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Triple-Band SiGe HBT Clapp and Hartley Oscillators Using Stacked Element-Selective Transistors

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Abstract

This paper presents triple-band SiGe HBT Clapp and Hartley oscillators for the next generation multi-band and multi-mode wireless radios. The oscillators connect a stacked element-selective transistor in parallel with two circuit elements and can provide a triple-band oscillation by switching only two circuit elements. The stacked element-selective transistor is a two-terminal device with base and collector short-circuited and thus can provide three different conditions of open, short and small capacitance. A triple-band oscillation becomes available by using these conditions. The implemented 0.35 μm SiGe HBT Clapp VCO has achieved a low-band oscillation of 0.81 GHz, a middle-band oscillation of 0.92 GHz, and a high-band oscillation of 1.01 GHz. The phase noise at 100 kHz offset varies from -93 to -102 dBc/Hz. On the other hand, the implemented 0.35 μm SiGe HBT Hartley VCO has achieved a low-band oscillation of 0.98 GHz, a middle-band oscillation of 1.04 GHz, and a high-band oscillation of 1.22 GHz. The phase noise at 100 kHz offset varies from -84 to -94 dBc/Hz.

Keywords: microwaves, multi-band, Clapp oscillator, Hartley oscillator, stacked element-selective transistor, SiGe HBT

1 Introduction

Multi-band and multi-mode VCOs have gathered much attention in the next generation multi-band and / or multi-mode wireless radios for a miniaturized size

of the circuit and module [1], [8]. Up to now, a variety of multi-band VCOs had been reported: a traveling wave VCO [2], an active inductor VCO [9], a transformer-coupled VCO [7] and a triple-band frequency generator using QVCO and Gilbert cell mixers [10]. Indeed, these VCOs can provide excellent multi-band performances, but require a number of circuit elements. Therefore, the circuit becomes much complicated in configuration, large in size and lossy in performance. In order to address these problems, the authors have presented novel switching techniques and multi-band resonators: a supply voltage switching [4], a forward / backward-bias switching [3], and a reconfigurable multi-band resonator [5]. As an alternative design approach, the authors have also shown a triple-band cross-coupled differential VCO with stacked element-selective transistors [6]. It has provided a triple-band oscillation by switching only two circuit elements. In this paper, the design, simulation, fabrication and, performance of the triple-band Clapp and Hartley oscillators using the stacked element-selective transistors are presented.

2 Circuit Design and Simulation

A schematic diagram of the triple-band Clapp and Hartley oscillators using the stacked element-selective transistors is shown in Fig. 1. The oscillators employ a common-collector configuration and thus an output signal can be derived from the emitter. Q_1 is a common-collector transistor and R_E is an emitter resistor for controlling a total current. L_C is a shunt coil for controlling a negative impedance generation. R_{B1} and R_{B2} is a base bias resistor. C_C is a decoupling capacitor. The oscillators employ a triple-band resonator comprised of a parallel LC circuit (L_1, L_2, C_1, C_2, and C_3) and stacked element-selective transistors (Q_2, Q_3). The stacked element-selective transistors are a two-terminal device with base and collector short-circuited and thus can provide three different conditions of open, short and small capacitance. A triple-band oscillation becomes available by using these conditions. V_C is a control voltage. A triple-band resonation can be obtained by setting a control voltage of V_C to -1V, 0V or +1V.

A schematic diagram of the triple-band Clapp and Hartley resonators using the stacked element-selective transistors is demonstrated in Fig. 2. The stacked element-selective transistors provide three different resonators. For V_C = -1V, Q_3 is short and Q_2 is open. That is, only L_1 is selected in Clapp-type and only C_1 is selected in Hartley-type. On the other hand, for V_C = +1V, Q_2 is short and Q_3 is open. That is, only L_2 is selected in Clapp-type and only C_2 is selected in Hartley-type. For V_C = 0V, both Q_2 and Q_3 become small capacitance. That is, both L_1 and L_2 are selected in Clapp-type and both C_1 and C_2 are selected in Hartley-type. A low-band resonant frequency (f_L), a middle-band resonant frequency (f_M) and a high-band resonant frequency (f_H) can be given as follows:

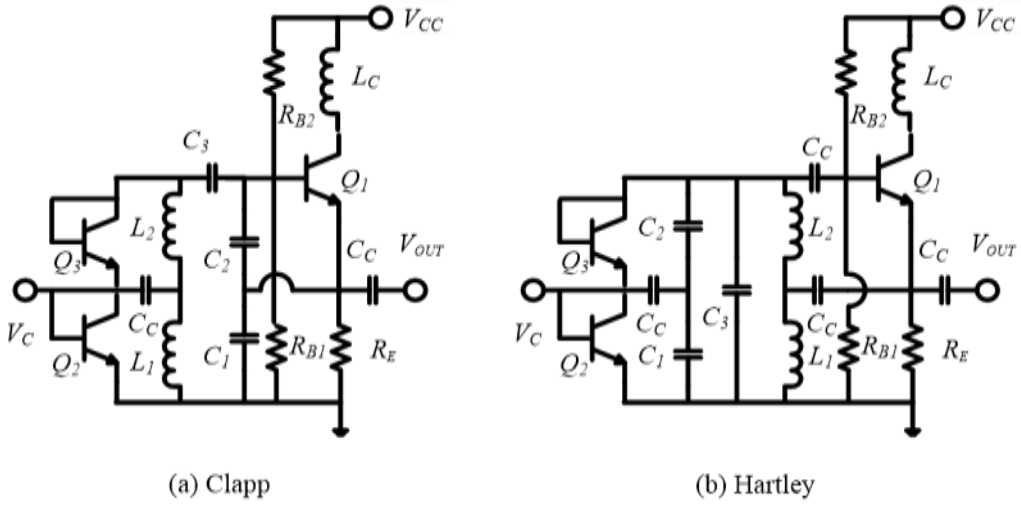


Fig. 1 Schematic diagram of the triple-band Clapp and Hartley oscillators using the stacked element-selective transistors.

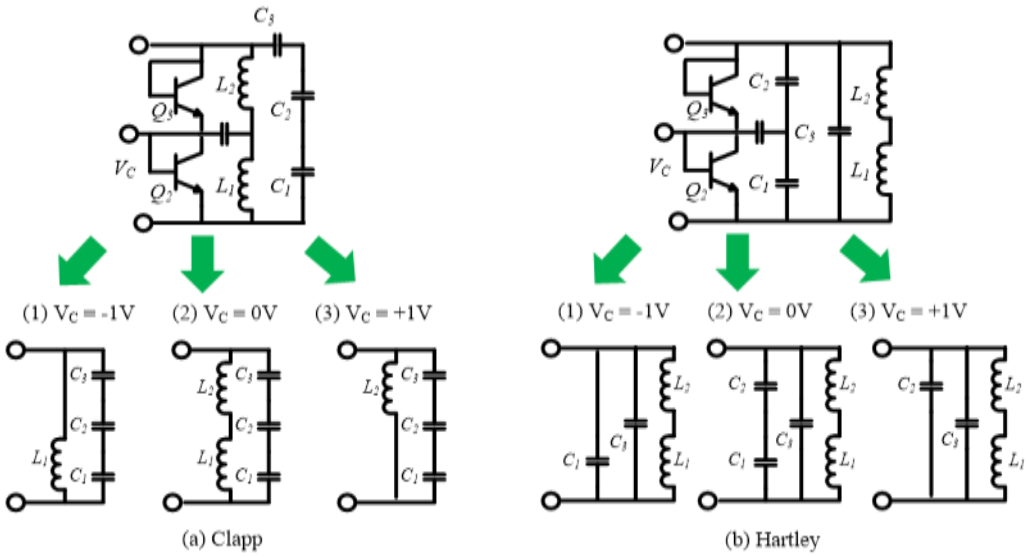


Fig. 2 Schematic diagram of the triple-band Clapp and Hartley resonators using the stacked element-selective transistors.

< Clapp-type >

$$f_L = \frac{1}{2\pi}\sqrt{\frac{1/C_1 + 1/C_2 + 1/C_3}{L_1 + L_2}} \tag{1}$$

$$f_M = \frac{1}{2\pi}\sqrt{\frac{1/C_1 + 1/C_2 + 1/C_3}{L_2}} \tag{2}$$

$$f_H = \frac{1}{2\pi}\sqrt{\frac{1/C_1 + 1/C_2 + 1/C_3}{L_1}} \tag{3}$$

< Hartley-type >

$$f_L = \frac{1}{2\pi\sqrt{(L_1 + L_2)(C_2 + C_3)}} \tag{4}$$

$$f_M = \frac{1}{2\pi\sqrt{(L_1 + L_2)(C_1 + C_3)}} \tag{5}$$

$$f_H = \frac{1}{2\pi}\sqrt{\frac{C_1 + C_2}{(L_1 + L_2)(C_1C_2 + C_2C_3 + C_3C_1)}} \tag{6}$$

It is assumed in Equations (1) to (6) that L_1 is smaller than L_2 for Clapp-type and that C_1 is smaller than C_2 for Hartley-type. The circuit element values consisting of the triple-band resonator are summarized in Table 1 for Clapp-type and Table 2 for Hartley-type, respectively. f_L, f_M and, f_H are calculated by using Equations (1) to (6) as well as Tables 1 and 2. The calculated results are plotted in Fig. 3 for Clapp-type and Fig.4 for Hartley-type. It is clearly demonstrated that a triple-band resonation has been obtained by switching a control voltage of V_C.

Table 1 Circuit element values of Clapp-type.

Element	Value	Element	Value
C_1 [pF]	6	C_C [pF]	1000
C_2 [pF]	7	L_1 [nH]	5.1
C_3 [pF]	3	L_2 [nH]	7.5

Table 2 Circuit element values of Hartley-type.

Element	Value	Element	Value
C_1 [pF]	1.5	L_1 [nH]	1
C_2 [pF]	3	L_2 [nH]	1
C_C [pF]	1000		

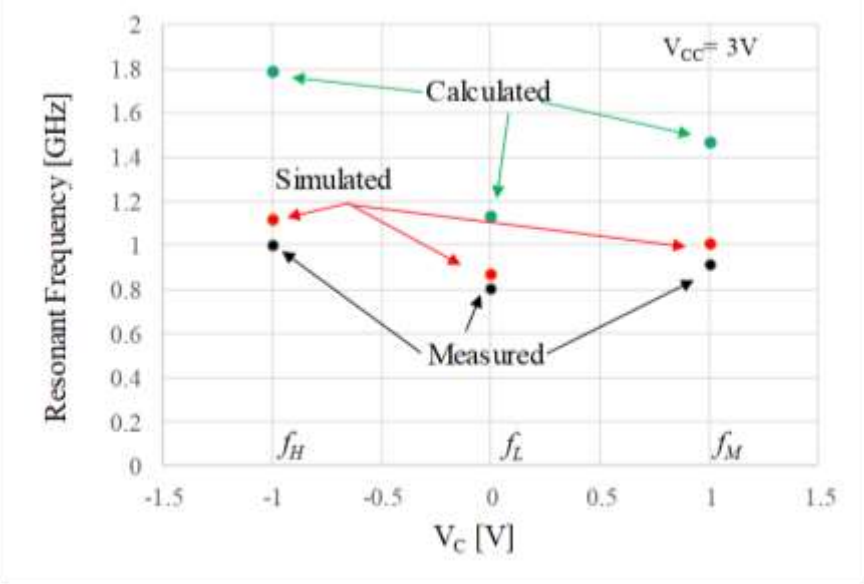


Fig. 3 Calculated, simulated and measured resonant frequencies of Clapp-type.

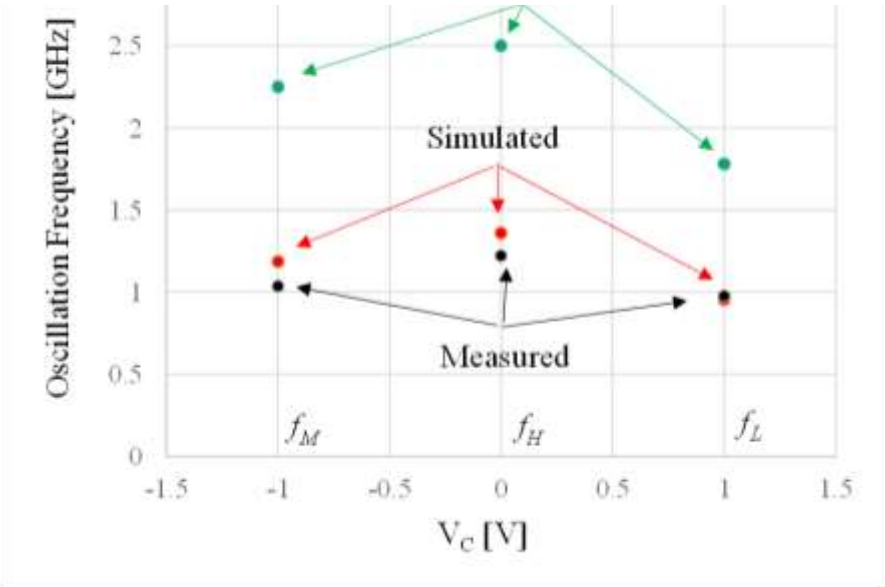
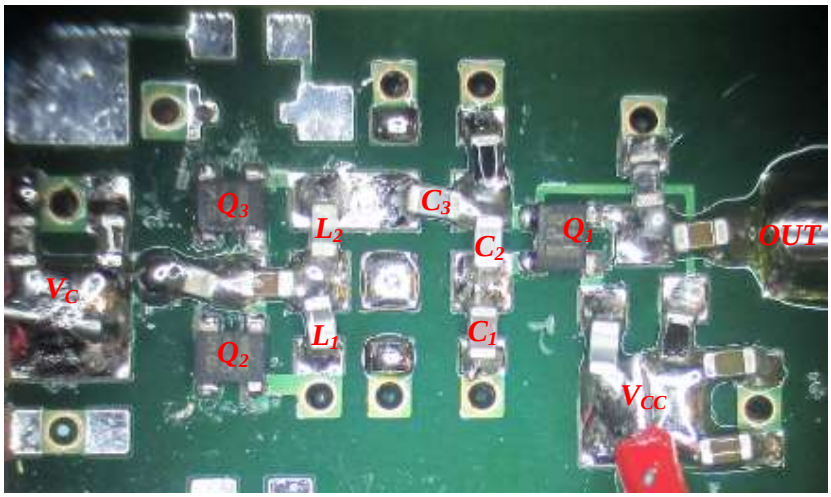


Fig. 4 Calculated, simulated and measured resonant frequencies of Hartley-type.

The circuit simulation has been accomplished for the schematic diagram of Fig. 1 by using ADS of Keysight Technologies. The simulated oscillation frequencies are also plotted in Figs. 3 and 4. The simulated oscillation frequencies become lower than the calculated resonant frequencies. It is because the intrinsic and parasitic elements of chip and distributed devices are actually included in the simulation. The precise nonlinear transistor model is also taken into account in the simulation. In the simulation, a supply voltage of V_{CC} was determined as 3V.

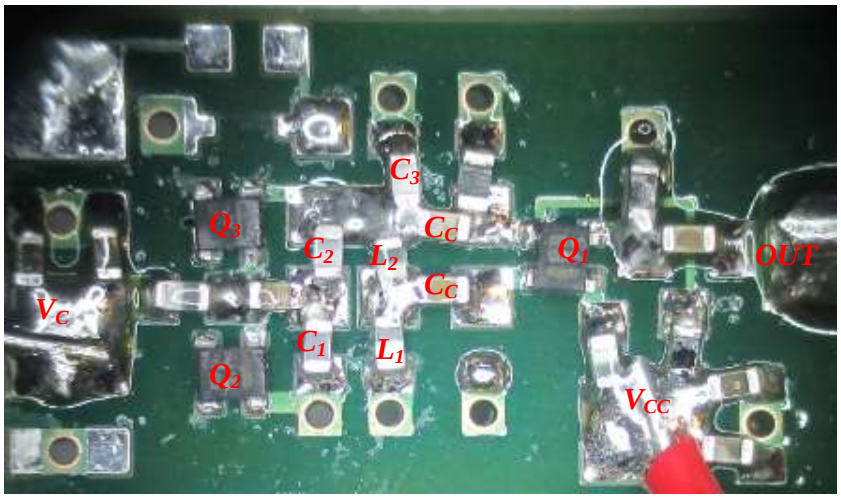
3 Circuit Fabrication and Performance

Photographs of the triple-band Clapp and Hartley oscillators using the stacked element-selective transistors are depicted in Figs. 5 and 6, respectively. The oscillators were fabricated on the FR-4 substrate with a dielectric constant of 4.4@1GHz and a tanδ of 0.016@1GHz. 1005-type chip resistors, capacitors, and inductors are mounted on the substrate by soldering. A surface mount type of the 0.35μm SiGe HBT with an f_t of around 25 GHz (Toshiba MT4S102T) is used as an oscillator device as well as a switching device. The circuit size is 8 x 14 x 1.2 mm^3, respectively.



8 x 14 x 1.2 mm^3

Fig. 5 Photograph of the triple-band Clapp oscillator.



8 x 14 x 1.2 mm^3

Fig. 6 Photograph of the triple-band Hartley oscillator.

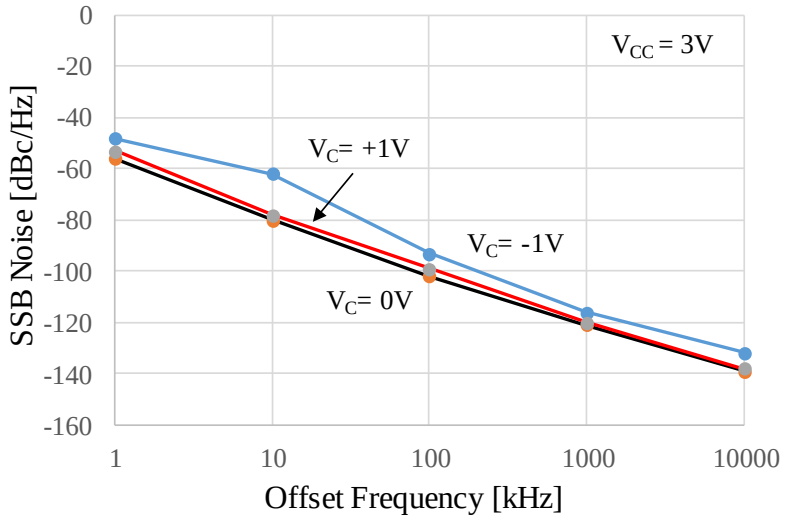


Fig. 7 Measured SSB noise of the triple-band Clapp oscillator.

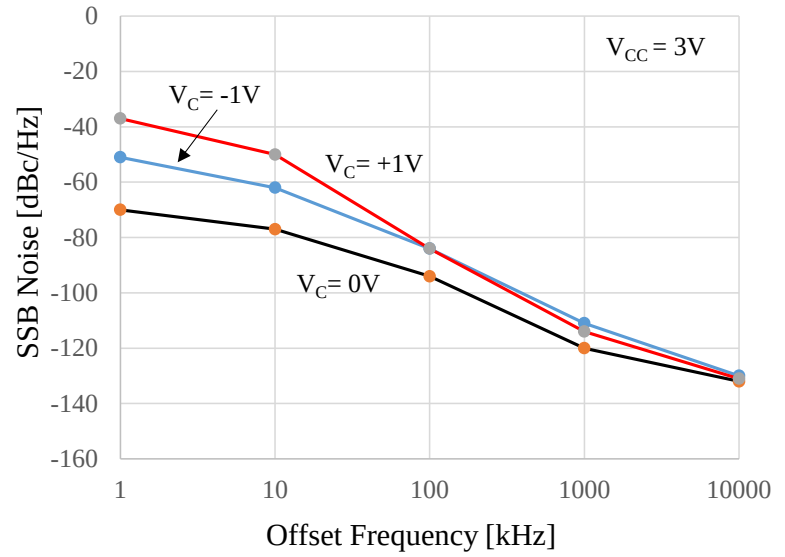


Fig. 8 Measured SSB noise of the triple-band Hartley oscillator.

Measured oscillation frequencies are also shown in Figs. 3 and 4, respectively. The triple-band Clapp VCO has achieved a low-band oscillation of 0.81 GHz, a middle-band oscillation of 0.92 GHz, and a high-band oscillation of 1.01 GHz. On the other hand, the triple-band Hartley VCO has achieved a low-band oscillation of 0.98 GHz, a middle-band oscillation of 1.04 GHz, and a high-band oscillation of 1.22 GHz. The measured and simulated oscillation frequencies are in good agreement for three different conditions. Measured SSB (Single Side Band) noise of the triple-band Clapp oscillator ware shown in Fig. 7. The phase noise at 100 kHz offset varies

from -93 to -102 dBc/Hz. Measured SSB (Single Side Band) noise of the triple-band Hartley oscillator ware shown in Fig. 8. The phase noise at 100 kHz offset varies from -84 to -94 dBc/Hz.

6 Conclusions

Design, simulation, fabrication and, a performance of the triple-band SiGe HBT Clapp and Hartley oscillators using the stacked element-selective transistors have been demonstrated. It has been clearly shown that a triple-band oscillator becomes available by switching only two circuit elements with the use of the stacked element-selective transistors. The stacked element-switching technique introduced in this paper would be one candidate for miniaturization of the multi-band oscillations for use in the next generation multi-band and / or multi-mode wireless radios.

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