Optimized Compact Active Downconverters Having Low Power Consumption and High Conversion Gain

B. P. Kumar, *Senior Member, IEEE*, G. R. Branner, *Life Member, IEEE*, D. Xu, and A. Ching

***Abstract*—An in-depth technique for modeling, optimized design, and fabrication of compact, active low power downconverters, operating at ~1 GHz, is presented in this paper. The designs employ precision computer models of active devices, developed to assist in providing optimal self oscillating mixer based designs. The designs yield measured conversion gains of up to 9 dB (for maximum bias power of 17.3 mW) and 6.5 dB (for maximum bias power as low as 1.7 mW).**

***Index Terms*—Active, bipolar, components, downconverters, wireless.**

I. Introduction

THERE is currently increasing requirement for efficient low power consumption components and subsystems for use in dynamic emerging communication system applications. One of the most crucial components of receiving systems for such applications are low noise downconverters. Realizations of such components typically utilize diodes [1] and more recently MESFETs and HEMTs with large bias power requirements as well as significant external local oscillator RF and bias power [2].

The self oscillating mixer (SOM) is a device which can perform all the essential functions for the aforementioned component while requiring less bias power, no local oscillator with its RF and bias power requirements, and less space. Over the past few years, a number of researchers have reported SOM realizations utilizing both MESFET [3] and bipolar active elements [4], [5]. These developments are primarily experimental and empirical in nature [3]. Recently, a new design approach employing Volterra series provides yet another method for analyzing these devices [3].

Building on our previous experience in this area [4], the current letter focuses on the development of very low power consumption self oscillating mixers (SOM) for the 1 GHz communication band. In contrast with earlier designs [4], these mixers were developed using precision active and passive computer models in an accurate harmonic balance based computer program, employed to provide optimized circuit performance. This has resulted in physically realized SOM circuits with *measured* conversion gains in excess of 9 dB, and power requirements ranging from 1.7 mW to 17.3 mW. This contrasts significantly with other SOM designs, with typical power requirement greater than 60 mW.

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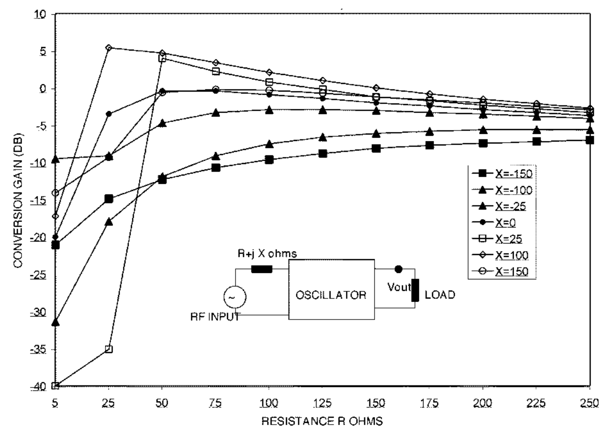


Fig. 1. Conversion gain curves as a function of RF source impedance $R + jX$ ohms. Bias = 2 V, RF Power = −20 dBm, IF frequency = 110 MHz.

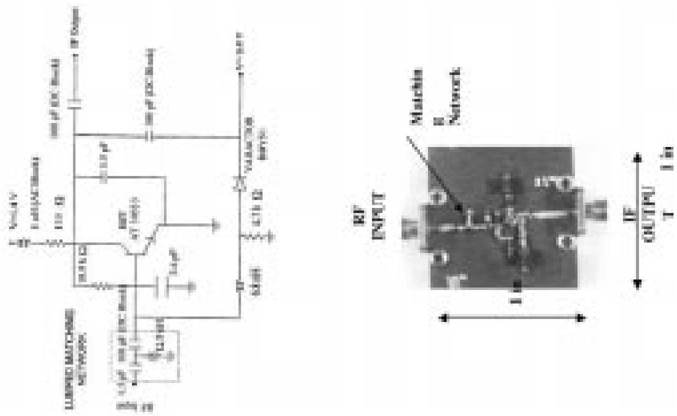
II. Development of CAD Models for Self Oscillating Mixer System Design

The overall SOM circuit consists of a cascade of appropriately synthesized input network, oscillator, and output network.

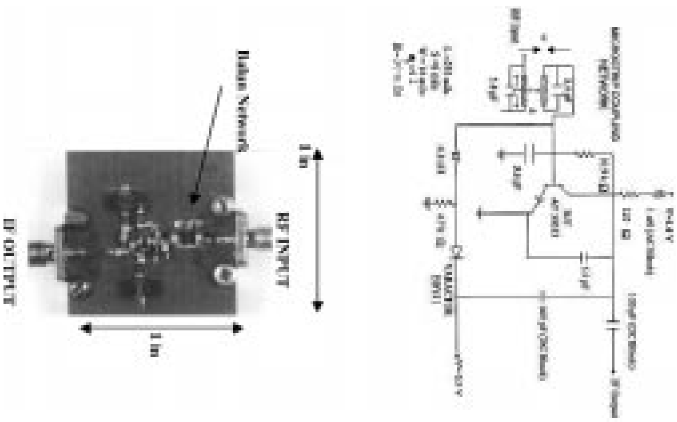
A. Modeling of Active Device and Oscillator

An important initial step in the SOM design is the development of a precision model for the active device employed in the internal oscillator of the overall system. The active device employed in this realization is the extremely low power HP-Avantek AT 30533 bipolar transistor. A very accurate nonlinear model for this device was developed, after a substantial modeling effort [5], from the device physics, static measurements, and S parameter measurements. The final active model[1] was developed from a three step iterative process [5]. ***Step 1:*** The transistor I_c–V_{ce} curves are measured on the semiconductor parameter analyzer (HP 4155A) and S parameters are measured using the HP 8510B under the bias conditions anticipated for the SOM. ***Step 2:*** A nonlinear physics based model is utilized whose parameters we optimized within physically reasonable bounds to provide an excellent fit to measured data. Final errors in this case are typically less than 5% over V_{ce} ranges of usage. ***Step 3:*** The parameters found in step 2 are constrained while optimizing the other parameters to provide a match to measured small signal scattering parameters. Final errors are less

[1]This model is an expanded and optimized version of the original HP/Agilent AT-30 533 Spice model, which is obtainable from HP/Agilent.



(a)



(b)

Fig. 2. (a) Schematic and photograph of self-oscillating mixer model SOM-1. (b) Schematic and photograph of self-oscillating mixer model SOM-2.

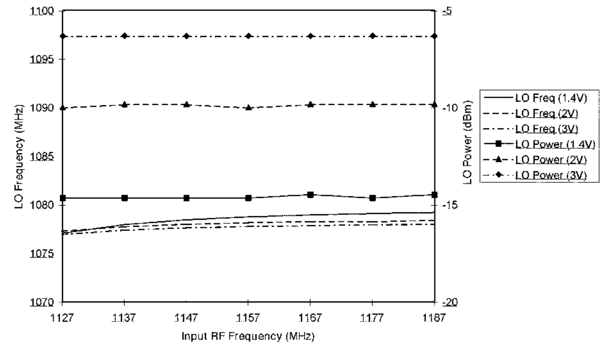
than 10% in magnitude and 10° in phase. The entire process is iterated until optimum results are obtained.

The oscillator portion of the SOM was designed employing large signal techniques similar to [5]. Subsequent figures will provide details to this design.

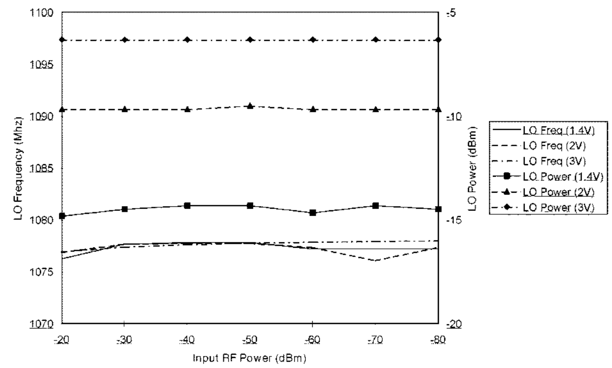
B. Modeling and Design of Input Matching Networks

The next aspect of the design process involves the synthesis of efficient networks to couple the RF signal energy into the oscillator circuit. Design of this network involves development of a circuit that will provide efficient matching of the passive generator impedance into a load (base of the transistor) that possesses a negative real part impedance at the bias point where oscillations occur. The design approach using HP/Agilent Microwave Design System (MDS) circuit simulation is described in the circuit insert portion of Fig. 1. The circuit insert shows the RF source located at the input to the oscillator with output voltage **Vout** developed across the load. In order to ascertain an efficient matching structure, search is performed over a broad range of R and X values, utilizing the MDS harmonic balance software to obtain the simulated conversion gain of the entire SOM system. Fig. 1 demonstrates the outcomes of this approach by illustrating plots of conversion gain versus resistance R, for different reactance values X.

These plots show sets of R and X values which provide optimal regions of higher conversion gain. The (R, X) values **selected from these regions** are used as design requirements for realizing input matching networks, as described in Section III. The two forms of input matching networks which were developed and fabricated are **a) lumped LC network**, and **b) compact microstrip balun network**. These are detailed in Section III.



(a)



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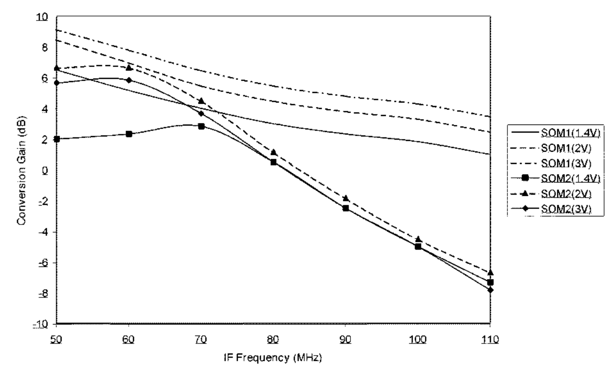

(c)

Fig. 3. (a) SOM-1: LO frequency versus input RF frequency. SOM-1: LO power versus input RF frequency. (b) SOM-1: LO frequency versus input RF power. SOM-1: LO power versus input RF power. (c) SOM-1 and SOM-2: Conversion gain versus IF frequency.

III. Circuit Fabrication and Measured Results

Two extremely low bias power consumption mixer circuits were modeled, optimized employing the design procedure described in Section II above, and realized using microstrip. These circuits were all fabricated on 20 mil thick duroid circuit board ($\varepsilon_r = 2.17$), and although the size of the circuits was com-

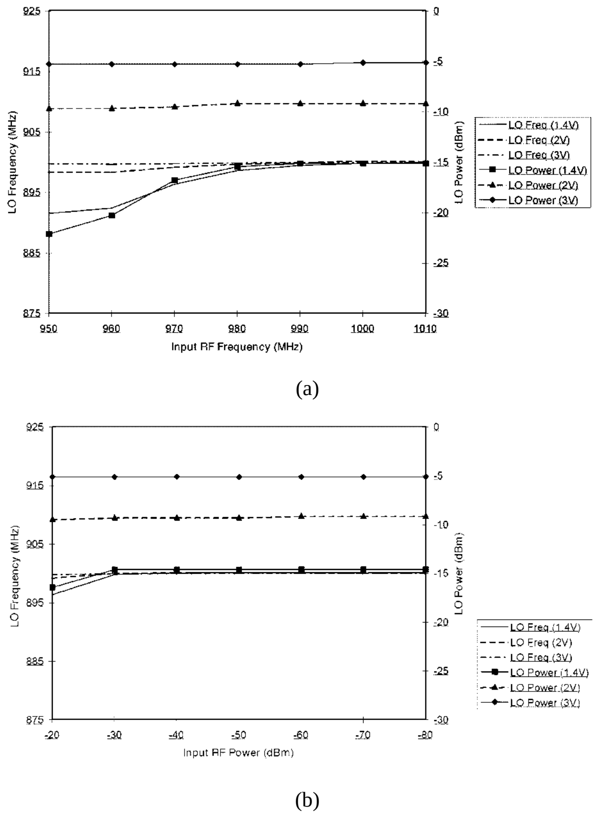

Fig. 4. (a) SOM-2: LO frequency versus input RF frequency. SOM-2: LO power versus input RF frequency. (b) SOM-2: LO frequency versus input RF power. SOM-2: LO power versus input RF power.

pactly confined to a 1 in $\times$ 1 in area, they are capable of further reduction. Both circuits were fabricated using photo lithographic process in the UC Davis Microwave laboratory and used high quality chip capacitors and inductors. The measured performance of these circuits is detailed in the following paragraphs.

The first SOM circuit (SOM-1), shown in Fig. 2(a), is designed for broadband operation to provide conversion gains over an IF frequency (f_{IF}) range of 50–110 MHz. The varactor diode in both the mixer circuits SOM-1 and SOM-2 plays the role of tuning the LO frequency over a given range. This circuit utilizes a high pass lumped LC matching network synthesized to meet specifications as described above in Section II. In this circuit, the design value used is $R + jX = 100 + j125$, which yields the matching circuit component values as: $L =$ 12.9 nH and $C = 1.62$ pF. Due to availability constraints, the values used are $L = 12.9$ nH and $C = 1.5$ pF. The RF signal is fed through this network into the oscillator to provide mixing action with a self oscillating frequency (f_{LO}) of ~1 Ghz.

Fig. 3(a)–(c) show measured performance data for SOM-1. The left handscale in Fig. 3(a) shows that for a bias of 1.4 V, stable SOM self-oscillation occurs at 1.077 Ghz, while the right-hand scale shows stable output power (nominal -14.7 ± 0.2 dBm) for a given range of RF frequencies from 1.127 to 1.187 Ghz (IF varying between 50–110 Mhz). Fig. 3(b) shows the effect of input RF power level on LO frequency and LO power for bias voltages of 1.4, 2.0, and 3.0 V. As with previous figures, excellent stability is evident. Fig. 3(c) is a plot of the conversion gain for SOM-1 for $50 \leq f_{IF} \leq 110$ Mhz utilizing an RF input power of -20 dBm and Vcc values of 1.4, 2.0, and 3.0 V. This figure demonstrates that, depending on the RF frequency, conversion gains as high as 9 dB are obtained for SOM-1 with 3 V bias and 50 Mhz IF output frequency.

Measured data on LO to RF leakage for SOM-1 is -30.17 dB, -21.33 dB and -18.83 dB for respective bias values of 1.4 V, 2 V, and 3 V. In both SOM-1 and SOM-2 circuits below, measured LO to IF leakage is ≥ -10 dB. It should be noted, however, that straightforward IF filtering can significantly improve this result.

Measured data on 1 dB gain compression yields respective values of -17.9 dBm for 1.4 V bias, -17.8 dBm for 2 V bias, and -17.9m dB for 3 V bias.

Typical currents drawn by the SOM-1 circuit is 1.24 mA (for bias of 1.4 V), 2.91 mA (for bias of 2 V), and 5.69 mA (for bias voltage of 3 V).

Fig. 4(a) and (b) and Fig. 3(c) describe the measured results for SOM-2. As with the previous design, this circuit is optimized to provide excellent conversion gain with low bias power requirements. These results demonstrate very good performance over a wide range of input RF frequencies from 950 Mhz to 1060 Mhz, with stable self oscillation at 900 Mhz. Measured data on LO to RF leakage for SOM-2 is -26.83 dB, -16.17 dB, and -14.67 dB for respective bias values of 1.4 V, 2 V, and 3 V. Measured data on gain compression are -23.5 dBm for 1.4 V bias, -5.2 dBm for 2 V bias, and 3.5 dBm for 3 V bias.

Typical currents drawn by the SOM-2 circuit is 1.38 mA (for bias of 1.4 V), 3.2 mA (for bias of 2 V), and 5.78 mA (for bias voltage of 3 V).

IV. Conclusion

This letter presents results of an in-depth technique for modeling, harmonic balance CAD-based optimization, design, fabrication, and testing of active low power consumption high conversion gain downconverters featuring the SOM approach. Designs yield measured conversion gains of up to 9 dB (for maximum bias power of 17.3 mW), 6.5 dB (for maximum bias power as low as 1.7 mW), and excellent measured stability to variation in input RF frequency and RF power.

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