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Comparative Characteristics between Microstrip-Line Resonator(HR) and Dielectric Resonator(DR) for Injection-Locked Oscillators(ILOs)

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Abstract

A hair-pin shaped microstrip-line resonator and a dielectric resonator for injection-locked oscillators have been designed and fabricated for the comparative studying of their characteristics. In general, a commonly used dielectric resonator shows lower phase noise value than hair-pin resonator in the free-running mode. In the injection-locked mode, however, a hair-pin resonator is superior to the dielectric resonator; the wider tuning range, the 22% improved locking bandwidth, the lower noise effect, the short term stability, and the higher power level. The planar structure of a hair-pin shaped microstrip-line resonator will be easily applied to monolithic microwave integrated circuits.

I. Introduction

The injection-locking oscillators(ILOs) with GaAs FET show promising features as the active components in the microwave integrated circuits(MICs) and monolithic microwave integrated circuits(MMICs). Injection-locking theory suggested by van der Pol [1] in the 1920s was applied to electrical oscillators in 1946 [2], and finally was developed for negative resistance injection-locked oscillators(ILOs) [3]. ILOs are commonly used to obtain high gain within a relatively narrow-frequency range by injecting an external RF signal into an oscillator. If a stable locking signal is injected, the oscillator will be stabilized and will amplify the locking signal. An ILO also can amplitude the limit of locking signal and detect a frequency modulated or phase modulated signal, and the injection-locked voltage-controlled oscillator (VCO) can perform phase modulation and amplification of locking signal at the same time.

The theory developed by Tajima and Mishima for ILO shows the relationship of the locking bandwidth(B), total voltage coupling factor(bc), and the external Q-factor of the resonator(Qext) as below [4]

$$B \propto \frac{1}{Q_{ext} \cdot b_c} \qquad (1)$$

The value of Q_{ext} depends on the characteristics of resonators.

In general, the cost-effective dielectric resonators(DRs) have been used as injection locked oscillators(ILOs). The commonly used DR is a cylindrical "puck" structure with a height and a radius. The use of a dielectric resonator may minimize the temperature dependence of the free-running oscillation frequency and the temperature dependence of the phase shift. Even though a oscillator with DR has high gain, high frequency and phase stability, and advanced noise compression in free-running mode, it would be limited in injection-locked mode because of higher Q-factor value. DRs are also unsuitable for MMICs implementation due to three-dimensional cylindrical structure. The hair-pin shaped microstrip-line resonators(HRs) have also proposed by Makimoto for the compact size and two-dimensional planar structure in MICs [5]. In the injection-locked mode, ILO with HR shows the more effective results because of lower Q-factor value [6,7,8].

In this paper, a microstrip-line HR and a DR have been designed and fabricated in a single-stage ILO as shown in Figure 1. A single-stage ILO consists of a nonlinear transmission-type amplifier, a resonator, matching circuits, and coupler with parallel feedback circuit. In order to calculate the locking bandwidth, there are some parameters such as an input voltage coefficient, an output voltage coefficient, an input voltage coupling factor, and an output voltage coupling factor [9].

II. Fabrication for ILOs with HR and DR

The single-stage ILOs have been designed and fabricated by microstrip-line HR and DR to operate around 11GHz. The circuit simulation has been performed by microwave CAD tool such as microwave design simulator(MDS). Around 20dB of power gain in single-stage ILO could be expected by HR or DR. The simulation of a single-stage ILO could be performed as following steps; designing of a single-stage amplifier with broadband characteristics, designing of oscillator by parallel feedback element, designing of resonator filter to operate around 11GHz, designing of -10dB directional coupler as an injection-locking source, and optimizing of these circuit elements into ILO circuits.

A GaAs MESFET (modal name: ATF13036 of Avantek company), which holds lower noise figures and minimization of phase perturbation, can be used as an active device of a single-stage amplifier. ILO circuit can be nonlinear modeled and simulated by the curtice cubic modeling method of MDS tool and S-parameter data of GaAs MESFET.

In an ILO with HR, a microstrip-line HR should be designed by the anti-phased coupled relation between gate and drain. In order to optimize the resonance condition, the coupling length and active feedback loop length are optimized by $\lambda_g/4$. The performance characteristics of ILOs with HR and DR have been compared on the same condition. The optimized layouts of ILOs with HR and DR are shown in Figure 2. The teflon($\varepsilon_r=2.6$ and thickness h =0.54mm) was used as substrate for fabrication of these ILOs layout.

III. Experimental Results and Analysis

In order to measure characteristics of ILOs with HR and DR, the network analyzer HP-8510C is used as injection source and the spectrum analyzer HP-8563E is used to detect the output signals.

In the free-running mode, in order to compare the characteristics of ILOs with HR and DR, the injection port of ILOs is terminated by 50Ω. As drain-source voltage(V_{ds}) of ILOs is biased from initial oscillation voltage 2.1V to saturation voltage 5.5V. When V_{ds} is biased as 4.3V, the fundamental frequencies of ILOs with HR and DR are 11.00GHz and 10.99GHz, respectively. As V_{ds} is biased above 5.5V, the output levels of ILOs are almost saturated. It is manifest that the output power level of ILO with HR is 0.17 dBm better than that of ILO with DR.

As the locking signal, with the fundamental frequency 11GHz and the injection power -14dBm, is injected into free-running mode by -10dB directional coupler, the free-running mode of ILOs could be synchronized by the fundamental frequency locking signal. Figure 3 shows output spectrums of ILOs with HR and DR within short term frequency range 10 KHz

in injection locking mode. The output power levels of ILOs with HR and DR are 12.83dBm and 11.17dBm, respectively. The short term stability, lower noise characteristics of AM, FM, and PM, and 12% advanced power level 12.83dBm could be obtained by ILO with DR.

Figure 6 shows that the phase noise characteristics of ILOs with HR and DR in locking mode are measured from the fundamental frequency 11*GHz* with 10*KHz* offset frequency. The phase noise value of ILO with HR and DR in free-running mode are -60.1dBc/*Hz* and -67dBc/*Hz*, respectively. As the locking signal with -86dBc/Hz phase noise value(10*KHz* offset frequency) is injected to these ILOs in free-running mode, the phase noise values of ILOs with HR and DR in locking mode are -84.5dBc/*Hz* and -85.3dBc/*Hz*, respectively. According to the locking signal with phase noise values(-113dBc/Hz with 100KHz offset frequency), the phase noise values are -107.9dBc/*Hz* for ILO with HR and -110.0dBc/*Hz* for ILO with DR. Therefore, as the injection signal low phase noise value is applied to these ILOs, the internal noise of free-running oscillator effects the characteristics of close-out carrier(100*KHz* offset frequency) noise but does not for close-in carrier(10*KHz* offset frequency) noise.

The output spectrums of the locking range in the ILO with HR is larger than the locking range(9*MHz*) in ILO with DR as shown in Figure 7. Since the values of Q_{ext} and b_c by microstrip-line HR are lower than those of DR in ILO, the locking range of ILO with HR can be 20% improved than that of ILO with DR. However, the spurious phenomena beyond the locking range in ILO with HR is increased.

Figure 8 shows the frequency shift value ($\omega_{inj}-\omega_0$) between the injection signal(ω_{inj}) and free-running frequency(ω_0) by the biased *drain-source voltage*(V_{ds}). The locking voltages of ILOs with HR and DR are from 3.8V to 5.5*V* and from 3.8*V* to 5.3*V*, respectively. The values of $\omega_{inj}-\omega_0$ at ILOs with HR and DR are from -5.75*MHz* to 5.75*MHz* and from -6*MHz* to 3*MHz*, respectively.

The PM noise characteristics of ILOs with HR and DR in free-running mode and locking mode by carrier offset frequency are shown in Figure 9. The PM noise value of ILO with DR is lower than that of ILO with HR in free-running mode. However, there are almost same PM noise values between ILOs with HR and DR in locking mode.

The gate port of ILOs is designed for fine tuning and good noise performance. However, the reflected signal by gate port, which causes spurious phenomena, can be terminated by 50Ω chip resistor. As the injection signal of ILOs is set by -14dBm, the output power, the injection gain, and locking bandwidth are shown in Table 1. When the injecting signal is varied by attenuator, the output power doesn't change. This result shows that ILO with HR as well as ILO with DR has good amplitude modulation(AM) compression characteristics.

V. Conclusion

Comparing characteristics of ILOs with HR and DR, ILO with HR results in a 22% improved locking range 11.5MHz with same level of phase modulation(PM) noise, and suggests some advantages as follows; a compact size without any Q-value degradation, an easier expansion of the applicable frequency range, an adjustment of resonance frequency range, and the suitable planar structure for MMICs. These characteristics clearly indicate that the resonance frequency tuning of ILO with HR can be easily achieved by adjusting the length of the parallel coupled lines in the hair-pin shaped microstrip line. According to these advantages, ILO with HR can be applied to the power coupled device in phased array antenna, the coupled VCO array system, the push-push oscillator, and other devices in MICs and MMICs.

References

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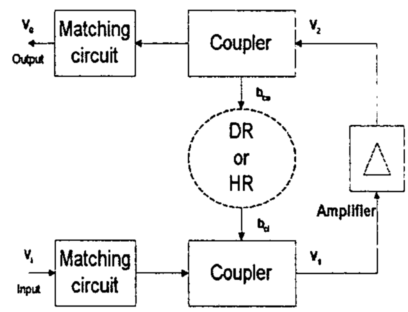
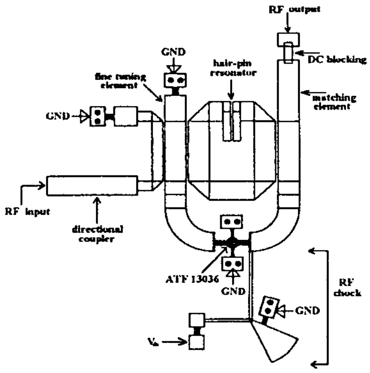
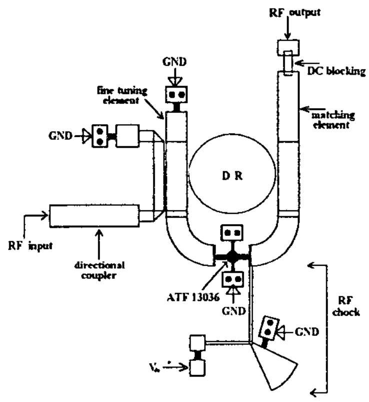


Figure 1. Schematic diagram of a single-stage ILO with HR or DR.



(a) ILO with HR



(b) ILO with DR

Figure 2. Layouts of the ILOs with HR and DR

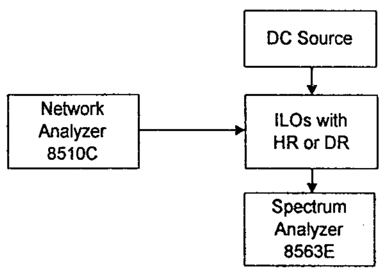
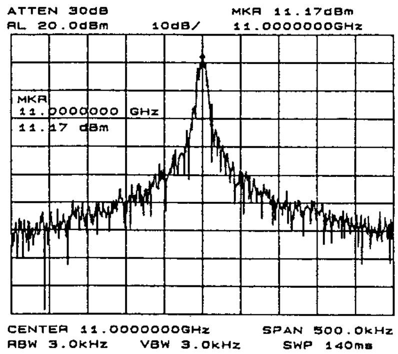
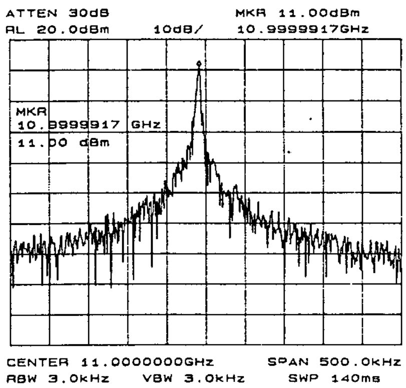


Figure 3. Schematic diagram of measurement equipment.

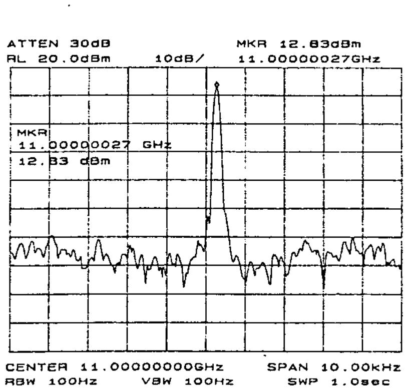


(a) ILO with HR

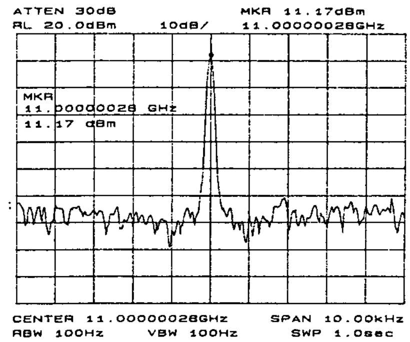


(b) ILO with DR

Figure 4. Free-running output characteristics of the ILOs with HR and DR.

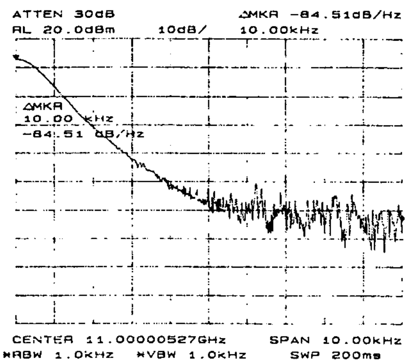


(a) ILO with HR

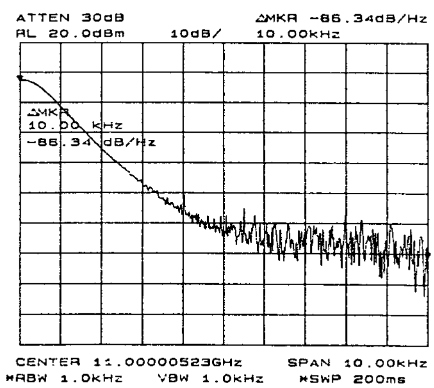


(b) ILO with DR

Figure 5. Output characteristic of the ILO with HR and DR.

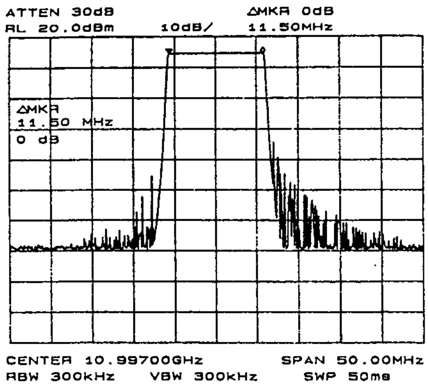


(a) ILO with HR

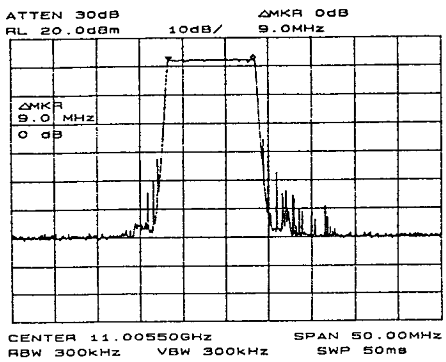


(b) ILO with DR

Figure 6. Phase noise characteristics of the ILOs with HR and DR.



(a) ILO with HR



(b) ILO with DR

Figure 7. Locking bandwidths of the ILOs with HR and DR.

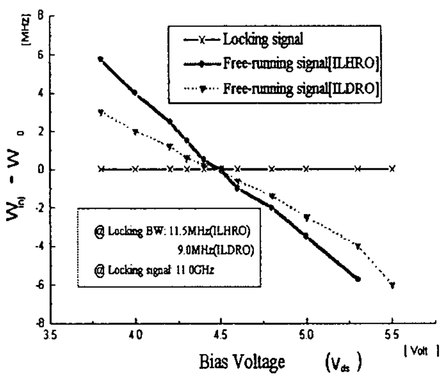


Figure 8. Frequency shift($\omega_{inj} - \omega_0$) values in the free-running mode

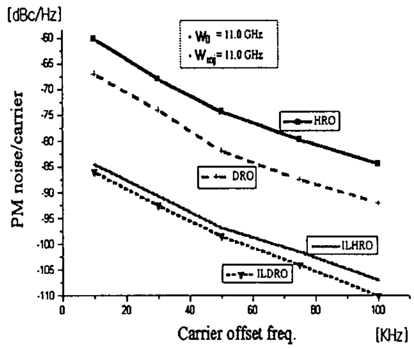


Figure 9. PM noises in the free-running mode and the injection-locked mode

Table 1. The performance specification of ILOs with HR and DR.

		ILO with HR	ILO with DR
Fundamental frequency		11.0 *GHz*	
Input power		-14 dBm	
Injection gain		≈20 dB	
Frequency tuning range		210 *MHz*	120 *MHz*
Output power		12.83 dBm	12 dBm
Locking bandwidth		11.5 *MHz*	9.0 *MHz*
Phase noise (Locking-mode)	10 *KHz*	-84.5dBc/*Hz*	-85.3dBc/*Hz*
	50 *KHz*	-91.0dBc/*Hz*	-94.5dBc/*Hz*
	100 *KHz*	-107.9dBc/*Hz*	-110.0dBc/*Hz*