A 20–40-GHz Push–Push Dielectric Resonator Oscillator

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Abstract —A novel coupling method is employed in the design of a push–push broad-band dielectric resonator oscillator for K- and Ka-band operation. The oscillators realized with this technique exhibit excellent spectral purity, power output, and suppression of spurious outputs.

I. Introduction

DURING THE PAST several years, a variety of microwave components which employ dielectric resonators have been developed due to the availability of low-cost, temperature-stable, high-permittivity materials. These materials are available from several manufacturers with a variety of dielectric constants and temperature coefficients. Their use maximizes the performance-to-size ratio for many filters and oscillators, thus enabling low-cost and manufacturable components to be realized [1], [2]. Hence, they become a logical choice for many fixed-frequency receiver/transmitter local oscillator applications.

Dielectric resonator oscillators can generally be classified as being either reflection or feedback oscillators. The reflection type of oscillator, which couples a dielectric resonator to the output circuit one-half wavelength away from the FET, exhibits significantly improved FM noise performance and frequency stability over that of a conventional oscillator. Reflection oscillators, however, do not achieve the low FM noise performance and high stability characteristic of feedback DRO's since optimum loaded circuit Q is not obtained. This condition exists because the gate/source circuit which dominates the frequency stability characteristics is constructed using low Q elements and is not strongly influenced by the presence of the resonator at the device output.

Shunt feedback oscillators, which couple the dielectric resonator between the gate and source or gate and drain circuits, exhibit excellent performance. However, an adequate model needed for analysis does not exist, limiting oscillator design largely to an empirical approach.

An alternative circuit which yields high stability and low FM noise is the series feedback oscillator (Fig. 1). The circuit consists of a high-gain, low-noise FET, a terminated 50-Ω microstrip transmission line connected to the FET gate, a coupled dielectric resonator, a shunt reactance connected to the FET source, and an impedance transformer (transmission line) connected to the drain port.

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Critical to the performance of this circuit is the placement of the dielectric resonator on the gate port of the FET where it is isolated from the output through the very low drain-to-gate capacitance inherent in the device. This isolation minimizes interaction between the oscillator output and input circuit, resulting in very high loaded circuit Q's.

However, at frequencies above 20 GHz, it is nearly impossible to effectively manufacture accurate, high-Q resonators. Physical handling is also a major problem since a 20-GHz resonator is in the order of 1 mm in diameter. At Ka-band frequencies, additional design problems arise, since the gain of even the best FET's currently available is marginal at frequencies between 26 and 40 GHz, resonator coupling would need to be excessive, thus destroying the inherent Q and spectral purity of the oscillator.

The above-mentioned drawbacks of a fundamental operation DRO at Ka-band frequencies can be eliminated by employing the following push–push oscillator design method. If the resonator is designed to operate at one half the desired operating frequency (10 to 20 GHz), the Q will be high and the resonator will be easy to manufacture and couple to the FET oscillator circuit. Several circuit conditions must still be met so that ample second-harmonic energy can be obtained.

II. Design Approach

Exceptional spectral purity can be obtained at the fundamental frequency by using a series feedback design approach [3]. The oscillator design begins by modeling the resonator coupling coefficient, loaded Q, and resonant frequency. There are various ways of modeling a dielectric resonator coupled to a microstrip transmission line. An accurate representation is to model the dielectric resonator as a parallel RLC network coupled to the transmission line through an ideal transformer (Fig. 2), as presented by Komatsu and Murakami [4]. Determination of the exact circuit parameters can be made using the existing theory, although this may be somewhat tedious. An alternative (and more straightforward) method of calculating these values (R, L, C, N) is to fit the calculated circuit performance to a set of measured data obtained from a dielectric resonator band-reject structure. It is important to point out that the coupling degenerates to a pure resistance at the resonant frequency; therefore, it is sufficient to model the

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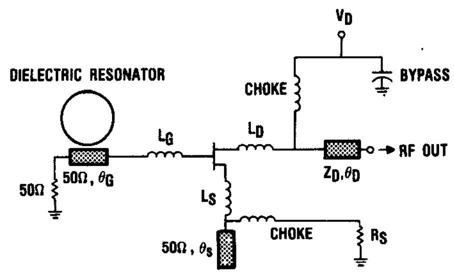

Fig. 1. Series feedback dielectric resonator FET oscillator.

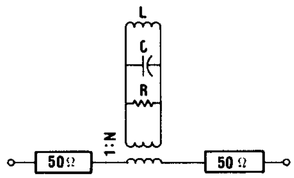

Fig. 2. Coupled resonator model.

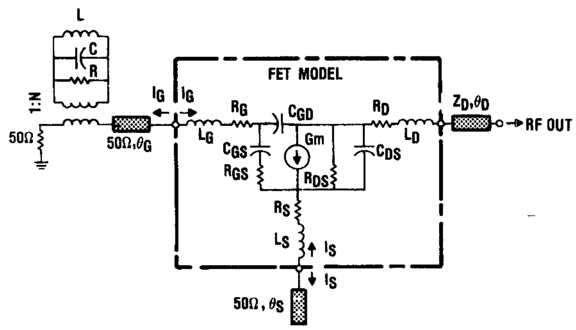

Fig. 3. Complete oscillator model.

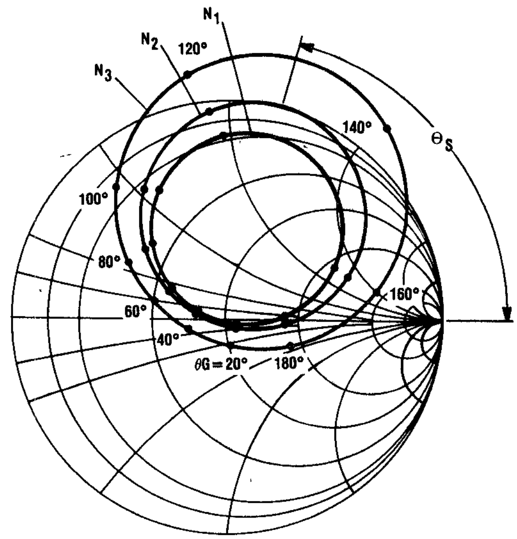

Fig. 4. Reflection coefficient, referenced from the FET source, as a function of resonator position (θ_G) and coupling (N).

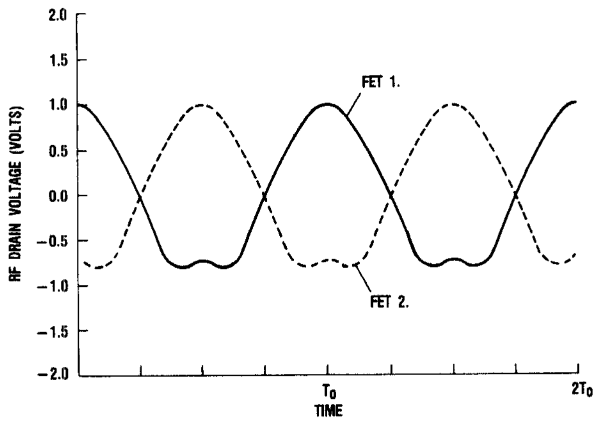

Fig. 5. Voltage waveform at each FET drain of push–push oscillator.

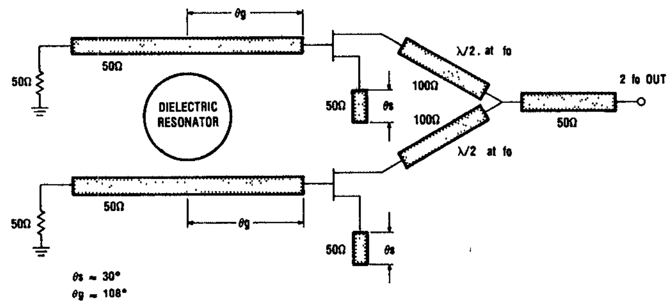

Fig. 6. Simplified push–push oscillator model.

coupling as a simple resistor when the analysis is conducted at the design center frequency.

The resonator, however, appears resistive at several frequencies since more than one mode is possible in the right circular cylindrical structure. The separation between higher order modes can be maximized by properly choosing the height-to-diameter ratio of the resonator. The Q and package size are also affected by this ratio. It should be noted that hybrid and higher order modes can also be excited with a similar coupling structure; therefore, the oscillator circuit must be designed to prevent oscillation at undesired frequencies.

The resonator dimensions were calculated using a computer solution based on the transverse resonance method [5], [6]. This solution predicts the resonant frequency of the $TE_{01\delta}$ mode to within 3 percent of the measured frequency. An accepted design procedure calls for the resonator thickness-to-diameter ratio to be between 0.3 and 0.5 to ensure that the $TE_{01\delta}$ mode is dominant.

The FET representation, which is a large-signal numerical model derived from a combination of nonlinear modeling at the 1-dB compression point, S-parameter measurements, and pulsed $I-V$ device characterization, must now be combined with the resonator equivalent circuit to form the complete oscillator model (Fig. 3). The design procedure now begins by mapping all circuit loads present on the gate port into the source port by varying the location and relative coupling of the dielectric resonator. The resonator position and coupling value are chosen for a reflection coefficient of unity (magnitude) referenced to the source. Then the proper amount of shunt reactance is added to conjugately match the source. These effects, as seen from the source of the FET, are illustrated in Fig. 4. All relevant circuit parameters are then optimized to obtain

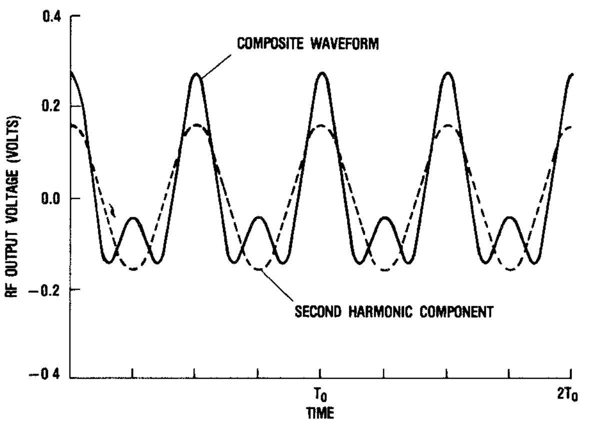

Fig. 7. Composite voltage waveform obtained by summing voltage at each FET drain.

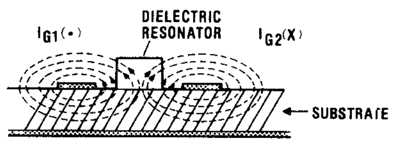

Fig. 8. Resonator coupling depicting opposite induced gate currents.

a maximum reflection coefficient at the drain for the desired frequency of operation.

The push–push approach can now begin by designing a single FET oscillator, as illustrated above, for operation at one half the desired output frequency. However, only the gate and source networks are obtained for the fundamental frequency design, since the output network must be optimized for maximum power output at the second harmonic of the resonator frequency. The output network was optimized with the aid of a nonlinear FET computer model [7]. This nonlinear model was also used to determine the optimum bias point for the FET which maximizes the second harmonic content in the oscillator's output waveform. A sample voltage waveform, which was calculated using nonlinear analysis, is shown in Fig. 5.

The fundamental energy of the push–push oscillator at the output must also be minimized. Several common methods can be employed, such as balancing the drain circuit between the two oscillator FET's or forcing the oscillator FET's to operate in an antiphasel mode.

Broad-band planar baluns exhibit poor amplitude and phase tracking at *K*-band frequencies, and suspended structures are difficult to integrate with other planar components. Thus, it is convenient to combine the outputs directly, using ordinary microstrip techniques, and operate the oscillators in an antiphasel mode. By using the circuit configuration of Fig. 6, a push–push oscillator was constructed. Key to its performance is the method of coupling used between the resonator and oscillator FET's. Since the gate circuits of each FET are on opposite sides of the resonator, the currents coupled at each gate will be exactly antiphasel (Fig. 7). Under these conditions, each oscillator FET is phase locked to the other, with their second-harmonic energy being in phase at the output of the

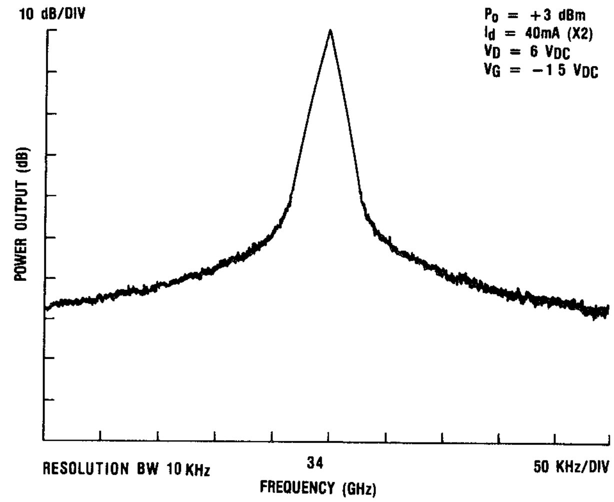

Fig. 9. Typical oscillator spectral performance.

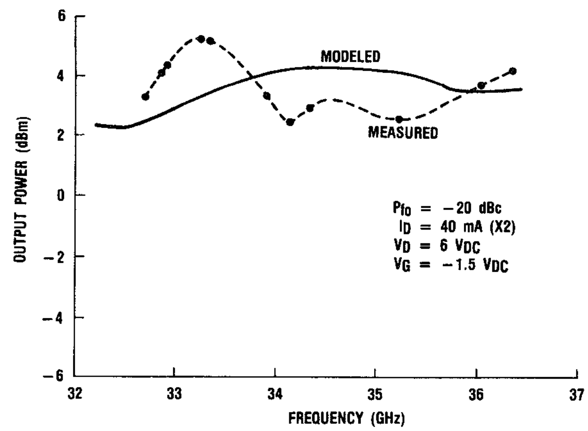

Fig. 10. Power output as a function of frequency.

oscillator. This mode of operation is very broadband and fails only when the resonator becomes too small to couple effectively to each gate circuit simultaneously.

In order to illustrate this technique, the voltage waveforms present at each FET drain which differ by 180° in phase (Fig. 5) can be algebraically summed. This composite waveform, which is shown in Fig. 8, has a strong second-harmonic content.

III. Measured Results

A typical spectral performance of the oscillator is shown in Fig. 9. The output frequency is approximately 34 GHz (midband) and the FM (SSB) noise level is a very respect able −99.8 dBc/Hz, measured at an offset frequency of 100 kHz. A typical DRO operating at 17 GHz would exhibit an FM noise level of approximately −110 dBc/Hz at the same offset frequency. Thus, this small difference can easily be explained by coupling and cavity variations as well as the nominal 6-dB degradation due to second-harmonic operation. The power output as a function of frequency, using a selection of resonators, is shown in Fig. 10. The power output corresponds quite well with the predicted performance obtained with the nonlinear FET

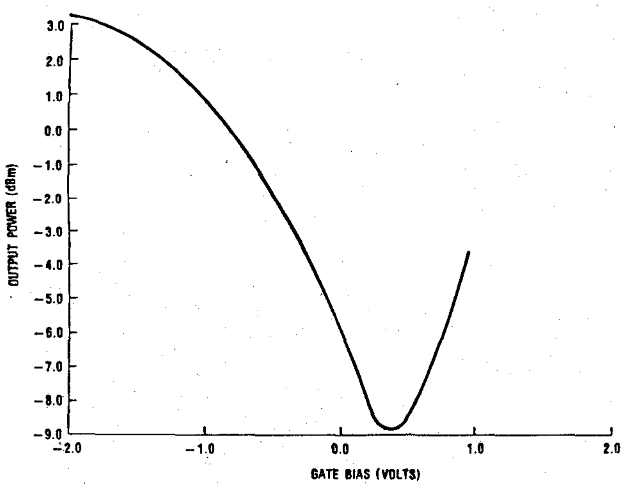

Fig. 11. Power output as a function of gate bias.

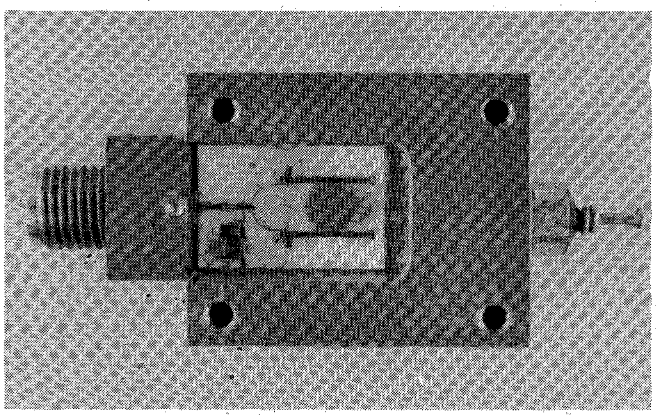

Fig. 12. Dielectric resonator push–push oscillator in test fixture.

computer model. It should be noted that the fundamental frequency is adequately suppressed by the circuit balance and is typically less than -10 dBm. This is equivalent to ~ 20 dB of suppression since the nominal power output of a 10–20-GHz DRO is approximately 15 dBm. The effect of gate bias versus power output is illustrated in Fig. 11. As expected, the second-harmonic energy is maximized when the FET is biased near pinchoff or forward conduction. The completed oscillator is shown in Fig. 12.

IV. Conclusion

By using the above design techniques, fixed-frequency dielectric resonator stabilized oscillators can easily be fabricated and reproduced for use as primary signal sources in the 20–40-GHz frequency range. Their performance compares favorably with fundamental oscillators operating in the 10–20-GHz frequency range. Monolithic push–push oscillators can also be realized using this technique.

References

[1] H. Abe, Y. Takayama, A. Higashisaka, and H. Takamizawa, "Highly stabilized low-noise GaAs FET integrated oscillator with a dielectric resonator in the *C*-band," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, pp. 156–162, Mar. 1978.

[2] A. P. S. Khanna, J. Obregan, and Y. Garault, "Efficient low-noise three port *X*-band FET oscillator using two dielectric resonators," in *1982 MTT-S Int. Microwave Symp. Dig.*, pp. 277–279.

[3] Kevin J. Anderson and A. M. Pavio, "FET oscillators still require modeling, but computer techniques simplify the task," *Microwave Systems News*, vol. 13, no. 9, pp. 60–66, Sept. 1983.

[4] Y. Komatsu and Y. Murakami, "Coupling coefficient between microstrip line and dielectric resonator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 34–40, Jan. 1983.

[5] T. Itoh and R. S. Rudokas, "New method for computing the resonant frequencies of dielectric resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, pp. 52–54, Jan. 1977.

[6] M. Dydyk, "Dielectric resonators add *Q* to MIC filters," *Microwaves*, vol. 16, pp. 150–160, Dec. 1977.

[7] D. L. Peterson, A. M. Pavio, and B. Kim, "A GaAs FET model for large-signal applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-32, pp. 276–281, Mar. 1984.

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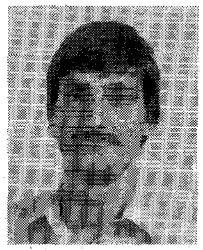

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