PUSH-PUSH DIELECTRIC RESONATOR OSCILLATOR

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ABSTRACT

A novel coupling method is employed in the design of a push-push broadband 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.

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 perform-ance-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 fre-quency 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.
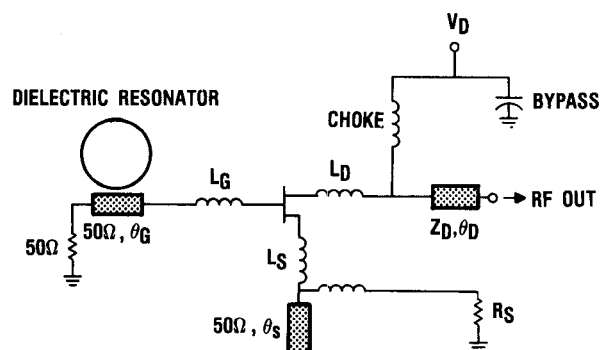

Figure 1   Series feedback dielectric resonator FET oscillator.

An alternative circuit which yields high stability and low FM noise is the series feedback oscillator (Figure 1). The circuit consists of a high gain, low-noise FET, a terminated 50 Ohm 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.

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. A completely different set of difficulties arise during the design of a Ka-band DRO. Since the gain of even the best FET's currently available is marginal at fre-quencies 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 fre-quencies 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

band and fails only when the resonator becomes too small to couple effectively to each gate circuit simultaneously.
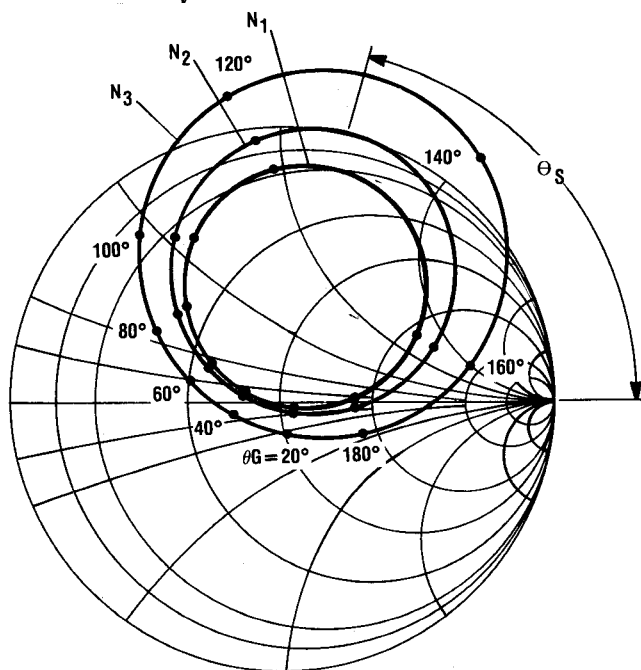

Figure 4   Reflection coefficient, referenced from the FET source, as a function of resonator position (θ_G) and coupling (N).
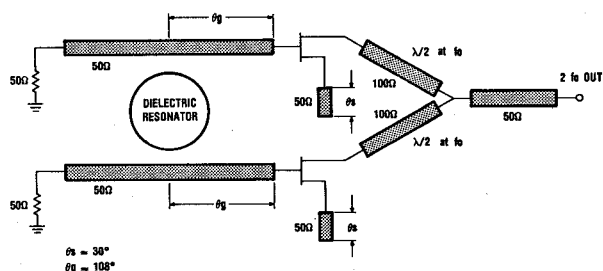

Figure 5   Simplified push-push oscillator model.
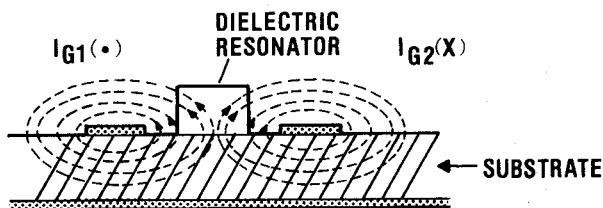

Figure 6   Resonator coupling depicting opposite induced gate currents.
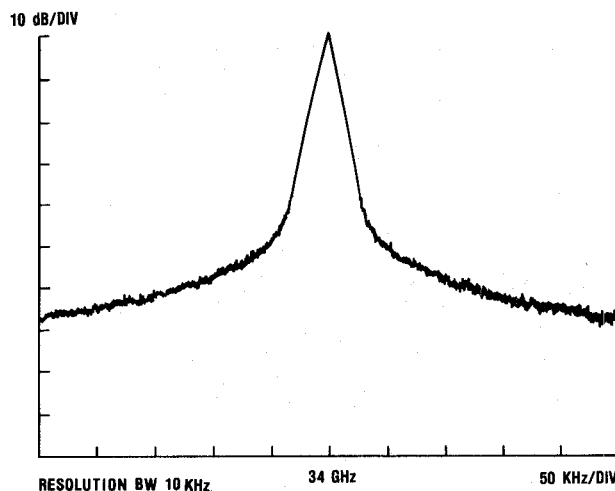

Figure 7   Typical oscillator spectral performance.

MEASURED RESULTS

A typical spectral performance of the oscillator is shown in Figure 7. The output frequency is approximately 34 GHz (mid-band) and the FM (ssb) noise level is a very respectable -99.8 dBc/Hz, measured at an offset frequency of 100 kHz. The power output as a function of frequency, using a selection of resonators, is shown in Figure 8. The power output corresponds quite well with the predicted performance obtained with the nonlinear FET computer model. The effect of gate bias versus power output is illustrated in Figure 9. As expected the second harmonic energy is maximized when the FET is biased near pinch-off or forward conduction. The completed oscillator is shown in Figure 10.
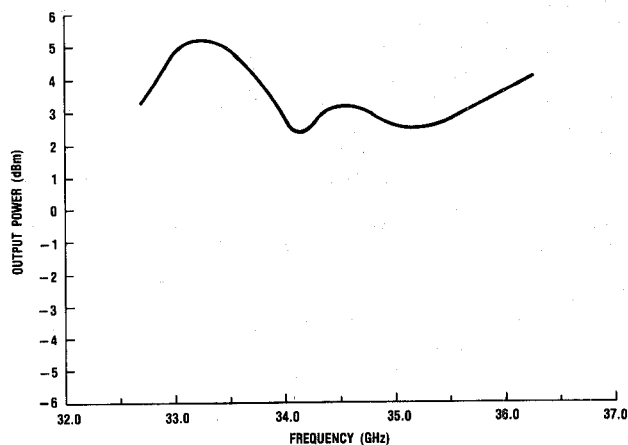

Figure 8   Power output as a function of frequency.

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.

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 (Figure 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 meas-ured 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 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 (Figure 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 Figure 4. All relevant circuit parameters are then optimized to obtain a
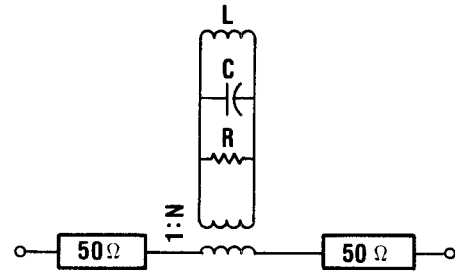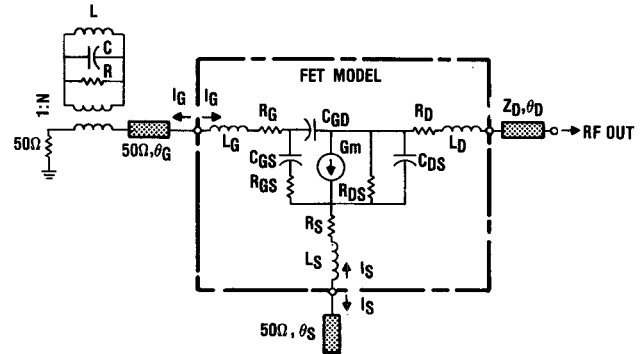

Figure 2   Coupled resonator model.

Figure 3   Complete oscillator model.

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 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 non-linear 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. 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.

Broadband 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 Figure 5, 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 at each gate will be coupled and exactly antiphasel (Figure 6). 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 oscillator. This mode of operation is very broad-
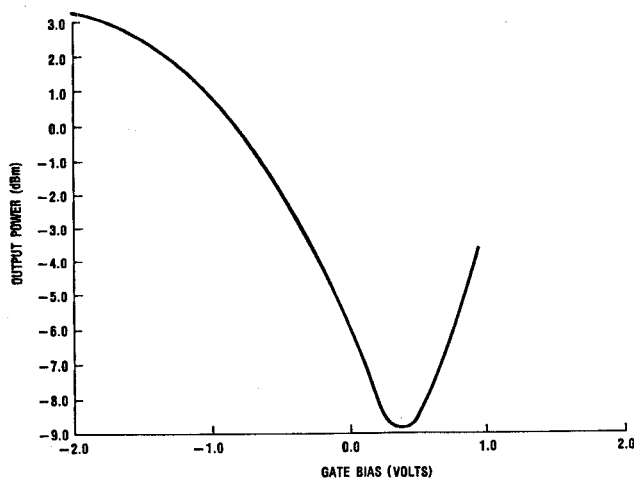
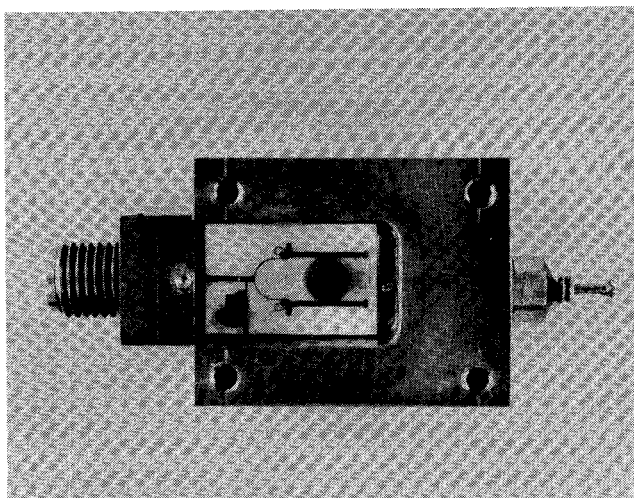Figure 9   Power output as a function of gate bias.

Figure 10   Dielectric resonator push-push oscillator in test fixture.

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 to 40 GHz frequency range. Their performance compares favorably with fundamental oscillators operating in the 10 to 20 GHz frequency range. Monolithic push-push oscillators can also be realized using this technique.

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