2(f)$$

$$Q(f) * C1(f) = \frac{1000}{2} \times \frac{225}{2} \times \left(\delta(f + f_{int}) + \delta(f - f_{int})\right) * \left(\delta(f + f_c) + \delta(f - f_c)\right)$$

$$Q(f) * C1(f) = 562500 \times \left(\delta(f + f_c + f_{int}) + \delta(f - f_c + f_{int}) + \delta(f + f_c - f_{int}) + \delta(f - f_c - f_{int})\right)$$

Excluding negative frequencies:

$$Q(f) * C1(f) = 562500 \times \left(\delta(f - f_c + f_{int}) + \delta(f - f_c - f_{int})\right)$$

$$I(f) * C1(f) + Q(f) * C2(f) = 2 \times 562500 \times \left(\delta(f - f_c + f_{int}) + \delta(f - f_c - f_{int})\right)$$

Therefore, the two sidebands occur at $\boldsymbol{f = f_c - f_{int}, and\ f_c + f_{int}}$ **= 5.999 MHz, and 6.001 MHz.**

Ideally, the frequency spectrum of the summation signal, $(\mathrm{I(t)} \times \cos(2\pi f_{int} t) + \mathrm{Q(t)} \times \sin(2\pi f_{int} t))$, should be as illustrated in figure 2.

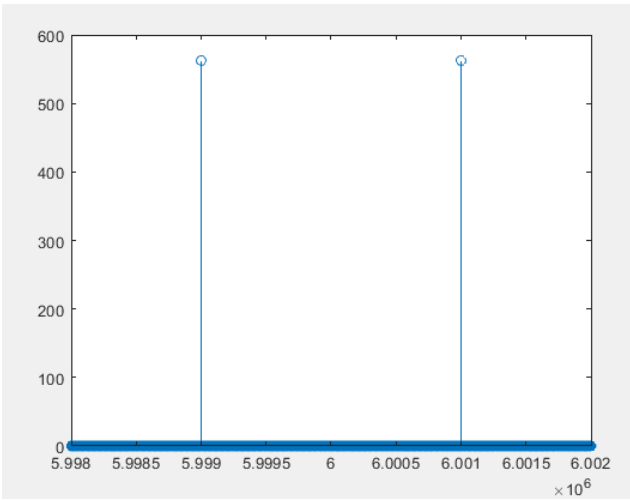

Figure 2. MATLAB simulation of the up-converted signal for an IF signal of a sine wave.

For a square wave as a baseband signal:

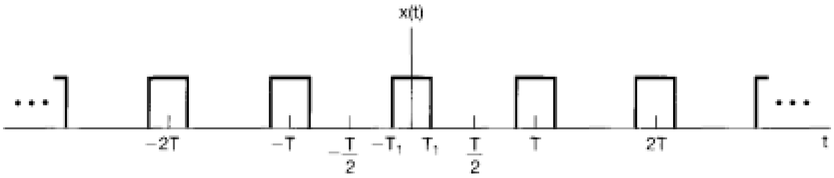

Figure 3. A periodic square wave

$FS(I(t)) = FS(Q(t)) = \ 1000 \sum_{k=-\infty}^{\infty} \frac{2\times\sin(kw_{int}T_1)}{kw_{int}T}$

$w_{int}T = 2\pi, and\ w_{int}T_1 = \ w_{int}\left(\frac{T}{4}\right) = \frac{\pi}{2}$, therefore,

$FS\big(I(t)\big) = FS\big(Q(t)\big) = \ 1000 \sum_{k=-\infty}^{\infty} \frac{\sin\left(\frac{k\pi}{2}\right)}{k\pi} = \frac{sinc(\frac{k\pi}{2})}{2}$, for a 50% ($T_1$ = 4T) duty cycle square wave, the Fourier series of the signal is a linear combination of complex sinusoids occurring at odd multiples of the fundamental frequency (odd harmonics). The Fourier transform is calculated as shown below.

$FT\big(I(t)\big) = FT\big(Q(t)\big) = 1000 \sum_{k=-\infty}^{\infty} a_k \delta(f - kf_{int}) = \ 1000 \sum_{k=-\infty}^{\infty} \frac{2\times sin(\frac{k\pi}{2})}{k} \times \delta(f - kf_{int})$, therefore,

$I(f) * C1(f) = \ 1000 \times \frac{225}{2} \times \left(\sum_{k=-\infty}^{\infty} \frac{2\times sin(\frac{k\pi}{2})}{k} \times \delta(f - kf_{int})\right) * \big(\delta(f + f_c) + \delta(f - f_c)\big)$, finally,

$I(f) * C1(f) + \ Q(f) * C2(f) = 1000 \times 225 \times \ \sum_{k=-\infty}^{\infty} \frac{2\times sin(\frac{k\pi}{2})}{k} \times \big(\delta(f - kf_{int} + f_c) + \delta(f - kf_{int} - f_c)\big)$

The Fourier transform is therefore the superposition of the samples of the sinc function occurring at $\boldsymbol{f = \ kf_{int} + f_c, and\ kf_{int} - f_c}$, with a decreasing amplitude due to the (1/k) factor, where k is an odd number, (sin for k even are zeros). A sketch of the expected waveform is shown in figure 4.

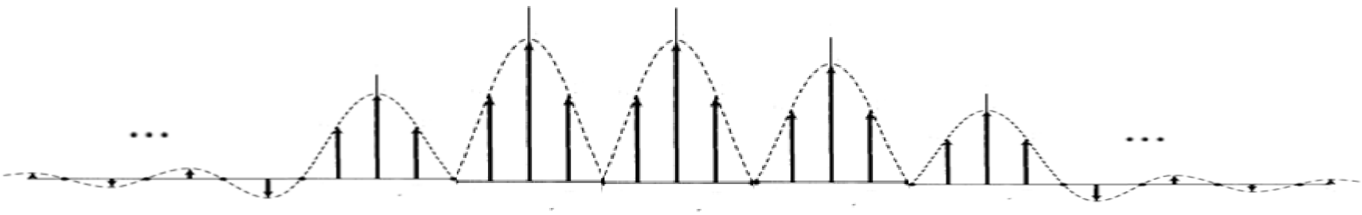

Figure 4. Sketch of theoretical result of the up-converted signal for an IF signal of a square wave.

Practical Results:

Figure 4 shows the results on the spectrum analyzer with an IF signal of a sine wave, and with RBW = VBW = 500kHz. Table 1 records obtained from the spectrum analyzer.

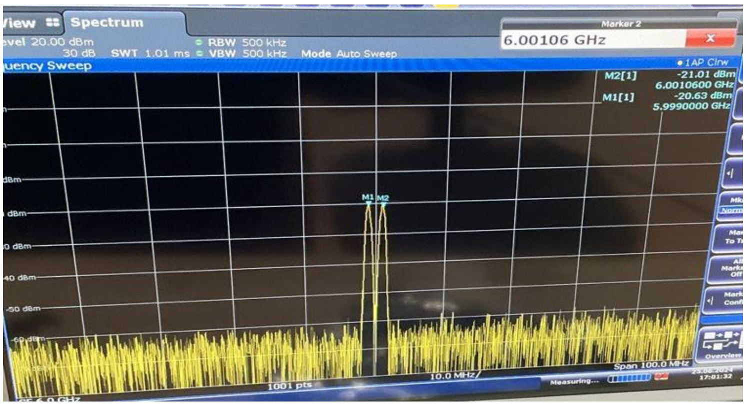

Figure 4. Spectrum analyzer results for an IF signal of a sine wave with RBW=VBW = 500kHz.

Table 1. Spectrum analyzer results for and IF signal of a sine wave, and RSB = VBW = 500kHz

Baseband signal: Sine wave		
RBW = VBW = 500kHz		
	Frequency	Power level
Carrier Signal	-	-
Side bands	5.999 GHz	-20.63 dBm
	6.001 GHz	-21.01 dBm
Noise floor	-60 dBm	

Figures 5-10 show the results on the spectrum analyzer with an IF signal of a square wave and with RBW = VBW = 500kHz, 1 kHz, 10 kHz, 100 kHz, 1 MHz and 10 MHz, respectively. Table 2 records the results obtained from the spectrum analyzer for each RBW & VBW.

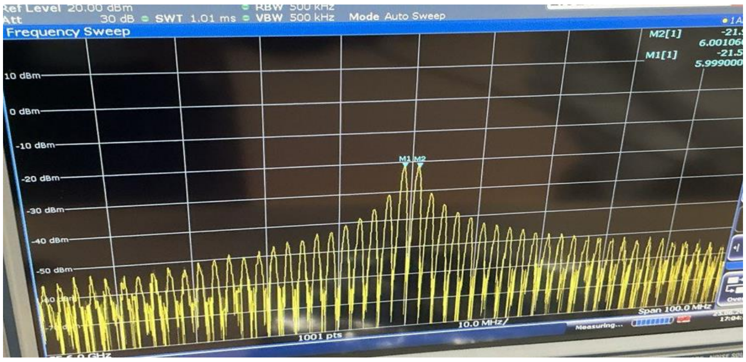

Figure 5. Spectrum analyzer results for an IF signal of a square wave with RBW=VBW = 500kHz.

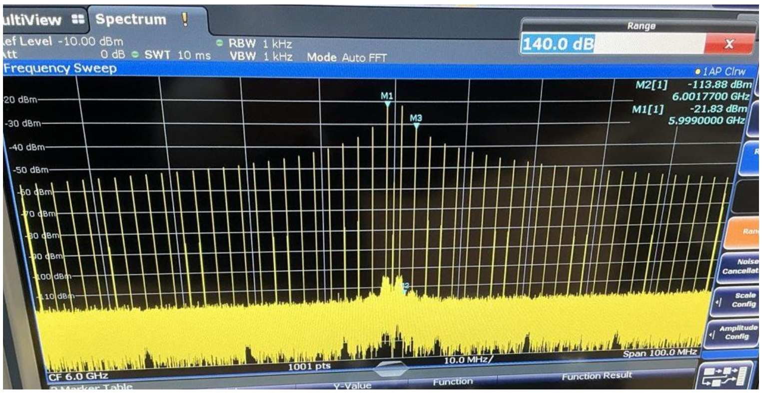

Figure 6. Spectrum analyzer results for an IF signal of a square wave with RBW=VBW = 1kHz.

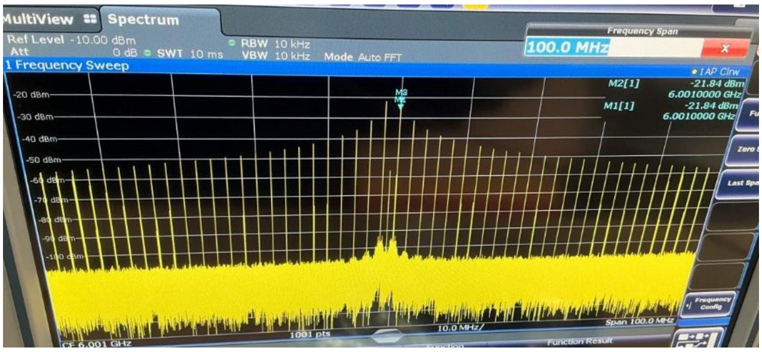

Figure 7. Spectrum analyzer results for an IF signal of a square wave with RBW=VBW = 10 kHz.

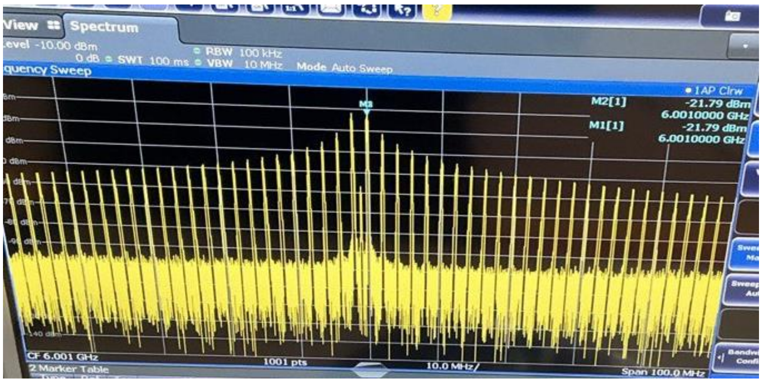

Figure 8. Spectrum analyzer results for an IF signal of a square wave with RBW=VBW = 100 kHz.

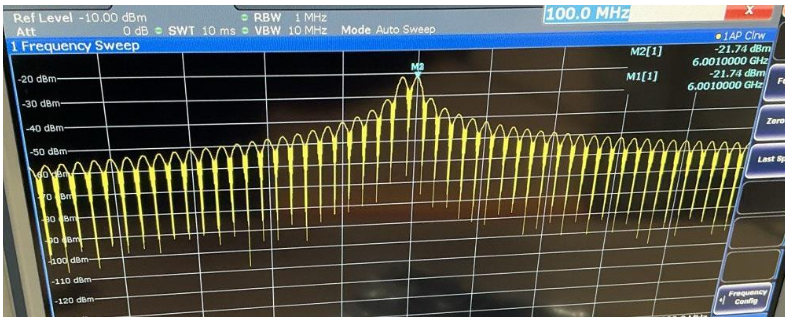

Figure 9. Spectrum analyzer results for an IF signal of a square wave with RBW=VBW = 1 MHz.

Figure 10. Spectrum analyzer results for an IF signal of a square wave with RBW=VBW = 10 MHz.

Table 2. Spectrum analyzer results for and IF signal of a square wave

	Baseband signal: Square wave											
	RBW = VBW = 500kHz		RBW = VBW = 1 kHz		RBW = VBW = 10 kHz		RBW = VBW = 100 kHz		RBW = VBW = 1 MHz		RBW = VBW = 10 MHz	
	Frequency (GHz)	Power level (dBm)	Frequency (GHz)	Power level (dBm)	Frequency (GHz)	Power level (dBm)	Frequency (GHz)	Power level (dBm)	Frequency (GHz)	Power level (dBm)	Frequency (GHz)	Power level (dBm)
Carrier signal	-	-	6 GHz	-61.59	6	-61.2 dBm	6 GHz	-61.0 dBm	-	-	-	-
Sidebands	6.001	-21.95	6.001	-21.83	6.001	-21.84	6.001	-21.79	6.001	-21.72	6.001 GHz	-17.79
	5.999	-21.58	5.999	-21.64	5.999	-21.84	5.999	-21.82	5.999	-21.72	-	-
	6.003	-31.1	6.003	-31.45	6.003	-31.0	6.003	-30.5	6.003	-31.2	-	-
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Analysis of Results

The theoretically estimated results match the practical results. As the RBW decreases, more signals could be viewed and the narrower the bandwidth of the individual signals were, and hence the closer they are to the ideal scenario of zero bandwidth of an impulse signal.

Conclusion

In this experiment, the concept of I/Q modulation was introduced by experimentally modulating a baseband signal and analyzing the resulting signal on a spectrum analyzer. The spectrum analyzer results were observed for a baseband signal of a sine and a square wave.