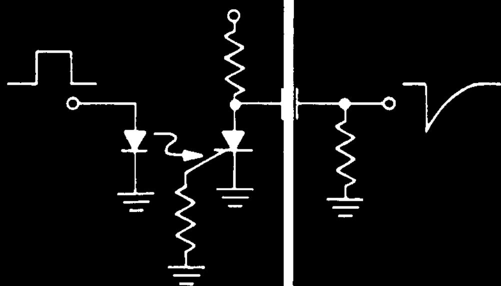
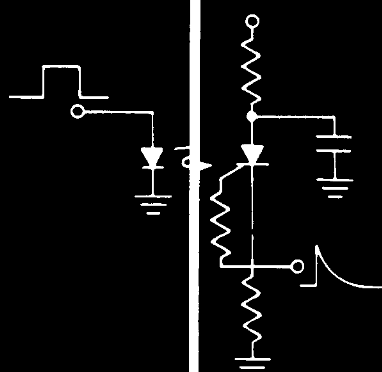
Monsanto GaAsLite Tips Vol. 1

(application information)





Monsanto

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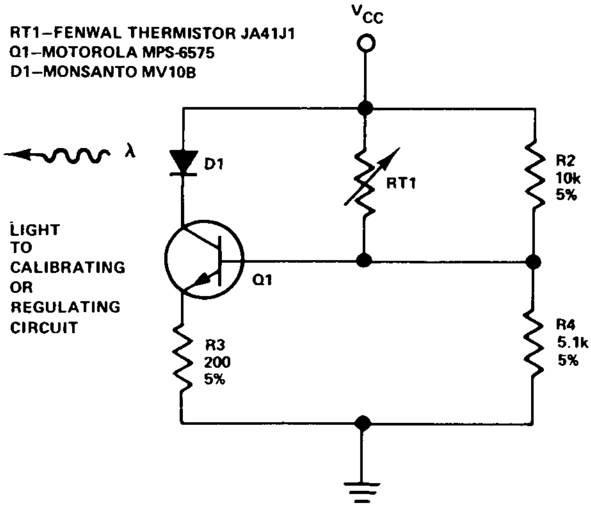
G. T. #

CONSTANT BRIGHTNESS LIGHT SOURCE

William Otsuka, Applications Manager
Monsanto Company, Cupertino, California



Constant brightness is a feature of this LED circuit which uses a thermistor to compensate the temperature coefficient of the diode.

LEDs have advantages as constant brightness sources

A light emitting diode (LED) can replace the incandescent lamp and provide constant brightness references for industrial equipment. The circuit shown combines good stability and control with low cost. Furthermore, there is no need to resort to optical feedback. Control is attained to ± 3% of the diode's brightness at ambient temperatures over the range from +10° to +50°C. Also, there is no need to compensate for aging or blackening as is the case with incandescent lamps.

The circuit relies on the stability inherent in solid state light sources as well as their long life. Unlike incandescent lights, light-emitting diodes do have thermal coefficients but they are predictable.

In the circuit shown, the thermistor, RT1, provides the necessary temperature compensation. The constant brightness circuit is driven from a regulated dc supply providing +12 volts. The forward current of diode D1 at ambient temperature is set by resistor R_3. Five percent tolerance resistors are sufficient for the 3 percent control this circuit provides.

The temperature characteristic of the light-emitting diode is improved at least one order of magnitude by the thermistor. The LED temperature coefficient is negative, and the diode's light output decreases with increases in temperature. However, increases in temperature also decrease the thermistor's resistance thus increasing the base drive of Q1 and, consequently, the diode current. As a result, the diode's light output remains constant over the temperature range. For falling temperatures, the forward current is lowered by the increase in the thermistor's resistance. In this manner, the current through the diode is reduced as the temperature decreases, and its light output again remains stable with temperature changes.

MODULATED IR BEAM CONTROL SYSTEM

R. C. Bach

INTRODUCTION

This is a description of an infrared transmitter and infrared receiver that uses Monsanto's light emitting diodes and detectors. This system detects and indicates the interruption of a beam of infrared light. It could count items on a conveyer belt, detect an intruder, automatically open doors, warn personnel of high voltage or high radiation; any application that uses an interrupted beam.

DESIGN

A design requirement was that the system be difficult to jam. The simplest solution to this problem is a pulsed light system that uses disturbances for resetting, rather than triggering. To achieve this, a missing light pulse counting circuit is used. Another requirement is, of course, economy.

THE TRANSMITTER

Figure 1 and figure 2 is the schematic of the infrared transmitting portion of this system. The Monsanto ME 5 infrared emitting diode is pulsed every 16.7 msec to a current magnitude of one ampere for a duration of about 1.5 msec. This is about a 10% duty cycle. At this level it is not necessary to use a heat sink on the ME 5. Also, a lens is not necessary if the distance the light is transmitted is 30 feet or less.

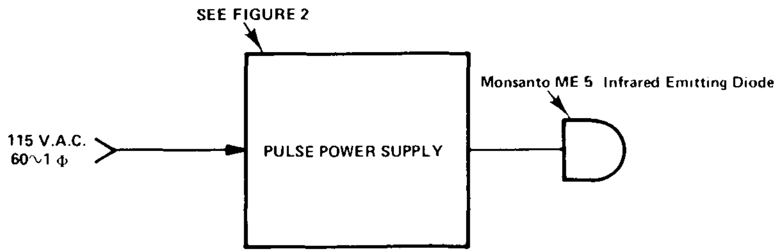
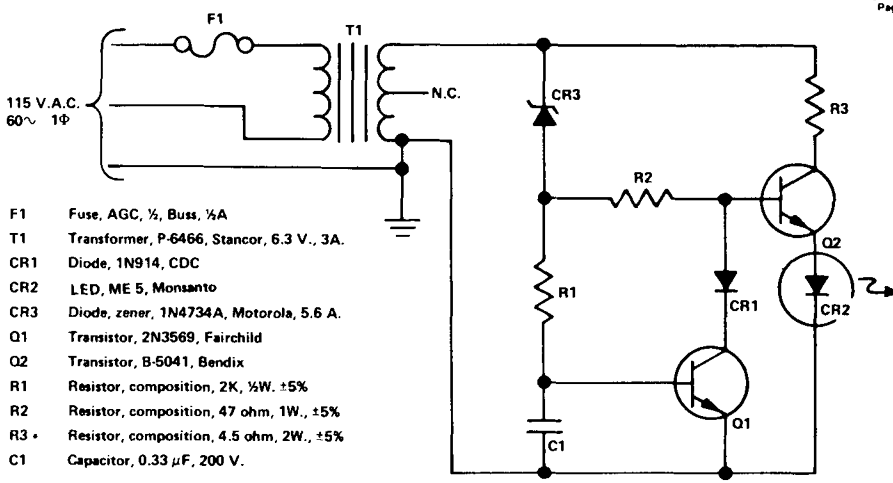


FIGURE 1 INFRARED TRANSMITTER

In figure 2, pulse width between the limits of 0.5 and 5.0 msecs is directly proportional to the capacitance of C1. Pulse magnitude between the limits of 0.3 and 3.0 amps is inversely proportional to the resistance of R3



F1	Fuse, AGC, ½, Buss, ½A
T1	Transformer, P-6466, Stancor, 6.3 V., 3A.
CR1	Diode, 1N914, CDC
CR2	LED, ME 5, Monsanto
CR3	Diode, zener, 1N4734A, Motorola, 5.6 A.
Q1	Transistor, 2N3569, Fairchild
Q2	Transistor, B-5041, Bendix
R1	Resistor, composition, 2K, ½W. ±5%
R2	Resistor, composition, 47 ohm, 1W., ±5%
R3 •	Resistor, composition, 4.5 ohm, 2W., ±5%
C1	Capacitor, 0.33 μF, 200 V.

• 2 each 9.1 ohm, 1W.

FIGURE 2 PULSE POWER SUPPLY

THE RECEIVER

Figures 3 through 7 are the schematics of the receiving part of this system. The Monsanto MD 2 photodiode shown in figure 4 is the receiving device for the pulsed infrared light produced by the ME 5 emitter. Figure 5 shows the amplifier (Q1) necessary to amplify the signal received and convert it to a saturated logic signal (Q2). This logic signal is used to reset the lockout counter and after being pulse-stretched, (Q1,C1,AR1, in figure 6) is displayed by the two Monsanto MV10A visible red light emitting diodes (LEDs). These LEDs not only indicate beam interruption but act as an aid in the initial test and alignment of the system. The counter (AR2, in figure 7) is being driven by the circuit shown in figure 8. The basic operation is this: the counter is counting 60 cycle (line frequency) pulses. If allowed to count to nine (16.7 msec x 9 = 0.15 sec) it will trigger the relay circuit shown in figure 5. Notice that K1 is normally energized and not self-holding.

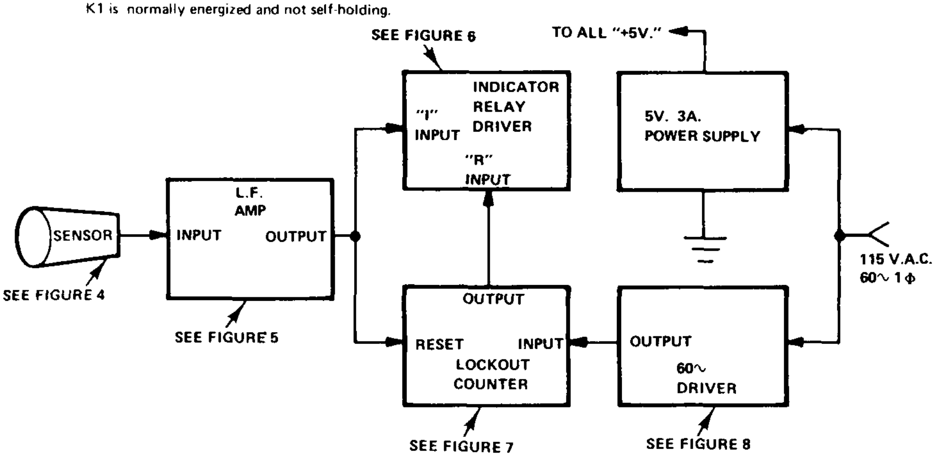
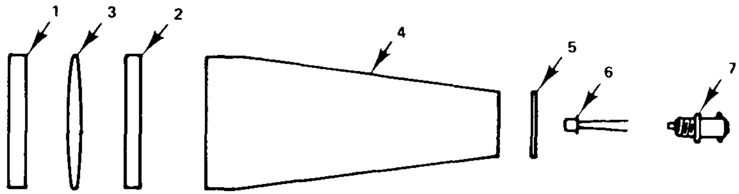


FIGURE 3 INFRARED RECEIVER



1	Bezel, CP1110P2, JAN Hardware, (see Appendix A)
2	Bezel, CP1110P2, JAN Hardware, (see Appendix A)
3	Lens, 85645, No. 6 Double Convex, Central Scientific Co., (see Appendix B)
4	CRT shield, S2001-1, JAN Hardware, (see Appendix C)
5	Mounting plate, rear, 1/8 inch, aluminum
6	Photodiode, MD 2, Monsanto
7	Connector, UG/657/U, Amphenol

NOTE

The sensor is connected to the L.F. amplifier by a 93 ohm coaxial cable, Textronix Inc. Part number 012-0075-00.

FIGURE 4 SENSOR

R1	Resistor, composition, 5.1 meg., ½W., ±5%
R2	Resistor, composition, 10 k., ½W., ±5%
R3	Resistor, composition, 510 k., ½W., ±5%
R4	Resistor, composition, 1 k., ½W., ±5%
Q1-Q2	Transistor, MPS-6575, Motorola
J1	Connector, UG/657/U, Amphenol
C1	Capacitor, disc, 0.01 μF, 100 V.
C2	Capacitor, disc, 0.02 μF, 100V.
C3	Capacitor, disc, 200 pF, 1000 V.

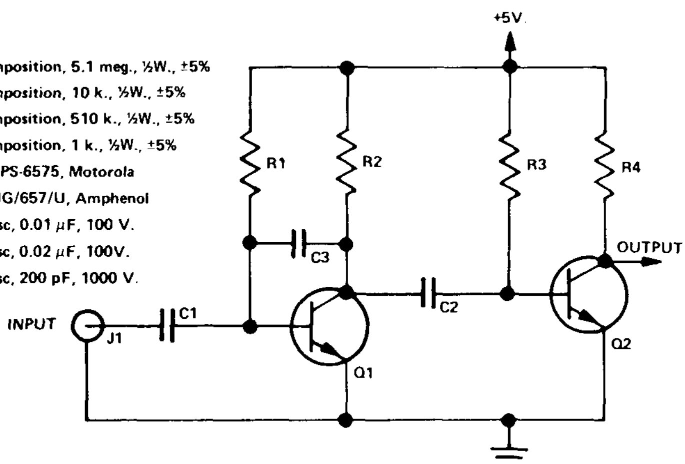
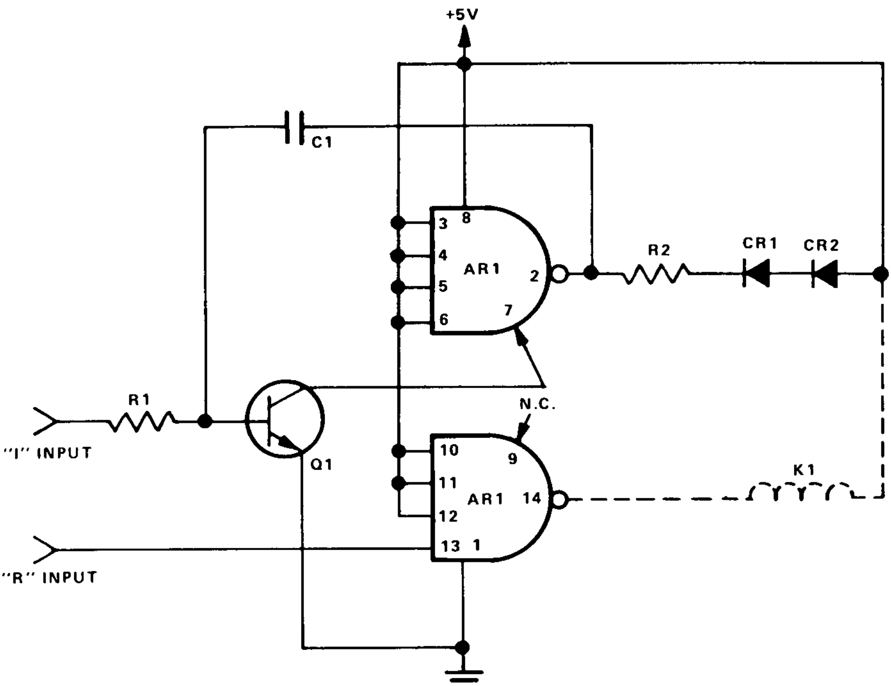
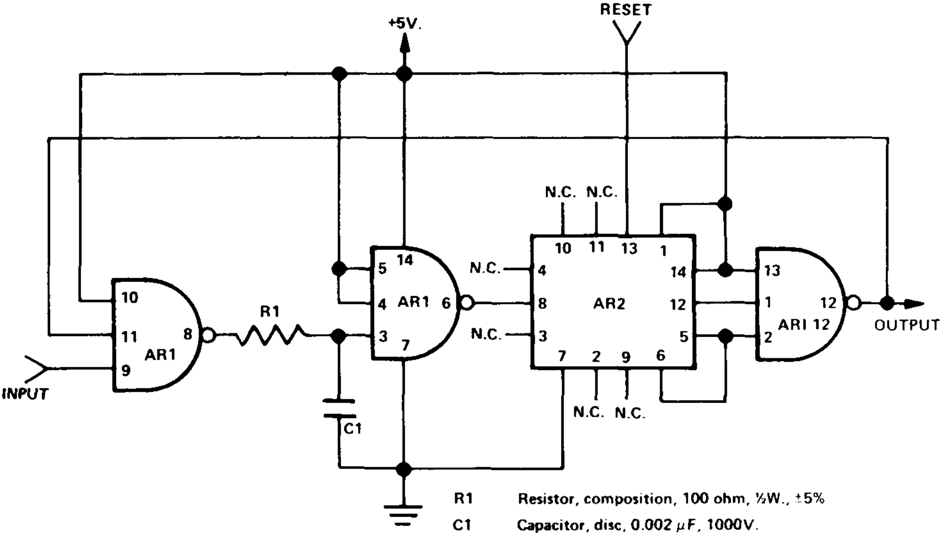


FIGURE 5 GENERAL PURPOSE L.F. AMPLIFIER FOR MD 1 TO I.C. LOGIC INTERFACE



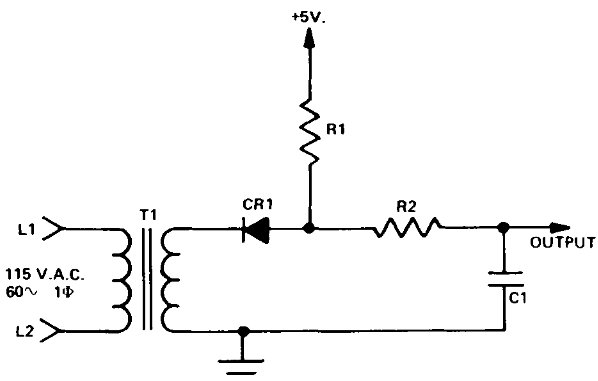
R1	Resistor, composition, 10 k, ½W., ±10%
R2	Resistor, composition, 39 ohm, ½W., ±10%
C1	Capacitor, disc, 0.2 μF, 100 V.
CR1, CR2	LED, MV 10A, Monsanto
AR1	Line Driver, 356A, Signetics
Q1	Transistor, 2N3569, Fairchild
K1	Relay (up to 40 mA)

FIGURE 6 INDICATOR–RELAY DRIVER



R1	Resistor, composition, 100 ohm, ½W., ±5%
C1	Capacitor, disc, 0.002 μF, 1000V.
AR1	NAND Gate, Trip. 3-in, 8470A, Signetics
AR2	Decade Counter/Storage Element, 8280A, Signetics

FIGURE 7 LOCKOUT COUNTER



T1	Transformer, P-4026, Stancor
CR1	Diode, 1N914, General Electric
R1	Resistor, composition, 1K, ½W., ±5%
R2	Resistor, composition, 390, ½W., ±5%
C1	Capacitor, disc, 0.05 μF

FIGURE 8 GENERAL PURPOSE DRIVER FOR I.C.
60 CYCLE LOGIC

ECONOMICS

The estimated cost of this system is based on the following:

- Material cost only - less Monsanto components.
- Components purchased in small quantities at wholesale prices.
- Components purchased are of industrial grade; not MIL or JAN.

Transmitter cost	$10.00 (less Monsanto's MD 2 and MV 10A)
Receiver cost	$50.00 (less Monsanto's ME 5)

APPENDIX

The system described here was demonstrated at WESCON 1969 by Monsanto's Electonic Special Products group. The transmitter and detector were 25 feet apart in a high ambient light. Spanning distances can be increased by possibly a decade by some, or all of the following:

- Increasing the infrared output of the transmitter by providing lens for the ME 5 or by increasing the pulse current of the ME 5
- Increasing the sensitivity of the receiver by adding a better lens to the ME 2 or by minor redesign of figure 2 so that a phototransistor may be used instead of the MD 2. However, if receiver sensitivity is increased a filter for visible light may be required.

G.T. 4

PHOTO SCR COUPLED PAIR

R. A. Hunt Sr.

INTRODUCTION

The advancements made in the last few years in light emitting diodes (LED) has opened a new field in optoelectronics. One of the applications is to couple a LED to a photo detector. The advantage of a coupled pair is the electrical isolation between the input and the output. Isolation between input and output is 10^{11} ohms with 2,500 volts breakdown and 3-picofarad coupling capacitance.

Monsanto Company offers coupled pairs with a photo resistor (MCR1), Si Pin photodiode (MCD1), phototransistor (MCT1), and photo SCR (MCS1) as a detector. Information on the MCR1, MCD1, MCT1, is readily available.

The photo SCR (MCS1), the latest addition to the line, has new and varied advantages. The MCS1 coupled pair is intended for applications where complete electrical isolation is required between low power circuitry such as integrated circuits and AC line voltages providing high speed switching or relay functions. Its bi-stable characteristics lends itself for use as a latching relay in direct-current circuits.

Because of the high current carrying capabilities of the MCS1, it can directly activate solenoids, motors, lamps, and other 120 volt AC loads. It can be used as a SPST relay with no contact bounce, microsecond response and solid state reliability. With its latching properties it can be used as an overload or protection device which requires manual reset. Some other applications are: general-purpose switching, phase control, logic functions, sample and hold switches, power distribution control, medical instrumentation, and power supply controls.

CHARACTERISTICS

The photo SCR is a latching (holding) device in a direct current giving it a build-in memory. It is a p-n-p-n switching device where the light intensity above the triggering level does not control the output current. In the off state the impedance of the SCR is over 10 megohms, in the on state it is less than 10 ohms

The current required in the LED to turn on the photo SCR is typically 4 mA. Figure 1 shows the delay between the turn-on of the LED and the turn-on of the SCR. The delay time can be reduced by increasing the LED driving current. When the LED current is at a minimum, the delay is typically 50 microseconds. By increasing the LED current this can be reduced to less than two microseconds. The rise time of the SCR is typically 50 nanoseconds and does not change with changes in LED driving current. The value of R_{GK} determines the sensitivity and holding current (I_H) of the SCR (Figures 2 and 3).

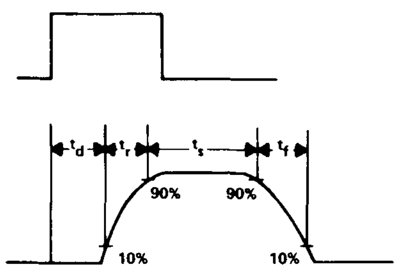


FIGURE 1 DELAY TIME BETWEEN INPUT AND OUTPUT PULSE

The power dissipation rating is a maximum of 250 mW at 25°C ambient and derates linearly at 3.30 mW/°C. The maximum DC load current cannot exceed 200 mA at 25°C. The maximum peak current depends on the duty cycle so as to stay within the average power rating of the device.

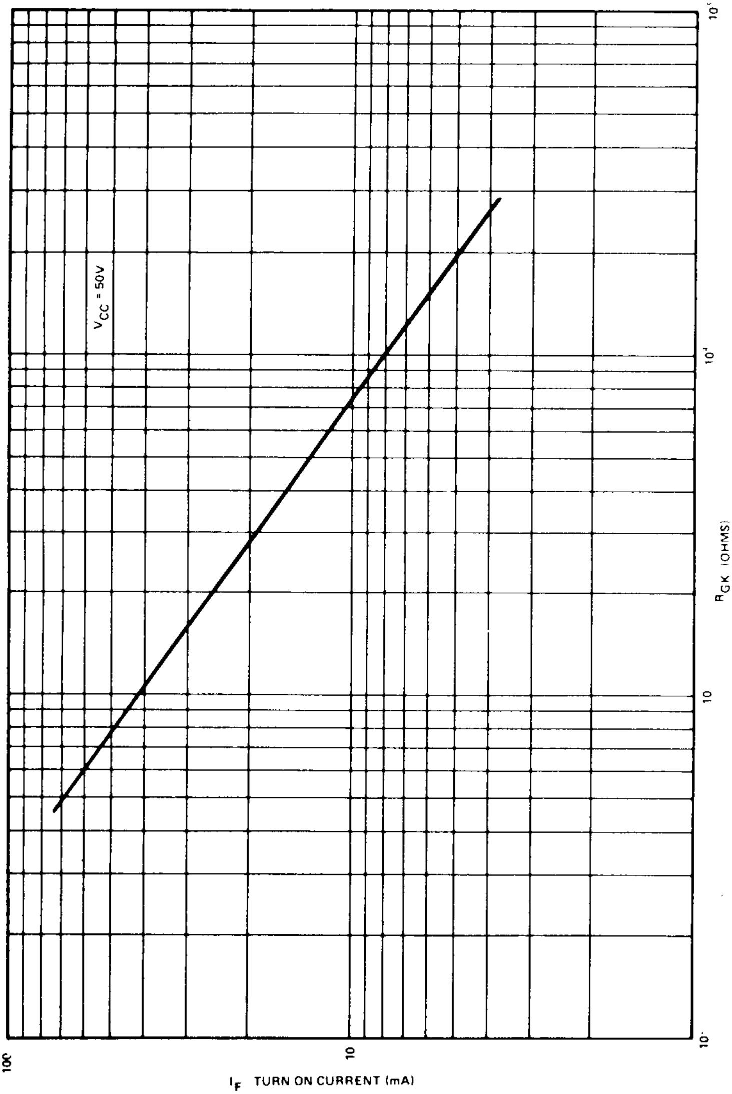


FIGURE 2 SCR SENSITIVITY

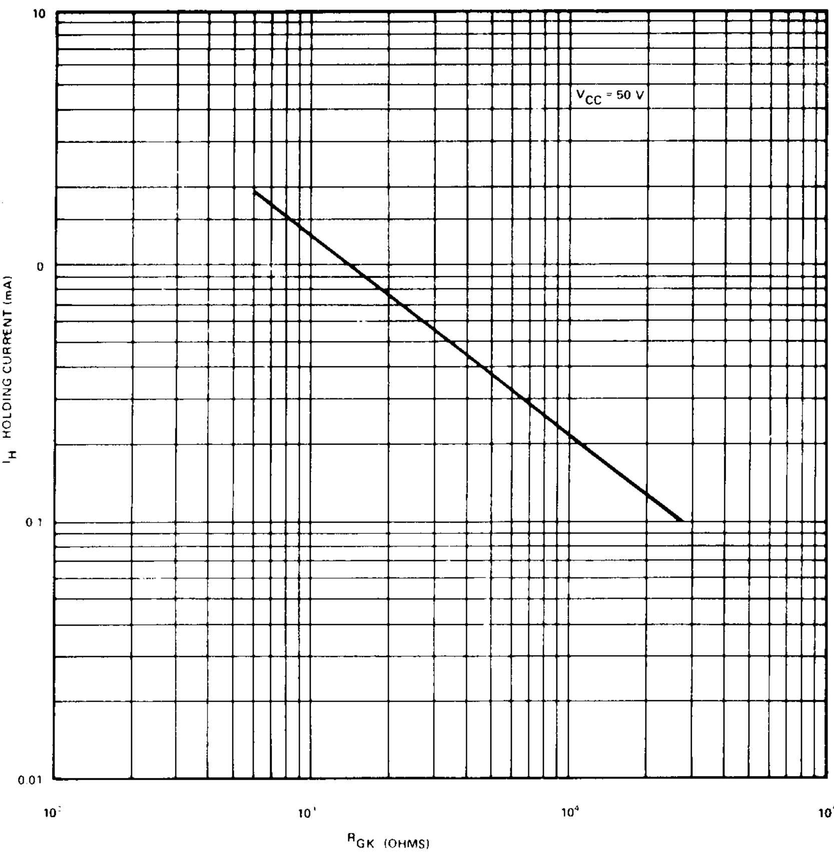


FIGURE 3 SCR SENSITIVITY

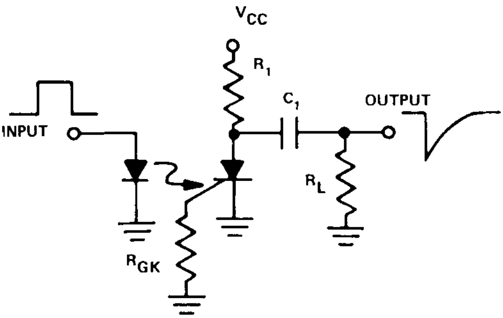


FIGURE 4A NEGATIVE OUTPUT PULSE

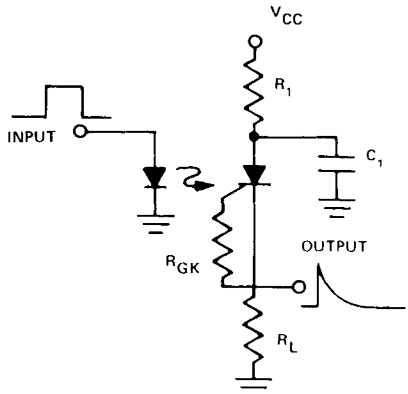


FIGURE 4B POSITIVE OUTPUT PULSE

CIRCUIT

The circuits shown in figure 4 can be used for pulsing applications where a positive or negative pulse is required. With the SCR "off" the capacitor C_1 will charge up to the applied voltage. The charging current must be less than the holding current to keep the device off. With a pulse applied to the LED, the SCR will turn on and the capacitor C_1 will charge through R_L. The pulse width and amplitude will be controlled by the value of R_L and C_1. The maximum repetition rate is determined by the R_1 C_1 time constant. To increase the repetition rate, a transistor can be added as shown in figure 5. The transistor Q_1 will supply a low resistance path for C_1 to charge up to the applied voltage. The SCR turn on, C_1 discharge, and the voltage drop across D_1, will reverse bias the base to emitter junction leaving only R_1 between the SCR and the power supply.

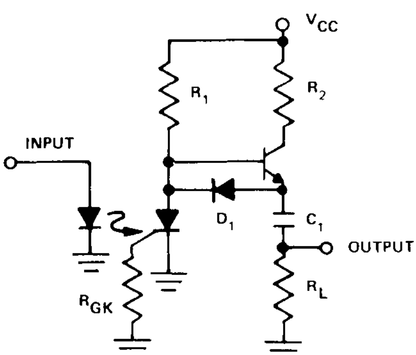


FIGURE 5 HIGH REPETITION RATE PULSE GENERATOR

The circuit shown in figure 6 uses the latching properties of the SCR. With the signal applied to the LED, the SCR will turn on and deliver to the load and will continue to conduct with no signal on the LED. The SCR is turned off by the reset switch.

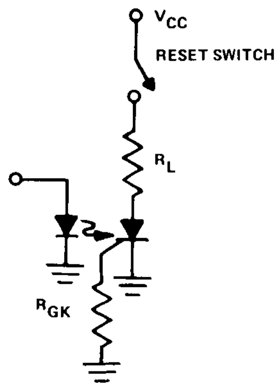


FIGURE 6 LATCHING RELAY

The SCR can be used with AC as well as DC. With AC, the device will block during the positive cycle with no signal applied to the LED. With a signal applied, the SCR will conduct during the positive cycle, and will act as a blocking diode during the negative cycle. The device will have to be retriggered before it will conduct during the next positive half cycle.

Figures 7A and 7B use an AC source and will provide half-wave rectified DC to the load with an applied signal and no output with no signal applied.

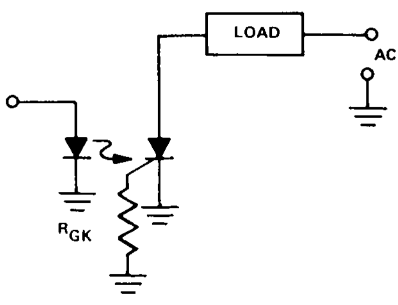


FIGURE 7A RECTIFIER

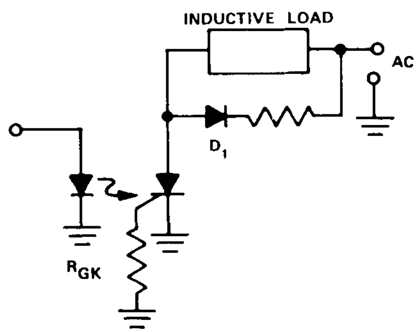


FIGURE 7B RECTIFIER WITH INDUCTIVE LOAD

The diode D_1 in figure 7B is used with inductive loads to allow the stored coil energy to circulate current through the load while the SCR blocks the negative half-cycle.

Figure 8 is a circuit which can deliver power to load number 1 with the LED off and can deliver power to load number 2 with an applied signal.

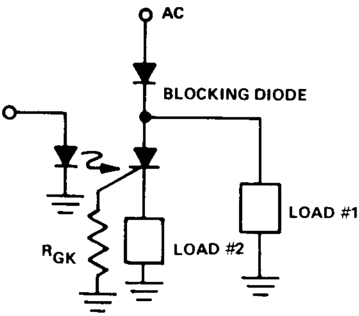


FIGURE 8

Figure 9 uses a diode bridge to convert the AC supply to fullwave rectified DC. The load may be placed in the AC or DC leg of the bridge.

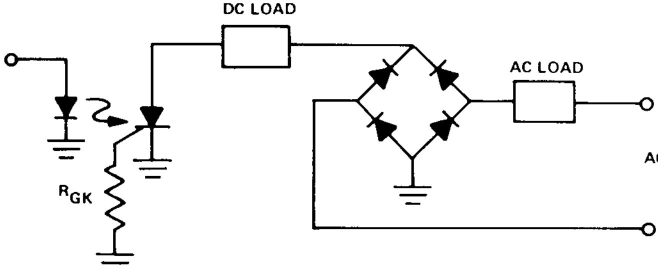
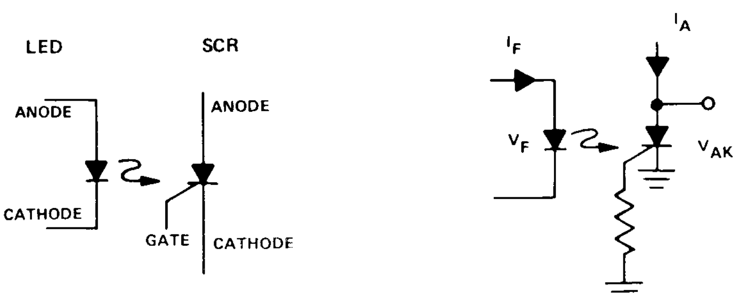


FIGURE 9



ELECTRICAL SYMBOLS

DEFINITIONS

LED

I_F	Forward current The forward current carried by the LED
i_F	Peak forward current The instantaneous forward current of the LED
V_F	LED on voltage The forward voltage drop across the LED in the "on" condition
V_R	Reverse voltage The maximum reverse voltage that may be applied to the LED
I_R	Reverse current The maximum reverse current that may be applied to the LED

SCR

I_A	Forward On Current The forward current flowing in the SCR from anode to cathode
I_A	Peak forward current The instantaneous peak forward current from anode to cathode
I_{AX}	Forward blocking current The current through the device when it is off from anode to cathode
V_{AX}	Forward blocking voltage The forward anode voltage when the device is off
V_{AK}	Anode on voltage The forward voltage drop across the SCR from anode to cathode in the on state
I_{AX}	Reverse blocking voltage The reverse anode voltage when the device is in the reverse blocking state
I_H	Holding current The minimum current through the device to maintain it in the on state
R_{GK}	Gate bias resistor The value of resistor connected between gate and cathode
t_d	Delay time The time interval required for the LED input pulse to reach 10% of its maximum value and the output pulse to reach 10% of its maximum amplitude.
t_r	Rise time The time required for a pulse to rise from 10% to 90% of maximum value
t_f	Fall time The time required for a pulse to fall from 90% to 10% of maximum value
t_{on}	Turn-on time The sum of the delay time and rise time.

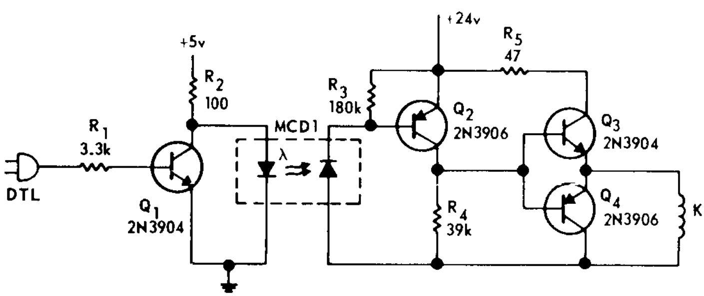
PHOTODIODE COUPLED PAIR ISOLATES DTL FROM A RELAY

William Otsuka

Many undesirable effects such as ground currents and spikes can arise in relay circuits. Photodiode coupled pairs eliminate many of these nuisances. ground currents are nonexistent since the relay needs no ground. In addition, the optical coupling provides a high isolation resistance of 100 gigohms between the diode-transistor logic and the relay circuit which does away with troublesome relay noise and spikes.

The light-emitting diode portion of the coupled pair is driven by an input signal which produces light whose intensity is proportional to the signal current. The photons are transmitted to the photodiode detector via a light pipe. Any variation in the input signal produces a proportional change at the output of the photodiode, which is normally operated with reverse voltage bias to provide the required voltage swing.

When the output signal of the diode-transistor logic is high, Q_1 is turned on, and no current flows in the light-emitting diode. No light to the detector causes the photodiode to be at its maximum impedance of 5 gigohms. Therefore, Q_2 cannot conduct, which in turn prohibits Q_3 from conducting. Since Q_3 provides the current path for relay K_1, the relay will not be energized. When the output of the DTL goes low, the circuit response is so fast K_1 energizes in a time virtually dependent on the mechanical relay response alone.

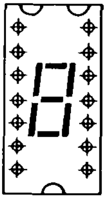


RELAY CHARACTERISTICS:
COIL IMPEDANCE = 400 Ω
ACTUATING CURRENT = 55 ma

Reprinted from **Electronics**, July 21, 1969

MULTIPLEXING AND INDIVIDUAL ADDRESSING THE MAN 1 SEVEN-SEGMENT DISPLAY

R. T. Gill



The MAN 1 is a seven-segment alpha-numeric display. It is made from a Gallium Arsenide Phosphide (GaAsP) semiconductor with a peak emission wavelength of 6500 A. The MAN 1 has a common anode construction with a 1/4-inch high character size and a standard 14 pin dual-in-line pin configuration. The display is compatible with integrated circuits.[1]

MULTIPLEX OPERATION FOR THE MAN 1

Through multiplexing techniques only one decoder/driver is used to drive up to 16 MAN 1 displays. The multiplex system becomes more economical than the individual approach for instruments with many readout digits. The economic crossover point is 6 digits, however system economics is dependent on IC pricing. As the number of digits increases, the multiplex system becomes more economical.

The following discussion is a detailed explanation of the multiplexed operation for the Monsanto MAN 1 display. The circuit shown will multiplex 8 displays and can be expanded to 16 by adding an additional anode decoder driver. The maximum forward voltage for the MAN 1, when used in multiplexed operation, is 3.4 volts at 20 mA.

The 32 bit shift register is loaded from the main memory with the coded numbers to be displayed by each MAN 1 (see figure 1). The write-information input set to a logic "O" level (gate 2) allows the words in the main memory to be shifted into the 32-bit register. At the same time, the write-information has enabled the ÷32 counter and it is counting the main system clock. After 32 counts, the display input is set to logic "O" (gate 1) inhibiting any further counter advancement or shift register loading. This also gates (gate 3) the 1.9 KHz oscillator on, thus cycling the 32-bit shift register. Simultaneously the divide-by-4 counter is activated. After each 4th oscillator clocking pulse, the digit word counter is advanced one count, this in turn will advance the anode driver to the next numeric. The 32-bit shift register is circulating the 8 BCD coded words that are to be displayed. The BCD information from the 32-bit shift register is decoded by the segment decoder, which drives the cathodes of all the MAN 1 displays simultaneously.[2]

The eight MAN 1 displays are wired in parallel and decoded by a single, seven-segment decoder (type 7448 or equivalent[4]). Each numeric has its own anode driver transistor (2N4355; total of eight). The transistor is controlled by the output of the anode decoder (see figure 2). The anode driver transistors must handle the peak desired current for each MAN 1 display. All of the MAN 1 display segment cathodes are wired in parallel through the drive transistor (2N3569, total of seven). The seven segment decoder addresses all of the MAN 1 displays simultaneously, but only one digit lights because only one has V_{CC} applied through the anode decoder/driver. The segment driver transistor must be capable of handling the peak current desired for each segment. The circuit shown in figure 2 is designed for a peak current of 80 mA per segment.

The 1.9 KHz oscillator provides a 60 Hz signal to each individual MAN 1. This frequency is fast enough to keep the viewer from noticing any flicker.

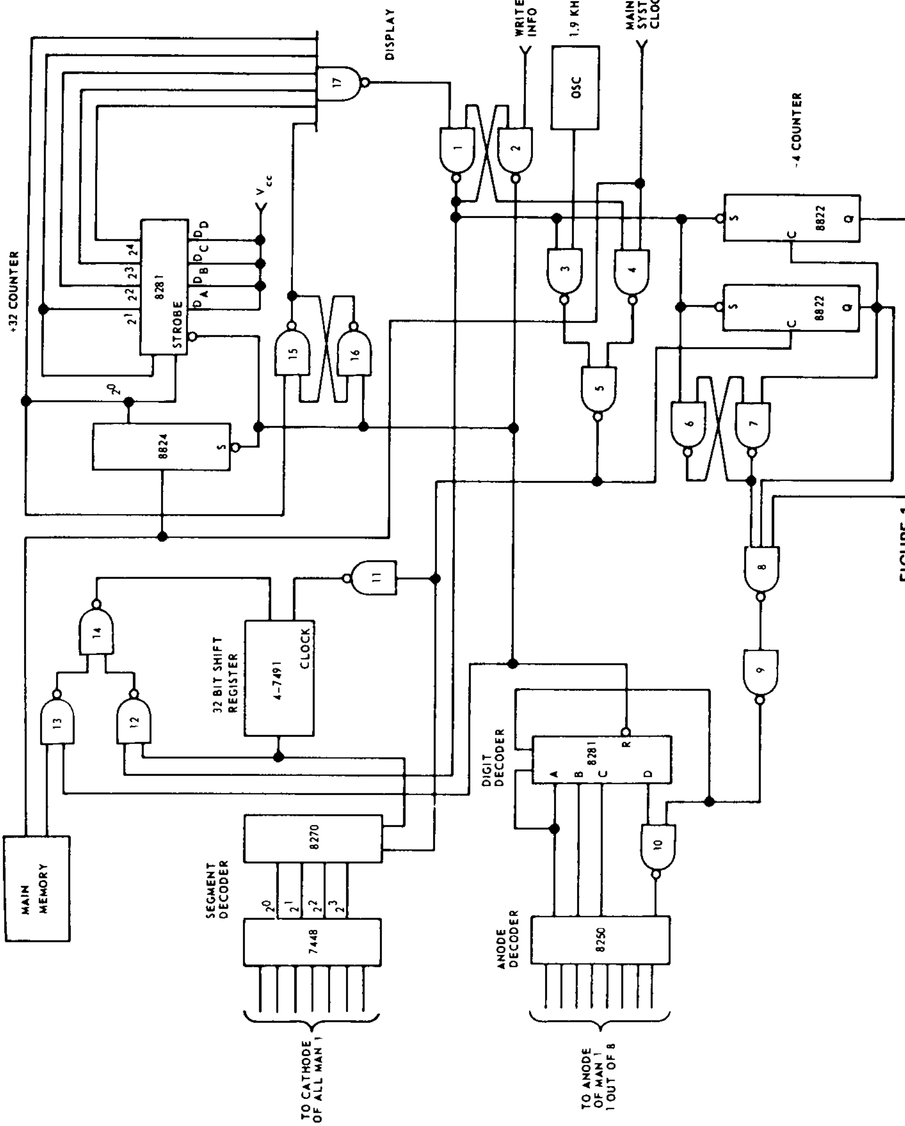

÷32 COUNTER
DISPLAY
WRITE INFO
1.9 KHz
OSC
MAIN SYSTEM CLOCK
÷4 COUNTER
8281
STROBE
Vcc
8824
8822
8822
32 BIT SHIFT REGISTER
4-7491
CLOCK
MAIN MEMORY
SEGMENT DECODER
8270
7448
TO CATHODE OF ALL MAN 1
DIGIT DECODER
8281
ANODE DECODER
8250
TO ANODE OF MAN 1 1 OUT OF 8

FIGURE 1

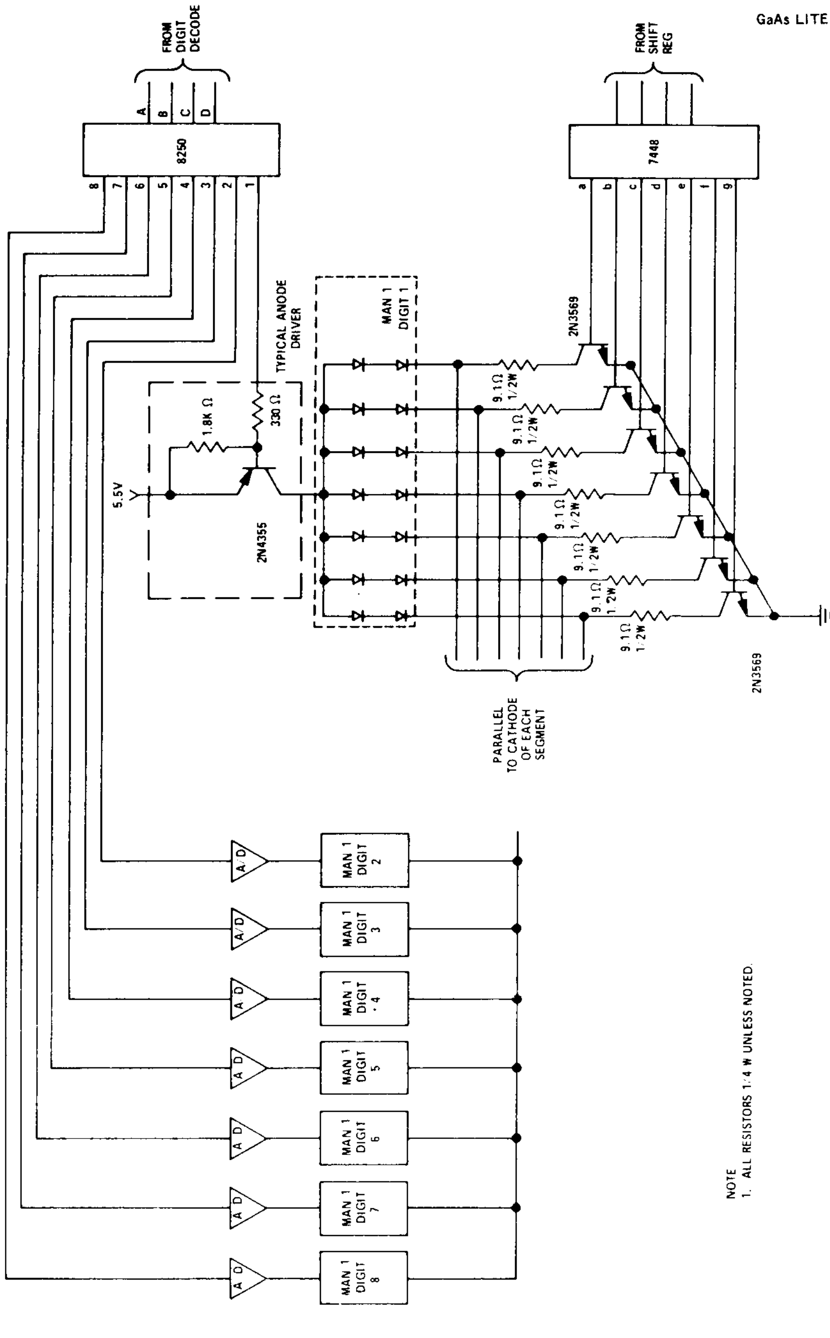


FIGURE 2

NOTE
1. ALL RESISTORS 1/4 W UNLESS NOTED.

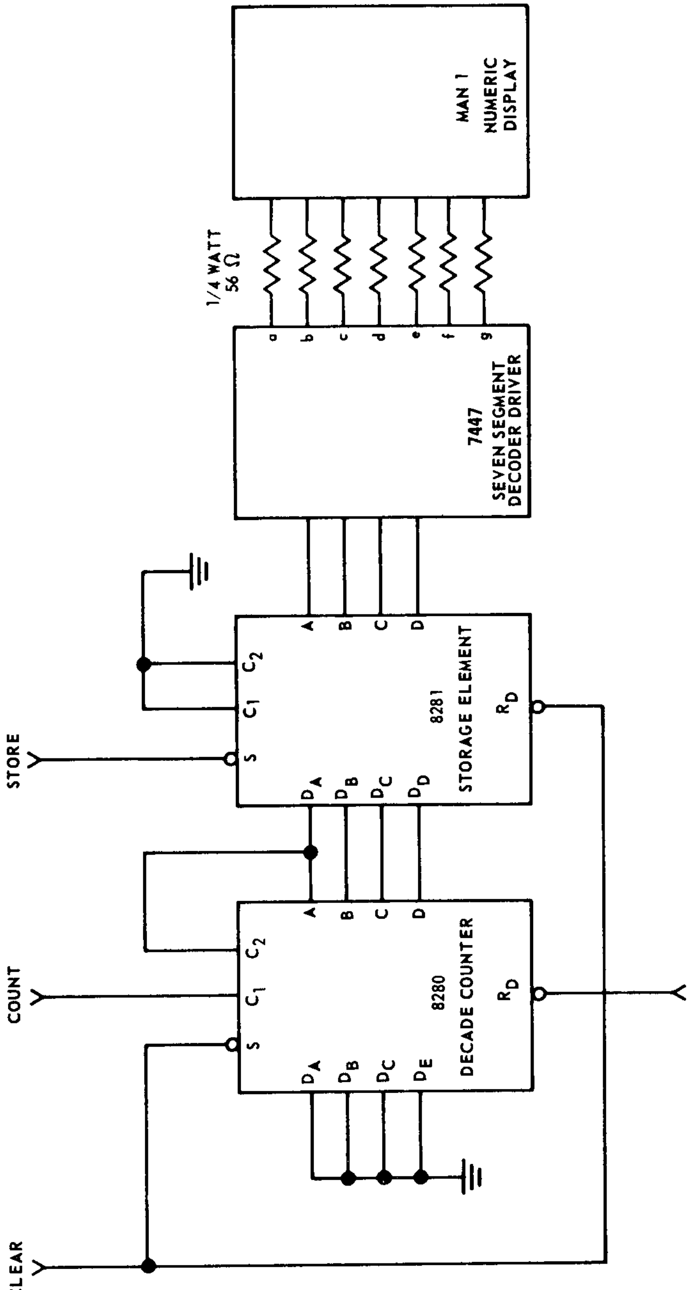

MAN 1
NUMERIC
DISPLAY
1/4 WATT
56 Ω
a
b
c
d
e
f
g
7447
SEVEN SEGMENT
DECODER DRIVER
A
B
C
D
C_2
C_1
S
8281
STORAGE ELEMENT
R_D
D_A
D_B
D_C
D_D
STORE
A
B
C
D
C_2
C_1
S
8280
DECADE COUNTER
R_D
D_A
D_B
D_C
D_E
COUNT
CLEAR
V_{cc} 5.0V

FIGURE 3

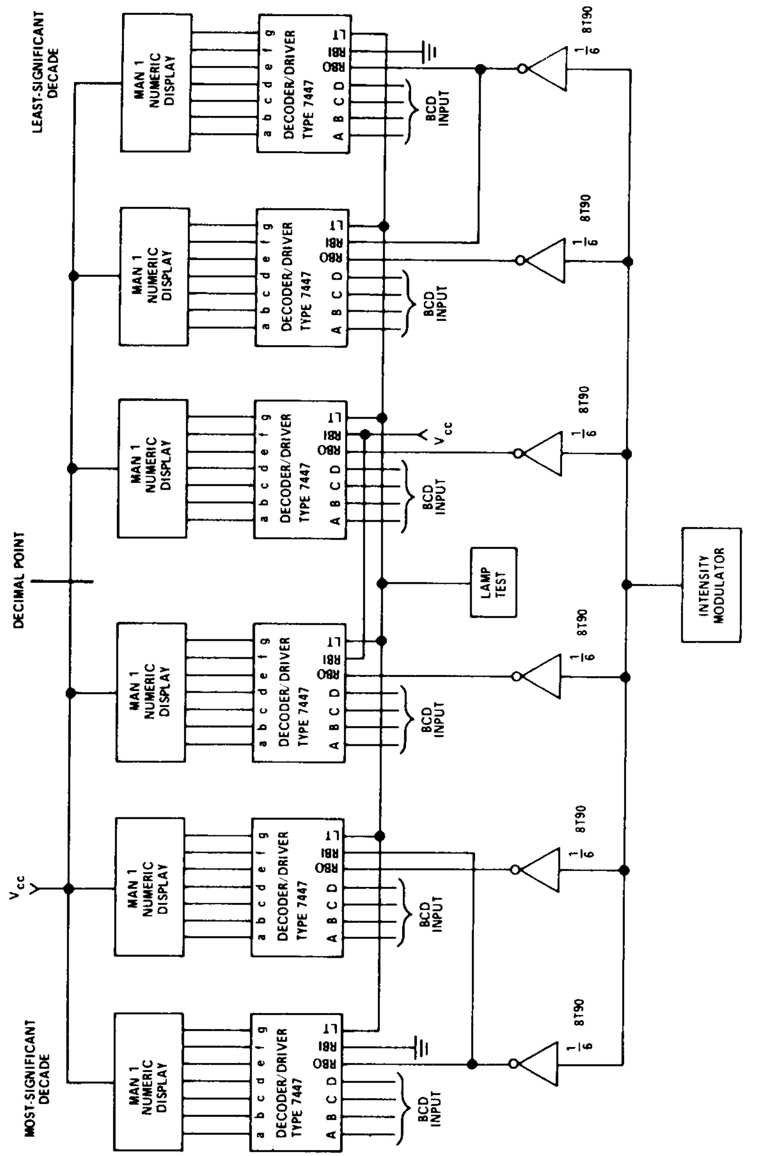

LEAST-SIGNIFICANT DECADE
MOST-SIGNIFICANT DECADE
DECIMAL POINT
V_{cc}
MAN 1 NUMERIC DISPLAY
a b c d e f g
DECODER/DRIVER TYPE 7447
A B C D
RBO
RBI
LT
BCD INPUT
$\frac{1}{6}$ 8T90
LAMP TEST
INTENSITY MODULATOR

FIGURE 4

INDIVIDUAL OPERATION FOR THE MAN 1

The individual operation of the MAN 1 display is shown in figure 3. This circuit uses a decoder/driver (type 7447 or equivalent[3]) for each numeric. The current through each segment is adjusted by the series resistor. The circuit shown will limit the current in each segment to 20 mA with a V_{CC} of 5 volts. The storage element is used to display a digit for a specific period of time or sample rate. This rate is controlled by the stroke input. Binary information is converted into 4 line BCD in the decade counter. The 4 line BCD is the required input to the seven segment decoder/driver. Any one or all of the elements can be eliminated if the customer's application requires it.[2]

FEATURES OF THE SEVEN SEGMENT DISPLAY SYSTEM

Because decoding doesn't use all the pins of the seven segment decoder/driver package other functions are incorporated. Typically these functions are (in the 16-pin package) ripple blanking output (RBO), ripple blanking input (RBI) and lamp test (LT). The additional functions allows the designer to add new features to the display system. The new features are zero suppression, intensity modulation and lamp test.

Zero Suppression

Zero suppression automatically blanks the leading and/or trailing edge zeroes in a multidigit decimal number. The resulting display is more easily read and conforms to normal writing practice. A six digit instrument without zero suppression will display the number 007.500, both the leading and trailing zeroes are lighted. The automatic blanking feature of the seven segment decoder/driver will display the number as 7.5, blanking the leading and trailing edge zeroes.

A six-digit decimal number with zero suppression for the two most-significant decades and two least significent decades is illustrated in figure 4. This circuit will automatically display the decimal number in the most readable form. Zero suppression is accomplished by grounding the RBI terminal of the most-significant and least-significant decode, and connecting the RBO output to the RBI input of the adjacent decade Note that the RBI input of the decades on either side of the decimal point are connected directly to the source voltage, inhibiting the zero blanking for the decades nearest the decimal point. For a movable decimal point the zero blanking connections must move with the ranging circuitry.

Intensity Control

Intensity control is accomplished by a variable frequency or pulse width control source connected through a buffer to the RBO terminal (see figure 4). Thus, the MAN 1 display brightness is proportional to the modulation frequency or duty cycle.

Lamp Test

Typically the lamp test will override all other inputs to the decoder/driver, allowing you to check the entire display. The lamp test circuit is shown in figure 4.

NOTES

1. *For more detailed specification, refer to the product data sheet.*
2. *The integrated circuits used in this discussion are Signetics 8000 series (Fairchild 9000 series or equivalent).*
3. *The decoder/driver used in this discussion is type 7447 (Fairchild 9317, RCA CD2501E or equivalent).*
4. *The decoder used in this discussion is type 7448 (Fairchild 9307 or equivalent).*

SILICON PIN PHOTODIODE

R. A. Hunt Sr.

INTRODUCTION

MONSANTO COMPANY now offers a Si PIN Photodiode to go with their line of LED's. The photodiode has a peak spectral response that matches the emission characteristics of the GaAs LED. The advantage of the PIN photodiode is the fast rise time, large gain bandwidth product, low applied voltage, wide spectral response, and low noise. The rise time is typically 0.5 nanoseconds with an applied voltage of -30 volts. The photodiode response ranges from 0.4 to 1.1 microns with a gain bandwidth product of several hundred MHz. Leakage current is typically 2.5 n A which is approximately three orders of magnitude lower than a typical output signal.

The photodiode is offered with two different lens, MD1 flat lens and MD2 round lens, which give an optical gain of two. The sensitivities, $2\mu A/mW/cm^2$ for MD1 and $4\mu A/mW/cm^2$ for MD2, are typical at a wavelength of 0.9 microns.

Some of the applications for this photodiode are: laser detecting, optical encoding, intrusion alarm or warning, process control, star trackers, and industrial control.

PHOTODIODE

A PIN photodiode is designed to operate in the reverse direction as shown in figure 1. With no light applied, the only current in the circuit is the reverse current of the diode (normally called dark current I_0). This current is relatively independent of the applied voltage (below breakdown) and is a result of thermal generation of hole-electron pairs. Dark current increases exponentially with temperature, approximately doubling every 10°C.

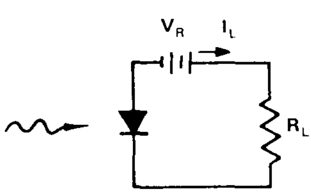


FIGURE 1 D.C. OPERATIONS

As light of the proper wavelength is applied, the reverse current increases proportionately to the intensity of the incident light. The photocurrent results from hole-electron pairs produced in the junction. The spectral response of **the photodiode is shown in figure 2.**

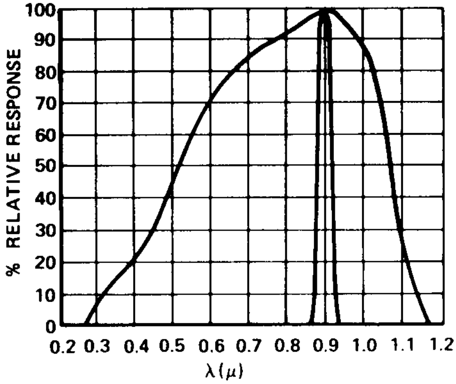


FIGURE 2 SPECTRAL RESPONSE OF PHOTODIODE

The sensitivity of the photodiode is given in μA/mW/cm². The sensitivity is measured as follows

$$S = \frac{I_L}{H}$$

Where I_L is the load current in μA and H is the power per unit area falling on the detector (irradiance) in μW/cm². Figure 3 shows photocurrent vs. irradiation of the MD 1. This curve shows the sensitivity of the MD 1 to a tungsten lamp operated at a color temperature of 2875°K and to a GaAs source. The detector is 2.3 times more sensitive to a GaAs source than a tungsten source having the same radiation flux density.

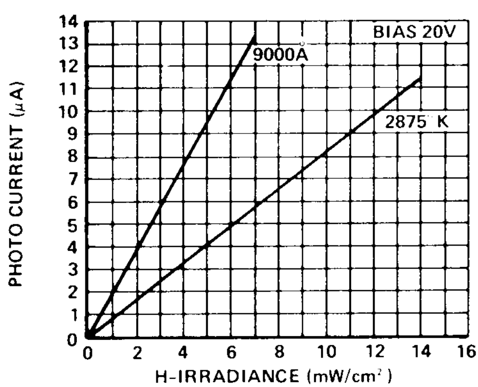


FIGURE 3 PHOTOCURRENT VS. IRRADIATION

EQUIVALENT CIRCUIT–

Figure 4 shows the equivalent DC current of a photodiode where I_S is the photocurrent: I_o dark current; C_j is the junction capacitance; V_D built in junction potential: R_S series resistance. Figure 5 shows the AC equivalent circuit of the diode where i_S is the AC component of photocurrent; and i_L is the ~omponent of the output current. R_S is the series and contact resistance, and in most cases can be neglected.

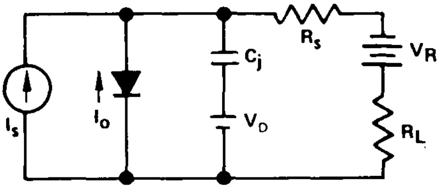


FIGURE 4 DC EQUIVALENT CIRCUIT

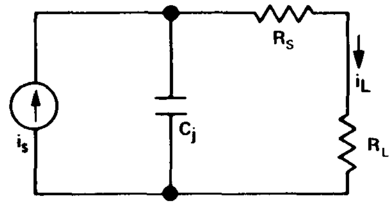


FIGURE 5 AC EQUIVALENT CIRCUIT

The high frequency cutoff f_c is given by:

$$f_c = \frac{1}{2\pi R_L C_j}$$

The load resistor and junction capacitance being the main limiting factor.

NOISE–

The noise in a semiconductor can be divided into three basic categories: thermal noise, shot noise, 1/f noise. At frequencies less than 1kHz the noise is predominantly 1/f and for frequencies between 1kHz and 1MHz is primarily thermal and shot noise. The noise equivalent circuit of a photodiode is shown in figure 6.

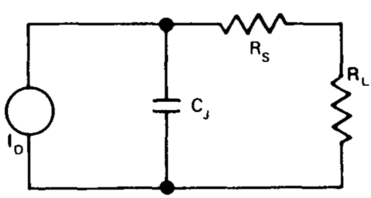


FIGURE 6 NOISE EQUIVALENT CIRCUIT

Thermal noise is given by:

$$\overline{i_{R_S}}^2 + \overline{i_{R_L}}^2 = \frac{4KTB}{R_S + R_L}$$

and is a result of random thermal motion of carriers within the conducting material.

Shot noise is given by:

$$\overline{i_N}^2 = 2 q I_o B$$

and is the result of random passage of discrete carriers across a barrier or discontinuity such as a semiconductor junction.

Thermal and shot noise have a "white" frequency characteristic and Gaussian amplitude distribution. The total noise generated is:

$$\overline{i_{N_o}} = \sqrt{2 q I_o B + \frac{4KTB}{R_S + R_L}}$$

and is predominantly a factor of bias, temperature, and bandwidth.

Two terms are used to describe the performance of detectors, NEP (noise equivalent power) and D* (dee star). NEP is the minimum radiant power required to produce a signal to noise ratio of unity and is given by:

$$NEP = \frac{i_N}{S}$$

The typical value of NEP for the MD1 and MD2 is 1.7×10^{-14} and 0.8×10^{-14} respectively. The units of NEP are watts/$\sqrt{Hz}$

D* is used to compare detectors of the same material but of different areas, and is given by:

$$D^* = \frac{\sqrt{A}}{NEP}$$

The typical value of D* for the MD1 and MD2 is 4.4×10^{12} and 8.8×10^{12}, respectively. The units of D* are cm$\cdot\sqrt{Hz}$/watts.

The larger the value of D* the more sensitive the detector. Knowing NEP you can calculate the minimum detectable output as follows:

$$i_s = S\ NEP$$

with a known value of load resistance the output voltage will be:

$$V_L = i_s R_L$$

TYPICAL ELECTRO-OPTICAL CHARACTERISTIC

The characteristic of the MD1 and MD2 has been measured to be linear within ±3% at room temperature. This is for light generated current from 200nA to 50μA where the measurement error is ±3%.

The following curves show the typical performance of the MD1 and MD2.

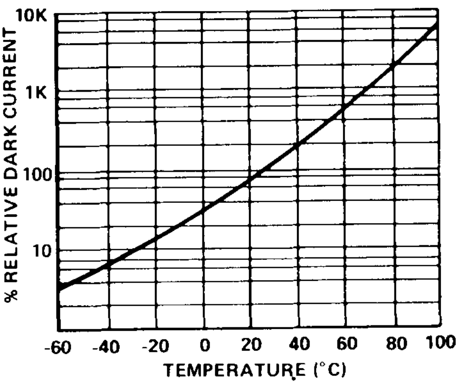


FIGURE 7 DARK CURRENT VS TEMPERATURE

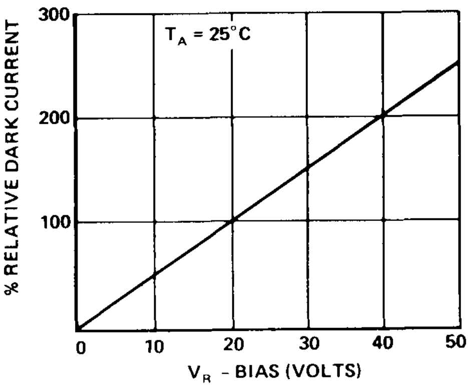


FIGURE 8 DARK CURRENT VS BIAS

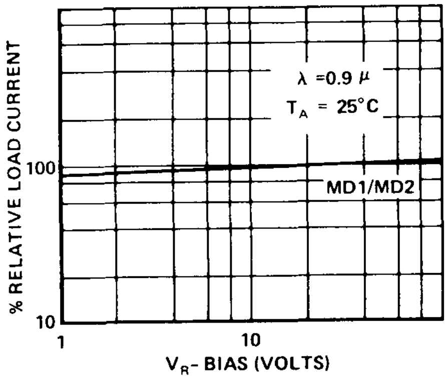


FIGURE 9 LOAD CURRENT VS BIAS

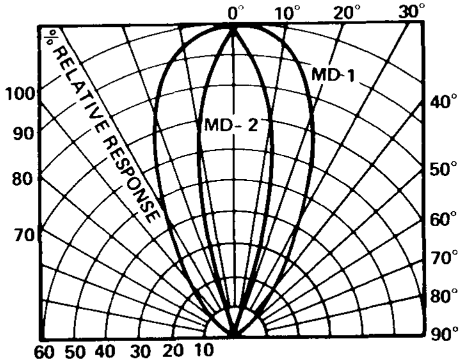


FIGURE 10 ANGULAR RESPONSE

PULSE CIRCUIT

One of the main advantages of the PIN photodiode is the fast rise time. The circuit shown in figure 11 uses a GaAs laser to measure the rise time of the photodiode.

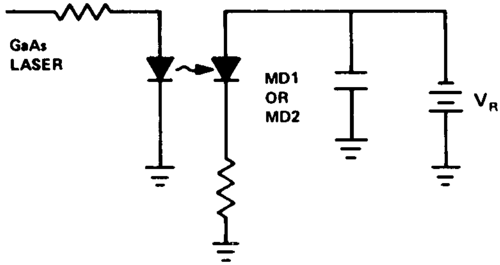


FIGURE 11

Figure 12 shows the rise time to be less than 0.5 nanoseconds. When building the circuit, make all leads as short as possible.

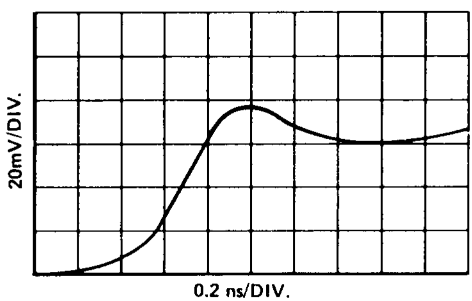


FIGURE 12 PHOTO DIODE OUTPUT

SYMBOLS

S = Detector

K = Boltzmann's constant, 1.38 x 10^{23} joule/°K

T = Temperature, °K

B = Bandwidth

q = Charge of electron, 1.6 x 10^{-19} coulomb

GaAs LITE TIPS No. 8

PULSED OPERATION OF THE LED

Richard T. Gill

INTRODUCTION

This GaAs Lite Tip deals with two important facets of the pulsed operation of light emitting diodes (LED). First is the ultrafast rise and fall time of the LED, which is shown to be at least 2.5 nanoseconds. Also a discussion of the types of detectors used at this speed and the switching circuits required to produce nanosecond performance. The second part will discuss the general pulsed mode of operation of the LED regarding the effect of light output due to a change in pulse width, duty cycle, or pulse amplitude. Included is a discussion of the relative merits of detectors, the effects of high junction temperature and excessive current density, graphs indicating the peak forward current versus duty cycle and peak forward current versus radiated output power.

RISE AND FALL TIME

The light rise time (t_r) of an LED is the time required for the leading edge of light pulse to increase from 10% to 90% of its final value. The light fall time (t_f) is the time required for the trailing edge of the light pulse to decrease from 90% to 10% of its initial value. Two different types of detectors were used to measure the light response of the LED, they are the photomultiplier tube and the silicon PIN Photodiode. Both detectors have nanosecond response time, with faster speeds achieved by the photodiode at the expense of lower sensitivity.

LED RISE TIME USING PM TUBE AS A DETECTOR

A photomultiplier system (Electro-Optics PM 101) consisting of a PM Tube (RCA7102) and a high speed socket was used to measure the light rise time of the LED.[1] The photomultiplier system rise time is 4.0 nanoseconds. Because of the comparatively high junction capacitance of the LED, a voltage source must be used to achieve the minimum light rise time. An avalanche switching circuit (See Figure I) with a 0.5 nanosecond current rise time was used to drive the LED.

In this measurement the value of capacitor C1 was 10pF, thus giving the avalanche switching circuit current pulse a rise time of 0.5 nanosecond and a peak current of 0.7 amp. An increase in the value of capacitor C1 will result in an increase in both peak current and rise time. A summary of the results obtained using the low impedance driving source is shown in Table I. It should be noted that the Electro-Optics PM101 system does not optimize the fall time of the RCA7102 PM Tube. Therefore fall time data of the LED could not be taken with the PM system.

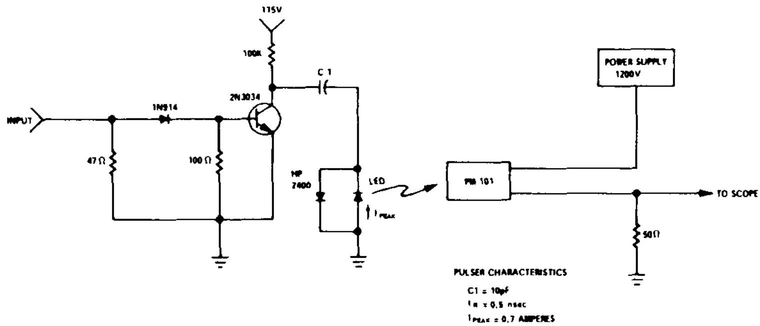


FIGURE 1

Because of the general availability of 50Ω systems, the light rise time was measured using this driving impedance. A Spencer Kennedy Laboratories pulse generator Model 503A with a rise time of 0.5 nanoseond was used to pulse the LED (See Figure II). A 49.9Ω resistor in series with the LED was used for impedance matching and to monitor the input current pulse. Adjustment of this resistor may be necessary to optimize the light pulse, as each LED has a small difference in dynamic resistance. A summary of the rise time data obtained using the 50Ω impedance driving source is shown in Table II. The variance between the minimum rise time value in the 50Ω driving system and the avalanche circuit is due to the difference in junction capacitance of the devices tested. The MV10A and MV10B had an average junction capacitance of 90pF and the MI20C averaged 140pF.

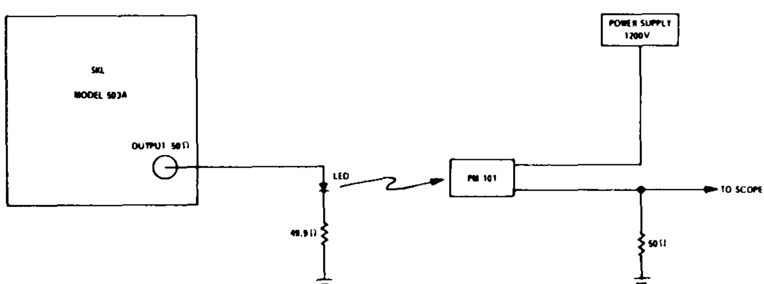


FIGURE II

DEVICE TYPE	t_r (ns)	DETECTOR
MV10A	*4.1	PM Tube
MV10B	*3.8	PM Tube
MI20C	*4.7	PM Tube
MI20C	**2.5	Photodiode

*These values reflect photomultiplier system limitation.
**This value reflects driving circuit limitations.

LOW IMPEDANCE SOURCE

TABLE I

DEVICE TYPE	t_r (ns)
MV10A	12
MV10B	14
MI20C	24

50 Ω IMPEDANCE SOURCE

TABLE II

LED RISE TIME USING PHOTODIODE AS A DETECTOR

The MONSANTO MD2 PIN photodiode was used to measure the light response of the LED. The rise time of this detector is less than 300 picoseconds. Because of the lower sensitivity of the PIN photodiode[2], compared to the photomultiplier system, the peak current in the avalanche switching circuit was increased to 2.8 amps by changing the value of C1 to 150pF (See Figure III). The system rise time was again attained using the photodiode as the detector. The limiting link in the chain being the current rise time (2.5 nanoseconds) of the avalanche switching circuit (See Table I). The waveforms shown in Figure IV are the input current pulse to the LED and the light output pulse. The silicon PIN photodiode was able to detect both the light rise time and fall time and shows them to be equal.

The PIN photodiode was used to measure the rise time of the LED in a 50Ω impedance system (see Figure V). The resulting rise time data was the same as that obtained with the photomultiplier system (Refer to Table II).

CONCLUSION

It has been shown that the light emitting diode has a rise time of at least 2.5 nanoseconds as measured by the PIN photodiode. This value is limited by the current rise time of the avalanche switching circuit, with the appropriate driving and detecting system, 1.0 nanosecond or less can conceivably be achieved. To produce nanosecond light pulses, the LED must be driven from a low impedance generator. It is extremely important to use fast pulse techniques when constructing the LED driving circuit.

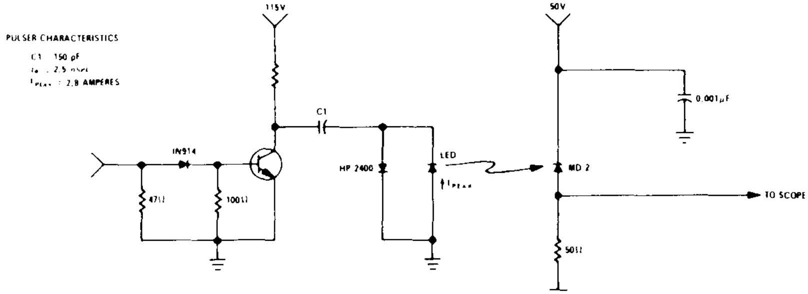


FIGURE III

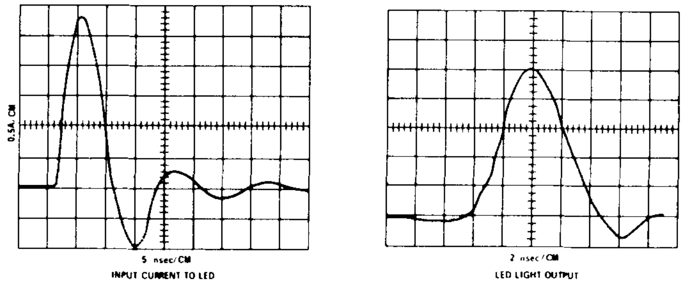


FIGURE IV

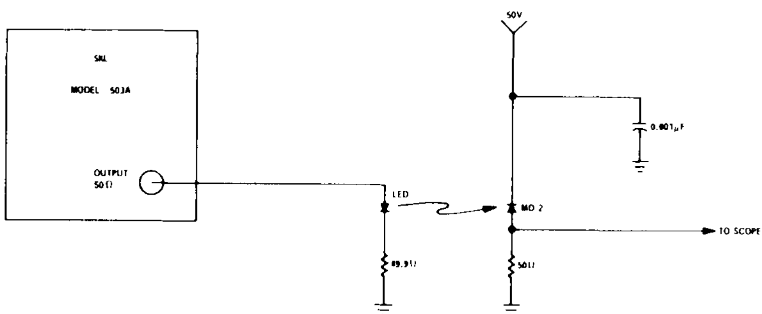


FIGURE V

GENERAL PULSED MODE OPERATION

Because of the combination of ultra fast light response time, large bandwidth and increased radiated output power, the LED is unique in terms of pulsed operation and a topic worth some discussion. Included in this discussion are the relative merits of the different types of detectors used in conjunction with the LED.

DETECTORS

The more common types of detectors are the photomultiplier tube, photodiode, phototransistor, and the solar cell. In general, detector sensitivity is inversely proportional to rise time, the exception being the photomultiplier tube which has both high sensitivity and nanosecond light response time. The disadvantages of the PM tube are its large size, high bias voltage, and high cost. The photodiode also has nanosecond response time but several orders of magnitude less sensitivity than the PM tube.[2] The main advantage of the photodiodes are faster response, low cost, ruggedness, small size, and low bias voltage The phototransistor has typically 100 times the sensitivity of the photodiode but has a rise time in the microsecond range. The solar cell is more efficient than either the photodiode or the phototransistor, but has the slowest response time of any of the above mentioned detectors. Still another advantage that all silicon detectors have is that the peak emission wavelength of the GaAs infrared diode (9000Å) matches the maximum sensitivity point of silicon; thus making the GaAs diodes the ideal emitters for silicon detectors.

GENERAL PULSING

When pulsing the LED there are two mechanisms that can cause poor light performance, permanent degradation, or even catastrophic failure. The mechanisms are high junction temperature and excessive current density. The graph shown in Figure VI gives the maximum recommended operating parameters with respect to peak current, pulse width and duty cycle. The values should be strictly followed to insure that the LED is always operated within safe limits.

After the peak current for a particular pulse width and duty cycle have been established, the graph shown in Figure VII will indicate the peak radiated output power for that particular peak input current. The peak radiated output power is normalized to the value indicated on the product data sheet.

HIGH JUNCTION TEMPERATURE

The effects of high junction temperature is easily identified by monitoring the light output pulse. As the junction temperature of the device increases, the light efficiency decreases. This will cause the light output pulse to have an exponential decay (See Figure VIII).

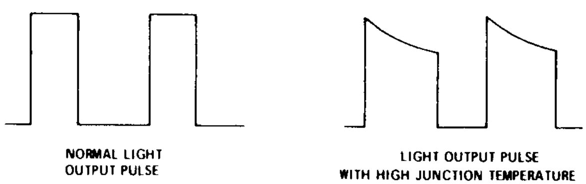


FIGURE VIII

EXCESSIVE CURRENT DENSITY

The effects of excessive current density are also easily identified by monitoring the light output pulse. Excessive current density will cause the LED efficiency to decrease. Therefore, for a given pulse width and duty cycle, the light output pulse will not increase with additional input current. It should be noted that generally the LED will not catastrophically fail and should a problem be noted the device should be immediately turned off, allowed to cool, and corrective action be taken to solve the problem. After the LED has sufficiently cooled it will return to its original performance.

CONCLUSION

When operating the LED in the general pulsed mode, it is important not to exceed the specified operating parameters with respect to peak current, pulse width, and duty cycle. To avoid possible damage to the LED one should refer to the graph shown in Figure VI for conditions recommended for pulsed operation. After the peak input current is established the graph in Figure VII will indicate the relative output power with respect to the typical DC performance.

NOTES:

1. *The light rise time was measured in the following Monsanto LED:*

A.	*MI20C*	*GaAs infrared diode*
B.	*MV10B3*	*GaAsP visible red diode*
C.	*MV10A3*	*GaAsP visible red diode*

For more detailed specification, refer to the product data sheets.

2. *The sensitivity of the Monsanto MD2 photodiode is typically* $4\,\mu A/m\omega/cm^2$ *for infrared radiation with a wavelength* (λ) *of 9,000* Å *and* $V_R = 20$ *volts.*

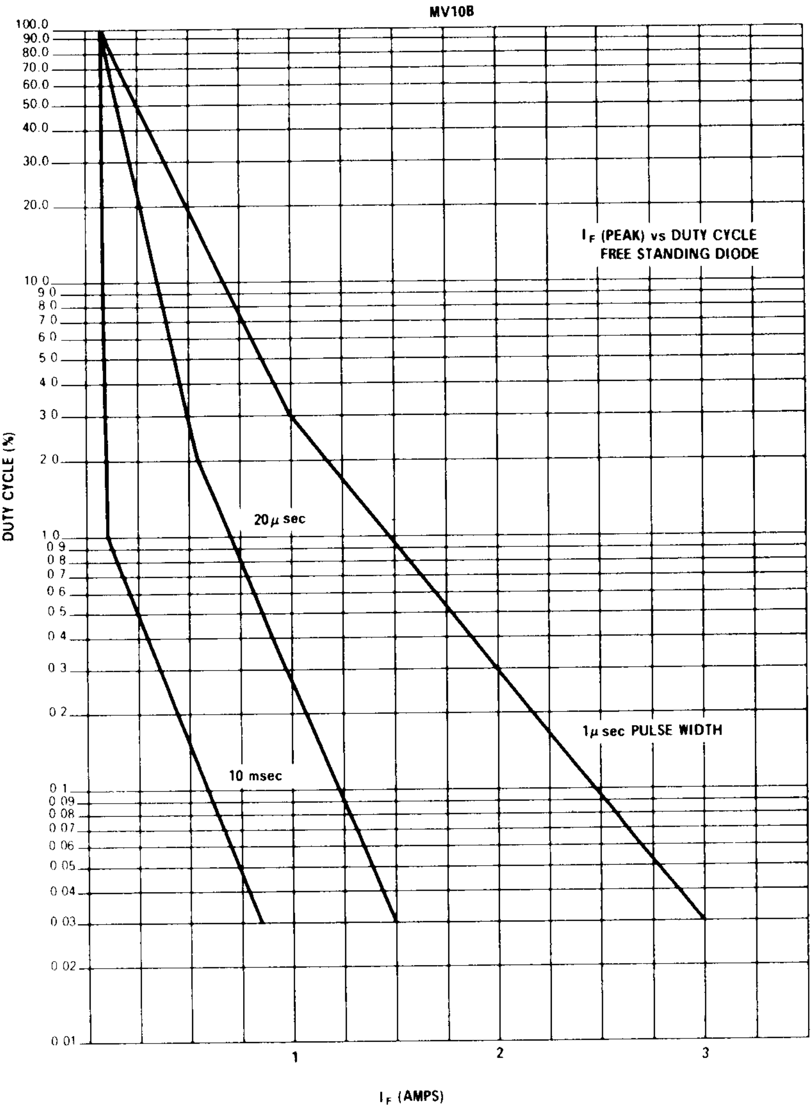

MV10B
I_F (PEAK) vs DUTY CYCLE
FREE STANDING DIODE
20μ sec
10 msec
1μ sec PULSE WIDTH
DUTY CYCLE (%)
I_F (AMPS)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
1
2
3

FIGURE VIa

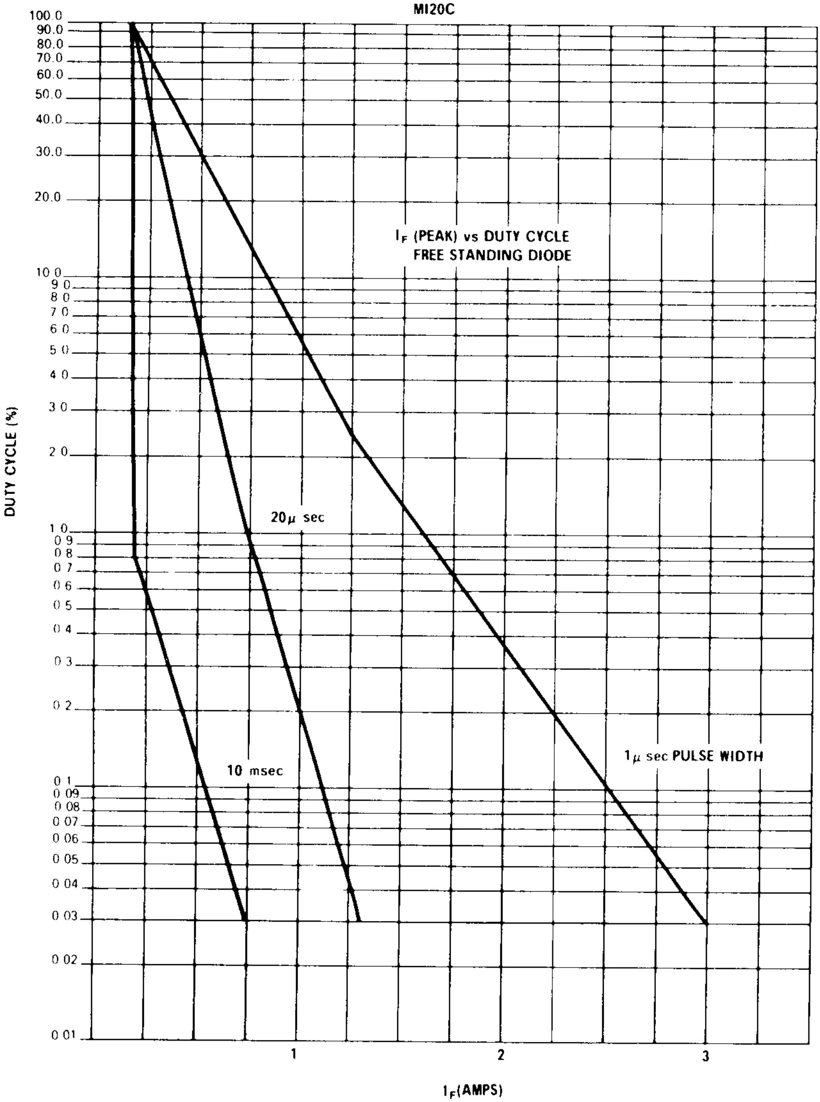

MI20C
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10 0
9 0
8 0
7 0
6 0
5 0
4 0
3 0
2 0
1 0
0 9
0 8
0 7
0 6
0 5
0 4
0 3
0 2
0 1
0 09
0 08
0 07
0 06
0 05
0 04
0 03
0 02
0 01
DUTY CYCLE (%)
I_F (PEAK) vs DUTY CYCLE
FREE STANDING DIODE
20μ sec
10 msec
1μ sec PULSE WIDTH
1
2
3
I_F(AMPS)

FIGURE VIb

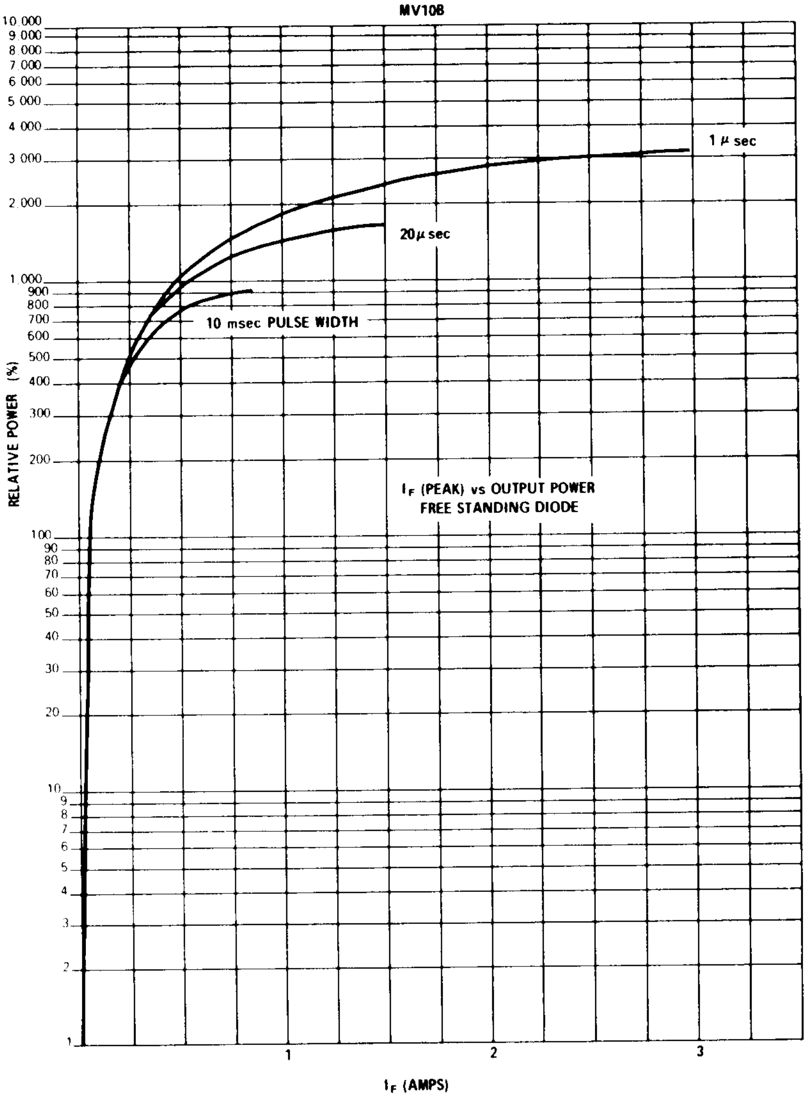

MV10B
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
RELATIVE POWER (%)
1 μ sec
20 μ sec
10 msec PULSE WIDTH
I_F (PEAK) vs OUTPUT POWER
FREE STANDING DIODE
1
2
3
I_F (AMPS)

FIGURE VIIa

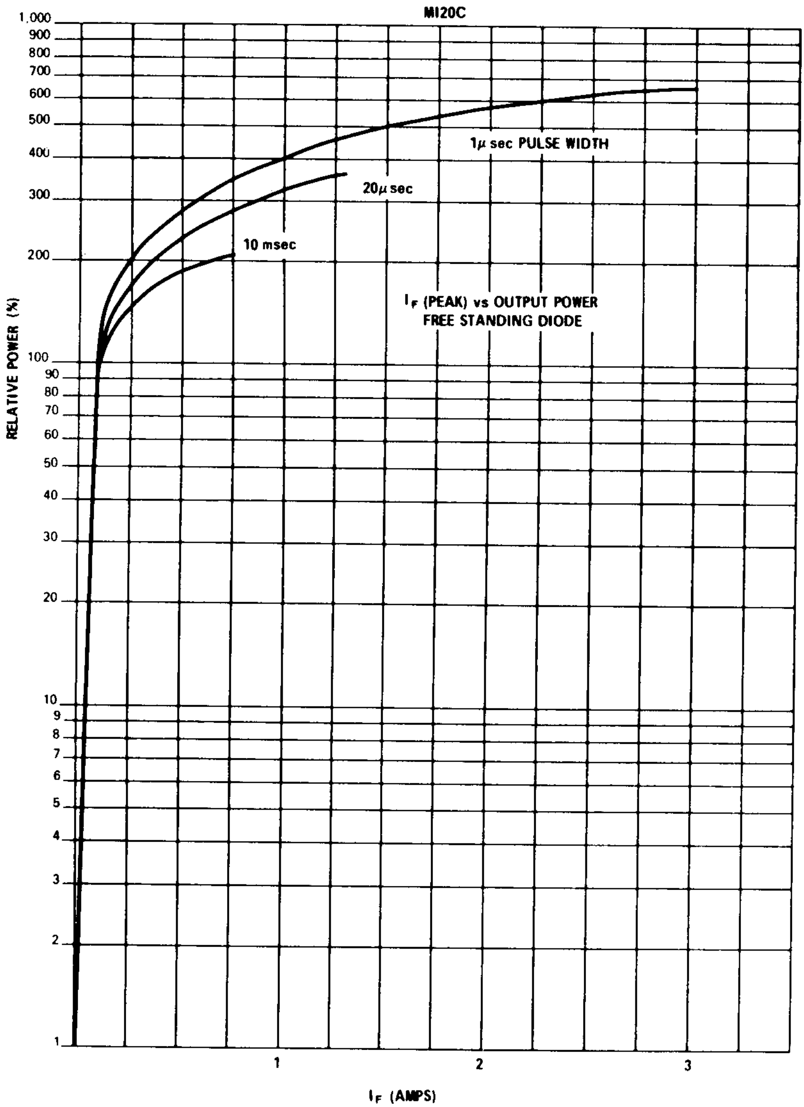

MI20C
1,000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
RELATIVE POWER (%)
1μ sec PULSE WIDTH
20μ sec
10 msec
I_F (PEAK) vs OUTPUT POWER
FREE STANDING DIODE
1
2
3
I_F (AMPS)

FIGURE VIIb

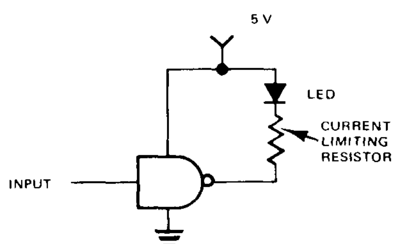
FILM ANNOTATION USING THE LED

Richard T. Gill

By definition, annotation means to make or furnish critical or explanatory notes or comment. Conventional methods of film annotation such as the neon lamp, spark-gap or gas discharge systems left the instrumentation engineer with much criticism and little explanation/information on his film. The light emitting diode LED will solve this problem because of its many advantages over the past methods used in film annotation. The most common use of the LED in photo instrumentation is the annotation of time and/or event marks on the edge of the film. This GaAs Lite Tip will discuss the advantages of the LED and the types of film recommended for use with the LED.

ADVANTAGES OF THE LED

The LED has many advantages over past methods used to annotate film. Excluding the LED, the most popular device used to annotate film is the neon lamp, which suffers from several difficulties when used as a light source for making film. The slow light rise and fall time of the neon lamp causes fuzzy leading and trailing edges on the annotation mark. The ultra fast rise and fall time of the LED eliminates this problem. An even larger problem is that the neon lamp, in total darkness, becomes erratic and may require many volts in excess of static values to start it. The light ambient condition is not a factor in the LED performance. Additional benefits derived by using the LED as the film marking device are the low voltage requirement (typically 1.65 volts @ I_F = 50 mA). The power consumption is also very small (typically 82.5 mW @ I_F = 50 mA); therefore practically no heat is generated by the LED. MONSANTO has pioneered planar technology along with the metalized contact in the LED. This allows the LED to have an unobstructed, uniformly lite emitting area of practically any desired shape. The LED is a high efficiency emitter having a typical radiated output power of 50μW (I_F = 50 mA and λ peak = 6700 Å). Because of the narrow band (monocromatic) emission of the LED all the radiated output power can be matched to the peak sensitivity of the film. The low voltage and power requirements of the LED make it compatible to integrated circuits. This compatibility with integrated circuits simplifies the task of modulating the LED (see Figure I).



LINE DRIVER
FIGURE I

The ruggedness of the LED makes it impervious to vibration. The LED also has solid state reliability (typically 10^6 hours life). Its small size makes the LED very desirable for the cramped quarters found in most cameras. The small size combined with planar technology allows the LED to be made into special arrays according to customer needs.

RECOMMENDED FILMS COMPATIBLE TO THE LED

The red visible light emitting diode is recommended for use with black and white film that has extended red spectral response. The following is a list of Kodak film types that are recommended for use with the LED 2479, 2496, 2485, and 2475. The typical response curve for the above film is shown in Figure II. The LED is a monochromatic (narrow band) light source having a typical spectral line half width of 400 Å .

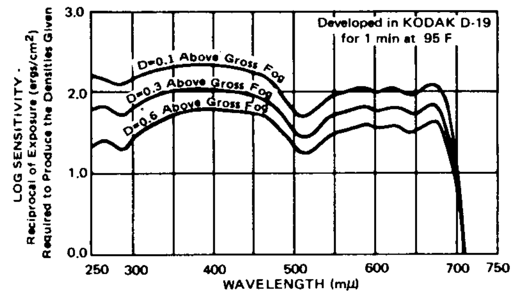


FIGURE II

Figure III shows the typical spectral response of the LED for use in conjunction with the intended red response films. To insure that all of the radiated output power approximates the film's peak sensitivity, the maximum peak wavelength of the LED should be less than 6700 Å.

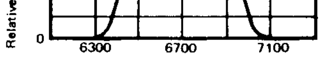


FIGURE III

Any MONSANTO red visible diode can be used with Kodak high speed infrared film. The following equation can be used to determine the amount of energy incident to the film surface from the LED.

$$\text{ergs/cm}^2 = \frac{\text{mA sec}}{10^4\ S}$$

where

S	is the detector sensitivity (used in place of film)
mA	is current output of detector
sec	is length of exposure time

In this test the LED should be positioned the same distance from the film as in the final application. An aperture should be placed in front of the detector with the same area opening as the annotation mark.

OPERATION OF THE LED

For normal DC operation the red visible LED has a forward current of 50 mA and a forward voltage of 1.65 volts. A unique feature of the LED is that the radiated output power is proportional to the input power. The LED has an extremely fast light rise and fall time (typically 14 nsec in a 50Ω impedance driving system with a bandwidth of 5 MHZ at the 3 db point). For more information on the pulsed operation of the LED refer to the General Pulsed Operation GaAs Lite Tip #8.

CONCLUSION:

The LED has many advantages over the conventional methods of marking film, among the more important are low power and voltage requirements, high efficiency, unobstructed emitting area, solid state reliability, and long life. It is essential to match the peak emission of the LED to the peak film sensitivity to insure maximum film exposure.

MONOLITHIC SEVEN SEGMENT DISPLAY—MAN-3

E. H. Lim

The Monsanto MAN-3 is a seven segment red alpha numeric display and is a totally solid state monolithic semiconductor device. This numeric is the third of a series of Monsanto solid-state displays and part of a family of GaAsP Lite emitting semiconductor devices developed by Monsanto Electronic Special Products.

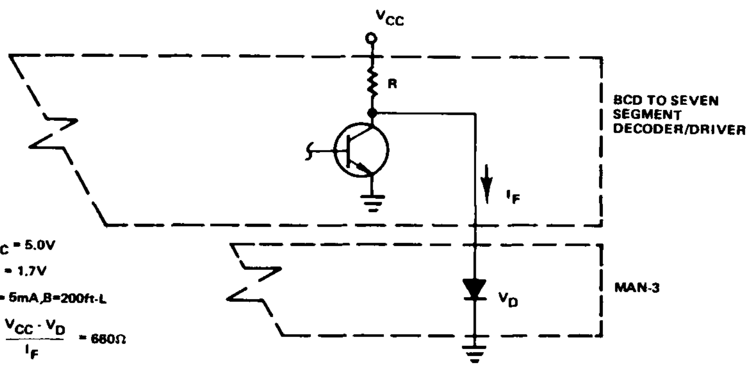
The MAN-3 brings to the display field all the demonstrated advantages of solid state technology, compact spacing, reliability, long life, shock resistance, low power requirements, and compatibility with conventional integrated circuits. The actual light emitting areas are planar, formed by zinc diffusion into N-type GaAsP wafers, and emits in the range of 6300Å to 7000Å (red). More than 200 foot-lamberts can be obtained with 8.5mW (5mA, 1.7 volt) power input per segment. Each of the seven segments is made up of five light emitting diodes. These diodes are interconnected by evaporated aluminum on the surface of the chips. The numeric is made with 10° slant from the vertical position for better appearance. The actual numeric dimensions are 0.116 x 0.067 inch while the package size is 0.240 x 0.168 inch. These dimensions are possible only with the use of a monolithic chip, and allow a packing density of at least 5 numerics per inch.

The chip is attached to a frame and cast in clear epoxy to protect the interconnections. The unit has single-plane readout for wide-angle viewing (150°). It can present any numeral from 0 to 9, plus the letters A, C, E, F, H, J, L, P, and U, and has a separate decimal point.

OPERATIONAL FEATURES

Each of the seven segments can be considered as a light emitting diode with a forward voltage of 1.7 volts at 5mA; this will produce a typical brightness of 200 foot-lamberts.

A circuit is shown below:



$V_{CC} = 5.0V$

$V_D = 1.7V$

$I_F = 5mA, B = 200ft\text{-}L$

$R = \frac{V_{CC} - V_D}{I_F} = 660\Omega$

CIRCUIT DIAGRAM

Because the brightness of the readout is directly proportional to input current, one may tune the units brightness from 0 to typically 500 foot-lamberts by varying the input current from 0 to a maximum of 10mA per segment.

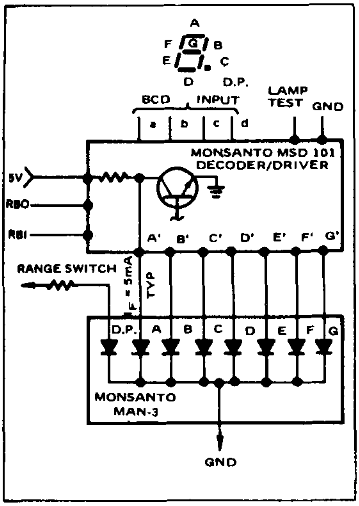
The package has nine pins bent on 0.100 inch centers. Printed circuit boards for individually addressing or strobing the unit are available from Monsanto Company. In addition, Monsanto offers the MSD101 BCD to seven segment decoder/driver which will directly drive the MAN3. The anode is individually addressable for connection to the corresponding outputs of BCD to seven segment decoder/driver having an active high level output. The cathode terminal is the reference pin, and must be connected to the ground.

APPLICATION

Applications include all types of computer readout and/or instrumentation readout where a visual alpha-numeric is required. Other applications will be in the computer, industrial, avionic and military markets for use as digital displays for desk calculators, portable instruments, and can also be used in annotating film. Particularly attractive are those where small size, compatibility with integrated circuits, wide viewing angles, and immunity from vibration damages are important.

Digital equipment using these numerics can be dramatically reduced in depth because of the virtual flatness of the display section and the elimination of the conventional power supply. The single plane viewing and wide viewing angle eliminate the parallax problems associated with cold cathode displays.

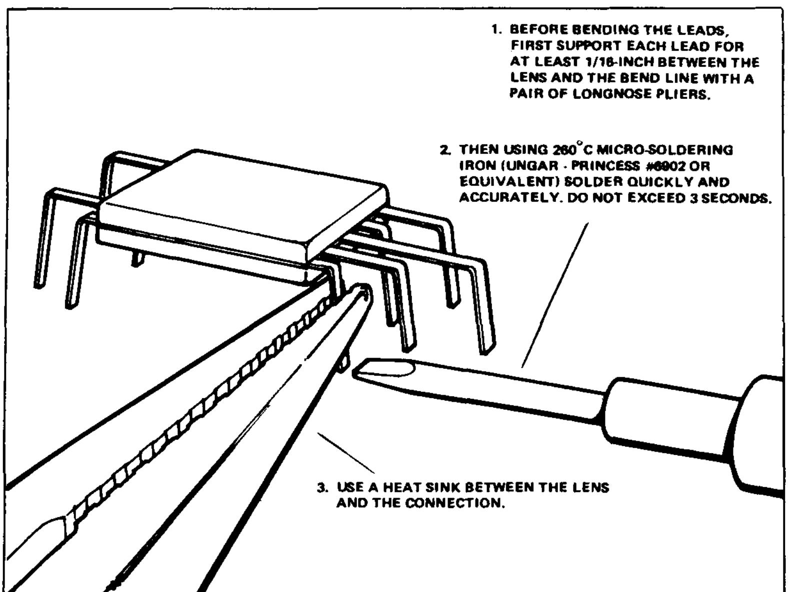
A major applications advantage of the MAN-3's segmented design is its ability to operate with any of several commercially available decoder/drivers. This approval gives the equipment designer a degree of flexibility not available with previous solid state numeric designs. For instance, many display applications do not require a decoder/driver for each digit. In some cases, strobing permits one decoder/driver to control several digits. Furthermore, separating the digit and its logic reduces the device's complexity, making it easier to design into present circuits. Viewing for instrument readouts is dramatically improved by using a segment of clear polarized red filter between the viewer and the numeric itself. This filter eliminates nearly all reflected light, from the substrate connectors or from the lens itself.



DECODER/DRIVER, FUNCTIONAL DIAGRAM

Input Code				Output Code							Display
d	c	b	a	A'	B'	C'	D'	E'	F'	G'	
0	0	0	0	1	1	1	1	1	1	0	0
0	0	0	1	0	1	1	0	0	0	0	1
0	0	1	0	1	1	0	1	1	0	1	2
0	0	1	1	1	1	1	1	0	0	1	3
0	1	0	0	0	1	1	0	0	1	1	4
0	1	0	1	1	0	1	1	0	1	1	5
0	1	1	0	1	0	1	1	1	1	1	6
0	1	1	1	1	1	1	0	0	0	0	7
1	0	0	0	1	1	1	1	1	1	1	8
1	0	0	1	1	1	1	1	0	1	1	9
1	0	1	0	0	0	0	0	0	0	1	–
1	0	1	1	0	0	0	0	0	0	0	Blank
1	1	0	0	0	1	1	0	1	1	1	H
1	1	0	1	0	0	0	1	1	1	0	L
1	1	1	0	1	1	0	0	1	1	1	P
1	1	1	1	0	0	0	0	0	0	0	Blank

TRUTH TABLE FOR MONSANTO MSD 101



MAN-3 -- SOLDERING CONSIDERATIONS

OPTO-ELECTRONIC TERMS & DEFINITIONS

OPTICAL PARAMETERS	UNITS	DESCRIPTION
P = radiant flux	W = watt	total radiated output power
H = irradiance	W/cm^2	incident radiant power
I_r = radiant intensity	W/str	point source intensity in a given direction
L_r = radiance	$W/str/cm^2$	area source intensity in a given direction
F = luminous flux	lm = lumen	total visible radiated flux
E = illumination	ft-c = foot candle = lm/ft^2	incident visible flux density
I_v = luminous intensity	C = candela = lm/str	point source visible intensity
L_v = luminance, brightness	ft-c = foot lamberts = $lm/str/\pi ft^2$	area source visible intensity
λ = Wavelength	Å = angstrom = 10^{-10} m	
	nm = nanometer = 10^{-9} m	
	μm = micron = 10^{-6} m	
ω = solid angle	str = steradian = area of sphere/radius^2	
θ = angle	radians, degrees	
S_{RCEO} = collector emitter radiation sensitivity	$mA/mW/cm^2$	
Duty cycle	% = 100(pps)(pulse width)	

ELECTRICAL PARAMETERS

I_F = forward current (d.c.)

I_R = reverse current (d.c.)

V_F = forward voltage (d.c.)

V_R = reverse voltage (d.c.)

r_f = forward dynamic resistance

V_{CE} = collector to emitter voltage

$V_{CE(SAT)}$ = collector to emitter saturation voltage

θ_{JA} = thermal resistance: junction to ambient

θ_{JC} = thermal resistance: junction to case

I_D = dark current in photodiode

f_c = high frequency cut-off

C_J = junction capacitance

BV_{ECO} = emitter to collector breakdown voltage with base open

UNITS

I,i = current	A = ampere
V,v = voltage	V = volt
P,p = power	W = watt
R,r = resistance	Ω = ohm
C,c = capicitance	F = farad
L - inductance	H = henry
t = time	s = second
f = frequency	Hz = hertz = cps
T = temperature	°C = degree centigrade
	°K = degree Kelvin

PULSE SYMBOLS

t_r = rise time

t_f = fall time

t_d = delay time

t_s = storage time

t_{on} = turn on time = $t_d + t_r$

pps = pulses per second

PREFIXES

K = kilo = 10^3

M = mega = 10^6

G = giga = 10^9

m = milli = 10^{-3}

μ = micro = 10^{-6}

n = nano = 10^{-9}

p = pico = 10^{-12}

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