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Design and Implementation of an Active Optical Data Tag

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Abstract

An emerging technology in the field of communications is Automatic Identification and Data Capture (AIDC) of objects. AIDC refers to the host of technologies used for automatic identification of objects, collection of data about them and storing the data on a computer or other information archival device. RFID’s and barcodes form the dominant part of the wide variety of technologies that come under AIDC. A possible alternative to Barcode and RFID technologies has been introduced in recent years. This technology, which exploits some of the features of both Barcode and RFID technologies uses light as the communication medium and hence is called Optical Identification (OPID). The Optical Tagging System Research Group of the Photonics System Development Laboratory at the University of Cincinnati has been focused on developing such a technology. As a part of this effort, the following work describes the Design and Implementation of an Active Optical Data Tag which is used in association with an Optical Data Tag Reader and hence proposed as an alternative to RFID technology. An active optical data tag differs from a semi-passive optical data tag by having an on-board power supply which helps in accomplishing extra work than that of a semi-passive optical data tag. This active optical data tag employs a variety of sensors that continuously track the information relative to the tag. The tag transmits all the information collected from the sensors along with the tag-ID back to the tag reader whenever interrogated by it.
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1 Introduction

Our day to day lives have become more and more dependent on the Embedded Systems, which have become a ubiquitous part of our modern technology driven society. The capabilities of these systems have been on the rise since the inception of integrated electronics and hence they find applications in almost all the fields of technology including the automobile and aerospace industry, railways, automotive devices and controls, medicine, communications industry and many others [1]. One such application of embedded systems in the field of communications is Automatic Identification and Data Capture (AIDC) of objects. AIDC is a generic term that refers to the host of technologies used for automatic identification of objects, collection of data about them and storing the data on a computer or other information archival device. Different technologies that come under AIDC include Radio Frequency Identification (RFID), barcodes, biometrics, smart cards, Optical Character Recognition (OCR), magnetic stripes etc. Among all these, RFID’s and the barcodes form the dominant technologies [2]. An alternative approach to the RFIDs would be to use light as the mode of communication. This gives rise to the concept of Optical Tagging System which can be referred to as an Optical ID (OPID). The Optical Tagging System Research Group of the Photonics System Development Laboratory at the University of Cincinnati has been focused on developing such a technology. As a part of this effort, the following work describes the Design and Implementation of an Active Optical Data Tag which is used in association with an Optical Data Tag Reader and hence proposed as an alternative to RFID technology.

1.1 Motivation

The field of Automatic Identification and Data Capture (AIDC) has evolved over the years. AIDC has found its importance in almost every sector of industry, commerce and services. It can
be said that it is used in nearly all fields that have something to do with the capture and processing of information relative to objects which can vary from raw materials to completed products and may even include vehicles, people and the locations/space they move around in [1].

A host of technologies that come under this huge wing of AIDC include:

- RFID (Radio Frequency and Identification)
- Barcodes
- Smart Cards
- Touch Memory
- Magnetic Stripes
- Biometrics
- Optical Character Recognition (OCR)
- Voice Recognition

Among this wide variety of technologies that are currently available for AIDC applications, RFID and barcodes form the dominant technologies that are used extensively [2].

**1.1.1 Comparison between barcode technology and RFID technology**

This section provides a short introduction to the dominant technologies of the AIDC along with a comparative analysis between the two.

**1.1.1.1 Barcodes**

Barcode technology is based on patterns that represent data in the form of lines of varying width and varying spacing. This is usually referred to as one-dimensional or 1D or linear barcode system. There is a system which has patterns that take the form of dots, squares and other geometric patterns and is usually referred to as 2D barcode system. These patterns that are spatially modulated are printed on a substrate suitable for them (such as paper or adhesive label).
A simple example of a barcode is shown in Figure 1. Barcode readers which are placed in the line-of-sight with respect to the barcodes are required to read and interpret the data coded into the barcodes [1] [4].

### 1.1.1.1 Advantages

The main advantages of barcode technologies include:

- **Low Cost:** The cost of a barcode is as low as $0.005. As cost plays a huge role when it comes to manufacturing products on a larger scale, it is very important to maintain the cost of the tag as low as possible.

- **High Speed:** Barcode readers have the capability to read the information from the barcode at a high speed.

- **High Reliability:** The data read by the barcode reader is known to be very reliable.

- **Low power:** As this technology doesn’t involve any powering up of circuits, the power consumption can be considered to be almost zero.

### 1.1.1.2 Disadvantages

- **Line-of-sight communication:** Barcode readers need to maintain a line-of-sight with respect with the barcode for its proper interpretation. Hence the barcodes cannot be read from any other direction.
• **Visibility:** The barcodes have to be placed external to the product/item so that they can be scanned by the reader. This places a limitation that considering a situation where the barcode is soiled/ripped off, there is no way to scan the item properly.

• **No unique identification:** The standard barcodes can only identify the manufacturer and the product but cannot differentiate between two similar products from the same manufacturer. Hence it cannot be used for unique identification of two similar products [5].

• **Short read range:** The maximum read range of the barcode readers varies from around 50mm (0.16ft) to around 250mm (0.8ft). This small read range doesn’t allow for identification over longer distances [6].

### 1.1.1.2 RFID (Radio Frequency and Identification)

RFID is an Automatic Identification technique that helps machines to identify the objects/persons and hence is considered as a branch of AIDC. As the name implies, radio waves are used in the RFID technology for automatic identification of an object/person. An RFID system is basically comprised of two components

- RFID tag or a transponder
- RFID reader

An RFID tag consists of a microchip which is attached to an antenna. The microchip is used not only for storing and processing information but also for modulating and demodulating the input RF signal. The antenna helps in enabling the chip to transmit the information relative to the tag. The working of an RFID system is as follows. The RFID reader has an antenna that sends out RF waves. The tag antenna, which is tuned to match the transmission frequency of the reader, receives the RF waves from the reader. The microchip on the tag demodulates the incident RF
signal and then modulates it with the information relative to the tag and transmits it back to the reader. The antenna at the RFID reader receives these reflected waves and converts the signal into computer compatible digital information [5]. A typical RFID application is shown in Figure 2.

1.1.1.2.1 Advantages

- **Longer read range:** The read range of RFID tags is much better when compared to that of barcode technology. In general the range of the low frequency or LF (around 125 KHz) tags lies in the range of around 1 foot or less while that of high frequency or HF (around 13.56 MHz) lies in the range of around 3 feet or less. Even higher read ranges of around 10 to 20 feet can be obtained using ultra high frequency (860-960 MHz) [5].

- **Higher information carrying capacity:** The RFIDs have the additional advantage of being able to convey more information than a barcode. This is made possible because of the in-built memory present in the microchip that is embedded in the tag [2].

- **Ability to change the information:** The RFIDs have the ability to modify the information encoded into the tag and the procedure is as simple as reprogramming the microchip in the tag. Since the barcodes are patterns of mere lines or symbols with
different widths and spacing printed on a substrate the data is unique and hence cannot be altered [2].

- **No line-of-sight requirement:** The RFIDs overcome this line-of-sight constraint present in the barcode technology. They can be read from any direction as long as the reader is within its read range [2].

### 1.1.1.2.2 Disadvantages

- **High Cost:** Though the cost of the RFID tag is relatively small at around $0.07 to around $0.30, it is significantly more costly than a printed barcode. Hence cost accounts for a huge difference when it is used in large production quantities. Also the tag reader is much more costly than a barcode reader. While the low frequency tag reader costs around $100 the high frequency tag reader costs around $200 - $300. The ultra high frequency tag readers are even more costly with a price of around $500 to $2000 [2].

- **Interference:** The RFIDs are highly subject to interference as the frequencies employed in the RFID technology are not unique. Further, there is not an internationally agreed upon frequency band for the RFID system. Hence this frequency band may overlap with the frequency band used by other technologies. This leads to the RFID transmitting information unnecessarily when it is not actually being interrogated by a reader [8].

- **Demanding environments:** The RFIDs can be affected adversely when it is brought in contact with metals or liquids [8].

### 1.1.2 OPID (Optical Identification) – An Alternative Proposal

A possible alternative to Barcode and RFID technologies has been introduced in recent years. This technology, which exploits some of the features of both Barcode and RFID technologies uses light as the communication medium and hence is called Optical Identification (OPID).
The advantages and disadvantages of this technology when compared to that of RFID are discussed below [9].

1.1.2.1 Advantages

- **Range:** The high frequency and the ultra high frequency RFIDs are able to achieve a range of a few feet or few meters respectively but not more than that. Larger read ranges can be achieved by means of an OPID which uses the light portions of the electromagnetic spectrum for communication. Light has wavelengths in the range from nanometers to microns which accounts to the frequency band lying between 100’s of picoHz to tens of femtoHz. Figure 3 shows the full electromagnetic spectrum with the position of the visible light spectrum identified. Optical frequencies are much higher than the ultra-high frequencies employed in RFID technologies. The higher the frequency, the shorter the wavelength and the higher the data transfer rate and the operating range. The OPIDs hence have a higher operation range of around hundreds of meters. This forms the basis of the biggest advantage of this technology.

![Figure 3: The Electromagnetic Spectrum [10]](image-url)
- **Data security:** The OPID technique requires that the reader maintains line-of-sight with the optical data tag. Hence this technique puts a limitation for a malicious read out and thus provides more security to the data transmission when compared to that of RFIDS. This is because the RFIDs don’t employ a line-of-sight technique and can be read from any direction unlike the OPIDs.

- **Low cost:** The OPID technique is a low cost affair when compared to that of RFIDs. Though the RFID tag is cheaper, the RFID reader is much more expensive. This is because it employs a transmitter and a receiver, a coupling element and a control unit all of which are required for activating, demodulating and decoding the RFID tag data. These can also be coupled with interfaces that help in converting the data decoded into a format that is compatible to a system/PC. The same process when employed in an OPID is a much cheaper technique as it basically involves a photo-detector/photo-diode for conversion of the incident light into appropriate current value.

### 1.1.2.2 Disadvantages

- **Location on the target:** The main drawback of the OPID technique lies in the limitation of placing the OPID tag on the exterior of the target. Unlike the RFIDs, where the tag can be embedded inside the target and still be read by the RFID reader, the OPID tag cannot be read unless and until it is visually exposed to the OPID reader.

- **Line of sight requirement:** Though this requirement comes as an added advantage in terms of security concerns, it does impose a limitation on the position of the reader with respect to that of the tag for correct interpretation of the data.
Looking at the advantages of OPIDs over RFIDs, a task of developing a working model of an Optical Tagging System was identified as a goal for the Optical Tagging System research group of PSDL at University of Cincinnati. This proposal forms the motivation for this Master’s thesis.

1.2 Problem Statement

The goal of developing a working model of an alternative automatic identification system based on an OPID technology platform bounds the basic problem statement of this thesis.

This optical communication system can be broadly divided into 2 basic modules

- Optical Data Tag Reader/Interrogator
- Optical Data Tag

Initially, there is no data transfer between the two modules. The data transfer starts when the reader directs a light beam onto the Optical Data Tag and triggers the system. The Optical Data Tag responds by modulating the incident light beam with respect to the data that it needs to communicate and sends it back to the reader in the form of a retro-reflected version of the interrogation beam. This modulated light beam received by the reader interprets the optical data into binary data and displays it on the display unit. This is how the optical communication is

![Figure 4: Basic Optical Communication Link in an OPID technology](image)

Figure 4: Basic Optical Communication Link in an OPID technology
achieved between the Optical Data Tag Reader and the Optical Data Tag. Hence it can be said that the basic problem statement was to develop a form of optical target identification technology and not an optical target verification technology. A basic optical communication link in an OPID technology is shown in Figure 4. A version of such an optical tag reader was developed as a part of the master’s thesis by Srikanth Gummalla of the PSDL [11]

1.2.1 Classification of Optical Data Tags

The Optical Data Tags can be broadly classified into two types:

- Semi-passive Data Tags
- Active Data Tags

The Semi-passive Data Tags will focus on an ultra-low power design and will gather their power from the ambient environment using an onboard solar panel. When the tag is not being interrogated by the reader, any unneeded circuitry is turned off in order to conserve power. A tag of this type was realized as a master’s thesis by Andrew Rupert of the PSDL [12]. Unlike the Semi-passive Data Tags, Active Data Tags have a long term internal power source to power the integrated circuits and then broadcast the signal/data to the reader. This kind of a data tag can be more reliable because of the long term on-board power supply.

Since the Active Data Tag has an internal source of power supply, it has the ability to accomplish more work than the Semi-passive Data tag and hence transmit more information. This thesis work involves the design and implementation of an Active Optical Data Tag.

1.3 Approach

This thesis involves the selection of appropriate sensors, interfacing circuitry and tag communication components necessary to implement an Active Optical Data Tag. To highlight the ability of the Active Optical Data Tag to do more work than a Semi-passive Data Tag,
several on-board sensors are included in the tag design. These sensors, continuously track information relative to the tag and transmit it along with the Tag-ID when the tag is interrogated by an optical tag reader.

The active optical data tag can be divided into two functional units.

- **Data Processing Unit**
- **Data Transmission Unit**

While the Data Processing Unit is responsible for collecting, processing and manipulating the data collected by the sensors incorporated into the tag, the Data Transmission Unit is responsible for transmitting the final data that has to be sent over to the Optical Data Tag Reader. Since the Data Processing Unit deals with the collection and manipulation of data, it has the following components

- **A variety of sensors**: These are used for monitoring the state of the tag continuously. These sensors hence form the base of the information center.

- **Microcontroller Unit**: A microcontroller is used for interfacing all the sensors, collecting the data from and processing them so as to make it compatible for data transmission. Hence the microcontroller forms the base of the Data Processing Unit.

The Data Transmission Unit deals with the transmission of data by modulating the incident light beam and reflecting it back in the same direction to the reader. Hence the Data Transmission Unit has the following two main components

- **LCD shutter**: An LCD shutter used for modulating the information it receives from the Data Processing Unit and help in the optical transmission.

- **Retro-reflector**: This is placed exactly behind the LCD shutter so that it helps in reflecting the incident light beam back to the reader.
Figure 5: An Active Optical Data Tag in an Optical Communication Link

The Figure 5 shows a block diagram for an Active Optical Data tag. As described above, the microcontroller unit in the Data Processing Unit collects information from all the sensors interfaced to it and then modulates the LCD shutter in the Data Transmission Unit to send data to the tag reader when the reader interrogates the tag with an incident light beam.

1.4 Thesis Outline

The remainder of this thesis is organized as follows:

Chapter 2 Design of the Data Processing Unit gives the details about the PIC microcontroller which forms the core component of the optical data tag. It also gives an introduction to the variety of sensors used in this implementation of an Active Optical Data Tag and provides sensor specifications and the criterion followed in the selection of sensors for the tag implementation. It also discusses in detail about the interfacing of sensors with the microcontroller.
Chapter 3 Design of the Data Transmission Unit gives an overview of how data transmission takes place between the optical data tag reader and the optical data tag. In this chapter, the data communication process is discussed in detail including descriptions of the LCD shutter and the retro-reflector and how each helps in the modulation of the incident laser beam and its reflection back to the reader.

Chapter 4 Printed Circuit Board Design focuses on the final layout of the Active Optical Data Tag on a Printed Circuit Board (PCB) and how the board matches the overall experimental setup of the Optical Data Tag. It also focuses on the placement and identification of the various components that form the tag.

Chapter 5 Results and Future Work includes all the results obtained during the experimentation with the individual components on bread board and also the final results with all of the components embedded on the PCB prototyped for the model. It also suggests future work possible based on this implementation of an Active Optical Tag.
2 Design of the Data Processing Unit

This chapter focuses on the design of the Data Processing Unit (DPU) which includes the selection of various components used in this unit, interfacing between them and how they serve the purpose of the data collection and data processing.

The Data Processing Unit in an active optical data tag is responsible for collection of a variety of data from all of the sensors attached to the tag. Further, the DPU process the collected sensor signals, convert them into digital data and finally sends the digital data to the Data Transmission Unit (DTU) for transmission to the Optical Tag Reader when interrogated. This chapter focuses on all the components used in the Data Processing Unit (DPU).

The Data Processing Unit of the active optical data tag can be broadly divided into three different modules

- Information/Data Source module
- Triggering module
- Data processing module

Each of the modules is described in detail in the following sections.

2.1 Information/Data Source Module

The main difference between an active and a passive tag is the amount of information that the tag is able to transmit on interrogation by the reader. Since the active data tag has an onboard power supply it has the ability to do extra work when compared with a passive tag. The Information Source Module forms the base of the information center and is primarily responsible for executing the extra work done by an active optical data tag.

In this thesis, the Information Source Module has the following components which constitute the majority of information that this active optical data tag transmits.
• Temperature Sensor
• Pressure Sensor
• Tilt Sensor

Hence it can be said that this module accommodates a variety of sensors which collect corresponding data and constitute the major source of information gathered by the tag. A detailed description of all the sensors used in this active optical data tag is given below.

### 2.1.1 Temperature Sensor

The temperature sensor as the name indicates is the sensor that is used to track the current temperature of the system to which the sensor is attached. This active optical data tag employs a TMP01 low power programmable temperature controller [13].

The main features of this temperature sensor are summarized below [13].

- **Temperature – Proportional Voltage Output**: It generates an output voltage which is proportional to the absolute temperature of the surroundings.

- **Temperature Range**: The range of temperatures that this temperature sensor can measure lies between -55°C to 125°C.

- **Temperature Coefficient**: It has a precise temperature coefficient of 5mV/K.

- **Accuracy**: The accuracy of this temperature sensor is very high and it has additional features like temperature compensation and band-gap type voltage reference.

- **User Programmable Temperature Trip Points**: It generates a control signal that specifies whether the device is either above or below a specific temperature range.

- **Compatibility**: It is TTL/CMOS compatible.

- **Wide Range Single-Supply Operation**: It can operate on a single supply which can vary between 4.5V and 13.2V.
- **Package:** It is available in a low-cost 8-pin mini-DIP (Dual In-line Package) and SO (Small Outline) packages.

The TMP01 is a linear voltage output temperature sensor that generates an analog output voltage which is proportional to the absolute temperature [13]. The functional block diagram of an 8-Pin DIP package of TMP01 is shown below in Figure 6. As can be seen from the figure, the TMP01 derives its power from an external voltage applied on pin 8 and generates an analog output voltage \( V_{\text{PTAT}} \), proportional to temperature on pin 5 [13]. Pins 2 (set high) and 3 (set low) can be used to set the trip points for the temperature sensor with the help of resistors \( R_1, R_2 \) and \( R_3 \). Depending on the values of the resistors, the voltages are set for set high and set low. This sensor has window comparators that compare the absolute temperature with the trip points set by the user and generates appropriate voltages on the output pins 6 and 7 - **UNDER** and **OVER** respectively [13].

This implies that the voltage on pin 6 goes low whenever the voltage associated with the current temperature goes below the voltage applied at set low and the voltage on pin 7 goes low whenever the voltage associated with the current temperature goes above the voltage applied at set high.

![Figure 6: Functional Block Diagram of TMP01 [13]](image-url)
Simply put,

When $V_{SETHIGH} < V_{PTAT}$, $\overline{OVER} = 0$

ELSE, $\overline{OVER} = 1$

When $V_{SETLOW} > V_{PTAT}$, $\overline{UNDER} = 0$

ELSE, $\overline{UNDER} = 1$

If there is no requirement of the trip-points feature of this sensor the pins SETHIGH and SETLOW can be connected to Vdd and ground respectively or can be simply left unconnected. Since this feature is not employed in the active optical tag, they are simply connected to the Vdd and ground respectively [13].

The connections of the temperature sensor as they appear in the active optical tag are shown in Figure 7. The output of the temperature sensor, VPTAT, which is an analog voltage, is converted to digital output by means of Analog-to-Digital Converter module present in the microcontroller of the data processing module.

---

**Figure 7: Temperature Sensor TMP01 in an Active Optical Data Tag**
2.1.2 Pressure Sensor

A pressure sensor is a type of sensor that is used to measure the pressure of gases/liquids. A wide variety of pressure sensors are available in the market for measuring different types of pressure. The pressure sensors can be typically classified into the following types depending on the type of pressure they measure [14].

- **Absolute Pressure Sensor:** This type of sensor is used to measure the pressure with reference to vacuum. This means that one end of the diaphragm of the pressure sensor is sealed with vacuum while the other end which is called the pressure port is exposed to atmosphere.

- **Gauge Pressure Sensor:** This type of sensor is used to measure the pressure with reference to atmospheric pressure at a given location. This means that one end of the diaphragm of the pressure sensor is exposed to atmosphere, while the pressure port is exposed to the air/liquid whose pressure has be measured. This implies that when the atmospheric pressure varies, the output of the pressure sensor also varies.

- **Differential Pressure Sensor:** This type of sensor is used to measure the difference between the pressures applied at the two ends of the diaphragm of the pressure sensor.

- **Sealed Pressure Sensor:** This sensor is almost similar to the Gauge pressure sensor because it measures the pressure with reference to atmospheric pressure. But in this case, the one end of the diaphragm is sealed with atmospheric pressure, while the other end is exposed. This implies that the pressure applied at one end is always constant.

There are a number of units to measure pressure. The SI unit of measuring pressure is Pascal (Pa) which is equal to 1 Newton per square meter (N.m\(^{-2}\)). The Non-SI unit of measuring pressure is
Pound-force per square inch (psi). The conversion between various pressure units is shown in Table 1. The value of atmospheric pressure in various units is given below.

**Atmospheric Pressure = 101325 Pa = 101.32 KPa = 14.696 psi**

The pressure sensor selected for use in the active optical data tag presented here is the MPX4250A, which is an integrated silicon absolute pressure sensor, on-chip signal conditioned, temperature compensated and calibrated [16]. The MPX4250A is designed to measure any absolute pressure within its range of measurement. It has the following features [16].

- **Wide Pressure range:** It has the ability to measure pressures in the range of 20 to 250 KPa (2.9 to 36.3 psi).
- **Analog Output voltage:** It generates an analog voltage ranging between 0.2V to 4.9V.
- **Compatibility:** It is specially designed for applications involving its interface with microcontroller or microprocessor with A/D conversion capabilities.
- **High Accuracy:** The maximum error percentage is 1.5 % over 0°C to 80°C giving rise to high accuracy.
- **Temperature Compensated:** It has temperature compensation over -40°C to +125°C.
- **Reduced Weight:** It offers reduction both in weight and volume when compared to other existing Hybrid Modules.

<table>
<thead>
<tr>
<th>Pressure Units</th>
<th>Pascal (Pa)</th>
<th>Pound force per square inch (psi)</th>
<th>Atmosphere(atm)</th>
<th>Bar (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pa</td>
<td>= 1Nm²</td>
<td>145.04 x 10⁶</td>
<td></td>
<td>10⁻⁵</td>
</tr>
<tr>
<td>1 psi</td>
<td>6894.76</td>
<td>= 1lbf/in²</td>
<td>68.04 x 10⁻⁵</td>
<td>68.9x10⁻³</td>
</tr>
<tr>
<td>1 atm</td>
<td>101,325</td>
<td>14.696</td>
<td>= 1 atm</td>
<td>1.01325</td>
</tr>
<tr>
<td>1 bar</td>
<td>100,000</td>
<td>14.503</td>
<td>0.98682</td>
<td>= 10⁹ dyn/cm²</td>
</tr>
</tbody>
</table>

Table 1: Various units of pressure and their conversion [15]
**UNIBODY PACKAGE PIN NUMBERS**

<table>
<thead>
<tr>
<th></th>
<th>Vout</th>
<th>4</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>GND</td>
<td>5</td>
<td>NC</td>
</tr>
<tr>
<td>3</td>
<td>Vs</td>
<td>6</td>
<td>NC</td>
</tr>
</tbody>
</table>

*NC stands for Not Connected*

**Table 2: Pin assignment to MPX4250A [16]**

- **Package:** It is available both in Thermoplastic Small Outline Packages (SOP) and Durable Epoxy Unibody Package as a 6-pin SIP (Single In-Line Package).

The Unibody packages and Small Outline packages of the MPX4250A Series are shown in Figure 8. The pin numbers of the Unibody package available as a 6-pin SIP and its configuration is shown in Table 2.

Since the output voltage produced by the pressure sensor is analog, there is a need of an interfacing domain for it to interact with the digital circuitry involving microcontroller. This is accomplished by means of an A/D conversion channel present within the microcontroller. Hence the output of the pressure sensor is given as an input to the ADC channel -10 of the MCU to

![UNIBODY PACKAGES](image1)
![SMALL OUTLINE PACKAGES](image2)

**Figure 8:** Pressure sensor, MPX4250A Series in Unibody and Small Outline Packages [16]
convert it into binary data. Figure 9 shows the connections of the pressure sensor in an active optical data tag.

2.1.3 Tilt Sensor

A tilt sensor is a type of sensor that helps in measuring the tilt status of the device. The DS series contactless tilt switch, DSBA1P from the NKK switches has been used in the active optical data tag. The DS series components contain two solid-state devices: an Infrared Light Emitting Diode and a photo transmitter [17]. When the switch is level, a bright nickel-plated ball rests at the focus point which helps in knowing the tilt status. This kind of tilt switch was selected for the application because of the following striking features [17].

- **Mercury-less**: Most of the tilt switches/sensors make use of mercury but this tilt switch replaces the traditional mercury and pendulum switches hence avoiding the damage that occurs due to spilling of the mercury.

- **High Reliability**: This tilt switch has a photo interrupter rather than contacts. This ensures high reliability for the tilt switch.
- **Sealed Construction:** The switch has a sealed construction that helps protect it from the environmental.

- **Compact Dimensions:** The compact dimensions of the tilt sensor helps in space saving and makes it ideal for high density mounting.

- **Crimped Terminals:** The crimped terminals of the switch help in secure mounting onto a printed circuit board and prevent dislodging during wave soldering.

- **Free Rotation:** The internal steel ball present in the tilt switch helps in free $360^0$ rotation of the switch.

- **Operating Angle:** The operating angle of the tilt switch is $\pm 30^0$ to $\pm 60^0$. This implies that the tilt switch is triggered when it is tilted beyond $30^0$ in any direction.

### 2.1.3.1 Operation of the tilt sensor

The operating characteristics of the tilt switch are tabulated in Table 3. The voltages $V_{OL}$ and $V_{OH}$ mentioned in the table below correspond to the output low and output high voltages of the tilt switch indicating the change in the tilt status of the switch. It can be noted from the data sheet that an output voltage of 4V (minimum) is produced when the tilt switch is tilted at an angle of $-60^0$ and the output voltage drops down to a voltage of 1V (maximum) when it is tilted back to the horizontal position [17].

### 2.1.3.2 Circuit considerations of the tilt sensor

This tilt switch has the following four terminals [17]

<table>
<thead>
<tr>
<th>Circuit Characteristics (ON-OFF)</th>
<th>Operating Angle</th>
<th>Returning Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>$V_{OL} \rightarrow V_{OH}$</td>
<td>$V_{OH} \rightarrow V_{OL}$</td>
</tr>
<tr>
<td></td>
<td>$\pm 30^0$ to $\pm 60^0$</td>
<td>Minimum $10^0$</td>
</tr>
</tbody>
</table>

Table 3: Output Characteristics of a tilt switch [17]
The circuit considerations of the tilt sensor are shown in Figure 10. The circuit specifications are given below:

\[
V_{cc} = 5V, \ R_2 = 100\, \Omega
\]

\[
I_f = 19mA \ (V_{cc} = 5V, \ R_1= 200\, \Omega) \ V_f\ of\ the\ LED,\ maximum = 1.3V
\]

The output voltage is obtained at the third terminal of the tilt switch and is denoted as \(V_o\). This voltage is connected to a voltage comparator as shown in Figure 11. A voltage comparator, as the name suggests, is an electronic device that compares two input voltages and switches its output indicating the higher voltage of the two input voltages. This is required to convert the analog voltage coming from the tilt switch to a digital output. The two input voltages for the comparator that are used in conjunction with the tilt switch are:

1) \(V_{in+}\) : Reference Voltage – \(V_r\) which is set at 0.6V

2) \(V_{in-}\) : Output Voltage of the tilt switch – \(V_o\)
In order to make the active optical data tag more compact and decrease its area, the comparator that is embedded in the microcontroller itself is used instead of using a separate dedicated comparator circuit. Of the two comparators present in the microcontroller, the second comparator, comp-2, is used with the tilt sensor. The function of the comparator with $V_{out}$ being the output of the comparator is summarized below:

$$V_{out} = \begin{cases} 
1; & \text{when } V_{in+} < V_{in-} \\
0; & \text{when } V_{in+} > V_{in-} 
\end{cases}$$

The tilt sensor as it appears in the active optical data tag is shown in Figure 11. The output of the comparator is read by the microcontroller and the status of the tilt switch is updated continuously. If the output of the comparator is 1, it implies that the tag to which the tilt switch is attached is tilted at an angle greater than or equal to $30^\circ$ in either of the directions. If the output of the comparator is 0, it implies that the tag is in the horizontal position or not tilted beyond an angle of $30^\circ$. 

**Figure 11 : Tilt sensor in an active optical data tag**
2.1.3.3 Tilt History

The active optical data tag successfully implements a special feature called tilt history with the help of the tilt sensor and the microcontroller. Tilt history as the name indicates is the feature where in there is a record of whether the tag has been ever tilted before or after the interrogation. This implies that the tag apart from transmitting the current tilt status also transmits the data relative to tilt history. This is transmitted using the variable, “thist”, in the microcontroller. If the tag is tilted before/after it is interrogated, the microcontroller sets this bit and transmits it. If the tag is always in the horizontal position, this bit always remains cleared and the tag transmits the same. Therefore, the tilt status of the tag as it appears at the receiver end and its description is shown below.

\[ \text{tilt} = \text{Y/N, thist} = \text{Y/N} \]  where

- ‘tilt’ indicates the current position of the tag,
- ‘thist’ indicates if the tag has ever been tilted before,
- ‘Y’ represents a Yes indicating that the tag is currently tilted or has been tilted and
- ‘N’ represents a No indicating that the tag is not currently tilted or has not been tilted

This feature can be really useful when it comes to applications wherein an indication of whether the product has been tilted before is required. For example, consider a case of postal deliveries of fragile products or products which shouldn’t be tilted. Having an optical data tag fixed to the package, we can keep a track of its tilt status until the product reached its destination by interrogating the tag fixed to it with the optical tag reader.

2.2 Triggering Module

The OPID identification technique requires interrogation by the optical tag reader for the optical data tag to transmit the data relative to the tag. This shows that there is a need of a good
triggering module on the optical tag end which transmits the information only when interrogated and not otherwise. Hence a triggering module can be thought of as a module that activates the data transmission only when the read beam is directed onto the data tag by the optical tag reader. A simple triggering module can be designed by the use of a photodetector followed by appropriate circuitry that helps in generating a signal that triggers the transmission of data that was collected by the sensors attached to the active optical data tag.

The triggering module in an active optical data tag has the following components

- Photodetector
- Trans-impedance Amplifier and
- Comparator

These components collectively make for a reliable triggering module that can be used within the tag. Figure 12 shows the block diagram of the triggering module in an active optical data tag. As it can be seen from the figure, the output of the photo diode which is a current is fed to a trans-impedance amplifier whose output is a voltage. This in turn is fed to a comparator where in it is compared to a reference voltage and generates a signal called the trigger signal which triggers

![Figure 12: Block Diagram of the Triggering Module in the Data Processing Unit](image)
the data transmission. A brief description of the components used in the triggering module is given in the following section.

2.2.1 Photodetector

The photodetector forms a vital component of the triggering system as it converts the optical signal to appropriate electric signal for processing. When an active optical data tag is interrogated by the incidence of a laser beam coming out of the tag reader, the triggering module needs to convert this optical signal into electric signal to activate the transmission. This task is carried out effectively with the help of photodetector. A photodiode is one such kind of a photodetector. A photodiode works on the principle of photo electric effect which is a phenomenon that describes the emission of electrons from matter due to the energy absorption from the electromagnetic radiation such as light. The following characteristics should be taken into account for the right choice of a photodiode.

- **High Responsivity**: Responsivity is a measure of sensitivity that takes into account the active area of a photodiode. This parameter is obtained by dividing the short-circuit photocurrent (mA-microamps) by the energy of the incident light per unit area (μW/cm²) [18].

- **High Sensitivity**: Sensitivity is also a very important trait of a photodiode. It is defined as the ratio of the short-circuit photocurrent generated by the photodiode (A-amps) and the energy of the incident light (W-Watts). The higher the sensitivity, the better the output response of the photodiode [18].

- **Low response time**: Any photodiode will take a certain amount of time to respond to a sudden change in incident light intensity. This is measured by the parameter called response time and it can be defined as the time taken by the output of the photo diode to
rise/fall from 10% to 90% / 90% to 10% of its final value. The lower the response time, the faster the output generated by the photo diode [18].

- **Low Dark Current:** Dark current is the leakage current that flows when the reverse voltage is applied across the junction of a photodiode in the absence of light. This dark current forms a source of noise when a photodiode is used in an optical communication system. Hence a photodiode with a low dark current is preferred in this application [18].

- **High Linearity:** Linearity is a characteristic of the photodiode which indicates the behavior of the photodiode when it is illuminated with linearly varying intensities of light. Hence a high linearity of the photodiode would indicate that as the intensity of the incident light increases linearly, the output current generated by the photodiode also increases linearly at the same rate [18].

- **High Reliability:** All the features above contribute to making the photodetector highly reliable in any application.

A Si photodiode, S2386-5K, from Hamamatsu that has all the above mentioned characteristics has been selected for the active optical data tag. The spectral response of the photodiode is

![Figure 13: Spectral Response of Si Photo Diode - S2386-5K and an image of the Photodiode itself [19]](image)
shown in Figure 13. It can be seen from the figure that it has a sensitivity of around 0.45 A/W at 650nm which is the wavelength of the incident laser beam from the optical tag reader. The response time of the photodiode is 1.8 us, $C_T = 730$ pF and $R_{sh}= 50 \, \text{G} \Omega$ [18]. The Spectral response shown in Figure 13 is at a typical room temperature of $25^0 \text{C}$ [19].

2.2.2 Trans-Impedance Amplifier

A trans-impedance amplifier, as the name indicates, converts an input current to an output voltage. Hence it is also called a Current–to–Voltage converter. The photodiode of the triggering module generates a current that is proportional to the incident light intensity. There is every need to convert this current output to a voltage so that it can be processed further. This task is carried out effectively by the trans-impedance amplifier. A simple trans-impedance amplifier can be constructed by using an operational amplifier and a feedback resistor $R_f$ as shown in Figure 14. This combination makes a close approximation to an ideal current–to–voltage converter with zero input and output impedance [20]. The figure also shows a feedback capacitance, $C_f$, in dashed lines, that helps in providing phase compensation for high gain applications [20]. The operation of this circuit can be simply explained basing on the basic principle of operation of an op-amp. The following points summarize the functionality of this simple circuit [21].

\[E_0 = -I \times R_f\]

\[C_f\]

\[R_f\]

\[\text{Op-amp}\]

\[I\]

\[E_0\]

\[\text{Figure 14: Trans-Impedance Amplifier using an op-amp [20]}\]
- An op-amp basic functionality is to see that no current flows into it. Since no currents flow into it, the input current $I_i$ has nowhere to go other than through the resistor $R_f$.

- Another main task of an op-amp is to maintain both its inverting and the non-inverting inputs at the same voltage. Since the non-inverting input is grounded, one of the terminals of the resistor $R_f$ which is connected to the inverting input of the op-amp is also maintained at zero potential. This simply means that the output voltage of the op-amp should be nothing but the voltage developed across the feedback resistor $R_f$. Hence the following equation satisfies.

$$E_0 = -I_i \cdot R_f$$

The values of the resistor and capacitor used in the active optical data tag are $R_f = 100K\Omega$, $C_f = 5pF$. These values have been chosen because there is a distinct difference between the outputs generated when a laser beam is shined upon it and when it is exposed to ambient light. The value of the output voltage generated for various values of $R_f$ and $C_f$ when a laser beam is shined upon the photodiode and when the photodiode is exposed to ambient light is tabularized in Table 4.

### 2.2.2.1 Selection of op-amp

The right selection of op-amp is very important for proper functioning of the trans-impedance

<table>
<thead>
<tr>
<th>Various values of resistors &amp; capacitors</th>
<th>Laser beam</th>
<th>Ambient Light</th>
<th>No light (In dark)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_f = 1M\Omega$ and $C_f = 10\mu F$</td>
<td>4.1V</td>
<td>1.16V</td>
<td>0V</td>
</tr>
<tr>
<td>$R_f = 100K\Omega$ and $C_f = 5pF$</td>
<td>4.3V</td>
<td>312mV</td>
<td>0V</td>
</tr>
<tr>
<td>$R_f = 5M\Omega$ and $C_f = 5pF$</td>
<td>4.3V</td>
<td>4.3V</td>
<td>0V</td>
</tr>
</tbody>
</table>

**Table 4: The output voltage of the trans-impedance amplifier for different values of resistors and capacitors**
amplifier. The op-amp chosen for use in the active optical data tag is LT1793 which is a low noise, pico-ampere bias current, JFET input op-Amp. This op-amp has the following striking features which makes its use more convincing [22].

- **Low Input Bias Current, Warmed Up:** A very low input bias current is maintained over the entire common mode range 10pA Max
- **Low Voltage Noise:** It has a low voltage noise of 8nV/√Hz Max
- **High Input Resistance:** It has a high input resistance of 10^{13}Ω
- **Very Low Input Capacitance:** It offers a very low input capacitance of 1.5pF
- **High Voltage Gain:** It also offers a high voltage gain of 1 Million Min
- **Gain-Bandwidth Product:** It has a typical gain – bandwidth product of about 4.2MHz
- **±5V Supplies:** The op-amp offers guaranteed specifications with ±5V power supply.

An op-amp requires a positive and a negative voltage supply for a proper operation. Since this op-amp requires ±5V supply, there is a need for a circuit that generates negative voltage supply. To serve this purpose, LTC1144, which is a monolithic CMOS switched-capacitor wide input range voltage converter, is used in the triggering module of the data tag [23]. This IC performs a supply voltage conversion from positive to negative for any inputs ranging between 2V to 18V.

![LTC1144 Diagram](image.png)

**Figure 15: Generating -15V from +15V [23]**
resulting in complementary voltages of -2V to -18V [22]. A typical application of generating a
negative voltage from a positive voltage supply using LTC1144 has the circuit considerations as
shown in Figure 15.

All the components mentioned in this section such as the photodiode, trans-impedance amplifier,
voltage converter and comparator are connected as shown in Figure 16. The output of the trans-
impedance amplifier is connected to a comparator to produce the required trigger signal which is
the basic functionality of the triggering module of the data processing unit. Since the
microcontroller used in the active optical data tag has two voltage comparators, it saves the space
to use the one of the two comparators for the triggering module too rather than using a dedicated
IC for a comparator.

2.2.3 Comparator

The voltage comparator used for triggering module has two of the following inputs:
- VOUT: The output voltage of the trans-impedance amplifier given to the inverting input of the comparator.

- Vref: A reference voltage of 0.6V generated within the microcontroller given to the non inverting input of the comparator.

The decision on the output of the comparator2 of the MCU, Vcomp2, is based on which of its two inputs is higher and follows the following equation:

\[ V_{\text{comp2}} = \begin{cases} 1; & \text{when } V_{\text{in+}} (/V_{\text{OUT}}) < V_{\text{in-}} (/V_{\text{ref}}) \\ 0; & \text{when } V_{\text{in+}} (/V_{\text{OUT}}) > V_{\text{in-}} (/V_{\text{ref}}) \end{cases} \]

When the output of the comparator is 1, the variable ‘trigger’ in the program code of the microcontroller is set to 1. Once the ‘trigger’ is set, the data transmission starts. This implies that the microcontroller sends appropriate signals along with the data to the Data Transmission Unit of the active optical data tag. The Data Transmission Unit starts to transmit the information by modulating the incident laser beam coming from the optical tag reader. This is how the triggering system triggers the transmission mechanism in an OPID.

### 2.3 Data Processing Module

Data Processing Module is the module where the major part of data processing takes place. Hence it can be considered to be the crux of the Data Processing Unit of the active optical data tag. The main features of the data processing unit involve the following.

- Conversion of the analog data coming from the temperature and the pressure sensor to digital data.

- Proper interpretation of the data coming from the tilt sensor by means of the comparator present within the microcontroller.
• Conversion of the data collected and processed from the sensors on-board to ASCII values so that it is easily readable at the receiver end.

• Proper interpretation of the data coming from the trans-impedance amplifier of the triggering module, thereby controlling the start and end of transmission.

• Controlling the overall flow of the algorithm implemented in the active optical data tag.

The main and the only constituent of this unit is the microcontroller which helps in achieving all the above mentioned features. The choice of microcontroller used in the active optical tag is very important because it needs to have high operating speed, low power features, interrupt capabilities and all the required units such as Analog-to-Digital Converter (ADC) and comparators. Of the wide variety of microcontrollers available in the market, an 8-bit microcontroller from the PIC-16MCU family of the microchip, **PIC16F690** is chosen for this application. Its selection is justified in the following section.

### 2.3.1 Microcontroller – PIC16F690

The PIC16F690 is a 20-pin flash based, 8-bit CMOS microcontroller with nano-watt technology. This microcontroller comes with a lot of striking features that makes it very suitable for its use in the active optical data tag. Some of the features that make it useful are listed below [24].

• **RISC Instruction Set:** It has only 35 instructions all of which are single cycle instructions except for the branches

• **Addressing modes:** It implements all the direct, indirect and relative addressing modes

• **Interrupt Capability:** It has multiple sources of interrupt that helps in implementing any feature suitable for the application.
- **Wide variety of clock source:** The oscillator module of the microcontroller allows selection features from a wide variety of clock sources so as to maximize the performance and minimize the power consumption.

- **Wide Operating Voltage:** It has a wide operating voltage range of 2.0V to 5.5V.

- **Low power features:** It can be very well used in low-power applications because of its low-power features. It has a stand-by current of 50nA @2.0V typical and an operating current of 11µA@32KHz and 22011µA@4MHz.

- **Sleep Mode:** It also has a special sleep mode which helps in power saving.

- **Various Modules:** It has a wide variety of modules such as Enhanced low current Watchdog Timer(WDT), Enhanced USART module, Enhanced Capture, Compare and PWM+ module, Synchronous serial port (SSP), I²C module (Master/slave modes), In-Circuit Serial Programming(ICSP) feature and 8-bit timer/counter modules. These special features help in its usage over a wide area of applications.

- **A/D Converters:** It has 12 ADC channels that help in conversion of data from analog to digital from 12 different sources with a 10-bit resolution.

![Figure 17: Pin summary of PIC16F690](image)

Figure 17: Pin summary of PIC16F690 [24]
- **Comparator module**: It has two analog comparator modules with a programmable on-chip voltage reference (CVREF) module.

- **I/O ports**: There are 18 general purpose I/O pins available for use. Depending on the peripherals enabled, some or all the pins may not be available as general purpose I/O.

The pin diagram and the pin summary of the PIC16F690 are shown in Figure 17 and Figure 18 respectively.

The main modules of the PIC16F690 that come into use in the active optical data tag are

- **ADC Modules**
- **Comparator Module**

A brief description of the circuit considerations of these modules in the PIC is given in the following sections. Also a detailed explanation of the algorithm implemented in the microcontroller is given in the sections to follow.
2.3.1.1 ADC Module

One of the main functions of the data processing unit is to collect the data from the sensors and to process it so as to make it compatible for transmission. The temperature and the pressure sensors used in this tag are analog sensors and hence the A/D converters are required for the conversion from analog data to digital data. The PIC16F690 has 12 in-built ADC channels that can be used for A/D conversion. Of these 12 ADC channels (AN0 – AN11), 2 ADC channels (AN10 and AN11) are dedicated to receive the data from the sensors continuously. The ADC converts an analog input to 10-bit binary representation of that signal. The analog input is multiplexed to a sample and hold circuit, the output of which is connected to the input of the converter. This converter generates a 10-bit binary result via successive approximation and stores the result in two ADC registers – ADRESL and ADRESH [24].

2.3.1.1.1 Configuring the ADC module

The following functions have to be considered when configuring the ADC [24].

- **Port configuration**: The pins that are selected as input to the ADC channel have to be configured as analog by setting the corresponding TRIS and ANSEL bits.

- **Channel selection**: An ADC channel is selected out of the 12 available ADC channels by settings the appropriate bits (CHS bits) of the ADCON0 register. This implies that the sample and hold circuit is connected to that particular channel selected.

- **ADC voltage reference selection**: A positive reference voltage can be either Vdd or any external voltage source. This is decided by the VCFG bit of the ADCON0 register.

- **ADC conversion clock source**: The conversion clock source is software selectable and there are seven different options- Fosc/2, Fosc/4, Fosc/8, Fosc/16, Fosc/32, Fosc/64, FRC dedicated internal oscillator. Time taken for one bit conversion is called TAD. Hence it
takes a total of 11 $T_{AD}$ periods and for proper conversion the appropriate $T_{AD}$ specification must be met.

- **Interrupt control**: The ADC module allows generating an interrupt upon successful completion of the A/D conversion. This feature can be enabled by setting the ADC interrupt enable bit (ADIE) of the PIE1 register.

- **Results formatting**: The 10-bit digital output produced is stored in two registers – ADRESL and ADRESH. By setting/clearing the ADFM bit of the ADCON0 register, the results can be stored in left justified/ right justified format.

The circuit connections of the temperature and the pressure sensor with respect to MCU are shown in Figure 19.

### 2.3.1.2 Comparator Module

The PIC 16F690 has the following two analog comparator modules used for analog voltage comparison and generation of digital signals, thus helping in interfacing analog circuits with digital circuits [24].

![Figure 19: Overview of the modules of MCU in an active optical data tag](image-url)
• **Comp1**: Dedicated for use in the triggering module and

• **Comp2**: Dedicated for use with the tilt sensor.

The usage of the comparators in the triggering module and with the tilt sensor is explained in the previous sections. In this section, we see as to how the MCU is configured to use these comparator modules. The main registers that are involved in the use of comparator module are [24].

• **CM1CON0**: Control and Configuration register of Comp1

• **CM2CON0**: Control and Configuration register of Comp1 and

• **VRCON**: Control register for the Voltage Reference Module.

The registers CM1CON0 and CM2CON0 contain the control and status bits of the following [24]

- Enable: Used to enable the respective comparator
- Input Selection: Used to select an input to the negative terminal (Vin-) of the comparator from a choice of 4 inputs (C12IN0-, C12IN1-, C12IN2, C12IN3- pins)
- Reference Selection: Used to select an input to the positive terminal (Vin+) of the comparator from a choice of 2 inputs (Voltage reference module, C1IN+ pins)
- Output Selection: Used to select if the output bit of the comparator is available to the user or not.
- Output Polarity: Used to select between the positive and negative polarity output.

The comparator voltage reference module helps in providing a voltage reference generated internally for the comparators. This is taken care of by setting and clearing the appropriate bits of the VRCON register. This module has the following features.

• This module is independent of the comparator configuration.

• Wide selection options for providing the voltage reference to the comparators.
o Fixed reference voltage of 0.6V

o Two 16-level voltage ranges – low range and high range – decided by the Vr<3:0> bits of the VRCON register.

2.3.2 Flow of the Algorithm

The flow of the algorithm implemented in the microcontroller is explained by means of a flow chart shown in Figure 20. The Appendix section provides the algorithm implemented in mikroC language.

The flow of the Algorithm represented in the flowchart is described in detail below:

1. Start of the algorithm

2. Initialize all the necessary variables to their default values such as int temperature =0, int pressure=0, char tilt = ‘N’ and char tilt history = ‘N’.

3. Start of Data Collection from all the sensors.

4. The ADC channel-11 of the microcontroller takes analog input from the temperature sensor and starts the conversion.

5. End of the A/D conversion and the 10-bit binary output is stored in the variable called ‘temperature’.

6. The ADC channel-10 of the microcontroller takes analog input from the pressure sensor and starts the conversion.

7. End of A/D conversion and the 10-bit binary output is stored in the variable called ‘pressure’.

8. The analog output from the tilt sensor is given as one of the inputs to the Comp2 of the microcontroller. The output of the Comp2 is analyzed.
Start

Start

Initialize the variables:
Temperature = 0,
pressure = 0, Tilt = N, Thist = N, Trigger = 0

ADC Channel 11 of the MCU unit reads data from the Temperature Sensor

ADC Channel 10 of the MCU unit reads data from the Pressure Sensor

The Comparator-2 of the MCU gets data from the Tilt Sensor

This implies that the tag is not tilted, Hence Tilt = N

O/P of Comp-2 = 1

This implies that the tag is tilted, Hence Tilt = Y

Tilt-history = Y

If trigger = 0

Y

N

O/P of Comp-1 = 1

The data tag has been interrogated, Hence trigger = 1.

Y

N

DATA COLLECTION

DATA PROCESSING AND TRANSMISSION

Digital O/P from ADC channel of Temperature Sensor is converted to corresponding ASCII code

Digital O/P from ADC channel of Pressure Sensor is converted to corresponding ASCII code

All the data is transmitted in the Manchester code

Pre-defined Delay (before the transmission starts all over again)

End

The data tag has been interrogated. Hence trigger = 1.

If trigger = 0

Y

N

Figure 20: Flow chart describing the flow of the algorithm implemented in the MCU
9. If the output is 1, it implies that the tilt switch (and hence the data tag) is in the tilted position. So the char variable ‘tilt’ is updated to a ‘Y’ implying a YES. Also the char variable ‘thist’ which indicates tilt-history is updated to a ‘Y’. Go to Step 11.

10. If the output is 0, it implies that the tilt switch (and hence the data tag) is not in the tilted position. So the char variable ‘tilt’ is updated to an ‘N’. Go to Step 11.

11. Check the value of the variable ‘trigger’.

12. If it has a value of 0, it implies that it hasn’t been triggered yet. Hence check the current status of the triggering module. Go to Step 14.

13. If the value of the ‘trigger’ is 1, it implies that it has been triggered already and hence the data transmission should proceed. Hence go to step 17.

14. The analog output from the triggering module is given as one of the inputs to the Comp1 of the microcontroller. The output of the Comp1 is analyzed.

15. If the output is 1, the variable ‘trigger’ is set to a value - 1. It simply implies that the laser is shined upon the data tag indicating that it has been interrogated. Hence the data tag should start the transmission and hence activates the Data Transmission Unit. Go to Step 16.

16. If the output is 0, the variable ‘trigger’ is set to a value – 0. This implies that the tag has not been interrogated yet. This implies that the Data Transmission Unit in not activated. Hence the data tag simply again starts collecting data from each of the sensors dynamically. Go to Step 2.

17. Before the final data transmission starts, it has to be further processed. This is because the binary data stored in the variables ‘temperature’ and ‘pressure’ is crude data. This data
has to be converted to ASCII code so that it is easily read at the receiver end (optical tag reader) ASCII conversion starts.

18. The variables ‘temperature’ and ‘pressure’ which are integer values are converted to corresponding ASCII codes.

19. All the data is now ready available for transmission. Manchester encoding is used for data transmission (and its significance is explained in the Chapter 3)

20. After all the data has been transmitted, there is a delay and then the transmission resumes. Go to Step 3.


Thus it can be seen from the algorithm that the data transmission begins only after it has been triggered by the microcontroller.
3 Design of the Data Transmission Unit

The Data Transmission Unit, as the name indicates refers to the unit that is responsible for the transmission of data in an OPID technique. This chapter deals in detail about this data transmission unit, its components, their functionality and the encoding technique employed for transmission. For an optical transmission to take place a light source at the transmitter end is needed. But employing a light/laser source at the transmitter end proves to be a very costly and clumsy affair. An alternative approach would be to modulate the incident light back to the receiver/reader with respect to the data that has to be transmitted. Here the data transmission unit needs to have a modulating as well as reflecting mechanism to achieve this goal. The same is achieved in an active optical data tag by means of a combined use of a retro reflector and an optical shutter. The basic setup of the data transmission unit is shown in Figure 21. Therefore it can be said that the Data Transmission Unit constitutes the following

- Retro reflector
- An Optical Shutter

In the sections to follow, there is a detailed explanation of the encoding scheme employed in an active optical data tag and the components used in the Data Transmission Unit.

![Basic setup of the Data Transmission Unit of an active optical data tag](image)

Figure 21: Basic setup of the Data Transmission Unit of an active optical data tag
3.1 Encoding technique

Selection of a data encoding technique is very important for any communication link. There are a wide variety of signal encoding techniques available for different combinations of input and output digital and analog signals. The encoding techniques can be basically classified into the following four types [25]

- Digital data, digital signal
- Analog data, digital signal
- Digital data, analog signal
- Analog data, analog signal

In an active optical data tag, the data that has to be transmitted is digital and has to be encoded into digital signal so that it can read by the optical tag reader. Hence it falls into the first class of the divisions identified above. Different encoding schemes available for use in the digital systems to represent the binary values ‘0’ and ‘1’ are given below [25].

- Nonreturn to Zero-Level (NRZ-L)
- Nonreturn to Zero Inverted (NRZI)
- Bipolar -AMI
- Pseudo ternary
- Manchester
- Differential Manchester
- B8ZS
- HDB3

Of all the above techniques, Manchester encoding has been selected for use in this application. Justification for this design decision is presented in the next section.
3.1.1 Manchester Encoding

Manchester encoding is a type of encoding in which encoding of each data bit has a transition from either a low level to a high level or a high level to a low level. This technique is simply summarized in the following points [25].

- A digital zero (0) is represented by a transition from high level to low level (i.e. \( 0 \rightarrow 1 \))
- A digital one (1) is represented by a transition from low level to high level (i.e. \( 1 \rightarrow 0 \))
- The transition occurs in the middle of each bit period.
- The transition itself serves as both the clock and the data.

This can be clearly seen in Figure 22. The Manchester encoded data of the binary information relative to the tag can be simply generated by the use of built-in functions of the Manchester library of mikroC shown below.

- **Man_Send**: This function is used to convert the binary data into Manchester encoded data and send it to one of the output ports of the microcontroller.

- **Man_Receive**: This function is used at the receiver end by the optical tag reader to decode the incoming Manchester encoded data sent by the active optical data tag.

The merits and demerits of this encoding scheme are briefed in the next section.

![Figure 22: Manchester Encoding Scheme [25]](image-url)
3.1.1.1 Advantages

The primary reasons for selecting the Manchester encoding scheme are as follows [25]

- **Self Clocking Feature:** The mid-bit transition of each bit in this encoding scheme helps in synchronization between the transmitter and the receiver. Hence it can be said to provide a self clocking feature.

- **Error detection:** This scheme has an additional capability of error detection because any binary level (‘0’ or a ‘1’) has a transition. An absence of transition cannot be decoded and hence the error can be detected.

- **No DC component:** This scheme doesn’t require a DC component for proper decoding at the receiver unlike the schemes such as NRZ which requires a true DC response for proper decoding.

- **In-built functions in mikroC:** This encoding scheme is not hard to implement as there are in-built functions in mikroC which help in generating the Manchester encoded data for any binary input as well as decoding the encoded data.

3.1.1.2 Disadvantages

The main disadvantages that crop up along with the advantages are mentioned below [25].

- **Transition at every bit:** The main feature of this encoding scheme is that there is a transition for every bit. This forms a disadvantage because this increases the power consumption with respect to the data transmission unit. The optical shutter that helps in transmission by modulating the data has to switch from dark to light mode or vice-versa for every bit that has to be sent over to the reader thus increasing the power consumption.

- **High bandwidth:** The Manchester encoding scheme requires double the band width when compared to a simple NRZ encoding scheme. It requires a modulation rate twice
that of NRZ to transmit the same amount of information. This becomes a disadvantage when there is a constraint on the bandwidth in a communication channel.

### 3.2 Retro Reflector

The retro reflector is a device that is used to reflect the incident light back in the same direction to the source with minimum scattering. This property can be achieved by means of corner cube that is formed by three mutually perpendicular mirrors that help in reflecting the light back to the source. The corner cube retro reflector works on the principle of total internal reflection [26]. The reflected power from the retro reflector depends on a variety of factors such as size and area of the retro reflecting surface, efficiency of the retro reflector used, and the distance between the source and the target [27]. Since the incident light gets reflected back to the reader, it has to travel double the distance between the source and the target and still be read effectively by the reader. This implies that the efficiency of the retro reflector is a major issue for the proper operation of the OPID technique.

Two types of retro reflectors were considered for the application [12].

- Reflexite Prismatic Sheeting retro reflector
- IMOS Microcube retro reflector

Reflexite Prismatic sheeting offers an easy, cost effective solution catering to the needs of different sizes and shapes. The material works effectively over a wide range of infrared and visible wavelengths [27]. The micro cube retro reflectors by IMOS retro reflect laser light in an accurate fashion. These reflectors consist of thousands of square micro mirrors thereby reflecting approximately 99% of the light [28].
The reflected power for the above two types of retro reflectors for a wide range of angles of incidence is shown by means of a graph in Figure 23 [12]. The following observations can be made from the graph.

- The reflected power from the retro reflector is at the peak when the angle of incidence is $0^0$.
- As the angle of incidence increases (in either direction), the reflected power decreases.
- The reflected power of the IMOS Microcube retro reflector is much higher when compared to that of Reflexite Prismatic retro reflector when the angle of incidence is centered on $0^0$.
- As the angle of incidence increases to around $35^0$ in either direction, the reflected power of the Reflexite Prismatic retro reflector is better than that of IMOS Microcube retro reflector.
- This implies that the performance of the IMOS Microcube is better for lower angles of incidence than that of Reflexite Prismatic retro reflector and vice versa for higher angles of incidence.

![Graph showing reflected power from the two types of retroreflectors](image)

Figure 23: Graph showing reflected power from the two types of retroreflectors [9]
From the observations made, a very obvious choice of IMOS Microcube retro reflector over the other retro reflector has been made. This is because better performance centered on $0^0$ angle of incidence is required than the performance at higher angles of incidence.

### 3.3 Optical shutter

Due to the absence of a light source in the optical data tag, there is a need for a modulating device that helps in modulating the incoming light beam. This is accomplished by means of an optical shutter. Hence an optical shutter forms the crux of the Data Transmission Unit for the active optical data tag because it helps in the transmission of the data to the reader by means of modulation. An FOS-ECS-PATM – which stands for Fast Optical Shutter, Electrically Commanded Surface, and Planar Alignment is used in the active optical data tag.

#### 3.3.1 Modes of Operation

An optical shutter generally operates in one of the following two modes of operation [29].

- **Normally white mode:** In this mode, optical shutter is in LIGHT state when no voltage is applied across it.
- **Normally black mode:** In this mode, optical shutter is in DARK state when no voltage is applied across it.

The FOS-ECS-TM shutter that is used in this application is operated in the *normally-white* mode.

Any optical shutter has the following two optical states [29].

a) Transparent state / LIGHT state (homogeneous texture)

b) Opaque state / DARK state (homeotropic texture)

Since the shutter is operated in the *normally-white* mode, the above mentioned transparent/LIGHT state is obtained when no voltage is applied to the optical shutter (voltage – OFF state) and opaque/DARK state is obtained when a voltage is applied to the cell(voltage – ON state).
The following important points have to be considered while operating the shutter in DARK state [29].

- The voltage that is required to obtain DARK state can range between 5.0V and 20V (i.e. 5.0 < V < 20).
- No long term DC component in driving voltage is recommended for proper operation of the shutter. Hence a square wave voltage with frequency ranging between 10 and 1000Hz (typical) is generally preferred to operate it in the DARK mode (i.e. 10 < f < 1000Hz).

The main features of this optical shutter are summarized below [29].

- **Dimensions and thickness**: It is available at a standard size of 1x1” and has a thickness of about 2.20 mm.
- **Ultra-fast switching speed**: This optical shutter provides ultra-fast switching speed with an optical switching frequency > 50Hz.

![Response time of the FOS-ECS-PA optical shutter](image)
• **Fast Activation switching speed:** The activation switching speed is defined as the time taken by the shutter to switch from LIGHT (OFF) to DARK (ON) state and is better explained in Figure 24. This shutter has an activation switching speed of $<0.1 \text{ms}$ at room temperature with applied voltage of $\pm 20 \text{V}$.

• **Fast Relaxation switching speed:** The relaxation switching speed is defined as the time taken by the shutter to switch from DARK (ON) to LIGHT (OFF) state and is better explained in Figure 24. This shutter has a relaxation switching speed of $< 4 \text{ms}$ at room temperature.

• **High Contrast Ratio:** Contrast ratio (CR) is defined as follows.

\[
CR = \frac{\text{Transmission through shutter in CLEAR state}}{\text{Transmission through shutter in DARK state}}
\]

This optical shutter offers a high contrast ratio $> 1:100$ with a typical ratio being $1:265$.

• **Maximum Transmittance:** The optical shutter has a maximum light-state transmittance, $T > 35\%$ at a wavelength of $550\text{nm}$ (non polarized incident light) in transparent (OFF) state and $T > 85\%$ for an incident light that is polarized in the same orientation as that of the entrance polarizer of the optical shutter. In the DARK (ON) state, It has a transmittance, $T < 0.5\%$ at the same wavelength of $550\text{nm}$.

### 3.3.2 Technical characteristics

The transmittance characteristics of the FOS-ECS-PA optical shutter optically switching at a frequency of 25Hz and 50 Hz is shown in the part 1(b) and 2(b) of Figure 25 below. The figure shows that the shutter can be very well switched a frequency of 50Hz. To protect the shutter from the impurity- ion migration occurring within the liquid crystal material, it is generally recommended by the manufacturers that the optical shutter be subjected to RMS voltages. This is best achieved by means of square-wave driving voltages with peak-to-peak voltage of 20V.
Figure 25: Transmittance characteristics of FOS-EPA-PM optical shutter at an optical switching frequency of 25Hz and 50Hz [29]
Figure 26: Bi-polar driving voltages of various frequencies applied to the optical shutter [29]
The shutter operates even for smaller voltages of 5V, but has better activation and relaxation switching speeds (which are quite essential to operate the shutter at higher frequencies) at higher voltages. Hence there is a need of a driving circuit for the optical shutter that helps in generating a 20V p-p square voltage. For an optical-switching frequency of 25Hz, a variety of frequencies of driving voltages (square wave) that can be applied to the shutter are shown in Figure 26 with part (a) having a square-wave frequency of 50Hz, part(b) having a square-wave frequency of 100Hz, and part (c) having a square wave frequency of 200Hz.

The data transmission rate achieved in an active optical data tag is 50bits/sec while 50bits correspond to the digital data that has to be transmitted and not the Manchester encoded data.

3.3.3 Driving Circuit for the optical shutter

The driving circuit for the optical shutter needs to generate a 20V square wave that modulates in accordance with the data as shown in Figure 26. This is accomplished by constructing a circuit consisting of MOSFETs which turn ON and OFF (appropriately according to their gate voltages) and thus apply the required voltage to the optical shutter. The circuit is shown in Figure 27[12]. This circuit consists of three N-channel enhancement mode MOSFETs – M1, M2 and M3. The

![Figure 27: Driving circuit for the FOS-EPA-PM optical shutter [12]](image)
MOSFETs M1 and M3 collectively accomplish the goal of applying a positive and a negative voltage alternatively when the optical shutter has to be operated in the DARK state. The gate of M1 is driven by a voltage generated by the PIC microcontroller. This voltage should be generated in such a fashion that during the time when the shutter has to be in DARK state, a square voltage with 20V p-p has to be applied to the shutter. This is explained in detail in the section 3.2.4 below.

The Manchester encoded data that has to be transmitted to the tag reader is applied to the gate of M3. The digital data that has to be transmitted should be inverted before it is sent to the driving circuit of the optical shutter (of the Data Transmission Unit). This is because

a) If a ‘0’ has to be transmitted, the shutter has to be in the DARK / opaque mode so that the incident light is not reflected back from the retro reflector and hence no light is received by the tag reader and it reads a ‘0’. For the shutter to be in DARK mode, a square voltage should be applied to the shutter. This implies a positive or a negative voltage of 20V be applied across the shutter

b) If a ‘1’ has to be transmitted, the shutter has to be in the transparent / LIGHT mode so that the incident light gets reflected back from the retro reflector to the tag reader and hence it reads a ‘1’. For the shutter to be in the LIGHT mode, no voltage / zero voltage has to be applied to the shutter.

The operation of the circuit is clearly explained below:

- When a positive voltage, ‘1’, is applied across the gate of M3, the MOSFET switch turns ON and the voltage across the LCD shutter is determined by the voltage applied across the gate of M1. If a ‘1’ is applied to the gate of M1, the MOSFET switch turns ON grounding the positive terminal of the optical shutter and the negative terminal is pulled
to 20V, implying that a negative voltage of 20V is applied to the shutter. Similarly, when a ‘0’ is applied to the gate of M1, M2 MOSFET switch turns ON grounding the negative terminal of the optical shutter and the positive terminal is pulled to 20V, implying that a positive voltage of 20V is applied to the shutter. Thus a square wave voltage is applied across the shutter when it is operated in the opaque / DARK state.

- When a zero voltage, ‘0’, is applied across the gate of M3, both the terminals of the optical shutter are pulled high and hence a zero voltage is applied across its terminals. Thus the shutter is operated in the transparent / LIGHT state.

Now the need arises for a circuitry that generates this 20V. This is generated by using a micro-power step-up DC-DC converter, LM2704 [30], available in a 5-lead SOT-23 package. The circuit considerations of LM2704 used in the active optical data tag is shown in Figure 28. The input to the circuit $V_{IN}$ is given from the onboard power supply of the active optical data tag and the output $V_{OUT}$ is diverted to the circuit that drives the optical shutter as shown in Figure 27.

### 3.3.4 Assembly Level Coding for Data Transmission Unit

The program implemented in the microcontroller of an active optical data tag has been partially written in a high level language, C, and partially in the assembly level language. The coding in C has been done using the software mikroC which is an advanced C compiler for PIC microcontrollers. The mikroC has variety of libraries available that facilitate development of

![Figure 28: Circuit considerations for LM2704 in an active optical data tag [30]](image)
various applications. The libraries of mikroC that are used in the program developed for an active optical data tag are

- **Manchester library:** This library has functions such as Man_Send() that are used to convert the binary data to Manchester encoded data and transmit the data to an output port.

- **ADC library:** This library has functions such as Adc_Read() that helps in activating an ADC channel of the MCU and obtaining the analog data from an input port.

- **PWM library:** This library has a variety of functions that are used to initiate the PWM module of a PIC and to generate square wave forms of required duty cycle.

- **LCD library:** This library has a variety of functions that are used for operating the LCD display. This has been used during the testing phase of active optical data tag design.

It has been mentioned in the section above that the input voltage to the gate M1 of the driving circuitry of the optical shutter comes from the PIC microcontroller. This voltage can be as simple as a square wave generated from the PWM module of the PIC. But generating a square wave from the PIC which drives the gate of M1 gives rise to other problems which inhibit its usage in the data tag. Problems that occur due to the PWM module include the generation of unwanted spikes at the receiver end. This is because the optical shutter has a zero voltage across its terminals for a short duration of time during the switching which makes it go into LIGHT state. Simply put, when the optical shutter has to operate in the DARK state, it alternatively switches between the DARK and LIGHT states instead giving rise to spikes at the receiver end.

Alternatively, this problem can be solved by varying the voltage across the gate of M1 with respect to the encoded data being sent to the gate of M3. This implies that when the first ‘1’ arrives at the gate M3, a ‘1’ is applied to the gate M1 and when the next ‘1’ arrives at gate M3, a
‘0’ is applied to the gate M1. Thus the voltage across the gate of M1 is alternatively switched with respect to the data applied across M3. To accomplish this task, changes have to be done at the assembly code level of the program. The algorithm implemented to achieve this is explained by means of a flowchart shown in Figure 29.

As can be seen from the flow chart, variables named flag and flag1 have been employed to accomplish the task. It can be seen clearly from the figure that Manchester encoding is employed for the data transmission. This implies that if a ‘1’ has to be transmitted a rising transition from 0 to 1 is generated and if a ‘0’ has to be transmitted a falling transition from 1 to 0 is generated. While these are generated the variables are changed correspondingly so as to produce a voltage (driving M1) which changes with respect to the encoded data (applied to M1).

This algorithm sees to it that the optical shutter is not subjected to a DC component for a long period of time thus ensuring its proper working without damage.
Initialization of variables:
int flag = 0;
char flag1 = 0;

Digital Data to be transmitted

If data = 0
Transmit 0
Delay of 1ms
if flag = 1
PortC.F5 = 0
else
flag1 = 1

Delay of 1ms

If flag1 = 1
If flag = 0
Transmit 0
flag1 = 0
Delay of 1ms

else
if flag = 1
Transmit 1
flag = flag (xor) 1
else
flag1 = 0

Transmit 1
flag = flag (xor) 1

if flag = 1
PortC.F5 = 0
else
PortC.F5 = 1

Delay of 1ms

Figure 29: Flowchart of the algorithm implemented for proper functioning of the optical shutter
3.4 On-board Power Supply Module

The main difference between an active optical data tag and a passive optical data tag lies with the amount of work each tag accomplishes. The extra work done by the active optical data tag can be justified by the presence of an on-board power supply in an active optical data tag. The active optical data tag has several electrical and integrated components all of which require a constant 5V supply for proper operation. Hence the on-board power supply needs to generate this 5V that caters the needs of all the components embedded on the tag.

The active optical data tag on-board power supply module has the following components.

- 9V Battery
- LM7805 – Voltage Regulator
- Single Pole Single Throw (SPST) Switch

All the power requirements of the active optical data tag are furnished by using a 9V alkaline battery. But this battery produces a constant voltage of 9V rather than the required 5V. Hence there is a need of a voltage regulator. LM7805 of the LM78XX series is a three terminal positive voltage regulator available in TO-220 package with a high operating temperature ranging between 0\(^\circ\) and 125\(^\circ\) [31]. The pin configuration of the LM7805 for use as a simple 9V-5V voltage regulator is shown in Figure 30.

![Figure 30: Circuit connections of a LM78XX series voltage regulator [31]](image)
Figure 31: The on-board power supply module in an active optical data tag [31]

Also, to facilitate the power savings, a switch is employed which provides the connection between the 9V power supply and the LM7805 regulator, only when turned on. A simple SPST switch can serve the purpose. The circuit considerations of the on-board power supply module as they appear in an active optical data tag are shown in Figure 31.
4 Printed Circuit Board Design

A PCB, or printed circuit board, is a board made of one or more layers of insulating materials with electrical conductors and is used to connect electronic components and provide them with mechanical support. Design of a PCB is comparatively easy and hence can be considered for developing a prototype for a huge circuit because it is rugged, highly reliable and inexpensive when manufactured in high volumes. Therefore developing a printed circuit board for an active optical data tag has been considered as a part of this thesis.

4.1 PCB layout

This section discusses in detail about the components used in an active optical data tag and their appearance in the PCB layout.

Figure 32: Overall Block Diagram of an active optical data tag
The final block diagram of an active optical data tag is shown in Figure 32. In the figure the data transmission unit and the on-board power supply module are shown in the dotted lines. The rest of the figure refers to the data processing unit. When the triggering module triggers the data processing module with the trigger signal, the data processing unit begins to transmit the data to the data transmission unit. The data transmission unit which consists of the combination of optical shutter and retro reflector (not shown in Figure 32) receives the data and modulates the incident light with respect to the incoming data from the data processing unit and reflects the light back to the tag reader. The tag reader receives the modulated light and decodes the information. Thus the OPID technique which helps in automatic identification and capture (AIDC) of objects is successfully accomplished.

Figure 33: PCB layout of an active optical data tag
ExpressPCB is a free PCB software used to design PCBs for complex circuits in a simple and easy fashion. This software has been used in the project to develop PCBs for an active optical data tag. A snapshot of the final layout of the PCB developed for an active optical data tag is shown in Figure 33. The properties of this PCB design are summarized below.

- **Small Size:** The compact size of the PCB layout is achieved by placing the components very close to each other and making it dense. The dimensions of the PCB designed are 3.75” x 2.65”.

- **Two Layered design:** A two layered design was chosen over an easy-to-design 4-layered approach because of the low cost of the former approach when compared to the latter. The following two layers have been used to design the PCB
  
  a) **Top Copper Layer:** This is shown in the RED color in Figure 33.
  
  b) **Bottom Copper Layer:** This is shown in the GREEN color in Figure 33.

- **Power supply and Ground rails:** The power supply rail is routed in the top copper layer and runs across half of the boundary of the PCB layout whereas the ground rail is routed in the bottom copper layer and runs across the other half of the boundary. This configuration is followed because it helps in easy routing of various signals and components to these rails. Also, wide traces of width 0.05” are used for power and ground rails as they carry significant current that the ordinary signals.

A detailed description of the components for use in the PCB layout is given below.

- **Integrated Circuits:** A variety of integrated circuits have been used in the active optical data tag and their description is given below.

a) **TMP01:** This is a temperature sensor from Analog Devices and is available in an 8-pin DIP package.
b) **MPX4250A**: This is a pressure sensor from Freescale Semiconductors and is available in a 6-pin SIP package.

c) **DSBA-1P**: This is a tilt sensor from NKK manufacturers and is available in a 4 pin package.

d) **PIC16F690**: This is a microcontroller from Microchip available in a 20-pin DIP package.

e) **LTC1793**: This is an operational amplifier from Linear Technology used as trans-impedance amplifier and is available in an 8-pin DIP package.

f) **LTC1144**: This is a voltage converter from Linear Technology used to generate negative voltages and is available in an 8-pin DIP package.

g) **LM2704**: This is a voltage DC/DC converter from National Semiconductor used to generate a 20V from an input 5V and is available in a SOT-23 package.

h) **SDM03MT40**: This is a Schottky diode from Diode Inc, used in the LCD driving circuitry as part of generation of 20V and is available in a SOT-26 package.

i) **LM7805**: This is a positive voltage regulator from Fairchild Semiconductor used for regulating the power supply and is available in a TO-220 package.

- **Battery source**: A 9V alkaline battery along with the battery clip is used as the source of power supply for the various components on an active optical data tag.

- **Transistors**: Three n-channel enhancement mode MOS Field Effect Transistors- M1, M2 and M3- are used in the data transmission unit as part of the LCD driving circuitry. These transistors are available in a TO-92 package.

- **Resistors**: A total of 9 resistors - R1, R2, R3, R4, R5, R6, R7, R8 and R9 - are used in the design of the active optical data tag. The resistors R1 and R2 are used in the 20V
generation circuitry. The resistors R3 and R4 are used as part of the LCD driving circuitry while R5 is used as part of the triggering module. The resistors R6 and R7 are used along with the tilt sensor while R8 and R9 are used in conjunction with the temperature and pressure sensor respectively.

- **Capacitors:** A total of 7 capacitors- C1, C2, C3, C4, C5, C6 and C7- are used in the design of the active optical data tag. The capacitors C1 and C2 are used as a part of 20V generation circuitry. The capacitors C3, C4 and C5 are used as part of the triggering module while the capacitors C6 and C7 are used in conjunction with the voltage regulator LM7805 as part of the on-board power supply module.

- **Inductors:** Only one inductor, L1 is used as part of 20V generation circuitry.

- **Photo diode:** A Si-Photodiode of S2386 series from Hamamatsu is used as part of triggering module.

- **Optical Shutter:** A FOS-ECS-PA optical shutter from the LC-TEC display manufacturers is used to modulate the incident laser beam with respect to the Manchester encoded data.

- **Switch:** A simple SPST switch is used for establishing the contact between the battery and the voltage regulator, LM7805 when in ON position thus helpful in power saving.
Figure 34: Printed Circuit Board Assembly of an active optical data tag

Figure 35: Project box encompassing the printed circuit board assembly in of an active optical data tag
A PCB was designed with respect to the block diagram of the active optical data tag shown in Figure 32 and populated with appropriate electrical and electronic components. A picture of the final printed circuit board assembly, which is nothing but a populated PCB, of an active optical data tag is shown in Figure 34.

From what has been discussed so far, the PCB doesn’t accommodate the retro reflector of the data transmission unit. This retro reflector has to be fixed behind the optical shutter for proper reflection. Also, for easy interrogation of the data tag, a small hole is drilled in the centre of the retro reflector and the photo diode of the triggering module is placed behind this hole. The entire setup is placed in a project box and a picture showing this setup is shown in Figure 35. From the figure it can be seen that the combination of optical shutter and the retro reflector is fixed to the project box and the photo diode is placed right behind the hole drilled on the retro-reflector.
5 Results and Future Work

All the previous chapters have discussed in detail about the design and implementation of an active optical data tag. This chapter focuses on the results obtained during the testing of various components of the design and testing of the system as a whole. It also throws light on the future work that can be carried out in this project.

The testing of the module designed can be divided into two phases.

- Component Testing
- System Testing

A detailed analysis of the results obtained during the testing is discussed in the sections below.

5.1 Component Testing

This section deals with the results obtained during the testing of individual components/modules.

The results of the Information/data source module of the Data processing Unit which consists of Temperature, Pressure and tilt sensor and its subsequent analysis is presented below. This is followed by the results of the optical shutter driving circuitry, data transmission unit, and other modules.

5.1.1 Temperature Sensor

The output of the temperature sensor, TMP01, used in the active optical data tag is an analog voltage which is given as input to the Analog-to-Digital Converter (ADC) Channel of the PIC microcontroller. The ADC channel of the microcontroller generates a 10-bit binary output thus converting the analog output to digital output. Two different outputs of the temperature sensor are discussed below.
Output Case #1

Figure 36 shows the Manchester encoded data of the binary output of the temperature as observed on a CRO at room temperature.

**Analysis:** The Manchester encoding function `Man_Send` which has the prototype: `void Man_Send(unsigned short data)` converts one byte of data into Manchester encoded data and also appends a “110” in front of data.

The 10-bit binary output from the ADC channel is stored in two bytes –lower byte and the higher byte. The higher byte has the first two bits (starting with MSB) and the lower byte has the remaining eight bits (including the LSB). The main features of the result shown in Figure 36 are summarized below.

- It is the output of the temperature sensor at room temperature.
- It shows the Manchester encoded lower byte followed by the Manchester encoded higher byte, thus containing the 10-bit binary output data of the ADC channel.
- It can be seen that lower byte = 00111000 and higher byte = 00000001, indicating that the 10-bit binary output produced is 0100111000.
• Converting into decimal value, Output = 312 indicating the 312\textsuperscript{th} division.

To evaluate the correct temperature in Kelvin scale, information regarding the accuracy of the ADC channel and the accuracy of the temperature sensor need to be known. Their evaluation is shown below.

a) Accuracy of the ADC channel:

• Since the ADC channel produces a 10-bit binary output, the total number of distinct values that it can generate = 2\textsuperscript{10} = 1024.
• The reference voltage for the ADC channel of the PIC is 5V/5000mV.
• Hence the accuracy of the ADC channel is given by 5000/1024 = 4.88mV/division.
• A higher accuracy can be obtained by decreasing the reference voltage.

b) Accuracy of the temperature sensor:

The minimum and the maximum voltages as generated by the temperature sensor are 1.09V and 1.99V corresponding to the temperatures of -55\textdegree C / 218K and 125\textdegree C / 398K respectively [13]. This implies that the accuracy of the temperature sensor is 5mV/K.

Having known the accuracy of the ADC channel and the temperature sensor, the evaluation of the correct temperature is easy and is shown below.

• Since the 10-bit binary output corresponds to 312\textsuperscript{th} division, it implies that the analog voltage produced by the temperature sensor = 312 x 4.88 = 1522.54 \sim 1523mV.
• Since the accuracy of the temperature sensor = 5mV/K, the 1523mV corresponds to \((1523mV) / (5mV/K) = 306.6K = (306.6 -273) ^\circ C = 31.6 ^\circ C.\)
• Hence the temperature = 31.6\textdegree C = 306.6K

This implies that the value of the temperature can be found simply by using the equation below.
Temperature = \frac{x+4.88}{5} \quad \text{where} \quad x \text{ denotes the decimal interpretation of the 10-bit binary output produced by the ADC channel.}

Output Case #2

Figure 37 shows the Manchester encoded data of the binary output of the temperature when a hot hair dryer is blown over the temperature sensor for some period of time.

Analysis: Figure 37 represents the temperature in the Manchester encoded format as shown on a CRO when hot air is blown over the temperature sensor. The main features of the result shown in Figure 37 are summarized below.

- It is the output of the temperature sensor when hot air is blew from the hair dryer onto the temperature sensor.
- It shows the Manchester encoded lower byte followed by the Manchester encoded higher byte, thus containing the 10-bit binary output data of the ADC channel.
- It can be seen that lower byte = 01011010 and higher byte = 00000001, indicating that the 10-bit binary output produced is 0101011010.
• Converting into decimal value, Output = 346 indicating the 346th division.

Having known the accuracy of the ADC channel and the temperature value, the evaluation of the correct temperature is easy and is shown below.

• Since the 10-bit binary output corresponds to 346th division, it implies that the analog voltage produced by the temperature sensor = 346 x 4.88 = 1688.48 ~ 1688mV.

• Since the accuracy of the temperature sensor = 5mV/K, the 1688mV corresponds to (1688mV) / (5mV/K) = 337.6K = (337.6 -273) °C = 64.6°C.

• Hence the temperature = 64.6°C = 337.6K

Thus it can be seen that the temperature sensor detects the change in temperature and produces a higher analog voltage that is converted into corresponding digital output.

5.1.2 Pressure Sensor

The pressure sensor, MPX4250A used in an active optical data tag is also an analog sensor producing voltage proportional to the absolute pressure. This analog voltage is given as input to the ADC channel of the microcontroller which converts analog data to digital data by generating
a 10-bit binary output. Figure 38 shows the Manchester encoded data of the binary output produced from the ADC channel connected to the pressure sensor as observed on a CRO. The main features of the result shown in Figure 38 are summarized below.

- It is the output of the pressure sensor at room temperature when no pressure is applied on it.
- It shows the Manchester encoded lower byte followed by the Manchester encoded higher byte, thus containing the 10-bit binary output data of the ADC channel.
- It can be seen that lower byte = 01101111 and higher byte = 00000001, indicating that the 10-bit binary output produced is 01001101111.
- Converting into decimal value, Output = 367 indicating the 367th division.

To evaluate the correct pressure in KiloPascal (KPa) scale, information regarding the accuracy of the ADC channel and the accuracy of the pressure sensor need to be known. Their evaluation is shown below.

**a) Accuracy of the ADC channel:**

- Since the ADC channel produces a 10-bit binary output, the total number of distinct values that it can generate = \(2^{10} = 1024\).
- The reference voltage for the ADC channel of the PIC is 5V/5000mV.
- Hence the accuracy of the ADC channel is given by 5000/1024 = **4.88mV/division**.
- A higher accuracy can be obtained by decreasing the reference voltage.

**b) Accuracy of the pressure sensor:**

The minimum and the maximum voltages as generated by the pressure sensor are 0.204V and 4.896V corresponding to the temperatures of 20KPa and 250KPa respectively [16]. This implies that the accuracy of the temperature sensor is given by
Accuracy = \frac{(4.896 - 0.204)}{(250 - 20)} = \frac{4.692}{230} = 0.0204 \text{ V/KPa} = 20.4 \text{ mV/KPa}.

Hence the accuracy of the pressure sensor = 20.4 \text{ mV / KPa}

Having known the accuracy of the ADC channel and the pressure sensor, the evaluation of the correct pressure is easy and is shown below.

- Since the 10-bit binary output corresponds to 367th division, it implies that the analog voltage produced by the temperature sensor = 367 x 4.88 = 1790.96 mV.
- Since the accuracy of the temperature sensor = 20.4 mV/K, the 1790.96 mV corresponds to \( \frac{1790.96 \text{ mV}}{20.4 \text{ mV/KPa}} = 87.79 \text{ KPa} \).
- Hence the pressure = 87.79KPa

This implies that the value of the pressure can be found simply by using the equation below.

\[ \text{Pressure} = \frac{x \times 4.88}{20.4} \]  where \( x \) denotes the decimal interpretation of the 10-bit binary output produced by the ADC channel.

5.1.3 Tilt Sensor

The tilt sensor, DSBA1P from the NKK manufacturers, used in an active optical data tag produces an analog voltage too like the other two sensors used in the tag. But since the analog voltage just indicates whether the tilt switch has been tilted or not, and provides no additional information a simple voltage comparator can serve the purpose by converting analog voltage to digital voltage. A voltage comparator has two inputs, \( V_{in+} \) and \( V_{in-} \) and produces an output, \( V_{out} \), following the equation below:

\[ V_{out} = 1; \text{ when } V_{in+} < V_{in-} \\
\quad = 0; \text{ when } V_{in+} > V_{in-} \]

Figure 39 shows the output of the comparator connected to the tilt switch when the tilt switch is tilted to an angle greater than 30°.
5.1.4 Step up voltage generation for the optical shutter

The Optical Shutter Driving Circuitry is needed for proper functioning of the optical shutter. This circuit needs a higher voltage of 20V and hence step up voltage generation from an input of 5V to an output of 20V is accomplished using the step up DC/DC converter, LM2704. Figure 40 justifies the working of the LCD driving circuitry.
Analysis: The figure above shows the output as observed on a CRO with its channel two and channel one connected to the input and output of the step up voltage generation circuitry respectively. It can be observed from the figure that the voltage shown in the channel one of the CRO is 5V and the voltage shown in the channel two is approximately around 20V. This proves the correct working of the optical shutter driving circuitry that involves a step-up voltage generation.

5.1.5 Driving circuitry of the optical shutter

The driving circuitry of the optical shutter sees to it that there is no long term dc component applied to the optical shutter. First, the PWM module of the PIC has been considered for generation of the square wave to do this function. Because of the occurrence of the spikes at the output of the receiver end a second technique has been taken into consideration. In this technique, the problem is solved by generating a voltage that varies with respect to the encoded data being sent to the optical shutter.
Figure 41: Output of the PWM module of the PIC

Figure 42: Occurrence of the spikes at the output on the reader end

Figure 43: A neat signal without any spikes at the output on the reader end

**Analysis:** Figure 41 shows the output of the PWM wave as observed on a CRO. The PWM module here produces a square wave with a frequency of 1 KHz and a duty cycle of 50%. This proves the correct functioning of the PWM module of the microcontroller. Figure 42 and Figure 43 show the output as observed on a CRO with its channel one connected to the output of the
PIC that drives the shutter and its channel two connected to the output of the comparator as observed at the reader’s end. The output at the tag reader end, when using the PWM module of the PIC to drive the optical shutter, is shown in Figure 42. The spikes that are produced can be clearly observed from the figure. The spikes can be attributed to the following. The optical shutter has a zero voltage across its terminals for a short duration of time during the switching which makes it go into LIGHT state. Simply put, when the optical shutter has to operate in the DARK state, it alternatively switches between the DARK and LIGHT states instead giving rise to spikes at the receiver end. These unwanted spikes can be taken care of by alternatively modulating the voltage across one of the transistors of the driving circuitry with respect to the encoded data sent from the PIC. The output at the reader end, when using this second technique, is shown in Figure 43. It can be clearly seen that the unwanted spikes have been eliminated and a neat signal is produced.

5.1.6 Data Transmission Unit

Data Transmission Unit of this active optical data tag contains the combination of retro reflector and the optical shutter. Proper working of this Data Transmission Unit can be shown by comparing the input given to the optical shutter with the output generated by the comparator at the receiver end which receives the reflected modulated light. The receiver end has a photo detector that is connected to a trans-impedance amplifier which is subsequently connected to a voltage comparator. This is the same circuit used in the triggering module of the Data Processing Unit in an active optical data tag. If the input to the optical shutter matches the output generated by the comparator at the receiver end, it implies that the combination of the optical shutter and retro reflector works fine thus fulfilling the purpose of OPID technique.
Figure 44: Figure showing the working of the Data Transmission Unit of the tag

Analysis: Figure 44 shows the output as observed on a CRO with its channel one connected to the output of the PIC which drives the optical shutter and channel two connected to the output of the comparator. It can be seen that the output on the channel two is exactly an inverted image of the output on channel one. This is because all the data is inverted before it is sent to the optical shutter of the transmission unit. For proper transmission and reception of data it has be inverted because the shutter operates in the normally-white mode. It can be clearly seen from the figure that the inverted data is inverted again by the optical shutter and hence the right data is received at the receiver end.

All the sections above have sufficiently justified the working of various components used in an active optical data tag.

5.2 System Testing

This section deals with the results obtained during the testing of the system as a whole. The system testing involves observing the output on the LCD display attached to the tag reader while the active optical data tag transmits the data.

Analysis: The system testing has been carried out on the bread board before the PCB design was considered. Figure 45 and Figure 46 shows the bread board implementation without the LCD.
shutter thus forming the wired communication link. The output of the PIC directly feeds the PIC at the optical tag reader. The output as read on the LCD display is shown in Figure 46. Interpretation of the data appearing on the LCD display is shown below.

- \textbf{Y} at the start of the data indicates that the data following the ‘Y’ is valid. The optical data tag when interrogated by the data tag reader begins to modulate the light and reflects it back to the reader. The duty of the tag reader is to look for a start byte (\texttt{0x0B}) and then read the next bytes until it reads the stop byte (\texttt{0x0E}). When it reads the start byte, it sends a \texttt{Y} to the LCD display indicating that the data is valid after a ‘\texttt{Y}’.

\textbf{Figure 45: Experimental Setup showing a wired communication link}

\textbf{Figure 46: Clear view of the LCD display shown in the Figure [45] above}
Figure 47: An active optical data tag being interrogated by the optical tag reader

Figure 48: Initial garbage values seen on the LCD display of the optical tag reader

Figure 49: The final valid data (after a Y) on the LCD display of the optical tag reader

- T = 304K indicates that the temperature is 310 degree Kelvin.
- P = 92KPa indicates that the absolute pressure is 92 KPa.
- tilt = N indicates that the tilt switch and hence the data tag is not in the tilted position.
• **thist = Y** indicates the tilt history representing that the tilt switch has been tilted before or after the tag has been interrogated.

Figure 47, Figure 48 and Figure 49 represent the pictures related to system testing with the final project box holding the populated PCB along with the retro reflector and the optical shutter. Figure 47 shows the active optical data tag being interrogated by the laser beam. Figure 48 shows the output as displayed on the LCD display of the optical tag reader. This figure shows that the LCD display shows some garbage values with an N at the beginning of the data. An ‘N’ at the beginning of the data shows that the data following the N is invalid. When an optical tag reader doesn’t detect the start byte of the transmission, it sends an ‘N’ to the LCD display saying that the data is invalid. Figure 49 shows the final valid output on the LCD display. The data is valid because of the occurrence of a ‘Y’ at the start. This data appears on the LCD display after some continuous transmission because the tag reader takes some time to synchronize with the transmitter which is the tag in this case.

### 5.3 Conclusions

From the various results presented in the sections above, it can be said that a proper transmission of data takes place between the transmitter and receiver thus forming a successful OPID technique. The following conclusions can be drawn from this thesis work.

- This OPID technique has been successfully tested at a distance of 2 meters.
- Manchester encoding scheme has been implemented to transmit the data because of its self-clocking feature.
- The highest transmission bit rate achieved by the active optical data tag is 50bits/sec, which implies a total of 100 bits/sec. This is because in a Manchester encoding scheme two binary levels are necessary to represent a single bit.
• Successful implementation of the technique has been achieved when light of sight is correctly maintained between the two units i.e. the reader and the tag.

• A working model of an active optical data tag has been implemented and successfully tested with the optical tag reader.

5.4 Future Work

There is a lot of scope for the future work in this project. The areas where there is a scope of future work are summarized below.

a) **Increasing the transmission rate:** The transmission rate is limited to 50bits/sec because of the limitation on the LCD shutter which cannot operate at higher frequencies. Having an alternate modulating mechanism such as an electro-wetting cell which can modulate the incident light at a higher frequency would increase the transmission bit rate.

b) **Using alternate modulating mechanisms:** The optical shutter FOS-ECS-PM makes use of polarizing films to operate. Using an alternative mechanism which doesn’t employ any polarizer yields better performance.

c) **Dynamic Programmability:** An additional feature of dynamic programmability can be implemented in the data tag. This feature might include dynamically changing the tag ID by means of configuration bits that help in programming the tag.

d) **Better encoding techniques:** Other encoding techniques can be thought of because the Manchester encoding scheme puts a limitation on the bandwidth and uses double the bandwidth when compared other basic encoding schemes like NRZ scheme. Also encoding techniques with better error correcting capabilities can be implemented.

e) **Power saving:** All the components/ICs in the active optical data tag are constantly powered by the battery, thus increasing the power consumption. This increase in the power
consumption can be taken care of by using some better power managements ICs. Also implementing sleep mode and interrupts in the program written onto the MCU help to a great deal in power saving. Sleep mode was not implemented in the program because the tilt sensor needs to continuously check the tilt status to maintain a tilt history.
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Appendix

This section presents the program written in the MCU using the high level language – mikroC.

**Mikro-C code:**

This is the high level code written in mikro-C and implemented using the mikro-C complier. This code is first converted to assembly level language using translator. Additional code is then added to the assembly level code generated. The final assembly level code is transferred to the PIC using the PICkit2 hardware.

```c
unsigned char Mcode;
unsigned short dutycycle;
unsigned char flag =0;
unsigned int flag1 =0;

void main()
{
    unsigned int temperature, pressure, actpressure;
    unsigned int trigger = 0;
    unsigned int i,j,k,ones,num1,num2;
    unsigned char temp1[5],temp2[5];
    unsigned char ans1[5], ans2[5];
    unsigned char tiltYN, tilthist = 'N';

    char temp[3]="T=";
    char pres[3]="P=";
    char tilt[6]="tilt=";
    char thist[7]="thist=";

    TRISA = 0xFB;               // Port RA2 is output for comp1 ie RA2/AN2/C1out; hence TRISA.RA2 = 0
    TRISB = 0xFF;               // PORT B is input analog inputs from pressure sensor is read through this port
    TRISC = 0x08;               // Port RC3 is input for comp2 ie RC3/AN7/ C12IN3- ; hence TRISC.RC3 = 1; and rest
    //are declared as 0 as output (manchester code) is send to port C
    INTCON.GIE = 0;            // Disable interrupts

    ANSEL = 0x82;               // Configure AN pins as digital I/O except for RA1/AN1/C12IN0- which accepts analog
    //v/g from the tilt sensor, hence declared as 1 and RC3/AN7/C12IN3- which accepts analog i/p from the opamp,
    //hence declared as 1
    ANSELH = 0x0C;              // AN10 and AN11 are the ADC channels for temp and Pressure sensors.Hence the 3rd &
    //4th bit from LSB of ANSELH are set as 1. All other analog channels are disabled(0) and used for ports
    ADCON0 = 0x89;              // Right justified result, VDD as Vref, AN2 as channel, GO bit =0, ADC is enabled
    ADCON1 = 0x00;              // A/D conversion clk = fosc/2

    CM1CON0 = 0xB4;            // for the comparator used to trigger the txn
    CM2CON0 = 0xB7;            // for the comparator used for tilt sensor
    VRCON = 0x10;              // Reference voltage = 0.6V of standard ref vlg
```

91
/* PWM_Init(250); // Initialize PWM1 module at (250x4=1000Hz)1KHz

Square waveform generation using PWM module and setting the duty cycle as 50%
PWM_Start(); // start PWM1
dutycycle = 127;
PWM_Change_Duty(dutycycle); */ // Changing the duty cycle to 50% as in square wave

Man_Send_Config(&PORTC,1); // Initialize manchester sender

while (1) // Start of program
{
    temperature = 0;
    pressure = 0;

    temperature = Adc_Read(11); // Get results of AD conversion from Channel-11 of portB RB5
    Delay_ms(1000);

    pressure = Adc_Read(10); // Get results of AD conversion from Channel-10 of portB RB4
    Delay_ms(1000);

    if (CM2CON0.F6 == 1) // Info from tilt sensor
        {
        tiltYN = 'Y';
        tilthist = 'Y';
        }
    else
        tiltYN = 'N';

    if (CM1CON0.F6 == 1)
        trigger = 1;

    /* Data Manipulation Starts*/

    num1 = temperature;
    actpressure = pressure/4 ;
    num2 = actpressure;
    i=0;
    j=0;
    k=0;
    ones=0;

    /* Converting int value of temperature obtained from temp sensor to characters*/
    while (num1!=0)
    {
        ones=num1%10; //get current ones digit
        temp1[i]=(char)(ones+48); //48=(int)'0';
        num1=num1/10; //remove current ones digit
        i++;
        /length of number

*/
for(j=i-1;j>=0;j--)
{
    ans1[k]=temp1[j];  //reorder string correctly in ans[]
k++;
    if (j==0)
        break ;
}

ans1[i]="0";          //add null char for end of string

/* Converting int value of pressure obtained from pressure sensor to characters*/
i=0;
j=0;
k=0;
ones=0;

while (num2!=0)
{
    ones=num2%10;                //get current ones digit
temp2[i]=(char)(ones+48); //48=(int)'0';
    num2=num2/10;        //remove current ones digit
    i++;                          //length of number
}

for(j=i-1;j>=0;j--)
{
    ans2[k]=temp2[j];        //reorder string correctly in ans[]
k++;
    if (j==0)
        break ;
}

ans2[i]="0";          //add null char for end of string

/* Data Manipulation Ends */

/***** Beginining of transmission in Manchester code*****/

if (trigger == 1)
{
    Mcode = 0x0B;
    Mcode = ~Mcode;
    Man_Send(Mcode);       // Send end marker
    Delay_ms(100);
/* Transmitting the characters : "Temp=" */
for(i=0;i<strlen(tempr);i++)      // Loop for transmitting temp 
{
    Mcode = tempr[i];
    Mcode = ~Mcode;
    Man_Send(Mcode);
    Delay_ms(90);
}

/*/ Transmitting the actual temperature in characters ie 300 (K) */ *
for(i=0;ans1[i]! = '0';i++)  // sending the new char string to the LCD display 
{
    Mcode = ans1[i];
    Mcode = ~Mcode;
    Man_Send(Mcode);
    Delay_ms(90);
}

/*/ Transmitting the Characters "K " */
Mcode='K';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);
Mcode=' ';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);

/*/ Transmitting the characters : "Pre="*/
for(i=0;i<strlen(pres);i++)      // Loop for transmitting pressure 
{
    Mcode = pres[i];
    Mcode = ~Mcode;
    Man_Send(Mcode);
    Delay_ms(90);
}

/*/ Transmitting the actual pressure in characters ie 376 (Kpa)*/
for(i=0;ans2[i]! = '0';i++)  // sending the new char string to the LCD display 
{
    Mcode = ans2[i];
    Mcode = ~Mcode;
    Man_Send(Mcode);
    Delay_ms(90);
}

/*/ Transmitting the characters : "KPa"*/
Mcode = 'K';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);
Mcode = 'P';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);
Mcode = 'a';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);
Mcode = ',';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);

/* Transmitting the characters : "Tilt= "*/
for(i=0;i<strlen(tilt);i++)      // Loop for transmitting tilt
{
    Mcode = tilt[i];
    Mcode = ~Mcode;
    Man_Send(Mcode);
    Delay_ms(90);
}
Mcode = tiltYN;
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);
Mcode = ',';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);

/* Transmitting tilt history*/
for(i=0;i<strlen(thist);i++)      // Loop for transmitting tilt hist
{
    Mcode = thist[i];
    Mcode = ~Mcode;
    Man_Send(Mcode);
    Delay_ms(90);
}
Mcode = tilthist;
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);
Mcode = ',';
Mcode = ~Mcode;
Man_Send(Mcode);
Delay_ms(90);
Mcode = 0x0E;
Mcode = ~Mcode;
Man_Send(Mcode);        // Send end marker
Delay_ms(1000);            // End of transmission
}                             // end of the first while loop
}                             // end of main