1. Introduction

A voltage controlled oscillator (VCO) is one of the important basic building blocks in analog and digital circuits. For example, a VCO is the main building block in phase locked loop (PLL) and clock generator circuits [1]. This paper presents the design of 2 types of oscillators that are continuously voltage tunable. The frequency changing for all oscillators is based on optically coupled photoresistor with 100 dB dynamic range [2]. The first is Wien-bridge oscillator with frequency range from approx. 0.1 Hz to 250 kHz with sinusoidal output. The Vactrol is used also for amplitude stabilization. The second oscillator is relaxation oscillator based on digital circuit with frequency range from 10 Hz to 9 MHz with square wave output. It is important to note that the control voltage and oscillator part are optically coupled.

Keywords: Wien-bridge oscillator, relaxation oscillator, phase locked loop, voltage controlled oscillator, photoresistor, quadrature oscillator.

Fig. 1 The optically coupled photoresistor - Vactrol

Fig. 2 Output resistance vs. input current for VTL5C1

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2. Optically coupled photoresistor characteristic

Vactrol consists of a 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 trademark introduced by Vactec, Inc.) offers 100dB dynamic range, fast response time, and very high dark resistance. Some technical parameters for VTL5C1 [2] 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 (logarithmic scales are used for both the X and Y axes).

The Wien-bridge oscillator consists of OA, where C, R; Rb are in positive feedback. The buffer OA, and diode bridge D, R; R, R, and OR, are used for automatic gain control. The output frequency is given as

\[
f_o = \frac{1}{2\pi CR Rb} \text{ [Hz, F, \Omega]} \quad (2)
\]

Resistance of OR is approximately

\[
R \approx \frac{k_{OR}}{i_D} = \frac{k_{OR}}{V_i/R_i} = k_{OR} \text{ [A, V, \Omega]} \quad (3)
\]

where \(k_{OR}\) is OR constant and \(i_D\) is current through OR LED diode. Suppose that the \(R_a=R_b=R\) in this case the output frequency is given by

\[
f_o = \frac{1}{2\pi CR Rb} = \frac{1}{2\pi CR k_{OR}} \text{ [Hz, F, \Omega]} \quad (4)
\]

Measured output frequency vs. input voltage is shown in Fig. 4. The frequency spectrum is shown in Fig. 5 (spectral quality is better than 50 dB).

3. Wide range voltage controlled Wien-Bridge oscillator

The voltage controlled Wien-bridge oscillator [3 - 5] is shown in Fig. 3. The operational amplifier OA, is used to form voltage controlled current source. The current \(i_D\) flows through diodes \(D_1\) and \(D_2\) of the OR, and OR. The output current is

\[
i_D = \frac{V_i}{R_i} \text{ [A, V, \Omega]} \quad (1)
\]

where \(V_i\) is input voltage and \(R_i\) is resistor connected to inverting input.
4. Amplitude control in quadrature sinusoidal oscillator

In this part another principle of the amplitude control of the quadrature sinusoidal oscillator is used. The block diagram of the quadrature oscillator with amplitude (energy) stabilization is presented in Fig. 6. The method is based on compensation of the parasitic dissipation parameters $-\alpha_1$ and $-\alpha_3$ by the multipliers connected in parallel along the dissipation blocks [6 and 7]. Desired value of the amplitude $A$ of the oscillator signals is fed into the amplitude control block. The quadrature outputs of the oscillator ($x_1$ and $x_2$) are also connected to the amplitude control block. Amplitude control is based on eq. (5) where ideal steady state is

$$x_1^2 + x_2^2 = (V_i \sin(2\pi f t))^2 + (V_i \cos(2\pi f t))^2 = V_i^2 \left( \sin^2(2\pi f t) + \cos^2(2\pi f t) \right) = V_i^2 = A$$

The amplitude is affected by means of PI (Proportional-Integrated) controller and multipliers controlled by $x_3$.

$$x_3 = k_x (A - x_1^2 - x_2^2) + k_1 \int (A - x_1^2 - x_2^2) dt \quad (6)$$

and block $k_y$ (in Fig. 6) is used for the balancing of different values of $\alpha_1$ and $\alpha_3$. In Fig. 7 the block diagram of compensated integrator is shown (top) and compensated integrator with OA (bottom). The compensated integrator with OA can be described by eq. (7) where $R, R_s$ is photoresistor controlled by current $i_r$.

$$V_i\frac{d}{dt}\frac{V_o}{V_o} = -\frac{R}{R} \frac{V_o}{V_o} + \frac{R_1 R_4 (i_s) V_o}{R_1 (R_s + R_3 (i_s)) R_3} \quad (7)$$

For ideal compensation of $R_0$,

$$\frac{1}{R_0} = \frac{R_2 R_3}{R_2 R_3 R_s + R_3 R_s} \quad (8)$$

therefore,

$$R_4 (i_s) = \frac{R_2 R_3 R_s}{R_2 R_3 R_s + R_3 R_s} \quad (9)$$

**Fig. 6** Block diagram of the amplitude control for quadrature oscillator with compensation of dissipations $\alpha_1$ and $\alpha_3$. Controller for amplitude control is based on PI controller.

**Fig. 7** The block diagram of amplitude control (top) and construction with optically coupled photoresistor (parasitic resistor $R_0$ is compensated).
5. Wide range voltage controlled relaxation oscillator

The relaxation oscillator uses one Schmitt trigger capacitor and resistor [8 - 11]. The circuit diagram of voltage controlled relaxation oscillator with output buffer is shown in Fig. 9.

The output frequency vs. supply voltage (with fixed $V_i=13$ [V]) is shown in Fig. 10. The output frequency vs. input voltage (with fixed $V_{cc}=15$ [V]) is displayed in Fig. 11.

![Freq spectrum](image1)

**Fig. 8** Frequency spectrum of proposed oscillator (with compensation of the dissipation)

The frequency spectrum of quadrature oscillator with dissipative parameters compensation is shown in Fig. 8.

![Circuit diagram](image2)

**Fig. 9** The circuit diagram of relaxation oscillator with output buffer. $R_1=1k$; $C=56 \mu F$; $OA_{-}TL071$; $IC_1$ - CD40109, OR - optically coupled photoresistors VTL5C1

![Freq vs supply](image3)

**Fig. 10** Output frequency vs. supply voltage for relaxation oscillator with constant $V_i=13$ [V] (solid line), approximation - dash line

![Freq vs input](image4)

**Fig. 11** Output frequency vs. input voltage for relaxation oscillator with $V_{cc}=15$ [V] (solid line), approximation - dash line

![Circuit diagram](image5)

**Fig. 12** The circuit diagram of linearized, relaxation oscillator with output buffer. $R_1=1k$; $C=56 \mu F$; $OA_1$, $OA_2$, $TL072$; $IC_1$ - CD40109, $D_1$, $D_2$ - Schottky diodes, OR - optically coupled photoresistors VTL5C1
Output frequency vs. input voltage of the linearized oscillator is displayed in Fig. 13. Measured values are in Table 1.

### 6. Conclusion

In this paper the 2 wide range simple V-f oscillators were described. For frequency control, the optically coupled photoresistor was used. The first is Wien-bridge oscillator with sinusoidal output with spectral quality greater than 50 dB. The second is linearized relaxation oscillator. All oscillators were constructed and measured. It is important to note that these oscillators can be used in different applications including PLL, frequency locked loop and low cost frequency synthesizers.

The new method for amplitude control of sinusoidal quadrature oscillators with high spectral quality based also on optically coupled photore sistors and PI controller was also described.

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### References

1. POPENDA, A.: The DFM Control System Based on PLL, *Communications - Scientific Letters of the University of Zilina*, No. 1, pp. 53-57, 2009.
2. VTL5C1, 5C2, Low Cost Axial Vactrols, PerkinElmer Optoelectronics, www.perkinelmer.com/opto.
3. LI, A.: Programmable Oscillator Uses Digital Potentiometers, Application note, AN-580, Analog Devices, 2002.
4. MANCINI, R., PALMER, R.: Sine-Wave Oscillator, Application Report SLOA060 - March 2001, Texas Instruments, 2001.
5. LINDBERG, E.: Oscillators - An Approach for a Better Understanding, Proc. of the 2003 European Conference on Circuit Theory and Design, Krakow, 2003.
6. OLIVEIRA, L. B., FERNANDES, J. R., FILANOVSky, I. M., VERHOEVEN, C. J. M., SILVA, M. M.: Analysis and Design of Quadrature Oscillators, *IEEE Trans. Neural Net.*, 9: 523-532, 1998.
7. JAIIKIA, W., PROMMEE, P.: Electronically Tunable Current-mode Multiphase Sinusoidal Oscillator Employing CCCDTA-based Alp i s Filters with Only Grounded Passive Elements, *Radioengineering*, vol. 20, No. 3, pp. 394-399, September 2011.
8. LINSAY P.S., WANG, D. L.: Fast Numerical Integration of Relaxation Oscillator Networks Based on Singular Limit Solutions, *IEEE Trans. Neural Net.*, 9: 523-532, 1998.
9. WEIGANDT, T. C, BEOMSUP, K., GRAY, P. R.: Analysis of Timing Jitter in CMOS Ring Oscillators, Proc. of IEEE Int. Symp. Circuits and Systems, vol. 4, pp. 27-30, London, June 1994.
10. Accurate and Efficient Frequency Evaluation of a Ring Oscillator, Application Note 4070-3, Agilent Technologies 2000.
[11] YUCHENG NI: Low-power CMOS Relaxation Oscillator Design with an On-chip Circuit for Combined Temperature-compensated Reference Voltage and Current Generation, Northeastern University, Electrical and Computer Engineering Master's Theses. Paper 127, 2014 http://hdl.handle.net/2047/d20004909.