FUNDAMENTAL-MODE PIERCE OSCILLATORS UTILIZING BULK-ACOUSTIC-WAVE RESONATORS IN THE 250 - 300 MHz RANGE

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ABSTRACT

Fundamental-mode Pierce Oscillators in the 250-300 MHz range have been realized utilizing a unique form of a bulk-acoustic-wave (BAW) resonator. Phase noise of -100 dbc/Hz (1 KHz offset) and output power levels of +6 dbm have been demonstrated. A linear-model design was used. The circuit topology and resonator fabrication technique show great promise for creation of monolithic circuits in the 200 MHz to 2 GHz range.

INTRODUCTION

The operating frequency of fundamental-mode crystal-controlled oscillators is restricted to the relatively low resonant frequencies of the crystal, typically several 10's of MHz, although ion-beam milling techniques have been used to fabricate quartz resonators operating to 525 MHz [1]. This paper describes the design and operation of a Pierce Oscillator using a BAW resonator composed of a thin ZnO film sputtered onto a Si membrane supporting structure [2]. This device, Fig. 1, has demonstrated fundamental resonances to 1 GHz and Q's of 9000. Preliminary results have been achieved with 200-300 MHz oscillators.

OSCILLATOR DESIGN

We show an active device that is used to sustain oscillations when constrained by the feedback network composed of the input tuning capacitor, C_i, the output tuning capacitor, C_o, and the BAW resonator, Fig. 2. The output signal is just above the series-resonant frequency of the resonator where good frequency stability is achieved due to the resonator's high-Q and resultant steep phase characteristic.

Analyses of this circuit usually consider the active device to be unilateral and the resonator to be lossless which allows for compact design equations [3]. When conditions of the circuit are altered, such as the output frequency or the type of active device (bipolar vs. GaAs FET), many of the original simplifications don't apply and the simplified design equations are of limited use. Oscillators designed for maximum power require large-signal measurements or extensive numerical modeling [4,5]. The oscillator design utilizes a general linear small-signal y-parameter model to predict the onset of oscillation.

The active device and resonator are considered as a composite device because their individual y-parameters are directly measureable. Then using Fig. 2,

$$y_A=\begin{bmatrix}(g_{iA}+jb_{iA}) & (g_{rA}+jb_{rA})\\ (g_{fA}+jb_{fA}) & (g_{oA}+jb_{oA})\end{bmatrix},\quad y_B=\begin{bmatrix}jb_{iB} & 0\\ 0 & jb_{oB}\end{bmatrix}. \tag{1}$$

We arrive at the oscillation condition by adding the elements of the two matrices and applying the Barkhausen criteria.

$$\begin{aligned} y_{11}y_{22} - y_{12}y_{21} &= 0 \\ &= (g_{iA}+j(b_{iA}+b_{iB}))(g_{oA}+j(b_{oA}+b_{oB})) \\ &\quad - (g_{rA}+jb_{rA})(g_{fA}+jb_{fA}) \end{aligned} \tag{2}$$

Eq. (2) requires that

$$(b_{iB}+b_{iA})(b_{oB}+b_{oA}) = g_{iA}g_{oA}+b_{rA}b_{fA}-g_{fA}g_{rA} \tag{3a}$$

$$\begin{aligned} b_{iB}g_{oA} + b_{ob}g_{iA} \\ = g_{rA}b_{fA}+b_{rA}g_{fA}-g_{iA}b_{oA}-b_{iA}g_{oA}. \end{aligned} \tag{3b}$$

Equation (3) is solved for $b_{iB}(C_i)$ and $b_{oB}(C_o)$. Not all solutions result in stable oscillations. Some solutions do not result in stable limit-cycles. A rigorous solution would have to incorporate a non-linear model.

EXPERIMENTAL RESULTS

Pierce oscillators were fabricated using individually mounted resonators, MRFC904 transistors, and input and output capacitors. Bias and matching components are contained within the biased-test stand. The components are mounted on a 11.4 mm square alumina substrate epoxied to a TO-5 header with interconnections realized with copper foil. Discrete components were used so that individual y-parameter data could be measured using an HP8505 network analyzer. A representative resonator has an f_s of 259.39 MHz, an f_p of 259.63 MHz, and a computed Q of 2200.

Figure 3 shows the SSB phase noise characteristics of two oscillators measured with an HP8566A spectrum analyzer. For the 259 MHz oscillator, the computed resonator Q is 2200 and C_o is 3 pF. The output power level is -24 dbm. At a frequency offset of 100 Hz, the measured phase noise is -66 dbc/Hz. For the 262 MHz oscillator, the computed resonator Q is 2400 and C_o is 15 pF. The output power level is -22 dbm. At a frequency offset of 100 Hz, the measured phase noise is

-77 dbc/Hz. Both phase-noise curves flatten out due to dynamic range limitations of the HP8566A and the test fixture. It was observed that the oscillator spectra and the spectrum of a synthesizer approached the same noise floor. Based upon a linear extrapolation of the near-in data, the computed phase noise at a 1 KHz offset is 104 dbc/Hz for the 259 MHz oscillator and -112 dbc/Hz for the 262 MHz oscillator. When allowed to stabilize within a thermal chamber, stabilities in excess of 1.9×10^{-8} have been observed during 4-minute sample periods. These data are considered "worst case" because the circuits contain no thermal-bias stabilization and the noise measurements did not correct for test equipment induced noise.

CONCLUSION AND FUTURE WORK

The design and operation of a UHF fundamental-mode oscillator using a ZnO BAW resonator has been described. Work is underway in the areas of non-linear and noise modeling and temperature stabilization. A resonator with a temperature coefficient exceeding AT-cut quartz has been described [6]. BAW GaAs resonators have been demonstrated at frequencies above 1 GHz [7]. Both Si and GaAs resonators offer a significant size reduction so that IC fabrication techniques will permit direct integration of the resonator with active devices resulting in a new class of RF/LSI circuits.

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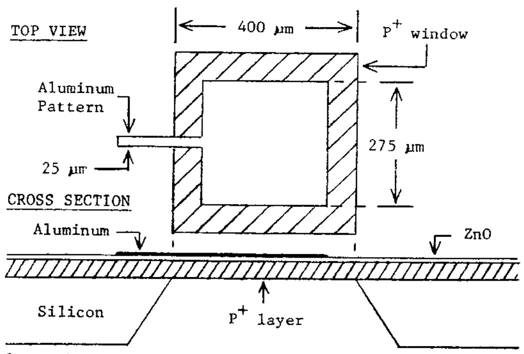

Fig. 1 Schematic of thin-film composite resonator

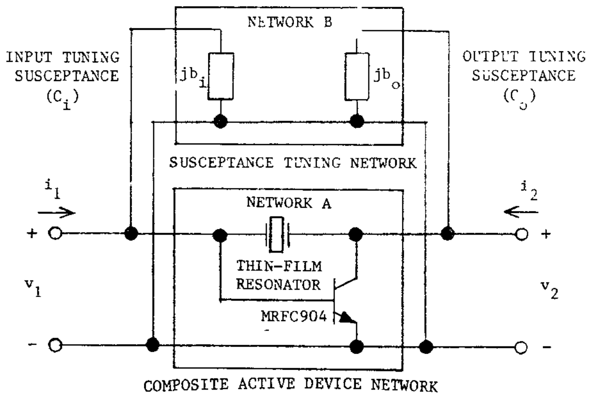

Fig. 2 Y-parameter model for Pierce Oscillator

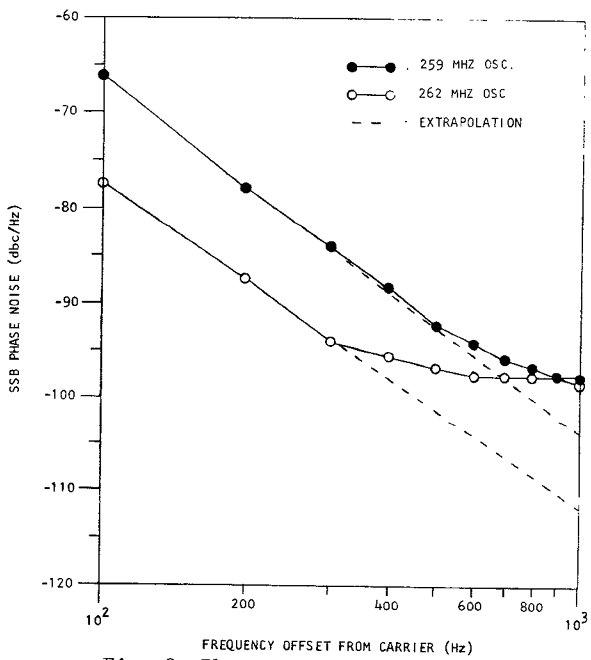

Fig. 3 Phase noise characteristics of Pierce Oscillators