A 2GHz Voltage Tunable FBAR Oscillator

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Abstract — This paper describes the design and measured performance of a low-noise varactor tuned oscillator based on Film Bulk Acoustic Resonator (FBAR) at 2 GHz. Using varactor tuning this oscillator demonstrated 2.5MHz frequency tuning range at 1985 MHz with a phase noise of –112 dBc/Hz at 10KHz from the carrier. This represents the first example of a low noise Si-Bipolar FBAR tunable oscillator.

I. INTRODUCTION

Clocks are an important part of all communication, computing and networking systems. Low jitter clocks are used in a large number of wired and wireless applications in the frequency ranges of 500 MHz to 5 GHz. Significant benefits can be realized by using micro-machining techniques and new materials in the design and fabrication of these devices. FBAR resonator technology is now available for use in this frequency range [1]. Alternate resonators include ceramic resonators, surface acoustic wave (SAW) resonators and planar transmission line resonators. Ceramic resonators are bulky in size compared to SAW resonators but offer better phase noise. Transmission line resonator oscillators require larger real estate and offer medium phase noise performance. An FBAR oscillator offers smaller size and competitive phase noise compared to a SAW oscillator. FBAR oscillators, therefore, provide small size, high performance, and low cost simultaneously. FBAR resonators can also potentially be integrated with the active devices to form a high Q integrated circuit oscillator.

An L Band fixed frequency FBAR oscillator was recently published [2]. In many of the practical applications narrowband tuning of the oscillator is necessary in order to lock it with a lower but much higher stability oscillator. The present paper represents the first frequency tunable temperature compensated FBAR oscillator which represents frequency tuning sufficient to cover the frequency drift over temperature, bias, load and time.

II. FBAR DEVICE

The Agilent FBAR is a three-layer structure with the top and bottom electrodes of molybdenum sandwiching a middle layer of oriented piezoelectric aluminum nitride. An air interface is used on both outer surfaces to provide high Q reflectors at all frequencies [1]. When RF signals are applied near the mechanical resonant frequency the piezoelectric transducer excites the fundamental bulk compression wave traveling perpendicular to the films.

A picture of an FBAR is shown in Fig. 1. As seen through the electrical terminals, the FBAR has an equivalent circuit model as shown in Fig. 2. An FBAR far from the resonant frequencies behaves like the plate capacitance Cp in series with the two resistors Rp and Rs. This resonator has a series resonant frequency and a parallel resonant frequency, which are typically 1-3% apart in frequency.

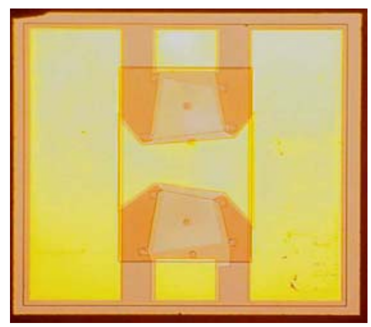

Fig. 1 *FBAR Chip 40 X 40 X 5 mils*

The Quality factor of the FBAR chip resonator was measured using |S21| in a band-stop configuration. The Unloaded Quality factor, Qu, was measured to be better than 500 for the series resonant frequency mode. FBAR devices are an excellent choice for small size, low cost filter and duplexer applications [3][4][5] in addition to low phase noise oscillators.

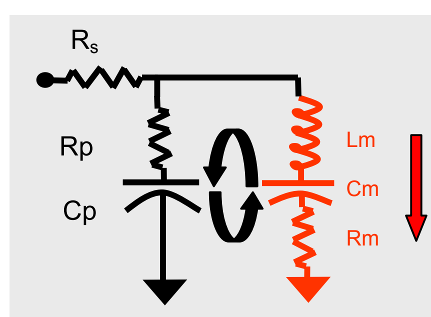

Fig. 2 *The equivalent circuit model for FBAR*

III. THE OSCILLATOR DESIGN

This FBAR Oscillator uses Agilent Technologies silicon bipolar device S526 as an active device. This device has 26 emitter fingers with emitter pitch of 5 micrometers.

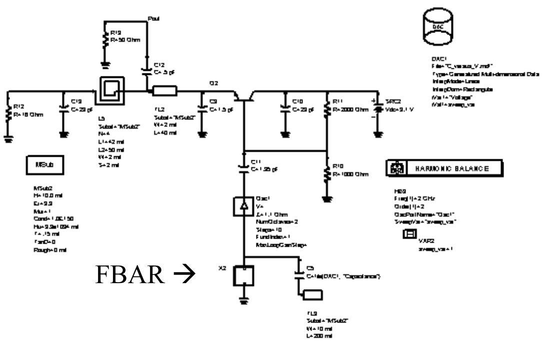

Fig. 3 *FBAR Oscillator Schematic*

Chip size is 13 mils x 13 mils. Negative resistance is created by using the bipolar device in the common collector configuration. FBAR resonator is used as a frequency-determining element in the base terminal. Output power is coupled from the emitter. Phase shift between the active device and resonator, used as a series feedback element, is optimized to meet the oscillation conditions as well as provide conditions for minimum phase noise in the oscillator. A hyper-abrupt varactor with

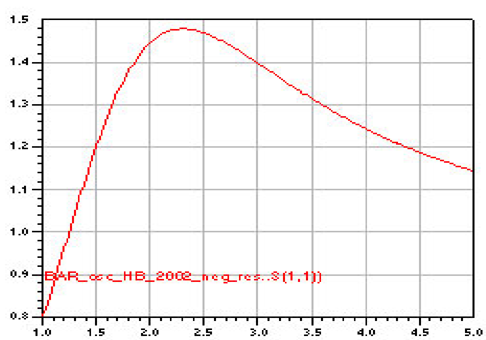

Fig. 4 *Plot of |S11| with Frequency (GHz)*

Cj4 of 2pf is lightly coupled to the FBAR resonator to achieve the frequency tuning.

Fig 4 shows the linear simulation of the negative resistance as seen from the base terminal of the active device. With the FBAR resonator having series and parallel resonant frequencies that are close to each other, oscillation conditions should be satisfied only at the desired resonance frequency which is aided by the fact that series and parallel resonances offer very different input impedances. In this case series resonance offering higher Q was used as the resonance frequency. Frequency tuning results of the non-linear simulation using Agilent ADS software are shown in fig. 5. Tuning sensitivity varies from 180KHz/V to 370KHz/V.

The FBAR resonator used typically offers temperature stability of 20 to 30 ppm per deg C. In any practical application, it is important that the frequency tuning range of a VCO covers the frequency drift over temperature, time, load and bias variation. Frequency drift over temperature is generally the single most important part of the overall frequency drift. Improved temperature performance can be achieved using known techniques.

The FBAR oscillator was fabricated on a 10-mil thick

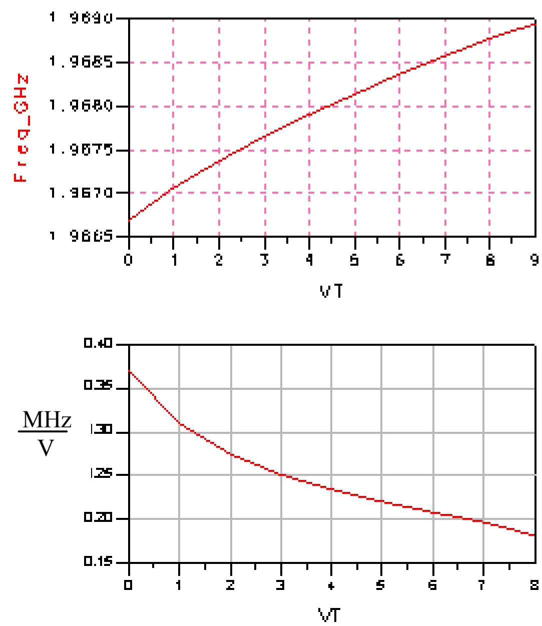

Fig. 5 *Frequency Tuning Characteristics*

alumina substrate of 250 mil x 250 mil using thin-film chip-and-wire technology. Components were attached using standard eutectic attach or epoxy attach. The FBAR resonator was bonded to the transmission lines using 1 mil bond wires. The alumina substrate was attached to an industry standard TO-8 header for testing. A silicon-bipolar transistor amplifier stage was added to increase the power output and isolate the oscillator from load variations. Active devices for the oscillator and amplifier were biased at +3.3V with appropriate bypass capacitors to minimize spurious as well EMI emissions.

IV. MEASUREMENTS

The FBAR oscillator performance was measured using standard techniques. Key measured parameters are as follows:

Frequency:	1985 MHz
Power Out:	10 dBm
Tuning Sensitivity:	180 - 370 KHz/V
Freq. Drift over temp.	0.4 MHz
Freq. Pushing (+/-5%):	200 KHz
Frequency Pulling (12dBr):	15 KHz
Second Harmonic:	-40 dBc
Phase Noise:	-112 dBc/Hz @10KHz
Phase Jitter over 12 KHz to 20MHz:	<0.1 ps
Frequency Tuning Range:	2.5 MHz
Tuning Voltage Range:	0 to 10 V
Bias:	3.3V, 35 mA

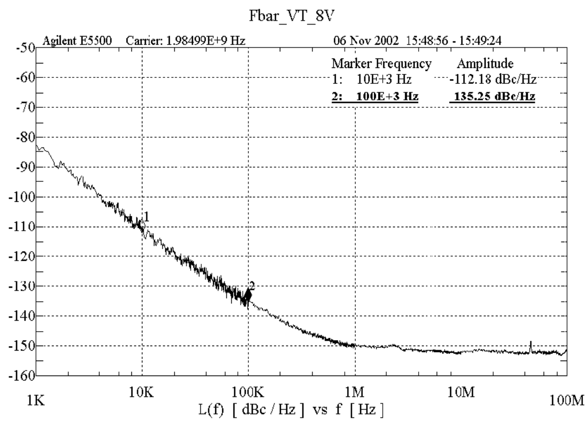

Fig. 6 *Phase Noise Plot of FBAR VCO*

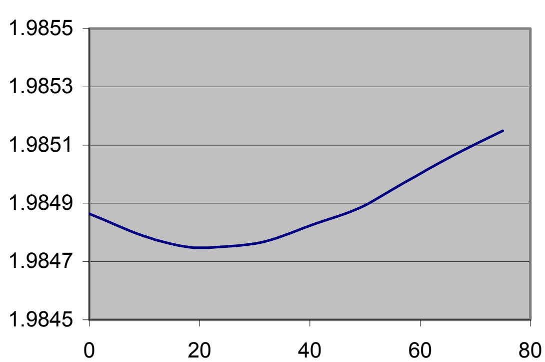

Fig.7 Frequency Variation with Temp (°C)

Phase jitter reported is converted from the measurement of integrated phase noise between 12KHz and 20MHz.

Center frequency of the oscillator was measured to be within 1% of the simulated result. This error can be attributed to the effects of parasitics and resonator model inaccuracy. Figure 6 represents the phase noise plot of the FBAR oscillator at 1.985 GHz. Phase noise of –112 dBc/Hz at 10KHz offset from the carrier represents an excellent phase noise performance given the small size of the resonator.

Compared to the fixed frequency FBAR oscillator [1], phase noise is degraded by about 2.5 dB, which is expected due to reduced loaded Q caused by varactor coupling to the resonator. Figure 7 represents frequency variation over temperature of the temperature

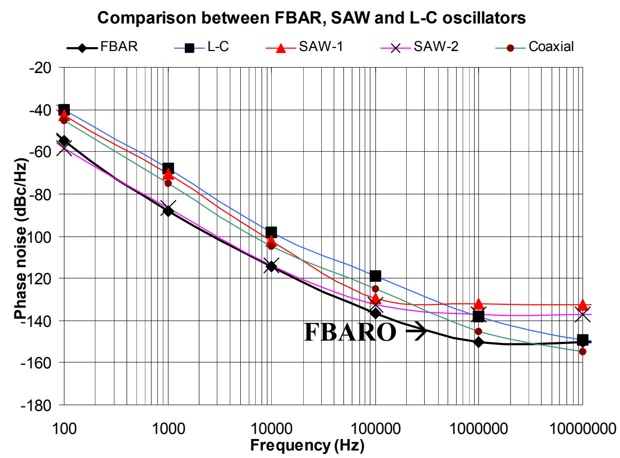

Fig. 8 *Phase noise comparisons for different oscillators*

compensated FBAR oscillator. The frequency drift corresponds to less than 4 ppm per deg C over a temperature range of 0 to 75 deg C.

Figure 8 compares phase noise performance of this FBAR oscillator with other oscillators in the frequency range. Five plots are shown: L-C oscillator, 2 SAW oscillators, coaxial oscillator and the FBAR oscillator. The L-C oscillator for comparison is a 2GHz oscillator using the same silicon bipolar device. The SAW1 oscillator phase noise however is based on a commercially available, small size, oscillator at 622 MHz with the phase noise scaled to 2GHz using standard 20 log (f2/f1) conversion factor. SAW2 is a high performance SAW oscillator. It can be seen that the FBAR oscillator has competitive phase noise compared with the SAW oscillator from 100 Hz up to 100KHz and has superior phase noise at offsets greater than 100 KHz. The FBAR oscillator also offers 15 to 20 dB phase noise improvement with respect to an L-C oscillator.

V. CONCLUSION

FBAR VCOs are a promising new type of oscillator with potentially wide applications in high-speed wire line and wireless communications as reference clocks or oscillators. The voltage-controlled oscillator presented in this paper shows excellent phase noise performance, small size, and low cost compared to competitive technologies. Frequency tuning achieved has been demonstrated to be more than frequency variation over temperature, bias and load variations.

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