A MMIC Subharmonically Pumped SSB Modulator

A. Pospishil, M. Russo, M. Singh

ITT Avionics Division
100 Kingsland Road, Clifton NJ 07014

ABSTRACT

An innovative monolithic Single Sideband Modulator (SSBM), which utilizes balanced subharmonically pumped mixers, has been developed. This SSBM is pumped at one half of the carrier frequency ($f_C/2$). The typical measured performance of this device is excellent with > 40dB carrier suppression, > 25dB undesired sideband suppression and < 10dB conversion loss over a carrier bandwidth of 14 to 19GHz. Double sideband suppressed carrier (DSBSC) and unsuppressed carrier operation is also achievable with the same device when appropriate modulation signals are applied.

INTRODUCTION

Single Sideband Modulators are frequently used in ECM systems to introduce a frequency offset to a microwave signal. Key performance parameters for such a SSBM are conversion loss and also suppression of the unmodulated signal (carrier suppression) and undesired intermodulation products (sideband suppression). This paper will describe a MMIC SSBM which utilizes subharmonically pumped mixers to achieve excellent performance characteristics. This SSBM is pumped at a frequency which is one half that of the carrier frequency and operates with quadrature IF inputs ranging from DC to 50MHz. When in-phase IF signals are applied, this device operates as a Double Sideband Suppressed Carrier (DSBSC) modulator. Also, when a negative DC bias is applied at one of the IF ports the modulator becomes unbalanced, and the carrier becomes unsuppressed. No tuning is required to optimize the SSBM's performance.

CONVENTIONAL SSBM's

The block diagram of a typical SSBM is shown in Figure 1. It consists of two balanced mixers, an in-phase power divider, and a quadrature 3dB hybrid. An RF input (f_C) is applied to the divider which drives the RF_{in} ports of the 2 mixers. Quadrature signals of equal amplitude are applied to the IF ports of the mixers. The signals appearing

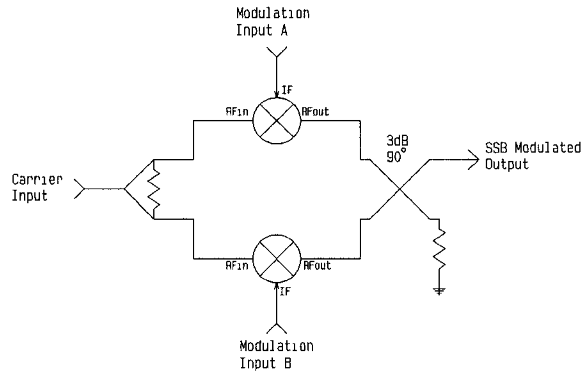

Figure 1 Block Diagram of a Conventional SSBM

at the RF_{out} ports of the mixers are DSBSC signals. These outputs are then combined through the 90° hybrid where either the upper (f_C+f_{IF}) or lower (f_C-f_{IF}) sideband cancels at the hybrid output while the other sideband adds. The sideband that adds is determined by which IF input leads or lags the other. In this configuration, carrier suppression is directly related to the RF_{in} to RF_{out} isolation of the mixers, while undesired sideband suppression is related to the amplitude and phase balance of the mixers and hybrids.

Normally, the IF inputs are used as the high level, or pump, signals for the mixers. This generally results in intermod products (particularly $f_C \pm 3f_{IF}$) which are suppressed only 10 to 20dB relative to the desired sideband. Intermod suppression can be improved by making the RF input the pump signal; however, this will severely degrade the carrier suppression. Using filters to further suppress the carrier and undesired sidebands is not practical since the IF frequencies are typically very low and cover many octaves (DC to several MHz). In order to simultaneously achieve excellent carrier and sideband suppression, mixers with very high (>60dB) LO to RF isolation must be used. For standard mixer configurations, isolation of this magnitude is very difficult to realize for LO bandwidths

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greater than a few percent. Even in narrowband applications, MIC SSBM's require tedious alignment to achieve high carrier and sideband suppression due to the extremely good phase and amplitude matching required.

MMIC SSBM DESIGN

The block diagram of the MMIC SSBM described here is similar to Figure 1. However, for this design, balanced subharmonically pumped mixers are employed [1]. A block diagram of this mixer is shown in Figure 2. A 180° hybrid is used to drive two pairs of antiparallel diodes. An antiparallel diode pair has unique mixing properties in that when a voltage:

$$V=V_{LO}\sin(w_{LO}t)+V_S\sin(w_S t)$$

is applied across the pair, the total current will contain only frequencies $nf_{LO}\pm mf_S$ where n+m is an odd integer [2]. Therefore, the antiparallel diode pair inherently suppresses the fundamental ($f_{LO}\pm f_S$) mixing products and also even harmonics of the LO ($2f_{LO}, 4f_{LO}, \ldots$). Pairs of diodes with essentially identical characteristics, like those processed in close proximity on a GaAs wafer, will provide excellent suppression of all even order products. For the SSBM presented here, the antiparallel diode pairs are pumped at $f_{LO}=f_C/2$ and the carrier signal $f_C=2f_{LO}$ is inherently suppressed, solely due to the balance of the diode pairs. The fundamental mixing products $f_{LO}\pm f_{IF}$ are also suppressed and low conversion loss is realized for the carrier sidebands at $2f_{LO}\pm f_{IF}$.

The balanced configuration shown in Figure 2 uses two pairs of diodes to also suppress the fundamental RF input (f_{LO}) signal at the mixer output. The common node of the 4 diodes, which is the RF_{out} port of the mixer, is a virtual ground to the applied fundamental and its odd harmonics. A schematic of the 180° hybrid is shown in

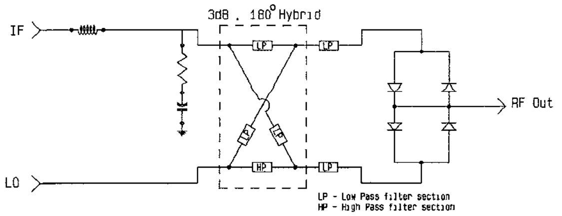

Figure 2 *Block Diagram of the balanced subharmonically pumped mixer used in the MMIC SSBM. Desired output signals appear at $2f_{LO}\pm f_{IF}$. The RF output port is virtual ground to the LO input.*

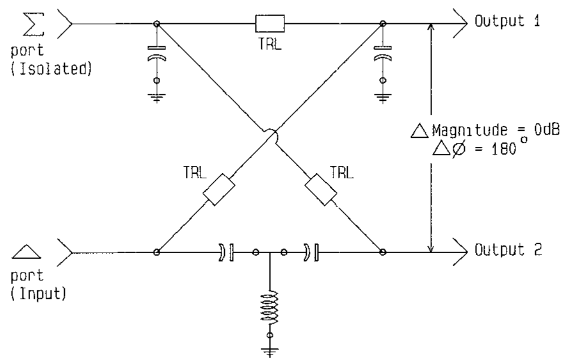

Figure 3 *Schematic of the 180° lumped element hybrid. An input at the Δ port is divided equally in amplitude and appears 180° out of phase at the 2 outputs. The Σ, Δ ports are isolated.*

Figure 3. This is a quasi-lumped element design which is analogous to a ring, or rat-race, hybrid. The transmission line sections of the ring hybrid are replaced here with low and high pass filter sections. Only 3-element filter sections were required for the modest bandwidth necessary for this design; good hybrid performance over multi-octave bandwidths is achievable by using filter sections with more elements. The isolated (Σ) port of the hybrid also provides a convenient point to apply the IF signal in-phase to the diode pairs in each mixer. This port is analogous to the center tap on a transformer. Low pass filters are inserted between the hybrid and diodes in order to present proper terminating impedances to the diodes.

A block diagram of the overall SSBM chip is shown in Figure 4. A single section Wilkinson divider is used to split and apply the $f_C/2$ pump signal to the mixers. A 3dB Lange coupler is used to combine the outputs of the mixers. The filters between the hybrids and mixers provide appropriate

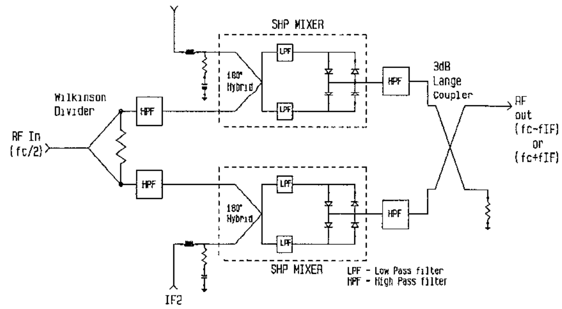

Figure 4 *Block Diagram of the MMIC subharmonically pumped SSBM.*

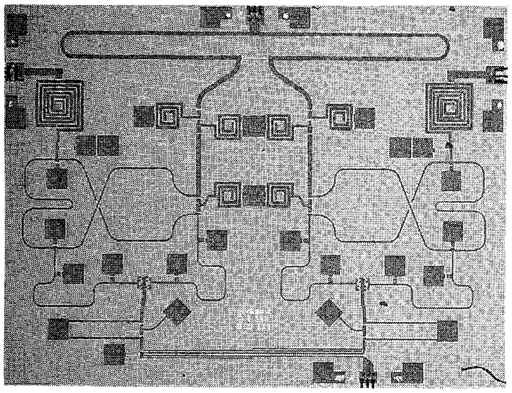

Figure 5 MMIC Subharmonically Pumped SSBM. Chip size is 4.3x3.2mm.

terminating impedances and some additional rejection of far-out-of-band signals.

MMIC FABRICATION

A photograph of the SSBM IC is shown in Figure 5. 125um thick wafers were processed using the ITT Multifunction Self-Aligned Gate (MSAG) process which has the capability to combine digital, analog, and power devices on the same wafer. Single finger (0.4um x 8um) planar schottky diodes were employed in the design as the nonlinear mixing elements.

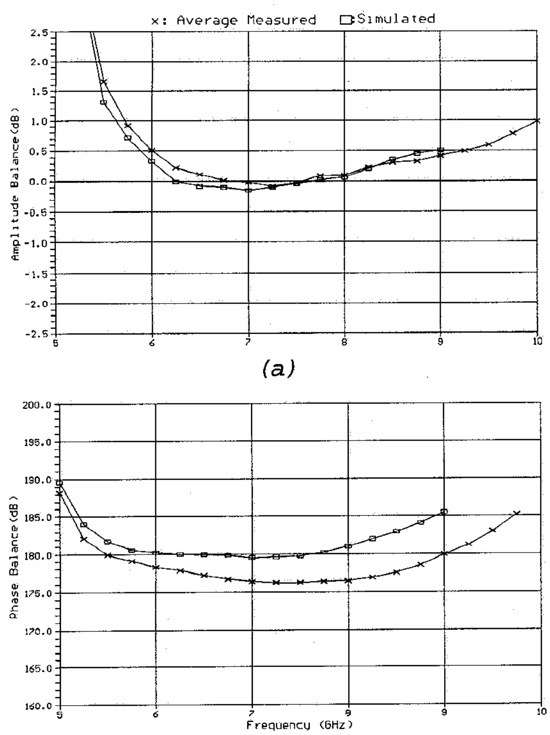

Figure 6 Measured and simulated amplitude (a) and phase (b) balance of the 180° hybrid used in the SSBM.

MEASURED PERFORMANCE

A "breakout" of the 180° hybrid was included in the SSBM mask set. Plots of measurement vs. simulation of this hybrid are shown in Figure 6. Phase and amplitude balance are typically better than 180°±5° and ±0.5dB.

Plots of typical measured performance for a packaged SSBM IC are shown in Figures 7 through 9. Figure 7 shows typical spectral plots of the SSBM output signal when the device is driven with a 7GHz, +15dBm LO. Figure 7a shows the SSB modulation performance with quadrature 1MHz IF signals @ -2dBm. After accounting for a total IF input power of +1dBm and test cable losses, the conversion loss calculates to less than 8dB. Carrier and sideband suppression are approximately 45dBc and 35dBc, respectively. DSBSC operation is shown in Figure 7b. Here, in-phase IF signals of 1MHz @ -2dBm each were applied. When one (or both) of the mixers is unbalanced by the application of a negative DC bias at the IF port(s) the carrier is not suppressed. Typical carrier

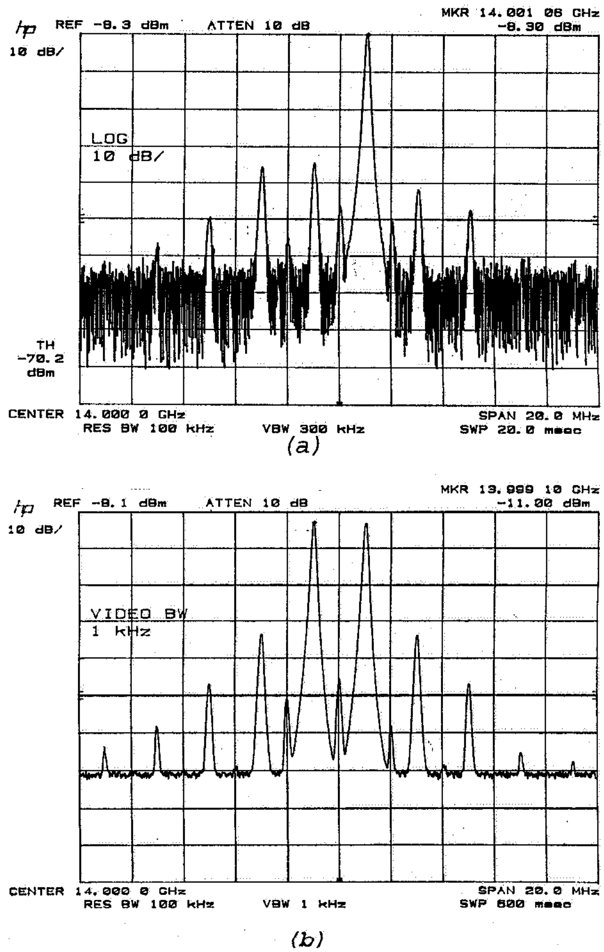

Figure 7 Typical spectral performance of the SSBM IC. SSB modulation is shown in (a) and DSBSC modulation is shown in (b).

output power, with a +15dBm LO signal and -.35VDC applied at both IF ports, is 0dBm.

Figures 8a, b, and c show the conversion loss, carrier, and sideband suppression performance of 8 different packaged IC's over a carrier bandwidth from 13 to 23GHz. Typical performance over the 14 to 19GHz band is >40dBc carrier suppression, >25dBc sideband suppression and <10dB conversion loss. Over the 13GHz to 23GHz band typical performance is >35dBc carrier suppression and >20dBc sideband suppression. No DC bias or IF phase adjustments were made to optimize this IC performance. Over narrow

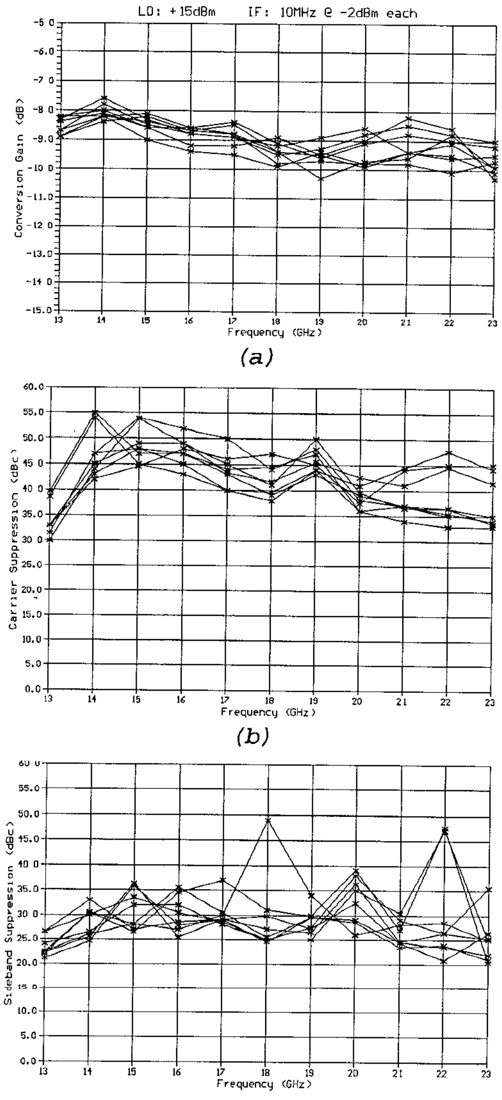

Figure 8 *Broadband Performance of 8 carrier mounted devices during SSB modulation operation. Shown are conversion loss (a), carrier suppression (b), and sideband suppression (c).*

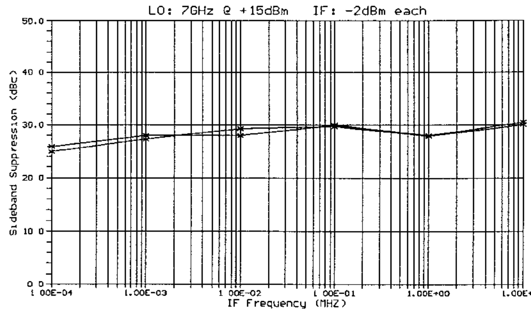

Figure 9 *Typical sideband suppression for fixed LO, swept IF inputs.*

bandwidths, performance can be significantly improved with such adjustments. A second pass design of this IC will include an improved output quadrature combiner. This is expected to result in sideband suppression on the order of 35dBc.

Figure 9 shows the sideband suppression performance of 2 devices when the IF frequency is swept from 100Hz to 10MHz. Measurements were made with a fixed LO of 7GHz @ +15dBm. Similar performance was measured at LO frequencies from 13 to 23GHz.

The SSBM performance was also characterized vs. temperature. Over a range of -55°C to +100°C, conversion loss variation is <±0.5dB and variation in carrier and sideband suppression is <±2dB. The LO power level was also varied from 13 to 17dBm with no significant change in performance.

CONCLUSIONS

An innovative subharmonically pumped SSBM IC which provides excellent broadband performance without the need for tedious and costly tuning has been designed and fabricated. With appropriate broadband hybrid circuits, similar performance over multi-octave bandwidths is achievable using the subharmonic pump approach.

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