RF Oscillator Simulation and Analysis In Multisim 12

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***Abstract*—Several classic RF oscillators are analyzed in this paper, including LC oscillators and quartz crystal oscillators. By doing simulations in Multisim 12, the oscillation frequencies are checked and the properties of different oscillators are compared.**

摘要—本文分析了常见的LC正弦波振荡器和石英晶体振荡器，利用Multisim12进行仿真实验，观察振荡器的输出频率并比较各振荡器的性能。

I. INTRODUCTION

Oscillators are a class of circuits with one terminal or port, which produce a periodic electrical output upon power up. While we studying for basic electronics classes, oscillator circuits are not unfamiliar and play an important role. However, simply generating some periodic output is not sufficient for modern high-performance RF receivers and transmitters. Issues of spectral purity and amplitude stability must be addressed, which leads to different designs of oscillator circuits. [1] There are two main types of oscillators: the linear or harmonic oscillator and the nonlinear or relaxation oscillator. The former produces a sinusoidal output while the latter produces a non-sinusoidal output, such as a square, sawtooth or triangle wave. Harmonic oscillators can be further divided into two types: feedback oscillators and negative resistance oscillators. The LC oscillator circuits and the crystal oscillator circuits covered in this paper all belong to feedback oscillators.

By studying and analyzing these oscillators with Multisim, one can obtain a deeper understand of feedback oscillators with different type of frequency selective filter using in the feedback loop. And knowing basic oscillator circuits well enables one to design oscillator circuit according to the situation and the requirements. In section II, the basic concepts of LC oscillators are introduced with some examples. To get a more stable output frequency, two improved capacitor feedback oscillators are given and simulated in section III. There is also another kind feedback oscillator using quartz crystal given in section IV. After the simulations and analysis, it goes to a conclusion.

II. LC OSCILLATORS

LC oscillators are commonly used in radio-frequency circuits because of their good phase noise characteristics and their ease of implementation. [2] LC oscillators use capacitors and inductors to construct the frequency selective filter in the feedback oscillator circuits. The general idea of oscillation by feedback is illustrated in Fig. 1. Two requirements [3] must be fulfilled in order to obtain oscillation in the closed loop circuit.

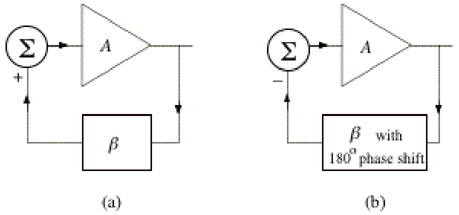


Fig. 1. Oscillation by feedback.

1) The closed loop gain must be greater than or equal to one.
2) The phase shift around the loop is N*360°, where N is an integer.

The resonant frequency of a LC oscillator can be calculated by Eq. 1.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

where L is the inductance in Henries, C is the Capacitance in Farads, and f_r is the output frequency in Hertz.

According to whether capacitors or inductors are connected to three points of the transistor, LC oscillators can be further divided into capacitor three-point oscillator (Colpitts oscillator) and inductor three-point oscillator (Hartley oscillator).

A. Colpitts Oscillator

The Colpitts oscillator uses a capacitive voltage divider network as its feedback source. The two capacitors, C1 and C2 are placed across a single common inductor, L as shown in Fig. 2. The voltage across C2 is applied to the base-emitter junction of the transistor, as feedback to create oscillations. Then C1, C2 and L form the tuned tank circuit with the condition for oscillations being: $X_{C1} + X_{C2} = X_L$.

The frequency of oscillation is approximately the resonant frequency of the LC circuit, which is the series combination of the two capacitors in parallel with the inductor:

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

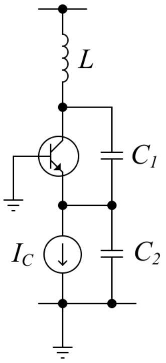


Fig. 2. Simple common base Colpitts oscillator.

The actual frequency of oscillation will be slightly lower due to junction capacitances and resistive loading of the transistor.

By changing the values of capacitors, C1 and C2 we can adjust the amount of feedback voltage returned to the tank circuit. However, large amounts of feedback may cause the output sine wave to become distorted, while small amounts of feedback may not allow the circuit to oscillate.

Then the amount of feedback developed by the Colpitts oscillator is based on the capacitance ratio of C1 and C2 and is what governs the the excitation of the oscillator. This ratio is called the “feedback fraction” and is given simply as:

$$\text{Feedback Fraction} = \frac{C_1}{C_2}\% \tag{3}$$

The Colpitts oscillator circuit used in the simulation is shown in Fig. 3. Connect an oscilloscope and a frequency counter to the output. Simulation results are shown in Fig. 4 and Fig. 5.

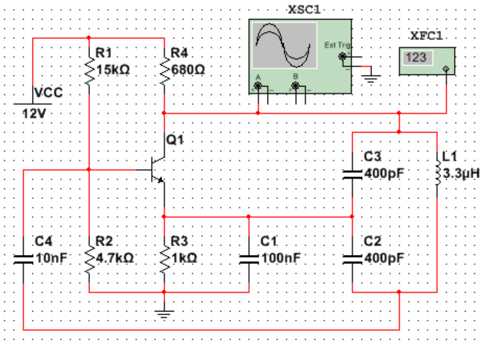


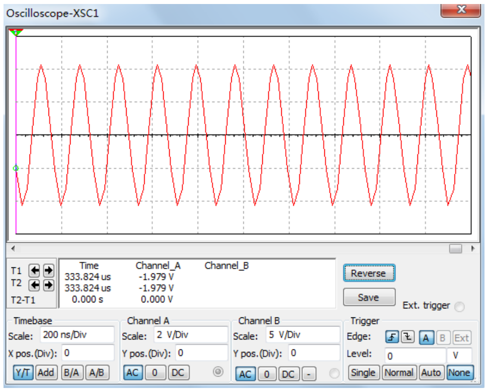
Fig. 3. Colpitts oscillator circuit for simulation.

Similarly, change the values of capacitors and inductor in the frequency selective filter. While we get a sinusoidal output, we can compare the output frequencies with the theoretic frequencies.

We can analyze the results that the built circuit is able to act as an oscillator with stable frequency. The output frequencies are a bit lower than the theoretic frequencies calculated using Eq. 1. And the resonant frequency can be changed by applying different capacitor or inductor value. However, changing the value of capacitors will also change the Feedback Fraction, which may affect the oscillatory condition.

TABLE I
COLPITTS OSCILLATOR CIRCUIT SIMULATION RESULT

C2(pF)	C3(pF)	L1(μH)	f_r(MHz)	f_{r0}(MHz)	Error
400	400	3.3	5.872	6.195	5.21%
400	300	3.3	6.333	6.691	5.35%
300	400	3.3	6.336	6.691	5.31%
400	400	2.2	7.192	7.587	5.21%


Oscilloscope-XSC1

	Time	Channel_A	Channel_B
T1	333.824 us	-1.979 V	
T2	333.824 us	-1.979 V	
T2-T1	0.000 s	0.000 V	

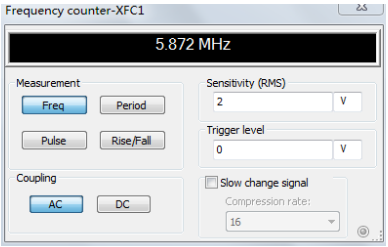
Timebase
Scale: 200 ns/Div
X pos.(Div): 0

Channel A
Scale: 2 V/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): 0

Trigger
Edge: A
Level: 0 V

Fig. 4. Colpitts oscillator circuit simulation oscilloscope result.


Frequency counter-XFC1

5.872 MHz

Measurement: Freq
Sensitivity (RMS): 2 V
Trigger level: 0 V
Coupling: AC
☐ Slow change signal
Compression rate: 16

Fig. 5. Colpitts oscillator circuit simulation frequency counter result.

B. Hartley Oscillator

A Hartley oscillator is the electrical dual of a Colpitts oscillator.

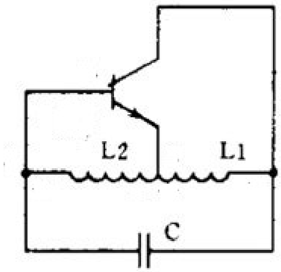


Fig. 6. Hartley oscillator circuit.

In a Hartley oscillator the oscillation frequency is determined by a tank circuit comprising of two inductors and one capacitor. As shown in Fig. 6, the inductors are connected in series and the capacitor is connected across them in parallel.

The frequency of oscillation can be estimated:

$$f_r = \frac{1}{2\pi\sqrt{(L_1 + L_2)C}} \tag{4}$$

And the Feedback Fraction is:

$$\text{Feedback Fraction} = \frac{L_2 + M}{L_1 + L_2 + M} \tag{5}$$

where M is the mutual inductance.

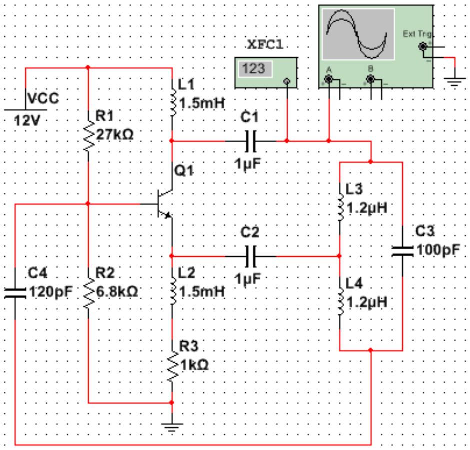


Fig. 7. Hartley oscillator circuit for simulation.

The Hartley oscillator circuit used in the simulation is shown in Fig. 7. The output waveform is shown in Fig. 8.

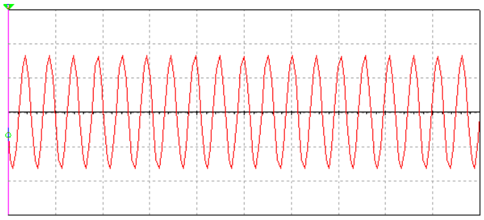


Fig. 8. Hartley oscillator circuit simulation result.

By changing the value of C3, the oscillator can generate different output frequencies while not changing the Feedback Fraction, where Hartley oscillators outperform Colpitts oscillators.

TABLE II
HARTLEY OSCILLATOR CIRCUIT SIMULATION RESULT

C(pF)	f_r(MHz)	f_{r0}(MHz)	Error
100	9.707	10.273	5.51%
82	10.766	11.345	5.10%
120	8.905	9.378	5.04%

III. IMPROVED CAPACITOR FEEDBACK OSCILLATORS

To improve the frequency stability, some improvements have been made to feedback oscillators. Here two improved capacitor feedback oscillator circuits are simulated.

A. *Clapp Oscillator*

The Clapp oscillator shown in Fig. is a refinement of the Colpitts oscillator. The single inductor found in the Colpitt oscillator is replaced by a series L-C combination. Addition of capacitor C3 in series with L improves the frequency stability and eliminates the effect of transistor parameters on the operation of the circuit. The operation of the circuit is the same as that of the Colpitt oscillator. Usually C3 is much smaller than C1 and C2. As the circulating tank current flows through C1, C2 and C3 in series, the equivalent capacitance is

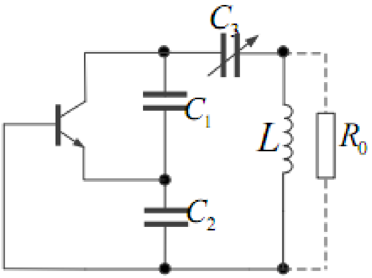


Fig. 9. Clapp oscillator circuit.

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} \approx C_3 \tag{6}$$

The frequency of oscillation is given as Capacitors C1 and C2 are kept fixed while capacitor C3 is employed for tuning purpose.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \approx \frac{1}{2\pi\sqrt{LC_3}} \tag{7}$$

The Clapp oscillator circuit used in the simulation is shown in Fig. 10. The output waveform is shown in Fig. 11. The output frequency is 19.037MHz, 5.27% lower than the theoretic output frequency.

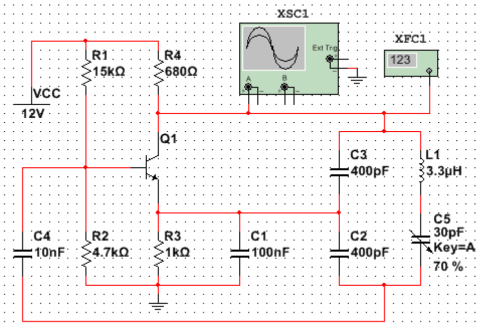


Fig. 10. Clapp oscillator circuit for simulation.

The resonant frequency can be changed while having no effect on oscillatory condition. However, when C3 is too small (15pF), the circuit can not behave as an oscillator. So the frequency range is quite small, which means Clapp oscillator is more suitable for fixed frequency oscillator. [4]

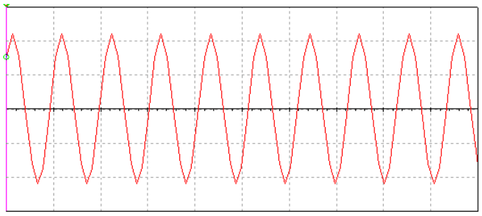


Fig. 11. Clapp oscillator circuit simulation result.

B. Seiler Oscillator

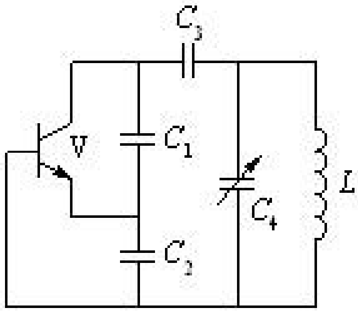


Fig. 12. Seiler oscillator circuit.

To increase the frequency range, Seiler oscillator is developed as shown in Fig. 12. The operation of Seiler oscillator is quite similar to Clapp oscillator other than paralleling a capacitor C4 to the inductor L. It also has the condition that C3 is much smaller than C1 and C2, then the equivalent capacitance is

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} + C_4 \approx C_3 + C_4 \qquad (8)$$

The frequency of oscillation is

$$f_r = \frac{1}{2\pi\sqrt{LC}} \approx \frac{1}{2\pi\sqrt{L(C_3 + C_4)}} \qquad (9)$$

The Seiler oscillator circuit used in the simulation is shown in Fig. 13. The output waveform is shown in Fig. 14. The output frequency is 12.101MHz, 12.64% lower than the theoretic output frequency.

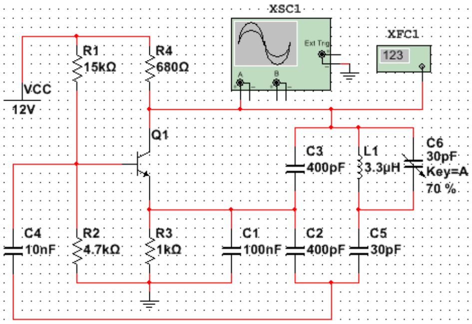


Fig. 13. Seiler oscillator circuit for simulation.

By changing the value of C6, the output frequency can be changed. The frequency range of Seiler oscillator are larger than that of Clapp oscillator.

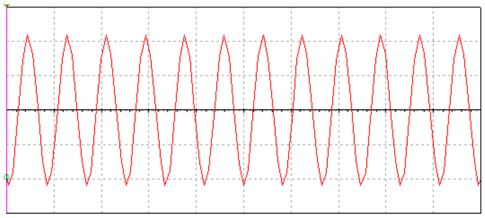


Fig. 14. Seiler oscillator circuit simulation result.

IV. QUARTZ CRYSTAL OSCILLATORS

Quartz crystal oscillators were developed for high-stability frequency references. Quartz crystal used in discrete crystal filters have an equivalent circuit as shown in Fig. 15. [3]

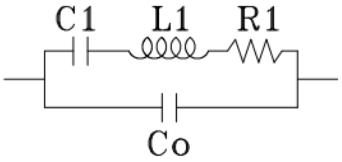


Fig. 15. Quartz crystal equivalent circuit.

The motional capacitance C1 and motional inductance L1 define the series resonance of the device by the equation

$$fs = 1/(2\delta((L_1 * C_1)^{1/2})) \qquad (10)$$

This is the point when the magnitude of the motional capacitance impedance equals the motional inductance impedance and thus they cancel out. In many cases the series resonance point can be approximated by finding the point of minimum impedance (this series resonant point is also near the zero phase shift point) and this minimum impedance will be approximately the motional resistance(R1) for these cases.

A. Series Type

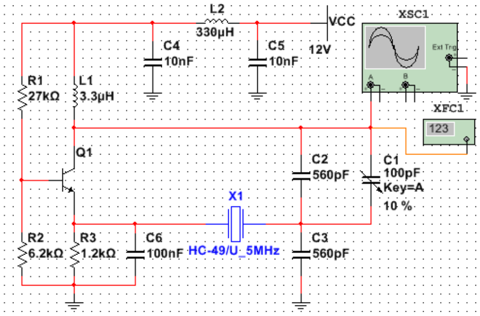
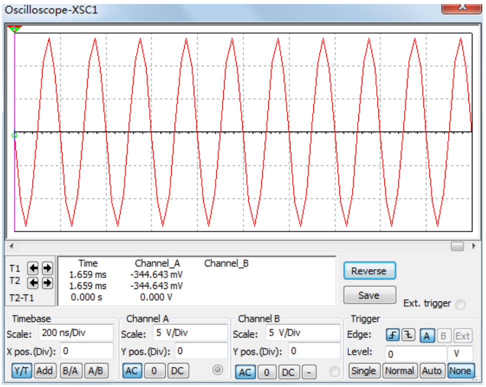


Fig. 16. Series quartz crystal oscillator circuit for simulation.

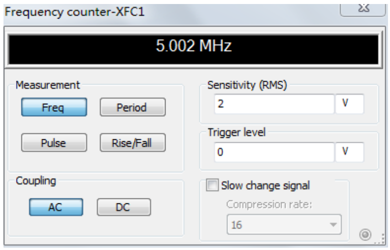
The series quartz crystal oscillator circuit used in the simulation is shown in Fig. 16. The quartz crystal is connected in series in the feedback loop. When the circuit operating at resonant frequency, the quartz crystal can been viewed as a wire, thus constructing a capacitor three-point oscillator circuit. The simulation results are shown in Fig. 17 and Fig. 18.



	Time	Channel_A	Channel_B
T1	1.659 ms	-344.643 mV	
T2	1.659 ms	-344.643 mV	
T2-T1	0.000 s	0.000 V	

Timebase Scale: 200 ns/Div
X pos.(Div): 0
Channel A Scale: 5 V/Div
Y pos.(Div): 0
Channel B Scale: 5 V/Div
Y pos.(Div): 0
Trigger Level: 0 V

Fig. 17. Series quartz crystal oscillator circuit simulation oscilloscope result.



5.002 MHz
Sensitivity (RMS): 2 V
Trigger level: 0 V
Compression rate: 16

Fig. 18. Series quartz crystal oscillator circuit simulation frequency counter result.

B. Parallel Type

The parallel quartz crystal oscillator circuit used in the simulation is shown in Fig. 19. The quartz crystal takes place of the inductor in a capacitor three-point oscillator. With C1, C2, C3, it constructs a parallel resonant tank. This circuit is also called Pierce oscillator. [5] The simulation results are shown in Fig. 20 and Fig. 21.

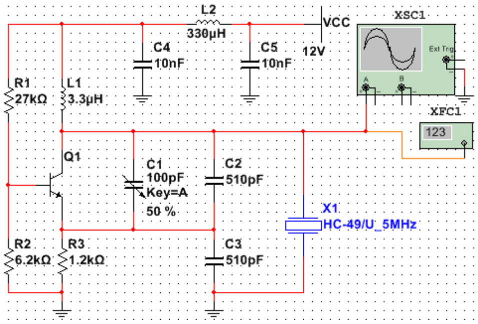
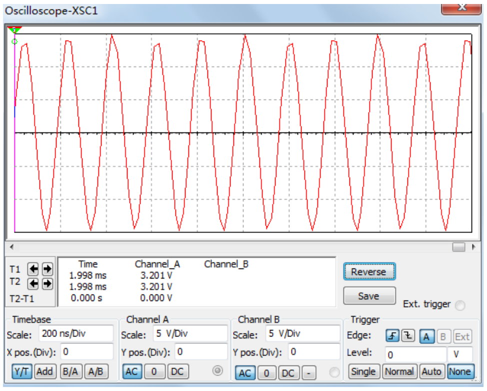


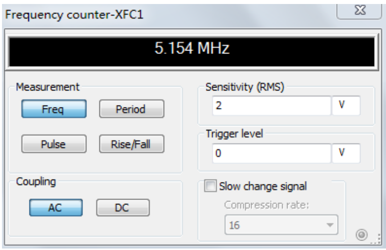
Fig. 19. Parallel quartz crystal oscillator circuit for simulation.



	Time	Channel_A	Channel_B
T1	1.998 ms	3.201 V	
T2	1.998 ms	3.201 V	
T2-T1	0.000 s	0.000 V	

Timebase Scale: 200 ns/Div
X pos.(Div): 0
Channel A Scale: 5 V/Div
Y pos.(Div): 0
Channel B Scale: 5 V/Div
Y pos.(Div): 0
Trigger Level: 0 V

Fig. 20. Parallel quartz crystal oscillator circuit simulation oscilloscope result.



5.154 MHz
Sensitivity (RMS): 2 V
Trigger level: 0 V
Compression rate: 16

Fig. 21. Parallel quartz crystal oscillator circuit simulation frequency counter result.

V. CONCLUSION

In this paper, three kinds of feedback oscillators are analyzed: LC oscillators, improved capacitor feedback oscillators, and quartz crystal oscillators. There are in total six specific oscillator circuits simulated in Multisim 12, two for each kind of feedback oscillators respectively. Among them, Colpitts oscillator and Hartley oscillator are easy to implement. Hartley oscillator can shift the output frequency without changing the Feedback Fraction. Both Clapp oscillator and Seiler oscillator can improve the frequency stability of capacitor feedback oscillators, while Seiler oscillator has a larger frequency range. Series or parallel quartz crystal oscillators has high frequency stability.

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