Current source and 555 timer make linear v-to-f converter

by Andrew McClellan
Case Western Reserve University, Cleveland, Ohio

In many situations it is desirable to linearly control the output frequency of a 555 timer circuit by adjusting a potentiometer or an input voltage. In the conventional astable configuration of the 555, the timing capacitor discharges and charges through one or two timing resistors. Thus the frequency is inversely related to changes in the timing components, and is also inversely related to changes in the control voltage.

However, inexpensive and accurate linear voltage-to-frequency conversion can be obtained from the 555 astable multivibrator circuit in Fig. 1. A voltage-dependent current I linearly charges the timing capacitor C so that output frequency increases linearly with the input control voltage V_{in}. During the charging phase of the cycle the capacitor voltage is given by:

$$V_C = V_{CC}/3 + It/C$$

Charging continues until V_C reaches $2V_{CC}/3$, making charging time t_c equal to $V_{CC}C/3I$.

At this point the capacitor rapidly discharges back to $V_{CC}/3$ through the ON resistance R_{CE} of the discharge transistor in the timer (pin 7). The discharge time, t_d, is approximately equal to $0.69R_{CE}C$.

The circuit is designed to make t_c much greater than t_d, so the period T of the multivibrator is very nearly equal to t_c and the frequency f becomes:

$$f = 3I/V_{CC}C$$

The 741 operational amplifier and transistor Q_3 form a voltage-dependent current source such that:

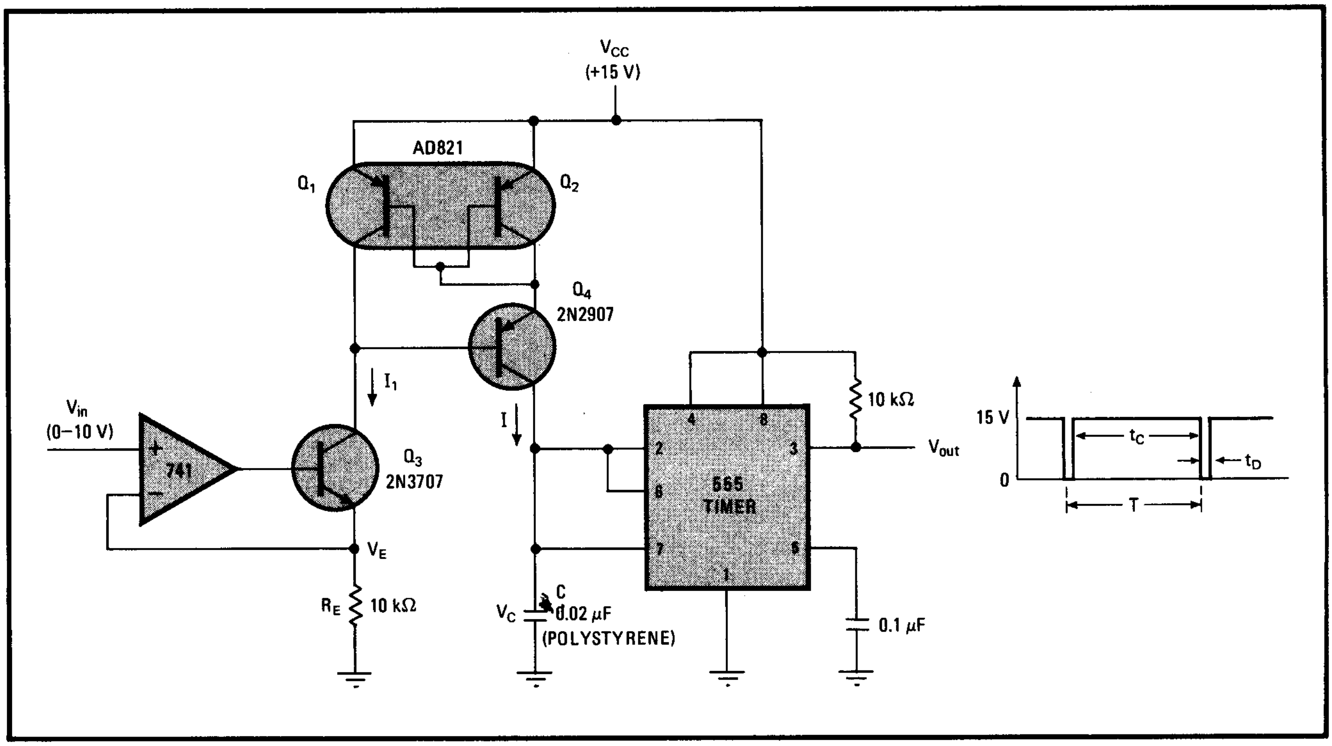
$$I_1 = (V_E/R_E)[\beta_3/(\beta_3+1)] = V_{in}/R_E \text{ (approx.)}$$

where β_3 is the forward current transfer ratio of Q_3. The op amp greatly reduces any drift due to change of V_{BE} in Q_3.

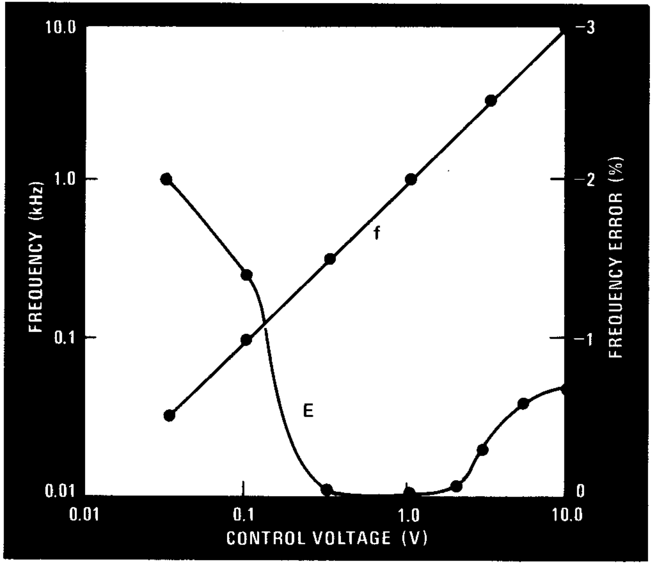
To allow the input voltage V_{in} to be referenced to ground, the capacitor is actually charged by current I from the current mirror formed by Q_1, Q_2, and Q_4 that makes I equal to I_1. The transistor Q_4 functions in a modified cascode configuration to increase the output impedance of the current source and increase the tracking of I_1 and I. Substituting V_{in}/R_E for I in the frequency equation gives:

$$f = 3V_{in}/R_ECV_{CC}$$

For a maximum input control voltage of 10 volts and the parameters used, the charging current can be easily varied over a range from 10 microamperes to 1 milliampere, and the output frequency in hertz is given by:



1. Linear voltage tuning. Inexpensive linear voltage-to-frequency converter uses an op-amp-driven transistor current source and a current mirror to charge the timing capacitor in a 555 astable multivabrator circuit from control voltage V_{in}.



2. Straight and accurate. Graphs show the experimental frequency-versus-voltage relationship, and the percentage departure from linearity, obtained with the circuit in Fig. 1.

$$f = 10^3 V_{\text{in}}$$

The experimentally obtained frequency and accuracy are shown in Fig. 2. At high frequencies (10 kilohertz) the non-zero discharge time (t_d) becomes significant and tends to make the frequency less than the predicted value. At low frequencies (100 hertz) the decreased transistor betas and the bias currents of the comparators (pins 2 and 6) decrease the voltage-to-current conversion factor and tend to also make the frequency less than the predicted value. This latter error may be compensated for to some degree by adjusting the offset of the 741 so that $V_E = V_{in} + 1.5$ mV. This has the effect of increasing the conversion factor at low input voltages without seriously affecting the accuracy at larger input voltages. Here this technique reduces the error in the 100-Hz region to less than ±0.4%.

For higher-frequency operation (1–100 kHz), it's better to reduce capacitor C to 0.002 microfarad, rather than decrease R_E; otherwise the ratio of t_d to t_c would become too large, and errors would result at the high end of the frequency range. □