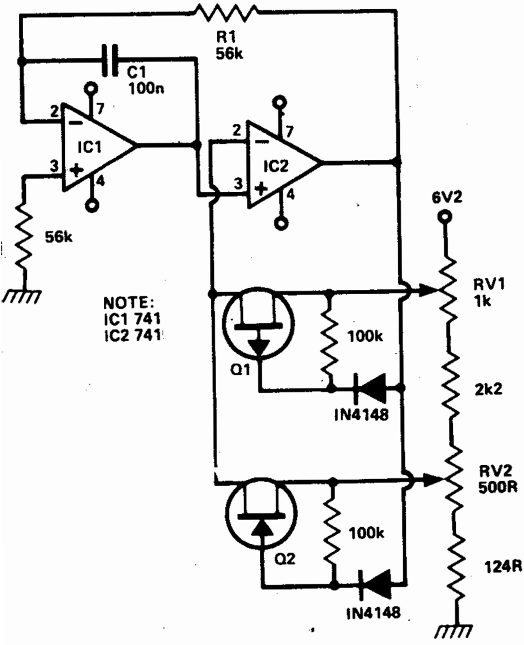
Triangle Generator

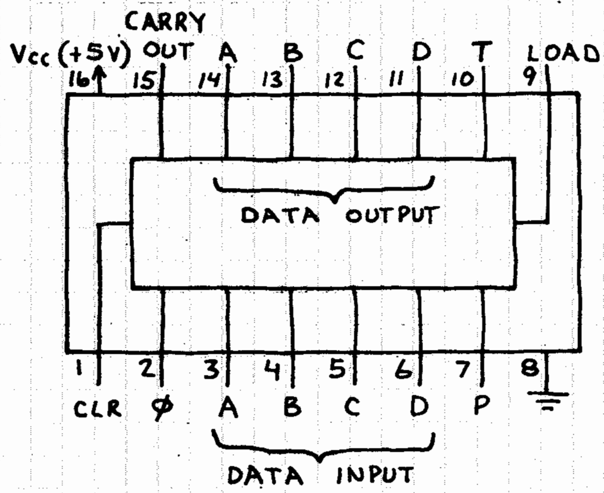
R.I. Harrison

The circuit consists of a comparator IC2 driving an integrator constructed from IC1, C1 and R1. The output of the two circuits is controlled by the JFET switches Q1 and 2. The peak and trough of the generator is controlled by RV1 and RV2 respectively. The frequency is set by C1 and R1.

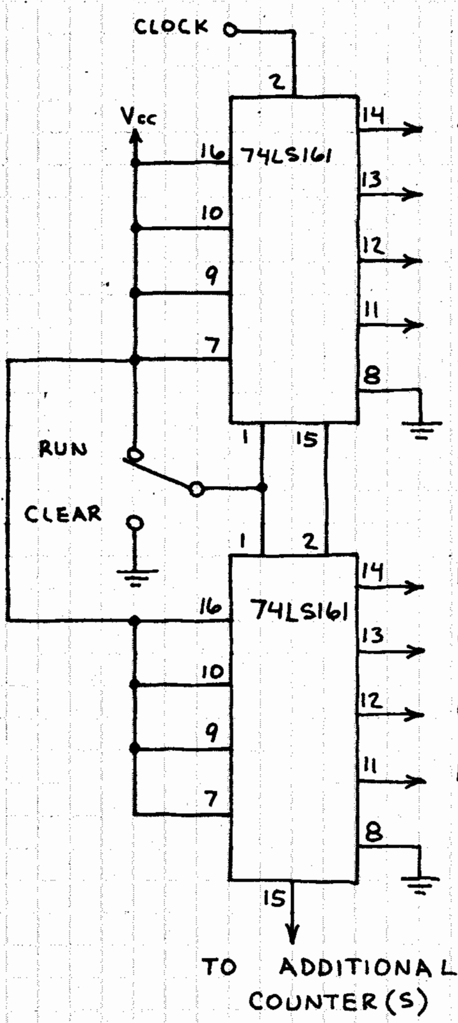


4-BIT UP COUNTER 74LS161

GENERAL PURPOSE BINARY COUNTER WITH PROGRAMMABLE INPUTS. COUNTER ACCEPTS DATA AT INPUTS WHEN LOAD INPUT GOES LOW. A LOW AT THE CLEAR INPUT RESETS THE COUNTER TO LLLL UPON THE NEXT CLOCK PULSE. P AND T ARE COUNT ENABLE INPUTS. BOTH P AND T MUST BE HIGH TO COUNT. THESE ENABLE INPUTS ARE NOT AVAILABLE WITH THE OTHERWISE MORE ADVANCED 74LS193.

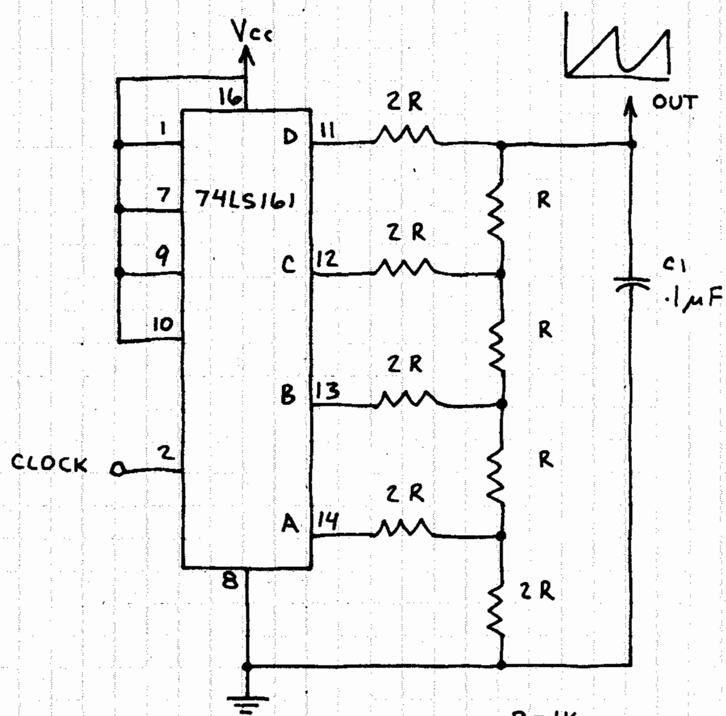


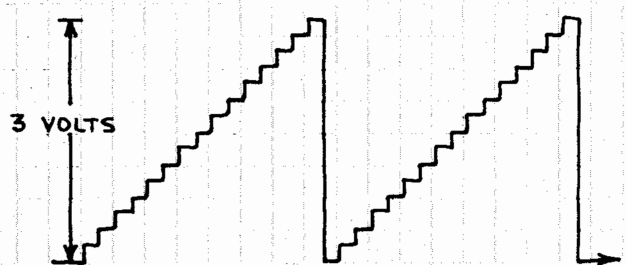
8-BIT COUNTER



OUTPUT A IS LOWEST ORDER BIT.

RAMP SYNTHESIZER





REMOVE C1 TO OBTAIN THIS STAIRCASE. FREQUENCY OF RAMP AND STAIRCASE IS 1/16 CLOCK FREQUENCY.

Ramp generator has separate slope and frequency controls

by Henrique Sarmento Malvar
Department of Electrical Engineering, University of Brazilia, Brazil

Isolating with four analog switches the frequency-determining portion of the circuit from that controlling the charging and discharging of its RC integrator, this ramp generator achieves independent selection of slope ratio and repetition rate. Such a unit is useful in a music synthesizer, where timbre must be changed without affecting a note's fundamental frequency.

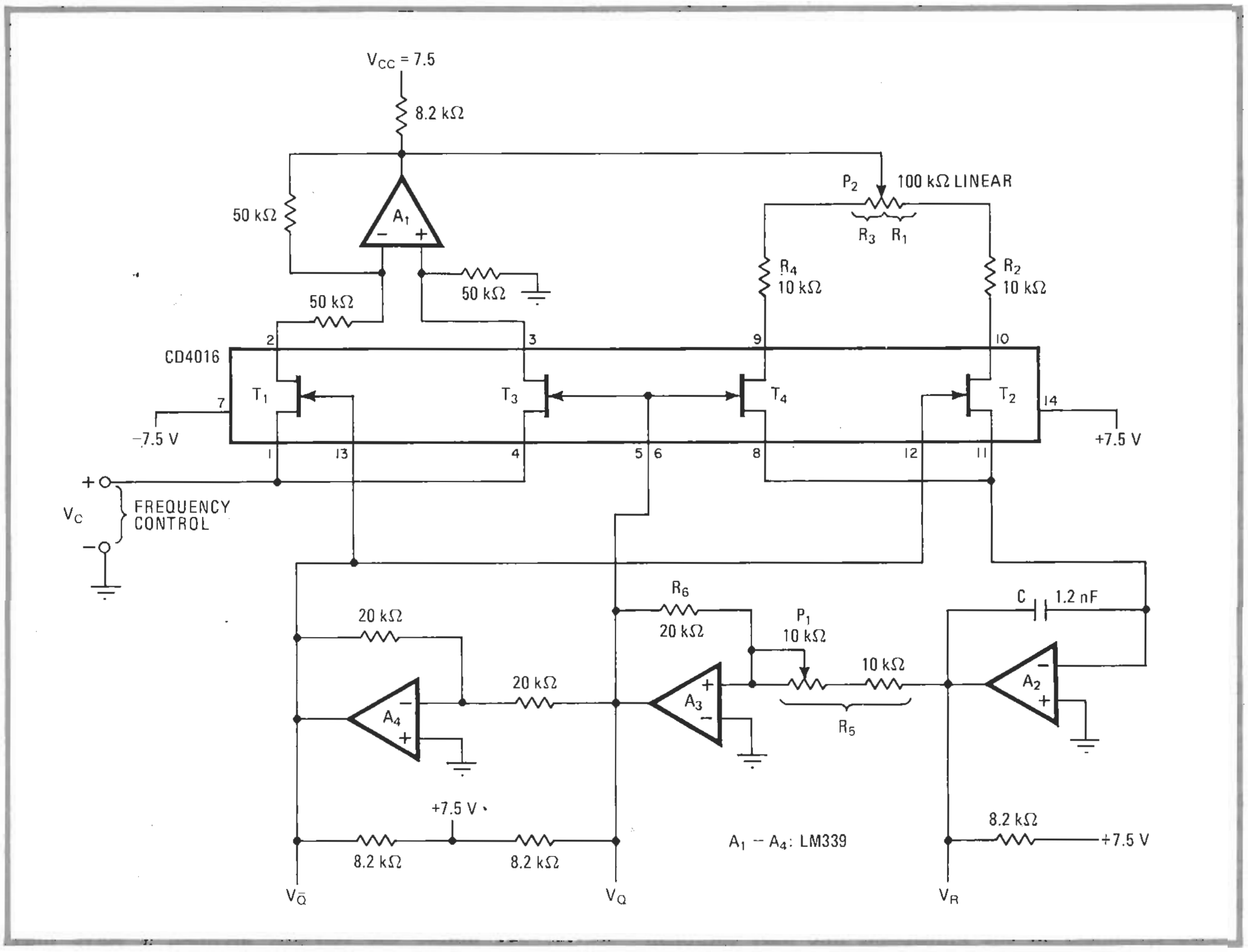
Analog gates T_1 and T_2 are initially switched on, and therefore V_c is applied via operational amplifier A_1 to the integrator built around A_2 (see figure). Thus, $-V_c$ appears at the inverting input of A_2, and its positive-going output reaches voltage V_H in $T_1 = 2V_HC(R_1+R_2)/V_c$ seconds, where $V_H = V_{cc}R_5/R_6$.

At this time, A_3 switches on and A_4 goes off. T_1 and T_2 are thus disabled, and T_3 and T_4 are brought high so that $+V_c$ is applied to the integrator. The output at A_2 thus falls linearly toward $-V_H$, where time $T_2 = 2V_HC(R_3+R_4)/V_c$.

The frequency of the ramp is given by:

$$f = 1/(T_1+T_2)$$
$$= R_6V_c/[2CR_5V_{cc}(R_1+R_2+R_3+R_4)] = kV_c$$

where k is a constant (in the approximate range of 1 kHz/V) that can be adjusted with potentiometer P_1. Because R_1+R_3 is a constant, it is seen that an adjustment in potentiometer P_2 will affect the slope ratio, but not the frequency. With the values shown, the slope ratio can be selected from 1/11 to 11. The slope ratio is given by $T_1/T_2 = (R_1+R_2)/(R_3+R_4)$. □



Separation. Transmission gates T_1–T_4 separate the portion of the ramp generator that determines the frequency from the circuitry that sets the charge and discharge times of its integrator, so that the up/down slope ratio and frequency can be independently selected. The inexpensive circuit, which costs less than \$10 and works in the audio range, is a useful timbre control in music synthesizers.

Timer generates sawtooth with switchable symmetry

by Roberto Tovar-Medina
Institute of Applied Mathematics, University of Mexico

With some inexpensive components, a 555 timer operating in the astable mode forms a circuit that generates triangular waves of selectable symmetry. The cost of the unit is below $6.

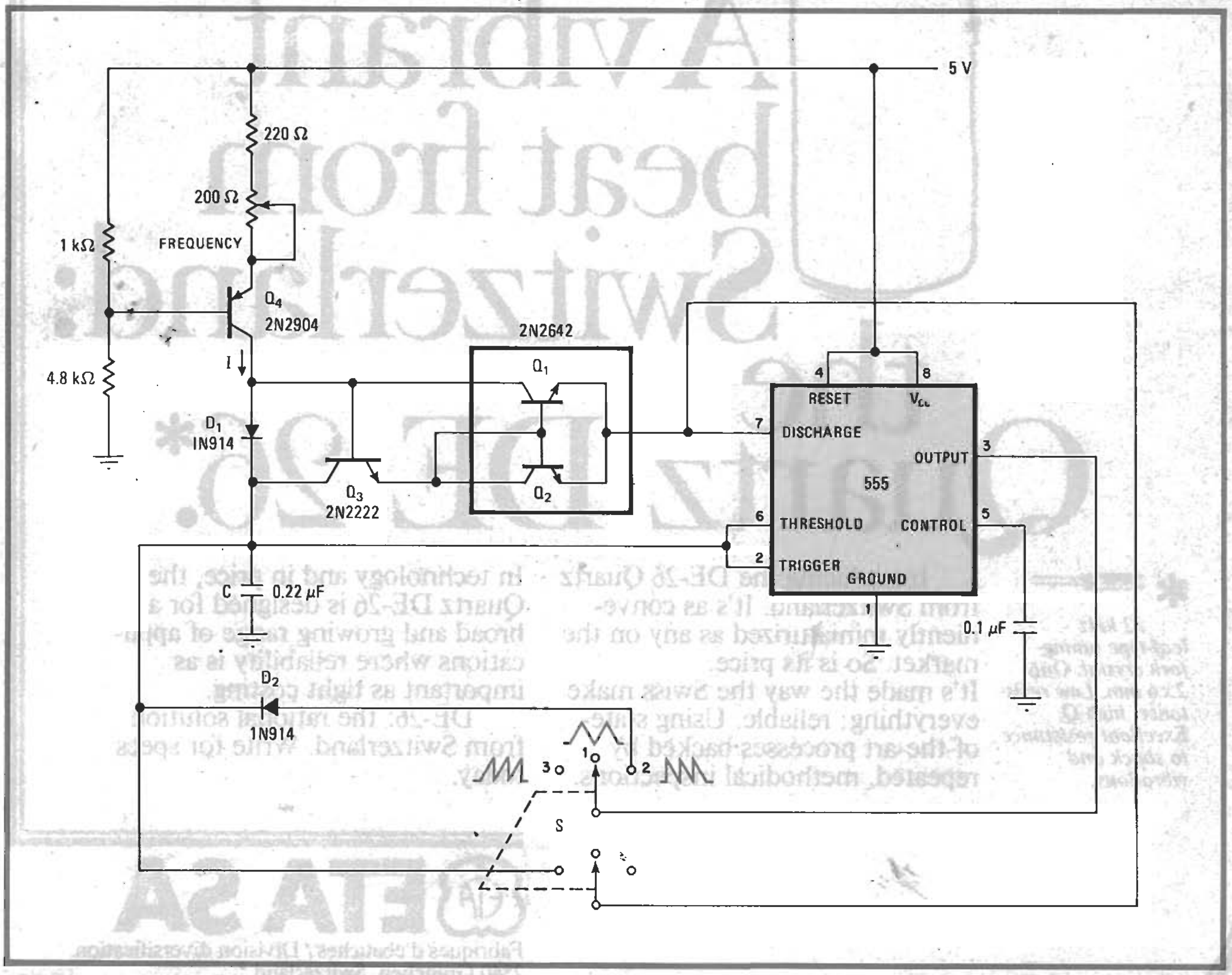
The triangular waves are generated by charging a capacitor with a constant current, I, and discharging the capacitor through a current mirror that sinks I. The symmetry is controlled by selecting the rate at which the capacitor is charged and discharged.

When capacitor C is virtually discharged and the switch, S, is at position 1 as shown, pin 7 of the 555 (the discharge port) is high, and Q_1 and Q_2 are off. Thus the capacitor is charged at a rate of It/C, where t is time, until the voltage at pin 6 (threshold port) of the 555 exceeds two thirds of the supply voltage, V_{cc}.

Pin 7 then moves low, Q_1 and Q_2 turn on, diode D_1 becomes back-biased, and C discharges through Q_1, Q_2, and Q_3 at a rate of It/C. When the voltage at pin 6 falls below a third of the supply voltage, pin 7 moves high again and the process repeats at a frequency given by $f = 3I/2CV_{cc}$. At low frequencies (below 1 kilohertz), D_1 may be omitted, because C can charge through the base-collector junction of Q_3. At high frequencies, D_1 must be included to avoid the discontinuities in the triangular waveform that are caused by switching.

A fast charge time is attained if the output of the 555 (pin 3) is connected to pin 6 through diode D_2. This connection is achieved by placing S in position 2. The discharge time is the same as before. Connecting the discharge port directly to the threshold pin yields a normal charge time and a fast discharge time. S must be placed in position 3 to achieve this symmetry. In either case, the operating frequency is exactly twice what it was previously, or $f = 3I/CV_{cc}$.

Given the component values shown, the circuit oscillates at about 1 kHz. It can be made to work at frequencies up to 30 kHz, however. □



Adjusting slope. Circuit built with 555, constant-current source, and current mirror generates triangle-type waves whose symmetry is selectable. Frequency is controlled by magnitude of I, which is adjusted with potentiometer. Three-position switch determines rate at which C is charged or discharged, so generator can produce standard or fast-rising sawtooth waves or waves that are truly triangular.

Timer IC stabilizes sawtooth generator

by Frank N. Cicchiello
Geometric Data Corp., Wayne, Pa.

A temperature-independent audio-frequency sawtooth generator that uses a 555 integrated-circuit time is shown on page 109. Its sawtooth output maintains linearity within 1%, and its output is available from a low-impedance source that is fully buffered from the timing circuitry.

The circuit is superior to the more conventional approach that develops a linear sawtooth by adding a constant-current pump to charge the sawtooth-forming capacitor. Since V_{BE} of the constant-current transistor changes with temperature in a conventional circuit, a corresponding change in its current would cause a variation in frequency of the output sawtooth. No such change occurs in this 555 circuit.

Connecting pin 2 to pin 6 (trigger and threshold inputs respectively) of the 555 causes it to trigger itself and free-run as an astable multivibrator. Consider the circuit action after the IC's internal discharge transistor (pin 7), having dumped the charge on the sawtooth-forming capacitor C_1 via R_3, has become an open circuit and allows C_1 to recharge.

C_1 begins to charge through R_1, R_2, and R_3 toward the supply voltage V_{CC}. For all practical purposes, the change in voltage at the junction of R_2 and R_3 is equal to that at the top side of C_1. This voltage change is applied to the base of a Darlington-type emitter follower, Q_1. Since Q_1 has virtually unity gain, it couples this same change in voltage back to the top side of R_2. As a result, the voltage across R_2 remains essentially constant during C_1's charging cycle and so produces the same effect (linear-ramping) as a constant-current source feeding C_1.

Once the linear sawtooth signal at pin 6 reaches a value of ⅔ V, the IC's internal comparator resets its flip-flops. The reset again activates the discharge transistor (pin 7), causing C_1 to dump through R_3; this action causes a new trigger wave to be applied to pin 2, thus repeating the circuit operational cycle.

Resistor R_3 is required to slow down the negative-discharge slope of the sawtooth wave form. Resistor R_4 is a parasite suppression resistor for Q_1. C_3 is a bypass capacitor on the voltage-control (pin 5) input of the IC, which is unused in this circuit.

The component and frequency relationships can be simply stated and easily implemented:

$R_1 = R_2$
R_2 *is equal to or greater than* $10\ R_5$
R_3C_1 *is equal to or greater than* 5×10^{-6} s
$R_4 = 1$ *kilohm*
R_5 *is equal to or greater than 100 ohms*
R_1C_2 *is greater than* $10\ R_2C_1$
$f = 1/C_1[0.75(R_1 + R_2) + 0.693\ R_3]$

As in the conventional exponential sawtooth generator circuit, the output frequency is independent of variations in supply voltage. Typical performance data is shown in the table. □

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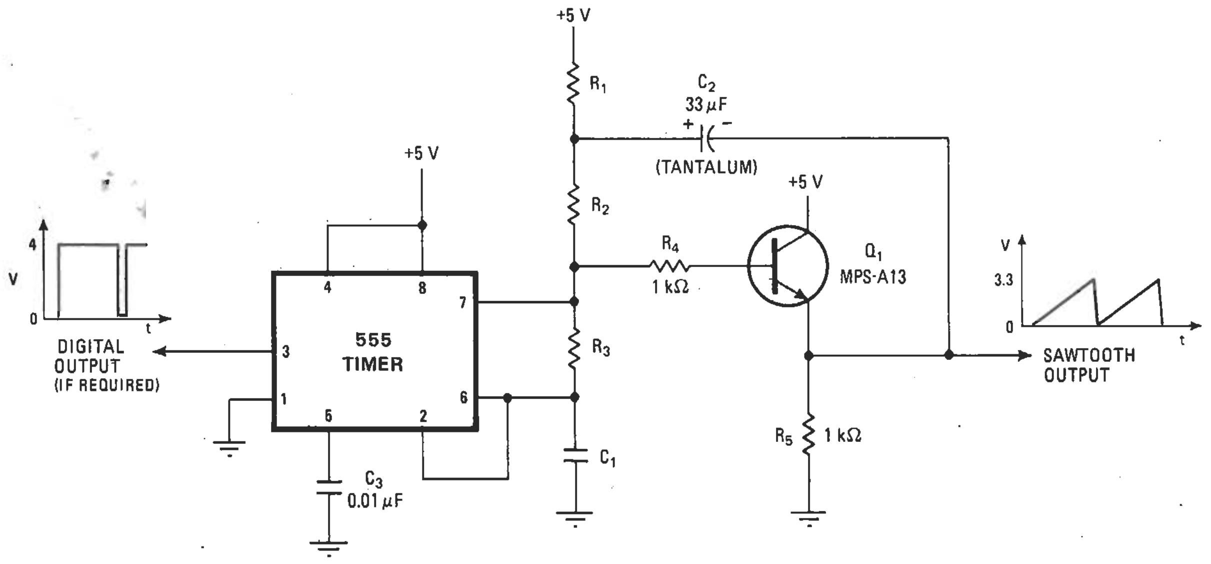

Frequency		R_3	R_1 & R_2	C_1
Computed	Measured			
54.2 kHz	50 kHz	5.1 kΩ	10 kΩ	1,000 pF
665 Hz	667 Hz	510 Ω	100 kΩ	0.01 µF
6.7 Hz	6.9 Hz	51 Ω	1 MΩ	0.1 µF

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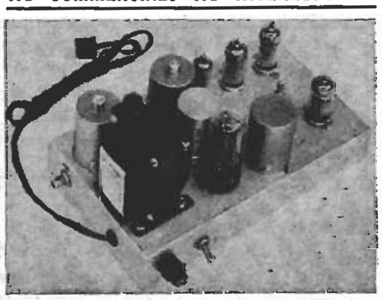

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DUAL-RATE SAWTOOTH GENERATOR

By FRANK H. TOOKER

This UJT multivibrator generates two sawtooth signals whose rates can be varied independently.

DID you know a unijunction sawtooth-waveform generator, such as the one shown in Fig. 1, can be made to generate waveforms of two different repetition rates alternately, as illustrated in the diagram of Fig. 2? In this circuit, *Q*1 fires first, producing a cycle of one frequency; then *Q*2 fires and produces a cycle at another frequency.

The two repetition rates are independent, and determined by the effective *RC* values in the emitter circuit of each UJT. As far as the repetition rates are concerned, capacitors *C*1 and *C*2 operate as a single capacitor having a value equal to the two tied in series.

In this demonstration circuit, repetition rates are determined by the setting of potentiometer *R*3. Therefore, when the resistances in the emitter circuits of *Q*1 and *Q*2 are equal, the repetition rates will be equal. However, if the potentiometer is adjusted so that one UJT has a lower emitter resistance than the other, the circuit with the lower resistance will fire more rapidly. And of course, with *R*3 connected as shown, increasing the repetition rate of one UJT decreases the rate of the other. But if two potentiometers are used—one in the emitter circuit of each, the rates are independently adjusted.

As long as the value of *C*2 is equal to the value of *C*1, the amplitude of the output signal at the two repetition rates will be very nearly equal (Fig. 2A). However, if one capacitor is smaller than the other, the output signal amplitude coming from that side of the circuit will be lower and the output waveform is similar to that shown in Fig. 2B, (assuming *C*2 is smaller than *C*1 and *Q*2 has the higher repetition rate). The maximum practical ratio of the two capacitors (*C*2 to *C*1) is about 5:1. Beyond this point, the output waveform begins to resemble that shown in Fig. 2C.

The output signal is actually available at the junction of capacitors *C*1 and *C*2, but because this must be considered a relatively high impedance point, the signal is fed to an FET source-follower, *Q*3, where a much lower impedance is available at the source electrode. Resistor *R*4 is not part of the dual-rate sawtooth generator proper. It is *Q*3's gate-return resistor. Signals of rectangular waveform are available at base-2 of each of the two UJT's. The mark-to-space ratio of these signals depends on the ratio of the resistances in the emitter circuits.

A circuit producing the waveform shown in Fig. 2A may be used as a dual-rate horizontal sweep oscillator in an oscilloscope. In this event, the rectangular waveforms at base-2 of each of the UJT's may be used to operate electronic switches which, in turn, would apply the two signals being observed, alternately, to the scope's vertical amplifier.

The circuit may also be used as a novel tone generator for an electronic organ. In this case, the emitter resistor in one of the two unijunction transistors is selected to produce the lower or fundamental frequency; the other UJT would have a potentiometer in its emitter circuit which could be adjusted to produce either the fundamental, or any harmonic frequency desired. ▲

Fig. 1. Dual UJT multivibrator has low-impedance FET output.

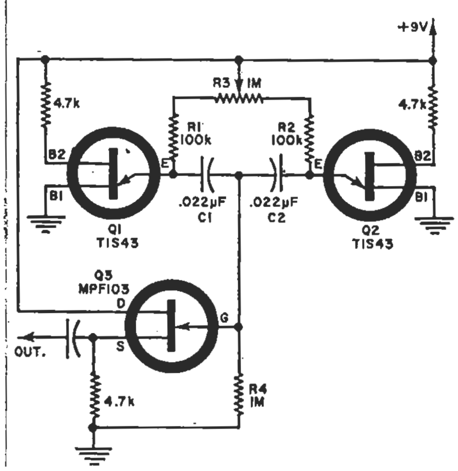
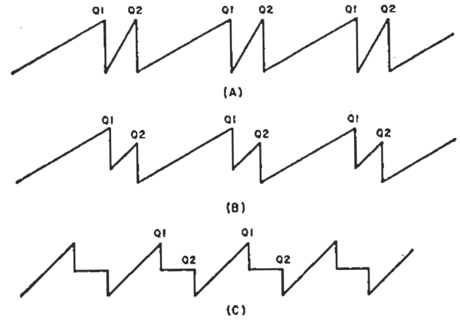


Fig. 2. (A) Waveforms when C1 equals C2 (Fig. 1). In (B) C2 is smaller than C1. (C) Capacitance ratio is greater than 5 to 1.



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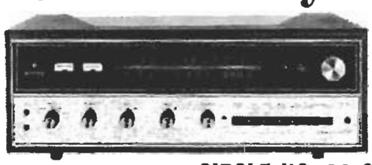

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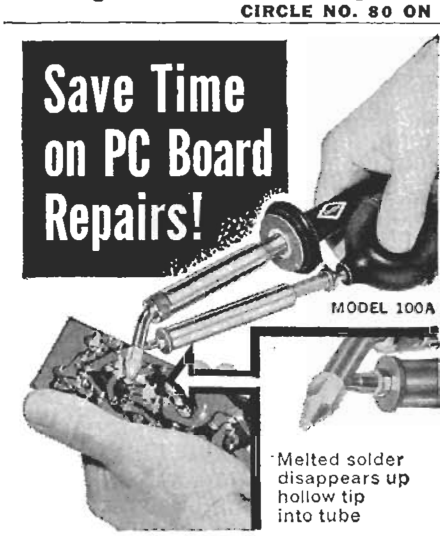

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IMPROVING SAWTOOTH LINEARITY

By FRANK H. TOOKER

ONE technique used to improve the linearity of a UJT sawtooth-wave generator is to feed the timing capacitor from a constant-current source. But this is not always convenient Another method is shown in Fig. 1.

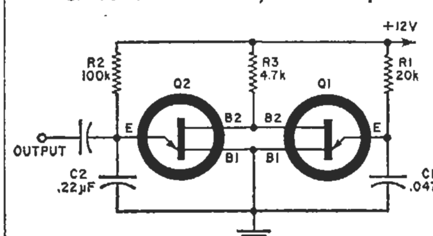
Here two UJT sawtooth-wave oscillators are independent except for the common base-2 resistor, $R3$. The time constant of $R2$-$C2$, in the emitter circuit of Q2, is much longer than that of $R1$-$C1$ in the emitter circuit of $Q1$. Thus, if the two oscillators were entirely independent, the repetition rate of $Q2$ would be slower than that of $Q1$. With $R3$ in the circuit, however, the firing rate of $Q2$ is determined by the firing rate of $Q1$. In other words, the two UJT's fire in unison and the UJT having the fastest firing rate determines the repetition rate

When a capacitor is charged, the charging rate is non-linear, that is, the charging rate is quite fast initially but slows more and more as the potential across the capacitor approaches that of the power supply. The initial portion of the charging curve is the most linear, because during this interval, the ratio of the voltage across the capacitor to that of the power supply is greatest. If only this portion of the curve is used, the linearity of the resulting sawtooth waveform is considerably improved.

Resistor $R1$ and capacitor $C1$ determine the repetition rate, while $R2$ and $C2$ determine the linearity. The larger the ratio of the two time constants, the better the linearity will be. But the larger the ratio, the lower will be the amplitude of the output signal.

For the circuit values shown in Fig. 1, the repetition rate is about 500 Hz and the output signal amplitude is 375 mV The relatively low output level is due to the unusually high ratio of the time constants in this particular setup—on the order of 50:1. A ratio of this order is rarely needed, but was used to demonstrate that the circuit will function even with this high a ratio of time constants. Much higher output and entirely satisfactory improvement in linearity is possible with ratios as low as 5:1. ▲

Fig. 1. In this UJT oscillator, R2 and C2 determine linearity of the output.



Q1,Q2—TIS43-TEXAS INSTRUMENTS UNIJUNCTION TRANSISTOR

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One Hundred Eighty-third in a Monthly Series by Lou Garner

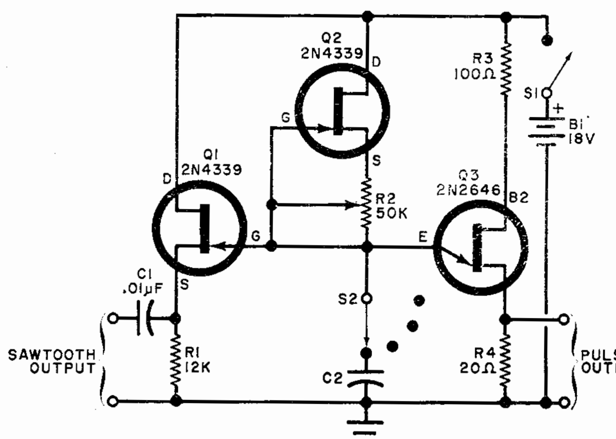
ALTHOUGH not as widely used as bipolar types, field-effect transistors (FET's) are exceptionally versatile devices. With moderate to very high input and output impedances and relatively low-current requirements, FET's offer the circuit designer performance characteristics comparable to those of vacuum tubes coupled with the low-power requirements and high efficiency of bipolar units. Increasingly popular with professional design engineers, FET's may be used as dc, a-f, r-f, VHF and UHF amplifiers and oscillators; as modulators, mixers or detectors; as switches, gates and choppers; and as variable resistors, voltage regulators and current limiters. Fully compatible with other devices, they may be used with UJT's, standard bipolars, SCR's, IC's, etc.

Whether you identify yourself as an electronics fan, experimenter, hobbyist, gadgeteer, technician, or practical engineer, then, you should welcome four recent offerings from a West Coast manufacturer, Siliconix, Inc. (2201 Laurelwood Rd., Santa Clara, CA 95054)—a new FET handbook and three kits of top quality FET devices at bargain counter prices.

Entitled *An Introduction to Field Effect Transistors*, the handbook is a 128-page, soft-cover, plastic-bound guide to the operation and application of FET's and related semiconductor products. Written at an intermediate, rather than elementary, level, the handbook should be of particular value to advanced experimenters, serious hobbyists, technicians, and practical engineers. Design equations are given where applicable, while mathematical treatments are featured in most of the theoretical sections. Numerous charts, graphs, tables and circuits are used to illustrate the text. Although a variety of valuable circuits is included in the volume, most are presented in basic form rather than as practical construction projects.

The sawtooth waveform generator illustrated in Fig. 1 is typical of the circuits described in the handbook. Suitable for use as the linear sweep generator in a solid-state oscilloscope, the circuit features a FET source follower buffer amplifier, *Q1*, a FET current limiter, *Q2*, and a UJT relaxation oscillator, *Q3*. Its repetition rate (or frequency) is determined by *R2*'s value and C2's capacitance. In practice, C2 is switch-

Fig. 1. This sawtooth generator is typical of circuits described in new FET handbook available from Siliconix, Inc.



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Siliconix's three FET Experimenter Kits are similar except for the numbers and types of devices offered in each. Kit #1, the smallest and least expensive, contains six devices in all, including two general purpose amplifiers, two VHF amplifiers, a VCR and a

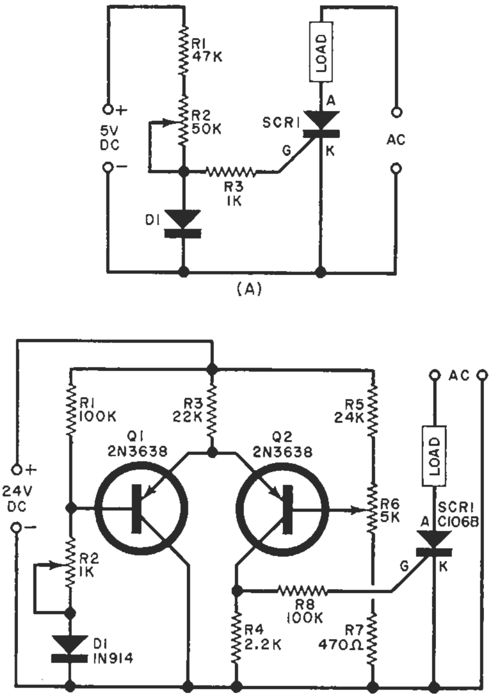

Fig. 2. When temperature rises above preset level, these circuits switch off load power. Circuit (B) is much more sensitive than (A).

current limiter (CL). A matched dual FET is featured in Kit #2, together with seven other units, including three general purpose amplifiers, a VHF amplifier, a switching type, a VCR, and a CL. Featuring an operational amplifier IC, Kit #3 also includes two general purpose amplifiers, a UHF amplifier, a VHF amplifier, a low resistance analog switch, a CL, and a matched dual pair.

The FET Experimenter Kits are available with or without the new handbook, but all three kits include a complete set of specification data sheets and useful application notes. Kits #1, #2 and #3 are priced at $6.50, $11.50 and $16.50, respectively, with handbook, or at only $5.00, $10.00 and $15.00 less handbook—a 50% savings compared to reguar net prices. The FET handbook may be purchased separately at $2.50/copy. If you can't talk about anything for fear of having the idea stolen. Now, a new service, provided for inventors by the U.S. Patent Office, provides for the acceptance and preservation for a limited time of "Disclosure Documents" as evidence of the dates of conception of inventions.

Under the new "Disclosure Document Program", a paper disclosing the invention and signed by the inventor may be forwarded to the Patent Office where it will be retained for two years and then destroyed unless it is referred to in related patent applications. This disclosure is not a patent application. When the inventor is ready to submit his patent application, he can refer to the disclosure document in his letter of transmittal.

Other details of the program are outlined in a brochure available from the U.S. Patent Office, Office of Information Service, Washington, D.C. 20231. Ask for "Disclosure Document Program."

Reader's Circuit. Widely used in switching, control and power-supply applications, the silicon controlled rectifier (SCR) is seldom encountered in other types of circuits, for its "all or nothing" conduction characteristic limits its use in oscillator and amplifier arrangements. Thus, the circuit shown in Fig. 1—a linear (sawtooth) sweep generator—is a somewhat unusual application for this device. Reader Nyle A. Steiner (K7NUH, 186 "S" Street, Salt Lake City, Utah 84103), who submitted the design, has achieved this unique mode of operation by combining the electrical characteristics of an SCR with those of a neon lamp. According to Nyle, the circuit will deliver a sawtooth signal of sufficient amplitude to provide direct horizontal drive for the typical cathode-ray tube used in most general-purpose oscilloscopes.

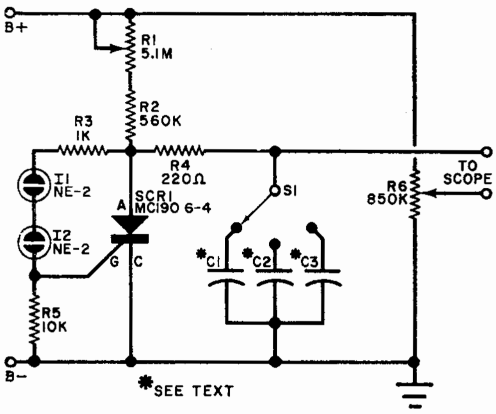

Fig. 1. An SCR is used in a rather unusual application in this linear (sawtooth) sweep generator.

In common with most relaxation oscillators, Nyle's circuit utilizes the charge-discharge features of an *RC* network to form the familiar sawtooth waveform. Referring to Fig. 1, *SCR1* and neon lamps (*I1* and *I2*) are in a non-conducting (open) state when d.c. is first applied. A capacitor selected by *S1*, is charged slowly by the d.c. source through *R1*, *R2* and *R4* until its voltage equals the combined ionization voltages of the neon lamps. At this point, the neon lamps "fire," furnishing gate current to *SCR1* through current limiting resistor *R3*, switching the SCR to a conducting status. This discharges the capacitor through *R4*. With the capacitor discharged, *SCR1* reverts to its non-conducting status, the neon lamps are extinguished, and the cycle repeats.

Potentiometer *R6* is not a functioning part of a basic circuit. It is included to provide a d.c. reference for beam centering when the circuit is used to furnish direct drive to a CRT's plates.

The circuit's repetition rate (frequency) depends on the supply voltage, the neon lamps' combined ionization voltage and, of course, on the time constant of the *RC* network which includes *R1*, *R2*, *R4* and the selected capacitor. The value of *R4* is relatively small, and therefore, can be ignored. A variable resistor is used for *R1* to serve as a fine frequency control, while selector switch *S1* provides a choice of capacitors (*C1*, *C2*, or *C3*) and thus acts as a coarse control or range switch.

All the parts used are readily available. Resistors *R2*, *R3*, *R4* and *R5* are half-watt resistors; *I1* and *I2* are type NE-2 or NE-51 neon lamps; and *SCR1* is a Motorola type MCR1906-4 or equivalent with, at least, a 200-volt rating. The timing capacitors, *C1*, *C2* and *C3*, should be good quality 400-volt plastic film or paper tubulars, with their values determined experimentally to provide the desired range of operating frequencies; generally, values from 0.01 μF to 0.25 μF will be used.

Neither parts nor wiring arrangements are critical and the circuit can be assembled using any of a variety of construction methods. The neon lamps should be shielded to exclude light, for these devices may be photosensitive. Virtually any well-filtered d.c. source furnishing in excess of 200 volts may serve as a power supply, but Nyle suggests at least 350 volts be used to insure a linear output signal.

Manufacturer's Circuit. Originally designed for use as a video amplifier in a monochrome TV receiver, the circuit shown in Fig. 2 could serve either as an untuned r.f.

operational amplifier designed for use with power supplies of from ±1 to ±18 volts. With a ±1 volt dc source and its quiescent current adjusted to 10 μA the device has a standby power requirement of *only 20 μW*. The UC4250 can furnish a gain of 100,000 into a 10,000-ohm load when operated on a ±6 volt supply, with its quiescent current adjusted to 30 μA.

In tests at Solitron, two miniature electronic watch batteries were used to power a square wave oscillator using the UC4250. The circuit's load current checked out at a mere 100 pA, thus indicating that the oscillator should be able to run continuously for 30 months on one set of batteries. Unfortunately, the actual operational battery life is somewhat less, for these small cells have a rated shelf life of only a little over 15 months. The circuit's power drain is so small, then, that its power supply batteries would fail chemically long before they are exhausted electrically. How about that for low power?

Micropower circuits are particularly useful in medical electronics, biological and geophysical telemetry, portable instrumentation, long-term monitoring, and miniature computers. A recent development in another field may make such circuits of even greater value in medical appliances.

Working with selective catalysts, Drs. J. H. Fishman and J. F. Henry at Leesona Corporation's Moos Laboratories Division (Great Neck, N.Y.) have developed experimental fuel cells using human blood as a source of both fuel and oxygen: In practice, two electrodes are immersed directly into the blood stream, one of which reacts with glucose and similar organic materials, the other with oxygen, to produce electric power. The experimental units tested to date yield approximately 5 μW for each square centimeter of electrode area. Although this power yield may be improved considerably as techniques are refined, it is already sufficient to operate circuits comparable to Solitron's UC4250.

Looking to the future, one day we may see implantable solid-state heart pacers and similar aids which are powered by the patient's own blood stream.

Your editors would be interested in hearing of any micropower circuits developed by our readers. If of general interest, we may find a place for it here.

Reader's Circuit. A practicing engineer as well as an enthusiastic experimenter, reader Eugene Richardson (310 East Mason Ave., Alexandria, VA 22301) feels that the programmable unijunction transistor, or PUT, has not received the attention it deserves and, therefore, is not as widely used by most hobbyists as are such familiar devices as transistors, SCR's, diodes and conventional unijunctions. As he points out, the PUT is an exceptionally versatile device.

Essentially an anode-gate thyristor, the PUT is functionally equivalent to standard unijunction devices, but has a number of superior features. Its stand-by and holding currents are much lower, its *on* resistance considerably lower, and its peak current rating much higher. Further, its firing threshold can be either programmed or made variable and, in addition, its inherent regenerative action gives it a fast-acting characteristic.

As evidence of the PUT's versatility, Eugene has submitted the sweep/frequency divider circuit illustrated in Fig. 1 for consideration and possible use by other experimenters. Capable of delivering either sawtooth or pulse waveforms, its output can be

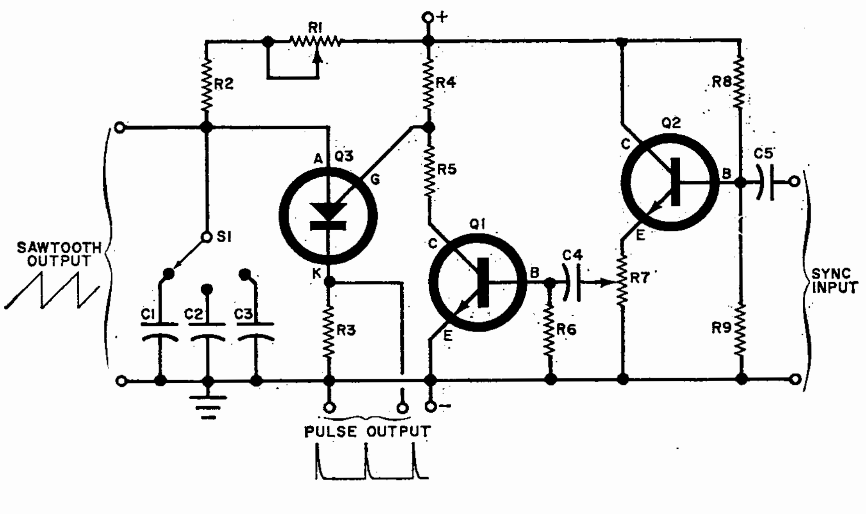

Fig. 1. Programmable unijunction transistor, Q3, is used in sweep/frequency divider circuit to deliver either sawtooth or pulse waveforms synchronized with an external signal.

synchronized with an external signal. He suggests that the circuit can be used as a general purpose waveform or pulse generator or, if preferred, incorporated into other equipment, such as an oscilloscope as a linear sweep, or in a counter as a pulse frequency divider.

In the circuit, the PUT, *Q3,* is used as a modified relaxation oscillator, with *Q1* serving as a bias control device and emitter-follower *Q2* as a sync amplifier/buffer. In operation, *Q3*'s anode-cathode capacitor (*C1*, *C2*, or *C3*.) is slowly charged toward source voltage through a series resistor (*R1* and *R2*), forming the leading ramp of a sawtooth waveform. During this period, *Q3*'s gate is maintained essentially at source voltage, because *Q1*, (part of the gate bias voltage-divider consisting of *R4*, *R5* and Q*1*'s emitter-collector resistance), is operated without base bias and acts as an open circuit. Under these conditions, the PUT cannot "fire" (i.e., switch to a conducting state).

If, at this time, a positive-going sync pulse is applied to *Q1*'s base, the transistor starts conducting, dropping the PUT's gate voltage below its anode voltage and causing it to fire, discharging the anode-cathode capacitor through cathode resistor *R3* and developing a sharp output pulse. With the capacitor discharged, *Q3*'s anode voltage drops and the device switches back to a non-conducting state, permitting the cycle to repeat.

For optimum operation, the sync pulse rate should be at a frequency comparable to *or higher than* the relaxation oscillator's "natural" frequency, as determined by the supply voltage and its anode-cathode RC time constant (*R1*-*R2* and *C1*, *C2* or *C3*). In fact, the sync pulse rate may be several times higher than the circuit's natural frequency, for the PUT will not fire until its anode voltage reaches a pre-established peak value. Since the output pulse rate (across *R3*) can be an integral fraction of the sync frequency, the circuit may be used as an effective frequency divider.

In practice, *S1* serves as a frequency range control, selecting various capacitor values and thus changing the relaxation oscillator's RC time constant. Similarly, variable resistor *R1* acts as a "fine frequency" control. Potentiometer *R7* provides an adjustment of sync amplitude.

Eugene has not specified component values for his circuit, indicating that these will be determined by the individual devices used, by the dc supply voltage, by the desired

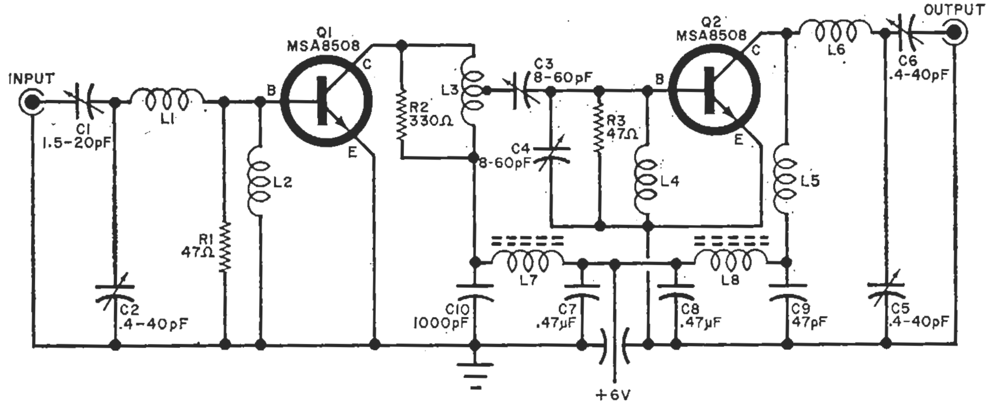

Fig. 2. R-f power amplifier employing npn VHF silicon power transistors can be used in either handheld, base station, or mobile applications. Operating frequency can be changed by varying LC values.

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CIRCLE NO. 9 ON READER SERVICE PAGE

Circuit Ideas

at high frequencies due to the time taken for the 709 amplifier to come out of saturation. The d.c. source should be relatively low impedance or have a small capacitor across it to avoid problems due to the changing input impedance of the circuit as it switches. Also the second amplifier must have a very high slewing rate, hence the use of a 709 amplifier with no compensating components.

J. W. Howden,
Bristol.

Voltage-controlled triangle generator

In the February issue H. Macdonald gave a circuit for a triangular-wave generator (Circuit Ideas, page 77). Here is a simpler circuit which is also a frequency-to-voltage converter. Excellent square and triangular waves are formed which may be used to produce sine waves by diode or f.e.t. shaping.

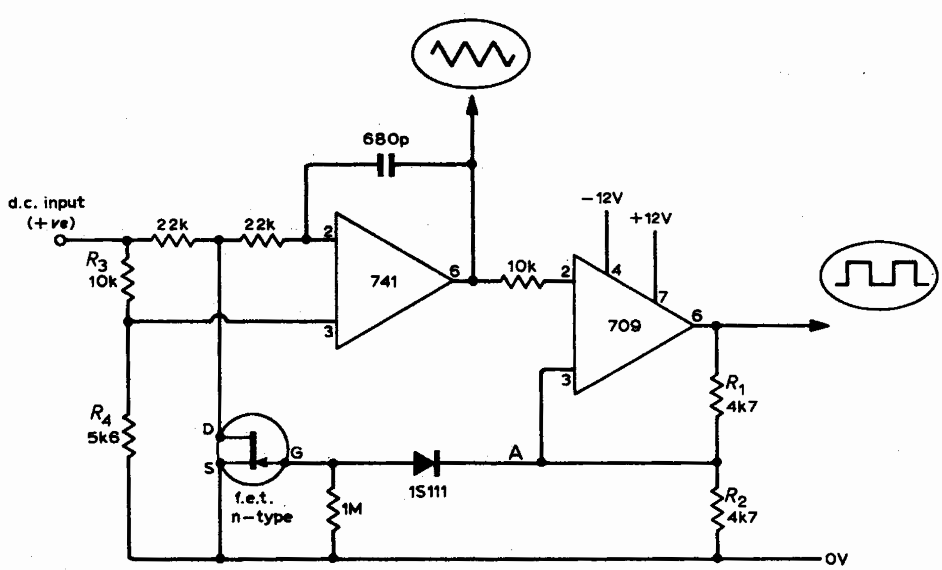
The circuit was designed to meet the following requirements for a specific application.

- Produce a frequency of 0-10kHz linearly related to a single control voltage, with a scaling of 1kHz per volt and zero frequency for zero volts control.
- Produce a good square wave and triangular wave suitable for sine shaping, i.e. constant amplitude.
- Circuit to be simple, reliable, self-starting with good temperature stability and zero warm-up time.

Mr. Price's circuit (Circuit Ideas, page 348 July issue) falls short of my specification in respect of the first requirement. Also, the frequency range of my circuit is much greater (0 to 10kHz compared with 100Hz to 3kHz), and Mr. Price's triangular waveform is not truly linear, but formed from a section of an "exponential" waveform. Other published circuits have also failed to meet this specification with the same degree of circuit simplicity as my own, e.g. Mr. Tidey's circuit (May, page 239) while giving the required outputs would require an additional amplifier to permit control by a single voltage, making the complete circuit a good deal more complex than shown in his diagram.

The circuit gives a good linear d.c.-to-frequency characteristic between 1Hz and 10kHz for up to 10V input, and works down to zero frequency. With a high-stability capacitor, the temperature coefficient is about 0.005% per deg. C between −40 and +100°C.

One of the advantages of the circuit is its flexibility: adjustment of the ratio of R_1 to R_2 gives triangular-wave amplitudes between 0 and 20V. The relative slopes may be adjusted with R_3 and R_4, and the bottom of the triangular wave can be clamped to almost any level by clamping the line A. Negative input voltages are easily dealt with by changing the f.e.t. type. With some modification, the unit can be made to operate over a wider frequency range, but normally some non-linearity occurs at very low input levels due to offset voltages, and



Versatile Triangle Wave Generator

A constructional project which forms a 'building brick' for more complex test systems

*by D. T. Smith**

This article describes a triangle wave generator whose frequency can be controlled in a variety of ways. Its frequency can be made to vary linearly with a potentiometer setting; the period can be made to vary linearly with a resistor and frequency can be varied exponentially over several decades, or swept with an input voltage. It uses cheap non-critical components, and is suitable for use from well below 1Hz to the MHz region. If required the triangle can be shaped to a sinewave, so that the oscillator can be used as a wide range or swept sinewave generator that avoids the problems associated with the direct generation of sinewaves at low frequencies. Also, a square wave output is available if required.

Principle of operation

A block diagram of the oscillator is shown in Fig. 1. The output of a constant current generator is fed through an electronic switch either directly to the capacitor C_1,

*Clarendon Laboratory, Oxford.

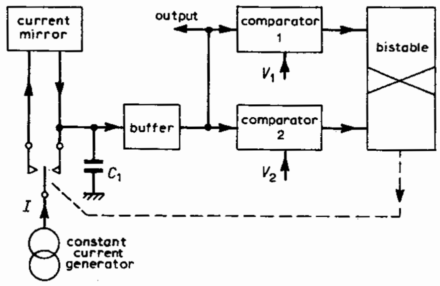


Fig. 1. A block diagram of the oscillator.

or via a "current mirror" circuit to C_1. This current mirror gives an output current equal in size but opposite in direction to its input current. Thus the capacitor voltage sweeps linearly—up or down as controlled by the switch. When the switch is feeding current to the current mirror, the capacitor voltage will sweep in the positive direction until the output exceeds the bias of the upper level comparator. Then the comparator triggers the bistable so that the switch reverses and the capacitor voltage sweeps in a negative direction. This continues until the output falls below the bias of the lower level comparator, when the bistable is triggered back to its original state and the cycle is repeated.

If the buffer has unit gain, and there is a difference, V, between the comparator bias levels, the capacitor voltage must change by 2V per cycle. Hence the frequency of oscillation is

$$f = \frac{1}{2C_1V}$$

Circuit details

Fig. 2 shows the circuit diagram of the oscillator (except for the current generator which is described later). The emitter coupled pair Tr_3, Tr_4 switch the input current, and the switch is controlled by 200mV signals from the bistable. In the current mirror Tr_1, Tr_2, the voltage drop caused by the input current flowing in R_1 and the emitter junction of Tr_1 equals the

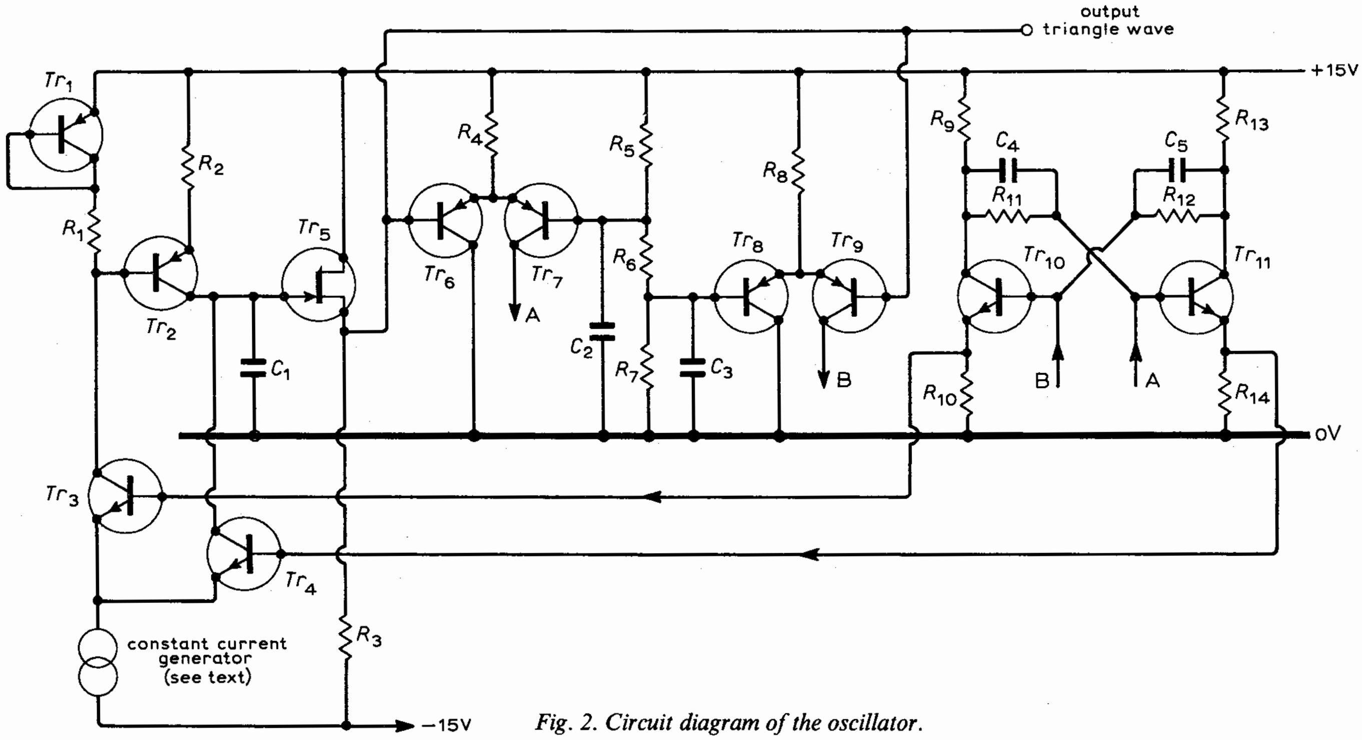


Fig. 2. Circuit diagram of the oscillator.

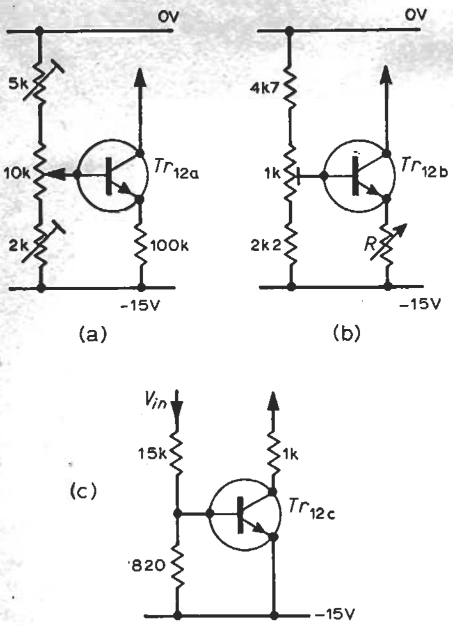
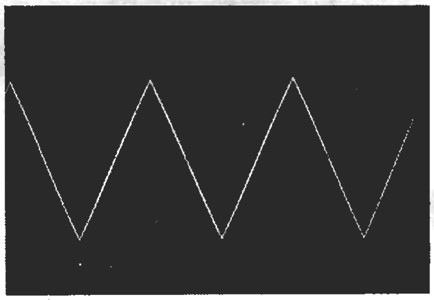


Fig. 3. (a) Current generator for the direct calibration of frequency. (b) Current generator for the direct calibration of period. (c) Current generator for a very wide frequency range.



The output waveform at 1kHz.

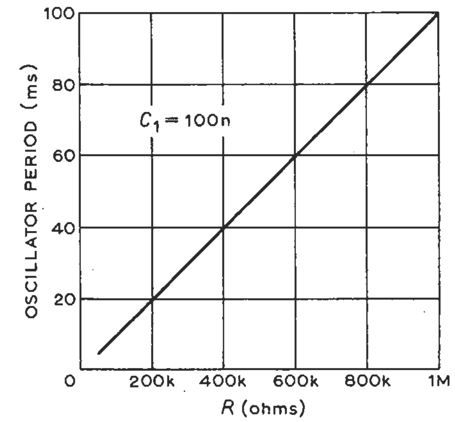


Fig. 5. Oscillator performance with current generator 4(b) demonstrating linear period calibration.

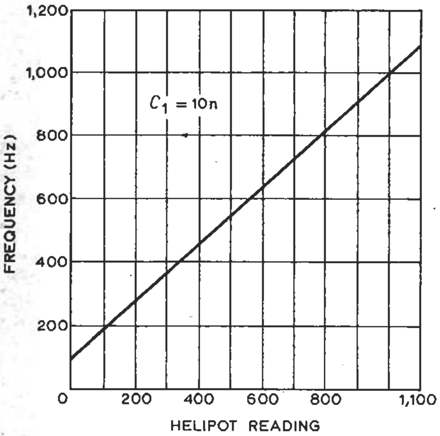


Fig. 4. The oscillator performance using the current generator shown in Fig. 4(a) demonstrating a linear frequency calibration.

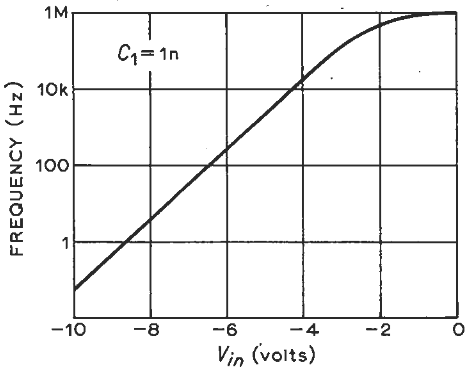


Fig. 6. Performance of the oscillator using the very wide frequency current generator.

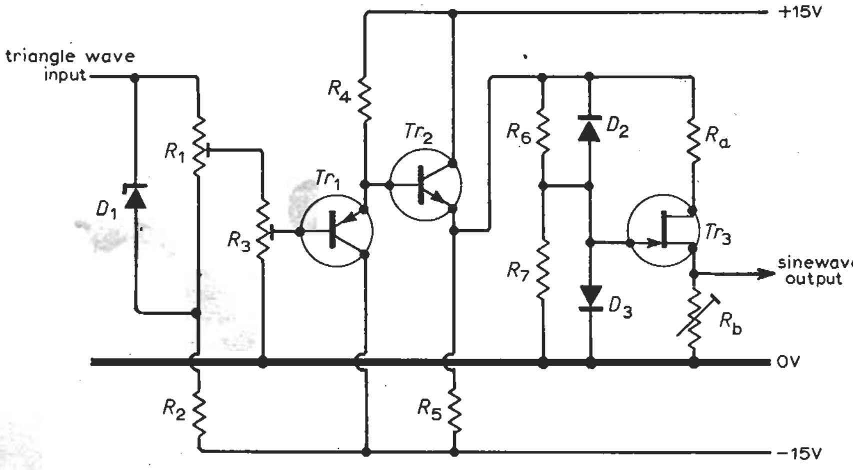


Fig. 7. A sine wave shaping circuit.

drop caused by the output current in R_2 and the emitter junction of Tr_2. Thus, if R_1 and R_2 are equal, and the transistors are similar, the output current will equal the input current, and with the values shown the circuit operates for currents ranging from below 1nA to about 500μA.

The capacitor voltage is buffered by a source follower Tr_5. The output is taken to the comparator Tr_6, Tr_7 and compared with a fixed bias of +10V. When the output exceeds +10V, Tr_7 conducts and triggers the bistable circuit Tr_{10}, Tr_{11}. The output is also fed to a second comparator Tr_8, Tr_9 and compared with a +5V bias, so that the bistable is reset when the output falls below +5V. The output is thus a triangle wave between the limits +5 and +10V. A photograph of the output waveform is shown on the left.

Constant current generator

The versatility of this oscillator stems largely from the fact that its frequency is controlled by a single current generator, and this generator can be adapted to meet a variety of needs. If only a single frequency is required, this generator can be a simple resistor to the negative line. Fig.3(a) shows a current generator suitable for use when an oscillator with a linear frequency calibration is wanted, as the frequency varies linearly with the potentiometer setting. If C_1 is 10nF and a ten turn helipot is used with the dial set to read from 1 to 11 turns, the trimmer potentiometers can be set to give maximum and minimum frequencies of 1100 and 100Hz. The oscillator frequency can then be read straight from the helipot dial, as is shown in Fig. 4. By switching the capacitor in decade steps, a useful test oscillator can be built to cover a wide range of frequencies.

If voltage control of frequency is required, a control voltage can be fed directly into the base of Tr_2 in place of the voltage from the potentiometer. When an oscillator calibrated in period is required, the current generator shown in Fig. 3(b) is suitable. This gives a period proportional to R, as shown in Fig. 5. The exponential relation between collector current and base-emitter voltage in a transistor can be used to give a very wide frequency range in one band, as was previously described for use with multivibrators[1]. Fig. 3(c) shows a suitable generator and its measured performance is shown in Fig. 6. When this circuit is used R_1 and R_2 should be changed to 470Ω to allow the current mirror to work up to 10mA.

Conversion to sine waves

A triangle wave with its reasonably low harmonic content can be used in many applications where a sinewave has been traditionally used. However, when a low harmonic content is necessary, the non-linear characteristics of a junction f.e.t. can be used to shape the triangle into a sinewave[2]. A suitable circuit is shown in Fig. 7. The d.c. output of the emitter follower is set to zero using R_1 and the amplitude set with R_2. The emitter follower is necessary to give a low impedance drive to the shaping circuit.

Some care in setting up is necessary here for good results. The V_p and I_{dss} of the f.e.t. should be measured (i.e., the gate bias where the drain current falls to zero, and the saturation current at zero gate bias), and the peak-to-peak input level set to about $2.7V_p$ with R_a and R_b set to about $\frac{V_p}{2I_{dss}}$. The input level is then adjusted for minimum 3rd harmonic and R_b set for minimum 2nd harmonic, using a wave analyser if available. A total harmonic content of less than 0.5% r.m.s. can be obtained with this circuit.

References

1. D. T. Smith, "Multivibrators with seven-decade range in period", *Wireless World*, Vol. 78, No. 1436, 1972, pp. 85–6.

2. R. D. Middlebrook and I. Richer, "Non-reactive filter converts triangular waves to sines", *Electronics*, Vol. 38, No. 5, 1965, pp. 96–101.

Components List (Figs. 2, 4)

Resistors

R_1	10k
R_2	10k
R_3	22k
R_4	4.7k
R_5	10k
R_6	10k
R_7	10k
R_8	10k
R_9	6.8k
R_{10}	100
R_{11}	10k
R_{12}	10k
R_{13}	6.8k
R_{14}	100

Capacitors

C_1	see text
C_2	0.1μF
C_3	0.1μF
C_4	4.7pF
C_5	4.7pF

Semiconductors

$Tr_1, Tr_2, Tr_6, Tr_7, Tr_8, Tr_9$	All 2N4061
$Tr_3, Tr_4, Tr_{10}, Tr_{11}, Tr_{12}$	All 2N5172
Tr_5	2N3819

Components List (Fig. 8)

Resistors

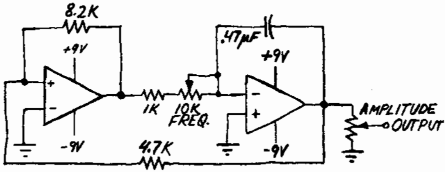
R_1	22k pot.
R_2	10k
R_3	100k pot.
R_4	100k
R_5	4.7k
R_6	1M
R_7	1M
R_a	see text
R_b	see text

Semiconductors

D_1	12V zener
D_2	1S44
D_3	1S44
Tr_1	2N4061
Tr_2	2N5172
Tr_3	2N3819

AN EASIER WAY TO DO IT

The triangle-wave generator shown in the Test Equipment Scene (May 1974) was doing things the hard way. My circuit is much simpler. It uses less than half the

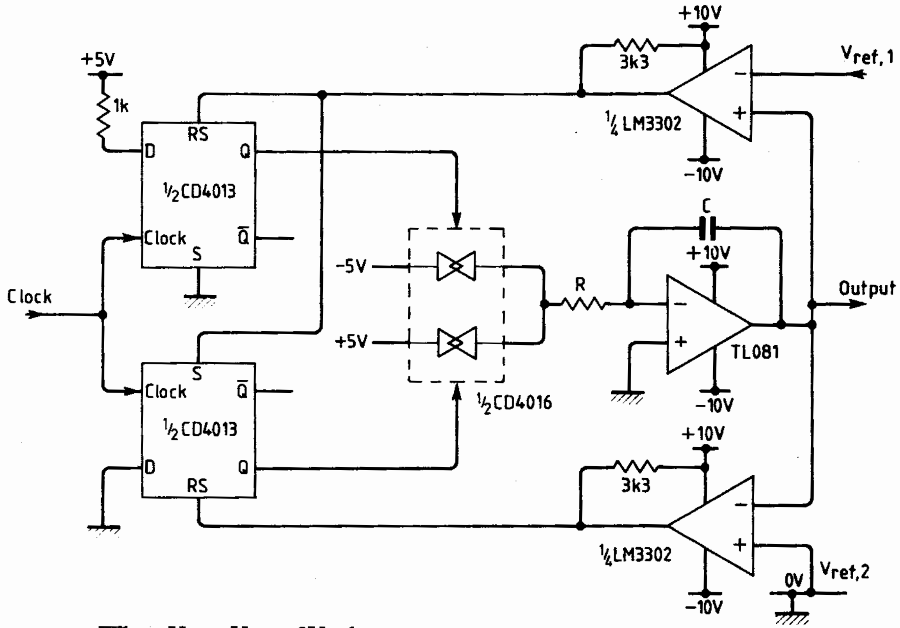


parts, but it doesn't sacrifice performance. It also features better linearity, which is important for test purposes. And the circuit is drift-free, eliminating the need for relatively expensive output capacitors. I have designed the circuit to be frequency-variable without the need to readjust the output level to maintain a constant amplitude.

WOLFGANG RUPPRECHT
Munich, Germany

CIRCUIT IDEAS

Clock-triggered triangular pulse generator



A double pulse is applied to the inverting input of a TL081 operational amplifier connected as an integrator and a triangular pulse is obtained at the output. The required double pulse is formed by two direct voltages −5V, +5V, applied to the integrator input *via* a pair of analogue switches. Two D-type flip-flops control these switches. The two flip-flops are triggered by the rising edge of the clock pulse applied to their clock inputs. When the clock-pulse triggers the two flip-flops, the First flip-flop's Q-output becomes equal to 1 and the Q-output of the second equal to 0. Consequently, one switch is enabled and the other disabled. Thus an input voltage equal to −5V is applied to the integrator. When no input voltage is applied to the integrator, $V_{out}=0$. Then, $V_{in}=-5V$ and V_{out} increases; when it equals the reference voltage $V_{ref.1}$ the output of the comparator goes high, and the first flip-flop's Q-output is reset to 0, while the second's Q-output is set to 1. Thus the switches change state, so that $V_{in}=+5V$ and V_{out} decreases. When $V_{out}=V_{ref2}=0V$, the output of the second comparator goes high resetting the Q-output of flip-flop 2 to 0. So both switches are disabled, and no input voltage is applied to the integrator. Consequently $V_{out}=0$ until the next rising edge of the clock pulse triggers the flip-flops. The duration of the triangular pulse is $T=2t_i$ where $t_i=1/RC$ is the time constant of the integrator.

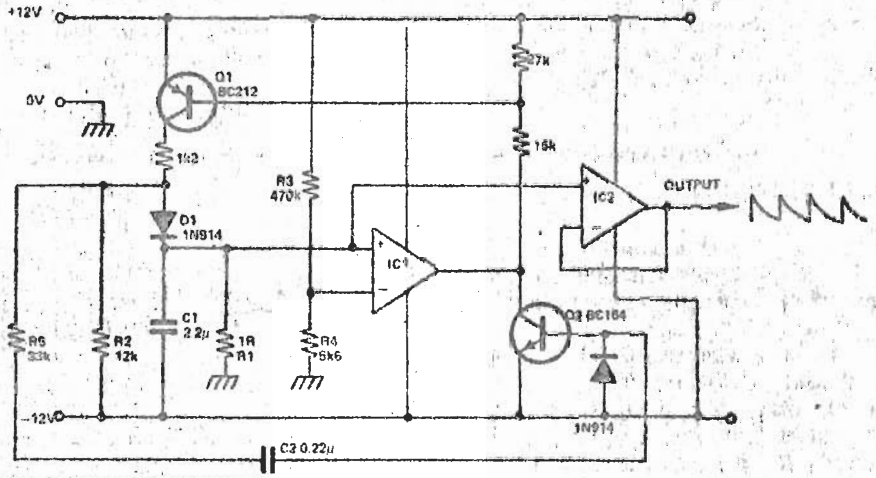
G. Tombras
Athens

EXPONENTIAL WAVEFORM GENERATOR

This circuit produces a waveform that decays exponentially from a set voltage to near-zero, and then rapidly resets to re-start the cycle.

Initially C1 is charged to +12V, and Q1, Q2 are both off. The timing capacitor there discharges slowly through R1, the exponentially decaying voltage appearing at low impedance at the output of unity-gain buffer IC2. R2 prevents the leakage current from Q1 affecting the discharge as D1 is reverse-biased. When the voltage on C1 reaches a value just above zero that is set by R3, R4, the open-collector O/P of IC1 goes low, turning on Q1 and rapidly recharging C1. IC1 of course reverts to its original state almost at once, but the recharge mode is prolonged for several milliseconds by the positive feedback loop through R5, C2 and Q2, to ensure C1 charges fully. After this time C2 is also fully charged, and Q2 turns off, turning off Q1, and allowing the slow discharge of C1 to begin again.

With the component values shown, each cycle lasts about ten seconds.



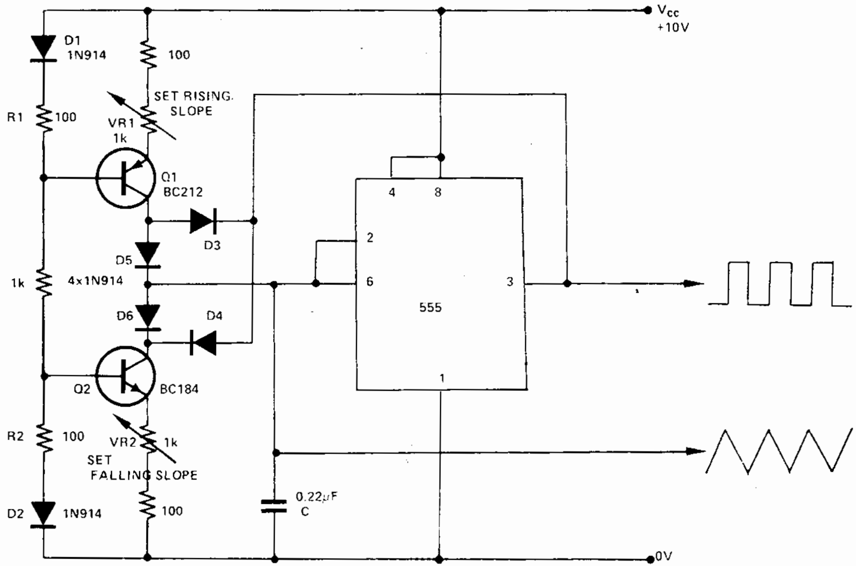
IC1 . . . An open-collector O/P comparator, eg LM339. IC2 . . . 741 or similar.

TRIANGLE GENERATOR WITH INDEPENDENT SLOPE SETTING

This free-running oscillator circuit generates a triangle waveform, the rising and falling slopes of which may be set by completely independent controls. Simultaneously the 555 output (pin 3) provides a rectangular waveform at low impedance that is synchronised with the triangle waveform.

Assuming the 555 output is low, the output of constant-current source Q1 is shorted to earth via diode D3, and diode D5 is reverse biased. During this time current source Q2 linearly discharges the timing capacitor C through D6, D4 being reverse biased. Eventually the voltage on C falls to $1/3V_{CC}$ (set by the internal potential divider that biases the two comparators in the 555) and the 555 output goes high. Now the output of Q2 is shorted away from the timing capacitor, and Q1 is allowd to linearly charge it up; when the capacitor voltage reaches $2/3V_{CC}$ the 555 output goes low again, and the cycle repeats.

The biasing networks R1D1 and R2D2 compensate for the changes in V_{CC}.



Serrodyne amplifier generates wideband linear ramp

by Roy Viducic
Loral Electronic Systems, Yonkers, N. Y.

Producing an extremely linear 200-V ramp or peak-to-peak sine wave over a frequency range of 50 kilohertz, this circuit is ideally suited for modulating the helix of a traveling-wave tube (serrodyning) or generating large voltages for circuit synchronizers. Because of the inherent symmetry of the circuit design, it can produce both positive-going and negative-going ramp waveforms.

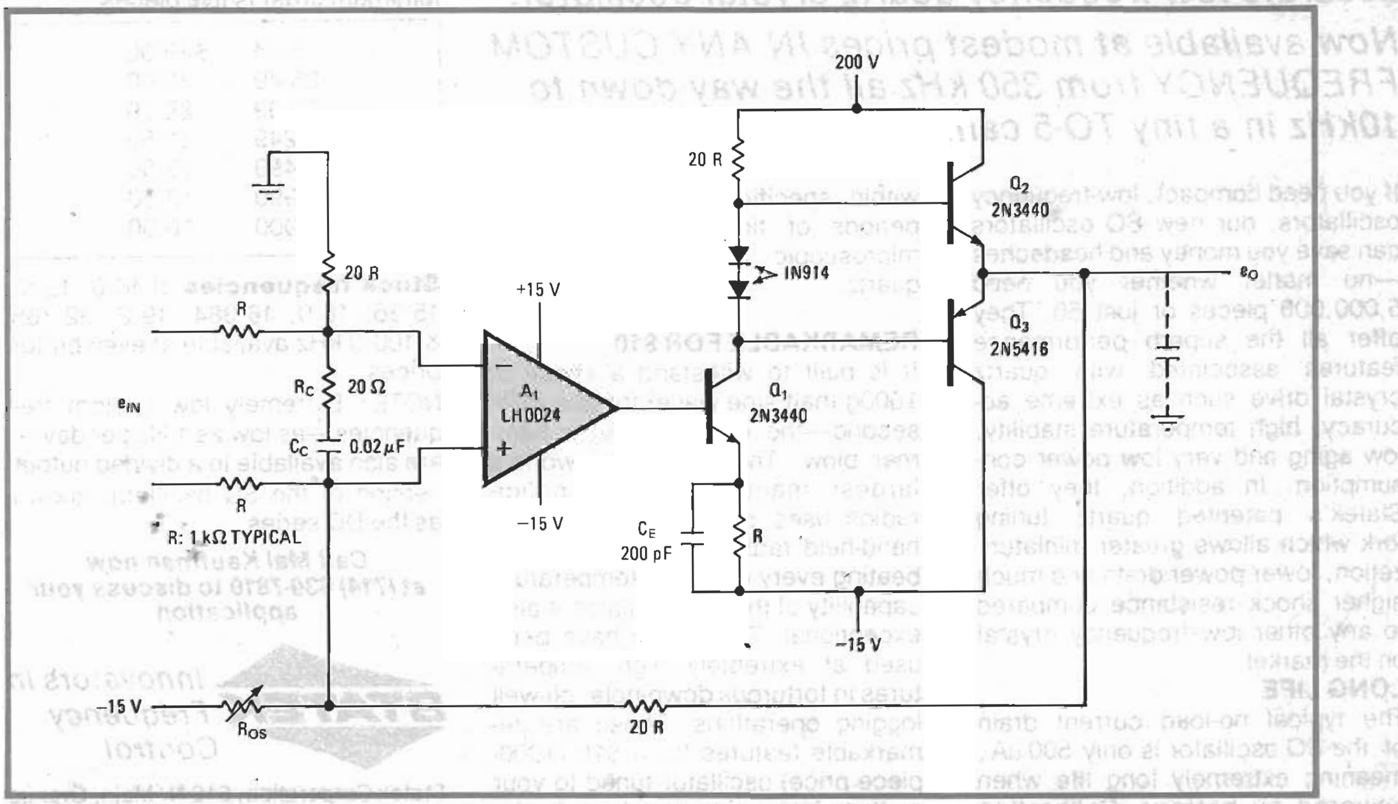
In addition to the advantages previously mentioned, the circuit offers:

- Low gain error through either input.
- Fast response for both ramp polarities—the output's flyback-settling time is 1 microsecond.
- Wide dc-offset capabilities.

To achieve this performance, an operational amplifier with a high slew rate and broadband response is used in a simple feedback arrangement.

The low-level ramp or sine wave signal is applied to either input of A_1. Note that the polarity of the ramp at the output is reversed if the input signal is applied to the opposite port of A_1. The broadband characteristics of A_1 provide sufficient output, even at a closed-loop gain of 20. This is the minimum loop gain required to obtain the linearity, precision, and dynamic range that were initially specified for this application.

After inversion and further amplification by Q_1, the signal passes through complementary-transistor pair Q_2–Q_3 to the output. Because Q_1 is designed for a closed-loop gain of 20, it is only necessary to swing 10 volts at the output of A_1, well within the operational amplifier's capabilities in its linear region.



Well-behaved. Feedback circuit provides high-voltage ramp or sinewave to capacitive loads exceeding 200 picofarads. Broadband op amp having high slew rate contributes to excellent linearity of waveforms over 50 kilohertz range. Flyback settling time is 1 μs.

Capacitor C_E compensates for the total base-to-emitter capacitance at Q_2 and Q_3, which act to reduce circuit speed. Network R_cC_c stabilizes the entire loop. Potentiometer R_{os} is used to adjust the output offset.

Considerable heat will be generated in Q_1–Q_3 because of high collector voltage. In spite of this, the power dissipated by them is well within the ratings of their TO-5 cases. Therefore, the transistors do not require external heat sinks. □

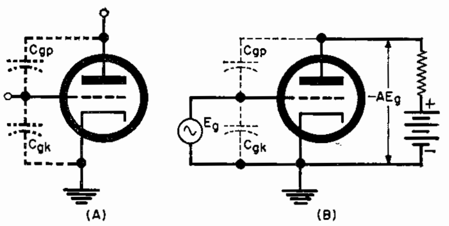


Fig. 1. (A) Triode interelectrode capacities and (B) equivalent amplifier circuit.

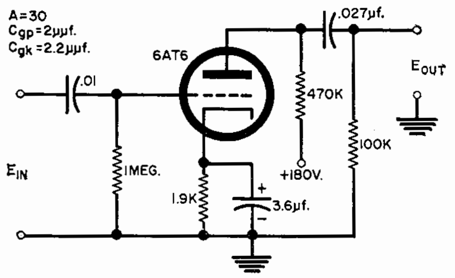


Fig. 2. Typical triode amplifier circuit.

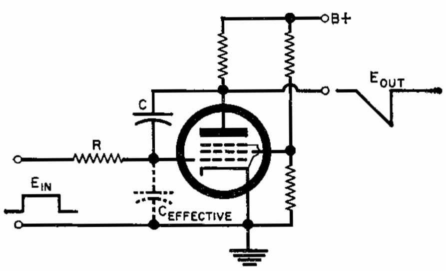
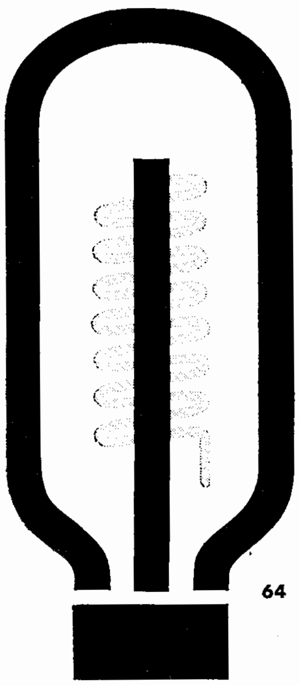


Fig. 3. The Miller sweep-generator circuit.

MILLER EFFECT & ITS USES



By LEE BISHOP

Meaning of this important electron-tube effect along with some interesting new uses for an old principle.

MANY of the latest electronic techniques are but applications of well-known and long-established principles. Parametric amplifiers fit this category, as do artificial capacitances produced by amplification. Devices of the latter category are applications of the principles first described and calculated by J. M. Miller back in 1919.

While the Miller equation can be found in any standard text, its derivation has become obscured to the point that it is almost impossible to find it anywhere. Because of the valuable insight the derivation of this equation provides the technician in analyzing tone controls, sweep generators, analogue computers, and other current devices, the Miller equations have been "re-discovered" in the following paragraphs.

What It Is

An unfortunate combination of the effects of tube interelectrode capacitances is responsible for the Miller Effect. Fig. 1A shows the capacitances involved. Looking into the tube's input circuit, the grid-to-cathode capacitance is immediately encountered, of course. This capacitance will act to short to ground any high frequencies in the input signal, thereby decreasing the gain of the stage at the higher frequencies. When a signal is applied to the input circuit, an amplified version appears at the plate of the tube. This amplified signal is 180 degrees out-of-phase with the signal on the grid and, since grid-to-plate capacitance couples the plate to the grid, the amplified signal is coupled into the grid circuit where it will also act to decrease the input signal. The effect is the same as if the grid-to-cathode capacitance has been increased. This is an extremely important consideration.

The next thing to be considered is just how much the input capacitance has been increased. In order to develop an equation, consider the circuit of Fig. 1B. The total input capacitance is thought of as being made up of two capacitances, the Miller capacitance caused by the feedback and the actual physical C_{gk}. Now the charge on a capacitor can be expressed by the well-known equation:

$$Q = CE \quad \ldots\ldots (1)$$

where: Q is the charge in coulombs; C is the capacitance in farads; and E is the voltage in volts.

Therefore, the charge on C_{gk} will be:

$$Q_1 = C_{gk}\,E_g \quad \ldots\ldots (2)$$

where E_g = a.c. grid voltage.

Now the charge on C_{gp} will be:

$$Q_2 = C_{gp}[E_g - (-AE_g)] = C_{gp}\,E_g(A+1) \quad \ldots (3)$$

where A = stage gain.

Since the preceding stage must supply charging current to both capacitances, the charges appear additive at the input.

Therefore:

$$Q_{in} = Q_1 + Q_2 = C_{gk}\,E_g + C_{gp}\,E_g\,(A+1) \quad (4)$$

As Q_{in} is the total charge of the input capacitance C_{in}, this capacitance is related by:

$$Q_{in} = C_{in}E_g \quad \ldots\ldots (5)$$

Combining Eq. 4 and Eq. 5 gives:

$$C_{in}E_g = C_{gk}\,E_g + C_{gp}\,E_g\,(A+1) \quad \ldots\ldots (6)$$

Simplifying, results in:

$$C_{in} = C_{gk} + C_{gp}\,(A+1) \quad \ldots (7)$$

Eq. 7 is the well-known Miller equation. This equation shows very clearly that the total effective input capacitance is determined not only by tube and distributed capacitances, but also by the gain of the stages. Understanding and using this equation provides the technician with a powerful tool in analyzing the operation of many modern circuits.

In order to get an idea of the magnitude of the Miller Effect, consider the circuit of Fig. 2. The stage gain for this particular circuit is 30. The tube capacitances are shown in the diagram. Applying these values to the Miller equation shows the effective input capacitance to be:

$$C_{in} = 2.2 + 2\,(30+1) = 64.2\ \mu\mu\text{f.}$$

The tube has an input capacity of only 2.2 $\mu\mu$f. but, when used in the circuit shown, the effective input capacity is 64.2 $\mu\mu$f. Actually the C_{gk} is a very minor part of the total. Miller Effect has accounted for 62 $\mu\mu$f. The equation points up very clearly the shortcomings of high-gain triode amplifiers at the higher frequencies.

Applications

The Miller Effect has been put to good use in the sweep generator circuit of Fig. 3. The plate-to-grid capacitance in this case is augmented by the use of a physical capacitor and stage gain has been increased by the use of a pentode. The effective capacitance from control grid to ground is the capacitor C multiplied by the gain of the stage.

For a positive-going square-wave input of the desired sweep duration applied to the control grid through R, the plate voltage waveform will be a negative-going saw-tooth. The positive signal at the control grid will tend to increase the plate current. The discharge of C, caused by the plate going negative, tends to reduce the plate current.

The behavior of this circuit can be predicted by using the Miller equation to estimate the size of the Miller capacitance between grid and ground. The Miller capacitor thus calculated is then considered to be charging to the gate voltage through resistor R for the duration of the gate. The waveform in the plate is the predicted grid waveform inverted and amplified by the stage gain. This circuit has the advantage of being able to produce very linear sweeps with very small values of R and C.

It is not generally realized that a Miller sweep circuit can be used to provide linear sweeps whose amplitude is on the order of 25 times that of the sweep generator plate voltage. The trick here is to use an inductance in the plate

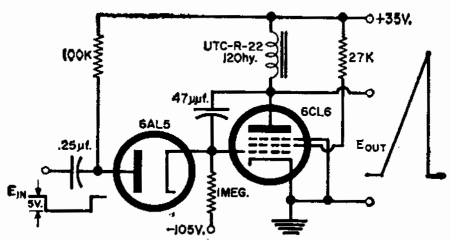


Fig. 4. Precision sweep generator with high-amplitude output saw-tooth waveform.

circuit. The collapsing field around the inductor provides the high voltage and the Miller capacitance provides the linearity. An actual circuit capable of producing linear sweeps of 1000 volts peak amplitude and extreme linearity with only 35 volts of "B" supply is shown in Fig. 4.

The Miller Effect finds universal application in analogue computers performing the calculus operation of integration. Assume, for example, that it is desired to convert speed to distance. The simple circuit of Fig. 5 is capable of doing this. If the voltage applied to the left side of resistor R were proportional to speed, and the RC time constant of the circuit were sufficiently long, the charge on the capacitor at any given instant would be representative of the distance traveled at that instant.

Unfortunately, with reasonable capacitance values, the charging rate would be far from linear as time increased. By using a sufficiently long RC —at least 10 times the period of the integration—the accuracy of the integration can be improved considerably and the charge on the capacitor at any given instant would be a better analogue of the distance traveled. The problem here is to find a large enough capacitor. One

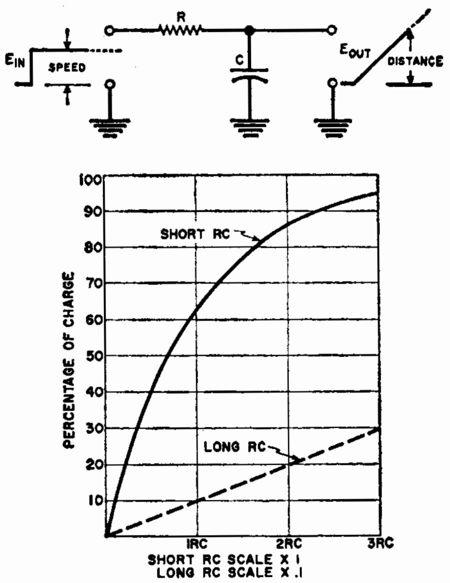


Fig. 5. Relationships in integrator circuit.

of the correct size for the average application would fill half a room.

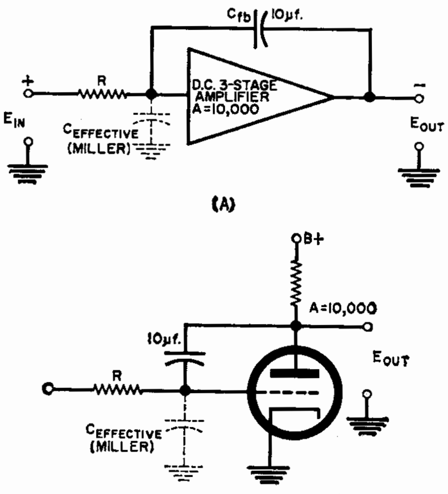
In practice, this large capacity is built up electronically with a device known as an integrating amplifier. The integrating amplifier and its Miller equivalent is shown in Fig. 6. In cases of this nature, where high amplifier gains and large feedback capacitors are used, the C_{gk} and the 1 can be dropped from the Miller equation because they are negligible. The equation for the Miller capacitance produced by an integrating amplifier then becomes:

$$C_{Miller} \cong C_{fb}\, G$$

where C_{fb} is the feedback capacitor and G is the amplifier gain. For the amplifier of Fig. 6, the Miller capacity would be 100,000 microfarads.

The Miller principle, although dating back to 1919, is as pertinent today as it was then. Many new and unusual circuit configurations use and will continue to use it. The devices illustrated here have been selected to review the effect and develop a method of analyzing circuits using the principle of amplified capacitance. -30-

Fig. 6. (A) Integrating amplifier arrangement along with (B) the Miller equivalent.



Non-Interference Seals for TV and FM Sets

FCC reminds all prospective purchasers that sets must comply with specified radiation limitations.

MOST TV and FM receivers and tuners act as miniature radio stations and radiate radio signals from their local oscillators and sweep circuits. Unless the receiver or tuner is carefully constructed and well-shielded, it can cause interference, not only to neighborhood receivers but also to sets used in commercial, police, fire, and aircraft communications.

To minimize this possibility, FCC regulations limit the amount of permissible radiation and require that TV and FM receivers and tuners manufactured after Dec. 31, 1957 have a seal or label affixed stating that they meet the radiation limits. Manufacturers and distributors are authorized to affix such a seal or label but only after the set has been tested for compliance.

The owner of the set is responsible for complying with FCC requirements. However, the Commission recognizes that the user cannot usually test the set to determine whether it meets the requirements. It therefore feels that the manufacturer or distributor should assume this obligation to his customers and affix the required seal so that the purchaser of the set is assured that it conforms with radiation requirements.

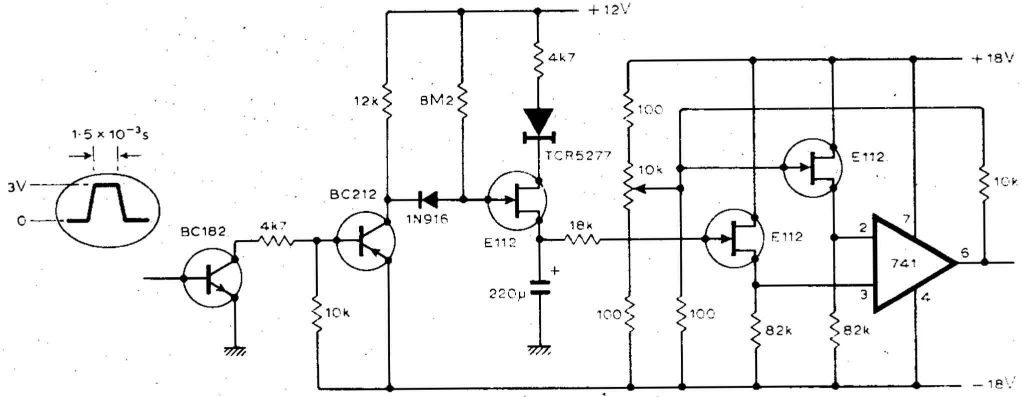
The Commission is receiving excellent cooperation from United States and foreign set manufacturers in this program. Most manufacturers are testing their receivers and tuners to insure that they comply with the regulations and are affixing the required seal or label as proof of compliance. However, some sets are being sold which do not carry the seal. It is possible that many of these may meet the radiation limits set up by the FCC, but that the manufacturers either have not made the prescribed tests or have not affixed a seal showing compliance.

The FCC notes that operation of a set manufactured after Dec. 31, 1957 which does not have such a label attached is prohibited by the rules. The Commission suggests that a buyer insist that the seal be attached to the receiver before a purchase is made. By so doing, he also will insure the continued cooperation of set manufacturers in the program. The owner of an unlabeled set which causes interference to his neighbor may be required to take remedial action or to stop using the interfering set. -30-

Ramp generator

A POSITIVE ramp can be generated by dumping charges on a capacitor. The amount of charge deposited after $t = n+1$ pulses will be $Q = It$. After five seconds $5 \times 10^{-4}Q$ will have been dumped on the capacitor which increases its volume from $V_0 = It/C$ to $V_1 = It^{n+1}/C$. This voltage is stored on the capacitor and decreases by an amount V_d which is determined by the internal resistance of the capacitor and the f.e.t. gate leakage current. Without any load to the capacitor the voltage across it will decrease by $9/10^{-8}$V/min. To obtain an output voltage which has little influence on the charge or discharge of the capacitor, a 741 with a high impedance duel f.e.t. input is used. The circuit shown generates a ramp from 0 to 5.3V.

D. Greenland,
Cambridge.



Dual-function amplifier eases circuit design

by Jim Williams
National Semiconductor Corp., Santa Clara, Calif.

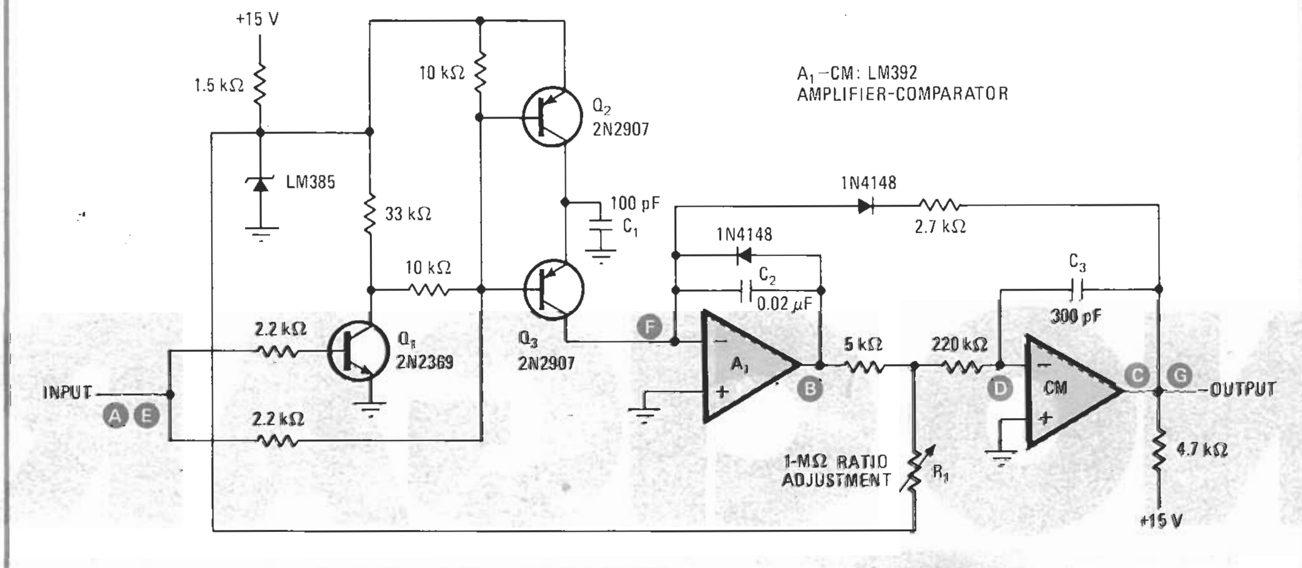
To simplify and cut the cost of the myriad of general-purpose and specialized circuits, chips like National's LM392 combine both amplifier and comparator functions on a single substrate. As has already been noted [*Electronics*, May 5, p. 142], it can be used to build a sample-and-hold circuit, a feed-forward low-pass filter and a linearized-platinum-resistor thermometer. This article will present designs for its use in the construction of a variable-ratio digital divider, an exponential voltage-to-frequency converter for electronic music, and a temperature controller for quartz-crystal stabilization.

Figure 1 shows a divider whose digital-pulse input can be divided by any number from 1 to 100 by means of a single-knob control. This function is ideal for bench-type work where the ability to set the division ratio rapidly is advantageous.

With no input signal, transistors Q_1 and Q_3 are off and Q_2 is on. Thus, the 100-picofarad capacitor (C_1) at the junction of Q_2 and Q_3 accumulates a charge equal to $Q_{cap} = C_1V_0$, where V_0 is the potential across the LM385 zener diode (1.2 volts), minus the saturated collector-to-emitter potential across Q_2.

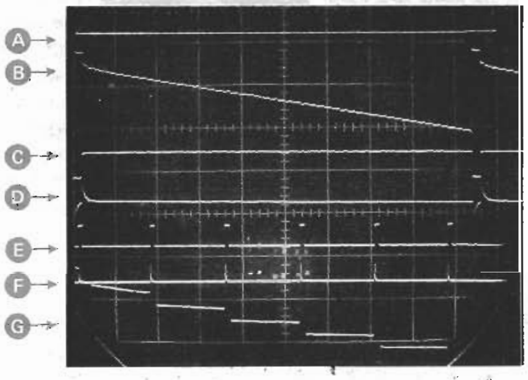
When the input signal to the circuit goes high (see trace A, in the photograph), Q_2 goes off and Q_1 turns on Q_3. As a result, the charge across C_1 is displaced into A_1's summing junction. A_1 responds by jumping to the value required to maintain its summing junction at zero (trace B).

This sequence is repeated for every input pulse. During this time, A_1's output will generate the staircase waveshape shown as the 0.02-microfarad feedback capacitor (C_2) is pumped by the charge-dispensing action to the A_1 summing junction. When A_1's output is

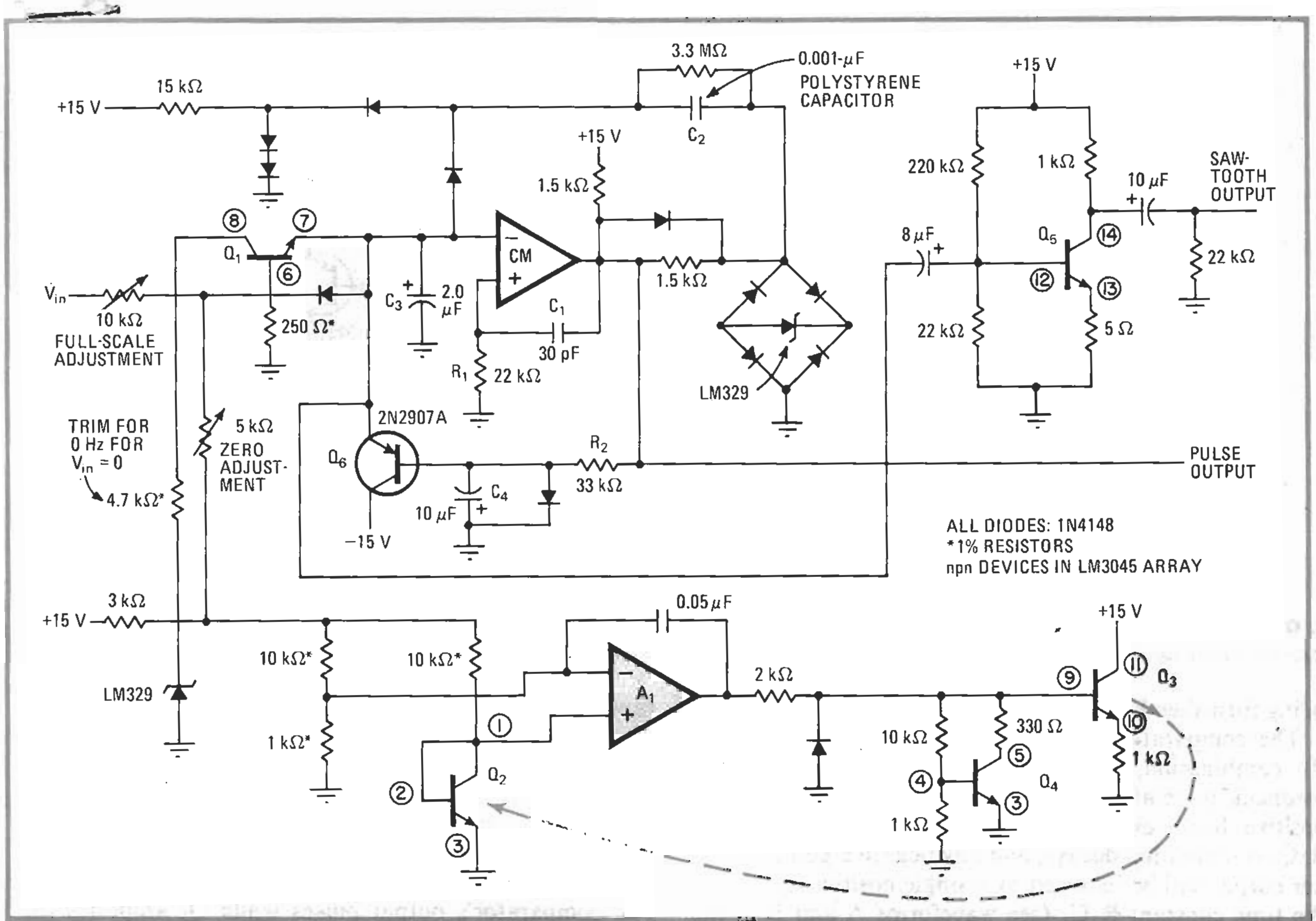


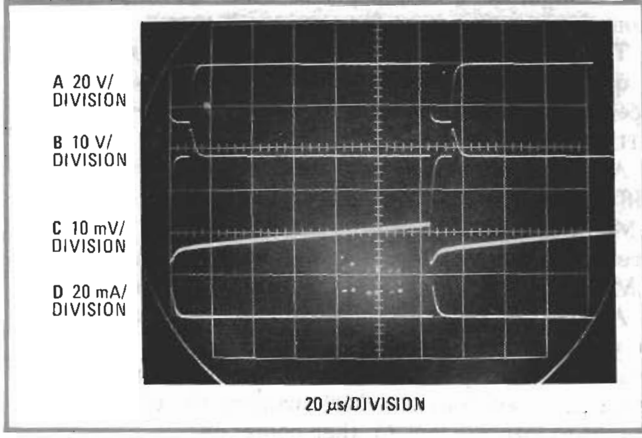
Trace	Vertical resolution (volts/division)*	Horizontal resolution (μs/division)
A	10	500
B	1	500
C	50	500
D	50	500
E	10	50
F	10 mA	50
G	0.1	50

*UNLESS OTHERWISE NOTED



1. Analog digitizer. A single-control potentiometer sets the digital signal's divider ratio from 1 to 100 using the LM392 comparator-amplifier chip. Thus, the division ratio may be rapidly set. Staircase signals are derived from a charge-balancing arrangement, which acts to maintain A_1's summing junction at a voltage null.





2. Sweet sawtooth. When combined with LM3045 transistor array, LM392 forms the heart of an exponential function generator that can easily be built. Waveform conformity to a pure exponential is excellent—±0.25% over the 20-Hz-to-15-kHz range. Thermal drift is minimized with a simple servo loop. Provision is made for eliminating servo lock-up under virtually all conditions.

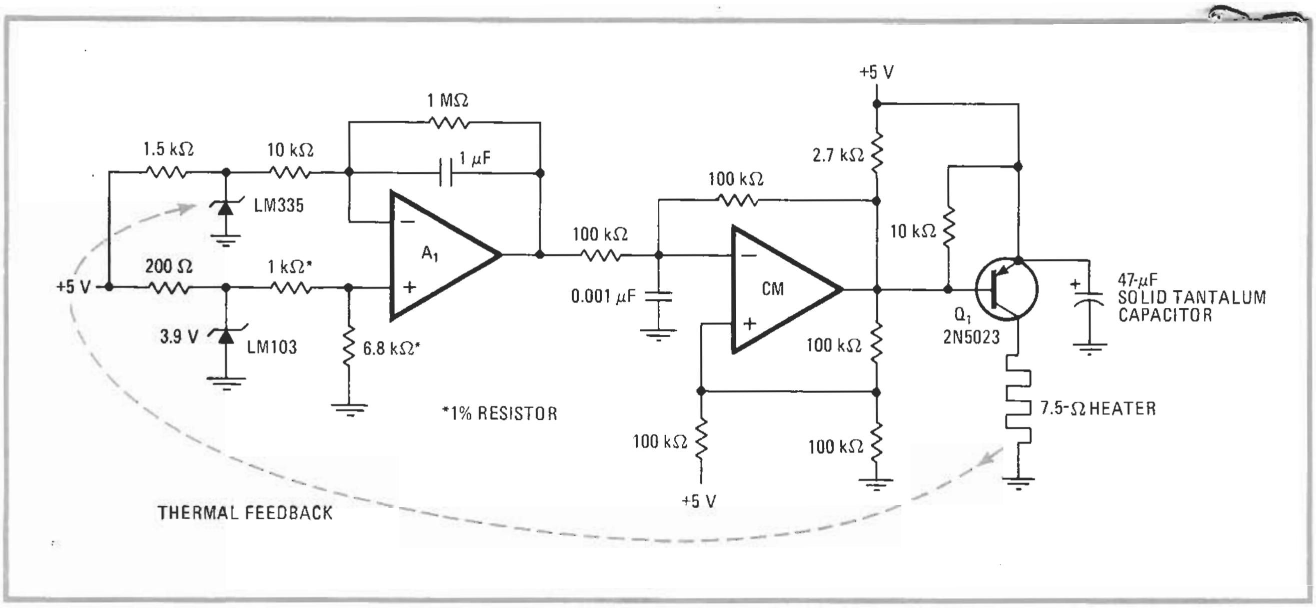
just great enough to bias the noninverting input of the comparator (CM) below ground, the output (trace C) goes low and resets A_1 to zero. Positive feedback to the comparator (trace D) is applied through the 300-pF capacitor (C_3), ensuring adequate reset time for A_1.

Potentiometer R_1 sets the number of steps in the ramp required to trip the comparator. Thus the circuit's input-to-output division ratio may be conveniently set. Traces E through G expand the scope trace to show the dividing action in detail. When the input E goes high, charge is deposited into A_1's summing junction F, and the resultant waveform G takes a step.

Professional-grade electronic-music synthesizers require voltage-controlled frequency generators whose output frequency is exponentially related to the input voltage. The one shown in Fig. 2 provides conformity within 0.25% over the range from 20 hertz to 15 kHz using a single LM392 and an LM3045 transistor array. These specifications will be adequate for all but the most demanding of applications.

The exponential function is generated by Q_1, whose collector current varies exponentially with its base-emitter voltage in accordance with the well-known relationship between that voltage and current in a bipolar transistor. An elaborate and expensive compensation scheme is usually required because the transistor's operating point varies widely with temperature. Here, Q_2 and Q_3, located in the array, serve as a heater-sensor pair for A_1, which controls the temperature of Q_2 by means of a simple servo loop. As a consequence, the LM3045 array maintains its constant temperature, eliminating thermal-drift problems in the operation of Q_1. Q_4 is a clamp, preventing the servo from locking up during circuit start-up.

In operation, Q_1's current output is fed into the summing junction of a charge-dispensing current-to-frequency converter. The comparator's output state is used to switch the 0.001-μF capacitor between a reference voltage and the comparator's inverting input, the reference



3. Oven cut. Quartz crystals are maintained at 75°C with this temperature controller, thus stabilizing output frequency of these sources. Switched-mode servo loop simplifies circuitry considerably. Long-term temperature accuracy is estimated at 10 parts per million.

being furnished by the LM329.

The comparator drives the capacitor C_1 and resistor R_1 combination, this network providing regenerative feedback to reinforce the direction of its output. Thus, positive feedback ceases when the voltage across the R_1C_1 combination decays, and any negative-going amplifier output will be followed by a single positive edge after the time constant R_1C_1 (see waveforms A and B in the photograph).

The integrating capacitor C_3 is never allowed to charge beyond 10 to 15 millivolts because it is constantly reset by charge dispensed from the switching of C_2 (trace C). If the amplifier's output goes negative, C_2 dumps a quantity of charge into C_3, forcing it to a lower potential (trace D). When a short pulse is transferred through to the comparator's noninverting input, C_2 is again able to charge and the cycle repeats. The rate at which this sequence occurs is directly related to the current into the comparator's summing junction from Q_1. Because this current is exponentially related to the circuit's input voltage, the overall current-to-frequency transfer function is exponentially related to the input voltage.

Any condition that allows C_3 to charge beyond 10 to 20 mV will cause circuit lock-up. Q_6 prevents this by pulling the inverting input of A_1 towards -15 V. The resistor and capacitor combination of R_2 and C_4 determines when the transistor comes on. When the circuit is running normally, Q_6 is biased off and is in effect out of the circuit.

The circuit is calibrated by simply grounding the input and adjusting first the zeroing potentiometer until oscillations just start and then the full-scale potentiometer so that the circuit's frequency output exactly doubles for each volt of input (1 V per octave for musical purposes). The comparator's output pulses while Q_5 amplifies the summing junction ramp for a sawtooth output.

The circuit in Fig. 3 will maintain the temperature of a quartz-crystal oven at 75°C. Five-volt single-supply operation permits the circuit to be powered directly from TTL-type rails.

A_1, operating at a gain of 100, determines the voltage difference between the temperature setpoint and the LM335 temperature sensor, which is located inside the oven. The temperature setpoint is established by the LM103 3.9-V reference and the 1-to-6.8-kilohm divider.

A_1's output biases the comparator, which functions as a pulse-width modulator and biases Q_1 to deliver switched-mode power to the heater. When power is applied, A_1's output goes high, causing the comparator's output to saturate low. Q_1 then comes on.

When the oven warms to the desired setpoint, A_1's output falls and the comparator begins to pulse-width–modulate the heater via the servo loop. In practice, the LM335 should be in good thermal contact with the heater to prevent oscillation in the servo loop. □

Programmable sine generator is linearly controlled

by S. Awad and B. Guerin

Laboratoire de la Communication Parlée, Grenoble, France

Because the frequency of this sine-wave oscillator is a linear function of a digitally controlled input, it is attractive for microprocessor and speech-synthesis applications. In addition, it is easy to implement—the digital controller, made up of two resistor modules, needs only to be inserted in place of the two passive resistors normally present in a standard sine-wave oscillator.

It can be shown from the basic circuit in the figure