

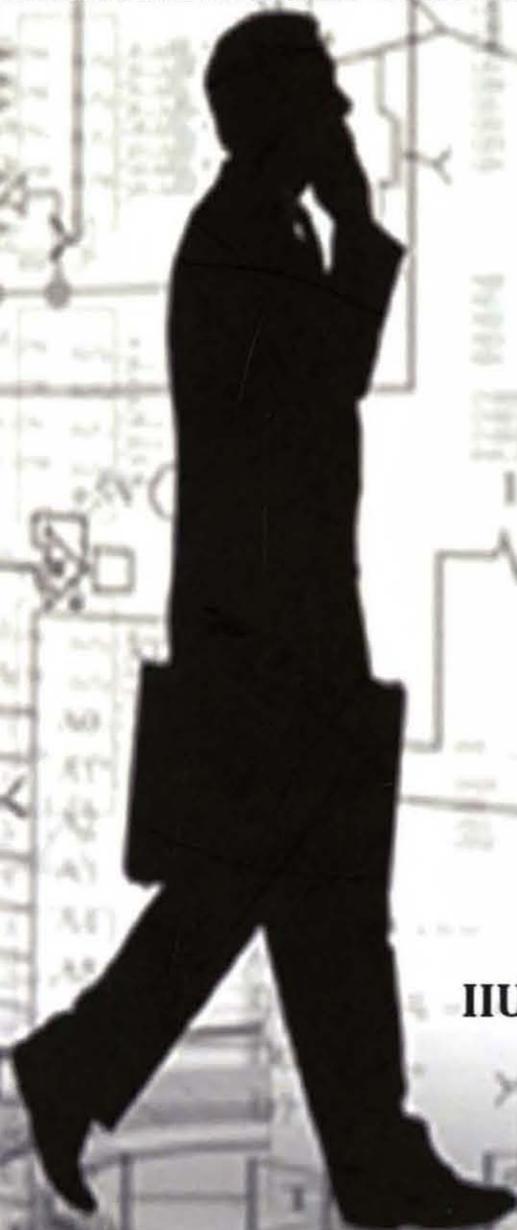
# PRINCIPLES OF TRANSDUCER DEVICES AND COMPONENTS

Edited by

**Sheroz Khan, International Islamic University Malaysia**

**Jalel Chebil, International Islamic University Malaysia**

**Othman O Khalifa, International Islamic University Malaysia**



**IIUM PRESS**

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## CONTENTS

Chapter		Page No.
1	RC CIRCUIT RESPONSE <i>Atika Arshad, Rumana Tasnim, Sheroz Khan, AHM Zahirul Alam</i>	1
2	RL CIRCUIT RESPONSE <i>Rumana Tasnim, Atika Arshad, Sheroz Khan, Musse Mohamod</i>	7
3	RLC CIRCUIT RESPONSE <i>Rumana Tasnim, Atika Arshad, Sheroz Khan, Musse Mohamod</i>	13
4	CAPACITIVE SENSING FOR NON-CONTACT MEANS OF MEASUREMENT <i>Rumana Tasnim, Atika Arshad, Sheroz Khan, Musse Mohamod, Nazmus Saquib</i>	19
5	SENSORS IN ELECTRONIC APPLICATIONS <i>Rumana Tasnim, Atika Arshad, Sheroz Khan, Musse Mohamod</i>	27
6	CONTACT TYPE AND NONCONTACT TYPE GAS FLOW MEASURING SENSORS <i>Rumana Tasnim, Atika Arshad, Nazmus Saquib, Sheroz Khan, Musse Mohamod</i>	33
7	OUTPUT CONTROL DEVICES: ACTUATORS <i>Rumana Tasnim, Atika Arshad, Sheroz Khan, Musse Mohamod</i>	39
8	INDUCTIVE POWER SYSTEM FOR ENERGY HARVESTING <i>Atika Arshad, Rumana Tasnim, Sheroz Khan, AHM Zahirul Alam</i>	45
9	ON THE ELECTRODE ARRANGEMENTS OF CAPACITIVE SENSOR FOR TWO PHASE GAS FLOW MEASUREMENT <i>Rumana Tasnim, Atika Arshad, Sheroz Khan, Musse Mohamod</i>	53
10	BASIC CONCEPT OF INDUCTANCE FOR INDUCTIVE TRANSDUCERS <i>Atika Arshad, Rumana Tasnim, Sheroz Khan, AHM Zahirul Alam</i>	59
11	MAGNETIC PROPERTIES FOR MAGNETIC TRANSDUCER <i>Atika Arshad, Rumana Tasnim, Sheroz Khan, AHM Zahirul Alam</i>	65
12	MAGNETIC, HYSTERESIS THEORY: APPLICATION PERSPECTIVE <i>Atika Arshad, Rumana Tasnim, Sheroz Khan, AHM Zahirul Alam</i>	71

13	THE PRINCIPLE OF RESISTIVE SENSING <i>Atika Arshad, Rumana Tasnim, Sheroz Khan, AHM Zahirul Alam</i>	75
14	SPIKES BLOCKING AND SURGE PROTECTION <i>Ahmad Lutfi Torla, Sheroz Khan, Asan Gani</i>	83
15	VOLTAGE SUPPLY AND VOLTAGE REGULATION <i>Ahmad Lutfi Torla, Sheroz Khan, Asan Gani</i>	89
16	FULL-WAVE RECTIFICATION OF A LOW-VOLTAGE SOURCE <i>Ahmad Lutfi Torla, Sheroz Khan, Asan Gani</i>	99
17	DESIGN OF DIFFERENTIAL RESISTIVE MEASURING SYSTEM AND ITS APPLICATIONS <i>Deji Abdulwahab, Sheroz Khan, Jalel Chebil</i>	107
18	LINEARIZING TECHNIQUES FOR SENSOR OUTPUT <i>Mohammad Tahir Siddiqi, Sheroz Khan, Ummer Siddiqi</i>	115
19	SENSOR AND SENSOR RESPONSE-ISSUES AND INTERFACING <i>Syed Masrur Ahmmad, Sheroz Khan, Anis Nurashinkin, Md Rasiuddin Khan</i>	119
20	UWB PULSE GENERATION SHAPING AND ANALYSIS <i>Zeeshan Shahid, Sheroz Khan, AHM Zahirul Alam</i>	133
21	POWER SUPPLY POWER-SUPPLY INTERFERENCE IN SMART SENSORS-TO-MICRONROLLER INTERFACE FOR BIOMEDICAL SIGNALS <i>Mohammad Ashraful, Sheroz Khan, Muhammad Ibrahimy</i>	139
22	RESPONSE AND INACCURACY ISSUES OF SENSORS <i>Mohammad Ashraful, Sheroz Khan, Muhammad Ibrahimy</i>	165
23	PERFORMANCE IMPROVEMENT OF SENSORS RESPONSE USING PIECE-WISE NON-LINEAR (PWL) A/D AND PULSE-WIDTH MODULATION (PWM) A/D TECHNIQUES <i>Ismaila Tijani, Sheroz Khan</i>	175
24	POWER SUPPLY INTERFERENCE IN SMART SENSOR MICROCONTROLLER INTERFACE <i>Ismaila Tijani, Sheroz Khan</i>	185

25	2.45 GHz PASSIVE RFID TAG ANTENNA MOUNTING ON VARIOUS PLATFORMS <i>Abubeker A. Yussuf, Md Rafiqul Islam, Sheroz Khan, Othman O. Khalifa, AHM Zahirul Alam</i>	201
26	ANALYSIS OF HYBRID STEPPER MOTOR PERFORMANCE UNDER THE INFLUENCE OF VOLTAGE SUPPLY INTERFERENCE <i>Abdulazeez F. Salami, Wahab A. Lawal, Sheroz Khan, Teddy Surya Gunawan, Sigit Puspito Wigati Jarot</i>	217
27	PC SOUND CARD BASED INSTRUMENTATION AND CONTROL <i>Teddy Surya Gunawan</i>	229
28	PIECE-WISE LINEAR ANALOG TO DIGITAL (PLADC) CONVERTER PROCESS <i>Abdulazeez F. Salami, Wahab A. Lawal, Sheroz Khan, AHM Zahirul Alam</i>	239
29	DESIGN AND IMPLEMENTATION OF AN OPTIMAL FUZZY LOGIC CONTROLLER USING EGENTIC ALGORITHM <i>Salami Femi Abdulazeez, Lawal Wahab Adetunji, Sheroz Khan, AHM Zahirul Alam, Momoh Jimoh E. Salami, Shihab Ahmed Hameed, Aisha Hasan Abdalla and Mohd Rafiqul Islam</i>	249
30	DESIGN AND HARDWARE IMPLEMENTATION OF CONDITIONING CIRCUIT FOR ACCURATE READING FROM TRANSDUCERS WITH NONLINEAR RESPONSES <i>Khairul Hasan, Aliza Aini Md Ralib, Ma Li Ya, Atika Arshad, Sheroz Khan</i>	265
31	TRANSDUCERS-TO-MICROCONTROLLER INTERFACES-SOFTWARE SOLUTION APPROACH <i>Lawal Wahab Adetunji, Salami Femi Abdulaziz, Sheroz Khan, AHM Zahirul Alam, Mohammad Rafiqul Islam, Shihab A. Hameed and Aisha Hasan Abdalla</i>	277
32	WAVELET ANALYSIS OF THE ECG SIGNALS FOR THREE COMMON HEART DISEASES IN JORDAN <i>Jalel Chebil, Jamal Al Nabulsi</i>	291
33	FUNCTIONAL ELECTRICAL STIMULATION SYSTEM AND PROFILE FOR WALKING <i>Noreha Abdul Malik</i>	303

34	FUZZY LOGIC BASED TEMPERATURE CONTROL OF THERMOELECTRIC COOLER FOR SINGLE PHOTON AVALANCHE DIODE APPLICATION	311
	<i>Nurul Izzati Samsuddin, Salmiah Ahmad, Nurul Fadzlin Hasbullah</i>	
35	SPECTRUM SENSING FOR COGNITIVE RADIOS	317
	<i>Izyan Munyanti Abu Hanifah, Siti Natrah Che Rus, Sigit Puspito Wigati Jarot</i>	
36	COGNITIVE RADIO VS INTELLIGENT ANTENNA	327
	<i>Siti Rabani Mat Nawati, Nurul Farhah Toha, Khaizuran Abdullah, M. Rafiqul Islam, Sheroz Khan</i>	
37	APPLICATION AND CASE STUDIES OF MAGNETIC INDUCTION	341
	<i>Atika Arshad, Rumana Tasnim, Sheroz Khan, A H M Zahirul Alam</i>	

## Chapter 28

# PIECE-WISE LINEAR ANALOG TO DIGITAL (PLADC) CONVERTER PROCESS

ABDULAZEEZ F. SALAMI, WAHAB A. LAWAL, SHEROZ KHAN, AHM ZAHIRUL ALAM

### 28.0 INTRODUCTION

Transducers are devices that transform energy from one form to another. Such transformation process may be applicable in the measurement of physical quantities, transfer of information and also in performing a certain control action. Transducers used as measuring devices are generally termed as sensors. Such transducers detect the changes in characteristics of a physical quantity and convert the change into a corresponding electrical signal. This is a common phenomenon when transducers are used to detect temperature, speed, force, liquid level or viscosity. On the other hand transducers, used to carry out control actions, are termed as actuators. These transducers usually convert an electrical signal into some form of physical control action such as heating or movement and are carried by the control devices. Various types of transducers exist meant for sensing and controlling different physical quantities. For example, a light dependent resistor (LDR) or a photodiode can be used to sense light intensity of an environment while lamps and LED displays can be used to control it. Likewise, a thermistor can be used to measure the temperature of an environment while a heater/fan can be used to control it and a tachometer can be used to measure the speed of a device while a stepper motor can be used to control it [1-3]. The focus of this chapter is on the problems and issues related to the interfacing of transducers when used as measuring devices or sensors in smart applications. Smart applications are also termed as tuned control for detecting changes in the parameter of interest which used to be ignorable in the traditional measurement and control systems.

The output signal generated from transducer sensors can either be analog or digital. Analog type sensors generate a continuous output signal for every change in the physical quantity being measured. This can be in the form of an output voltage varying proportionally in relation to changes in the physical quantity. An example of such sensors is a thermistor that changes its resistive value for every change in the external temperature of the environment. Digital type sensors on the other hand produce discretized output levels that represent an on/off switch. Such sensors can be in the form of a proximity switch to detect objects, or a level switch to detect if a tank is empty or full. No matter the output is analog or digital, transducers are to be interfaced to the external world on one side and to the digital systems on the other side. This chapter addresses the errors related to the nonlinear behavior of transducers which they exhibit when deriving information of the physical parameter of the external world devices. Here, the nonlinearity issue is explained

### 28.1. Linearizing the Ideal PLADC Characteristics:

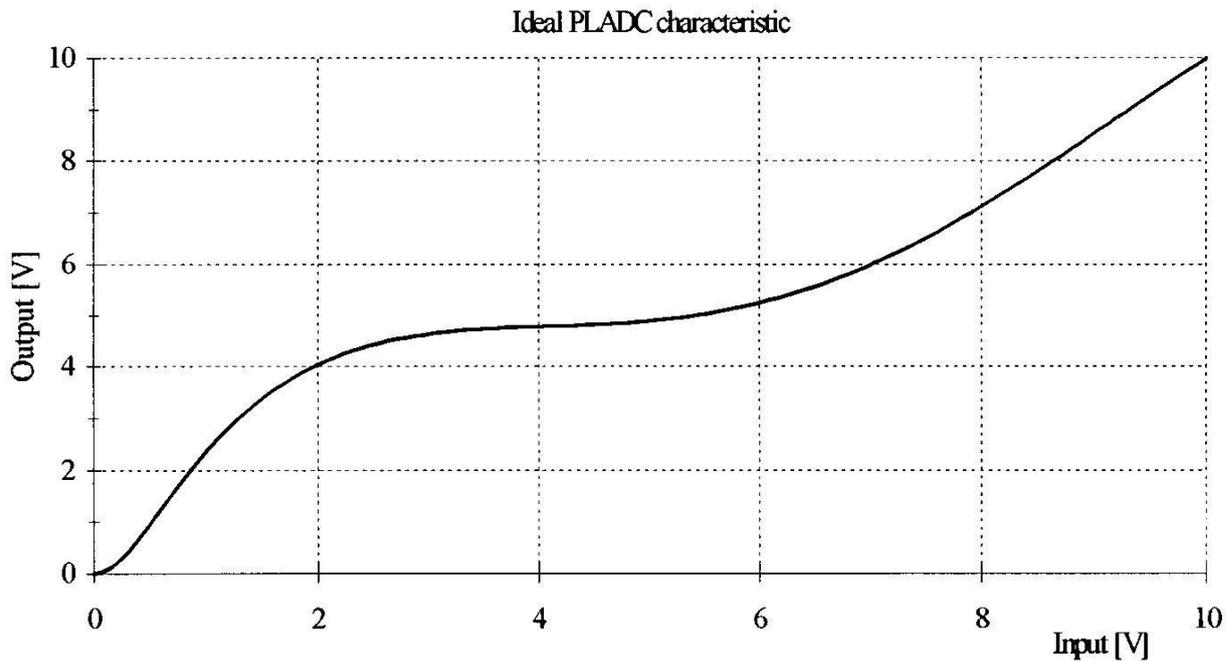


Figure 28.1: Ideal PLADC Characteristic

In order to easily and effectively linearize the Ideal PLADC characteristic, the curve was broken down into a number of linear segments with break voltages uniquely marking the boundaries between each segment on the curve. There are two reasons for this linearization process, namely; (1) to find a simple and comparatively precise estimate for the ideal curve (2) to make simulations easier and faster because the complexity of linear equations is far much better than that of polynomials and exponential equations. Hence, the linearized curve is as illustrated below:

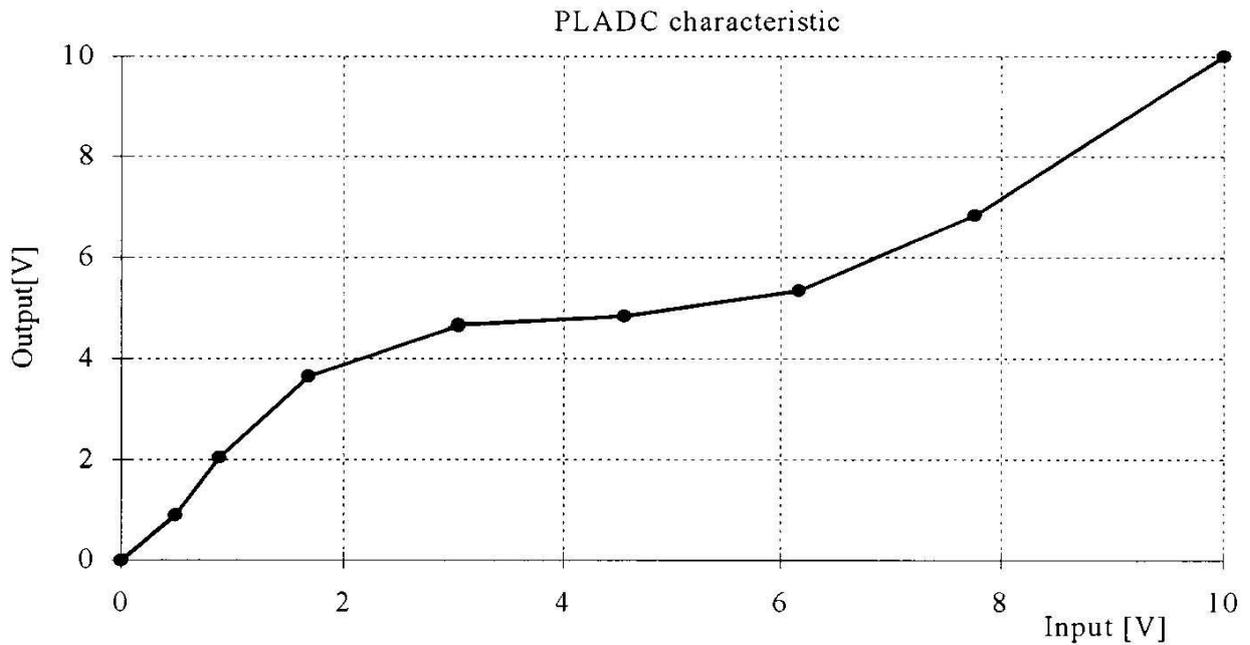


Figure 28.2: Piece-wise Linear Characteristic

A proper observation of the figure above will reveal that the new characteristic comprises of eight linear segments together with their break voltages (in black dots) marking the boundaries of the segments. The equations for these segments can be expressed mathematically as:

1.  $V = 1.925V_i$   $(0 \leq V_i < 0.46)$
2.  $V = 2.9167V_i - 0.49585$   $(0.46 \leq V_i < 0.86)$
3.  $V = 2.0769V_i + 0.1827$   $(0.86 \leq V_i < 1.66)$
4.  $V = 0.6977V_i + 2.5101$   $(1.66 \leq V_i < 2.98)$
5.  $V = 0.1633V_i + 4.13$   $(2.98 \leq V_i < 4.55)$
6.  $V = 0.3137V_i + 3.4437$   $(4.55 \leq V_i < 6.12)$
7.  $V = 0.9020V_i - 0.1779$   $(6.12 \leq V_i < 7.72)$
8.  $V = 1.4167V_i - 4.167$   $(7.72 \leq V_i \leq 10)$

Where V is the Output Voltage and  $V_i$  is the Input Voltage.

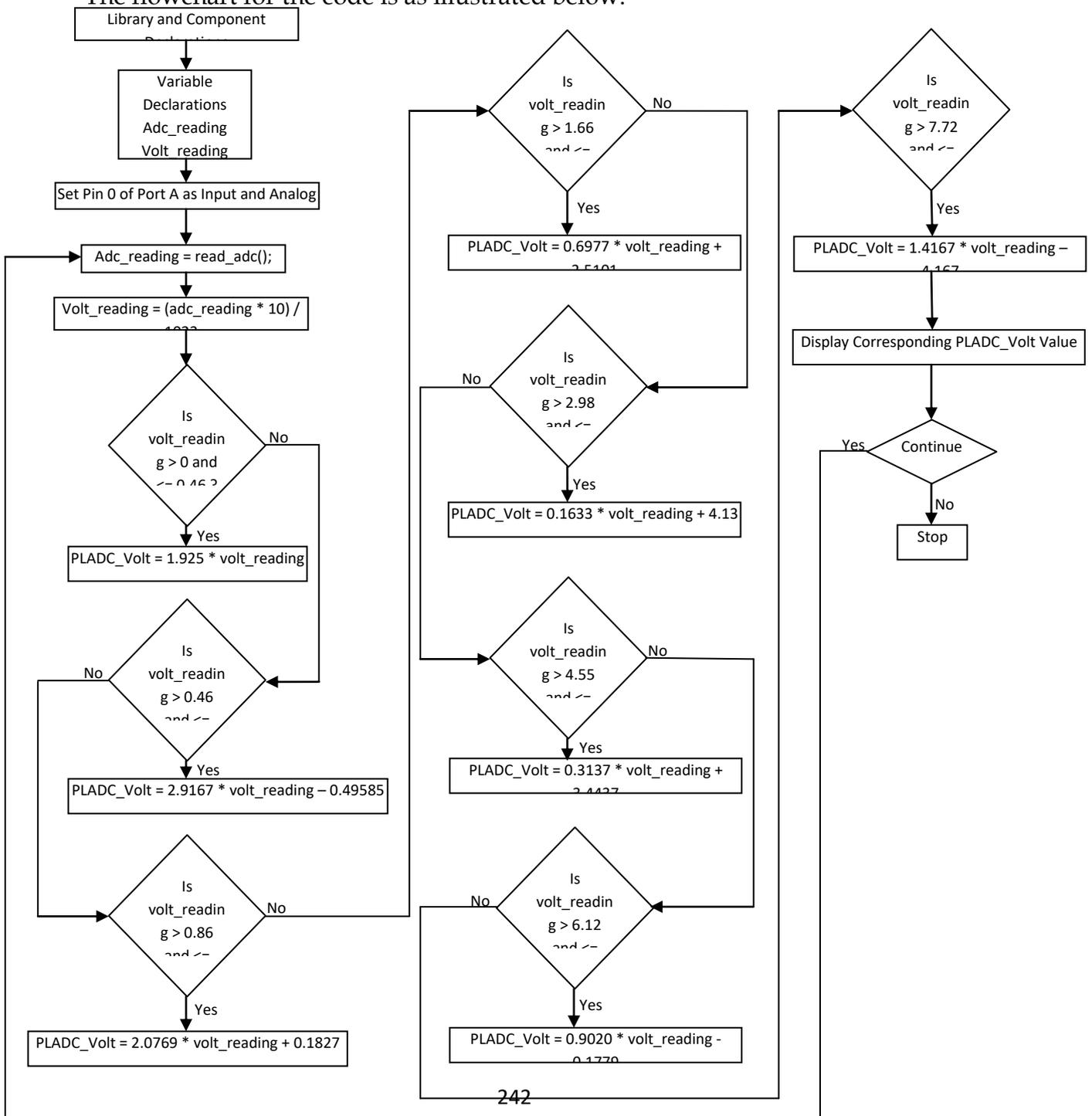
### 28.2. Converting the Equations into Codes:

With the knowledge of these equations, an embedded code was written for the PIC16F877A Microcontroller through the PIC CCS C Compiler with the following details:

- Take in the analog readings of the inboard potentiometer which is on a scale of 0 to 1023
- Set the analog readings to their appropriate values in the range of 0 to 10. These are the Input Voltages ( $V_i$ ).

- Turn the eight linear equations into a set of IF-THEN-ELSE statements for the determination of the corresponding Output Voltage (V) from the right Input Voltage ( $V_i$ ).
- Process and Pass the Input Voltages ( $V_i$ ) into their respective IF-THEN-ELSE code fragments.
- Calculate the resulting Output Voltage (V) and display the result.
- Run the simulation numerous times to get many values of V for  $V_i$
- Stop the simulation when sufficient data is amassed.

The flowchart for the code is as illustrated below:



In the case of this experiment, the program was simulated several times with 64 values of Input Voltage ( $V_i$ ) to obtain a correspondingly large value for the Output Voltage ( $V$ ). The values are as shown in the table below:

Table 28.1: Input and Corresponding Output Voltage Values

ADC Readings	Volt Readings	PLADC Volt Readings
0	0	0
16	0.156402	0.301075
32	0.312805	0.60215
48	0.469208	0.872689
64	0.62561	1.328869
80	0.782013	1.785049
96	0.938416	2.131696
112	1.094819	2.456529
128	1.251221	2.781362
144	1.407624	3.106195
...	...	...
1024	10	10

The resulting graph obtained by plotting the Volt Readings against the PLADC Volt Readings is as illustrated below. It is obvious that this graph is similar to the original PLADC characteristic showing that the values used in the linear equations are good approximates.

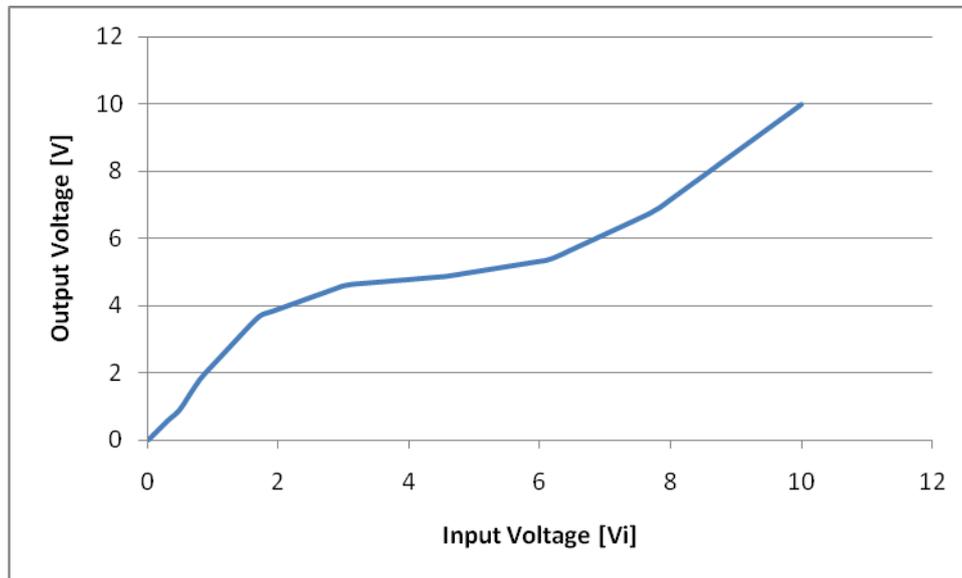


Figure 28.3: Approximated PLADC Characteristic

### 28.3. Characterizing the Ideal PLADC Curve:

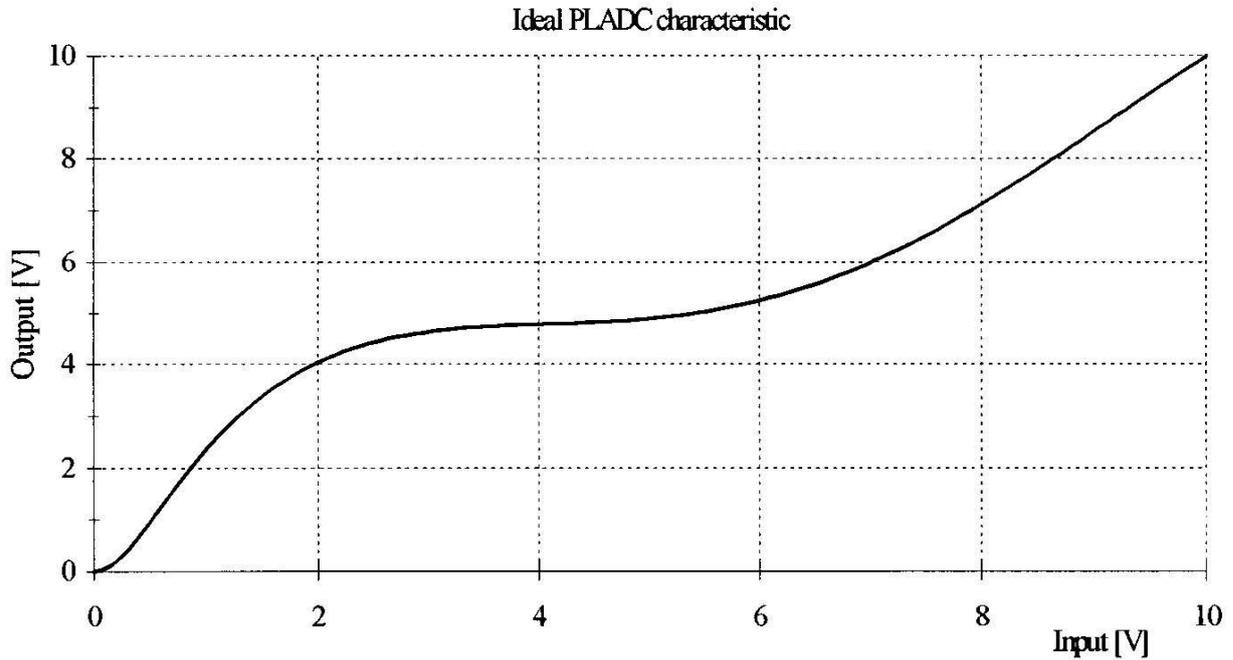


Figure 28.4: Ideal PLADC Characteristic

The Ideal PLADC Curve above needs to be mathematically represented as original, accurate and precise as possible in order to generate values from this curve and determine the error by comparing it with the PLADC characteristic. To achieve this, the trendline (regression) function in the Excel application was used to determine the suitable polynomial equation for the curve which is in this case  $y = -0.0044x^4 + 0.1219x^3 - 1.0606x^2 + 3.8961x - 0.4855$ . The values generated from this polynomial and the error calculated is as shown in the table below:

Table 28.2: Input Voltage, Output Voltage, Ideal PLADC Values and Error

ADC Readings	Volt Readings	PLADC Volt Readings (PVR)	Approx. Ideal PVR	Error
0	0	0	0	0
16	0.156402	0.301075	0.3036198	-0.838153506
32	0.312805	0.60215	0.633131936	-4.893440774
48	0.469208	0.872689	0.881578	-1.008305561
64	0.62561	1.328869	1.330003	-0.085262966
80	0.782013	1.785049	1.804032	-1.052254062
96	0.938416	2.131696	2.33399715	-8.667583405
112	1.094819	2.456529	2.662404345	-7.732685126
128	1.251221	2.781362	2.956955661	-5.938325795
144	1.407624	3.106195	3.219979206	-3.533693814
...	...	...	...	...
1024	10	10	10.3155	-3.0585

Using Excel, the plot of this polynomial is as shown below:

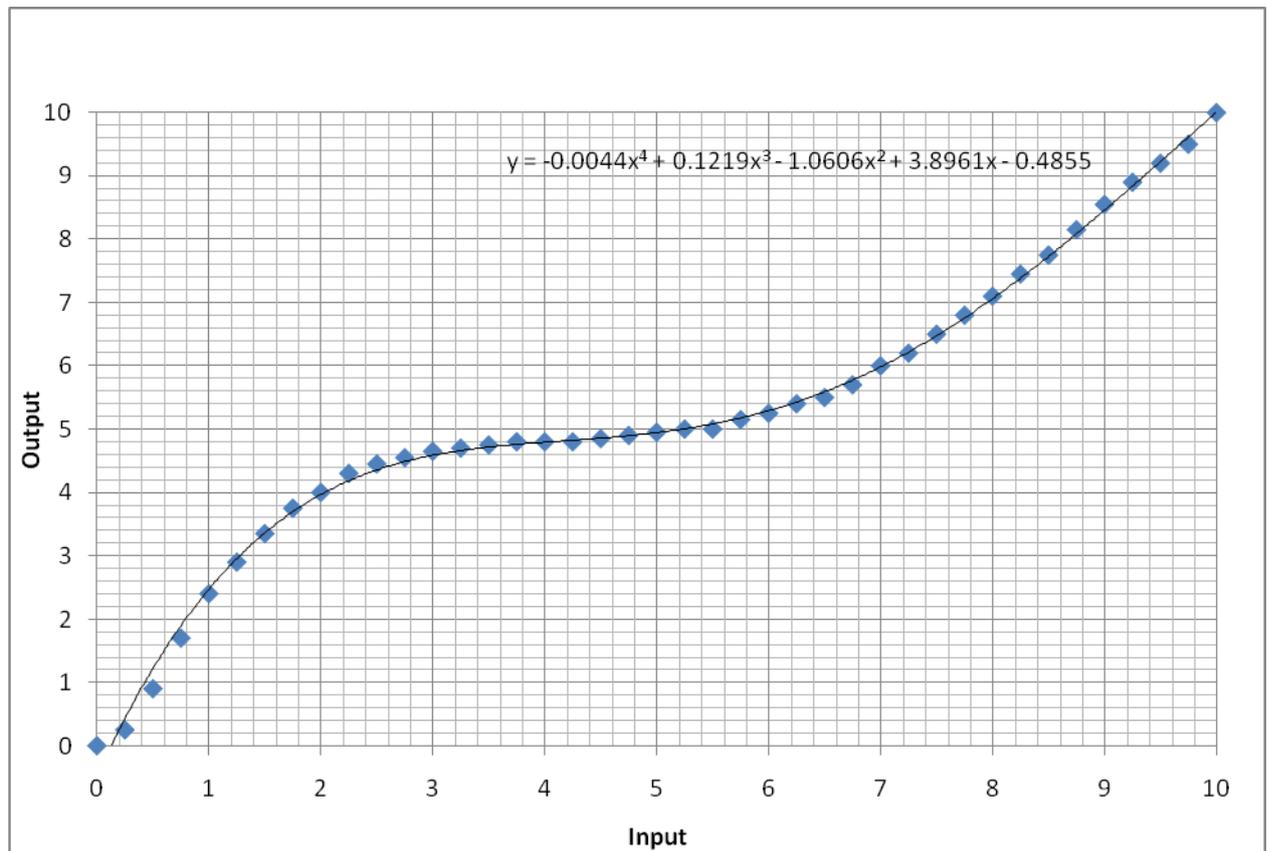


Figure 28.5: Approximated Ideal PLADC Characteristic

The plot of the Error values against the ADC readings is as shown below:

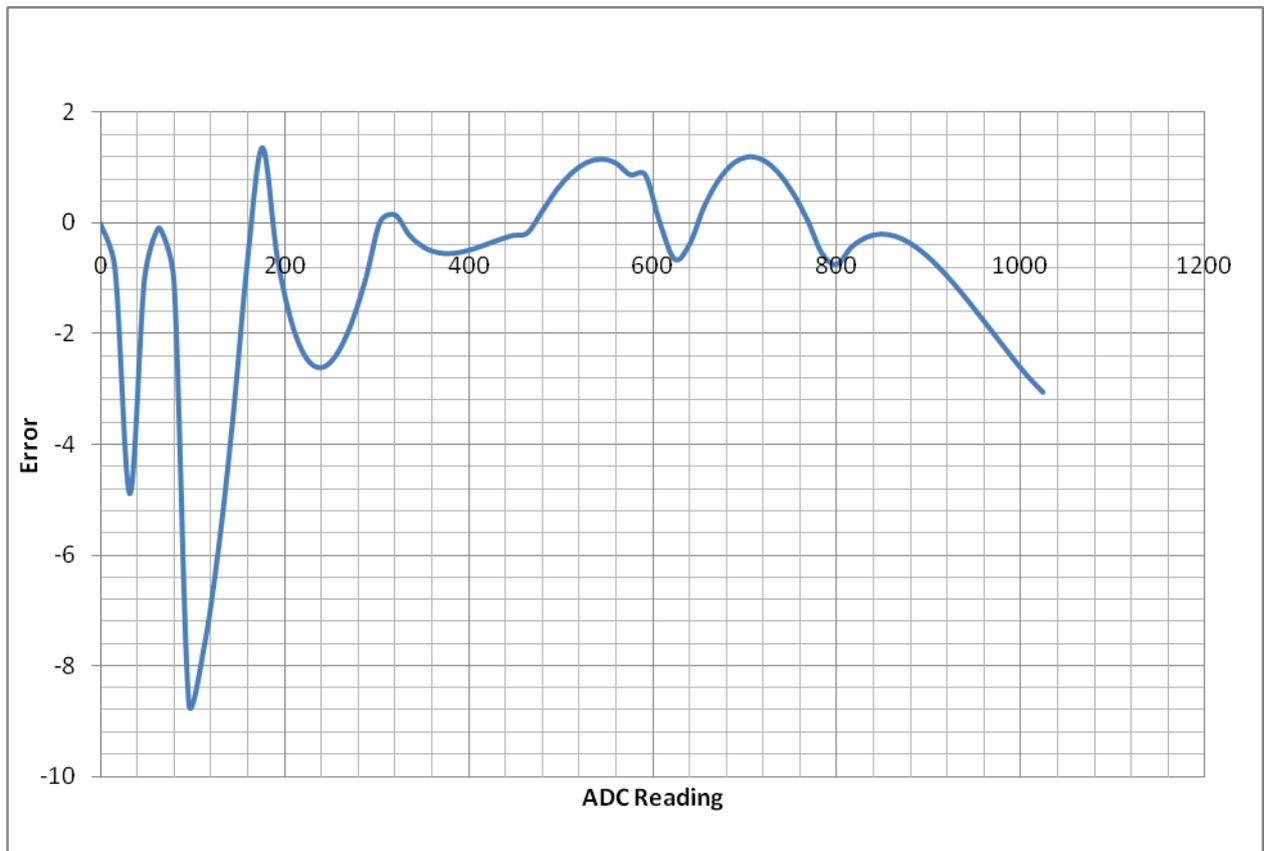


Figure 28.6: Error Plot

#### 28.4. Conclusion

The transducer response characteristics have been analyzed, and the resulting errors in reading these sensors directly have been shown. The analysis and simulation carried out so far on nonlinearity issues show that a piecewise nonlinear method can be used to reduce the error of nonlinearity to a reasonable degree of accuracy. Also, the results show that better results could be better with the increase of the number of segments a given response curve is divided into.

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