TUNABLE MAGNETOSTATIC SURFACE WAVE OSCILLATOR AT 4 GHz

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ABSTRACT

An oscillator tunable from 1.8 GHz to 4.0 GHz has been fabricated using a Magnetostatic Surface Wave (MSSW) 2-port etched groove resonator as the frequency selective element, and a bipolar transistor amplifier for gain in the feedback loop. The theory for a resonator based oscillator is summarized, including the effect of loop gain, amplifier noise loop power, and resonator Q on oscillator noise. Noise and amplitude characteristics of the oscillator are reported over the tuning range. FM phase noise is comparable to YIG sphere oscillators and optimization should yield significant improvement.

Introduction

The use of a resonator element for the frequency selective element of a tunable feedback oscillator is common practice. In the frequency range above 2 GHz, Surface Acoustic Wave (SAW) resonator filters, which operate very effectively in the VHF/UHF range, experience significant technical difficulties[1]. In particular, operation above 3 GHz requires submicron device dimensions and exhibits large propagation losses. Tunable, high Q, low loss yttirum iron garnet (YIG) sphere resonator oscillators operate well at microwave frequencies, but fabrication procedures are tedious and expensive, and loaded Q's of greater than 100 are difficult to obtain.

This paper describes an oscillator based on Magnetostatic Surface Wave (MSSW) resonator of the type described by Owens, et al.[2] as the feedback element. The MSSW resonator (similar in some respects to SAW resonators) utilizes MSSW propagation in low line width ($\Delta H <$ 0.5Oe) thin film YIG grown by liquid phase epitaxy[3]. MSSW are slow, dispersive, magnetically dominated electromagnetic waves propagating in a magnetically biased ferrite material at microwave frequencies (1-20 GHz). MSSW occur when the bias field $\bar{H}$ lies in the plane of the film and is orthogonal to the propatation direction $\bar{k}$. The MSSW is characterized by magnetic energy which is confined primarily to either surface of the ferrite slab depending on the propagation direction relative to the bias field orientation, and each wave with its own propagation characteristics.

As in the SAW case, a resonator consists of a pair of wavelength selective periodic reflecting arrays separated by a delay section. These elements are arranged relative to the propagation path to form a resonator cavity and a means for transduction is established within the cavity. The resonator used in this study was a two-port MSSW reflecting array resonator with an input-output transducer pair located in the resonant cavity; the geometry of this device is shown in Figure 1 (see reference 2). This structure is of particular interest due to its inherent isolation between input and output ports and ease of application in filter and oscillator systems. These resonators retain the desirable features of tunability and microwave frequency operation and since in principle any wavelength can be obtained at any frequency by bias field adjustment, submicron wavelengths are not required and conventional microelectronics fabrication techniques are used for device fabrication.

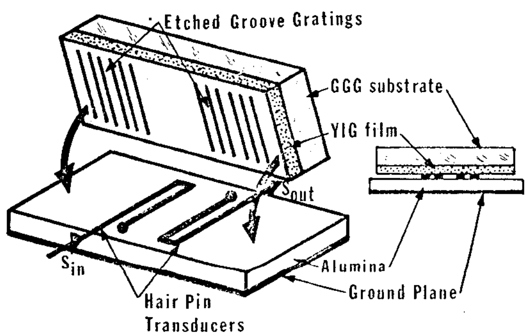

Fig. 1: Schematic of a two-port Magnetostatic Surface Wave etched groove resonator.

Theory

The resonator significantly affects the oscillator performance by determining the operating frequency and affecting the noise characteristics by way of the oscillator Q.

The resonator cavity can be considered equivalent to a microwave Fabry-Perot resonator[4] if the concept of an effective mirror plane is introduced.[5] The distance, d, the effective mirror plane is located into an array can be determined using the reactance slope parameter, the rate of phase change of the reflection factor, at the insertion loss notch;

$$d = \frac{1}{2\nu_g} \quad \frac{\delta\Phi}{\delta\omega} \qquad (1)$$

where ν_g is the group velocity, Φ is the phase, and ω the radian frequency. Thus for a resonator the effective cavity is the sum of the forward and reverse mirror plane distances and the center spacing, $L = d_F + d_R + \ell$. The mode spacing is also dependent on the effective cavity spacing as

$$\Delta f_m = \frac{1}{(T_F + T_R) L} \qquad (2)$$

where T_F and T_R are the forward and reverse time delays (corresponding to the upper and lower surface waves).

Of essential interest are the associated quality factors or Q's. Defined in terms of the insertion loss and frequency response, the Q is equivalent to the reciprocal fractional bandwidth, $\omega_o/\Delta\omega$ where $\Delta\omega$ is the half-power bandwidth at the resonator frequency, ω_o. The total Q of the resonator may be attributed to that of external factors such as the transducer affects and end reflections, Q_{ext}, and the unloaded quality factor, Q_u. This latter term is made up of the array factors, Q_r, and the material loss Q_m. The total Q is

$$\frac{1}{Q_T} = \frac{1}{Q_r} + \frac{1}{Q_m} + \frac{1}{Q_{ext}} \qquad (3)$$

Matthaei[6] defines the array quality in terms of the mirror plane distance and the geometric mean of the forward and reverse reflection coefficients, ρ, as

$$Q_r = \frac{2\pi}{\lambda_o(1-|\rho|^2)} \quad (4) \qquad (4)$$

where λ_o is the resonant wave length. Finally, for MSW in epitaxial YIG the material quality factor is directly proportional to the resonant frequency and inversely related to the geometric means of the propagation loss factor and group delays for the forward and reverse waves, α and ν_g respectively

$$Q_m = \frac{\omega_o}{2\alpha\nu_g} \qquad (5)$$

(for .5 Oe YIG at 3 GHz; $Q_m > 3000$).

The FM phase noise of a resonator stabilized oscillator is related to the amplified front end noise of the associated amplifier which is returned in the effective bandwidth of the resonator. Lewis[6] has derived the related phase noise for delay line stabilized oscillators. In terms appropriate to the resonator stabilized oscillator, the expression given by Lewis is

$$\text{FM Noise} = 10 \log \left[\frac{G^2 \, kT \, F \, f_o^2 \, B}{Q^2 \, P_o \, (\Delta f)^2}\right] \; dB_c/H_z , \qquad (6)$$

where G is the amplifier gain, k is Boltzmann's constant, T the absolute temperature, F the amplifier noise figure, f_o the oscillator frequency, Q the resonator quality factor, P_o the feedback power and Δf the frequency offset from the carrier.

Oscillators of different types can be compared by the figure of merit Qf_o. For quartz stabilized oscillators at 100 MHz, $Qf_o \sim 10^{13}$ Hz. For SAW resonator stabilized oscillators,[8,9] $Qf_o \sim 2.8 \times 10^{13}$ Hz at frequencies up to 2 GHz. Owens, et al.[2] reported Q = 800 at 3 GHz with $Qf_o = .24 \times 10^{13}$ Hz for MSSW etched groove resonators. Thus, the MSSW etched groove resonator oscillator compares favorably with bulk quartz and SAW oscillators with higher operating frequency, larger fabrication geometries and furthermore is inherently magnetic field tunable. Furthermore, as less lossy resonators are designed and built, the limiting material Q (equation 5) becomes the determinant quantity and $Q_m \propto f_o$ so the figure of merit for MSSW based resonators improves at higher frequencies.

Experimental Results

The oscillator was fabricated of discrete elements as shown in Figure 2. The amplifier was an Avantek model AMN-4002 N with 41 dB gain and 4.5 dB noise figure. The resonator used consisted of a pair of etched groove arrays (see Figure 1) with 71.25 μm on a 15 μm thick Epi-YIG film. The Spectrum Analyzer used was a Hewlett Packard 8566A/9825A system programmed for FM noise measurements. To measure the open loop response of the system, the feedback loop was broken at the point X in Figure 2 and a Hewlett Packard 8410B Network Analyzer with an 8690A/8699B sweep oscillator. A typical open loop response of the system at 3.1 GHz is shown in Figure 3. The insertion loss of the resonator at resonance was ∿20 dB between 1.8 and 4.0 MHz. As indicated by Equations 3 and 5, Q_T for the resonator is a function of frequency, as is shown in Figure 4.

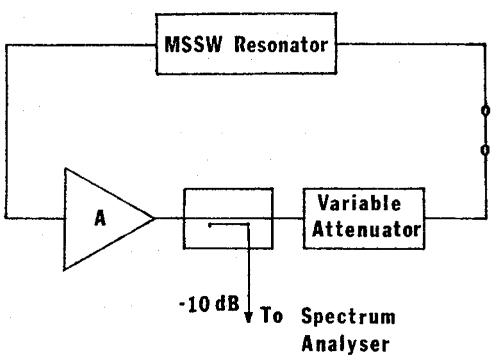

Fig. 2: Experimental arrangement for characterization of the 4 GHz. MSSW resonator stabilized oscillator.

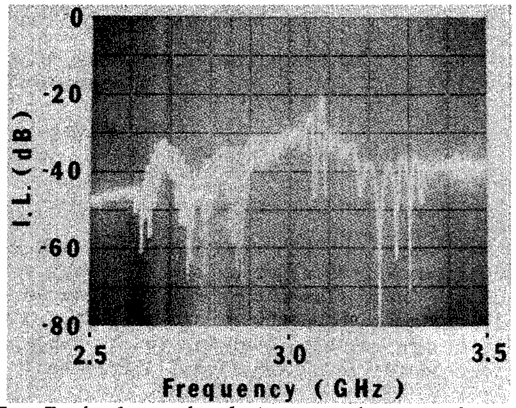

Fig. 3: Typical passband characteristics of the MSSW etched groove resonator at 3.1 GHz.

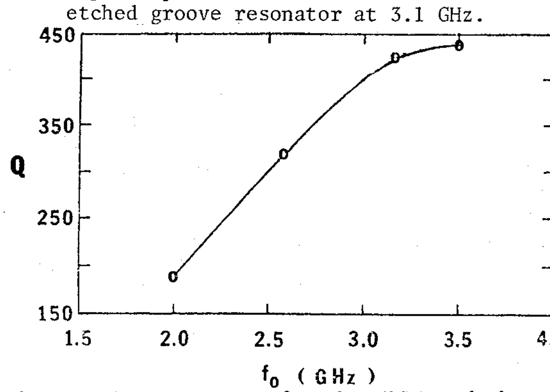

Fig. 4: Total resonator Q for the MSSW etched groove resonator as a function of frequency.

With the oscillator connected as in Figure 2, the oscillator output characteristics were measured as function of frequency by variation of the bias magnetic field. Single mode operation was observed from 1.8 GHz to 4.0 GHz. Typical oscillator line spectra are shown at 2.0 GHz, and 4.0 GHz in Figures 5 and 6. The sidebands have noticeably greater noise at 2.0 GHz than at 4.0. This is due to a combination of lower Q and lower power level for single mode operation. The phase noise was measured and in Figures 7, 8 and 9; experimental results are shown for 2.0 GHz, 3.5 GHz and 4.0 GHz. The roll-off with increasing frequency offset is as expected from Equation 6 and agrees well with the theoretical expression. At intermediate frequency offsets of approximately 10 kHz to 100 kHz there is some excess phase noise. At low frequency offsets, the phase noise reaches a maximum value of approximately -50 dB_c/Hz.

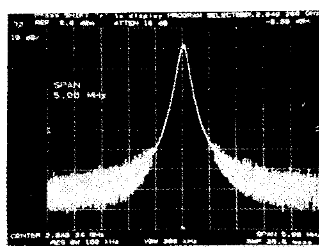

Fig.5: MSSW resonator based oscillator line at 2.0 GHz.

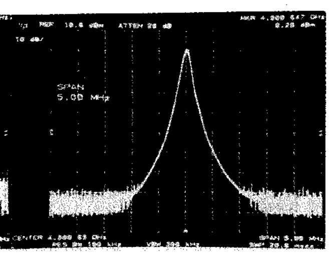

Fig.6: MSSW resonator based oscillator line at 4.0 GHz.

Conclusions

A continuously tunable MSSW etched groove resonator stabilized oscillator has been realized over a frequency range of 1.8 to 4.0 GHz. Single mode operation with good phase noise characteristics was obtained over the entire frequency range. As a matter of comparison, the oscillator phase noise for an HP 8620C

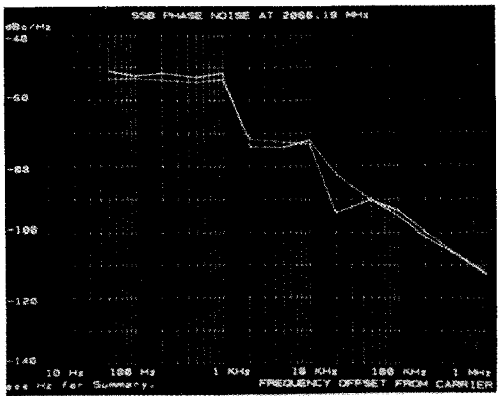

Fig. 7: Phase noise of the MSSW etched groove resonator stabilized oscillator at 2.0 GHz.

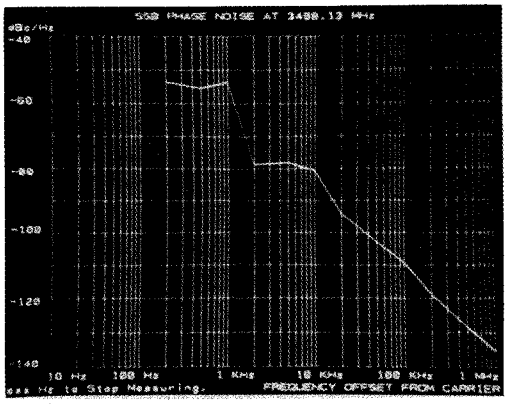

Fig. 8: Phase noise of the MSSW etched groove resonator stabilized oscillator at 3.5 GHz.

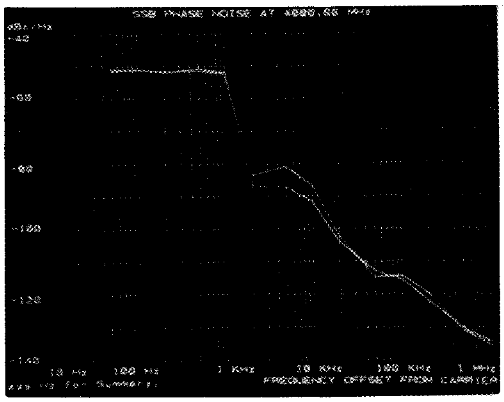

Fig. 9: Phase noise of the MSSW etched groove resonator stabilized oscillator at 4.0 GHz.

sweep oscillator was measured at 3 GHz and is shown in Figure 10. For further comparison, the phase noise scaled by Equation 6 for a resonator of 800 Q, 10 dB insertion loss feedback stabilizing an amplifier with 5 dB noise figure is shown as a dashed line. The points represent data sheet figures for a YIG-TEK model 322 YIG sphere oscillator and an Avantek model VTD 2800 varactor tuned oscillator. The oscillator reported in this study is comparable to, or surpasses, the noise figure performance of the sweep oscillator and the commercial oscillators. The projection for an optimized oscillator shows superior performance is possible with an MSSW etched groove resonator

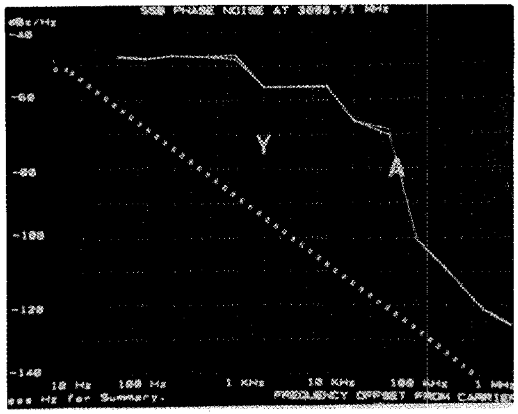

Fig. 10: Phase Noise for a Hp 8620C sweep oscillator at 3.0 MHz. Dashed line: scaled by equation 6 for an optimized MSSW oscillator.
Y: Yigtek Model 322.
A: Avantek Model VTD 2800

stabilized oscillator.

Further performance improvements are anticipated: Temperature compensation procedures[10] can improve long term stability. A Q of 800 was assumed for comparison purposes in Figure 10, but material considerations leave an upper limit of several thousand open to possible realization. Figures of merit, Qf_o, for MSSW oscillators would then surpass bulk oscillators for 10 GHz operation. This performance can be obtained through further optimization of resonator structure and fabrication, transducer design and amplifier feedback optimization. Thus magnetostatic wave devices are a likely candidate for yet another systems application: 2 to 20 GHz tunable oscillators.

Acknowledgments

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