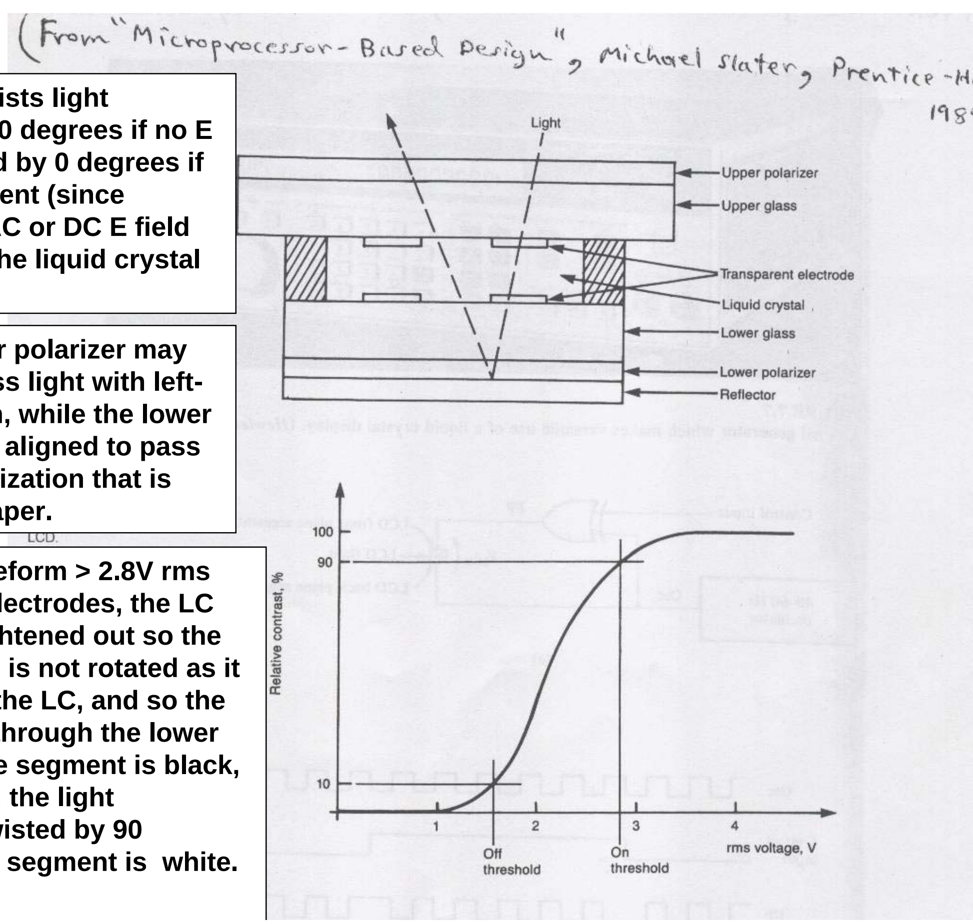
Microcontroller Interfacing: Selected Topics

- Operation of LCD Displays
- Common Input Devices
- Common Output Devices and Actuators

Liquid crystal twists light polarization by 90 degrees if no E field present, and by 0 degrees if an E field is present (since presence of an AC or DC E field straightens out the liquid crystal molecules).

NOTE: The upper polarizer may be aligned to pass light with left-right polarization, while the lower polarizer may be aligned to pass light with a polarization that is into/out of the paper.

Thus an AC waveform > 2.8V rms applied across electrodes, the LC molecules straightened out so the light polarization is not rotated as it passes through the LC, and so the light never gets through the lower polarizer, and the segment is black, but if < 1.7V rms, the light polarization is twisted by 90 degrees, and the segment is white.



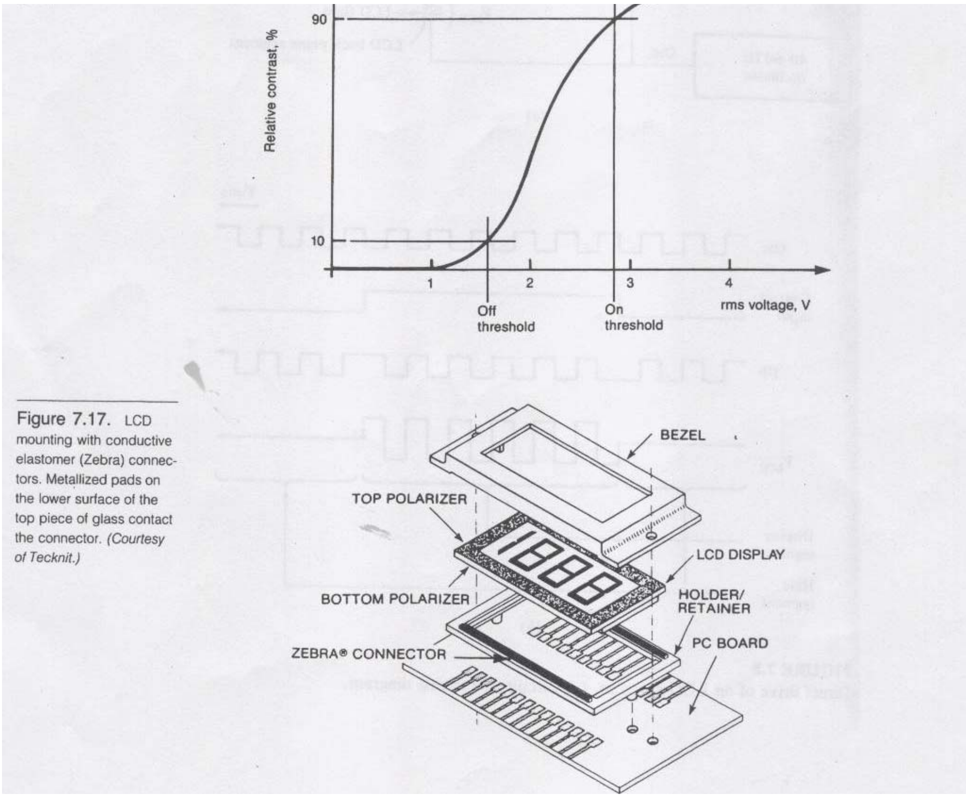
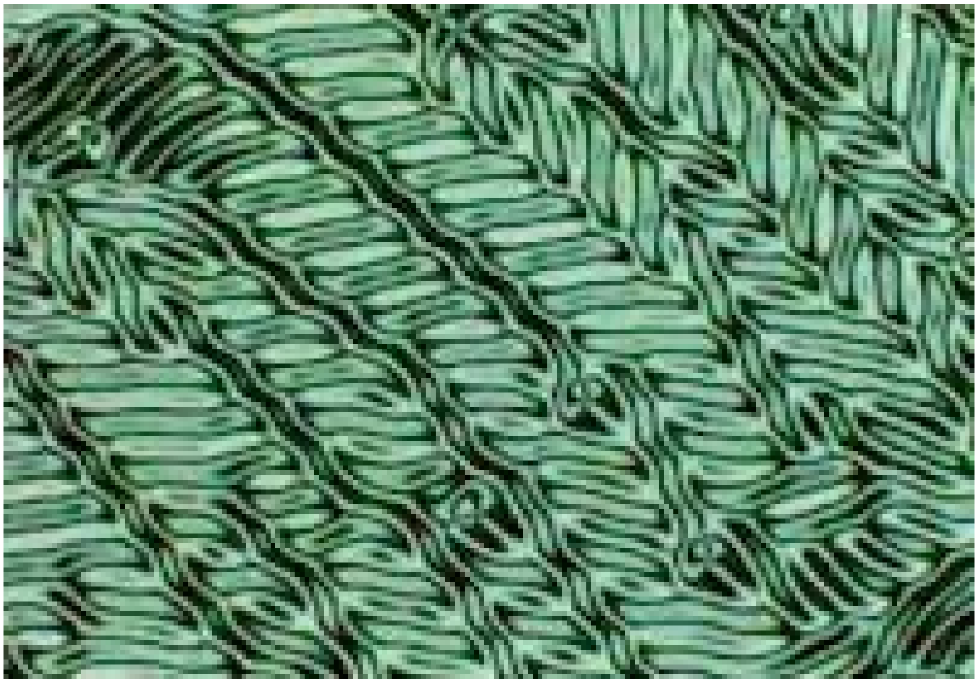


Figure 7.17. LCD mounting with conductive elastomer (Zebra) connectors. Metallized pads on the lower surface of the top piece of glass contact the connector. *(Courtesy of Tecknit.)*

Liquid crystals encompass a broad group of materials that posses the properties of both a solid and a liquid. More specifically, they are a liquid with molecules oriented in one common direction (having a long range and repeating pattern-- definition of a crystal), but have no long range order in the other two directions. For example, all the molecules form lines are oriented in the Y direction (up and down), but they posses no common ordering in the x direction (disorder is also assumed in the Z direction). To more easily visualize this, think a 1-molecule-thick slice (one layer of molecules to be exact) of a block of liquid crystal material. If you examined another slice, the molecules would still be oriented in the Y direction, but they would be in different positions along the X-axis. By stacking millions of these thin slices, the Z direction is built up and as a result of the change in relative position on the x-axis, the Z direction has no long range order.

Liquid crystals must be aligned to the top and bottom pieces of glass in order to obtain the desired twist. In other words, the 90 degree twist is formed by anchoring the liquid crystal on one glass plate and forcing it to twist across the cell gap (the distance between the two glass plates) when contacting the second plate. Furthermore, The actual image quality of the display will be dependent on the surface alignment of the LC material. The method currently used for aligning liquid crystals was developed by the Dai-Nippon Screening (English= Big Japan Screening) Company. The process consists of coating the top and bottom sheets of glass with a Polyimide based film. The top piece of glass is coated and rubbed in a particular orientation; the bottom panel/polyimide is rubbed perpendicular (90 degrees for TN displays) with respect to the top panel. It was discovered that by rubbing the polyimide with a cloth, nanometer (1 X 10 - 9 meters) size grooves are formed and the liquid crystals align with the direction of the grooves. It is common that when assembling a TN LC cell, it will be necessary to eliminate patches of nonuniform areas. The two parameters required to eliminate the nonuniformities and complete the TN LC display are pretilt angle and cholesteric impurities.

- There's more to building an LCD than simply creating a sheet of liquid crystals. The combination of four facts makes LCDs possible:
  - **Light can be polarized.**
  - **Liquid crystals can transmit and change the polarization of polarized light.**
  - **The structure of liquid crystals can be changed by an electric field.**
  - **There are transparent substances that can conduct electricity.**
- An LCD is a device that uses these four facts in a surprising way. To create an LCD, you take **two sheets of polarized glass**. A special polymer that creates microscopic grooves in the surface is rubbed on the side of the glass that does not have the polarizing film on it. The grooves must be in the same direction as the polarizing film.
- You then add a **coating of nematic liquid crystals** to one of the filters. The grooves will cause the first layer of molecules to align with the filter's orientation. Then add the second piece of glass with the **polarizing film at a right angle** to the first piece. Each successive layer of TN molecules will gradually twist until the uppermost layer is at a 90-degree angle to the bottom, matching the polarized glass filters.
- As light strikes the first filter, it is polarized. The molecules in each layer then guide the light they receive to the next layer. As the light passes through the liquid crystal layers, the molecules also change the light's plane of vibration to match their own angle. When the light reaches the far side of the liquid crystal substance, it vibrates at the same angle as the final layer of molecules. If the final layer is matched up with the second polarized glass filter, then the light will pass through.



Twisted Nematic Liquid Crystal
Image courtesy Dr. Oleg Lavrentovich, Liquid Crystal Institute

We have seen that a typical LCD display segment requires <1.7V rms "front-to-back" electrode to turn OFF the segment, and >2.8V rms to turn ON the segment.

HOWEVER, the *<u>dc component</u>* or *<u>average value</u>* of the "front-to-back" electrode voltage waveform MUST BE 0, or the LCD display will suffer permanent damage.

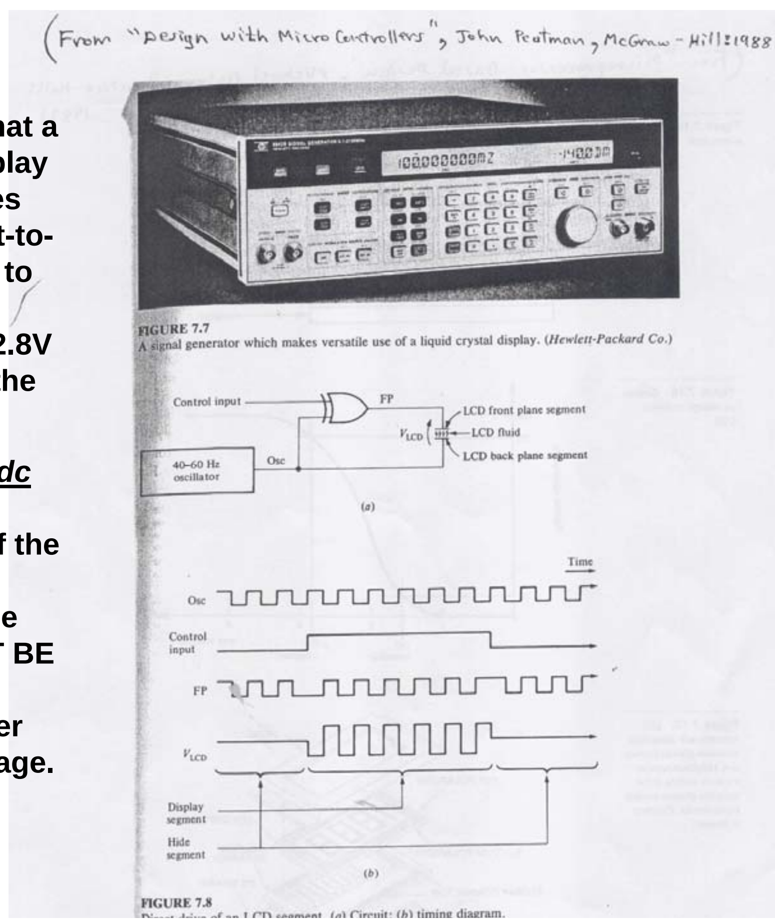
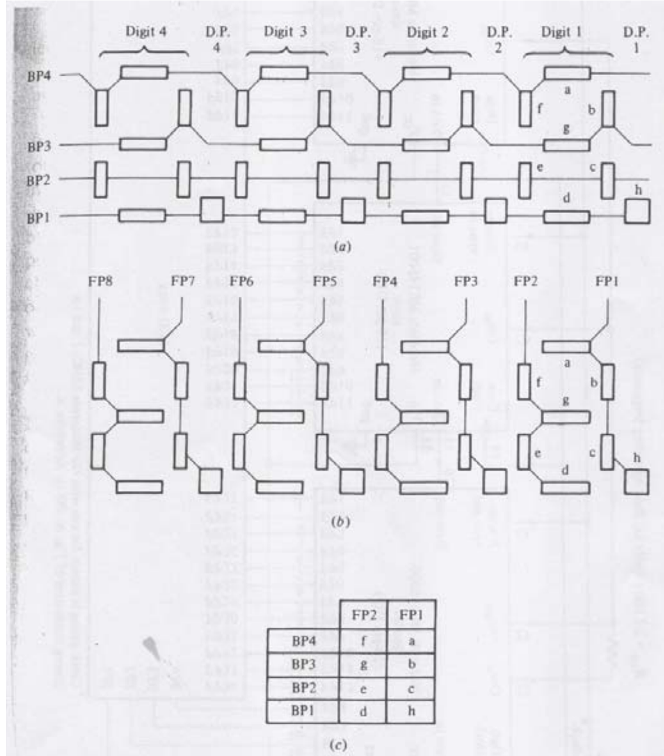


FIGURE 7.7
A signal generator which makes versatile use of a liquid crystal display. (*Hewlett-Packard Co.*)

FIGURE 7.8
Direct drive of an LCD segment. (*a*) Circuit; (*b*) timing diagram.

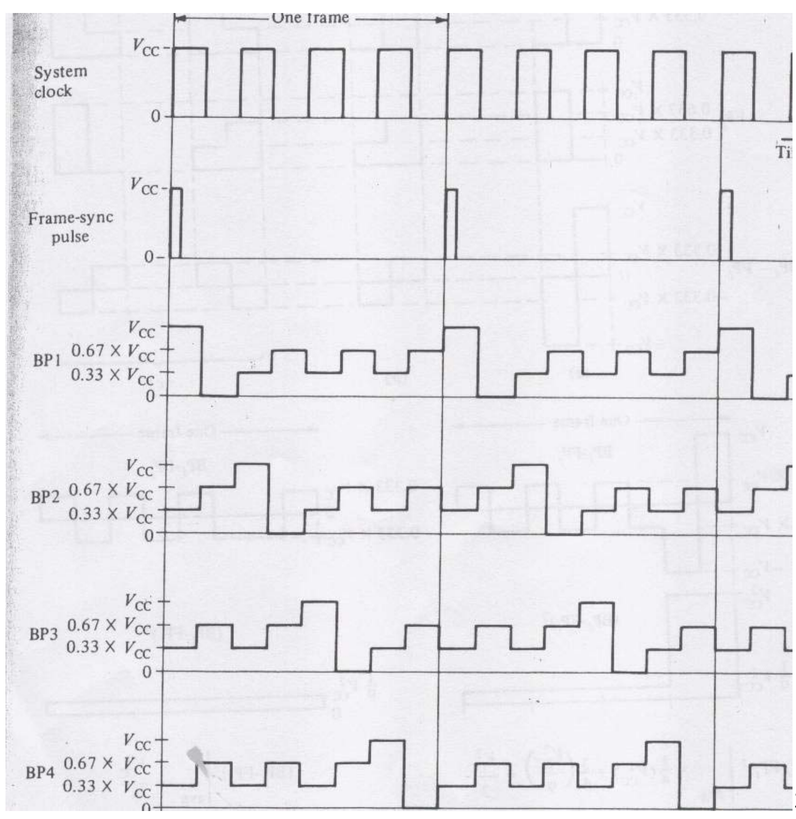
Note how the FP1 electrodes are passed under by one BP1, one BP2, one BP3, and one BP4 electrode. The same goes for the FP2, FP3, …, FP8 electrodes.



	FP2	FP1
BP4	f	a
BP3	g	b
BP2	e	c
BP1	d	h

FIGURE 7.11
Typical 2 × 4 multiplex format for seven-segment numeric display. (*a*) Backplane; (*b*) front-plane; (*c*) segment truth table.

Note that the BP signals are always the same, and are shown below for 1:4 LCD display multiplexing.



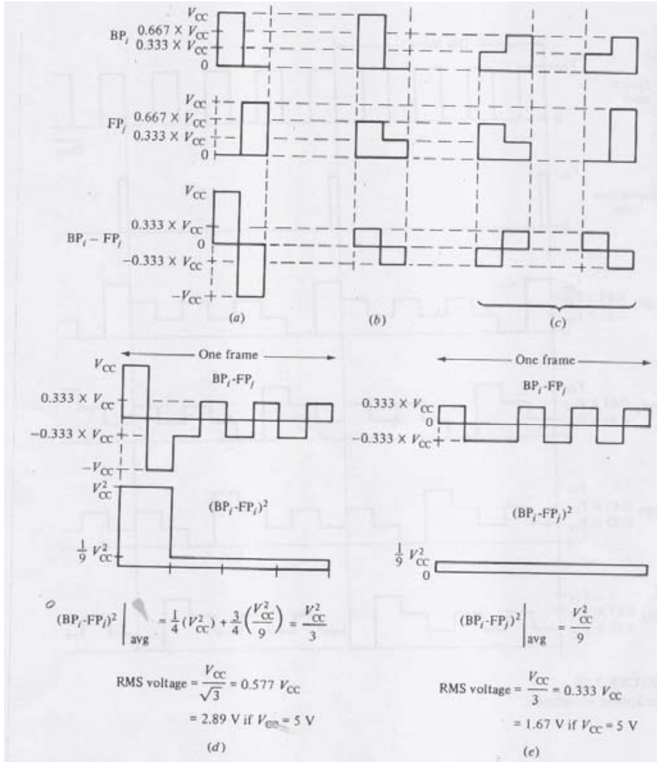


FIGURE 7.21
Determination of RMS voltages across on and off segments. (*a*) Selected quarter-frame on; (*b*) selected quarter-frame off; (*c*) deselected quarter-frame possible waveforms; (*d*) on segment RMS voltage determination; (*e*) off segment RMS voltage determination.

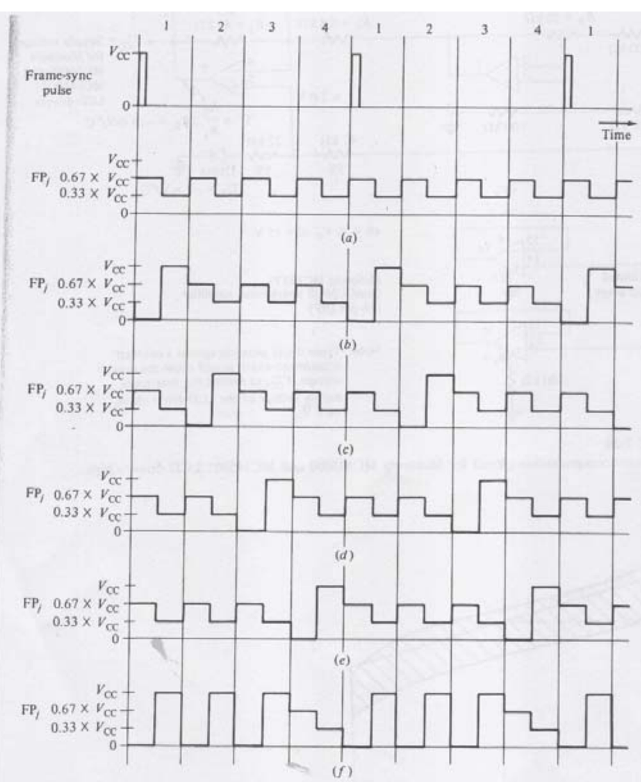


FIGURE 7.22
Frontplane waveforms. (*a*) All four segments off; (*b*) segment 1 (bottom segment) on; 2, 3, and 4 off; (*c*) segment 2 on; 1, 3, and 4 off; (*d*) segment 3 on; 1, 2, and 4 off; (*e*) segment 4 on; 1, 2 and 3 off; (*f*) segments 1, 2, and 3 on; 4 off.

CUSTOM LCD Display Example using 1:4 Multiplexing:

NOTE: Top two edge finger connections on left and right side are the four backplane connections. The rest of the edge fingers are frontplane connections which connect to exactly four segments.

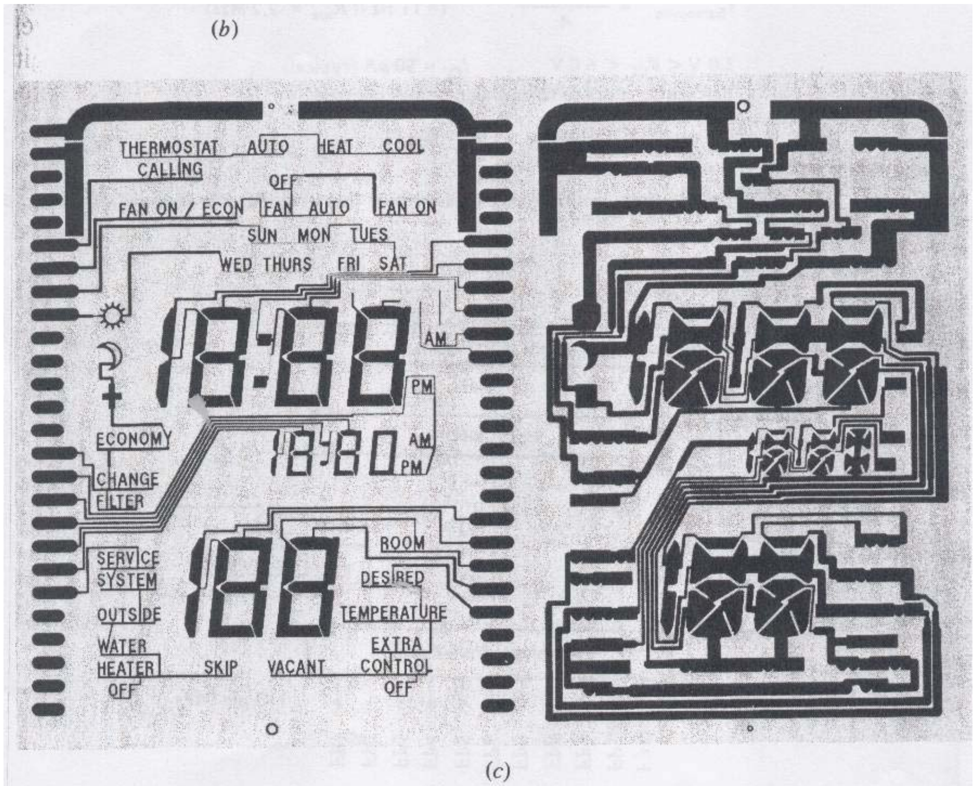
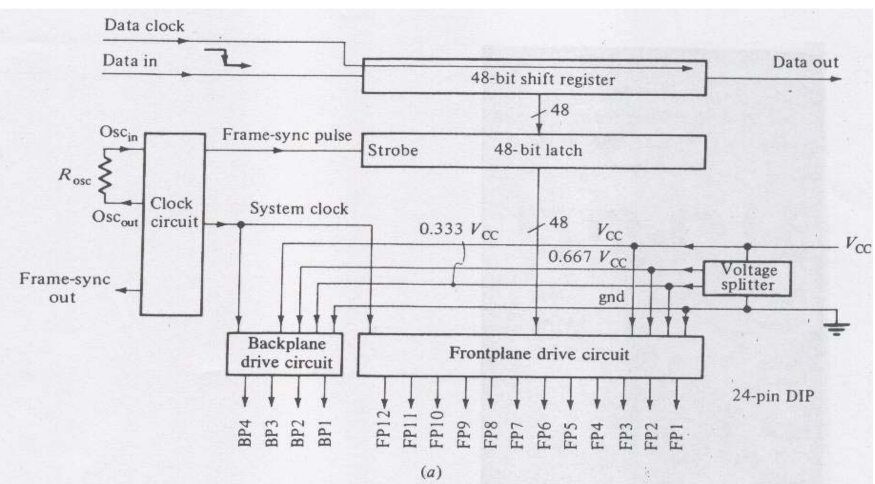


FIGURE 7.9 *(continued)*



$$f_{\text{system clock}} \approx \frac{100 \times 10^6}{R_{osc}} \text{ Hz} \qquad (= 45 \text{ Hz if } R_{osc} = 2.2 \text{ M}\Omega)$$

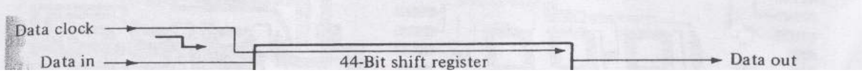
$$f_{\text{frame-sync}} = \frac{f_{\text{system clock}}}{4} \qquad (= 11 \text{ Hz if } R_{osc} = 2.2 \text{ M}\Omega)$$

$3.0 \text{ V} < V_{CC} < 6.0 \text{ V}$; $I_{CC} = 50\ \mu\text{A}$ (typical)

V_{CC} can be adjusted to optimize display contrast

(b)

FIGURE 7.15
Motorola MC145000 serial input, multiplexed LCD driver (master). (*a*) Block diagram; (*b*) a few specifications.



V_{CC} can be adjusted to optimize display contrast

(*b*)

FIGURE 7.15
Motorola MC145000 serial input, multiplexed LCD driver (master). (*a*) Block diagram; (*b*) a few specifications.

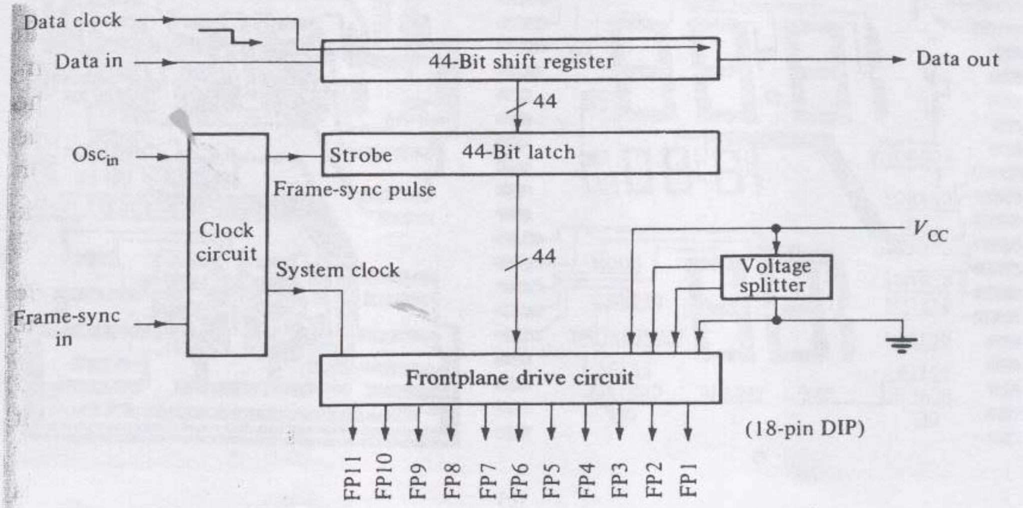


FIGURE 7.16
Motorola MC145001 serial input, multiplexed LCD driver (slave).

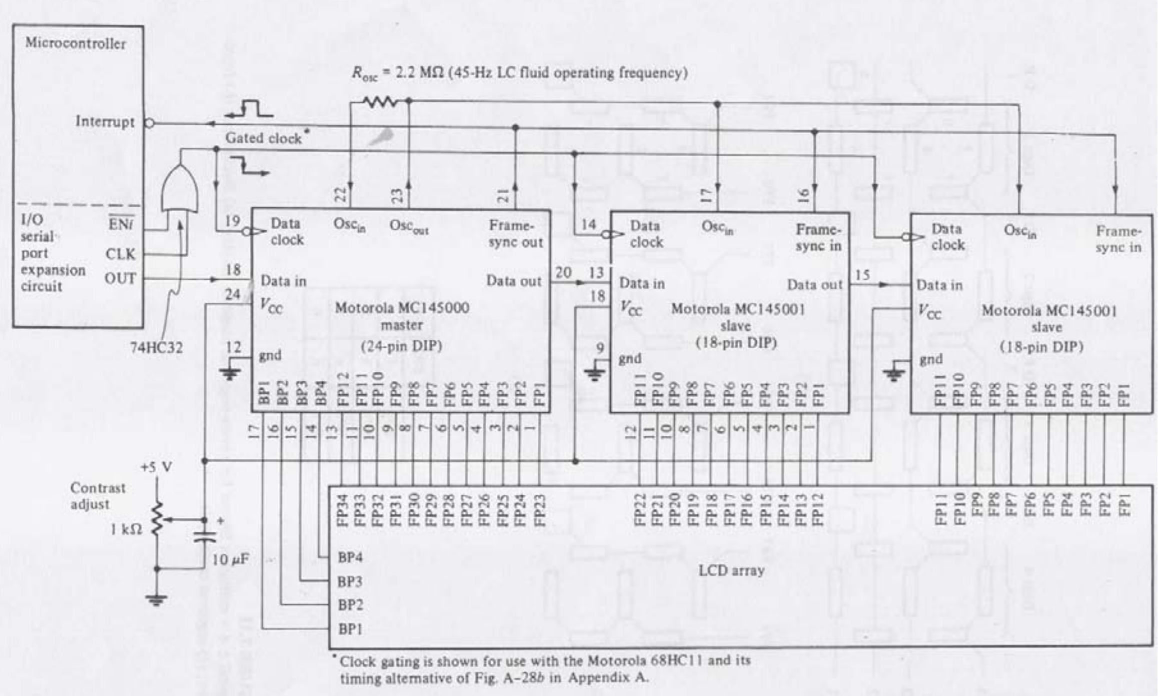


FIGURE 7.13
Multiplexed LCD display circuit.

FIGURE 7.24
Temperature compensation circuit for Motorola MC145000 and MC145001 LCD driver chips.

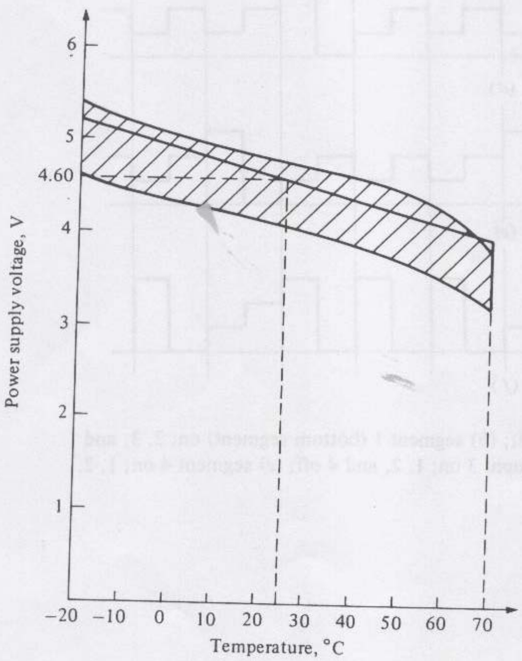


FIGURE 7.25
Recommended linear temperature compensation of −14 mV/°C for operation between −20 and +70°C. (*N. V. Philips.*)

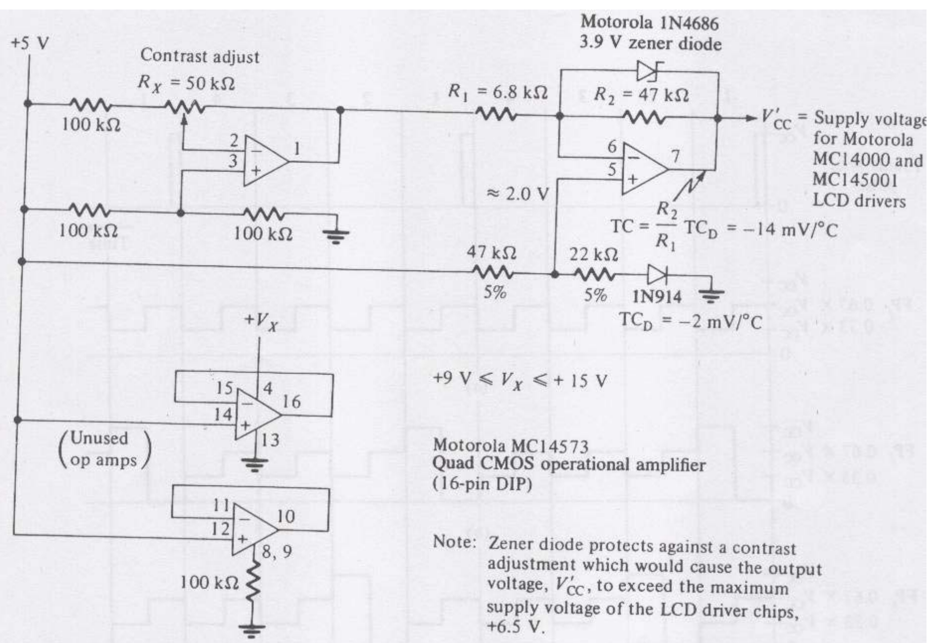
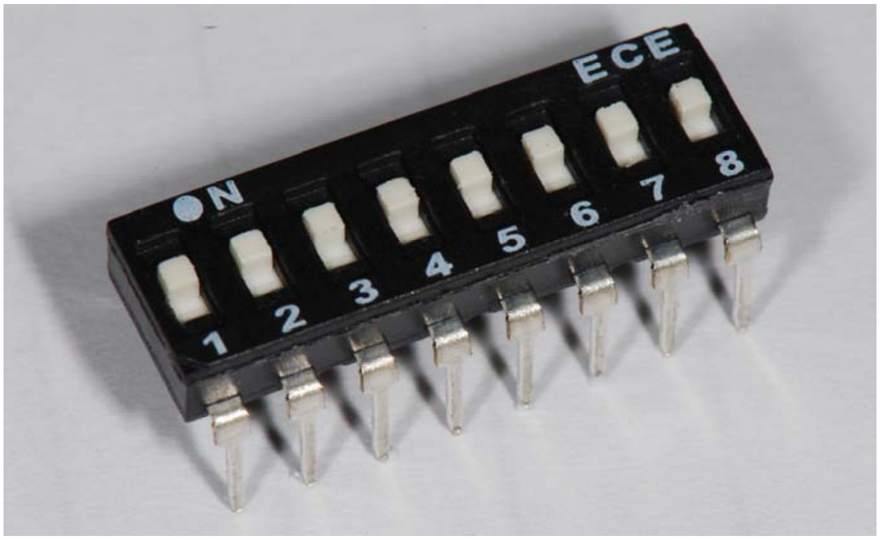


FIGURE 7.24
Temperature compensation circuit for Motorola MC145000 and MC145001 LCD driver chips.

INPUT DEVICES FOR EMBEDDED DESIGN

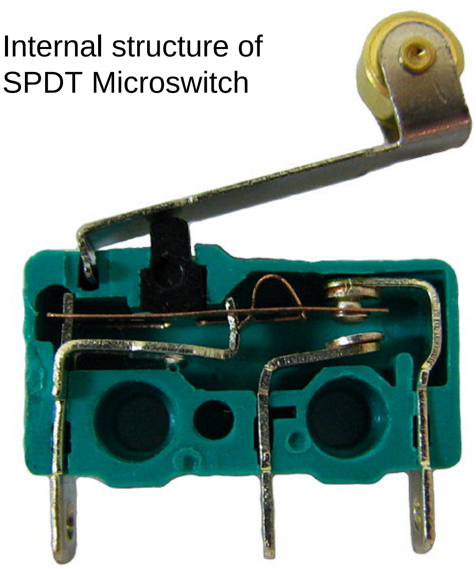
1. Switches

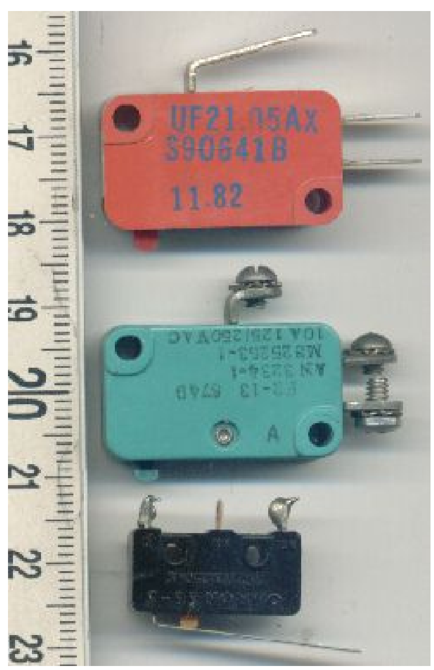
A. DIP SWITCH



B. Microswitch

Internal structure of
SPDT Microswitch





- A **micro switch** is a generic term used to refer to a small electric switch that is able to be actuated by very little physical force.
- They are very common due to their low cost and extreme durability, typically greater than 1 million cycles and up to 10 million cycles for heavy duty models. This durability is a natural consequence of the design. Internally a stiff metal strip must be bent to activate the switch. This produces a very distinctive clicking sound and a very crisp feel. When pressure is removed the metal strip springs back to its original state.
- Common applications of micro switches include computer mouse buttons and arcade game's joysticks and buttons. Micro switches are commonly used in tamper switches on gate valves on fire sprinkler systems and other water pipe systems, where it is necessary to know if a valve has been opened or shut.
- The defining feature of micro switches is that a relatively small movement at the actuator button produces a relative large movement at the electrical contacts, which occurs at high speed (regardless of the speed of actuation).
- Most successful designs also exhibit mechanical *hysteresis* meaning that a small reversal of the actuator is insufficient to reverse the contacts; there must be a significant movement in the opposite direction. Both of these characteristics help to achieve a clean and reliable interruption to the switched circuit.

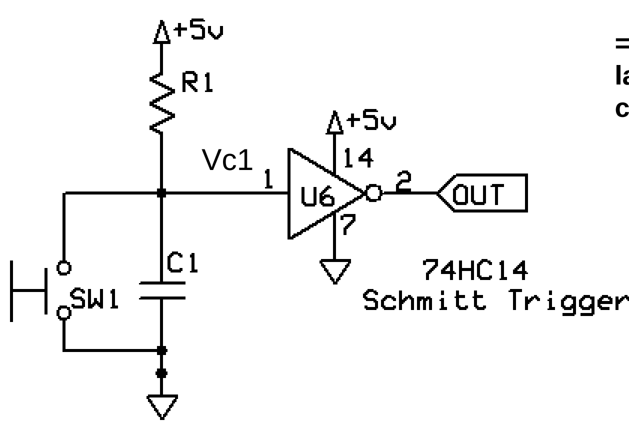
C. SPST Switch Debouncing

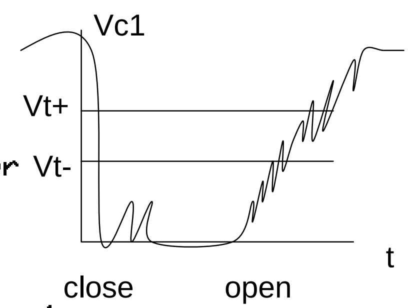
(Needed when driving a counter, etc.)

Schmitt Input Hysteresis:

Vt- = 1.5 V, Vt+ = 2.5 V

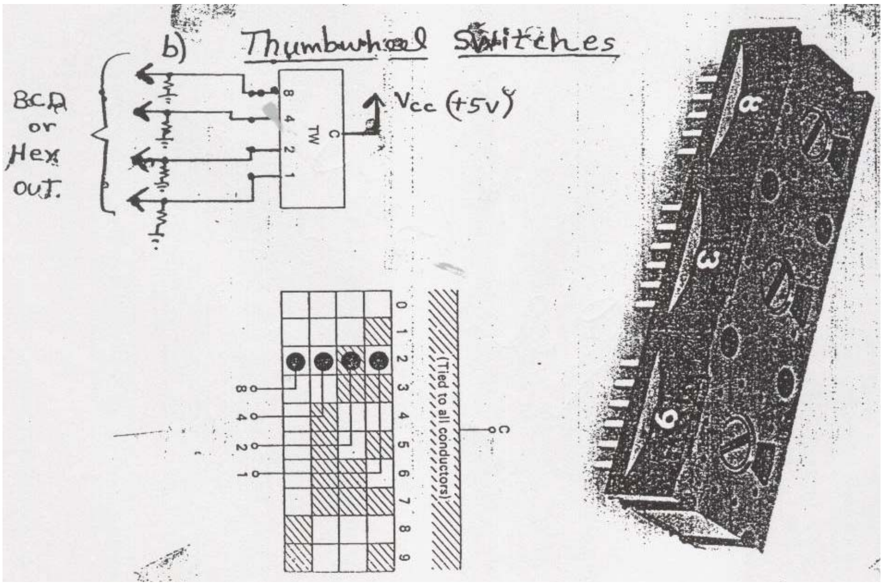
=> AC noise on Vc1 may be as large as 2.5-1.5 = 1 v without causing output changes.





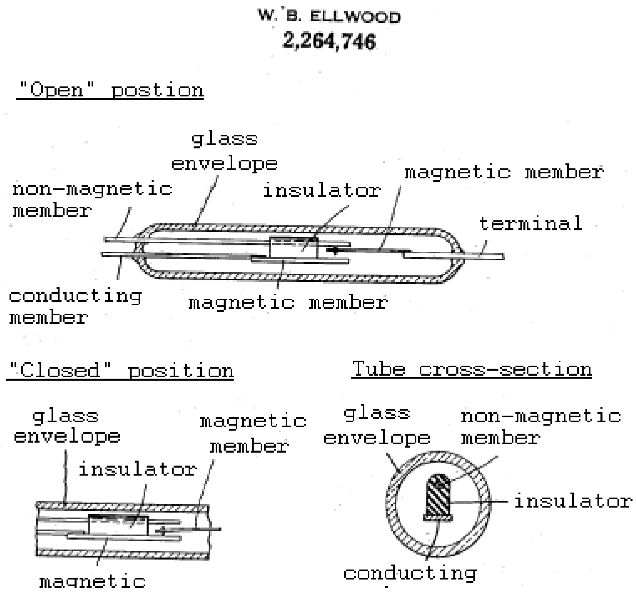
Choose RC > duration of bounce, in seconds

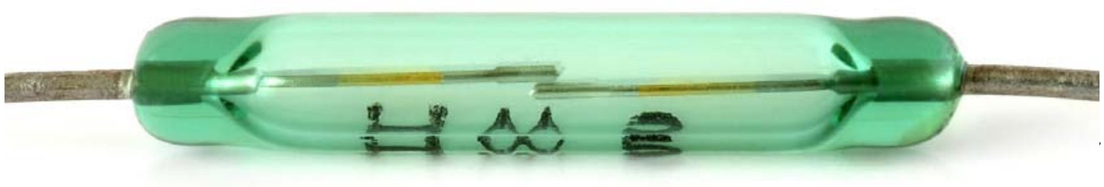
D. BCD Encoded Thumbwheel Switch



E. Magnetic Reed Switch

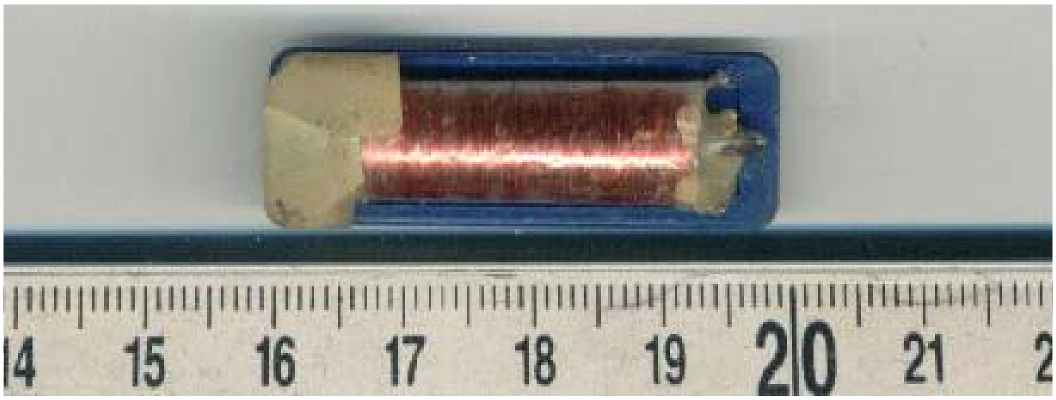
- The reed switch contains two magnetizable and electrically conductive ferromagnetic reeds which have end portions separated by a small gap when the switch is open.
- The reeds are hermetically sealed in opposite ends of a tubular glass envelope to guard against contact corrosion.
- A magnetic field (from an electromagnet or a permanent magnet) will cause the contacts to pull together, thus completing an electrical circuit. The stiffness of the reeds causes them to separate, and open the circuit, when the magnetic field ceases
- It was invented at Bell Telephone Laboratories in 1936 by W. B. Elwood





- One important quality of the switch is its sensitivity, the amount of magnetic energy necessary to actuate it. Sensitivity is measured in units of Ampere-turns, corresponding to the current in a coil multiplied by the number of turns. Typical pull-in sensitivities for commercial devices are in the 10 to 60 AT range.
- Thus a small coil of wire may be wound around the reed switch to turn it into a reasonably sensitive reed relay.
- Reed switches are commonly used in mechanical systems as proximity switches, in door and window sensors in burglar alarm systems and in safety interlocks.
- Reed switches were formerly used in the keyboards for computer terminals, where each key had a magnet and a reed switch actuated by depressing the key.
- Speed sensors on bicycles use a reed switch to detect when the magnet on the wheel passes the sensor.

- A reed switch combined with an electromagnet becomes a reed relay. The electromagnet consists of a coil with the reed switch inside. Reed relays are used when high operating speed is required, or where very low-level signals must be switched.



F. Software scanned keypad

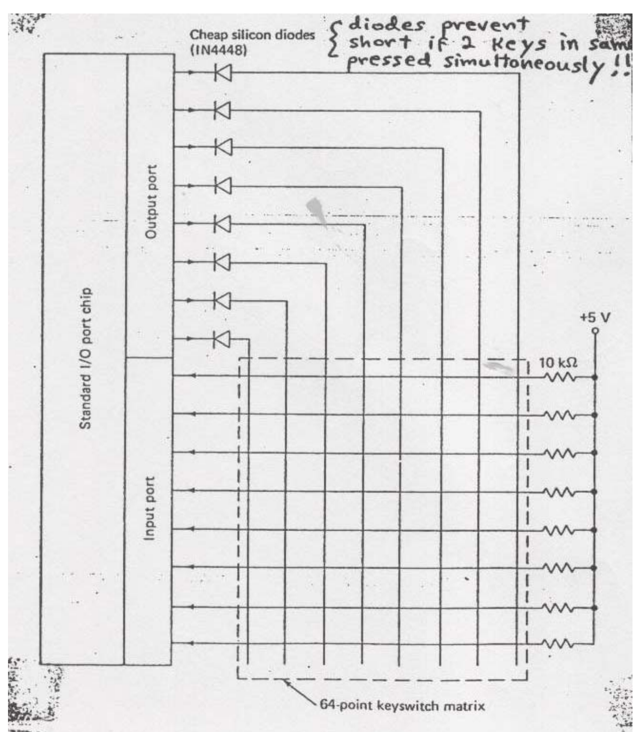
(**Scanning accomplished *without* using bidirectional ports**)

64 key keypad scanned using one 8-bit output port and one 8-bit input port.

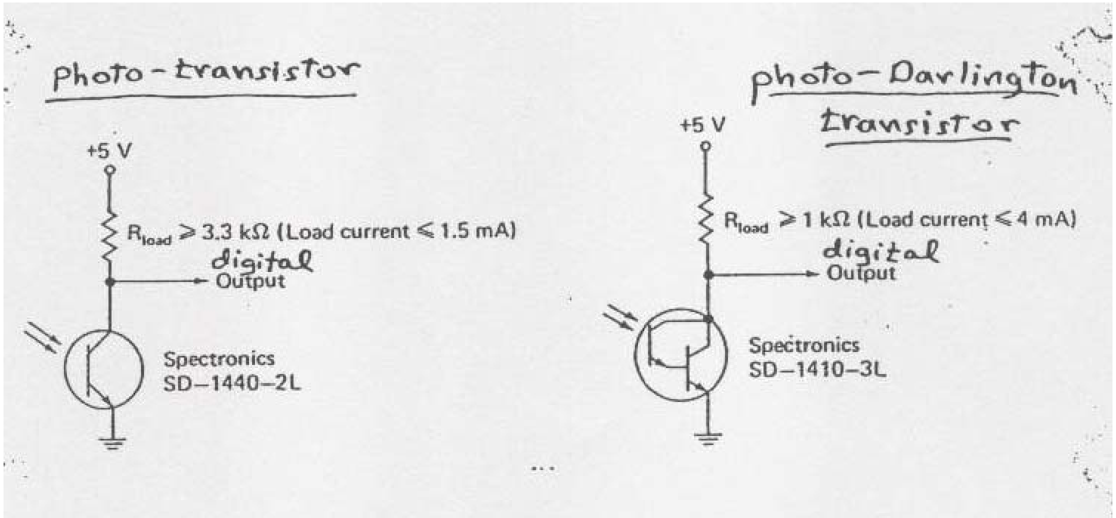
Output port scans keypad by repetitively cycling (scanning) through the following output sequence:

01111111
10111111
11011111
11101111
11110111
11111011
11111101
11111110

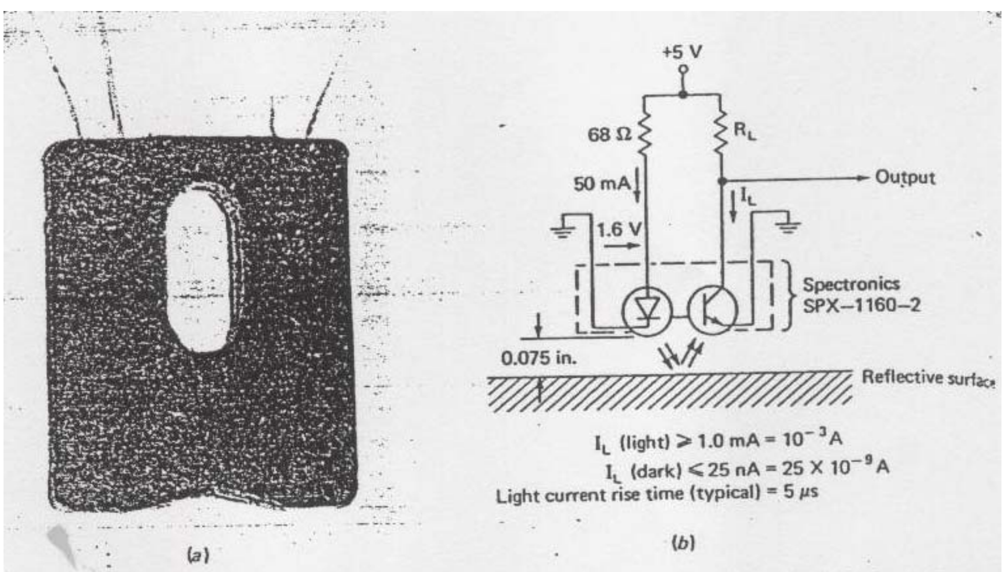
After each number is output, the input port is read, and if 0xFFis read the scan continues.
If some other value than 0xFF is read (just one 0),scanning stops, and the position of the 0 at the output port and the position of the 0 read at the input port locate the key that was pressed!



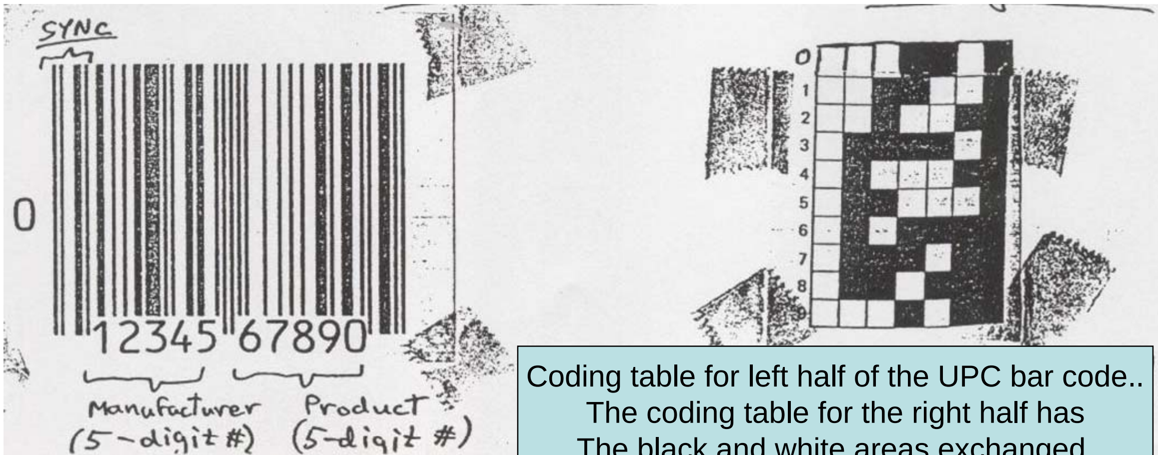
G. Optoelectronic Switches



Reflective Optoelectronic Switch



UPC Bar Code Scanning Wand

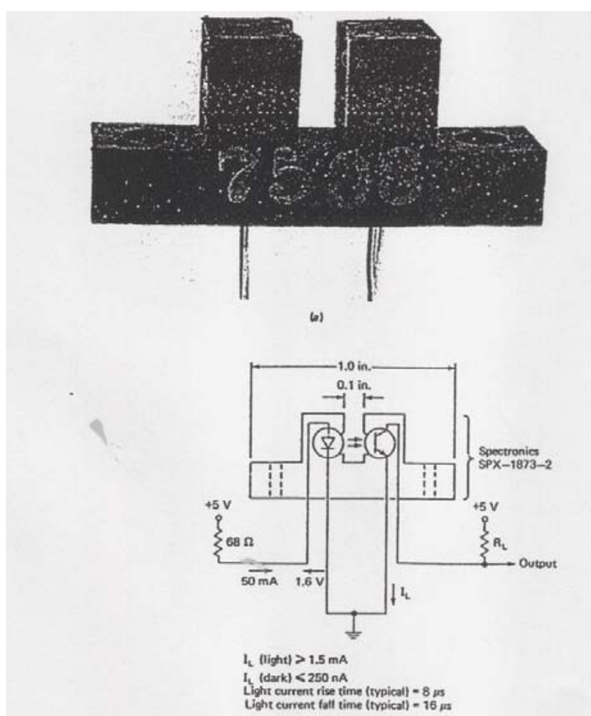


Coding table for left half of the UPC bar code..
The coding table for the right half has
The black and white areas exchanged.

Using a reflective optoelectronic switch as the scanning wand, black => high level (1) and white => low level (0). Note the 101 SYNC patterns at both ends of the code and the middle 0101 pattern

Transmissive Optoelectronic Switch

Light Emitting Diode (LED) and Phototransistor (PT) face each other from opposite sides of the sensor. When an object interrupts the light beam, the output rises from 0V to 5 V.



Optical Tachometer

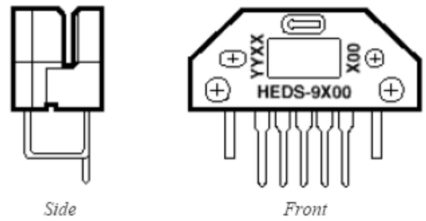
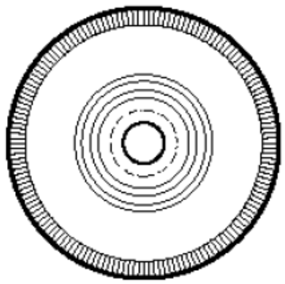


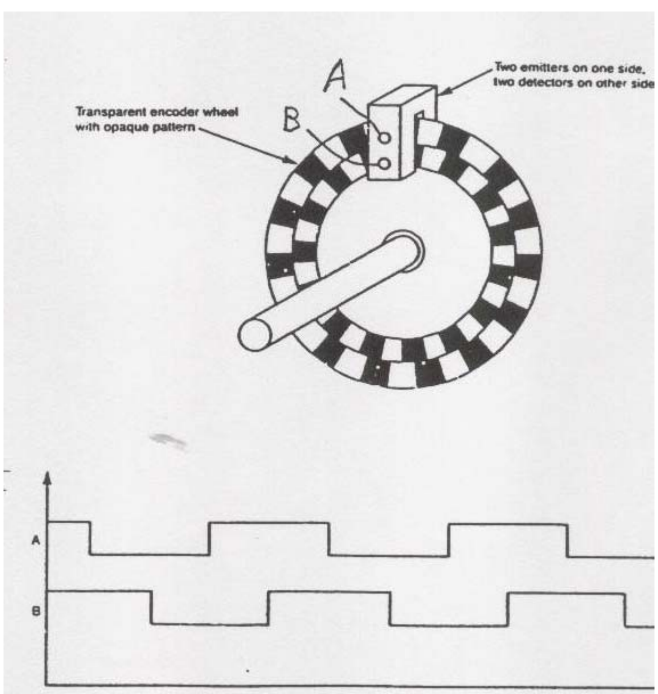
Figure 1.4 - HEDS-9100 optical incremental encoder module for the optical tachometer



If codewheel has 360 equally spaced light/dark changes around its periphery, then the number of output pulses counted in 1 second yields the speed of angular rotation in degrees/second.

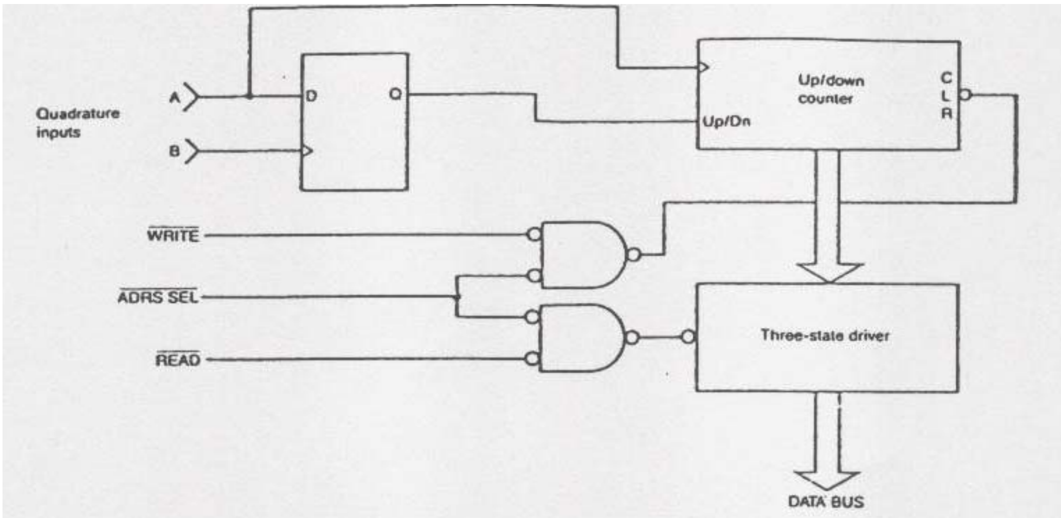
Figure 1.5 - HEDS-5120 codewheel for the optical tachometer

Sensing Direction of Rotation as well as angular displacement



Count rising edges of A to determine the angular displacement. Check level on B when A rises in order to deduce direction of rotation (either Clockwise (B=1) or CounterClockwise (B=0)

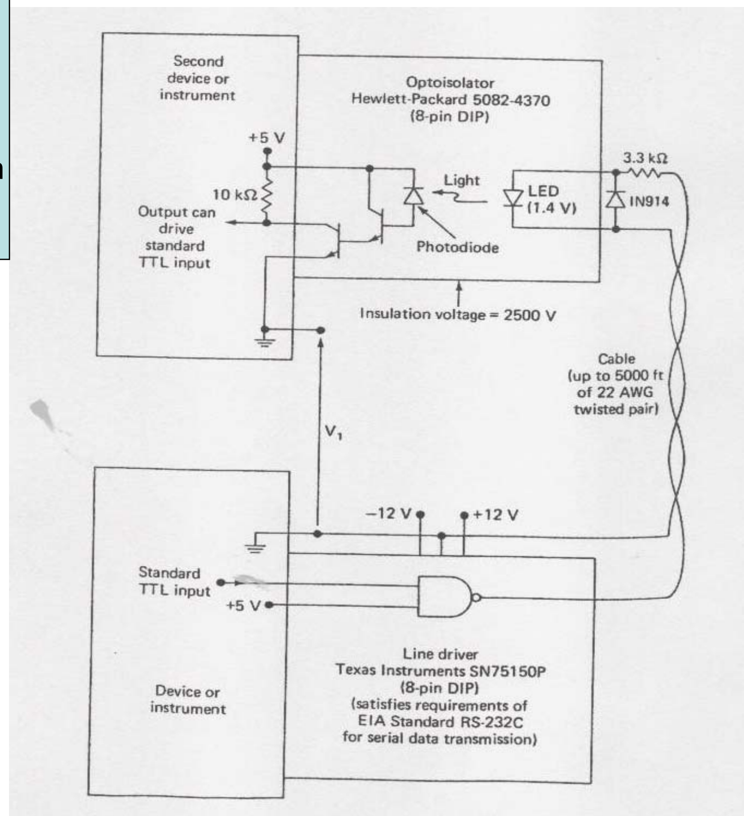
Displacement sensing for mouse, trackball, or dc motor in robotics



Optoisolator

- Consider a transmissive optoelectronic switch with its air gap sealed. What good is this?
- Actually, it is still quite useful!
- It may be used in signal transmission and electrical shock isolation systems!
- For example, in the digital communication link shown on the next slide, the grounds at the two sites are at different potentials which differ by V1 volts. (During an electrical storm, the difference in ground potentials at two different sites might be as high as 2500 V!). If these grounds were connected directly together, excessive current would flow through the ground wire, and the wire will melt.
- Use of the optoisolator no longer requires the grounds to be tied together between the two remote locations.

Using an optoisolator
To provide
Ground Fault
Isolation in a
Digital Communication
Link



H. Magnetic Sensing without moving parts – Hall Effect Switch

Unlike a permanent magnet moving past a "inductive pickup" coil, which, by Faraday's Law of Induction, is more sensitive to faster moving magnets, the Hall Effect Switch is position, not velocity, dependent. Even the presence of a stationary magnet can be detected with the Hall Effect Device.

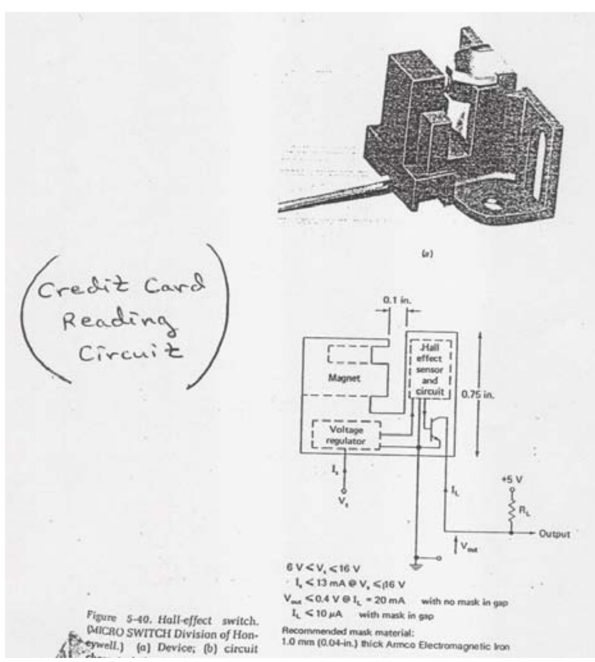
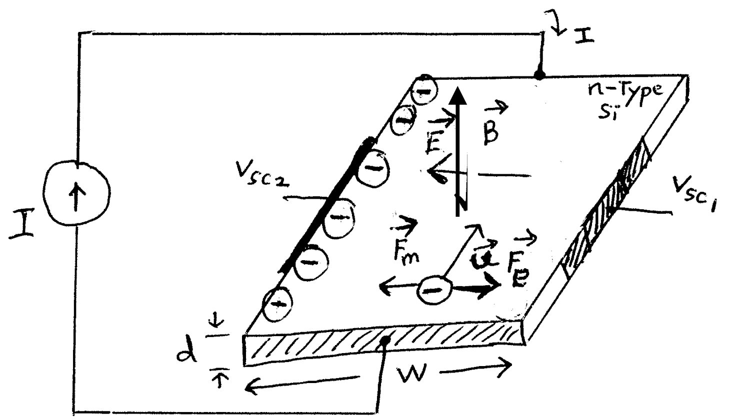


Figure 5-40. Hall-effect switch. (MICRO SWITCH Division of Honeywell.) (a) Device; (b) circuit



$\vec{F}_m = q\,\vec{u} \times \vec{B}$ where q = magnitude of charge on electron = **1.6×10^{-19} C**

$|\vec{F}_m| = q\,|\vec{u}|\,|\vec{B}|$ $\quad \vec{u}$ = electron drift velocity

$F_m = q\,u\,B$

$I = n\,q\,(wd)\,u \Rightarrow u = \dfrac{I}{nqwd}$

n = doping level = # charge carriers/m^3

$\left(\frac{1}{m^3}\right)(C)(m^2)\left(\frac{m}{s}\right) \Rightarrow C/s$ = Amperes

$$\therefore F_m = q\left(\frac{I}{nqwd}\right)B$$

$$F_e = q\,E = q\left(\frac{V_{sc_1} - V_{sc_2}}{W}\right)$$

AT equilibrium

$$F_m = F_e$$

$$q\left(\frac{I}{nqwd}\right)B = q\left(\frac{V_{sc_1} - V_{sc_2}}{W}\right)$$

$\Rightarrow$ Hall Voltage

$$(V_{sc_1} - V_{sc_2}) = \frac{IB}{ndq}$$

$$\therefore V_{sc_1} - V_{sc_2} \propto B$$

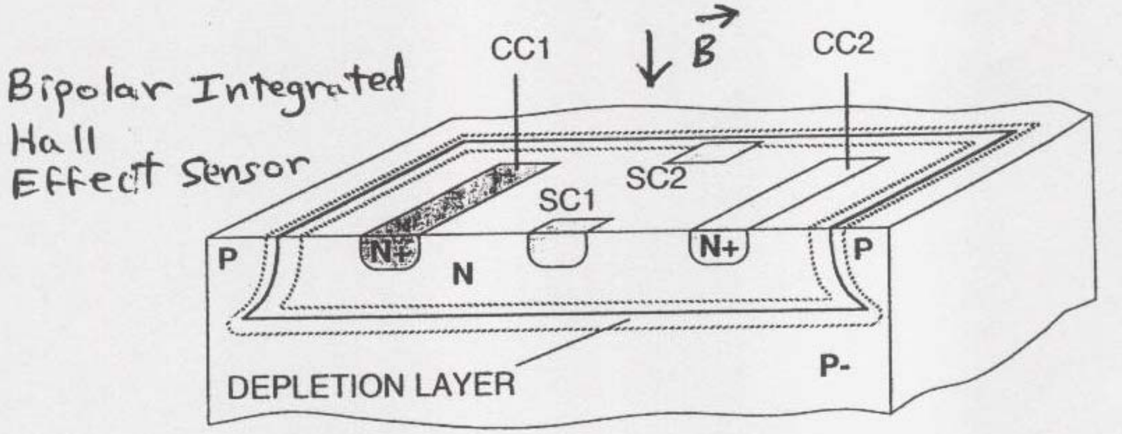


Fig. 11 Structure of integrated Hall plate in bipolar IC technology. The symbols are explained in the text. (After Ref. 3)

Note that the P-type substrate is connected to the lowest voltage in the circuit (ground) so that the N-type material used in the Hall effect device forms a reverse biased "isolation junction" that isolates the Hall effect device from the rest of the circuitry on the IC.

Integrated Hall Effect Sensor

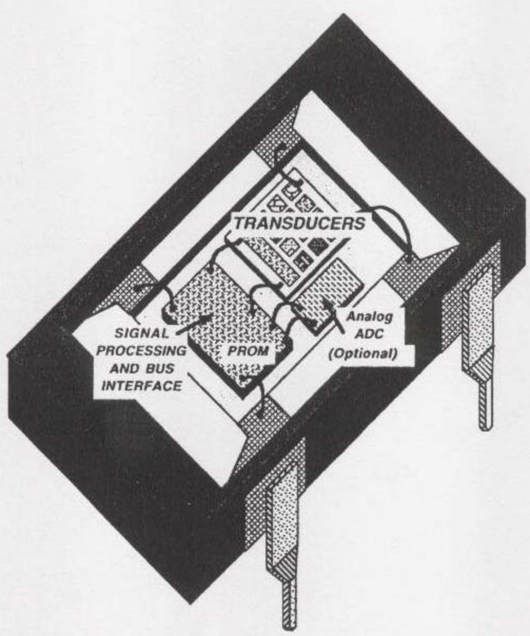


Fig. 6 Schematic representation of a "fifth-generation" hybrid sensing node. (After Refs. 6, 9)

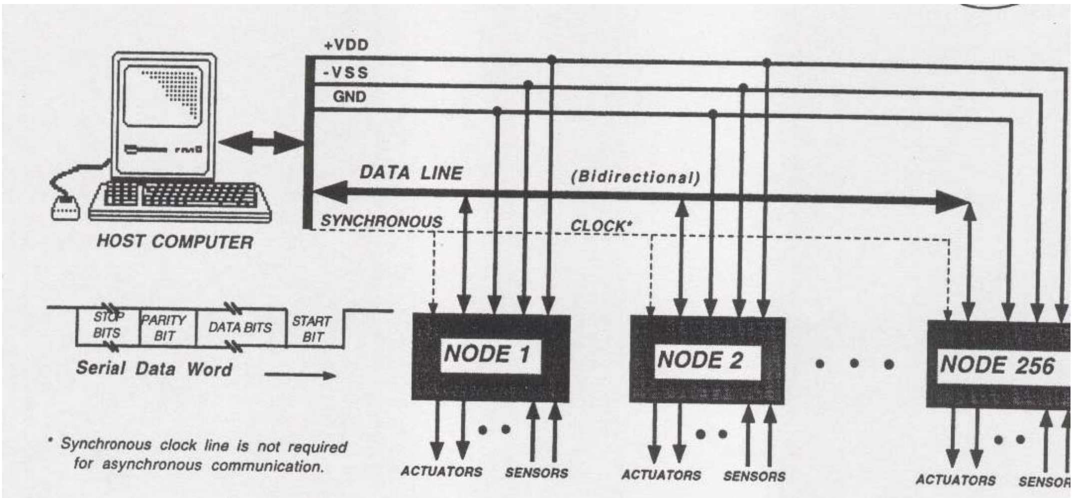


Fig. 5 Diagram and organization of the Michigan Serial Bus Standard (MSS). (After Refs. 6, 9)

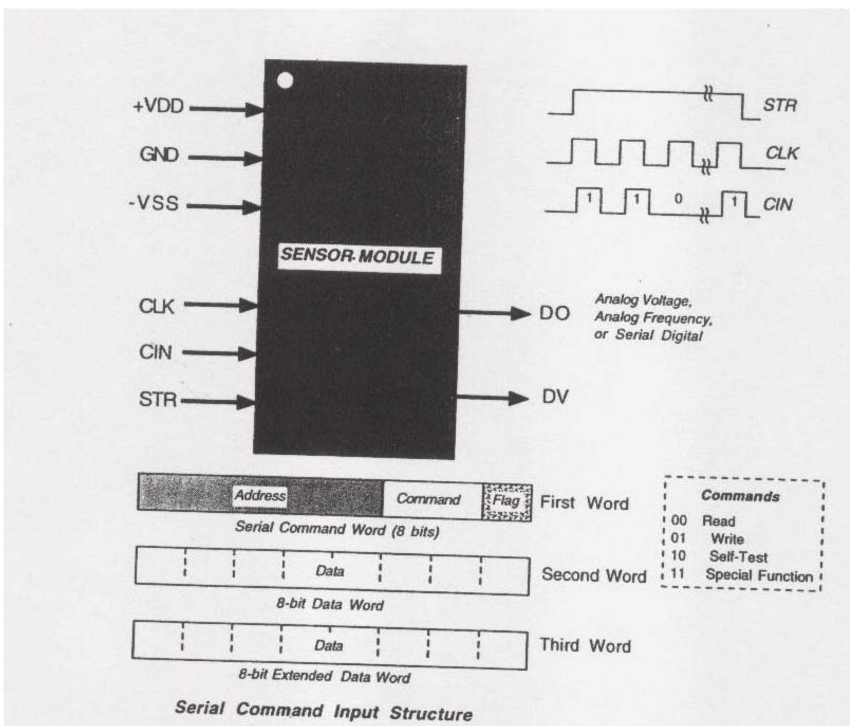
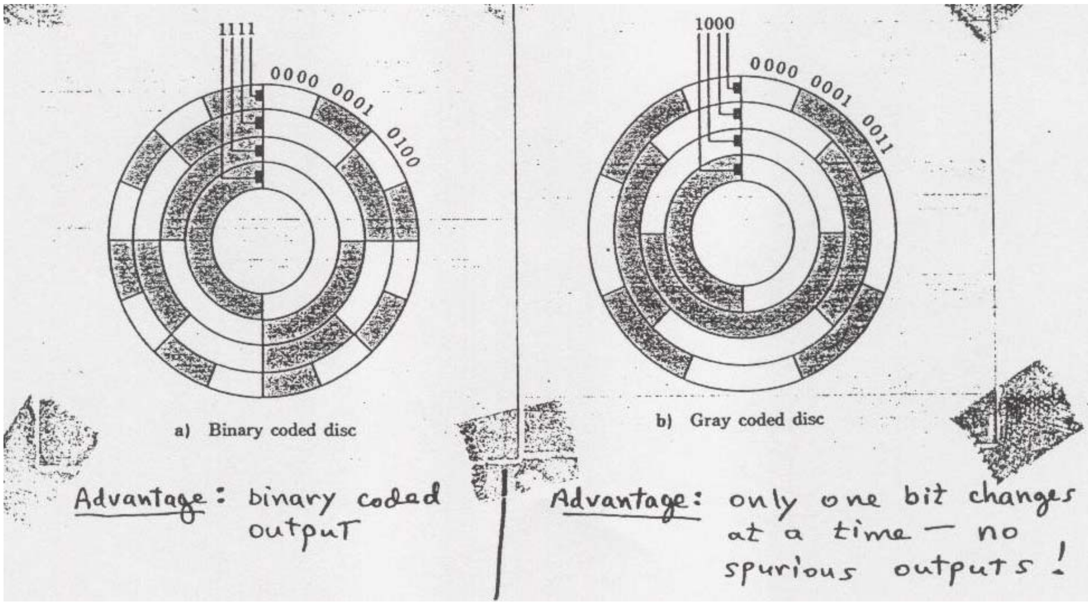
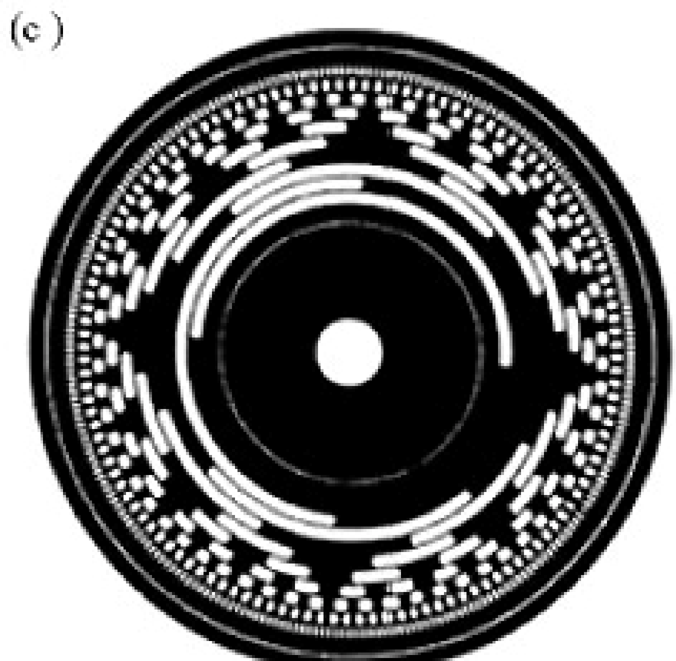


Fig. 7 Standardized eight-line sensor front-end interface and its command ...

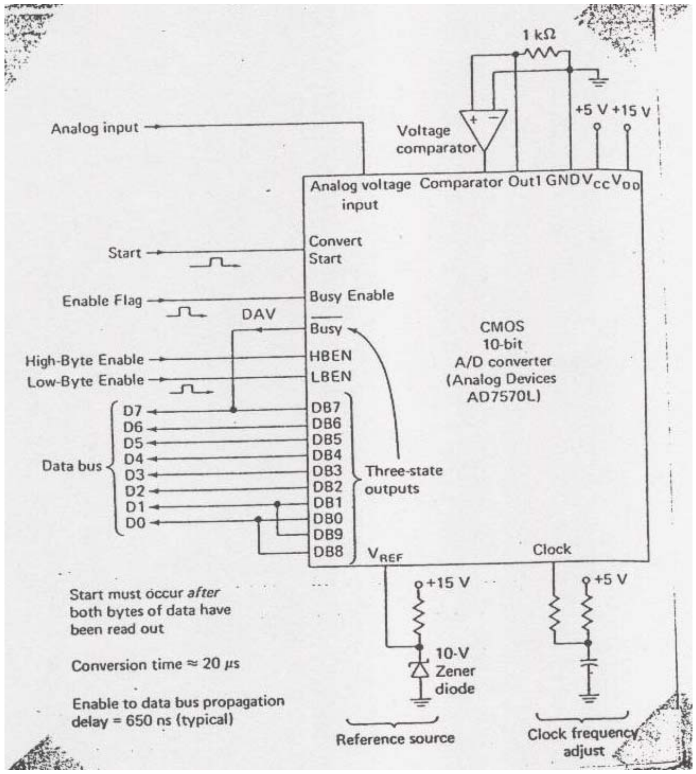
2. Digital Shaft Angle Encoder (Binary vs. Gray Coded)



Optical Gray-Coded Encoder Disk



3. Interfacing Analog Sensors via A/D Converter



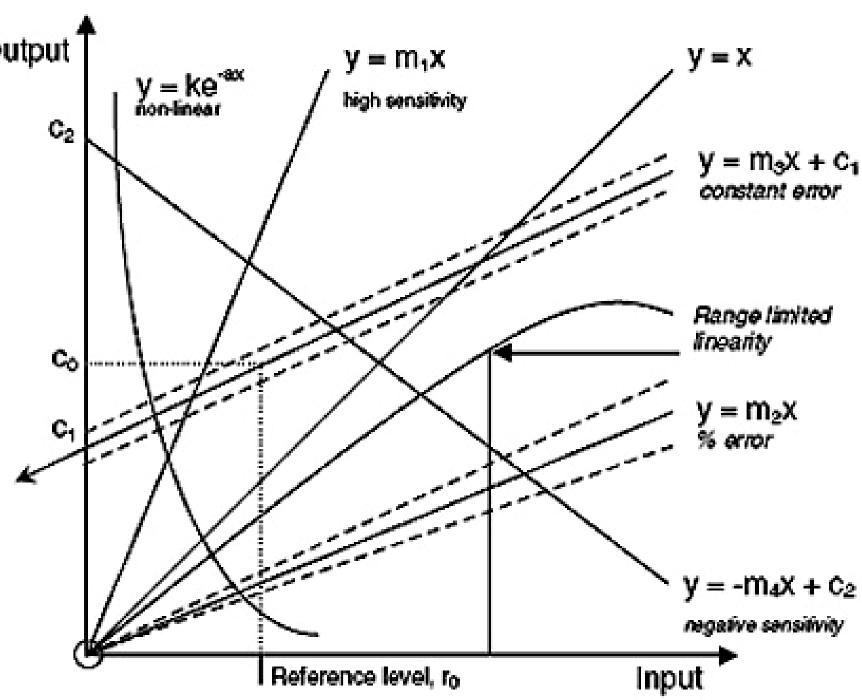
The A/D Converter makes it possible to connect many different kinds of Analog Sensors (Transducers) to a microcontroller. Such transducers convert any different physical quantities that occur naturally in analog form into analog voltage, which then converted by the A/D into binary numbers. For example: transducers are available for measuring:

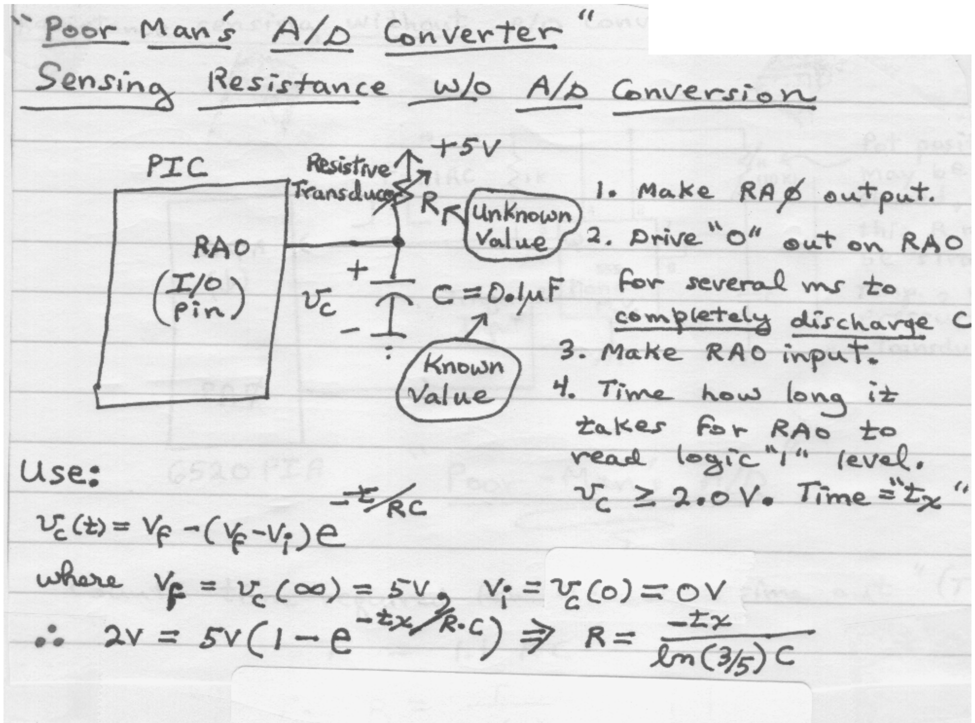
- Displacement (position)
- Velocity
- Acceleration
- Temperature
- Pressure
- Light Intensity,
- Light Color (Wavelength)
- Humidity
- Etc., Etc, Etc.

Analog Sensor Characteristics

- Sensors have certain characteristics which should be specified in the data sheet:
  - Sensitivity
  - Offset
  - Range
  - Linearity
  - Error
  - Accuracy
  - Resolution
  - Stability
  - Reference level
  - Transfer function and Interdependence.

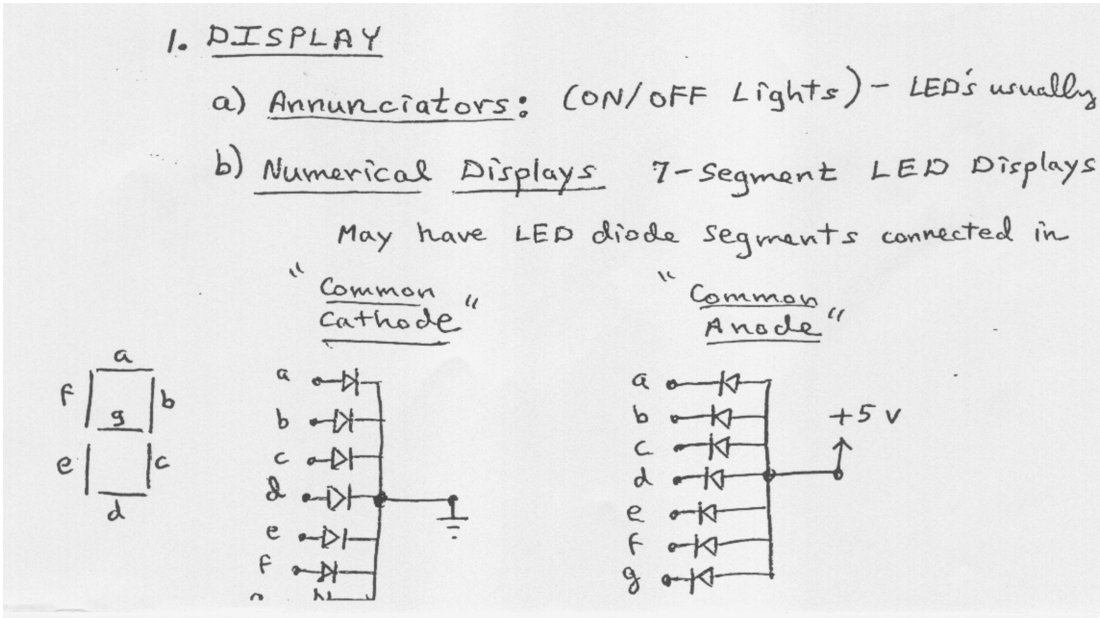
Analog Sensor Specifications:





Output Devices/Actuators

LED Displays

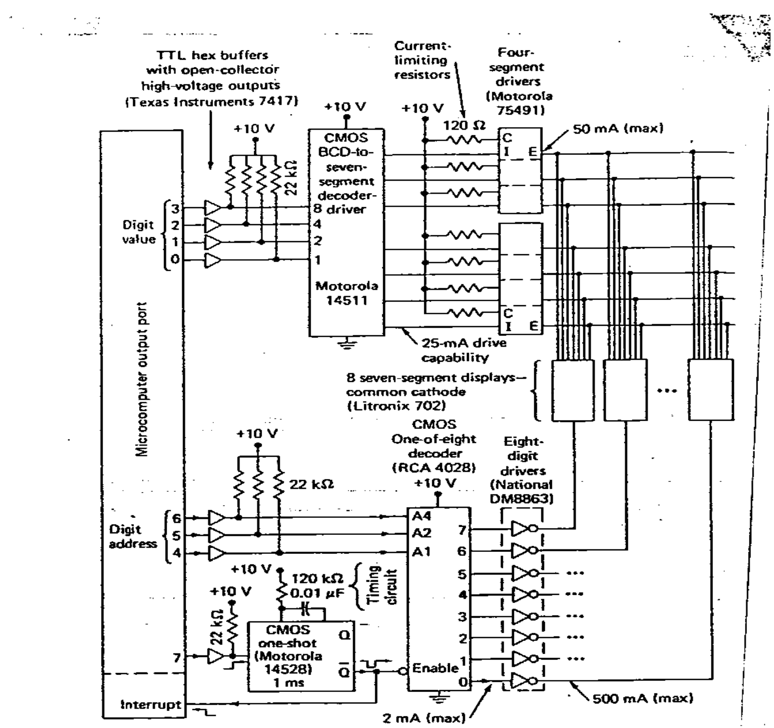

1. DISPLAY

a) Annunciators: (ON/OFF Lights) – LED's usually

b) Numerical Displays 7-Segment LED Displays

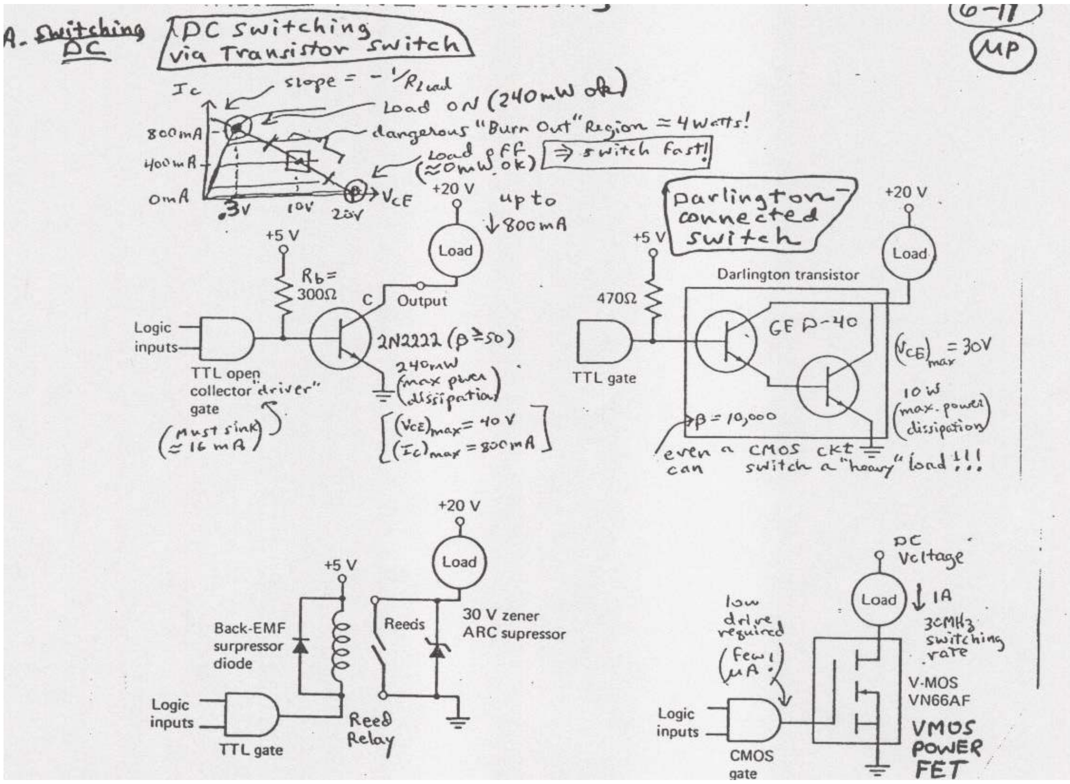
May have LED diode segments connected in "Common Cathode" "Common Anode"

Multiplexed 8-Digit 7-Segment LED Display

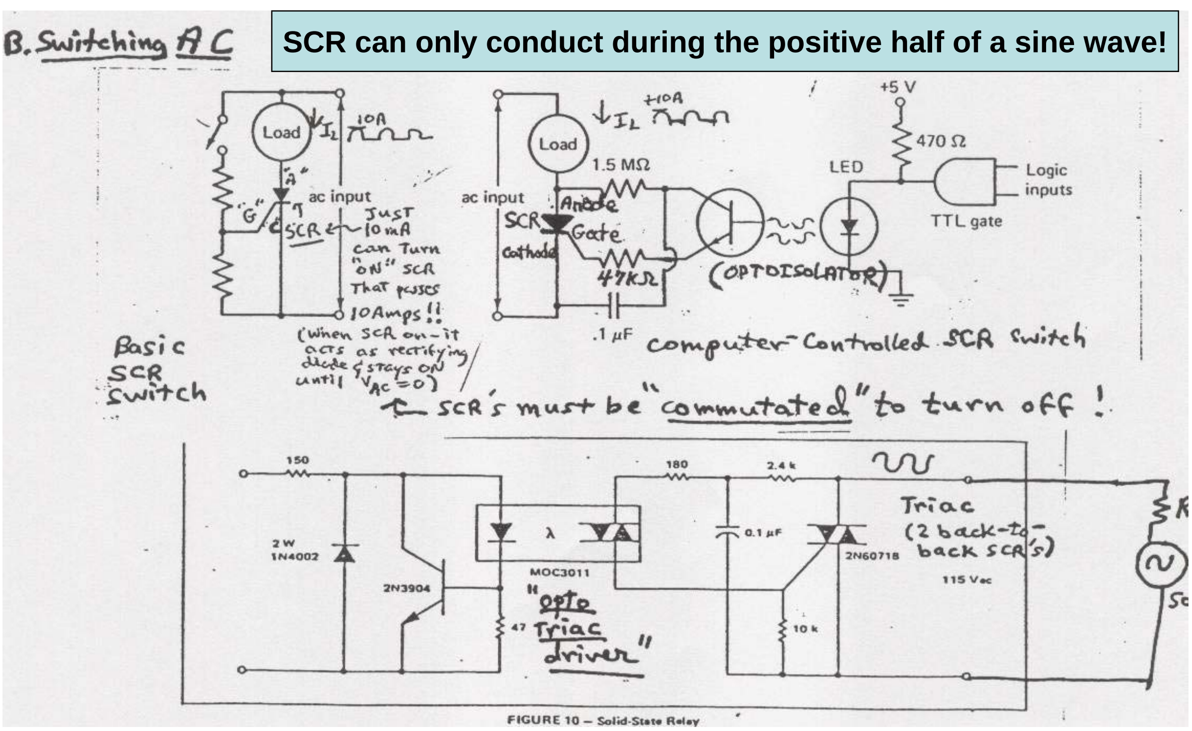


Multiplexed numeric display.

Driving high power loads (Solenoids, stepper motors, lamps, etc.)



SCR can only conduct during the positive half of a sine wave!

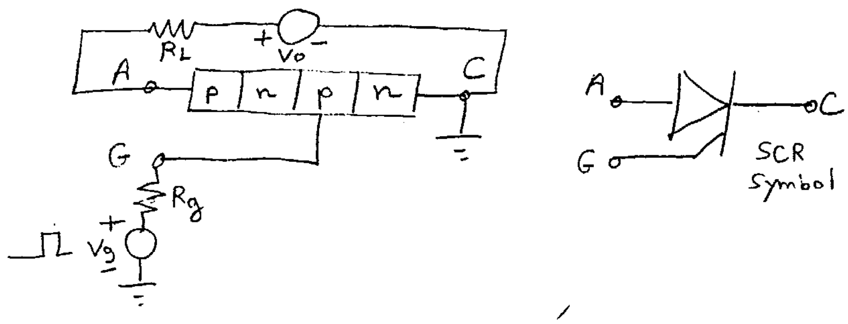


Triac can conduct during both positive and negative half of a sine wave

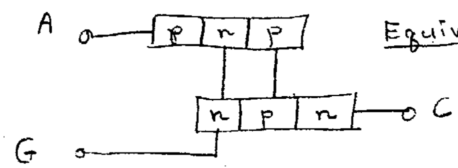
How an SCR (Silicon Controlled Rectifier) Works

(6-

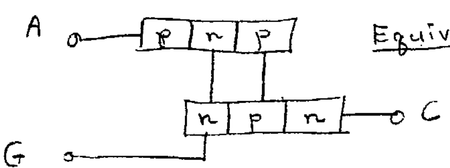
The SCR is a 4-layer p-n-p-n structure, as shown below



The SCR can be thought of as 2 overlapping BJT transistors, one pnp and one npn, as shown below:

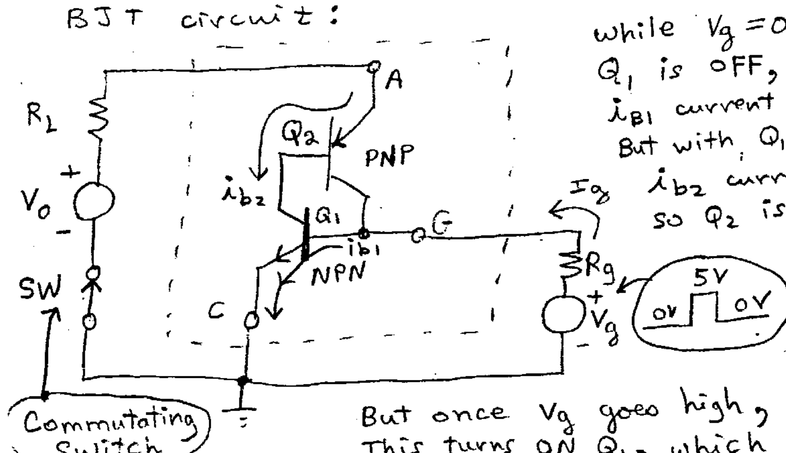


Equivalent View of SCR pnpn structure



Equivalent View of SCR pnpn structure

Thus the SCR can be envisioned as the following BJT circuit:



while $V_g = 0$ (initially) Q_1 is OFF, since No i_{B1} current flows. But with Q_1 OFF, No i_{b2} current can flow, so Q_2 is also OFF.

Thus Q_1 holds Q_2 OFF and Vice versa.

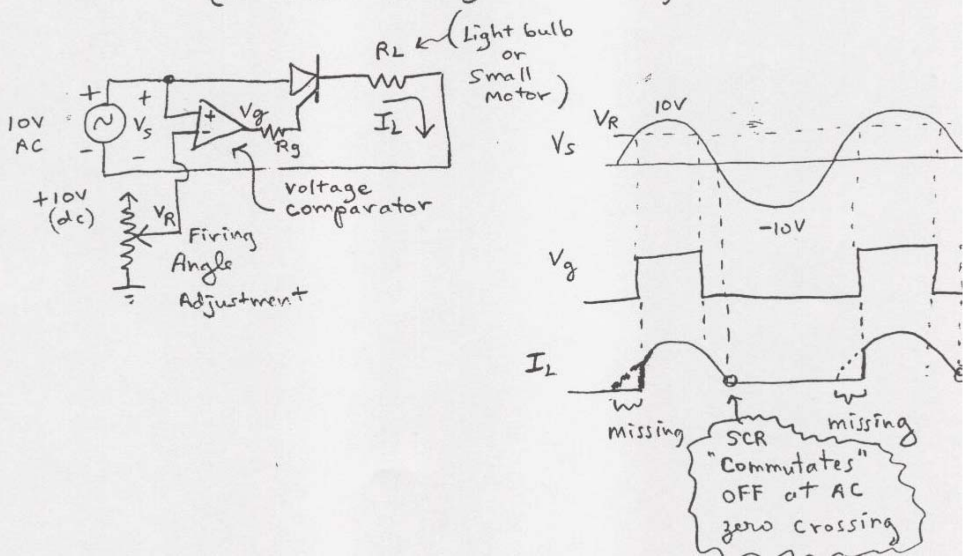
But once V_g goes high, i_{b1} flows. This turns ON Q_1, which provides a path to ground for i_{b2}, thus Q_2 comes ON, which provides an alternate path for i_{b1} to keep Q_1 ON even after V_g returns to zero! Thus Q_2 holds Q_1 ON and Vice versa.

Note that only after V_G returns to zero and when V_o drops $\leq$ 0V. or the SW is opened, will the two transistors go back OFF again, thus re-entering their initial (unlatched) state. (6-

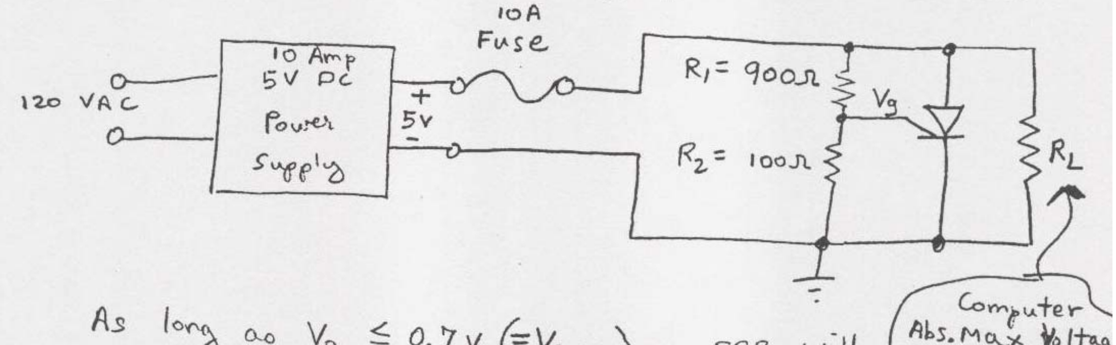
Also note that when $V_o < 0$, the SCR will not come on, even when V_g goes high. This is because the base-emitter junction of the pnp transistor Q_2 can't be forward-biased when Q1 comes ON. Thus, when switching AC loads, the SCR only turns ON (while V_g is high) during the positive half of each cycle; the turned ON SCR acts like a rectifying diode, with a forward voltage drop of $(V_{CE})_{SAT} + V_{BE} \approx 0.8V$.

SCR Application Examples

Ex #1 Firing-angle Controlled AC motor Controller (or Electric light dimmer)



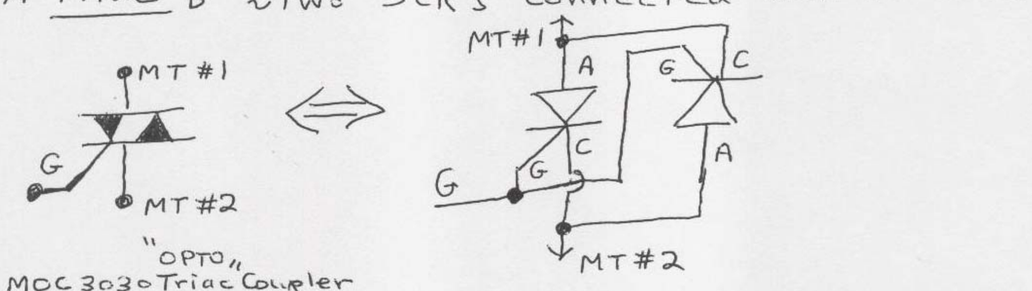
Ex 2 "DC Crowbar" Power Supply Protection Circuit



As long as $V_g \le 0.7\,V \; (=V_{BEQ_1})$, SCR will remain OFF, but if 5V DC Power Supply ever fails and begins to put out $\ge 7V$, the V_g value exceeds $7\left(\frac{R_2}{R_1+R_2}\right) = 7\left(\frac{1}{10}\right) = 0.7\,V$, and the SCR triggers ON, and the 10A Fuse is blown before any damage is done to the load (R_L).

Triacs: Switching BOTH halves of the 60 Hz AC Cycle

A Triac is ≈two SCR's Connected back-to-back



"OPTO" MOC3030 Triac Coupler

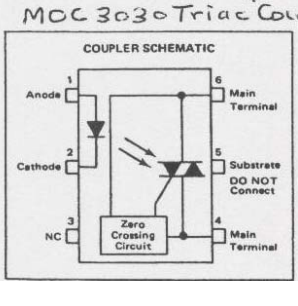
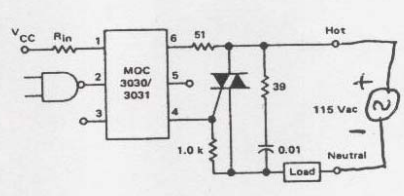


FIGURE 3 – HOT-LINE SWITCHING APPLICATION CIRCUIT



Typical circuit for use when hot line switching is required. In this circuit the "hot" side of the line is switched and the load connected to the cold or neutral side. The load may be connected to either the neutral or hot line.

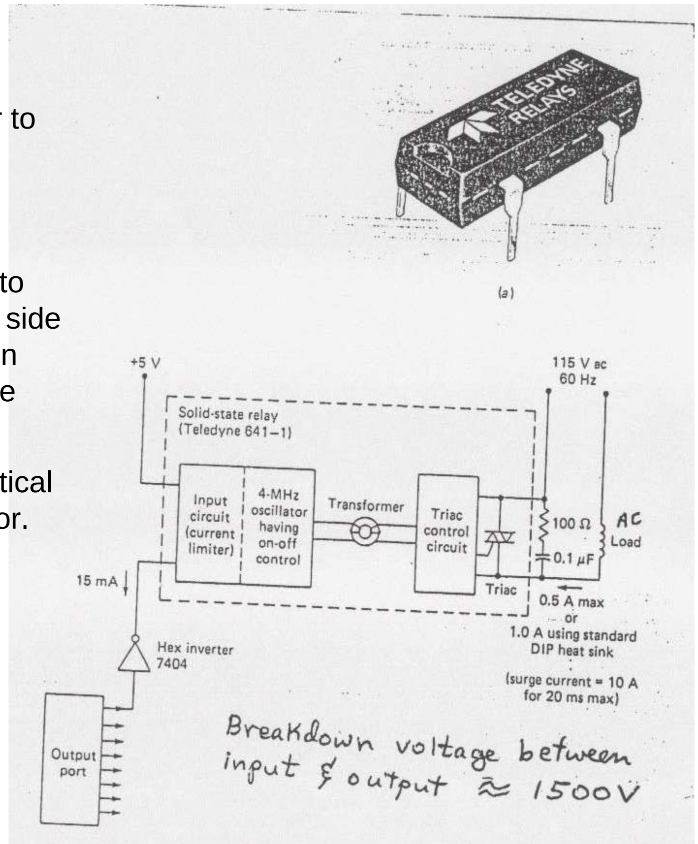
R_{in} is calculated so that I_F is equal to the rated I_{FT} of the part, 15 mA for the MOC3031 or 30 mA for the MOC3030. The 39 ohm resistor and 0.01 μF capacitor are for snubbing of the triac and may or may not be necessary depending upon the particular triac and load used.

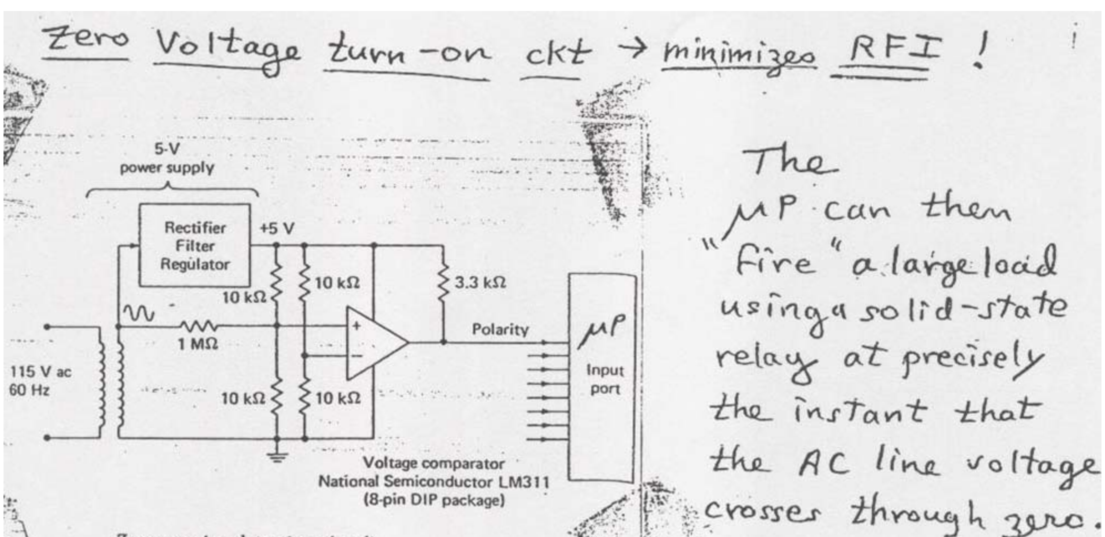
Solid-state Relay

-Allows microcontroller to switch on/off a high current, 115 VAC load device.

-Magnetically Isolated to protect microcontroller side from lightning strikes on the 115 VAC power line side.

-Could also employ optical isolation via optoisolator.

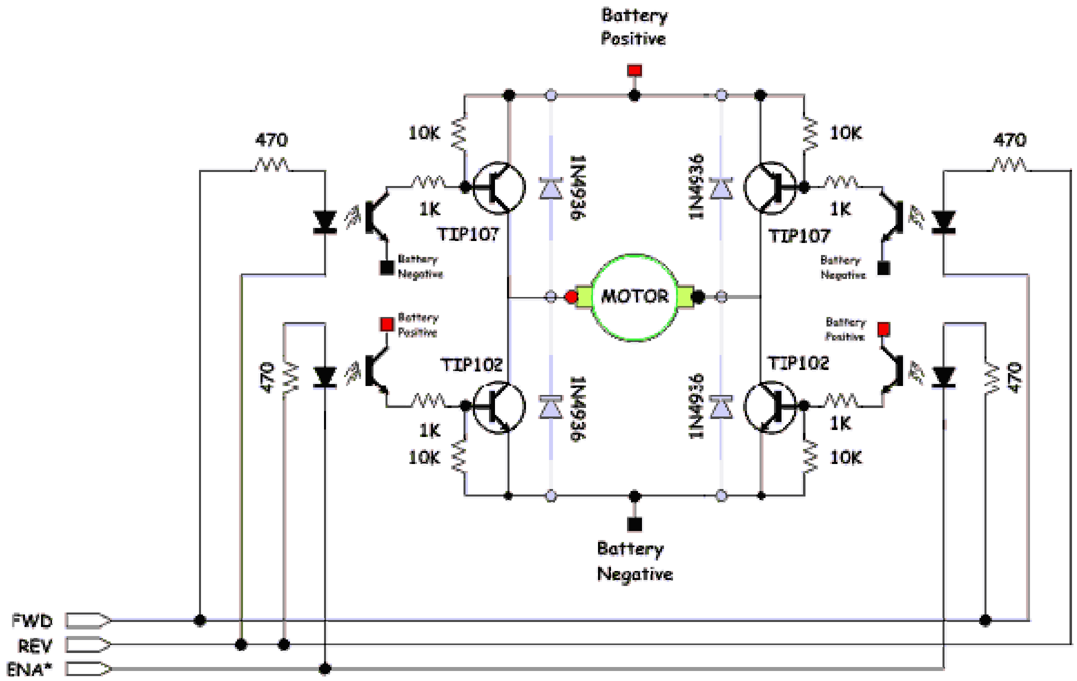




Zero-crossing detection circuit.

H-bridge --- Bidirectional DC Motor Control

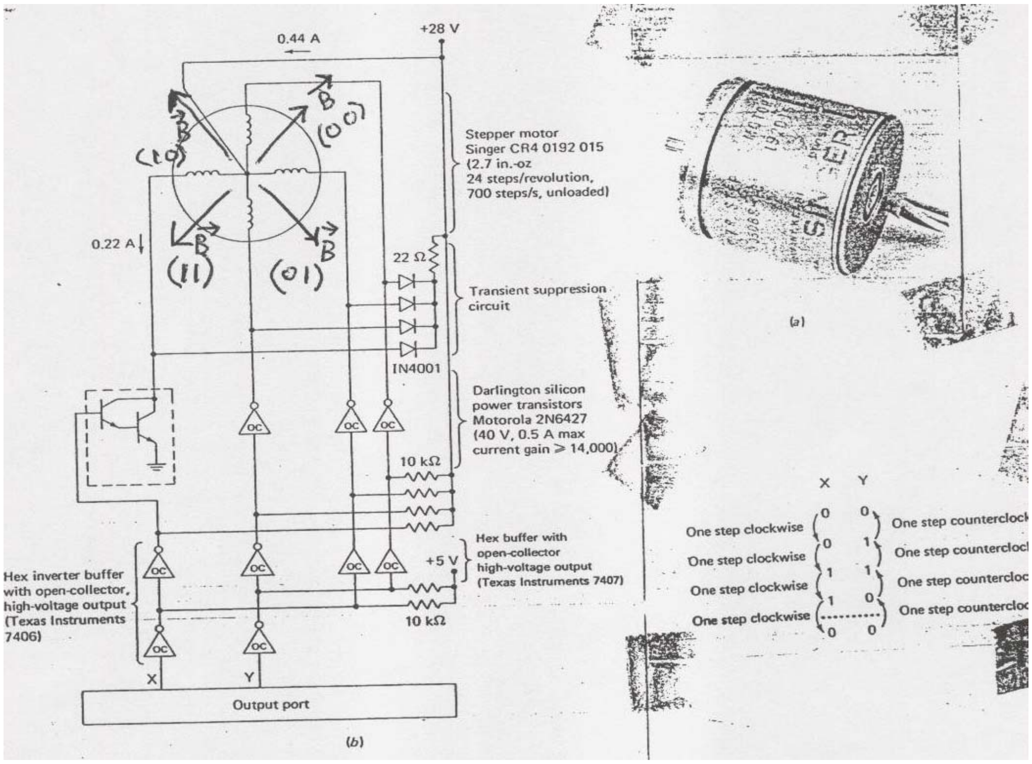
Note: TIP107's are PNP and act as current sources.
TIP102's are NPN and act as current sinks.



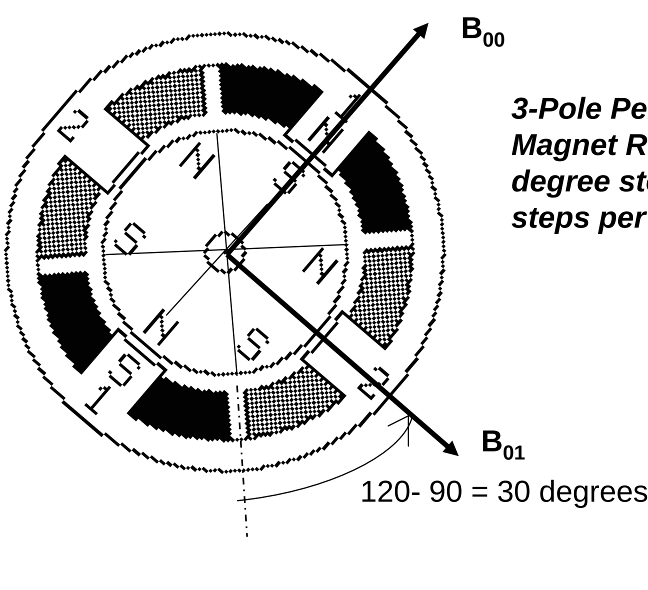
FWD	REV	ENA*	Description
1	0	0	Turn on upper left source and lower right sink. (go forward)
1	0	1	Disable lower right sink. When "ENA*" is fed a PWM signal the bridge modulates the "forward" current through the motor.
1	1	0	Turn on both lower left sink and lower right sink, shorting the motor. This causes a rotating motor to stop rotating so this mode is called "Braking."
1	1	1	Disable both lower sinks. When "ENA*" is fed a PWM signal the bridge modulates the "braking" of the motor.
0	1	0	Turn on the upper right source and lower left sink. (go backward)
0	1	1	Disable lower left sink. When "ENA*" is fed a PWM signal the bridge modulates the "reverse" current through the motor.
0	0	0	Turn off all sources and sinks. Motor coasts. Braking is NOT engaged.
0	0	1	Turn off all sources and sinks. Motor coasts. Braking is NOT engaged.

Permanent Magnet Stepper Motor

=> Magnetic field steps 90 degrees / revolution from B_{00} to B_{01} to B_{11} to B_{10}



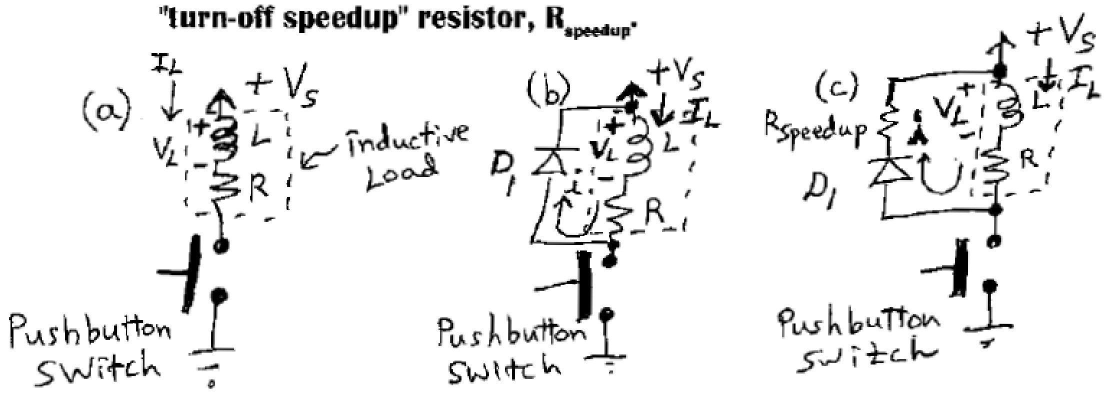
- **Assume that the rotor is made up of *3 permanent "bar" magnets* equi-angularly spaced at 120 degrees with respect to each other.**
- **Imagine that one of the South (S) poles of the rotor is initially aligned with the initial magnetic field "B_{00}"**
- **When the microcontroller steps the magnetic field by 90 degrees (from B_{00} to B_{01}), the nearest south pole is attracted into alignment with B_{01}, and the rotor rotates counter clockwise by 120 – 90 = 30 degrees.**
- **Due to symmetry, it is easy to see that this process repeats with each 90 degree step of the magnetic field B, and the motor executes 30 degree steps, or 12 steps per revolution as the B field is stepped from B_{00} -> B_{01} -> B_{11} -> B_{10}… etc.**



3-Pole Permament Magnet Rotor => 30 degree stepsize, or 12 steps per revolution

Switching Inductive Loads: Diode Transient Protection

Fig. 1-32 Switching Inductive Loads (a) without diode transient suppression (b) with diode transient suppression (c) with "turn-off speedup" resistor, $R_{speedup}$.



Consider the inductive load switching circuit shown in Fig. 1-32(a). The inductive load might be a motor, solenoid, or relay, which is modeled as an inductance, L, in series with a resistance, R. When the switch is ***closed***, current gradually builds up according to the well-known general first-order differential equation RL circuit solution, which holds for t > to:

$$i_L(t) = I_F - \left(I_F - I_I\right)\cdot \exp\left[\frac{-\left(t - t_o\right)}{\tau_{RL}}\right] \qquad \text{for } t > t_o \quad (1 - 44)$$

where
- I_F is the final inductor current, (Vs/R)
- I_I is the initial inductor current, (0)
- t_o is the time that the switch is closed, (0)
- τ_{RL} is the RL circuit "time constant", (L/R)

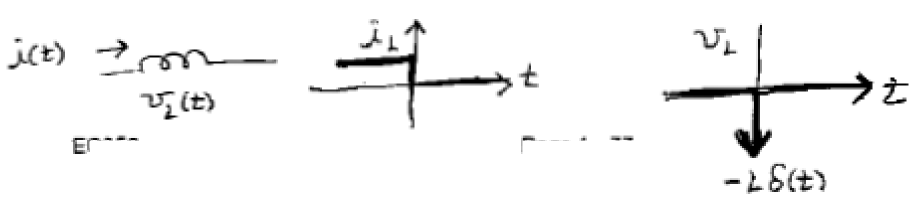
Hence, for our case, (1-45) becomes

$$I_L(t) = \frac{Vs}{R}\cdot\left[1 - \exp\left[\frac{-t}{\left(\frac{L}{R}\right)}\right]\right] \qquad \text{for } t > 0 \qquad (1 - 45)$$

Because the inductor current changes *gradually* (exponentially) between its initial value (0) and its final value (***Vs/R***), there will be no large voltage developed across the inductor during turn-on. The inductor voltage will start at the source voltage level, ***Vs***, then exponentially decay toward zero. This is because the voltage across an inductor is given by

$$v_L(t) = L\cdot\frac{d}{dt}i_L = Vs\cdot\exp\left[\frac{-t}{\left(\frac{L}{R}\right)}\right] \qquad \text{for } t > 0 \qquad (1-46)$$

However, when the switch is ***opened,*** say at time ***t = 0***, current immediately falls from **Vs/R** to ***0***, since the switch suddenly breaks the current path.



Thus the current through the inductor is forced to immediately decrease to zero, and ***di_L/dt*** is a negative impulse function, then by the first half of (1-46),

$$v_L(t) = -L\cdot\delta(t) \qquad (1-47)$$

In reality, the negative voltage spike (called the ***inductive kick***) does not become infinite as (1-47 predicts, since the very high voltage that begins to develop (several hundred volts) across the switch contacts ($v_L(t)$ - Vs) causes a spark to jump between the opening switch contacts (this is called ***switch contact arcing***) that allows the current to decrease at a more gradual rate. Even so, the arcing eventually pits and corrodes the switch contacts, eventually causing the switch to fail.

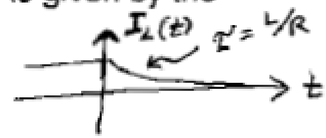
The inductive kick problem can be eliminated by placing a diode across the inductive load, as shown in Fig. 1-32(b). The diode is OFF when the switch is closed, since the voltage across the load is positive. But during turn-off, as the voltage goes negative, the diode comes on and clips the voltage at the safe level of -0.7 V! No contact arcing will result, but it will take some time after the switch is opened for the load current to actually turn off.

The situation is analogous to that of a human (switch) trying to stop a train (the current through an inductor) by brute force (stepping in front of it and pushing). (The inductance of the inductor is analogous to the mass of the train). It is likely that the human will fail to stop the train (and die!), just as the switch will fail due to contact arcing!

But with the diode in place, the human has gotten smart. To stop the train, he switches the train to a circular "run-around" track, and the train will gradually stop.

The inductive load is effectively shorted-out by the diode, and the decrease in load current (after the switch is opened) is given by the general RL circuit formula (1-44):

$$I_L(t) = I_F - (I_F - I_I)\, e^{-(t-t_0)/\tau}$$



$$I_L(t) = \frac{V_S}{R}\cdot \exp\left[-\frac{t}{\left(\frac{L}{R}\right)}\right] \qquad (1 - 48)$$

Now $I_F = 0$

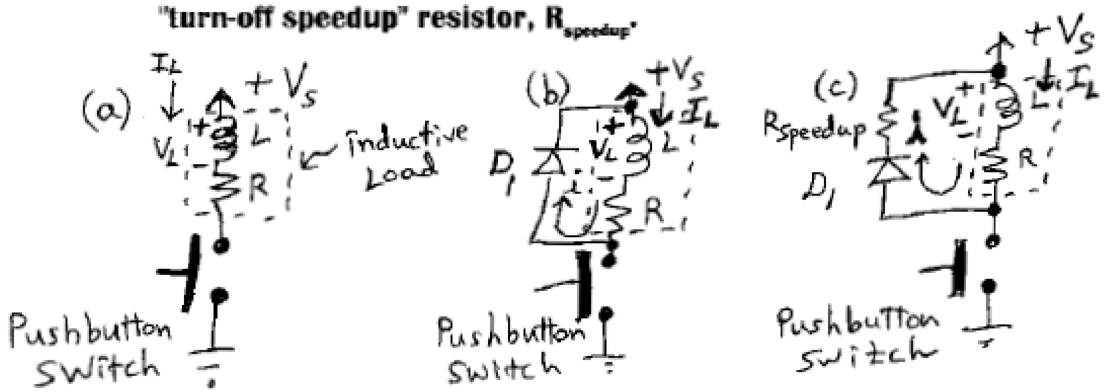
$I_I = V_S/R$

$\tau = L/R$

It is clear from (1-48) that the rate at which the inductor current decays (the rate at which the "train speed" decays on the run-around track) is set by the time constant L/R, in one time constant, the current has decayed to exp(-1) = 37% of its initial value, Vs/R.

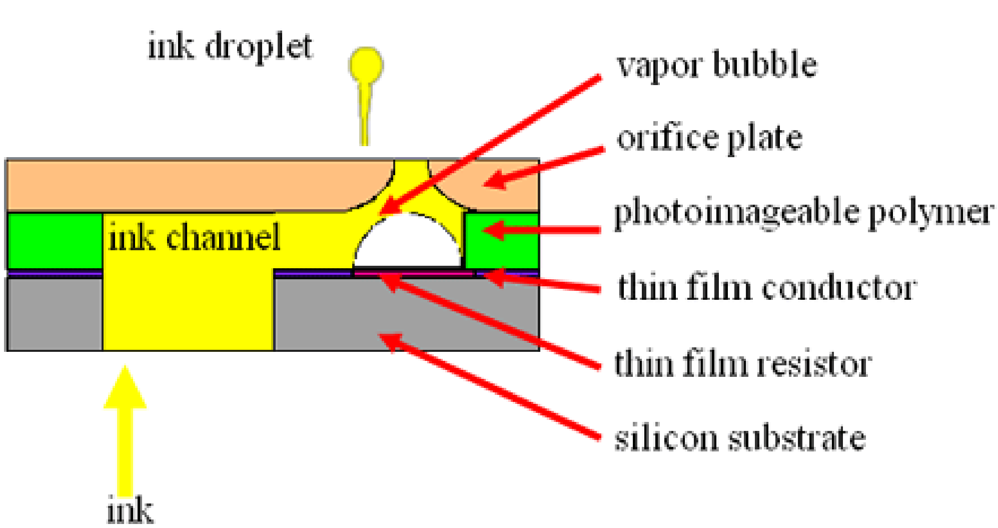
Turn off time can be decreased (at the expense of allowing higher voltages across the switch as its contacts break) by adding an external "turn-off speedup" resistor in series with the diode, as shown in Fig. 1-32(c), thus decreasing the time constant. Now the time constant is decreased to the value $\tau = L / (R + R_{speedup})$.

Fig. 1-32 Switching Inductive Loads (a) without diode transient suppression (b) with diode transient suppression (c) with "turn-off speedup" resistor, $R_{speedup}$.

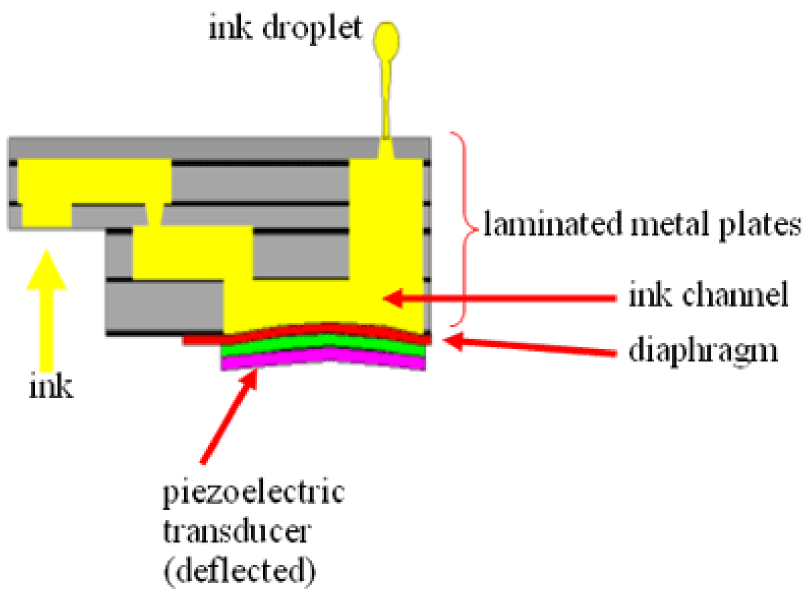


Inkjet Printer

THERMAL INK JET



PIEZOELECTRIC INK JET



Positioning the ink dots

- **Accurate placement of ink dots on the page is critical to achieving uniform colors without banding.**
- **Optical encoders precisely control the location of the printed dots, both across and down the page.**
- **An optical encoder consists of three main components:**
  - **a light emitting diode,**
  - **a photodetector,**
  - **and a transparent code wheel or code strip positioned between the light emitter and the detector.**
- **The motion of the ink jet carriage across the page is controlled by a long plastic code strip which extends across the full width of the print zone.**
- **This code strip passes between a light emitter and detector mounted on the moving carriage.**

- **To the casual observer, this plastic strip might look like an unimportant light gray piece of flimsy plastic sheet material, but it is actually one of the keys to the precision of the whole ink jet mechanism.**
- **It consists of a dense array of precision black stripes printed on a thin sheet of clear plastic, which make it look from a distance like it is a uniform color of light gray.**
- **As the carriage passes each stripe, the light beam is interrupted and the photodetector generates a synchronization pulse which controls the timing of the ink drop ejection.**
- **These synchronization signals insure that the ink drops are printed in accurate locations even if there is some variation in the carriage velocity, or if the carriage is accelerating or decelerating near the beginning or end of its travel.**

Color LCD Display

- Passive LCD Display Panels use a simple grid to supply the charge to a particular pixel on the display.
- Creating the grid is quite a process!
- It starts with two glass layers called **substrates**.
- One substrate is given columns and the other is given rows made from a transparent conductive material. This is usually **indium-tin oxide**.
- The rows or columns are connected to **integrated circuits** that control when a charge is sent down a particular column or row.
- The liquid crystal material is sandwiched between the two glass substrates, and a polarizing film is added to the outer side of each substrate.

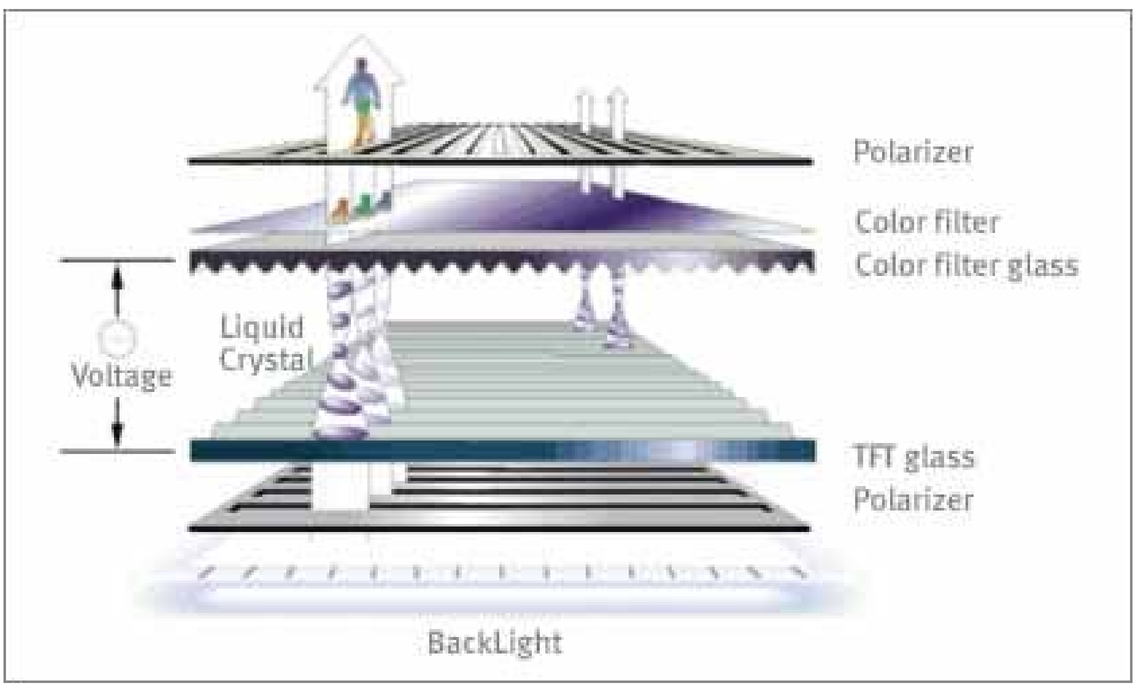
- **Active-matrix LCDs** depend on **thin film transistors** (TFTs).
- Basically, TFTs are tiny switching transistors and capacitors.
- They are arranged in a matrix on a glass substrate.
- To address a particular pixel, the proper row is switched on, and then a charge is sent down the correct column.
- Since all of the other rows that the column intersects are turned off, only the capacitor at the designated pixel receives a charge.

- The capacitor is able to hold the charge until the next refresh cycle.
- And if we carefully control the amount of voltage supplied to a crystal, we can make it untwist only enough to allow some light through.
- By doing this in very exact, very small increments, LCDs can create a **gray scale**. Most displays today offer 256 levels of brightness per pixel.

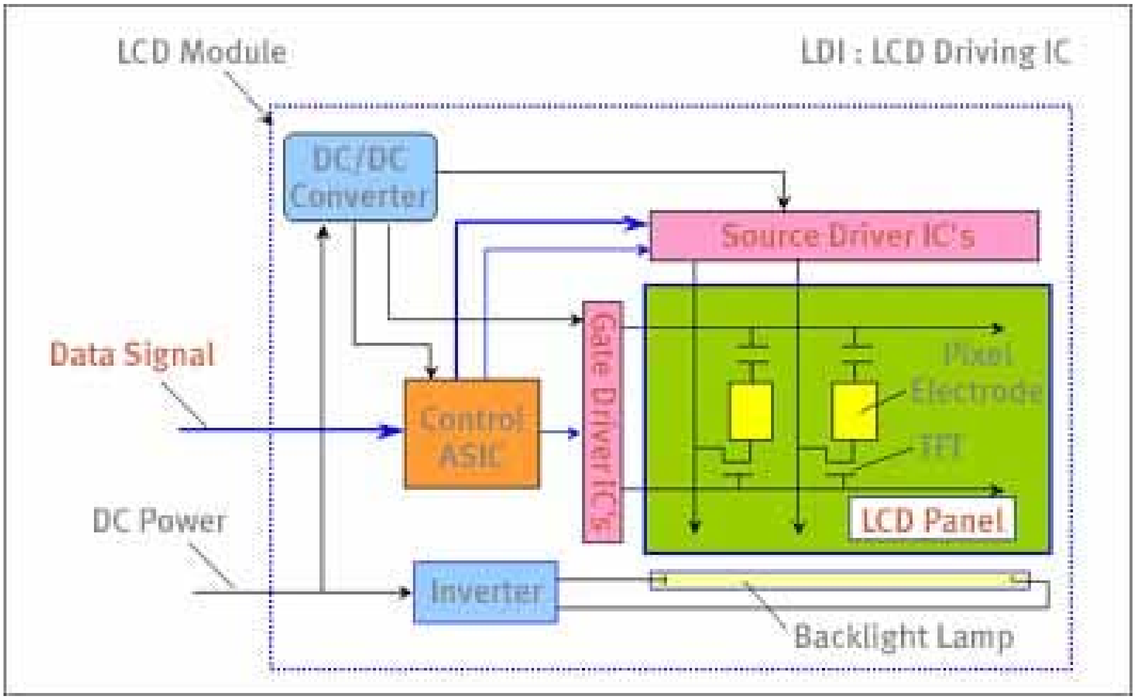
- An LCD that can show colors must have **three subpixels** with red, green and blue color filters to create each color pixel.
- Through the careful control and variation of the voltage applied, the intensity of each subpixel can range over **256 shades**.
- Combining the subpixels produces a possible palette of **16.8 million colors** (256 shades of red x 256 shades of green x 256 shades of blue).
- These color displays take an enormous number of transistors.

- For example, a typical laptop computer supports resolutions up to 1,024x768. If we multiply 1,024 columns by 768 rows by 3 subpixels, we get 2,359,296 transistors etched onto the glass!
- If there is a problem with any of these transistors, it creates a "bad pixel" on the display.
- Most active matrix displays have a few bad pixels scattered across the screen.

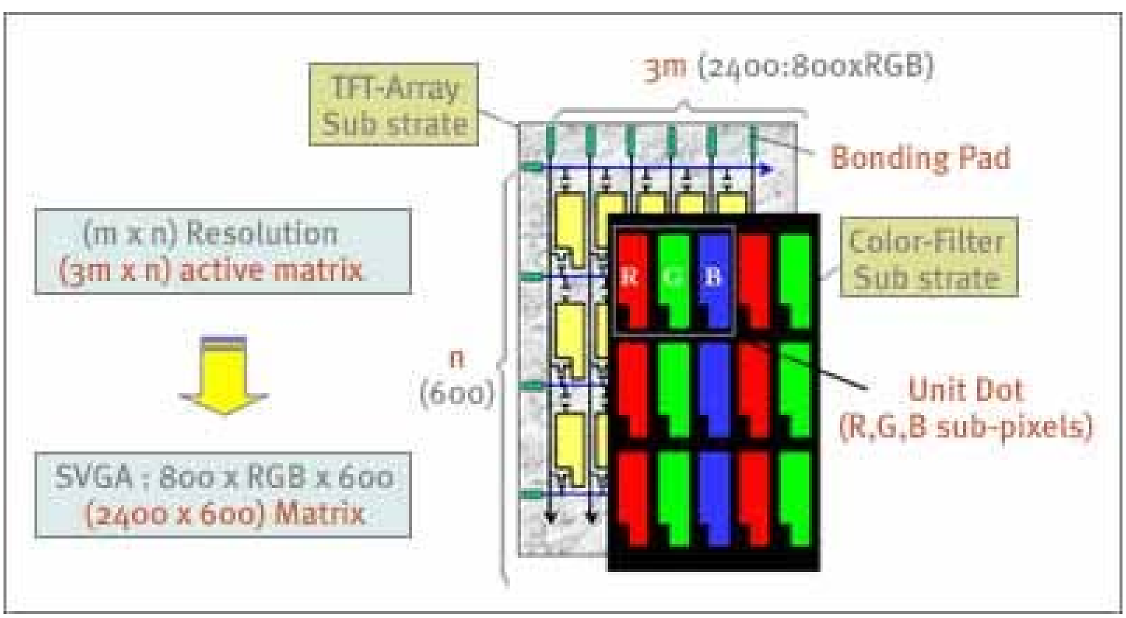
Color TFT LCD Panel



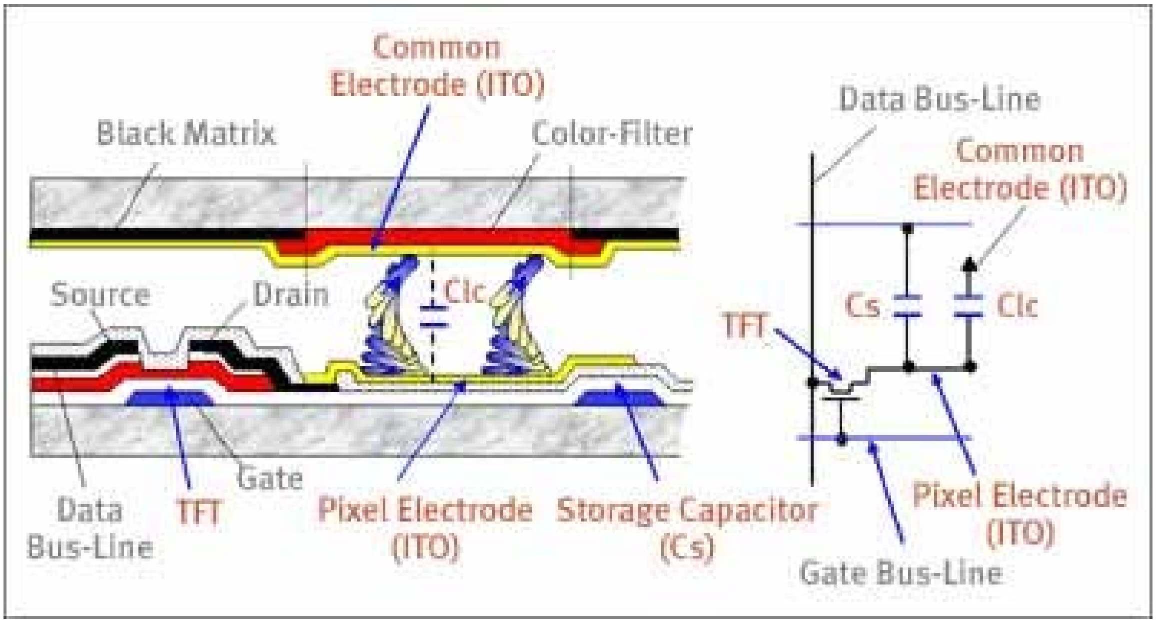
Driving TFT LCD Display Pixel



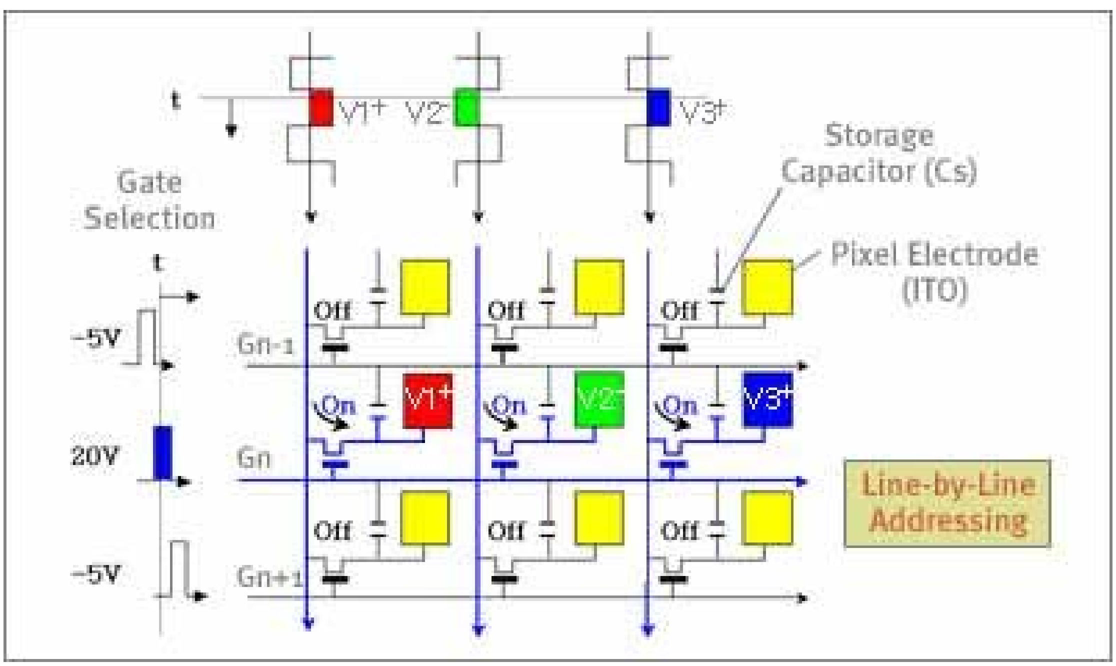
Structure of Color TFT Panel



Vertical Structure of Pixel



Active Addressing of 3 x 3 Matrix



Examples of how RGB subpixels create a colored pixel