IMPROVED TIMER CONTROL

by J. A. Fryer

This is an explanation of a very simple circuit change for 555 or 7555 timers that improves the precision and stability of variable control over frequency ranges up to 4:1, by adding one extra resistor.

The circuit can be adjusted to work over higher ratios but low-end drift grows exponentially; a need for a wide range of control can be satisfied economically by using this circuit in a 2:1 range to clock a binary counter IC with stage switching with no loss in precision. This extension also allows very low frequencies to be generated without hard-to-obtain or less stable large component values.

These very usefl low-cost timer IC's get their intrinsic clock stability at a fixed frequency because they are controlled by internal reference voltages of 1/3 and 2/3 V_{CC} from a chain of three nominally equal resistors: these drift, but they drift together very closely and the ratio controls the device. This idea can be applied to external control components, so that the maximum to minimum frequency ratio is set by a pair of resistors, and any drift in a low-cost control potentiometer does not affect output. The pot. can be changed at wear-out while preserving the frequency scale, which turns out to be almost linear in frequency.

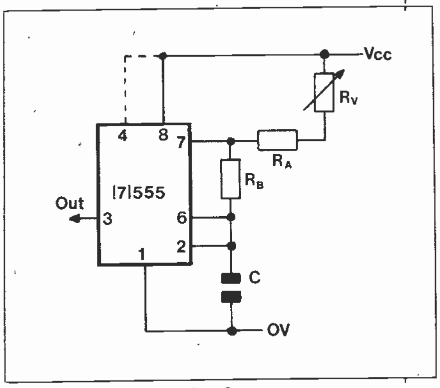

Figure 1. Simplest circuit.

The usual circuit, with a simple frequency control Rv, is shown in Fig. 1. The times of the two part-cycles are

$\frac{C \times R_B}{1.46}$ for discharge, and

$\frac{C(R_B+R_A+R_V)}{1.46}$ for charge

of capacitor C. These add and invert for frequency:-

$f = \frac{1.46}{C(R_A+R_V+2R_B)}$ Hz (megohms, microfarads)

The basic device accuracy is ± 2%, with a little more if V_{CC} changes, and a temperature coefficient of 50 parts per million (or ppm) per degree C. In clockwork terms that is 4.32 seconds per day per degree, a performance not given by clockwork at IC prices.

Trying to use a low-cost pot. for Rv causes immediate problems: at ± 20%, frequency at the low end is in a 40% band at worst; the pot. drift will exceed that of all the other parts; the scale is linear in period, not frequency, and gets very cramped at one end for high control ratios. There are ways to reduce these problems, but the only way to achieve precision is to use a high-cost potentiometer, and a good one will cost more than a crystal.

Another approach is to use the device "control" terminal (pin 5), which lets an external voltage force the 2/3V_{CC} reference down for a faster cycle or up towards V_{CC} for a slower one. This works, but for stability a lot

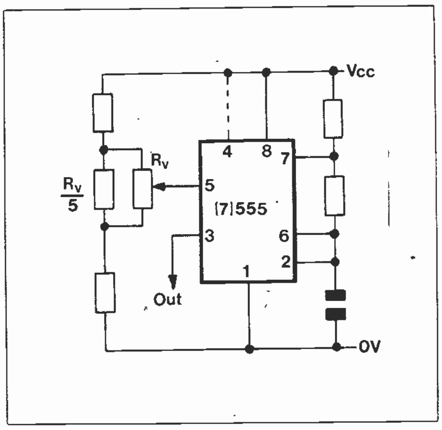

Figure 2. "Control" system.

of power is needed from the external voltage source. The internal resistors are of silicon, with a ± 50% production spread, a worse temperature drift than carbon pots., and a quite high voltage variation. An external resistor chain has to "swamp" these variations by having less than one-tenth the resistance of the internal chain for a start. If the external system includes a 20%-grade pot., its variations need another factor of at least five in waste current. With nominal IC chain totals of 15Kohm and 150K (555 and low-current 7555), a design has to start at 300 or 3000 ohms, and less for any real stability. However, the terminal is useful for very wide but not very steady control. Figure 2 shows a fully-padded circuit, which can be simplified with a high-grade pot.

In this "control" mode, capacitor C is charged towards V_{CC} as in the original circuit but the upper trip level is varied. This principle can be inverted, keeping the trip point at 2/3 but altering the charging level at source to something less than V_{CC}. If a 70% source were used, C would take several time-constants to reach 67% instead of less than one. There is a control limit at a source of 67%: below this the cycle never completes, and close to it drift and noise become problems. The inverted circuit works quite well for small ranges of control, and is shown in Figure 3.

The extra resistor R_C has been added, and R_V moved. At the high and low ends of the control range the pot. is obviously not in circuit. The top frequency is set by R_A and R_C in parallel, and at the low end C is charged towards a fraction $R_C/(R_C+R_A)$ of V_{CC}. The control ratio is given by the resistor ratio in a slightly awkward index equation, which is easier to use when tabulated.

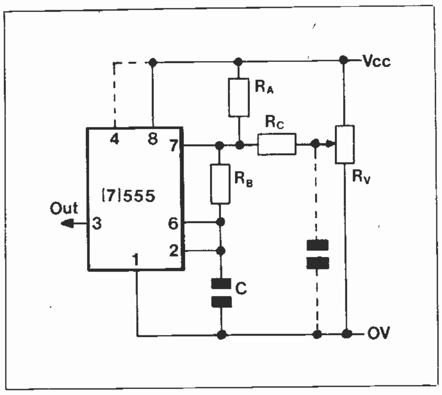

Figure 3. Modified circuit.

At intermediate control settings there is clearly going to be some steady change between the two extremes, and without making one more condition it is not clear what form it takes. This extra condition is that R_V must be well below R_C; when this is so, the actual value of R_V hardly affects the frequency equation, only its setting fraction of V_{CC}. The pot. can be ±20% and subject to drift without disturbing operation.

The condition is easy to achieve: R_C is already at least $2R_A$, and R_A can be kept very high except at very high frequency. Values of half a megohm will accommodate a 20K pot. with no difficulty, and there is improved stability but not the power loss of the standard "control" system.

There is an equation for frequency against V_{CC} fraction, which is slightly logarithmic. Solving it shows that control is very nearly linear: better than 2% error at 2:1, less than 5% at 4:1. These are about the limits for low-cost pots. with a 0.5 dB or 6% specification. If there is a need for something better, a slightly better pot. has to be used, and it then makes sense to correct the theoretical curvature by one more resistor from ground to slider, which gives total correction at 3 points on the scale.

The table here gives the most useful design ratios:-

F_{max}/F_{min}	R_C/R_A Theory	R_C/R_A Actual	R_A/R_T
2	3.500	3.3 + 0.2	1.30
3	2.500	2.3 + 0.2	1.435
4	2.21..	2.15 + 0.15	1.453

The R_A/R_T column is a design aid; the whole of the table assumes R_B is very low compared with R_A. If it is not, stability is not affected, but the frequency ratios are changed and need to be worked out for the actual values, or found on plug-board. If a need for a long pulse makes R_C too close to $2R_A$, it is better to use a dual IC package weith one half as a fixed monostable triggered by the variable half with low R_B.

The design calculations are just as for fixed frequency use except for R_C.

(1) Set Fmax and the wanted control ratio.

(2) The original design formula is turned over into the form

$C \times R_T = F_{max}$ Hz, Mohm, microfarads

1.46

Continued on page 15

IMPROVED TIMER CONTROL

Continued from page 7

and the time constant found. R_T is the effective timing resistance of R_A and R_C in parallel.

(3) Pick a trial value of C, and find R_T to match it. As a guide, keep C low and R high within reason: C under 1 nF makes strays important, R over about 470K may present problems of selection from a limited standard range. If both C and R look too high at low frequencies, consider using a fast oscillator and divider: this could be more stable, smaller and cheaper with no waiting for special-value parts.

(4) Use the table to get R_A from R_T, and then work out Rc as well. These are not directly usuable values: there are called "design centre values", before allowing for adjustment of tolerances.

(5) Tolerancing:-

IC		±2%
V_{CC}	effect	±0.25% for 0.25v regulator offset
C		±1%
R		±1%

Worst-case sum ∓4.25%

There is no need to use 1% parts: other grades can be just as stable, but they alter the tolerance sum.

Take away the tolerance allowance from the design centre RA, and compare this result with available preferred values. If close, just continue; if far away, either:

or (a) try a different C

(b) use the next lower value and add the difference to the adjuster design

or (c) try a sum of two fixed resistors: a small extra one need not be of 1% grade for 1% results.

When settled, allow twice the tolerance fraction of RA as the necessary range of adjustment, adding on any rounding-up if R_A has been reduced much to a standard value.

(6) Check the required adjuster range against standard values, remembering the adjuster may be ±20% itself. With a design using wide-spec. parts, the adjuster may end up very large, and selecting a fixed resistor on test for part of the adjustment will improve stability.

So far this is exactly what is done for a fixed-frequency oscillator with the standard circuit.

(7) R_C needs an adjustment allowance first of all equal to R_A's, and then an extra 5-6% for worst-case IC tolerances. With 1% parts, this means taking 10% from the design centre R_C, and allowing for up to 20% adjustment range.

One of the resistor adjustments can be replaced by capacitor adjustment, but often a full range of parts is not available.

When built, setting-up is easy enough: adjust R_A at F_{max}, then R_C at F_{min}, and repeat to overcome a slight interaction.

There are no special layout problems: six plugboards and two PCB's have worked well, despite trying to bundle wires and adding short antennas to suspect points. Take "reset" (pin 4) to V_{CC} if not in use; for the 555, 100nF and 10nF supply and "control" decoupling. The 7555 does not need supply decoupling, and usually control will behave without it. If the control pot. is remote, prepare to decouple the DC end of R_C. Otherwise, just keep everything cool and check Vcc regulation for real stability. If in doubt, use a local 78L05 with steady load.

The output will drive two standard loads — 74/LS/ALS/CMOS — via 470-820 ohms; a resistor helps in any later fault diagnosis and prevents faults spreading through a system, if speed is not critical.

The expected stability can be found in worst-case from the component sums:—

IC	±50 ppm per degree C
V_{CC}	negligible, 78L05
C	- 150 ppm/degree (polystyrene)
R	± 100 ppm/deg.C

and it is very unlikely drift will exceed 0.1% for a 5 degree case temperature change. This is about as good as can be had from an RC oscillator with no oven or special components.

For interest, R in the circuit can be replaced by two fixed resistors: their junction with Rc is then a good linear FM input terminal for a 20% voltage swing. A dual IC can be used for sweep — with care not to upset its timing — or frequency shift keying. A simple D-to-A converter allows other codings.

Their 4:1 circuit makes a very useful metronome with a range of 70-280 pulses per minute: good as clockwork and easier to set, with more range.