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2.1 \textit{Introduction to the Basic Components in the Design}

For the design and development of the PC based instrumentation system, we need to know some fundamentals of the basic components viz.,

(a) PCB Design and Fabrication \\
(b) Sensor and Transducer \\
(c) Power Supply \\
(d) Analog to Digital Converter (ADC) \\
(e) Sample and Hold Circuit \\
(f) Signal Conditioning Circuit \\
(g) Clock Signal Generator Circuit \\
(h) MAX232 (RS-232 Line Driver IC) \\
(i) Microcontroller Selection

2.2 \textit{PCB Design and Fabrication}

Electronic equipment is a combination of electrical and electronic components which are connected together in order to produce a certain designed function. The use of miniaturization and sub-miniaturization in electronic equipment design gives birth to a new technique in inter-component wiring and assembly that is popularly known as the printed circuit board. Printed circuit boards are the most frequently used interconnection technology for components in electronic products.

A schematic diagram is a graphical representation of interconnections of various electronic, electrical and electromechanical components of an equipment. The schematic is the first step in an electronic circuit design because it displays and identifies the components that make up the equipment. Further, the first step in designing a printed circuit is to convert the schematic diagram in to an art master. The schematic
Basic Components
diagram does not show any of the mechanical details of the printed circuit board. A schematic is the focal point for a product's electronic data and can be viewed as a set of crucial business documents that capture the decisions affecting all aspects of the product. In a schematic diagram, the symbol represents either what the component does in the circuit or how it is physically constructed. All electronic components have been designated when represented on a schematic diagram.

The basic function of a printed circuit is to provide support for circuit components and to interconnect the components electrically. In order to achieve these objectives, various printed wiring types have been developed. They vary in base material (laminate), conductor type, number of conductor planes, rigidity, etc. Design and layout broadly includes the perspective of total system hardware, which includes not only the printed circuit but each and every component in its final form. Design and layout considerations must also address the interaction and relation between the components and assemblies throughout the system [1].

Computer-aided design (CAD)

Computer-aided design provides an interface between the PCB designer and the computer. The combination of a graphic terminal (video display unit), an input device and a functional keyboard gives the designer an automated drawing board, which brings about a significant improvement in productivity. In recent years, there has been a phenomenal growth in the availability of software for the design of printed circuit boards.

A CAD system with various possibilities offers tremendous advantages over manual methods of designing. An important advantage is the reduced time for the layout procedure. Also, in many cases, the capability to make circuit modifications simple simultaneously provides a completely updated production documentation.

With the assistance of CAD, higher package densities can be achieved and complex circuitry with a larger number of ICs per board are realized, which can hardly be arranged by a manual design. The resulting patterns are constantly of the same high precision and of a consistent quality. In a multi-layer board design, especially, interac-
Basic Components

CAD design plays an important role in the design process.

The CAD design process is usually started with a schematic or logic diagram. This can be either in the sketch form or an electronic transfer from a Capture system. It is followed by the merging of the netlist with the physical layout design. The board outline is then created in accordance with the input requirements. The placement technique is then selected for placing the components. Once the placement process is complete, the routing phase of the design is applied.

During the design process and on completion of the layout, the system can check design errors like space violations, land-to-hole size ratios, and clearance for automated insertions, among other things. This is perhaps the most significant benefit of CAD systems in their ability to check the design in real-time.

Image transfer

Image transfer basically involves the transfer of the conductor pattern from the film master on to the copper clad base material or any other metal clad laminate. In the fabrication of the PCB, the two methods common for image transfer are:

- Photo printing method; and
- Screen printing method.

Photo Printing

This is an extremely accurate process, which is generally applied to the fabrication of semiconductors and integrated circuits wherein the conductor widths are typically in the region of a few microns. Although such a precision technique is not required in the production of general purpose PCBs, yet where conductor widths of 100 mm are required and for PCBs for professional applications, the photo printing process is resorted to.
Screen printing is a printing technique that uses a woven mesh to support an ink-blocking stencil. The attached stencil forms open areas of mesh that transfer ink or other printable materials which can be pressed through the mesh as a sharp-edged image onto a substrate. Screen printing is also a stencil method of print making in which a design is imposed on a screen of polyester or other fine mesh, with blank areas coated with an impermeable substance, and ink is forced into the mesh openings of the mesh by the fill blade or squeegee and onto the printing surface during the squeegee stroke. A screen is made of a piece of mesh stretched over a frame. A stencil is formed by blocking off parts of the screen in the negative image of the design to be printed; that is, the open spaces are where the ink will appear on the substrate [2].

Laminate Surface Preparation

The difficulties most often encountered in PCB fabrication arise due to insufficient cleaning of the laminate surface. Therefore, the laminate should be free from oil, grease, dust, fingerprints and foreign particles. Possible sources causing contamination could be the equipment used for shearing, drilling, punching or air from the air compressor. Very good cleaning methods are required to prepare the laminate surface. The methods commonly used are:

(i) Manual Cleaning Process  This includes:
   ★ Chemical Cleaning; and
   ★ De-greasing (vapour or aqueous)
(ii) Mechanical Cleaning

Etching

Etching is one of the major steps in the chemical processing of the subtractive PCB process. By this process, the final copper pattern is achieved by selective removal of all the unwanted copper to retain the desired circuit patterns. The copper which is not protected by an etch resist is removed by the etching process. The following are the
commonly used etching methods:

- Chemical etching or chemical machining;
- Electrochemical etching or chemical milling; and
- Mechanical etching (by milling).

Several chemicals are used for etching. The most common etchants are:

- Ferric chloride;
- Ammonium perasulphate;
- Chromic acid;
- Cupric chloride; and
- Alkaline ammonia.

Ferric chloride etching solutions are widely used in the ‘print’ and ‘etch’ process in the PCB industry. Ferric chloride has a high etch rate and high copper dissolving capacity. It is used with screen inks, photo-resist and gold plated boards. As the ferric chloride etchant attacks tin, this is not suitable for tin or tin-lead plated boards [1].

**Drilling**

Drilling operation is one of the important mechanical processes in the manufacture of printed circuit boards. Its purpose is of two fold:

i. To provide component lead mounting precisely, with structural integrity, and

ii. To establish an electrical interconnection between the top, bottom and sometimes intermediate conductor pathways.

Proper drill bit size should be selected for drilling the designed PCB. Generally 0.5, 0.6, 0.8, 1.0, 1.2, 1.5, 2.0 mm bit sizes are commonly used.
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Soldering

Soldering is a process for joining metal parts by making use of any of the various fusible alloys called solder, whose melting temperature is lower than that of the material to be joined, and whereby the surface of the parts create an intermolecular bond, without becoming molten. A soldered connection ensures metal continuity. On the other hand, when two metals are joined to behave like a single solid metal by bolting, or physically attaching to each other, the connection could be discontinuous. Sometimes, if there is an insulating film of oxides on the surfaces of the metals, they may not be even in physical contact. The disadvantages of mechanical joints versus soldering are that oxidation will continually occur on the surface and will increase the electrical resistance [3].

2.3 Sensor and Transducer

Most real-world events and their measurements are analog. That is, the measurements can be taken on a wide, nearly continuous range of values. The physical quantities of interest can be as diverse as temperature, pressure, light, humidity, force, velocity, or position etc. For measurement using an electronic data acquisition system, these quantities must first be converted to electrical quantities such as voltage, current, or impedance. Most of the modern electronic, electrical and electro-mechanical system use sensors as inputs and actuators as outputs. Sensor is a device that senses the signals from different form of energies and gives into electrical form. It can be considered as a part of the interface between the physical world and the world of concerned electronic or electrical devices. The other part of this interface is an actuator which converts electrical signal into mechanical. A transducer is defined as a device that converts energy from one form to another. Sensor and actuator are forms of transducer. There is a slight difference between sensor and transducer. The purpose of sensor is to sense and measure; its efficiency is immaterial, provided the figure of efficiency is known. But, for a transducer, the efficiency of conversion is important. Sensor is an integral part of a measurement system which includes signal conditioning, signal processing, and analog to digital converter etc. from the signal conditioning view point sensors can be divided into active and passive sensors. Active sensors are the sensors which require
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external electrical excitation for sensing whereas passive sensors are self generating [4, 5, 6]. Typical sensors and their outputs are given in the following Tab. 2.1.

Transducers sense physical phenomena and provide electrical signals that the DAQ system can measure. For example, thermocouples, RTDs, thermistors, or IC sensors convert temperature into an analog signal that an ADC can measure. Other examples include strain gauges, flow transducers, and pressure transducers, which measure force, rate of flow, and pressure, respectively. In each case, the electrical signals produced are proportional to the physical parameters they are monitoring.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensor</th>
<th>Type of Sensor</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Thermocouple</td>
<td>Passive</td>
<td>Voltage</td>
</tr>
<tr>
<td></td>
<td>Semiconductor</td>
<td>Active</td>
<td>Voltage / Current</td>
</tr>
<tr>
<td></td>
<td>RTD</td>
<td>Active</td>
<td>Resistance</td>
</tr>
<tr>
<td></td>
<td>Thermistor</td>
<td>Active</td>
<td>Resistance</td>
</tr>
<tr>
<td>Humidity</td>
<td>Polymer (capacitive)</td>
<td>Active</td>
<td>AC Voltage</td>
</tr>
<tr>
<td></td>
<td>Polymer (resistive)</td>
<td>Active</td>
<td>AC Voltage</td>
</tr>
<tr>
<td>Light Intensity</td>
<td>LDR</td>
<td>Active</td>
<td>Resistance</td>
</tr>
<tr>
<td></td>
<td>Photodiode</td>
<td>Passive</td>
<td>Current</td>
</tr>
<tr>
<td>Force / Pressure</td>
<td>Strain Gauge</td>
<td>Active</td>
<td>Resistance</td>
</tr>
<tr>
<td></td>
<td>Piezoelectric</td>
<td>Passive</td>
<td>Voltage</td>
</tr>
<tr>
<td>Acceleration</td>
<td>Accelerometer</td>
<td>Active</td>
<td>Capacitive</td>
</tr>
<tr>
<td>Displacement</td>
<td>LVDT</td>
<td>Active</td>
<td>AC Voltage</td>
</tr>
</tbody>
</table>

Tab. 2.1: Typical sensors and their outputs

In our design implementation we have chosen temperature, humidity and light as the physical parameters to be measured. For measuring the temperature, different sensors that are used in many fields include thermocouples, resistive temperature detectors (RTDs and thermistors). The factors for the selection of sensor that we take into account include the inherent accuracy for durability, range of operation, susceptibility to external noise influences, ease of maintenance and installation, handling during installation (delicacy), ease of calibration, and type of environment it will be used in.
Temperature Sensor

Temperature sensors have electrical parameters that vary with temperature, following well-characterized transfer functions. In fact, nearly all electronic components have properties which vary with temperature. Many of them could potentially be temperature transducers if their transfer functions were well behaved and insensitive to other variables. Some of them are thermocouple, thermistor, Resistance temperature detectors (RTDs), monolithic IC temperature transducer etc.

The monolithic temperature transducer is a semiconductor temperature sensor combined with all the required signal conditioning circuitry and located in one integrated circuit. This device typically produces an output voltage proportional to the absolute temperature, with very good accuracy and sensitivity (a typical device produces an output of 10 mV per degree Kelvin over a temperature range of 0-100 degrees Celsius). The output of this device can usually go directly into an ADC with very little signal conditioning. The temperature sensor used in my design is LM35 [7]. LM35 Temperature Sensor IC is shown in Fig. 2.1. Pin Layout and typical sensor connection are shown in Fig. 2.2 and Fig. 2.3 respectively. The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1/4 °C at room temperature and ±3/4 °C over a full -55 to +150 °C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35s low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 μA from its supply, it has very low self-heating, less than 0.1 °C in still air. The LM35 is rated to operate over a -55 °C to +150 °C temperature range, while the LM35C is rated for a -40 °C to +110 °C range (-10 °C with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.
Basic Components

Fig. 2.1: LM35 Temperature Sensor

Fig. 2.2: Pin Layout of the LM35 Temperature Sensor

Fig. 2.3: LM35 Temperature Sensor Connection

Features

Calibrated directly in ° Celsius (Centigrade)
Linear + 10.0 mV/ °C scale factor
0.5 °C accuracy guaranteeable (at +25 °C)
Rated for full -55°C to +150 °C range
Low cost due to wafer-level trimming
Operates from 4 to 30 volts
Less than 60 μA current drain
Low self-heating, 0.08 °C in still air
Nonlinearity only ±1/4°C typical
Low impedance output, 0.1 W for 1 mA load
**Humidity Sensors**

Relative humidity is the moisture content of the air compared to air completely saturated with moisture and is expressed as a percentage.

**Resistive Hygrometer Sensors**

There are resistive hygrometer elements whose resistance vary with the vapor pressure of water in the surrounding atmosphere. They usually contain a hygroscopic (water-absorbing) salt film, such as lithium chloride, which ionizes in water and is conductive with a measurable resistance. These devices are usable over a limited humidity range and have to be periodically calibrated, as their resistance may vary with time, because of temperature and humidity cycling, as well as exposure to contaminating agents.

**Capacitive Hygrometer Sensors**

There are also capacitive hygrometer elements that contain a hygroscopic film whose dielectric constant varies with humidity, producing a change in the device’s capacitance. Some of these can be more stable than the resistive elements. The capacitance is usually measured using an AC bridge circuit.

The humidity sensor used in our design is Honeywell HIH-4000 Series [8]. Honeywell Humidity Sensor HIH 4000 Series is shown in fig. 2.4. The HIH-4000 Series Humidity Sensors are designed specifically for high volume OEM (Original Equipment Manufacturer) users. Direct input to a controller or other device is made possible by this sensor's linear voltage output. With a typical current draw of only 200 μA, the HIH-4000 Series is often ideally suited for low drain, battery operated systems. Tight sensor interchangeability reduces or eliminates OEM production calibration costs. Honeywell Humidity Sensor HIH 4000 Series is shown in Fig. 2.4. Individual sensor calibration data is available. Fig. 2.5 shows characteristics of the Honeywell humidity sensor HIH-4000 series with typical 2nd order curve fit. Voltage output (2nd order curve fit) is given by
Basic Components

\[ V_{out} = 0.00003(sensorRH)^2 + 0.0281(sensorRH) + 0.820, \text{ typical at } 25^\circ C \]  \hspace{1cm} (2.1)

Temperature compensation for this sensor is given by

\[ V_{out} = (0.0305+0.000044 T-0.0000011 T^2)(SensorRH)+(0.9237-0.00417+0.000040 T^2), \]  \hspace{1cm} (2.2)

where, \( T = \text{Temperature in } ^\circ C \)

Fig. 2.4: Honeywell Humidity Sensor HIH 4000 Series

The HIH-4000 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a competitively priced, solderable SIP (Single In-line Package). Available in two lead spacing configurations, the RH sensor is a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning. The sensing element’s multilayer construction provides excellent resistance to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals. Some features of this sensor are as follows:

Features

Molded thermoset plastic housing
Linear voltage output vs %RH
Basic Components

Fig. 2.5: Characteristics of the Honeywell Humidity Sensor HIH - 4000 Series with typical 2nd order curve fit

Laser trimmed interchangeability
Low power design
High accuracy
Fast response time
Stable, low drift performance
Chemically resistant

Light Sensor

Light / Optical sensors are used for detecting light intensity. Typically, they respond only to particular wavelengths or spectral bands. One sensor may respond only to visible light in the blue-green region, while another sensor may have a peak sensitivity to near-infrared radiation. Some of them are light dependence resistor (LDR), photodiode, phototransistor, charge-coupled device (CCD) etc.

To measure the intensity of light we have chosen LDR - 5mm Part No. VT90N1,
from PerkinElmer Optoelectronics, which is essentially a light dependent resistor having 6 K Ω at 10 Lux to 200 K Ω at darkness [9]. LDR Light Sensor VT900 is shown in Fig. 2.6. Two cadmium sulphide (CdS) photoconductive cells with spectral responses similar to that of the human eyes are used. The cell resistance falls with increasing light intensity.

Features

- LDR, 200KOHM, 80mW, VT900 SERIES
- Power Rating: 80mW
- Dark Resistance: 200kohm
- Series: VT900
- Operating Temperature Range: -40°C to +75°C
- Voltage Rating: 100V
- Resistor Case Style: Radial Leaded

Fig. 2.6: LDR Light Sensor

2.4 Power Supply

A power supply section is the regulated DC power supply of +5 Volt, +12 Volt and -12 Volt. Rectification of the AC supply is carried out using bridge diodes DB107 [10]. Three terminal regulators are used to obtain regulated voltages. LM78XX gives a +ve voltage of xx Volts and LM79XX gives a -ve voltage of xx Volts. For positive voltage regulator IC input is connected to pin 1 of LM78XX, Pin 2 is connected to the ground and Pin 3 is connected to output. For negative voltage regulator IC input is connected to pin 2 of LM79XX, Pin 1 is connected to the ground and Pin 3 is connected to output. The output of the designed Power Supply is regulated DC voltages with short circuit
Basic Components

protection. The LM78XX or LM79XX series of three terminal regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shutdown and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current [11, 12].

Fig. 2.7: Schematic of the designed regulated Power Supply

Fig. 2.8: PCB Layout of the designed regulated Power Supply

2.5 Analog to Digital Converter (ADC)

In physical, world parameters such as temperature, pressure, humidity, and velocity are analog signals in nature. A physical quantity is converted into electrical signals, by using appropriate sensors or transducer. Then such analog signals are converted to digital signals by using appropriate analog-to-digital converter (ADC). Thus, an ADC
translate the analog signals to digital signal. ADC are the most widely used devices for data acquisition [13].

The most popular method of analog to digital conversion is successive approximation method. It has an excellent compromise between accuracy and speed. An unknown voltage $V_{in}$ is compared with a fraction of reference voltage $V_r$. For n-bit digital output comparison is made n times with different fractions of $V_r$ and the value of a particular bit is set to 1, if $V_{in}$ is greater than the set fraction of $V_r$. The bit is set to 0, if $V_{in}$ is less than the set fraction of $V_r$. This fraction is given by

$$\left[ \sum_{i=0}^{n} b_i 2^{-i} \right] V_r$$

(2.3)

where $b_i$ is either 0 or 1 [14].

The ADC 0804 is the most widely used chip and we have also used it in the initial stage when single channel design was considered. It uses successive approximation technique for analog to digital conversion. Later, the analog to digital converter is shifted to ADC 0808. Because ADC 0804 has only one analog input, while ADC 0808 has 8 channels of the analog inputs [15, 16]. This ADC allows us to monitor up to 8 different parameters using a single chip. The 8 analog input channels are multiplexed and selected according to the requirement. In ADC 0808/0809, $V_{ref}$ (+) and $V_{ref}$ (-)
set the reference voltage. If $V_{\text{ref}}(-) = \text{Gnd}$ and $V_{\text{ref}}(+) = 5\text{V}$, the step size is $5\text{V}/255 = 19.60\text{mV}$. The reference voltage is obtained across a zener diode of 5.1 V.

In ADC 0808/0809 there is no self clocking and therefore clock must be provided from an external source to the CLK pin. The clock frequency is from 10 KHz to 1280 KHz. The typical value is 640 KHz. In our case clock is supplied from our designed clock generator circuit using Schmitt Trigger NOT gate (IC 7414) at 700 KHz.

There are 8 clock periods per approximation. Even though there is no conversion in progress the ADC0808/ADC0809 is still internally cycling through these 8 clock periods. A start pulse can occur any time during this cycle but the conversion will not actually begin until the converter internally cycles to the beginning of the next 8 clock period sequence. As long as the start pin is held high no conversion begins, but when the start pin is taken low the conversion will start within 8 clock periods. The EOC output is triggered on the rising edge of the start pulse. It, too, is controlled by the 8 clock period cycle, so it will go low within 8 clock periods of the rising edge of the start pulse. One can see that it is entirely possible for EOC to go low before the conversion starts internally, but this is not important, since the positive transition of EOC, which occurs at the end of a conversion, is what the control logic is looking for. Once EOC goes high this signals the interface logic that the data resulting from the conversion is ready to be read. The output enable (OE) is then raised high.

For serial and USB based data acquisition, PIC microcontrollers PIC12F675 and PIC18F4550 have built in ADC of 10-bit resolution [17, 18]. The overall operation is controlled by the firmware program.

2.6 Sample and Hold Circuit

For rapidly changing analog inputs a sample-and-hold circuit is required. To ensure correct conversions, the analog input has to remain stable while the conversion is taking place. A sample-and-hold circuit ensures that the analog signal is stable by sampling the signal at the desired measurement time and storing it, usually as a charge on a
capacitor. The converter uses this stored signal as the input is to be converted. For rapidly changing inputs, sample-and-hold chips like the LF398 are available.

![Schematic diagram of LF398](image)

**Fig. 2.10:** Schematic diagram of LF398

![Acquisition Time](image)

**Fig. 2.11:** Acquisition Time for LF398

The LF198/LF298/LF398 are monolithic sample-and-hold circuits which utilize BI-FET technology to obtain ultra-high dc accuracy with fast acquisition of signal and low droop rate [19]. Operating as a unity gain follower, dc gain accuracy is 0.002% typical and acquisition time is as low as 6 μs to 0.01%. A bipolar input stage is used to achieve low offset voltage and wide bandwidth. Input offset adjust is accomplished with a single pin, and does not degrade input offset drift. The wide bandwidth allows the LF398 to be included inside the feedback loop of 1 MHz op amps without having stability problems. Input impedance of $10^{10}$ Ω allows high source impedances to be used without degrading accuracy. P-channel junction FETs are combined with bipolar
devices in the output amplifier to give droop rates as low as 5 mV/min with a 1 \( \mu \text{F} \) hold capacitor. The JFETs have much lower noise than MOS devices used in previous designs and do not exhibit high temperature instabilities. The overall design guarantees no feed-through from input to output in the hold mode, even for input signals equal to the supply voltages.

**Features**

- Operates from \( \pm 5 \text{V} \) to \( \pm 18 \text{V} \) supplies
- Less than 10 \( \mu \text{s} \) acquisition time
- TTL, PMOS, CMOS compatible logic input
- 0.5 mV typical hold step at \( \text{Ch} = 0.01 \mu \text{F} \)
- Low input offset
- 0.002\% gain accuracy
- Low output noise in hold mode
- Input characteristics do not change during hold mode
- High supply rejection ratio in sample or hold
- Wide bandwidth
- Space qualified, JM38510

Logic inputs on the LF398 are fully differential with low input current, allowing direct connection to TTL, PMOS, and CMOS. Differential threshold is 1.4V. The LF398 will operate from \( \pm 5 \text{V} \) to \( \pm 18 \text{V} \) supplies. An "A" version is available with tightened electrical specifications.
Acquisition Time

The acquisition time is the time taken by the 'sample and hold circuit' to charge the capacitor 'Ch' from the level of the holding voltage to the new value of input voltage after the input voltage is applied to the hold capacitor.

Conversion Time

The time required for the A/D converter to complete a single conversion once the signal has been sampled.

Throughput Rate or Samples Per Second (SPS)

The time required for the converter to sample, acquire, digitize, prepare, and output a conversion.

Aperture Time

The aperture time is the delay between the hold command and the moment at which the input voltage is applied to the hold capacitor. It is very small, in nano second range.

Selection of Hold Capacitor

The hold capacitor 'Ch' should be made of dielectrics having low hysteresis such as polysterene, polypropylene and teflon. The acquisition time depends on the value of hold capacitor.

2.7 Signal Conditioning Circuit

The electrical signals generated by the transducers must be optimized for the input range of the DAS. Signal conditioning accessories can amplify low-level signals, and
then isolate and filter them for more accurate measurements. In addition, some transducers require voltage or current excitation to generate a voltage output.

**Amplifier**

Most of the signals from the sensors are Low-level signals and it should be amplified to increase the resolution and to reduce noise. For the highest possible accuracy, the signal should be amplified so that the maximum voltage range of the conditioned signal equals the maximum input range of the analog-to-digital converter (ADC). A schematic diagram of the amplifier circuit used for signal conditioning is shown in Fig. 2.12. It uses an ultra low offset voltage operational amplifier OP07 [20].

![Schematic diagram of the amplifier circuit used for signal conditioning](image)

*Fig. 2.12: Schematic diagram of the amplifier circuit used for signal conditioning*

**Isolation**

The system being monitored may contain high-voltage transients that could damage the computer. To isolate the transducer signals from the computer for safety purposes, isolation is used.

An additional reason for needing isolation is to make sure that the readings from the DAS are not affected by differences in ground potentials or common-mode voltages. When the DAS board input and the signal being acquired are each referenced
to "ground", problems occur if there is a potential difference in the two grounds. This
difference can lead to what is known as a ground loop, which may cause inaccurate
representation of the acquired signal, or if too large, may damage the measurement
system. Using isolated signal conditioning modules will eliminate the ground loop
and ensure that the signals are accurately acquired.

Filtering

The purpose of a filter is to remove unwanted signals from the signal that are trying to
measure. A noise filter is used on DC-class signals such as temperature to attenuate
higher frequency signals that can reduce the accuracy of the measurement.

AC-class signals such as vibration often require a different type of filter known as
an antialiasing filter. Like the noise filter, the antialiasing filter is also a lowpass filter;
however, it must have a very steep cutoff rate, so that it almost completely removes
all frequencies of the signal that are higher than the input bandwidth of the board. If
the signals are not removed, they would erroneously appear as signals within the input
bandwidth of the board.

Excitation

Signal conditioning also generates excitation for some transducers. Strain gauges, ther­
mistors, and RTDs, require external voltage or current excitation signals. Signal con­
ditioning modules for these transducers usually provide these signals. RTD measure­
ments are usually made with a current source that converts the variation in resistance to
a measurable voltage. Strain gauges, which are very low-resistance devices, typically
are used in a Wheatstone bridge configuration with a voltage excitation source.

Linearization

Another common signal conditioning function is linearization. Many transducers, such
as thermocouples, strain gauges, and RTDs have nonlinear responses to changes in the
phenomena being measured.

It is important to understand the nature of the signal, the configuration that is being used to measure the signal and the effects of the surrounding environment. Based on this information, that can easily be determined, whether signal conditioning will be a necessary part of the DAQ system.

2.8 Clock Signal Generator Circuit

Counter/timer circuitry is useful for many applications, including counting the occurrences of a digital event, digital pulse timing, and generating square waves and pulses. The clock frequency determines how fast you can toggle the digital source input. With higher frequency, the counter increments faster and therefore can detect higher frequency signals on the input and generate higher frequency pulses and square waves on the output. Clock generator circuit can be designed in various ways. Clock signal can also be generated by designing multivibrator using 555 timer IC. One of the most common way is by using schmitt trigger logic gate IC [21]. Schmitt trigger logic gate ICs are also available for TTL gates like IC 7414, which is hex schmitt trigger inverter, the threshold voltages $V_{UT}$ (upper threshold) and $V_{LT}$ (lower threshold) are 1.7V and 0.9 V respectively. A simple wave generator can be made using such schmitt trigger inverter as shown in the following Fig. 2.13

![Fig. 2.13: Circuit diagram of a clock generator using schmitt trigger inverter](image)
If its output is HIGH, the capacitance $C$ charges with the time constant $\tau = RC$. When the capacitor discharges through the output resistor of the gate which is in saturation. When $V_c$ reaches $V_{LT}$, the output voltage $V_0$ goes LOW. Then, the capacitor discharge through the output resistor of the gate which is in saturation. When $V_c$ reaches $V_{LT}$, the output voltage goes HIGH. This process goes on and a square waveform is obtained at $V_0$ as shown in Fig. 2.14

![Waveform of the signal from clock generator](image)

**Fig. 2.14:** Waveform of the signal from clock generator

The time period of the generated square wave is given by

$$T = T_1 + T_2$$ (2.4)

where, $T_1$ is the on time and $T_2$ is the off time. The expression for frequency is given by

$$f = \frac{1}{T} = \frac{1}{kRC}$$ (2.5)
The value of the constant $k$ depends on the types of the Schmitt trigger logic gate ICs, as the propagation delay varies with type. For Philips NXP 74HC14, $k = 0.6$ and for 74LS14, $k = 0.8$. For ADC 0804 (National Semiconductor) $k = 1.1$ [22, 23]. Hence for ADC0804, the expression for frequency is given by

$$f = \frac{1}{1.1RC} \quad (2.6)$$

For proper operation of the ADC, the frequency range of the ADC and duty cycle should be properly adjusted. For ADC 0804 the frequency range is 100 Hz to 800 kHz and duty cycle should be between 40% to 60%.

### 2.9 MAX232 (RS-232 Line Driver IC)

The MAX232 is an integrated circuit, first created by Maxim Integrated Products, that converts signals from an RS-232 serial port to signals suitable for use in TTL compatible digital logic circuits. The MAX232 is a dual driver/receiver and typically converts the RX, TX, CTS and RTS signals [24]. The drivers provide RS-232 voltage level outputs (approx. ± 7.5 V) from a single + 5 V supply via on-chip charge pumps and external capacitors. This makes it useful for implementing RS-232 in devices that otherwise do not need any voltages outside the 0 V to + 5 V range, as power supply design does not need to be made more complicated just for driving the RS-232 in this case. The receivers reduce RS-232 inputs (which may be as high as ± 25 V), to standard 5 V TTL levels. These receivers have a typical threshold of 1.3 V, and a typical hysteresis of 0.5 V. The later MAX232A is backwards compatible with the original MAX232 but may operate at higher baud rates and can use smaller external capacitors 0.1 $\mu F$ in place of the 1.0 $\mu F$ capacitors used with the original device.[1] The newer MAX3232 is also backwards compatible, but operates at a broader voltage range, from 3 to 5.5 V.


It is helpful to understand what occurs to the voltage levels. When a MAX232 IC receives a TTL level to convert, it changes a TTL Logic 0 to between +3 and +15 V, and changes TTL Logic 1 to between -3 to -15 V, and vice versa for converting from
RS232 to TTL. The RS232 Data Transmission voltages at a certain logic state are opposite from the RS232 Control Line voltages at the same logic state. The following Table 2.2 shows the RS-232 Voltage Levels [25].

<table>
<thead>
<tr>
<th>RS232 Line Type &amp; Logic Level</th>
<th>RS232 Voltage</th>
<th>TTL Voltage to/from MAX232</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Transmission (Rx/Tx) Logic 0</td>
<td>+3 V to +15 V</td>
<td>0 V</td>
</tr>
<tr>
<td>Data Transmission (Rx/Tx) Logic 1</td>
<td>-3 V to -15 V</td>
<td>5 V</td>
</tr>
<tr>
<td>Control Signals (RTS/CTS/DTR/DSR) Logic 0</td>
<td>-3 V to -15 V</td>
<td>5 V</td>
</tr>
<tr>
<td>Control Signals (RTS/CTS/DTR/DSR) Logic 1</td>
<td>+3 V to +15 V</td>
<td>0 V</td>
</tr>
</tbody>
</table>

Tab. 2.2: RS-232 Voltage Levels

2.10 Microcontroller Selection

Criteria for choosing a microcontroller for the design and development of a DAS can be categorized as under:

(i) The first and foremost criterion for choosing a microcontroller is that it must meet the task at hand efficiently and cost effectively [26]. In analyzing the needs of a microcontroller-based project, it is seen whether an 8-bit, 16-bit or 32-bit microcontroller can best handle the computing needs of the task most effectively. Among the other considerations in this category are:

(a) Speed - The highest speed that the microcontroller supports

(b) Packaging - Package format may be in DIP (dual inline package) or a QFP (quad flat package), or some other packaging. This is important in terms of space, assembling, and prototyping the end product.

(c) Power consumption - This is especially critical for battery-powered products.

(d) The number of I/O pins and the timer on the chip.

(e) How easy it is to upgrade to higher - performance or lower consumption versions.

(f) Cost per unit - this is important in terms of the final cost of the product in which a microcontroller is used.
(ii) The second criterion in choosing a microcontroller is how easy it is to develop products around it. Key considerations include the availability of an assembler, debugger, a code-efficient compiler, technical support.

(iii) The third criterion in choosing a microcontroller is its ready availability in need, quantities both now and then in the future. Thus by considering the criterion, we started with microcontroller PIC12F675 and then moved to PIC18F4550 from Microchip PIC family [17, 18]. PIC is a family of modified Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1650 originally developed by General Instrument’s Microelectronics Division. The name PIC initially referred to “Peripheral Interface Controller” [27, 28, 29, 30].

2.11 Hardware Components

Some of the hardware components used in real data acquisition systems can be discussed as under:

Digital IC Families

The TTL family of digital ICs is one the most popular digital ICs. The 74xx was the first of the TTL family. Since then many improvements in device processes and fabrication technologies have led to the introduction of more families offering improved performance over the standard 74xxx family. The various subfamilies in this series offer high speed of operation, low power dissipation, robust performance, and wide availability. The various subfamilies are 74LS, 74ALS, 74S, and 74F series for different applications.

The CMOS family is another important family of ICs. The 4000 series from Fairchild was the original member of the CMOS family. The components of this family offer very low power dissipation and wide supply voltage operation compared to the TTL [31].
**Logic Levels and Noise Margins**

Digital components need a supply voltage to operate. The voltage levels at input and output are related to the supply voltage levels. It may seem that if the digital circuit operates at +10V, the logic low is 0V and logic high is +10V. This is not so. A range of voltages around the two supply levels (0 and +10V) qualifies as a valid logic low and logic high. Logic levels are simply the range of voltages used to represent the logic states 0 and 1 [31].

For a low-power TTL component, which operates at +5V supply voltage, the specifications require that, for error-free operation, an input voltage of up to 0.8V qualifies as logic low. Thus, an input voltage between 0 and 0.8V qualifies as logic low. An input voltage with a minimum of 2.0V qualifies as logic high. This means that an input voltage between 2.0 and 5.0 V qualifies as logic high. Table 2.3 shows the comparison between the logic levels of CMOS and TTL ICs.

<table>
<thead>
<tr>
<th></th>
<th>CMOS</th>
<th>TTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic 1</td>
<td>more than 2/3 $V_{DD}$</td>
<td>more than 2 V</td>
</tr>
<tr>
<td>Logic 0</td>
<td>less than 1/3 $V_{DD}$</td>
<td>less than 0.8 V</td>
</tr>
<tr>
<td>Intermediate</td>
<td>between 1/3 and 2/3 $V_{DD}$</td>
<td>between 0.8 V and 2 V</td>
</tr>
</tbody>
</table>

*Tab. 2.3: Comparison of the logic levels of CMOS and TTL*

The low-power TTL specification guarantees that the maximum logic low output of the device will be 0.4V and a minimum logic high voltage will be 2.4V. These are called the worst-case output levels of the device.

Noise margin is defined as the difference in the voltage levels (for a given logic) of the input and output of a device. The maximum acceptable input voltage level for logic low is 0.8V. The maximum output voltage level for logic low is 0.4V, so the noise margin for logic low is 0.4V. For the high-level noise margin, we must consider the input and output voltages at the high end of the range. A minimum voltage input of 2.0V qualifies as logic high. The device would generate a minimum output voltage of 2.4V for logic high. The difference is 0.4V. So for LS TTL components, the noise margin is 0.4V. Noise margin figures vary from family to family. For the noise margin of a particular device, the data sheet for the device should be referred. The Logic levels...
2.12 System Design and Implementation

For the design and development of the proposed system, the methodology used involves the hardware and software implementation [33, 34]. Implementation of the system involves the following steps:

1. Circuit Design: Selection of microcontroller and other interfacing devices, as per system requirement. Design of hardware circuit and its testing in laboratory with some input signals from the sensors.

2. PCB Design and Fabrication: Drawing of schematic diagrams and the design of circuit board layout for the development of the circuit board, then fabrication of the the design layout to PCB.

3. Hardware Modifications: Making any hardware changes found necessary after the initial hardware design and tests, to produce a revised circuit board schematic diagram and layout for the improvement of the performance and functionality.

4. Software Design: Developing algorithm for the system, as per functionality, coding and testing and upgradation according to the requirement.
5. Integration and Final Testing: Integrating the entire hardware, firmware and software modules and its final testing for data acquisition process.

6. System Design: System hardware assembly including microcontroller and its interface with ADC, and development of the related firmware and application program or software, etc. for proper functioning of the designed DAS.
REFERENCES


References


