RAMP GENERATOR

Ramp generators are found in many circuit applications where a linear change of some voltage is required. For example, ramp voltages are used to generate the x and y scan voltages in a CRT or in electronic motor controllers. A voltage that rises or falls linearly in time can be generated very simply, by charging a capacitor at a constant rate over a period of time. When a capacitor is charged from a simple voltage source V_o, via a series resistor R, the voltage on the capacitor rises according to the well-known exponential relationship $V_C = V_o(1 - e^{-t/RC})$. This voltage is not a linear ramp, because the charging current is not constant. To render the ramp voltage linear, a constant current source must be substituted for the resistor-voltage source combination, to provide the desired linearity. Now all that is required is a system of controlling the pattern and rate of capacitor charge and discharge, to determine whether the circuit is a triangle-wave or sawtooth-wave generator.

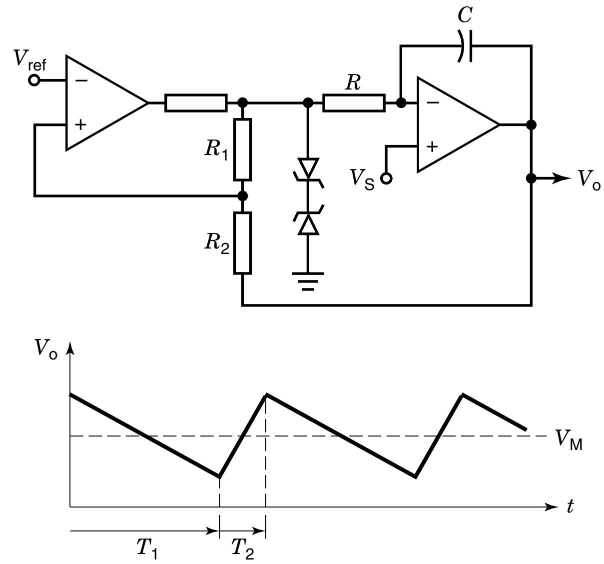

Figure 2. Triangle-wave generator using an integrator and showing the relationship between T_1 and T_2.

GENERATING A RAMP VOLTAGE

The next sections contain some examples of how practical circuits might be constructed using comparators, discrete components and a 555 timer. The ramp period in all of these circuits is effectively calculated from the magnitude of the voltage swing, the magnitude of charging current, and the value of timing the capacitor, although, in those circuits, employing integrators it is convenient to use the expression for the integrator output in the derivation of output period.

Non-linear Ramp

Consider the square wave generator circuit based on a regenerative comparator (Schmitt Trigger) shown in Fig. 1. This circuit works by feeding back the output voltage V_o via the resistor R to provide a current that charges and discharges the capacitor C in an oscillatory manner. Whenever the output changes state, the positive input to the comparator snaps to a new value, above or below earth potential, providing the regenerative action. The changing V_C causes the differential input to become less and eventually to change sign, at which point the output changes state again. If one looks at the capacitor voltage, V_C, also shown in Fig. 1, one can see that this is an approximation to a triangle wave, but is not linear as explained above.

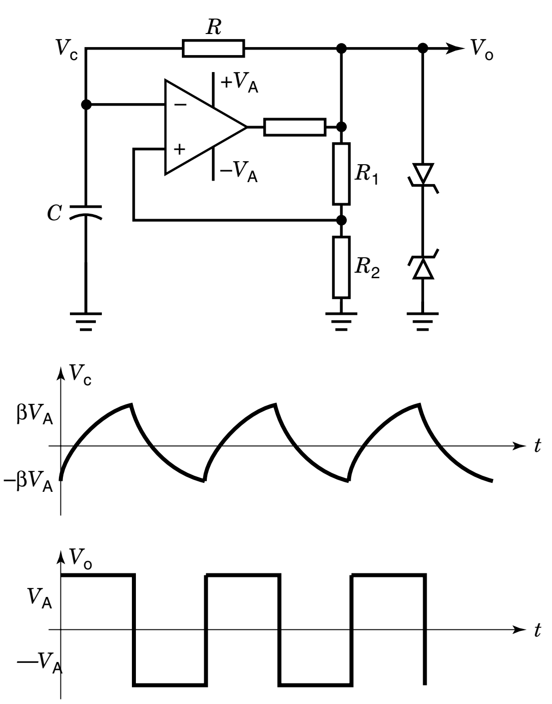

Figure 1. Square-wave generator showing the presence of a nonlinear ramp voltage on the timing capacitor.

An operational amplifier integrator circuit can be used to ensure that the capacitor charging current is constant and the linear ramp output of the circuit then only need be fed back to the comparator input to produce a circuit that is simultaneously a square wave and triangle-wave generator. This approach requires just one further change to the circuit. Since an integrator is an inverting circuit, such feedback will produce a ramp voltage on the comparator that is in antiphase with that required to make the two inputs converge, and can be corrected by connecting an inverting buffer between the integrator and the capacitor.

Triangle-Wave Generator

A slightly different approach has been taken in the circuit shown in Fig. 2. The square-wave output of the comparator is applied to an integrator as described, but the integrator output is then fed back to the noninverting input of the comparator rather than the inverting input, thus eliminating the need for an additional inverting buffer (1,2). The frequency of the output, f_o, for this circuit is (2):

$$f_o = \frac{R_1}{4R_2RC}\left[1 - \frac{V_S^2}{V_A^2}\right] \tag{1}$$

The median point of the output waveform is set according to Eq. (2) and the ratio of ramp-up and ramp-down periods,

$T_1 : T_2$, is set by Eq. (3), where the comparator output switches between $\pm V_A$ (2).

$$V_M = V_{ref}\left(\frac{R_1 + R_2}{R_1}\right) \tag{2}$$

$$\frac{T_1}{T_2} = \frac{V_A + V_S}{V_A - V_S} \tag{3}$$

Even though the $T_1 : T_2$ ratio can be varied widely, this circuit is not such a good choice if a sawtooth waveform is required, since either T_1 or T_2 is then required to be zero. If a single ramp is required rather than the repetitive output provided by this circuit, it can be easily converted to monostable operation (1).

This circuit has a useful operating frequency range up to about 40 kHz, with the limit set by the comparator output slew rate. A general purpose operational amplifier can easily be used here, but for higher frequency operation a high slew rate device, such as an LM6365, can be used to extend the maximum frequency (depending on the voltage swing required). However, it should be noted that bipolar operational amplifiers do not generally provide full rail to rail output voltage swing, which can lead to drift in the Schmitt Trigger thresholds, so for general use, an FET output operational amplifier which does give full rail to rail voltage swing is a better choice.

Current Source-Controlled Circuit

The direct approach, shown in the circuit of Fig. 3, uses one current source to charge the timing capacitor and a second to discharge it, so that the rising and falling slopes are set by the ratio of the current sources. The charge and discharge of the capacitor is once again controlled by a regenerative comparator, this time connected to a complementary pair of switches. When the comparator output is high, S_1 is closed, allowing C to be charged by I_1, while S_2 is open. When the differential input to the comparator changes sign, its output changes state and S_2 is closed, while S_1 is open, and C can be discharged via I_2, until the comparator differential input changes sign again. This circuit can be easily used for sawtooth generation, since one or the other of the current sources

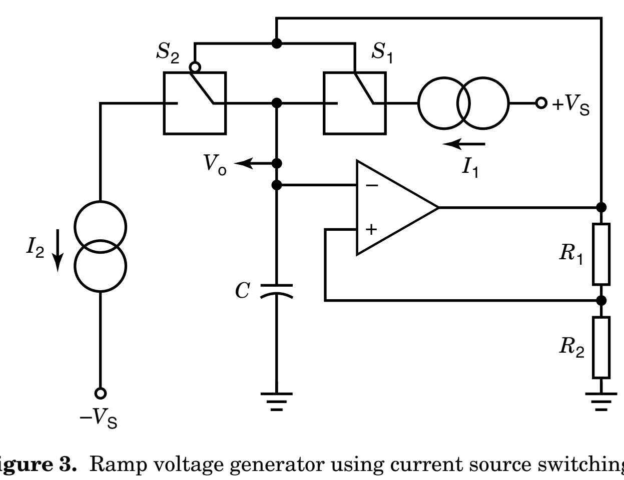

Figure 3. Ramp voltage generator using current source switching for triangle or sawtooth output, showing the action of S_1 and S_2 to charge and discharge C.

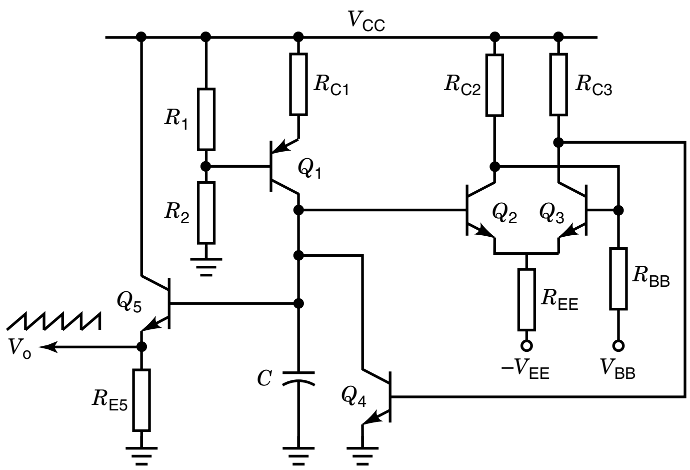

Figure 4. Sawtooth generator constructed from discrete components which also makes use of a (single transistor) current source.

can be omitted and replaced by a short circuit, so that C can be charged or discharged using a very short time constant circuit. The current sources themselves could be either simple current regulator connected BJTs or FETs, or a more complex current regulator device, depending on the accuracy and stability required. Once again, the maximum useful operating frequency is set by the comparator output slew rate, but may be pushed beyond the normal operating range of the comparator if great accuracy is not required (and also no use is being made of the square-wave output). Note that if the output is driving a low impedance load, a buffer circuit will be required to prevent load current from affecting the charge and discharge rates of C.

Sawtooth Circuit Using Discrete Devices

It is usually simpler to use operational amplifier-based circuits, where the specifications allow, but their slew rate limit can be overcome by using discrete components, and one implementation of a sawtooth generator is shown in Fig. 4. The *p-n-p* Q_1 is configured as a current source, but a more accurate current regulator circuit could be substituted, if required. The collector current from Q_1 charges the timing capacitor, C, with the capacitor voltage used as the input to the differential pair Q_2 and Q_3 connected as a Schmitt Trigger. Initially, let Q_2 be off and Q_3 be on. When the voltage on the base of Q_2 rises above that on the base of Q_3, the circuit switches regeneratively, so that its output at the collector of Q_3 goes high. This output, in turn, switches on Q_4 and discharges C turning Q_2 off and Q_3 on again.

This configuration has one disadvantage, in that Q_4 must conduct both the discharge current from C and the charging current from Q_1. Q_4 must accommodate both of these currents, and the discharge of C is thus slowed. A useful modification is to use the Schmitt Trigger output from the collector of Q_3, to set the base voltage on Q_1, so that it switches on and off in antiphase with Q_4, but output levels of the Schmitt Trigger must be compatible with the bias requirements of Q_1.

The input switching levels for the Schmitt Trigger can be varied by changing V_{BB}, allowing the circuit to be used as a voltage to frequency converter if desired, since the time taken

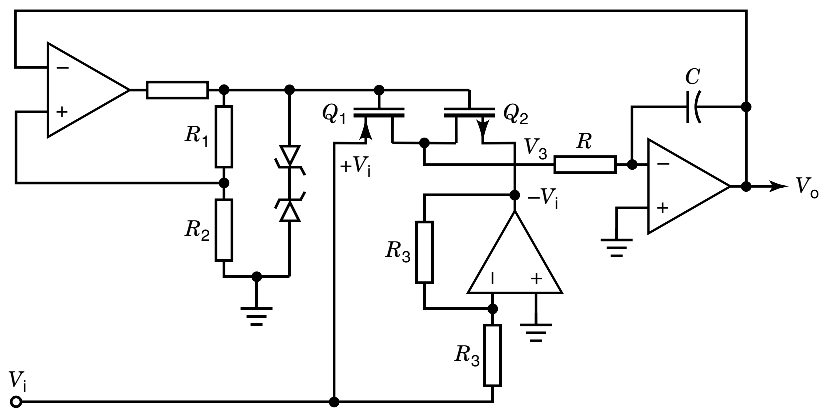

Figure 5. Voltage-controlled circuit for triangle-wave generation illustrating the use of a CMOS inverter to integrate the correct polarity of the input voltage V_i.

for the capacitor voltage to ramp to the switching point will vary. Q_5 is simply an emitter follower to buffer the load.

VOLTAGE-CONTROLLED ARCHITECTURES

Some of the circuits can be modified to operate in voltage-controlled mode, an example of which is shown in Fig. 5, and is based on the triangle-wave generator from Fig. 2. Here the comparator output controls two MOS transistors, Q_1 and Q_2, acting as a CMOS inverter, effectively selecting either the voltage on the n-channel source or the voltage on the p-channel source. The input control voltage, V_i, is applied to the p-channel source and its inverse is applied to the n-channel source, via the unity gain inverting amplifier. Thus the integrator is integrating $\pm V_i$ rather than the comparator output, so that the slope rate of the integrator output now depends upon V_i. Since the voltage required at the input of the comparator to cause it to switch is constant, the effect is that output frequency, f_o, depends on V_i and, where the comparator output switches between $\pm V_A$, is given by (2):

$$f_o = \frac{V_i}{V_A} \cdot \frac{1 + R_1/R_2}{4RC} \tag{4}$$

Note that the presence of the CMOS inverter circuit, in effect, provides the additional inverter missing from the original triangle-wave generator (as discussed above) and the feedback connection is brought to the inverting input of the comparator this time. The operation is once again limited by amplifier slew rate and the frequency varies linearly over a reasonably large range. Care must be taken, however, to ensure that V_i does not become too large; otherwise, the amplifier inverting V_i will saturate and the circuit will not function correctly.

Figure 6 shows a further approach, where the circuit is an extension of the current source-controlled circuit. Voltage-controlled switches are switched between their open and closed states by the operational amplifier output. The capacitor charge and discharge current is set by the voltage-controlled current sources whose control voltage is determined by the input voltage V_i.

USING THE 555

555 integrated circuit components are used in many timing circuits, as well as in ramp generators. Figure 7 shows a sawtooth circuit, which makes use of the THRESHOLD (TH) and TRIGGER (TR) inputs and the DISCHARGE (DIS) terminal (3). The capacitor C is charged via the p-n-p transistor working as a current source. When the voltage on the capacitor is high enough to activate the TH input, C is discharged quickly through the DIS pin (achieved by turning on an internal discharge transistor). When the voltage on C has fallen to the value that activates the TR input, the discharge transistor is turned off and the cycle begins again. The voltage on the capacitor is therefore a sawtooth wave, which varies between 1/3 V_{CC} and 2/3 V_{CC} (in a 555 the TH input is activated for a voltage greater than 2/3 V_{CC} and the TR input is activated for a voltage less than 1/3 V_{CC}). A buffer is required as before to avoid loading the capacitor. The frequency of operation can be calculated from the values of V_{CC}, C, and the current source.

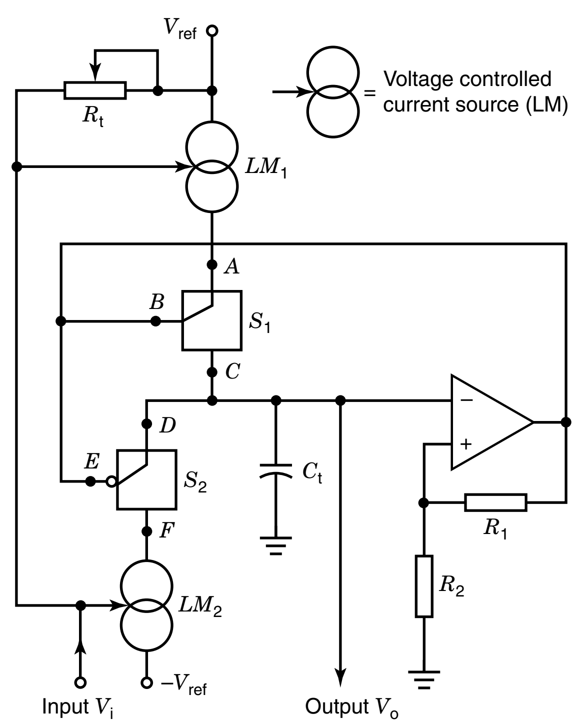

Figure 6. Voltage-controlled circuit providing variable frequency triangle or sawtooth output using voltage-controlled current sources switched to charge and discharge C.

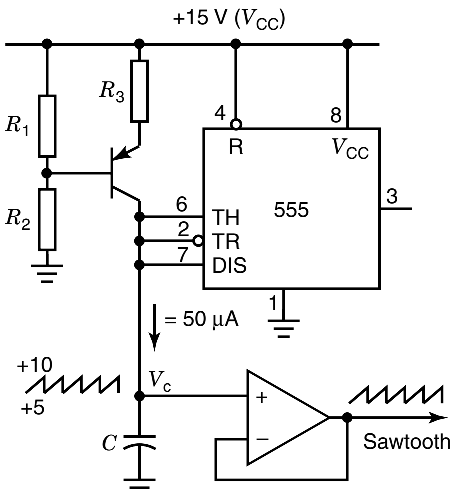

Figure 7. 555 timer circuit for sawtooth-wave generation using a transistor current source to charge C and the DIS terminal to discharge C.

If a triangle wave is required, the circuit of Fig. 8 can be used (3), which operates in a similar way to the sawtooth circuit. It does not make use of the DIS pin, but does require a bidirectional current source, which can be implemented as two current-regulator-connected JFETs in series (e.g., 1N5287, providing about 33 mA). Current flow is bidirectional, because one JFET will regulate the current, while the other behaves like a forward-biased diode, due to gate-drain conduction, and the square wave output of the 555 is used to drive the current sources. When the 555 output is at V_{CC} the capacitor charges up to 2/3 V_{CC}, whereupon the output switches to 0 V and the capacitor discharges to 1/3 V_{CC}, causing the output to switch back to V_{CC} again. Once again, the output varies between 1/3 V_{CC} and 2/3 V_{CC}, and an output buffer is required. Finally, if this circuit is used with a 5 V power supply it is essential to use a CMOS 555 variant, because bipolar 555s typically have a high output, two-diode drops below V_{CC}. This would then leave insufficient voltage across the current sources, to allow for conduction (about 1 V for the current regulator and a further 0.7 V for the gate-drain diode). The CMOS 555, however, produces a full-range output swing.

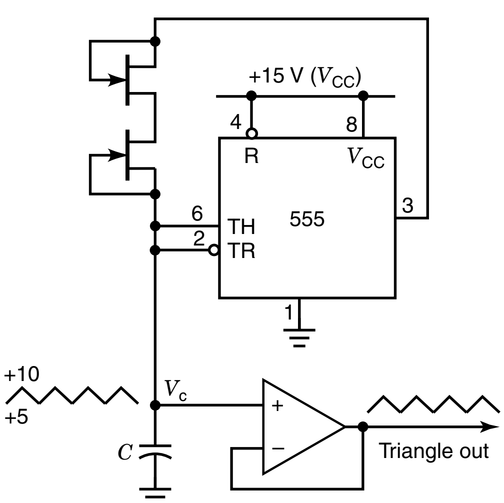

Figure 8. 555 timer circuit for triangle-wave generation which uses two current-regulator-connected JFETs to provide charge and discharge current for C.

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RANDOM ACCESS MEMORIES. See SRAM CHIPS.

RANDOMNESS. See PROBABILITY.