MONOLITHIC, LUMPED ELEMENT, SINGLE SIDEBAND MODULATOR

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ABSTRACT

In monolithic microwave integrated circuit (MMIC) technology, at frequencies below 18 GHz, distributed elements consume too much valuable GaAs real estate to be cost-effective. An appreciable reduction in surface area without a degradation in electrical performance can be realized with the use of lumped elements. This paper describes the design and performance of a monolithic single sideband modulator that employs lumped element technology to achieve a compact circuit. For this design, the carrier frequency is 6.9 GHz and the modulating signal is in the range of 0 to 500 MHz. Therefore, the lower sideband is 6.4 to 6.9 GHz and the upper sideband is 6.9 to 7.4 GHz.

INTRODUCTION

At frequencies below 18 GHz, distributed element circuits such as the conventional 180° transmission line hybrid or "rat-race" hybrid occupy too much GaAs surface area to be cost-effective. An appreciable reduction in surface area can be realized with the use of lumped element designs. For example, a transmission line hybrid was unacceptable for use in the balanced mixer design at 7 GHz since a quarter wavelength transmission line is approximately 3400 µm long. The lumped element hybrid that was used and is described in this paper measures 600 µm square for over a 50 times reduction in surface area over an electrically equivalent transmission line version. The design technique used was to derive equivalent "pi" and "tee" networks [1] for the transmission line segments of both distributed element hybrids and the Wilkinson power combiner. An alternative design approach that employs two differential field-effect transistor (FET) pairs [2] similarly offers the advantages of monolithic implementation. However, the approach presented here offers lower conversion loss with comparable carrier suppression and unwanted sideband suppression.

CIRCUIT DESIGN

A single sideband modulator is basically an upconverter that generates a single sideband suppressed carrier output without the use of filters. A block diagram of a single sideband modulator is shown in figure 1 along with the frequency spectrum of its output for upper sideband suppression. Either the lower sideband or the upper sideband can be selected by exchanging the I and Q inputs. The circuit is comprised of two balanced mixers, a branch line hybrid to input the carrier frequency, and a Wilkinson power combiner for summing the two mixer outputs. The signals generated by mixer 1, assuming that its IF port is the I-port,

$$E_1 = C * M\sin\omega_c t * \sin\omega_m t$$

and mixer 2, assuming that its IF port is the Q-port,

$$E_2 = C * M\cos\omega_c t * \cos\omega_m t$$

are recombined in phase via a Wilkinson power combiner:

$$E_1 + E_2 = C * M(\sin\omega_c t * \sin\omega_m t + \cos\omega_c t * \cos\omega_m t)$$

$$E_1 + E_2 = C * M\cos(\omega_c - \omega_m)t$$

Only one signal at the difference frequency, in this case the lower sideband, is generated. Similarly, interchanging the modulating signals on the mixers will generate the upper sideband only.

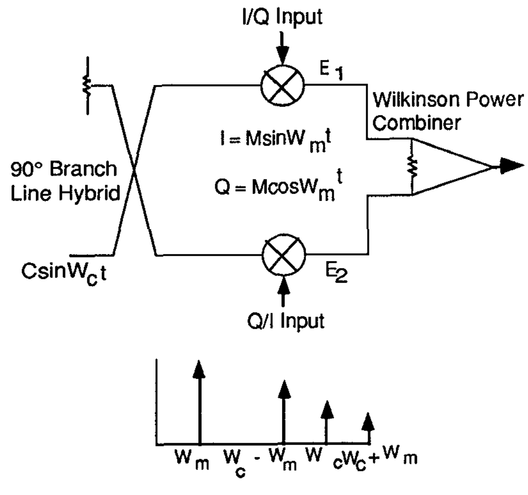

Figure 1. Block Diagram of a Single Sideband Modulator and the Frequency Spectrum of its Output for Upper Sideband Suppression

This analysis assumes that one half of the circuit is a mirror image of the other. In reality, however, they are a mirror image only to a certain degree. Therefore, the undesired sideband will appear on the output of the device, though its level will be much lower than that of the desired sideband.

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The difference between the levels of two sidebands measured in decibels is called an unwanted sideband suppression. It can be expressed in terms of amplitude and phase unbalances of the two transmission paths. In theory, the use of monolithic technology should provide a much better match between the two halves of the circuit in comparison to MIC technology since the two halves of the circuit are processed on the same substrate in close proximity to one another.

A 90° hybrid is required to apply the carrier frequency to each mixer in phase quadrature. Since this design is to be implemented in MMIC form, the traditional branch line hybrid, which is comprised of quarter wavelength long 50- and 35-ohm transmission lines, is too large physically at 6.9 GHz to be practical. The Lange coupler is another option but it too is physically large. Therefore, to achieve small physical size, a lumped element version of the branch line hybrid is used. The quarter wavelength transmission line elements of the branch line hybrid are replaced by lumped element, low pass sections. A schematic of the lumped element, branch line hybrid is shown in figure 2(a). The coupling loss of the hybrid is a maximum of 1.7 dB at the band edges (6.4 and 7.4 GHz), the VSWR of all four ports is better than 1.7:1, and the isolation is greater than 14 dB from 6.4 to 7.4 GHz. An attractive feature of the lumped element, branch line hybrid is that the hybrid output ports remain in phase quadrature over a wide bandwidth--typically greater than 25 percent.

An in-phase power combiner is needed to sum the outputs of each mixer. The traditional Wilkinson power combiner, which uses quarter wavelength, 70-ohm transmission lines, is too large physically for operation from 6.4 to 7.4 GHz. Therefore, a lumped element version is used. As in the branch line hybrid, low pass sections are used to replace the quarter wavelength lines. A schematic of the lumped element, Wilkinson power combiner is shown in figure 2(b). The combining loss of the circuit is less than 0.8 dB across the band, the VSWR of all three ports is better than 1.35:1, and the isolation of the isolated ports is greater than 20 dB.

A 180° hybrid is an integral part of the balanced mixer used in the single sideband modulator. The traditional rat-race hybrid is too large physically to be practical for this application. Here, as in the branch line hybrid and the Wilkinson power combiner, a lumped element version is used to reduce the surface area of the hybrid. As before, low pass sections are used to replace the quarter wavelength lines and the three quarter wavelength line is replaced with a high pass section. A schematic of the lumped element, 180° hybrid is shown in figure 2(c). The coupling loss of the hybrid is less than 1.5 dB, the VSWR of all four ports is better than 1.3:1, and the isolation of the isolated ports is greater than 27 dB across the entire frequency band. The 180° phase difference between the coupled ports is constant across the entire band which accounts for the excellent isolation.

Two balanced mixers are utilized in the single sideband modulator. A schematic of one balanced mixer is shown in figure 3. The balanced mixer employs high pass filters, which appear as open circuits to the modulation signal, at both the carrier input port and the RF output port. Carrier suppression is achieved by the inherent isolation of the 180° lumped element hybrid. The mixer diodes are formed from 100-μm gate width depletion mode MESFETs which have the source and drain contacts interconnected. A harmonic balance, nonlinear simulator was used to design the matching network for the device. The diode is matched at the frequency of the carrier signal so as to minimize the conversion loss.

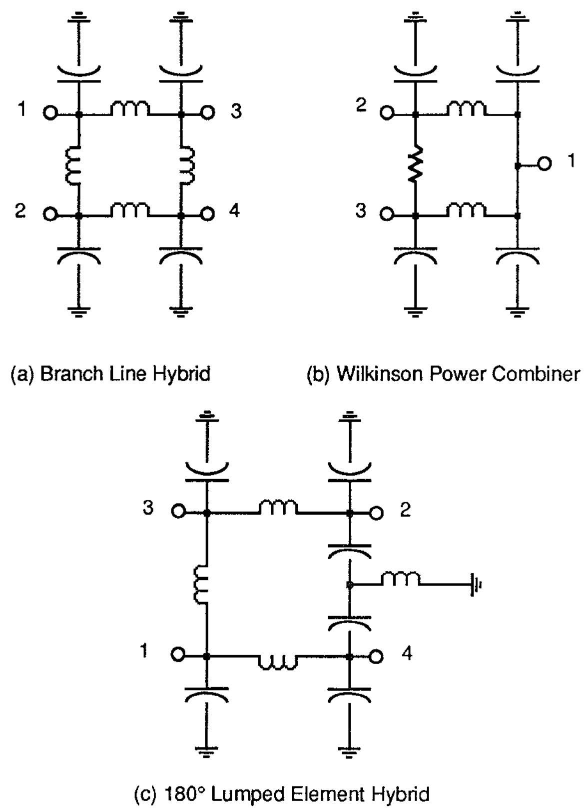

Figure 2. Schematics of the Lumped Element Circuits

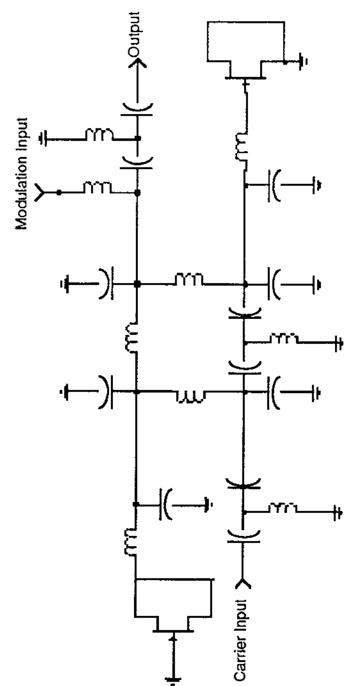

Figure 3. Schematic of the Balanced Mixer

CIRCUIT PERFORMANCE

The circuit schematic and a layout of the single sideband modulator are shown in figures 4 and 5, respectively. The chip measures 2230 µm x 3000 µm. A simulated frequency spectrum plot for the output port of the single sideband modulator is displayed in figure 6. The power level of the I/Q input signal at 500 MHz is 0 dBm while the power level of the carrier signal at 6.9 GHz is 16 dBm. The undesired sideband suppression is 34.4 dB, the carrier suppression is 20 dB, and the conversion loss is 6.4 dB. Actual test data is displayed in figure 7.

Upper bounds on the performance of the modulator were derived from an assessment of the circuit components based on computer simulations. The conversion loss of the balanced mixer was expected to be less than 10 dB, and the loss of the power combiner was expected to be less than 1 dB. The sum of these losses yields a maximum conversion loss of 8 dB for the modulator. The isolation of the 180° hybrid was expected to exceed 27 dB. This specification combined with the 2 dB loss of the branch line hybrid and the loss of the power combiner yielded a carrier suppression of 20 dB minimum. The excellence with which the 180° phase relationship of the lumped element hybrids can be maintained over the entire frequency range led to a 20-dB sideband suppression.

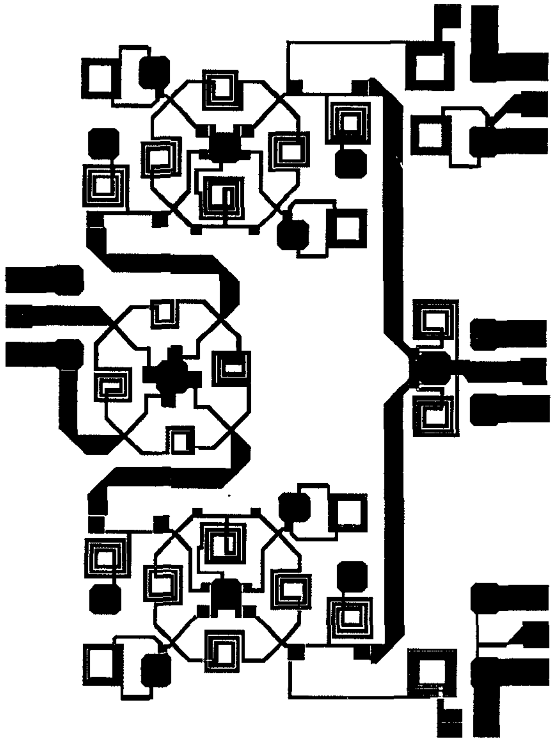

Figure 5. Layout of the Single Sideband Modulator Which Measures 2230 µm x 3000 µm

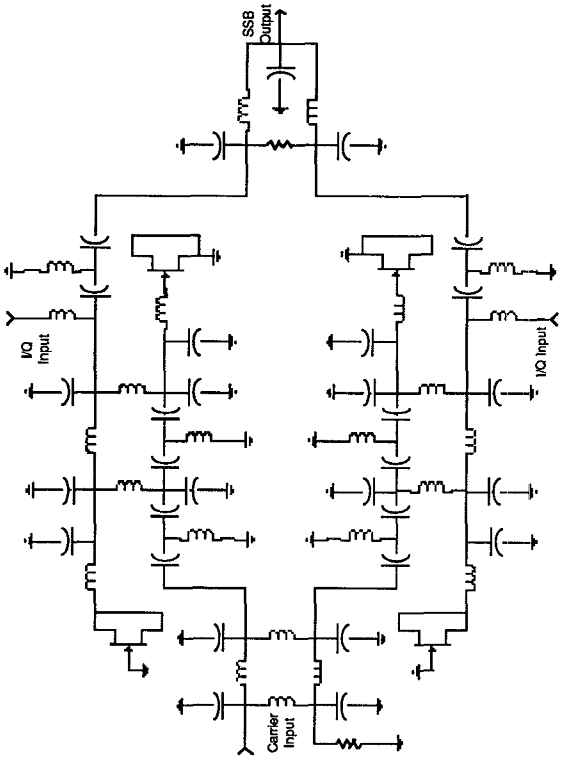

Figure 4. Schematic of the Single Sideband Modulator

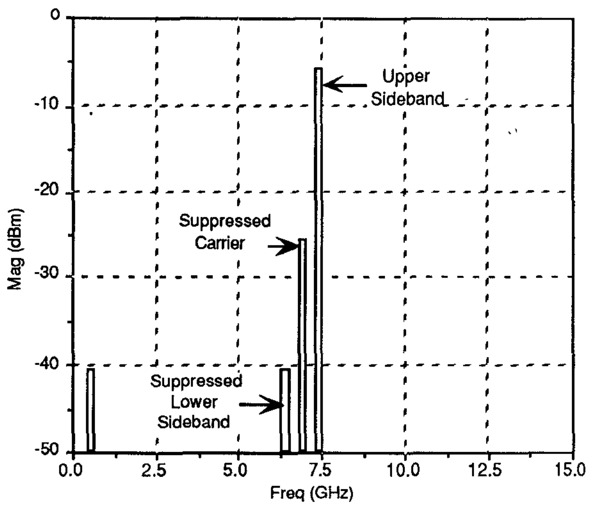

Figure 6. Frequency Spectrum of the Single Sideband Modulator Output Port

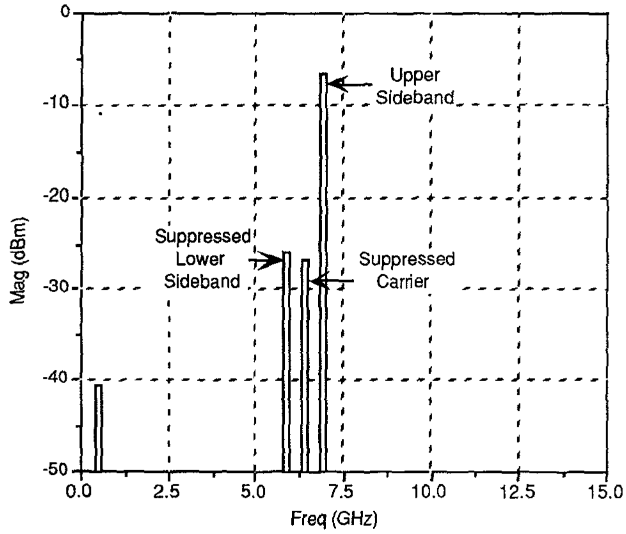

Figure 7. Actual Test Data for the SSB Modulator (Carrier Frequency = 6.4 GHz, IF = 500 MHz, Lc = 7 dB, Carrier Suppression = 20 dB, Sideband Suppression = 18 dB)

CONCLUSION

A technique for the design of a lumped element, single side-band modulator has been described which yields electrical performance comparable to the distributed element version but with significantly smaller surface area. The balanced design exploits the advantage of monolithic technology to provide a close match between the two halves of the circuit to improve the phase cancellation of the unwanted sideband at the output port.

REFERENCES

[1] S. J. Parisi, "180° Lumped Element Hybrid," 1989 IEEE MTT-S International Microwave Symposium Digest, Vol. 3, pp. 1243-1246.

[2] S. D. Thompson and A. M. Pavio, "A Monolithic Double Balanced Single Sideband Modulator," 1987 IEEE MTT-S International Microwave Symposium Digest, Vol. 2, pp. 899-902.