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A low-cost dual-slope triangular/square wave generator

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A new dual-slope triangular/square wave generator is presented. The circuit uses few active and passive components and can be easily integrated. Experimental results obtained from a breadboard implementation, using discrete transistors, show that by using a grounded resistor the frequency of oscillation can be tuned in the range 1.7 kHz–3.5 kHz without disturbing the slopes the positive-going and the negative-going edges of the triangular wave.

1. Introduction

Triangular/square wave generators are widely used in a wide range of applications in instrumentation and measurement systems. This justifies the development of a large number of triangular/square wave generators using a variety of active elements (see Chang 1984, Cheng and Larson 1985, Taha 1985, Taha *et al.* 1985, Karnal *et al.* 1987, Spencer and Angell 1990, Siskos and Tombras 1992, Gerstenhaber and Murphy 1994, Abuelma'atti and Al-Shahrani 1998 a, b, Cicekoglu and Kuntman 1998, Cicekoglu and Toker 1999, Almashary and Alhokail 2000, and references cited therein). These generators invariably suffer from one or more of the following disadvantages:

1. Use of excessive number of active elements; for example transistors, diodes, operational amplifiers, current-conveyors, current-feedback operational amplifiers, counters, analog-to-digital converters and memory devices.
2. Use of excessive number of capacitors and/or resistors.
3. Use of floating variable resistors to control the frequency and/or the slope of the triangular-wave positive- and negative-going edges; thus electronic control of these parameters is not feasible.
4. Use of floating capacitors; thus high frequency operation may not be feasible.
5. Cannot generate dual-slope triangular waves.

The major intention of this paper is, therefore, to present a simple low-component dual-slope triangular/square wave generator using a grounded capacitor, one operational amplifier with two resistors configured as a comparator with hysteresis, eight bipolar transistors forming two cascode current-mirrors, and two grounded resistors for controlling the slopes of the positive- and negative-going edges of the resulting triangular wave.

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2. Proposed circuit

Figure 1 shows the proposed circuit. The operational amplifier and the resistors R_1 and R_2 form a comparator with hystresis, that is a Schmitt trigger, with output voltages either V_{sat+} or V_{sat-} and threshold voltages $V_{TH} = \beta V_{sat+}$ and $V_{TL} = \beta V_{sat-}$ where $\beta = (R_2/(R_1 + R_2))$. When the output voltage of the Schmitt trigger is V_{sat+}, the upper current mirror formed by transistors Q_1–Q_4 produces a constant current $I_1 = ((V_{sat+} - 2V_{BE})/R_3)$. This current charges the capacitor C linearly with time at a rate of I_1/C. When the voltage across the capacitor reaches V_{TH} the output of the Schmitt trigger switches to V_{sat-}, the lower current-mirror formed by transistors Q_5–Q_8 produces a constant current $I_2 = ((|V_{sat-}| - 2V_{BE})/R_4)$. This current discharges the capacitor C linearly with time at a rate of I_2/C. When the voltage across the capacitor reaches V_{TL}, the output voltage of the Schmitt trigger switches to V_{sat+} and the cycle is repeated. Thus, the slope of the positive-going edge of the capacitor voltage and the charging time of the capacitor will be given by

$$S_1 = \frac{V_{sat+} - 2V_{BE}}{CR_3} \tag{1}$$

and

$$T_1 = C\frac{V_{TH} - V_{TL}}{I_1} \tag{2}$$

Similarly, the slope of the negative-going edge of the triangular wave and the discharging time will be given by

$$S_2 = \frac{|V_{sat-}| - 2V_{BE}}{CR_4} \tag{3}$$

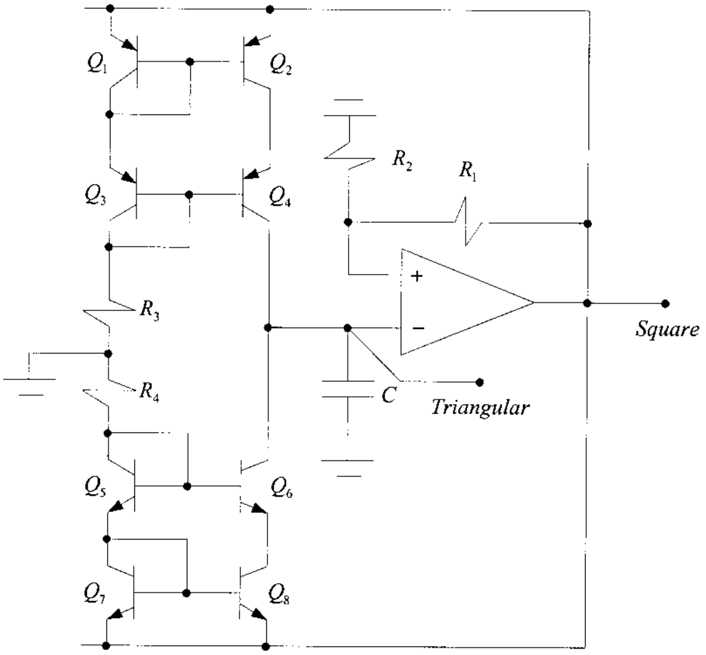


Figure 1. Proposed dual-slope triangular/square wave generator.

and

$$T_2 = C\frac{V_{\mathrm{TH}} - V_{\mathrm{TL}}}{I_2} \tag{4}$$

Substituting values of I_1 and I_2 into equations (2) and (4), the frequency of oscillation can be expressed as

$$f = \frac{1}{T_1 + T_2} = \frac{1}{C}\left[\frac{1}{V_{\mathrm{TH}} - V_{\mathrm{TL}}}\right]\left[\frac{V_{\mathrm{sat}+} - 2V_{\mathrm{BE}}}{R_3} + \frac{|V_{\mathrm{sat}-}| - 2V_{\mathrm{BE}}}{R_4}\right] \tag{5}$$

With $V_{\mathrm{sat}+} = |V_{\mathrm{sat}-}|$, as is usually the case, equation (3) reduces to

$$f = \frac{1}{T_1 + T_2} = \frac{1}{C}\left[1 + \frac{R_1}{R_2}\right]\left[\frac{V_{\mathrm{sat}+} - 2V_{\mathrm{BE}}}{2V_{\mathrm{sat}+}}\right]\left[\frac{1}{R_3} + \frac{1}{R_4}\right] \tag{6}$$

Equations (1), (3) and (6) show that, while it is possible to control the frequency of oscillation by adjusting the resistors R_1 and/or R_2 without disturbing the slopes of the positive- and negative-going edges of the triangular waveform obtained across the capacitor C, the slopes of this triangular waveform cannot be controlled without disturbing the frequency of oscillation. It is, therefore, recommended to start by controlling the slopes of the positive- and negative-going edges of the triangular wave by adjusting the grounded resistors R_3 and R_4 respectively, and then controlling the frequency of oscillation by adjusting the grounded resistor R_2 and/or the floating resistor R_1.

3. Experimental results

The proposed dual-slope triangular/square wave generator was experimentally tested using the µA741 operational amplifier, 2N3906 pnp transistors and 2N3904 npn transistors. Figure 2 shows the variation of the frequency of oscillation with the

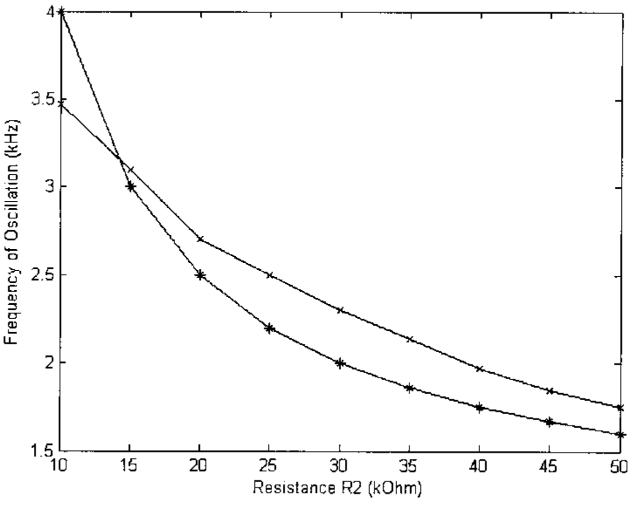
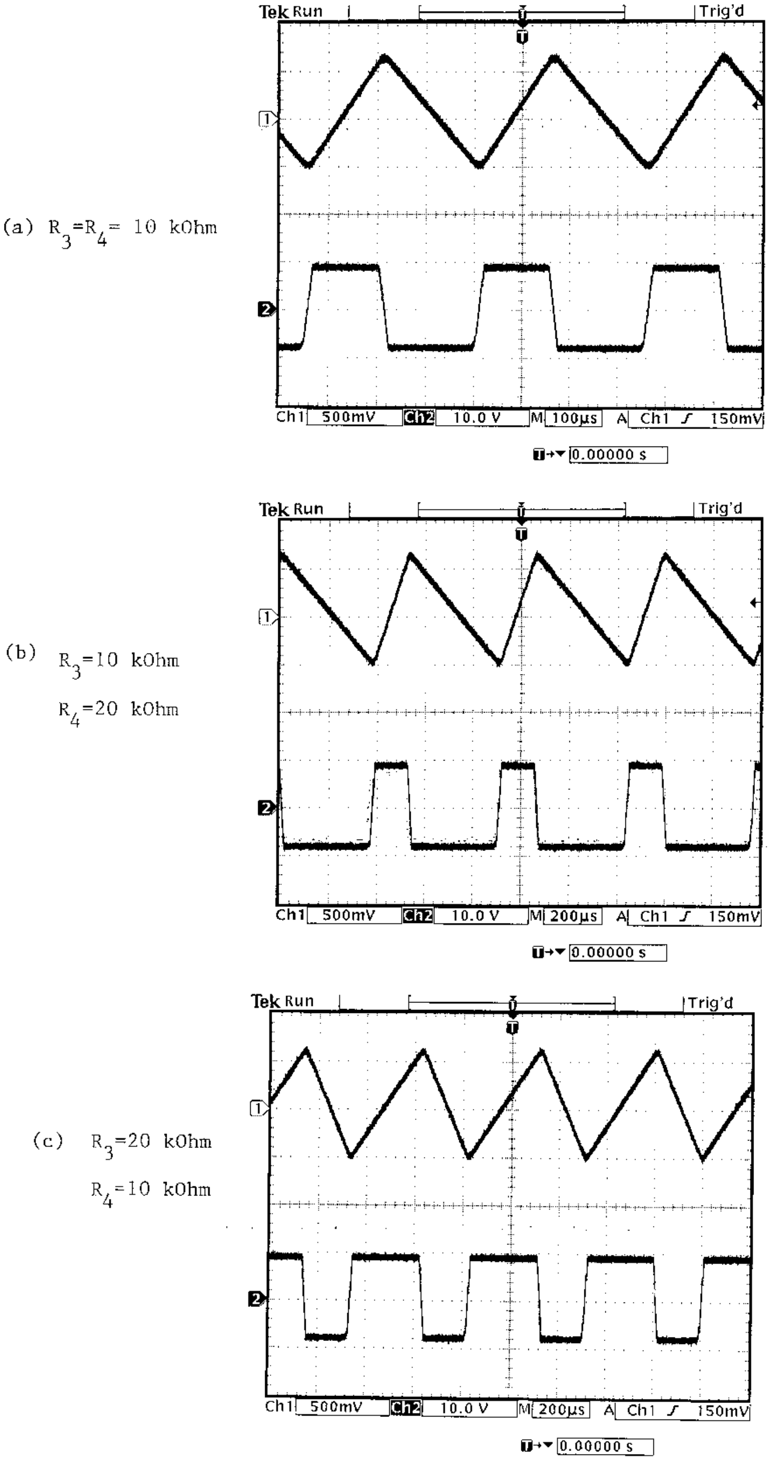


Figure 2. Variation of the frequency of oscillation with the grounded resistor R_2. *, Calculated equation (6); +, measured with $C = 0.1\,\mu\mathrm{F}$, $R_1 = 30\,\mathrm{k\Omega}$, $R_3 = R_4 = 10\,\mathrm{k\Omega}$ and dc supply voltage = ± 5 V.


(a) $R_3=R_4=$ 10 kOhm

(b) $R_3=10$ kOhm
$R_4=20$ kOhm

(c) $R_3=20$ kOhm
$R_4=10$ kOhm

Figure 3. Experimental results obtained for different values of R_3 and R_4. $C=0.1\,\mu\text{F}$ in all cases. (*a*) $R_3=R_4=10\,\text{k}\Omega$; (*b*)$R_3=10\,\text{k}\Omega$, $R_4=20\,\text{k}\Omega$; (*c*) $R_3=20\,\text{k}\Omega$, $R_4=10\,\text{k}\Omega$.

resistance R_2 obtained with $C = 0.1\,\mu\text{F}$, $R_1 = 30\,\text{k}\Omega$, $R_3 = R_4 = 10\,\text{k}\Omega$ and dc supply voltage of the operational amplifier $= \pm 5\,\text{V}$. Typical output waveforms obtained for different scenarios of R_3 and R_4 are shown in figure 3. It appears from figures 2 and 3 that the experimental and theoretical results are in good agreement.

4. Conclusion

A simple dual-slope triangular/square wave generator has been presented. The circuit used one operational amplifier, eight transistors configured as two cascode current-mirrors and four resistors. The frequency of oscillation and the slopes of the positive- and negative-going edges of the triangular wave can be tuned using grounded resistors. However, while the frequency of oscillation can be controlled without disturbing the slopes, the latter cannot be controlled with disturbing the frequency of oscillation. This paves the way for electronic analog and digital programmability by replacing the grounded resistors either by JFET transistors or operational transconductance amplifiers configured as grounded resistors.

It is worth mentioning here that since the triangular output is taken from the capacitor, then a load resistance placed across the capacitor to ground would take its current from the capacitor charging (or discharging) current. This would affect the linearity of the output triangular waveform and the charging (or discharging) time and consequently the frequency of oscillation. This loading effect can be avoided by inserting a unity-gain buffer between the capacitor and the load.

The results reported here were obtained using a breadboard implementation; no attempt was made to use nearly matched discrete transistors. Obviously, an integrated circuit implementation avoiding stray capacitances and using nearly matched transistors would result in higher frequencies of operation and better agreement between the measured and calculated results.

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