COPLANAR AND MICROSTRIP OSCILLATORS IN SiGe SIMMWIC TECHNOLOGY

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ABSTRACT

Oscillators in SiGe SIMMWIC HBT technology have been realized in coplanar and a newly developed microstrip environment. Coplanar 24 GHz LC oscillators show 8.7 dBm output power and a phase noise of -99 dBc/Hz @ 100kHz offset. Coplanar 27 GHz VCO´s yield 12.5 dBm output power and a tuning range of 1.28GHz. Microstrip 27 GHz VCO´s show 5 dBm output power and a phase noise better than -90 dBc/Hz @ 100kHz offset.

INTRODUCTION

The penetration of millimeterwave systems into civil markets will be greatly dependent on the availability of millimeter wave integrated circuits (MMICs). The advantages of such devices are obvious: high bandwidths allow for high data rates in communication applications as well as high resolution in sensor systems with the benefit of small-size antennas. It is expected that by using monolithic solutions for the front-end components the cost targets of mass markets can be met.

Most promising seems a silicon based solution as the wafer sizes (up to 12 inch) and the high availability of silicon substrates favor a cost effective mass production. Furthermore, due to the continuous improvement of Si RF device characteristics (CMOS, SiGe HBT, SiGe HFET) Silicon technology is penetrating the microwave and millimeter wave region. One approach for this is SIMMWIC (silicon millimeter wave integrated circuit) technology [1], which uses high resistivity silicon (HRS) substrates to achieve low transmission line attenuation characteristics.

Excellent results have been reported already on SiGe HBT SIMMWIC oscillators concerning maximum operation frequency [2]. In this paper, results are shown on a low noise coplanar 24 GHz SiGe HBT LC oscillator, a coplanar 27 GHz SiGe HBT voltage controlled oscillator (VCO), and a low phase noise microstrip 27 GHz SiGe HBT VCO with a recently developed MST technology [3].

SiGe SIMMWIC TECHNOLGY

The Si/SiGe heterojunction bipolar transistor (HBT) provides a three-terminal silicon device which is well behaved and capable of working at millimeter wave frequencies. Compared with the bipolar junction transistor, the Si/SiGe HBT offers the possibility of high base doping for low base resistance and a short base transit time by reducing the base thickness thus resulting in high cut-off frequencies, low noise behavior, and high current gain.

The HBT´s are fabricated on high resistivity silicon with $\rho > 4000\ \Omega$cm. The complete layer structure of the HBT is grown without interruption by silicon molecular beam epitaxy (Si-MBE) [4]. An inverse doping profile is used with $N_{base} = 8*10^{19}\ cm^{-3} > N_{emitter} = 1.5*10^{18}\ cm^{-3}$. To optimize the RF performance, a thin base of 30 nm width including the spacer-layers to avoid outdiffusion of the Boron dopant into the emitter and collector is used. Details on the fabrication process of the transistors are described in [5] and [6], respectively. A double mesa fabrication process is used with a <100> orientation of the emitter fingers to control the underetch of the emitter finger-metal for a self-aligned base contact. A trench etch around the intrinsic HBT is performed to minimize influence of the parasitics. Passivation is performed with a low temperature (270°C) PECVD silicon nitride layer. Gold metallization is used for the transistor, passive elements, and the transmission lines.

The SiGe HBT fabrication process for the coplanar design differs from that for the microstrip design, since for the microstrip fabrication process a differentially grown epitaxy was used. The resulting SiGe-HBT's with 6 emitter fingers (1µm x 7µm) exhibit f_t values up to 40 GHz and $f_{max,MAG}$ values up to 85 GHz for the coplanar process and f_t values up to 40 GHz and $f_{max,MAG}$ values up to 60 GHz for the microstrip process. The maximum current capability of this type with six emitter-fingers reaches about 50 mA, the breakdown-voltage exceeds 5V.

COPLANAR 24 GHZ LC OSCILLATOR

Accurate CAD models were developed for the coplanar elements of the SiGe MMIC process. The equivalent circuit descriptions were derived using the CPW model of [7] and 3D em simulations. They were verified by measurements of test structures up to 110 GHz [8]. Large-signal simulations were performed applying a VBIC large-signal SiGe-HBT model [9].

Fig. 1 shows the layout of the coplanar 24 GHz LC oscillator. Chip size is 2.2 x 2.0 mm^2 . The layout is not yet optimized with regard to chip size. The HBT is integrated in a common-base configuration. 50 Ω CPW's with 50 µm ground-to-ground spacing are used.

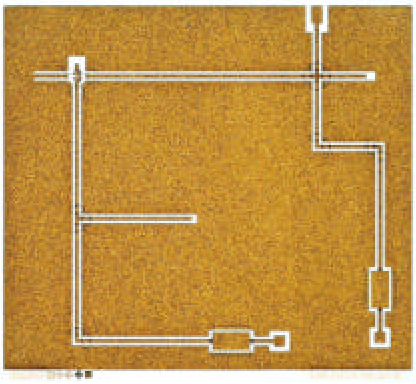

Fig 1: Chip photo of the 24 GHz LC oscillator.

A maximum output power of +8.7 dBm at 23.7 GHz could be achieved at an operation point with V_{CB} = 3.75V, V_{BE} = -0.87V, and I_C = 27 mA. Phase noise was measured by means of a spectrum analyzer and battery operation of the oscillator. Fig 2 shows the output spectrum measured with a resolution bandwidth of 3 kHz and a video bandwidth of 100 Hz. Tab. 1 gives the measured parameters. The noise floor of the spectrum analyzer is -116 dBm/Hz and is close to the measured noise at an offset of 500 and 1000 Hz.

Offset	SSB phase-noise
50 kHz	-88 dBc/Hz
100 kHz	-99 dBc/Hz
200 kHz	-105 dBc/Hz
300 kHz	-111 dBc/Hz
500 kHz	-117 dBc/Hz
1000 kHz	-120 dBc/Hz

Tab. 1: SSB phase-noise data of the 23.7 GHz oscillator

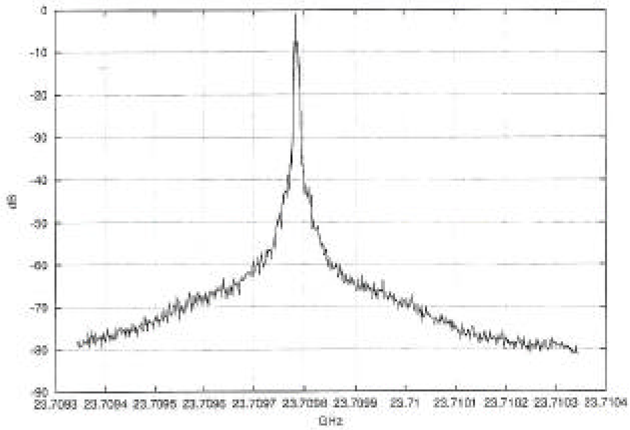

Fig. 2: Phase noise spectrum (RBW=3kHz, VBW=100Hz).

COPLANAR 27 GHZ VCO

In addition to the fixed-frequency oscillators, VCO´s were realized, in coplanar design. Fig. 3 presents the layout of the 27 GHz VCO. Chip size is 2140 x 2310 μm^2. A series-feedback common-base configuration is used together with distributed elements. A varactor diode is connected to the emitter resonator line. The varactor capacitance changes effective line length and thus tunes the oscillator.

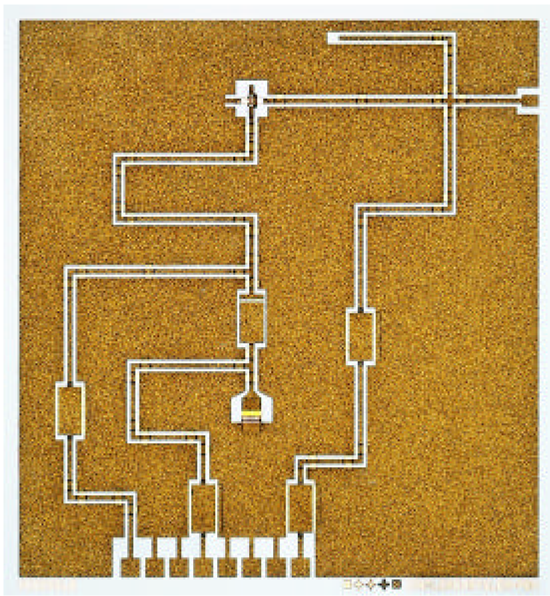

Fig 3: Chip photo of the 27 GHz VCO

For the varactor, the base and collector layers of the SiGe HBT are used. Fig. 4 shows a SEM of the varactor diode.

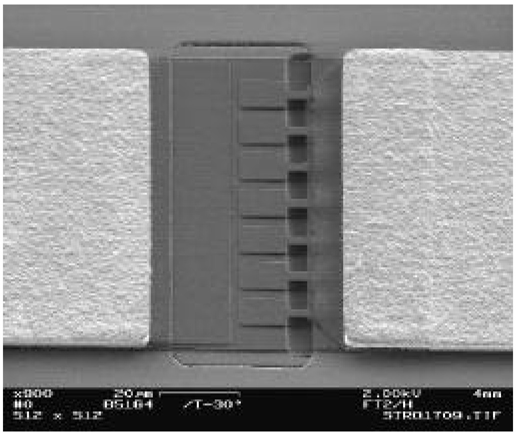

Fig. 4 SEM of the varactor diode

In Fig 5, tuning range and output power are plotted. A maximum output power of 12.5 dBm at 26.7 GHz is achieved. The tuning range with a tuning voltage from 0 to 2 Volt is 1.28 GHz with a maximum steepness of 430 MHz/V.

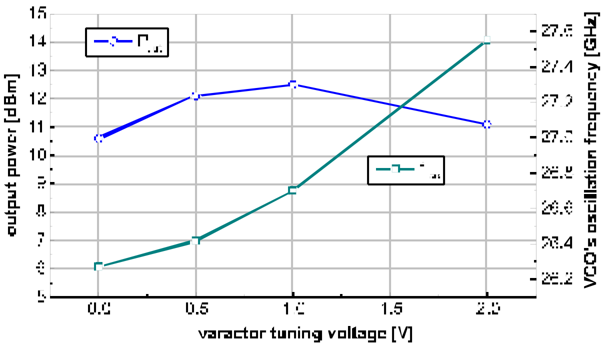

Fig. 5: Output power and tuning range of the 27 GHz VCO.

MICROSTRIP 27 GHZ VCO

In spite of the increased technological efforts (wafer thinning down to 100 µm, backside processing, via-hole technology) microstrip transmission (MST) line technology was investigated as well. MST enables high Q resonators, lower attenuation, better RF packaging characteristics and well-known design and simulation software. Our recently developed MST technology uses 100 µm substrate thickness and circular via-holes with vertical sidewalls and a diameter of 80 µm [3]. Passive elements like resistors, MIM capacitors and spiral inductors have been realized, tested and modeled [3].

This MST technology was combined with a Si/SiGe HBT technology which uses for the microstrip technology differentially grown Si MBE layers with 30% Ge in the base layer, a double mesa fabrication process with self stopping emitter etching, self aligned base contacts, trench isolation etching and LT-CVD (low temperature-chemical vapor deposition)) deposited silicon nitride isolation. The f_T and f_{max} values of the differential grown and processed SiGe HBT are 40 and 60 GHz. The f_{max} value is due to the not yet-optimized differential processing technology 20 GHz lower than in our standard non-differential coplanar SiGe HBT process. The base and collector layers are used for the varactor (see Fig. 4). Fig. 6 shows a schematic of the circuit design. To achieve low phase noise the resonator was realized in a slightly coupled extendable line structure. A reflection type oscillator design in common-base configuration is used. The emitter is connected to a resonator line, which can be tuned by a varactor. The circuit design and chip photo is shown in Fig. 7.

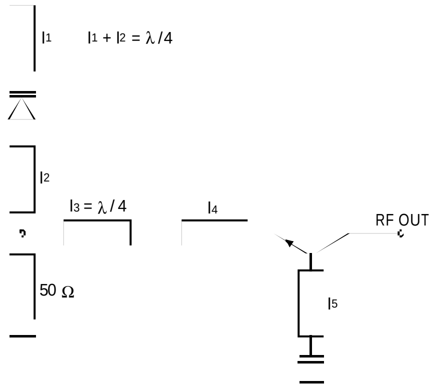

Fig. 6: Schematic layout of 27 GHz microstrip VCO

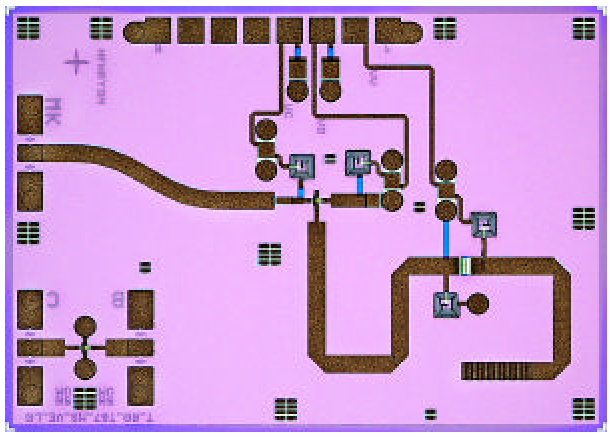

Fig. 7: Chip photo of 27 GHz microstrip VCO. Chip size is 2.7 mm x 1.9 mm.

Fig. 8 shows the output spectrum measured with a resolution bandwidth of 30 kHz. The measurement was done using a spectrum analyzer performing a single sweep in delay mode to cope with the oscillation frequency fluctuations due to the free running device under test. Center frequency of oscillation is 27.45 GHz. From the output spectrum a SSB phase-noise value of better than –90dBc/Hz at 100 kHz offset is found, which represents an extremely good value for a voltage controlled oscillator. Fig. 9 shows the uncorrected output power as a function of varactor tuning voltage. For a varactor tuning voltage from 1 to 7 Volt the output power remains constant. Since line and transition losses (>3dB) have not been subtracted from the measured 2dBm output power the expected total output power is 3dB higher (5dBm). Fig. 9 also shows the frequency of the oscillator as a function of varactor tuning voltage. The frequency changes from 26.8 GHz at 0V to 27.62 GHz at 7V. Total frequency change is 800 MHz, total frequency tuning with constant output power (1V-7V) is 400 MHz.

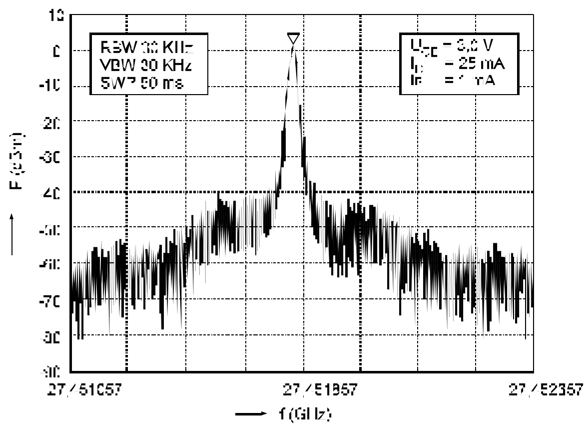

Fig.8: Output spectrum: SSB phase-noise measured from this spectrum is -92 dBc/Hz at 100 kHz offset

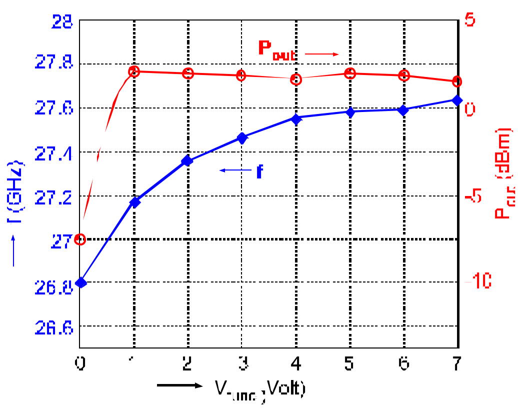

Fig. 9: Oscillation frequency and output power as a function of varactor tuning voltage

Conclusion

Coplanar and microstrip oscillators in SiGe SIMMWIC technology have been realized. With both technologies, excellent low phase-noise characteristics are achieved showing the great potential of SiGe HBT´s and SIMMWIC technology.

Acknowledgements

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