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A Workable Use of Floating-Body SOS MOSFET as a Transconductance Mixer

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1. Introduction

With its highly insulating sapphire substrate, the submicron silicon-on-sapphire (SOS) CMOS technology is attractive for the low-cost implementation of RFIC because of the minimal high frequency substrate loss and the integration of the on-chip passive components of high quality factor. However, just like other variants of SOI technology, the SOS MOSFET suffers the same floating-body effects. It can be impediments for analog and RF circuits due to possible circuit problems [1]. Although there have been some RF circuit building blocks implemented using SOS/SOI CMOS technology [2], the use of floating-body SOS MOSFET for upconversion mixer, which is a frequency-translational circuit, has not been explored.

In this paper, a feasible use of floating-body SOS MOSFET for RF transcondutance mixer is presented. Based on the DC characteristics of the floating-body SOS MOSFET, the mixer operation is devised.

2. Experimental Conditions

The SOS MOSFET's without body-contact were fabricated using a commercial 0.5-μm SOS CMOS process with silicon film thickness of 120 nm and a minimum drawn gate length of 0.8-μm. The SOS MOSFET's were designed using conventional multifinger layout (17 fingers each of 15.4 μm) and connected in a single-stage common-source configuration with ground-signal-ground pads for the input and output ports. The DC measurements were first made and the measured DC device characteristics are shown in Fig. 1. In the RF mixer measurement (Fig. 2), the small-signal IF (intermediate frequency) voltage of 400 MHz and the large-signal LO (local oscillator) voltage of 1.6 GHz are combined using a 2-way hybrid. The combined signal is then injected to the gate terminal through a bias-tee. The output power of the upconverted RF signal is detected using a spectrum analyzer.

3. Operation Principles and Results

From the measured DC output characteristics, I_{DS} versus V_{DS} as shown in Fig. 1(a), the drain current I_{DS} of the SOS nMOSFET clearly has a DC kink at certain drain voltages V_{DS}. With increasing V_{DS}, the floating-body of SOS nMOSFET causes a premature soft breakdown after the DC kink, which indicates the potential seriousness of the floating-body effect. Both the DC kink and the premature soft breakdown can be alleviated with body contacts but at the expenses of more complicated layout, larger device area and increased parasitic capacitance.

Despite the static DC kink measured in the output characteristics, the drain saturation current I_{DSsat} of the floating-body SOS MOSFET has an approximate square-law transfer characteristics, I_{DS} versus V_{GS} (Fig. 1(b)). This results in a transcondutance g_m varied almost linearly with the gate voltage V_{GS} at the saturation region. The linear g_m at the saturation region can be exploited for transconductance mixer. When the floating-body SOS MOSFET is biased at V_Q and a large-signal input voltage (e.g. $v_{LO}(t)=V_{LO}\cos(\omega_{LO}\,t)$) is applied to the gate input,

$$g_m(t) \approx \mu C_{ox}(W/L)\{v_{LO}(t) + V_Q - V_T\}$$

using a long channel approximation. The output current i_{OUT} will be the product of the time-varying g_m and the small-signal input signal:

$$i_{OUT}(t) = g_m(t)\, v_{IF}(t) \propto v_{LO}(t)\, v_{IF}(t)$$

An RF signal mixing (frequency translation) is then achieved with the multiplication of the two signals in the time domain. The non-linear equivalent circuit model for the operation of the RF mixer is shown in Fig. 3.

A single-gate FET RF up-conversion mixer based on the above principles has been configured (Fig. 2). The power conversion gain has been measured to be about 1.5 dB for a 50 Ω output load. The non-linearity measurement was performed with two-tone test and the measured output spectrum is shown in Fig. 4. The corresponding IP3 plot is shown in Fig. 5 showing a reasonable input IP3 of about 5 dBm. A performance summary of the RF transconductance mixer using the floating-body SOS MOSFET is listed in Table 1. Although a 3 V power supply was used in the measurement, the transconductance mixer design is indeed able to operate at a very low-voltage as long as the square-law transfer characteristic holds.

3. Conclusions

The feasible approach of using floating-body SOS MOSFET as an RF transconductance mixer has been demonstrated. Exploiting the approximate square-law transfer characteristic of the floating-body SOS MOSFET, the single-gate FET upconversion mixer achieves power conversion gain with high output bandwidth and reasonable linearity.

Acknowledgements

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References

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[2] R. A. Johnson et al., *IEEE Transactions on Electron Devices*, vol. 45, no. 5, pp. 1047-1054, May 1998.

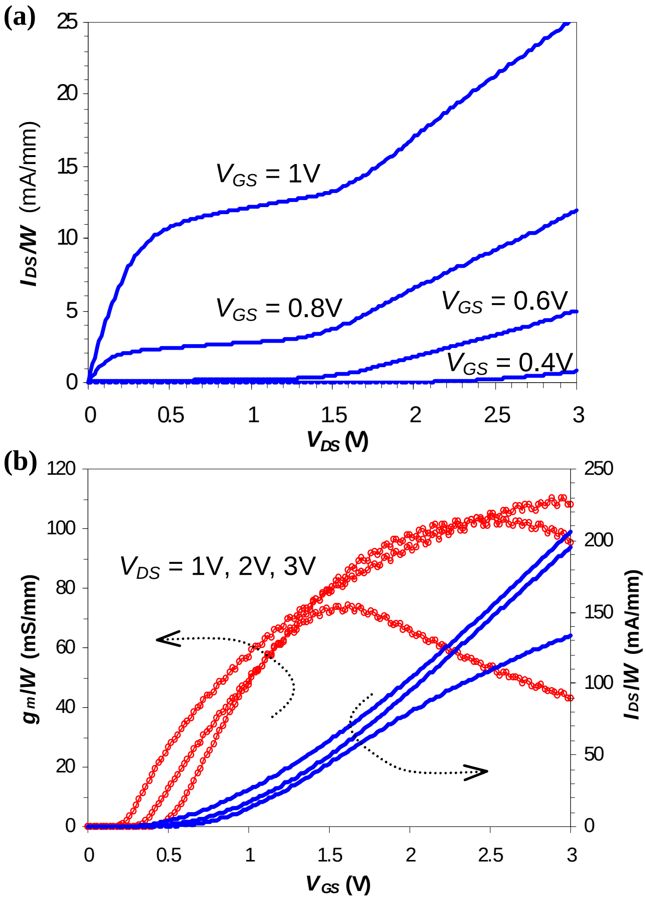

Fig. 1 The DC device characterisitcs of the floating-body partially-depleted SOS nMOSFET showing the DC kink (a) output characteristics; (b) transfer characteristics.

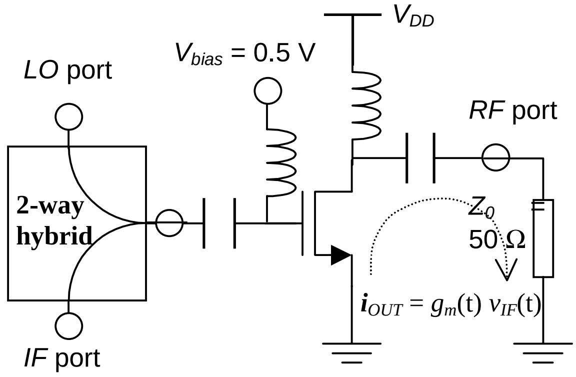

Fig. 2 The schematic diagram of the measurement set-up of the SOS MOSFET as a single-gate FET up-conversion mixer.

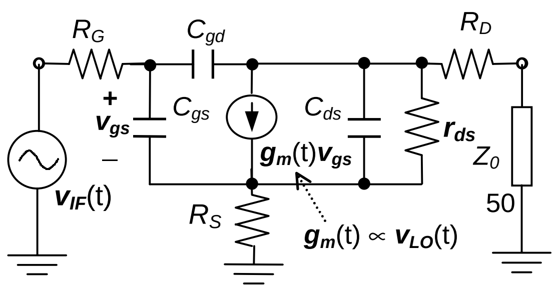

Fig. 3 The non-linear equivalent circuit model of the transconductance mixer with single-gate SOS MOSFET

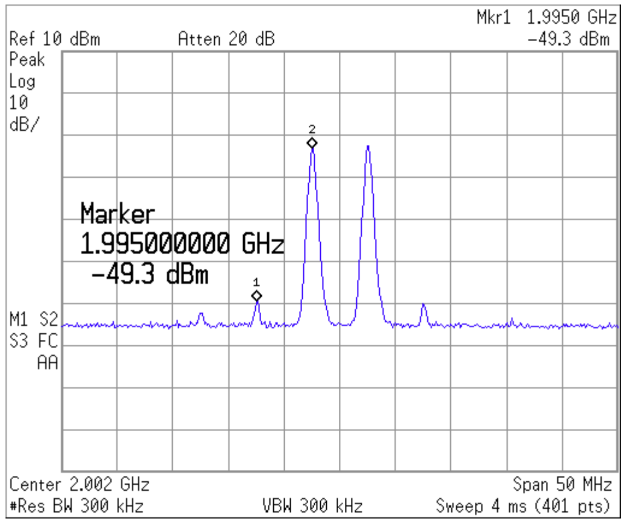

Fig. 4 The measured output spectrum of two-tone test (IP3, IMD measurement) of the single-gate FET up-conversion mixer

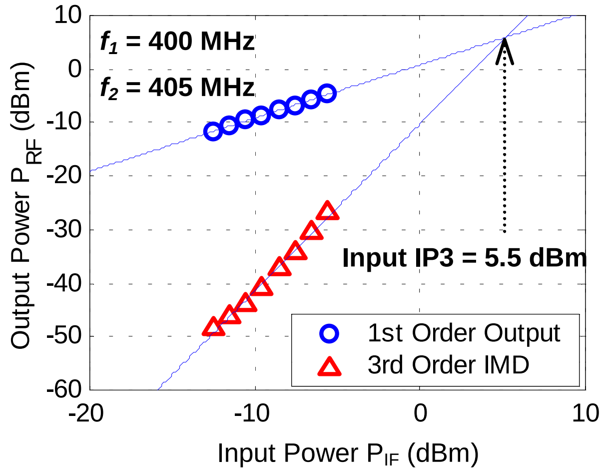

Fig. 5 The determination of the third order intermodulation intercept point of the SOS single-gate FET up-conversion mixer.

Table 1 The performance summary of the floating-body SOS MOSFET as a single-gate FET up-conversion mixer.

RF Frequency	2.0 GHz
LO Frequency	1.6 GHz
IF Bandwidth	400 MHz
LO Power	5.5 dBm
Supply Voltage V_{DD}	3.0 V
DC Bias	0.55 V
Current Consumption I_{DS}	8.0 mA
Power Conversion Gain	1.4 dB
IP3 (Input)	5 dBm
1-dB Compression (Input)	-10 dBm
Technology	0.5 μm SOS CMOS (L_{min} = 0.8 μm)