A Phase Noise Reduction Technique in Microwave Oscillator Using High-Q Active Filter

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***Abstract*—This letter presents a 10-GHz oscillator that uses a high-Q active filter to reduce the phase noise. The loaded Q of active filter is obtained at about 500. This oscillator is compared with another oscillator which uses a passive filter. The difference of two oscillators' Q is estimated at 12.5 times the open-loop gain simulation. The measured result of phase noise at 100-kHz offset shows maximum 10-dB reduction with high-Q active filter.**

***Index Terms*—Active filter, oscillator, phase noise.**

I. INTRODUCTION

SINCE modern RF communication systems need a low-phase noise carrier source, there have been many reports on low phase noise oscillators. Among these, the use of the high-Q resonator, such as dielectric resonator (DR), is most widely employed in microwave oscillator and shows reliable results [1], [2]. However, since such a high-Q resonator is composed of different material and has a three-dimensional (3-D) shape, it requires a separate process for its placement on the circuit. This problem is currently an obstacle to the monolithic microwave integrated circuits (MMICs) for mass fabrication. Therefore, to achieve high-Q property on a planar structure is necessary for a low-cost and low-phase noise oscillator.

In the meantime, the other approach has been carried out utilizing active circuits in the field where the high-Q filter is demanded [3], [4]. Active filters, fabricated on a planar structure, can provide a high-Q property without a high-Q resonator. If those active filters can also reduce the phase noise like the passive resonator, low cost and low phase noise oscillators can be achieved with them. But, in spite of this prospect, there have hardly been any reports on phase noise reduction of microwave oscillators using a high-Q active filter.

This paper presents a 10-GHz oscillator using a high-Q active filter. The used active filter is designed to have a loaded Q of 500 with a $\lambda/2$ microstrip line resonator. For comparison, another oscillator was fabricated using a passive filter. Quality factors (Q) of open loop gain of active filter oscillator (AFO) and passive filter oscillator (PFO) are 500 and 40, respectively. The measured results of the phase noise at 100 kHz offset shows $-93.8 \sim -100.85$ dBc/Hz with AFO and $-88.4 \sim -90.9$ dBc/Hz with PFO depending on the bias point.

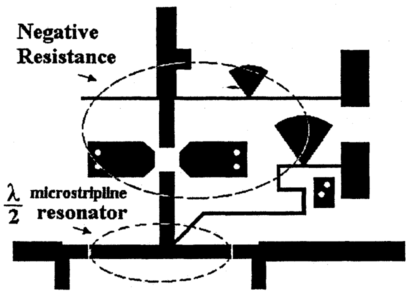

Fig. 1. Layout of the active filter.

II. ACTIVE FILTER

A half wavelength ($\lambda/2$) microstrip line was chosen as resonator. Unloaded Q of the resonator ona teflon substrate ($\varepsilon_{\mathbf{r}} = 2.52$, $\tan\delta = 0.002$, and the thickness $= 0.504$ mm) at 10 GHz is calculated to 272 by

$$Q_u = \frac{\beta}{2\alpha} = 272. \tag{1}$$

With a gap coupling on both ends of the resonator, it acts as a bandpass filter [3]. Differently from the active filter proposed in [3], which uses $\lambda/4$ coupled line for the negative resistance connection, we attached the negative resistance to resonator directly for the small size, as shown in Fig. 1. The proper negative impedance needed to cancel out the inner resistance of a resonator can be adjusted according to the attaching location in the middle of the resonator.

Negative resistance was designed with NE32484A HEMT using a series feedback at the source in order to make $-R\,\Omega$ appear from the gate. Although the magnitude of $-R$ was adjusted to cancel the inner resistance of the resonator, total resistance in the active filter circuit is larger than zero due to the gap-coupled loads. For this reason, oscillation in the active filter could not happen.

Fig. 2 is the response of the active filter measured with -10-dBm input power. It shows 20 MHz of 3-dB bandwidth [loaded Q of 500 by (2)]. This value is beyond the limit of the resonator's unloaded Q. Hence, the high-Q property needed for the low-phase noise oscillator can be obtained with a low-Q resonator in a planar structure

$$Q_L = \frac{f_0}{BW_{3\,\mathrm{dB}}} = 500. \tag{2}$$

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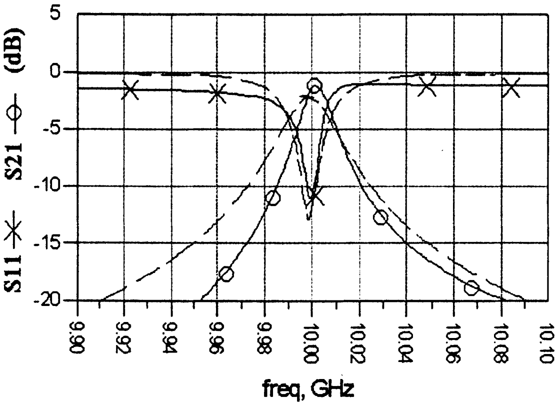
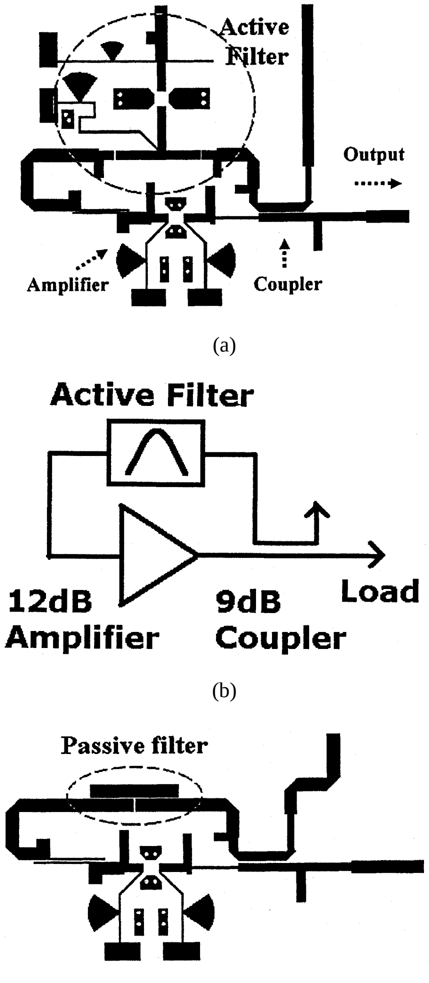


Fig. 2. Measured (solid line) and simulated (dashed line) response of the active filter.



(a)

(b)

(c)

Fig. 3. (a) Layout of the AFO, (b) the equivalent circuit diagram of the AFO, and (c) the layout of the PFO.

III. OSCILLATOR DESIGN

The oscillator was designed at 10 GHz using this high-Q active filter. As shown in Fig. 3(a) and (b), we adopted a parallel feedback topology which is composed of a 12-dB amplifier, a 9-dB coupler, and a filter to control the input power of the active filter by the coupler. The device for the amplifier is NE32484A HEMT, the same as that of the negative resistance. All components are matched to 50 Ω at input and output ports for reasonable estimation of the open-loop gain's Q by S21 and for the convenience of the loop phase adjustment. For comparison, another oscillator that uses a passive filter was also designed, as depicted in Fig. 3(c). The passive filter uses the same resonator, but has more coupling through a $\lambda/4$ line for enough loop gain. The Q factors of the two oscillators were compared by open-loop gain [5]. That was simulated as S21 from the input of the amplifier to the output of the filter with 50-Ω termination. Loaded Q factors of loop gain were estimated to 500 on the AFO and 40 on the PFO, as shown in Fig. 4.

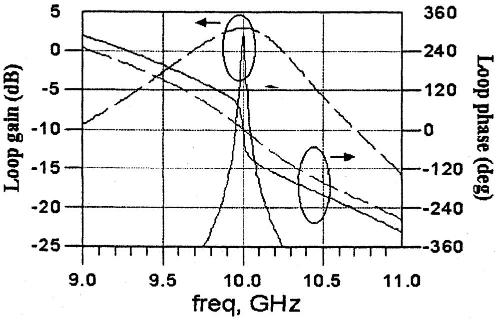


Fig. 4. Simulated open-loop gains of the AFO (solid line) and the PFO (dashed line).

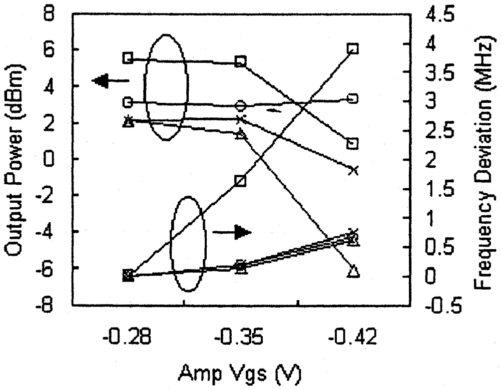


Fig. 5. Measured output power and frequency deviation of the AFO (O: Ids of filter = 9 mA, $X = 7$ mA, $\Delta = 3$ mA) and the PFO ([]).

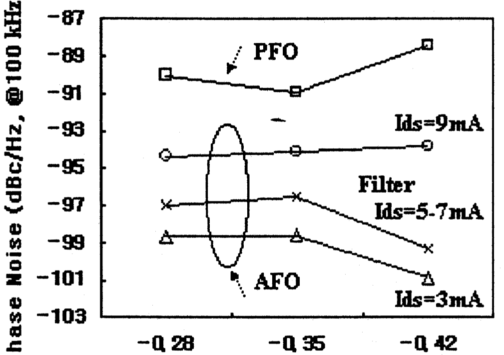
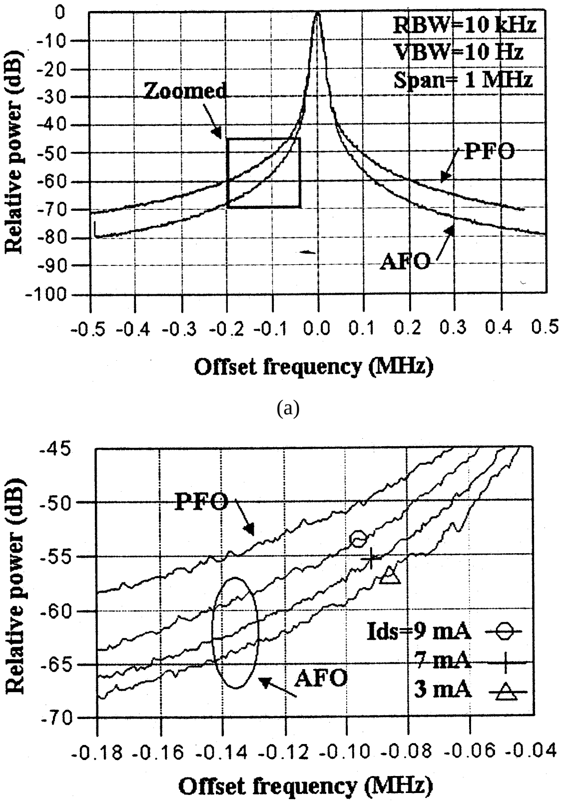


Fig. 6. Measured phase noise of the AFO and the PFO, depending on the bias of amplifier and filter.



(b)

Fig. 7. Measured power spectrum of the AFO and the PFO, depending on the bias of active filter. (a) Overlaid and (b) zoomed.

IV. MEASUREMENTS AND RESULTS

As shown in Fig. 5, the output power of the AFO was lower than that of the PFO by 3–4 dB. The reason is assumed that the gain of the active filter goes down slightly when the input power increases differently from the passive filter. From the measured result of the frequency deviation depicted in Fig. 5, one could see the evident difference in frequency stability. The AFO shows only a maximum 0.75 MHz of deviation against the PFO's 3.9 MHz, which is about five times that. The measured phase noises at 100-kHz offset on a different bias than the amplifier and the filter are compared in Fig. 6. It shows 3–10 dB improvement of phase noise when the active filter was used. From the result that the bias current of the active filter shows a dominant effect on phase noise, we could assume that the active device in the active filter acts as noise source. Therefore, the way to minimize noise is to reduce the bias current of the active filter. For graphical comparison, Fig. 7 shows measured relative output spectrum in overlaid and zoomed view.

V. CONCLUSION

A 10-GHz oscillator utilizing a high-Q active filter was proposed. The oscillator has a high-Q property for low phase noise without using the 3-D passive resonator. The measured result showed 3–10 dB phase noise reduction in comparison with the use of the passive filter. This result exhibits a potential prospect of the AFO as a low-cost and a low-phase noise oscillator due to its fully compatibleness with the MMIC.

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