10 GHz FREQUENCY-CONVERTOR SILICON BIPOLAR MMIC

Indexing terms: Microwave devices and components, Frequency convertors, Bipolar devices, Integrated circuits

A microwave self-oscillating mixer (SOM) functioning as a frequency convertor with conversion gains up to 17 dB at 5 GHz is reported. The SOM consists of an $f_T = 10$ GHz silicon bipolar monolithic microwave integrated circuit (MMIC) and a dielectric resonator (DR). It down-converts signals up to 9 GHz with conversion gain. The highest measured frequency of oscillation for a microstrip packaged device was 10·7 GHz.

Introduction: Monolithic microwave feedback amplifiers using a silicon bipolar Darlington pair have been reported with usable gain up to 6 GHz.[1] Bipolar transistor SOMs have long been used in radio applications as autodyne mixers,[2] and microwave diode SOMs are used in Doppler radar systems.[3] More recently, several microwave SOMs have been reported based on GaAs technology, using both single-gate[4,5] and dual-gate[6] 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.

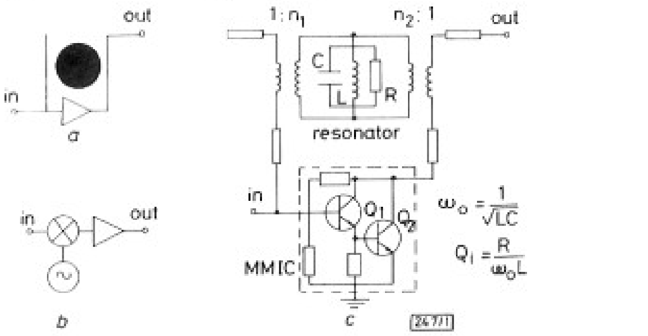

Fig. 1 *Schematic (a) and functional block (b) diagrams, and equivalent circuit (c) of SOM*

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_1 in the Darlington pair is the nonlinear element that both limits the amplitude of oscillation and generates the frequency products. Transistor Q_2 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 $f_T = 10$ GHz nitride self-aligning process featuring interdigitated 0·75 μm-wide arsenic-doped emitters with 4 μm emitter-to-emitter pitch, 2 μm-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 20 GHz f_{max} (where the maximum available gain equals 0 dB). The extremely small die size (0·3 mm × 0·35 mm) and the single bias supply requirement of the MMIC allow compatibility with standard microwave transistor packages.

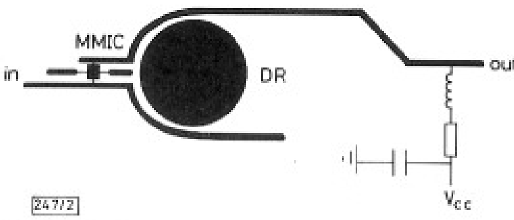

Fig. 2 *SOM board showing MMIC, DR and bias*

Experimental results: An experimental prototype was fabricated using a 31 mil (0·79 mm)-thick, epoxy-glass (FR4) board (dielectric constant = 4·8). The MMIC was packaged in a 70 mil (1·78 mm) microstrip ceramic package and mounted on the board as shown in Fig. 2. Plated through-holes directly under the two ground leads on the package were used to ensure proper grounding.

Using a DR with a resonant frequency of 5·15 GHz, a dielectric constant of 37 and an unloaded Q of 7000, a television receive-only (TVRO) down-convertor was realised. The input band from 3·7 GHz to 4·2 GHz was converted to the 0·95 GHz to 1·45 GHz IF band. With the MMIC biased at 35 mA and 8 V (from a 15 V power supply and a 200 Ω resistor), it exhibits 9 ± 1 dB conversion gain (Fig. 3), 12 dB SSB noise figure, input and output VSWRs better than 2·5 : 1, 8 dBm output compression point, 17·5 dBm two-tone third-order intercept point, and inband single-tone intermodulation suppression greater than 70 dBc (for −20 dBm input power).

With the same dielectric puck, an RF signal was down-converted to 70 MHz with 17 dB of conversion gain, and a 1 GHz signal was up-converted to 6·15 GHz with 2 dB of conversion gain. Using a DR with a resonant frequency of 6·4 GHz, a 9 GHz signal was translated to 2·6 GHz with 3 dB of gain.

At 10·7 GHz, a DR with a dielectric constant of 29 was used to obtain an unloaded Q of 10 000. In this case, a 9 GHz input

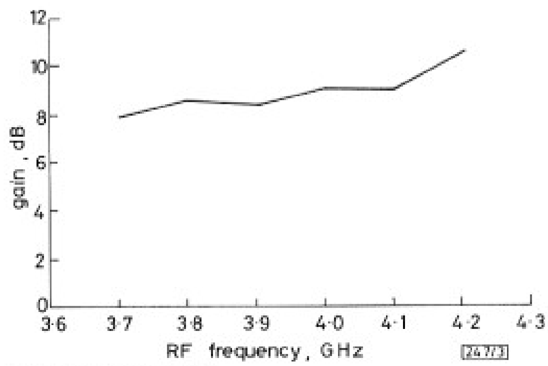

Fig. 3 *Conversion gain*

signal was down-converted to 1·7 GHz with 0 dB of conversion gain, and a 12·5 GHz signal was translated to 1·8 GHz with 4 dB 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 convertor has been presented. Silicon bipolar transistors with 0·5 μm emitter width, 2 μm emitter-emitter pitch, and f_{max} greater than 35 GHz have already been reported.[7] This promises even higher frequencies of oscillation and higher frequencies where conversion gain is achievable.

Acknowledgments: The authors wish to acknowledge the work of S. Taylor in the design of the MMIC as an amplifier, and thank him for his suggestions and support. Thanks are due to L. Levitt for his assistance with the boards, and to A. Adar for valuable discussions on the design of the filters. The authors gratefully acknowledge Dr. C. P. Snapp and Dr. J. F. Kukielka for their encouragement, guidance and many useful suggestions during the course of this work.

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27th August 1986

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