77 GHz VCO Design Using a Coupled-Line Inductor with Spiral-Shaped EBG Structure

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***Abstract* — This paper includes 77 GHz VCO design using a coupled-line inductor with spiral-shaped electromagnetic band-gap (EBG) structure. The coupled-line inductor enhances Q due to its low substrate loss. Thus, phase noise performances of VCO can be improved. However, the length of coupled-line will be long owing to its low inductance per unit length. EBG structure is applied to reduce its size. The 3-D EM simulation is performed to show its enhancement of inductance and Q. The simulated inductance and Q of proposed coupled-line with EBG structure are 114.0 pH and 30.70 at 77 GHz, respectively. The VCO core is designed with proposed coupled-line inductor.**

***Index Terms* — VCO, Electromagnetic Bandgap (EBG), Coupled-Line Inductor**

I. INTRODUCTION

As performance of CMOS device has been recently improved, CMOS technology can be applied to millimeter-wave circuits such as 77-GHz automotive radar systems. In the case of voltage-controlled oscillators (VCOs), it is great concern to achieve low phase noise performance because the VCO significantly affects the sensitivity of a system which requires a fast tuning speed, such as radar systems.

To improve phase noise characteristics of VCO, enhancing resonator quality factor (Q) has been considered significant. Conventional on-chip loop inductor or transmission line inductor has low Q factor owing to its serious substrate loss at millimeter-wave frequency. Differential coupled-line can reduce losses, but length of the line will be long due to its low inductance per unit length. To increase inductance and Q of the coupled-line, electromagnetic bandgap (EBG) structure which is periodic made of dielectrics or metals is applied. EBG structure has been widely applied not only to suppress the surface waves as EBG structure prevents the spreading of surface waves in gap band area [1] or to design a slow-wave microstrip line with low insertion loss and wide stop-band [2], but also to increase inductance and Q of inductors [3]. By applying this technique to ground plane, the length of the coupled-line inductor can be reduced.

Therefore, this paper represents a 77 GHz VCO using high-Q coupled-line inductor with EBG structure.

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Ministry of Science, ICT & Future Planning (MSIP) (No. 2009-0083495).

II. COUPLED-LINE DESIGN

Fig. 1(a) shows designed coupled-line inductor with EBG structure. The coupled-line can be modeled using the familiar differential LRCG network as depicted in Fig. 1(b) where L, C, R, and G are inductance, capacitance, series resistance, and shunt conductance per unit length, respectively. Smaller R corresponds to less series loss; smaller G corresponds to less shunt loss. The series and shunt losses due to R and G directly affect coupled-line Q [4]. Width of the line, gap between two lines, and length of the line are 5 μm, 4 μm, 200 μm, respectively. Replacing the uniform ground plane of the conventional coupled-line inductor with spiral-shaped EBG ground plane creates increased inductance and Q.

Fig. 2(a) is the coupled-line inductor with uniform ground plane. Fig. 2(b) shows the coupled-line inductor without ground plane. Fig. 2(c) is the graph of EM-simulated inductance and Q. It is clearly shown that the inductance and Q are increased by using EBG structure ground plane. Inductance of proposed coupled-line inductor is 114 pH, coupled-line inductor without ground plane is 98.5 pH, coupled-line inductor with uniform ground plane is 84.2 pH at 77 GHz. The Q is 30.7, 27.3, and 18.5, respectively. By using spiral-shaped EBG structure, inductance is increased about 16 % and Q is increased about 12.5 % compared to without spiral-shaped EBG structure (no ground plane).

III. CIRCUIT DESCRIPTION AND RESULTS

Fig. 3 is a schematic of a designed 77 GHz VCO core and a buffer with injection-locking (IL) technique which means that the oscillator output frequency is locked into the injected periodic continuous signal frequency [5]. LC resonator of the core consists of the proposed coupled-line inductor with spiral-shaped EBG structure and varactor pair. The buffer is composed of small transistors (M1, M2) to inject VCO signal to oscillating buffer, a large sized cross-coupled pair to generate high output power, and differential-to-single balun. Therefore, the designed IL buffer can operate not only a buffer but also a driver amplifier [6].

The simulated VCO performances are shown in Table 1. In order to reduce error between simulation and measurement, circuits are designed by measured transistor model and full-EM simulated passive networks including metal routing. The process is 1P8M 65 nm CMOS.

IV. CONCLUSION

In this paper, 77 GHz VCO design using a coupled-line inductor with spiral-shaped EBG structure is proposed. The coupled-line has high Q property due to low loss but the line length will be long. Thus, EBG structure is applied to the coupled-line inductor to reduce the line length. EM-simulated line inductance and Q is 114.0 pH and 30.70, respectively. FOM of the designed VCO with the proposed line inductor is -190.17. This work offers encouraging prospects for millimeter wave VCOs.

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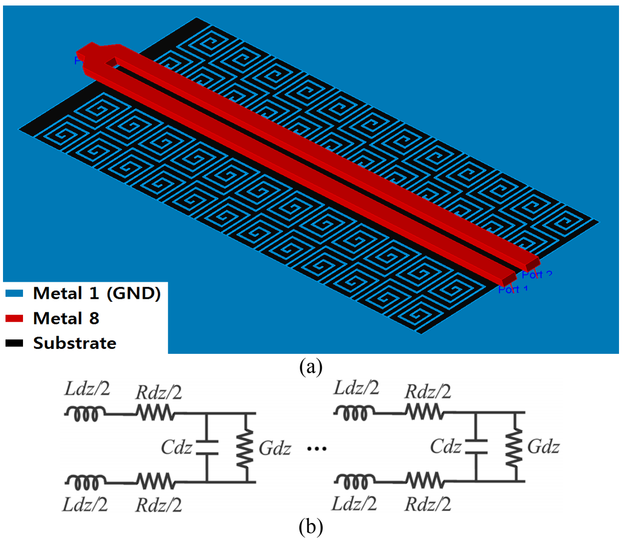

Figure 1. (a) Designed coupled-line inductor with EBG structure.
(b) Differential LRCG model for the coupled-line.

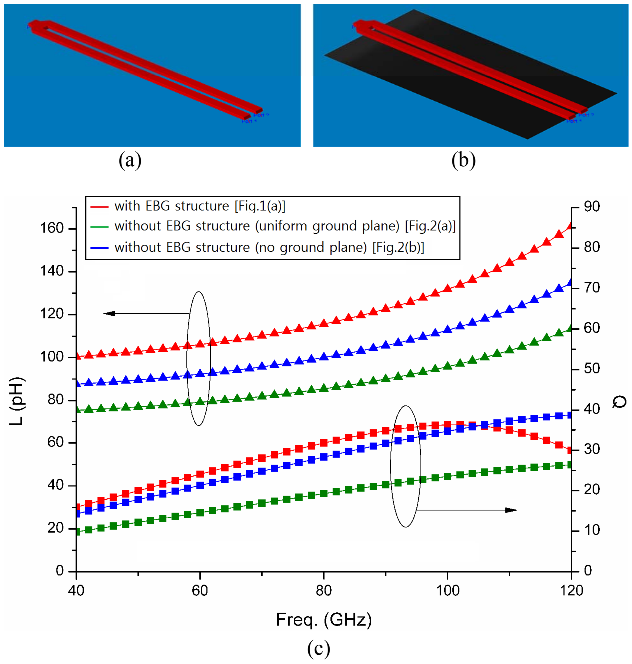

Figure 2. (a) Coupled-line inductor with uniform ground plane.
(b) Coupled-line inductor without ground plane.
(c) EM-simulated inductance and Q.

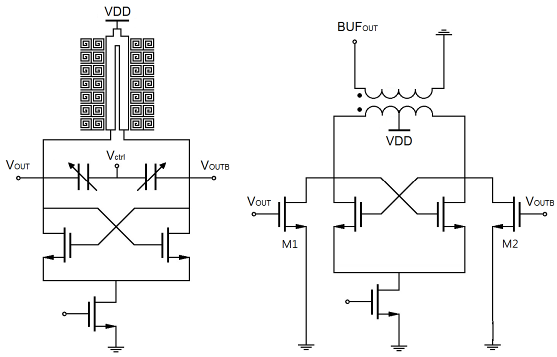

Figure 3. Schematic of designed VCO and IL buffer

TABLE I. SUMMARY OF DESIGNED VCO

Technology	1P8M 65nm CMOS
Center frequency	77 GHz
Tuning range	2.2 GHz
Phase noise @ 1MHz offset	-95 dBc/Hz
P_{out}	3.7 dBm
DC power consumption	Core 1.8 mW / Buffer 31.8 mW
FOM	-190.17

$$FOM = L\{\Delta f\} + 10\log\left[\left(\frac{\Delta f}{f_{osc}}\right)^2 \cdot P_{dc}\right]$$