10 GHz FREQUENCY-CONVERTER SILICON BIPOLAR MMIC

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A microwave self-oscillating mixer (SOM) functioning as a frequency converter with conversion gains up to 17dB at 5GHz is reported. The SOM consists of an f_r = 10GHz silicon bipolar monolithic microwave integrated circuit (MMIC) and a dielectric resonator (DR). It down-converts signals up to 9GHz with conversion gain. The highest measured frequency of oscillation for a microstrip packaged device was 10.7GHz.

Introduction: Monolithic microwave feedback amplifiers using a silicon bipolar Darlington pair have been reported with usable gain up to 6GHz. Bipolar transistor SOMs have long been used in radio applications as autodyne mixers, and microwave diode SOMs are used in Doppler radar systems. More recently, several silicon MMICs have been reported based on GaAs technology, using both single-gate and dual-gate MESFETs. This letter presents a microwave SOM consisting of a self-biased, silicon bipolar Darlington pair MMIC and a DR. The operation and advantages of the Darlington pair as an amplifier-mixer-oscillator will be discussed.

Circuit configuration: Fig. 1 shows the schematic and functional block diagrams and the equivalent circuit of the SOM. As an oscillator, the MMIC provides current gain and the DR is the frequency-determining element in the feedback loop. For a given current gain of the IC and a given intrinsic Q of the resonator, the amplitude and phase Barkhausen criteria for oscillation are satisfied by adjusting the coupling ratio of the transformers and the length of the transmission lines, respectively; in practice this is easily accomplished by properly placing the dielectric puck. The first advantage of using a Darlington pair over a single transistor is that it has current gain at higher frequencies, thus significantly extending the upper limit of the frequency of oscillation.

When the circuit oscillates, if a signal is present at the input of the SOM it mixes with the local oscillator (LO) signal. Transistor Q_2 in the Darlington pair is the nonlinear element that both limits the amplitude of oscillation and generates the frequency products. Transistor Q_1 operates as an output amplifier. A properly sized and biased Darlington pair will have a lower reflection coefficient at microwave frequencies than a single device, facilitating the matching of the device and enabling operation over a broader frequency band. Furthermore, the biases of Q_1 and Q_2 are set to independently control the amplitude of oscillation and the conversion gain. This can offer advantages in noise figure and/or distortion performance.

The MMIC was fabricated using an f_r = 10GHz nitride self-aligning process featuring interdigitated 0.75-μm-wide arsenic-doped emitters with 4μm emitter-to-emitter pitch, 2μm thick local oxide isolation, ion implantation, thin-film polysilicon resistors and gold metallisation. Since the maximum frequency of oscillation (f_max) of a bipolar transistor is inversely proportional to the emitter width and to the emitter to emitter pitch, submicrometre photolithography was a key element in obtaining a basic transistor with a higher than 20GHz f_max (where the maximum available gain equals 0dB). The extremely small die size (0.3mm x 0.35mm) and the single bias supply requirement of the MMIC allow compatibility with standard microwave transistor packages.

Experimental results: An experimental prototype was fabricated using a 31mil (0.79-mm)-thick, epoxy-glass (FR4) board (dielectric constant = 4.8). The MMIC was packaged in a 70mil (1.78-mm) microstrip ceramic package and mounted on the board as shown in Fig. 2. Plated through-holes directly under the ground leads on the package were used to ensure proper grounding.

Using a DR with a resonant frequency of 4.15GHz, a dielectric constant of 37 and an unloaded Q of 5000, a television receive-only (TVRO) down-converter was realised. The input band from 3.7GHz to 4.2GHz was converted to the 0.85GHz to 1.45GHz IF band. With the MMIC biased at 35mA and 8V (from a 15V power supply and a 200Ω resistor), it exhibits 9±1dB conversion gain (Fig. 3). 12dB SSB noise figure, input and output 85dBm better than 5.41.8dBm output compression point, 17.5dBm two-tone third-order intercept point, and inband single-tone intermodulation suppression greater than 70dBc (for -20dBm input power).

With the same dielectric puck, an RF signal was down-converted to 70MHz with 17dB of conversion gain, and a 1GHz signal was up-converted to 6.15GHz with 2dB of conversion gain. Using a DR with a resonant frequency of 6.4GHz, a 9GHz signal was translated to 2.6GHz with 3dB of gain.

At 10.7GHz, a DR with a dielectric constant of 29 was used to obtain an unloaded Q of 10000. In this case, a 9GHz input signal was down-converted to 1.7GHz with 9dB of conversion gain, and a 12.5GHz signal was translated to 18GHz with 4dB of loss. Further improvements can be expected at these very high frequencies by using a less lossy glass-Teflon board.

Summary and conclusions: A microwave self-oscillating mixer functioning as a frequency converter has been presented. Silicon bipolar transistors with 0.5-μm emitter width, 2μm emitter-emitter pitch, and f_max greater than 35GHz have already been reported. This promises even higher frequencies of oscillation and higher frequencies where conversion gain is achievable.

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