

A 10 GHz FREQUENCY CONVERTER IC USING A SILICON DARLINGTON-CONNECTED  
TRANSISTOR PAIR . \*

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ABSTRACT.

A Microwave Self-Oscillating Mixer (SOM) functioning as a frequency converter with conversion gains up to 17dB is reported. The SOM consists of a 10GHz  $f_T$  silicon bipolar Monolithic Microwave Integrated Circuit (MMIC) and a Dielectric Resonator (DR). It downconverts signals up to 9GHz with conversion gain. The highest measured frequency of oscillation for a microstrip packaged device was 10.7GHz.

INTRODUCTION.

Low cost, small size, reproducible performance and multi-functional integration are the desired attributes of the next generation of microwave components. MMICs are developing as a class of circuits that can potentially fulfill these requirements by displacing specific hybrid circuits and subsystems. A simple SOM is presented that meets these goals.

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

Figure 1. shows the schematic, functional block diagram, and 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 Q1 in the Darlington pair is the non-linear element that both limits the amplitude of oscillation and generates the frequency products. Transistor Q2 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 bias of Q1 and Q2 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 circuit was simulated in SPICE using small and large signal analysis. At microwave frequencies it is imperative that the models used in the simulation be accurate, if the analysis is to be of any value. Special consideration was given to the correct modeling of the high frequency effects of the transistors and the parasitic elements in the circuit.

The MMIC was fabricated using a 10GHz  $f_T$  nitride self-aligning process featuring interdigitated 0.75 micrometer wide arsenic-doped emitters with 4 micrometer emitter to emitter pitch, 2 micrometer thick local oxide isolation, ion implantation, thin-film polysilicon resistors and gold metallization. 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, submicrometer 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 (.3mm X .35mm) and the single bias supply requirement of the MMIC, allows compatibility with low-cost, standard microwave transistor packages. Figure 2. shows a microphotograph of the chip mounted in a 70 mil package.

The dielectric resonator is made of a low loss, temperature stable and high permittivity ceramic material. Due to these characteristics, a conveniently sized and high Q resonator can be realized in the frequency range of 4GHz to 40GHz.

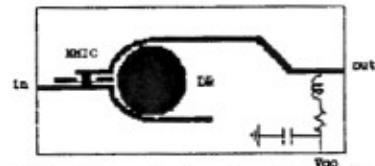


Figure 3. SOM board showing the MMIC, DR and bias.

\* Patent Applied For

## EXPERIMENTAL RESULTS.

An experimental prototype was fabricated using a 31 mil thick, epoxy-glass (FR4) board (dielectric constant = 4.8). The MMIC was packaged in a 70 mil, microstrip ceramic package and mounted on the board as shown in Figure 3. Plated through-holes directly under the two ground leads on the package were used to assure proper grounding.

Using a DR with a resonant frequency of 5.15GHz, a dielectric constant of 37 and an unloaded  $Q$  of 7,000, a television receive only (TVRO) downconverter was realized, the input band from 3.7GHz to 4.2GHz, being converted to the 0.95GHz to 1.45GHz IF band. With the MMIC biased at 35mA and 8V (from a 15V power supply and a 200ohm resistor), it exhibits 8dB conversion gain, 13dB SSB noise figure, input and output VSWRs better than 2.5:1, 8dBm output compression point, 17.5dBm two-tone third-order intercept point, and in-band single-tone intermodulation suppression greater than 70dBc (for a -20dBm input signal). Figure 4. shows the excellent agreement between the measured and simulated conversion gain. The SOM, being a two-port oscillator, exhibits a large LO frequency component at the RF and IF ports; filters are required, whenever LO suppression is desired.

With the same dielectric puck, an RF signal was downconverted to 70MHz with 17dB of conversion gain, and a 1GHz signal was upconverted 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 10,000. In this case, a 9GHz input signal was downconverted to 1.7GHz with 0dB of conversion gain, and a 12.5GHz signal was translated to 1.8GHz with 4dB of loss. The oscillator frequency spectrum is shown in Figure 5. 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

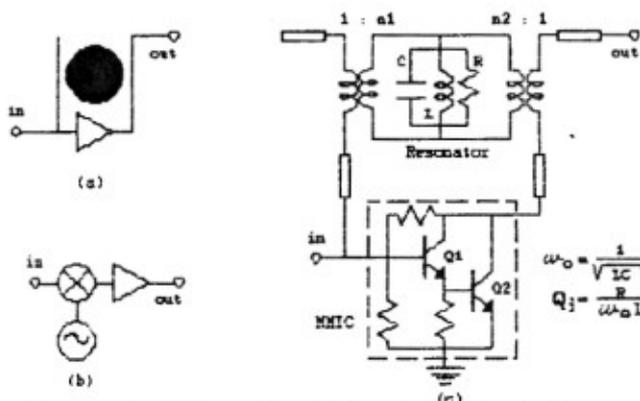


Figure 1. Schematic (a), functional block diagram (b), and equivalent circuit (c) of SOM.

been presented. Its mode of operation has been explained and its most significant experimental results have been given. The excellent agreement between measured and simulated data is attributed to the detailed modeling of the transistors and the parasitic elements in the circuit.

The SOM, being a two-port oscillator, can be used in other applications such as transmission-type injection-locked oscillators and as Doppler radar detectors.

Silicon bipolar transistors with 0.5 micrometer emitter width, 2 micrometers emitter-emitter pitch, and  $f_{MAX}$  greater than 35GHz have already been reported [7]. This promises even higher frequencies of oscillation and higher frequencies where conversion gain is achievable. Advances in dielectric resonators are also continuing, with DR oscillators now operating in the millimeter frequency range.

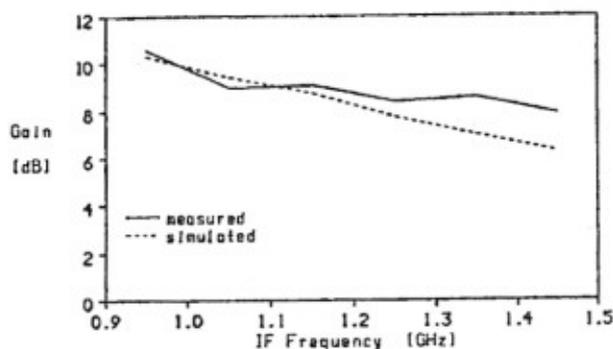


Figure 4. Measured and simulated performance of the SOM as a TVRO downconverter

## 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 Drs. C.P.Snapp and J.F.Kukielka for their encouragement, guidance and many useful suggestions during the course of this work.

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