AN APPROACH TO REALIZING MULTI-OCTAVE PERFORMANCE IN GaAs-FET YIG-TUNED OSCILLATORS

Cristopher F. Schiebold

Watkins-Johnson Company

Palo Alto, California

Abstract

An approach to developing multi-octave GaAs-FET YIG-tuned oscillators is described. A short discussion of the theory is given, followed by a presentation of experimental results for a 3.5 to 19.5 GHz YIG-tuned oscillator.

Introduction

YIG resonators possess several qualities that make them attractive for very broadband oscillator applications. They are tunable over greater than decade bandwidths, have excellent tuning linearity, and can exhibit unloaded Q's ranging from 1000 to 10,000. An equivalent circuit of a spherical YIG resonator with a coupling loop is shown in Figure 1. L_O, C_O, and R_O are calculable from well known formulas [1], L_C is the inductance of the loop used to couple the YIG sphere.

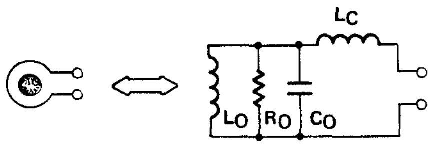

Figure 1. Equivalent Circuit of a YIG Resonator

Using negative resistance theory, a YIG-tuned oscillator may be modeled by Figure 2. Conditions for oscillation are achieved when

$$Y_Y = -Y_D \qquad (1)$$

or, the sum of the admittances is equal to zero. When using small-signal parameters, the conditions for oscillation are generally described as:

$$G_Y(\omega) + G_D(V,\omega) \leq 0 \qquad (2)$$

and

$$B_Y(\omega) + B_D(V,\omega) = 0 \qquad (3)$$

where equation (2) assures the existence of growing oscillations. Stable oscillations can be achieved only when equation (1) is satisfied and Kurokawa's stability criterion [2] is met. This is given by:

$$\left(\frac{\delta B_D}{\delta V}\right)\left(\frac{dG_Y}{d\omega}\right) - \left(\frac{\delta G_D}{\delta V}\right)\left(\frac{dB_Y}{d\omega}\right) < 0 \qquad (4)$$

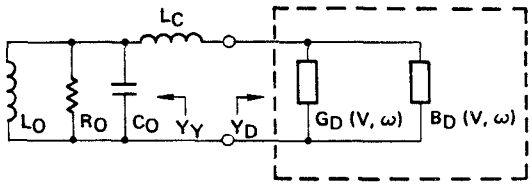

Figure 2. Negative Resistance Model

YIG oscillators are governed by an additional restriction which involves spurious resonances associated with L_C, the coupling-loop inductance. If the oscillator circuit generates a negative conductance with an associated capacitive susceptance, a spurious oscillation can occur with L_C. Traditionally, this problem has been circumvented by using the common-gate topology shown in Figure 3. Assuming the simplified FET model of Figure 4, negative conductance is present only when the susceptance is inductive.

$$G_D = \frac{g_m}{1 - \omega^2 C_{GS} L_F} \qquad (5)$$

$$B_D = \frac{j\omega C_{GS}}{1 - \omega^2 C_{GS} L_F} \qquad (6)$$

Inclusion of additional FET parasitics in the model of Figure 4 will limit the band of negative conductance, and generate a shift from inductive to capacitive susceptance at the high end of the negative-conductance band. By making L_C small enough, spurious oscillations can be avoided, allowing conditions for only YIG-tuned oscillation. Bandwidths of much greater than one octave, however, are difficult to achieve using GaAs FETs in this topology [3,4]. (It should be noted silicon bipolar transistors exhibit very broadband response in the common-base topology, primarily due to their high transconductance.)

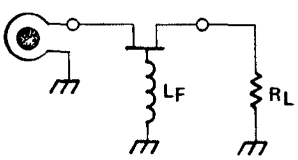

Figure 3. Common-Gate YIG-Tuned Oscillator

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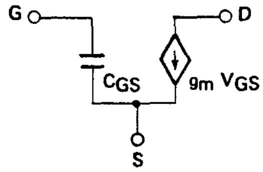

Figure 4. Simplified FET Model

The Coupled-Source Oscillator

An oscillator topology more suited to the inherent properties of the GaAs FET is the common-source circuit. This is shown in Figure 5. Using the simplified model of Figure 4, the common-source oscillator exhibits an admittance seen by the YIG resonator of:

$$G_D = \frac{-\omega^2 g_m C_{GS} C_F}{g_m^2 + \omega^2 (C_F + C_{GS})^2} \qquad (7)$$

$$B_D = \frac{\omega^3 C_F C_{GS}(C_F + C_{GS})}{g_m^2 + \omega^2 (C_F + C_{GS})^2} \qquad (8)$$

The obvious disadvantage of the common-source oscillator for use with a YIG resonator is that the input susceptance is capacitive. The advantage is that negative conductance can be achieved over very broad bandwidths. Typically these bandwidths can be greater than four octaves.

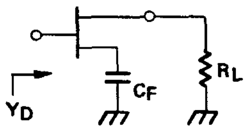

Figure 5. Common-Source Oscillator

Several techniques were investigated to utilize the bandwidth of the common-source topology while avoiding the spurious oscillation associated with the coupling loop. The idea was to tailor the negative conductance through control of the feedback element, C_F, such that the coupling-loop resonance could be placed outside the negative-conductance band. One method of accomplishing this is shown in Figure 6. In this oscillator, the feedback capacitor, C_F, has been replaced by a parallel resonant circuit. Above $\omega = 1/\sqrt{L_F C_F}$, the feedback looks capacitive and negative conductance is obtained. Below $\omega = 1/\sqrt{L_F C_F}$, the feedback looks inductive and no negative conductance is present. By selecting L_C such that the spurious resonance is placed below $\omega = 1/\sqrt{L_F C_F}$, only YIG-tuned oscillations can occur. Bandwidths of one octave to one and one-half octaves can be achieved with this circuit.

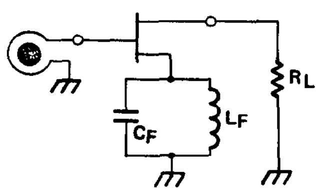

Figure 6. Common-Source Oscillator with Frequency-Selective Feedback

An extension of this concept was to replace the parallel resonant feedback circuit with a second YIG resonator as is shown in Figure 7. By placing the tuning and feedback resonators in the same magnetic structure, feedback and hence negative conductance will be present only at the frequency of YIG-tuned oscillation. This eliminates the possibility of spurious oscillations, and bandwidths of greater than two octaves can be realized.

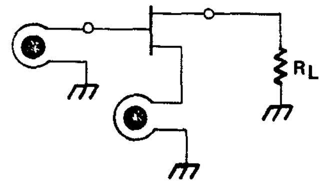

Figure 7. Two-YIG Realization of the Common-Source Oscillator

A variation of the two-YIG approach was to eliminate the feedback resonator and couple the source directly to the gate (tuning) resonator. This circuit is depicted in Figure 8. As with the two-YIG circuit, non-YIG-tuned oscillations are eliminated and broad tuning bandwidths can be achieved. Experimental results will be presented for the coupled-source oscillator showing a practical realization of the circuit with coverage in excess of two octaves.

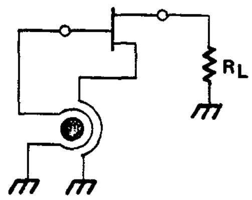

Figure 8. Coupled-Source Oscillator

Obregon, LeTron, et al [5, 6] reported using similar topologies to the two-YIG and coupled-source oscillators, but described the circuit as operating in the common-gate mode with the gate resonator functioning as a tunable feedback inductor. Because of the symmetry of these circuits, there could be some ambiguity on whether they operate as a common-gate or common-source circuit. It should be noted, however, these oscillators do exhibit two separate and distinct modes of operation. Common-gate or common-source operation can be enhanced by altering coupling loop inductances and geometries.

Experimental Results

Figure 9 shows the coupled-source oscillator topology being used for 3.5 GHz to 19.5 GHz coverage. The active device is a recessed-gate GaAs FET with approximately .5 μm x 300 μm gate dimensions. The YIG resonator is 14 mils in diameter with a saturation magnetization of 1000 Gauss. Output matching is accomplished with a four-element lowpass network with provisions for DC biasing and blocking. The match was formulated using small-signal modeling in conjunction with large-signal data collected from load pull measurements. Figure 10 shows performance data for the coupled-source oscillator. The extremely low harmonics and highly linear tuning are both characteristic of the coupled-source topology.

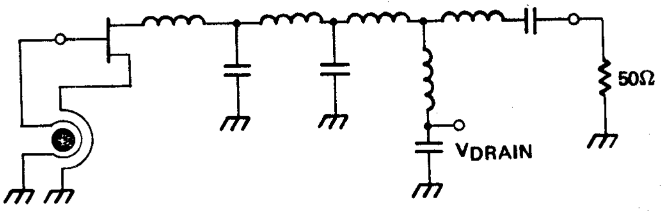

Figure 9. 3.5 - 19.5 GHz Coupled-Source Oscillator

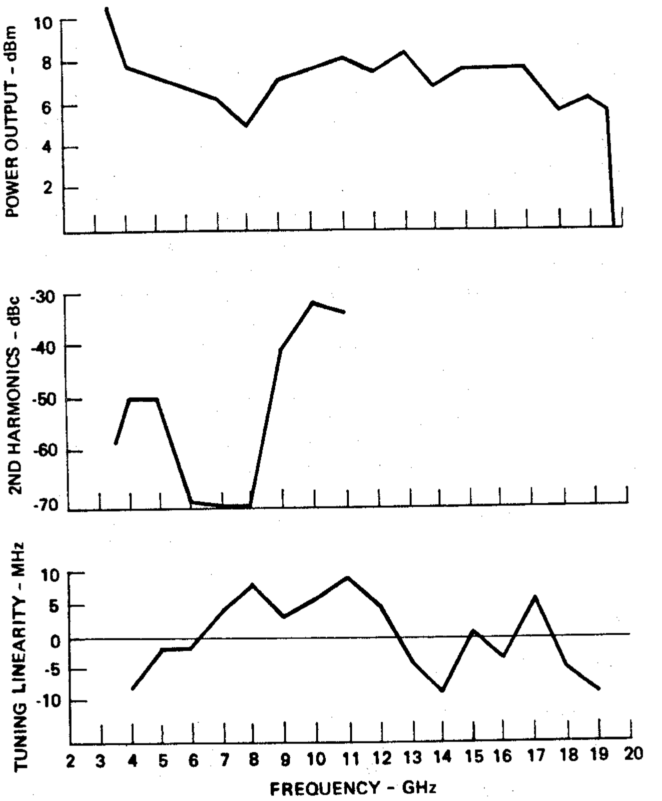

Figure 10. Performance Data for Coupled-Source Oscillator

Figure 11 is a photograph of a production prototype of the coupled-source oscillator with a 6-18 GHz balanced amplifier being used as a buffer. The oscillator circuit is fabricated on BeO substrates and utilizes laser-drilled holes for grounding. Because of the high thermal conductivity of the BeO, the FET can be mounted directly on the substrate and no carrier is required. This approach yields a simple and inexpensive oscillator assembly which needs only to be clamped to the magnetic housing. Despite the bandwidth limitations imposed by the balanced amplifier, this oscillator covers 5.0 GHz to 18.3 GHz from -55°C to +85°C with ±5 MHz linearity, and a minimum power output of +12 dBm.

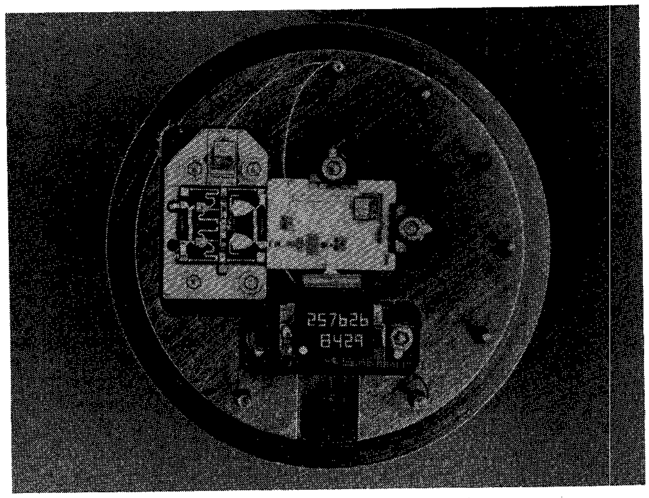

Figure 11. Production Prototype of Coupled-Source Oscillator

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