A Simplified Subharmonic I/Q Modulator

This passive vector modulator uses opposite polarity diode pairs for frequency doubling to extend the range of operation

By Ian Doyle M/A-COM Eurotec Operations

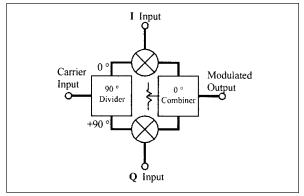
n I/Q modulator is frequently used in modern digital communication systems. This passive vector modulator consists of a quadrature hybrid, two balanced mixers and an in-phase power combiner. With the increase in frequency of operation, from 900 MHz to 1800 MHz and beyond, the subharmonic modulator is getting more attention in digital communication system design. The component count for the subharmonic modulator is similar to the fundamental I/Q modulator except the diodes used in the subharmonic version are anti-parallel pairs.

These subharmonic modulators offer some distinct advantages over existing fundamental I/Q modulators. The local oscillator (LO) signal required is half the RF frequency of interest which provides LO to RF isolation in the order of 60 dB. The carrier suppression is greater than 50 dBc and there is suppression of the even L x even R and odd L x odd R products. This paper will show the circuit designs used and review the trades off between using fundamental modulators and subharmonic modulators, with illustrating data.

The technique of amplitude modulation has been extensively used in the telecommunications industry. It consists of varying the amplitude of a RF carrier wave with a modulating, or information signal. It can be shown that the modulated carrier, $v_{\rm c}$ can be expressed as:

$$\begin{aligned} v_c &= V_c \sin\!\omega_c t \, + \, [(mV_c)/2] \, \cos(\omega_c - \omega_m) t \, - \\ & [(mV_c)/2] \, \cos(\omega_c + \omega_m) t \end{aligned}$$

The equation shows that the AM carrier wave contains three frequency components. The first part of the above equation expresses the carrier frequency, the second part is the lower sideband

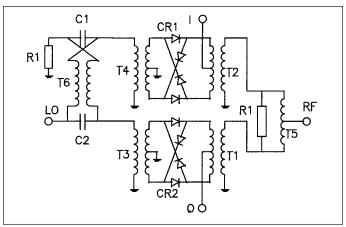


■ Figure 1. Block diagram of the I/Q modulator.

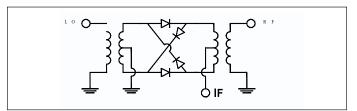
(LSB) and finally the third part is the upper sideband (USB). Single sideband transmission techniques are used in multichannel communication systems because there is a saving in carrier power and on one sideband power. Adjacent channels can be used for other information signals leading to economy of bandwidth. Due to this reduction in carrier power and 50 percent reduction in bandwidth, SSBSC (single sideband suppressed carrier) systems are commonly used in modern telecommunication systems. Using the phase-shift method, a SSBSC signal is generated using two DSBSC (double sideband suppressed carrier) signals. These DSBSC modulators, known as balanced modulators, has one of its carrier and modulation signals shifted by 90° relative to the other. Combining the outputs of the DSBSC modulators yields the SSBSC signal v_0 :

$$v_o = mV_c[\cos(\omega_c - \omega_m)t]$$

which, by observing the previous equation, shows it to be the lower sideband only.



■ Figure 2. Schematic of the fundamental I/Q modulator.



■ Figure 3. Schematic of a double balanced mixer.

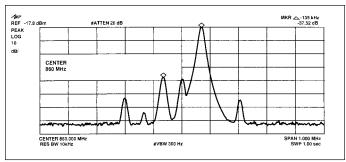
Fundamental I/O modulator

The basic I/Q modulator consists of four very common RF components; two mixers, a quadrature hybrid and an in-phase power combiner, configured as shown in Figure 1. In the modulation mode, the carrier signal activates the mixers and the modulation (information) signal is small with respect to the carrier.

To meet size and cost objectives, the modulator circuit has been designed for simplicity. The schematic diagram of Figure 2 shows a circuit realization having a minimum number of components. The quadrature hybrid, narrowband crossover quad, is the simplest type available. Other wideband quadrature hybrids are available. However the number of components required is increased along with cost and size.

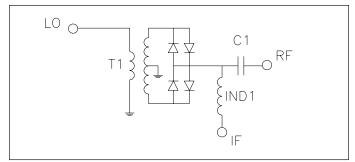
Double balanced ring mixers, similar to Figure 3, are used consisting of two transformers and a diode quad. An impedance transformation has been incorporated into the output of the transformer to raise the mixer output impedance to 100 ohms. This results in a direct transformation to 50 ohms impedance at the modulator output through the action of the output combiner, thus saving the autotransformer that is usually required in the combiner. Not only is the cost and size of the autotransformer saved, but its insertion loss is also avoided, with a resultant improvement in the modulator conversion loss.

I/Q Modulator



■ Figure 4. Performance curve of the fundamental I/Q modulator at 860 MHz.

The mixers operate as biphase modulators, switching from 0° to 180° depending on the inputs to the I and Q ports. They switch phase at the carrier rate with the output amplitude signal proportional to the amplitude of the modulated input signal. Errors in the modulator will appear as phase and amplitude errors, and also as lack of suppression in the undesired sideband. These errors are caused by the imperfections in the modulator components. Transmission phase and amplitude errors in the hybrids and mixers result in unbalanced transmission through the two sides of the modulator. When the resulting transmission vectors are summed in the output combiner, imperfect cancellation occurs in the undesired



■ Figure 5. A single balanced subharmonic mixer.

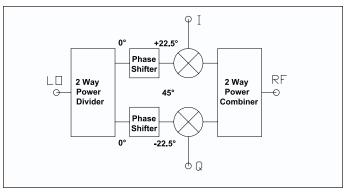
sideband along with errors in the vector states.

Observing the typical performance of a fundamental I/Q modulator, at 860 MHz, in Figure 4, the conversion loss is 7.8 dB, carriers suppression is 38 dBc with single sideband suppression at 38 dBc. The $3\times I$ and $5\times I$, harmonic huppression components, are measured at 54 dBc and 70 dBc, respectively. This modulator was operated using an 860 MHz LO signal applied at +10 dBm with 67 kHz I/Q signals applied at -10 dBm.

Subharmonic I/O modulator

The subharmonic I/Q Modulator consists of similar RF components to the fundamental I/Q modulator.

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■ Figure 6. Block diagram of the subharmonic I/Q modulator.

Whereas the mixers used in the fundamental modulator are typically double balanced, the subharmonic modulator uses subharmonic mixing to generate its USB signal. A typical single balanced subharmonic mixer is shown in Figure 5. The balance transformer is placed on the LO port since it is usually more efficient to balance out the local oscillator as it is the stronger signal. Using this configuration, it can be shown that the (even L \times even R) and the (odd L \times odd R) products are cancelled, along with the (even L \times odd R) products at the LO port and the (odd L \times even R) products at the RF and IF ports. In this schematic, a filter network is required to diplex the RF input signal and the (even L \times odd R) IF output signal. The typical performance parameters for this single balanced subharmonic mixer are:

 $\begin{array}{lll} \bullet & \text{Conversion loss} & \sim 8 \text{ dB} \\ \bullet & \text{LO - RF Isolation (2LO to RF)} & \sim 60 \text{ dB} \\ \bullet & \text{Low LO Power operation} & \sim +5 \text{ dBm} \\ \end{array}$

However, one major drawback for this type of mixer is a lower input RF 1 dB compression point since the LO drive power is lower. In these subharmonic mixers, it is critical that the diodes are well matched to give the LO - RF isolation required. The principle of operation is such that the even and odd order mixing components

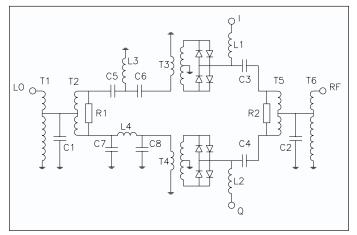
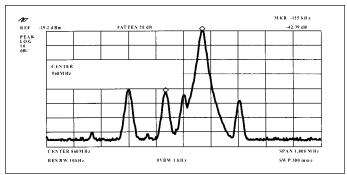


Figure 7. Schematic diagram of the subharmonic I/Q modulator.



■ Figure 8. Performance curve of the subharmonic I/Q modulator at 860 MHz.

are separated; the even order current components circulate within the antiparallel pair loops while the odd order current components circulate in the external circuit. Therefore a mixer using antiparrallel pair diodes achieves efficient mixing between the RF and the second LO harmonic due to the third order mixing product, i.e. the odd order current component.

The replacement of the mixers in the fundamental I/Q modulator circuit with single balanced subharmonic mixers does not allow the I/Q modulator to operate. An important characteristic to observe is that, when obtaining second harmonic operation using subharmonic mixers, the phase of the LO is affected. If two subharmonic mixers are fed with the LO in phase quadrature, as in the fundamental I/Q modulator situation, there will be no sideband rejection. This stems from the fact that the phase is squared resulting in a 180° phase differential between the output of the two mixers. However, when these are combined in a zero degree combiner they will cancel if the I/Q phase differential is 0° and add if the I/Q phase differential is 180°. When the I/Q signals are in phase quadrature some cancellation occurs but no sideband rejection is observed.

The circuit shown in Figure 6 (patent pending) will resolve this particular situation. The LO is fed through a 2-way 0° power divider with each output arm being fed into a phase shifter network that generates –22.5° and +22.5°. Therefore, two signals are applied to the subharmonic mixers with a 45° phase difference between them.

Upon entering the subharmonic mixing stage, the phase is squared resulting in a 90° phase differential between the input of the two mixers. After the subharmonic mixing the outputs of the 2 mixers are combined in the 2-way 0° power divider to generate the required RF signal. To further explain this function, observe the schematic diagram in Figure 7 (patent pending). Here the LO is fed through an autotransformer and an isolating transformer onto the two phase shifters that genrate the necessary -22.5° and $+22.5^{\circ}$ phase shifts.

These two signals are fed into the subharmonic mixers. The outputs of the two mixers are fed to a power combiner consisting of an autotransformer and an isolating transformer. This provides the correct phase shift to achieve sideband rejection. As explained previously, the

	LO Power dBm		
	+10	+12	+14
Conversion Loss	7.7 dB	9.2 dB	11 dB
Carrier Suppression	45 dBc	45 dBc	45 dBc
Single Sideband Suppression	30 dBc	42 dBc	31 dBc

■ Table 1. Sensitivity to LO power variation.

	Fundamental I/Q Modulator	Subharmonic I/Q Modulator
RF Frequency	860 MHz	860 MHz
LO Frequency	860 MHz	430 MHz
LO Drive Level	+10 dBm	+12 dBm
I/Q Frequency	67 kHz	67 kHz
I/Q Drive Level	–10 dBm	-10 dBm
Conversion Loss	7.8 dB	9.2 dB
Carrier Suppression	38 dBc	46 dBc
SSB Suppression	38 dBc	42 dBc
Tune Carrier Suppression	Yes	No
Tune SSB Suppression	Yes	Yes
Barrier Diodes Used	Low	High

■ Table 2. Comarison of the modulator types.

RF and IF ports are diplexed to separate the signals to their respective ports.

Again, observing the performance of a subharmonic I/Q modulator, at 860 MHz, in Figure 8, the conversion loss is 9.2 dB, carrier suppression is 46 dBc with single sideband suppression at 42 dBc. The $3\times I$ and $5\times I$ harmonic suppression components, are measured at 41 dBc and 70 dBc respectively. This modulator was operated using a 430 MHz LO signal applied at +12 dBm with 67 kHz I/Q signals applied at -10 dBm. The RF frequency is twice the LO frequency of operation. The single sideband suppression can be tuned to 40 dBc over the similar bandwidth to the fundamental modulators. As in fundamental modulators, the frequency range of the quadrature hybrid determines the bandwidth. High barrier diodes are required to operate the subharmonic modulator. This is due to the high dynamic range required for today's telecommunication systems, especially with the reduced 1 dB compression point as mentioned previously. The single sideband suppression and conversion loss are sensitive to variations in LO power as they will increase if the mixers are overdriven and underdriven. For optimum operation there is a LO power level window. See Table 1.

Comparison of fundamental vs. subharmonic types

Operating the two types of modulators under similar test conditions, i.e. RF frequency of 860MHz with an I/Q frequency of 67 kHz at -10 dBm, the results in Table 2 were obtained. As explained previously, the single sideband suppression for both modulators depends largely on the performance of the quadrature hybrid and its fre-

quency bandwidth.

The conversion loss for the subharmonic modulator, was found to be 1.5 dB worse than the fundamental I/Q modulator, while there is a 10-15 dB improvement in the carrier suppression for the subharmonic modulator, depending on frequency. The 2×LO isolation is the parameter that achieves this excellent result. For high volume manufacturability concerns, the carrier suppression of the subharmonic I/Q Modulator does not require any tuning, unlike some high frequency fundamental I/Q modulators using "wire wound" technology. This elimination of tune time provides a cost advantage. Since cost is a major factor in RF component development, the high barrier antiparallel diodes are expensive relative to the low barrier ring quads frequently used in fundamental I/Q modulators.

Summary and conclusion

The subharmonic modulator offers enhanced carrier suppression performance over existing fundamental modulators. The implementation of the subharmonic I/Q modulator in system designs eliminates the need for external circuitry to reduce carrier suppression. The subharmonic modula-



tor also provides the RF System designer with a solution for high frequency direct modulation using low frequency VCOs or synthesizers. The savings in component cost and real estate are critical in modern system design. A photo of the packaged modulator is shown above.

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About the author

Ian Doyle holds the B.Eng. degree in Electronic Engineering from Cork Institute of Technology, Ireland. He is currently a Design Team Leader at M/A-COM Eurotec, where his primary responsibility is the design of RF passive components for wireless applications.

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He can be reached at M/A-COM Eurotec Operations, Loughmahon

Technology Park, Blackrock, Cork, Ireland; tel: +353 21 808330; fax: +353 21 359935; E-mail: doylei@amp.com