PRINCIPLES OF TRANSDUCER DEVICES AND COMPONENTS

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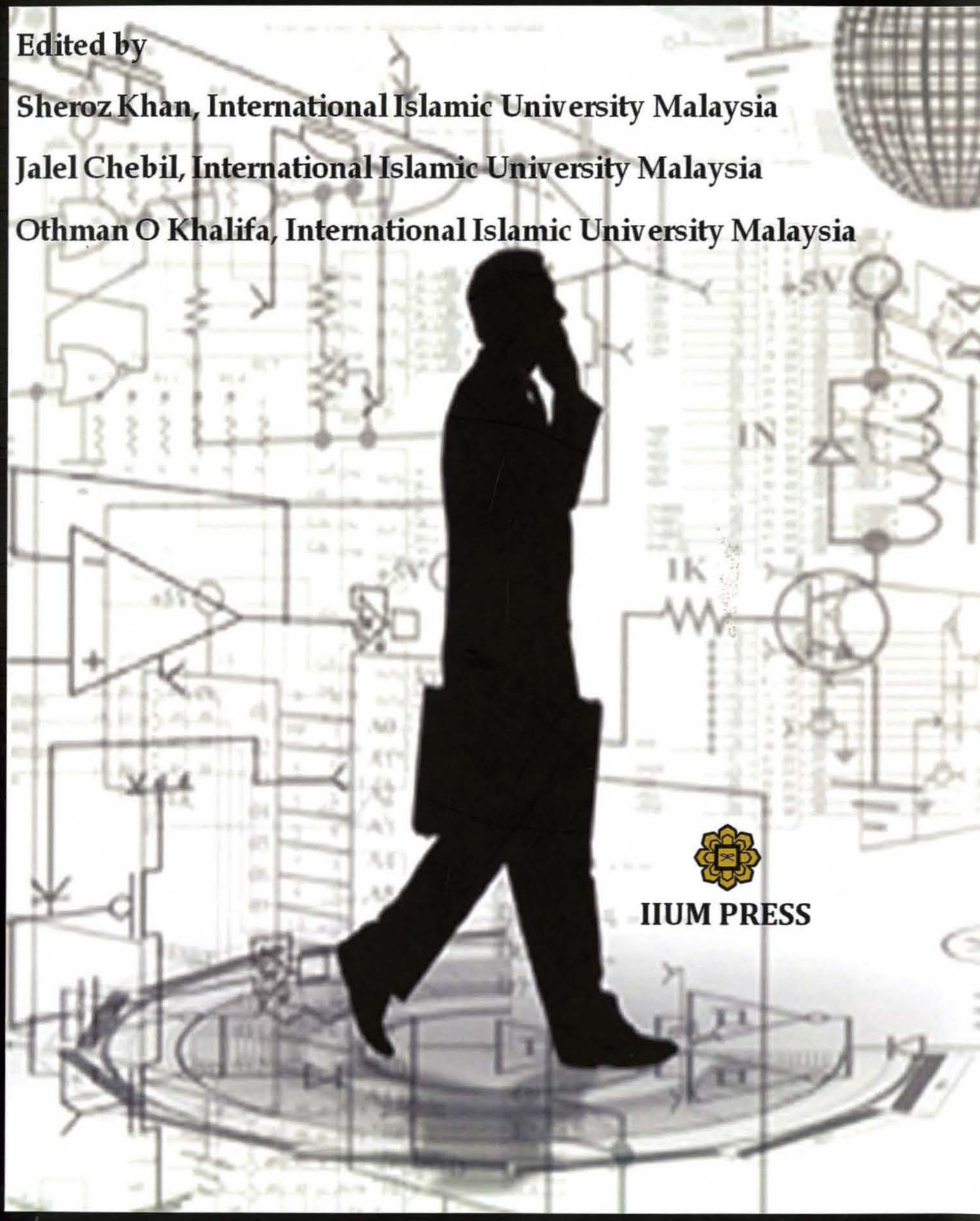

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CONTENTS

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 word 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:

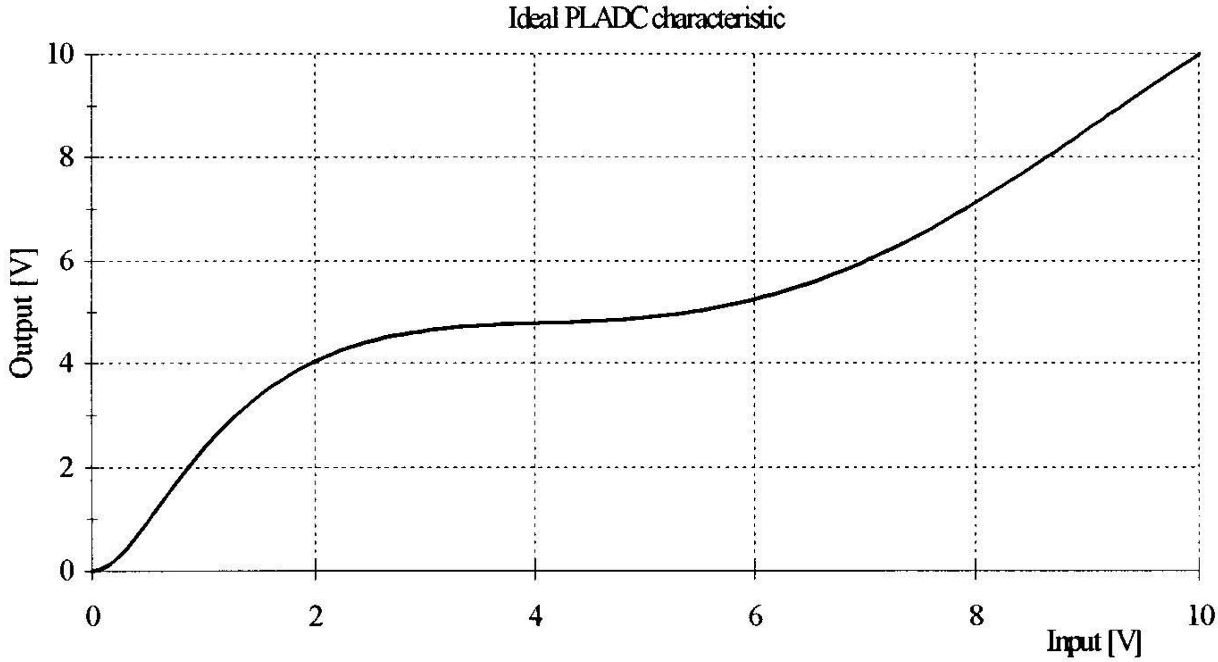


Figure 28.1: Ideal PLADC Characteristic

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:

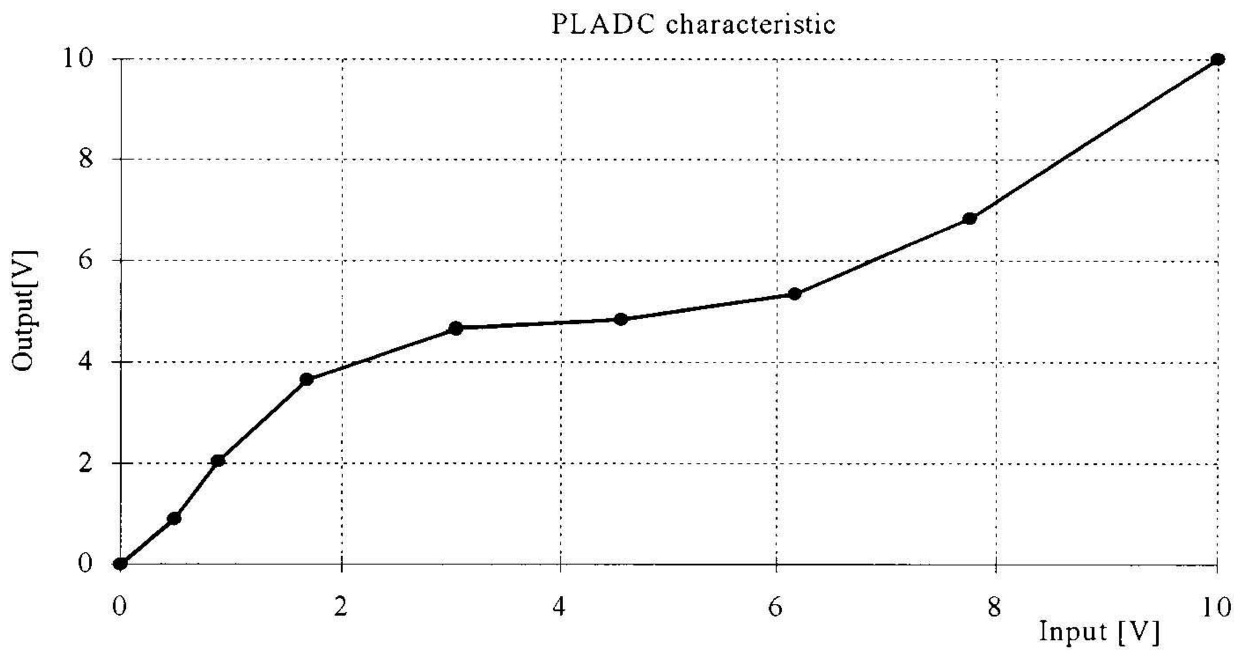


Figure 28.2: Piece-wise Linear Characteristic

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. $V = 0.3137V_i + 3.4437$ $(4.55 \leq V_i < 0.46)$
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.

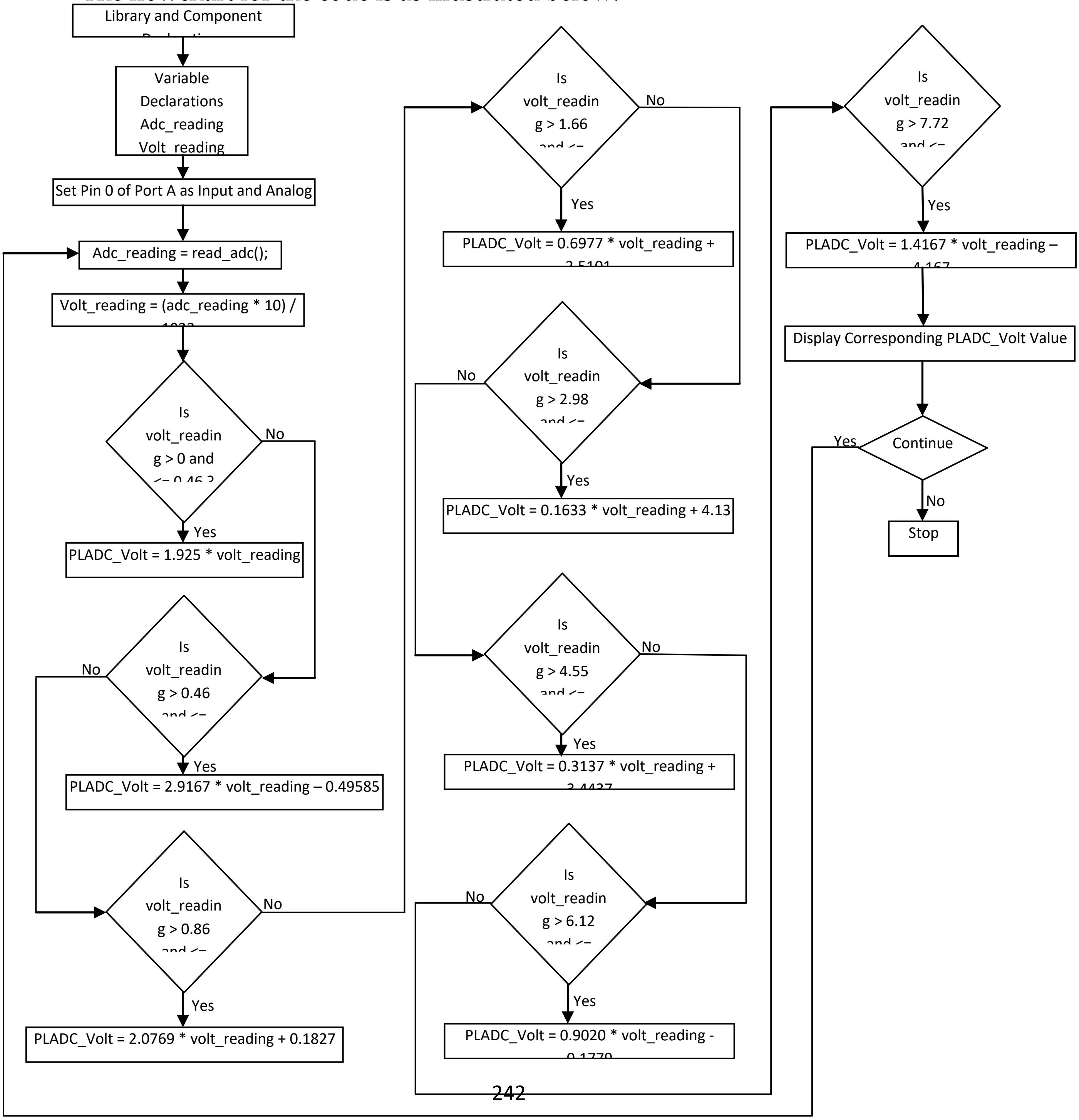
28.2. Converting the Equations into Codes:

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.

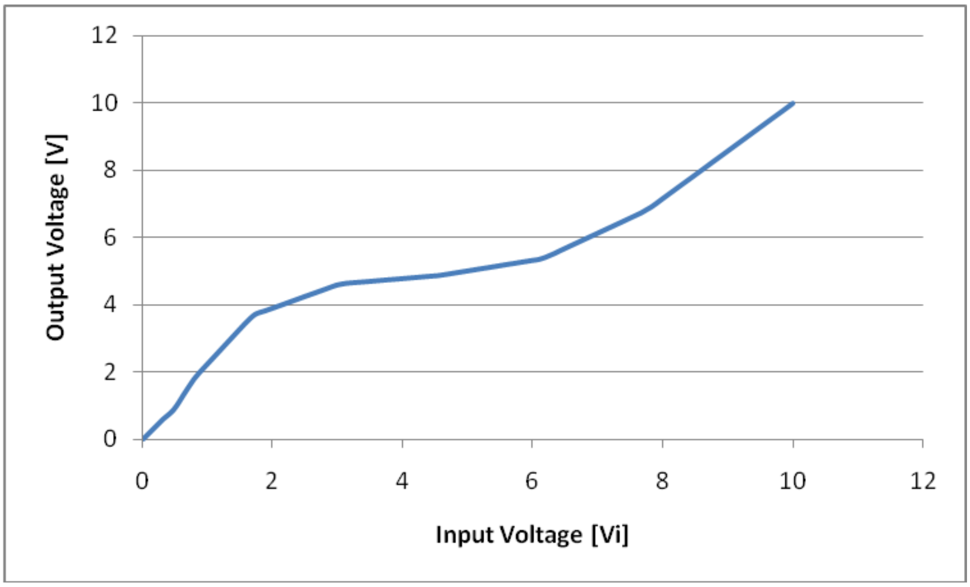


Figure 28.3: Approximated PLADC Characteristic

28.3. Characterizing the Ideal PLADC Curve:

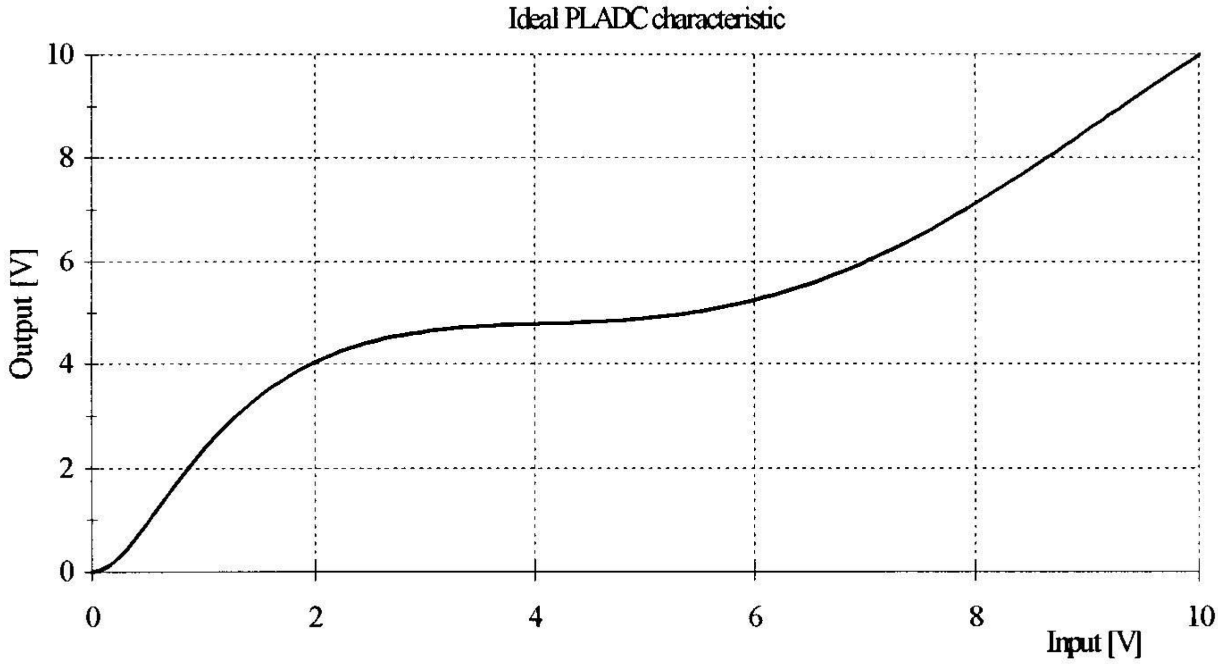


Figure 28.4: Ideal PLADC Characteristic

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 treadline (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:

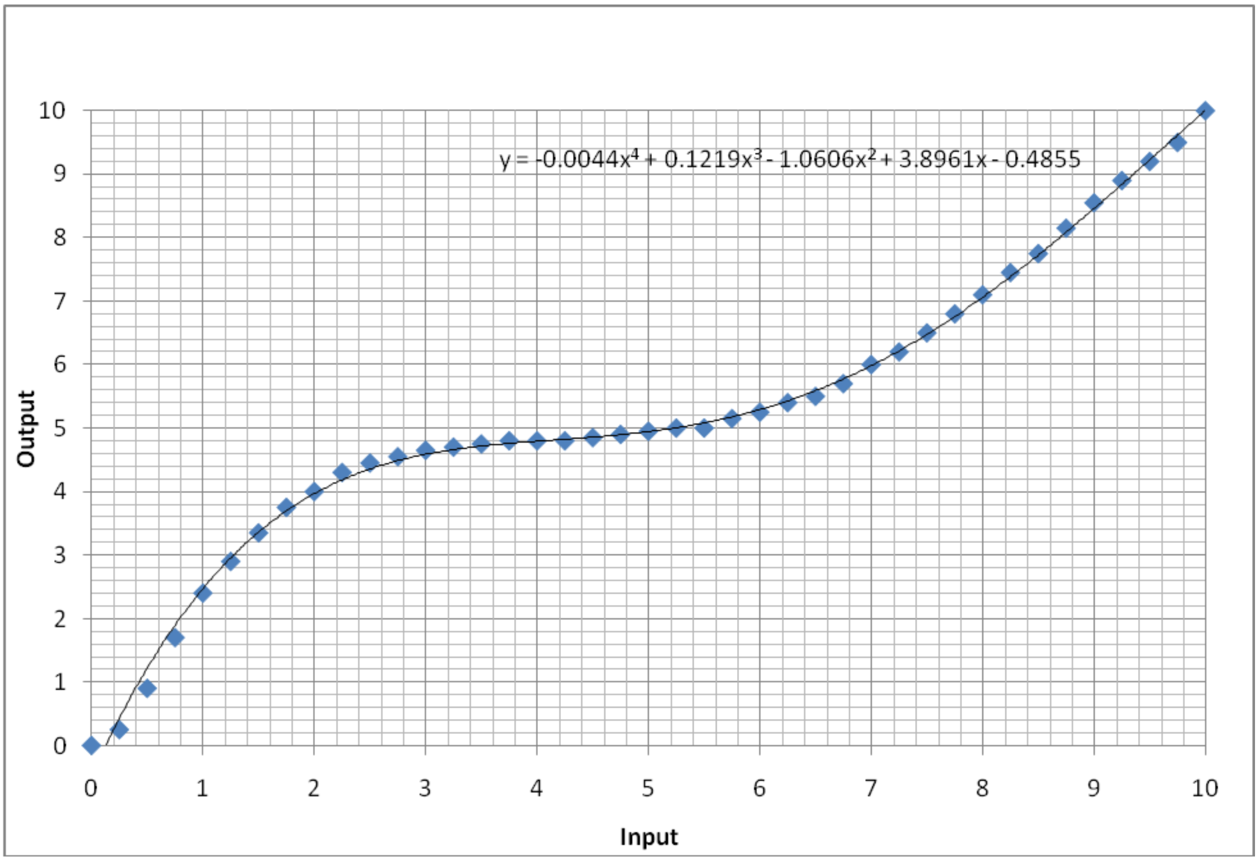


Figure 28.5: Approximated Ideal PLADC Characteristic

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

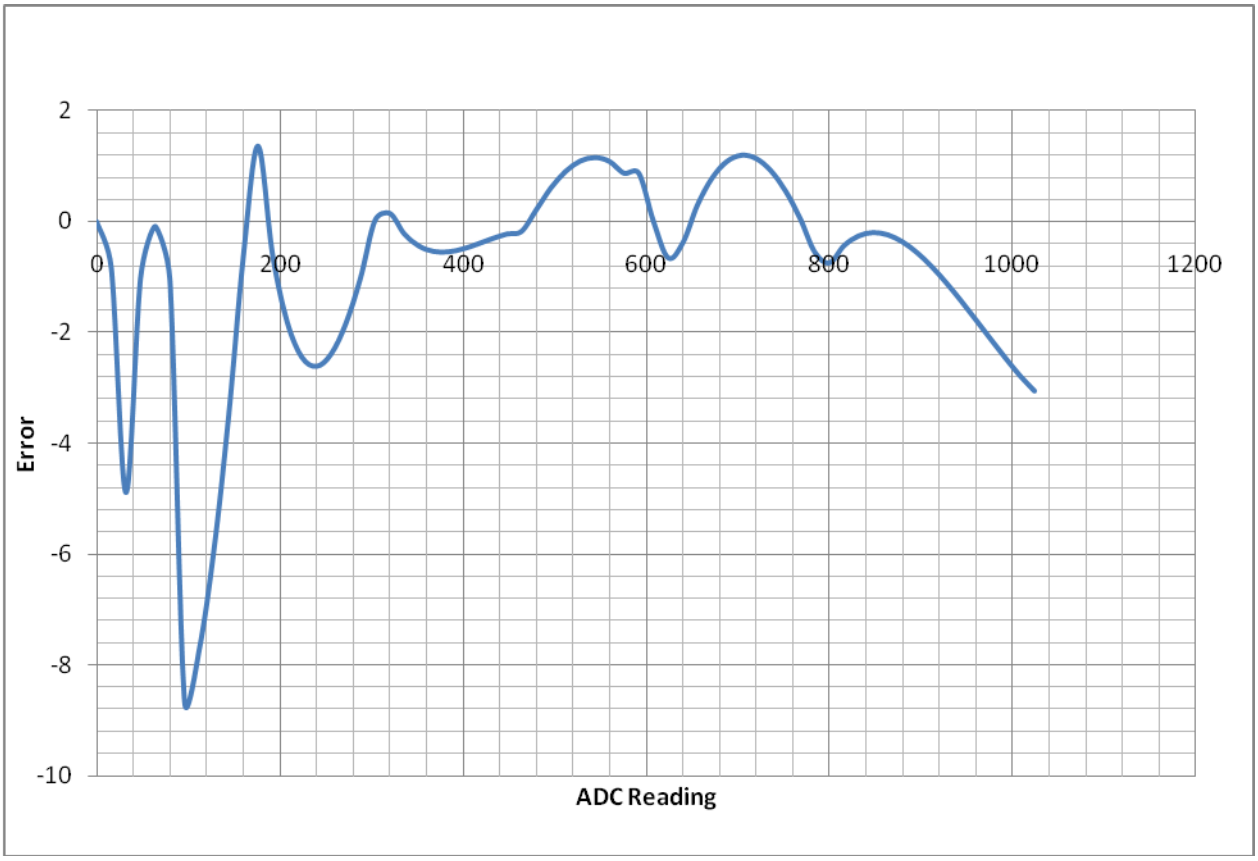


Figure 28.6: Error Plot

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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