HIGH PERFORMANCE GaAs C-BAND AND Ku-BAND MMIC OSCILLATORS

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ABSTRACT

A number of monolithic single-ended and push-pull oscillator chips were developed for C-band and K_u-band applications. The chips were used to build dielectric resonator oscillators (DROs) and voltage controlled oscillators (VCOs) in both frequency bands. These MMICs also have integrated a buffer amplifier at the oscillator output to provide better load isolation and power output stability. The oscillators demonstrated performance similar to conventional hybrid circuitry; however, the MMIC circuits will provide circuit simplicity with improved reliability, decreased size and reduced manufacturing cost.

MMIC CIRCUIT DESCRIPTION

Previous work on monolithic VCOs has shown excellent performance over the 2-18 GHz band [1]. The oscillator chips reported in this work all consist of a negative resistance oscillator stage with an additional buffer amplifier stage on one monolithic die. Two MMIC oscillator chips will be discussed in this paper: a single-ended C-band chip and a K_u-band push-pull chip. Both chips have an identical block diagram, as shown in Figure 1. Each MMIC chip contains an oscillator, an amplifier and all associated bias circuitry.

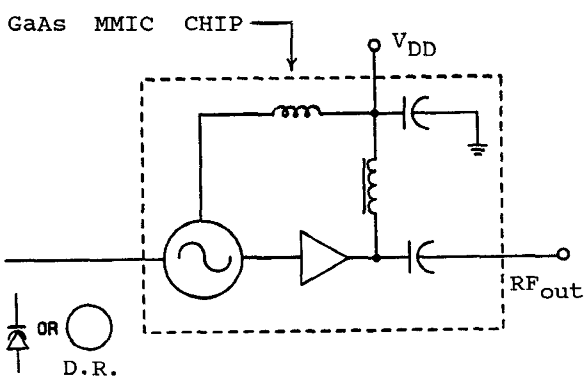

FIGURE 1. BLOCK DIAGRAM OF GaAs MMIC OSCILLATOR.

This circuit topology offers several advantages. A negative resistance oscillator can be used in several different kinds of oscillators, including DROs and VCOs. The incorporation of the buffer amplifier isolates the resonator from the load and minimizes the effects of frequency pulling. The buffer amplifier stage also operates in saturation, which provides constant output power and minimizes output power variation with temperature.

The oscillator circuits consist of a common source oscillator stage with a capacitive reactance in the source leg of the circuit. This reactance provides feedback through the internal C_{gs} of the FET to create the required negative resistance over a broad frequency range. The source capacitive feedback circuit provides negative resistance over greater than octave bandwidths.

A novel biasing scheme was used in the oscillator chips which minimizes the bias current required by the MMIC. Only 20 mA of dc current is required to supply both the oscillator and the buffer amplifier. The dc current flows in series through the two stages using this bias scheme. Each stage is also set up to act as active load for the other stage, setting the dc voltage and current bias levels for each stage. With an 8 Vdc bias, the C-band oscillator provides +13 dBm of RF output power while drawing only 19 mAdc bias.

The amplifier stage is a conventional common source amplifier stage. Some feedback was added from the drain to the gate of the amplifier to improve the output VSWR over the required bandwidth. The amount of feedback was kept to a minimum to keep the saturated output power of the amplifier as high as possible.

The saturated output power of the amplifier is fairly constant over temperature, which keeps the oscillator's output power within ±1 dB over the -54 to +85°C temperature range, in most cases. The reverse isolation to the resonator was measured at -25 to -30 dB for these chips, which provides the excellent frequency pulling

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figures for the final oscillators. Although the buffer stage is operating in saturation, the second harmonic levels for the oscillators are still maintained below -20 dBc.

The MMIC was designed for maximum yields. Only high-yield components such as implanted FETs, implanted resistors and small MIM capacitors were used. The implanted FETs have 0.5 um gate lengths. The metalization is in two layers with a first metal layer and an airbridge metalization layer above the first metal. The circuit completely avoided the use of yield degrading elements such as via holes. The size of the MMIC die was kept to a minimum to maximize the number of die produced on a wafer. The C-band circuit measured 0.9 X 0.9 mm, while the K_u-band circuit measured 1.2 X 1.2 mm. With these die sizes, between 3000 and 5000 die are produced on a 3 inch wafer.

Because the use of via holes was avoided, the K_u-band oscillator chip was designed using a balanced or push-pull configuration. In this configuration, the circuit is duplicated in a "mirror image." Each side of the circuit operates 180° out of phase with respect to the other side of the circuit, so a virtual ground is formed along the center line of the circuit. The signals at the outputs are combined through a balun for interface to an unbalanced output transmission line. The virtual ground forms the needed RF ground and eliminates the need to use via holes to form good RF grounds in the center of the die. This is especially important at higher frequencies such as K_u-band, where minimum inductance to ground is required for maximum gain and maximum bandwidth. Because this problem is not as critical at C-band, a conventional single-ended scheme without via holes was used on the C-band chip.

The resonator element is the only element required externally to the MMIC to form an oscillator. The non-integration of the resonator provides flexibility in the application of the chip. Very high-Q external resonator elements can be used with the MMIC, such as dielectric resonators in DROs or varactor diodes in VCOs. These elements are connected to the negative resistance terminal of the MMIC in such a way that RF power is reflected back to the MMIC at resonance.

C-BAND OSCILLATORS

The C-band oscillator chip used a single-ended design scheme for both the oscillator and amplifier. Figure 2 is a photograph of the C-band MMIC die. This chip was used to build both a VCO and a DRO.

The VCO was realized by connecting a varactor diode to the negative resistance pad of the MMIC. A series resonant circuit was formed between the bond wire

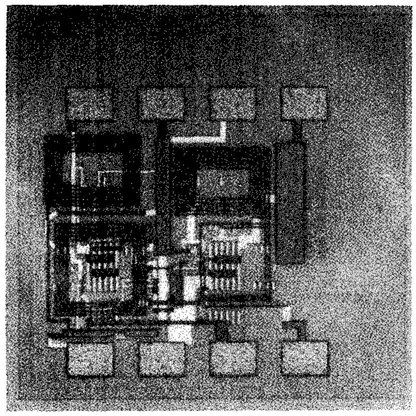

FIGURE 2. PHOTOGRAPH OF C-BAND MMIC OSCILLATOR DIE.

inductor and the varactor. A hybrid circuit was formed using MIC techniques to assemble and package the VCO. Figure 3 is a photograph of the VCO in a transistor package.

The VCO tunes from 4.2 to 5.5 GHz with 0 to 25 V of tuning voltage. The output power is +13.5 dBm with ±0.5 dB flatness over the tuning range, with the second harmonic below -25 dBc. The dc bias requirement is +8 Vdc at 19 mAdc. Figure 4 presents the tuning and power curve for the oscillator.

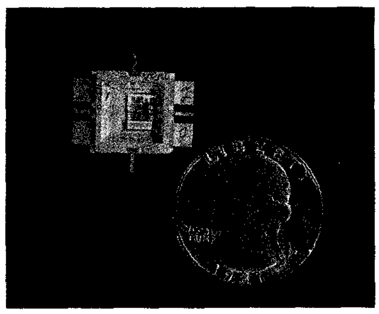

FIGURE 3. C-BAND VCO IN TRANSISTOR HOUSING.

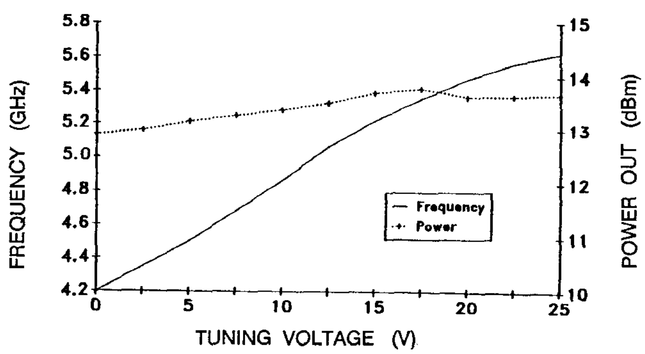

FIGURE 4. VCO TUNING CURVE.

A 5 GHz DRO was also built using a packaged MMIC chip. This DRO was built with the MMIC in a hermetic package assembled on a soft board substrate [2]. A photograph of the DRO is shown in Figure 5. The size of the final oscillator is determined by the size of the dielectric resonator; however, some size reduction is realized for the final oscillator because the buffer amplifier is incorporated in the MMIC die, eliminating the space required for a hybrid amplifier with discrete oscillator approach.

The DRO shows exceptional RF performance with good spectral purity. The electrical performance of the DRO is summarized in Table I. The low phase noise level is obtained because the high level of negative resistance allows the dielectric resonator to be decoupled from the microstrip coupling line, maximizing the loaded Q of the resonator [3]. A plot of SSB phase noise of the oscillator is shown in Figure 6. The frequency pulling data is also excellent, due to the high reverse isolation provided by the buffer amplifier and the oscillator, as well as the high loaded Q of the decoupled resonator.

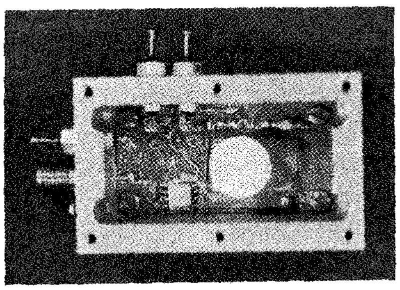

FIGURE 5. C-BAND DRO IN HOUSING.

Voltage-tuned DROs were also built using the MMIC and similar construction by coupling a varactor diode to the dielectric resonator [4]. These oscillators are tunable by 12 MHz with a 0 to 10 V varactor voltage. More voltage tuning is available by coupling the varactor more tightly to the resonator, but SSB phase noise will be degraded with tighter coupling.

K_u-BAND OSCILLATORS

A separate MMIC oscillator was developed for operation at K_u-band frequencies. This chip uses a balanced design scheme for both the oscillator and the amplifier and shows negative resistance over the 12 to 18 GHz frequency band, with input return loss measured at +4 dB. A photograph of the MMIC is shown in Figure 7. This chip measures 1.2 X 1.2 mm and uses 0.5 um gate length FETs.

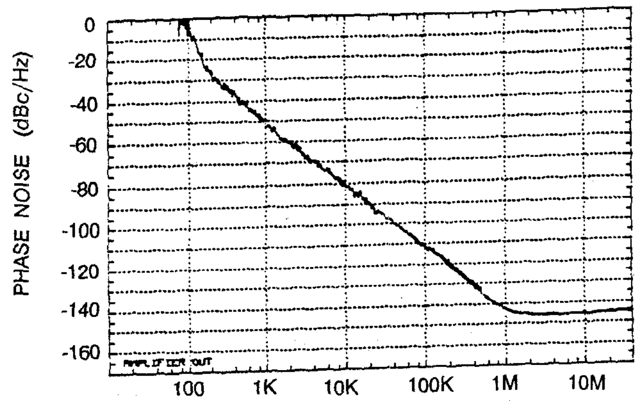

FIGURE 6. C-BAND DRO PHASE NOISE.

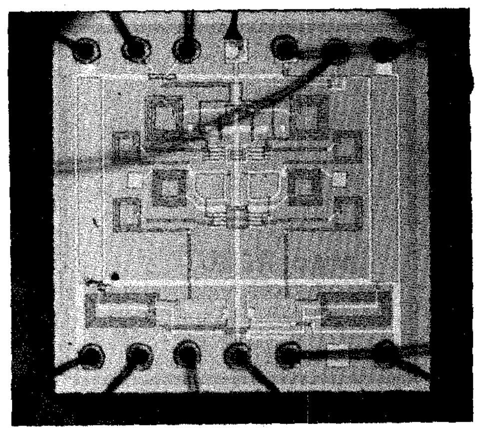

FIGURE 7. K_u-BAND MMIC OSCILLATOR CHIP.

A DRO operating at 13 GHz was built using this MMIC. The oscillator was assembled using MIC techniques with alumina microstrip transmission lines coupling into the dielectric resonator [5]. A photograph of the K_u-band DRO is shown in Figure 8. The microstrip lines couple into the dielectric resonator on opposite edges to produce the required 180° phase difference between each leg of the push-pull circuit. The resonator is suspended on a forsterite dielectric standoff to lift the resonator off the ground plane and improve the loaded Q of the resonator.

The K_u-band DRO demonstrates good RF performance with the same desirable pulling figures as were present with the C-band oscillators. A summary of the electrical performance of the K_u-band DRO is also given in Table I. The output power variation with temperature is very low for this circuit. This is due to the buffer amplifier operating deeply into saturation and the bias scheme which provides constant current through the GaAs FETs in the MMIC.

The K_u-band DRO has good SSB noise performance, with the output spectrum shown in Figure 9. The oscillator shows slightly degraded loaded Q from the results at C-band. This is due to the increase in frequency and the additional loss introduced from coupling two microstrip lines into the resonator.

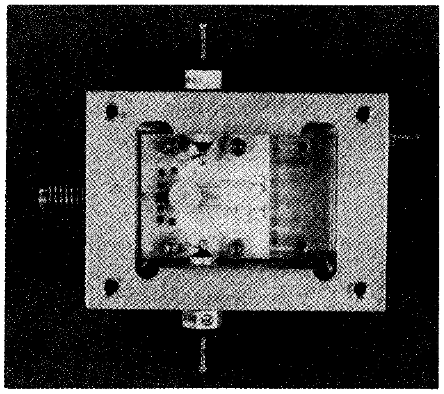

FIGURE 8. K_u-BAND DRO IN HOUSING.

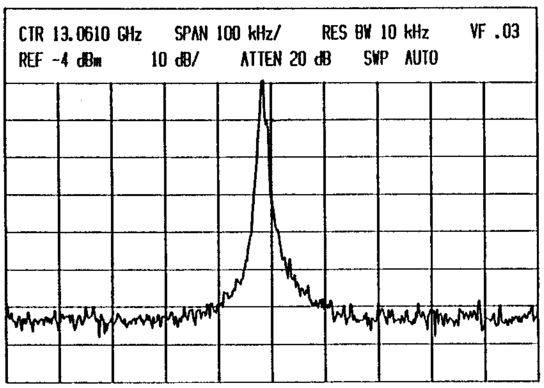

FIGURE 9. K_u-BAND DRO OUTPUT SPECTRUM.

SUMMARY

GaAs MMIC technology has been demonstrated to be valuable in several microwave source applications. With MMIC oscillators designed for versatility, one die can be used to meet several applications. The small die size allows maximum flexibility in packaging. The MMICs can be assembled in hermetic packages as small as standard transistor packages or placed directly into hybrid MIC circuits.

The integration of a buffer amplifier in addition to a basic oscillator enhances the overall performance of the oscillator. The amplifier minimizes frequency pulling and output power variation. When used in oscillator subsystems, monolithic circuits can provide several other advantages over discrete components, including reduced cost, less assembly time, higher level of system integration and improved reliability.

	Frequency Band		
Parameter	C-band	Ku-band	Units
Frequency	5.027	13.120	GHz
Output Power	+12	+10	dBm
SSB Phase Noise:			
100 kHz	-115	-100	dBc/Hz
10 kHz	-88	-70	dBc/Hz
Frequency Pulling	.02	.001	% (3:1 VSWR)
Bias Voltage	8	11	Volts
Bias Current	19	35	mA
Stability measured from -54 to +85 °C			
Freq Stability	+2	+5	ppm/°C
Power Stability	±0.75	±0.5	dB

TABLE I. DRO PERFORMANCE SUMMARY.

ACKNOWLEDGEMENTS

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REFERENCES

[1] B. N. Scott et al., "A Family of Four Monolithic VCO MIC's Covering 2-18 GHz," 1984 *IEEE Monolithic Circuits Symposium Digest*, pp. 58-61.

[2] H. Abe, Y. Takayama, A. Higashisaka, and H. Takayama, "A Highly Stabilized Low-noise GaAs FET Integrated Oscillator with a Dielectric Resonator in the C-band," *IEEE Trans. Microwave Theory Tech., Vol. MTT-26*, Mar. 1978, pp. 156-62.

[3] D. Kajfez, "Incremental Frequency Rule for Computing the Q-Factor of a Shielded TE_{omp} Dielectric Resonator," *IEEE Trans. Microwave Theory Tech. (Correspondence), Vol. MTT-32*, Aug. 1984, pp. 941-43.

[4] K. Lee and W. Day, "Varactor Tuned Dielectric Resonator GaAs FET Oscillator in X-band," 1982 *IEEE MTT-S Dig.*, pp. 274-76.

[5] O. Ishihara, T. Mori, H. Sawano, and M. Nakatani, "A Highly Stabilized GaAs FET Oscillator Using a Dielectric Resonator Feedback Circuit in 9-14 GHz," *IEEE Trans. Microwave Theory Tech., Vol. MTT-28*, Aug. 1980, pp. 817-24.