Wireless World Circard

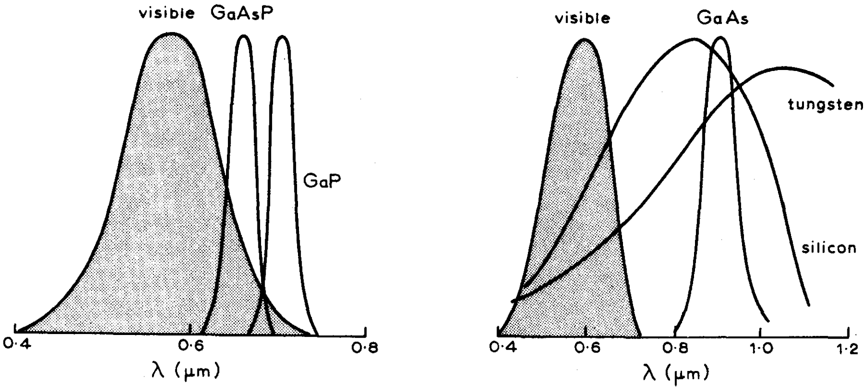
Series 9: Optoelectronics

The relative merit of infra-red/visible light sensors as far as spectral response is concerned, is easily assessed in three illustrations of the article introducing the optoelectronics cards. From Fig. 9 in particular it's clear why cadmium sulphide (CdS) photoconductive cells are used in photographic work. Card 10 gives the various performance and application details, together with those pertaining to silicon and selenium photovoltaic cells. Card 11 shows how to use them in comparing intensities and for integrating intensity over a period of time. Another card, number 7, gives ways of interfacing phototransistors with various logic circuits, pointing out that silicon photodiodes give sufficient current to directly operate c.m.o.s. circuits.

Three cards show how to use light-emitting diodes in various ways, one of them, number 5, giving basic design guidelines. Digital circuits can be driven using one of the six circuits on card 2, covering t.t.l., d.t.l., r.t.l. and c.m.o.s. circuits, while op-amps can be interfaced according to card 6. L.e.ds by themselves can act as voltage level indicators for the range 1·2 to 2·2 volts and higher voltages can be simply indicated by adding a series Zener diode. In many voltage-limiting circuits, l.e.ds can simply replace the limiting diodes, giving simple overload indication.

Some useful data on optical isolators are included on five cards, especially card 8, which points out some characteristics not always quoted by manufacturers.

Optoelectronics: devices and applications



Figs. 1 & 2. Materials used in light-emitting diodes are chosen to give the desired colour. Although GaAsP diodes are of compararable efficiency to GaP diodes, they appear brighter because eye response is greater in that region (Fig. 1, left).

Three aspects of the link between light and electronic circuitry are considered in this article: detection and measurement of light, generation of light from an electrically operated source, and use of light as an intermediary in some electronic process. Of the wide array of optoelectronic devices available a small number cover a wide range of requirements. More specialized components, such as semiconductor lasers, photomultipliers, must be left to a later series.

The electronics industry is seeing a production and pricing pattern in one family of optoelectronic devices reminiscent of the t.t.l. war at its fiercest. Light-emitting diodes have changed from an r & d novelty to a consumer component with great rapidity and are already falling to a price level comparable with the transistors used to drive them. They will replace filament and neon lamps for a wide variety of applications and it is on their characteristics that this series concentrates as far as light generation is concerned.

Light-emitting diodes are p-n junctions governed by the same rules as silicon diodes. The choice of materials is devided by the spectrum of light required while the efficiency can depend critically on doping levels. The most common materials are gallium arsenide and gallium phosphide (and other compounds) (Figs 1 & 2) with a current requirement of 5 to 50mA for normal brightness. The resulting p.d. is in the range 1 to 2V (Fig. 3) making the diodes compatible with both linear and digital circuits. Relative intensity of the lamp is an almost linear function of current over a wide range of currents (Fig. 4) falling at higher temperatures.

Response of the human eye is greatest in the yellow/green region of the spectrum, and the gallium arsenide-phosphide devices (Fig. 1) — which emitters peak in the red — appear less bright than otherwise comparable-efficiency yellow diodes. Nonetheless, economies of scale dictate the use of the lower-cost red l.e.ds for most applications.

Emission in other parts of the electromagnetic spectrum is possible with suitable materials including the highly specialized semiconductor lasers with a very narrow spectral response. Pulsed operation with low duty-cycle high-current pulses gives the highest efficiency with such devices, and they find application in optical communication systems.

Solid-state light-sensitive devices are based either on p-n junctions (photodiode, photovoltaic cell, phototransistors) or polycrystalline materials (CdS photoconductive cells). Light falling on a p-n junction if of short enough wavelength generates hole-electron pairs. Current flows if the p-n junction is short-circuited (Fig. 5) or connected to a low-resistance load; current is proportional to the intensity of light falling on the junction, and the terminal p.d. for a silicon diode may be up to about 0.5V (Fig. 6).

A specialized form of photodiode, the photovoltaic cell, is used as a power source. Selenium, or more commonly now silicon, is the material used and the cells are arranged to have a high surface area to maximize their light catchment. Although having non-linear characteristics, the simple maximum-power-transfer theorem gives a first order answer for the optimum load (Fig. 7) i.e. that load which maximizes the output power is given by $R_{opt} = V_{oc}/I_{sc}$. The theorem applies to linear systems but gives reasonable results for some non-linearity.

Further increase in load resistance or illumination makes for little extra p.d. as it becomes comparable with the p-n junction barrier potential. In a phototransistor the collector-base junction is illuminated and the transistor amplifies the resulting current. Currents of 10mA and more are possible but the speed of response is slower than for the diode alone when reverse biased. This latter mode is the fastest with a separate d.c. supply providing a high field to sweep

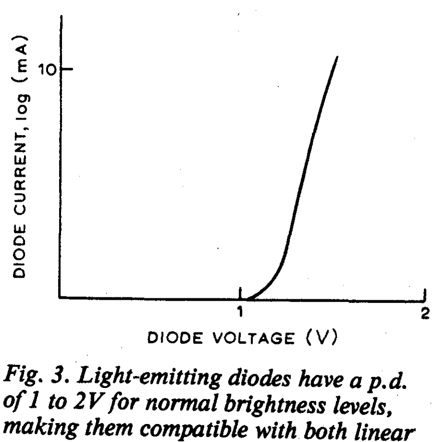


Fig. 3. Light-emitting diodes have a p.d. of 1 to 2V for normal brightness levels, making them compatible with both linear and digital circuits.

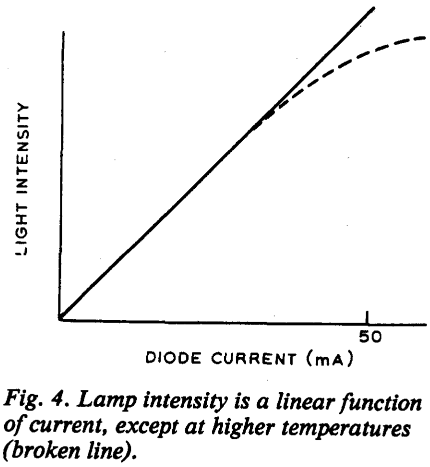
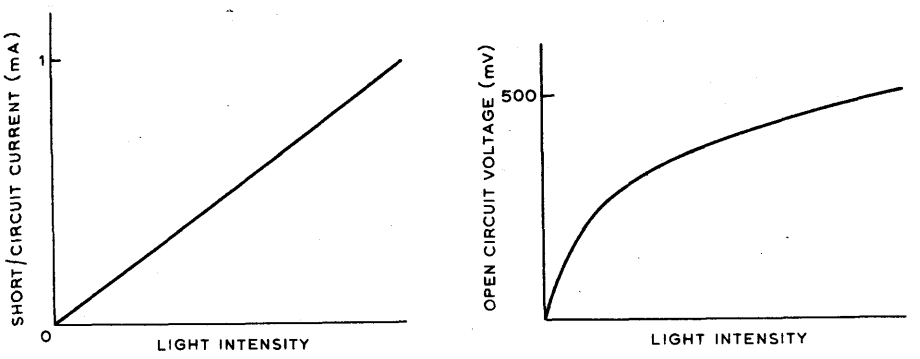


Fig. 4. Lamp intensity is a linear function of current, except at higher temperatures (broken line).



Figs. 5 & 6. In light-sensitive devices based on a p-n junction, current is a linear function of light intensity falling on the junction (Fig. 5, left). Open-circuit voltage can be as high as 0.5V with silicon photodiodes (Fig. 6, right).

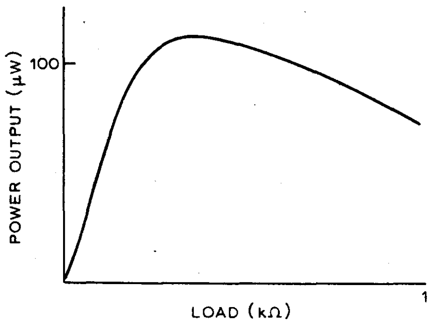


Fig. 7. For selenium or silicon photo voltaic diodes maximum power is delivered for a load given by open-circuit voltage divided by short-circuit current.

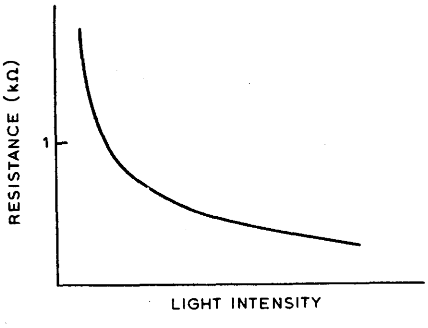


Fig. 8. Photoconductive cells using cadmium sulphide normally have a non-linear light intensity solidus current characteristic although the voltage-current curve is linear.

the carriers out of the junction. The limiting effect on speed of response is often the RC time constant of the external circuit particularly as the currents are low, forcing the use of large resistors where large voltage swings are needed. Any voltage swing up to the supply voltage may be obtained provided that the supply voltage does not exceed the diode reverse-breakdown voltage.

Any other semiconductor device or circuit using a p-n junction may in principle be made into an optoelectronic device with suitable packaging. Thus photothyristors can be obtained which are fired by an optical pulse, though they are presently restricted to relatively low-current applications e.g. for firing a higher power thyristor. In this case the photothyristor needs to have high voltage breakdown characteristics but can be a low-power device supplying pulses of a few tens of mA to the power device.

Photo-Darlingtons and other transistor combinations are equally feasible where higher output currents are desired in linear circuits, but in many cases it is equally simple to combine a photodiode or phototransistor with other conventional transistors. M.o.s. devices are very useful in optoelectronic circuits, with the threshold voltage varied by the light intensity. By adapting the m.o.s. processes, complex circuits have been recently produced by i.c. manufacturers, to provide outputs capable of driving small relays and switching at preselected light intensity.

Cadmium sulphide photoconductive cells have a very high resistance in the absence of light, with the resistance falling rapidly with increasing light intensity (Fig 8). At all light intensities the device has a linear V/I characteristic, and for some devices the variation of conductance with light is itself almost linear. As the spectral response of CdS cells closely matches that of the human eye (Fig 9), they are used in photographic equipment. These cells have to be used with some external power supply, a.c. or d.c., as they do not generate any power. The advantage is that the power controlled in the load can be large enough to operate a wide range of lamps and relays.

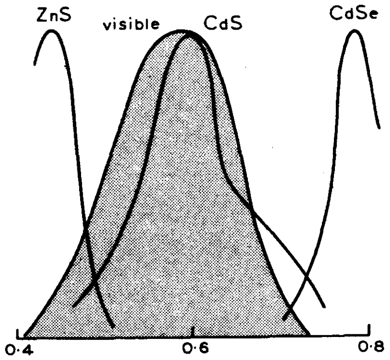
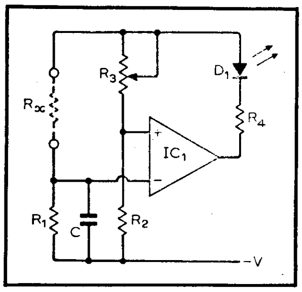


Fig. 9. Because the spectral response of cadmium sulphide cells matches eye response they are widely used in photographic applications.

A powerful tool for designers made possible by recent development is the photon coupler. This is typically an 8-pin dual-in-line package containing a light-emitting-diode tightly coupled, optically, to a silicon phototransistor. There is no electrical connection and breakdown voltages between the two sections of several kilovolts have been achieved. Similarly the capacitance coupling is small, and these devices are ideal for transmitting signals between circuits where direct electrical connection is impossible or inadvisable. Examples of such situations include firing of thyristors from grounded source and coupling between digital systems where ground noise is a problem.

Optoelectronics has passed the healthy infant stage and is developing into a mature branch of engineering where the choice is wide enough to encourage all designers to extend their skills.

Null, level and overload l.e.d. indicators



Typical performance

Supply: −9V
IC: 301
Diode: TIL209
R_1, R_2: 10kΩ
R_3: 10kΩ variable
C: 1μF
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 l.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: 100Ω to 1MΩ. 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_1: 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.

Circuit modifications

- While op-amp may be used as null indicator for ground-referred voltages this may require ±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. ≈ 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 (≈ 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 1kΩ 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

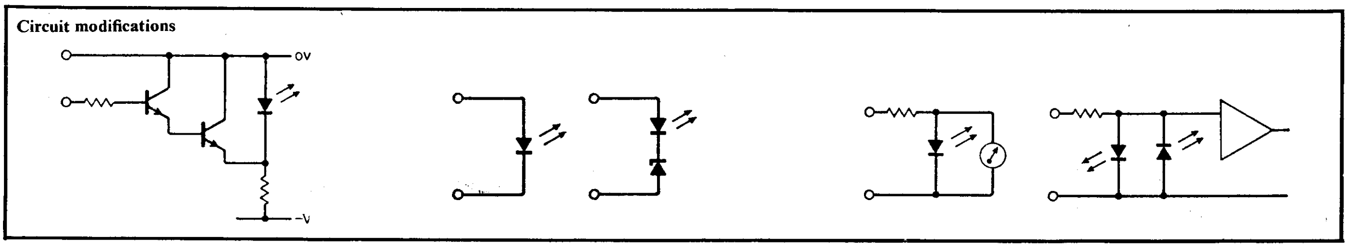
Loughmane, M. H., Light-emitting diode pair forms null indicator, *Electronics*, 2 Aug. 1971, p.58.

Steen, T. J., Three-l.e.d. circuit indicates a.c. or d.c. and polarity, *Electronic Design*, 25 May 1972, p.68.

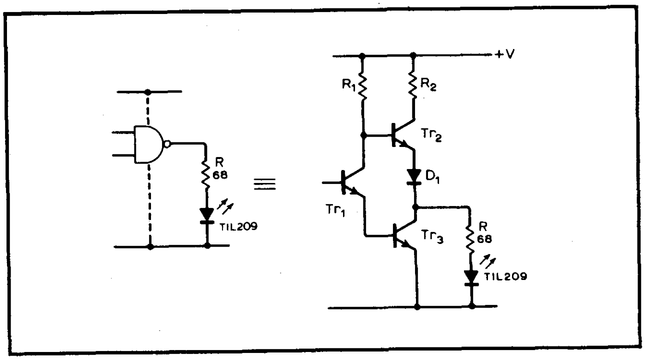
Cross references

Series 9, cards 5 & 11.

Circuit modifications

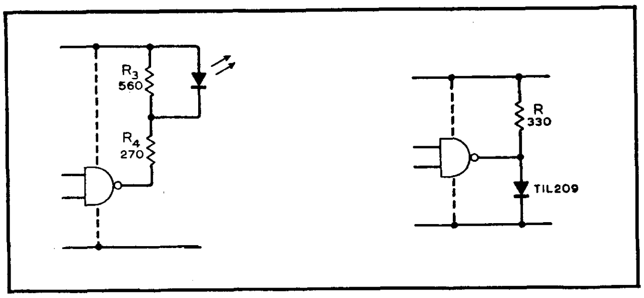


Driving l.e.ds: digital circuits



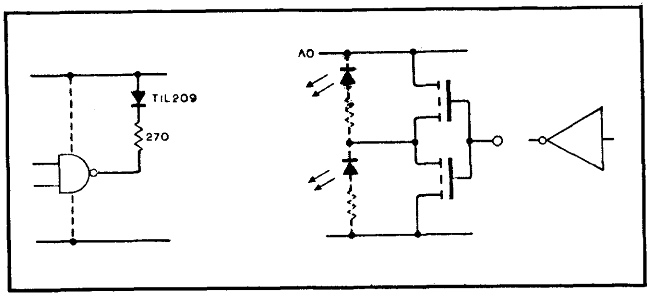
Circuit - 1 t.t.l. logic 1 indication
The totem-pole output stage has both pull-up and pull-down active devices. When Tr$_1$ is driven into conduction by input logic signals, Tr$_3$ conducts also. The low saturation voltage of Tr$_1$, together with junction p.ds of Tr$_2$ and D$_1$ prevent Tr$_2$ from being forward biased. The l.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 l.e.d., R may be dispensed with.

Circuit - 2 t.t.l. logic 0 indication
In previous circuit internal resistors R$_1$, R$_2$ plus junction p.ds limit current to l.e.d., simplifying drive conditions. For logical 0 output, Tr$_3$ becomes near short circuit and R$_3$, R$_4$ limit l.e.d. current while providing passive pull-up to switch l.e.d. off rapidly. This configuration is more wasteful of current (below, left).

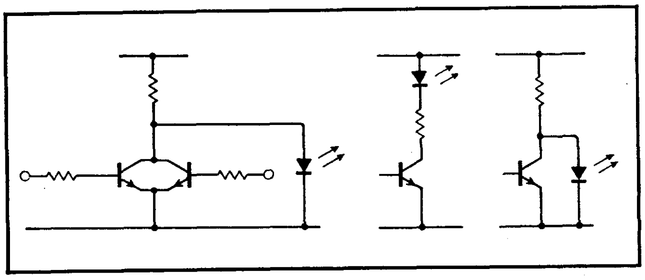


Circuit - 3 d.t.l. logic 1 indication
Simpler output circuit of d.t.l. demands load resistor R supplying current to l.e.d. when output transistor is off. R chosen to define current in l.e.d. When conducting, corresponding to logical 0, the current is diverted from the l.e.d. into transistor. More current is drawn with l.e.d. off than when it is on (above, right).

Circuit - 4 d.t.l. logic 0 indication
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 - 5 driving with m.o.s.
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 interent 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 - 6 r.t.l. and open collector t.t.l.
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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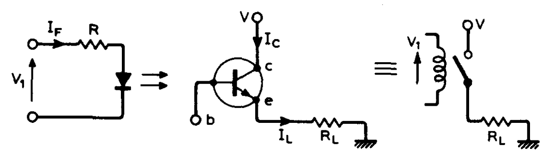
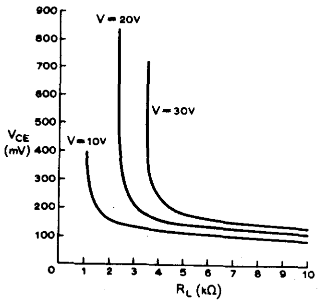
Switching with an opto-isolator



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



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 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 10kΩ 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.

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 10kΩ, R_2 100Ω and R_L 10kΩ, minimum V_3 is 4V and maximum V_4 is 4V. Range for V_1 and V_2: up to ±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.

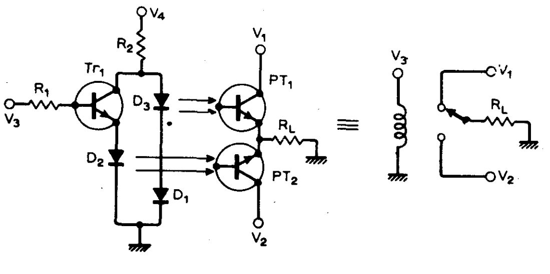
References

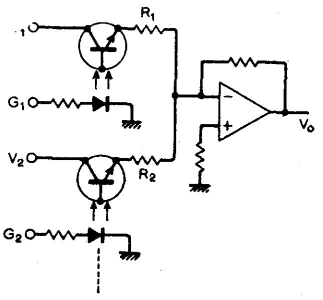
1. Gliger, D. F., Increase phototransistor bandwidth, *Electronic Design*, vol. 21, April 1973.
2. Das, S., Multiplexing analogue signals with optically coupled isolators. *Int. J. Electronics*, vol. 34, April 1973.
3. Bottini, M., *EDN/EEE*, 15 April, 1972.

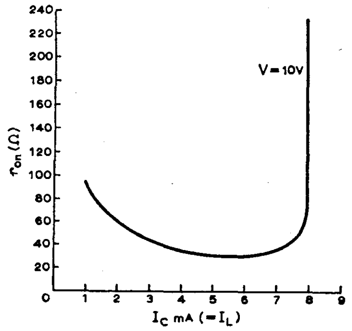
Cross references

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

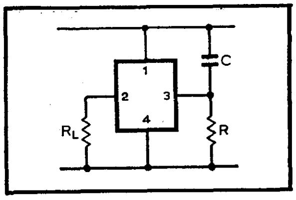
Further applications



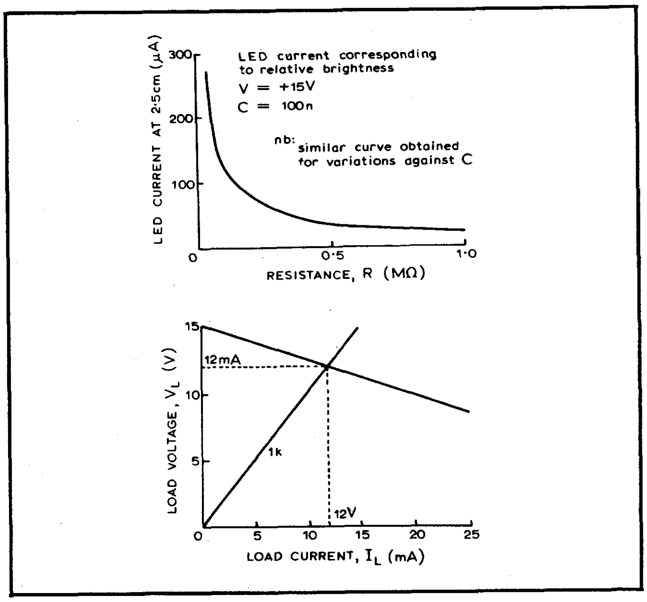




Integrated-circuit optoelectronic switch



Typical performance
High sensitivity:
R: 680kΩ, R_L: 1kΩ
C: 220nF
Supply: 15V
Ambient light excluded
Output switches for 150μA in l.e.d. (TIL209) at distance of 2·5cm with optimum alignment. With l.e.d. and IPL15 in contact (negligible leakage) switching initiated by <10μA in l.e.d.
Low sensitivity:
R: 100kΩ
C: 3.3nF
Switching at room ambient levels.
Load voltage on-condition: 12V
Load voltage off-condition: ≈0V



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.

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 47kΩ to 1.5MΩ
C 2nF to 2μF
R_L 330Ω to ∞
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 generation of a 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.

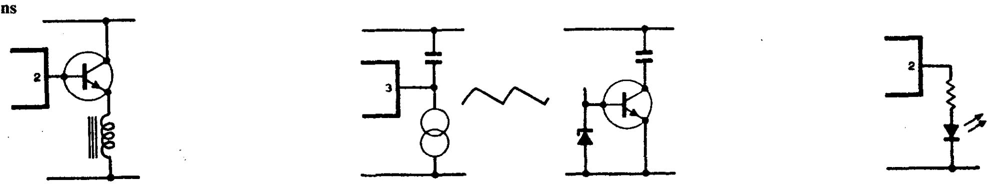
Further reading

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.

Circuit modifications



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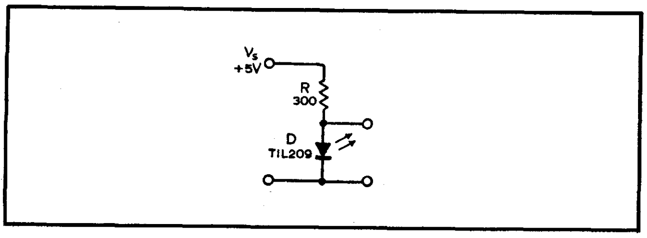
Series 9: Optoelectronics 5

Characteristics and applications of l.e.ds

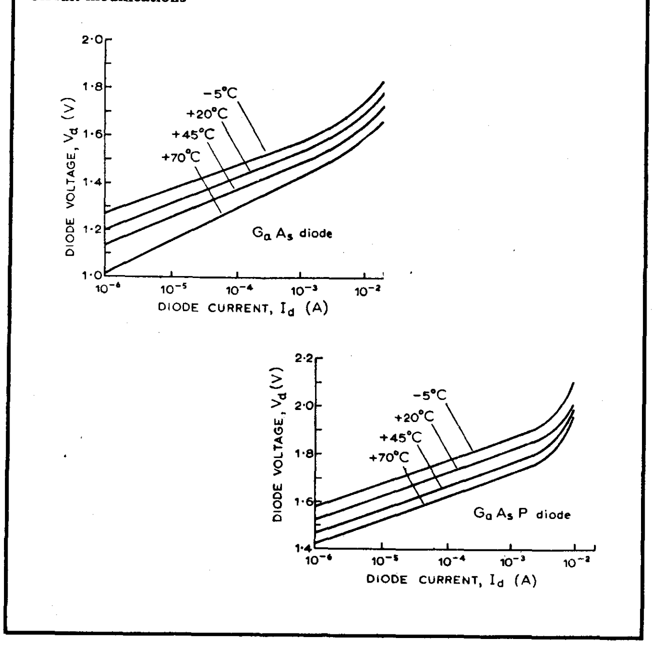


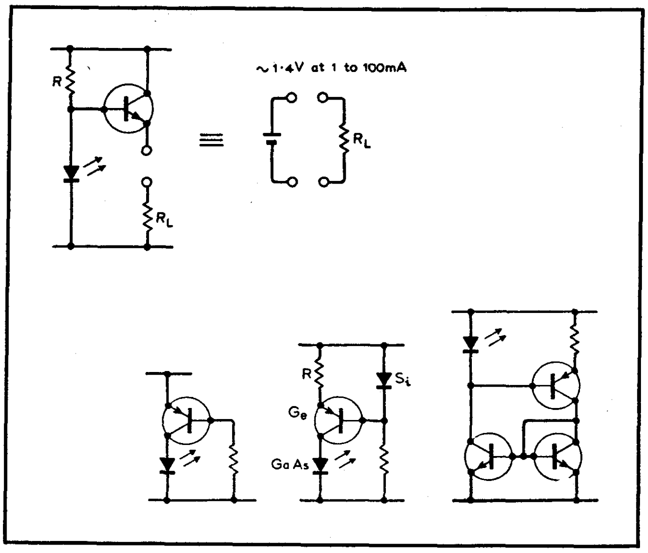
Circuit description

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 (≈ -2mV/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.

Circuit modifications





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 ≈10mA 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.

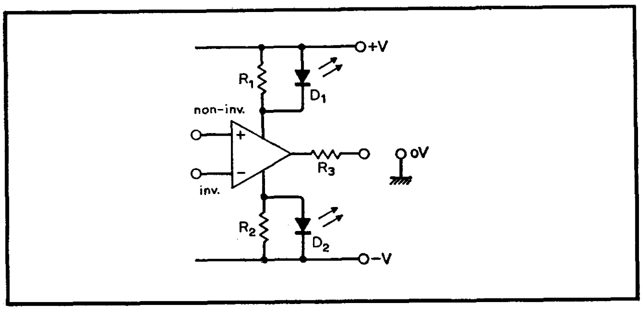
Texas Instruments, Measuring l.e.d. output, *Electronic Equipment News*, March 1971, pp. 24-8.

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.

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.

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.

Lamp control by op-amp difference mode

Supplies: ±15V, CM: ±12V

DM	R_3	D_1	D_2	Notes
+	0	on	off	L.e.d. current limited by op-amp s/c current limit
−	0	off	on	Current may be reduced by increasing R_3
+	$-V_s$	on	off	D_1, D_2 may glow for R_1, $R_2 > 150\Omega$
−	$-V_s$	off	off	
+	$+V_s$	off	off	
−	$+V_s$	off	on	
Difference mode voltage i.e. V non inv. −V 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: 220Ω R_2: 220Ω R_3: 220Ω D_1, D_2:TIL209

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.

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 500Ω). 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.ds with p.ds 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 150Ω to 1kΩ.

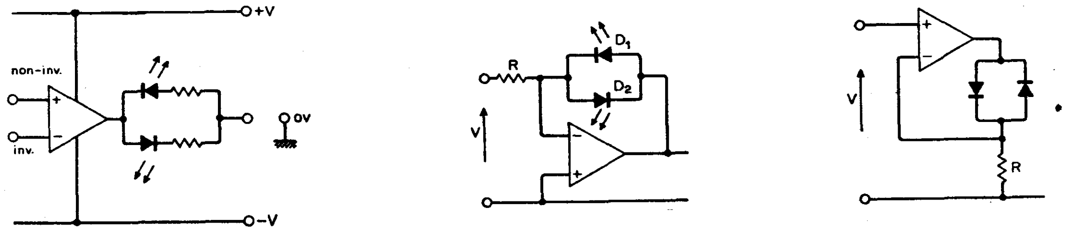
Circuit modifications

- 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 intput. 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.ds 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.ds but with a very high input impedance (above, right).

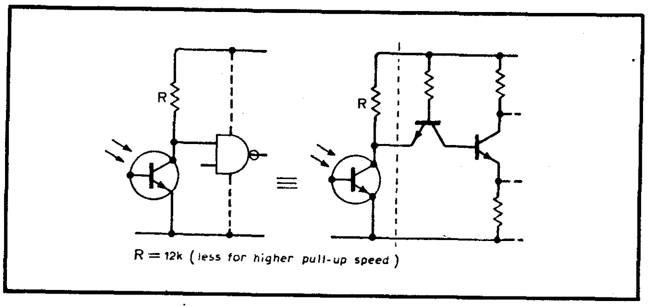
Cross references

Series 9, cards 2 & 11.

Circuit modifications

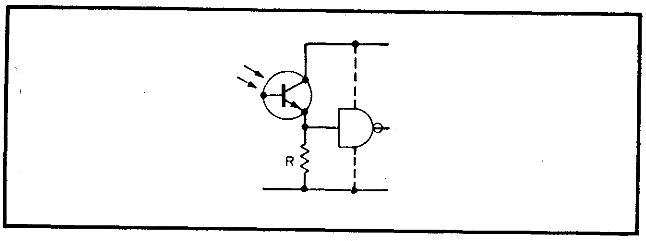


Phototransistor logic circuit drivers



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.os 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 locigal '0' when illuminated. This demands a higher light intensity for r.t.l. with the values given.

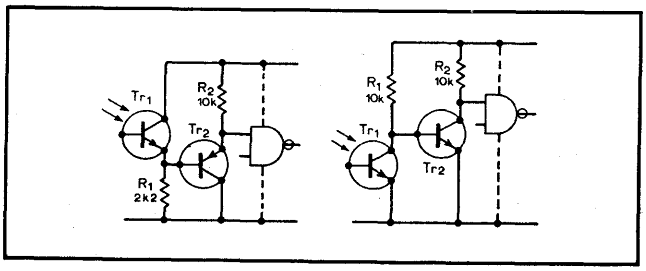


Circuit description

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 → 300Ω and requiring excessive current from the phototransistor as R → 0. With a negative rail the quiescent voltage at the gate may be zero, while the on-current required is minimized.

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

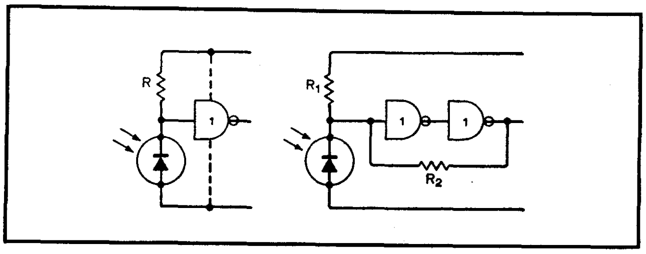
The input impedance of c.m.o.s. circuits is so high that photodiodes can readily produce enough current to give a high logic-level swing by choosing R large enough; e.g. $R = 1M\Omega$ requires a photocurrent of $< 10\mu A$ in diode for V_s of 10V. Diode speed can be high and R should be minimized to 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

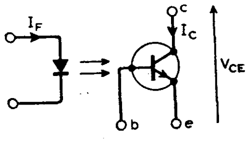
Korn, S. R., Photo Couplers, General Electric application note 200.62.

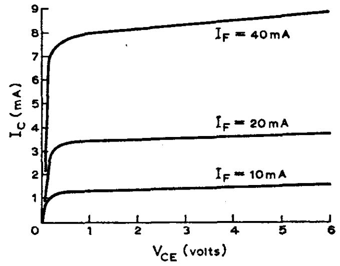
Cross references

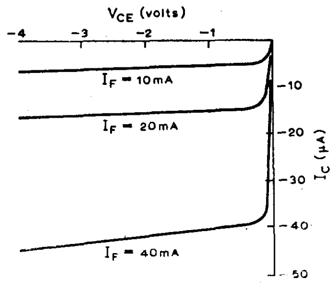
Series 9, cards 3, 8, 9 & 11.



Optically-coupled isolator: static characteristics



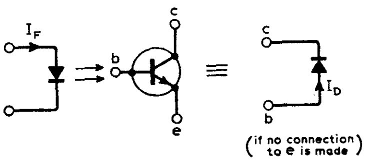




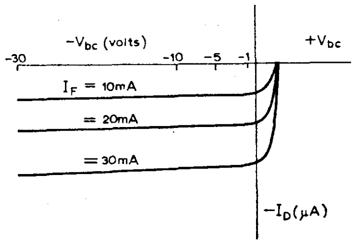
Component description using TIL112
Optically-coupled isolators are generally used for their isolation properties, replacing switches, pulse transformers, etc. Their output side may be simply a photodiode which is fairly fast, a phototransistor which is slower but has a higher output current (because 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 l.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).

Alternative components ISO-LIT12, MCT26, OP1032, OP1062.

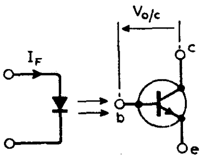
Photodiode operation

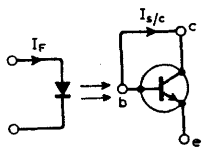


Photodiode characteristics

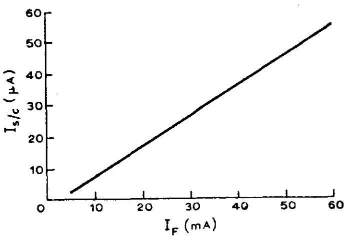


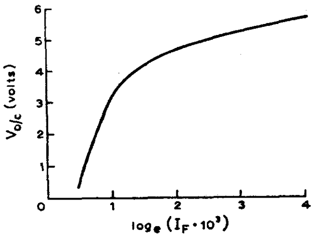
Photovoltaic operation





Photovoltaic characteristics





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

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

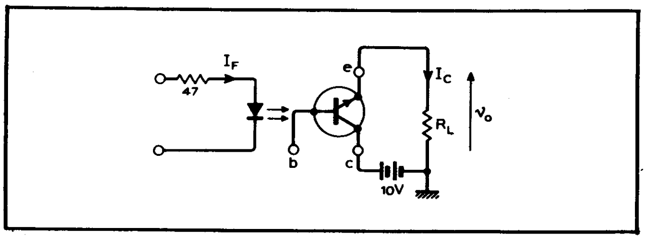
Further reading
Electronic Design, 1971, vol. 19, no. 11, pp. 44-55, and no. 12, pp. 46-52.

Cross references
Series 9, cards 3, 4, 7 & 10.

Wireless World Circard

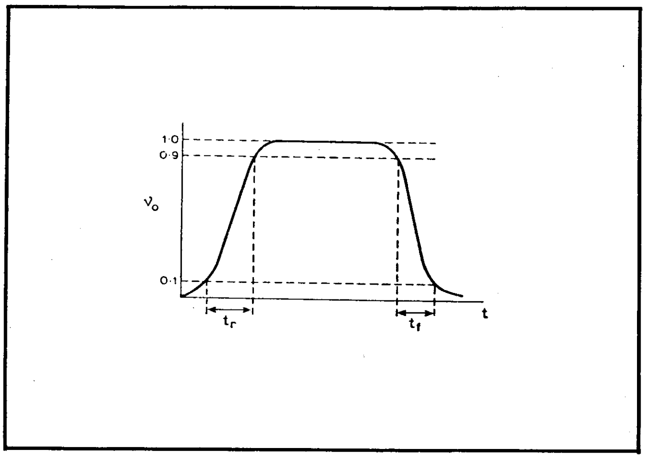
Series 9: Optoelectronics 9

Optically-coupled isolator: pulse characteristics



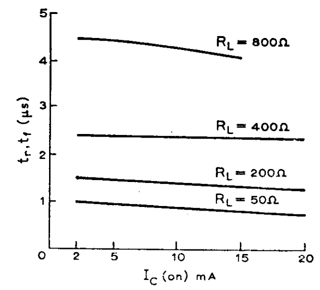
Measurement data
Phototransistor TIL112. V_o monitored on c.r.o. with 1MΩ, 28pF input impedance.

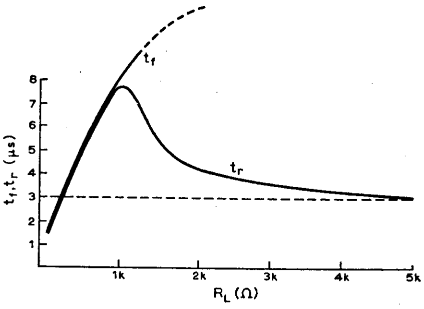
I_F generated from pulse source having 10ns rise and fall times when feeding 50-Ω load.

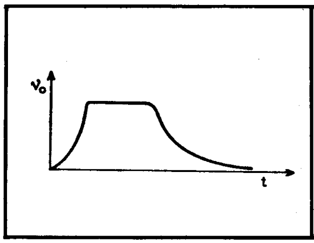


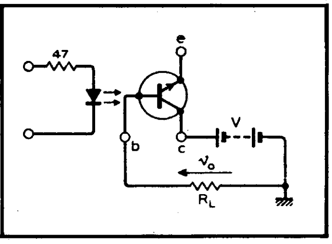
Experiment description
Graph top right was obtained by varying I_F to obtain particular values of I_C, and by deduction V_{CE}, and then measuring t_r and t_f. Values of t_f were identical, within experimental error, to the values for t_r. Clearly t_r and t_f are proportional, though not linearly, to 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 right 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.









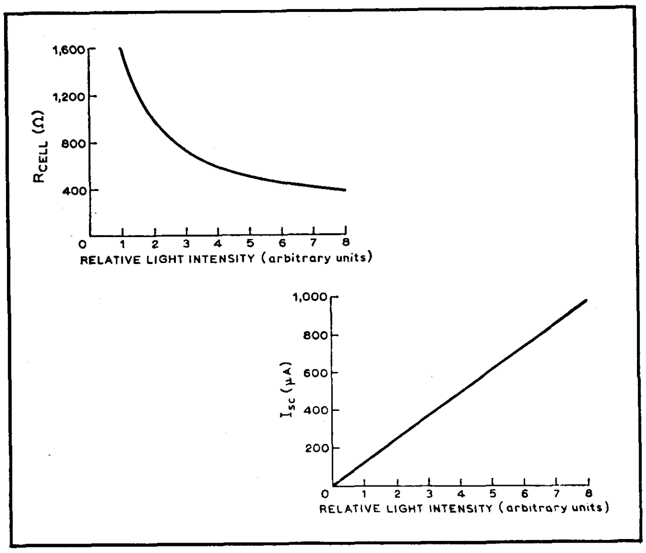
Alternative components
ISO LIT12, MCT26, OP1032, OP1062.

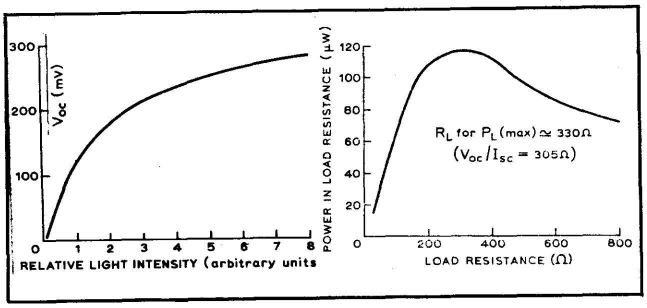
Photodiode operation, shown in above, provides smaller rise times (< 1μs) but generally smaller current capability since the load current is the transistor base current which is light-controlled. The maximum value of V is 30V and R_L can be increased until V_o is approximately equal to V. When feeding 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.

Photoconductive and photovoltaic cells

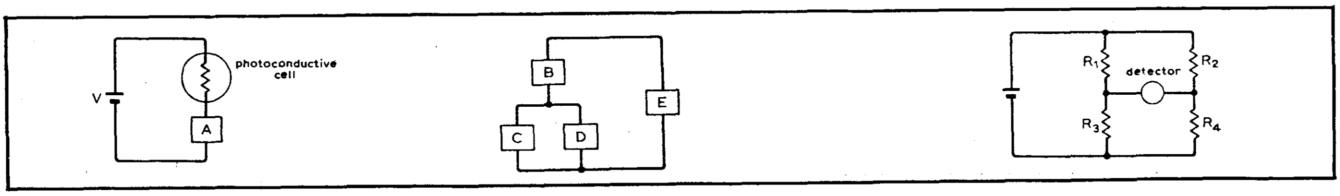




Typical characteristics
A photoconductive cell of the cadmium sulphide type behaves as an ohmic impedance which depends on incident illumination. Graph on left shows the variation of cell resistance as a function of light intensity to be $R_{\text{cell}} \propto 1/(\textit{light intensity})^n$ where 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 $R_{\text{Lopt}} = V_x/I_{sc}$ as predicted by linear circuit theory. However in practice, maximum load power is obtained with a resistance close to that predicted above.



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 micro-ammeter 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.

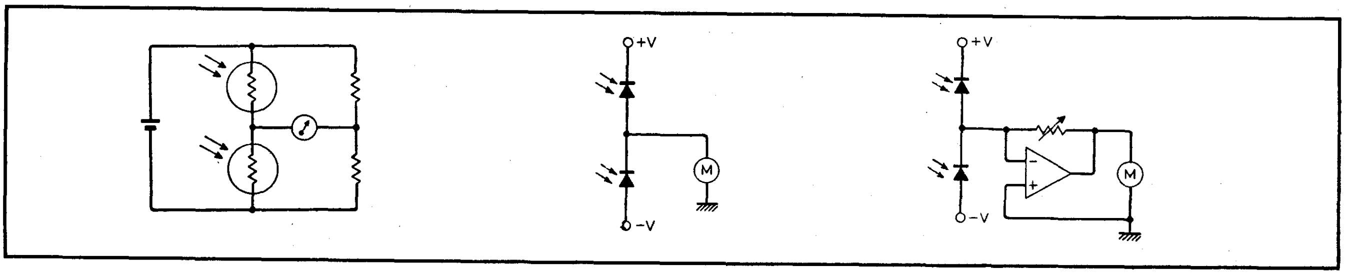
A second common arrangement is shown, middle, where E is normally a power source. With B as a resistor, C a relay coil and D a photoconductive cell, the latter shunts current from the relay until the light source is removed when the relay operates due to the increase in photocell resistance. If B is 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.

Cross references
Series 9, cards 8 & 11.

Light intensity measurement and detection

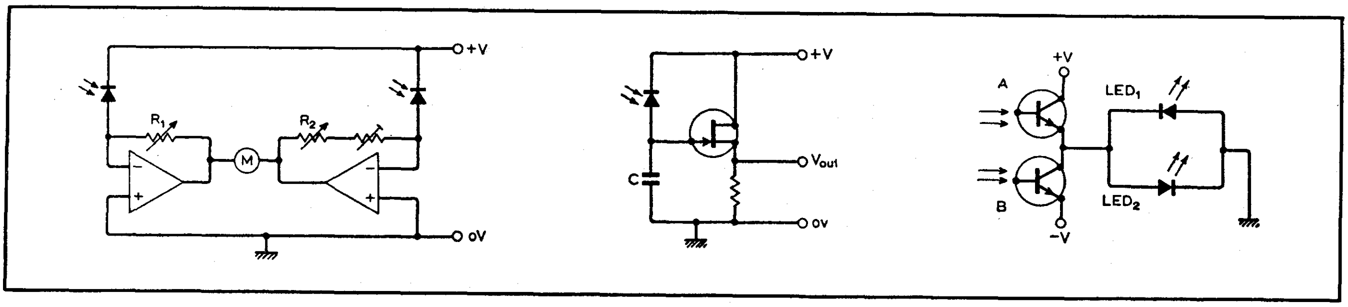


Light intensity measurement and detection
Circuit shows a normal Wheatstone bridge circuit where two resistors have been replaced by photoconductive cells of the cadmium sulphide type. If the two cells have accurately matched characteristics the bridge can be used to measure the relative light intensity 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 being 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.



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, and disturbing the integrating function, 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 l.e.ds are extinguished. Both l.e.ds 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.

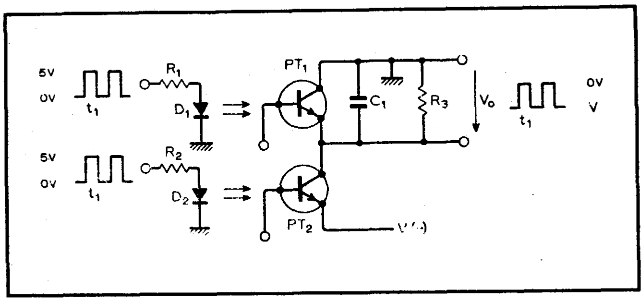
Vaisnys, A., LED-phototransistor coupler isolates analog signals, *Electronic Design*, 13 April, 1972. p.90.

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

Wireless World Circard

Series 9: Optoelectronics 12

Choppers and rectifiers



Typical performance

Opto-isolators TIL112
R_1, R_2: 100Ω; R_3: 10kΩ
C_1: 10pF
Drive frequency: 1kHz
Drive pulse height 5V
V: 10mV from 10−Ω source
V_o=10mV pk-pk, reading 5mV on r.m.s.-calibrated mean-rectified instrument.

With $V = 0$ volt d.c. measurement of V_o is 0.05mV and a.c. measurement is 0.13mV. With l.e.d. drive varying from 3 to 6V, meter change <1%. With drive at 5V and C_1 varying from 10pF to 0.01μF, meter change <2%. With drive at 5V and R_3 varying from 2 to 33kΩ. meter change <4%.

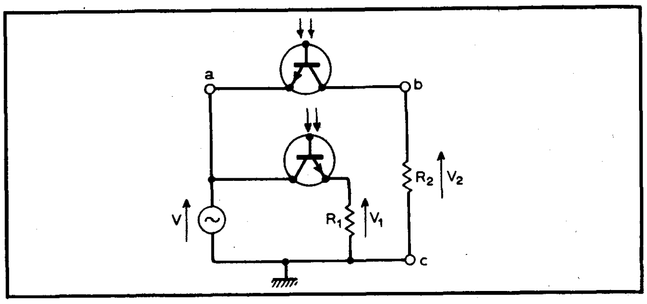
Circuit description

Circuit 1 shows a chopper circuit using a pair of opto-isolators 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.ds are driven in anti-phase 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 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.ds 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 $\overline{Q}$ 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.ts 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

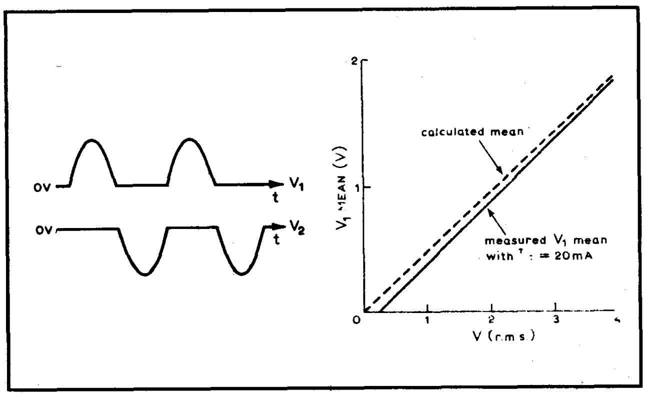
Pulse generator for diode emitters, W.W. 1972, p. 18.



Performance data

R_1, R_2: 1.5kΩ
V: 0 to 4V 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.

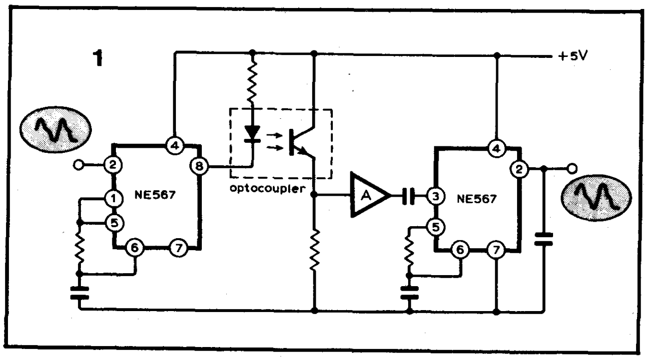
Wireless World Circard

Series 9: Up-date

Optoelectronics

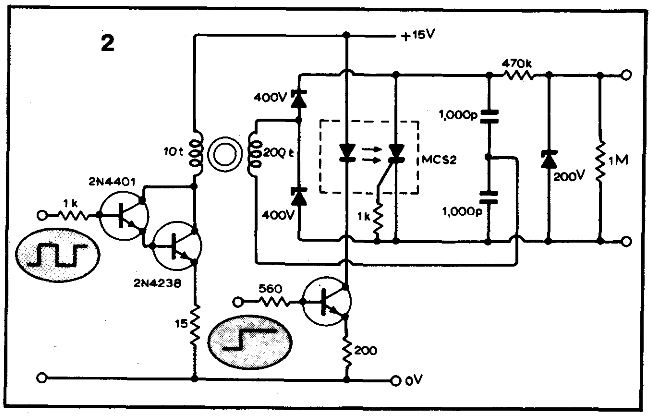
1. Transmission of analogue data via an optical link removes the problem of noise at the interface between two parts of a system due to earth loops, common supply lines etc. Alternatively it permits the two parts to be at quite different potentials. Non-linearities in the l.e.d. and phototransistor or in other transmitter/receivers distort the waveform, and a solution is to use a frequency-modulated carrier. In the example shown two phase-locked loop i.cs are used, one as a frequency modulator, using only the v.c.o. section, while the other demodulates the signal after transmission via the optical link.

Light-coupled isolator uses phase locked loops, *Electronic Engineering*, vol. 46, May 1974, p.19.



2. Complete isolation between drive circuitry and transducer is particularly important in medical electronics – in some cases primarily for safety reasons, in others where ground loops create difficulties. A pulse circuit is shown in which an electrode is fed by a section of a circuit having no power supply. A toroid is fed with short duration pulses, around 30μs, derived from a 555 timer (not shown). These are stepped up, rectified, filtered, regulated and, if required, attenuated. An inhibit pulse to the 555 can simultaneously operate the l.e.d. bringing the thyristor into conduction rapidly discharging the capacitors.

Sonsino, J. Toroid and photo-SCR prevent ground loops in high isolation biological pulser, *Electronics Design*, vol. 21, June 21, 1973, p.128.



3. The current in a correctly biased phototransistor is an almost linear function of the light intensity. If that current also flows in a capacitor then a linear ramp results. The circuit shown is a basic op-amp astable in which the bridge rectifier allows bidirectional current flow in the capacitor while restricting the phototransistor to unidirectional current.

With the given component values the reference article indicates a change in oscillator frequency from 50Hz to 50kHz for 0.02 to 20mW cm^{-2} of radiant energy from a tungsten lamp. Because of the almost constant current nature of the photo transistor aided by the small ramp size (small hysteresis) the capacitor waveform should be a rear-perfect triangular wave.

Miller, M. Introduction to Optoelectronics, ch. 17 in Semiconductor Circuit Design Vol. II, Texas Instruments, Ed. Norris, B.