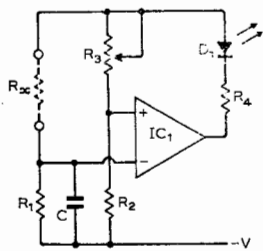


## Null, level and overload I.e.d. indicators



**Typical performance**  
 Supply: -9V  
 IC: 301  
 Diode: TIL209  
 $R_1, R_2$ : 10k $\Omega$   
 $R_3$ : 10k $\Omega$  variable  
 $C$ : 1 $\mu$ F  
 LED lights for  $R_x < R_3$   
 Zero offset typically 1 to 2mV—may be trimmed out.

### Circuit description

Light-emitting diodes are convenient indicators of out-of-balance conditions in bridges provided the unbalance signal is sufficiently amplified. Using an operational amplifier for which the common-mode input range can include one side of the supply, a simple Wheatstone Bridge can be used for rapidly determining resistance.

In the circuit shown, with  $R_1 = R_2$  bridge balance is achieved when  $R_3$  is adjusted to equal  $R_x$ . The lower limit of  $R_x \rightarrow 0$  (though with zero offset problems in op-amp) while the upper limit is set by  $R_3$  and the minimum input current of amplifier.

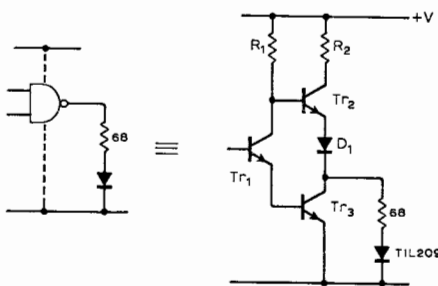
As shown, the I.e.d. is off for  $R_x > R_3$  which makes bridge convenient for portable use with unknown contacts normally open. Quiescent current is standby current of op-amp plus current in  $R_2$  and supply voltage is not critical. Bridge uses whole of available supply voltage to maximize sensitivity and limit is set by zero offset in amplifier.

Capacitor C minimizes hum pickup effects with hand-held probe. Method can also be applied with rectified a.c. supply if C is omitted and leads/unknown can be well-screened.

### Component changes

- $R_1$ : 100 $\Omega$  to 1M $\Omega$ . At lower values current drain is excessive. At high end amplifier input current unbalances bridge.
- $R_2$ : As above. Accuracy of matching of  $R_1, R_2$  or a suitable ratio determines overall accuracy.
- $R_3$ : Range chosen to suit  $R_x$ . A linear pot is easier to calibrate.
- C: Not critical; used to minimize effects of hum pickup.
- IC<sub>1</sub>: Any op-amp if bridge balance is achieved at potentials near midpoint of supply. For  $R_3, R_x$  small, amplifier common-mode range must extend near to most positive supply potential. 301, 307.
- $D_1, R_4$ : Not critical.  $R_4$  not required if op-amp has internal current limiting.  $D_1$ : HP 5082-4440, Monsanto MV5094, etc.

## Driving I.e.ds: digital circuits

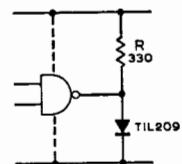
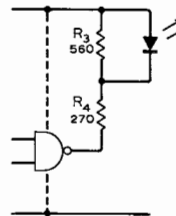


### Circuit description—1

The totem-pole output stage has both pull-up and pull-down active devices. When  $Tr_1$  is driven into conduction by input logic signals,  $Tr_3$  conducts also. The low saturation voltage of  $Tr_1$ , together with junction p.d.s of  $Tr_2$  and  $D_1$  prevent  $Tr_3$  from being forward biased. The I.e.d. is effectively short-circuited, speeding fall-time of light pulse. With  $Tr_1$  off,  $Tr_3$  receives no bias but  $Tr_2$  is biased via  $R_1$  to positive supply. If higher current allowable in I.e.d., R may be dispensed with.

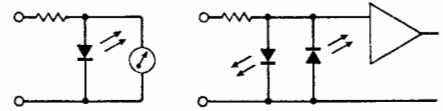
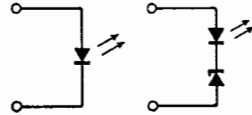
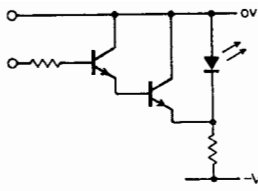
### Circuit description—2

In previous circuit internal resistors  $R_1, R_2$  plus junction p.d.s limit current to I.e.d., simplifying drive conditions. For logical 0 output,  $Tr_3$  becomes near short circuit and  $R_3, R_4$  limit I.e.d. current while providing passive pull-up to switch I.e.d. off rapidly. This configuration is more wasteful of current (below, left).



### Circuit description—3

Simpler output circuit of d.t.l. demands load resistor R supplying current to I.e.d. when output transistor is off. R chosen to define current in I.e.d. When conducting, corresponding to logical 0, the current is diverted from the I.e.d. into transistor. More current is drawn with I.e.d. off than when it is on (above, right).



### Circuit modifications

- While op-amp may be used as null indicator for ground-referred voltages this may require  $\pm$  supplies. By using a Darlington pair and a GaAs l.e.d., the transistors will conduct for input voltages close to zero (l.e.d. p.d.  $\approx 1.4V$  at 5mA). For negative inputs transistors non-conducting, all current flows in l.e.d.; for positive inputs all currents diverted into transistors. If input  $> +500mV$  input base-collector becomes forward biased.
- The l.e.d. is a simple fixed voltage level indicator ( $\approx 1.2$  to 2.2V depending on type) provided source can supply sufficient current to illuminate, yet insufficient to damage device. Voltage level can be increased by series zener diode(s).
- The l.e.ds can replace diodes in voltage limiting circuits while indicating overload. Examples include voltmeter

protection with a series limiting resistor to protect l.e.d. For a high resistance voltmeter of say 1V f.s.d. a resistor of  $1k\Omega$  could limit current to l.e.d. safely from inputs up to 50V with small meter error under normal conditions. Limiting of amplifier inputs would also allow indication of polarity of overload or presence of a.c. (both l.e.ds illuminated).

### Further reading

- Loughmane, M. H., Light-emitting diode pair forms null indicator, *Electronics*, 2 Aug. 1971, p.58.  
 Steen, T. J., Three-l.e.d. circuit indicates a.c. or d.c. and polarity, *Electronic Design*, 25 May 1972, p.68.

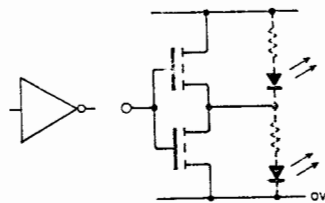
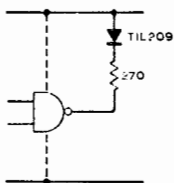
### Cross references

Series 9, cards 5 & 11.

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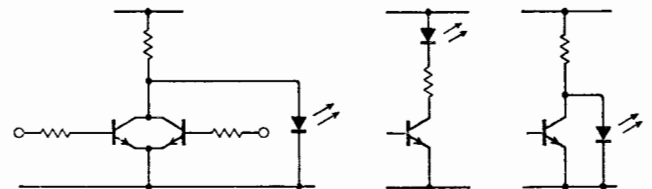
### Circuit description—4

The load has still to be taken between output and supply positive. As with t.t.l. resistive limiting is required. This configuration has advantage over previous that power consumption is much reduced when l.e.d. is off corresponding to logical 1 at output (below, left).



### Circuit description—5

Complementary m.o.s. inverters have one device at a time conducting. As these devices have comparable but complementary characteristics the load may equally be placed between output and the + or 0 lines. Selecting suitable output stages, the inherent current limiting of the m.o.s. transistors may be sufficient to allow direct drive without the resistor. Care must be taken at the much higher voltages that may be used with c.m.o.s. (above, right).



### Circuit description—6

RTL output stage has transistor with collector load. With transistor off the current flows in the l.e.d., operated at the nominal supply voltage for r.t.l. the resulting l.e.d. current is low. Open-collector t.t.l. stages may be treated similarly to d.t.l. outputs.

### Summary

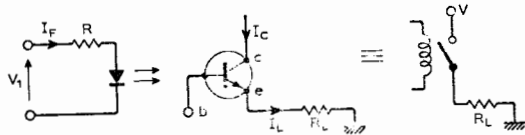
In all cases a minimum current of about 5mA is likely to be needed for good visibility. Typically around 10mA is used and the l.e.d. p.d. is 1.5 to 2.2V. This p.d. exhibits little change for a given device and subtracted from the supply voltage indicates the required series resistance  $R = (V_s - V_{l.e.d.}) / I_{l.e.d.}$   
 Alternative l.e.ds: HP 5082-4440  
 HP 5082-4444  
 Monsanto MV5094  
 RS Components LED2

### Cross references

Series 9, cards 5, 6 & 11.

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Switching with an opto-isolator

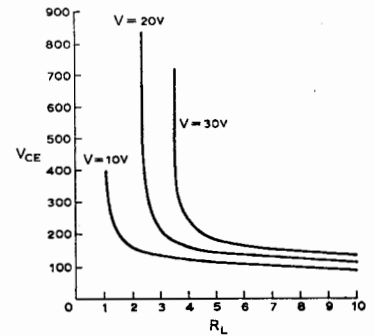


Circuit description

Opto-isolators are used where electrical isolation between input and output is essential. They find use in medical electronics, applications where noise problems are met, and as a replacement for relays and pulse transformers. Circuit shows an opto-isolator in a single-pole, single-throw switch configuration. When used as a switch the transistor must operate in the saturated region of its characteristics (card 8, this series) when  $I_F$  is applied. This is ensured if  $V/R_L$  is less than the current at the knee of the characteristic for the particular  $I_F$  used. Graph shows that the greater the value of  $R_L$  the smaller is the value of the voltage drop over the transistor.  $R_L$ , however, can not be increased indefinitely—if it becomes comparable to  $r_{off}$  then voltage will appear over

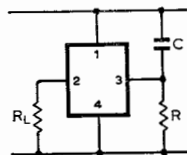
Typical performance

Opto-isolator: TIL112  
 For  $I_F=40mA$  and  $V_{CE}$  on  $<300mV$ :  
 $R_L > 1.25k\Omega$  for  $V=10V$   
 $R_L > 2.5k\Omega$  for  $V=20V$   
 $R_L > 4k\Omega$  for  $V=30V$   
 (see graph on right)  
 $r_{off} = V_{CE}/I_C$  with  $I_F=0$   
 $> 5M\Omega$   
 $r_{on} = V_{CE}/I_C$  with  $I_F \neq 0$   
 (see graph over)



$R_L$  when  $I_F$  is zero. The characteristics show that the volt drop over the transistor is reduced the larger the value of  $I_F$ . For example, a 50% reduction in  $V_{CE}$  was observed when  $I_F$  was increased from 15 to 60mA,  $V$  and  $R_L$  being fixed at 20V and 10k $\Omega$  respectively. In addition, for a given  $V$ , increasing  $I_F$  allows lower values of  $R_L$  to be used. For this device  $V_1$  must exceed 1.2V for the photodiode to conduct. Information on possible switching rates is on card 9, this series, and may be increased, see ref. 1. Alternative components: OP1032, OP1062, MCT26, ISO-LIT12.

Integrated-circuit optoelectronic switch

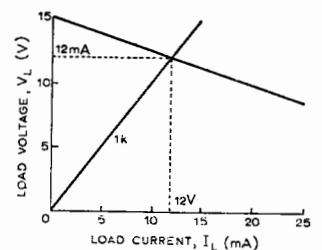
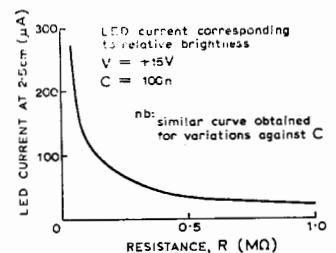


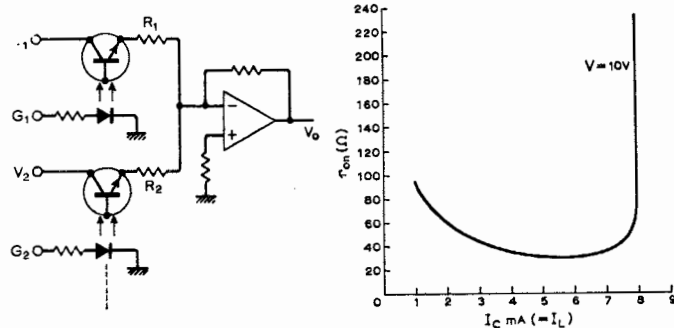
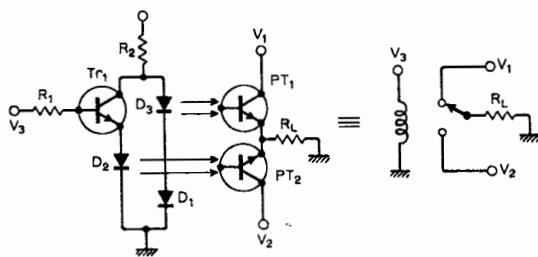
Circuit description

Circuit is that of a photo-sensitive trigger in which the voltage at the output (pin 2) changes by a large amount when the light intensity on the device exceeds a threshold level. This level may be varied over a very wide range by choice of  $R$  and  $C$ . These control the frequency of oscillation of an internal oscillator, in which the current in  $R$  controls the fall-time and an internal switch the rise-time. The resulting waveform is fed to an internal circuit with a threshold set by the light intensity, while a small amount of hysteresis prevents the output switching back and fore on small variations in that intensity. The output voltage swing is equal to the supply voltage on open circuit, but can supply enough current to operate a need relay or drive a transistor operating a higher power relay.

Typical performance

High sensitivity:  
 $R: 680k\Omega, R_L: 1k\Omega$   
 $C: 220nF$   
 Supply: 15V  
 Ambient light excluded  
 Output switches for  $150\mu A$  at distance of 2.5cm with optimum alignment. With LED1 & IPL15 in contact (negligible leakage) switching initiated by  $<10\mu A$  in i.e.d.  
 Low sensitivity:  
 $R: 100k\Omega$   
 $C: 3.3nF$   
 Switching at room ambient levels.  
 Load voltage on-condition: 12V  
 Load voltage off-condition:  $\approx 0V$





### Further applications

A single-pole, double-throw switch can be constructed as shown above. When  $V_3$  is less than 0.6V,  $Tr_1$  is off and current passes through  $D_3$  and  $D_1$  (a general-purpose diode). Phototransistor  $PT_1$  then conducts and  $V_1$  is applied to the load,  $R_L$ . When  $Tr_1$  conducts, however, the voltage across  $Tr_1$  and  $D_2$  falls below that necessary to make  $D_1$  and  $D_3$  conduct because the voltage across  $Tr_1$  when conducting is less than that necessary to make  $D_1$  conduct.  $PT_1$  is then switched off,  $PT_2$  is switched on and  $V_2$  is applied to  $R_L$ . As shown above,  $V_1$  and  $V_2$  must both be positive. If either is negative then reversing the appropriate collector and emitter connections is necessary.

With  $R_1$  of 10k $\Omega$ ,  $R_2$  100 $\Omega$  and  $R_L$  10k $\Omega$ , minimum  $V_3$  is 4V and maximum  $V_4$  is 4V. Range for  $V_1$  and  $V_2$ : up to  $\pm 30V$ . Use of an opto-isolator with a photo-darlington output stage increases current to the load.

Opto-isolators may be used in multiplexing circuits as shown above (ref. 2).

$G_1$  and  $G_2$  are gating signals which allow  $V_1$  and  $V_2$  to pass to the op-amp in sequence. Resistors  $R_1$  and  $R_2$  may be different if  $V_1$  and  $V_2$  have to be weighted as well as multiplexed.

### References

1. Gligler, D. F., Increase phototransistor bandwidth, *Electronic Design*, vol. 21, April 1973.
2. Das, S., Multiplexing analogue signals with optically coupled isolators. *Int. J. Electronics*, vol. 34, April 1973.
3. Bottini, M., *EDN/EEE*, 15 April, 1972.

### Cross references

Series 9, cards 4, 7, 8, 9 & 12.

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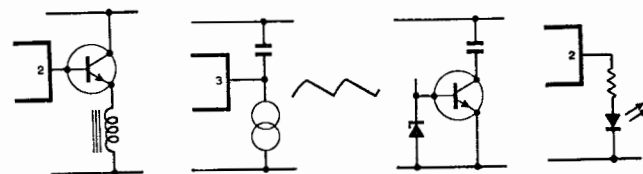
By setting a large RC time constant the sensitivity can be increased to the level at which the light from a match can be detected at a distance of several feet. Output is compatible with t.t.l. circuits as well as c.m.o.s. Spectral response of the circuit is such that it responds to the output of filament lamps as well as the low-cost light-emitting diodes. Speed of response is less than that of the frequency of oscillation, but at moderate sensitivities, switching rates of up to 1kHz are possible, making the circuit suitable for counting objects in most industrial systems.

### Component changes

- R 47k $\Omega$  to 1.5M $\Omega$
- C 2nF to 2 $\mu$ F
- $R_L$  330 $\Omega$  to  $\infty$
- $I_L$  up to 20mA
- Supply 12 to 18V (some units operate down to 9V)
- Time constant determines sensitivity of the circuit to light intensity.

### Circuit modifications

- Output current is sufficient to drive a reed relay directly or digital circuits such as t.t.l. Addition of an emitter follower allows higher-current relays to be driven (left-most circuit).



- Internal functioning of the i.c. requires the generating ramp waveform whose frequency determines the sensitivity of light detection. This waveform is available at pin 3 and the ramp may be linearized by an external current generator.
- If the output is used to drive a light-emitting diode or filament lamp via a transistor then the optical equivalent of a Schmitt trigger results. The l.e.d. is switched to a fixed brightness at some pre-selected level of light input to the i.c.

### Further reading

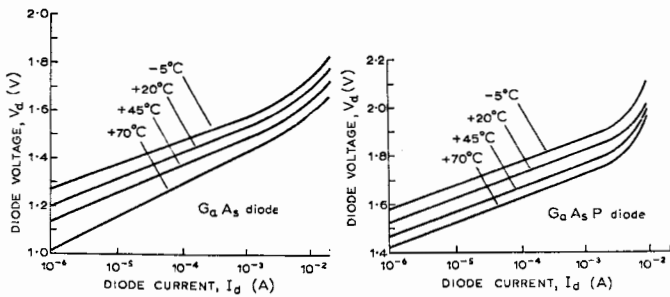
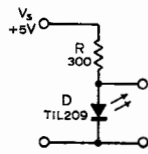
Noble, P. J. W., Cost advantages of integrated optoelectronic sensors, *Electronic Components*, 28 July 1972, pp.724-6.

### Cross references

Series 9, cards 3 & 8.

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Characteristics and applications of l.e.ds

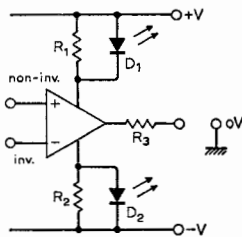


Circuit description

The device is a semiconductor p-n junction; gallium arsenide or gallium arsenide-phosphide being the most commonly used semiconductors for l.e.ds radiating at the red end of the spectrum. Other diodes are available with, for example, green emissions but low-cost units are presently restricted to red. Current levels are typically 5 to 25mA through the forward-biased junction and the terminal p.d. is typically 1.5 to 2.2V. These levels are compatible with the outputs of operational amplifiers, comparators, t.t.l. circuits and some m.o.s. circuits. The *v-i* characteristic is identical in kind to that of the silicon p-n junction with equal increments in p.d. for a given multiple, in current i.e.  $V \propto \log_e I$ . At currents above a few milliamperes, the bulk resistance of the material dominates and the p.d. rises linearly with current. The p.d. falls with rising temperature having a comparable coefficient to silicon p-n junctions ( $\approx -2\text{mV/K}$ ) and the diode may be used as a simple voltage reference at the same time as providing illumination.

The supply voltage should be large enough to allow the series resistor to be the dominant element in fixing the diode current. The diodes may also be operated in a pulsed mode with higher peak currents and low duty cycles. This mode is common for diodes forming part of an alpha-numeric display where a single decoding device drives a number of diode arrays in succession at a rate fast enough to avoid flicker effects, i.e. allowing the eye to respond to mean levels of brightness.

Op-amp/comparator driving of l.e.ds



Circuit description

If two light-emitting diodes are connected in the supply lines of an op-amp having low quiescent current then resistors may be placed in parallel with the l.e.ds to ensure that the p.d. across them in the quiescent state is insufficient to produce illumination. Provided the inputs are maintained at a common-mode potential (c.m.) within the guaranteed operating range for the particular amplifier, then a small difference-mode signal at the inputs controls the illumination of the l.e.ds. The amplifiers used have internal current limiting that prevents the l.e.d. current exceeding a safe value. For low current l.e.ds, or where the amplifier has no current limiting the output may have a series limiting resistor added. Which lamps are lit will also depend on whether the output is taken to the zero,  $+V_s$  or  $-V_s$  lines. Leaving the output free of direct loading by the l.e.ds allows all the normal feedback circuits to be used to produce Schmitt, astable and monostable characteristics.

Lamp control by op-amp difference mode

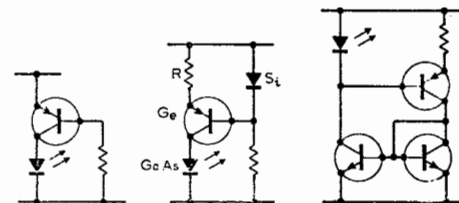
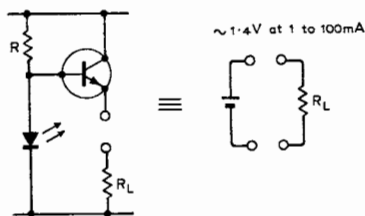
Supplies:  $\pm 15\text{V}$ , CM:  $\pm 12\text{V}$

DM	$R_3$	$D_1$	$D_2$	Notes
+	0	on	off	L.e.d. current limited by op-amp s/c current limit. Current may be reduced by increasing $R_3$ .
-	0	off	on	$D_1, D_2$ may remain for $R_1, R_2 > 150\Omega$ .
+	$-V_s$	on	off	
-	$-V_s$	off	off	
+	$+V_s$	off	off	
-	$+V_s$	off	on	

Difference mode voltage i.e. (non inv.) $-V(\text{inv.})$	Potential to which free end of $R_3$ is connected	$D_1$ reduces positive voltage applied to op-amp	$D_2$ reduces negative voltage applied to op-amp	IC:741 $R_1: 220\Omega$ $R_2: 220\Omega$ $R_3: 220\Omega$ $D_1, D_2: \text{TIL209}$
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For CM voltages within 1.5V from most negative potential on i.c. output latches into positive state with same result as for DM+ regardless of relative voltages applied to inverting and non-inverting inputs. Some op-amps (LM307, etc.) will follow above table for CM voltages up to and including most positive voltage on op-amp.



### Circuit modifications

● Because of their comparable drift with temperature, the l.e.d. and a silicon transistor may be used as a simple voltage regulator in which the transistor acts as an emitter follower. For a GaAsP l.e.d., the output voltage is around 1.4V if the l.e.d. current is  $\approx 10\text{mA}$  and the transistor operated well below its maximum current rating. With a suitable transistor (BFY50, BFR41, 2N3053) the circuit makes a good replacement for a single dry cell while operating from an unregulated supply of say 3 to 5V at currents of up to 100mA or so. At higher currents substitute 3055 transistor to minimize  $V_{be}$  drop.

● To operate a l.e.d. from the lowest possible supply voltage, a transistor may be used to drive the l.e.d. While the base current of the transistor and hence its collector current falls with falling supply, the l.e.d. current may be sustained at a reasonable level or supplied to within a few tens of millivolts of the l.e.d. terminal p.d. Any low-voltage constant-current circuit may be substituted including those using Si/Ge transistor/diode combination or those based on current-mirrors (see Circards series 6).

### Further reading

Yen, T. T., LED doubles as sensor, *Electronics*, 4 Dec. 1972, p.113.

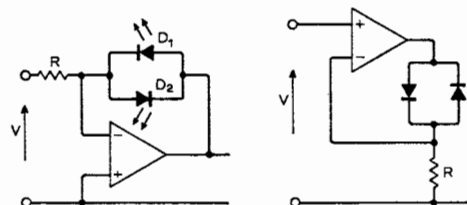
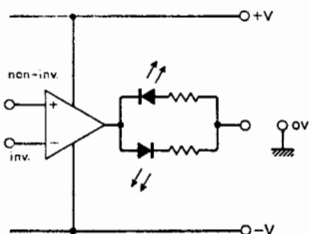
Texas Instruments, Measuring l.e.d. output, *Electronic Equipment News*, March 1971, pp. 24-8.

LEDs have advantage as constant-brightness sources, in 400 Ideas for Design, Hayden, vol. 2 1971, pp.277/8.

### Cross references

Series 9, cards 1, 2 & 11.

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Where the status of the input need only be indicated by a single on/off l.e.d. the other may be removed and replaced by a shortcircuit. If negative feedback is applied then for small differences at the inputs neither l.e.d. will be significantly illuminated.

### Component changes

● The op-amp may be any general-purpose type such as 741, 748, 301, 307. Used as a comparator there is no feedback and presence or absence of compensation capacitors affects only speed of response.

● In circuit over and circuit above, high-speed comparators such as 710, 711, 311, etc., may be used where rapid pulse response is required. If no current limiting is available internally, protect amplifier/l.e.d. by series resistor (100 to 500 $\Omega$ ). Some comparators only have single polarity outputs allowing on/off applications only.

● Diodes  $D_1$ ,  $D_2$  may be gallium arsenide, gallium arsenide-phosphide l.e.d.s with p.d.s of 1.5 to 3V and currents of 530mA. TIL209, HP 5082-4484, Monsanto MV5094, RS LED2.

● Resistors  $R_1$ ,  $R_2$  chosen to prevent illumination by quiescent currents. Typically 150 $\Omega$  to 1k $\Omega$ .

### Circuit modifications

● The l.e.d. may be connected directly to the output of the op-amp and again by taking the l.e.d(s) to the zero-volts line changeover of lamp illumination takes place for small changes in the differential input. This can be applied to a red/green pair of lamps for example. Again limiting resistors may be used. Single-ended supplies with one l.e.d. to either supply line gives simple on/off indication. Parallel series resistors prevent illumination in the nominally off state (left).

● As well as monitoring op-amp output states when used as comparator, the l.e.d.s may be placed in the feedback path. The input resistance of the circuit is R and the current in the l.e.d. is  $V/R$  with  $D_1$  lit for V negative and  $D_2$  for V positive. Emission from the conducting l.e.d. is a nearly linear function of the input voltage (above, left).

● Feedback may be series-applied at the input giving a similar output in the l.e.d.s but with a very high input impedance (above, right).

### Cross references

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Phototransistor logic circuit drivers



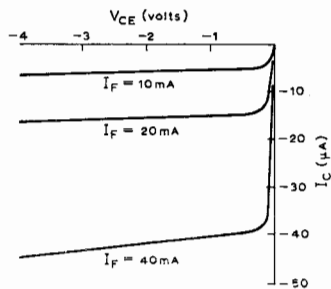
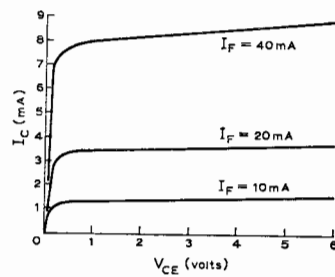
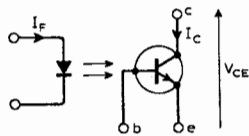
Circuit description

This circuit is applicable in principle to most forms of digital circuit including t.t.l., d.t.l., r.t.l. and c.m.o.s. logic. The value of R may differ considerably, and that shown is suitable for t.t.l. and d.t.l. With c.m.o.s. the value can be increased for higher sensitivity with rise and fall times that become limited by the correspondingly increased input circuit time constants. Circuits of the r.t.l. type require lower values of R (say 2.7 to 4.7kΩ) to ensure that the input is effectively logical '1' with the phototransistor non-conducting. In each case the phototransistor must provide a current flow sufficient to bring the input down to logical '0' when illuminated. This demands a higher light intensity for r.t.l. with the values given.

Circuit description

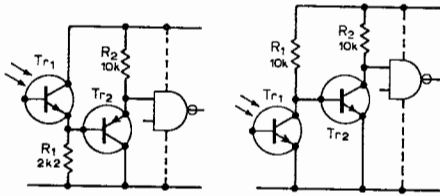
For r.t.l. and c.m.o.s. gates the value of R may be the same as that used for the previous circuits, i.e. 2.7 to 4.7kΩ for r.t.l. and from 10kΩ upwards for c.m.o.s. To achieve a time logical '0' at the input with t.t.l., d.t.l. either the resistance to ground must be low, say < 300Ω, or an additional negative bias time be available. The choice of R is a compromise between worsening noise level margins when  $R \rightarrow 300\Omega$  and requiring excessive current from the phototransistor as  $R \rightarrow 0$ . With a negative rail the quiescent voltage at the gate may be zero, while the on-current required is minimized.

Optically-coupled isolator: static characteristics



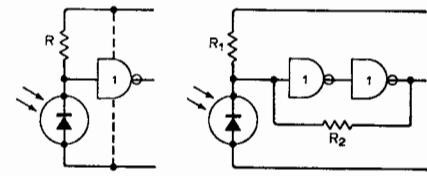
Component description

Optically-coupled isolators are generally used for their isolation properties, replacing switches, pulse transformers, etc. Their output side may be simply a photodiode which is fairly fast, a phototransistor which is slower but has a higher output current (because of the higher output current they may be faster than a photodiode if feeding a highly capacitive load) or a photo-darlington circuit. The component under test is a silicon n-p-n phototransistor activated by a gallium arsenide i.e.d. The characteristics given are not claimed to be typical in a quantitative sense though they will be qualitatively. The graphs point out some aspects of the characteristics not quoted by the manufacturer. The photodiode requires approximately 1.2V in the forward direction and the characteristics are identical in form to that for a normal transistor, except that the drive signal is  $I_F$  rather than  $I_b$ . As access to the base is available, the transistor can be controlled by base current drive or by optical means (diode current drive).



**Circuit description**

Conventional transistor amplifiers may be interposed between the phototransistor and the logic circuit to overcome the problems associated with t.t.l. driving. The first method shown leaves a minimum logical '0' input of one  $V_{be}$ , worsening the noise margin. The second circuit interchanges the positions of  $Tr_1$  and  $R_1$  while adding a logic inversion by using  $Tr_2$  in common emitter mode. This retains overall function required (phototransistor illuminated gives logical '1' at input) and retains good noise margin as  $Tr_2$  can saturate almost to ground level.



**Circuit description**

The input impedance of c.m.o.s. circuits is so high that photodiodes can readily produce enough current to give a high logic-level swing by choosing  $R$  large enough; e.g.  $R = 1M\Omega$  requires a photocurrent of  $< 10\mu A$  in diode for  $V_s$  of 10V. Diode speed can be high and  $R$  should be minimized to avoid excessive rise times. Fall time is dominated by diode current in conduction. Complementary symmetry allows the interchange of diode and  $R$  and the use of inverting or non-inverting gates as well as nand/nor elements. To avoid output jitter, positive feedback is applied overall (two inverting or one non-inverting buffer). Hysteresis is controlled by the ratio  $R_1:R_2$ . The output transition is also speeded up and allows operation of succeeding counters from slowly-changing light intensities.

**Further reading**

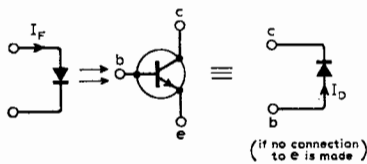
Korn, S. R., Photo Couplers, General Electric application note 200.62.

**Cross references**

Series 9, cards 3, 8, 9 & 11.

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**Photodiode operation**



**Photovoltaic operation**

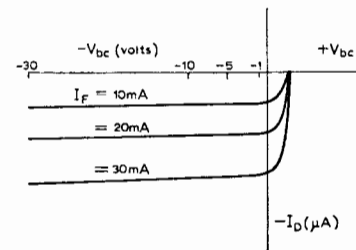


$V_{o/c}$  measured with instrument having  $1M\Omega$  input resistance  
 $I_{s/c}$  measured with instrument having terminal volt drop of less than 12mV.

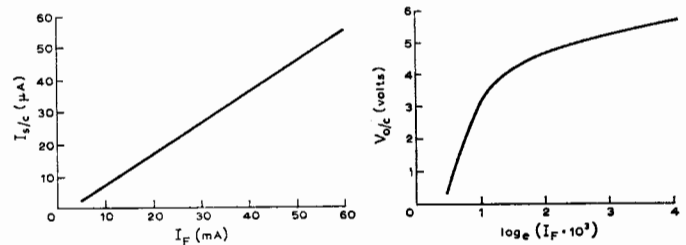
**Further reading**

Electronic Design, 1971, vol. 19, no. 11, pp. 44-55, and no. 12, pp. 46-52.

**Photodiode characteristics**



**Photovoltaic characteristics**



Graph left shows that, over a wide range of  $I_F$  (corresponding to  $I_F > 10mA$ ),  $V_{o,c} \propto \log I_F$ .  
 Graph right shows  $I_{s/c} \propto I_F$

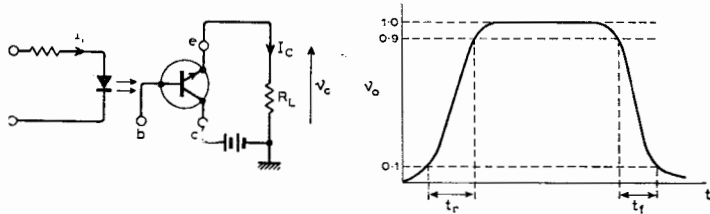
**Cross references**

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Optically-coupled isolator: pulse characteristics



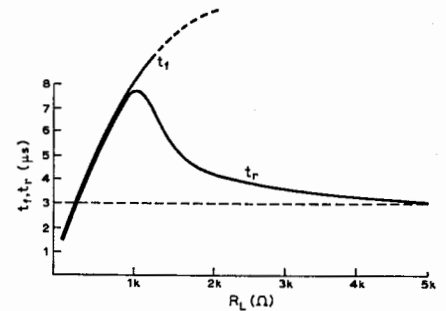
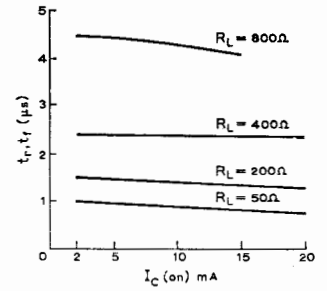
Experiment description

Graph top right was obtained by varying  $I_F$  to obtain particular values of  $I_C$ , and by deduction  $V_{CE}$ , and then measuring  $t_r$  and  $t_f$ . Values of  $t_f$  were identical, within experimental error, to the values for  $t_r$ . Clearly  $t_r$  and  $t_f$  are proportional, though not linearly, to  $R_L$  and are only slightly affected by  $I_C$ . The transistor operating point in all of these graphs is outside the saturated region of the static characteristics (card 8, this series).

Graph at bottom right was obtained by keeping  $I_F$  constant at a value such that  $I_C$  when supplying a short circuit was 10mA. In this case  $R_L$  was varied sufficiently to obtain readings when transistor was saturated. Graph above shows a typical pulse shape for low  $R_L$  and graph over for high  $R_L$ , giving saturated operation. Operation in the saturated region, as is done when using the transistor as a switch (card 3, this series), alters the pulse shape and causes the graphs of  $t_r$  and  $t_f$  to diverge.

Measurement data

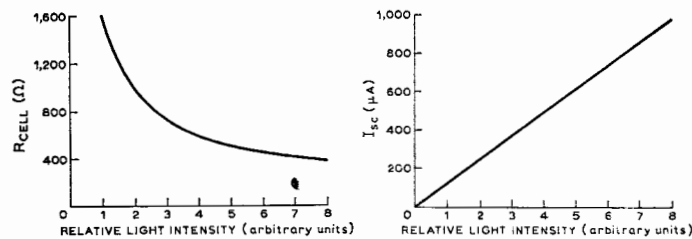
Phototransistor TIL112.  $V_o$  monitored on c.r.o. with  $1M\Omega$ ,  $28pF$  input impedance.  $I_F$  generated from pulse source having 10ns rise and fall times when feeding  $50\Omega$  load.



Alternative components

ISO LIT12, MCT26, OP1032, OP1062.

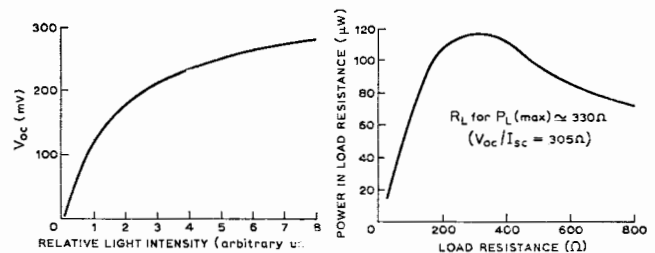
Photoconductive and photovoltaic cells



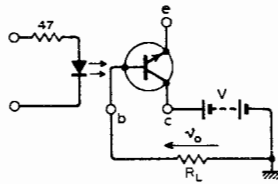
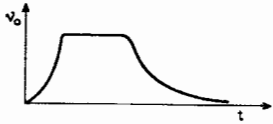
Typical characteristics

A photoconductive cell of the cadmium sulphide type behaves as an ohmic impedance which depends on incident illumination. Graph on left shows the variation of cell resistance as a function of light intensity to be  $R_{cell} \propto 1/(\text{light intensity})^n$  where  $n$  is typically in the range 0.5 to 1.0. When connected in a circuit fed from an external source the resulting current can be controlled or modulated by the light intensity falling on the photocell. Such cells do not respond instantaneously to changes in light intensity due to their inherent capacitance and may therefore be considered to have a time constant which depends on the existing and previous illumination. Cell rise time normally exceeds its fall time and both responses are slower at low light levels. Response time to pulsed light-changes falls with increase in light intensity and decrease in ambient temperature.

Although silicon and selenium photovoltaic cells are fabricated by different processes, their electrical characteristics are very



similar. Both types have a p-n semiconductor junction, the photo-sensitive layer being p-type in the silicon cell and n-type with selenium. If a photon of the appropriate wavelength strikes a valence electron, the latter may receive sufficient energy to convert it into a conduction electron. Because each photon releases a single photoelectron the short-circuit current is proportional to light intensity, see second graph and to cell area. Open-circuit voltage of a photo-voltaic cell is a logarithmic function of light intensity—third graph. Hence the terminal voltage is proportional to the log of the photo-generated current. The cell is therefore a non-linear device which can be represented by a current generator in parallel with a real diode possessing bulk resistance leakage resistance and capacitance. These cells are used for energy conversion but the load resistance for maximum power transfer is not given by  $R_{Lopt} = V_x/I_{sc}$  as predicted by linear circuit theory. However in practice, maximum load power is obtained with a resistance close to that predicted above.



Photodiode operation, shown in above, provides smaller rise times ( $< 1\mu\text{s}$ ) but generally smaller current capability since the load current is the transistor base current which is light-controlled. The maximum value of  $V$  is 30V and  $R_L$  can be increased until  $V_o$  is approximately equal to  $V$ . When feeding a capacitive load or a large-value resistor, corresponding to large output voltage swing, the rise time will increase.

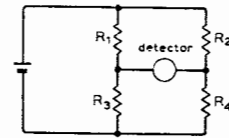
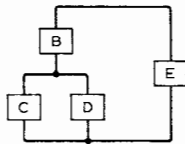
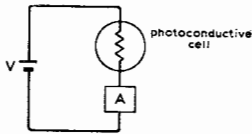
#### Further reading

Geiger, D. F., Increase phototransistor bandwidth, *Electronic Design*, no. 8, vol 21, April 1973.

#### Cross references

Series 9, cards 3, 7 & 12.

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#### Applications

Many photoconductive cell applications employ the simple series circuit shown left. Often the p.d. across the component A can be usefully employed for a control function that is dependent on the light intensity falling on the photocell in which case A would normally be a resistor. If A is the coil of a relay its current may be held below the operate value until the photocell resistance falls with increase in illumination. A contact of the relay could be used to open the lamp circuit thus providing a repetitive flashing signal. If A is a microammeter it can be calibrated to serve as a light intensity or exposure meter. If a is a lamp which illuminates the photocell when it is on, the circuit can be made into a "lock-on" type by illuminating the photocell from another source which is then removed. If A is a resistor and a suitably-engraved disc is rotated to modulate the light falling on the photocell, the waveform available across the resistor can be made sinusoidal, complex or noise-like.

A second common arrangement is shown, middle, where E is normally a power source. With B as a resistor, C a relay coil and D a photoconductive cell, the latter shunts current from the relay until the light source is removed when the relay operates due to the increase in photocell resistance. If B is the lamp illuminating the photocell then lamp failure causes the relay and its associated equipment to be isolated from the supply. If E is the amplifier input circuit, B a coupling

capacitor, C a photovoltaic cell and D a resistor, the p.d. across the latter will follow the signal variations due to illumination of the photocell through, for example, a film sound track.

The bridge shown right is also widely used and can be driven from a photovoltaic cell or bank of cells for resistance measurement. If  $R_3$  is replaced by a photovoltaic cell used as a photoconductive element that "backs-off" the supply voltage the circuit can be used as a sensitive exposure meter. If  $R_1$  and  $R_2$  are both photoconductive cells driven from the outputs of the left and right channels of a stereo amplifier via lamps the detector becomes a balance indicator. Photovoltaic cells can be used to charge batteries, operate low-power electronic equipment, charge capacitors to operate a photoflash and actuate relays directly from a light source to operate higher power equipment.

#### Further reading

National Semiconductor Linear Applications Manual—AN4-5, AN20-5, AN20-8, AN31-17, 1972.

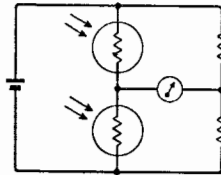
Transimpedance circuit for use with selenium photoelectric cells—*Jnl of Physics-Scientific Instruments*, vol. 5, 1972, p. 745. Smith, P. S., 50 Photoelectric Circuits and Systems, Iliffe, 1972, sections A & B.

#### Cross references

Series 9, cards 8 & 11.

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Light intensity measurement and detection

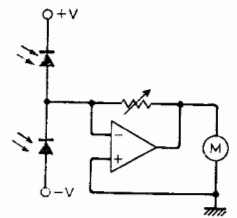
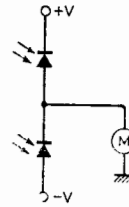


Light intensity measurement and detection

Circuit shows a normal Wheatstone bridge circuit where two resistors have been replaced by photoconductive cells of the cadmium sulphide type. If the two cells have accurately matched characteristics the bridge can be used to measure the relative light intensity from two different sources. When illuminated simultaneously from the source the unbalance current gives a measure of the degree of mismatch between the cells.

Photodiodes could be used in place of the photoconductive cells above in which case the unbalance current will be virtually independent of supply voltage and of the p.d. across the meter as the diodes are effectively constant-current sources; i.e. the circuit shown middle is applicable where the supply voltages are uncritical and meters requiring up to about 1 volt terminal p.d. could be used.

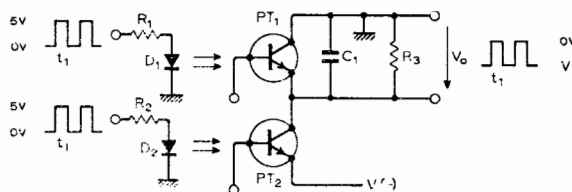
In either of these circuits the unbalance current could be fed to the input of a feedback operational amplifier where the output voltage could be set to, say, 0-10 volt for a given



difference in light intensities. circuit right is one such arrangement. The system is bipolar, i.e. either light intensity could be greater than the other with the meter reading proportional to their difference.

To monitor the ratio of two light intensities the circuit shown over can be used. Resistors in the feedback networks of the operational amplifiers can be scaled to accommodate the initial unbalance between the photodiode sensitivities and to set the desired ratio of light intensities. The observed unbalance voltage will be the ratio  $R_1/R_2$  multiplied by the ratio of the sensitivities of the photodiodes. When the diodes feed into an operational amplifier it is equally feasible to use positive feedback to obtain a switching action at a given level of light intensity, i.e. to make the circuit a form of Schmitt trigger.

Choppers and rectifiers



Circuit description

Circuit shows a chopper circuit using a pair of optoisolators with phototransistor output stages. Diodes  $D_1$  and  $D_2$  are light-emitting diodes driving the phototransistors  $PT_1$  and  $PT_2$  respectively. When one of the phototransistors is illuminated, its collector to emitter path becomes of low resistance (card 3) though with an offset voltage term inherent to the bipolar nature of the device. If the l.e.d.s are driven in antiphase then only one phototransistor is on at a time and either the signal voltage is applied to the resistor  $R_3$  through  $PT_2$  with  $PT_1$  non-conducting or  $PT_2$  blocks the signal while  $PT_1$  absorbs any current which leaks through  $PT_2$ . This is a conventional series-shunt chopper but energized by optical rather than direct electrical pulses, thereby avoiding the breakthrough of spikes into the output circuit. Use of the shunt transistor  $PT_1$  is not essential if the d.c. signal  $V$  is large but it does have the advantage that any stray or load capacitance represented by  $C_1$  can be rapidly discharged during the off part of the cycle, i.e. the fall time will be comparable to the rise time (card 9). This in turn is important where the

Typical performance

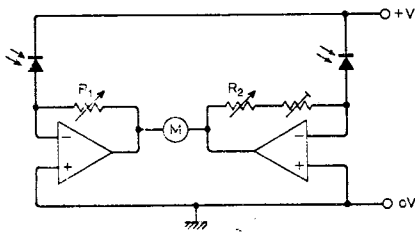
Opto-isolators TIL112 reading 5mV on r.m.s.- from 3 to 6V, meter calibrated mean-rectified change < 1%. With drive at 5V and  $C_1$  varying instrument. from 10pF to 0.01μF, measurement of  $V_o$  is meter change < 2%.  
 Drive frequency: 1kHz With V zero d.c. 0.05mV and a.c. measurement is 0.13mV. varying from 33 to 2kΩ, meter change < 4%.  
 Drive pulse height 5V  
 V: 10mV from 10-Ω source  
 $V_o = 10mV$  pk-pk, With l.e.d. drive varying

signal to be chopped is a rapidly varying one in which case the chopping frequency has to be as much above the signal frequency as possible.

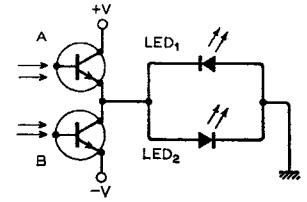
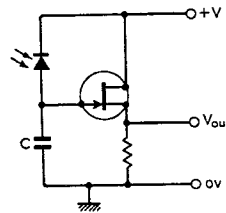
The drive circuits for the l.e.d.s can be conventional (card 6, series 8, card 2) but as they require to be antiphase they could be from the collectors of a standard two transistor astable or from the Q and  $\bar{Q}$  outputs of any t.t.l. counter circuits. If the chopped waveform is then fed to an a.c. amplifier the output can be rectified. Or better still rectified by a second pair of photo transistors synchronized with the drive pulses. The method is applicable to photo-f.e.t.s where the absence of a d.c. offset term allows chopping of much smaller signals. A third possibility is to use cadmium sulphide photoconductive cells in place of the phototransistors although the chopping frequency cannot then be as high. For positive values of V the collector-emitter connections of both phototransistors would have to be reversed.

Further reading

Pulse generator for diode emitters, W.W. 1972, p. 18.



Another type of light intensity measurement is involved when determining the total light from a source over a period of time, i.e. an integrating procedure. As the photodiode is essentially a current source, it is not necessary to use a feedback integrator. As shown middle, the current from the photodiode may simply be fed to a capacitor so that the p.d. built up across the capacitor is to a first-order approximation measure of the integral of the light intensity over the exposure time. For example, this could be used in a camera to control the time for which the shutter is open; closing the shutter when a certain total amount of light has reached the indicator and hence the film. To avoid loading the capacitor, it should be followed by a field-effect transistor, or similar high input impedance amplifier. This problem would not be so serious if the photodiode were used with an operational amplifier in a conventional integrator. By replacing the capacitor C with a resistor, the circuit could be applied to light intensity control. The simple circuit shown on the right can be used when it is desired to detect the presence or absence of given light sources



rather than to determine their intensity. The pair of light-emitting diodes connected in parallel back-to-back are fed from two phototransistors that are separately energized by the light beams A and B. This is a simple logic circuit in which LED1 will emit for a negative output which occurs when phototransistor B is on and phototransistor A is off. LED2 emits for the opposite state of A on and B off. If neither phototransistor is illuminated both i.e.s are extinguished. Both i.e.s could emit light if the phototransistors are not well matched and/or the light sources are of unequal intensity.

#### Further reading

National Semiconductor Linear Applications Manual AN8-8, AN31-3, AN31-18, 1972.

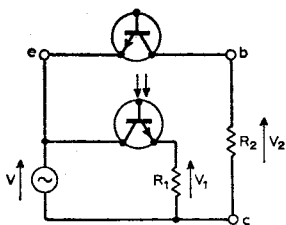
Graeme, J., Op-amp boosts phototransistor speed, *Electronic Design*, 2 March, 1972. p.62.

Vaisnys, A., LED-phototransistor coupler isolates analog signals, *Electronic Design*, 13 April, 1972. p.90.

#### Cross references

Series 9, cards 1, 2, 5, 6, 7 & 10.

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#### Performance data

$R_1, R_2: 1.5k\Omega$

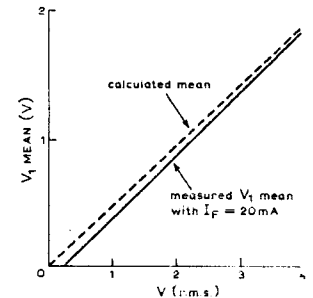
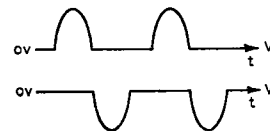
$V: 0 \text{ to } 4V \text{ r.m.s.}$

Signal frequency: 10kHz

Opto-isolators TIL112

$I_F$  (not shown) 20mA for both opto-isolators.

Graph obtained with these values.



#### Circuit description

Circuit 2 shows a pair of opto-isolators being used as simple diodes to provide a half-wave rectified signal which could be fed to a mean-reading instrument to effectively measure the value of the signal voltage, V. For this, branch abc is not necessary—it simply shows that both positive and negative half cycles can easily be obtained. The advantage of this circuit is that the volt drop across the transistor when conducting (card 8) in the forward direction is much less than that across a normal semiconductor diode (0.6V). Hence the phototransistor can be used as a rectifier for low voltages. When operating in the forward direction the phototransistor is operating in its saturated region and this together with the maximum reverse voltage (4V in this case) determines the value of  $R_1, R_2$ .

Circuit operation is not very sensitive to the value of  $I_F$ . Although the forward characteristic of the phototransistor as a diode is better than that of a diode its reverse characteristic is poorer. This can be greatly improved if  $I_F$  is made zero during that half of the cycle in which the phototransistor is nominally non-conducting. This could be done by driving  $I_F$  from a comparator whose input is the signal, V. All the other standard methods of improving diode performance could also be used, e.g. card 1, series 4.

#### Cross references

Series 9, card 8

Series 4, card 1.

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