NOVEL I/Q MODULATORS MIX CELLULAR SIGNALS

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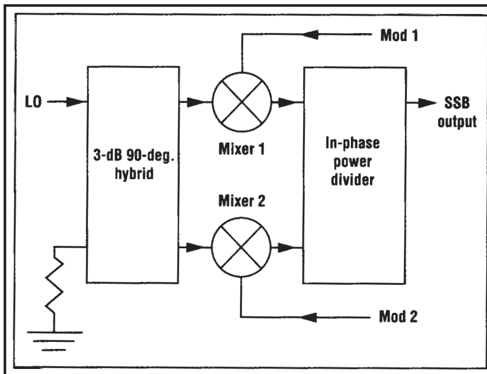
Single Sideband (SSB) or in-phase (I)/quadrature (Q) modulators are used extensively in communications systems, including cellular and personal-communications-systems (PCS) networks. Although the basic design is fairly mature, it has been completely revamped thanks to an innovative technique developed by Synergy Microwave Corp. The novel approach is based on subharmonic mixing techniques and is applicable from about 140 to 3000 MHz.

In a communications receiver, SSB or I/Q modulators are useful in discriminating and removing the lower sideband (LSB) or upper sideband (USB) generated during frequency conversion, especially when the sidebands are very close in frequency and attenuation of one of the sidebands cannot be achieved with filtering. This is the case with audio and video modulation, where signals from DC to 10 MHz must be converted to a higher frequency that is appropriate for transmission. In such cases, both sidebands will be very close in frequency to the carrier frequency. With an I/Q modulator, one of the sidebands is easily canceled or attenuated along with its carrier.

Attenuation of the carrier has been the most troublesome aspect in the design of passive I/Q modulators. Isolation between the local-oscillator (LO) port and the RF port of the mixers, which is the main parameter in determining carrier rejection, is usually insufficient at frequencies above 200 MHz.

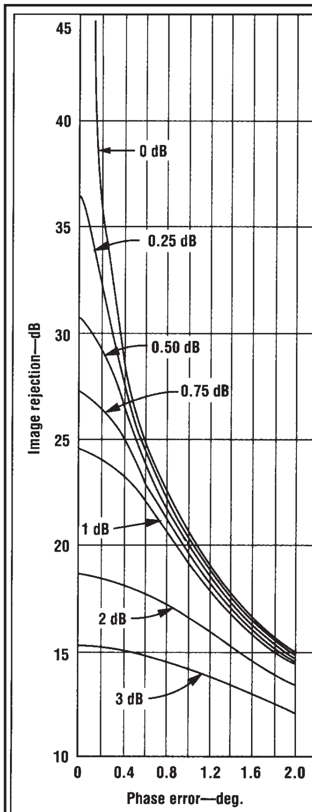
I/Q modulator designs were basically comprised of two double-balanced mixers (Fig. 1). The mixers are fed at the LO ports by a carrier phase-shifted through a 90 deg. hybrid. Thus, the carrier signal's relative phase is 0 deg. to one mixer and 90 deg. to the other mixer. Modulation signals are fed externally in phase quadrature to the two mixers' IF ports. The mixers' modulated output signals are combined through a two-way, in-phase power divider/combiner.

The circuit forms a phase-cancellation network to one of the sidebands and a phase-addition network to the other sideband. The carrier is somewhat attenuated and is directly dependent on the inherent LO-to-RF isolation of the mixers and the modulating signal level. In a standard line of I/Q modulators from Synergy, USB suppression results when the first modulation port (MOD 1) is fed with a signal that is 90 deg. in advance of the signal feeding the second modulation port (MOD 2). Opposite phasing can be arranged by changing the internal phase polarity of the mixers or by interchanging the 90-deg. hybrid output ports to the LO ports of the mixers.



1. An SSB modulator matches two high-frequency mixers, a 90-deg. hybrid, and an in-phase power combiner to produce an SSB output signal.

The phase and amplitude imbalances between the various components used in the manufacturing of the I/Q modulators must be tightly maintained for optimum SSB rejection. Matching of the two mixers for conversion loss and insertion phase is extremely critical, since differences in these parameters will add to amplitude- and phase-imbalance errors. The 90-deg. hybrid in the LO port must be in nearly perfect phase quadrature.



2. The level of SSB rejection improves as the phase- and amplitude-imbalance performance of an SSB modulator improves.

Phase- and amplitude-imbalance errors adversely affect sideband suppression (Fig. 2). In most cases, a typical passive I/Q modulator operates with a carrier input level of +10dBm, which is required to drive the diodes in the mixers to operate in the linear range. The dynamic range of these mixers can be significantly improved by using diodes with a higher barrier height. The LO signal in this case must be increased in order to drive these diodes into conduction in their linear range.

Carrier rejection is also a problem when designing an SSB modulator, since only a few decibels of suppression can be achieved in standard high-frequency models. In the past, the major contributor to carrier suppression was the inherent LO-to-RF isolation through the mixers. Unfortunately, this isolation is usually poor at cellular frequencies (800 to 1000 MHz), where at least 25-dB carrier rejection is necessary. In some cases, designers feed a small amount of DC into the IF ports to control the carrier rejection, which complicates the driver circuitry and calls for temperature compensation when operating at different temperatures.

As an example, an SSB modulator is assumed to operate with +10-dBm LO drive with each modulating signal at -10 dBm and in phase quadrature to each other when applied to the modulating ports (MOD 1 and MOD 2). The result will be a modulated signal at -16 dBm, assuming 6-dB conversion loss. For 20-dB carrier rejection with respect to the desired modulated signal, the carrier must be at -36 dBm, which translates to LO-to-RF isolation of 46 dB.

By employing a the sub-harmonic approach, the engineers at Synergy have extended the performance of SSB modulators beyond the limits of conventional designs. The approach is based on the use of subharmonic mixers in place of fundamental-frequency mixers. Subharmonic mixers use anti-parallel diode pairs in their construction. [1-3] Matched anti-parallel diode pairs used in single-ended or single-balanced mixer configurations cancel even-order intermodulation products (such as 2LO x 2RF, 3LO x 3RF, etc.) at all ports.

Single-ended mixers lack the port-to-port isolation needed for SSB modulator applications. Odd-order products of the RF and LO frequencies (even LO x odd RF) and (odd LO x even RF) appear on all ports, requiring extensive filtering for satisfactory performance. For a single-balanced mixer, even harmonics of the LO combining with odd harmonics of the RF appear at the IF port, whereas odd harmonics of the LO combining with even harmonics of the RF appear at the RF and IF ports. This assumes that a balanced transformer is placed at the LO port, which is a logical choice due to the fact that the highest level signal appears at the LO port. Since the desired odd-order IF products appear at both the RF and IF ports, a need arises for a diplexing network to isolate the RF and IF signals.

The subharmonic modulator design provides a unique way to isolate the RF and IF signals. A single-balanced harmonic mixer offers good LO-to-RF and LO-to-IF isolation but poor RF-to-IF isolation. Fortunately, harmonically-related signals are spaced well apart in the frequency spectrum, simplifying filtering of harmonically-related signals.

Harmonic mixing also works well with low LO power levels, with somewhat lower 1-dB compression on the RF port than with fundamental-frequency mixing. The ability to operate with LO frequencies that are a fraction of the carrier frequency (1/2, 1/4, 1/6, etc.) significantly reduces the cost of an LO source, especially at higher frequencies. Also, using lower-frequency LO sources helps avoid the signal-leakage problems inherent with higher-frequency LO sources. Minimizing signal leakage, especially at higher frequencies, becomes expensive and bulky. Subharmonic mixing offers several advantages:

(1) The technique offers the ability to operate at LO frequencies that are 1/2, 1/4, or 1/6 of the carrier frequency. For example, for an IF of 100 MHz at an RF of 2 GHz, the LO can be (2000-100)/2 = 950 or 1050 MHz.
(2) The LO's even harmonics are strongly attenuated.
(3) The filtering requirements for fundamental frequency and odd harmonic signals of the LO are not critical.
(4) The cost of generating the LO is reduced due to the fact that the LO frequency need only be a fraction of the carrier frequency.

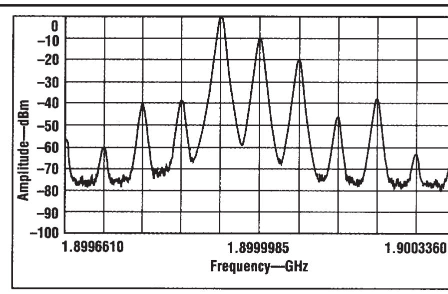
The novel design approach has opened the way for a new line of products specifically designed for applications in the cellular bands. Models for cellular frequency coverage extend from 810 to 2500 MHz with applications in a wide range of systems, including the Advanced Mobile Phone Service (AMPS), the Digital European Cordless Telephone (DECT) system, the European Global System for Mobile Communications (GSM), the Nordic Mobile Telephone (NMT) system, the North American Digital Cellular (IS-54 and IS-95 standards) system, the Japanese Personal Handy Phone (PHP), and the Total Access Communications System (TACS). As an example of the performance improvements possible with the subharmonic mixers, units were evaluated at both cellular (935 to 960-MHz) and PCN/PCS (1.8-to-1.9GHz) bands. For a conventional SSB modulator at 1.9 GHz fed with +10dBm modulation signals, carrier rejection is barely 10 dB (Fig. 3).

Sideband rejection can be improved by tuning, but the carrier rejection is controlled by the LO-to-RF isolation of the double-balanced mixers. Conventional double-balanced mixers with high isolation at cellular and PCN bands are very expensive and large when special techniques are used to improve LO to-RF isolation. In contrast, the subharmonic nature of the new approach allows the use of lower-frequency, less-expensive components in the modulators' construction.

The subharmonic modulators offer an improvement of more than 15 dB in carrier suppression compared to the conventional approach.

The measured VSWR (return loss) at the LO and RF ports is better than 1.50:1 (Figs. 4 and 5). Measurements made on

3. This plot of carrier and sideband rejection was measured for a conventional SSB modulator operating at 1.9 GHz.



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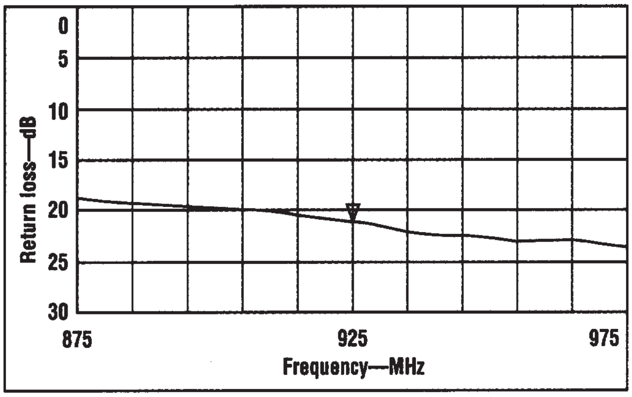
a cellular-band SSB modulator reveal carrier rejection on the order of 40 dB. Typical insertion loss is 7 dB while sideband rejection is 30 dB (Fig. 6).

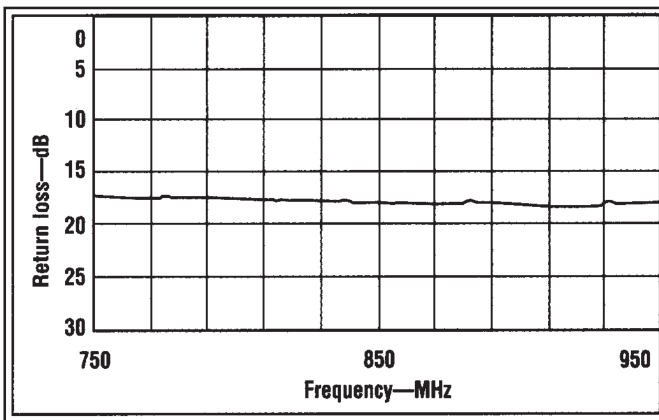
By the virtue of harmonic mixing, even-order mixing products are attenuated by about 30 dB with respect to the desired modulated output signal. The fundamental-frequency feed through into the output port is approximately 5 dB lower than the desired modulated signal, whereas the fourth harmonic mixing with the modulating signal is approximately 10 dB lower. Typical loss for fourth-harmonic mixing is 17 to 19 dB while maintaining 30 dB of carrier rejection.



4. The SSB modulator's return loss was measured at the local-oscillator (LO) port.

Since harmonically-related products are well-spaced in frequency, filtering undesired signals is relatively inexpensive using standard octaveband bandpass filters. Low-cost commercial bandpass filters typically offer better than 40-to-50-dB attenuation of unwanted harmonic signals. Constant-impedance bandpass filters offering good impedance match at desired stopbands can also be used in cases where harmonically related products require impedance termination within a system.

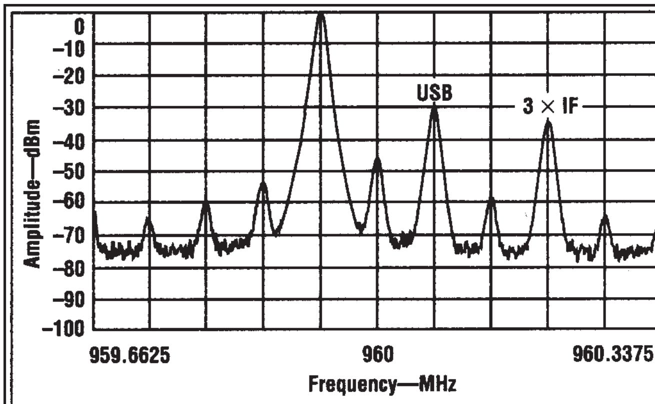
The subharmonic modulator design is easily retrofitted to custom frequencies. Conversion of an SSB modulator with output frequency corresponding to twice the LO frequency to one with output corresponding to four times the LO frequency requires only one component change, in the form of a signal-combining network at the modulator's output. Although the conversion loss of the fourth-harmonic LO component mixing with the modulating signal is in the vicinity of 18 dB, the cost of generating the LO is drastically reduced with the subharmonic modulator. In spite of higher signal loss, the carrier rejection is still at least 30 dB at the fourth harmonic, and harmonically related products can be eliminated with an inexpensive filter.



5. The novel harmonic SSB modulator's return loss was measured at the RF port.

References:

1. Joseph T. Lee, "*Balanced Subharmonic Mixers*" *Microwave Journal*, August 1983.
2. Don Neuf, "*Fundamental versus Harmonic Mixing*" *Microwave Journal*, 1984.
3. Bert Henderson, "*Full-Range Orthogonal Circuit Mixers Reach 2 to 26 GHz*", *Microwave Systems News*, January, 1982.



6. This plot of carrier and sideband rejection was measured for the novel harmonic SSB modulator operating at cellular frequencies.