30 GHz CMOS Self-Oscillating Mixer for Self-Heterodyne Receiver Application

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***Abstract*—A 30 GHz CMOS-based self-oscillating mixer (SOM) is demonstrated for millimeter-wave self-heterodyne receiver applications. When injection-locked by transmitted LO carrier, the SOM provides constant and sufficient LO power for mixing process independent of transmitted LO power level. The SOM based on the cross-coupled VCO architecture is realized in 0.13 μm CMOS process. It has down-conversion loss of about 30 dB and requires the minimum LO injection power of −32 dBm.**

***Index Terms*—CMOS, injection-locking, millimeter-wave, self heterodyne systems, self-oscillating mixer (SOM).**

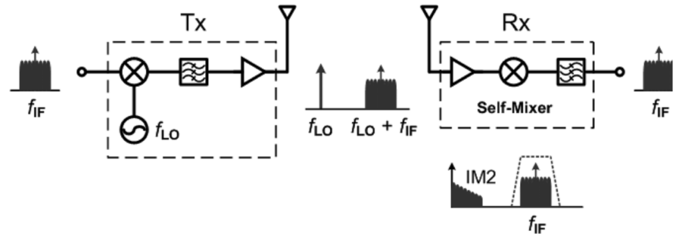

Fig. 1. Schematic diagram of self-heterodyne systems. Received IF signal quality has immunity on local oscillator phase noise of transmitter.

I. Introduction

THE millimeter-wave band is attracting significant research interests for high-speed and small coverage wireless applications such as WPAN (wireless personal area network), WLAN (wireless local area network), vehicle collision avoidance, and security or medical imaging. These applications require small volume, low power and low-cost transceivers. Although many great advances have been recently made in RF CMOS device and circuit technologies, there is on-going research interests for further reducing implementation costs of millimeter-wave circuits. Interests in self-heterodyne system are one example [1], [2]. In this scheme, the transmitter sends modulated RF signal together with LO carrier and the receiver down-converts the RF signal by self-mixing, as shown in Fig. 1. Because transmitter LO noise can be canceled out by the self-mixing process in receiver, a low cost LO source with relatively poor phase noise performance can be used in the transmitter, eliminating the need for receiver LO.

In order to obtain the highest IF output power by self- mixing in the self-heterodyne receiver, the transmitted LO carrier and RF signal power should be the same [1]. This is a disadvantage in that about half of the transmission power should be used for LO carrier transmission, which does not carry any information. Moreover, because the resulting IF power linearly depends on both LO and RF powers, reduction in the received channel power will affect IF power by a factor of 2 [3], [4].

In this letter, a self-oscillating mixer (SOM) [5] is proposed that can be used as the self-mixer and solve the above problems.

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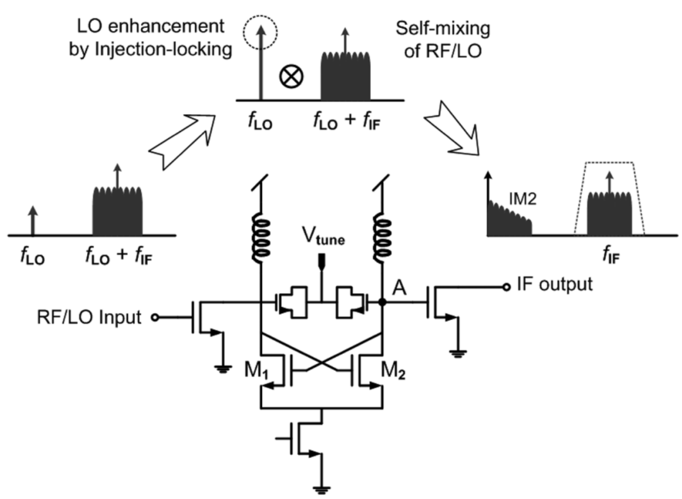

Fig. 2. Schematic diagram and operating principle of self-oscillating mixer. LO power enhancement by injection locking improves conversion efficiency.

As shown in Fig. 2, an SOM oscillates by itself and generates high power LO signal which is used for frequency down-conversion of the RF signals to IF band within the SOM. Because the mixing efficiency of an SOM depends only on the self-generated LO power independent of the received LO power, we can reduce the transmission LO power. The transmitted LO is used for injection-locking of the SOM. It maintains phase correlation between LO and RF signals for mixing process so that the down-converted IF signal has low phase noises. As a result, the SOM works like a limiting amplifier of the received LO to a fixed power level offering the constant conversion efficiency even when received LO power changes. A prototype 30 GHz SOM was realized in standard 1P8M 0.13 μm CMOS process and its performances are evaluated in this letter.

II. Oscillation and Injection Locking of SOM

The SOM was designed based on a 30 GHz cross-coupled voltage-controlled oscillator as shown in Fig. 2. The oscillator core is composed of a cross-coupled NMOS pair having 32 μm

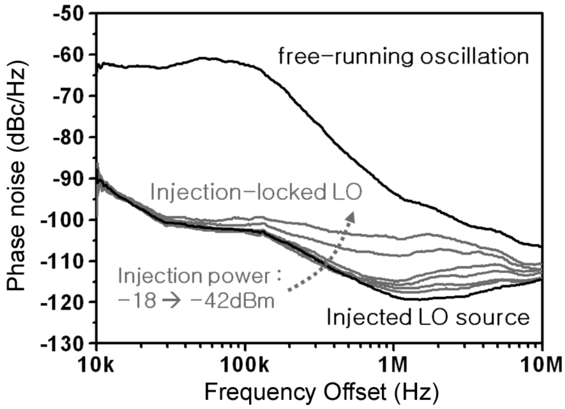

Fig. 3. Measured phase noise of oscillation output when the injected LO powers are −42, −37, −32, −27, −22, −18 dBm. Lower injected LO power causes larger discrepancy of injection-locked LO phase noise from injected LO source.

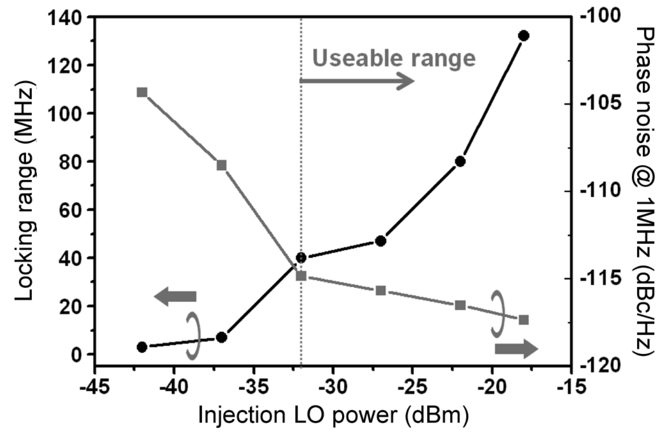

Fig. 4. Measured locking range and locked VCO phase noise at 1 MHz frequency offset as a function of injected LO power.

width. The input and output transistor sizes are determined so that output impedance of the input transistor is identical to the input impedance of the output transistor. The inductors are implemented with short-circuited stubs having inductance of 110 pH and Q of 13.5 at 30 GHz. The oscillator core including buffers draws 22 mA from a 1.2-V supply. Measurement was performed with an on-wafer probing set-up having cable and attenuator loss of 10 dB at 30 GHz. The measured free-running oscillation frequency ranges from 25.8 to 30.06 GHz with the tuning voltage control of NMOS varactors from 1 V to 2 V. The free-running output power is about +2 dBm and the phase noise ranges from −93.5 to −98.8 dBc/Hz at 1 MHz frequency offset. For mixing operation, the RF and LO signals are injected into the SOM through a common source input buffer. Locking of the free-running oscillator by injected LO is simultaneously achieved with mixing operation of the input RF with injected LO signals in the SOM. The output IF signals can be obtained through the common source output buffer.

Injection-locking characteristics of the SOM were evaluated by measuring oscillation output with an RF spectrum analyzer when 30 GHz band LO was injected to the input buffer. With injection locking, the output LO phase noise follows that of the injected LO if the offset frequency is less than the locking bandwidth [6]. If not, the output phase noise follows that of a free-running oscillator. The locking bandwidth is proportional to the injected LO power [7]. Consequently, when the injected LO power is very low (< −32 dBm in our case), the output LO phase noise deviates from that of the injected LO as shown in Fig. 3.

Fig. 4 shows the measured locking bandwidth and resulting oscillator phase noise as a function of injected LO power. In the SOM operation, the imperfect locking of the oscillator by injected LO may weaken the correlation between RF and LO signals resulting in phase noise degradation of the output IF signal. Consequently, the injection LO power should be larger than −32 dBm for proper operation.

III. Mixing Characteristics

For experimental verification of the SOM operation, 30 GHz band RF and LO signals were generated and injected to the SOM. The resulting IF signal was measured with an RF spectrum analyzer with 20 dB amplification as shown in Fig. 5. In self-heterodyne systems, the receiver should recover a high purity IF signal from noisy RF signals degraded by a noisy LO source. In this experiment, 30 GHz LO source was frequency modulated by 300 KHz sine wave in order to emulate high phase noise. The 500 MHz IF signal was frequency up-converted to 30 GHz band by the frequency modulated LO source so that the RF and LO signals are both noisy and correlated. With band-pass filtering, the upper sideband of the up-converted RF was rejected and LO carrier power was suppressed.

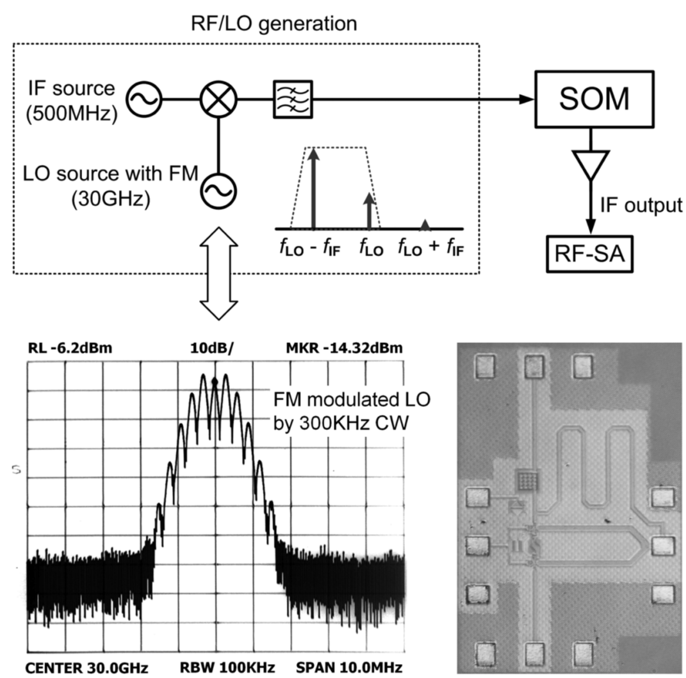

Fig. 5. Experimental setup for measurement of SOM characteristics and chip photograph of the prototype. RF and LO signals are generated with a mixer and filtered to lower the LO power. FM modulated LO source was used to verify the SOM operation assuming low phase noise LO in transmitter.

Self-mixing of RF and LO signals in the SOM produces 500 MHz IF signal shown in Fig. 6(a) and (b). In Fig. 6(b), there are two side lobes separated by 300 KHz from the main lobe. This is due to the frequency modulated LO source. The

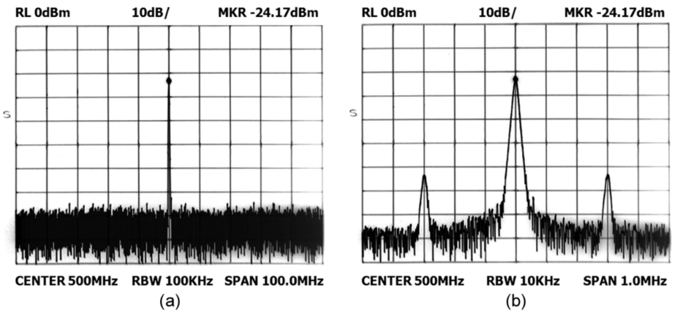

Fig. 6. Spectrum of output IF from the SOM with (a) 100 MHz and (b) 1 MHz span where injected LO power is −17 dBm.

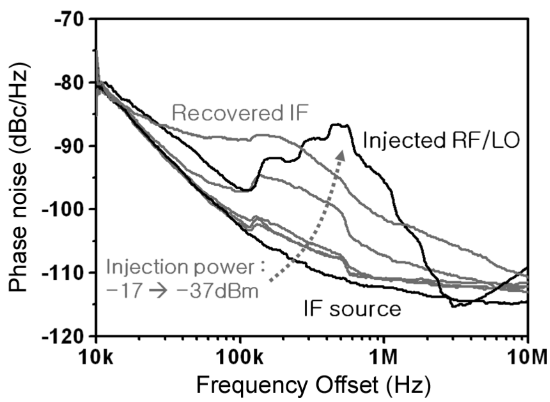

Fig. 7. Phase noise of output IF where injected LO powers are −37, −32, −27, −22, −17 dBm. Low power LO injection causes phase noise degradation if output IF signal.

effect of these side lobes can be also observed in Fig. 7, but they do not seriously affect the overall performance.

Fig. 8 shows the conversion gain of the SOM and output phase noise of recovered IF signal as a function of injected LO power. The RF injection power is fixed at about −10 dBm. The conversion gain is nearly independent of injected LO power because the SOM can supply high power LO for mixing by itself. However, the SOM has a lower limitation on injected LO power. Fig. 7 shows the phase noise of recovered IF signal when injected LO power is controlled from −37 dBm to −17 dBm in 5 dB step. When the injected LO power is sufficient, the output phase noise follows that of input IF source indicating successful recovering. However, as the injection LO power is reduced, the phase noise of the recovered IF signal is seriously degraded. This is because the injection locking of the SOM by LO is not sufficient. The required LO power for proper operation of the SOM is about −32 dBm, and conversion loss is about 30 dB independent of the LO power. The SOM has relatively high conversion loss because the inductor acts as a short circuit to the IF signal at node A in Fig. 2 causing loss. Nevertheless, the conversion loss of the SOM is still about 10 dB better than CMOS

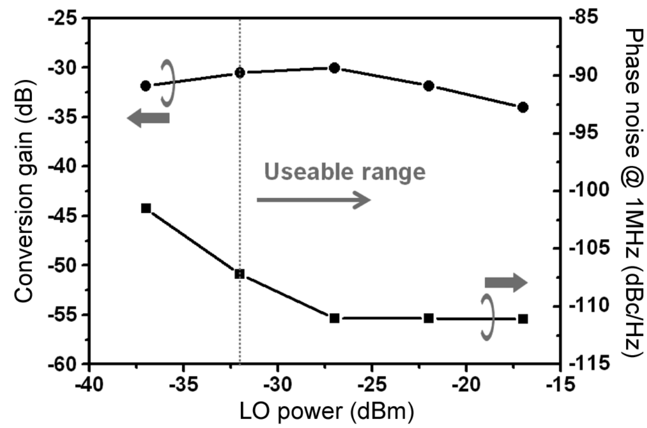

Fig. 8. Conversion gain of SOM and phase noise of output IF at 1 MHz frequency offset as a function of injected LO power. Conversion gain is nearly independent on injected LO power. Over −32 dBm LO injection power, SOM can recover high purity IF signal with low phase noise.

Schottky-barrier diode mixer with the same injection LO power of −32 dBm [4].

IV. Conclusion

A 30 GHz CMOS self-oscillating mixer (SOM) was demonstrated that can be used for the self-heterodyne receiver. The SOM can frequency down-convert 30 GHz RF signals into IF band with a constant conversion loss of 30 dB independent of transmitted LO power. Also by injection locking, the correlation between transmitted RF and LO signals is maintained in SOM so that low phase noise IF signal can be recovered. The minimum required injection LO power for proper frequency and phase locking of SOM is about −32 dBm. We believe our CMOS SOM with simplicity can be useful for short-range millimeter-wave transceiver applications.

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