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A Differential Complementary Colpitts Oscillator based on Common Drain Topology

Mehdi Azadmehr, Igor Paprotny, Yngvar Berg

Abstract—**In this paper we present a new topology complementary differential Colpitts oscillator. The circuit is realized by stacking one PMOS common drain Colpitts oscillator on top on a NMOS common drain Colpitts oscillators. Measurements of a prototype implemented with discrete components have been used to verify the correct operation of the system. The Oscillator was realized using the integrated circuits ALD1105 connected to a $100\mu H$ and a Crystal with a resonance frequency of 4,915MHz. The oscillator connected to the crystal showed a phase noise of -95 dBc/Hz at 100KHz offset.**

Index Terms—**Colpitts, Complementary, Crystal, Oscillator, Common Drain.**

I. Introduction

Oscillators are the most important analog circuits today and are being used in different applications such as clock generators in digital systems, in communication systems [1] for modulation and demodulation of signals and as front-end for resonating sensors [2]. Colpitts oscillators [3], [4], invented by Edwin H. Colpitts in 1918 is one of the most popular and oldest oscillator circuit topologies available today. Initially, the purpose of this design was to simplify vacuum tube oscillators, but it has proven to be as effective now as then. Colpitts oscillators are very adaptable and versatile and can be designed using most types of transistors technologies available today. They can be used to produce differential and quadrature signals [5], [6], [7], to operate at frequencies above $100GHz$ [7], [8] and work with voltages down to $20mV$ [9] to be powered by a thermoelectric power sources.

Figure 1 shows the most common Colpitts configurations today. What characterizes Colpitts is its feedback which is made of two series connected capacitors in parallel with an inductor. The inductor can be replaced by a crystal or Film Bulk Acoustic Resonator (FBAR) to gain better stability and produce high quality oscillations. In circuits 1 a) and b) the inductor is connected between ground and to the either the input or the output and one capacitance between the input and the output. In these two configurations the amplifier is non-inverting. In the case of circuit c) where the inductive part is connected between the input and the output, the amplifier is inverting type. If the inductor in this configuration is replaced by a crystal, this circuit is called a Pierce oscillator after its inventor G. E. Pierce. Is it important to note that the grounded nodes in feedback are ac grounds and can also be connected to VDD. These amplifiers can be realized by single transistor amplifiers such as common gate, common drain and common source using MOSFETS or their equivalent circuits in Bipolar Junction Transistors(BJT).

One of the main reason for the popularity of Colpitts oscillators is their good cyclostationary noise properties compared to other topologies such as ring Oscillators and cross Coupled [10], [6]. Another reason for the popularity of the Colpitts oscillators today is that they can easily be implemented in modern CMOS technologies where high quality capacitors can be made with high precision using different metal layers. This allows the capacitors in the feedback to be made on chip and the inductive part or the high Q resonators such as FBARs placed outside the chip.

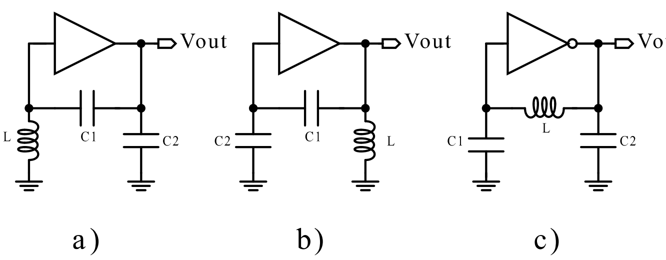

Fig. 1. Colpitts Topology, a) the inductance is connected to the input, b) the inductor is connected to the output and c) the inductor is connected between the input and the output and the amplifier needs to be inverting.

The oscillation frequency of the Colpitts oscillators in Fig. 1, if we ignore the parasitics in the circuit, is equal to the resonance frequency of the LC tank given by:

$$f_t = \frac{1}{2\pi\sqrt{L\frac{C_1C_2}{C_1+C_2}}} \quad (1)$$

II. Common Drain Colpitts Oscillator

Figure 2 shows the circuit implementation of Colpitts oscillator shown in Fig. 1 a) using a common drain amplifier. This configuration is described in detail in various literature [11], [12], [13], [14], [15] and widely used in communication systems implemented using either inductor or a crystal. An analysis of the start up characteristics of this circuit can be found in [16] and a detailed design procedure and analysis method can be found in [4].

Single-ended oscillators are more susceptible to external noise and environmental variations caused by changes in temperature and/or power supply. This is the main reason that differential versions are often preferred. Another reason for choosing differential oscillators, especially at high frequencies, is that frequency up- and down-conversion of the signals becomes much easier. Figure 3 shows a balanced Colpitts

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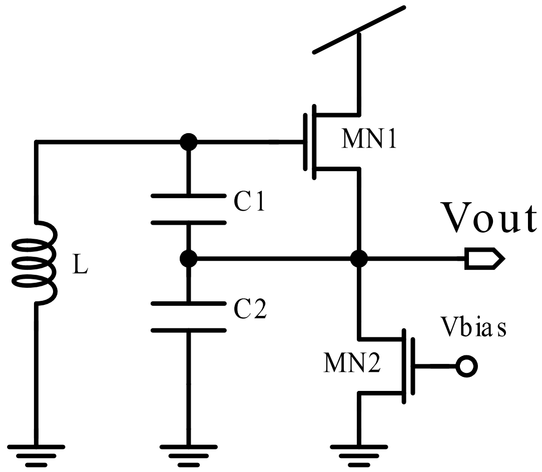

Fig. 2. A Colpitts oscillator realized using a common drain amplifier.

differential oscillator [17]. This circuit is basically made of two common drain Colpitts oscillator connected back to back to each other through an inductor. This configuration has in addition better start-up properties due to the fact that two active components contribute to its oscillation. One main drawback of this circuit is that the power consumption is doubled compared to the single-ended oscillator and the circuit has only active pull-up of the signal by NMOS transistors. These are the reason that some complementary differential oscillators have been presented. To make a complementary version of the differential oscillator, one can instead of connecting the single-ended oscillators back to back, stack two oscillators on top of each other as shown in Fig. 4 and replace the two inductors with one connected between the two oscillators as shown in Fig. 5. Similar approaches have earlier been proposed for Common gate Colpitts [18] and cross coupled Oscillators [19]. Figure 6 shows the Small Signal Model (SSM) of the Complementary Differential Common Drain (CDCD) Colpitts presented in Fig. 5. In the SSM we have kept the passive components in order show that this circuit resembles to the Balanced Differential Common Drain (BDCD) Colpitts oscillator shown in Fig. 3. In this configuration the capacitors add in series and the resonance frequency is then given by:

$$f_t = \frac{\sqrt{2}}{2\pi\sqrt{L\frac{C_1C_2}{C_1+C_2}}} \quad (2)$$

Where C1=C4 and C2=C3. This equation is also valid for the configuration in Fig. 3.

III. Measurement

A prototype of the CDCD Colpitts oscillator was fabricated using discrete components in order to verify the correct operation of the system. The transistors were implemented using IC ALD1105 with threshold voltages of 0.7 V and powered by a power supply of 25V. The high supply voltage was chosen to overcome the speed limitation in the IC and increase its driving capability for more accurate measurements. Our measurements showed that the circuit worked with voltages down to 9 volts with this IC. The capacitors in the circuit were chosen as follows: $C1 = C4 = 10pF$ and $C2 = C3 = 7pF$. The circuit was

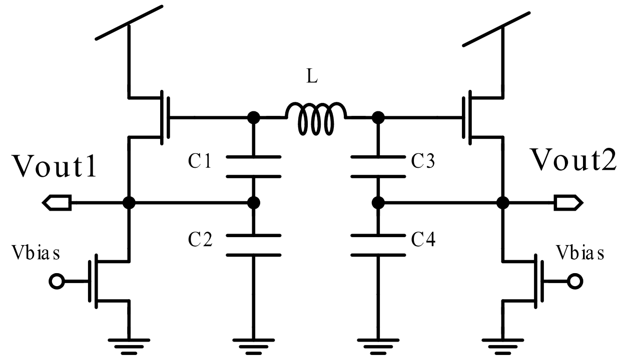

Fig. 3. BDCD Colpitts oscillator

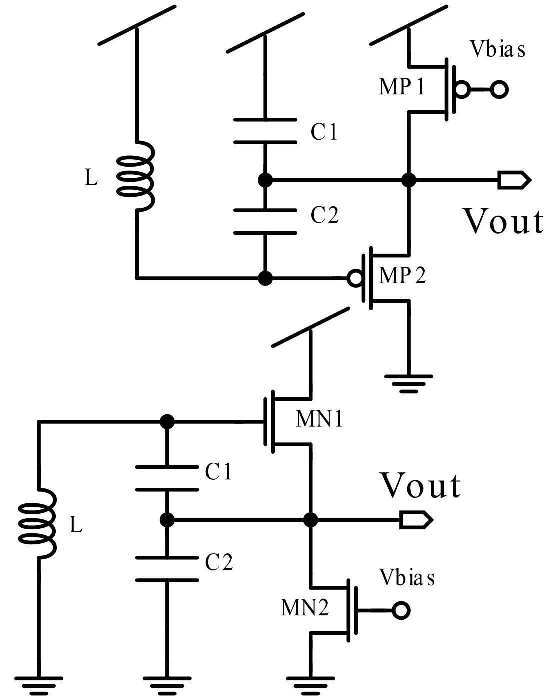

Fig. 4. Schematic of the single ended Colpitts oscillator realized using NMOS and PMOS

tested using both an $100\mu H$ inductor and a Quartz crystal from IQD Frequency Products with a resonance frequency of $4.91520MHz$ and frequency tolerance of $30.00ppm$. The Phase noise of the oscillator connected to the crystal was measured to $-95dBc/Hz$ at an offset of $100KHz$. This is a relatively low value which is due to use of discrete components on a simple PCB without any effort to reduce the noise or increase the circuits immunity to external noise sources as the main goal is to prove the concept. In order to see the full potential of the oscillator circuit, it needs to be implemented using state of the art CMOS technologies and be connected to a high Q resonator such as a FBAR.

Fig.7 shows the transient measurement result of the circuit connected to the crystal resonator. The red curve is node e, the orange curve is the node marked as $VDD/2$ in Fig. 5 and $Vout1$ is the output signal of the circuit shown in Fig. 5. If the circuit was fully balanced, the node $VVD/2$ would be constant at $VDD/2$. However due to the unbalanced NMOS and PMOS transistors in the IC a variation in this node is recorded which will in turn affect the stability of the amplitude of the output signal. In our measurement bias

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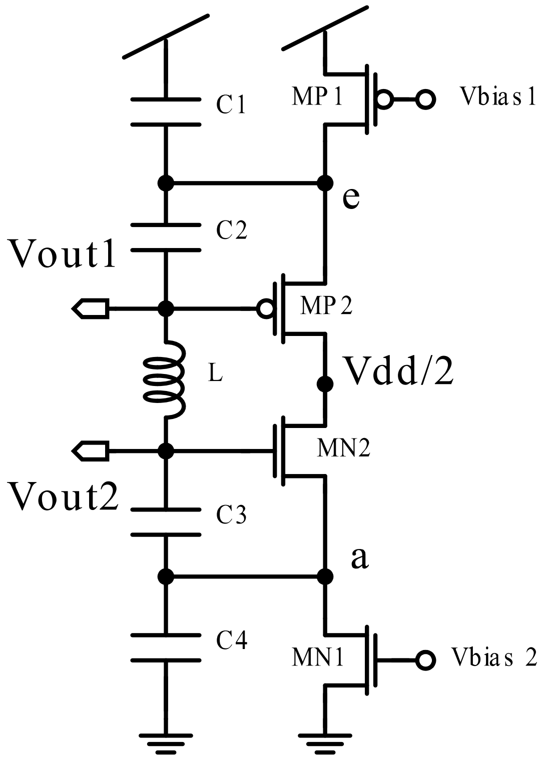

Fig. 5. Schematic of the CDCD Colpitts oscillator.

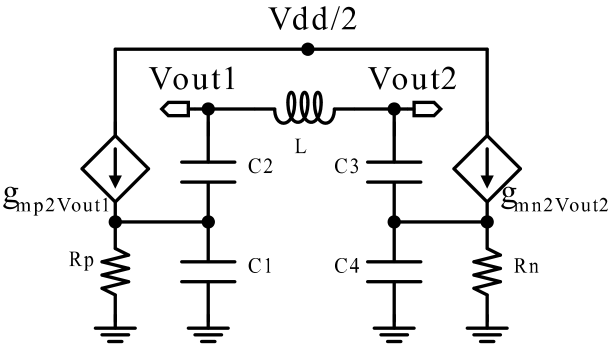

Fig. 6. Small Signal model of the CDCD Colpitts oscillator.

voltages Vbias 1 and 2 were used to improve the balance of the circuit. The power consumption for this circuit was measured to $17mA$ which can be reduced by decreasing the power supply voltage.

Fig.8 shows the spectrum of the oscillator connected to the crystal. The three curves shown are when the minimum, average and maximum function from spectrum analyzer is used when recording the response. Fig.9 shows the transient response when the crystal was replaced by a $100uH$ inductor which is similar to the response of the circuit connected to the crystal. The frequency was measured to $4.28MHz$. The frequency spectrum of this circuit is shown in Fig. 10.

In the measurements common drain amplifiers were used as buffer at the measuring nodes, however both the frequency and the amplitude of the signal measured was affected by the probes. One can observe this as difference between the transient measurements in Figs. 9 and Fig.7 at node e compared to the Out1. In Figs. 9 its behavior is inverted compared to Vout1 but in 9 it is delayed which was caused by the load from the measuring probe connected to it. It also shows that the oscillator with crystal connected to it was more stable.

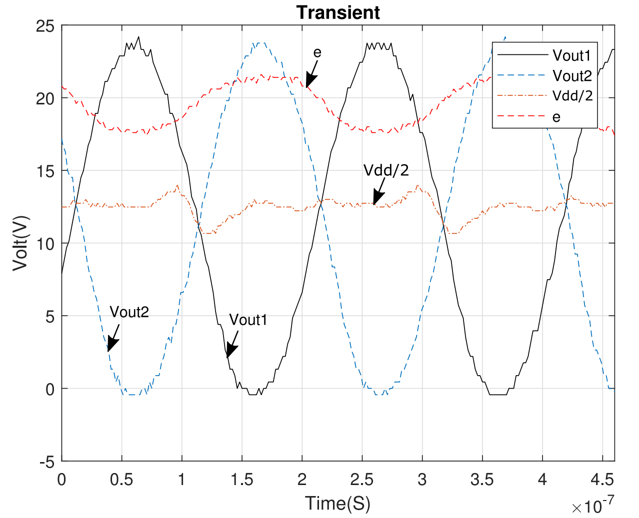

Fig. 7. Transient response of the Colpitts oscillator connected to a crystal with a resonance frequency of $4.915MHz$

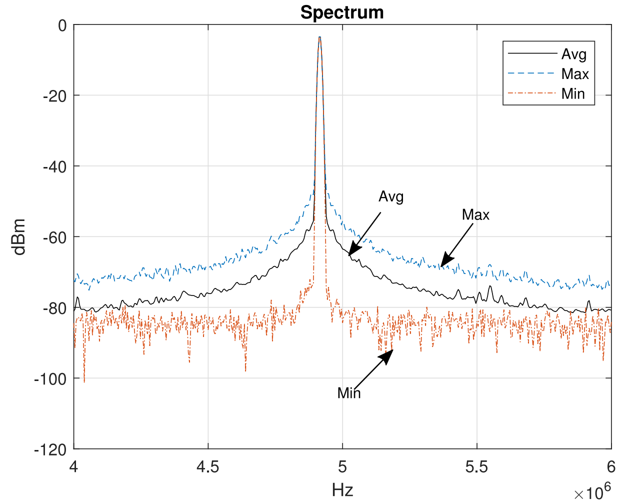

Fig. 8. Frequency spectrum of the oscillator connected to a crystal with a resonance frequency of $4.915MHz$.

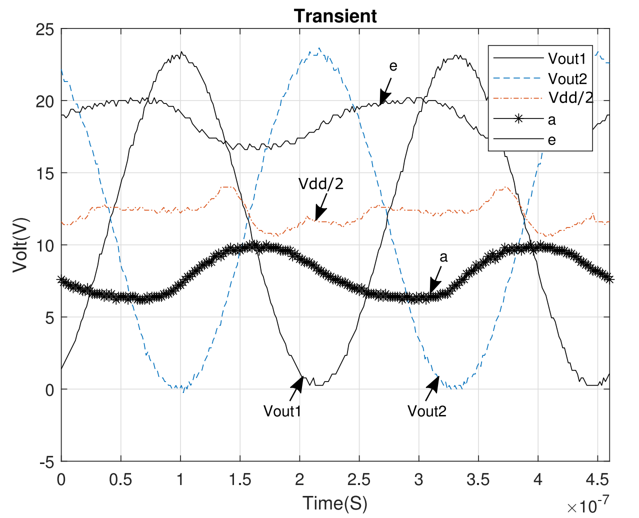

Fig. 9. Transient response of the CDCD Colpitts oscillator with an $100\mu H$ inductor produces a frequency of ca $4.28MHz$.

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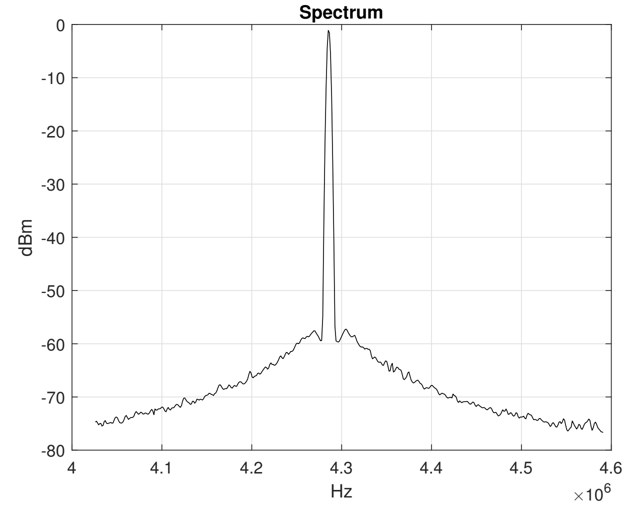

Fig. 10. Frequency spectrum of the CDCD Colpitts oscillator connected to an inductor ploted using the average function.

IV. Conclusion

In conclusion, we realized and verified the operation of a new differential complementary Colpitts oscillator realized by stacking two single-ended oscillators. The oscillator was measured when connected to a crystal and an inductor. When connected to the crystal a phase noise of $-95dBc/Hz$ at a $100KHz$ offset was measured. If the output is taken across the inductor, care must be taken by using appropriate buffering to avoid affecting the effective inductance which may result in unwanted instability and change in frequency.

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