Monolithic VCO Using A Novel Active Inductor

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ABSTRACT

A novel high-Q tunable active inductor utilizing a common-source cascode FET with a lossy active inductor feedback is described. Using this active inductor, we propose a monolithic VCO with a frequency tuning range from 1.66 GHz to 2.2 GHz in a compact area of 0.7 x 1.2 mm^2.

INTRODUCTION

To replace a low-Q spiral inductor with high-Q tunable one in MMICs, a number of researches have been done. Hara et al. reported a simple but lossy active inductor using a common-source cascode FET with a resistive feedback [1]. Later, it was extended to the common-gate FET feedback topology [2-4]. In other approaches, active inductors were realized with negative resistance technique, where an inductance was employed in the feedback loop of a common-collector BJT [5] or a common-drain FET [6] to compensate for the loss of the inductor . However, a bandpass filter using the approach resulted in large chip size due to large spiral feedback inductors and required the integration of varactors for center frequency tuning [6].

In this paper, a new active inductor is proposed and applied to the design of a monolithic VCO. Instead of a large spiral inductor, we introduce a compact lossy active inductor in the feedback loop of a common-source cascode FET to achieve high Q-factor and tunability.

INDUCTOR DESIGN

In the proposed active inductor shown in Fig. 1 the resistive feedback of common-source FET [1] is substituted by the resistive and inductive feedback to realize high Q-factor. C_t, R_f and L_f are external gate-source capacitance, feedback resistance and inductance, respectively, and the other elements are intrinsic to FET. The impedance Z of this active inductor is given by

$$\mathrm{Re}[Z] = \frac{\left(1-\frac{\omega^2}{\omega_r^2}\right)\left(1-\frac{\omega^2}{\omega_g\omega_f}\right)\left(\frac{1}{g_m}\right)+\frac{\omega^2}{\omega_g^2}R_f}{\left(1-\frac{\omega^2}{\omega_g\omega_f}\right)^2+\frac{\omega^2}{\omega_g^2}}$$

$$\mathrm{Im}[Z] = \frac{\omega}{\omega_g}\frac{\left(1-\frac{\omega^2}{\omega_g\omega_f}\right)R_f-\left(1-\frac{\omega^2}{\omega_r^2}\right)\left(\frac{1}{g_m}\right)}{\left(1-\frac{\omega^2}{\omega_g\omega_f}\right)^2+\frac{\omega^2}{\omega_g^2}}$$

where $\omega_r = [1/L_f(C_{gs} + C_t)]^{1/2}$, $\omega_g = g_m/(C_{gs} + C_t)$ and $\omega_f = 1/R_fC_{ds}$. From these equations it is can be shown that the inductance and series resistance of the inductor can be controlled by R_f and L_f. In the frequency range where $\omega_r^2 <$

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$\omega^2 < \omega_g \omega_f$, resistance of the inductor can be zero or negative and inductance larger than that of the single resistive-feedback inductor.

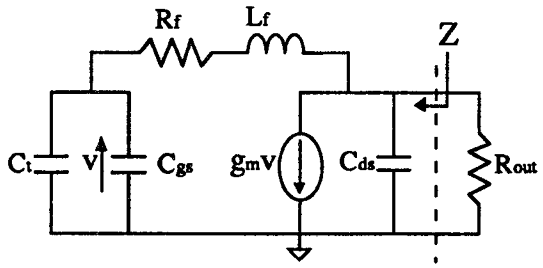

Fig. 1. Common-source FET with resistive and inductive feedback.

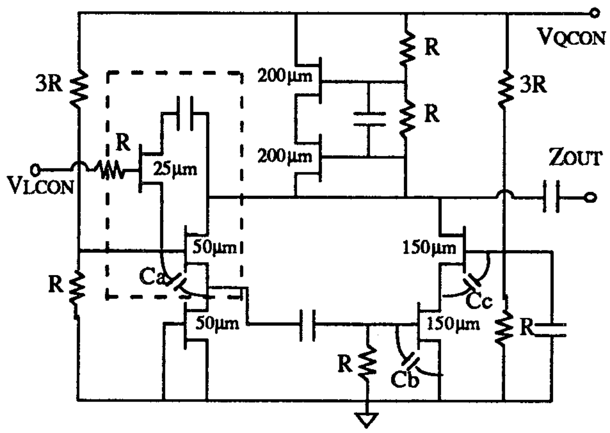

Fig. 2. Schematic diagram of the proposed high-Q tunable active inductor.

Fig. 2 shows the circuit diagram of the proposed active inductor. C_a, C_b and C_c are external gate-source capacitors for capacitance tuning, and the other passive elements are biasing resistors and DC-blocking or AC-bypassing capacitors. A cascode FET is used to increase the output resistance of biasing circuit. The used FETs have the nominal gate length of 1µm and the current cutoff frequency of 12 GHz. The dashed box indicates the lossy active inductor with a variable resistor feedback, which is used as the resistive and inductive feedback of the common-source cascode FET. By controlling the gate voltage of a cold FET, the feedback resistance and inductance are varied and the high-Q tunable inductor is realized in the limited frequency range.

Circuit simulation was accomplished through the use of the EEsof software with measured data. Simulated tuning charateristics of inudctance and Q-factor are shown in Fig. 3 and Fig. 4. At the frequency of 1.9 GHz, the

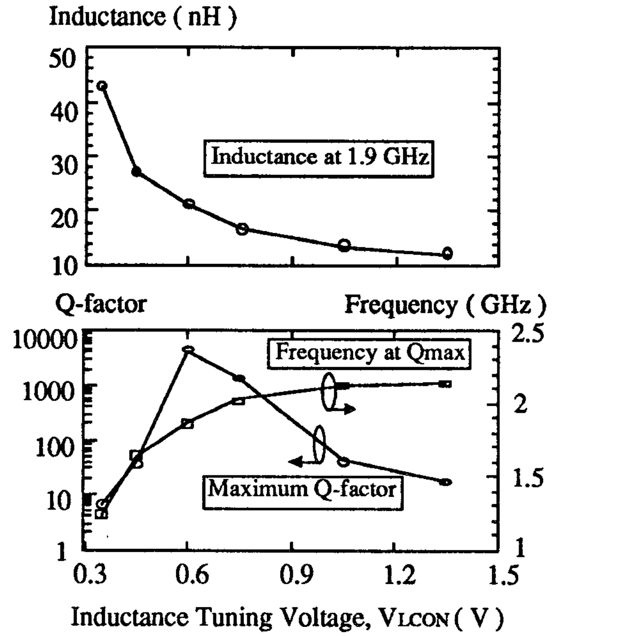

Fig. 3. Simulated inductance tuning charateristics of the active inductor.

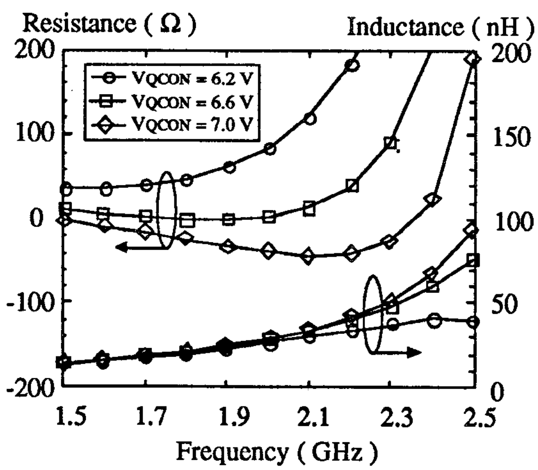

Fig. 4. Simulated Q-factor tuning charateristics of the active indutor.

inductance is varied from 12 nH to 43 nH and the series resistance from 60 Ω to -32 Ω with 9 % inductance change. It should be noted that inductance and Q-factor can be independently controlled by two bias voltages, V_{LCON} and V_{QCON}.

VCO APPLICATION

The proposed new active inductor was applied to the design of a monolithic VCO. The circuit schematic is given in Fig. 5. For the oscillator circuit, a conventional Colpitts topology was chosen with the high-Q tunable active inductor as a part of oscillation frequency tuning resonator. High Q-factor of the resonator is indispensable for easy oscillation and low phase noise. Ouput signal of the oscillator is coupled to 50 Ω load through a source follower with 50 Ω output resistance. As shown in Fig. 6, the frequency tuning range of 1.66 GHz to 2.2 GHz and the output power of -2.7 dBm to -1.2 dBm were achieved in the circuit simulation. The mask layout of the designed VCO is shown in Fig. 7. No spiral inductor was used to reduce chip size. The chip size is 0.7 x 1.2 mm^2 including an active inductor with a compact 0.5 x 0.6 mm^2 area.

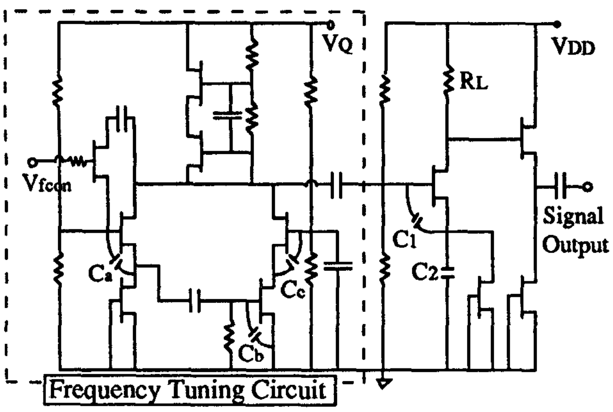

Fig. 5. Circuit diagram of the proposed VCO.

CONCLUSION

We have proposed a new high-Q tunable active inductor for L, S-band MMIC applications. The tunability of inductance and Q-factor was proved by the circuit simulation. Using this active inductor, we have designed a monolithic VCO operating at the frequency from 1.66 GHz to 2.2 GHz in a compact chip size.

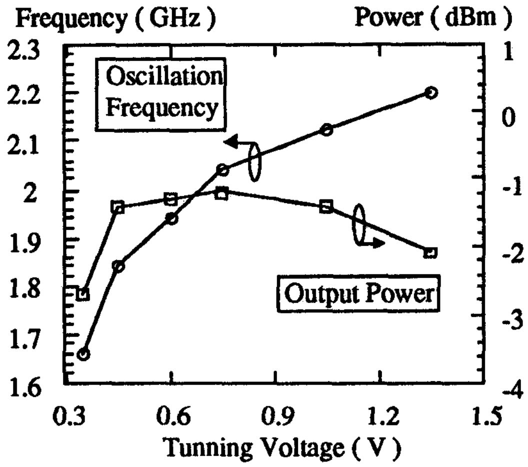

Fig. 6. Simulated performances of the VCO.

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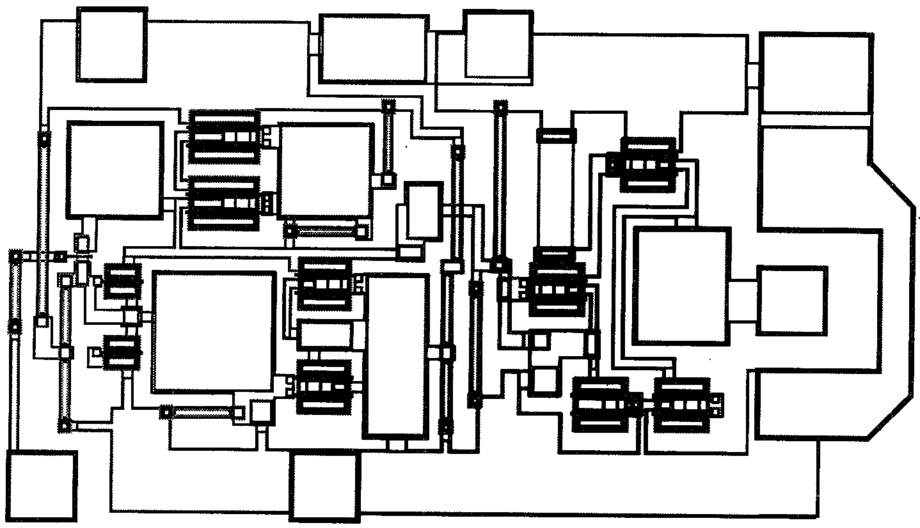

Fig. 7. The layout of the designed VCO.