# Some Applications of A Programmable Power Switch/Amplifier

by L. R. Campbell and H. A. Wittlinger

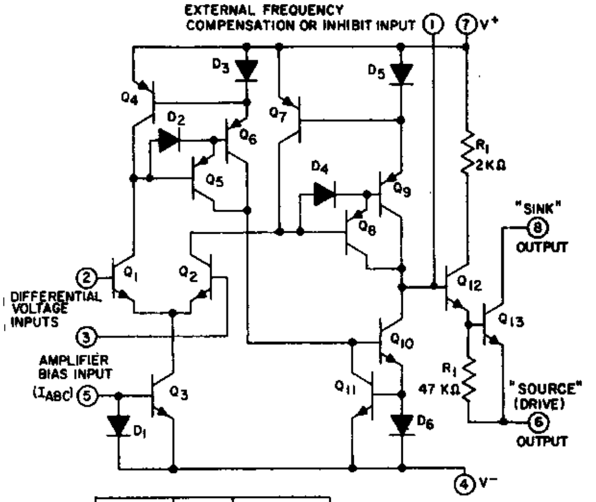
The RCA-CA3094 unique monolithic programmable power switch/amplifier IC consists of a high-gain preamplifier driving a power-output amplifier stage. It can deliver average power of 3 watts or peak power of 10 watts to an external load, and can be operated from either a single or dual power supply. This Note briefly describes the characteristics of the CA3094, and illustrates its use in the following circuit applications:

- Class A instrumentations and power amplifiers
- Class A driver-amplifier for complementary power transistors
- Wide-frequency-range power multivibrators
- Current- or voltage-controlled oscillators
- Comparators (threshold detectors)
- Voltage regulators
- Analog timers (long time delays)
- Alarm systems
- Motor-speed controllers
- Thyristor-firing circuits
- Battery-charger regulator circuits
- Ground-fault-interrupter circuits

## Circuit Description

The CA3094 series of devices offers a unique combination of circuit flexibility and power-handling capability. Although these monolithic IC's dissipate only a few microwatts when quiescent, they have a high current-output capability (100 milliamperes average, 300 milliamperes peak) in the active state, and the premium-grade devices can operate at supply voltages up to 44 volts.

Fig. 1 shows a schematic diagram of the CA3094. The portion of the circuit preceding transistors $Q_{12}$ and $Q_{13}$ is the preamplifier section and is generically similar to that of the RCA-CA3080 Operational Transconductance Amplifier (OTA).[1,2] The CA3094 circuits can be gain-programmed by either digital and/or analog signals applied to a separate Amplifier-Bias-Current ($I_{ABC}$) terminal (No. 5 in Fig. 1) to control circuit sensitivity. Response of the amplifier is essentially linear as a function of the current at terminal 5. This additional signal input "port" provides added flexibility in many applications. Thus, the output of the amplifier is a function of input signals applied differentially at terminals 2 and 3 and/or in a single-ended configuration at terminal 5. The output portion of the monolithic circuit in the CA3094 consists of a Darlington-connected transistor pair with access provided to both the collector and emitter terminals to provide capability to "sink" and/or "source" current.



| OUTPUT MODE | OUTPUT TERM. | INPUTS | |
|---|---|---|---|
| | | INV. | NON-INV. |
| "SOURCE" | 6 | 2 | 3 |
| "SINK" | 8 | 3 | 2 |

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*Fig. 1—CA3094 circuit schematic diagram.*

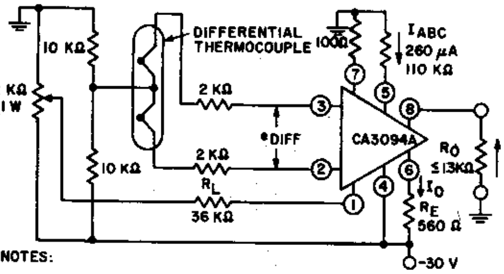
The CA3094 series of circuits consists of six types that differ only in voltage-handling capability and package options, as shown below; other electrical characteristics are identical.

| Package Options | Maximum Voltage Rating |
|---|---|
| CA3094S; CA3094T | 24 V |
| CA3094AS; CA3094AT | 36 V |
| CA3094BS; CA3094BT | 44 V |

The suffix "S" indicates circuits packaged in TO-5 enclosures with leads formed to an 8-lead dual-in-line configuration (0.1" pin spacing). The suffix "T" indicates circuits packaged in 8-lead TO-5 enclosures with straight leads. The generic CA3094 type designation is used throughout this Note.

### Class A Instrumentation Amplifiers

One of the more difficult instrumentation problems frequently encountered is the conversion of a differential input signal to a single-ended output signal. Although this conversion can be accomplished in a straightforward design through the use of classical op-amps, the stringent matching requirements of resistor ratios in feedback networks make the conversion particularly difficult from a practical standpoint. Because the gain of the preamplifier section in the CA3094 can be defined as the product of the transconductance and the load resistance ($g_m R_L$), feedback is not needed to obtain predictable open-loop gain performance. Fig. 2 shows the CA3094 in this basic type of circuit.



NOTES:

PRE-AMP. GAIN ($A_V$) = $g_m R_L$ = (5) ($10^{-3}$) (36) ($10^3$) = 180 (OUTPUT AT TERMINAL 1)

FOR LINEAR OPERATION: DIFFERENTIAL INPUT $\leq |\pm 26 \text{ mV}|$ (WITH APPROX. 1% DEVIATION FROM LINEARITY)

OUTPUT VOLTAGE ($E_O$) = $A_V$ ($\pm e_{diff}$) = (180)(±26 mV) = ± 4.7 V

OUTPUT CURRENT, $I_O \approx \frac{4.7 \text{ V}}{560\ \Omega} = 8.35$ mA

$$I_O \approx \frac{(g_m R_L)(e_{diff})}{R_E}$$

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*Fig.2—Open-loop instrumentation amplifier with differential input and single-ended output.*

The gain of the preamplifier section (to terminal No. 1) is $g_m R_L = (5 \times 10^{-3})(36 \times 10^3) = 180$. The transconductance $g_m$ is a function of the current into terminal No. 5, $I_{ABC}$, the amplifier-bias-current. In this circuit an $I_{ABC}$ of 260 microamperes results in a $g_m$ of 5 millimhos. The operating point of the output stage is controlled by the 2-kilohm potentiometer. With no differential input signal ($e_{diff} = 0$), this potentiometer is adjusted to obtain a quiescent output current $I_O$ of 12 milliamperes. This output current is established by the 560-ohm emitter resistor, $R_E$, as follows:

$$I_O \approx \frac{(g_m R_L)(e_{diff})}{R_E}$$

Under the conditions described, an input swing $e_{diff}$ of ±26 millivolts produces a variation in the output current $I_O$ of ±8.35 milliamperes. The nominal quiescent output voltage is 12 milliamperes times 560 ohms or 6.7 volts. This output level drifts approximately –4 millivolts, or –0.0595 per cent, for each °C change in temperature. Output drift is caused by temperature-induced variations in the base-emitter voltage of the two output transistors, $Q_{12}$ and $Q_{13}$.

Fig. 3 shows the CA3094 used in conjunction with a resistive-bridge input network; and Fig. 4 shows a single-supply amplifier for thermocouple signals. The RC networks* connected between terminals 1 and 4 in Figs. 3 and 4 provide compensation to assure stable operation.

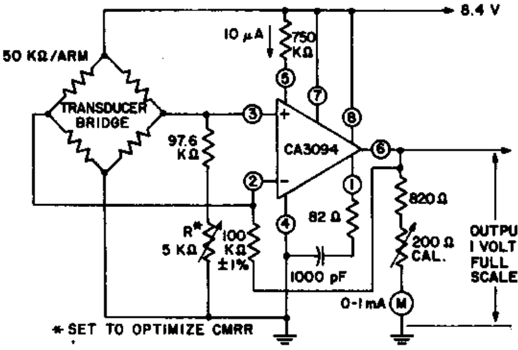

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*Fig.3—Single-supply differential-bridge amplifier.*

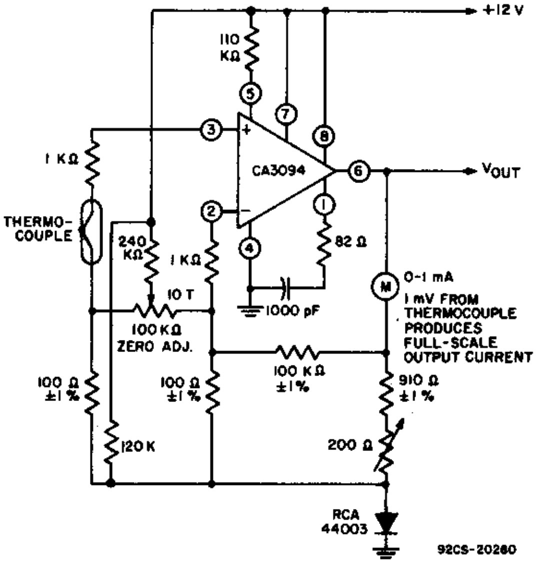

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*Fig.4—Single-supply amplifier for thermocouple signals.*

### Class A Power Amplifiers

The CA3094 is attractive for power-amplifier service because the output transistor can control current up to 100 milliamperes (300 milliamperes peak), the premium devices

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*The components of the RC network are chosen so that $\frac{1}{2\pi RC} \approx 2$ MHz.

(CA3094B) can operate at supply voltages up to 44 volts, and the TO-5 package can dissipate power up to 1.6 watts when equipped with a suitable heat sink that limits the case temperature to 55°C.

Fig. 5 shows a Class A amplifier circuit using the CA3094A that is capable of delivering 280 milliwatts to a 350-ohm resistive load. This circuit has a voltage gain of 60 dB and a 3-dB bandwidth of about 50 kHz. Operation is stable without the use of a phase-compensation network. Potentiometer R is used to establish the quiescent operating point for class A operation.

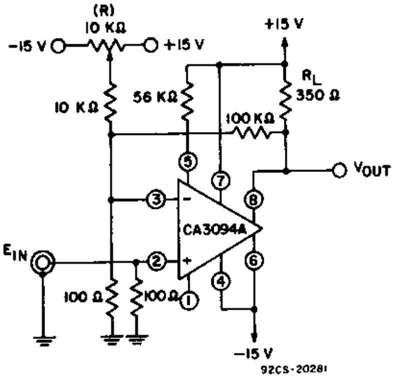
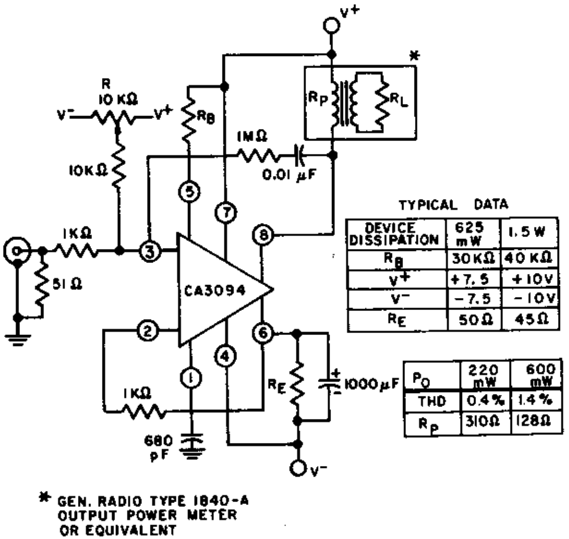


*Fig.5–Class-A amplifier – 280-mW capability into a resistive load.*

The circuit of Fig. 6 illustrates the use of the CA3094 in a class A power-amplifier circuit driving a transformer-coupled load. With dual power supplies of +7.5 volts and −7.5 volts, a base resistor $R_B$ of 30 kilohms, and an emitter resistor $R_E$ of 50 ohms, CA3094 dissipation is typically 625 milliwatts. With supplies of +10 volts and −10 volts, $R_B$ of 40 kilohms, and $R_E$ of 45 ohms, the dissipation is 1.5 watts. Total harmonic distortion is 0.4 per cent at a power-output level of 220 milliwatts with a reflected load resistance $R_P$ of 310 ohms, and is 1.4 per cent for an output of 600 milliwatts with an $R_P$ of 128 ohms. The setting of potentiometer R establishes the quiescent operating point for class A operation. The 1-kilohm resistor connected between terminals 6 and 2 provides dc feedback to stabilize the collector current of the output transistor. The ac gain is established by the ratio of the 1-megohm resistor connected between terminals 8 and 3 and the 1-kilohm resistor connected to terminal 3. Phase compensation is provided by the 680-picofarad capacitor connected to terminal 1.



TYPICAL DATA

| DEVICE DISSIPATION | 625 mW | 1.5 W |
|---|---|---|
| $R_B$ | 30 KΩ | 40 KΩ |
| $V^+$ | +7.5 | +10V |
| $V^-$ | −7.5 | −10V |
| $R_E$ | 50 Ω | 45 Ω |

| $P_O$ | 220 mW | 600 mW |
|---|---|---|
| THD | 0.4% | 1.4% |
| $R_P$ | 310Ω | 128Ω |

* GEN. RADIO TYPE 1840-A OUTPUT POWER METER OR EQUIVALENT

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*Fig.6–Class-A amplifier with transformer-coupled load.*

### Class A Driver-Amplifier for Complementary Power Transistors

The CA3094 configuration and characteristics are ideal for driving complementary power-output transistors;[3] a typical circuit is shown in Fig. 7. This circuit can provide 12 watts of audio power output into an 8-ohm load with intermodulation distortion (IMD) of 0.2 per cent when 60-Hz and 2-kHz signals are mixed in a 4:1 ratio. Intermodulation distortion is shown as a function of power output in Fig. 8.

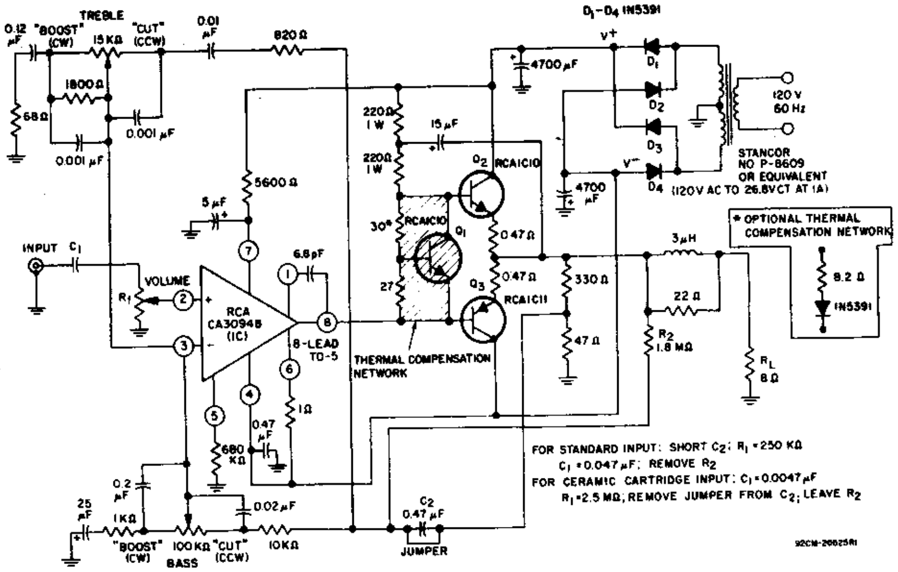
The large amount of loop gain and the flexibility of feedback arrangements with the CA3094 make it possible to incorporate the tone controls into a feedback network that is closed around the entire amplifier system. The tone controls in the circuit of Fig. 7 are part of the feedback network connected from the amplifier output (junction of the 330- and 47-ohm resistors driven by the emitters of $Q_2$ and $Q_3$) to terminal 3 of the CA3094. Fig. 9 shows voltage gain as a function of frequency with tone controls adjusted for "flat" response and for responses at the extremes of tone-control rotation. The use of tone controls incorporated in the feedback network results in excellent signal-to-noise ratio. Hum and noise are typically 700 microvolts (83 dB down) at the output.

In addition to the savings resulting from reduced parts count and circuit size, the use of the CA3094 leads to further savings in the power-supply system. Typical values of power-supply rejection and common-mode rejection are 90 dB and 100 dB, respectively. An amplifier with 40-dB gain and 90-dB power-supply rejection would require a 31-millivolt power-supply ripple to produce one millivolt of hum at the output. Therefore, no filtering is required other than that provided by the energy-storage capacitors at the output of the rectifier system shown in Fig. 7.

For applications in which the operating temperature range is limited (e.g., consumer service) the thermal compensation network (shaded area) can be replaced by a more economical configuration consisting of a resistor-diode combination (8.2 ohms and 1N5391) as shown in Fig. 7.

### Power Multivibrators (Astable and Monostable)

The CA3094 is suitable for use in power multivibrators because its high-current output transistor can drive low-impedance circuits while the input circuitry and the frequency-determining elements are operating at micropower levels. A typical example of an astable multivibrator using the CA3094 with a



FOR STANDARD INPUT: SHORT $C_2$; $R_1$ = 250 KΩ
$C_1$ = 0.047 µF; REMOVE $R_2$
FOR CERAMIC CARTRIDGE INPUT: $C_1$ = 0.0047 µF
$R_1$ = 2.5 MΩ; REMOVE JUMPER FROM $C_2$; LEAVE $R_2$

**For 12-W Audio Amplifier Circuit**

| | | |
|---|---|---|
| Power Output (8Ω load, Tone Control set at "Flat") | | |
| Music (at 5% THD, regulated supply) | 15 | W |
| Continuous (at 0.2% IMD, 60 Hz & 2 kHz mixed in a 4:1 ratio, unregulated supply) See Fig. 8 | 12 | W |
| Total Harmonic Distoration | | |
| At 1 W, unregulated supply | 0.05 | % |
| At 12 W, unregulated supply | 0.57 | % |
| Voltage Gain | 40 | dB |
| Hum and Noise (Below continuous Power Output) | 83 | dB |
| Input Resistance | 250 | kΩ |
| Tone Control Range | See Fig. 9 | |

*Fig.7—12-watt amplifier circuit featuring true complementary-symmetry output stage with CA3094 in driver stage.*

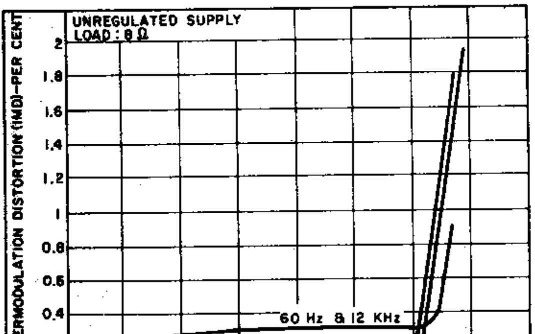


*Fig.8—Intermodulation distortion vs. power output.*

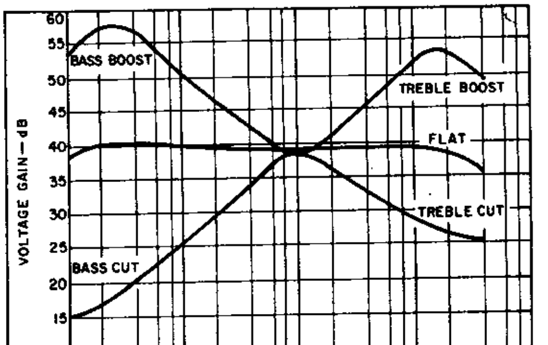


*Fig.9—Voltage gain vs. frequency.*

dual power supply is shown in Fig. 10. The output frequency $f_{OUT}$ is determined as follows:

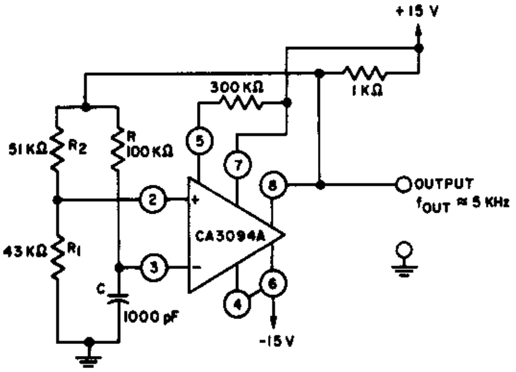
$$f_{OUT} = \frac{1}{2RC\ln[(2R1/R2)+1]}$$

If R2 is equal to 3.08 R1, then $f_{OUT}$ is simply the reciprocal of RC.

Fig. 11 is a single-supply astable multivibrator circuit which illustrates the use of the CA3094 for flashing an incandescent lamp. With the component values shown, this circuit produces one flash per second with a 25-per-cent "on"-time while delivering output current in excess of 100 milliamperes. During the 75-per-cent "off"-time it idles with micropower consumption. The flashing rate can be maintained within ±2 per cent of the nominal value over a battery voltage range from 6 to 15 volts and a temperature excursion from 0 to 70°C. The CA3094 series of circuits can supply peak-power output in excess of 10 watts when used in this type of circuit. The frequency of oscillation $f_{OSC}$ is determined by the resistor ratios, as follows:

$$f_{OSC} = \frac{1}{2RC\ln\left[(2R_1/R_2) + 1\right]}$$

where
$$R1 = \frac{R_A R_B}{R_A + R_B}$$



NOTE: $f_{OUT} = \frac{1}{2RC\ln\left(\frac{2R_1}{R_2} + 1\right)}$; If $R_2 = 3.08 R_1$, $f_{OUT} = \frac{1}{RC}$

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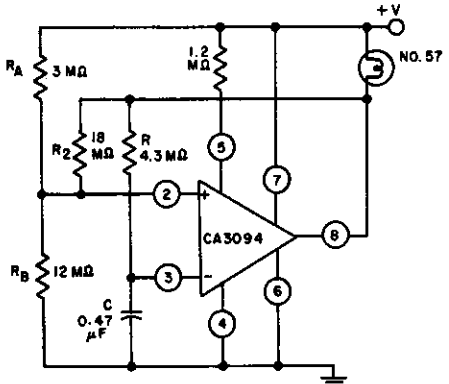
*Fig. 10—Astable multivibrator using dual supply.*



FEATURES

- 1 FLASH/SEC. $f_{OSC} = \frac{*1}{2RC\ln\left[(2R_1/R_2+1)\right]}$ WHERE $R_1 = \frac{R_A R_B}{R_A + R_B}$
- 25 % DUTY CYCLE
- FREQUENCY INDEPENDENT OF $V^+$ FROM 6-15 V DC

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*Fig. 11—Astable multivibrator using single supply.*

Provisions can easily be made in the circuit of Fig. 11 to vary the multivibrator pulse length while maintaining an essentially constant pulse repetition rate. The circuit shown in Fig. 12 incorporates a potentiometer Rp for varying the width of pulses generated by the astable multivibrator to drive a light-emitting diode (LED).

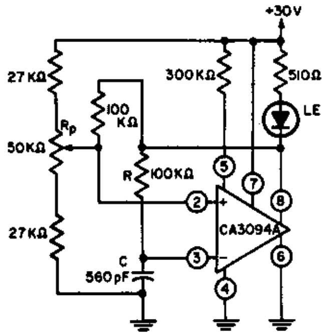

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*Fig. 12—Astable power multivibrator with provisions for varying duty cycle.*

Fig. 13 shows a circuit incorporating independent controls ($R_{ON}$ and $R_{OFF}$) to establish the "on" and "off" periods of the current supplied to the LED. The network between points "A" and "B" is analogous in function to that of the 100-kilohm resistor R in Fig. 12.

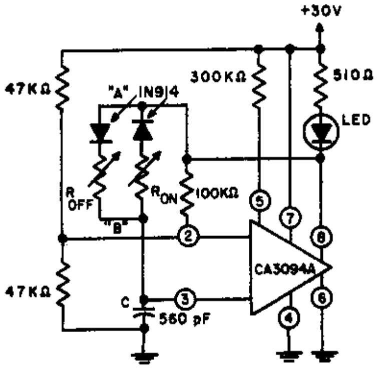

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*Fig. 13—Astable power multivibrator with provisions for independent control of LED "on-off" periods.*

The CA3094 is also suitable for use in monostable multivibrators, as shown in Fig. 14. In essence, this circuit is a pulse counter in which the duration of the output pulses is independent of trigger-pulse duration. The meter reading is a function of the pulse repetition rate which can be monitored with the speaker.

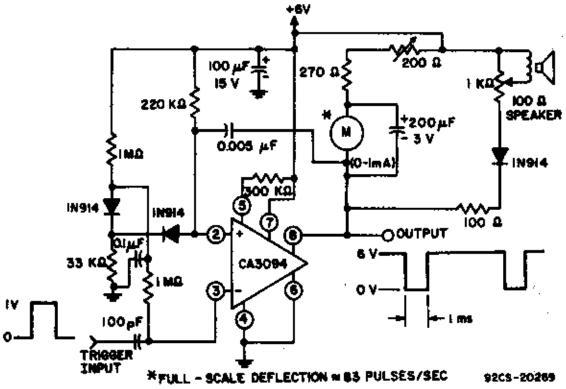

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*Fig. 14—Power monostable multivibrator.*

### Current- or Voltage-Controlled Oscillators

Because the transconductance of the CA3094 varies linearly as a function of the amplifier bias current ($I_{ABC}$) supplied to terminal 5, the design of a current- or voltage-controlled oscillator is straightforward, as shown in Fig. 15. Fig. 16 and 17 show oscillator frequency as a function of $I_{ABC}$ for a current-controlled oscillator for two different values of capacitor C in Fig. 15. The addition of an appropriate resistor (R) in series with terminal 5 in Fig. 15 converts the circuit into a voltage-controlled oscillator. Linearity with respect to either current or voltage control is within 1 per cent over the middle half of the characteristics. However, variation in the symmetry of the output pulses as a function of frequency is an inherent characteristic of the circuit in Fig. 15, and leads to distortion when this circuit is used to drive the phase detector in phase-locked-loop applications. This type of distortion can be eliminated by interposing an appropriate flip-flop between the output of the oscillator and the phase-locked discriminator circuits.

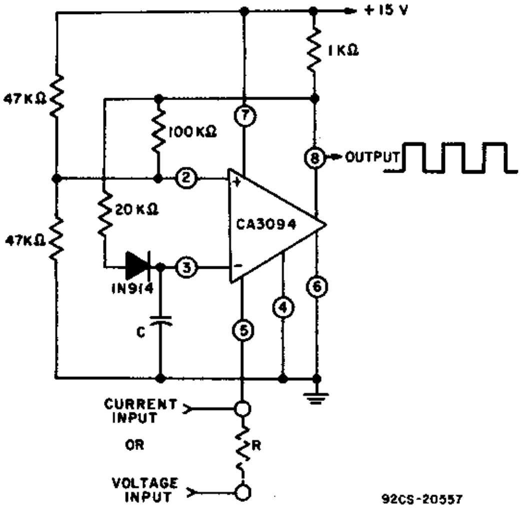

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*Fig. 15—Current- or voltage-controlled oscillator.*

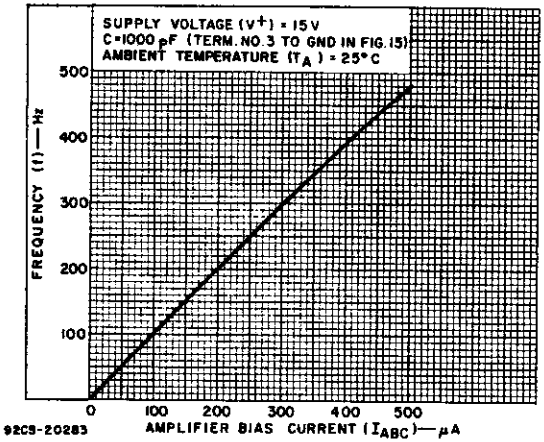

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*Fig. 16—Frequency as a function of $I_{ABC}$ for C=1000 pF for circuit in Fig. 15.*

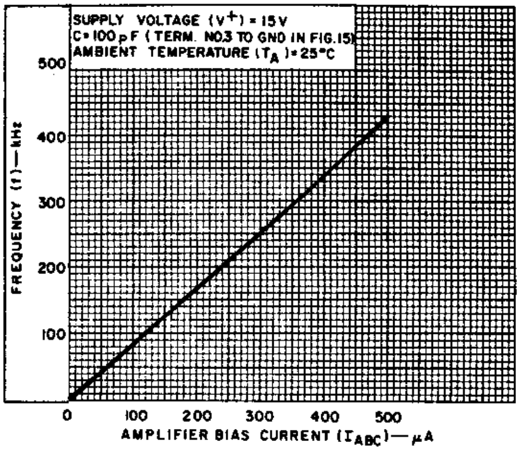

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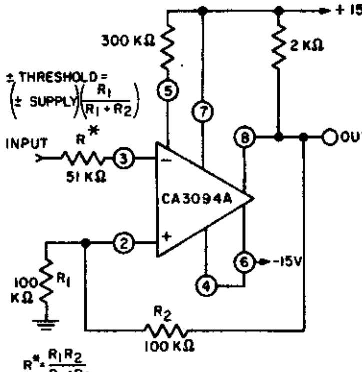
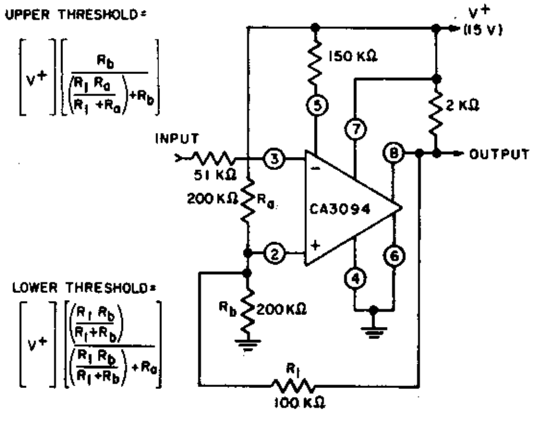
*Fig. 17—Frequency as a function of $I_{ABC}$ for C=100 pF for circuit in Fig. 15.*

### Comparators (Threshold Detectors)

Comparator circuits are easily implemented with the CA3094, as shown by the circuits in Fig. 18. The circuit of Fig. 18(a) is arranged for dual-supply operation; the input voltage exceeds the positive threshold, the output voltage swings essentially to the negative supply-voltage rail (it is assumed that there is negligible resistive loading on the output ter-



(a) DUAL SUPPLY



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(b) SINGLE SUPPLY

*Fig. 18—Comparators (threshold detectors) – dual- and single-supply types.*

minal). An input voltage that exceeds the negative threshold value results in a positive voltage output essentially equal to the positive supply voltage. The circuit in Fig. 18(b), connected for single-supply operation, functions similarly.

Fig. 19 shows a dual-limit threshold detector circuit in which the high-level limit is established by potentiometer R1 and the low-level limit is set by potentiometer R2 to actuate the CA3080 low-limit detector.[1,2] A positive output signal is delivered by the CA3094 whenever the input signal exceeds either the high-limit or the low-limit values established by the appropriate potentiometer settings. This output voltage is approximately 12 volts with the circuit shown.

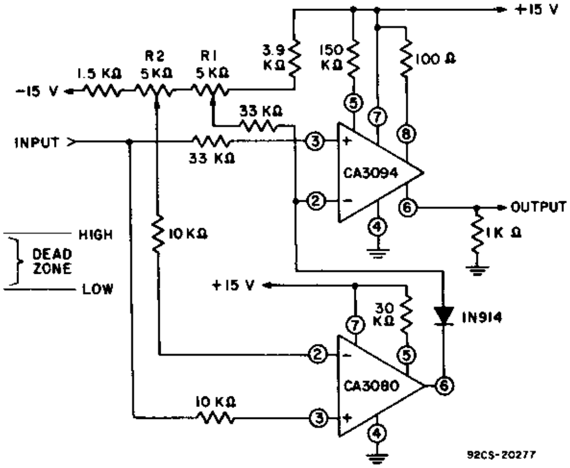


*Fig. 19—Dual-limit threshold detector.*

The high current-handling capability of the CA3094 makes it useful in Schmitt power-trigger circuits such as that shown in Fig. 20. In this circuit, a relay coil is switched whenever the input signal traverses a prescribed upper or lower trip point, as defined by the following expressions:

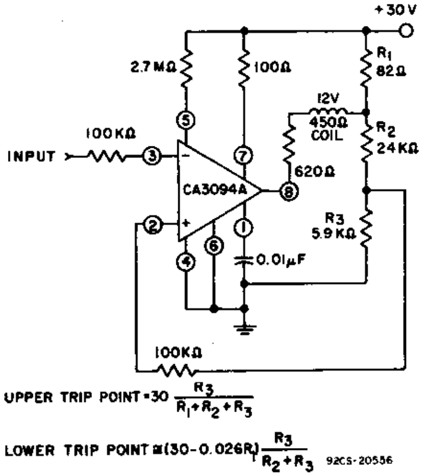


*Fig. 20—Precision Schmitt power-trigger circuit.*

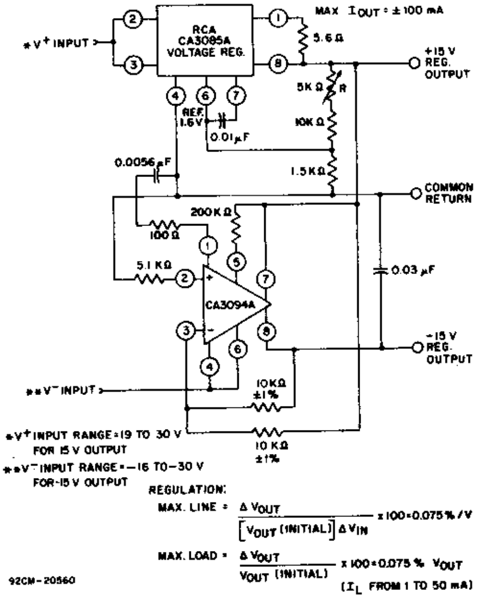
$$\text{Upper Trip Point} = 30 \left(\frac{R3}{R1 + R2 + R3}\right)$$

$$\text{Lower Trip Point} \cong (30 - 0.026R1) \frac{R3}{R2 + R3}$$

The circuit is applicable, for example, to automatic ranging. With the values shown in Fig. 20, the relay coil is energized when the input exceeds approximately 5.9 volts and remains energized until the input signal drops below approximately 5.5 volts.

**Power-Supply Regulators**

The CA3094 is an ideal companion device to the CA3085 series regulator circuits[4] in dual-voltage tracking regulators that handle currents up to 100 milliamperes. In the circuit of Fig. 21, the magnitude of the regulated positive voltage provided by the CA3085A is adjusted by potentiometer R. A sample of this positive regulated voltage supplies the power for the CA3094A negative regulator and also supplies a reference voltage to its terminal 3 to provide tracking. This circuit provides a maximum line regulation equal to 0.075 per cent per volt of input voltage change and a maximum load regulation of 0.075 per cent of the output voltage.



*V+ INPUT RANGE = 19 TO 30 V FOR 15 V OUTPUT

**V- INPUT RANGE = -16 TO -30 V FOR -15 V OUTPUT

REGULATION:

$$\text{MAX. LINE} = \frac{\Delta V_{OUT}}{[V_{OUT}(\text{INITIAL})]\,\Delta V_{IN}} \times 100 = 0.075\%/\text{V}$$

$$\text{MAX. LOAD} = \frac{\Delta V_{OUT}}{V_{OUT}(\text{INITIAL})} \times 100 = 0.075\%\ V_{OUT}$$

($I_L$ FROM 1 TO 50 mA)

*Fig. 21—Dual-voltage tracking regulator.*

Fig. 22 shows a regulated high-voltage supply similar to the type used to supply power for Geiger-Mueller tubes. The CA3094, used as an oscillator, drives a step-up transformer which develops suitable high voltages for rectification in the RCA-44007 diode network. A sample of the regulated output voltage is fed to the CA3080A operational transconductance amplifier through the 198-megohm and 910-kilohm divider to control the pulse repetition rate of the CA3094. Adjustment of potentiometer R determines the magnitude of the regulated output voltage. Regulation of the desired output voltage is maintained within one per cent despite load-current variations of 5 to 26 microamperes. The dc-to-dc conversion efficiency is about 48 per cent.

**Timers**

The programmability feature inherent in the CA3094 (and operational transconductance amplifiers in general) simplifies the design of presettable timers such as the one shown in

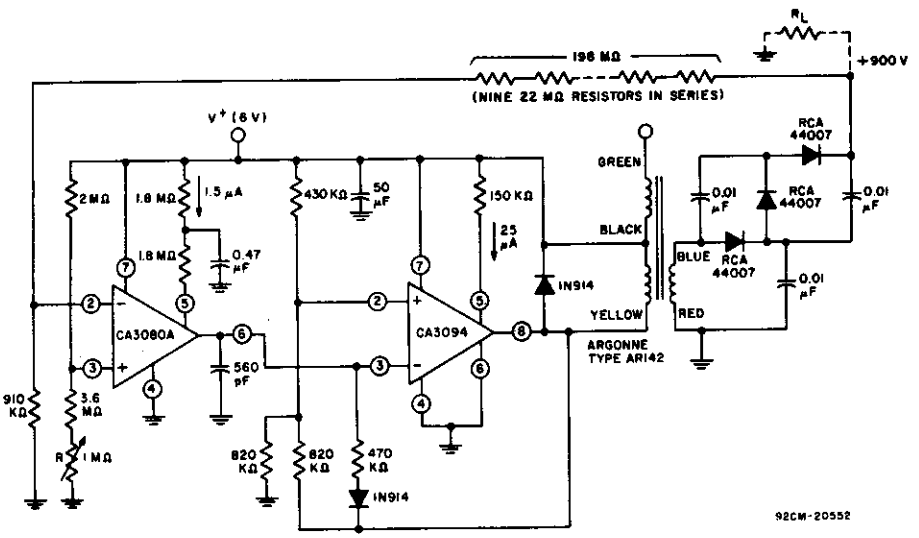


Fig.22—Regulated high-voltage supply.

Fig. 23. Long timing intervals (e.g., up to 4 hours) are achieved by discharging a timing capacitor $C_1$ into the signal-input terminal (e.g., No. 3) of the CA3094. This discharge current is controlled precisely by the magnitude of the amplifier bias current $I_{ABC}$ programmed into terminal 5 through a resistor selected by switch S2. Operation of the circuit is initiated by charging capacitor $C_1$ through the momentary closing of switch $S_1$. Capacitor $C_1$ starts discharging and continues discharging until voltage $E_1$ is less than voltage $E_2$. The differential input transistors in the CA3094 then change state, and terminal 2 draws sufficient current to reverse the polarity of the output voltage (terminal 6). Thus, the CA3094 not only has provision for readily presetting the time delay, but also provides significant output current to drive control devices such as thyristors. Resistor $R_5$ limits the initial charging current for $C_1$. Resistor $R_7$ establishes a minimum voltage of at least 1 volt at terminal 2 to insure operation within the common-mode-input range of the device. The diode limits the maximum differential input voltage to 5 volts. Gross changes in time-range selection are made with switch S2, and vernier trimming adjustments are made with potentiometer $R_6$.

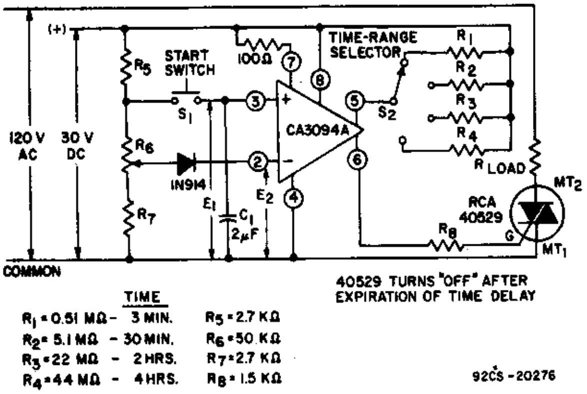


Fig.23—Presettable analog timer.

In some timer applications, such as that shown in Fig. 24, a meter readout of the elapsed time is desirable. This circuit uses the CA3094 and the CA3083 transistor array[5] to control the meter and a load-switching triac. The timing cycle starts with the momentary closing of the start switch to charge capacitor $C_1$ to an initial voltage determined by the 50-kilohm vernier timing adjustment. During the timing cycle, capacitor $C_1$ is discharged by the input bias current at terminal 3, which is a function of the resistor value $R_1$ chosen by the time-range selection switch. During the timing cycle the output of the CA3094, which is also the collector voltage of $Q_1$, is "high". The base drive for $Q_1$ is supplied from the positive supply through a 91-kilohm resistor. The emitter of $Q_1$, through the 75-ohm resistor, supplies gate-trigger current to the triac. Diode-connected transistors $Q_4$ and $Q_5$ are connected so that transistor $Q_1$ acts as a constant-current source to drive the triac. As capacitor $C_1$ discharges, the CA3094 output voltage at terminal 6 decreases until it becomes less than the $V_{CEsat}$ of $Q_1$. At this point the flow of drive current to the triac ceases and the timing cycle is ended. The 20-kilohm resistor between terminals 2 and 6 of the CA3094 is a feedback resistor. Diode-connected transistors $Q_2$ and $Q_3$ and their associated networks serve to compensate for nonlinearities in the discharge-circuit network by bleeding corrective current into the 20-kilohm feedback resistor. Thus, current flow in the meter is essentially linear with respect to the timing period. The time periods as a function of $R_1$ are indicated on the Time-Range Selection Switch in Fig. 24.

### Alarm Circuit

Fig. 25 shows an alarm circuit utilizing two "sensor" lines. In the "no-alarm" state, the potential at terminal 2 is lower than the potential at terminal 3, and terminal 5 ($I_{ABC}$) is driven with sufficient current through resistor $R_5$ to keep the output voltage "high". If either "sensor" line is opened, shorted to ground, or shorted to the other sensor line, the output goes "low" and activates some type of alarm system.

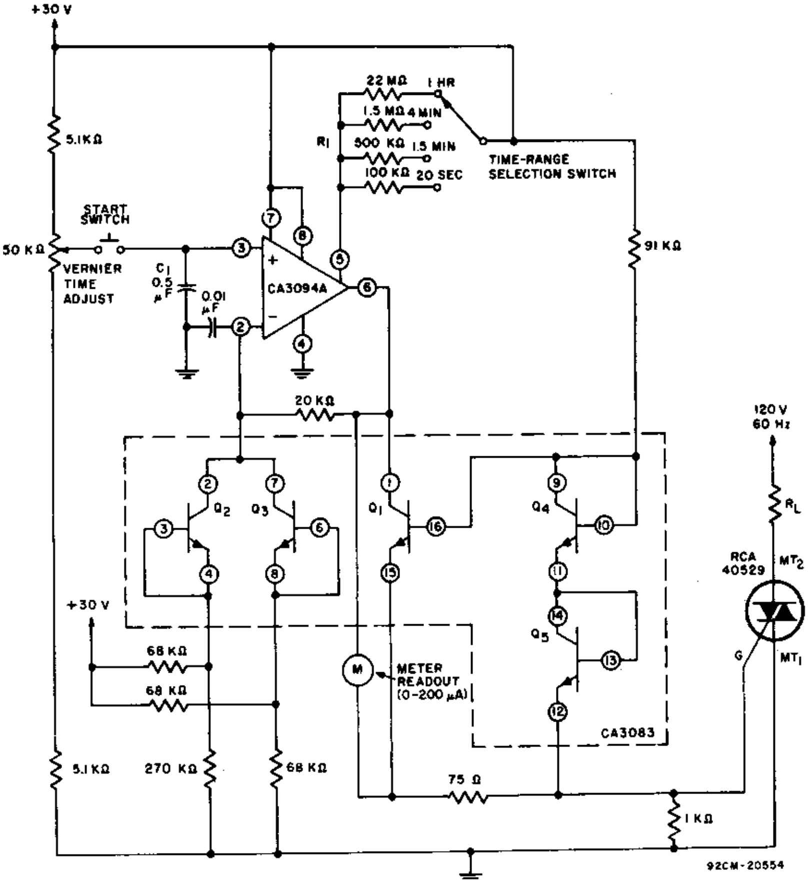


*Fig.24—Presettable timer with linear readout.*

The back-to-back diodes connected between terminals 2 and 3 protect the CA3094 input terminals against excessive differential voltages.

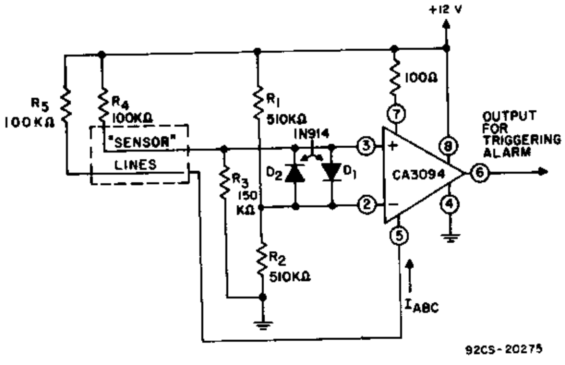


*Fig.25—Alarm system.*

### Motor-Speed Controller System

Fig. 26 illustrates the use of the CA3094 in a motor-speed controller system. Circuitry associated with rectifiers $D_1$ and $D_2$ comprises a full-wave rectifier which develops a train of half-sinusoid voltage pulses to power the dc motor. The motor speed depends on the peak value of the half-sinusoids and the period of time (during each half-cycle) the SCR is conductive.

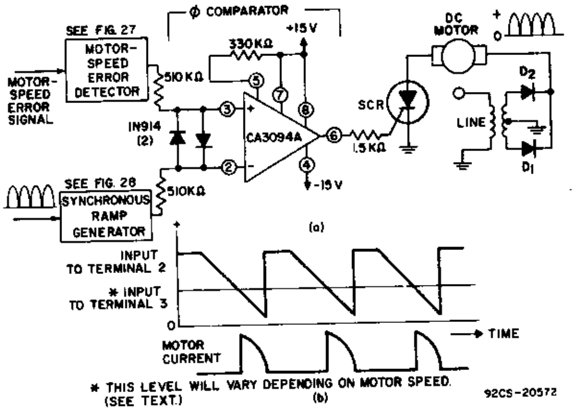


*Fig.26—Motor-speed controller system.*

The SCR conduction, in turn, is controlled by the time duration of the positive signal supplied to the SCR by the phase comparator. The magnitude of the positive dc voltage supplied to terminal 3 of the phase comparator depends on motor-speed error as detected by a circuit such as that shown in Fig. 27. This dc voltage is compared to that of a fixed-amplitude ramp wave generated synchronously with the ac-line-voltage frequency. The comparator output at terminal 6 is "high" (to trigger the SCR into conduction) during the period when the ramp potential is less than that of the error voltage on terminal 3. The motor-current conduction period is increased as the error voltage at terminal 3 is increased in the positive direction. Motor-speed accuracy of ±1 per cent is easily obtained with this system.

**Motor-Speed Error Detector.** Fig. 27(a) shows a motor-speed error detector suitable for use with the circuit of Fig. 26. A CA3080 operational transconductance amplifier is used as a voltage comparator. The reference for the comparator is established by setting the potentiometer R so that the voltage at terminal 3 is more positive than that at terminal 2 when the motor speed is too low. An error voltage $E_1$ is derived from a tachometer driven by the motor. When the motor speed is too low, the voltage at terminal 2 of the voltage comparator is less positive than that at terminal 3, and the output voltage at terminal 6 goes "high". When the motor speed is too high, the opposite input conditions exist, and the output voltage at terminal 6 goes "low". Fig. 27(b) also shows these conditions graphically, with a linear transition region between the "high" and "low" output levels. This linear transition region is known as "proportional bandwidth". The slope of this region is determined by the proportional bandwidth control to establish the error-correction response time.

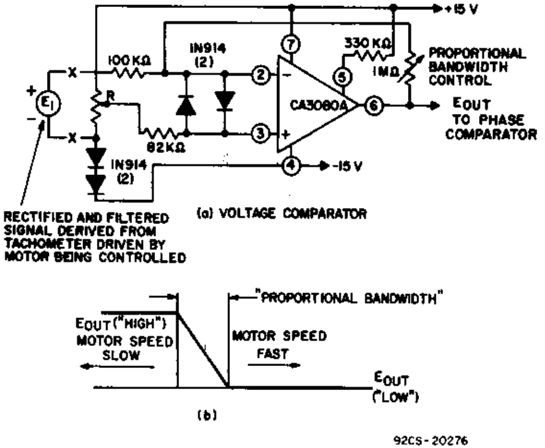


*Fig. 27—Motor speed error detector.*

**Synchronous Ramp Generator.** Fig. 28 shows a schematic diagram and signal waveforms for a synchronous ramp generator suitable for use with the motor-controller circuit of Fig. 26. Terminal 3 is biased at approximately +2.7 volts (above the negative supply voltage). The input signal $E_{IN}$ at terminal 2 is a sample of the half-sinusoids (at line frequency) used to power the motor in Fig. 26. A synchronous ramp signal is produced by using the CA3094 to charge and discharge capacitor $C_1$ in response to the synchronous toggling of $E_{IN}$. The charging current for $C_1$ is supplied by terminal 6. When terminal 2 swings more positive than terminal 3, transistors $Q_{12}$ and $Q_{13}$ in the CA3094 (Fig. 1) lose their base drive and become non-conductive. Under these conditions, $C_1$ discharges linearly through the external diode $D_3$ and the $Q_{10}$, $D_6$ path in the CA3094 to produce the ramp wave. The $E_{out}$ signal is supplied to the phase comparator in Fig. 26.

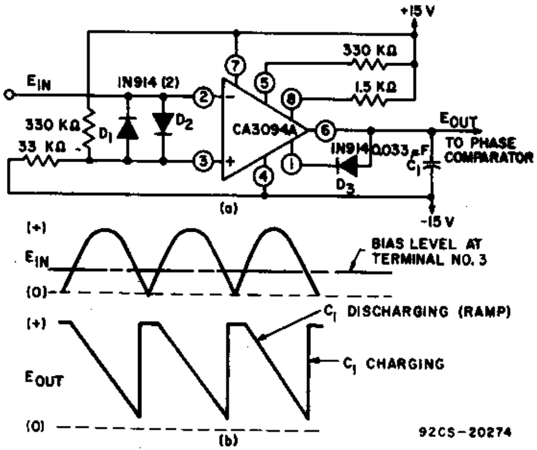


*Fig.28—Synchronous ramp generator with input and output waveforms.*

## Thyristor Firing Circuits

**Temperature Controller.** In the temperature control system shown in Fig. 29, the differential input of the CA3094 is connected across a bridge circuit comprised of a PTC (positive-temperature-coefficient) temperature sensor, two 75-kilohm resistors, and an arm containing the temperature set control. When the temperature is "low", the resistance of the PTC-type sensor is also low; therefore, terminal 3 is more positive than terminal 2 and an output current from terminal 6 of the CA3094 drives the triac into conduction. When the temperature is "high", the input conditions are reversed and the triac is cut off. Feedback from terminal 8 provides hysteresis to the control point to prevent rapid cycling of the system. The 1.5-kilohm resistor between terminal 8 and the positive supply limits the triac gate current and develops the voltage for the hysteresis feedback. The excellent power-supply-rejection and common-mode-rejection ratios of the CA3094 permit accurate repeatability of control despite appreciable power-supply ripple. The circuit of Fig. 29 is equally suitable for use with NTC (negative-temperature-coefficient) sensors provided the positions of the sensor and the associated resistor R are interchanged in the circuit. The diodes connected back-to-back across the input terminals of the CA3094 protect the device against excessive differential input signals.

**Thyristor Control from AC-Bridge Sensor.** Fig. 30 shows a line-operated thyristor-firing circuit controlled by a CA3094 that operates from an ac-bridge sensor. This circuit is particularly suited to certain classes of sensors that cannot be operated from dc. The CA3094 is inoperative when the high side of the ac line is negative because there is no $I_{ABC}$ supply to terminal 5. When the sensor bridge is unbalanced so that terminal 2 is more positive than terminal 3, the output stage of the CA3094 is cut off when the ac line swings positive, and the output level at terminal 8 of the CA3094 goes "high". Current from the line flows through the 1N3193 diode to charge the 100-microfarad reservoir capacitor, and also provides current to drive the triac into conduction. During the succeeding negative swing of the ac line, there is sufficient remanent energy in the reservoir capacitor to maintain conduction in the triac.

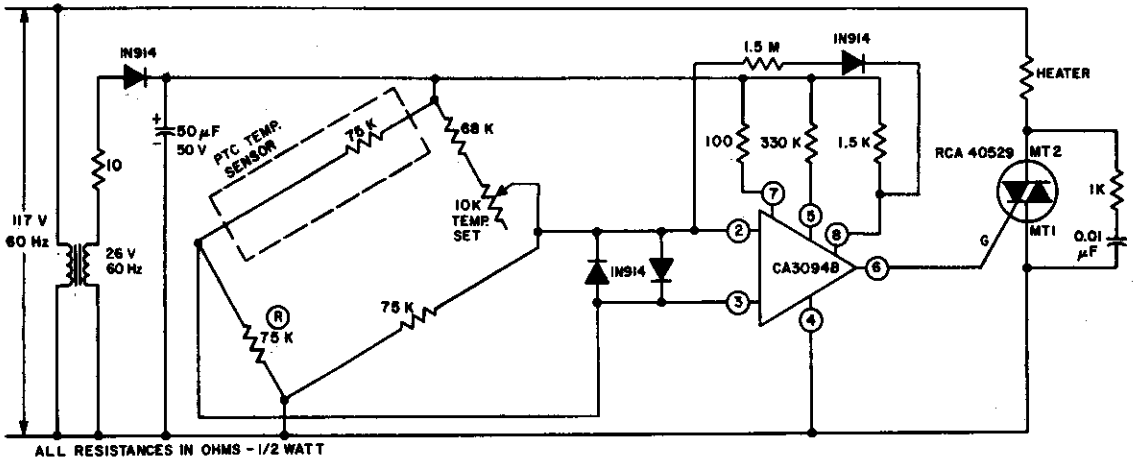


*Fig.29—Temperature controller.*

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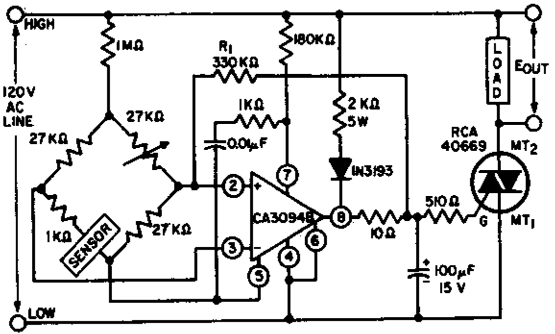

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*Fig.30—Line-operated thyristor-firing circuit controlled by ac-bridge sensor.*

When the bridge is unbalanced in the opposite direction so that terminal 3 is more positive than terminal 2, the output of the CA3094 at terminal 8 is driven sufficiently "low" to "sink" the current supplied through the 1N3193 diode so that the triac gate cannot be triggered. Resistor $R_1$ supplies the hysteresis feedback to prevent rapid cycling between turn-on and turn-off.

### Battery-Charger Regulator Circuit

The circuit for a battery-charger regulator circuit using the CA3094 is shown in Fig. 31. This circuit accurately limits the peak output voltage to 14 volts, as established by the zener diode connected across terminals 3 and 4. When the output voltage rises slightly above 14 volts, signal feedback through a 100-kilohm resistor to terminal 2 reduces the current drive supplied to the 2N3054 pass transistor from terminal 6 of the CA3094. An incandescent lamp serves as the indicator of charging-current flow. Adequate limiting provisions protect the circuit against damage under load-short conditions. The advantage of this circuit over certain other types of regulator circuits is that the reference voltage supply doesn't drain the battery when the power supply is disconnected. This feature is important in portable service applications, such as in a trailer where a battery is kept "on-charge" when the trailer is parked and power is provided from an ac line.

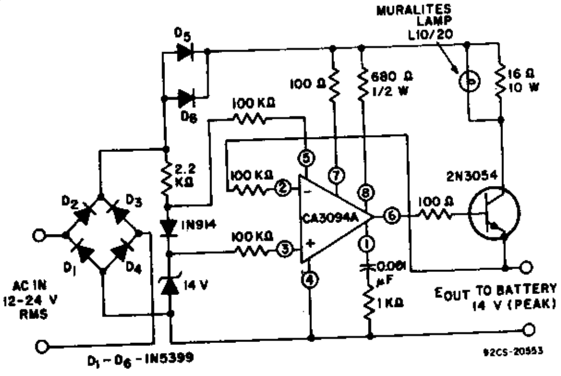

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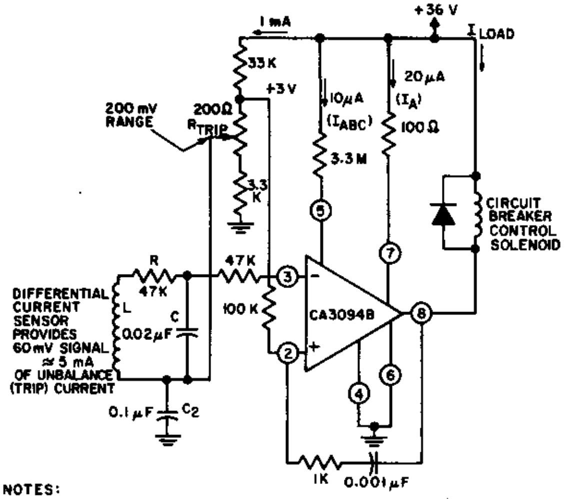
*Fig.31—Battery-charger regulator circuit.*

### Ground-Fault Interrupters (GFI)

Ground-fault-interrupter systems are used to continuously monitor the balance of current between the high and neutral lines of power-distribution networks. Power is interrupted whenever the unbalance exceeds a preset value (e.g., 5 milliamperes). An unbalance of current can occur when, for example, defective insulation in the high side of the line permits leakage of current to an earth ground. GFI systems can be used to reduce the danger of electrocution from accidental contact with a "high" line because the unbalance caused by the leakage of current from the "high" line through a human body to ground results in an interruption of current flow.

The CA3094 is ideally suited for GFI applications because it can be operated from a single supply, has adequate sensitivity, and can drive a relay or thyristor directly to effect power interruption. Fig. 32 shows a typical GFI circuit. Vernier adjustment of the trip point is made by the $R_{TRIP}$ potentiometer. When the differential current sensor supplies a signal that exceeds the selected trip-point voltage level (e.g., 60 millivolts), the CA3094 is toggled "on" and terminal 8 goes "low" to energize the circuit-breaker trip coil. Under quiescent conditions, the entire circuit consumes approximately 1 milliampere. The resistor R, connected to one leg of the current sensor, provides current limiting to protect the CA3094 against voltage spikes as large as 100 volts. Fig. 32 also shows the pertinent waveform for the GFI circuit.



NOTES:

1. ALL RESISTORS IN OHMS, 1/2 WATT, ±10%
2. RC SELECTED FOR 3db POINT AT 200 Hz
3. $C_2$=AC BY-PASS
4. OFFSET ADJ. INCLUDED IN $R_{TRIP}$
5. INPUT IMPEDANCE FROM 2 TO 3 EQUALS 800 K.
6. WITH NO INPUT SIGNAL TERMINAL 8 (OUTPUT) AT +36 VOLTS

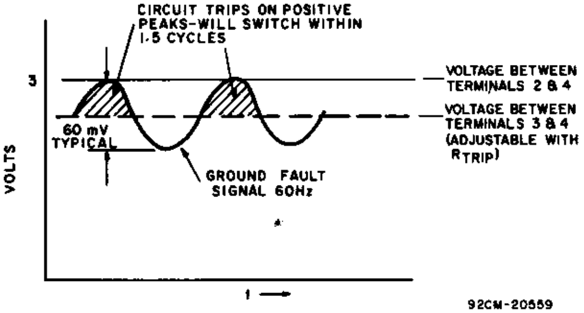


*Fig.32–Ground fault interrupter (GFI) and waveform pertinent to ground fault detector.*

Because hazards of severe electrical shock are a potential danger to the individual user in the event of malfunctions in GFI apparatus, it is mandatory that the highest standards of good engineering practice be employed in designing equipment for this service. Every consideration in design and application must be given to the potentially serious consequences of component malfunction in such equipment. Use of "reliability-through-redundancy" concepts and so-called "fail-safe" features is encouraged.

## Acknowledgments

The authors thank A. Sheng and R. Baird for their assistance in designing some of the circuits described in this Note.

## References

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2. Applications of the CA3080 and CA3080A High Performance Operational Transconductance Amplifiers, RCA Application Note ICAN-6668.
3. L. Kaplan and H. A. Wittlinger, "An IC Operational-Transconductance-Amplifier (OTA) with Power Capability". Paper originally presented at the IEEE Chicago Spring Conference on Broadcast and TV Receivers, June 1972. Reprinted by the RCA Solid State Division as Publication No. ST-6077.
4. RCA Published Data for CA3085, File No. 491.
5. RCA Published Data for CA3083, File No. 481.