ELECTRONICALLY TUNABLE RC SINUSOIDAL OSCILLATORS

Senior Researcher Valeriu FLORESCU
INSTITUTE FOR NUCLEAR RESARCH PITESTI, ROMANIA

Abstract

This paper presents two types of active configurations for realizing electronically tunable RC sinusoidal oscillators. The type-1 network employs two grounded scaled resistances KR_1 and KR_2, where K is scaling factor. The frequency of oscillation W_0 is controlled conveniently by adjusting K, since W_0 appears in the form $W_0 = 1/K\sqrt{R_1C_1R_2C_2}$. For realizing the scaled resistances, an active configuration is proposed, which realizes $KR_i = R_i/(1+f(V_B))$, where $f(V_B)$ denotes a function of a controlling voltage V_B. Thus the frequency tuning can be effected by controlling a voltage V_B. The type-2 oscillator uses two periodically switched conductances. It is shown that the tuning of oscillation frequency can be done by varying the pulsewidth-to-period ratio (τ/T) of the periodically switched conductances.

Introduction

Continuously tunable RC sinusoidal oscillators have found applications in various instrumentation and measuring devices. In realizing a tunable oscillator, one or more elements must be varied in order to vary the frequency of oscillation. Elements such as resistors and low valued capacitors can be varied mechanically or by using specialized devices such resistors and varicap diodes. These methods present practical problems, especially where high accuracy is desired. Howard and Pederson [1] and Grebene [2] have describe the realization of Wien-bridge voltage-controlled oscillators for integrated circuits. The frequency of oscillation W_0 for this type of oscillator is $W_0 = 1/\sqrt{C_1R_1C_2R_2}$. Hence the oscillators can be tuned to different frequencies by varying R's or C's or both. In [1], R_1 and R_2 are varied by using FET's as voltage variable resistors. This method is not very satisfactory because of the nonlinear characteristics of the FET resistances which cause distortion at the output of oscillators. In [2] one capacitance say C_1, is multiplied by an amplifier gain using Miller effect, i.e., $C_1 = C_{10}(1+A_2)$, where A_2 is the amplifier gain. The oscillation frequency W_0 is then varied by varying A_2. In this method the waveform distortion is avoided by simultaneously varying the feedback amplifier gain A_1. An alternative approach for realizing voltage controlled RC sinusoidal oscillators has been described by Sun [3]. He has proposed a class of circuits, which employ two feedback amplifiers. One amplifier of fixed gain A_1 is used to constrain the natural frequencies of the circuits to the imaginary axis of the complex frequency of oscillation.

The primary purpose of this paper is to show that tunable RC sinusoidal oscillators may be realized by employing scaled resistance elements in conjunction with unscaled capacitances.

The tuning procedure may considered as frequency scaling the transfer function T(s). Thus a tunable transfer function is given by T(Ks) or T(s/K), where K or K, the frequency scaling parameter, are functions of controlling quantity. The simplest form of controlling quantity would be a tuning voltage V_B or the pulsewidth-to-period (τ/T) of a set of periodically switched conductances such that K or K is determinated directly by V_B or τ/T, respectively.

Type-1 oscillator

Consider the network configuration of Fig. 1, which involves a finite-gain differential amplifier defined by

$$V_0 = A_0(V_1 - V_2) \qquad (1)$$

and two time-invariant scaled-resistances (KR_1, KR_2) in conjunction with two unscaled capacitance (C_1, C_2), where K is a dimensionless variable, hereafter referred to as a scaling factor. It is assumed that the amplifier has an infinite input impedance and zero output impedance, and its voltage gain is independent of frequency. The voltage transfer function of the network of Fig. 1 can be obtained as

$$\frac{V_0}{V_i} = T(sK) = A_0\left[\frac{V_1}{V_i} - \frac{V_2}{V_i}\right] = \frac{A_0 K s R_2 C_2}{K^2 s^2 + Ks\left(\frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} + \frac{1}{C_1 R_2}\right)} + \frac{1}{C_1 R_1 C_2 R_2} \qquad (2)$$

where s is a complex frequency. The open-loop frequency response of the system is obtained from (2) by substituting jW for s.

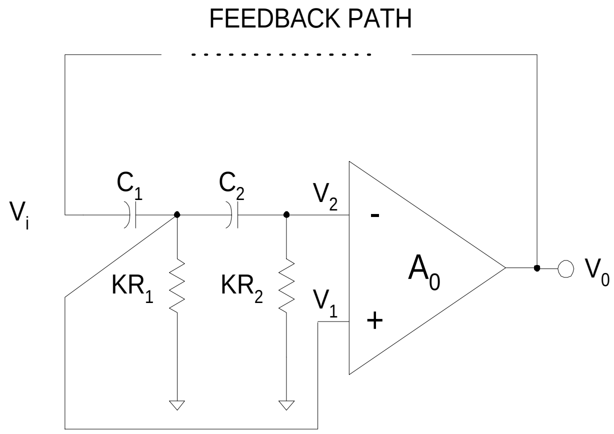


Fig. 1. Type-1 RC oscillator configuration involving time-invariant scaled-resistances KR_1 and KR_2.

Now the transfer function of (2) becomes

$$T(jWK)=\frac{\dfrac{jW_0KA}{R_2C_2}}{-K^2W^2+jKW(\dfrac{1}{R_1C_1}+\dfrac{1}{R_2C_2}+\dfrac{1}{C_1R_2})}+\frac{1}{R_1C_1R_2C_2} \tag{3}$$

when the feedback loop in Fig. 1 is closed, the frequency of oscillation W_0 of the system and the gain A_0 required for their maintenance can be determined from

$$T(jWK)=T(jW_0K)=1\,. \tag{4}$$

Application of the criterion of (4) to the second-order function of (3) yields

$$A_0=1+\frac{R_2C_2}{R_1C_1}+\frac{C_2}{C_1} \tag{5}$$

and

$$W_0=\frac{1}{K}\sqrt{\frac{1}{R_1C_1R_2C_2}} \tag{6}$$

which show that the oscillation maintenance gain A_0 is independent of the scale factor K whereas the oscillation frequency W_0 is inversely proportional to the scale-factor K. thus the oscillator can be tuned to any desired frequency by varying the scale-factor K.

Electronically Variable Scaled-Resistance Elements

The first step in the realization of T(Ks) is to realize grounded scaled-resistance in the form KR_i (i=1,2), where the scale-factor K should be varied by some electronic means. For this purpose a configuration is proposed in Fig. 2(a) which involves a voltage-controlled amplifier (VCA) and a resistor R_i. The voltage gain of the VCA is given by

$$\frac{V_0}{V_1}=-A=-f(V_B) \tag{7}$$

where $f(V_B)$ denotes a function of V_B. The input current can be obtained as

$$i=\frac{V_i-V_0}{R_i}=(1+A)R_iV_i \tag{8a}$$

$$=1+f(V_B)R_iV_i\,. \tag{8b}$$

Therefore, the simulated driving point resistance is given by

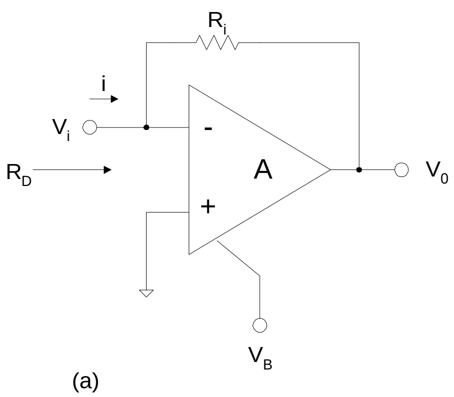
$$R_D = \frac{R_i}{1 + f(V_B)} = KR_i \quad (9)$$

where we define

$$K = \frac{1}{1 + f(V_B)}. \quad (10)$$

In the preceding realization, we have assumed that the amplifier has infinite input impedance and zero output impedance.

A practical realization of Fig. 2(a) is shown in Fig. 2(b) which involves a differential pair whose gain is a function of the voltage V_B. To study the performance of the voltage variable resistance R_D, a practical circuit is constructed using R_i=100 KΩ. The test results have been given in Table I.



(a)

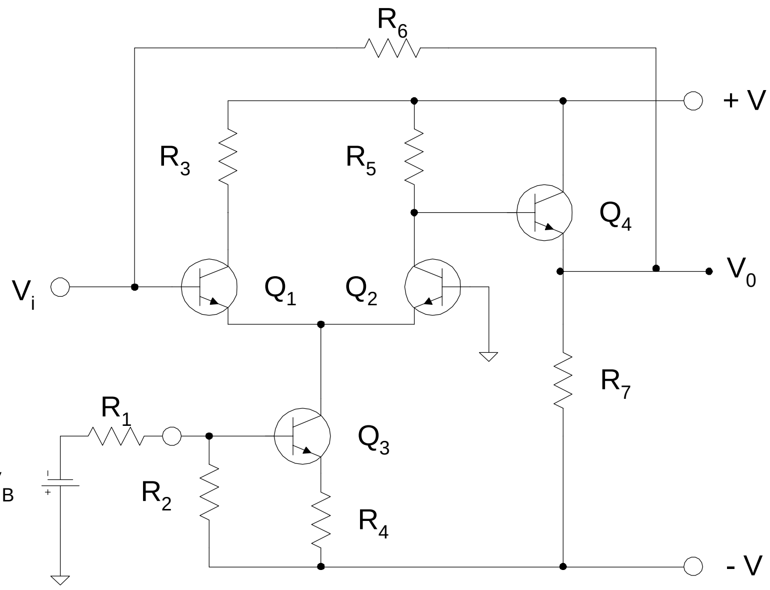


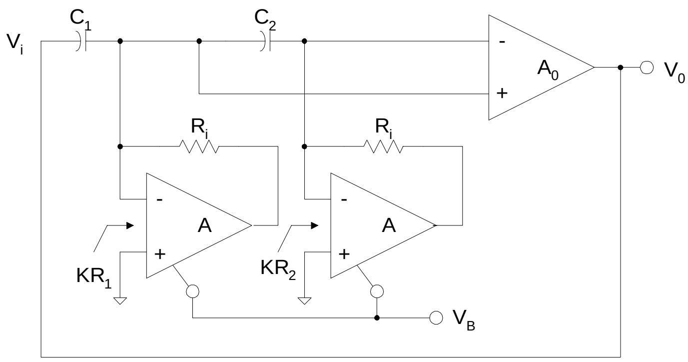
Fig. 2. Realization of time-invariant electronically tunable scaled resistance. (a) Basic configuration. (b) A practical realization.

Table I
Voltage Variable Resistance

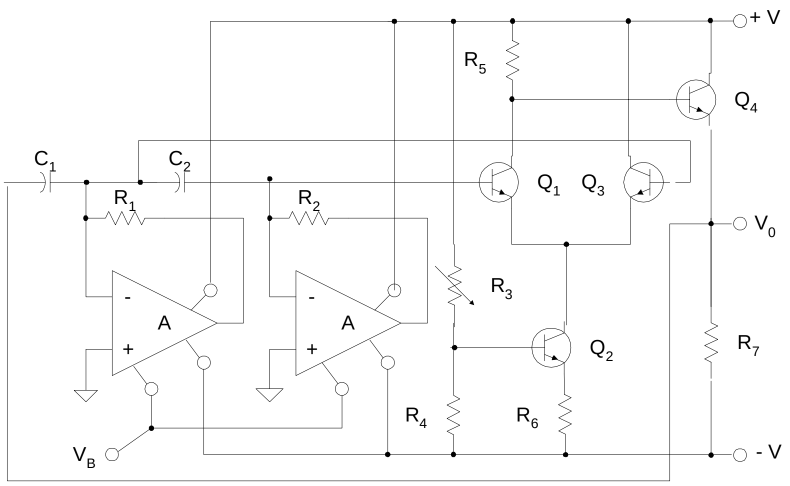
V_B (volts)	-15	-10	-5	0	5	10	15
$1/R_D$ (mmho)	$79\cdot10^{-2}$	$66\cdot10^{-2}$	$54\cdot10^{-2}$	$41\cdot10^{-2}$	$26\cdot10^{-2}$	$13\cdot10^{-2}$	$3\cdot10^{-2}$

Designed of Type-1 Oscillator

Application of scaled resistance R_D of Fig. 2 in Fig. 1 (in place of KR_1 and KR_2) generates a class of electronically tunable RC sinusoidal oscillators as shown in Fig. 3(a). A discrete component circuit based on Fig. 3(a) is built as shown in Fig. 3(b). For A_0 amplifier we have used a differential pair cascaded to an emitter follower. The potentiometer R_3 is adjusted to obtain suitable gain so that the oscillator starts to oscillate with proper amplitude and small harmonic distortion.



(a)



(b)

Fig. 3. Electronically tunable type-1 oscillator.
(a) Basic configuration. (b) A practical circuit.

R_3 then remains fixed through the tuning process. For experimental circuit we have used C_1=C_2=0.1μF, R_1=R_2=100KΩ. The test result of the oscillator is shown in Table II. These result indicate that the frequency tuning range f_{max}/f_{min} for this practical circuit is 26.3 and the amplitude variation is less than 1 dB. The practical limit of the tuning range is determined by the linear range of the VCA. In general, the tuning range of the experimental circuit is limited by the saturation voltage and cutoff voltage of the transistor Q_3 of Fig. 2(b).

Table II
Performance of Type-1 Oscillator

VB (volts)	-15	-10	-5	0	5	10	15
Frequency (Hz)	1264	1054	890	654	415	208	48
Amplitude Variation (dB)	-0.8	-0.6	-0.4	-0.4	-0.4	-0.4	0

Type-2 Oscillators

Consider the networks of Fig. 4 which consists of two periodically switched conductances (denoted by K(t)G1 and K(t)G2) in conjunction with two unswitched capacitances (C1, C2). The scaling factor K(t) is a discontinuous discrete periodic time function with average value K. a sketch of K(t) is given in Fig. 5 which gives

$$K(t) = K_1 u(t-nT) - u(t-nT-\tau) + K_2[u(t-nT-\tau) - u\{t-(n+1)T\}] \qquad (11)$$

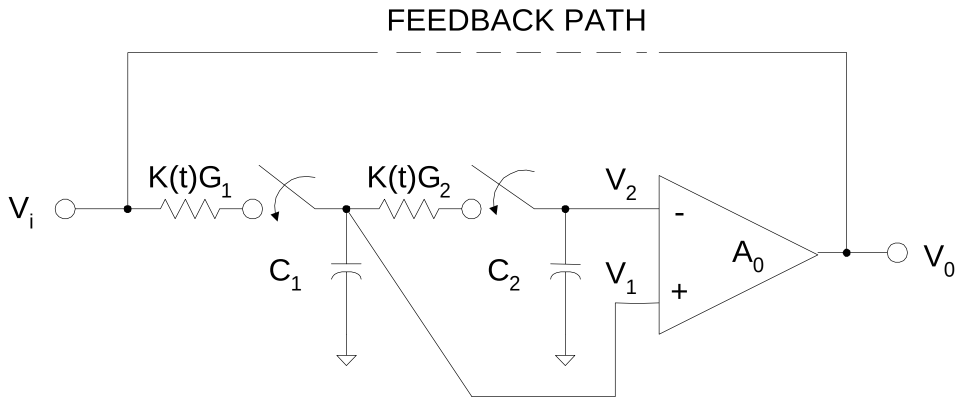
with $n = -\infty \cdots +\infty$.
It can shown easily that

$$\underline{K} = K_1\,\tau/T + K_2(1-\tau/T) \qquad (12)$$

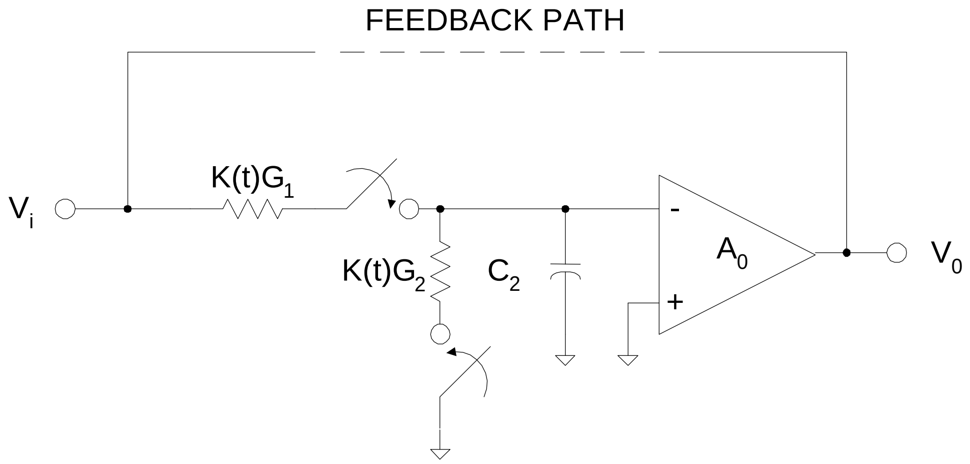
If we constrain the output voltage to be across a capacitance within the network as shown in Fig. 4, the impulse response $h_c(t,T)$ of a time-varying network with conductances $K(t)G_1$ and $K(t)G_2$ is given by [4]

$$\lim h_c(t,T) = \underline{K}(a_1 e^{b_1 \underline{K} t} + a_2 e^{b_2 \underline{K} t}) \qquad (13)$$

where the coefficients a_i and b_i (i=1,2) are the functions of G_i and C_i (i=1,2), and independent of $\underline{K}$.



(a)



(b)

Fig. 4. Type-2 oscillator configurations containing periodically switched conductances

Consequently, the voltage transfer function of Fig. 4 can be obtained in the form:

$$\frac{V_0}{V_1} = T(\frac{s}{K}) = \frac{\frac{A_0 G_1 C_2 s}{K}}{\frac{s^2}{K_2} + \frac{s}{K}(C_1 G_2 + C_2 G_1 + C_2 G_2) + G_1 G_2} \tag{14}$$

The open-loop frequency response of the system is obtained by putting s=jW.

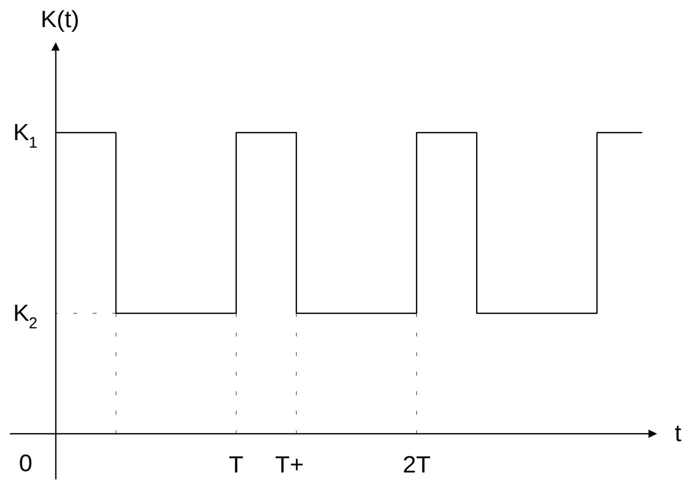


Fig. 5. Time variation of switched conductances

When the feedback in Fig. 4 is closed, the oscillation frequency W_0 and maintenance gain A_0 can be obtained from (4) as

$$W_0 = K\sqrt{\frac{G_1G_2}{C_1C_2}} \tag{15}$$

$$A_0 = \begin{cases} 1+\frac{G_2}{G_1}+\frac{C_1G_2}{C_2G_1} \rightarrow \text{for Fig.4(a)} \\ 1+\frac{G_2}{G_1}+\frac{C_2G_1}{C_1G_2} \rightarrow \text{for Fig.4(b)} \end{cases}, \tag{16}$$

which shows that the oscillation frequency can be controlled by the scaling factor <u>K</u> without affecting the maintenance gain A_0.

Design of Type-2 Oscillator

The purpose is to illustrate our method of frequency scaling by design a tunable RC oscillator having periodically switched conductances. Using the configuration of Fig. 4(b), a practical circuit has been constructed as shown in Fig. 6. Practical values of the circuit elements are given in the design. The switched conductances are realized by connecting two conductances in parallel and switching one in and out of the circuit with a FET switch. To prevent the switching waveform from interfering with the analog voltage being switched, a diode is placed in series with the gate as shown in Fig. 6. A speedup capacitor is placed in parallel with the diode to ensure that the FET switches on rapidly. Tuning of oscillation frequency is done by varying pulsewidth-to-period ratio (τ/T). The value of τ/T is varied by adjusting τ for a constant period T. The test result of the oscillator is shown in Table III.

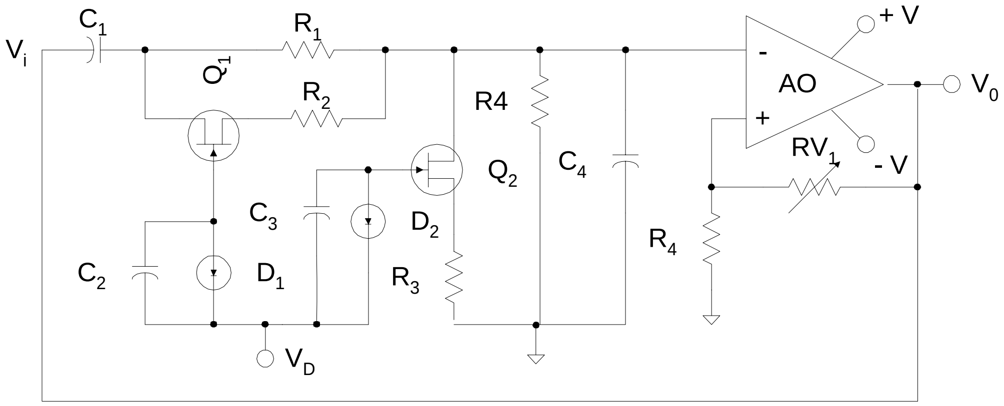


Fig. 6. A practical type oscillator

Table III
Performance of Type-2 Oscillator

τ/T	1.0	0.8	0.6	0.4	0.2	0.1
Oscillation Frequency (Hz)	3981	3344	2707	2069	1433	1114

Conclusion

For realizing electronically tunable RC sinusoidal oscillators, two types of configurations have been proposed in this paper. The type-1 network uses two ground scaled resistances, which are used as a means of controlling the oscillation frequency. For realizing the scaled resistances, an active configuration has been proposed, which involves a VCA and a resistance. It is shown that the scaling factor K is a function of the controlling voltage V_B. Thus the frequency tuning is done by varying the voltage V_B. These types of oscillator are strictly analog and rely for accuracy on the fact that the RC building block has got excellent low-sensitivity properties. The type-2 oscillators employ two periodically switched conductances. In this case, the tuning of oscillation frequency is effected by controlling the pulsewidth-to-period ratio (τ/T) of the periodically switched conductances. This provides a means of tuning network functions accurately and should prove to be very useful in low frequency applications.

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