A Single-Chip Coplanar 0.8-μm GaAs MESFET *K*/*Ka*-Band DRO

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***Abstract*—This letter describes the design and measured results of a monolithic coplanar (CP) transmission line-based GaAs MESFET dielectric resonator oscillator (DRO) for K/Ka-band applications. The dielectric resonator (DR) is on chip. The measured output power was 11 dBm at 26.17 GHz for a conversion efficiency of 5.5%. The chip probed phase noise was −118.7 dBc at 1 MHz off carrier. This represents the first reported instance of a DRO being fabricated using a CP transmission line topology.**

***Index Terms*—Microwave oscillators, millimeter-wave oscillator, MMIC.**

I. Introduction

RECENTLY, there has been much interest in providing broad-band wireless access to fixed networks via millimeter-wave radio transmission in the frequency band 27.5–29.5 GHz. Local multipoint distribution service (LMDS) could be used to provide wireless access to services ranging from one-way video distribution and telephony to fully interactive switched broad-band multimedia applications. Oscillators are an important component of such microwave communications systems. With the increase in system operating frequency, as well as cost and mobility concerns, there has been a need for better performing oscillators with an emphasis on low noise, small size, low cost, and high efficiency. Dielectric resonators (DR's), due to their high Q and small size, have long been used as the frequency determining element in MIC transistor oscillators, also known as dielectric resonator oscillators (DRO's). Many different configurations of DRO's have been reported, all using a form of series or parallel feedback to induce the negative resistance condition required for oscillation [1]. Reference [2] provides a review of the different active elements used in microstrip DRO circuits. Most recently, hybrid InP/InGaAs HBT DRO's operating in the 24–27-GHz range were reported [3]. In fact, with the advent of suitable high frequency materials, DRO oscillators up to 81 GHz were reported [4].

The DR can resonate in a number of modes and frequencies depending on the material, dimensions, enclosure proximity, and shape. In microstrip media, cylindrically shaped DR's are most often used, and are designed to operate in the $TE_{01\delta}$ mode [5]. This allows the magnetic fields of the resonator to couple into the fringing magnetic fields of the microstrip line.

Coplanar (CP) transmission line structures have recently been gaining popularity as an alternative to microstrip lines for high-frequency applications. CP lines eliminate the requirement for vias to the ground plane, and they have two degrees of freedom in the selection of the transmission line dimensions in order to achieve a desired impedance. However, as of yet, DRO's have not been fabricated based on a CP transmission line topology. So far, all DRO's cited in the open literature have utilized microstrip transmission lines.

This letter describes the design and measured results of a monolithic coplanar waveguide transmission line-based series feedback GaAs MESFET DRO for K/Ka-band applications. The letter outlines the design process, gives experimental results, and then provides a brief comparison to other DRO technologies. As far as we know, this represents the first reported DRO being fabricated using a CP transmission line structure.

II. Oscillator Design

The active device utilized in this circuit was an 0.8-μm gate length GaAs MESFET with a gate width of 280 μm. As the common-source configuration has a f_T of only ≅ 20 GHz and a f_{MAX} of 35 GHz, therefore the common-gate configuration with an $f_{\mathrm{MAX}} \cong 60$ GHz was employed. In this letter, the DR was used as a series feedback and frequency determining element. The series feedback configuration was used due to the requirement to couple to only a single transmission line as compared to the necessity to couple to two lines in a parallel feedback case [6].

The design was performed on HP Eesof™ Libra™ series IV simulation software in the oscillator test bench. A transistor used as an oscillator can be represented as a two-port negative resistance [6]. A schematic diagram of the circuit is shown in Fig. 1, and a photograph of the actual circuit is shown in Fig. 2. Z_L represents the matching at the source of the FET, and Z_T represents the DR placed a certain transmission line length away from the transistor. Capacitive feedback between the source and the drain was utilized to ensure that the FET was potentially unstable ($C_{FB} = 0.08$ pF). To start the oscillation, the impedance of the DR (Z_T) was selected to be in the unstable region of the terminating stability circle. This was achieved by placing an undercoupled DR [5], a specific transmission line length away from the terminating port. The lateral distance and vertical height between the DR and the

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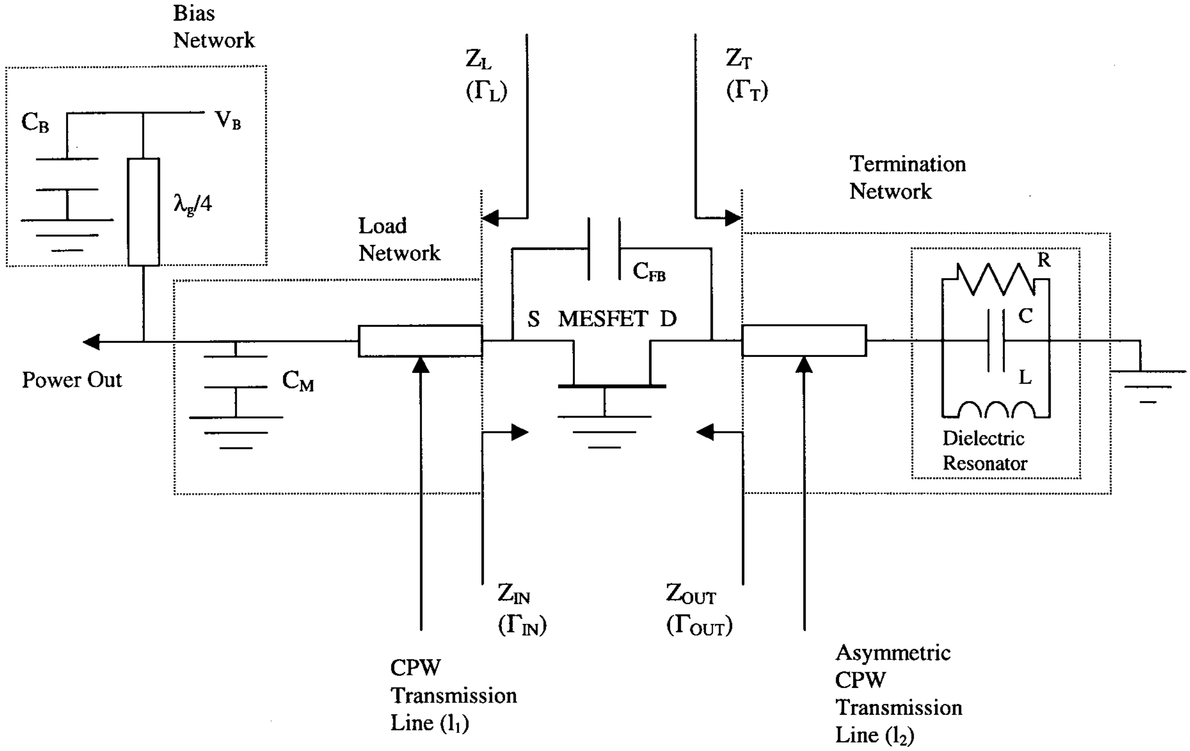

Fig. 1. Circuit block diagram.

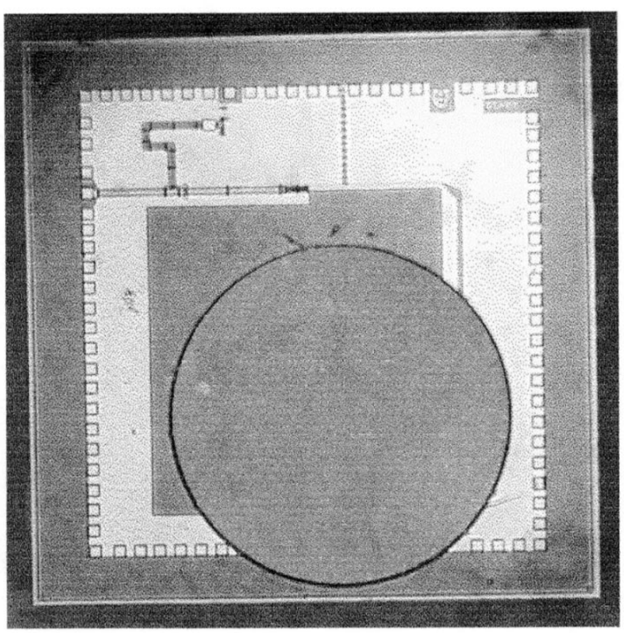

Fig. 2. Photograph of DRO circuit.

transmission line controls the amount of coupling ($|\Gamma_T|$). For the $TE_{01\delta}$ mode, a reflection coefficient approximately equal to 0.8 was obtained at the resonant frequency of the DR when it was placed laterally close to the line, and on top of the passivation layer. Γ_{IN} along with Z_{IN} were then determined from (1), where the S parameters represent the active device

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_T}{1 - S_{22}\Gamma_T}. \quad (1)$$

The DR was modeled as a simple RLC circuit with an unloaded $Q \cong 13\,070$. The cylindrically shaped DR ($\varepsilon_r = 30$) was supplied by Trans-Tech, and had a $f_O \cong 26.5$ GHz (when mounted on a 320-μm glass substrate). Z_L was chosen to meet the oscillation condition [6] given by

$$Z_L = \frac{-R_{IN}}{3} - X_{IN}. \quad (2)$$

It has been shown that when either of the ports are made to oscillate, the other port is also oscillating [6]. In order to keep the design physically compact; Z_L was implemented by a lumped capacitance placed the required transmission line length away from the (Γ_{in}) port of the transistor. The biasing network was realized with a quarter-wavelength 75-Ω coplanar waveguide (CPW) line and a bias capacitor to ground.

It was found that adequate coupling could not be achieved between a CPW transmission line and the DR due to the small fringing fields in the transmission line slots, and that the $TE_{01\delta}$ mode of the DR could not be coupled into with the DR resting on a ground plane. As a result, an asymmetrical coplanar transmission line configuration was used on the termination port of the amplifier. This transmission line type has fringing fields similar to a microstrip line, and in addition allows the DR to sit on the passivation layer of the GaAs substrate rather than on a ground plane. This modification allows for adequate coupling between the magnetic fields of the transmission line and the magnetic fields of the adjacent DR.

III. Experimental Results

The measurements were taken with a bias voltage of 3.5 V and a current of 66 mA, the output power after calibration

TABLE I
COMPARISON OF PERFORMANCE OF DRO'S WITH DIFFERENT ACTIVE ELEMENTS

DRO Transistor	Technology	Frequency (GHz)	RF Power (mW)	Efficiency (%)	N/C$_{fm}$ (dBc/Hz)	Ref
GaAs MESFET 0.25 X 120 um gate	monolithic	23	16	7	-100 @100 KHz	[2]
Si/SiGe HBT 1 X 20 um emitter	hybrid	23.2	7	11.4	-92 @100 KHz	[2]
GaAs MESFET 0.8 X 280 um gate	monolithic	26.17	12.6	5.5	-118.7 @ 1 MHz	This paper
InP/InGaAs HBT 2 X 15 um emitter	hybrid	26.5	2.5	12	-105 @100 KHz -126 @ 1 MHz	[3]
InP/InGaAs HEMT 0.25 X 120 um gate	hybrid	81.9	1	1.5	-97 @100 KHz -90 @ 1 MHz	[4]

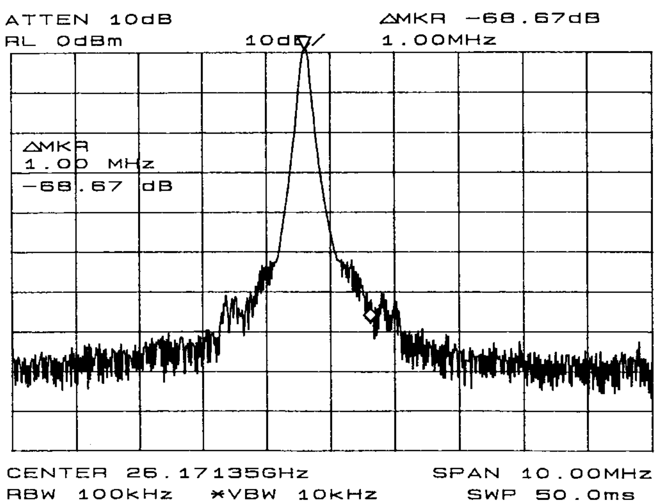

Fig. 3. DRO output power spectrum.

was 11.0 dBm at 26.17 GHz for a conversion efficiency of 5.5%. The phase noise was −118.7 dBc at 1-MHz off carrier. The measured results are shown in Fig. 3. These results were obtained through microwave, on chip, probing with the DR placed on top of the chip passivation layer with no metallic lid or packaging used. This compares to a simulated output power of 12.84 dBm at 27.74 GHz using the simple RLC DR model that used a loaded Q of 1000. The discrepancy arises from the fact that the transistor was modeled only to 20 GHz and the large signal model was extrapolated to 27 GHz. An additional uncertainty is that the actual loaded Q or coupling is unknown. Although this DRO is intended for the integrated radio on a chip [7], it is possible to have a coplanar DR circuit off chip to reduce the overall cost. A comparison between different DRO technologies is presented in Table I. The results show that this configuration provides similar performance characteristics to other technologies.

IV. CONCLUSIONS

The monolithic coplanar transmission line GaAs MESFET DRO had good results, which are comparable to other technologies. At the oscillation frequency of 26.17 GHz, the measured output power was 11 dBm with a conversion efficiency of 5.5%. The phase noise was −118.7 dBc at 1 MHz off the carrier. This represents the first reported instance of a DRO being fabricated using a coplanar transmission line structure.

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