Planar Realization of Low Phase Noise 15/30 GHz Oscillator/Doubler Using Surface Mount Transistors

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***Abstract*—This paper presents the application of a novel high-Q planar waveguide resonator for microwave oscillator design. The waveguide cavity is made in printed-circuit-board process, first using a routed cut followed by a plated via-through-hole. Measurements show that the oscillator stabilized by the resonator delivers an output power of 14 dBm at 15 GHz and a phase noise of −98 dBc/Hz at 100 kHz offset from the carrier, under 5-V single bias. Experiments indicate the predominance of the waveguide resonator by a 13-dB phase noise improvement at 100 kHz offset against the microstrip oscillator.**

***Index Terms*—High-Q resonators, microstrip, oscillators, planar circuits.**

I. INTRODUCTION

EMERGING wireless communications have necessitated the development of compact and low noise oscillator for stringent wireless standards. However, the low noise performance of oscillators primarily relies on high-Q (quality factor) of the resonators [1]. Frequently, most microwave/millimeter-wave RF modules involve high-Q cavity-stabilized or dielectric-resonator (DR)-stabilized oscillators. DR can be easily blended into the NRD type millimeter-wave module, thereby enabling a high-quality oscillator accompanies the nonplanar structure. However, the cavity resonator in general is too cumbersome for use in practical compact oscillator circuits. This work accordingly presents a new approach to realizing high performance oscillators, utilizing hybrid integration of SMT discrete devices on all-planar printed-circuit-board (PCB).

The total Q-factor of a conventional microstrip resonator declines rapidly as the thickness of the substrate increases, largely because of the radiation loss [2]. However, according to Fig. 1, the microstrip resonator with enclosed sidewalls around its three open perimeters exhibits a much higher Q that attributes to the amelioration of radiation loss, thereby motivating the design of a high-Q planar resonator in all-planar PCB process. The relatively high-Q, low profile, and easy-fabrication characteristics of planar resonator make it attractive for compact and low noise oscillator designs in microwave/millimeter-wave circuits. To investigate the merits of the planar waveguide resonator, two 15-GHz oscillators with identical circuit topologies are presented for comparison whereas the resonators are made by planar waveguide and conventional microstrip, respectively. Additionally, a single-stage 15/30 GHz doubler is designed and driven by the oscillator, for realizing an all-planar millimeter-wave source in the 30-GHz indoor WLAN transmitter prototype [3] using cost-effective PCB fabrication process.

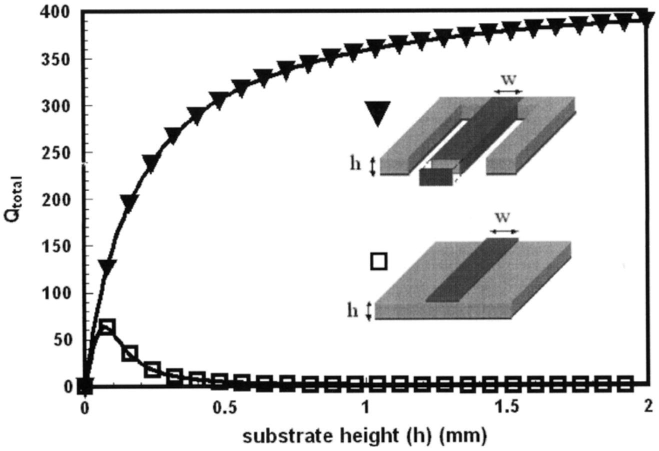

Fig. 1. Total Q-factor of 15-GHz microstrip resonators (w $= 1.2$ mm, $\epsilon_r = 3$, and $\tan\delta = 0.002$).

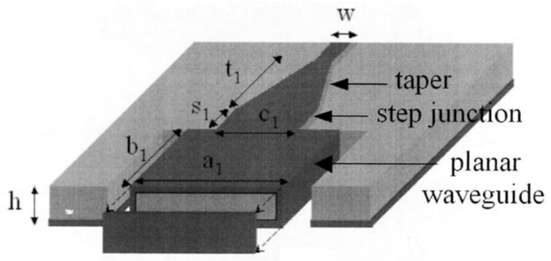

Fig. 2. Configuration of planar waveguide resonator, the front sidewall is opened for illustration ($\epsilon_r = 3.0$, $\tan\delta = 0.002$, w $= 1.22$ mm, h $= 0.508$ mm, $a_1 = 11.5$ mm, $b_1 = 8.6$ mm, $c_1 = 3.6$ mm, $s_1 = 1$ mm, and $t_1 = 3.4$ mm).

II. PLANAR RESONATOR

Microstrip resonators in planar circuits typically have the compelling advantages such as simplicity in fabrication, low cost, and the integration capability with other circuits. However, the poor Q-factor mainly attributes to radiation loss that limits their use in high-performance oscillator design. To circumvent these problems while remaining the planar facilities, this work

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incorporates a printed rectangular waveguide in the resonator design. Fig. 2 illustrates the proposed resonator. The step junction and tapered microstrip serve as the mode converter, posing the H-plane field discontinuity between the microstrip and waveguide [4]. The top surface of the rectangular waveguide lines up with the printed microstrip line, and shares the same ground plane. The other three open side walls are made first by routed cuts followed by a plated via-through-hole process, forming a planar rectangular waveguide cavity in PCB process. Another trial $\lambda/4$ short-end microstrip resonator is designed for comparative study of the 15-GHz oscillator. Both resonators are realized on the same Duroid RO3003 substrate with a thickness of 0.508 mm, a relative permittivity of 3, and a loss tangent of 0.002. The conductivity of the plated metal and the sidewall glued silver pastes (if applied) are 5.8×10^7 and 5×10^6 (siemens/meter), respectively. Dimensions are also specified to determine a parallel resonance at 15 GHz as verified by the field solver, HFSS. Moreover, the $\lambda/4$ microstrip resonator is designed to yield a wide transverse geometry for a high Q-factor. Simulation indicates that the total Q-factors in the microstrip resonator and planar waveguide case are approximately 60 and 300, respectively.

III. ALL PLANAR OSCILLATOR AND DOUBLER

The oscillator was designed using packaged pHEMT NEC 32 584C. Curves fitting in the linear and nonlinear models are carried out according to measurement data. Fig. 3 shows the circuit schematics of the oscillator and doubler, depicting a self-biased floating-gate oscillator with resonators connected to source. Interestingly, the short-circuited waveguide resonator simultaneously provides a series feedback and dc current path. Consequently, only a single bias voltage need be applied to the drain. The resonators at source are two different trial versions containing planar waveguide cavity and the $\lambda/4$ microstrip resonator, both are adjusted to make the same transistor oscillation at 15 GHz for comparison. The outputs of the oscillators are constituted by a dc-blocked $\lambda/4$ couple line section tuned at 15 GHz. Following the oscillator, a single-stage common source frequency doubler is designed, using Litton LPD200 pHEMT device packaged by a dual-mode configuration that supports both microstrip and coplanar waveguide modes [5]. The biasing point of the doubler is chosen to be 0 V at the gate and 3 V at the drain, respectively. A $\lambda/4$ shunt open stub followed by drain, serves as a trap to suppress the 15-GHz fundamental signal whereas passing the 30-GHz second harmonic to the load. Fig. 4 shows the fabricated all-planar oscillator and doubler.

IV. EXPERIMENT RESULTS AND DISCUSSIONS

Oscillation frequency, output power, and phase noise are measured using the Wiltron 3680K test fixture and an HP 8565E spectrum analyzer. Fig. 5(a) plots the measured power spectrum of the oscillators using two different trial resonators, showing a stable output power of 14 dBm at 15 GHz. Measurement of the single-sideband phase noise was determined from the spectrum analyzer through a resolution bandwidth correction [6]. The oscillator stabilized by planar waveguide has a phase noise of −98 dBc/Hz at 100 kHz offset, corresponding to 13 dB phase noise improvement compared with that of the microstrip resonator. The superior performance attributes to the noise immunity against gate loadings provided by floating-gate, and the relative higher resonator Q-factor. Moreover, this oscillator requires only a single supply voltage since the pHEMT attempts to oscillate while automatically building up the gate bias. Table I shows the performance comparison of this work to that of recently published oscillators at frequency bands nearby. The planar-waveguide stabilized oscillator presented in this work, from Table I, shows a comparable or even better performance with respect to both output power and phase noise, under an unloaded Q-factor of only 300, and without external nonplanar components, such as DR.

Driving the doubler with the 15-GHz waveguide stabilized oscillator, Fig. 5(b) shows an output power of 9 dBm at 30 GHz

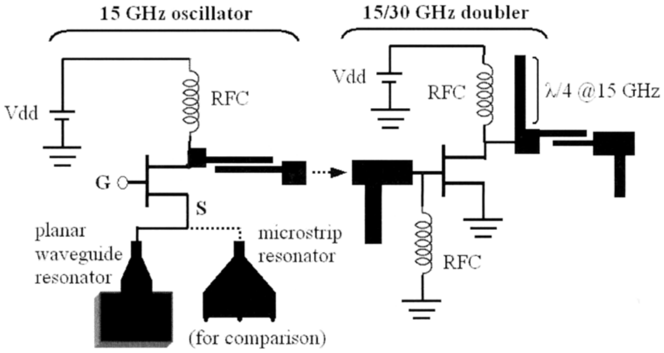


Fig. 3. Circuit schematics of the reported all-planar oscillator and doubler.

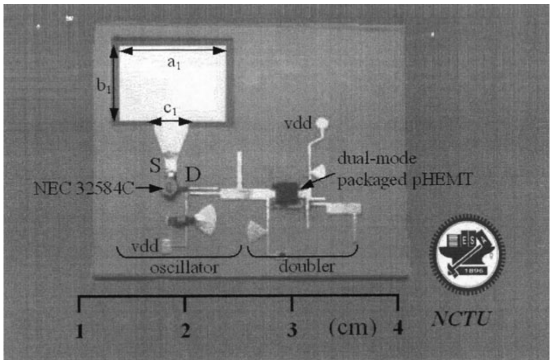
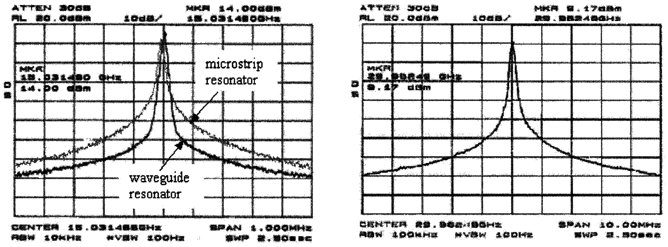


Fig. 4. Photograph of the fabricated all-planar oscillator and doubler.



(a) (b)

Fig. 5. (a) Measured output spectrum of the 15-GHz oscillators and (b) the 15/30-GHz doubler driven by the 15-GHz waveguide stabilized oscillator.

TABLE I
PERFORMANCE COMPARISON BETWEEN THIS WORK AND RECENTLY PUBLISHED OSCILLATORS

	Badnikar *et al.* [7]	Gresham *et al.* [8]	Lee *et al.* [9]	This Work
Technology	Hybrid, DRO	Hybrid, DRO	Hybrid, DGS	Hybrid
Device	HEMT	pHEMT	pHEMT	PHEMT
f_0 (GHz)	17.463	19	9.86	15
P_{out} (dBm)	4.7	>12 (with buffer Amplifier)	7.4	14
Phase Noise (dBc/Hz @100kHz)	-113	<-85	-98.2	-98

and phase noise of -102 dBc/Hz at 1-MHz offset. Measurements reveal the great potential of applying all-planar circuits to millimeter-wave modules.

V. CONCLUSION

This work presents a new approach to improve the performance of the planar hybrid microwave oscillator, either with respect to output power or phase noise. The proposed planar waveguide resonator together with innovative circuit designs yield a 14-dBm output power at 15 GHz and a phase noise of -98 dBc/Hz at 100-kHz offset. The frequency doubler driven by the oscillator exhibits a 9-dBm output power at 30 GHz and a phase noise of -102 dBc/Hz at 1-MHz offset, providing an alternative method to establish high-quality DR-free oscillators, as well as the feasibility to integrate with planar circuits with SMT packaged devices.

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