HIGHLY STABLE 35 GHz GaAs FET OSCILLATOR

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ABSTRACT

A 35 GHz FET oscillator stabilized with a dielectric resonator has achieved a single sideband noise-to-carrier ratio of -87 dBc/Hz at fm = 25 kHz, external $Q \simeq 3000$, and frequency stability of 1 ppm/^{o}C. Using this oscillator as the LO, a compact MIC Ka-band receiver was also developed.

INTRODUCTION

Recent improvements in GaAs FET device technology have introduced a young and potentially superior device technology at millimeter-wave frequencies, which is currently dominated by a diode technology. For millimeter-wave oscillator applications, GaAs FET devices require less DC power and consequently, exhibit less thermally induced frequency drift, and are more efficient and more stable than their diode counterparts. In addition, GaAs FET devices are suitable for monolithic circuit integration which has the potential for producing low cost, high performance millimeter-wave components.

Recently, several dielectric resonator stabilized FET oscillators operating in Ka-band have been reported (1),(2). The published results mostly dwell on the oscillator's output power performance with no mention of the FM noise performance. In this paper, we report the development of a highly stabilized low-noise Ka-band FET DRO. By studying in detail the effect of the dielectric resonator placement on the oscillator's FM noise, along with implementing a coupled line output network to achieve a high oscillator external Q, we achieved a single sideband noise-to-carrier ratio of -87 dBc/Hz at fm = 25 kHz and a temperature stability of 1 ppm/^{o}C using a single resonator approach. This represents the best reported FM noise of a Ka-band FET DRO.

FET DRO Design and Evaluation

The FET oscillator approach is illustrated in Figure 1. It consists of the FET device in a Colpitts common drain oscillator circuit with a high Q dielectric resonator controlling the frequency of oscillation. The FET device employed is a quarter micron gate device with a gate length of 150 μm and a typical fmax of 80 GHz. The output power is coupled through a parallel coupled line which reflects an RF short to the drain of the FET. The degree of the coupling can be adjusted empirically by varying the length of the coupled section. The dielectric resonator, positioned adjacent to a 50 ohm transmission line, is coupled into the oscillator circuit by magnetic coupling. This line is terminated at one end with a

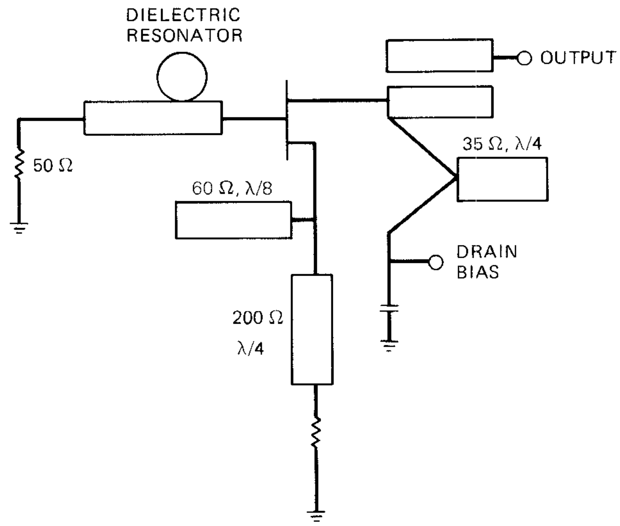

Figure 1 Circuit diagram of a Common Drain FET DRO.

50 ohm load and is connected at the other end to the gate of the FET. The advantages of this approach are summarized as:

1. Generates high, low Q negative resistance
2. Stable, no spurious oscillation
3. Resonator coupling is independent of output coupling.

A photograph of the FET DRO is shown in Figure 2. The MIC oscillator consists of two 10 mil thick fused quartz substrates, the FET device, the dielectric resonator and miscellaneous bias components. The FET device is mounted on a ground rib between the substrates for minimum thermal resistance. The dielectric resonator material used here is Murata Erie's (ZrSn)TiO_4 which has a $\epsilon r \simeq 38$ and a Tcf - 0ppm/^{o}C. The unloaded Q of the resonator is approximately 2000 at 35 GHz. The top cover contains the tuning slug which permits $\pm$50 MHz mechanical tuning of the oscillator without sacrificing the stability and output power.

The oscillator's Qex was measured using the injection locking technique (3). It was measured as a function of D, the distance between the edge of the dielectric resonator and the microstrip line, for three different values of S, the output coupled line spacing. Figure 3 shows the oscillator Qex and the associated

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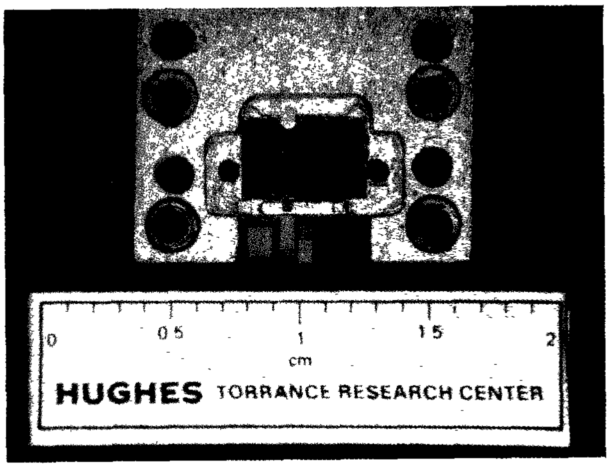

Figure 2 Photograph of hybrid MIC 35 GHz DRO.

output power. In the case of Vd = 2.5 V and S = 1 mil, as D is increased from 0 to 8 mils, Qex improved from 1085 to 2922, and the associated power dropped from 4 dBm to 1 dBm. In the case of Vd = 4.5 V, S = 0 mil and D = 2 mils, we achieved the highest output power, 10.5 dBm; however, the Qex is rather low, only 248.

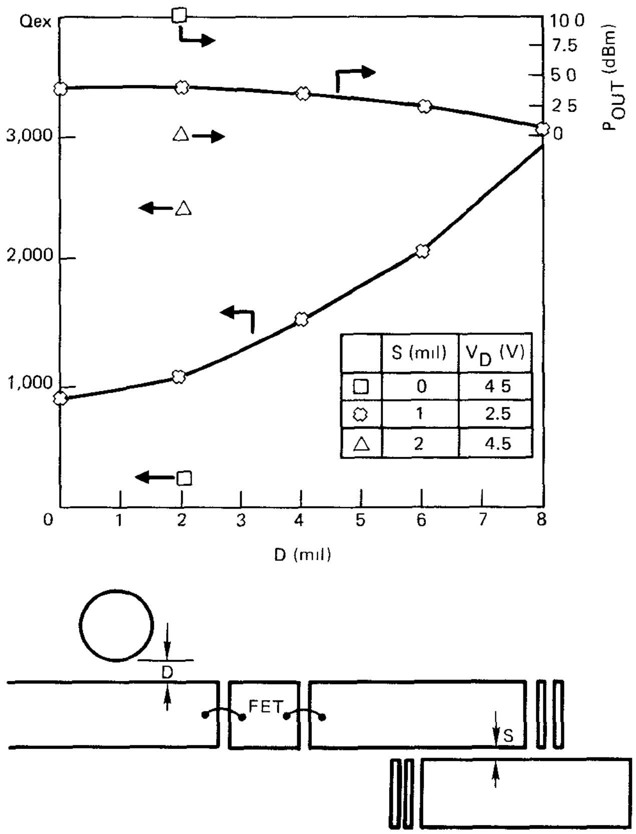

Figure 3 Oscillator Qex as a function of D and S.

The FM noise of the DRO was measured using a Ka-band delay-line discriminator measurement system (4). The measurements were done at fm = 10 kHz and 25 kHz away from the carrier. Figure 4 shows the measured oscillator FM noise and the associated output power as a function of D for the case of S = 1 mil. As D is varied from 0 to 8 mils, the Nop/C (single sideband noise-to-carrier ratio) experienced a 15 dB improvement for both fm = 10 kHz and fm = 25 kHz. The best Nop/C is achieved at D = 8 mils, where Nop/C is -78 dBc/Hz at fm = 10 kHz and is -87 dBc/Hz at fm = 25 kHz. Figure 5 shows the output spectrum for this case. The associated output power is 1 dBm.

The temperature stability of the oscillator is illustrated in Figure 6 for two different resonator positions. In the case of D = 0 mil (tight coupling), the total temperature variation over -40°C to 60°C is 8.5 MHz, which corresponds to an oscillator frequency temperature coefficient of 2.4 ppm/°C. As the resonator coupling is reduced with D = 4 mils, the total temperature variation over the same range improved to 3.5 MHz, which corresponds to a oscillator frequency temperature coefficient of 1 ppm/°C.

Ka-Band MIC Receiver Design

Using this oscillator, a compact MIC Ka-band receiver was also developed. It consists of a bandpass filter, balanced mixer, isolator and the FET DRO as the local oscillator as shown in Figure 7. A photograph of the complete receiver is shown in Figure 8. The RF signal is coupled from the waveguide input to the microstrip line with an E-field probe transition. The overall dimensions of the receiver are 1.0" x 0.75" x 1.07".

The balanced mixer employs a 3-section, 3 dB branch line coupler which was constructed on a 10 mil thick quartz substrate. To facilitate operation with low levels of LO power, silicon beam-lead diodes were used in the mixer. The mixer conversion loss was 7.0 dB with an LO drive of 2 dBm and an IF of 300 MHz. As the

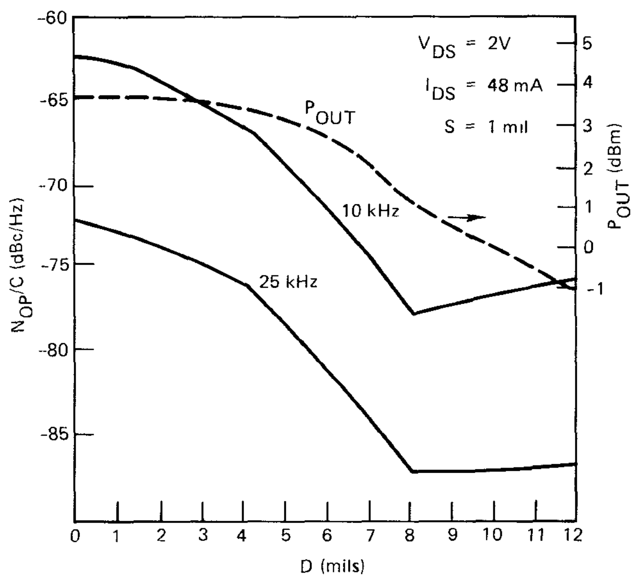

Figure 4 Oscillator Phase noise measurement as a function of D and S.

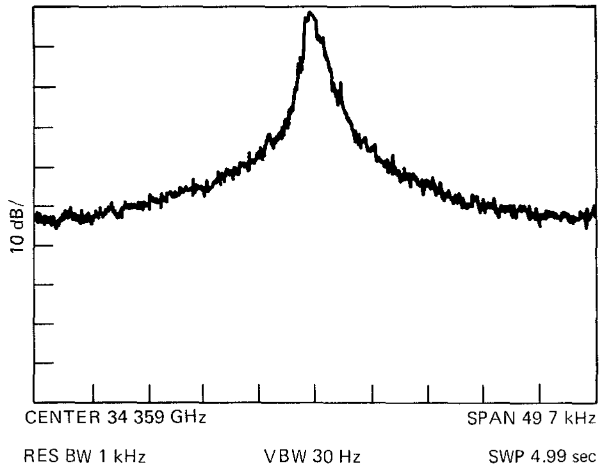

Figure 5 Oscillator output spectrum at S = 1 mil and D = 8 mils.

LO power dropped below this power level, the conversion loss increased significantly.

To minimize load-pulling effects on the oscillator, a ferrite microstrip isolator was used at the output of the oscillator in the receiver assembly. The isolator was constructed on an 8 mil thick substrate of Transtech TT-2111 material. This isolator achieved 20 dB isolation with less than 1 dB insertion loss at 35 GHz.

The complete receiver unit exhibited a conversion loss of 7.7 dB. The receiver exhibited a "clean" IF spectrum with a typical residual FM noise of approximately 2 kHz peak-to-peak on the spectrum analyzer.

CONCLUSION

A 35 GHz dielectric resonator stabilized FET oscillator was developed. The effects of the resonator placement on the oscillator's power, phase noise, Qex and temperature performance were studied. A Ka-band MIC receiver utilizing this FET DRO as the local oscillator was also developed. A silicon beam-lead diode mixer was employed in the receiver to reduce the local oscillator power requirement. This receiver is suitable for low cost applications where "crystal oscillator" stability is not required.

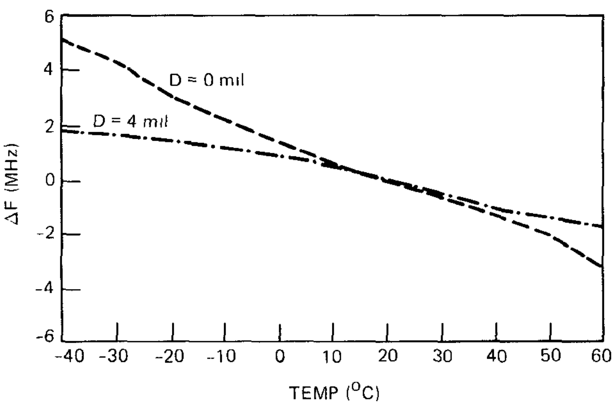

Figure 6 Oscillator temperature performance under two different resonator coupling conditions.

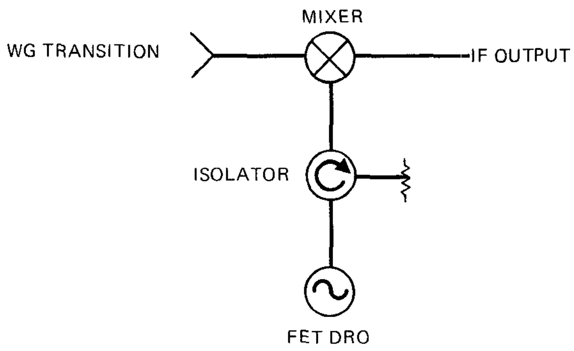

Figure 7 Millimeter-wave Receiver system diagram.

ACKNOWLEDGEMENTS

This work was performed under the joint sponsorship of Hughes Industrial Electronics Group and Missile Systems Group. The authors wish to thank T. Mazilu, T. Trinh and Y. Shih for their contributions to this development work.

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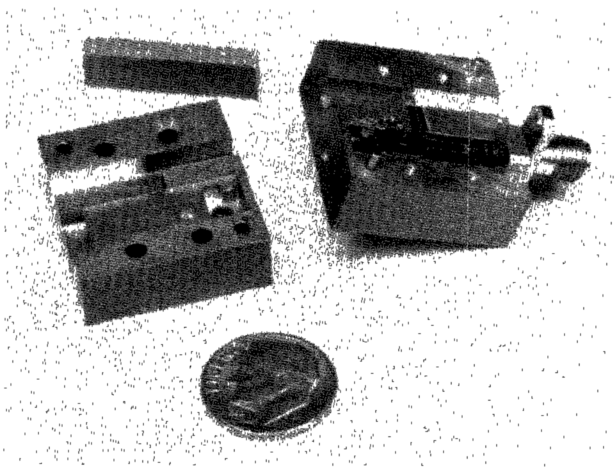

Figure 8 Photograph of 35 GHz MIC Receiver.