A 20-GHz-Band Subharmonically Injection-Locked Oscillator MMIC with Wide Locking Range

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***Abstract*— A monolithic subharmonically injection-locked oscillator (ILO) with wide frequency tuning range using a shunted varactor diode inserted to the oscillation loop is presented. A 20-GHz-band ILO is fabricated that achieves the wide injection locking range of more than 700 MHz at each subharmonic factor up to 32. In addition, the phase-noise degradation rate of the ILO against the subharmonic factor is close to 6 dB/oct. The ILO configuration is extremely suitable for realizing low-cost and low-phase-noise millimeter-wave monolithic microwave integrated circuit (MMIC) sources.**

I. INTRODUCTION

THE millimeter-wave region is becoming important for future communication systems such as indoor wireless local area networks (LAN's), satellite communication, and radar systems. Accordingly, several millimeter-wave sources using dielectric resonator oscillators (DRO's) and phase-locked oscillators (PLO's) have been reported [1]–[3]. PLO's are more suitable for monolithic microwave integrated circuit (MMIC) implementation and synthesizer development than DRO's. However, PLO's contain many components such as voltage-controlled oscillators (VCO's), frequency dividers, and PFC's, resulting in high cost due to complex multichip packaging. Furthermore, to realize millimeter-wave frequencies they need additional frequency multipliers and amplifiers because of the operation frequency limitation of frequency dividers. The frequency multipliers necessitate an expensive radio frequency (RF) filter at the output port, so serious difficulties arise when realizing fully monolithic synthesizers.

The authors proposed a monolithic subharmonically injection-locked oscillator (ILO) chain, a cascade of low/high frequency-band ILO's, as a attractive candidate to solve the above problems [4], [5]. The ILO chain is suitable for simple and low-cost millimeter-wave sources because it can achieve much higher multiplication ratios with only one or two chips [6]. Additionally, the ILO chain suppresses adjacent spurs at higher multiplication ratios due to the enhancer effect of the second ILO, suggesting the elimination of RF filters. However, conventional ILO's do not have enough locking range at higher order subharmonics and strongly demand frequency tuning to adjust their center frequencies. This letter proposes a newly designed ILO which has frequency tuning ability through the insertion of an active shunted-varactor into the oscillation loop. A 20-GHz-band ILO is fabricated and found to achieve the wide locking range of more than 700 MHz at subharmonic factors n from one to 32. Furthermore, the measured phase-noise degradation rate against subharmonic factor is close to 6 dB/oct, the same as frequency multipliers. The measured results mean the ILO configuration is extremely suitable for realizing low-cost and low-phase-noise millimeter-wave MMIC synthesizers.

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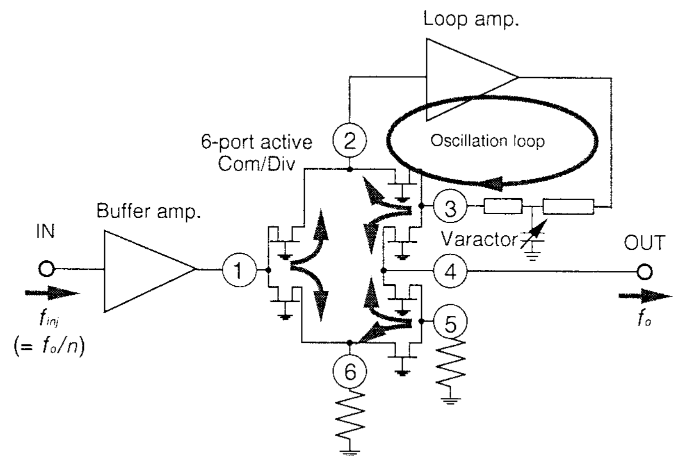

Fig. 1. Circuit schematic of a newly designed injection-locked oscillator.

II. CIRCUIT DESIGN

The circuit scheme and signal flow for the proposed ILO is shown in Fig. 1. The ILO has a simple configuration consisting of a six-port active combiner/divider and amplifiers. The loop amplifier and combiner/divider are connected to form an oscillation loop. The active combiner/divider, which consists of three active in-phase dividers (a pair of common-gate-FET's (CGF's) [7]) connected to one another through their high-impedance output ports to provide a nonreciprocal six-port circuit, operates in an ultrawide-band frequency range approaching the field-effect transistor (FET) cutoff frequency. Therefore, the combiner/divider is suitable for injecting subharmonic signals of various orders.

The oscillation frequency of the ILO is determined by the total phase shift of the loop. In the ILO as shown in Fig. 1, a shunted varactor inserted to the oscillation loop works a variable phase shifter. Accordingly, the ILO achieves wide oscillation frequency range controlled by the varactor. The shunted-varactor is superior to series varactors in terms of loss and size because the dc bias port for the varactor is electrically isolated to the oscillation loop. When the low/high ILO's have frequency tuning ability, respectively, it is very

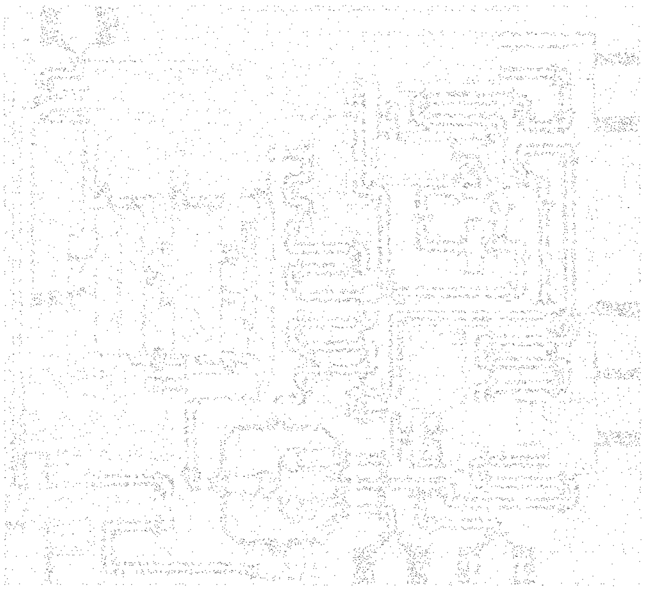

Fig. 2. Photograph of a fabricated 20-GHz-band injection-locked oscillator MMIC (chip size: 1.4 × 1.4 mm^2).

easy to realize ILO chan configuration for a millimeter-wave source. The basic circuit topology as shown in Fig. 1 can be available at any frequencies from the C-band to the millimeter-wave frequencies, although some improvements should be to the active combiner/divider for millimeter-wave applications [4].

III. Measured Results

Fig. 2 shows a photograph of the fabricated 20-GHz-band ILO MMIC, which used 0.2-μm HEMT's. The chip size is only 1.4 × 1.4 mm^2. The ILO MMIC operates at 6-V/4 V/2 V/ −2 V and 100 mA. The 14–24-GHz 10-dB gain loop amplifier and the six-port active combiner/divider combine to realize a 720° phase shift in the 20-GHz band. The delay line length totals 2.25 mm, 130° at 20 GHz and a varactor is implemented by a 100-μm-wide T-gate HEMT as a Schottky diode. The 0.3–5-GHz 20-dB-gain buffer amplifier was designed to degrade the gain gradually beyond 5 GHz, which increases the injection-locking ability at higher order subharmonics. Therefore, the ILO locks even to the 32nd subharmonic signal at the injection power of 5 dBm. In addition, the ILO achieves its widest locking range at the fourth subharmonic due to the frequency characteristic of the buffer amplifier. On the other hand, measured locking range at the fundamental is narrower than those at the fourth subharmonic because the buffer amplifier has 1-dB loss at 19 GHz.

We measured the free-running oscillation frequency and output power of the ILO as a function of varactor bias V_c. The ILO achieves wide frequency tuning range from 18.71 to 19.33 GHz by applying the dc bias of 0.1 to −2 V, and tuning sensitivity of 750 MHz/V at $V_c = -0.2$ V. The output power is 3.2 ± 1.2 dB over the tuning range of 600 MHz. We measured the injection-locking range of the ILO for the control bias values of 0.1, −0.2, −0.6, and −2.0 V. As an example,

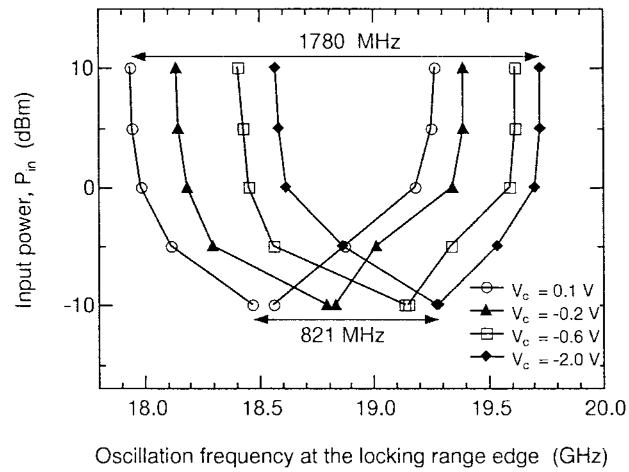

Fig. 3. Measured locking range for varactor bias, V_c, values of 0.1, −0.2, −0.6, and −2.0 V at the fourth subharmonic.

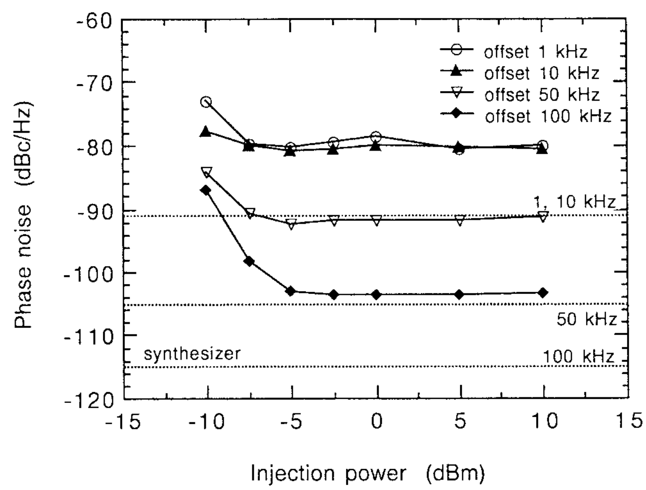

Fig. 4. Phase-noise characteristic as a function of the injection power at the fourth subharmonic.

Fig. 3 shows the locking range versus the injection power characteristics at the fourth subharmonic. The ILO performs the injection locking range of more than 700 MHz, even for low injection power. In addition, the ILO can achieve wide locking range, possibly 10 wider than with a conventional ILO, at the injection power of −10 dBm.

The phase noise of the ILO was directly measured using an HP8566B spectrum analyzer. Fig. 4 shows the phase-noise characteristic as a function of the injection power at the fourth subharmonic. The measured phase-noise degradation rate against subharmonic factor is 6 dB/oct, which equals that of frequency multipliers. Though the phase-noise degradation increases with signal injection, which is away from the center of the locking range [8], the optimum oscillation frequency is easily achieved in the proposed ILO by adjusting the varactor bias. At the injection power of −5 dBm, the degradation value is minimum at any subharmonic factor.

IV. Conclusion

We have presented the development of an ILO MMIC that achieves wide locking range, even at higher order subharmonics. A 20-GHz-band ILO was fabricated utilizing a varactor diode as an ideal wide-band 32-frequency multiplier. Measured results show the ILO chain, a cascade of low/high frequency-band ILO's with wide tuning range, is extremely suitable for realizing low-cost and low-phase-noise millimeter-wave MMIC oscillators and synthesizers.

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