Flame detector
A flame offers a low conductance path to ground. In series with \( R_1 \) and \( R_2 \), that conductance defines a range of potentials on the gate of \( \text{Tr}_1 \), that leaves the emitter of \( \text{Tr}_2 \) at a high enough potential to keep \( \text{D}_1 \) out of conduction, but not so high as to bring \( \text{Tr}_4 \) into conduction via \( R_7 \). Hence \( \text{Tr}_6 \). \( \text{Tr}_5 \) conduct holding on the relay—interlocked with the supply for fail-safe operation. If the flame is extinguished \( \text{Tr}_1 \) gate goes high, driving \( \text{Tr}_2 \) and \( \text{Tr}_3 \), reducing the base potential of \( \text{Tr}_1 \) and cutting of \( \text{Tr}_2 \) and hence the output.

The mid-section of the circuit offers a window action with the relay being held on for a restricted range of flame resistances, higher and lower values giving drop-out. The resistance is high requiring a high input resistance buffer; the output is

Smoke detector
When detecting the interruption of light by smoke, to avoid the effects of ambient illumination etc., the light beam may be chopped at source and the resulting a.c. from \( \text{Tr}_1 \) (see over) used via buffer \( \text{Tr}_4 \) to trigger the monostable circuit around \( \text{Tr}_3 \), \( \text{Tr}_4 \). This prevents the potential applied to \( R_{15} \) from rising sufficiently to fire the thyristor. If the load is a horn having an interrupter switch in series with its coil, the thyristor can cease conduction on removal of the gate drive (alternatively a.c. drive to the load would be required).
Wireless World Circard  
Series 13:  
Alarm Circuits—3

Time delay and generator circuits

Circuit description
An IC, such as the 555, with internal comparators driving a set-reset flip-flop offers great flexibility in the design of alarm systems. With pin 2 high, the capacitor is held low via pin 7. A negative-going edge on 2 allows R1 to charge C1 until the potential on 6 passes 2VCC/3, when the original state is restored.

- Linking the inputs of the two comparators (2 and 6) to the discharge path (7) causes the potential at the common point to cycle between VCC/3 and 2VCC/3, set by an internal potential divider. For both circuits the output has switching characteristics comparable to a T.T.L. gate because of a similar poten-pole output stage. An audible alarm is available by connecting a loudspeaker (3-25Ω) between VCC and pin 3. If VCC is +5V, the on/off condition of the alarm may be controlled by driving pin 4 from the output of a T.T.L. gate.

- An astable can also be constructed by feedback from the output to the paralleled comparator inputs. When the output is high, C1 is charged positively through R1 until the upper threshold is passed; the output switches low and C1 is discharged until the trigger value set by pin 2 is passed. Timing is set by the less well-defined output amplitude, and the frequency is less stable than the basic circuit. Addition of R6 varies mark-space ratio.

- If the reset terminal 4 is coupled to an RC network as shown, then a time-delay can be introduced at switch-on, before which firing of the circuit as a monostable can be achieved.

Wireless World Circard  
Series 13:  
Alarm Circuits—2

Bridge circuits

Components
ICs: 741, VCC ±15V
R1 to R4: 10kΩ, R5: 1MΩ
Bridge voltage: 1.5V (Fig. 2)

Circuit description
Three bridge configurations are shown. In each case the bridge is composed of four resistors, R1 to R4, and the circuits are basically Wheatstone bridges with balance occurring for R1/R2 = R3/R4. Substitution of impedances Z1 to Z4 would leave the balance requirements unchanged, and other variants such as the Wien bridge can be produced. For resistive elements it may be possible to supply the bridge and amplifier from a common d.c. supply and a high-gain op-amp protects the potentiometer from balance. A small amount of positive feedback via R4 helps reduce jitter in the output when close to balance, but gives hysteresis to the balance sensing.

- If a separate supply is required for the bridge, one bridge balance point may be grounded, removing the need for high common-mode rejection for the amplifier. The errors in all these circuits include voltage offset of the amplifier, 1-5mV for untrimmed general-purpose op-amps, and input currents/offset, 10nA to 1μA for conditions as before. For balance detection to within 0.1% this implies bridge voltages in excess of 1V and currents of up to 1mA.

- By opening the bridge and embedding the amplifier in the network as shown, balance is achieved for the same relationship between the resistances, but with input and output both with respect to ground. This circuit has no output that is a linear function of the departure of R4 from the balance condition (R1, R2, R4 assumed constant as reference resistors). For d.c. applications the input may be one or other of the supply voltages. In all cases best sensitivity is achieved for R3/R4→1. If the resistor whose value is being sensed has to have a low resistance, power wastage is avoided by keeping the other pairs of resistances high.

- Another method of achieving input and output as ground-referred signals, is to use an amplifier with push-pull outputs and single-ended input. A simple case is the single transistor as shown where the power supply, if properly bypassed, closes the bridge when used for a.c. measurement/sensing.
A monostable using c.m.o.s. inverters can use very high-value resistors, giving time delays of >1s with capacitors of <1μF. As shown, a short-duration excursion of the input from + to ground sets the output to zero for the monostable period (about 3s) because the output of the first inverter is high, as is the input of the second until R₄ can pull the gate down by charging C₃. The high impedance makes such monostables useful as touch-operated circuits.

A related astable circuit shows an additional resistor R₄, which isolates C₃ from the rapid charge/discharge imposed by the gate protection diodes in both these circuits. The resistor improves the timing stability.

The output stage of an astable/monostable circuit is important where high voltage/current/power is required. For the 555 timer, the output stage is similar to the typical t.t.l. output (as shown above) but with a Darlington-connected top section. The positive output is thus at least 1V below supply while the low output can be to within 0.1V of ground at low currents. Above 50mA the voltage drops may reach 2V and 1V respectively.

For some applications the open-collector output of t.t.l. devices such as SN7401 gives convenient driving of loads, while other devices such as SN7406 will withstand collector-emitter voltages of up to 30V.

Further reading

Cross references
Series 3, card 9.
Series 13, card 5.

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The example shown would pass all frequencies except the notch frequency defined by 1/RC, though with appreciable attenuation near the notch.

For many purposes, the availability of a centre-tapped supply provides a "phantom-bridge" action. If the ratio of positive to negative supplies remains constant then taking one input of the sense amplifier to the centre-tap leaves only a half-bridge externally. Used for example with photodiodes, the output voltage is proportional to the unbalance currents in the diodes i.e. to the degree of unbalance in the illumination of the diodes. Because the diodes act as constant-current devices the circuit is much more tolerant of drift in the centre-tap than for purely resistive elements. The negative feedback gives a linear output-unbalance characteristic. Reversal of the amplifier input terminals would give positive feedback, introducing a switching action and hysteresis as in the first diagram.

Some i.c.s have internal potential dividers which can effectively form part of a bridge. The 555 timer, for example, has its two comparators tapped at ⅓ and ⅔ of the supply voltage via a resistor chain with very good stability to the ratio of their values; the absolute values are not important for such an application. The lower-threshold detector ("trigger") when held high prevents any output change (input 1 is assumed high) regardless of the status of the reset terminal. The reset terminal regains control only when the trigger input falls below the level accurately defined by the potential divider. With the trigger taken from an external potential divider containing the required sensing element the bridge—balance sensing can be obtained.

Further reading

Cross references
Series 1, cards 9 & 10, series 9, cards 1 & 11.
Series 13, cards 1 & 3.

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Wireless World Circard Series 13: Alarm Circuits—4

Level sensing and load driving

![Circuit diagram]

**Circuit description**
The basic level-sensing circuits shown may be used with or without positive feedback, to obtain an output change as the input passes a defined level or levels. For $R_2 \rightarrow \infty$, $R_1 \rightarrow 0$, amplifier gain determines the range of input voltages for which the output is not switched hard to one or other extreme. (Typically 1 to 20mV for comparators, required to operate at high speeds: 0.1 to 5mV for op-amps where accuracy of level-sensing makes their slower operation an acceptable penalty.)

Hysteresis introduced by positive feedback allows the circuit to latch into a final state after the first excursion through a given level, provided the input cannot reverse its sense sufficiently to pass back through the other switching level.

These circuits can thus perform the combined functions of level-sensing and set-reset action required in many alarms if for example the signal is a positive-going voltage initiating the set action, while the reset action is a negative-going pulse over-riding the former e.g. a resistor taken from the non-inverting input to the negative rail.

![Circuit diagram]

**Applications of 555 timer**

![Circuit diagram]

**Circuit description**
The 555, designed as a timing circuit with either monostable or astable operation, has internal circuit functions that allow it to be used for many other purposes. In alarm systems, the power output stage that permits currents of either polarity of up to 200mA (though 50mA minimizes voltage losses) means that lamps and relays can be driven quite readily.

When used as an astable circuit the output square wave can be applied to a loudspeaker to give an audible alarm, while a voltage fed to the control terminal modulates the frequency for warble or two-tone effects. As a monostable circuit it can be used to provide delays from microseconds to minutes, allowing, for example, a warning alarm to be held for a defined period of time after the appearance of the condition being detected. In such cases the condition (closure of a switch in a burglar alarm for example) is converted into a negative-going pulse, applied to the trigger input. A further application for the device involves the controlled hysteresis provided by the two comparators biased from an internal potential divider. With $V_1 > V_{ref}$, the output is driven negative via the flip-flop which ignores any further excursions of $V_1$ about $V_{ref}$ in either sense. When $V_1$ falls below $V_{ref}$, the flip-flop is reset, the output going positive. In the astable circuit $V_1 = V_2$, $V_{ref} = 2V_1/3$, $V_{ref} = V_1/3$ and the capacitor is charged and discharged between $V_1/3$ and $2V_1/3$.

**Typical performance**

IC: NE555V (Signetics), $V_1 = 10V$

$R_1: 2.2k\Omega$, $R_2: 10k\Omega$

$k = 0.6$, $D_1: 5.6-V$ Zener diode

Upper set point: $5.7V$ ($V_2$)

Lower set point: $4.75V$ ($V_1/2k$)

Output swing: $9V$ for $R_1 \approx 250\Omega$

If $R_1$, $D_1$ omitted, $V_{ref} = 2V$, $V_{ref} = V$ and set points become $2V$ and $V/k$. 

**Table 1**

<table>
<thead>
<tr>
<th>IC</th>
<th>$V_1$</th>
<th>$V_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE555V</td>
<td>10V</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1**

- An adaptation of the output stage shown in Fig. 5 gives an output when the p.d. across either $R_1$ or $R_2$ exceeds about 0.6V. In the former case this corresponds to a positive input voltage defining sufficient positive supply current via $R_4$ i.e. $V_1/R_1/R_3 \approx 0.6V$. Similarly a negative input voltage switches the output via $T_3$. The switching action is not particularly sharp as it uses only the gains of the transistors.

- A standard window comparator gives sharper switching but requires two amplifiers/comparators and still requires an additional transistor is an output swing comparable to supply voltage is required e.g. for efficient switching of lamps relays etc., particularly at higher currents.
A previously-described output stage (series 2) gives push-pull drive using one op-amp as driver. Resistors $R_1$, $R_2$ are selected to keep $T_{r1}$, $T_{r2}$ out of conduction in quiescent state. The op-amp is used in any of the sensing/oscillating modes that result in p.d.s across $R_3$ sufficient to drive $T_{r1}$, $T_{r2}$ into conduction. Either may be used alone for driving lamps, relays, or the circuit as shown may be capacitively coupled to a loudspeaker for a.c. power drive.

- An output stage using a bridge configuration requires antiphase switching at the inputs, but gives a load voltage whose peak-peak value is twice the supply voltage. This is equally applicable to audio alarms or to driving of servo systems for which it was designed.

- Complementary m.o.s. buffers may be used to drive complementary output transistors as shown and with the aid of an additional inverter a similar stage provides a bridge output. The transistor base current is limited to a few milli-ampere but in all these output stages, short-duration current spikes may occur during the output transitions. Diode protection against inductive voltage spikes as in Fig. 5 should be used for loudspeaker, relay and solenoid loads.

- Any of the output transistors may in principle be replaced by the compound transistor pairs if higher peak currents are needed. To reduce the above requirements it is worth considering the use of f.e.t. devices as the input transistor of the pair.

Further reading
Main circuits—pp.1-6; lamp control circuits—pp.344-9;
trigger circuits—pp.889-907.

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Component changes
IC: Motorola MC1455. Separate comparators could be used with independent reference voltages or a single comparator with hysteresis defined by feedback—see Series 2.

$V_N$: 4.5 to 18V. At low voltages the saturation voltages at the output may not allow adequate drive to electromechanical/ filament lamp loads.

$R_1$, $D_1$: Any network to provide constant voltage at control input. Voltage may be to within 1V of common line or positive supply, but for optimum performance should be close to $2V_N/3$.

$R_2$: 1k to 1MΩ. At low values, excessive loading of source; at high values inaccuracies due to threshold current of up to 0.25mA.

Circuit modifications
- Use as battery charger illustrates method well (above). Upper threshold when $k_1V_{H1} = V_D$; lower threshold when $k_4V_{L1} = V_D/2$. When upper threshold is exceeded output at pin 3 reverse-biases diode $D_3$ and battery discharges into load when present. As voltage $V_N$ falls below lower threshold voltage at pin 3 rises and charges battery through limiting resistor $R_4$. Hysteresis may be reduced towards zero for $V_N/k_1 + V_D/2k_4$.

- To increase hysteresis, the potential at pin 5 may be reduced following a transition through the upper threshold. This may be done as in Fig. 2 by using output pin 3 via a diode—both thresholds are varied if the diode is replaced by a resistor.

- The increased swing simplies the triggering of a following 555 used as a Schmitt trigger, as the capacitor voltage in Fig. 2 can approach zero. Complete alarm systems can be based on such circuits combining level sensing, time delays and waveform generation, as well as audible alarms.

Further reading

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Wireless World Circard Series 13: Alarm Circuits—6

Frequency sensing alarm

Circuit description
The circuit is a monolithic m.o.s. i.e. which uses external RC elements to fix the frequencies at which the circuit provides a switching action. If does so via two separate switching times defined by \( C_1 R_1 \) and \( C_2 R_2 \) as from a pair of monostable circuits with the second time interval being initiated at the end of the first. The input may be a repetitive signal of arbitrary waveform, provided the amplitude is in excess of 100mV pk-pk (though it should not exceed 20V pk-pk). Internally this is presumably squared by a Schmitt type of circuit to trigger the monostables. Three distinct conditions may exist; if the period of the received signal is \( t_1 = \frac{1}{f} \) and the two delays are \( t_1 = k \) \( C_1 R_1 \), \( t_2 = k \) \( C_2 R_2 \), then \( t < t_1 < t_2 < t_1 + t_2 \). These conditions are distinguished by additional internal circuitry that allows sensing of frequencies above a given datum or within a given band with a switched output that can be made to latch on or off, toggle at a lower frequency \((f/20)\), and hold on during signal failure or for temporary interruptions of the signal.

The upper frequency in the band mode or the datum in the datum mode is set by \( t_1 \) and the lower band-frequency by \( t_1 + t_2 \). The circuit provides frequency-sensing function similar to comparators Schmitt-triggers and window-comparators.

Typical performance
IC: FX101 (Consumer Microcircuits)
- 12V supply, -3mA + load current
\( V_{in} \): 250mV pk-pk to pin 1
\( R_1 \), \( R_2 \): 470kΩ
\( C_1 \): 22nF, \( C_2 \): 10nF, \( C_3 \): 0.1μF
Ground pins: 2, 3, 9.
Output on for: \( f > 150 \text{Hz} \) \((f = 1/0.6C_1R_1)\).

Pin 1 signal input:
2 grounded, holds switch state during signal loss.
open, switch off.
ground via 'C', switch off after signal break of \( 200 \text{ms}/\mu \text{F} \) for 'C'.
3 ground, circuit automatically resets on change off.
open, switch latches when turned off.
5 link to 8, switch latches when turned on. Ground 3.
link to 8 via 'C', hysteresis in datum point of 'C'/\( C_1 \)×
100%.
9 ground, datum mode, switches on for \( f > f_2 \).
open, band mode, on for \( f_2 > f > f_3 \).
link to pin 5, output toggles at \( f/20 \) when in band.

Wireless World Circard Series 13: Alarm Circuits—7

Digital alarm annunciators

ICs: 1-3, 5, 7-15
4, 6, 8×SN7400
4, 6, 8×SN7410
LED1: TIL209,
LED2: MLED750
\( R_1 \): 3.3kΩ, \( R_2 \): 68Ω

Circuit function
It is assumed that a fault condition is the opening of relay contact \( RL_1 \), though any other sensor that maintains the NAND-gate input terminal at a low (0') level is adequate. A fault will turn off a "safe" green light and illuminate a "danger" red light, and operate an audible alarm. When the "recognise" push-button is depressed, the red light stays on, but the alarm is silenced. When the fault clears, the alarm is restarted, the green light comes on and the red light goes off.

The "recognise" button is again pushed to reset circuit to its normal state.

Circuit operation
Consider the circuit in its normal state where inputs \( R, T \) and \( F \) are at zero volts (or binary zero) i.e. \( R = T = F = 0 \). This makes \( X = 0 \) (\( X = 1 \)), \( Y = 0 \) (\( Y = 1 \)) and hence LED1 is energised (green) and LED2 (red) is off.
If a fault occurs, \( RL_1 \) opens, \( F \) goes high (or binary one) i.e. \( F = 1 \), causing \( X = 0 \) (\( X = 1 \)), but the state of \( Y \) (and \( Y \)) remains as before. Hence \( A = 1 \), and triggers audible alarm. Pushing the recognise button causes \( R = 1 \), and as \( F = 1 \), \( T = 0 \), then \( Y = 1 \) (\( Y = 0 \)), but \( X \) does not change. LED1 remains on, but \( A = 0 \), and alarm stops. This state will be maintained until the fault is cleared.
When the fault is cleared, \( R = F = T = 0 \), \( Y \) does not change, but \( X = 0 \) (\( X = 1 \), \( Y = 0 \)). Hence LED2 is illuminated, \( A = 1 \), and the alarm operates.
Final recognition of the fault clearance is obtained from \( R = 1 \), which will return circuit to its normal state i.e. for \( R = 1 \), \( F = T = 0 \), \( Y = 0 \) and \( X = 0 \).
Depression of the test button will check LED1 and the alarm, when started from normal state with LED2 on.

Circuit modification
As \( X, X, Y, Y \) are available, the exclusive-OR function of \( A \) can be obtained as shown.
Component changes

\( V_{dd} \): -12 to -22V some samples operate with reduced accuracy down to -8V.

\( V_{in} \): 0.1 to 20V pk-pk

freq. set points: 0.01Hz to 50kHz.

response time: within 5 to 10 cycles of receipt of correct frequency.

\( R_1, R_2 \): 100k to 1MΩ

\( C_1, C_2 \): 250pF to 1μF

\( C_3 \): 10nF to 1μF (not critical)

Circuit modifications

- As the lower frequency in the band mode is affected by time constant \( C_2 R_2 \) in the original circuit while the upper frequency is not, variation of \( R_2 \) increases the band by variation of its lower bound only. For \( C_1 = C_2 \), variation in the tapping point of \( R_C \) in (a) at left leaves the sum of the time constants unchanged at \( (R_A + R_B + R_C) C \) i.e. it is the lower frequency that remains constant while the upper frequency is changed.

- Variation in both frequencies while retaining a reasonably constant ratio of \( f_1 / f_2 \) (the equivalent of a constant Q), can be achieved by varying the common bias applied to the resistors. If strong dependence on supply voltage is to be avoided the bias voltage should be supply-proportional as in (b).

- Constant-current sources allow linear control of period against a separate reference voltage, which may be supply-proportional.

- Filament lamps may be driven via an additional transistor, currents up to 100mA or so being provided by circuit on right. Direct drive of reed relays, i.e..ds is possible though current is marginal.

Further reading


FX101: Consumer Microcircuits data sheet D/026.

Cross references

Series 1, cards 6 & 7.

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**Circuit description**

Complementary-m.o.s. devices may be used in the circuit above to minimize stand-by power consumption.

Normal safe condition obtains with \( L = A = 0, F = 1 \). When the fault-switch closes, \( F = 1 \) and since \( L \) is already high, \( X = 0 \). Hence \( L = 0, L = 1 \), opening gate IC1. Also since \( F = 0, Y = 0 \), and hence \( A \) is forced to zero, therefore \( A = 1 \). This transition may be used to switch an audible alarm. Simultaneously the oscillator gate is opened which will cause lamp flashing at a rate determined by the astable frequency.

If the fault is rectified, the alarm condition is maintained until the clear button is pressed causing \( C \) to be low. Hence \( L = 1, \) and will latch in this condition via memory circuit IC2 and IC3. Also \( L = 0, \) thus \( A = 0, \) this condition being maintained via IC4 and IC5, and the alarm is silenced.

Circuit description

Arrangement right allows detection of first-fault occurrence from three sensors \( S_1, S_2, S_3 \), this number being restricted by the number of inputs available per NAND-gate.

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Filament lamps are widely used as visual alarm indicators and often connected in the collector-emitter circuit of a bipolar transistor that is switched on and saturated under alarm conditions. These lamps have a positive temperature coefficient of resistance with a large difference of resistance between the cold and hot states—see Graph 1 which is typical for a 6-V, 100-mA panel lamp. When switched on across a voltage source, a large current surge flows in the lamp, and switching transistor, which then decays exponentially to its normal or rated value in the hot state. This surge may be many times the rated current, or even higher, shortens the life of the lamp, may destroy the switching transistor or blow the power supply fuse. Graph 2 shows the typical initial surge characteristic of a 6-V, 60-mA panel lamp having a thermal time constant of about 2ms.

When lamps are used as flashing alarms, the initial surge current is as shown in Graph 2 but the surge current on successive pulses depends on the thermal time constant and the time between flashes. Graph 3 shows the typical variation in surge current when a 6-V, 60-mA panel lamp is switched on for 5 s then off for 10 s seconds.

If the p.d. applied to the lamp is gradually increased the current rises in a controlled manner to its normal operating value, prolonging the life of the lamp and reducing the probability of transistor damage. A simple arrangement is shown above where Tr2 is normally held on and saturated with a low value of VCEsat holding Tr1 and the lamp off. Under alarm conditions, the base drive to Tr2 is removed and the capacitor charges through Rb. The base voltage of Tr1 rises exponentially so that the lamp surge current is avoided.

Signal domain conversion

Voltage-to-current conversion
It is often required to supply signals to relatively long transmission lines in which case the signal is more convenient in current form rather than as a voltage. Thus, voltage-to-current converters are useful and may be realized using operational amplifiers especially if the load is floating. Figs. 1 & 2 show the more common forms of the former being an inverting type and the latter non-inverting. In both Figs. I = \( \frac{V_{in}}{R_1} \) and is independent of the load impedance, but the source and operational amplifier must be able to supply this load current in Fig. 1, whereas little source current is needed in Fig. 2 due to the high input impedance of the amplifier. Fig. 3 shows another floating-load V-to-I converter which requires little source current if \( R_s \) is large and allows \( I_L \) to be scaled with \( R_s \), the operational amplifier supplying the whole of the load current; \( I_L = V_{in}(1/R_1 + R_2/(R_1R_2)) \). The circuit of Fig. 4 is suitable for V-to-I conversion when the load is grounded. When \( R_4 = R_3R_4 \) the load current is \( I_L = \frac{V_{in}}{R_4} \) and the current source impedance seen by the load very high.

Current-to-voltage conversion
If a device is best operated when fed from a voltage source but the available signal is in the form of a current, a current-to-voltage converter will be required, one example being shown in Fig. 5. Current is fed to the summing junction of the operational amplifier which is a virtual earth so that current source sees an almost-zero load impedance. Input current flows through \( R_4 \) producing an output voltage of \( V_{out} = -R_1 \) volts/amp. The only conversion error is due to the bias current of the operational amplifier which is algebraically summed with \( I_L \). The output impedance is very low due to the use of almost 100% feedback.
To prevent damage to Tr1 should the lamp become short-circuit, a resistor RC could be included in Tr1's free collector, but this would reduce the lamp voltage in normal operation. Circuit above shows a modification that allows an almost normal lamp voltage and also limits the short-circuit current to the desired value by using only a small RC value and a saturating transistor Tr2.

Relays are used to actuate alarm devices that need to be isolated from their control circuitry for various reasons such as their current, voltage or power requirements being incompatible with the electronic circuits. Circuit right, a commonly used relay drive circuit which takes into account both the resistive and inductive properties of the relay coil. When actuated, the steady-state coil current is fixed by the coil resistance and supply voltage, but when Tr1 is turned off the inductance of the coil causes the collector voltage to rise towards a level greatly exceeding VCC if the protective diode D1 were omitted. Diode D1 allows VCC to rise only slightly above VCC before the diode conducts to dissipate the energy stored in the relay coil. When Tr1 turns on D1 is reverse-biased and does not affect the operation. The diode must be able to withstand a reverse voltage slightly greater than VCC and be able to conduct the relay-coil discharge current for a brief time. Transistor Tr1 must have a Vce rating exceeding VCC and be capable of carrying the relay operating current. If a relay is required to operate when an input level exceeds a certain predetermined value, it may be included in a Schmitt trigger circuit; e.g. the relay coil and protective diode could replace R4 in the basic circuit of series 2, card 2.

If the alarm indication uses a i.e.d. or alpha-numeric array of i.e.d.s consult series 9, cards 2, 5 & 6.

Further reading

Cross references
Series 2, card 2.
Series 9, cards 2, 5 & 6.
Series 13, cards 4 & 7.

Frequency-to-voltage conversion
Diode-pump, transistor-pump and op-amp pump circuits are widely used for low-cost frequency to voltage conversion. Another circuit, using a single LM3900 quad current-differencing amplifier package, is the phase-locked loop shown in Fig. 7 which uses the v.c.o. of Fig. 6. Amplifier A2 is in the LM3900 package used as a phase comparator having a pulse-width modulated output depending on the phase difference between V1in and Vout of the v.c.o. Resistor R4 and C4 form a simple low-pass filter which makes the d.c. output vary in the range +V to +V/2 as the phase difference changes from 180° to 0°. This direct voltage controls the frequency of the v.c.o. and its lock range may be increased by using the fourth amplifier in the package as a d.c. amplifier between the filter and the integrator. Centre-frequency of the p.I.I. is about 3kHz with: R1, R2 1MΩ; R3 510kΩ; R4, R5, R6 30kΩ; R7, R8 1.2MΩ; R9 62kΩ; C1 1nF; C4 100nF; V= +4 to +36V.

Further reading
Linear Applications—Application notes AN20 and AN72, National Semiconductor 1973.

Cross references
Series 3, cards 3, 5 & 10.
Series 13, cards 1 & 6.
Pressure, temperature and moisture-sensitive alarms

Pressure-sensitive alarm
A pressure-sensitive alarm may be made using a specially-modified transistor known as the Pitran. It is a planar n-p-n transistor having a diaphragm mounted in the top of its metal can which is mechanically coupled to its base-emitter junction. When a pressure is applied to the diaphragm a reversible charge is produced in the transistor characteristics. The mechanical pressure input can be used to directly modulate the electrical output of the transistor which may be fed to the alarm circuitry e.g. via a comparator or Schmitt trigger which switches state when the input pressure to the Pitran exceeds or falls below some critical level. The Pitran may be connected as a single-ended-input single-ended-output stage, as shown left or as a differential-input balanced-output stage, as shown middle. Conventional transistor circuit design techniques may be used for the Pitran stages. Linear output voltages of up to one-fifth of the total supply voltage are obtainable.

Temperature-sensitive alarm
Circuit above shows the input circuitry of an alarm which may be operated by the output signal from the operational amplifier when the temperature monitored by the probe transistor exceeds a pre-determined value. The temperature-sensing transistor is a low-cost n-p-n type that can produce a resolution of less than 1 deg C in a temperature range of 100 deg C. If the operating current of the probe transistor is made proportional to temperature, the non-linearity of its base-emitter voltage may be minimized, being less than 2mV in the temperature range -55 to +125°C. Zener diodes set the input voltage to 1.2V and this is applied through R4 to fix capable of drawing a relay coil to produce the warning signal. At the same time when Tr4 conducts, the collector of Tr4 goes negative and hence via positive feedback through R4 the base of Tr4 remains negative, even if Vba is set back to zero. Hence, a latching action is obtained, which keeps the warning signal on. The warning signal will only be removed if the power supply is removed.

Security, water level and automobile alarms

Circuit description
Component R4 is the resistance in the search loop which if obtained using two 100kΩ resistors allows one to include switches either in series with the loop or in parallel with either resistor, or both. In the latter case changing a switch condition from open to closed in the parallel case and from closed to open in the series case can give rise to either a positive voltage or a negative voltage being applied to the diode bridge; the bridge is, of course, balanced initially. The diode bridge being a full wave rectifier will apply a negative Vba to the following circuit in either case.

The bridge resistors are large valued to minimize current drain from the battery but requires that the following circuit have a large input resistance. Hence the Darlington pair Tr1 and Tr2 is employed.

When Vba goes negative, Tr1 and with it Tr2, conducts. Transistor Tr3 then drives Tr4, which is a higher power device capable of drawing a relay coil to produce the warning signal. At the same time when Tr4 conducts, the collector of Tr4 goes negative and hence via positive feedback through R4 the base of Tr4 remains negative, even if Vba is set back to zero. Hence, a latching action is obtained, which keeps the warning signal on. The warning signal will only be removed if the power supply is removed.

Capacitors C1 and C2 are required to prevent spurious pulses from triggering the alarm, in the case of C1, and to prevent switching transients from triggering the alarm when the alarm is being reset, in the case of C2.

Component values

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1, R2, R4</td>
<td>150kΩ</td>
</tr>
<tr>
<td>R3, R5</td>
<td>200kΩ</td>
</tr>
<tr>
<td>R6, variable</td>
<td>250kΩ</td>
</tr>
<tr>
<td>R7</td>
<td>27kΩ</td>
</tr>
<tr>
<td>R8</td>
<td>470kΩ</td>
</tr>
<tr>
<td>C1, C2</td>
<td>0.33μF</td>
</tr>
</tbody>
</table>

Brake light monitor (circuit over)
Both of the identical counter-wound coils are wound round the reed relay. Hence the relay switch will only close, giving a dashboard warning, if either of the brake lights fails either with an open circuit or short circuit.
the operating current of the probe transistor. Resistor $R_4$ may be adjusted to make amplifier's output zero at 0°C and $R_5$ is used to calibrate the output voltage to 100mV/deg $C_r$ or any other scaling factor, independently of the $V_{out}=0$ condition. $R_1$, $R_2$ 12k$\Omega$; $R_3$ 3k$\Omega$; $R_4$ 5k$\Omega$; $R_5$, $R_6$ 100k$\Omega$; $D_1$, $D_2$ LM113; $T_R$ 2N2222; $A_1$ LM112; $V \pm 15V$.

**Moisture-sensitive alarm**

A low-cost audible alarm which operates when the electrodes of the input sensor become damp due to increased in humidity, direct contact with water, rain or snow is shown above. The sensor is conveniently made from parallel-strip printed circuit board or commercial equivalent, so that increase in moisture at the strips produces a very small current to $T_R$ base via $R_1$ which forms a high-gain compound pair with $T_R$ which switches hard on. Transistors $T_3$ and $T_4$ form the audible alarm multivibrator, that acts as a load on the compound pair, having a repetition rate determined by the $C_1R_6$ time constant. A piercing note at about 2.5kHz is produced with $R_1$, $R_3$ 100k$\Omega$; $R_4$ 1k$\Omega$; $C_1$ 10nF; $T_R$, $T_R$ Trx 300; $T_R$ OC71; LS 8-8 loudspeaker; $V \pm 9V$.

A flashing display with a rate of about 2Hz may be obtained by replacing the loudspeaker with a 6-V, 60-mA panel lamp and changing the values of $R_4$ to 470k$\Omega$ and $C_1$ to 2.2uF.

**Further reading**


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**Water level alarm**

This circuit is designed to produce a note from the loudspeaker when the sensor input terminals are shorted. As such it can be used for many applications apart from suggested water level/rain alarm. When the input terminals are shorted base drive to $T_R$ via $R_1$ is obtained, and the supply voltage is switched to the unijunction relaxation oscillator comprising $T_{3,4}$, $R_6$ and $C$ (card 4, series 3). A train of pulses of period mainly determined by the product $R_6C$ is then presented to the base of $T_{3,4}$ thereby producing pulses of current through the loudspeaker. The loudspeaker alarm note can be altered by altering the product $R_6C$. Considerable effective output can be obtained by selecting the note to correspond to the resonant frequency of speaker. In practice the alarm will sound for any resistance between zero and five megohms.

The quiescent current of the unit is of the order of nanoamps so that battery life is many months even if the unit is switched off. Provision to test the battery condition is made by switch position 2 which should cause $T_2$ to switch on the oscillator provided the battery is in good condition.

For water level sensing two conducting rods spaced an inch, or less, apart and positioned at the required level is all that is required.

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**Component values**

$R_1$: 100k$\Omega$

$R_2$: 3.3k$\Omega$

$R_3$: 270$\Omega$

$C$: 0.5uF

$T_{3,4}$: 2N2926 (G) switch positions

1 - rain
2 - test
3 - off

LS: 8-8 loudspeaker
Supply voltage: 9V

For a rain alarm two rods separated by some blotting paper will suffice. When the blotting paper becomes wet contact between the rods is made, the alarm sounds and the washing is saved once more (provided the missus isn't away shopping).

**Component changes**

Resistor $R_4$ may be any value up to 5M$\Omega$ provided a true shorting of the sensor input terminals is obtainable. The $R_6C$ product is dictated by the pitch of the note required. Resistor $R_5$ should be much less than $R_2$ e.g. $R_5/10$.

**Further reading**


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Electromechanical alarms

Electromechanical transducers are obtainable in a wide variety of types: they may be d.c. or a.c., resistive, reluctive or capacitive, contacting or non-contacting, analogue or digital, linear or angular, etc. Insofar as most alarm systems use a comparator (cross ref. 1) to compare the signal with a reference and as d.c. signals are easily compared we shall assume here that any a.c. systems are followed by signal conditioning equipment which includes a rectifier (cross ref. 2) of some sort so that the effective output is d.c.

Displacement alarm

Circuit shows a reluctive displacement transducer, of the differential transformer type, followed by a demodulator to provide the d.c. output shown in graph. The core, which is shown in its zero output position, is attached to the member whose displacement is required. The core is generally made from high permeability ferromagnetic material so that flux linkages with and hence the e.m.fs of the secondary coils are highly dependent on the position of the core relative to the coils. Reluctive transducers generally have a displacement span of between 0.01 and 120in, in rectilinear form, and between 0.05 and 90° in angular form. As the induced e.m.fs are proportional to frequency, very sensitive system can be made at high frequencies.

Capacitive transducers are used in situations where very small displacements have to be measured and/or non-contacting measurement has to be performed. Photoclectric/digital measurements (again non-contacting) are used when high accuracy is required, although fairly low cost versions can be constructed if accuracy is not essential.

Velocity alarm

Linear velocity transducers are most commonly used in the vibrations field where the displacement of the member whose velocity is required is small. Essentially, they consist of a coil moving in a permanent magnetic field, the coil e.m.f. being proportional to the speed. As a large proportion of the speed producing systems are driven by motors one can generally obtain information on linear speed from a knowledge of angular speed. This can be obtained by various types of a.c. or d.c. tachometers, but with the increasing use of digital instrumentation, toothed rotor, photoelectric and similar systems are becoming increasingly common. Diagram shows basis of operation of the toothed rotor tachometer and the...
corresponding output when the rotor is rotated by the shaft of a motor. The output waveform is obtained because of the changing flux pattern caused by the changing magnetic circuit. If the output signal is fed to a zero crossing comparator (cross refs. 1, 3) or to a Schmitt trigger (cross ref. 1) one will then obtain a train of pulses, each pulse representing the passage of a rotor tooth past the permanent magnet. Obviously the pulse frequency is proportional to the shaft speed. If the train of pulses is then fed to a frequency-to-voltage converter a direct voltage proportional to shaft speed is obtained and this can be fed to a comparator to give an alarm if it exceeds a predetermined level. Because the number of teeth on the toothed rotor can easily be varied, the range of speeds measurable by this technique is extremely large. Further, the rotor can easily be constructed in any workshop, no great precision being required for many applications. Both heads on a coupling between two shafts often suffice as the toothed rotor.

Acceleration alarm
Acceleration transducers all have one feature in common viz the seismic mass, M. The basic acceleration transducer is shown below. The case of the system is attached to the body whose acceleration is required. Due to a constant acceleration the seismic mass exerts a force \( Ma \) which in the steady state will stretch or compress the spring by an amount \( x \) where \( Ma = Kx \), \( K \) being the spring constant. The dashpot simply provides damping whilst the mass is moving. If we know \( M \) and \( K \) then a measure of \( x \) gives a signal proportional to the acceleration. This can be done by any displacement transducer of suitable dimensions and sensitivity. Frequently, however, the spring arrangement is a leaf spring arrangement with strain gauges attached. The spring deflection gives rise to changes in resistance in the strain gauges which if connected in a Wheatstone bridge circuit gives a voltage proportional to the deflection and, hence, to the acceleration. As the Wheatstone bridge can be supplied from a d.c. source there is no need for rectifiers before feeding to a comparator. Strain gauge bridges usable up to 750Hz have been built.

For higher frequencies piezoelectric crystals replace the spring. The crystal produces a charge or voltage across its terminals when subjected to the stress of the seismic mass under acceleration. However, the output impedance of the crystal is large and amplifiers with an input impedance in excess of 500M\( \Omega \) typically have to be used. Furthermore, the cable between the crystal and the amplifier requires to have low capacitance and to be free from friction induced noise. On the other hand very large accelerations (\( > 100g \)) can be measured and they can be used over a large temperature range (\( 570^\circ C \) for a lead metaniobate crystal).

Further reading
Considine, Encyclopedia of Instrumentation and Control, McGraw-Hill.

Cross references
Series 2, Comparators and Schmitts.

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