Simple electronically tunable oscillators

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Abstract

This paper presents different types of electronically tunable oscillators; therefore frequency of such oscillators can be controlled by voltage or current. The square wave output and sinusoidal output oscillators are presented. All described oscillators have potential using in different application in telecommunications and measuring devices, e.g. phase locked loops, modulation and detection. The oscillators were constructed and measured.

1. Introduction

Electronically tunable oscillators (ECO) is one of the important basic building blocks in analog and digital circuits. For example, in telecommunications it is used for phase modulators, quadrature mixers [1], and single-sideband generators [2]. In measurement system, ECO is employed for vector generator or selective voltmeters [3]. For example, a VCO is the main building block in phase locked loop (PLL) and clock generator circuits. There are two main classes of oscillator: relaxation and sinusoidal. Relaxation oscillators generate the triangular, sawtooth and other nonsinuoidal waveforms. It is possible use different approach for frequency control (and amplitude stabilization of sinusoidal oscillators), eg. digital potentiometers [4, 5] or tranconductance operational amplifiers [6, 7]. This paper presents the design of several types of simple oscillators which are continuously tunable. The frequency changing for several oscillators is based on optically coupled photoresistor (Vactrol) with 100 dB dynamic range [8]. For voltage control the optically coupled photoresistors are connected to linear voltag-current converters. It is important to note that digital potentiometers can be used as well.

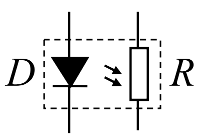

Fig. 1. The optically coupled photoresistor - Vactrol.

2. The optically coupled photoresistors properties

The optically coupled photoresistors consists of LED diode and photoresistor (Fig. 1). A photoresistor or light-dependent resistor (LDR) or photocell is a resistor whose resistance decreases with increasing light intensity. Optically coupled photoresistor (OR), also called photoresistive opto-isolator or vactrol (after a genericized trademark introduced by Vactec, Inc.), offers 100dB dynamic range, fast response time, and very high dark resistance. Some technical parameters for VTL5C1 [5] are: Min. isolation Voltage @ 70% Rel. humidity: 2500 VRMS; Max. resistor power: 175 mW; Max. resistor voltage: 100 V; Max LED current: 40 mA; Response time to 63% final R_{ON} 2.5 ms. The measured output resistance vs. input current is shown in Fig. 2 where logarithmic scales are used for both the X and Y axes.

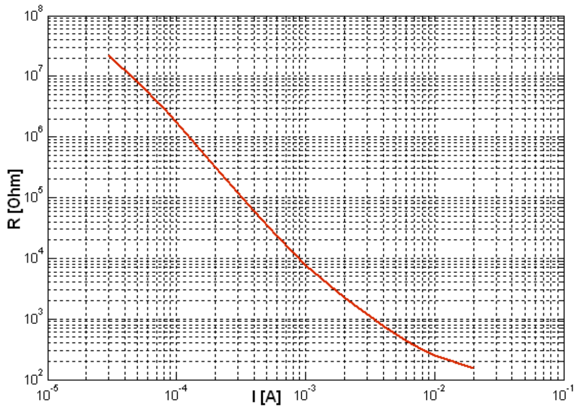

Fig. 2. The Output resistance vs. input current for VTL5C1.

3. Controlled ring oscillator

A conventional ring oscillator uses N odd numbers of inverter stages (delay stages), connected in a close loop chain [9]. The ring oscillators have numerous useful features, e.g.: It can be easily designed with different types of technology, it can achieve its oscillations at low voltage, it can provide high frequency oscillations with dissipating low power, it can be electrically tuned, it can provide multiphase outputs etc. The conventional ring oscillator based VCO uses variable bias currents to control its oscillation frequency. However, when the bias current is quite small, the voltage swing of the VCO will become slower (longer rise/fall time). That is not desirable in some applications.

Assume that the gates to source parasitic capacitances are equal. The frequency of the ring oscillator [10] can be found as

$$f_o = \frac{1}{2N\tau} \qquad \text{[Hz, s]} \qquad (1)$$

where τ is the delay of the inverter stage. This paper proposes a new type of a VCO ring oscillator where frequency is controlled by optically coupled photoresistor. The circuit diagram is shown in Fig. 3 where one photoresistor is used. Such ring oscillator has 2 different delay and therefore frequency (for N=3) is

$$f_o = \frac{1}{2\left(\tau_1 + 2\tau_2\right)} \qquad \text{[Hz, s]} \qquad (2)$$

where τ_1 is delay of stage with photoresistor and τ_2 is delay of other stages. The τ_1 is

$$\tau_1 = RC \approx \frac{k_1}{i_d} C = \frac{k_1}{V_i} C \qquad \text{[s, }\Omega\text{, A, V]} \qquad (3)$$

where k_1 is constant, R is photoresistor resistance, C capacitor, i_d is current through the LED diode and V_i input voltage. Substituting (3) into (2) will give

$$f_o \approx \frac{1}{2\left(C\frac{k_1}{V_i} + 2\tau_2\right)} = \frac{V_i}{2\left(Ck_1 + 2\tau_2 V_i\right)} \qquad \text{[Hz, F, V]} \quad (4)$$

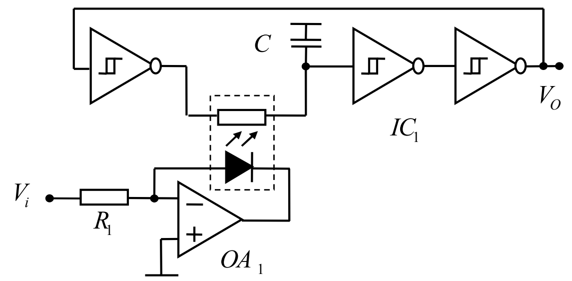

Fig. 3. The Voltage controlled 3 stage ring oscillator. R_1=1k; C=56 pF; OA-TL071; IC_1- 74HC14.

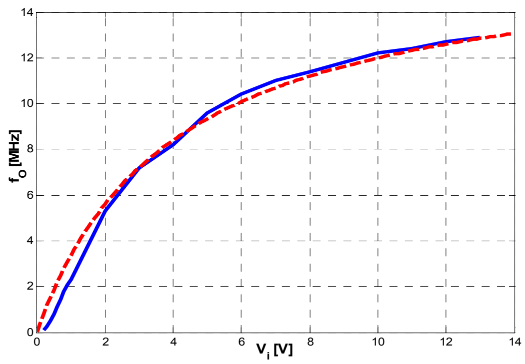

Fig. 4. Output frequency vs. input voltage for ring oscillator measured (solid line), simulation – dash line.

$$f_o \approx \frac{4.2V_i}{\left(1 + 0.25V_i\right)} \qquad \text{[MHz, F, V]} \qquad (5)$$

It is important to note that eq. (5) is valid for C=56 pF and R_1=1 kΩ [11]. In some applications the spread frequency spectrum is advantage. The measures spread spectrum of ring oscillator is displayed in Fig. 5.

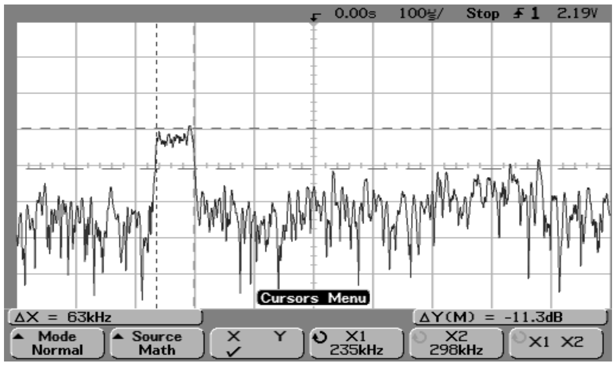

Fig. 5. The spread spectrum of voltage controlled ring oscillator

In Fig. 4 is shown measured output frequency vs. input voltage (solid line) and approximation (dash line) given by

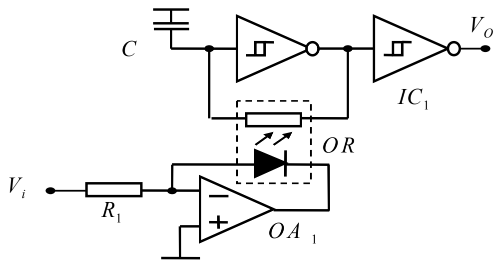

Fig. 6. The circuit diagram of relaxation oscillator with output buffer. R_1=1k; C=56 pF; OA-TL071; IC_1- CD40109, OR -. optically coupled photoresistors VTL5C1

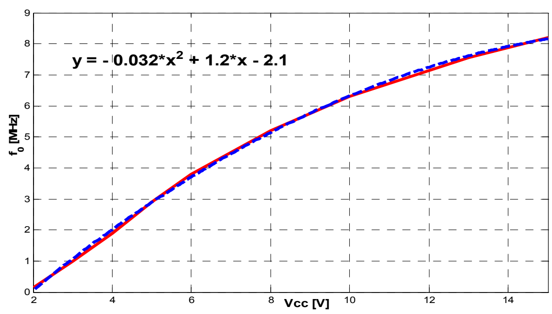

Fig. 7. The Output frequency vs. input voltage for relaxation oscillator with Vcc=15 [V] (solid line), approximation – dash line

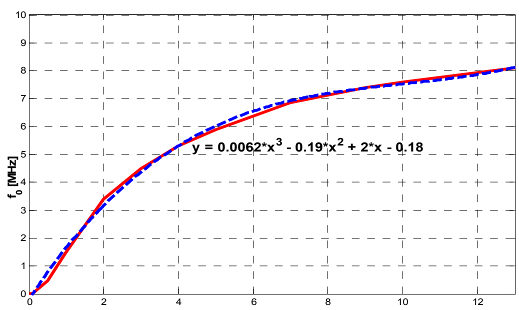

Fig. 8. Output frequency vs. supply voltage for relaxation oscillator with constant Vi=13 [V] (solid line), approximation – dash line

3. Controlled relaxation oscillator

The relaxation oscillator uses one Schmitt trigger capacitor and resistor [12-15]. The circuit diagram of voltage controlled relaxation oscillator with output buffer is shown in Fig. 6.

The output frequency vs. supply voltage (with fixed V_i=13 [V]) is shown in Fig. 7. The output frequency vs. input voltage (with fixed V_{CC}=15 [V]) is displayed in Fig. 8. The dependence of output frequency vs. supply voltage can be used for linearization of output frequency versus input voltage (or current). The circuit diagram of linearized, relaxation oscillator with output buffer is shown in Fig. 9 [16]. Linearization is based on supply voltage increasing together with input voltage. The OA_2 is used as power source for $V_i \geq 2.3$ V. The supply voltage is given by eq. (6):

$$V_{ss} = \begin{cases} \approx 2.3 & if \ \ V_i < 2.3 \\ V_i & if \ \ V_i \geq 2.3 \end{cases} \qquad [\text{V}] \qquad (6)$$

Output frequency vs. input voltage of the linearized oscillator is displayed in Fig. 10.

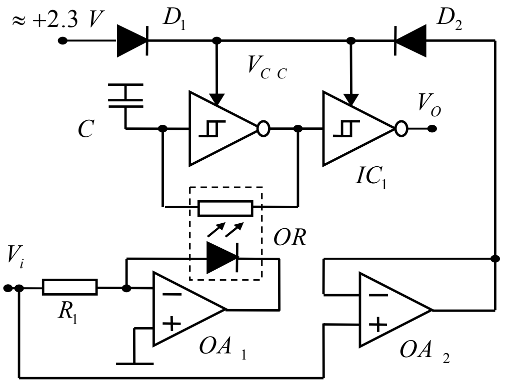

Fig. 9. The circuit diagram of linearized, relaxation oscillator with output buffer. R_1=1k; C=56 pF; OA_2, OA_2 -TL072; IC_1-CD40109, D_1, D_2 - Schottky diodes, OR - optically coupled photoresistors VTL5C1

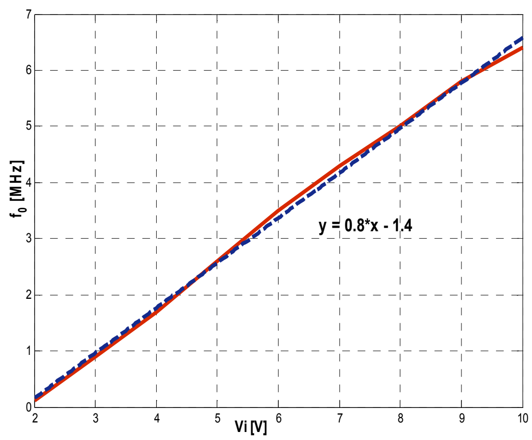

Fig. 10. Output frequency vs. input voltage for linearized relaxation oscillator (see Fig. 12). Measured values – solid line, approximation – dash line

4. Sinusoidal - Wien-bridge oscillator

The voltage (current) controlled Wien-bridge oscillator [17, 18] is shown in Fig 11. The operational amplifier OA_1 is used to form voltage controlled current source. The current i_D, flow through diodes D_1 and D_2 of the OR_1 and OR_2. The output current is

$$i_D = \frac{V_i}{R_1} \qquad [\text{A, V, }\Omega] \qquad (7)$$

where V_i is input voltage and R_1 resistor connected to inverting input.

The Wien-bridge oscillators consists of OA_2, where C; R_A; R_B are in positive feedback. The buffer OA_3 and diode bridge D, R_3, R_4, R_5 and OR_3 are used for automatic gain (amplitude) control [19]. The output frequency is given as

$$f_o = \frac{1}{2\pi C\sqrt{R_A R_B}} \qquad [\text{Hz, F, }\Omega] \qquad (8)$$

Resistance of OR is approximately

$$R \approx \frac{k_{OR}}{i_D} = \frac{k_{OR}}{V_i / R_1} = \frac{k_{OR} R_1}{V_i} \qquad [\text{A, V, }\Omega] \qquad (9)$$

where k_{OR} is OR constant and i_d is current through OR LED diode. Consideration of the R_A=R_B=R the output frequency is

$$f_o = \frac{1}{2\pi C\sqrt{R_A R_B}} = \frac{1}{2\pi CR} \approx \frac{V_i}{2\pi C R_1 k_{OR}} \qquad [\text{Hz, F, }\Omega] \ (10)$$

Measured output frequency vs. input voltage is shown in Fig. 12. The frequency spectrum is shown in Fig. 13 (spectral quality is better than 50 dB).

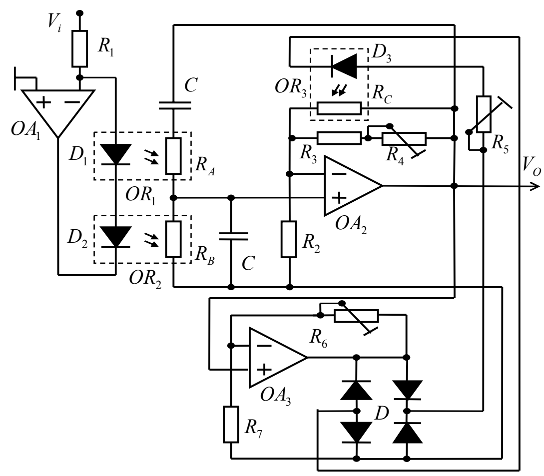

Fig. 11. The Voltage controlled Wien-bridge oscillator with buffer amplifier. R_1=1k; C=1n; R_2=10k; R_3=15k; R_4=10k; R_5=1k; R_6=R_7=10k; OA-TL074; D - 4x Schottky diodes, OR_1-OR_3 optically coupled photoresistors VTL5C1

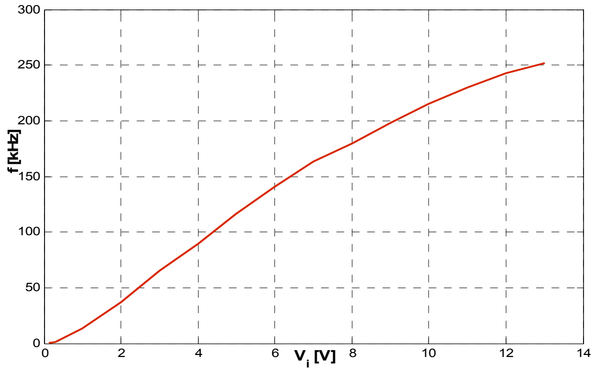

Fig. 12. Output frequency vs. input voltage for Wien-bridge oscillator

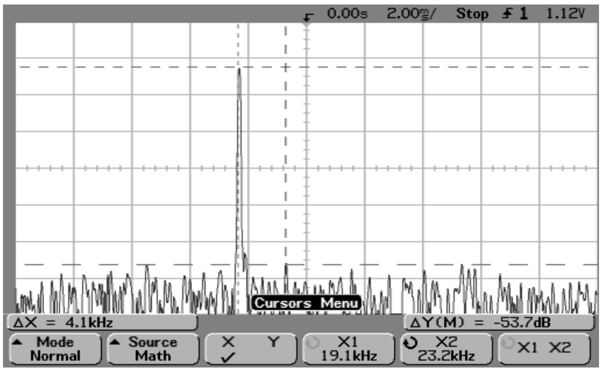

Fig. 13. The frequency spectrum of voltage controlled Wien-bridge oscillator

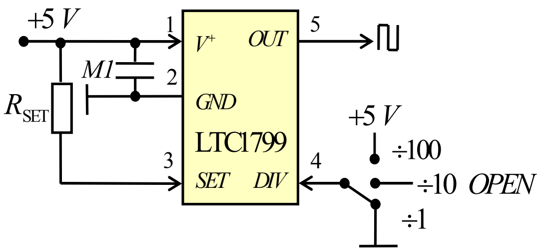

Fig. 14. The basic connection of oscillator LTC1799

5. Wide range square wave oscillator

In this part the wide range resistor set oscillator LTC1799 is described [20]. The LTC1799 operates with a single 2.7V to 5.5V power supply and provides a rail-to-rail, 50% duty cycle square wave output. The frequency-setting resistor can vary from 3kΩ to 1MΩ to select a master oscillator frequency between 100kHz and 33MHz (5V supply), see Fig. 14. The three-state *DIV* input determines whether the master clock is divided by 1, 10 or 100 before driving the output, providing three frequency ranges spanning 1kHz to 33MHz (5V supply). The oscillator frequency is programmed by a single external resistor (R_{SET}) according

$$f_o = \frac{10^{11}}{N \bullet R_{SET}} \qquad [\text{Hz}, \Omega] \qquad (11)$$

Where $R_{SET} \in \langle 3\text{k}\Omega \div 1\text{M}\Omega \rangle$ and N is value of three divider settings. Pin 4 should be tied to GND for the ÷1 setting, the highest frequency range. Floating Pin 4 divides the master oscillator by 10. Pin 4 should be tied to V+ for the ÷100 setting, the lowest frequency range.

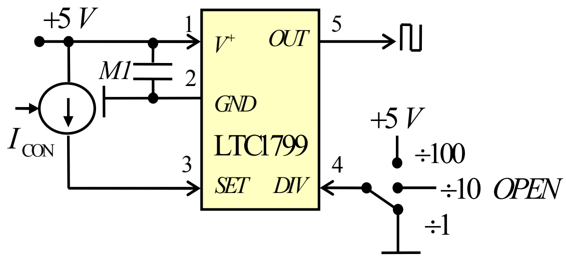

Fig. 15. Connection of current controlled oscillator LTC1799

The oscillator may be programmed by any method that sources a current into the *SET* pin (Pin 3). The circuit in Fig. 15 sets the oscillator frequency using a programmable current source and in the expression for f_{OSC}, the resistor R_{SET} is replaced by the ratio of 1.13V/I_{CON}. The voltage difference between *V*+ and *SET* is approximately 1.13V, therefore, the Fig. 15 circuit is less accurate than if a resistor controls the oscillator frequency.

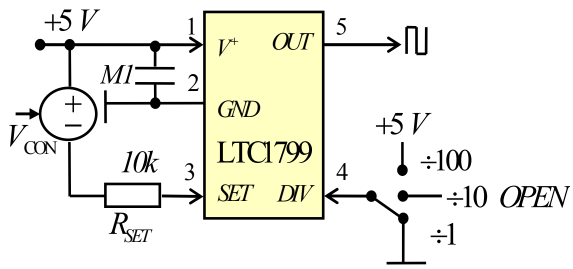

Fig. 16. Connection of voltage controlled oscillator LTC1799

Fig. 16 shows the LTC1799 configured as a VCO. A voltage source is connected in series with an external 10k resistor. The output frequency, *OUT*, will vary with V_{CON}, that is the voltage source connected between V+ and the *SET* pin. Again, this circuit decouples the relationship between the input current and the voltage between V+ and *SET*; the frequency accuracy will be degraded. The oscillator frequency, however, will monotonically increase with decreasing V_{CON}.

5. Conclusion

In this paper the several wide range simple oscillators were described. For frequency control, the optically coupled photoresistor was used. The square wave output, ring, relaxation and linearized relaxation oscillator were described. The Wien-bridge oscillator with sinusoidal output with spectral quality greater then 50 dB was also shown. On the end, the wide range, square wave oscillator with divider was presented. All oscillators were tested and measured.

It is important to note that these oscillators can be used in different application including PLL, frequency locked loop and low cost frequency synthesizers.

6. Acknowgledment

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