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THIN-FILM YIG OSCILLATORS WITH LOW PHASE NOISE AND HIGH SPECTRAL PURITY

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ABSTRACT

Two broadband bipolar thin-film YIG oscillators have been developed, one having frequency coverage of 2.7 to 7.5 GHz with phase noise of -109 dBc at 10 kHz at a 3.0 GHz carrier. Another 0.5 to 2.0 GHz circuit exhibits -55 dBc second harmonic levels and is much more stable than a similar YIG-sphere circuit. This paper discusses design and measurement of thin-film resonators, as well as practical improvements that stabilize thermal drift.

INTRODUCTION

Magnetostatic-wave (MSW) resonators made from thin-film YIG have several potential advantages over traditional YIG-sphere resonators in oscillator applications due to their higher unloaded Q's and planar geometries. We report both a bipolar transistor oscillator which tunes from 2.7 to 7.5 GHz with very low phase noise (-109 dBc at 10 kHz from the carrier) and a bipolar oscillator for 0.5 to 2.0 GHz operation which has -55 dBc second harmonics, which favorably compares with -18 dBc from a current YIG sphere oscillator of similar tuning range.

REVIEW OF MAGNETOSTATIC-WAVE RESONATORS

Magnetostatic-waves (MSWs) are slow, dispersive, magnetically-dominated waves which propagate in thin-film YIG at microwave frequencies under magnetic bias similar to that used for YIG spheres. Unlike microwave interaction in a one-port spherical YIG resonator, however, these waves are launched by a microstrip transducer and travel through the material to an edge, where they are reflected and then re-absorbed by the transducer; YIG spheres operate on the uniform precession of magnetic dipoles and ideally experience no such traveling-wave phenomena. Because of the rectangular geometry in which MSWs propagate, they occur in three varieties: forward volume waves (FVW), backward volume waves (BVW), and surface waves (SW), each a function of the DC magnetic field's alignment relative to the material[1].

MSFVWs are well-suited for one-port resonators in transistor oscillators[2] because the magnetic field is applied normal to the plane of the YIG material (Figure 1), and these resonators exhibit loaded Q's of ~1000, compared to ~200 for a sphere[1]. The resonators used in this work have demonstrated values of ~1800 or more (Figure 2). Moreover, the simplicity of this resonator assembly is quite attractive from a manufacturing standpoint; unlike spheres, there is little time-consuming alignment involved. Equally as important from this standpoint is the resonant behavior of doped material, which is required for operation below 2 GHz: At equal levels of doping, resonance occurs at lower frequencies for planar than for spherical devices. This allows for more latitude in resonator selection, since the doping of YIG is rather inexact, with tolerances getting looser as the doping gets heavier.

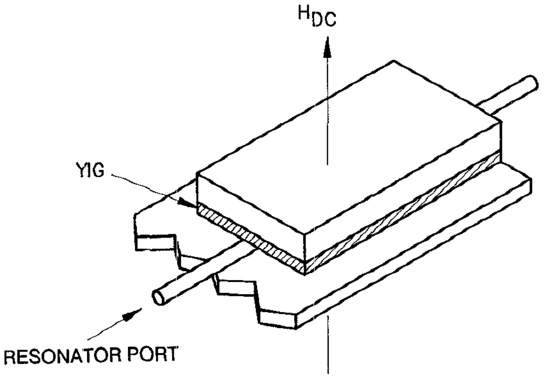

Figure 1. A One-Port MSFVW Resonator with a Microstrip Transducer and Applied Magnetic Bias Field

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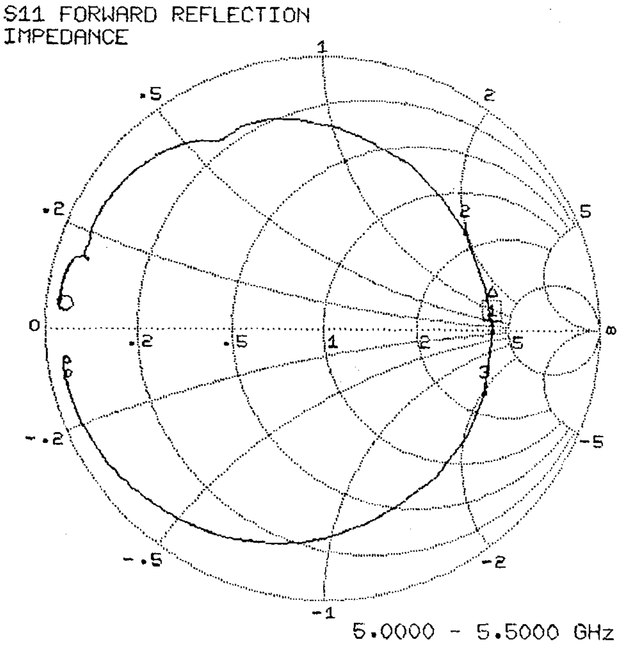

Figure 2. Measured S_{11} of the MSFVW One-Port Resonator at 5.25 GHz

Oscillators based on MSW resonators are not, however, without their disadvantages: Unlike sphere-based resonators, MSW resonators do not tune with the gyromagnetic ratio of 2.8 MHz/Oe. However, any nonlinearity in the tuning characteristic of a modern YIG oscillator can be adequately corrected with a digital coil driver. MSW resonators also require larger magnet pole pieces than spheres because of their larger areas per unit volume. This makes for a slower-tuning and more expensive magnet shell. Finally, these devices have strong tendencies to drift in frequency over temperature, although they have been compensated to a +4 ppm/°C level[3]. To counteract the tendency to drift, we have developed a novel heater structure (Figure 3).

This structure is analogous to a YIG sphere heater rod, but is adapted to the planar geometry of the MSW resonator. It consists of a machined slab of BeO which slides into an appropriate copper heater block for support and to conduct heat to the resonator. The resonator itself is attached to the BeO slab with thermally-conductive epoxy and "hangs" from the bottom of the slab, directly over the microstrip transducer. Advantages of this arrangement are in its ease of thermal control over the YIG slab, simple mechanical design, and provision for fine adjustment of the magnetic field coupling to the YIG slab by vertical screw-type adjustment of the heater block.

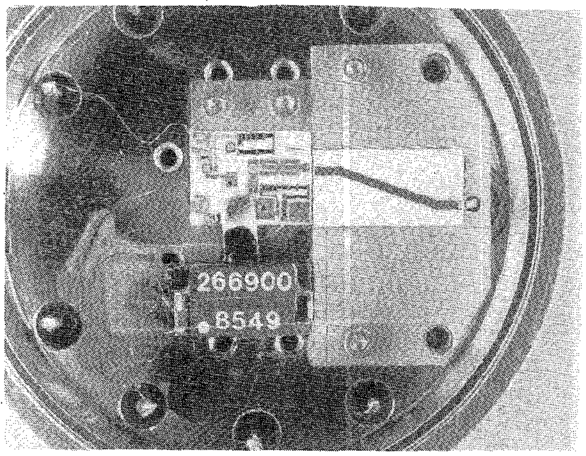

Figure 3. Photograph of a 2.5 to 7.5 GHz MSFVW YIG Oscillator with Heater Structure

CHARACTERIZING THE RESONATORS

The resonators were first characterized as one-port networks by constructing a test magnet shell to accommodate several different microstrip transducer structures having coaxial transitions to facilitate using a network analyzer. The magnet shell was a symmetrically split 5 cm Hypernik cube with a 2 cm diameter pole piece and two 4.6 cm diameter coils. Various transducer designs were built on alumina and tested in combination with a series of YIG slabs, the ones for the high-band oscillator being of pure YIG and having a thickness of 100 μm while the ones for the low-band circuit being doped to a 4 π M_s of 1200 Oe and 75 μm thick. All films were obtained from Airtron; the pure YIG slabs had ferrimagnetic line widths of substantially less than 1 Oe at 9 GHz. Mylar spacers of thicknesses between 50 and 150 μm were used to decrease the coupling of spurious modes to the resonators, while uneven breakage of the ends of each resonator effectively attenuated width modes. Typical data for one of the resonators constructed is given in Table 1.

F_0 (GHz)	Q	Radiation Resistance (ohms)
1.776	296	55
5.13	1710	200
5.326	1775	200
10.153	1269	55
10.258	2052	80
12.019	1717	200

Table 1: Typical data for a resonator with a high-band, low-impedance microstrip transducer measuring 66 x 1524 μm, built on 380 μm alumina with a 1.4 x 0.84 mm pure YIG slab and 127 μm Mylar spacer.

CIRCUIT DESIGNS

Both oscillator circuits described are based on the resonated base topology[4]. The high-band circuit was modified from an existing design based on an NEC 644 bipolar transistor, with a published noise figure of 3.0 dB at 4.0 GHz and 7.5 mA collector current. The microstrip transducer was made of a 75 μm diameter gold bond wire and a 75 μm Mylar spacer was used with a 1.4 x 0.84 mm pure YIG slab. The circuit's unbuffered output power and tuning range are shown in Figure 4 while its phase noise at 3.0 GHz and 10 mA collector current is shown in Figure 5. This performance exceeds that depicted in [2] by 4 dB.

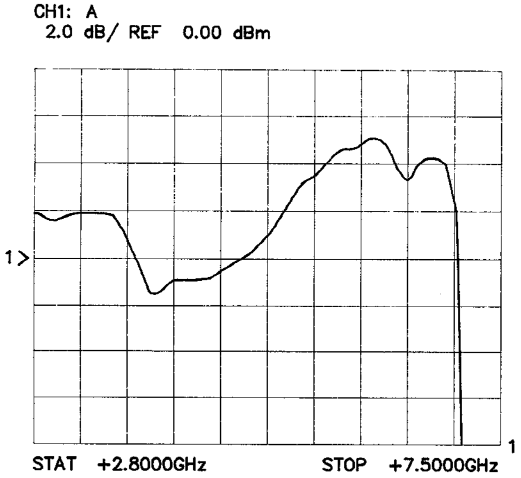

Figure 4. High-Band Oscillator Output Power Over Frequency

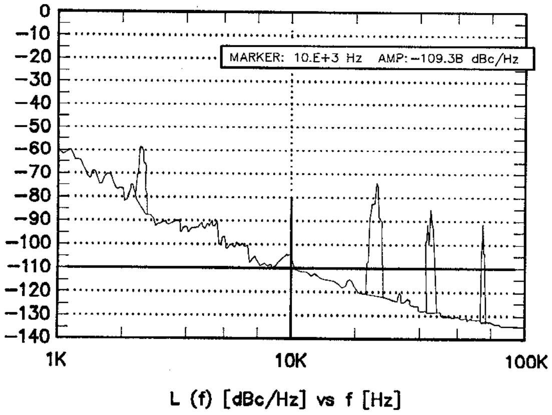

Figure 5. High-Band Oscillator Phase Noise at 3.0 GHz

The low-band circuit was based on an NEC 02100 bipolar transistor and a resonator structure scaled from the high-band circuit to address the 0.5 to 2.0 GHz band. This circuit exhibited substantially better spectral purity than a production YIG-sphere-based circuit, both close-in as shown in Figure 6, and in terms of harmonic levels, as compared in Figures 7 and 8. Figure 8 shows the worst-case harmonic performance for this circuit across the tuning band.

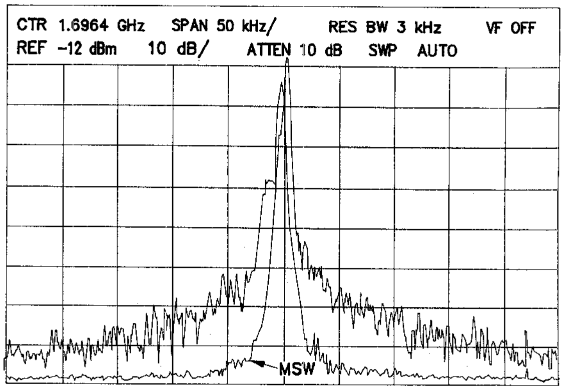

Figure 6. Close-In Frequency Stability of MSW Oscillator vs. a Production YIG Sphere Oscillator

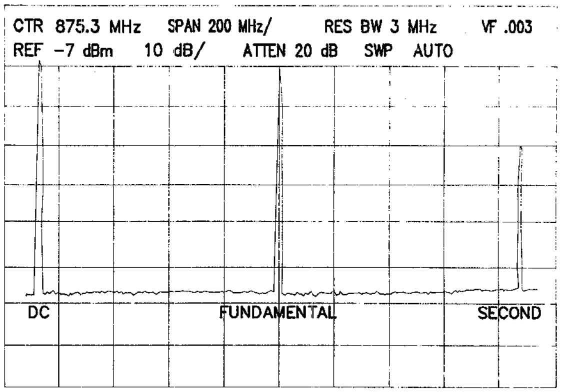

Figure 7. Harmonic Spectrum of a Typical YIG Sphere Bipolar Transistor Oscillator

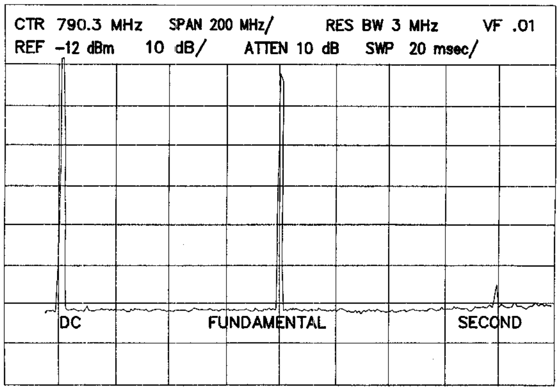

Figure 8. Worst-case Harmonic Spectrum of a MSW Bipolar Transistor Oscillator in the 0.5-2 GHz band

CONCLUSIONS

Microwave oscillators built with MSFVW resonators have been shown to be simple in concept and relatively easy to build in execution. Their performance as shown above can exceed current YIG sphere-based designs, although they are not without their drawbacks. The circuits discussed could be improved with better magnet structures and with buffer amplifiers to increase output power. Thermal drift has been largely countered with appropriate slab heating, much as is currently done with spheres, while the novel heater structure also promotes adjustment of coupling.

ACKNOWLEDGEMENTS

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