A New Phase Noise Reduction Method of Oscillator by Loaded Q Improvement Using Dual Feedback Topology

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***Abstract*—This letter presents a new method to reduce the phase noise in oscillator based on the loaded Q improvement approach. A hairpin resonator is weakly coupled to the two microstrip lines to improve the loaded Q of it and the dual feedback topology is used to enable the start-up oscillation condition to be satisfied. The high loaded Q property of the resonator in the proposed oscillator circuit is analyzed using the CAD simulation. For comparison the phase noise performances of the conventional hairpin resonator oscillator and the oscillator using the dual feedback are measured. Measurements show that the oscillator using the dual feedback exhibits a low phase noise performance of −109.1 dBc/Hz at 100-KHz offset at 10 GHz, which is reduced by about 10 dB compared to that of the conventional one.**

***Index Terms*—Dual feedback, loaded Q, oscillator, phase noise.**

I. Introduction

Since the phase noise is one of the most important design parameter in the microwave oscillators, many researches have been reported to reduce the phase noise. The most promising technique to realize a low phase noise oscillator is to employ a high quality (Q) resonator such as dielectric resonator. However, it cannot be used in microwave monolithic integrated circuit (MMIC) on chip due to its nonplanar structure. In recent years, there have been new technologies to design oscillators for planar structures [1]–[7]. Unfortunately, the phase noises of them are not good as much as the nonplanar resonator oscillators because of the low quality factors of the planar resonators.

Therefore improving the loaded Qs of the planar resonators is necessary to reduce the phase noises in planar oscillators. In general, high loaded Q can be obtained by the weak coupling of the resonator, but this causes no oscillation since the loop gain cannot exceed one.

In this letter, a new method to increase the loaded Q of the planar resonator and reduce the phase noise in oscillator using the dual feedback topology is presented. The measured phase noise of the oscillator using the proposed method is −109.1 dBc/Hz at 100-KHz offset at 10 GHz, which is reduced by about 10 dB compared to that of the conventional one.

Manuscript received May 7, 2004; revised October 1, 2004. This work was supported by the University IT Research Center Project.

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Digital Object Identifier 10.1109/LMWC.2004.840980

II. Operating Principle of Oscillator Using Dual Feedback Topology

Fig. 1(a) shows the circuit diagram of the conventional hairpin resonator oscillator. The strong coupling between the hairpin resonator and the microstrip line enables the start-up oscillation condition to be satisfied, but the loaded Q is not high as shown in Fig. 4.

One possible method to improve the loaded Q of the resonator is the weak coupling to the microstrip line [see Fig. 1(b)]. In this case, the start-up oscillation condition cannot be satisfied because of low $|\Gamma|$ as shown in Fig. 4.

Fig. 2 shows the circuit diagram of the proposed oscillator. The resonator is weakly coupled to the two microstrip lines and a part of the drain output is connected to the upper coupling port of the resonator through the transmission line using a divider, in this work a Wilkinson divider. Notice that two paths of signal (A and B) influence on the total $|\Gamma|$. The signal path A means reflection from the hairpin resonator and the signal path B means transmission through the active device, divider and hairpin resonator.

If there is no signal path B, the $|\Gamma|$ is low and oscillation cannot occurred as in Fig. 1(b). However, the $|\Gamma|$ is increased due to the signal path B and the oscillation start-up condition is satisfied. In addition, the loaded Q of the resonator is higher than that of the strongly coupled resonator since the two couplings is weak.

The oscillator using this technique can be considered as the dual feedback oscillator [8], which was proposed to enhance the negative resistance and efficiency at the high frequency band. On the other hand, the dual feedback topology in this work is used to improve the loaded Q of the resonator and reduce the phase noise.

To analyze the operating principle of the proposed technique quantitatively, the circuit simulation should be performed. Fig. 2 also shows the simulation set-up to calculate the Γ. First, the power is injected from the port 1. Then, the incident power to the resonator (S_3^-) and reflected power from the resonator (S_2^-) can be calculated using the ideal power sampler. Hence, the Γ can be calculated using

$$\Gamma = \frac{S_2^-}{S_3^-} = \frac{\frac{S_2^-}{S_1^+}}{\frac{S_3^-}{S_1^+}} = \frac{S_{21}}{S_{31}}. \quad (1)$$

Fig. 5 shows the measured phase noises depending on the drain bias voltages. Measurements show that the phase noises

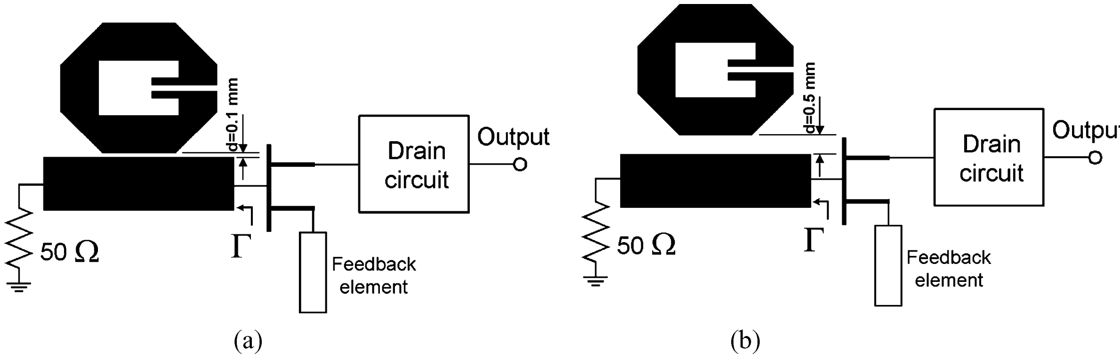

Fig. 1. Circuit diagram of the (a) conventional hairpin resonator oscillator and (b) weakly coupled resonator oscillator (no oscillation).

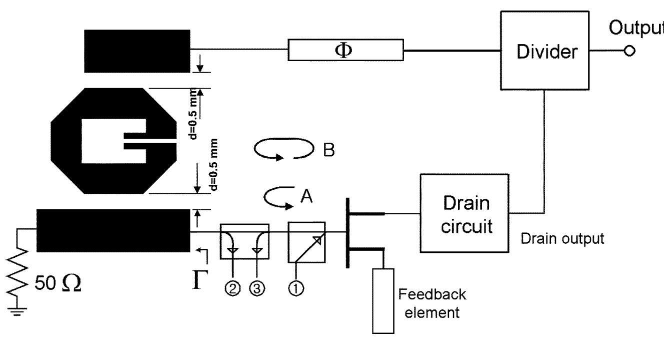

Fig. 2. Circuit diagram of the oscillator using the dual feedback topology.

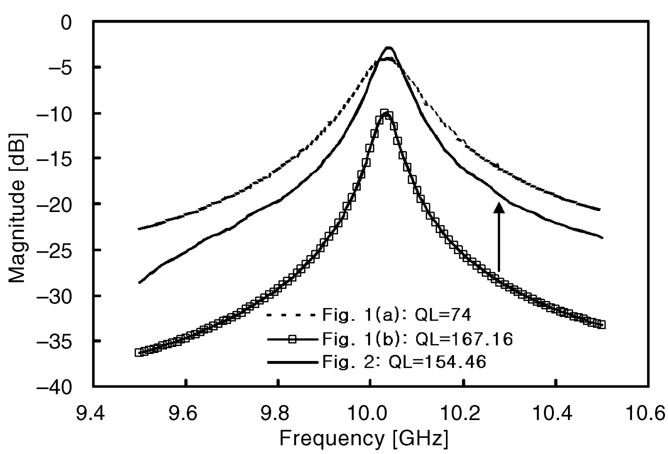

Fig. 3. Characteristics of the $|\Gamma|$ of Fig. 1(a), Fig. 1(b), and Fig. 2.

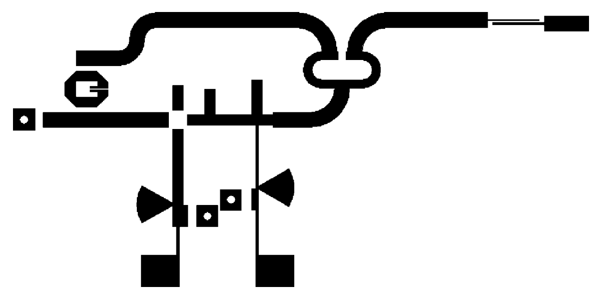

Fig. 4. Layout of the proposed oscillator using the dual feedback topology.

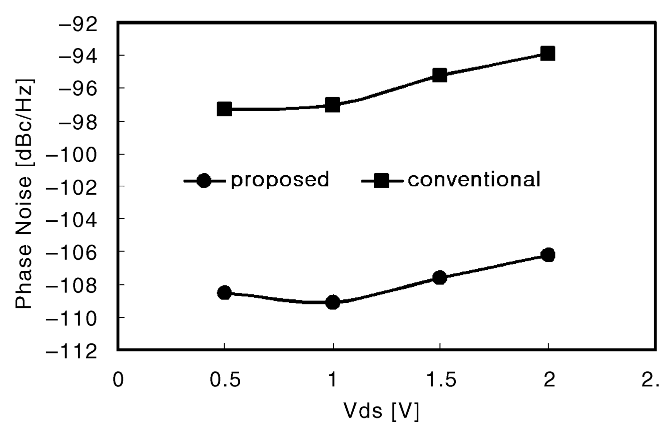

Fig. 5. Measured phase noise performances (100-KHz offset) depending on the drain bias voltages (Vgs $= -0.35$ V).

of the oscillator using the dual feedback topology are lower than those of the conventional oscillator by 10–12 dB. Fig. 3 shows the characteristics of the $|\Gamma|$ of Fig. 1(a), Fig. 1(b), and Fig. 2, respectively. It should be noted that the proposed technique increases the $|\Gamma|$ and enables the circuit to oscillate with higher Q than the conventional oscillator as discussed above. Therefore, the reduction of the phase noise is expected. Moreover, the oscillator uses only one active device, which means there is no additional noise source.

III. Measurements and Results

The conventional hairpin resonator oscillator [Fig. 1(a)] and the oscillator using the dual feedback topology (Fig. 2) were designed using the nonlinear approach [9] with a hybrid technique. The NE 32484 HEMT devices and the Teflon substrate of 0.504-mm thickness and a dielectric constant of 2.52 were used. Fig. 4 shows the layout of the proposed oscillator using the dual feedback topology.

The phase noise characteristics were measured using a HP 8566B spectrum analyzer. The phase noise can be calculated taking into account a resolution bandwidth of the spectrum analyzer based on the definition of the phase noise [10].

To demonstrate the high Q property of the dual feedback oscillator, the pulling figure measurements must be performed for the constant VSWR with all phases [11]. From the measurement the external Qs of the oscillator using the dual feedback topology and that of the conventional oscillator were 1008.8 and 164.43, respectively (VSWR is 1.1104), and the ratio was about 6.14.

However, the ratio of the real Qs of these two oscillators is not 6.14 but 3.07 since the load pulling effect with a Wilkinson divider at the output is about half of the load pulling effect without

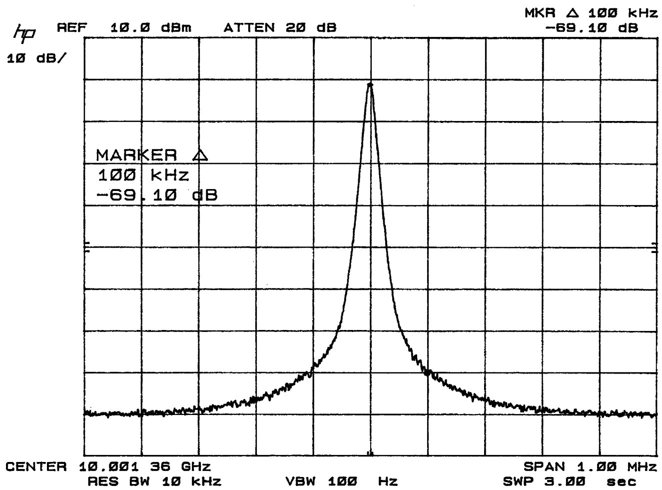

Fig. 6. Output spectrum of the oscillator using the dual feedback topology (Vgs $= -0.35$ V, Vds $= 1$ V).

it at the output. This implies 9.76-dB reduction of the phase noise, which is in good agreement with the measured results.

The output powers of the oscillator using the dual feedback topology is 0.43 dBm and 4.22 dBm at Vds $= 1$ V, Vds $= 2$ V, and (Vgs $= -0.35$ V), respectively, considering the cable loss. These are 3-dB lower than those of the conventional oscillator as expected from the existence of the Wilkinson divider. Fig. 6 shows the measured output spectrum of the oscillator using the dual feedback topology.

IV. Conclusion

The proposed technique, which uses the weakly coupled resonator and the dual feedback topology to improve the loaded Q of the resonator, is shown to be an effective method to reduce the phase noise in oscillators. The oscillator using the dual feedback topology exhibits a low phase noise performance of -109.1 dBc/Hz at 100-KHz offset at 10 GHz, which is considered to be the lowest phase noise result of the oscillator fabricated at 10 GHz using a HEMT device for fully planar structure. It is expected that the proposed technique would be effectively applicable to the low cost, low phase noise MMIC and MIC oscillators.

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