An S/C-Band SiGe HBT Differential VCO Using a Novel HPF-Type Resonator Comprised of the Chip Inductors for a Higher Oscillation Frequency

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Abstract

An S/C-band SiGe HBT differential VCO has been developed for the next generation wireless radios. It employs a novel HPF-type resonator having a parallel LC circuit in place of the conventional series capacitance to achieve a higher oscillation frequency. This resonator can be constructed from only the chip inductors with the use of their parasitic capacitance to achieve a miniaturized size. The differential oscillator, which employs a novel HPF-type resonator with triple 1005-type 1nH chip inductors and 0.35μm SiGe HBTs with an f_t of 25GHz, has achieved an oscillation frequency of 4.21GHz, an output power of -16.5dBm, a current of 2.67mA, and a phase noise of -104dBc/Hz at 100kHz offset for a V_{CC} of 3V. As compared with the case using the conventional HPF-type resonator, the oscillation frequency becomes around 0.91GHz higher. The differential VCO, which employs a Si varactor diode with a capacitance ratio of 2.5, has achieved an oscillation from 3.36 to 4.03GHz, an output power of greater than -16.8dBm, a current of less than 2.93mA, and a phase noise of less than -100dBc/Hz at 100kHz offset for a V_{CC} of 3V. This is the first report on the differential VCO using only chip inductors as a resonator element.

1. Introduction

The frequency used in the recent wireless radios has come up to C/X-band including 5.2GHz of Wireless LAN [1], 5.8GHz of WiMAX [2], and 7.2 to 10.2GHz of UWB [3]. In order to achieve a higher oscillation frequency of the differential VCO, the resonant frequency of the HPF-type resonator in addition to the cutoff frequency of the device need to be increased. Especially for the differential VCO using the commercially available chip inductors or capacitors, the oscillation frequency is restricted to the value of chip inductors or capacitors. As for the 1005-type chip inductors or capacitors, the minimum values are generally 1nH and 0.3pF, which gives around 6.5GHz of resonant frequency. To achieve a higher oscillation frequency, the inductors have to be combined in parallel or the capacitors connected in series, which makes the circuit loss and size larger. As an alternative method, the multi-band resonator [4] can produce a higher resonant frequency. The additional multi-band element, however, also makes the circuit loss and size larger. To address this problem, a novel HPF-type resonator for a higher oscillation frequency is presented. It employs a parallel LC circuit in place of the conventional series capacitance, which provides a higher resonant frequency. The parallel LC circuit can be easily constructed from a single chip inductor since it has a parasitic capacitance in parallel. The differential oscillator, which employs a novel HPF-type resonator with triple 1005-type 1nH chip inductors and 0.35μm SiGe HBTs with an f_t of 25GHz, has achieved an oscillation frequency of 4.21GHz, an output power of -16.5dBm, a current of 2.67mA, and a phase noise of -104dBc/Hz at 100kHz offset for a V_{CC} of 3V. As compared with the case using the conventional HPF-type resonator, the oscillation frequency becomes around 0.91GHz higher. The differential VCO, which employs a Si varactor diode with a capacitance ratio of 2.5, has achieved an oscillation from 3.36 to 4.03GHz, an output power of greater than -16.8dBm, a current of less than 2.93mA, and a phase noise of less than -100dBc/Hz at 100kHz offset for a V_{CC} of 3V. The novel HPF-type resonator presented in this paper would be one of the candidates for achieving a higher oscillation frequency of the differential VCO without degrading the circuit size and performance.

2. Differential Oscillator Using a Novel HPF-Type Resonator

A schematic diagram of the differential oscillator using the conventional or a novel HPF-type resonator is shown in Fig. 1. In contrast with the conventional HPF-type resonator shown in Fig. 1(a), the novel HPF-type resonator shown in Fig. 1(b) employs the chip inductor represented as a parallel LC circuit (L_2, C_1) in the series branch. These resonators have a resonant frequency of f_1, f_2 and a band-stop frequency of f_3 shown in Fig. 1(c), which are given as the following equations:

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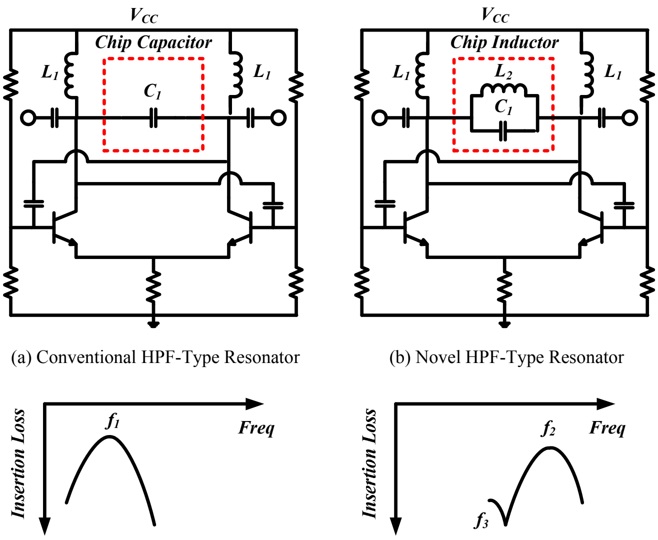

(a) Conventional HPF-Type Resonator (b) Novel HPF-Type Resonator

(c) Frequency Responses of the Resonator

Fig. 1 Schematic diagram of the differential oscillator using the conventional or a novel HPF-type resonator

$$f_1 = \frac{1}{2\pi\sqrt{2L_1C_1}} \tag{1}$$

$$f_2 = \frac{1}{2\pi}\sqrt{\left(\frac{1}{2L_1C_1} + \frac{1}{L_2C_1}\right)} \tag{2}$$

$$f_3 = \frac{1}{2\pi\sqrt{L_2C_1}} \tag{3}$$

As clearly shown in Equations (1) to (3), the resonant frequency f_2 is higher than f_1 as well as f_3, which demonstrates that the oscillation frequency can be increased with the use of the chip inductor in place of the chip capacitor. L_2 and C_1 of the 1005-type chip inductors (1.0 x 0.5 mm^2) with an inductance value from 1 to 100nH are summarized in Table 1. Based on the data in Table 1, f_1, f_2 and f_3 are calculated and plotted in Fig. 2. In the calculation of f_1, L_1 and C_1 are assumed to be 1nH and 0.3pF as a realizable minimum value. It is clearly shown that f_2 becomes much higher than f_1 as the inductance value becomes smaller.

Table 1 L_2 and C_1 of the 1005-type chip inductors

L [nH]	L2 [nH]	C1 [pF]
100.0	98.0	0.270
82.0	82.0	0.220
68.0	68.0	0.190
56.0	56.0	0.180
47.0	47.0	0.175
39.0	38.0	0.170
27.0	26.0	0.160
22.0	22.0	0.150
15.0	14.0	0.140
10.0	10.0	0.135
5.6	5.6	0.130
3.0	3.0	0.100
2.0	1.9	0.100
1.0	0.9	0.100

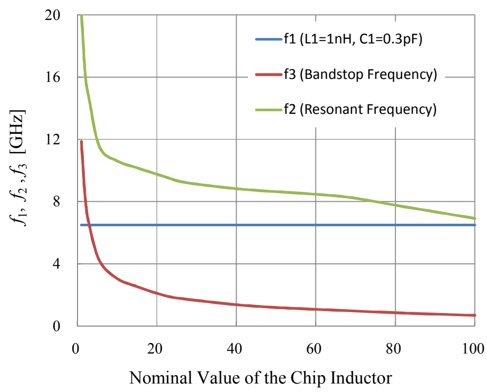

Fig. 2 Calculated f_1, f_2 and f_3

In order to make sure the usefulness of the novel HPF-type resonator, the differential oscillators have been designed, fabricated and tested. The differential oscillator employs 1005-type chip inductors, capacitors and resistors as a circuit element, a surface mount type of SiGe HBTs (Toshiba MT4S102T) and Si varactor diodes (Philips BB145) as a semiconductor device. Measured oscillation frequency, output power and current are shown in Fig. 3. The differential oscillator has achieved the maximum oscillation frequency of 4.21GHz, an output power of -16.5dBm, a current of 2.67mA, and a phase noise of -104dBc/Hz at 100kHz offset for a V_{CC} of 3V. The oscillation frequency of the differential oscillator using the conventional HPF-type resonator was 3.3GHz for a V_{CC} of 3V. Thus the oscillation frequency becomes 0.91GHz higher with the use of the novel HBF-type resonator. Moreover, phase noise performance was compared for the differential oscillator with the chip capacitor of 0.3pF in Fig. 1(a) and that with the chip inductor of 100nH in Fig. 1(b), which have nearly the same value for C_1. The measured results are shown in Fig. 4. There was no distinct difference between both oscillators.

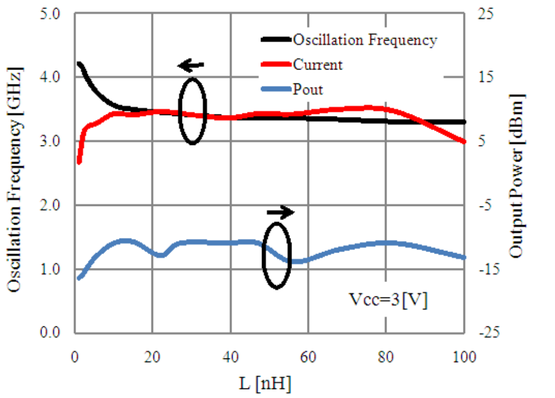

Fig. 3 Measured oscillation frequency, output power and current of the differential oscillator

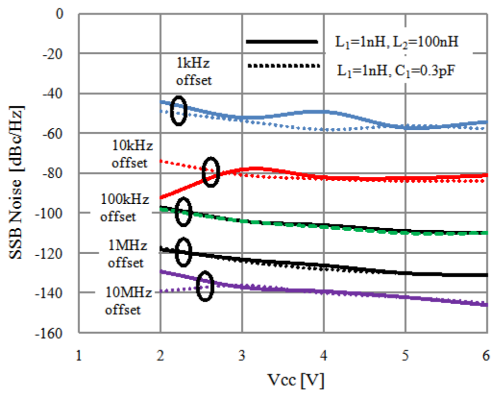

Fig. 4 Measured phase noise performance with a parameter of V_{CC}

3. Differential VCO Using a Novel HPF-Type Resonator

A schematic diagram of the differential VCO using the novel HPF-type resonator is shown in Fig. 5. A back-to-back configuration of the varactor diodes is connected in parallel with the novel HPF-type resonator. The varactor diode (Philips BB145) employed in the VCO has a capacitance ratio of 2.5. V_C is a control voltage of the varactor diode. A photograph of the differential VCO is shown in Fig. 6. The differential VCO was fabricated on FR-4 substrate. 1005-type chip inductors, capacitors, a surface mount type of SiGe HBTs (Toshiba MT4S102T) and Si varactor diodes (Philips BB145) are mounted on the substrate by soldering. The circuit size is 13 x 14 x 1.2 mm^3.

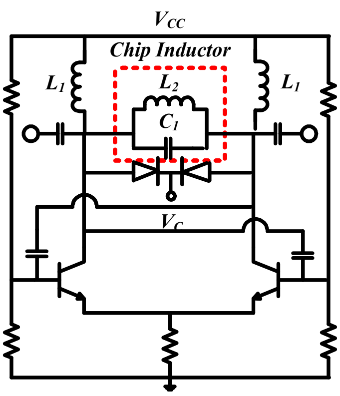

Fig. 5 Schematic diagram of the differential VCO using a novel HPF-type resonator

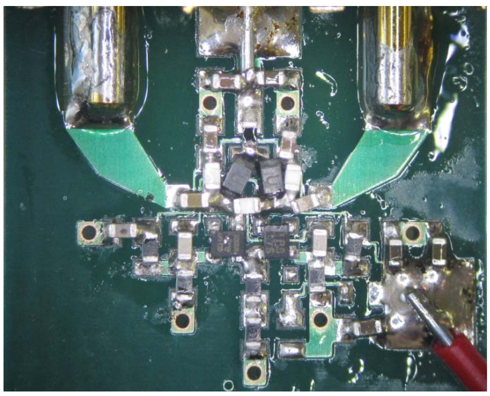

Fig. 6 Photograph of the differential VCO using a novel HPF-type resonator

Measured oscillation frequency, output power and current are shown in Fig. 7 as well as phase noise in Fig. 8. The control voltage of V_C was varied from 4 to 9V for a V_{CC} of 3V. The differential VCO has achieved an oscillation from 3.36 to 4.03GHz, an output power of greater than -16.8dBm, a current of less than 2.93mA, and a phase noise of less than -100dBc/Hz at 100kHz offset.

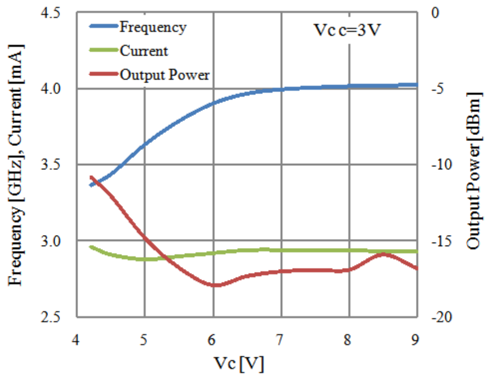

Fig. 7 Measured oscillation frequency, output power and current of the differential oscillator with a parameter of V_C

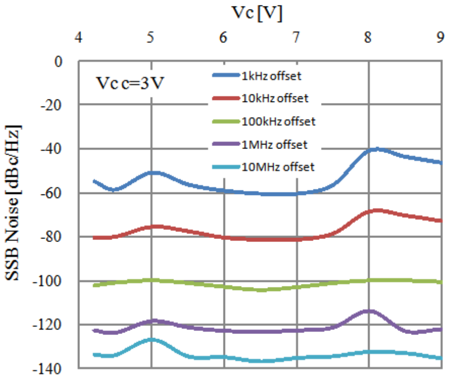

Fig. 8 Measured phase noise of the differential VCO with a parameter of V_C

5. Conclusion

An S/C-band SiGe HBT differential VCO using a novel HPF-type resonator has been presented. The novel HPF-type resonator comprised of a parallel LC circuit can be easily constructed from only the chip inductors with the use of their parasitic reactance. Therefore it can provide a higher resonant frequency and a miniaturized size. The differential oscillator, which employs a novel HPF-type resonator with triple 1005-type 1nH chip inductors and 0.35µm SiGe HBTs with an f_t of 25GHz, has achieved an oscillation frequency of 4.21GHz, an output power of -16.5dBm, a current of 2.67mA, and a phase noise of -104dBc/Hz at 100kHz offset for a V_{CC} of 3V. As compared with the case using the conventional HPF-type resonator, the oscillation frequency becomes around 0.91GHz higher. In addition, the differential VCO, which employs a Si varactor diode with a capacitance ratio of 2.5, has achieved an oscillation from 3.36 to 4.03GHz, an output power of greater than -16.8dBm, a current of less than 2.93mA, and a phase noise of less than -100dBc/Hz at 100kHz offset for a V_{CC} of 3V. From these results, the novel HPF-type resonator presented in this paper can be considered to be useful for realizing a high oscillation frequency and a miniaturized size of the differential VCO.

6. References

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