WIDEBAND CAVITY TUNED GaAs FET OSCILLATOR

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ABSTRACT

The design and performance of a cavity tuned GaAs FET oscillator operating from 5.35 to 12.75 GHz with FM capability is described. Experimental data of power, FM frequency response, FM linearity, and SSB phase noise are presented.

Introduction

The GaAs FET has become in recent years a major active device in the design of a number of microwave components. Applications utilizing GaAs FET's include low-noise amplifiers,[1] multipliers,[2] power amplifiers,[3] active mixers,[4] and oscillators.[5] To date most of the oscillators reported on have been limited to relatively narrow band operation. In this paper we report on a wideband cavity tuned oscillator covering 5.35 to 12.75 GHz and having FM capability. The design of the oscillator proceeded essentially in three steps. First, selection of a resonant circuit suitable for a low cost, low-noise oscillator capable of greater than octave bandwidth. Second, determination of the best transistor configuration for this particular resonant circuit. Third, design of the circuit suitable for frequency modulation.

Oscillator Design Criteria

When the selective circuit is tuned at a given frequency, no extra resonances should appear in the range in which the transistor is potentially capable of oscillating. In the central part of the band where the oscillation and its second harmonic are strong, it is advisable to prevent the presence of a spurious resonance at this harmonic frequency. Failure to do so might result in output power reduction and a significant perturbation of the frequency modulation. Thus, it should be clear that the tuning circuit suitable for octave bandwidth operation should be free of extra resonances over approximately a 3:1 frequency range at the low end of the band. TE and TM cavities are not acceptable because of the large number of modes in relatively narrow bands. Varactor-tuned circuits do not exhibit enough selectivity and, of course, their resonant frequency is very sensitive to the electrical noise superimposed on the varactor bias. For these reasons oscillators using such tuning circuits are noisy. YIG-tuned circuits have very good selectivity and are capable of multi-octave tuning. Unfortunately, like varactor-tuned circuits, they are very sensitive to any electrical noise present on the tuning current. Consequently, it was decided that a quarter wavelength TEM cavity was the best choice since such a cavity exhibits a fairly good selectivity and a 3:1 band free of resonances. The radial dimensions are selected to minimize losses and keep the frequency range of interest free of TE and TM resonances.

Circuit Choice

A complete discussion of oscillator configurations suitable for use with a coaxial resonator is extremely lengthy. For brevity we shall limit ourselves to point out a few important features related to the two configurations shown in Figure 1. In (a) the feedback mechanism is achieved by the inductance in series with the base. This configuration is widely used with YIG resonators. However, small signal analysis of the circuit (including the S parameters for the particular FET being considered for the active device) indicated a smaller bandwidth than that which could be obtained with the circuit in Figure 1(b). Also, because of the broadband nature of the output matching network, the output signal would contain a large amount of second harmonic.

Next, consider the Colpitts configuration (b) which was selected for our oscillator. The feedback is achieved by the capacitive divider made up of the internal gate-source capacitor and the hybrid (internal + external) source-drain capacitor. The resonator which is used both as a matching network and as a selective circuit, attenuates the harmonic content of the output signal.

The complete oscillator is shown schematically in Figure 2. All the elements within the dotted line are mounted on a sapphire substrate, with the capacitive coupling element parallel to the tuning rod. It is easy to adjust the capacitive coupling of the microcircuit to the cavity by simply changing the penetration of the substrate into the cavity. Similarly, the coupling of the load to the cavity is easily changed by adjusting the location of the coupling loop. The inductance L, which is in parallel with the feedback capacitor, imposes a limitation at the low end of the band. At high frequencies, the inductance L may cause additional resonances and a risk of stray oscillations. However, in practice it is possible to build an inductor that gives broad bandwidth without parasitic high frequency oscillations.

An innovation of this oscillator design is the capability for the distribution of several oscillator and FM micro-circuits radially and along the length of the cavity in order to increase the power and bandwidth.

In its simplest form, the small signal impedance at the gate-drain terminal of the FET is (refer to Figure 1(c))

$$Zgd = (Zgs + Zt) + g_m\,(Zgs\;Zt) \qquad (1)$$

where Zt is the parallel combination of the drain-source capacitance and feedback impedance. The feedback impedance itself consists of L and C in parallel; and Zgs is the gate-source capacitance. Negative resistance is contributed solely by the second term in Equation (1), which is non-positive real and proportional to g_m. Further examination of Equation (1) reveals that the negative resistance is inversely proportional to the square of the frequency, while the reactance is capacitive. The condition for oscillation is

$$Zgd + Zres = 0, \qquad (2)$$

while the conditions for oscillation start-up have been given by Kurakawa.[6]

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Poor grounding of the sliding center conductor of the coaxial line at the bottom of the cavity can cause erratic tuning. For this reason we developed a broadband non-contacting choke instead of a simpler but less reliable spring contact system. The choke shown in Figure 2 consists of low impedance-high impedance steps. The function of the choke is to electrically terminate the cavity with a very low impedance, thereby limiting the cavity resonator length to $\lambda/4$. The choke's electrical requirements are for very low impedance over a broad bandwidth, while the mechanical requirements include low microphonics, controlled thermal expansion, and long life.

Frequency Modulation

FM is provided by the circuit in the lower dashed rectangle of Figure 3. Two back-to-back varactor diodes mounted on a sapphire substrate are capacitively coupled to the cavity by means similar to that used for the FET. This provides the decreasing capacitance required to get flat deviation over the range of operation of the oscillator. The purpose of the back-to-back series diode configuration is to reduce the generation of harmonics by the varactors. Bias is provided via thin-film resistors R1 and R2.

In order to minimize incidental AM and degradation of the cavity Q, a specially developed GaAs Schottky barrier varactor diode was used. This device has Cjo = 1.2 pF and a cut-off frequency exceeding 400 GHz at -6 volts.

Experimental Results

Figures 4 - 7 present experimental results of a prototype oscillator designed from the principles just described. Figure 4 gives data of oscillator power over the band 5.35 to 12.75 GHz. This prototype oscillator utilizes two oscillators and two FM microcircuits distributed in the cavity so as to achieve the wide bandwidth. The power typically exceeds 10 dBm.

Peak-to-peak FM deviation versus CW frequency for a varactor bias in the range -6 to -16 volts is given in Figure 5. FM flatness is quite good across the band with a worst case tolerance being about ± 15 percent. The maximum deviation can be increased or decreased by changing the max-min voltage drive on the varactors.

Figure 6 shows the variation of FM deviation versus varactor drive voltage with CW frequency as a parameter. The frequency range is 5.3 to 12.8 GHz in 100 MHz increments. The log-linear character of this plot suggests the use of exponential shaping in order to achieve low FM distortion rather than traditional breakpoint shaping. Space does not allow a discussion here, but excellent results have been obtained using the former technique.

Single sideband phase noise is one of the most important parameters for a high performance oscillator. Figure 7 shows the noise of the prototype oscillator in a 1 Hz bandwidth at 10 kHz offset from the carrier. The data has been smoothed for this presentation. SSB phase noise is seen to be typically less than -80 dBc over most of the band, falling to -75 dBc at the high frequency end. This level of noise is considered quite good for FET devices and this range of oscillator frequencies.

Conclusions

A brief description of design principles and extensive experimental data for a prototype wideband, cavity-tuned FET oscillator have been presented. Power, FM flatness, FM linearity, and SSB phase-noise data showed excellent characteristics over the prescribed bandwidth.

References

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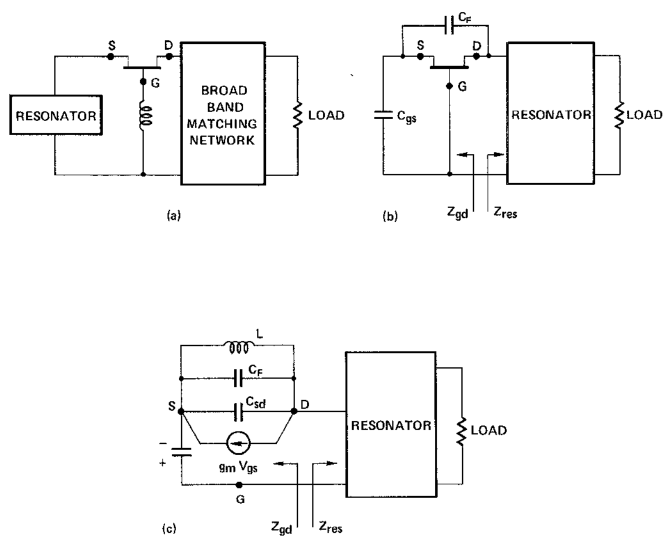

Figure 1: Oscillator Circuit Configurations Suitable for Use with a Coaxial Resonator.

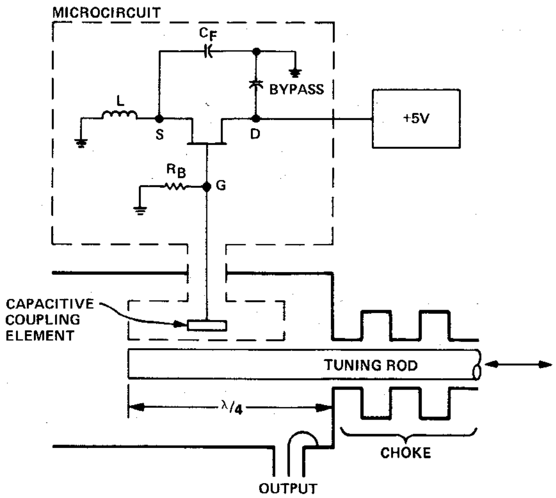

Figure 2: Schematic Drawing of the Prototype Oscillator with One RF Micro-circuit and no FM Micro-circuits.

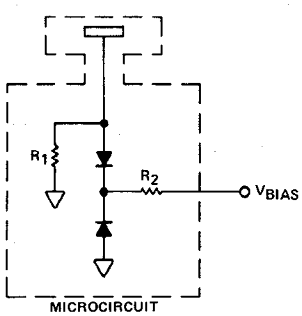

Figure 3: Schematic Drawing of the FM Micro-circuit.

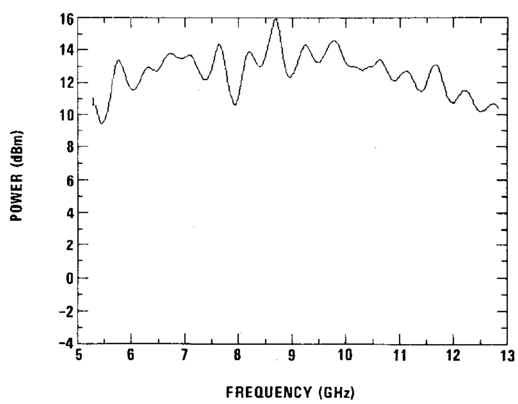

Figure 4: Measured Output Power versus Frequency of the Prototype Oscillator.

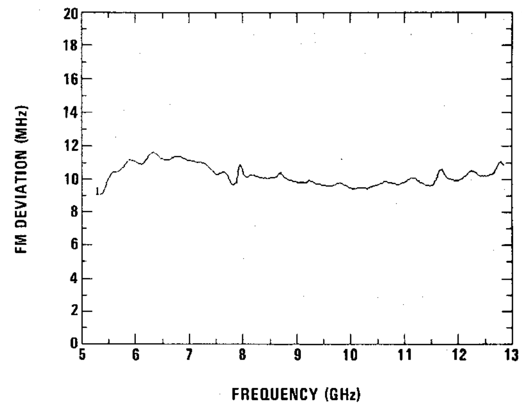

Figure 5: Measured Peak-to-Peak FM Deviation versus CW Frequency of the Prototype Oscillator.

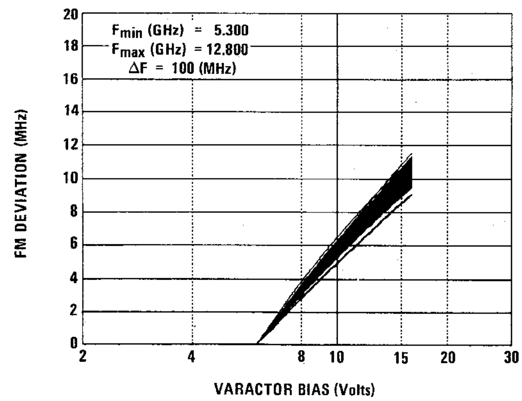

Figure 6: Measured FM Deviation versus Varactor Voltage of the Prototype Oscillator (5.3 GHz < F < 12.8 GHz).

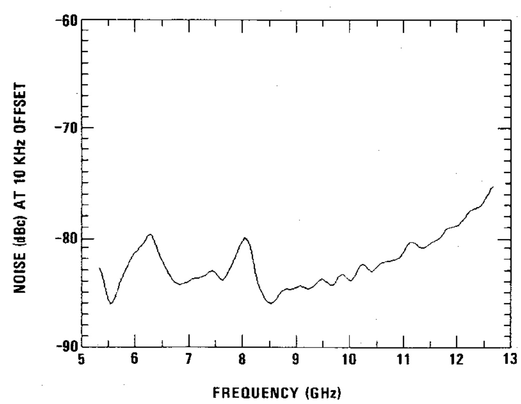

Figure 7: Measured Single-Sideband Phase Noise in a 1 Hz Bandwidth at 10 KHz Offset from the Carrier versus CW Frequency of the Prototype Oscillator.