YIG-TUNED GaAs FET OSCILLATORS

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Abstract

The design and construction of a C-X straddle band YIG-tuned oscillator with 4 GHz frequency coverage is presented. A 1μ-gate GaAs FET is used for the active element, and is tuned by a YIG sphere. A one-stage single ended GaAs FET buffer amplifier is included to enhance overall performance. Power output is a minimum of 5 mW at 10 GHz, and overall performance is equal or superior to that offered by alternative swept frequency sources.

Introduction

Commercially available bipolar transistors provide marginal performance at frequencies above 8 GHz. The emergence of the GaAs FET, with its superior gain and f_T, allows the design of tuneable sources utilizing 3 terminal devices to be extended to these higher frequencies. This paper first discusses the design philosophy and circuit development of a 6 to 10 GHz GaAs FET oscillator. The design and realization of a buffer amplifier is then presented, and the performance results of the integrated thin-film oscillator/amplifier are discussed. It will be shown that superior efficiency, pushing, pulling, and harmonic content over alternative active sources has resulted.

Broadband GaAs FET Oscillator Design

One of the first commercially available GaAs FET's was the NEC V244, a 1μ-gate device. A study of the circuit configurations for this chip GaAs FET shows the common gate configuration to have the possibility of suitable feedback-induced broadband negative resistance. The measured common gate S-parameters are shown in Figure 1. The effect of common lead feedback can be seen by mapping the right-half-plane impedances onto the two port S-parameters of the device.[1, 2] An example of this is shown for S_{11} at 10 GHz in Figure 2. Similar plots are made for the other three S-parameters. Examination of these plots at 6 and 10 GHz, and various frequencies in between, indicates that common lead inductance provides the proper feedback required for oscillations. The source of the GaAs FET is connected to the YIG sphere and coupling loop. A YIG sphere acts as a linearly tuneable (with an applied magnetic field) high Q parallel resonant circuit. The output power is taken from the drain through the matching circuit to 50 ohms.

Once the optimal common lead inductance is determined, the drain matching circuit must be designed. The mapping of the right-half-plane impedances as drain loads onto S_{11} at various frequencies indicates the required range of load impedance. An example of such a plot at 10 GHz is shown in Figure 3. For oscillations to occur, the feedback and load impedance must be chosen so that

$$|\Gamma_y| > \frac{1}{|\Gamma_S|} \quad \text{and} \quad \text{Arg}\,\Gamma_y = \text{Arg}\,\Gamma_S$$

where $\Gamma_S = S_{11}$,

for all frequencies in the band of interest. Figure 4 defines the appropriate reflection coefficients. The technique of using measured small signal S-parameters in the design of an oscillator, which is a large signal device, has been questioned. No information as to absolute power output, harmonic content, or spectral purity can be obtained. However, small signal S-parameters provide a reasonably accurate prediction of the range of frequencies over which the device will oscillate. The variation in output power across the band was found to be roughly proportionate to the variation in magnitude of the negative resistance predicted by the use of S-parameters.

Networks to synthesize the required gate inductance and the appropriate load impedance as a function of frequency were designed using microstrip constraints. Computed sensitivity analysis of the circuit elements shows the value of the gate inductance to be a critical factor. Thus, the inductor was fabricated on a quartz microstrip suspended substrate, giving excellent repeatability of the circuit performance. The drain matching circuit was constructed using microstripline on alumina. The completed thin-film oscillator has a frequency range of operation which closely matches the range predicted by computer analysis of the circuit and device. The power output is a function of the bias point which is empirically within the FET safe operating region. As predicted by the computer analysis, the range of frequency coverage can be shifted by changing the value of the feedback inductance. During alignment the frequency coverage was easily changed to cover X-band, 8-12 GHz, by adjusting L_f. Several oscillators were built using FET's from different fabrication lots but with similar dc parameters, and were found to have minimal performance variation.

Broadband Buffer Amplifier Design

To increase the power output across the band and provide additional load isolation, a one-stage single ended buffer amplifier was designed for the oscillator. The design of this GaAs FET amplifier differs somewhat from those covered in the literature[3], in that the gain must be shaped to compensate for the decreasing power with increasing frequency characteristic of the oscillator. The gain of the amplifier was designed to be 0 dB at 6 GHz and 8 dB (G_{max}) at 10 GHz. Since the oscillator will not work into a large VSWR, the input VSWR of the amplifier must be reasonably good. To achieve the desired gain slope with good VSWR, a resistively loaded input matching network was used. The linear amplifier was designed using a chip 1μ-gate V244 in the common source configuration. The input and output matching circuits were designed based on measured S-parameters and the gain and VSWR constraints. Computer analysis and optimization of the circuit for the desired gain vs frequency and VSWR was done. The thin-film circuit was built with alumina and quartz microstrip.. Owing to accurate characterization of the GaAs FET, only minor adjustments were required to tune the amplifier. The gain vs frequency and input impedance of the amplifier are shown in Figures 5a and 5b, respectively. The gain is within 0.5 dB of that predicted by the computer analysis, while the input VSWR is somewhat larger than that predicted.

Integrated Oscillator/Amplifier Performance

The basic circuit of the integrated oscillator/amplifier unit is shown in Figure 6. Bias is applied through the regulator internal to the unit to provide power supply isolation. The electromagnet is used to provide the magnetic field which tunes the YIG sphere, and thus the oscillator, to the desired frequency. The power output versus frequency is shown in Figure 7. Performance versus temperature of the unit is good, with a slight decrease in power out occurring as the temperature is increased to +75°C. Table I summarizes the overall performance of the unit. Performance is superior or equal to YIG-tuned oscillators built with alternative devices. For example, a typical bulk effect YIG-tuned oscillator covering X-band requires a dc power of about 12 volts at 400 mA (4.8 watts), for an average RF power output of about 30 mW (efficiency ≅ 0.6%); and has a pulling figure of ±3 MHz into a 1.67:1 VSWR. The GaAs FET oscillator and amplifier requires about 6 volts at 55 mA (330 mW), for an average RF power output of about 10 mW (efficiency = 3%); and has a pulling figure of ±0.4 MHz into a 1.67:1 VSWR.

Summary

The computer aided design procedure presented here has shown good agreement with the results obtained on a wide band GaAs FET YIG-tuned oscillator with integral buffer amplifier. The GaAs FET's used in this work were designed for small signal, low power, low noise figure linear amplifier applications. As the power GaAs FET's under development become available, much higher power outputs will become achievable. In conclusion, the results show that the GaAs FET can be used to build wide frequency range tunable oscillators with frequency and power performance formerly attainable only with bulk effect devices. In addition, the GaAs FET has much better efficiency and pulling figure than the bulk effect devices. As the GaAs FET technology continues to advance, improved power and frequency performance should soon be achievable.

Acknowledgements

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References

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2. G. E. Bodway, "Circuit Design and Characterization of Transistors By Means of Three-Port Scattering Parameters," Microwave Journal, May 1968, Vol. 11, No. 5).

3. M. G. Walker, F. T. Mauch, and T. C. Williams, "Cover X-Band with an FET Amplifier," Microwaves, Oct. 1975 (Vol. 14, No. 10, p. 36).

TABLE I

PERFORMANCE OF YIG-TUNED GaAs FET OSCILLATOR

SPECIFICATION	UNITS	PERFORMANCE
Frequency	GHz	6 GHz to 10 GHz
Power Out	dBm	+7.2 to +13.0
Power Variation (Full Band)	dB	±2.9
Frequency Pulling, 1.67 VSWR any ϕ	MHz	±0.4
Frequency Pushing, MHz/Volt	MHz/Volt	0
Frequency Stability	kHz/°C	±150
Harmonic Spurious	dBc	-23
In-Band Spurious	dBc	Better than -60
Linearity	MHz	±3.3
Response Time (Full Band Step)	mS	2.1
Hysterisis	MHz	1.8
Sensitivity	MHz/mA	12.8
Coil Resistance	Ohms	4.2
FM Coil Sensitivity	kHz/mA	172
Power Supply	Volts mA	+15 55

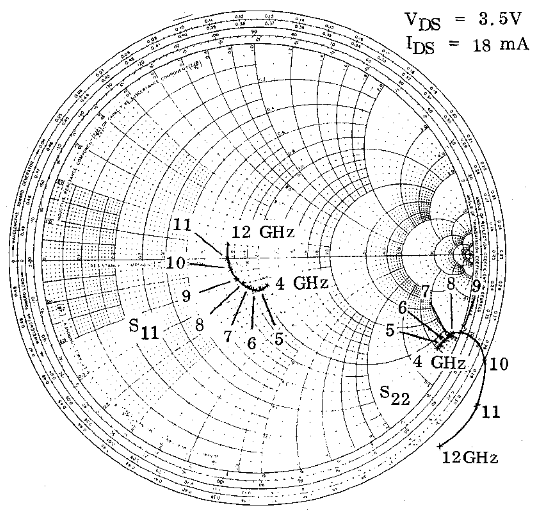

Figure 1 Measured GaAs FET S-Parameters

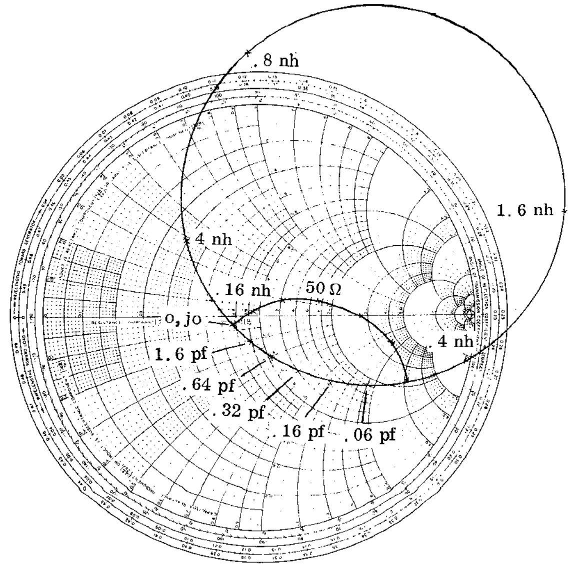

Figure 2 Mapping of Common Lead Feedback on S_{11}

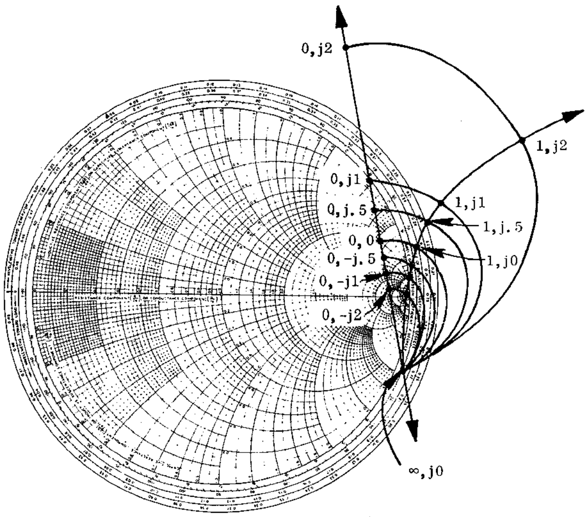

Figure 3 Mapping of Load Impedance on S_{11}

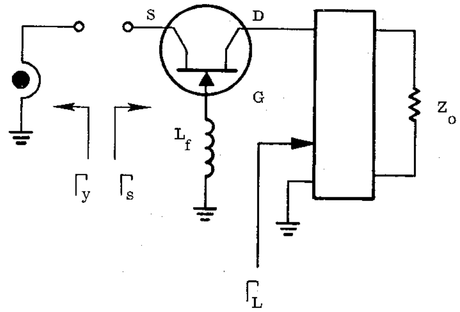

Figure 4 Schematic of the Basic Oscillator Circuit, Defining the Various Reflection Coefficients

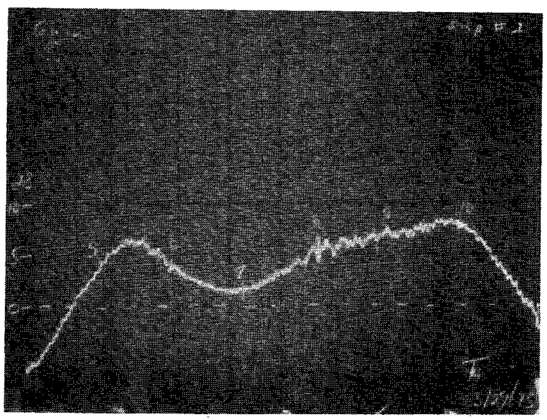

Figure 5a Gain Versus Frequency of the GaAs FET Buffer Amplifier

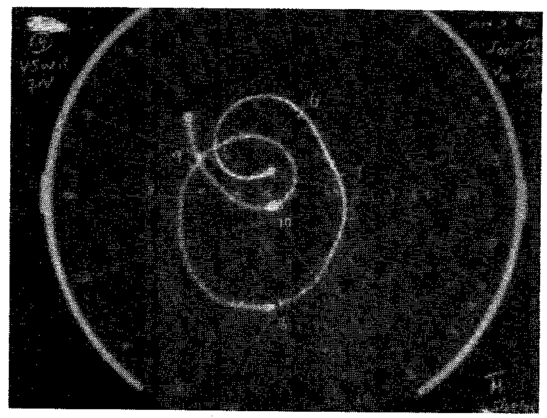

Figure 5b Input VSWR Versus Frequency

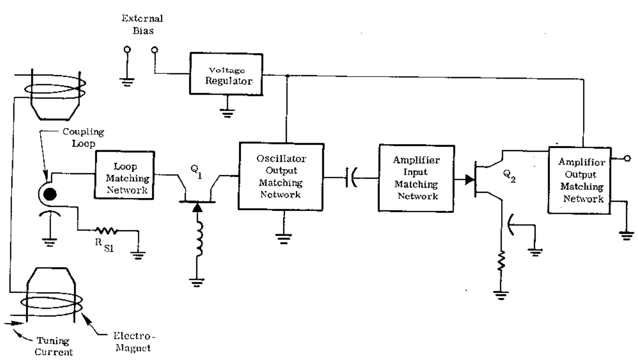

Figure 6 Schematic of the Integrated Oscillator/Amplifier

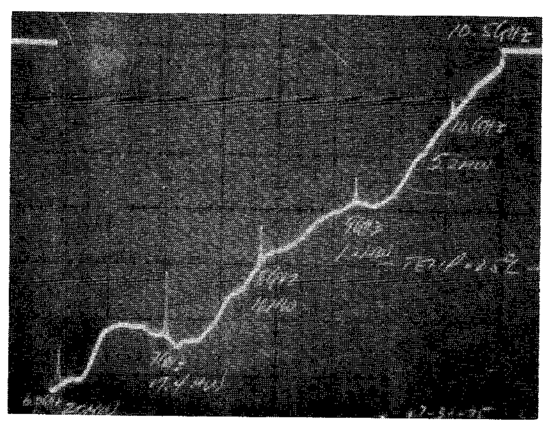

Figure 7 Power Output Versus Frequency