Injection-Locked Oscillator Chain: A Possible Solution to Millimeter-Wave MMIC Synthesizers

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ABSTRACT

An injection-locked oscillator (ILO) MMIC chain, which cascades low/high frequency-band ILO's, is proposed for simple and cost-effective millimeter-wave local oscillators and synthesizers, and primary 5-GHz-band and 50-GHz-band ILO MMIC's, which are injection-locked at subharmonic factors from 1 to 1/16 and from 1 to 1/4 respectively, are demonstrated.

INTRODUCTION

Millimeter-wave system applications are growing up recently, and several millimeter-wave sources using dielectric resonator oscillators (DRO's) and phase-locked oscillators (PLO's) have been reported [1]-[4]. PLO's are more suitable for MMIC implementation and synthesizer development than DRO's. However, PLO's contain many components such as VCO's, frequency dividers and PFC's, resulting in a high cost and complex multichip packaging. Furthermore, they need additional frequency multipliers and amplifiers at millimeter-wave frequencies because of the operation frequency limitation of frequency dividers.

In this paper, a subharmonic injection-locked oscillator (ILO) MMIC chain is proposed for the local oscillators and synthesizers used at millimeter-wave frequencies, and fabricated primary 5-GHz-band and 50-GHz-band ILO MMIC's for the first and second stages respectively, are demonstrated. Each ILO MMICs is simple constructed with an active combiner/divider and a loop amplifier with an adequate delay line. The active combiner/dividers (A-C/D's) are designed so that they meet each operation requirement. The 5-GHz-band A-C/D is a non-reciprocal 6-port circuit that suppresses spurs from the output port, and 50-GHz-band A-C/D employs low-impedance lines at the output ports to enhance the loop gain at millimeter-wave frequencies. The 5-GHz-band ILO MMIC exhibits output spectra with low spurs of less than -34 dBc for any subharmonic factors, and the 50-GHz-band ILO MMIC shows an injection locking ability at subharmonic factors from 1 to 1/4 without a buffer amplifier. Measurement results show the subharmonic ILO MMIC chain is very attractive for building simple and low-cost millimeter-wave frequency sources and synthesizers .

ILO CHAIN CONCEPT AND DESIGN

The significant advantage of the ILO MMICs is their simple configuration, which is constructed with an active combiner/divider and a loop amplifier with an adequate delay line [5]-[8]. In addition, their phase noise characteristic depends on the injection signal purity, and the degradation rate against subharmonic factor is very close to 6 dB/oct, which is the same as frequency multipliers [5]. Furthermore, the ILO MMIC exhibits a wide locking-range even at subharmonic factors, 1/n of less

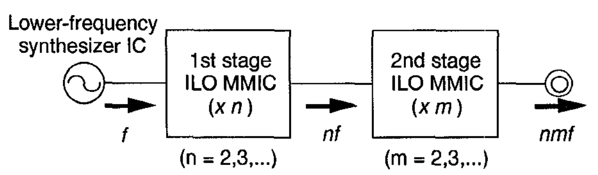

Fig. 1 Configuration of millimeter-wave synthesizers using the ILO MMIC chain.

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than 1/2 reaching 1/16, with an input buffer amplifier. This means additional frequency multipliers and amplifiers are unnecessary, and two-chip or one-chip integration of a much higher level of multiplication is possible. Therefore, a subharmonic ILO chain cascading low/high frequency-band ILO's is a possible solution to millimeter-wave MMIC oscillators and synthesizers, when the ILO MMIC chain uses a commercially available (or already developed) synthesizer IC to provide a reference signal around 1-GHz, and multiplies the reference by n x m (n, m = 2, 3, ...) as shown in Fig. 1.

The important design issues for the ILO chain are (1) the suppression of spurs from the output port of the first-stage ILO to achieve stable operation of the second one and obtain a pure output spectrum in the millimeter-wave region; and (2) how to provide enough loop gain for the second-stage ILO in spite of the performance degradation of the millimeter-wave amplifier. For these issues, the each A-C/Ds implemented in the external feedback path for an amplifier as heart of the ILO MMICs are improved.

A. FIRST-STAGE ILO

The circuit topology and signal flow for the 5-GHz band ILO MMIC is shown in Fig. 2. The A-C/D is a non-reciprocal 6-port circuit [9]. The 6-port A-C/D consists of three active in-phase dividers (a pair of common-gate-FET's (CGF's)) connected to one another at the high impedance output ports. A 0.1-20 GHz 6-port A-C/D and a 3.5-7 GHz 10-dB loop amplifier are combined to make the phase shift in the loop 360 degrees at the 5-GHz-band. The 0.3-2 GHz 15-dB buffer amplifier is designed to degrade the gain gradually beyond 2 GHz in order to enhance the locking ability at higher-order subharmonics. The 6-port A-C/D suppresses spurs from output port ④ because none of signals divided at input port ① are delivered to output port ④ [10].

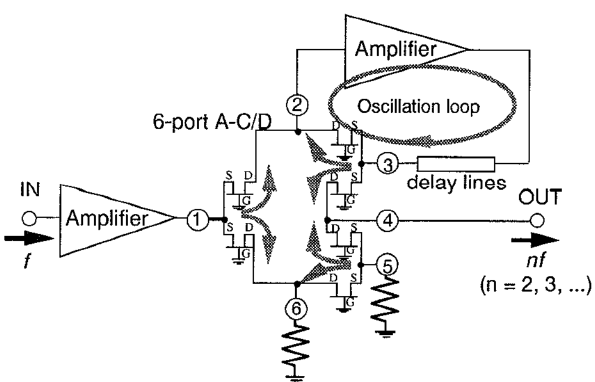

Fig. 2 Circuit schematic of a 5-GHz-band ILO MMIC.

B. SECOND-STAGE ILO

The circuit topology and signal flow for the 50-GHz band ILO MMIC is shown in Fig. 3. The A-C/D for the second-stage ILO is a non-reciprocal 4-port circuit with low-impedance lines, which work as an impedance transformer and enhance the coupling gain from port③ to port ② and ④ at millimeter-wave frequencies. The improvement could reach 5 dB by lowering the impedance as shown in Fig. 4. The 4-port A-C/D and the loop amplifier are combined to make the phase shift in the loop 720 degrees at the 50 GHz-band. The 48-58 GHz, 10-dB loop amplifier is composed of two stage common-source-FET's (CSF's) with a 100-μm gate width. The low impedance lines connecting to the output ports of the A-C/D are 35 Ω, 0.52 mm and the delay line is 0.7 mm or 80 degrees.

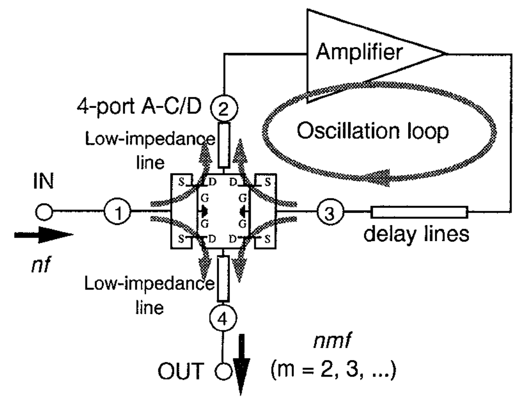

Fig. 3 Circuit schematic of a 50-GHz-band ILO MMIC.

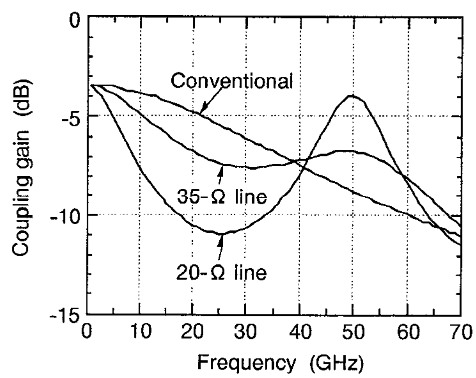

Fig. 4 Coupling gain characteristic from port ③ to port ② and port ④ of an active combiner/divider with low-impedance lines.

MEASURED RESULTS

Figure 5 shows a photograph of the 5-GHz band ILO MMIC. The chip size is 1.8 x 3.8 mm^2. The ILO MMIC operates at 5 V/ -5 V and 150 mA. Measured injection locking range characteristic of this ILO for subharmonic factors, 1/n from 1 to 1/16, is shown in Fig. 6, which is similar to a conventional one [5] using 4-port A-C/D. Figure 7 shows the normalized output spectra of a fabricated 5-GHz-band ILO MMIC and a conventional one when 8-th subharmonic signal is injected. Since input signal leakage from input port ① to output port ④ is suppressed at frequencies up to the cut-off frequency, the total value of undesired signal out of output port ④ becomes less than -34 dBc. Especially noteworthy is that the injection signal and its second harmonic generated in a buffer amplifier is reduced more than 30 dB compared with the conventional ILO using 4-port A-C/D.

Figure 8 shows the fabricated 50-GHz-band ILO MMIC, which uses 0.1-μm pseudomorphic AlGaAs/ InGaAs/GaAs HEMTs. The chip size is only 1.2 x 0.9 mm^2. The ILO MMIC operates at 1.5 V and 35 mA. Figure 9 compares the spectra of free-running and injection-locked oscillation. The spectral width with free-running is about 2 MHz which indicates that the oscillator has a very low effective Q. This feature is extremely advantageous for wide-band injection locking [5]. Figure 10 shows the measured locking ranges for the subharmonic factors, 1/m from 1 to 1/4, where the injection power is estimated at the input port of the A-C/ D. This ILO can be locked by the fourth subharmonic at the input power of 5 dBm without a buffer amplifier. The oscillation output power from the ILO MMIC is larger than -5 dBm for each value of m. When a buffer amplifier is used, the locking range is greatly improved and higher-order-subharmonic operation can be obtained, as reported in [5].

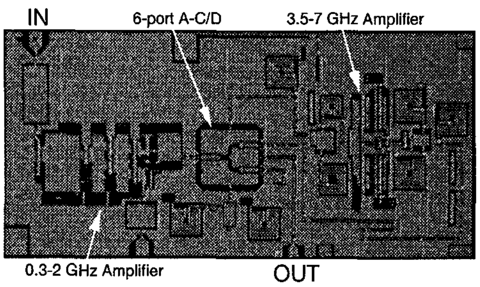

Fig. 5 Photograph of the 5-GHz-band ILO MMIC.

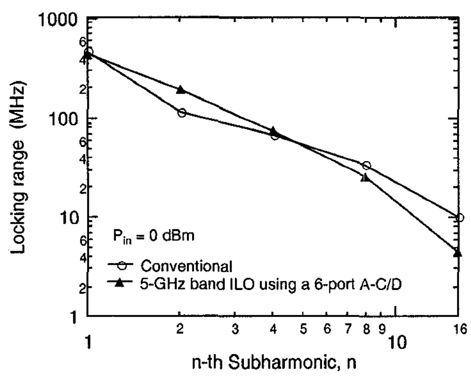

Fig. 6 Comparison of measured injection-locking range characteristic between the 5-GHz-band ILO using a 6-port combiner/divider and a conventional one using a 4-port combiner/divider [5].

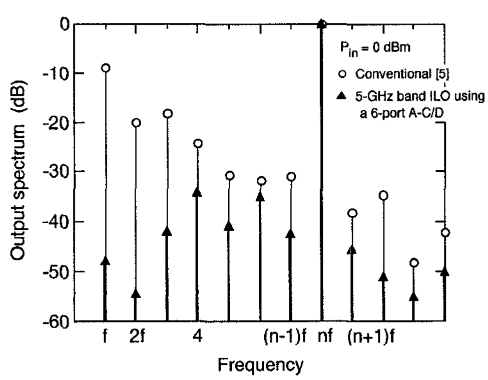

Fig. 7 Comparison of normalized output spectra between the 5-GHz-band ILO using a 6-port combiner/divider and a conventional one using a 4-port combiner/divider [5] at 8-th subharmonic.

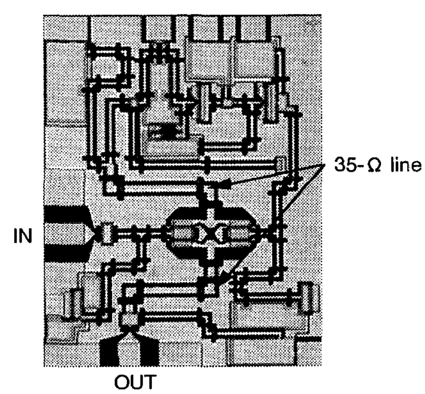

Fig. 8 Photograph of the 50-GHz-band ILO MMIC.

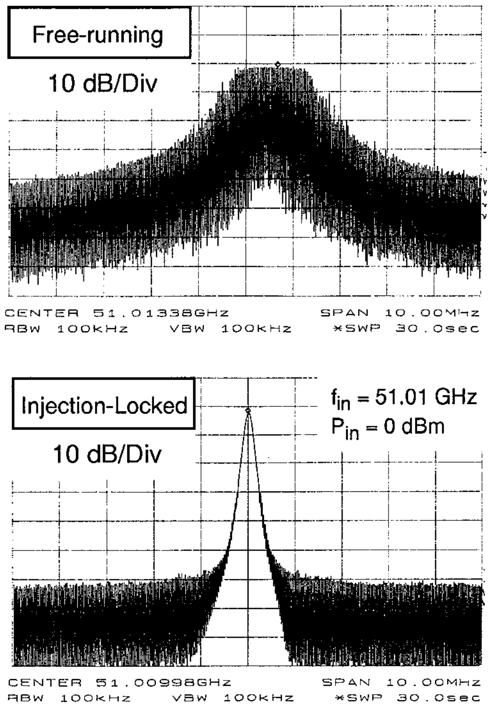

Fig. 9 Comparison of free-running and injection-locked oscillation spectra.

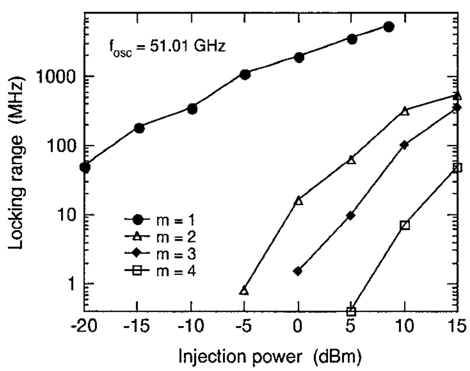

Fig. 10 Measured injection locking rang versus injection power.

CONCLUSION

A subharmonic ILO MMIC chain has been proposed for simple and cost-effective millimeter-wave sources, and primary 5-GHz-band and 50-GHz-band ILO MMIC's were demonstrated, focusing on active combiner/divider designs. The ILO MMIC chain is suitable for fully monolithic and low-cost MMIC synthesizers. Furthermore, the ILO MMIC chain configuration is easily applicable to other frequencies with some modification in the loop design, resulting in a rapid response to millimeter-wave systems and a great reduction in the MMIC development cost.

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