MIC MODULATOR WITH ELECTRONICALLY VARIABLE CARRIER CANCELLATION CIRCUIT

by

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Abstract

Experiments with various cancellation techniques for improving the LO to RF isolation of a double balanced mixer have resulted in the development of (1) a microstrip single sideband up converter with 45 dB carrier isolation over a wide tuning range and (2) an electronically controlled continuously variable MIC phase and amplitude modulator.

General

An image and carrier cancellation mixer can be useful as a low cost coherent single sideband suppressed carrier (SSBSC) transmitter or as a local oscillator source. For these applications, it is often desired to generate a signal of up to +3 dBm that is offset from a high level (+13 dBm) microwave input signal by an amount equal to the receiver IF frequency. Furthermore, the carrier and all sidebands must be at least 30 dB below the desired output signal. System engineers frequently use the term "FOG" (Frequency Offset Generator) to describe such a device.

When one attempts to achieve the low carrier feedthrough levels just described with a conventional image rejection mixer, a problem occurs because of the limited LO to RF isolation of even the best double balanced mixers. For example, if a mixer with 30 dB LO to RF isolation is used to obtain an output signal of, say 0 dBm, by mixing a 30 MHz IF signal of +10 dBm and LO signal of +13 dBm, the output spectrum would consist of 2 sidebands of about 0 dBm and an LO leakage signal of (+13 dBm - 30 dB isolation) or -17 dBm. Thus the carrier level at the output is only 17 dB below the desired sidebands. The conventional solution to the problem might be to use a narrow-band filter or an externally coupled LO signal that is adjusted in phase and amplitude to cancel the LO leakage signal appearing at the output. In practice, the external loop is usually formed by suitable input and output couplers with intermediate phase and amplitude compensators.

Figure 1 shows the typical configuration and how the cancellation bandwidth is affected by the external path length relative to that of the mixer. If bulky waveguide components are used, there could be a considerable difference in path lengths resulting in narrow bandwidth.

Reference 1 illustrates the dependence of extra carrier rejection on the amplitude and phase difference of the correction and error signal. The same graph is also useful for determining the image rejection limits if a single sideband modulator were used.

Another common technique of reducing the carrier level is to use a narrow-band filter at the mixer output. This technique is not easy to implement especially if the carrier is only 30 MHz away at X-Band, because of the high unloaded Q requirements for the resonators.

Description of New Technique

The essential principle of operation for the RHG carrier cancellation mixer is that if an internally generated cancellation signal can be made to nearly "track" the frequency variations of the LO leakage, then a broader band cancellation is possible. The circuit technique used to accomplish this is to employ a separate mixer diode quad, driven by the same LO with phase and amplitude tracking to the other active mixers. The extra mixer quad is made to act as a variable attenuator by appropriate DC bias. The attenuation of the quad is adjusted to match the LO leakage thus producing a cancellation voltage which is added to the output of the modulator. The anti-phase tracking of the two signals is inherent in the circuitry. If desired, the phase of the correction signal can also be varied electronically by employing an additional "bridge quad" of 4 varactor diodes.

Figure 2 shows how the two quads, one using varistors (mixer or pin diodes), the other using varactors (variable capacitances), perform the functions of variable amplitude and phase. The varactor quad is actually a lattice network and is bandwidth limited by the impedance inverting lines which convert the two variable negative reactances to positive equivalent variable inductances. Depending upon how the varistors are biased, an additional 0/180 degree phase control is obtained.

In order to explain how these theoretical concepts are achieved in a practical MIC design, we must first review the basic double balanced mixer circuit and a microwave equivalent of this circuit, utilizing broadband microstrip baluns.

Review of Double Balanced Modulator/Mixer

Figure 3 shows the low frequency model of a double balanced modulator including the resistive and reactive elements of the ring quad which are ideally, but never perfectly balanced.

Figure 4 shows a microwave equivalent of the double balanced mixer used at RHG.[2] In this design the unbalanced RF and LO microstrip lines are transformed to a balanced feed for the diode quad by gradually altering the width of the ground plane conductor. (See dotted pattern in Figure 4.) Such a structure will act as a multioctave microwave balun provided that the ratio of "even" to "odd" mode impedance of the two conductors is very high and the odd mode impedance is not changed abruptly.[3] For simplicity, the IF circuitry has been omitted from the equivalent microwave model, but in practice, the DC and low frequency signals are coupled to the quad by high impedance chokes.

It is of interest to note that a small bias voltage at the IF terminal will tend to unbalance the quad causing LO voltage to appear on the RF line. Ideally, the phase of the leakage signal will reverse if the polarity of the DC unbalance signal is reversed. (This quality is, of course, why double balanced mixers can be used as biphase modulators. Experiments with the microwave mixer at RHG have shown that it is possible to also rebalance a quad with a small DC offset voltage and obtain up to 65 dB LO to RF isolation, provided that high quality baluns are used, thereby restricting the unbalancing components to the diode alone. However, when the mixer is unbalanced by external or "even mode" circuit loading such as ground chokes, cover effects etc., the simple technique of applying a DC offset voltage will not work. For these more difficult applications, the second mixer quad is employed to produce the cancellation voltage. The physical MIC circuit layout of the extra "quad" will be discussed in the next section.

Description of Single Sideband Suppressed Carrier (SSBSC) or (Imageless Mixer With Carrier Cancellation)

In order to test the validity of the tracking cancellation scheme, work was begun on a single sideband up converter that was designed to be used as a test signal source which is offset but correlated to a high level microwave input signal in C-Band. Figure 5 shows the layout of the resulting microstrip circuitry. The +13 dBm carrier is applied in phase to all three mixers. (The center mixer generates the cancellation signal, hence the total input to output line lengths are meandered to have equal path lengths to that of the outside pair of image cancellation mixers.) The RF output quadrature hybrid is a tandem three section design. This results in low coupling per section, thus making the etched gaps between coupled lines somewhat less critical. The carrier cancellation signal, from the center mixer is capacitively coupled to the output hybrid and, as a result, is bandwidth limited to 10% for 20 dB extra carrier rejection. (See Figure 6 for output spectrum with and without carrier cancellation.) The particular application of this converter did not require multioctave bandwidth and therefore the bandwidth limitations imposed by the capacitance coupling were acceptable. The varactor phase shifting technique was not used on this model. Instead, a small piece of teflon was cemented on the meandered line for trimming.

The undesired output sideband or image is nominally rejected by 25 dB owing to the quadrature IF input coupling and RF output recombination. It is possible to further improve the image rejection by tuning the terminated output line to produce a cancellation voltage at this frequency. Notice in Figure 6 that the RF level dependent products $F_o \pm 3\ f_{IF}$ are reversed in rejection relative to the desired outputs of $f_o \pm f_{IF}$. This is due to the fact that the IF quadrature hybrid will operate at the third harmonic of the input (i.e., 3 X 30 or 90 MHz) but with leading and lagging outputs interchanged.

Conclusions

A technique for utilizing the properties of a schottky ring quad to control the amplitude of a carrier canceling voltage in a modulator has been described. In addition, the balanced quad (with 4 varactors instead of varistors) has been shown useful as a variable phase shifter with nearly constant loss. Both circuits described depend upon the existence of a wide-band balun that is formed by altering the normally wide unbalanced microstrip ground plane in a manner that produces a known "odd mode" impedance variation. If desired, all functions can be combined together as in Figure 2 to form a combination: (A) 0/180° biphase modulator; (B) variable attenuator or switch; and (C) a variable phase shifter. Undoubtedly, there could be other signal processing applications for such a device besides that reported here, to supply a controllable correction voltage.

Acknowledgement

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References

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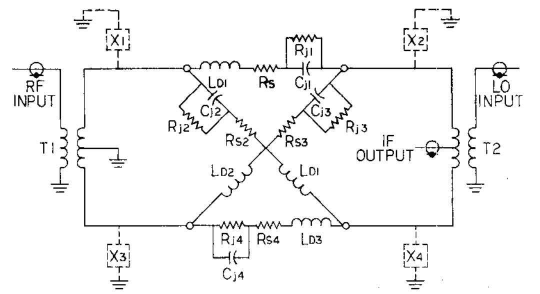
2. D. Neuf, "Double balanced microwave mixer using balanced microstrip baluns", Patent No. 3652941.
3. G. Matthaei, L. Young, E.M.T. Jones, "Microwave filters, impedance-matching networks and coupling structures".



Rj(1-4)=DIODE JUNCTION RESISTANCE
Cj(1-4)=DIODE JUNCTION CAPACITANCE
Rs(1-4)=DIODE SPREADING RESISTANCE
LD(1-4)=DIODE LEAD INDUCTANCE
X(1-4)=DIODE TO CASE REACTANCE (EVEN MODE UNBALANCE)

FIG. 3
EQUIVALENT CIRCUIT OF DOUBLE BALANCED MODULATOR SHOWING UN-BALANCING CIRCUIT ELEMENTS

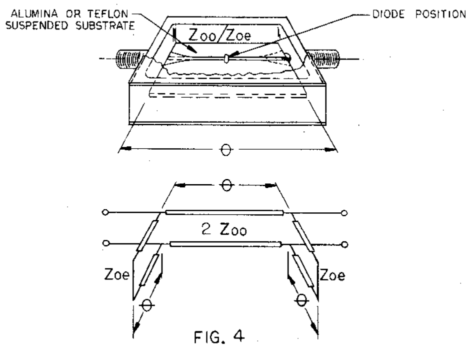
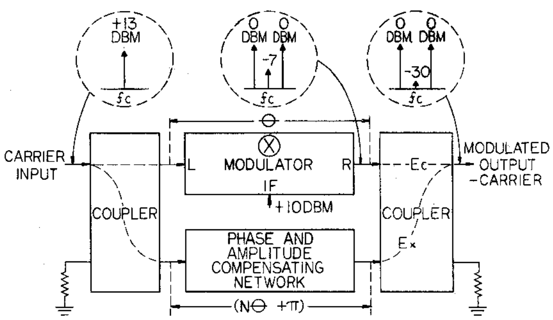


FIG. 4
MICROWAVE EQUIVALENT CIRCUIT OF TWO CASCADED BALUNS



$$\text{EXTRA CANCELLATION} = 10 \log_{10} \left[\frac{1 + \frac{2K}{1+K^2} \cos \Delta\phi}{1 - \frac{2K}{1+K^2} \cos \Delta\phi} \right] \quad K = \frac{|Ec|}{|Ex|}, \Delta\phi = \text{FROM IDEAL } 180° \text{ DIFF.}$$

FIG. 1 CONVENTIONAL EXTERNAL CARRIER CANCELLATION LOOP

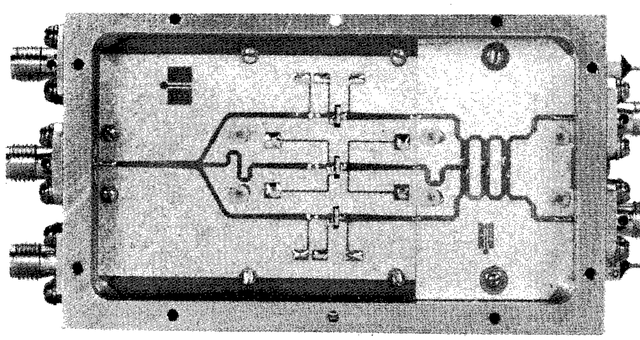


FIG. 5 SINGLE SIDE-BAND MODULATOR WITH CARRIER CANCELLATION LOOP

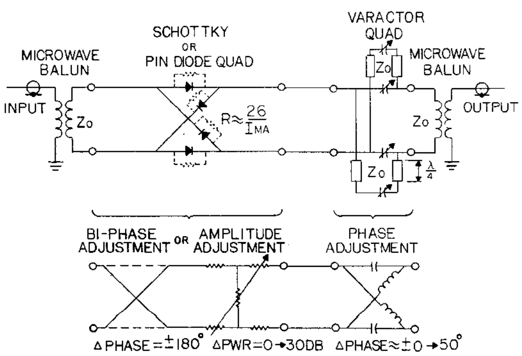


FIG. 2 BALANCED MIC PHASE AND AMPLITUDE COMPENSATING NETWORK

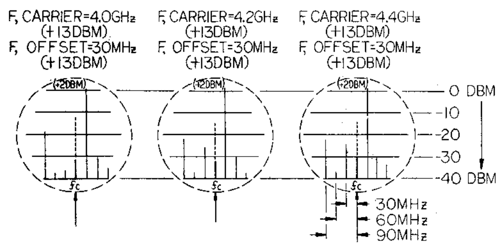


FIG. 6
OUTPUT SPECTRUM OF SINGLE SIDE-BAND MODULATOR WITH CARRIER CANCELLATION LOOP