

LINEARITY AND MONOTONICITY OF A 10-BIT, 125 MHZ, SEGMENTED  
CURRENT STEERING DIGITAL TO ANALOG CONVERTER

Charles C. Bittle, BSEE

Thesis Prepared for the Degree of  
MASTER OF SCIENCE

UNIVERSITY OF NORTH TEXAS

May, 2000

APPROVED:

Perry R. McNeill , Major Professor  
Eric Soenen, Industrial Representative,  
Texas Instruments Incorporated  
Mitty C. Plummer, Committee Member  
William A. Russell, Committee Member  
Albert B. Grubbs, Chair of the Department  
of Engineering Technology  
C. Neal Tate, Dean of the Robert B. Toulouse  
School of Graduate Studies

Bittle, Charles C., Linearity and monotonicity of a 10-bit, 125 MHz, segmented current steering digital to analog converter. Master of Science (Engineering Technology), May 2000, 116 pp., 7 tables, 53 illustrations, references, 18 titles.

The purpose of this research is to determine the linearity and monotonicity of the THS5651IDW digital to analog converter (DAC), a prototype of the future Texas Instruments TLV5651, 10-bit, 125 MHz communication DAC. Testing was conducted at the Texas Instruments facility on Forest Lane, Dallas, Texas. Texas Instruments provided test equipment, software and laboratory space to obtain test data. Analysis of the data found the DAC to be monotonic since the magnitude of the differential nonlinearity (DNL) was less than  $\pm 1$  least significant bit (LSB) and the integral nonlinearity (INL) was less than  $\pm 0.5$  LSB. The study also showed that the DAC has primarily negative DNL although the DNL is well within the desired specification.

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## ACKNOWLEDGMENTS

I express my gratitude to my advisor and major professor Dr. Perry R. McNeill. His scientific curiosity, encouragement, and guidance throughout this work have been necessary for this thesis.

I thank my graduate coordinator Dr. Michael R. Kozak for his confidence, encouragement and guidance throughout my graduate program and in writing this thesis.

I thank my Industrial advisor Dr. Eric Soenen, Mixed Signal Design Manager, Semiconductor Group of Texas Instruments Incorporated, Dallas, Texas, under who the binary/segmented current steering digital to analog converter was developed and who provided me with this research project.

I thank Rudy McGlothlin for use of the Texas Instruments, Inc. laboratory and equipment; Ifran Chaudhry for his guidance; and Mounir Fares for his assistance.

I express my gratitude to my committee members Dr. Mitty C. Plummer and Dr. William A. Russell for their guidance.

I thank my friend and librarian Edward Gonzalez for his assistance.

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## CHAPTER 1

### INTRODUCTION

Digital-to-analog converters (DACs) are devices by which digital processors communicate with the analog world. Although DACs are used as key elements in analog-to-digital converters (ADCs), they find numerous applications as stand-alone devices from Cathode Ray Tube displays to modern digital communication systems. The basic function of the DAC is the conversion of a digital number into an analog signal as shown in Figure 1. The conversion can be accomplished in terms of voltage, current, and charge division using resistor ladders, current steering circuits, and switched capacitors [1].

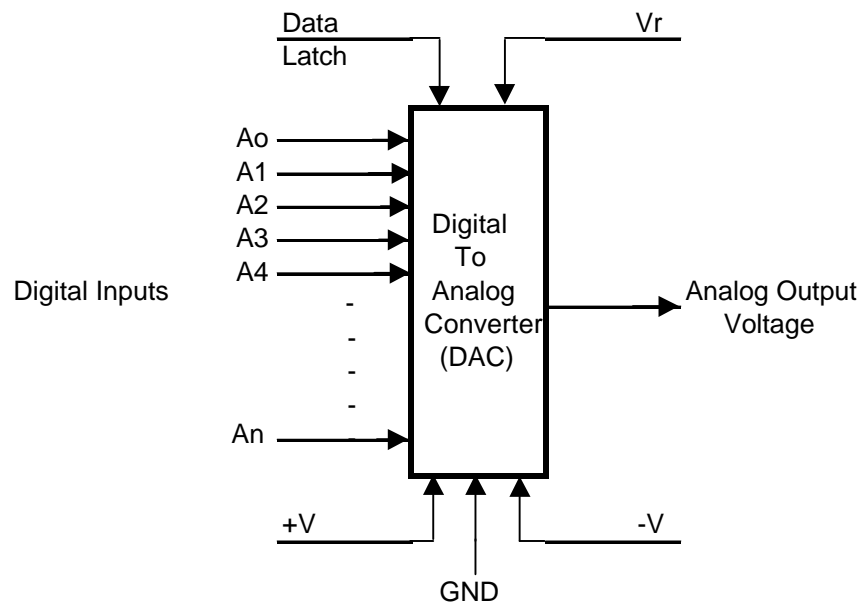


Figure 1. Generic DAC diagram [2].

Performance of a DAC can be specified in terms of its linearity and monotonicity. Linearity is expressed as differential nonlinearity (DNL) and integral nonlinearity (INL) as shown in Figure 2. The magnitude of the DNL and INL determines the monotonicity of the DAC [3].

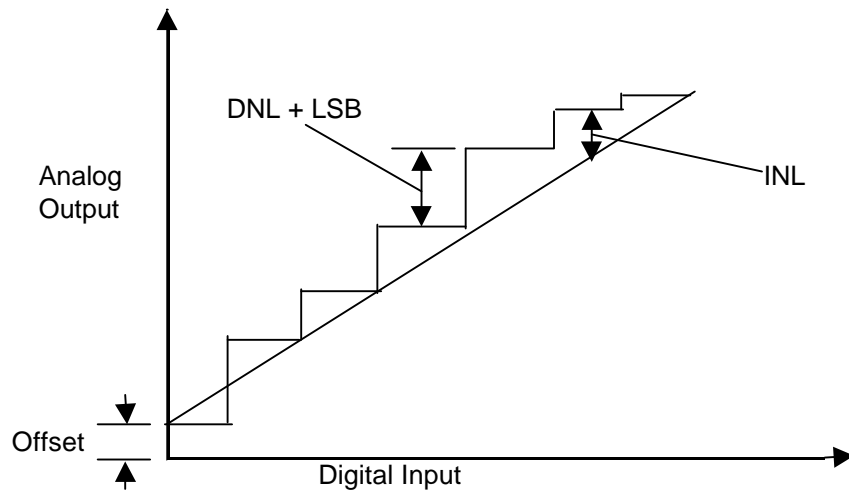


Figure 2. DNL and INL diagram [1].

A monotonic DAC is one in which, at any point in the characteristic from zero to full scale, an increase in the digital code results in an increase in the absolute value of the output voltage as shown in Figure 3. The source of large DNL and INL is the binary weighting of a DAC. For example, the most significant bit (MSB) has a weight of one half of the full range in a binary weighted DAC. If the MSB weight is smaller than the ideal value, the analog output change can be smaller than the resolution of the DAC when the digital input changes from one MSB to a higher MSB at the midpoint of the DAC's full range. If this decrease is greater than one least significant bit (LSB), the binary weighted DAC becomes nonmonotonic as shown in Figure 4 [3].

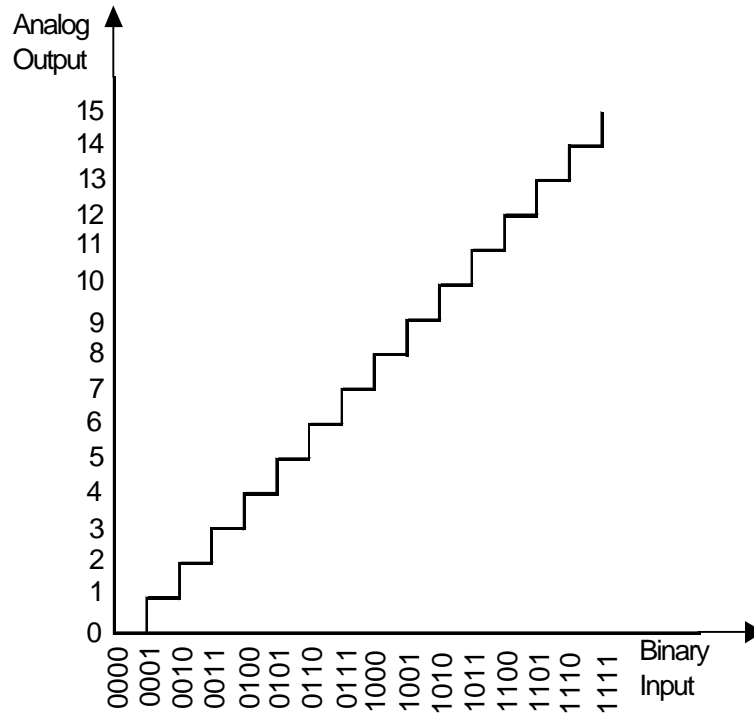


Figure 3. Monotonic output of a generic 4-bit DAC [5].

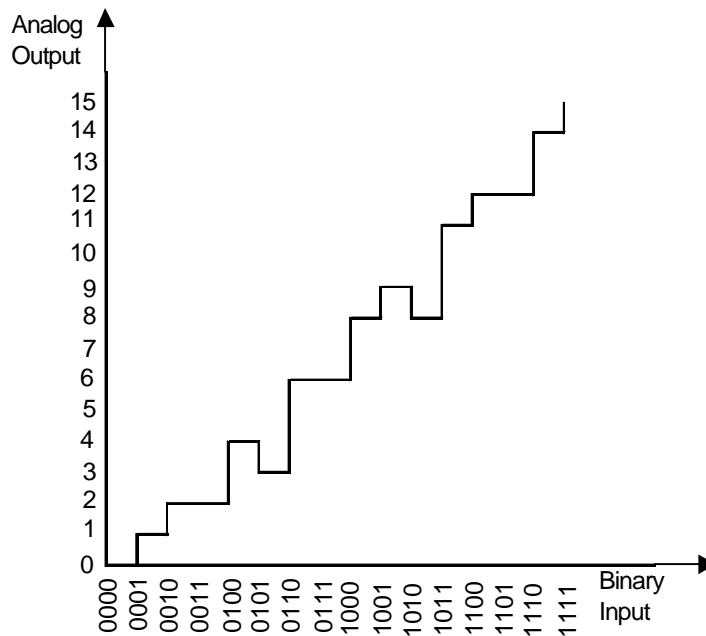


Figure 4. Nonmonotonic output of a generic 4-bit DAC [5].

The segmented current steering DAC uses several conversion partitions or segments to overcome the source of nonmonotonicity described above for binary weighted DACs. The ideal N-bit segmented current steering DAC is made of  $2^N$  elements for thermometer coding. Binary-to-thermometer code conversions are shown in Table I. For example, the binary *011* is converted to three *1*'s and one *0*. This code can be viewed as a thermometer that is *filled* up to the topmost ONE in the column and hence the name *thermometer code* [1].

Binary			Thermometer						
A	B	C	T1	T2	T3	T4	T5	T6	T7
0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0
0	1	0	1	1	0	0	0	0	0
0	1	1	1	1	1	0	0	0	0
1	0	0	1	1	1	1	0	0	0
1	0	1	1	1	1	1	1	0	0
1	1	0	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1

Table I. Binary to thermometer code conversion [1].

However, it is impractical to implement high resolution DACs using  $2^N$  elements because the number of elements grows exponentially as N increases [3]. The segmented current steering DAC being studied in this research project is divided into three segments, which are MSB, mid-bit (MID), and LSB. Each segment is made of identical current source elements. Current source elements for MSB and MID segments are selected by

thermometer code while the LSB current source element, the basic current source, remains a binary weighted bit. These segments reduce the number of components required to produce a 10-bit segmented current steering DAC and still maintain monotonicity [6].

#### Purpose of the Research

The purpose of this research is to determine the linearity and monotonicity of Texas Instruments' THS5651IDW, 10-bit, 125 MHz, segmented current steering DAC [6]. This DAC is a prototype version of the proposed production model, TLV5651, 2.7V-5.5V, 10-bit, 125 MHz, Communication DAC [7].

#### Statement of the Problem

The problem addressed in this thesis is the monotonicity of the Texas Instruments' THS5651IDW prototype DAC. A nonmonotonic DAC will actually reverse in some portion of the full conversion scale, leading to the same output voltage for two different digital inputs [4]. The monotonicity of this prototype DAC will directly impact the decision to manufacture the production model [6].

#### Research Questions

There are two research questions addressed in this study. They are presented in terms of null ( $H_0$ ) and alternative ( $H_a$ ) hypothesis as follows:

1. For differential nonlinearity (DNL),

$$H_{01}: \mu_{dnl} = \mu_d \quad (1)$$

$$H_{a1}: \mu_{dnl} \neq \mu_d \quad (2)$$

where

$\mu_{dnl}$  is the magnitude of the DNL, and

$\mu_d$  is within  $\pm 1$  LSB.

2. For integral nonlinearity (INL),

$$H_{o2}: \mu_{inl} = \mu_i \quad (3)$$

$$H_{a2}: \mu_{inl} \neq \mu_i \quad (4)$$

where

$\mu_{inl}$  is the magnitude of the INL, and

$\mu_i$  is within  $\pm 0.5$  LSB.

### Significance of the Research

Speed and precision of DACs are a serious concerns for cellular phone base station designers. Communication DACs are used in the transmit path of cellular phone base stations. Segmented current steering DACs are faster than other DAC architectures as they can directly drive resistive loads and do not need high speed amplifiers. The current is never turned off, but steered to either of two load lines designed into the DAC. Monotonicity of a DAC is critical in digital control applications and especially in cellular phone base stations. The segmented current steering DAC architecture inherently guarantees monotonicity and avoids catastrophic analog output errors [3]. Results of this study will directly impact the decision to manufacture the production model [6].

### Assumptions

The following assumptions apply to the research performed in this thesis:

1. The environment of the test laboratory will not impact test results since the THS5651IDW DAC is designed to operate in a free air temperature range of



-40 °C to 85 °C [8]. The free air temperature of the test laboratory was maintained at 25 °C.

2. Handling of DACs prior to testing will not impact test results since the human handling each DAC was attached to a grounded strap and DACs were placed in static shielding bags [7].
3. Texas Instruments' test equipment used in this research did not impact test results since this equipment has a long history of 24 hours a day usage and has been calibrated on a regular schedule.

#### Limitations

The following limitations will apply to this research:

1. The study will be limited to the Texas Instruments' THS5651IDW DAC.
2. All testing will be preformed at Texas Instruments' laboratory.
3. Texas Instruments' proprietary information will not be included in this research.
4. The test system in Texas Instruments' laboratory will be used for this research.

## CHAPTER 2

### REVIEW OF LITERATURE

#### Linearity

Differential nonlinearity (DNL) is a measure of the deviation of the actual digital to analog converter (DAC) output voltage step size from the ideal voltage step for one least significant bit (LSB), as shown in Figure 2 of Chapter 1 [1].

A formula for calculating DNL is the following [3]:

$$\text{DNL (i)} = [ V_{\text{out}} (D_{i+1}) - V_{\text{out}} (D_i) - V_{\text{ref}} / 2^N ] / [ V_{\text{ref}} / 2^N ] , \quad (5)$$

for  $i = 0, 1, \dots, 2^N - 2$  (LSB)

where

$V_{\text{out}}$  = the output voltage,

$V_{\text{ref}}$  = the reference voltage,

$N$  = the DAC's number of bits, and

$D$  = the digital word.

Integral nonlinearity (INL) is a measure of deviation of the actual DAC output voltage from a straight line drawn between two end points as shown in Figure 2 of Chapter 1[1]. A formula for calculating INL is the following [3]:

$$\text{INL (i)} = [ V_{\text{out}} (D_i) - i \times V_{\text{ref}} / 2^N ] / [ V_{\text{ref}} / 2^N ] , \quad (6)$$

for  $i = 0, 1, \dots, 2^N - 1$  (LSB)

where

$V_{\text{out}}$  = the output voltage,

$V_{\text{ref}}$  = the reference voltage,

$N$  = the DAC's number of bits, and

$D$  = the digital word.

There are several definitions of INL that may result from how the end points are defined. In some DAC architectures the two end points are not exactly 0 and  $V_{ref}$ . The non-ideal reference point causes an offset error, while the non-ideal full-scale range gives rise to a gain error. In most DAC applications, these offset and gain errors resulting from the non-ideal endpoints do not matter, and the INL can be better defined as a relative measure using a straight line linearity concept rather than the end point linearity in the absolute measure. The straight line can be defined as two end points of the actual DAC output voltages or as a theoretical straight line adjusted to best fit the actual DAC output characteristics. The former definition is sometimes called end point linearity, while the latter is called best straight-line linearity [3].

The best straight-line linearity was used to measure the INL of the THS5651IDW DAC. A least squares fit of the data to a line was made to determine the slope and intercept that corresponded to the LSB and offset. INL and DNL were calculated as follows [3], [7]:

$$INL(i) = [\text{Measured value}(i) - \text{Best fit value}] / \text{LSB}, \text{ for } i = 0, 1, \dots, 2^N - 1 \quad (7)$$

$$DNL(i) = INL(i+1) - INL(i), \text{ for } i = 0, 1, \dots, 2^N - 1 \quad (8)$$

#### Monotonicity

A monotonic DAC is one in which, at any point in the characteristic from zero to full scale, an increase in the digital code results in an increase in the absolute value of the output voltage. Nonmonotonic converters may actually reverse in some portion of the characteristic, leading to the same output voltage for two different digital inputs [4].

Monotonicity is inherently guaranteed, if an N-bit DAC is made of  $2^N$  elements for thermometer decoding; the magnitude of its DNL is within  $\pm 1$  LSB [3]; and the magnitude of its INL is within  $\pm 0.5$  LSB [9]. However, it is impractical to implement high resolution DACs using  $2^N$  elements; because the number of elements grows exponentially as N increases. Therefore, to guarantee monotonicity in practical applications, segmented DACs have been implemented using thermometer coding [3].

### Segmented Converters

In some applications, accuracy does not imply absolute linearity but rather differential linearity, which is very critical because an error between two successive steps larger than a half LSB cannot be tolerated. Difficulty occurs when changes of most significant bits (MSBs) occur. To overcome this problem, segmented converters were designed. The idea is to divide the full conversion scale into segments. In this case, passing from one segment to another is achieved in a smooth manner [4].

### THS5651IDW 10-bit DAC

The THS5651IDW is a 10-bit prototype member of the Texas Instruments' communication series of high performance, low power complementary metal oxide semiconductor (CMOS) field-effect transistor DACs. Figure 5 is a top view of the THS5651IDW DAC. This DAC was designed for the transmit signal path of communication systems. The single supply operating range of 2.7 to 5.5 Volts and low power dissipation are suited for portable applications [8].

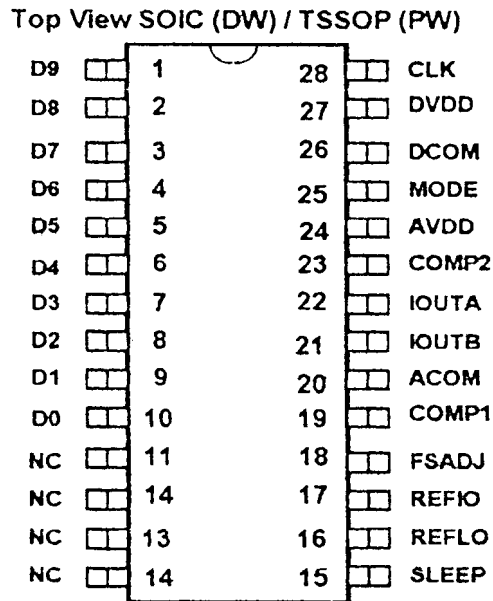


Figure 5. Top view of the THS5651IDW DAC [8].

A block diagram of the THS5651IDW DAC is shown in Figure 6. The THS5651IDW has 20 mA current outputs with greater than 100 k $\Omega$  output impedance. Differential current outputs are provided to support single-ended or differential applications. Each current output may be tied directly to an output resistor to provide two complementary, single-ended 1.25 voltage outputs or fed directly into a transformer. IOUT1 goes from 0 to full scale when all digital inputs are ones. IOUT2 goes from full scale to 0 when all digital inputs are ones (complementary to IOUT1). IOUT1 was used for this research project [8].

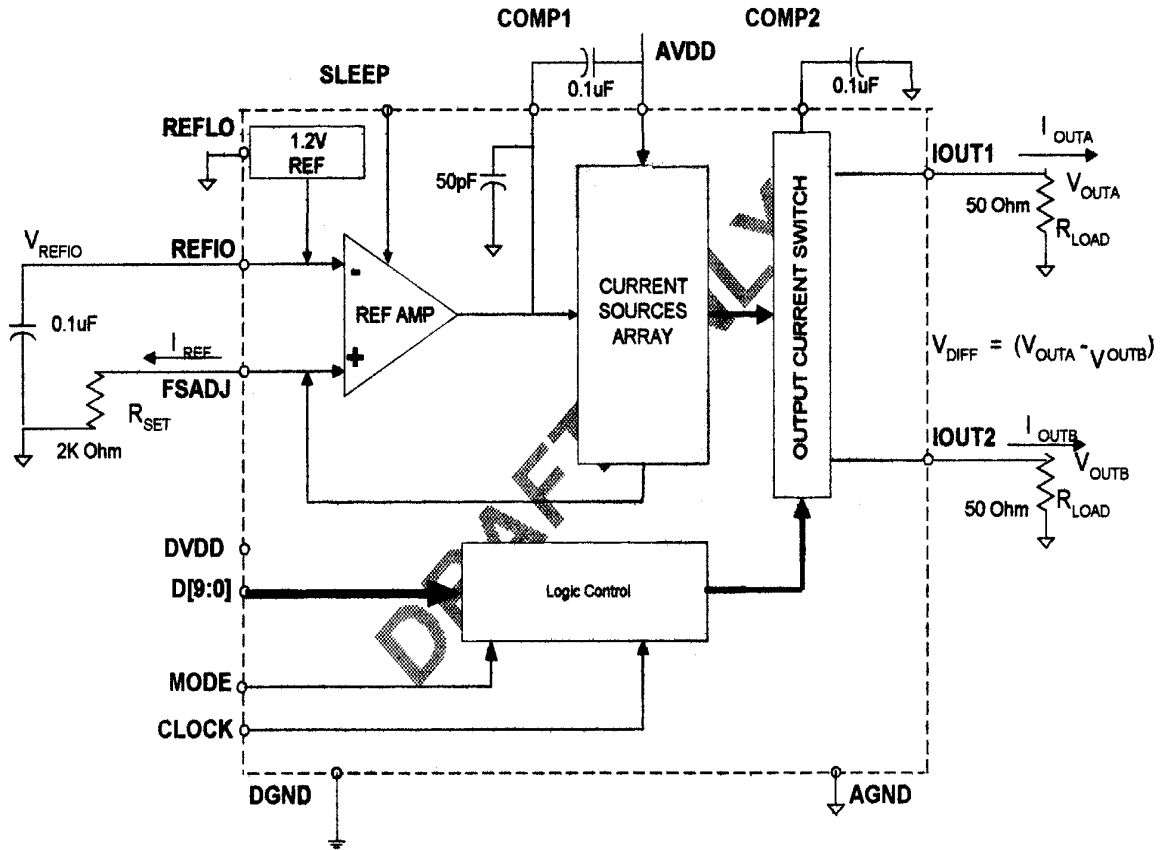


Figure 6. Block diagram of the THS5651IDW DAC [8].

The THS5651IDW is a 5-4-1 segmented current steering DAC. The number of current cells in each  $N$ -bit segment is  $2^N - 1$ . The 1 segment refers to the LSB current cell. Table II shows the 5-4 segmentation of the 17 x 32 current array in more detail. The 4 segment refers to the mid-bit (MID) segment. In this segment, there are 15 separate MID unit current cell pairs that are located down the center diagonal of the 17 x 32 current

array. The 5 segment refers to the most significant bit (MSB) segment. In this segment, there are 31 separate current cells. Each MSB current cell consists of 16 unit current cell pairs connected in a diagonal pattern. Each segment is like a separate DAC [10].

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32		
1		MSB 15	MSB 24	MSB 16	MSB 23	MSB 10	MSB 29	MSB 5	MSB 18	MSB 12	MSB 27	MSB 3	MSB 20	MSB 9	MSB 30	MSB 6	MSB 17	MSB 14	MSB 25	MSB 1	MSB 22	MSB 11	MSB 28	MSB 4	MSB 19	MSB 13	MSB 26	MSB 2	MSB 21	MSB 8	MSB 31	MSB 7		
2		MID 15		15	24	16	23	10	29	5	18	12	27	3	20	9	30	6	17	14	25	1	22	11	28	4	19	13	26	2	21		MSB 8	
3		MSB 31	7		MID 13		15	24	16	23	10	29	5	18	12	27	3	20	9	30	6	17	14	25	1	22	11	28	4	19	13	26		MSB 2
4		MSB 21	8	31	7		MID 11		15	24	16	23	10	29	5	18	12	27	3	20	9	30	6	17	14	25	1	22	11	28	4	19		MSB 13
5		MSB 26	2	21	8	31	7		MID 9		15	24	16	23	10	29	5	18	12	27	3	20	9	30	6	17	14	25	1	22	11	28		MSB 4
6		MSB 19	13	26	2	21	8	31	7		MID 7		15	24	16	23	10	29	5	18	12	27	3	20	9	30	6	17	14	25	1	22		MSB 11
7		MSB 28	4	19	13	26	2	21	8	31	7		MID 5		15	24	16	23	10	29	5	18	12	27	3	20	9	30	6	17	14	25		MSB 1
8		MSB 22	11	28	4	19	13	26	2	21	8	31	7		MID 3		15	24	16	23	10	29	5	18	12	27	3	20	9	30	6	17		MSB 14
9		MSB 25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 1		15	24	16	23	10	29	5	18	12	27	3	20	9	30		MSB 6
10		MSB 17	14	25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 2		15	24	16	23	10	29	5	18	12	27	3	20		MSB 9
11		MSB 30	6	17	14	25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 4		15	24	16	23	10	29	5	18	12	27		MSB 3
12		MSB 20	9	30	6	17	14	25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 6		15	24	16	23	10	29	5	18		MSB 12
13		MSB 27	3	20	9	30	6	17	14	25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 8		15	24	16	23	10	29		MSB 5
14		MSB 18	12	27	3	20	9	30	6	17	14	25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 10		15	24	16	23		MSB 10
15		MSB 29	5	18	12	27	3	20	9	30	6	17	14	25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 12		15	24		MSB 16
16			10	29	5	18	12	27	3	20	9	30	6	17	14	25	1	22	11	28	4	19	13	26	2	21	8	31	7		MID 14		MSB 15	
17				MSB 10	MSB 29	MSB 5	MSB 18	MSB 12	MSB 27	MSB 3	MSB 20	MSB 9	MSB 30	MSB 6	MSB 17	MSB 14	MSB 25	MSB 1	MSB 22	MSB 11	MSB 28	MSB 4	MSB 19	MSB 13	MSB 26	MSB 2	MSB 21	MSB 8	MSB 31	MSB 7				

Table II. Segmented current cell array pattern for THS5651IDW DAC [10].

A generic current cell is shown in Figure 7. This diagram illustrates the basic concept of how the THS5651IDW DAC operates (The actual current cell diagram used in the THS5651IDW DAC is Texas Instruments' proprietary information). Transistors M1 and M3 are on when the input digital bit is 0. An analog voltage is present at IOU<sub>TB</sub> and no analog voltage is developed at IOU<sub>T</sub>. A digital input of 1 at the input turns off transistor M3 and turns on transistor M2. Thus, an analog voltage is present at IOU<sub>T</sub> and none at IOU<sub>TB</sub>. In a 10-bit DAC all 1024 M2 transistors are connected to IOU<sub>T</sub> and all 1024 M3 transistors are connected to IOU<sub>TB</sub>. When all digital inputs are 0s, IOU<sub>TB</sub> has full-scale voltage and IOU<sub>T</sub> has zero voltage. When all digital inputs are 1s, IOU<sub>T</sub> has full-scale voltage and IOU<sub>TB</sub> has zero voltage [10].

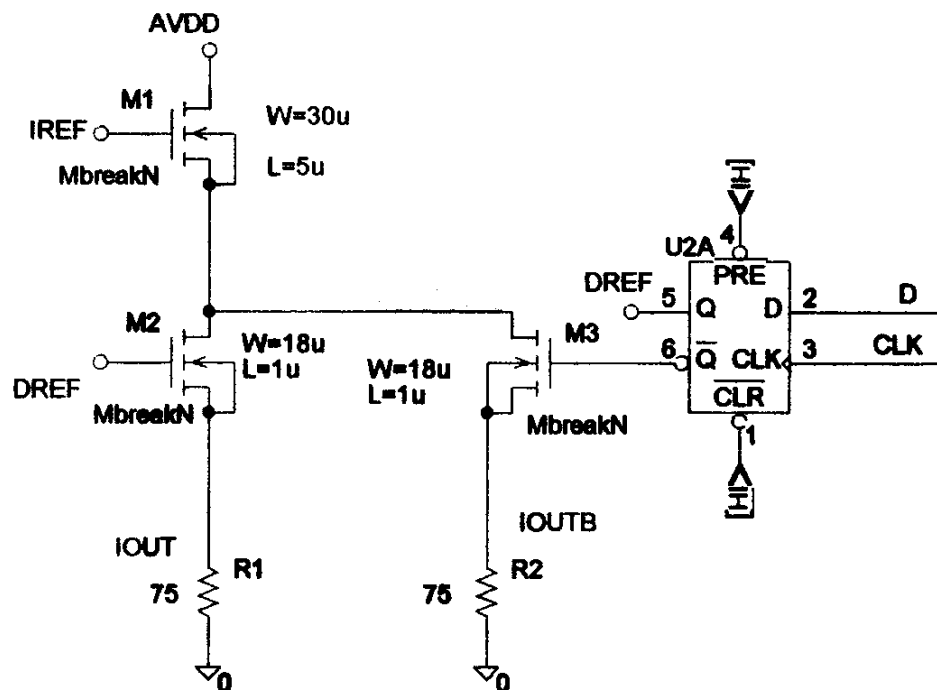


Figure 7. A generic current cell [10].



## Software

LabView<sup>®</sup> and MATLAB<sup>®</sup> software were used for this research project.

LabView<sup>®</sup> (**L**aboratory **V**irtual **I**nstrumentation **E**ngineering **W**orkbench) is a graphical programming language that has been adopted throughout industry, academia, and government laboratories as the standard for data acquisition and instrument control software [11]. A LabView<sup>®</sup> software program, developed by Texas Instruments, was used for data acquisition, calculation of INL and DNL values, and instrument control. This program is included in Appendix A. MATLAB<sup>®</sup> software has become popular in engineering fields and can be considered the world standard for simulation and analysis of linear and nonlinear dynamic systems [12]. MATLAB<sup>®</sup> software shown in Appendix D was developed during this research project. It was used to calculate the analog voltage output resulting from each current cell pair in the current cell array of Table II above and to plot Figure 10 and 11 of Chapter IV.

## CHAPTER 3

### METHODOLOGY

#### Description of Population and Sample

One wafer of THS5651IDW digital to analog converters (DACs) was manufactured. A population of 3000 DACs was produced from this wafer [7].

The equation for determining the sample size is as follows [13]:

$$n = Z^2 pq/h^2 \quad (9)$$

where,

$Z = 2$  or  $3$  for  $95\%$  or  $99\%$  confidence, respectively,

$h$  = half-interval width ( $0.5$  LSB for DNL and  $0.25$  LSB for INL),

$p$  = proportion of sample which is defective,

$q = 1-p$ , and

$n$  = sample size.

If an estimate of  $p$  is not given, a conservative approach to sample size determination allows  $p$  and  $q$  to be values that make the product of  $pq$  as large as possible. That is  $p = q = 0.5$ . Thus,  $pq = 0.25$  [13].

For  $99\%$  confidence interval, a sample size of  $9$  DACs is required for DNL tests and a sample size of  $36$  DACs is required for INL tests. Therefore, a sample size of  $36$  DACs was used for DNL and INL tests. Texas Instruments selected a sample of  $36$  DACs using a random number table [7].

## Research Design

The dependent explanatory variable is the output voltage of the DAC. The independent explanatory variable is the digital input (bits) to the DAC. The controlled variable is the current array pattern of the DAC. The extraneous variable is static charge applied to each DAC during handling. This variable could destroy a DAC. Two methods were used to eliminate the extraneous variable. First, DACs were placed in static shielding bags when not mounted on the test board and transported to and from the test laboratory. Second, the human handling each DAC was attached to a grounded strap. If the human became disconnected from the grounding strap a beeper would sound. The DAC is designed to operate in a free air temperature range of -40 °C to 85 °C [8]. The free air temperature of the test laboratory was maintained at 25 °C [7]. The environment of the test laboratory was not considered a variable for this study.

## Equipment

Texas Instruments provided the test equipment used in this project. Figure 8 is a block diagram of test equipment. The Hewlett-Packard (HP) E3631A power supply provided power to the test board and DAC. Voltage can be adjusted from the front panel or programmed by a computer program using the HP developed **General Purpose Interface Bus (GPIB)** or Institute of Electrical and Electronic Engineers Standard 488-1975 [11] port on the power supply [14]. The Tecktronics HFS9009 stimulus system provided the digital input to the DAC. The HFS 9009 has the ability to produce the DC levels needed to drive logic lines directly and can be programmed by a computer program through GPIB port on the stimulus system. The HFS 9DG1 data time generator card installed in the HFS 9009 provides four channels of stimulus [15]. A HP 3458A

multimeter sampled output voltages of the DAC and transmitted digitized signals to the computer through the multimeter's a GPIB port to a computer [16]. The Analog Device (AD) 9760 evaluation board (EB) contains the necessary electronics to evaluate 8, 10, 12, 14 bit DACs. One DAC can be inserted into a 28-pin socket for testing [17]. Equipment settings were 1 analog volt maximum output, 40  $\mu$  seconds between samples, and 1024 samples. Data was collected at the  $V_{OUTA}$  (Iout1) port shown in Figure 6 of Chapter 2.

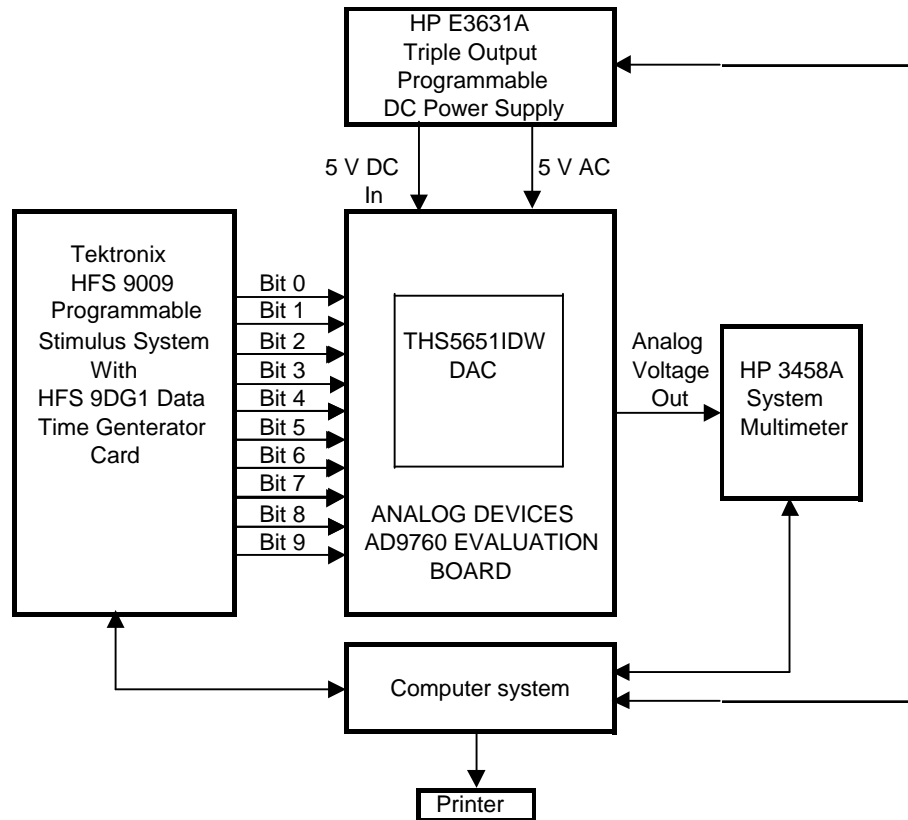


Figure 8. Block diagram of test equipment.

## LabVIEW® Software

Texas Instruments' developed LabVIEW® software programs were used in this research. Linearity.vi is the hierarchical virtual instrument (VI) program that displayed the main software menu. This VI is the only LabVIEW® software program shown in Appendix A since development of this software was not part of this research. Texas Instruments' proprietary information, indicated as a **?**, was removed from this VI program [7]. Linearity.vi has 10 case stations and contains the main menu as shown in Figure 9. Case stations are as follows [7]:

1. Case 0 initializes the program.
2. Case 1 brings up the main menu shown in Figure 4. (Cases 2 through 9 are called according to which menu switch is selected.)
3. Case 2 allows the set up information to be changed for different DAC tests when the **Configuration** switch is selected.
4. Case 3 allows the pattern generator to be set up for different DAC tests when the **Setup Pattern Generator** switch is selected.
5. Case 4 reads Multimeter output voltages and calculates INL and DNL values when the **Take Measurement** switch is selected.
6. Case 5 opens the graph window to display INL and DNL when the **Display Graphs** switch is selected.
7. Case 6 saves data to a file when the **Save Data** switch is selected.
8. Case 7 prints a report when the **Print Report** switch is selected.

9. Case 8 exits the program when the **Exit** switch is selected.
10. Case 9 displays the INL and DNL graphs when the **Display Graphs** switch is selected.

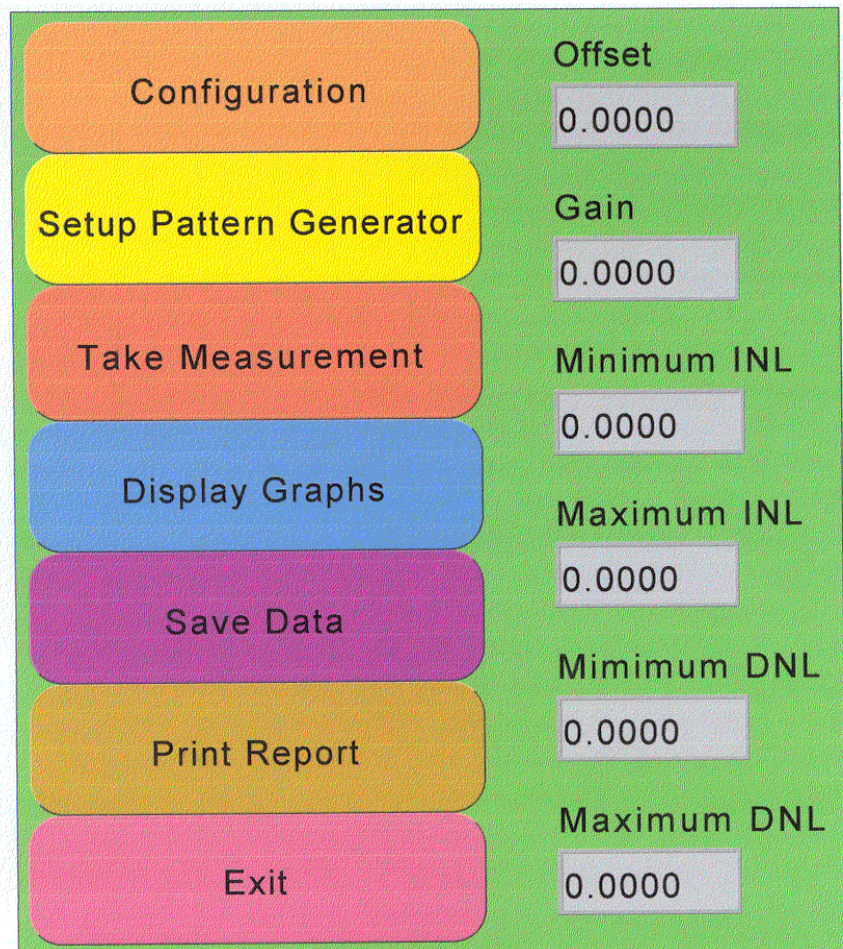


Figure 9. Front panel of LabVIEW<sup>®</sup> software program [7].

A DAC was inserted into a socket on the test board. The **Take Measurement** switch was selected. Voltage outputs of the DAC were acquired for 1024 codes. The software used these voltage values to calculate INL and DNL values. The **Display Graphs** switch was selected. INL and DNL graphs appeared to the right of the menu shown in Figure 9. These graphs were inspected before saving the data. The **Save Data** and **Print Report** switches were selected. Data was saved to a disk and graphs were printed. This was repeated for all 36 DACs.

## CHAPTER 4

### ANALYSIS AND RESULTS

The LabVIEW<sup>®</sup> program shown in Appendix A was used to record the analog output voltage, calculate the integral nonlinearity (INL) and differential nonlinearity (DNL), and plot INL and DNL values. INL and DNL graphs for all 36 digital to analog converters (DACs) are included in Appendix B. This data was also stored in a text format compatible with Microsoft Excel software. The analog voltage, INL, and DNL for all 1024 samples of each DAC were printed using Microsoft Excel, 21 pages per DAC for a total of 756 pages. Minimum and maximum values of INL and DNL were determined and tabulated in Table III.

Null ( $H_0$ ) and alternative ( $H_a$ ) hypothesis comparison for DNL and INL are as follows:

1. Table III shows that DNL for all 36 DACs is within  $\pm 1$  least significant bit (LSB). Equation 1 of Chapter 1 was met for DNL Therefore, the  $H_{01}$  hypothesis was accepted.
2. Table III shows that INL for all 36 DACs is within  $\pm 0.5$  LSB. Equation 3 of Chapter 1 was met for INL Therefore, the  $H_{02}$  hypothesis was accepted.

Since both  $H_0$  hypothesis were met, the Texas Instruments' THS5651IDW, 10-bit, 125 MHz, segmented current steering DAC is monotonic.



DAC	INL		DNL	
	Min.	Max.	Min.	Max.
1	-0.03107	0.2281	-0.0365	0.1567
2	-0.1661	0.1551	-0.0794	0.0554
3	-0.01973	0.193	-0.0703	0.0834
4	-0.1656	0.1716	-0.0921	0.053
5	-0.2128	0.2225	-0.0915	0.0837
6	-0.135	0.1312	-0.0958	0.0491
7	-0.1607	0.1478	-0.0576	0.1199
8	-0.1439	0.1159	-0.0784	0.0793
9	-0.1557	0.1874	-0.0493	0.1308
10	-0.1751	0.2016	-0.1206	0.0343
11	-0.163	0.1585	-0.0732	0.0796
12	-0.1684	0.1629	-0.0569	0.1157
13	-0.2099	0.1489	-0.0497	0.1598
14	-0.1556	0.175	-0.0946	0.0551
15	-0.1571	0.1447	-0.0805	0.0973
16	-0.1652	0.1231	-0.1018	0.0458
17	-0.2668	0.1906	-0.0908	0.0885
18	-0.2319	0.1524	-0.1539	0.0432
19	-0.3182	0.2647	-0.0413	0.1604
20	-0.2032	0.1626	-0.0587	0.1024
21	-0.1847	0.1235	-0.0765	0.0707
22	-0.185	0.1312	-0.1285	0.0418
23	-0.2049	0.1725	-0.0479	0.1265
24	-0.1497	0.163	-0.0698	0.0732
25	-0.1354	0.1021	-0.0668	0.1108
26	-0.1797	0.111	-0.0549	0.0676
27	-0.2314	0.2248	-0.1216	0.0636
28	-0.1721	0.1836	-0.1298	0.0608
29	-0.2962	0.2041	-0.0615	0.1153
30	-0.2039	0.1424	-0.0589	0.1038
31	-0.1656	0.1836	-0.1021	0.1211
32	-0.2813	0.1885	-0.0711	0.0724
33	-0.1945	0.2107	-0.1682	0.0372
34	-0.1546	0.1615	-0.0547	0.1374
35	-0.1468	0.163	-0.1154	0.0516
36	-0.1115	0.0944	-0.0875	0.0504

Table III. Minimum and maximum LSB values of INL and DNL.

Graphs of DNL in Appendix B show that the DAC has primarily negative DNL although the DNL is well within the desired monotonic specification. Texas Instruments requested a further study of data to determine if the cause of this phenomenon was a problem area in the current cell array [18].

### Mid-Bits

Table IV shows the mid-bits (MIDs) for DAC 10 and Table V shows the average MIDs for all 36 DACs. Referring to Appendix C, the first MID of DAC 10 is located at code 2 (0.0019 volts). The other 14 MIDs were calculated as follows:

$$\text{MID-n} = [\text{Volts}_{(i+2)} - \text{Volts}_{(i)}] \quad (10)$$

For  $i = \text{code } 2, 4, 6, \dots, 30$

$n = 2, 3, 4, \dots, 15$

MID	Volts
1	0.0019
2	0.00188
3	0.00189
4	0.00191
5	0.00191
6	0.00189
7	0.0019
8	0.00191
9	0.00192
10	0.00192
11	0.00191
12	0.00189
13	0.00192
14	0.0019
15	0.0019

Table IV. Mid-Bits of DAC 10.

MID	Volts
1	0.001912
2	0.001888
3	0.001888
4	0.001895
5	0.001896
6	0.001901
7	0.001893
8	0.001897
9	0.001901
10	0.001895
11	0.001897
12	0.001896
13	0.0019
14	0.001902
15	0.001908

Table V. Average MIDs for 36 DACs.

## Most Significant Bits

Table VI shows the most significant bits (MSBs) for DAC 10 and Table VII shows the average MSBs for all 36 DACs. Referring again to Appendix C, the first MSB of DAC 10 is located at code 32 (0.03046 volts). The other 30 MSBs values were calculated as follows:

$$\text{MSB-n} = [\text{Volts}_{(i+32)} - \text{Volts}_{(i)}] \text{ volts} \quad (11)$$

For  $i = \text{code } 32, 64, 128, \dots, 992$

$n = 2, 3, 4, \dots, 31$

MSB	Volts
1	0.030378
2	0.030363
3	0.030361
4	0.030366
5	0.030379
6	0.030381
7	0.030358
8	0.030352
9	0.030383
10	0.030376
11	0.030371
12	0.030382
13	0.030369
14	0.030368
15	0.030373
16	0.030352
17	0.030379
18	0.03037
19	0.030366
20	0.03036
21	0.030343
22	0.030358
23	0.030364
24	0.030346
25	0.030368
26	0.030341
27	0.030349
28	0.03035
29	0.030352
30	0.030344
31	0.030327

MSB	Volts
1	0.03046
2	0.0304
3	0.03038
4	0.03037
5	0.03045
6	0.03041
7	0.03046
8	0.03039
9	0.0304
10	0.03047
11	0.03037
12	0.03042
13	0.03043
14	0.03042
15	0.03044
16	0.03038
17	0.03039
18	0.03046
19	0.03034
20	0.03035
21	0.03037
22	0.03046
23	0.03041
24	0.03036
25	0.03038
26	0.03037
27	0.03039
28	0.03043
29	0.03038
30	0.03037
31	0.03038

Table VI. MSBs for DAC 10.

Table VII. Average MSBs for 36 DAC.

The MATLAB<sup>®</sup> program shown in Appendix D used the above MID and MSB data to calculate the millivolt output of each current cell pair for the current array shown in Table II of Chapter 2. Calculated data shown in Appendices E and F was used to plot overhead views shown in Figure 10 for DAC 10 and Figure 11 for the average of all 36 DACs. The white color represents unused current cell pairs that separate the MIDs from each other. Shades of gray represent equal millivolt values. Figures 10 and 11 do not indicate a major problem area in either current array.

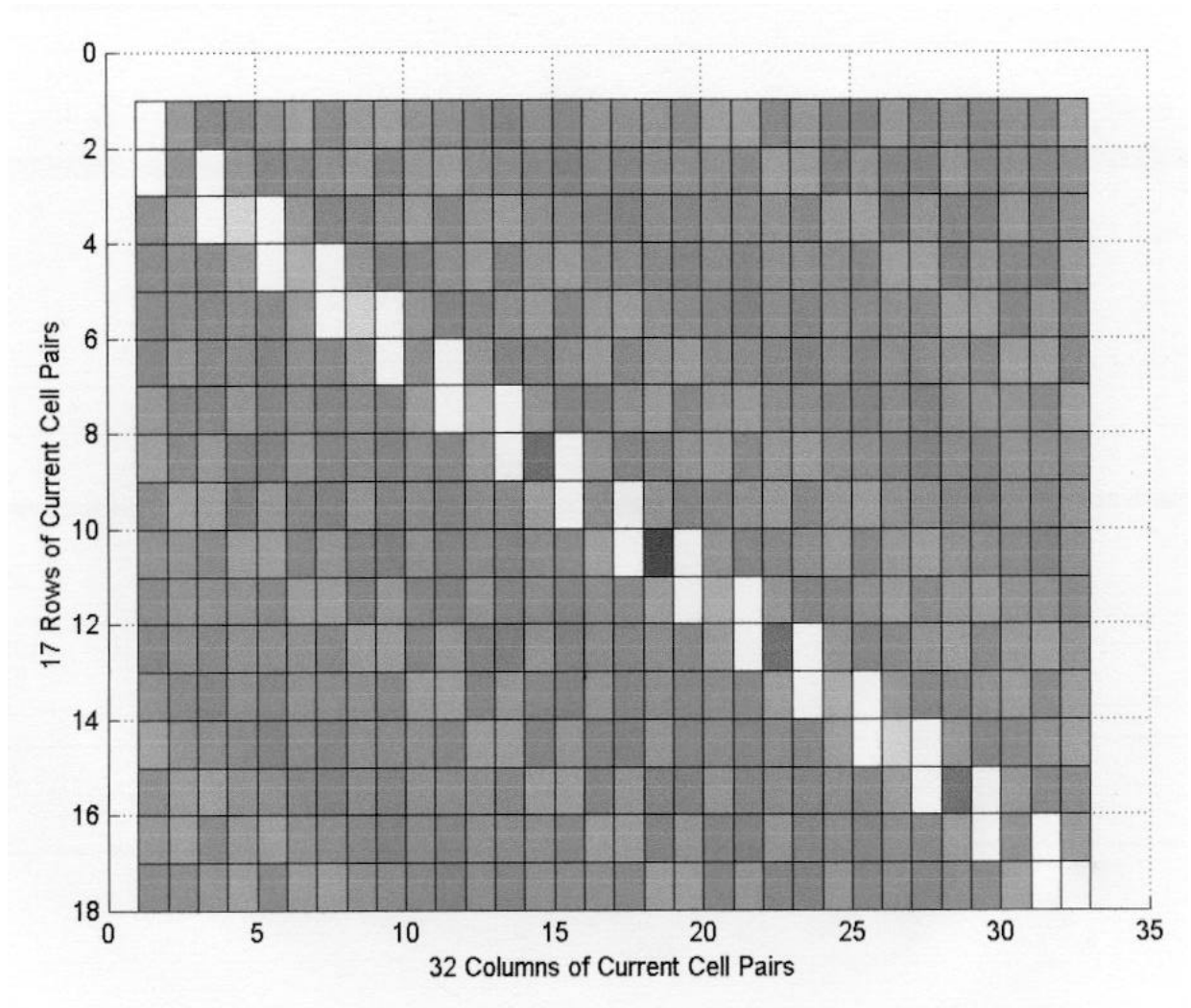


Figure 10. Voltage output of current cell pairs for DAC 10.

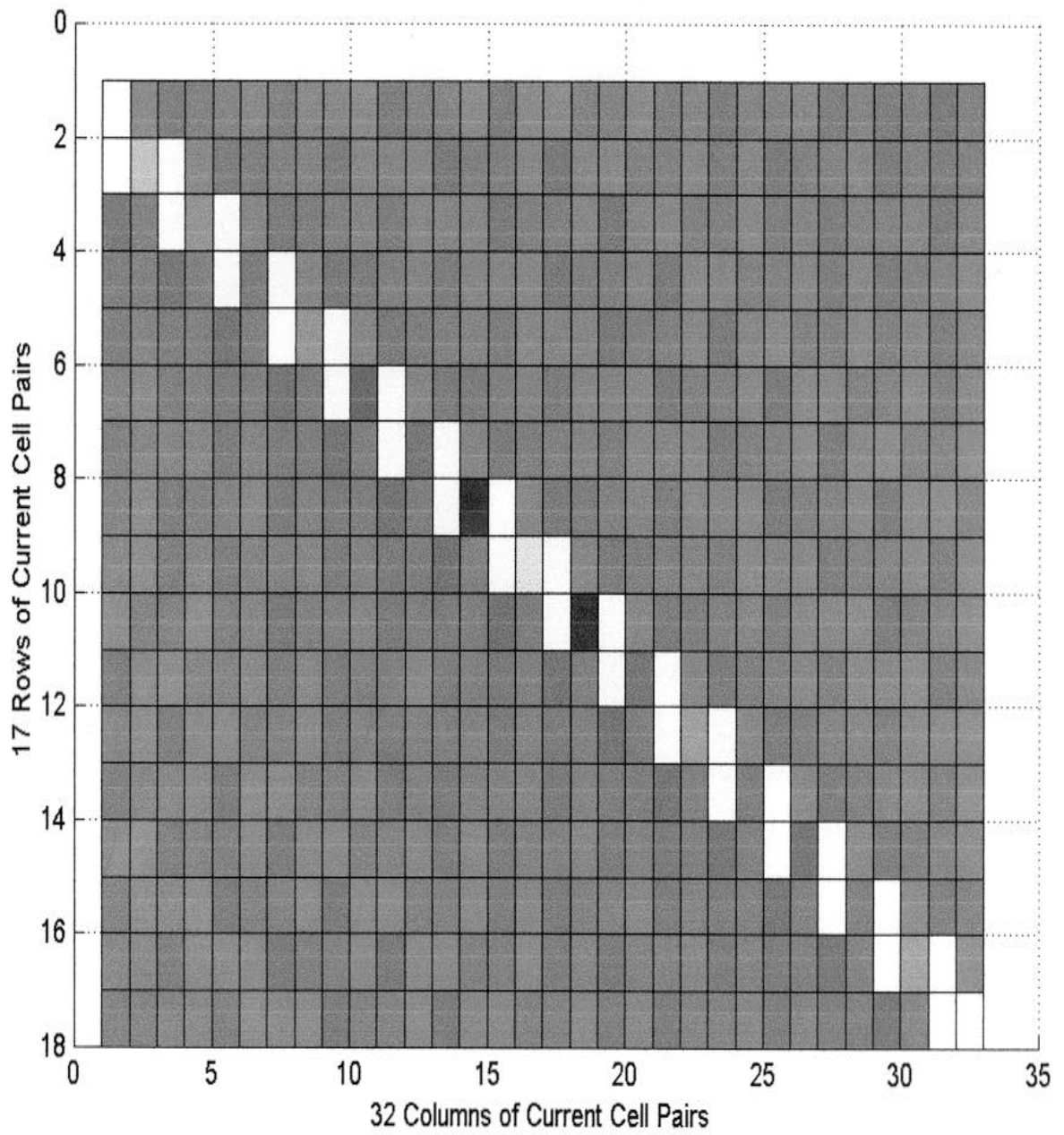


Figure 11. Average voltage output of current cell pairs for all 36 DACs.

## CHAPTER 5

### CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research was to determine the linearity and monotonicity of Texas Instruments' THS5651IDW, 10-bit, 125 MHz, segmented current steering digital to analog converter (DAC).

#### Conclusion

Analysis of the data found the Texas Instruments' THS5651IDW DAC to be monotonic since the magnitude of the differential nonlinearity (DNL) was less than  $\pm 1$  least significant bit (LSB) and the integral nonlinearity (INL) was less than  $\pm 0.5$  LSB. Plots of DNL showed that the DAC has primarily negative DNL although the DNL is well within the desired specification. Texas Instruments requested a further study of data to determine if the cause of the negative DNL phenomenon was a problem area in the current cell array [18]. Plots of the voltage output of each current cell pairs did not indicate a major problem area in the current cell array.

#### Recommendations

Recommendations for future research are listed as follows:

1. The research should be extended to develop a theoretical model of a current array pattern that will produce a symmetrical DNL. The solution to this problem will directly impact the yield of the product.
2. A study should be made to determine if the linearity of the analog to digital converter in the Hewlett-Packard 3458A System Multimeter causes the negative DNL phenomenon experienced in this research.

APPENDIX A  
LABVIEW<sup>®</sup> SOFTWARE



Student Edition

Linearity.vi

C:\Program Files\National Instruments\LabVIEW\Linearity.vi

Last modified on 02/01/1999 at 8:58 AM

Printed on 10/14/1999 at 8:45 AM

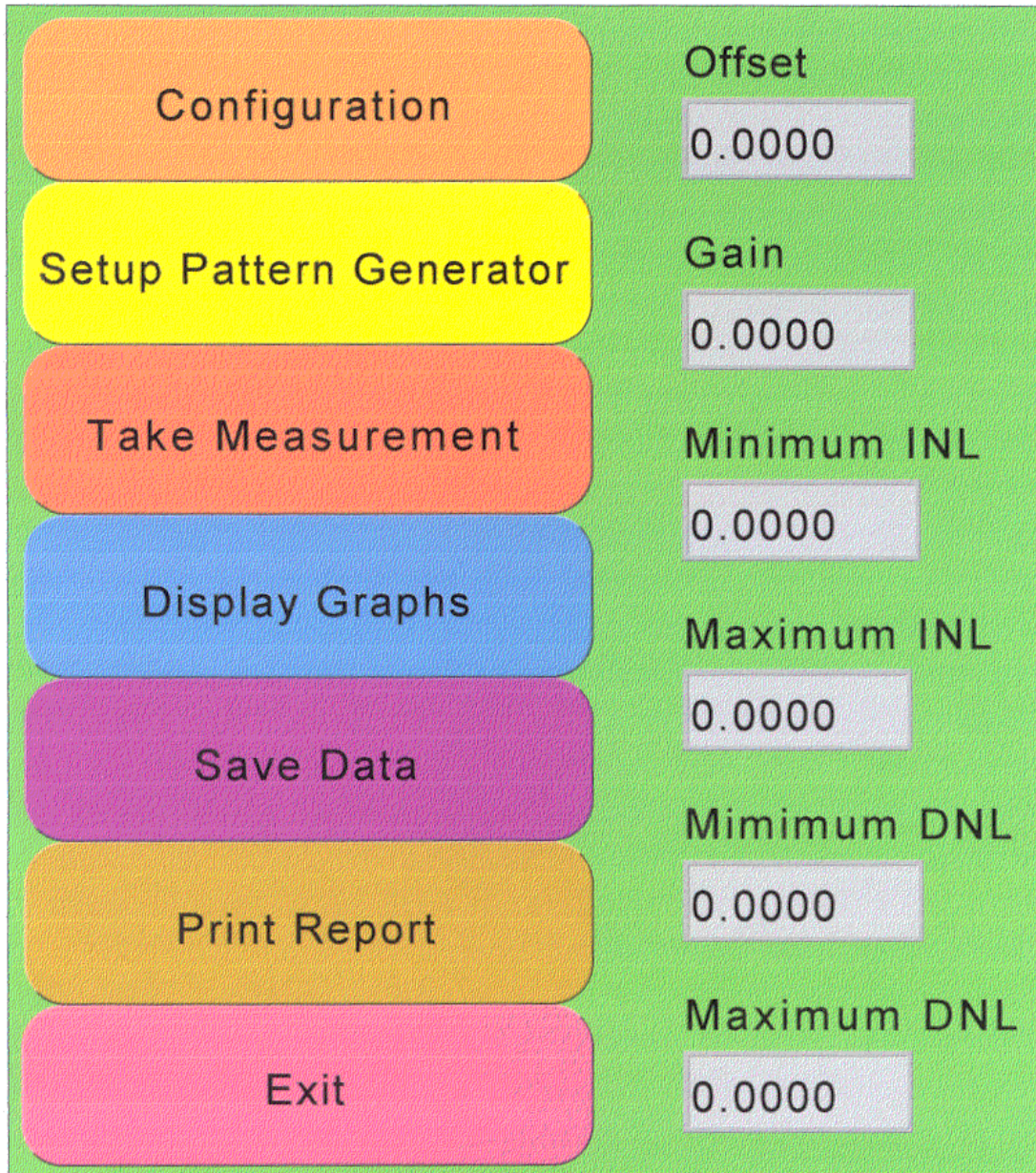


Figure 12. Main menu panel of LabView® software program.



Student Edition  
 Linearity.vi  
 C:\Program Files\National Instruments\LabVIEW\Linearity.vi  
 Last modified on 02/01/1999 at 8:56 AM  
 Printed on 10/14/1999 at 8:31 AM

Block Diagram

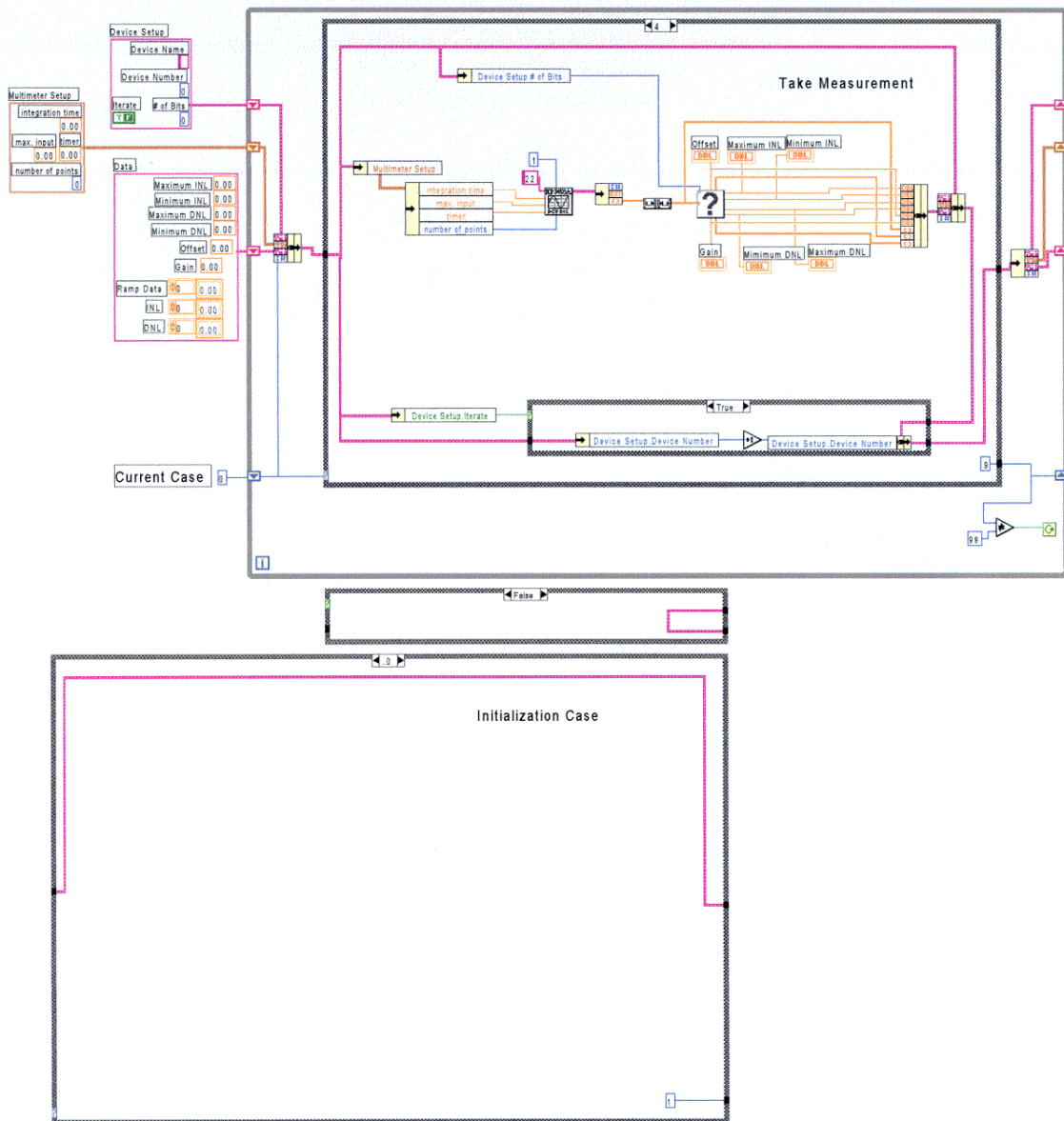


Figure 13. Case 0 and 4 of LabView® software program.

Student Edition  
Linearity.vi  
C:\Program Files\National Instruments\LabVIEW\Linearity.vi  
Last modified on 02/01/1999 at 8:56 AM  
Printed on 10/14/1999 at 8:31 AM

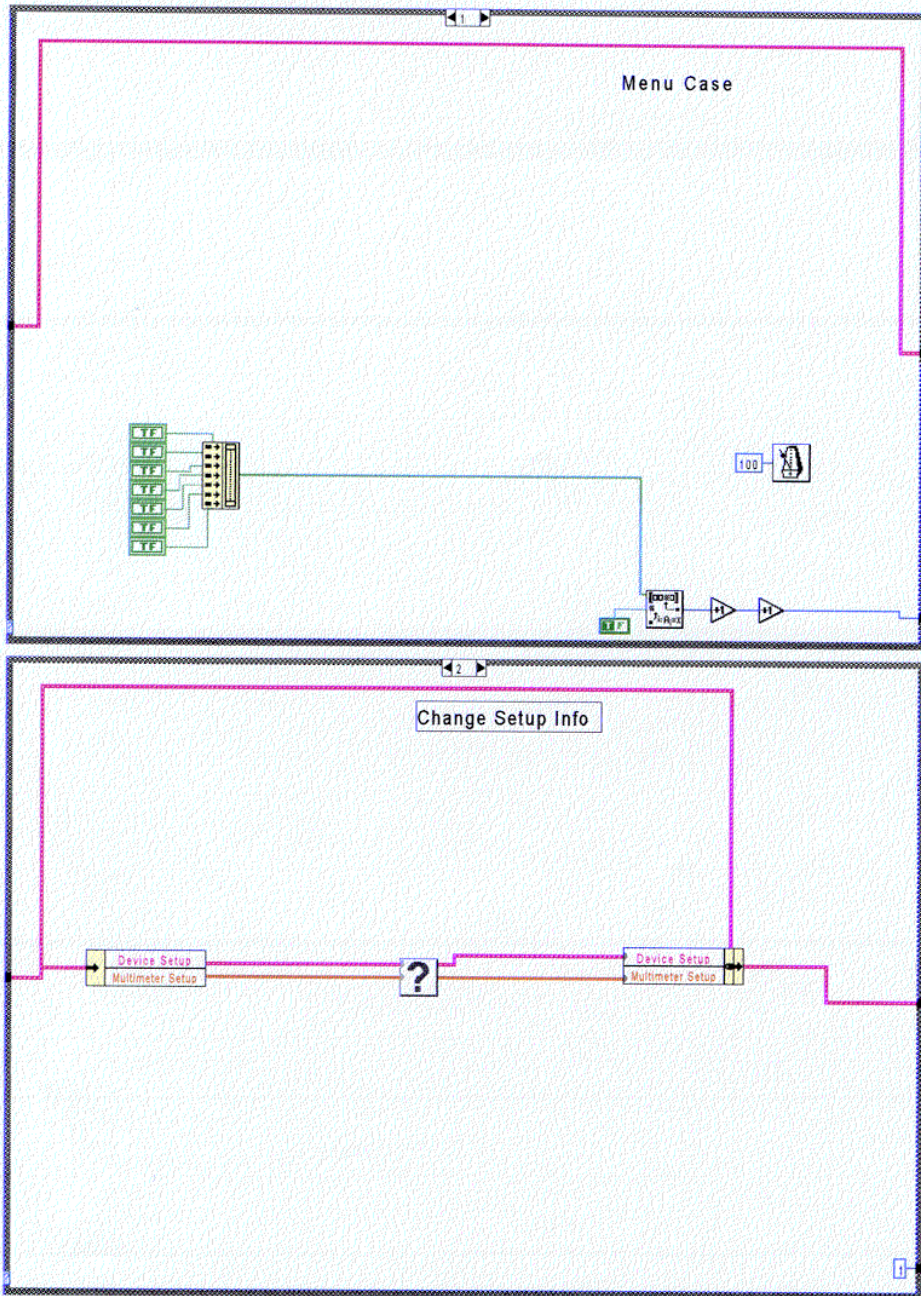


Figure 14. Case 1 and 2 of LabView<sup>®</sup> software program.

Student Edition

Linearity.vi

C:\Program Files\National Instruments\LabVIEW\Linearity.vi

Last modified on 02/01/1999 at 8:56 AM

Printed on 10/14/1999 at 8:31 AM

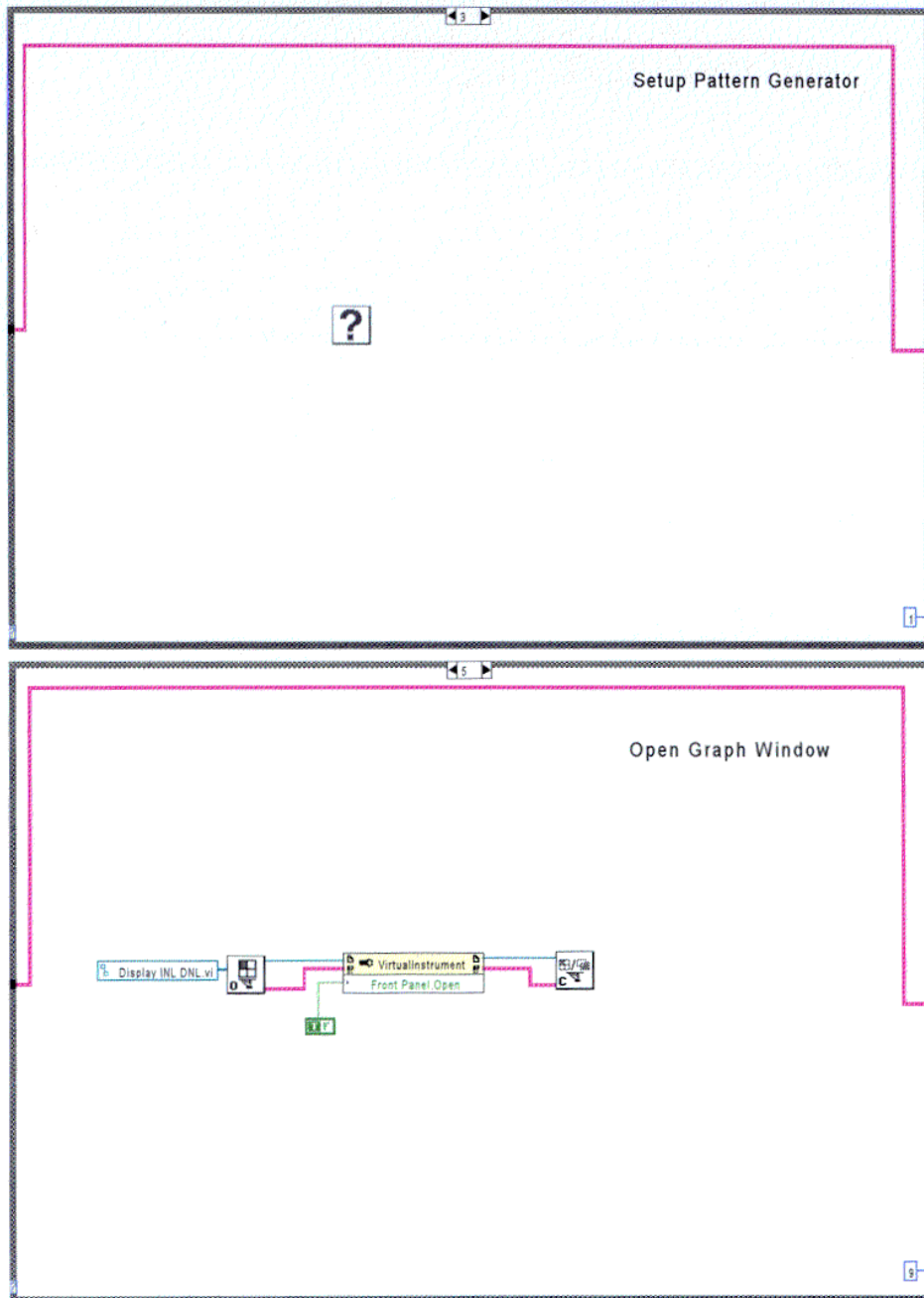


Figure 15. Case 3 and 5 of LabView® software program.



Student Edition

Linearity.vi

C:\Program Files\National Instruments\LabVIEW\Linearity.vi

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Printed on 10/14/1999 at 8:32 AM

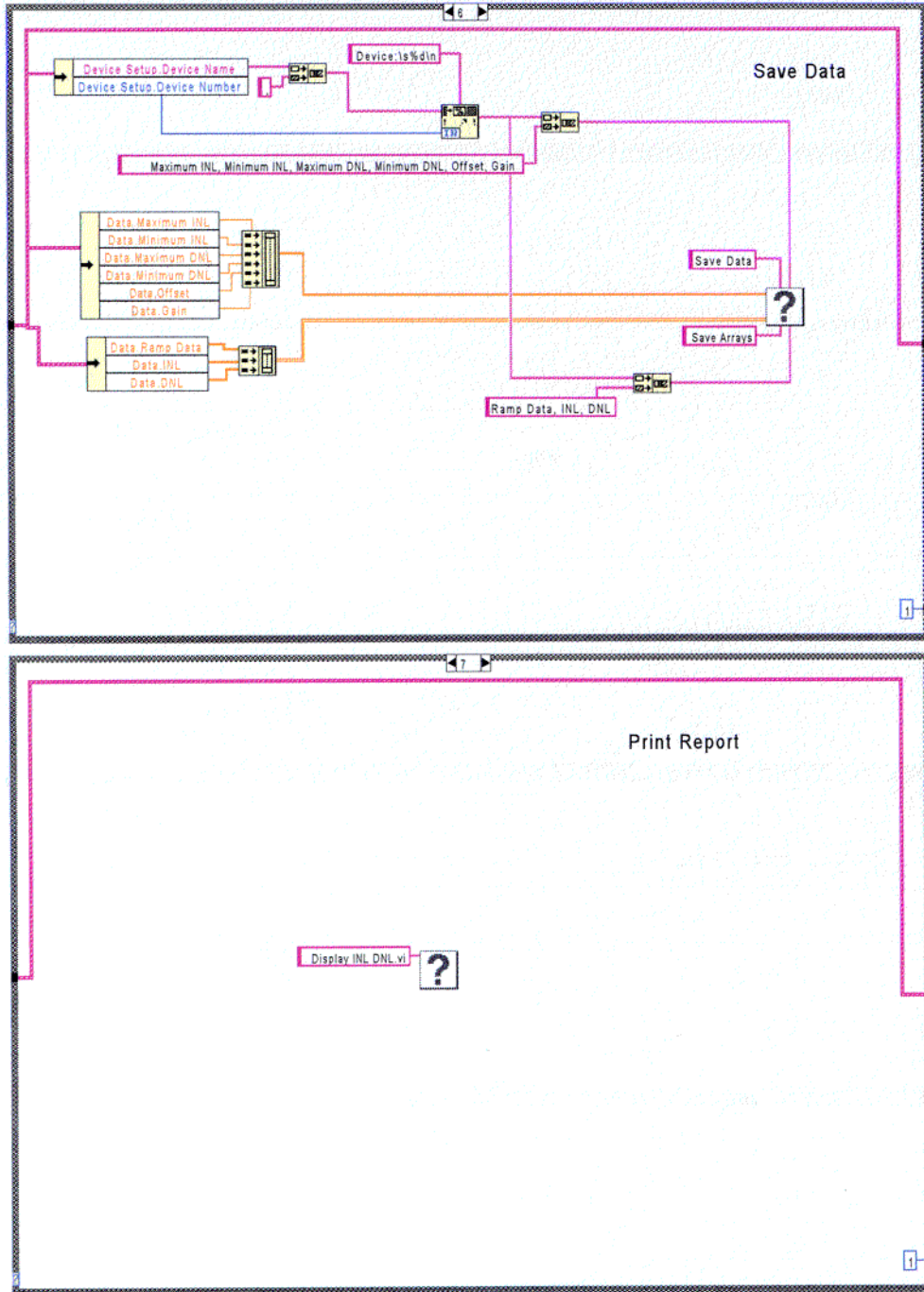


Figure 16. Case 6 and 7 of LabView<sup>®</sup> software program.

Student Edition  
Linearity.vi  
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Last modified on 02/01/1999 at 8:56 AM  
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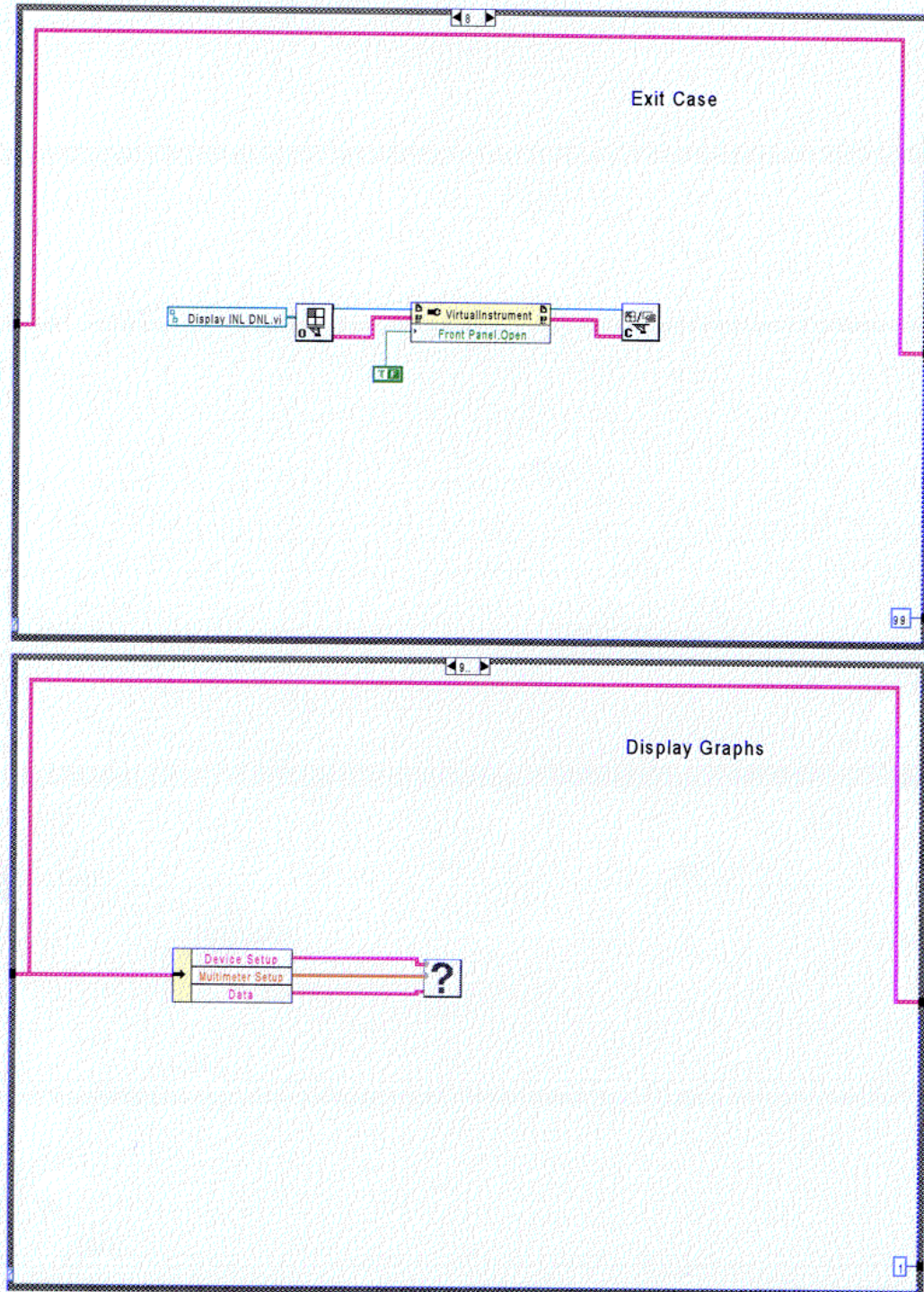


Figure 17. Case 8 and 9 of LabView® software program.

APPENDIX B  
GRAPHS OF DIFFERENTIAL NONLINEARITY (DNL)  
And  
INTEGRAL NONLINEARITY (INL)

Display INL DNL.vi

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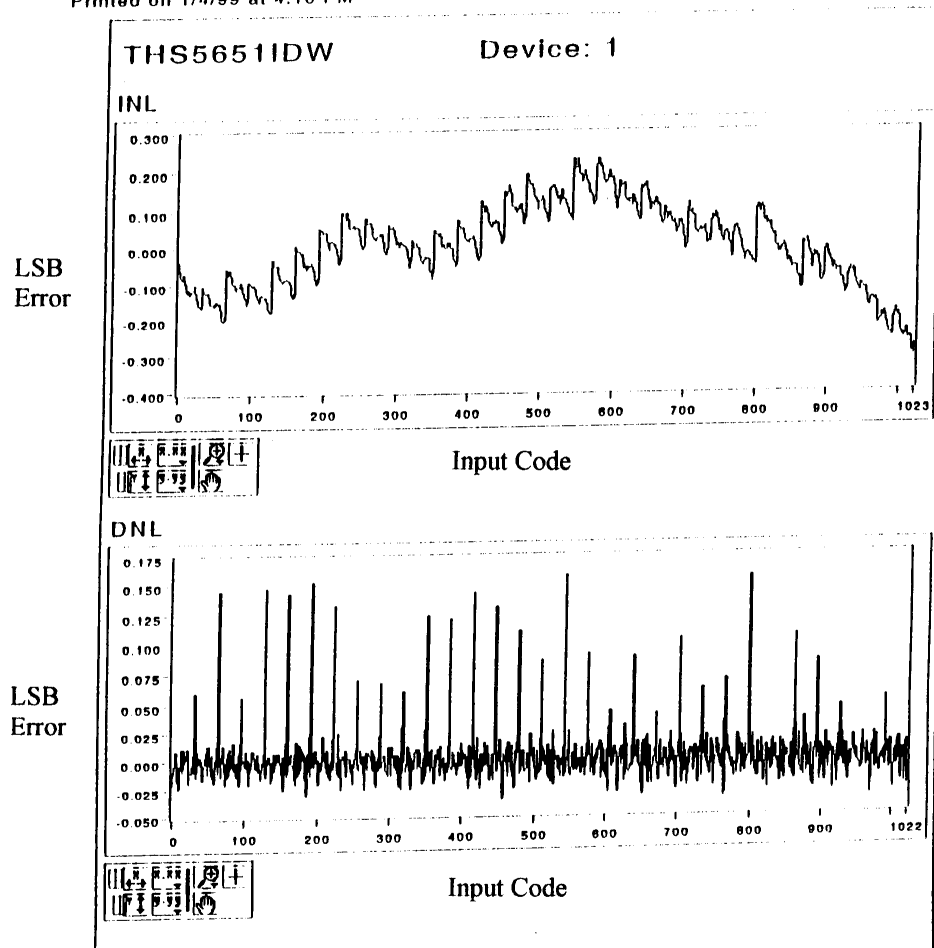


Figure 18. INL and DNL graphs for DAC 1.

Display INL DNL.vi

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Printed on 1/4/99 at 4:29 PM

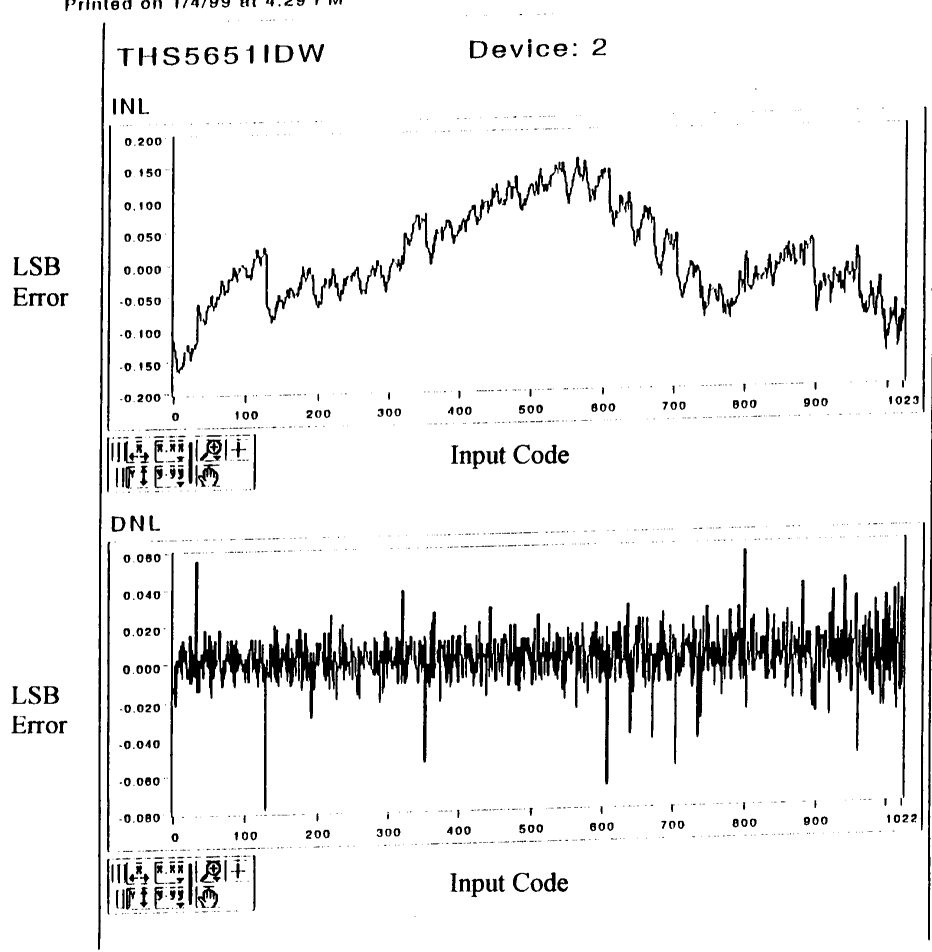


Figure 19. INL and DNL graphs for DAC 2.



Display INL DNL.vi

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Printed on 1/4/99 at 4:52 PM

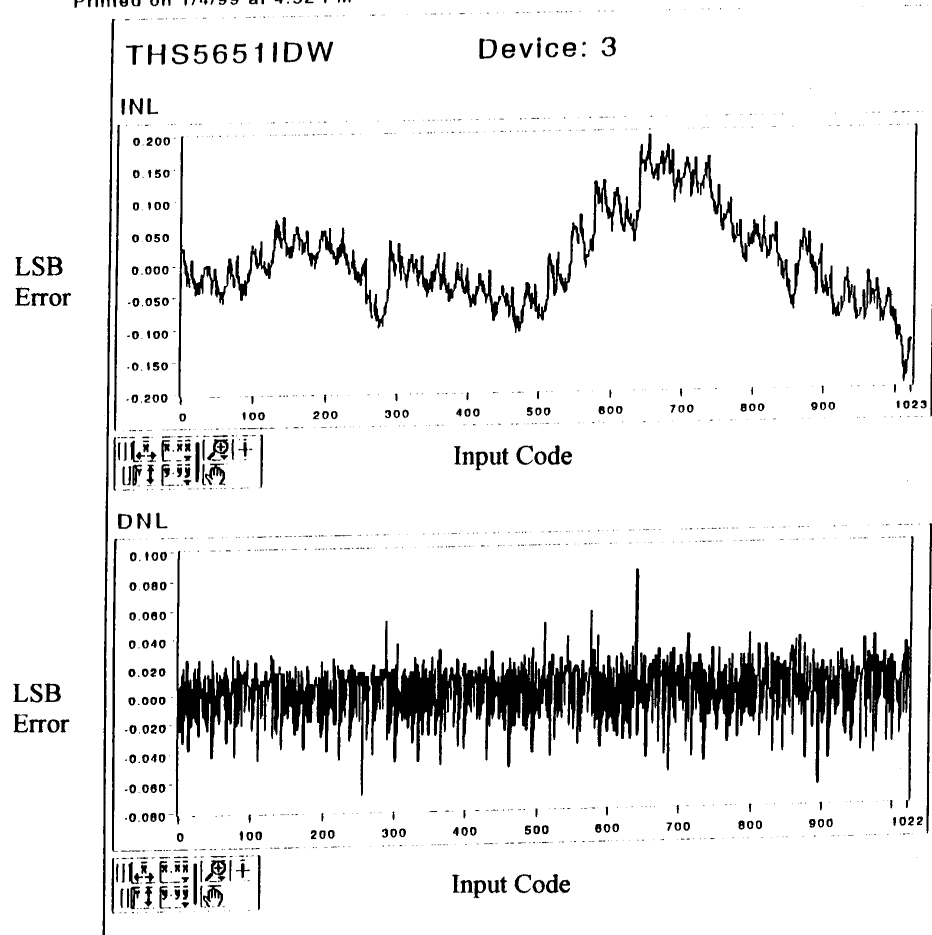


Figure 20. INL and DNL graphs for DAC 3.

Display INL DNL.vi

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Printed on 1/4/99 at 4:57 PM

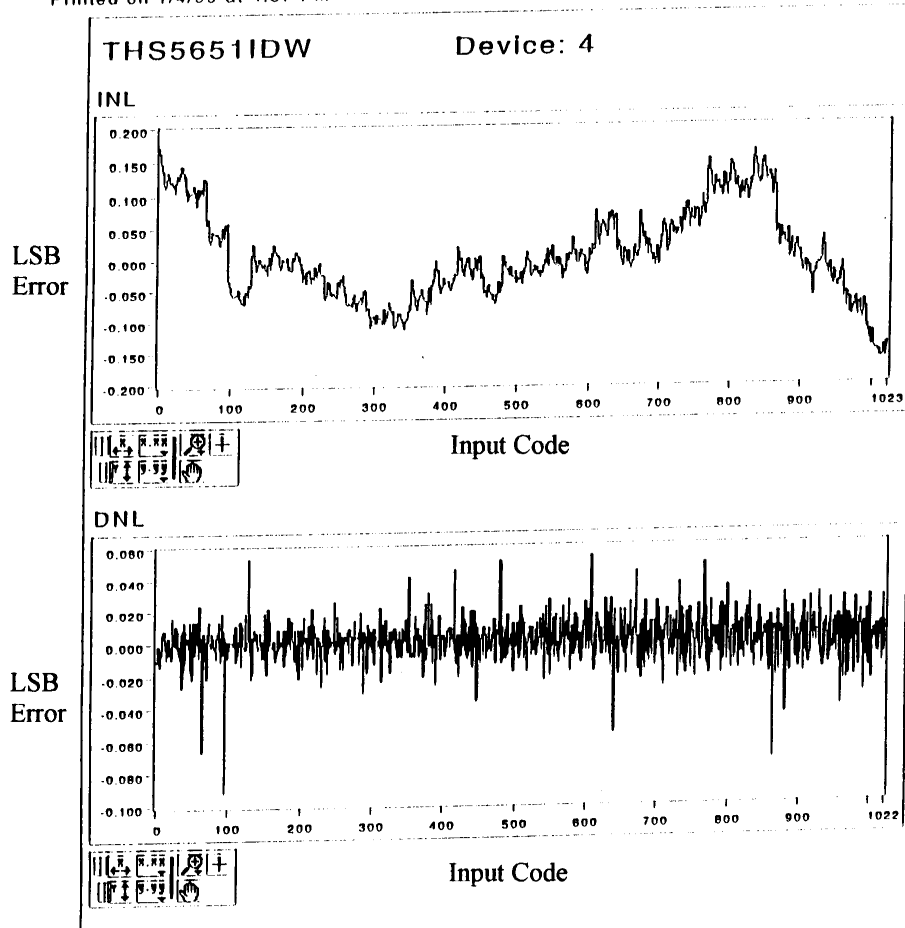


Figure 21. INL and DNL graphs for DAC 4.

Display INL DNL.vi

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Printed on 1/4/99 at 5:00 PM

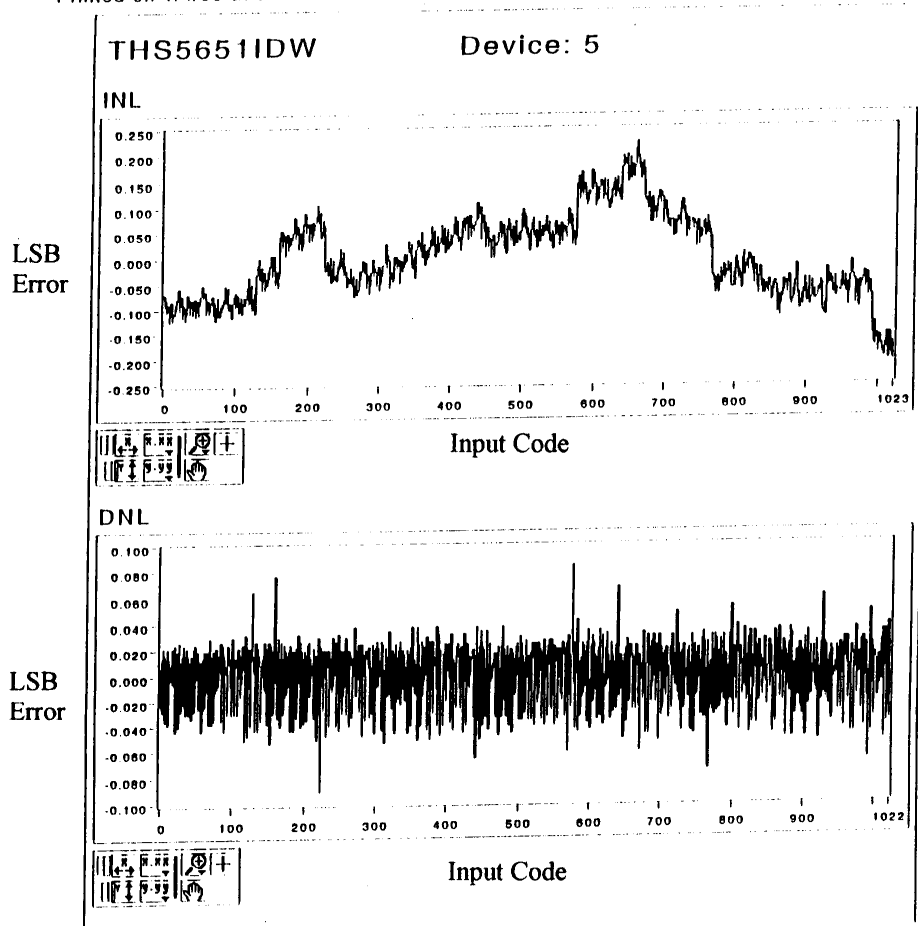


Figure 22. INL and DNL graphs for DAC 5.

Display INL DNL.vi

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Printed on 1/4/99 at 5:03 PM

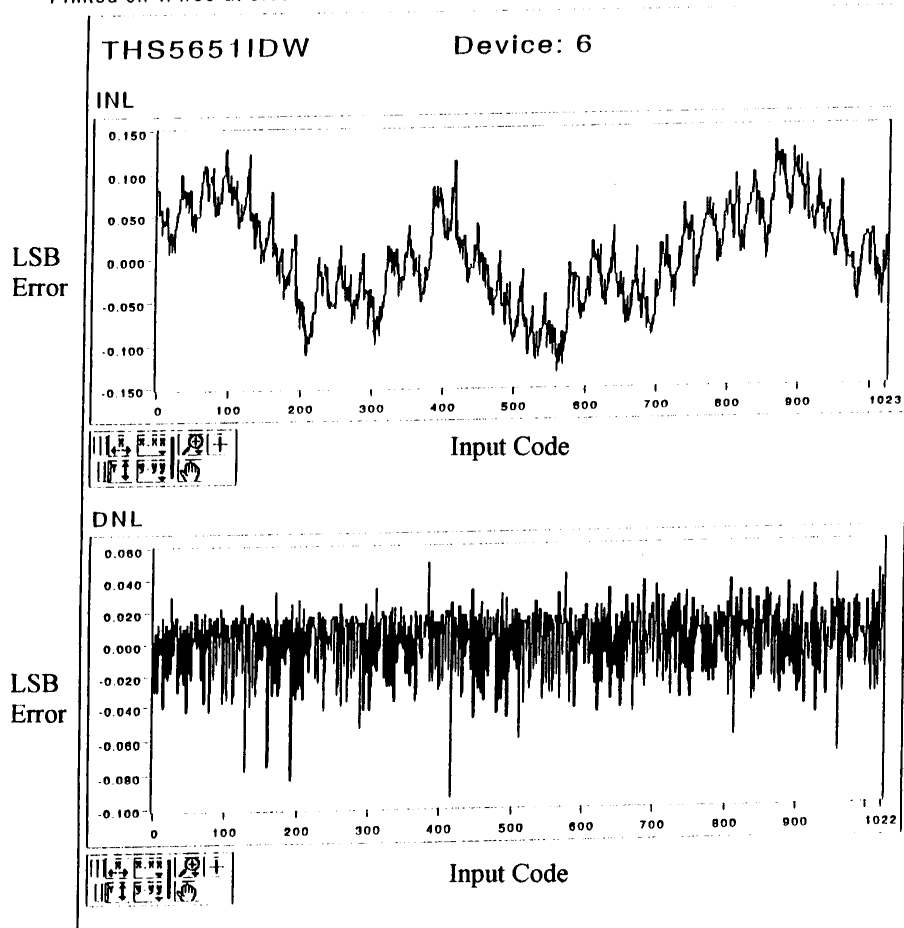


Figure 23. INL and DNL graphs for DAC 6.

Display INL DNL.vi

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Printed on 1/4/99 at 5:13 PM

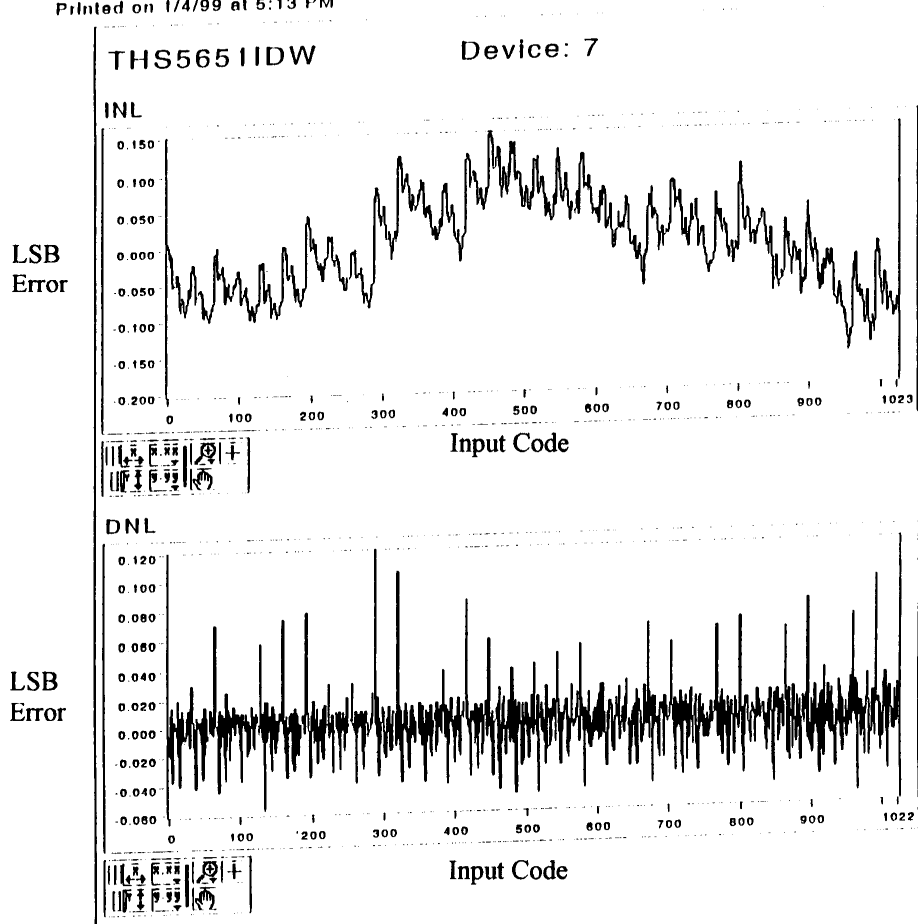


Figure 24. INL and DNL graphs for DAC 7.

Display INL DNL.vi

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Printed on 1/4/99 at 5:17 PM

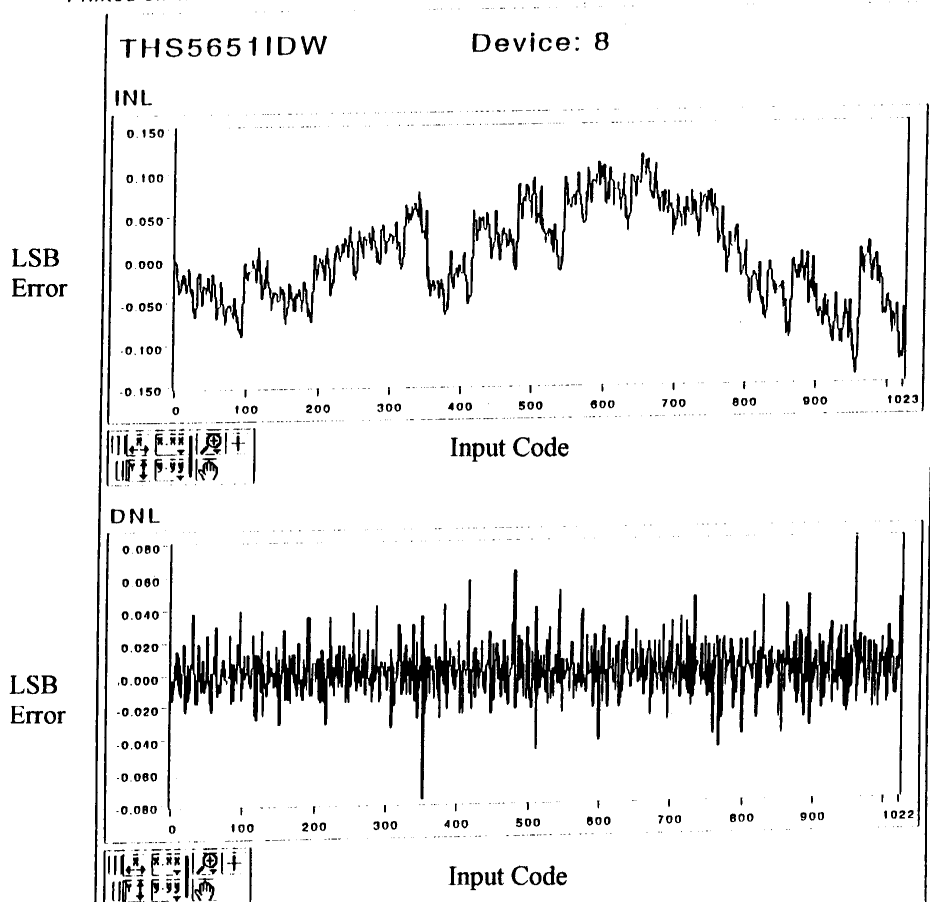


Figure 25. INL and DNL graphs for DAC 8.

Display INL DNL.vi

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Printed on 1/4/99 at 5:24 PM

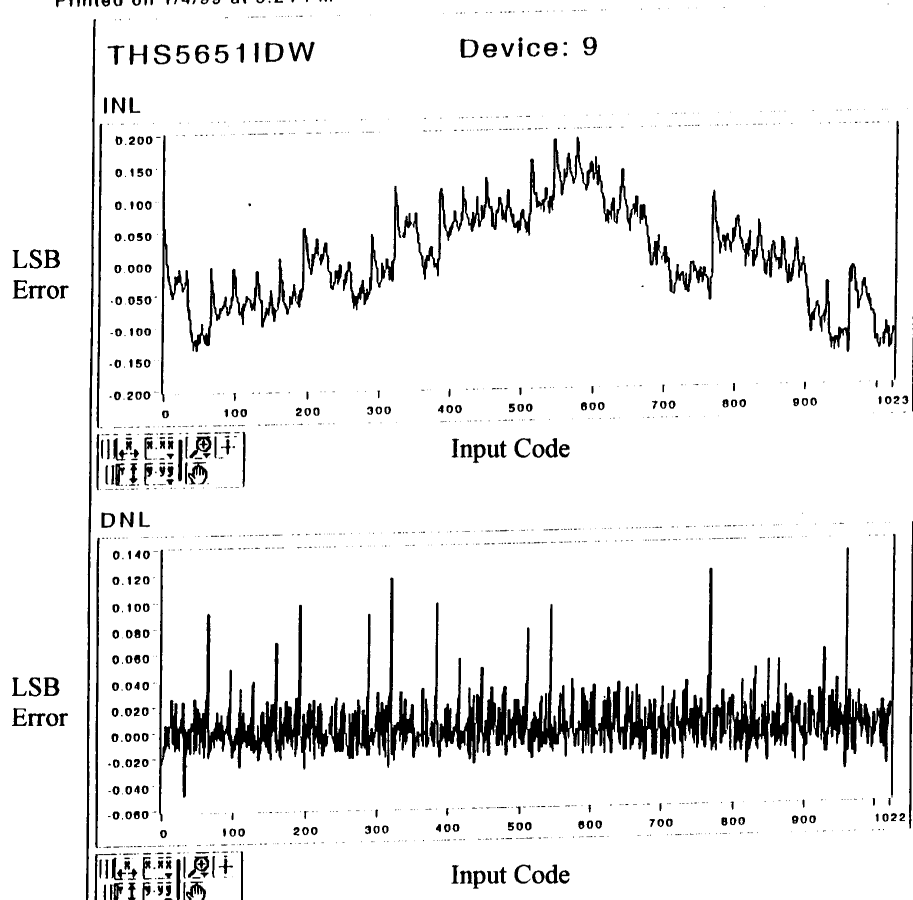


Figure 26. INL and DNL graphs for DAC 9.

Display INL DNL.vi

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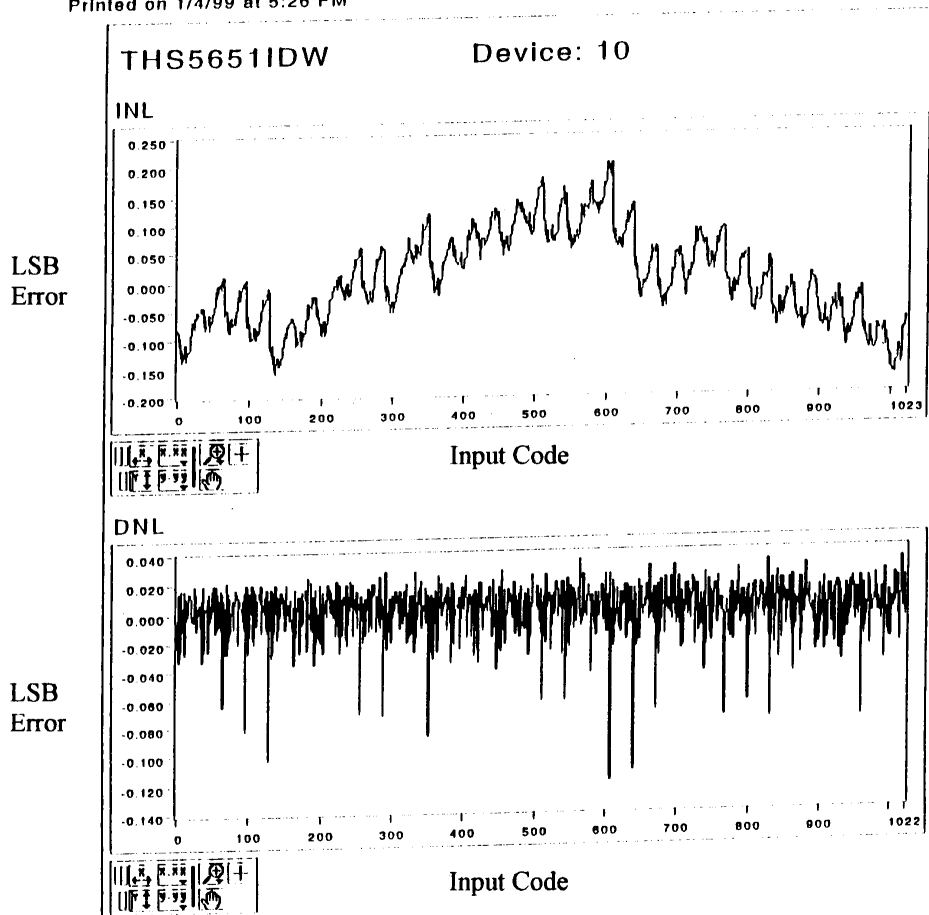


Figure 27. INL and DNL graphs for DAC 10.



Display INL DNL.vi

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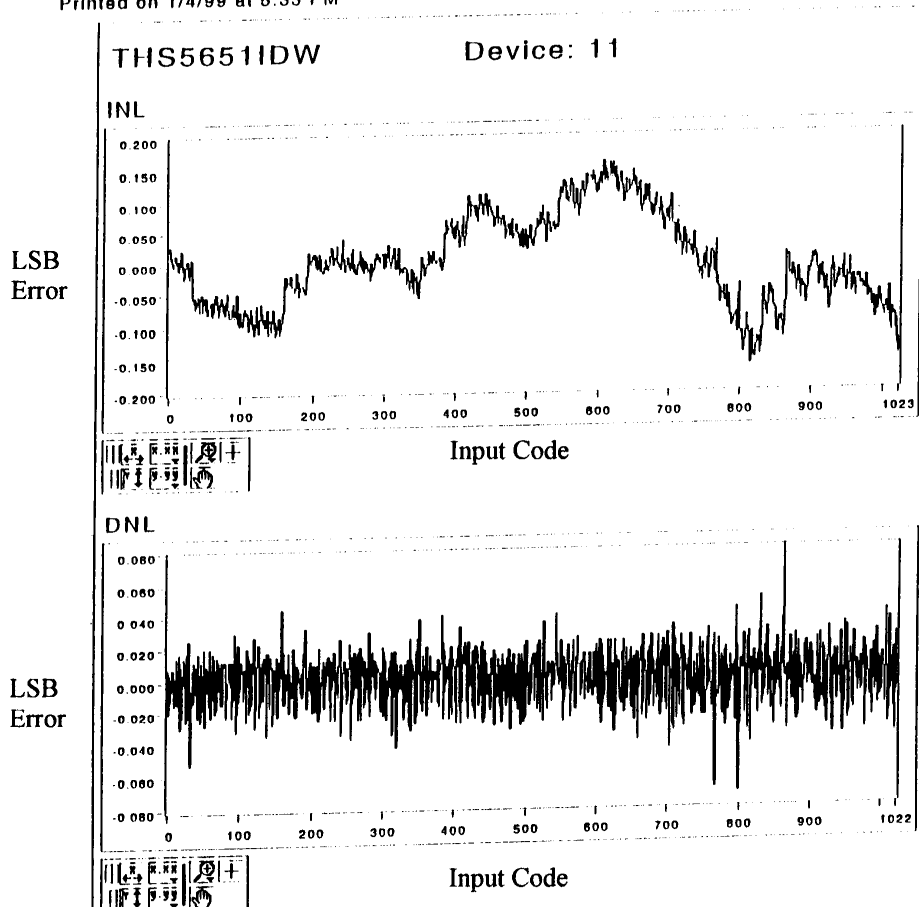


Figure 28. INL and DNL graphs for DAC 11.

Display INL DNL.vi

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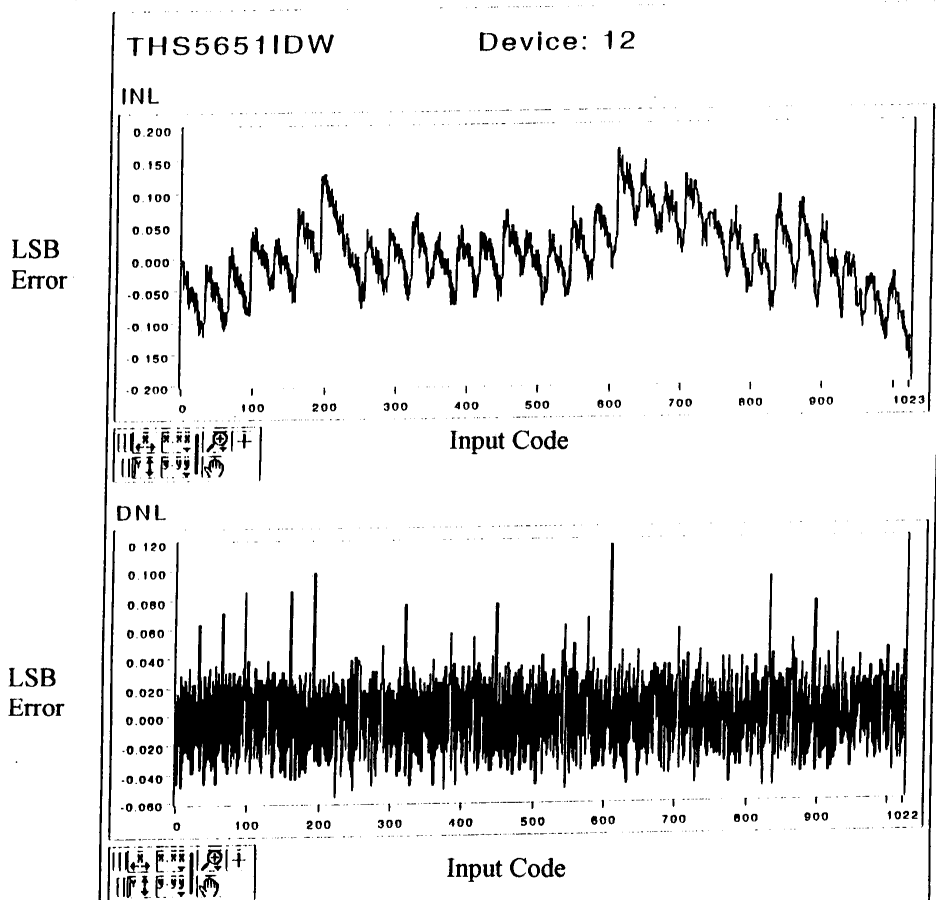


Figure 29. INL and DNL graphs for DAC 12.

Display INL DNL.vi

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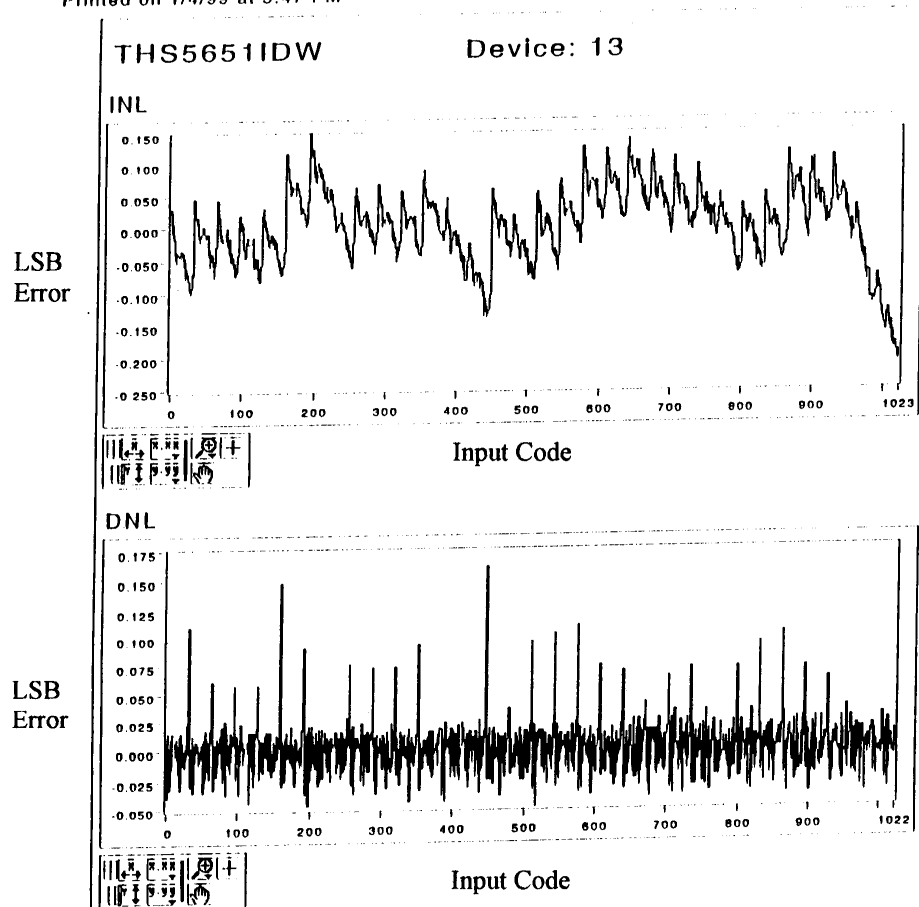


Figure 30. INL and DNL graphs for DAC 13.

Display INL DNL.vi

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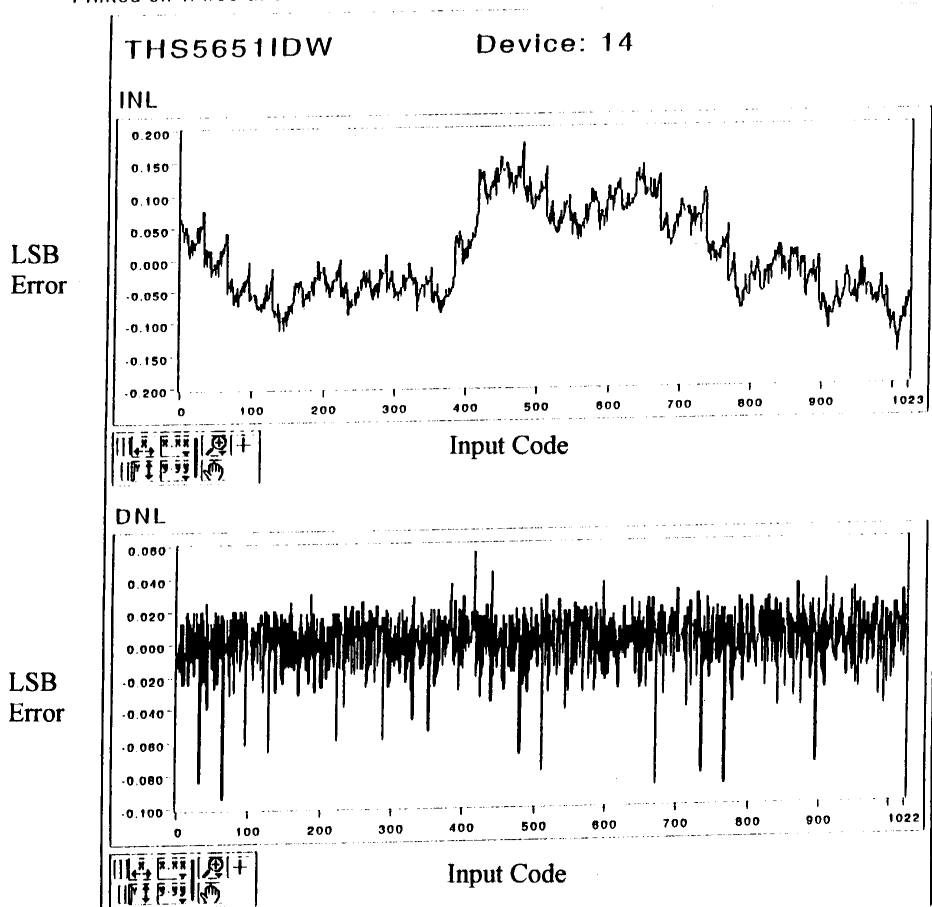


Figure 31. INL and DNL graphs for DAC 14.

Display INL DNL.vi

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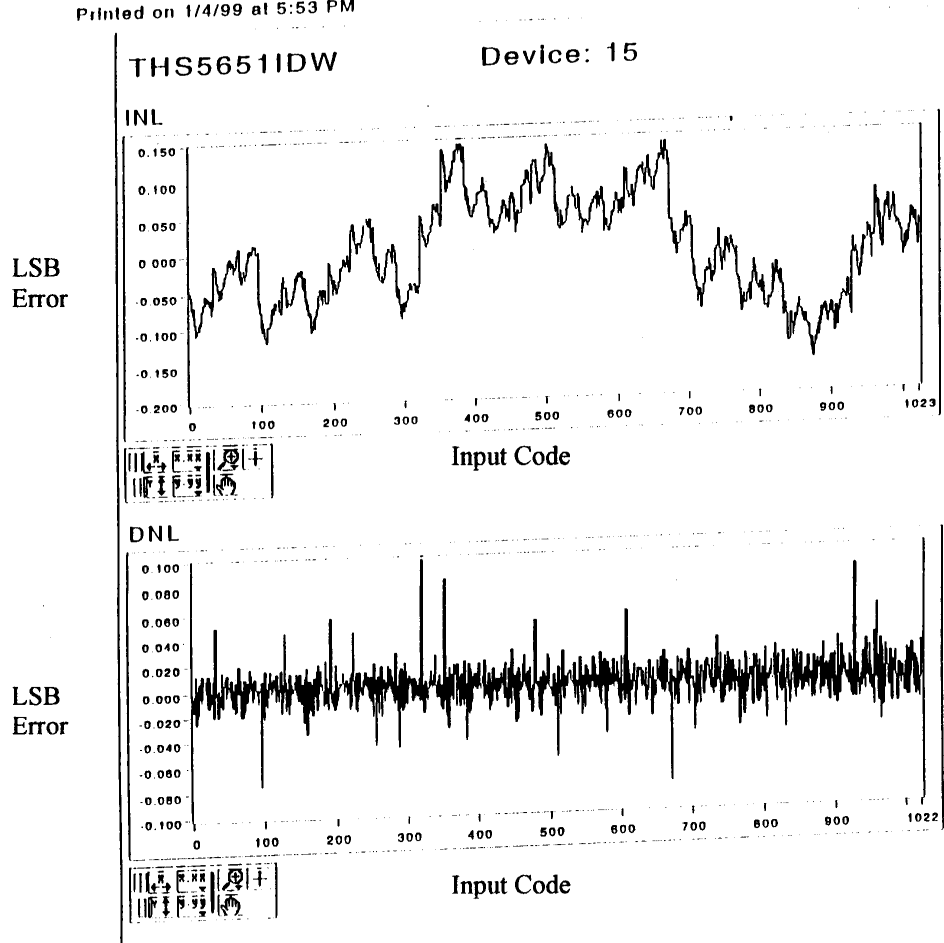


Figure 32. INL and DNL graphs for DAC 15.

Display INL DNL.vi

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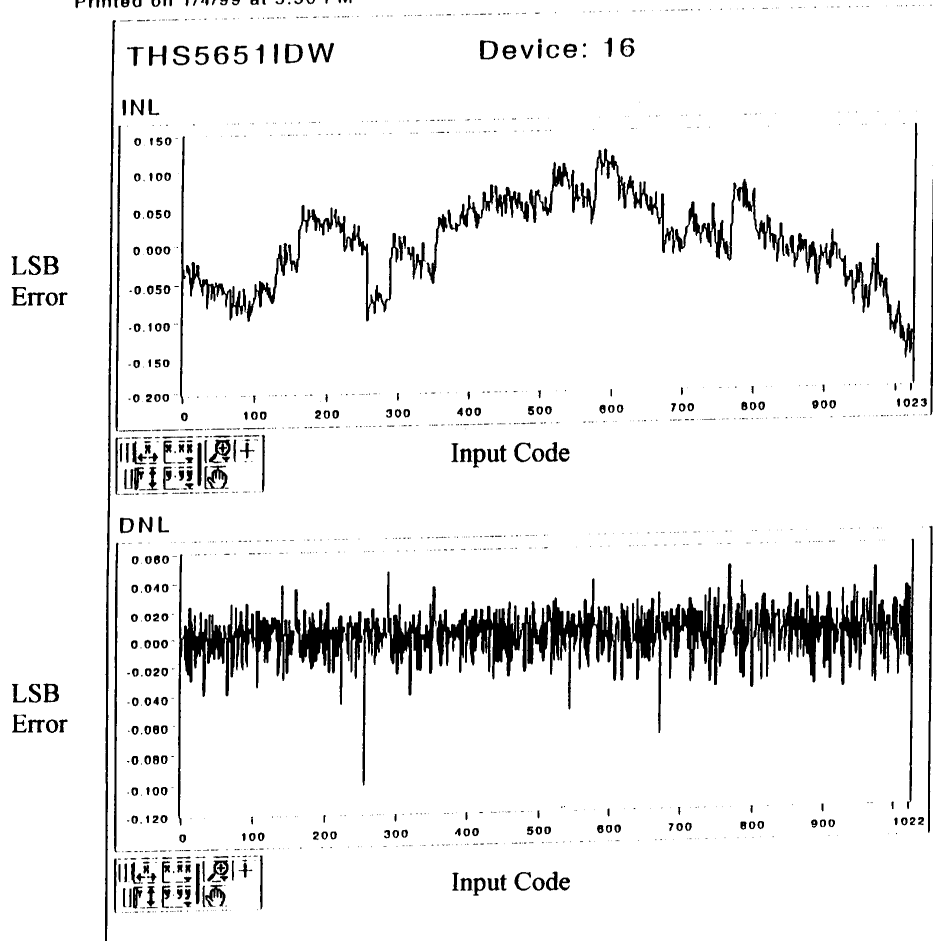


Figure 33. INL and DNL graphs for DAC 16.

Display INL DNL.vi

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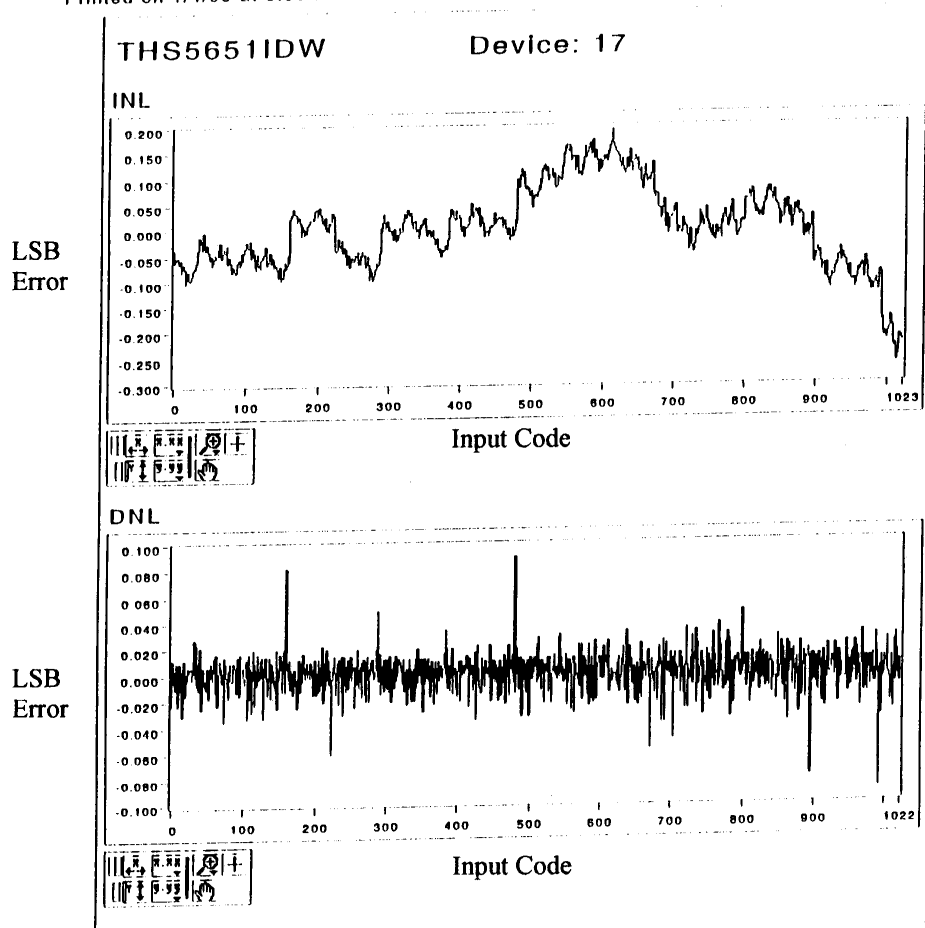


Figure 34. INL and DNL graphs for DAC 17.

Display INL DNL.vi

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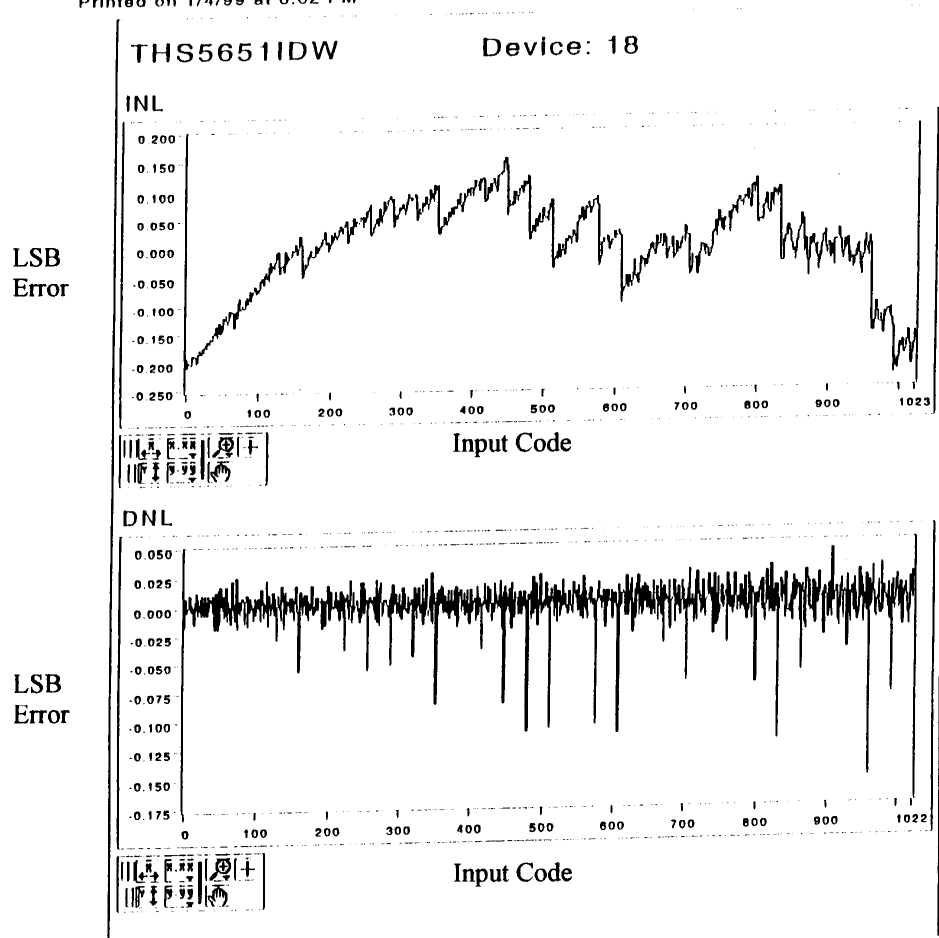


Figure 35. INL and DNL graphs for DAC 18.



Display INL DNL.vi

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Printed on 1/4/99 at 6:09 PM

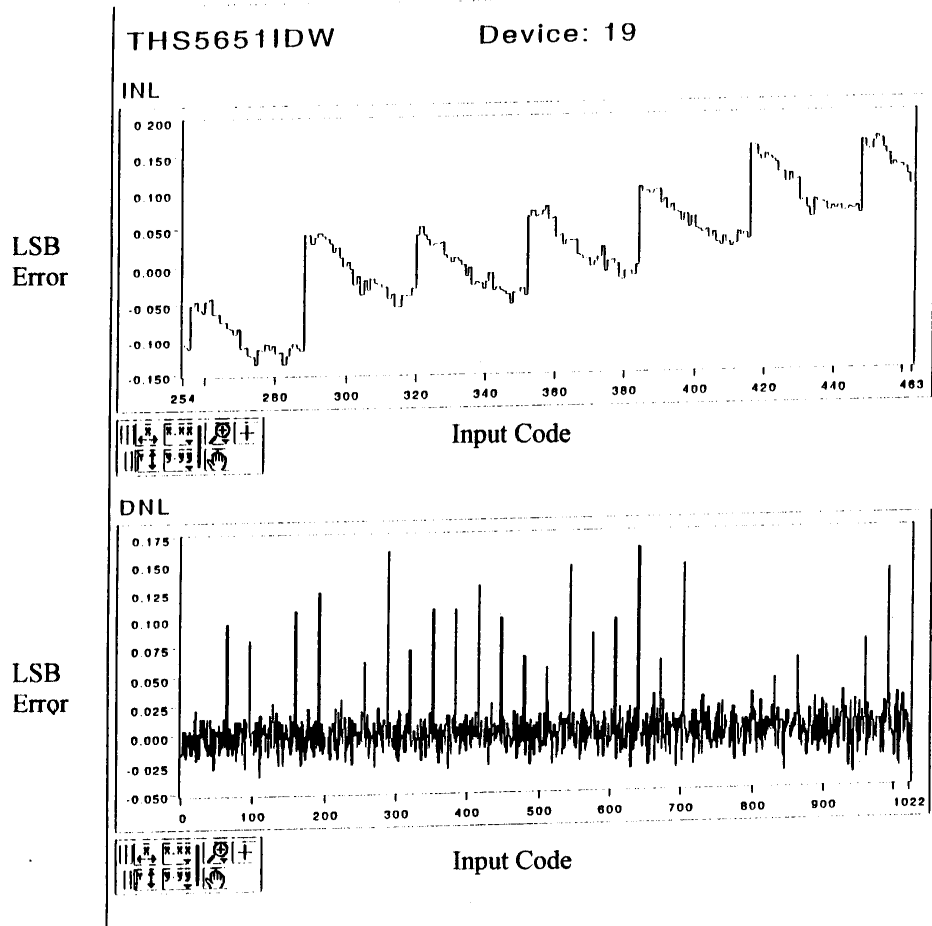


Figure 36. INL and DNL graphs for DAC 19.

Display INL DNL.vi

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Printed on 1/4/99 at 8:28 PM

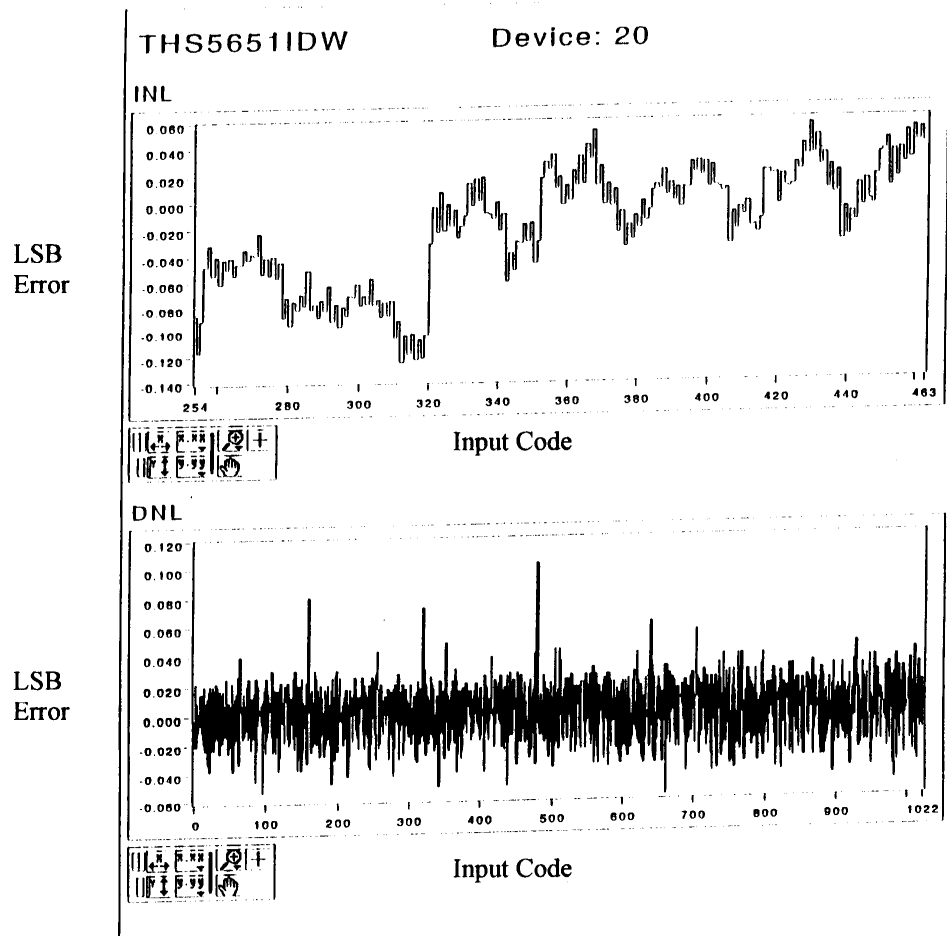


Figure 37. INL and DNL graphs for DAC 20.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:31 PM

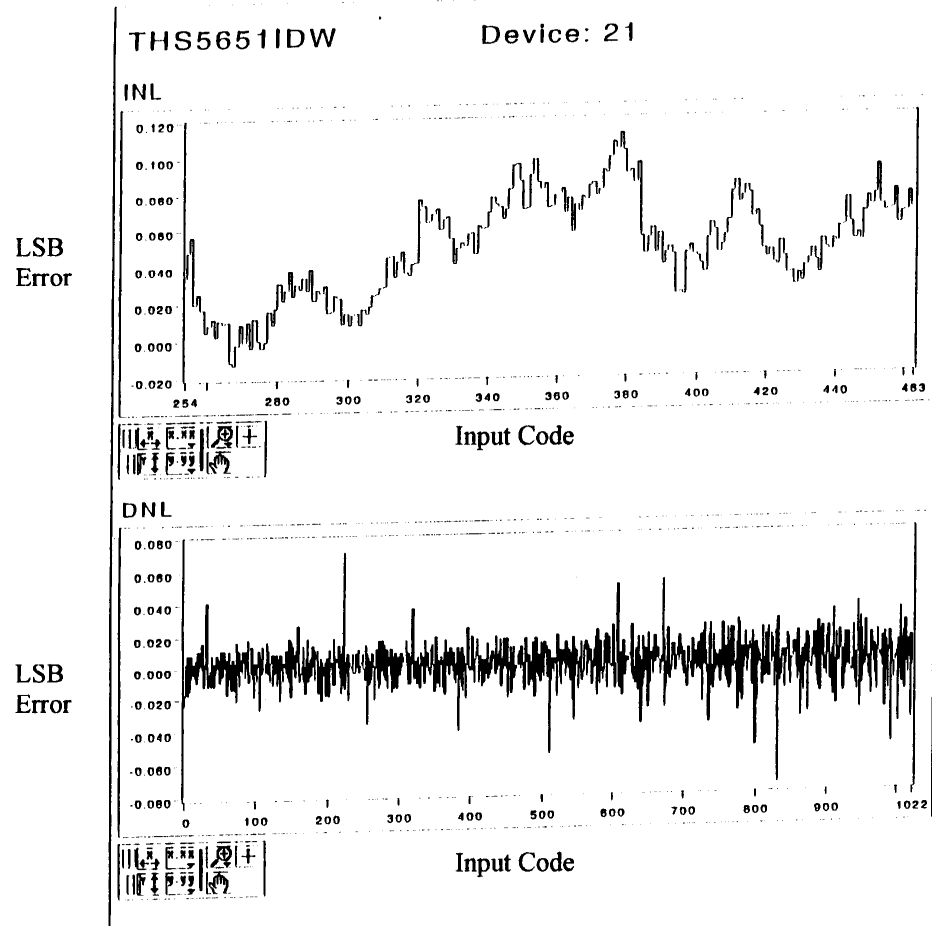


Figure 38. INL and DNL graphs for DAC 21.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:33 PM

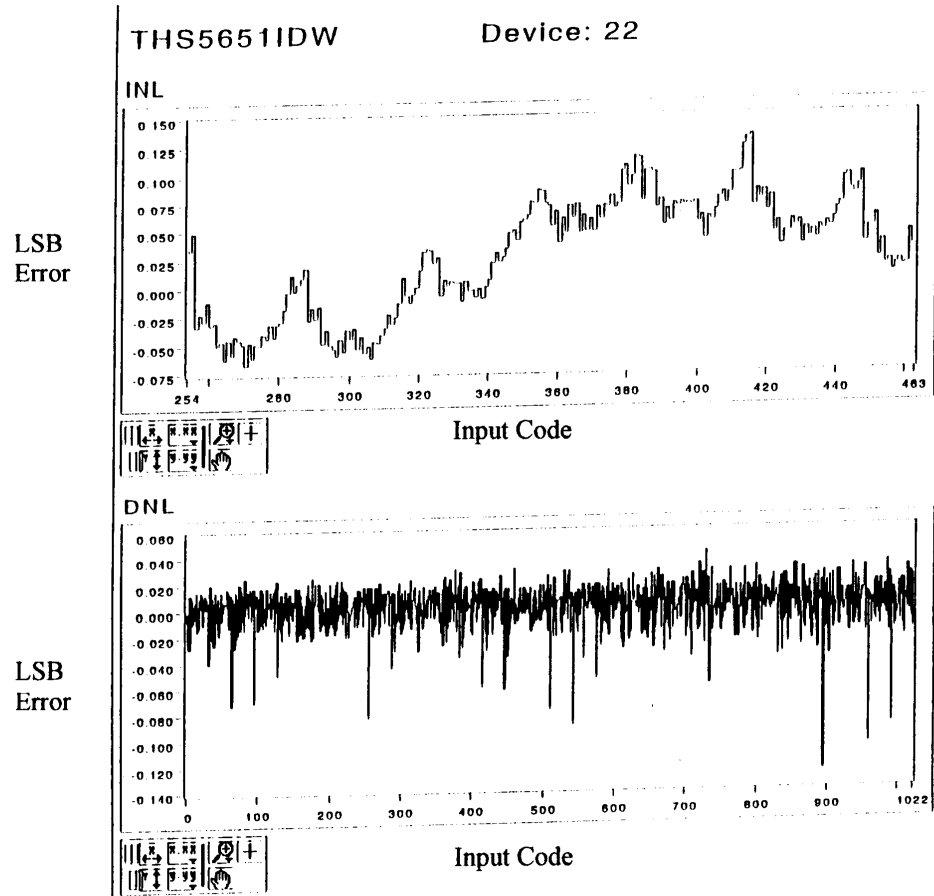


Figure 39. INL and DNL graphs for DAC 22.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:36 PM

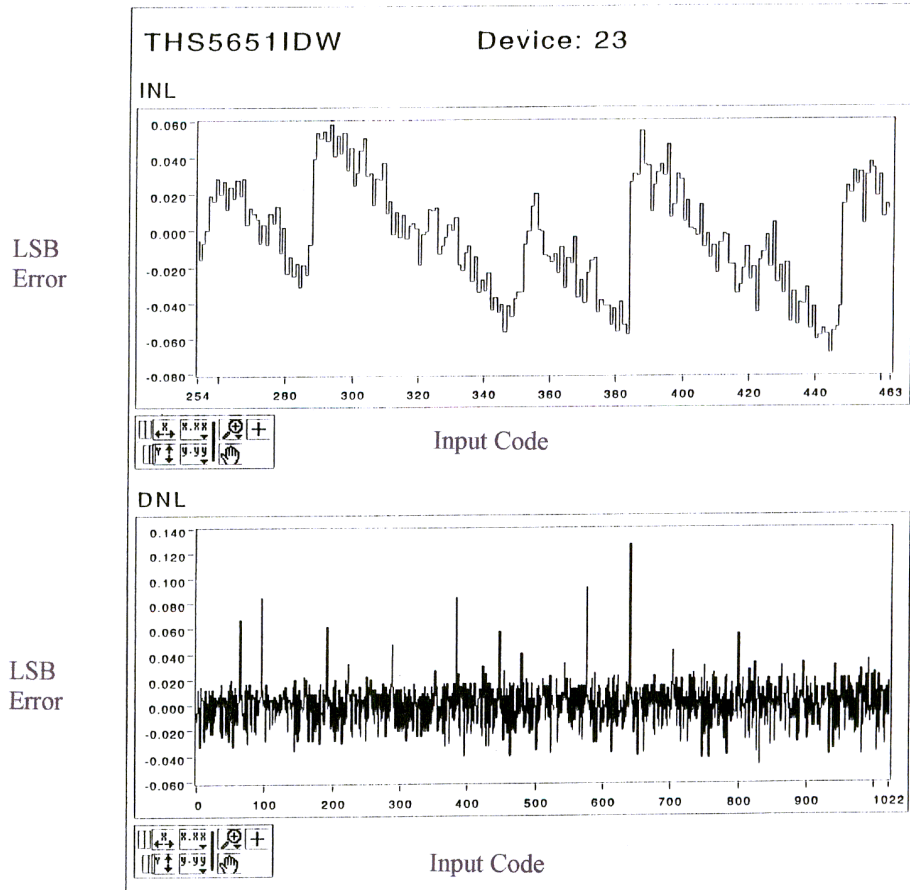


Figure 40. INL and DNL graphs for DAC 23.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:38 PM

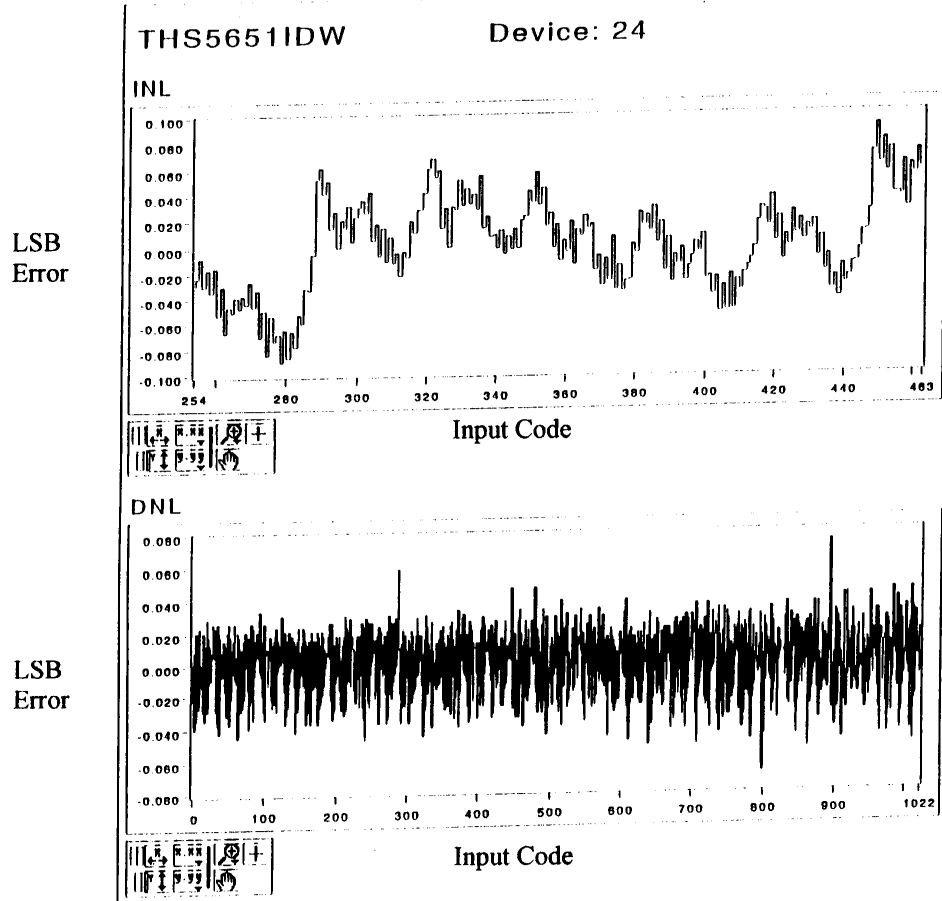


Figure 41. INL and DNL graphs for DAC 24.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 8:41 PM

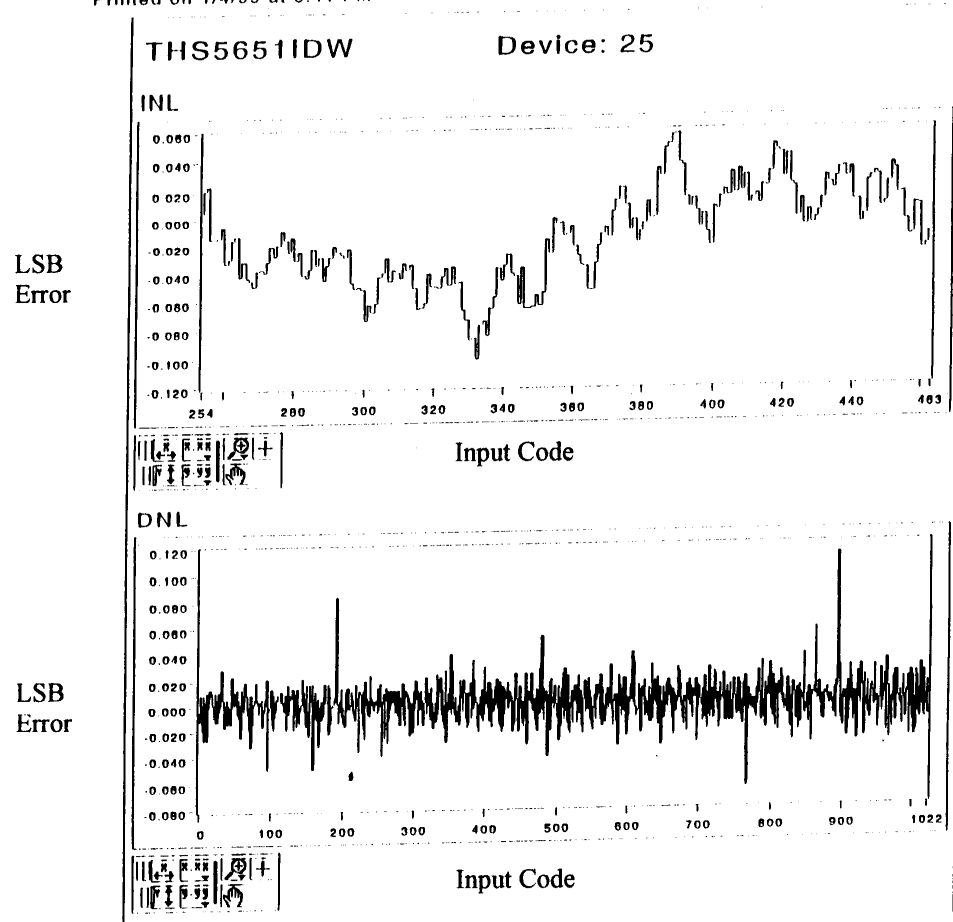


Figure 42. INL and DNL graphs for DAC 25.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:44 PM

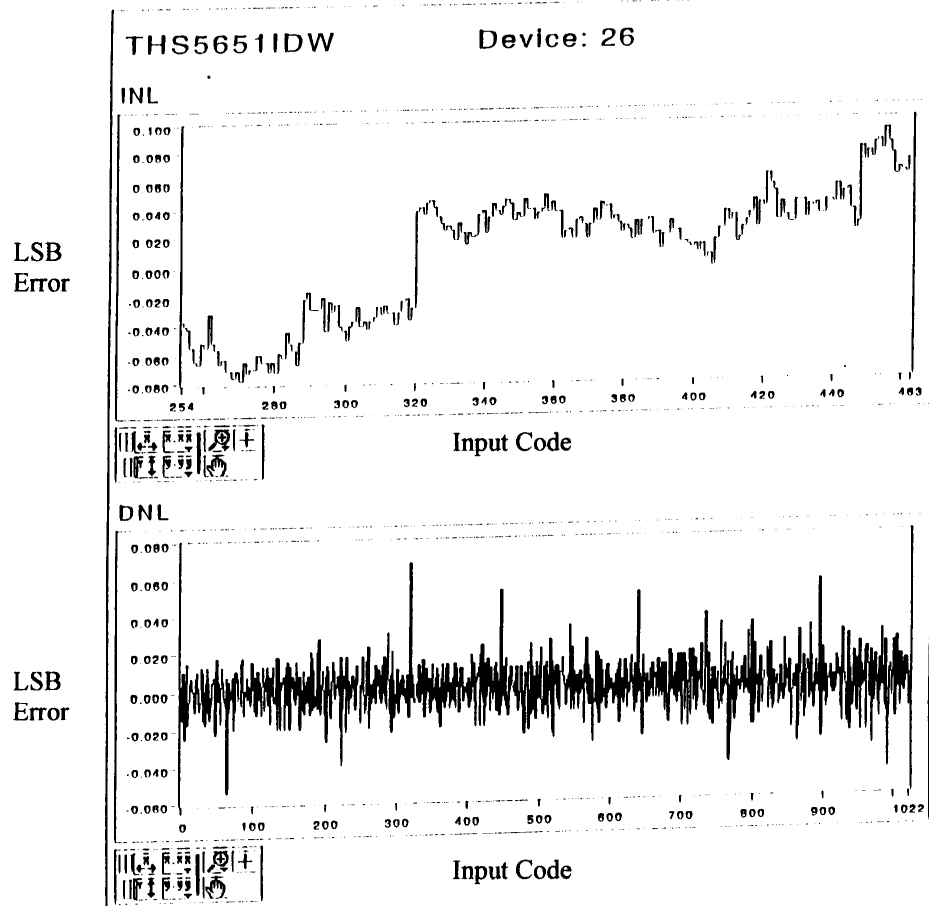


Figure 43. INL and DNL graphs for DAC 26.



Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:46 PM

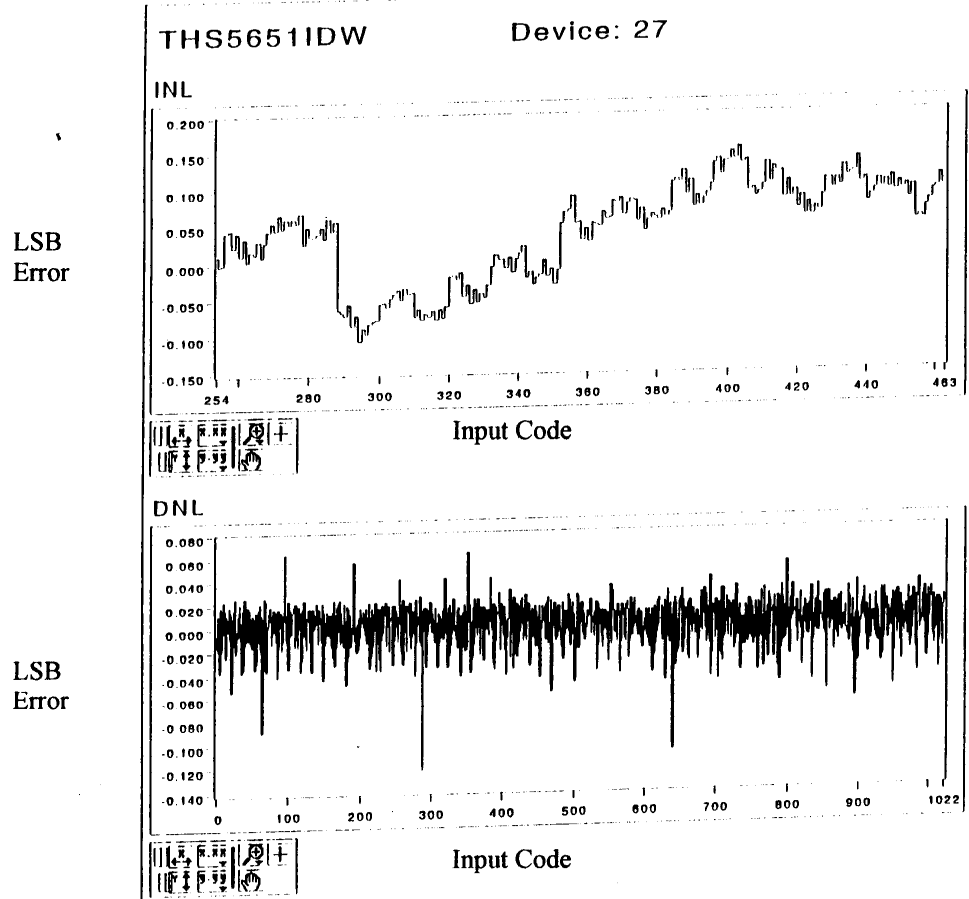


Figure 44. INL and DNL graphs for DAC 27.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:48 PM

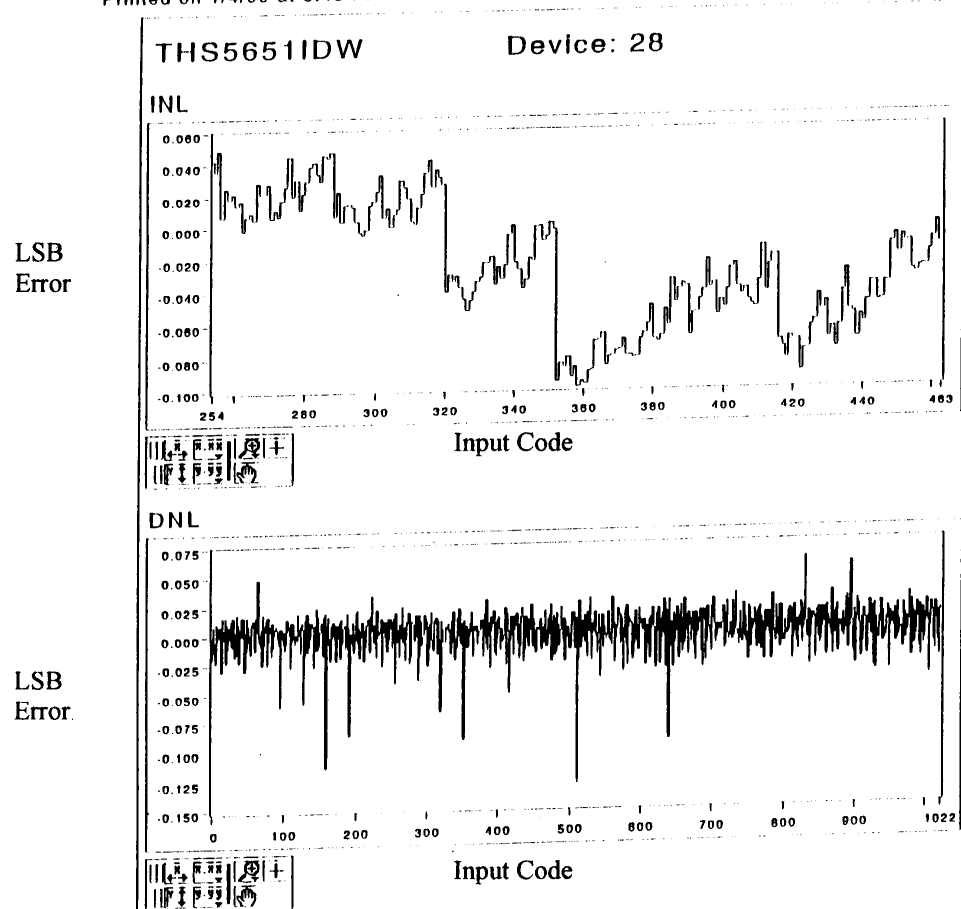


Figure 45. INL and DNL graphs for DAC 28.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 8:52 PM

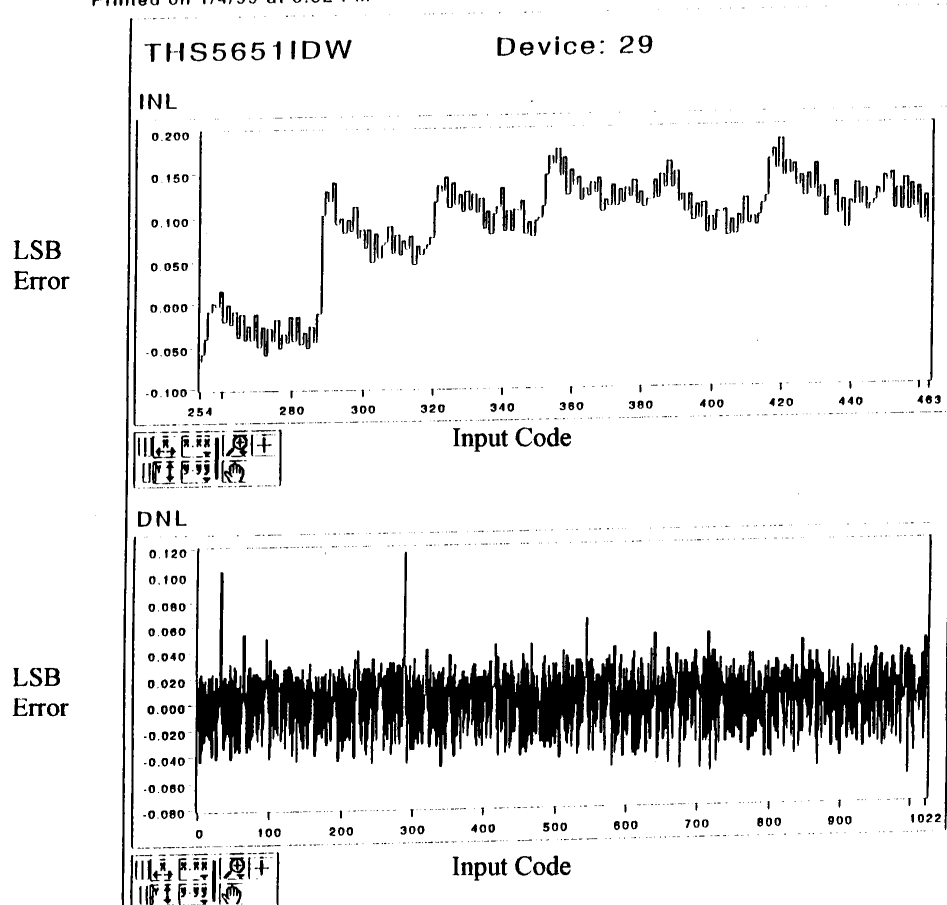


Figure 46. INL and DNL graphs for DAC 29.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:54 PM

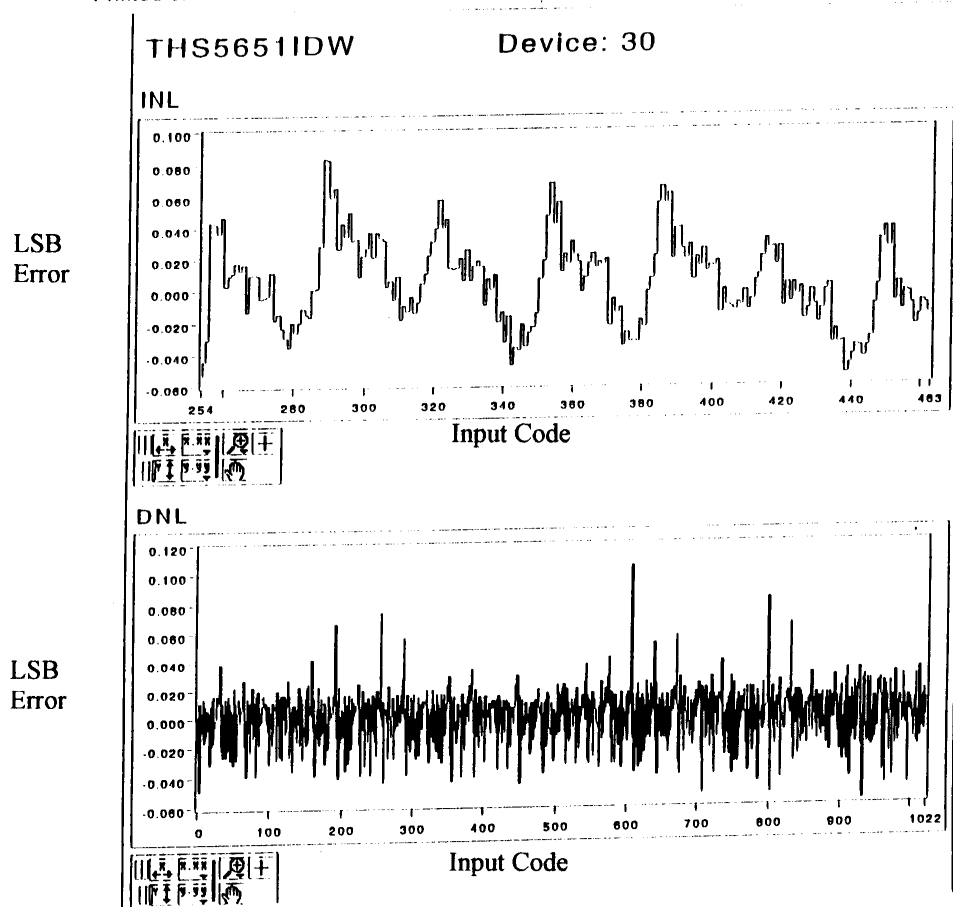


Figure 47. INL and DNL graphs for DAC 30.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:56 PM

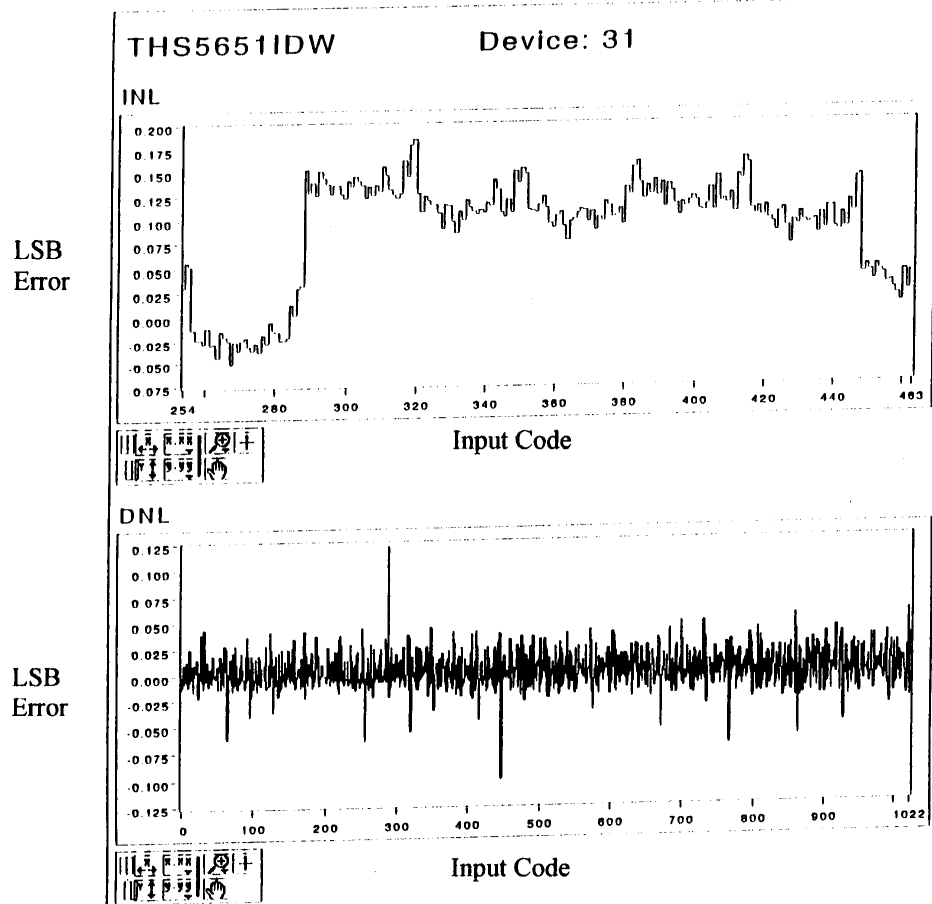


Figure 48. INL and DNL graphs for DAC 31.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:57 PM

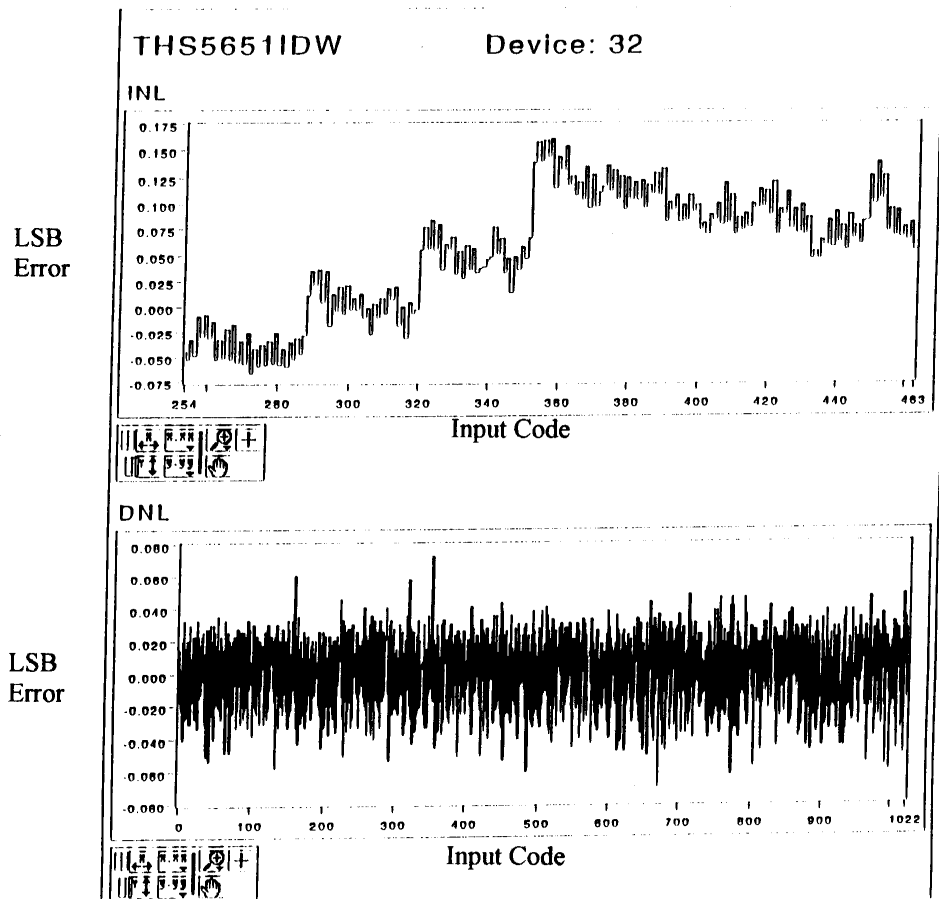


Figure 49. INL and DNL graphs for DAC 32.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 6:59 PM

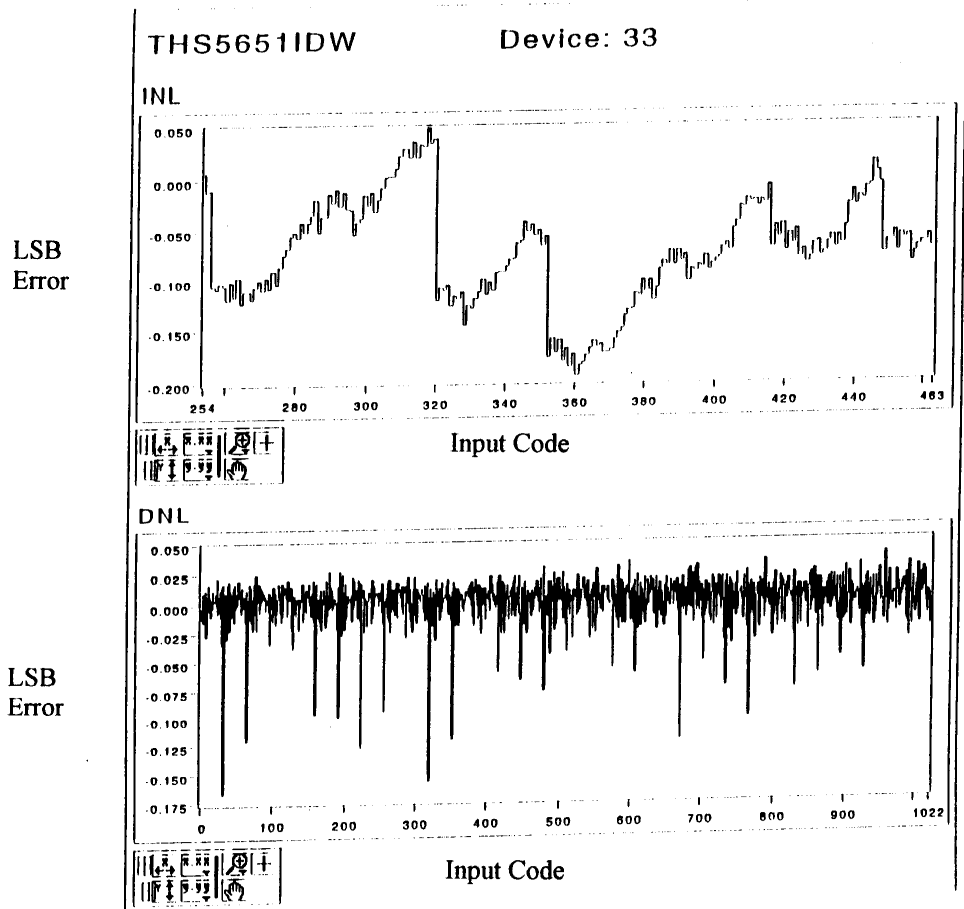


Figure 50. INL and DNL graphs for DAC 33.

Display INL DNL.vi

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 7:01 PM

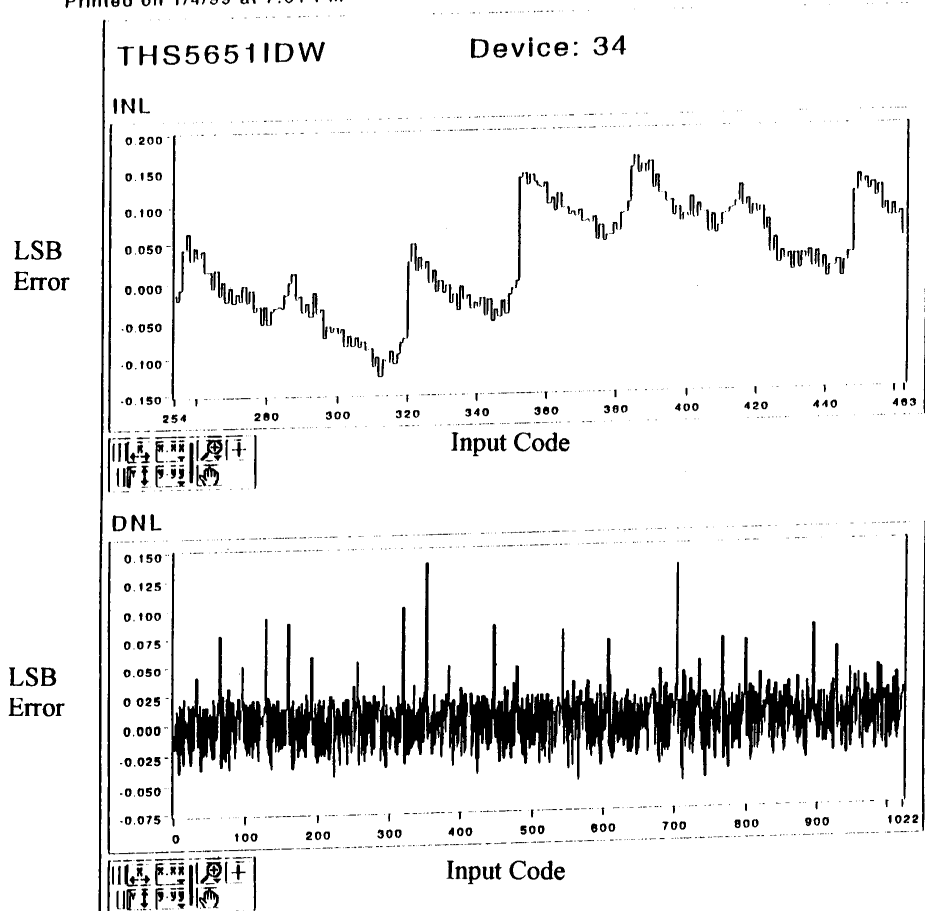


Figure 51. INL and DNL graphs for DAC 34.



Display INL DNL.VI

Last modified on 1/4/99 at 4:14 PM

Printed on 1/4/99 at 7:02 PM

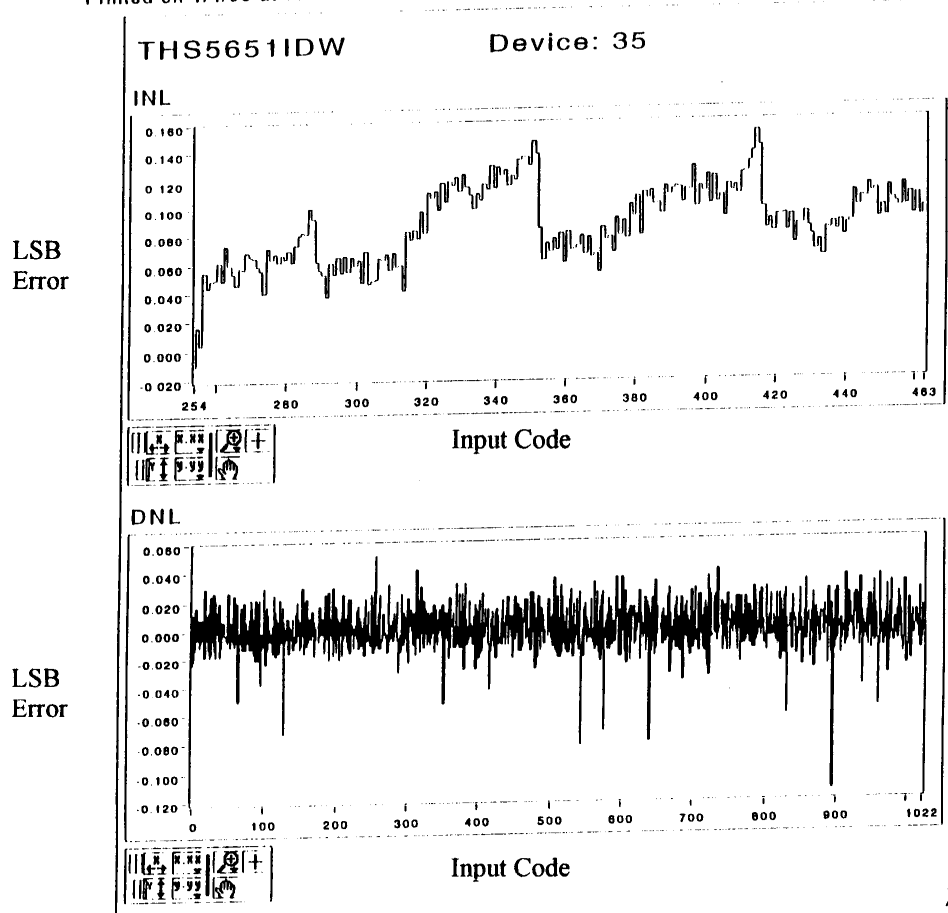


Figure 52. INL and DNL graphs for DAC 35.

Display INL DNL.v

Last modified on 1/4/99 at 4:14 PM  
Printed on 1/4/99 at 7:04 PM

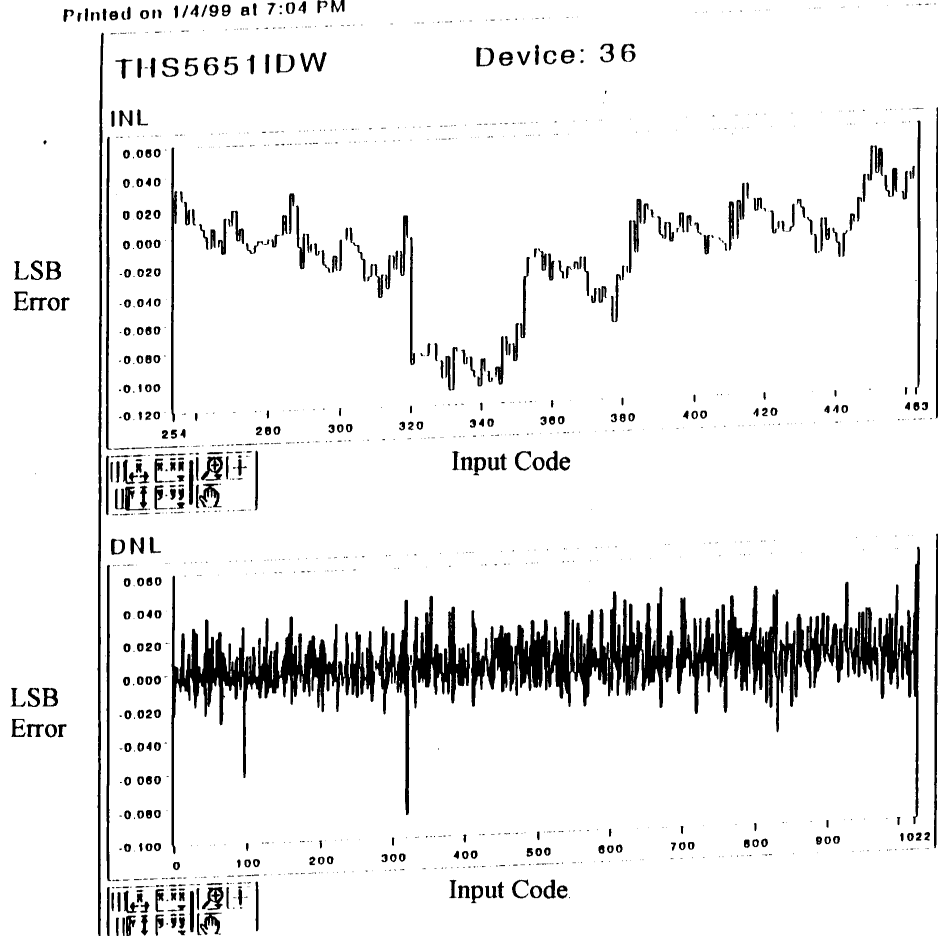


Figure 53. INL and DNL graphs for DAC 36.

APPENDIX C  
EXAMPLE OF DATA  
(THS5651IDW DEVICE 10)

### THS5651IDW DEVICE 10

<u>ANALOG VOLTS</u>	<u>LSB ERROR</u>		<u>Code</u>	<u>Bit LOCATION</u>
<u>OUTPUT</u>	<u>INL</u>	<u>DNL</u>		
0.00003	-0.07981	-0.00570	0	offset
0.00097	-0.08552	-0.02319	1	LSB
0.00190	-0.10871	0.01428	2	MID1
0.00286	-0.09443	-0.03319		
0.00378	-0.12761	0.01428	4	MID2
0.00475	-0.11333	-0.02569		
0.00567	-0.13902	0.01678	6	MID3
0.00664	-0.12224	-0.01070		
0.00758	-0.13294	0.00429	8	MID4
0.00853	-0.12866	0.00429		
0.00949	-0.12437	0.01678	10	MID5
0.01045	-0.10759	-0.02819		
0.01138	-0.13578	0.01178	12	MID6
0.01234	-0.12399	-0.00321		
0.01328	-0.12720	0.00928	14	MID7
0.01424	-0.11792	-0.00321		
0.01519	-0.12112	0.00429	16	MID8
0.01615	-0.11683	0.01428		
0.01711	-0.10255	0.01428	18	MID9
0.01807	-0.08827	0.01178		
0.01903	-0.07649	0.00928	20	MID10
0.01999	-0.06720	-0.00570		
0.02094	-0.07291	-0.00071	22	MID11
0.02189	-0.07362	-0.00570		
0.02283	-0.07932	0.01928	24	MID12
0.02380	-0.06004	-0.00321		
0.02475	-0.06325	0.01428	26	MID13
0.02571	-0.04897	-0.01070		
0.02665	-0.05967	0.00429	28	MID14
0.02760	-0.05538	-0.00071		
0.02855	-0.05609	0.00429	30	MID15
0.02951	-0.05180	0.00679		
0.03046	-0.04501	0.00179	32	MSB1
0.03142	-0.04322	-0.00820		
0.03236	-0.05143	0.00928		
0.03332	-0.04214	-0.03319		
0.03424	-0.07533	0.01928		
0.03520	-0.05605	-0.02569		
0.03613	-0.08174	0.00429		
0.03708	-0.07745	0.00179		
0.03804	-0.07566	0.00429		
0.03899	-0.07137	0.00429		
0.03994	-0.06708	0.01178		
0.04091	-0.05530	-0.02569		
0.04183	-0.08099	0.01428		
0.04280	-0.06671	-0.00570		
0.04374	-0.07241	0.00679		
0.04470	-0.06563	-0.00321		
0.04564	-0.06883	0.01678		
0.04661	-0.05205	0.00179		

0.04756	-0.05026	0.00928		
0.04852	-0.04098	0.01928		
0.04949	-0.02170	0.00928		
0.05045	-0.01242	-0.01320		
0.05139	-0.02562	0.01928		
0.05235	-0.00634	-0.01070		
0.05329	-0.01704	0.01428		
0.05426	-0.00276	-0.00820		
0.05520	-0.01096	0.00928		
0.05616	-0.00168	-0.01070		
0.05710	-0.01238	0.01678		
0.05806	0.00440	-0.01070		
0.05900	-0.00630	0.01428		
0.05997	0.00798	-0.06566		
0.06086	-0.05768	0.00928	64	MSB2
0.06182	-0.04840	-0.00321		
0.06276	-0.05160	0.00429		
0.06372	-0.04731	-0.02819		
0.06464	-0.07550	0.02178		
0.06561	-0.05373	-0.02819		
0.06653	-0.08191	0.01428		
0.06750	-0.06763	-0.01820		
0.06843	-0.08583	0.01178		
0.06939	-0.07405	0.01178		
0.07035	-0.06226	0.00179		
0.07130	-0.06047	-0.01320		
0.07224	-0.07367	-0.00071		
0.07319	-0.07438	0.00429		
0.07415	-0.07009	0.00928		
0.07510	-0.06081	-0.01070		
0.07604	-0.07151	0.00679		
0.07700	-0.06472	0.01678		
0.07797	-0.04794	0.01178		
0.07893	-0.03616	0.01428		
0.07989	-0.02188	0.01178		
0.08085	-0.01009	-0.02069		
0.08178	-0.03079	0.00928		
0.08274	-0.02150	0.00928		
0.08370	-0.01222	0.00429		
0.08466	-0.00793	0.00179		
0.08561	-0.00614	0.00429		
0.08656	-0.00185	-0.00570		
0.08751	-0.00756	0.00928		
0.08847	0.00173	-0.01070		
0.08941	-0.00897	0.01428		
0.09037	0.00531	-0.08315		
0.09124	-0.07784	0.01928	96	MSB3
0.09221	-0.05856	-0.01570		
0.09314	-0.07426	0.00429		
0.09410	-0.06997	-0.02819		
0.09502	-0.09816	0.01428		
0.09599	-0.08388	-0.01570		
0.09692	-0.09958	0.00429		
0.09787	-0.09529	-0.00071		
0.09882	-0.09600	0.01928		

0.09979	-0.07672	-0.01820
0.10073	-0.09492	0.01678
0.10169	-0.07814	-0.02069
0.10262	-0.09883	0.00179
0.10357	-0.09704	0.01428
0.10454	-0.08276	-0.00820
0.10548	-0.09096	0.00179
0.10643	-0.08917	0.00928
0.10739	-0.07989	0.01178
0.10835	-0.06810	0.01428
0.10932	-0.05382	0.00679
0.11027	-0.04704	0.01928
0.11124	-0.02776	-0.01320
0.11218	-0.04096	0.00429
0.11313	-0.03667	0.00179
0.11408	-0.03488	0.00679
0.11504	-0.02809	-0.00071
0.11599	-0.02880	0.01178
0.11695	-0.01702	-0.01070
0.11789	-0.02772	0.01678
0.11886	-0.01094	-0.01320
0.11979	-0.02414	0.00928
0.12075	-0.01485	-0.10314
0.12161	-0.11799	0.00179
0.12256	-0.11620	-0.01070
0.12350	-0.12690	0.01678
0.12446	-0.11012	-0.03069
0.12538	-0.14081	0.01428
0.12635	-0.12653	-0.02819
0.12727	-0.15471	0.00679
0.12823	-0.14793	-0.01320
0.12917	-0.16113	0.01928
0.13013	-0.14185	-0.00071
0.13108	-0.14256	0.01178
0.13204	-0.13077	-0.01820
0.13298	-0.14897	0.01178
0.13394	-0.13719	-0.01070
0.13488	-0.14789	0.00679
0.13584	-0.14110	-0.00321
0.13678	-0.14431	0.01428
0.13775	-0.13003	0.00679
0.13870	-0.12324	0.01178
0.13966	-0.11146	0.01178
0.14062	-0.09967	0.00429
0.14158	-0.09538	-0.00071
0.14253	-0.09609	0.00928
0.14349	-0.08681	-0.01070
0.14443	-0.09751	0.01928
0.14540	-0.07823	-0.00071
0.14635	-0.07894	0.00679
0.14730	-0.07215	-0.00071
0.14825	-0.07286	0.00679
0.14921	-0.06607	-0.00570
0.15015	-0.07178	0.00928
0.15111	-0.06249	-0.00321

128

MSB4

0.15206	-0.06570	-0.00321	160	MSB5
0.15301	-0.06891	-0.01070		
0.15395	-0.07961	0.00429		
0.15490	-0.07532	-0.03568		
0.15582	-0.11100	0.01678		
0.15678	-0.09422	-0.01570		
0.15772	-0.10992	0.00429		
0.15867	-0.10563	0.00179		
0.15962	-0.10384	0.00179		
0.16057	-0.10205	0.01178		
0.16154	-0.09027	0.00679		
0.16249	-0.08348	-0.02819		
0.16342	-0.11167	0.01178		
0.16438	-0.09989	-0.00071		
0.16533	-0.10060	0.01428		
0.16629	-0.08631	-0.00820		
0.16723	-0.09452	0.00429		
0.16819	-0.09023	0.00928		
0.16915	-0.08094	0.01678		
0.17011	-0.06417	0.00928		
0.17107	-0.05488	0.01678		
0.17204	-0.03810	-0.02569		
0.17296	-0.06379	0.02427		
0.17394	-0.03952	-0.00071		
0.17489	-0.04023	-0.00321		
0.17583	-0.04343	-0.00321		
0.17678	-0.04664	0.02178		
0.17775	-0.02486	-0.01320		
0.17869	-0.03806	0.01178		
0.17965	-0.02628	-0.01070		
0.18059	-0.03698	0.01178		
0.18155	-0.02520	-0.03568		
0.18247	-0.06088	0.01678	192	MSB6
0.18343	-0.04410	-0.02069		
0.18436	-0.06479	0.00429		
0.18532	-0.06051	-0.01320		
0.18625	-0.07370	-0.00071		
0.18720	-0.07441	-0.01820		
0.18814	-0.09261	0.01928		
0.18911	-0.07333	-0.02069		
0.19004	-0.09402	0.00679		
0.19099	-0.08724	0.00679		
0.19195	-0.08045	0.01428		
0.19291	-0.06617	-0.02819		
0.19384	-0.09436	0.00679		
0.19479	-0.08757	-0.00071		
0.19574	-0.08828	0.00928		
0.19670	-0.07900	0.00679		
0.19766	-0.07221	-0.00321		
0.19860	-0.07542	0.01928		
0.19957	-0.05614	0.00928		
0.20053	-0.04685	0.01678		
0.20150	-0.03007	0.00179		
0.20245	-0.02828	-0.00071		
0.20340	-0.02899	0.01428		

0.20436	-0.01471	-0.00071		
0.20531	-0.01542	0.00928		
0.20627	-0.00613	-0.00321		
0.20722	-0.00934	0.00429		
0.20817	-0.00505	-0.00071		
0.20912	-0.00576	0.00928		
0.21008	0.00353	-0.01570		
0.21102	-0.01217	0.02178		
0.21199	0.00960	-0.00820		
0.21293	0.00140	0.00679	224	MSB7
0.21389	0.00819	-0.01570		
0.21482	-0.00751	0.01928		
0.21579	0.01177	-0.02819		
0.21671	-0.01642	0.00928		
0.21767	-0.00714	-0.01570		
0.21861	-0.02283	0.00928		
0.21957	-0.01355	-0.01570		
0.22050	-0.02925	0.01178		
0.22146	-0.01746	0.00928		
0.22242	-0.00818	0.00429		
0.22337	-0.00389	-0.01820		
0.22431	-0.02209	0.01928		
0.22528	-0.00281	-0.02319		
0.22620	-0.02600	0.01178		
0.22717	-0.01422	-0.00820		
0.22811	-0.02242	0.00429		
0.22906	-0.01813	0.02178		
0.23003	0.00364	0.00179		
0.23098	0.00543	0.01428		
0.23195	0.01972	0.01928		
0.23292	0.03899	-0.01570		
0.23385	0.02330	0.00928		
0.23481	0.03258	0.00679		
0.23577	0.03937	0.00179		
0.23672	0.04116	-0.00071		
0.23767	0.04045	0.01428		
0.23863	0.05473	-0.01070		
0.23957	0.04403	0.00679		
0.24053	0.05082	0.00679		
0.24149	0.05760	0.00179		
0.24244	0.05939	-0.07066		
0.24332	-0.01127	0.01178	256	MSB8
0.24428	0.00052	-0.00570		
0.24523	-0.00519	0.00679		
0.24618	0.00160	-0.02069		
0.24711	-0.01909	0.00429		
0.24807	-0.01481	-0.01570		
0.24900	-0.03050	0.00928		
0.24996	-0.02122	-0.01570		
0.25090	-0.03692	0.00179		
0.25185	-0.03513	0.00179		
0.25280	-0.03334	0.01678		
0.25377	-0.01656	-0.01320		
0.25470	-0.02976	0.00179		
0.25566	-0.02797	-0.00820		



0.25660	-0.03617	0.01428		
0.25756	-0.02189	-0.01070		
0.25850	-0.03259	0.01928		
0.25947	-0.01331	0.00928		
0.26043	-0.00403	0.01928		
0.26140	0.01525	0.01178		
0.26236	0.02704	0.01178		
0.26332	0.03882	-0.01320		
0.26426	0.02562	0.01178		
0.26522	0.03740	-0.00321		
0.26617	0.03420	0.00928		
0.26712	0.04348	-0.00820		
0.26807	0.03528	0.02427		
0.26904	0.05955	-0.01070		
0.26998	0.04885	0.00928		
0.27094	0.05814	-0.00570		
0.27188	0.05243	0.00429		
0.27284	0.05672	-0.07316		
0.27372	-0.01644	-0.00071	288	MSB9
0.27467	-0.01714	-0.01820		
0.27560	-0.03534	0.02677		
0.27658	-0.00857	-0.01570		
0.27751	-0.02427	0.00928		
0.27847	-0.01498	-0.02569		
0.27940	-0.04067	-0.00071		
0.28035	-0.04138	-0.01320		
0.28128	-0.05458	0.00928		
0.28224	-0.04529	0.00928		
0.28320	-0.03601	0.00179		
0.28415	-0.03422	-0.02069		
0.28508	-0.05491	0.01178		
0.28604	-0.04313	-0.00321		
0.28699	-0.04634	0.01178		
0.28795	-0.03455	-0.00071		
0.28890	-0.03526	0.01428		
0.28987	-0.02098	0.00429		
0.29082	-0.01669	0.01428		
0.29178	-0.00241	0.01178		
0.29275	0.00937	-0.00071		
0.29369	0.00866	-0.00071		
0.29464	0.00796	0.01428		
0.29561	0.02224	-0.01070		
0.29655	0.01154	0.01428		
0.29751	0.02582	-0.00321		
0.29846	0.02261	0.00928		
0.29942	0.03190	-0.00820		
0.30036	0.02369	0.01428		
0.30132	0.03798	-0.00321		
0.30227	0.03477	0.01428		
0.30323	0.04905	0.00679		
0.30419	0.05584	0.01928	320	MSB10
0.30516	0.07511	-0.02069		
0.30609	0.05442	-0.00071		
0.30704	0.05371	-0.01820		
0.30797	0.03552	0.01178		

0.30893	0.04730	-0.01570
0.30987	0.03160	0.01178
0.31083	0.04339	-0.01570
0.31176	0.02769	0.01178
0.31273	0.03947	0.01178
0.31369	0.05125	0.01178
0.31465	0.06304	-0.02819
0.31557	0.03485	0.02677
0.31655	0.06162	-0.01820
0.31748	0.04342	0.00679
0.31844	0.05021	-0.00071
0.31939	0.04950	-0.00570
0.32033	0.04380	0.01428
0.32129	0.05808	0.00429
0.32225	0.06237	0.01678
0.32321	0.07915	0.02178
0.32419	0.10092	-0.01070
0.32513	0.09022	-0.00321
0.32607	0.08702	0.00429
0.32703	0.09130	-0.00071
0.32798	0.09060	0.00429
0.32893	0.09489	0.01678
0.32990	0.11166	-0.00820
0.33084	0.10346	0.00179
0.33179	0.10525	0.01178
0.33275	0.11704	-0.00570
0.33370	0.11133	-0.08815
0.33456	0.02318	0.00928
0.33552	0.03247	-0.01320
0.33646	0.01927	0.01178
0.33742	0.03105	-0.02819
0.33834	0.00286	0.00928
0.33930	0.01215	-0.03319
0.34022	-0.02104	0.00928
0.34118	-0.01175	-0.00321
0.34213	-0.01496	0.01428
0.34309	-0.00068	-0.00820
0.34403	-0.00888	0.01178
0.34499	0.00290	-0.02819
0.34592	-0.02528	0.02427
0.34689	-0.00101	-0.00570
0.34784	-0.00671	0.00179
0.34879	-0.00492	0.00679
0.34974	0.00186	0.00928
0.35070	0.01115	0.01928
0.35167	0.03042	-0.00321
0.35262	0.02722	0.00679
0.35358	0.03400	0.00179
0.35453	0.03579	0.00429
0.35548	0.04008	0.00928
0.35644	0.04937	0.00429
0.35739	0.05366	0.01178
0.35836	0.06544	-0.01320
0.35929	0.05224	0.01678
0.36026	0.06902	0.00429

352

MSB11

0.36121	0.07331	0.00179		
0.36217	0.07510	-0.00820		
0.36311	0.06690	0.00928		
0.36407	0.07618	-0.03568		
0.36498	0.04050	0.01928	384	MSB12
0.36595	0.05977	-0.02069		
0.36688	0.03908	0.01428		
0.36785	0.05336	-0.02319		
0.36877	0.03017	-0.00071		
0.36972	0.02946	-0.00321		
0.37067	0.02626	0.00179		
0.37162	0.02805	0.00429		
0.37258	0.03233	0.00179		
0.37353	0.03412	0.00429		
0.37448	0.03841	0.00928		
0.37544	0.04770	-0.02569		
0.37637	0.02201	0.00179		
0.37732	0.02380	-0.00570		
0.37826	0.01809	0.01678		
0.37923	0.03487	0.00179		
0.38018	0.03666	0.00179		
0.38113	0.03845	-0.00071		
0.38208	0.03774	0.01678		
0.38305	0.05452	0.02427		
0.38402	0.07880	0.00928		
0.38498	0.08808	-0.01820		
0.38591	0.06989	-0.00071		
0.38686	0.06918	0.01178		
0.38782	0.08096	0.00928		
0.38878	0.09025	0.01178		
0.38974	0.10203	0.00429		
0.39070	0.10632	-0.01820		
0.39163	0.08812	0.00928		
0.39259	0.09741	-0.00820		
0.39353	0.08920	0.01178		
0.39449	0.10099	-0.03069		
0.39541	0.07030	0.01428	416	MSB13
0.39638	0.08458	-0.01320		
0.39732	0.07138	0.01178		
0.39828	0.08317	-0.02569		
0.39920	0.05747	0.01178		
0.40016	0.06926	-0.03568		
0.40108	0.03357	0.01928		
0.40205	0.05285	0.00179		
0.40300	0.05464	0.01928		
0.40397	0.07392	-0.00071		
0.40492	0.07321	-0.00071		
0.40587	0.07250	-0.01320		
0.40680	0.05930	0.00429		
0.40776	0.06359	-0.00071		
0.40871	0.06288	0.00429		
0.40966	0.06717	0.00179		
0.41061	0.06896	0.00928		
0.41157	0.07825	-0.00071		
0.41252	0.07754	0.00928		

0.41348	0.08682	0.00679		
0.41444	0.09361	0.01678		
0.41540	0.11039	-0.00071		
0.41635	0.10968	0.00928		
0.41731	0.11897	0.00179		
0.41826	0.12076	-0.00071		
0.41921	0.12005	-0.01820		
0.42015	0.10185	0.02178		
0.42112	0.12363	-0.01070		
0.42206	0.11293	-0.00071		
0.42301	0.11222	-0.00321		
0.42395	0.10901	0.01178		
0.42492	0.12080	-0.04068		
0.42583	0.08012	-0.00071	448	MSB14
0.42678	0.07941	-0.01320		
0.42771	0.06621	0.01678		
0.42868	0.08299	-0.02569		
0.42961	0.05730	0.01178		
0.43057	0.06908	-0.02819		
0.43149	0.04089	0.02677		
0.43247	0.06767	-0.01320		
0.43340	0.05447	0.00928		
0.43436	0.06375	-0.00321		
0.43531	0.06055	0.01428		
0.43627	0.07483	-0.02319		
0.43720	0.05163	-0.00071		
0.43815	0.05093	-0.00321		
0.43910	0.04772	0.00928		
0.44006	0.05701	0.01428		
0.44102	0.07129	0.00679		
0.44198	0.07807	0.00429		
0.44293	0.08236	0.01178		
0.44389	0.09414	0.00928		
0.44485	0.10343	-0.00071		
0.44580	0.10272	-0.00570		
0.44675	0.09702	0.01678		
0.44771	0.11380	0.01928		
0.44868	0.13307	0.00679		
0.44964	0.13986	-0.01570		
0.45057	0.12416	0.00928		
0.45153	0.13345	-0.00570		
0.45247	0.12774	0.00679		
0.45343	0.13453	-0.01070		
0.45437	0.12383	0.01178		
0.45533	0.13561	-0.01820		
0.45627	0.11742	0.01678	480	MSB15
0.45723	0.13420	-0.01070		
0.45817	0.12349	-0.00820		
0.45911	0.11529	-0.01070		
0.46005	0.10459	0.00679		
0.46101	0.11138	-0.01320		
0.46195	0.09818	0.01178		
0.46291	0.10996	-0.01320		
0.46385	0.09676	-0.00321		
0.46479	0.09356	0.00928		

0.46575	0.10284	0.01428
0.46672	0.11712	-0.03069
0.46764	0.08643	0.00928
0.46860	0.09572	-0.01820
0.46953	0.07752	0.00429
0.47048	0.08181	0.00179
0.47144	0.08360	0.02427
0.47241	0.10788	0.00429
0.47336	0.11216	0.00679
0.47432	0.11895	0.00679
0.47528	0.12574	0.00679
0.47623	0.13252	0.00679
0.47719	0.13931	0.00179
0.47814	0.14110	0.01678
0.47911	0.15788	-0.00071
0.48006	0.15717	0.00429
0.48101	0.16146	0.00928
0.48197	0.17075	-0.00820
0.48291	0.16254	0.01428
0.48388	0.17682	-0.01570
0.48481	0.16113	0.00429
0.48576	0.16542	-0.06316
0.48665	0.10225	-0.00820
0.48760	0.09405	-0.01820
0.48853	0.07585	0.00928
0.48949	0.08514	-0.02319
0.49042	0.06195	0.02427
0.49139	0.08622	-0.02319
0.49232	0.06303	0.00429
0.49327	0.06732	0.00179
0.49422	0.06911	0.01178
0.49519	0.08089	0.00429
0.49614	0.08518	0.00928
0.49710	0.09446	-0.02819
0.49802	0.06627	0.00928
0.49898	0.07556	-0.01070
0.49992	0.06486	0.00179
0.50087	0.06665	0.01178
0.50183	0.07843	-0.00321
0.50278	0.07522	0.00429
0.50373	0.07951	0.01928
0.50470	0.09879	0.01678
0.50567	0.11557	0.01428
0.50663	0.12985	-0.00570
0.50758	0.12415	0.00679
0.50853	0.13093	0.00928
0.50949	0.14022	0.00179
0.51044	0.14201	-0.00071
0.51139	0.14130	0.01928
0.51236	0.16058	-0.03069
0.51328	0.12989	0.01928
0.51425	0.14917	-0.00071
0.51520	0.14846	0.00179
0.51615	0.15025	-0.06316
0.51704	0.08709	0.01178

512

MSB16

544

MSB17

0.51800	0.09887	-0.03319		
0.51892	0.06568	0.02178		
0.51989	0.08746	-0.02319		
0.52082	0.06427	0.01178		
0.52178	0.07605	-0.02569		
0.52271	0.05036	0.01678		
0.52368	0.06714	-0.01070		
0.52462	0.05644	0.00179		
0.52557	0.05823	0.00179		
0.52652	0.06002	0.01428		
0.52748	0.07430	-0.01320		
0.52842	0.06110	0.01178		
0.52938	0.07289	0.01178		
0.53034	0.08467	-0.00820		
0.53128	0.07647	-0.00820		
0.53223	0.06826	0.00679		
0.53318	0.07505	0.01428		
0.53415	0.08933	0.00679		
0.53510	0.09612	0.03427		
0.53609	0.13038	-0.00570		
0.53703	0.12468	-0.01070		
0.53797	0.11398	-0.00071		
0.53892	0.11327	-0.00820		
0.53986	0.10507	0.02427		
0.54084	0.12934	-0.00570		
0.54178	0.12364	0.00179		
0.54273	0.12543	-0.00321		
0.54368	0.12222	0.00429		
0.54463	0.12651	-0.00570		
0.54558	0.12080	0.00928		
0.54654	0.13009	0.01678		
0.54750	0.14687	0.00928	576	MSB18
0.54846	0.15615	0.00429		
0.54942	0.16044	0.00928		
0.55038	0.16973	-0.04318		
0.55128	0.12655	0.00928		
0.55224	0.13583	-0.00570		
0.55319	0.13013	0.00429		
0.55414	0.13442	-0.01070		
0.55508	0.12372	0.00429		
0.55604	0.12801	-0.00820		
0.55698	0.11980	0.01178		
0.55794	0.13159	-0.01820		
0.55887	0.11339	0.00679		
0.55983	0.12018	0.00179		
0.56078	0.12197	0.01178		
0.56174	0.13375	-0.00570		
0.56269	0.12804	0.00179		
0.56364	0.12983	0.00429		
0.56459	0.13412	0.00429		
0.56555	0.13841	0.01678		
0.56651	0.15519	0.01178		
0.56747	0.16697	-0.00820		
0.56842	0.15877	0.00679		
0.56937	0.16556	0.01178		

0.57033	0.17734	0.02427		
0.57131	0.20162	-0.01570		
0.57224	0.18592	0.00928		
0.57320	0.19520	-0.01570		
0.57414	0.17951	0.00928		
0.57510	0.18879	-0.01320		
0.57603	0.17559	0.02427		
0.57701	0.19986	-0.12062		
0.57784	0.07924	-0.00071	608	MSB19
0.57879	0.07853	-0.01320		
0.57973	0.06533	0.01928		
0.58070	0.08461	-0.02569		
0.58162	0.05892	0.01428		
0.58259	0.07320	-0.01070		
0.58353	0.06250	-0.00071		
0.58448	0.06179	-0.00570		
0.58542	0.05609	0.01428		
0.58639	0.07037	-0.00071		
0.58733	0.06966	-0.00071		
0.58828	0.06895	-0.01320		
0.58922	0.05576	0.01178		
0.59018	0.06754	-0.01570		
0.59112	0.05184	0.01178		
0.59208	0.06362	0.01178		
0.59304	0.07541	0.00429		
0.59399	0.07970	0.00179		
0.59495	0.08149	0.00179		
0.59590	0.08328	0.01678		
0.59686	0.10005	0.01678		
0.59783	0.11683	-0.02069		
0.59876	0.09614	0.01678		
0.59973	0.11292	-0.01070		
0.60067	0.10222	0.01428		
0.60163	0.11650	-0.00321		
0.60258	0.11329	0.01428		
0.60354	0.12758	-0.01070		
0.60448	0.11687	0.01428		
0.60544	0.13116	-0.00321		
0.60639	0.12795	0.00429		
0.60735	0.13224	-0.11313		
0.60819	0.01911	0.01428	640	MSB20
0.60915	0.03339	-0.02069		
0.61008	0.01270	0.00928		
0.61104	0.02198	-0.02569		
0.61197	-0.00371	-0.00820		
0.61291	-0.01191	-0.01820		
0.61384	-0.03011	0.01928		
0.61481	-0.01083	-0.02319		
0.61574	-0.03402	-0.00071		
0.61669	-0.03473	0.01428		
0.61765	-0.02045	0.01428		
0.61862	-0.00617	-0.00071		
0.61957	-0.00688	-0.00570		
0.62051	-0.01258	0.00179		
0.62146	-0.01079	0.00679		

0.62242	-0.00400	-0.00071		
0.62337	-0.00471	0.00429		
0.62432	-0.00042	0.00429		
0.62528	0.00386	0.01678		
0.62624	0.02064	0.00429		
0.62720	0.02493	0.00928		
0.62816	0.03422	-0.00820		
0.62910	0.02601	0.02927		
0.63008	0.05529	-0.00570		
0.63102	0.04958	-0.00570		
0.63196	0.04388	-0.00321		
0.63291	0.04067	0.00928		
0.63387	0.04995	-0.00820		
0.63481	0.04175	0.01428		
0.63578	0.05603	-0.01070		
0.63672	0.04533	0.00679		
0.63767	0.05212	-0.07066		
0.63856	-0.01854	0.01428	672	MSB21
0.63952	-0.00426	-0.01820		
0.64045	-0.02245	0.01678		
0.64142	-0.00567	-0.03319		
0.64234	-0.03886	0.00429		
0.64329	-0.03457	-0.01820		
0.64422	-0.05277	0.01928		
0.64519	-0.03349	-0.00820		
0.64614	-0.04169	0.00179		
0.64709	-0.03990	0.00429		
0.64804	-0.03561	0.00429		
0.64900	-0.03133	-0.01820		
0.64993	-0.04952	0.02178		
0.65090	-0.02775	-0.00071		
0.65185	-0.02845	0.00679		
0.65280	-0.02167	-0.00321		
0.65375	-0.02487	0.00679		
0.65471	-0.01809	0.00429		
0.65566	-0.01380	-0.00321		
0.65661	-0.01700	0.00928		
0.65757	-0.00772	0.02178		
0.65854	0.01406	-0.00820		
0.65948	0.00585	0.00679		
0.66044	0.01264	0.00179		
0.66139	0.01443	0.02927		
0.66237	0.04370	-0.00570		
0.66331	0.03800	0.00679		
0.66427	0.04478	-0.01070		
0.66521	0.03408	0.00429		
0.66616	0.03837	-0.00820		
0.66711	0.03017	0.02178		
0.66808	0.05194	-0.00570		
0.66902	0.04624	-0.01070	704	MSB22
0.66996	0.03554	-0.02819		
0.67088	0.00735	0.01178		
0.67185	0.01913	-0.02819		
0.67277	-0.00906	0.00429		
0.67372	-0.00477	-0.02569		



0.67465	-0.03046	-0.00321
0.67560	-0.03366	0.00928
0.67655	-0.02438	0.01678
0.67752	-0.00760	-0.00071
0.67847	-0.00831	0.01678
0.67944	0.00847	-0.00570
0.68038	0.00277	-0.00321
0.68133	-0.00044	0.01178
0.68229	0.01134	0.00928
0.68325	0.02063	-0.00820
0.68419	0.01243	0.00679
0.68515	0.01921	0.02178
0.68612	0.04099	0.00928
0.68708	0.05027	0.01928
0.68805	0.06955	0.01678
0.68901	0.08633	-0.02569
0.68994	0.06064	-0.00321
0.69088	0.05743	0.00679
0.69184	0.06422	0.01678
0.69281	0.08100	-0.00321
0.69375	0.07779	0.00679
0.69471	0.08458	-0.01570
0.69565	0.06888	0.00179
0.69660	0.07067	-0.01320
0.69753	0.05747	0.00928
0.69849	0.06676	-0.01320
0.69943	0.05356	0.00429
0.70039	0.05785	-0.00071
0.70134	0.05714	0.00928
0.70229	0.06642	-0.04318
0.70320	0.02325	0.02427
0.70418	0.04752	-0.02569
0.70510	0.02183	-0.00820
0.70604	0.01363	-0.00071
0.70699	0.01292	0.00679
0.70795	0.01970	0.01928
0.70892	0.03898	0.00179
0.70987	0.04077	-0.01820
0.71080	0.02258	0.01178
0.71176	0.03436	-0.02319
0.71269	0.01117	0.00928
0.71365	0.02045	0.00679
0.71461	0.02724	-0.00570
0.71555	0.02153	0.01678
0.71652	0.03831	0.01178
0.71748	0.05010	0.01678
0.71845	0.06688	-0.00071
0.71940	0.06617	-0.01070
0.72034	0.05547	0.02178
0.72131	0.07724	-0.00071
0.72226	0.07654	0.00679
0.72321	0.08332	0.00179
0.72416	0.08511	-0.00321
0.72511	0.08191	0.00679
0.72607	0.08869	0.00179

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MSB23

0.72702	0.09048	-0.00321		
0.72797	0.08728	-0.00820		
0.72891	0.07907	-0.07565		
0.72979	0.00342	-0.00570	768	MSB24
0.73073	-0.00229	-0.00570		
0.73168	-0.00799	0.00429		
0.73263	-0.00370	-0.00321		
0.73358	-0.00691	-0.01070		
0.73452	-0.01761	-0.01820		
0.73545	-0.03581	0.01178		
0.73641	-0.02402	-0.02069		
0.73734	-0.04472	0.01428		
0.73831	-0.03043	0.01678		
0.73927	-0.01366	0.00679		
0.74023	-0.00687	-0.02319		
0.74116	-0.03006	0.00928		
0.74212	-0.02078	0.00928		
0.74307	-0.01149	-0.00321		
0.74402	-0.01470	-0.00570		
0.74497	-0.02040	0.01678		
0.74593	-0.00362	-0.00071		
0.74688	-0.00433	0.02677		
0.74786	0.02244	0.00679		
0.74881	0.02923	0.00679		
0.74977	0.03601	-0.01070		
0.75071	0.02531	0.01178		
0.75167	0.03710	-0.00820		
0.75261	0.02889	-0.00321		
0.75356	0.02569	0.01178		
0.75452	0.03747	0.00429		
0.75548	0.04176	-0.00820		
0.75642	0.03356	-0.00321		
0.75737	0.03035	0.00429		
0.75832	0.03464	0.01178		
0.75928	0.04642	-0.06566		
0.76017	-0.01924	0.01428	800	MSB25
0.76113	-0.00496	-0.01820		
0.76207	-0.02316	-0.01320		
0.76300	-0.03635	-0.02069		
0.76393	-0.05705	0.00429		
0.76489	-0.05276	-0.00570		
0.76583	-0.05846	0.00679		
0.76679	-0.05168	-0.01070		
0.76773	-0.06238	0.01428		
0.76869	-0.04810	0.00928		
0.76965	-0.03881	0.01678		
0.77062	-0.02203	-0.02069		
0.77155	-0.04273	-0.00071		
0.77250	-0.04344	-0.00071		
0.77345	-0.04414	0.00429		
0.77440	-0.03986	-0.00321		
0.77535	-0.04306	-0.00071		
0.77630	-0.04377	0.00679		
0.77725	-0.03698	0.01678		
0.77822	-0.02020	0.00679		

0.77918	-0.01342	0.01428		
0.78014	0.00086	-0.00570		
0.78108	-0.00484	0.00679		
0.78204	0.00195	-0.00820		
0.78298	-0.00626	0.00179		
0.78394	-0.00447	-0.00321		
0.78488	-0.00767	0.01178		
0.78584	0.00411	-0.00321		
0.78679	0.00090	0.03177		
0.78777	0.03267	-0.02069		
0.78870	0.01198	0.01428		
0.78967	0.02626	-0.07815		
0.79054	-0.05189	-0.00071	832	MSB26
0.79149	-0.05260	-0.02069		
0.79242	-0.07330	0.01928		
0.79339	-0.05402	-0.00321		
0.79434	-0.05722	-0.00321		
0.79528	-0.06043	-0.02569		
0.79621	-0.08612	0.00679		
0.79717	-0.07933	-0.00820		
0.79811	-0.08754	0.01928		
0.79908	-0.06826	0.02427		
0.80005	-0.04398	0.00679		
0.80101	-0.03720	-0.03568		
0.80192	-0.07288	0.01178		
0.80288	-0.06110	-0.00570		
0.80383	-0.06680	0.01928		
0.80480	-0.04753	-0.02319		
0.80572	-0.07072	0.00928		
0.80668	-0.06143	0.01928		
0.80765	-0.04215	0.00179		
0.80860	-0.04036	0.01178		
0.80957	-0.02858	0.00679		
0.81052	-0.02180	-0.01320		
0.81146	-0.03499	0.00928		
0.81242	-0.02571	-0.00321		
0.81337	-0.02892	0.00429		
0.81432	-0.02463	0.00179		
0.81527	-0.02284	0.01928		
0.81624	-0.00356	-0.00321		
0.81719	-0.00677	-0.01070		
0.81813	-0.01747	-0.02069		
0.81906	-0.03816	0.02178		
0.82003	-0.01638	-0.04568		
0.82093	-0.06206	0.00679	864	MSB27
0.82189	-0.05527	-0.01570		
0.82283	-0.07097	0.00429		
0.82378	-0.06668	-0.01320		
0.82472	-0.07988	0.00429		
0.82567	-0.07559	-0.00071		
0.82662	-0.07630	0.00429		
0.82758	-0.07201	-0.00820		
0.82852	-0.08022	0.01928		
0.82949	-0.06094	-0.03319		
0.83041	-0.09412	0.01928		

0.83137	-0.07485	-0.02069		
0.83230	-0.09554	0.00429		
0.83326	-0.09125	0.00928		
0.83422	-0.08197	0.00928		
0.83518	-0.07268	-0.00570		
0.83612	-0.07839	0.00679		
0.83708	-0.07160	0.02927		
0.83806	-0.04233	0.01428		
0.83902	-0.02805	0.00429		
0.83997	-0.02376	0.00928		
0.84093	-0.01448	0.00429		
0.84189	-0.01019	0.01428		
0.84285	0.00409	-0.00071		
0.84380	0.00339	-0.00321		
0.84475	0.00018	-0.00321		
0.84569	-0.00303	-0.00570		
0.84664	-0.00873	0.00179		
0.84759	-0.00694	-0.01320		
0.84853	-0.02014	0.00179		
0.84948	-0.01835	0.00679		
0.85044	-0.01156	-0.03069		
0.85136	-0.04225	-0.01320	896	MSB28
0.85229	-0.05545	-0.00820		
0.85324	-0.06365	0.00429		
0.85419	-0.05936	-0.02569		
0.85512	-0.08505	0.01428		
0.85608	-0.07077	-0.01320		
0.85702	-0.08397	0.00179		
0.85797	-0.08218	-0.00820		
0.85891	-0.09039	0.01178		
0.85987	-0.07860	0.00679		
0.86083	-0.07182	0.01928		
0.86180	-0.05254	-0.03069		
0.86272	-0.08322	0.00679		
0.86368	-0.07644	-0.00321		
0.86462	-0.07964	0.00179		
0.86557	-0.07785	-0.02319		
0.86650	-0.10105	0.01428		
0.86747	-0.08677	0.00179		
0.86842	-0.08498	0.01428		
0.86938	-0.07069	0.01428		
0.87035	-0.05641	0.01428		
0.87131	-0.04213	-0.01320		
0.87225	-0.05533	0.00679		
0.87320	-0.04854	0.00179		
0.87416	-0.04675	0.01178		
0.87512	-0.03497	-0.02569		
0.87604	-0.06066	-0.00321		
0.87699	-0.06387	0.01428		
0.87795	-0.04959	0.01178		
0.87891	-0.03780	0.01678		
0.87988	-0.02102	-0.00820		
0.88082	-0.02923	-0.03069		
0.88174	-0.05991	0.01428	928	MSB29
0.88271	-0.04563	-0.00570		

0.88365	-0.05134	0.00928
0.88461	-0.04205	-0.03818
0.88552	-0.08023	-0.00071
0.88647	-0.08094	-0.02319
0.88740	-0.10413	0.00429
0.88836	-0.09985	-0.02319
0.88928	-0.12304	0.01428
0.89025	-0.10876	0.01428
0.89121	-0.09447	0.00429
0.89217	-0.09019	-0.01570
0.89310	-0.10588	0.01178
0.89406	-0.09410	-0.00820
0.89500	-0.10230	-0.00321
0.89595	-0.10551	0.01678
0.89692	-0.08873	-0.00570
0.89786	-0.09444	0.01428
0.89883	-0.08015	0.01928
0.89979	-0.06088	0.01178
0.90076	-0.04909	0.01428
0.90172	-0.03481	-0.00570
0.90266	-0.04052	0.00429
0.90362	-0.03623	-0.01070
0.90456	-0.04693	0.01178
0.90552	-0.03515	-0.00570
0.90646	-0.04085	0.01178
0.90743	-0.02907	-0.00820
0.90837	-0.03727	-0.00321
0.90931	-0.04048	0.00179
0.91027	-0.03869	0.01928
0.91124	-0.01941	-0.07815
0.91211	-0.09756	0.01428
0.91307	-0.08328	-0.01820
0.91401	-0.10148	0.01428
0.91497	-0.08720	-0.02069
0.91590	-0.10789	0.00179
0.91685	-0.10610	-0.01570
0.91779	-0.12180	0.00179
0.91874	-0.12001	-0.00820
0.91968	-0.12821	-0.00071
0.92063	-0.12892	0.01928
0.92160	-0.10964	0.01678
0.92257	-0.09286	-0.02819
0.92349	-0.12105	0.00429
0.92444	-0.11676	-0.00570
0.92539	-0.12246	-0.00570
0.92633	-0.12817	-0.00321
0.92728	-0.13138	0.00179
0.92823	-0.12959	0.00679
0.92919	-0.12280	0.00179
0.93014	-0.12101	0.02178
0.93111	-0.09923	0.01178
0.93207	-0.08745	-0.00570
0.93302	-0.09315	-0.00321
0.93396	-0.09636	0.00429
0.93492	-0.09207	-0.00570

960

MSB30

0.93586	-0.09778	0.00179		
0.93682	-0.09599	0.00179		
0.93777	-0.09420	-0.01070		
0.93871	-0.10490	0.01178		
0.93967	-0.09311	-0.00570		
0.94061	-0.09882	0.01178		
0.94157	-0.08704	-0.03818		
0.94249	-0.12522	0.02427	992	MSB31
0.94346	-0.10094	-0.00820		
0.94440	-0.10915	-0.00820		
0.94535	-0.11735	-0.01820		
0.94628	-0.13554	-0.00321		
0.94723	-0.13875	-0.02319		
0.94815	-0.16194	0.00928		
0.94911	-0.15266	0.00928		
0.95007	-0.14337	-0.02319		
0.95100	-0.16657	-0.00570		
0.95194	-0.17227	0.00429		
0.95290	-0.16798	-0.00321		
0.95385	-0.17119	-0.00071		
0.95480	-0.17190	-0.00321		
0.95574	-0.17510	0.02178		
0.95671	-0.15333	-0.00071		
0.95766	-0.15404	0.00429		
0.95862	-0.14975	0.00679		
0.95957	-0.14296	0.01928		
0.96054	-0.12368	-0.00820		
0.96148	-0.13189	-0.00071		
0.96243	-0.13259	-0.02569		
0.96336	-0.15828	0.00679		
0.96432	-0.15150	0.02427		
0.96529	-0.12722	0.03177		
0.96627	-0.09545	-0.00321		
0.96722	-0.09866	0.00679		
0.96817	-0.09187	-0.00321		
0.96912	-0.09508	0.01928		
0.97009	-0.07580	-0.00820		
0.97103	-0.08401	0.00179		
0.97198	-0.08222	0.00000		

APPENDIX D  
MATLAB<sup>®</sup> SOFTWARE PROGRAM

```
%THS5651IDW DAC CURRENT ARRAY PLOT PROGRAM
```

```
load arr2.txt
```

```
x=arr2';
```

```
%mid bits 1-15
```

```
cv(1,1)=0;
```

```
cv(17,32)=0;
```

```
cv(9,16)=x(1)*1000;
```

```
cv(10,18)=x(2)*1000;
```

```
cv(8,14)=x(3)*1000;
```

```
cv(11,20)=x(4)*1000;
```

```
cv(7,12)=x(5)*1000;
```

```
cv(12,22)=x(6)*1000;
```

```
cv(6,10)=x(7)*1000;
```

```
cv(13,24)=x(8)*1000;
```

```
cv(5,8)=x(9)*1000;
```

```
cv(14,26)=x(10)*1000;
```

```
cv(4,6)=x(11)*1000;
```

```
cv(15,28)=x(12)*1000;
```

```
cv(3,4)=x(13)*1000;
```

```
cv(16,30)=x(14)*1000;
```

```
cv(2,2)=x(15)*1000;
```

```
%msb 1
```

```
cv(1,20)=(x(16)*1000)/16;
```

```
cv(2,22)=(x(16)*1000)/16;
```

```
cv(3,24)=(x(16)*1000)/16;
```

```
cv(4,26)=(x(16)*1000)/16;
```

```
cv(5,28)=(x(16)*1000)/16;
```

```
cv(6,30)=(x(16)*1000)/16;
```

```
cv(7,32)=(x(16)*1000)/16;
```

```
cv(8,13)=0;
```

```
cv(9,2)=(x(16)*1000)/16;
```

```
cv(10,4)=(x(16)*1000)/16;
```

```
cv(11,6)=(x(16)*1000)/16;
```

```
cv(12,8)=(x(16)*1000)/16;
```

```
cv(13,10)=(x(16)*1000)/16;
```

```
cv(14,12)=(x(16)*1000)/16;
```

```
cv(15,14)=(x(16)*1000)/16;
```

```
cv(16,16)=(x(16)*1000)/16;
```

```
cv(17,18)=(x(16)*1000)/16;
```

```
cv(17,18)=(x(16)*1000)/16;
```

```
%msb 2
```

```
cv(1,28)=(x(17)*1000)/16;
```

```
cv(2,30)=(x(17)*1000)/16;
```

```
cv(3,32)=(x(17)*1000)/16;
```

```
cv(4,5)=0;
```

```
cv(5,2)=(x(17)*1000)/16;
```



```

cv(6,4)=(x(17)*1000)/16;
cv(7,6)=(x(17)*1000)/16;
cv(8,8)=(x(17)*1000)/16;
cv(9,10)=(x(17)*1000)/16;
cv(10,12)=(x(17)*1000)/16;
cv(11,14)=(x(17)*1000)/16;
cv(12,16)=(x(17)*1000)/16;
cv(13,18)=(x(17)*1000)/16;
cv(14,20)=(x(17)*1000)/16;
cv(15,22)=(x(17)*1000)/16;
cv(16,24)=(x(17)*1000)/16;
cv(17,26)=(x(17)*1000)/16;
%msb 3
cv(1,12)=(x(18)*1000)/16;
cv(2,14)=(x(18)*1000)/16;
cv(3,16)=(x(18)*1000)/16;
cv(4,18)=(x(18)*1000)/16;
cv(5,20)=(x(18)*1000)/16;
cv(6,22)=(x(18)*1000)/16;
cv(7,24)=(x(18)*1000)/16;
cv(8,26)=(x(18)*1000)/16;
cv(9,28)=(x(18)*1000)/16;
cv(10,30)=(x(18)*1000)/16;
cv(11,32)=(x(18)*1000)/16;
cv(12,21)=0;
cv(13,2)=(x(18)*1000)/16;
cv(14,4)=(x(18)*1000)/16;
cv(15,6)=(x(18)*1000)/16;
cv(16,8)=(x(18)*1000)/16;
cv(17,10)=(x(18)*1000)/16;
%msb 4
cv(1,24)=(x(19)*1000)/16;
cv(2,26)=(x(19)*1000)/16;
cv(3,28)=(x(19)*1000)/16;
cv(4,30)=(x(19)*1000)/16;
cv(5,32)=(x(19)*1000)/16;
cv(6,9)=0;
cv(7,2)=(x(19)*1000)/16;
cv(8,4)=(x(19)*1000)/16;
cv(9,6)=(x(19)*1000)/16;
cv(10,8)=(x(19)*1000)/16;
cv(11,10)=(x(19)*1000)/16;
cv(12,12)=(x(19)*1000)/16;
cv(13,14)=(x(19)*1000)/16;
cv(14,16)=(x(19)*1000)/16;
cv(15,18)=(x(19)*1000)/16;

```

```

cv(16,20)=(x(19)*1000)/16;
cv(17,22)=(x(19)*1000)/16;
%msb5
cv(1,8)=(x(20)*1000)/16;
cv(2,10)=(x(20)*1000)/16;
cv(3,12)=(x(20)*1000)/16;
cv(4,14)=(x(20)*1000)/16;
cv(5,16)=(x(20)*1000)/16;
cv(6,18)=(x(20)*1000)/16;
cv(7,20)=(x(20)*1000)/16;
cv(8,22)=(x(20)*1000)/16;
cv(9,24)=(x(20)*1000)/16;
cv(10,26)=(x(20)*1000)/16;
cv(11,28)=(x(20)*1000)/16;
cv(12,30)=(x(20)*1000)/16;
cv(13,32)=(x(20)*1000)/16;
cv(14,25)=0;
cv(15,2)=(x(20)*1000)/16;
cv(16,4)=(x(20)*1000)/16;
cv(17,6)=(x(20)*1000)/16;
%msb6
cv(1,16)=(x(21)*1000)/16;
cv(2,18)=(x(21)*1000)/16;
cv(3,20)=(x(21)*1000)/16;
cv(4,22)=(x(21)*1000)/16;
cv(5,24)=(x(21)*1000)/16;
cv(6,26)=(x(21)*1000)/16;
cv(7,28)=(x(21)*1000)/16;
cv(8,30)=(x(21)*1000)/16;
cv(9,32)=(x(21)*1000)/16;
cv(10,17)=0;
cv(11,2)=(x(21)*1000)/16;
cv(12,4)=(x(21)*1000)/16;
cv(13,6)=(x(21)*1000)/16;
cv(14,8)=(x(21)*1000)/16;
cv(15,10)=(x(21)*1000)/16;
cv(16,12)=(x(21)*1000)/16;
cv(17,14)=(x(21)*1000)/16;
%msb 7
cv(1,32)=(x(22)*1000)/16;
cv(2,1)=0;
cv(3,2)=(x(22)*1000)/16;
cv(4,4)=(x(22)*1000)/16;
cv(5,6)=(x(22)*1000)/16;
cv(6,8)=(x(22)*1000)/16;
cv(7,10)=(x(22)*1000)/16;

```

```

cv(8,12)=(x(22)*1000)/16;
cv(9,14)=(x(22)*1000)/16;
cv(10,16)=(x(22)*1000)/16;
cv(11,18)=(x(22)*1000)/16;
cv(12,20)=(x(22)*1000)/16;
cv(13,22)=(x(22)*1000)/16;
cv(14,24)=(x(22)*1000)/16;
cv(15,26)=(x(22)*1000)/16;
cv(16,28)=(x(22)*1000)/16;
cv(17,30)=(x(22)*1000)/16;
%msb 8
cv(1,30)=(x(23)*1000)/16
cv(2,32)=(x(23)*1000)/16;
cv(3,3)=0;
cv(4,2)=(x(23)*1000)/16;
cv(5,4)=(x(23)*1000)/16;
cv(6,6)=(x(23)*1000)/16;
cv(7,8)=(x(23)*1000)/16;
cv(8,10)=(x(23)*1000)/16;
cv(9,12)=(x(23)*1000)/16;
cv(10,14)=(x(23)*1000)/16;
cv(11,16)=(x(23)*1000)/16;
cv(12,18)=(x(23)*1000)/16;
cv(13,20)=(x(23)*1000)/16;
cv(14,22)=(x(23)*1000)/16;
cv(15,24)=(x(23)*1000)/16;
cv(16,26)=(x(23)*1000)/16;
cv(17,28)=(x(23)*1000)/16;
%msb 9
cv(1,14)=(x(24)*1000)/16;
cv(2,16)=(x(24)*1000)/16;
cv(3,18)=(x(24)*1000)/16;
cv(4,20)=(x(24)*1000)/16;
cv(5,22)=(x(24)*1000)/16;
cv(6,24)=(x(24)*1000)/16;
cv(7,26)=(x(24)*1000)/16;
cv(8,28)=(x(24)*1000)/16;
cv(9,30)=(x(24)*1000)/16;
cv(10,32)=(x(24)*1000)/16;
cv(11,19)=0;
cv(12,2)=(x(24)*1000)/16;
cv(13,4)=(x(24)*1000)/16;
cv(14,6)=(x(24)*1000)/16;
cv(15,8)=(x(24)*1000)/16;
cv(16,10)=(x(24)*1000)/16;
cv(17,12)=(x(24)*1000)/16;

```

```

%msb 10
cv(1,6)=(x(25)*1000)/16;
cv(2,8)=(x(25)*1000)/16;
cv(3,10)=(x(25)*1000)/16;
cv(4,12)=(x(25)*1000)/16;
cv(5,14)=(x(25)*1000)/16;
cv(6,16)=(x(25)*1000)/16;
cv(7,18)=(x(25)*1000)/16;
cv(8,20)=(x(25)*1000)/16;
cv(9,22)=(x(25)*1000)/16;
cv(10,24)=(x(25)*1000)/16;
cv(11,26)=(x(25)*1000)/16;
cv(12,28)=(x(25)*1000)/16;
cv(13,30)=(x(25)*1000)/16;
cv(14,32)=(x(25)*1000)/16;
cv(15,27)=0;
cv(16,2)=(x(25)*1000)/16;
cv(17,4)=(x(25)*1000)/16;
%msb 11
cv(1,22)=(x(26)*1000)/16;
cv(2,24)=(x(26)*1000)/16;
cv(3,26)=(x(26)*1000)/16;
cv(4,28)=(x(26)*1000)/16;
cv(5,30)=(x(26)*1000)/16;
cv(6,32)=(x(26)*1000)/16;
cv(7,11)=0;
cv(8,2)=(x(26)*1000)/16;
cv(9,4)=(x(26)*1000)/16;
cv(10,6)=(x(26)*1000)/16;
cv(11,8)=(x(26)*1000)/16;
cv(12,10)=(x(26)*1000)/16;
cv(13,12)=(x(26)*1000)/16;
cv(14,14)=(x(26)*1000)/16;
cv(15,16)=(x(26)*1000)/16;
cv(16,18)=(x(26)*1000)/16;
cv(17,20)=(x(26)*1000)/16;
%msb 12
cv(1,10)=(x(27)*1000)/16;
cv(2,12)=(x(27)*1000)/16;
cv(3,14)=(x(27)*1000)/16;
cv(4,16)=(x(27)*1000)/16;
cv(5,18)=(x(27)*1000)/16;
cv(6,20)=(x(27)*1000)/16;
cv(7,22)=(x(27)*1000)/16;
cv(8,24)=(x(27)*1000)/16;
cv(9,26)=(x(27)*1000)/16;

```

```

cv(10,28)=(x(27)*1000)/16;
cv(11,30)=(x(27)*1000)/16;
cv(12,32)=(x(27)*1000)/16;
cv(13,23)=0;
cv(14,2)=(x(27)*1000)/16;
cv(15,4)=(x(27)*1000)/16;
cv(16,6)=(x(27)*1000)/16;
cv(17,8)=(x(27)*1000)/16;
%msb 13
cv(1,26)=(x(28)*1000)/16;
cv(2,28)=(x(28)*1000)/16;
cv(3,30)=(x(28)*1000)/16;
cv(4,32)=(x(28)*1000)/16;
cv(5,7)=0;
cv(6,2)=(x(28)*1000)/16;
cv(7,4)=(x(28)*1000)/16;
cv(8,6)=(x(28)*1000)/16;
cv(9,8)=(x(28)*1000)/16;
cv(10,10)=(x(28)*1000)/16;
cv(11,12)=(x(28)*1000)/16;
cv(12,14)=(x(28)*1000)/16;
cv(13,16)=(x(28)*1000)/16;
cv(14,18)=(x(28)*1000)/16;
cv(15,20)=(x(28)*1000)/16;
cv(16,22)=(x(28)*1000)/16;
cv(17,24)=(x(28)*1000)/16;
%msb 14
cv(1,18)=(x(29)*1000)/16;
cv(2,20)=(x(29)*1000)/16;
cv(3,22)=(x(29)*1000)/16;
cv(4,24)=(x(29)*1000)/16;
cv(5,26)=(x(29)*1000)/16;
cv(6,28)=(x(29)*1000)/16;
cv(7,30)=(x(29)*1000)/16;
cv(8,32)=(x(29)*1000)/16;
cv(9,15)=0;
cv(10,2)=(x(29)*1000)/16;
cv(11,4)=(x(29)*1000)/16;
cv(12,6)=(x(29)*1000)/16;
cv(13,8)=(x(29)*1000)/16;
cv(14,10)=(x(29)*1000)/16;
cv(15,12)=(x(29)*1000)/16;
cv(16,14)=(x(29)*1000)/16;
cv(17,16)=(x(29)*1000)/16;
%msb 15
cv(1,2)=(x(30)*1000)/16;

```

```

cv(2,4)=(x(30)*1000)/16;
cv(3,6)=(x(30)*1000)/16;
cv(4,8)=(x(30)*1000)/16;
cv(5,10)=(x(30)*1000)/16;
cv(6,12)=(x(30)*1000)/16;
cv(7,14)=(x(30)*1000)/16;
cv(8,16)=(x(30)*1000)/16;
cv(9,18)=(x(30)*1000)/16;
cv(10,20)=(x(30)*1000)/16;
cv(11,22)=(x(30)*1000)/16;
cv(12,24)=(x(30)*1000)/16;
cv(13,26)=(x(30)*1000)/16;
cv(14,28)=(x(30)*1000)/16;
cv(15,30)=(x(30)*1000)/16;
cv(16,32)=(x(30)*1000)/16;
cv(17,31)=0;
%msb 16
cv(1,4)=(x(31)*1000)/16;
cv(2,6)=(x(31)*1000)/16;
cv(3,8)=(x(31)*1000)/16;
cv(4,10)=(x(31)*1000)/16;
cv(5,12)=(x(31)*1000)/16;
cv(6,14)=(x(31)*1000)/16;
cv(7,16)=(x(31)*1000)/16;
cv(8,18)=(x(31)*1000)/16;
cv(9,20)=(x(31)*1000)/16;
cv(10,22)=(x(31)*1000)/16;
cv(11,24)=(x(31)*1000)/16;
cv(12,26)=(x(31)*1000)/16;
cv(13,28)=(x(31)*1000)/16;
cv(14,30)=(x(31)*1000)/16;
cv(15,32)=(x(31)*1000)/16;
cv(16,29)=0;
cv(17,2)=(x(31)*1000)/16;
%msb17
cv(1,17)=(x(32)*1000)/16;
cv(2,19)=(x(32)*1000)/16;
cv(3,21)=(x(32)*1000)/16;
cv(4,23)=(x(32)*1000)/16;
cv(5,25)=(x(32)*1000)/16;
cv(6,27)=(x(32)*1000)/16;
cv(7,29)=(x(32)*1000)/16;
cv(8,31)=(x(32)*1000)/16;
cv(9,17)=0;
cv(10,1)=(x(32)*1000)/16;
cv(11,3)=(x(32)*1000)/16;

```

```

cv(12,5)=(x(32)*1000)/16;
cv(13,7)=(x(32)*1000)/16;
cv(14,9)=(x(32)*1000)/16;
cv(15,11)=(x(32)*1000)/16;
cv(16,13)=(x(32)*1000)/16;
cv(17,15)=(x(32)*1000)/16;
%msb 18
cv(1,9)=(x(33)*1000)/16;
cv(2,11)=(x(33)*1000)/16;
cv(3,13)=(x(33)*1000)/16;
cv(4,15)=(x(33)*1000)/16;
cv(5,17)=(x(33)*1000)/16;
cv(6,19)=(x(33)*1000)/16;
cv(7,21)=(x(33)*1000)/16;
cv(8,23)=(x(33)*1000)/16;
cv(9,25)=(x(33)*1000)/16;
cv(10,27)=(x(33)*1000)/16;
cv(11,29)=(x(33)*1000)/16;
cv(12,31)=(x(33)*1000)/16;
cv(13,25)=0;
cv(14,1)=(x(33)*1000)/16;
cv(15,3)=(x(33)*1000)/16;
cv(16,5)=(x(33)*1000)/16;
cv(17,7)=(x(33)*1000)/16;
%msb 19;
cv(1,25)=(x(34)*1000)/16;
cv(2,27)=(x(34)*1000)/16;
cv(3,29)=(x(34)*1000)/16;
cv(4,31)=(x(34)*1000)/16;
cv(5,9)=0;
cv(6,1)=(x(34)*1000)/16;
cv(7,3)=(x(34)*1000)/16;
cv(8,5)=(x(34)*1000)/16;
cv(9,7)=(x(34)*1000)/16;
cv(10,9)=(x(34)*1000)/16;
cv(11,11)=(x(34)*1000)/16;
cv(12,13)=(x(34)*1000)/16;
cv(13,15)=(x(34)*1000)/16;
cv(14,17)=(x(34)*1000)/16;
cv(15,19)=(x(34)*1000)/16;
cv(16,21)=(x(34)*1000)/16;
cv(17,23)=(x(34)*1000)/16;
%msb 20
cv(1,13)=(x(35)*1000)/16;
cv(2,15)=(x(35)*1000)/16;
cv(3,17)=(x(35)*1000)/16;

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```

cv(4,19)=(x(35)*1000)/16;
cv(5,21)=(x(35)*1000)/16;
cv(6,23)=(x(35)*1000)/16;
cv(7,25)=(x(35)*1000)/16;
cv(8,27)=(x(35)*1000)/16;
cv(9,29)=(x(35)*1000)/16;
cv(10,31)=(x(35)*1000)/16;
cv(11,21)=0;
cv(12,1)=(x(35)*1000)/16;
cv(13,3)=(x(35)*1000)/16;
cv(14,5)=(x(35)*1000)/16;
cv(15,7)=(x(35)*1000)/16;
cv(16,9)=(x(35)*1000)/16;
cv(17,11)=(x(35)*1000)/16;
%msb 21
cv(1,29)=(x(36)*1000)/16;
cv(2,31)=(x(36)*1000)/16;
cv(3,5)=0;
cv(4,1)=(x(36)*1000)/16;
cv(5,3)=(x(36)*1000)/16;
cv(6,5)=(x(36)*1000)/16;
cv(7,7)=(x(36)*1000)/16;
cv(8,9)=(x(36)*1000)/16;
cv(9,11)=(x(36)*1000)/16;
cv(10,13)=(x(36)*1000)/16;
cv(11,15)=(x(36)*1000)/16;
cv(12,17)=(x(36)*1000)/16;
cv(13,19)=(x(36)*1000)/16;
cv(14,21)=(x(36)*1000)/16;
cv(15,23)=(x(36)*1000)/16;
cv(16,25)=(x(36)*1000)/16;
cv(17,27)=(x(36)*1000)/16;
%msb 22
cv(1,21)=(x(37)*1000)/16;
cv(2,23)=(x(37)*1000)/16;
cv(3,25)=(x(37)*1000)/16;
cv(4,27)=(x(37)*1000)/16;
cv(5,29)=(x(37)*1000)/16;
cv(6,31)=(x(37)*1000)/16;
cv(7,13)=0;
cv(8,1)=(x(37)*1000)/16;
cv(9,3)=(x(37)*1000)/16;
cv(10,5)=(x(37)*1000)/16;
cv(11,7)=(x(37)*1000)/16;
cv(12,9)=(x(37)*1000)/16;
cv(13,11)=(x(37)*1000)/16;

```



```

cv(14,13)=(x(37)*1000)/16;
cv(15,15)=(x(37)*1000)/16;
cv(16,17)=(x(37)*1000)/16;
cv(17,19)=(x(37)*1000)/16;
%msb 23
cv(1,5)=(x(38)*1000)/16;
cv(2,7)=(x(38)*1000)/16;
cv(3,9)=(x(38)*1000)/16;
cv(4,11)=(x(38)*1000)/16;
cv(5,13)=(x(38)*1000)/16;
cv(6,15)=(x(38)*1000)/16;
cv(7,17)=(x(38)*1000)/16;
cv(8,19)=(x(38)*1000)/16;
cv(9,21)=(x(38)*1000)/16;
cv(10,23)=(x(38)*1000)/16;
cv(11,25)=(x(38)*1000)/16;
cv(12,27)=(x(38)*1000)/16;
cv(13,29)=(x(38)*1000)/16;
cv(14,31)=(x(38)*1000)/16;
cv(15,29)=0;
cv(16,1)=(x(38)*1000)/16;
cv(17,3)=(x(38)*1000)/16;
%msb 24
cv(1,3)=(x(39)*1000)/16;
cv(2,5)=(x(39)*1000)/16;
cv(3,7)=(x(39)*1000)/16;
cv(4,9)=(x(39)*1000)/16;
cv(5,11)=(x(39)*1000)/16;
cv(6,13)=(x(39)*1000)/16;
cv(7,15)=(x(39)*1000)/16;
cv(8,17)=(x(39)*1000)/16;
cv(9,19)=(x(39)*1000)/16;
cv(10,21)=(x(39)*1000)/16;
cv(11,23)=(x(39)*1000)/16;
cv(12,25)=(x(39)*1000)/16;
cv(13,27)=(x(39)*1000)/16;
cv(14,29)=(x(39)*1000)/16;
cv(15,31)=(x(39)*1000)/16;
cv(16,31)=0;
cv(17,1)=(x(39)*1000)/16;
%msb 25
cv(1,19)=(x(40)*1000)/16;
cv(2,21)=(x(40)*1000)/16;
cv(3,23)=(x(40)*1000)/16;
cv(4,25)=(x(40)*1000)/16;
cv(5,27)=(x(40)*1000)/16;

```

```

cv(6,29)=(x(40)*1000)/16;
cv(7,31)=(x(40)*1000)/16;
cv(8,15)=0;
cv(9,1)=(x(40)*1000)/16;
cv(10,3)=(x(40)*1000)/16;
cv(11,5)=(x(40)*1000)/16;
cv(12,7)=(x(40)*1000)/16;
cv(13,9)=(x(40)*1000)/16;
cv(14,11)=(x(40)*1000)/16;
cv(15,13)=(x(40)*1000)/16;
cv(16,15)=(x(40)*1000)/16;
cv(17,17)=(x(40)*1000)/16;
%msb 26
cv(1,27)=(x(41)*1000)/16;
cv(2,29)=(x(41)*1000)/16;
cv(3,31)=(x(41)*1000)/16;
cv(4,7)=0;
cv(5,1)=(x(41)*1000)/16;
cv(6,3)=(x(41)*1000)/16;
cv(7,5)=(x(41)*1000)/16;
cv(8,7)=(x(41)*1000)/16;
cv(9,9)=(x(41)*1000)/16;
cv(10,11)=(x(41)*1000)/16;
cv(11,13)=(x(41)*1000)/16;
cv(12,15)=(x(41)*1000)/16;
cv(13,17)=(x(41)*1000)/16;
cv(14,19)=(x(41)*1000)/16;
cv(15,21)=(x(41)*1000)/16;
cv(16,23)=(x(41)*1000)/16;
cv(17,25)=(x(41)*1000)/16;
%msb 27
cv(1,11)=(x(42)*1000)/16;
cv(2,13)=(x(42)*1000)/16;
cv(3,15)=(x(42)*1000)/16;
cv(4,17)=(x(42)*1000)/16;
cv(5,19)=(x(42)*1000)/16;
cv(6,21)=(x(42)*1000)/16;
cv(7,23)=(x(42)*1000)/16;
cv(8,25)=(x(42)*1000)/16;
cv(9,27)=(x(42)*1000)/16;
cv(10,29)=(x(42)*1000)/16;
cv(11,31)=(x(42)*1000)/16;
cv(12,23)=0;
cv(13,1)=(x(42)*1000)/16;
cv(14,3)=(x(42)*1000)/16;
cv(15,5)=(x(42)*1000)/16;

```

```

cv(16,7)=(x(42)*1000)/16;
cv(17,9)=(x(42)*1000)/16;
%msb 28
cv(1,23)=(x(43)*1000)/16;
cv(2,25)=(x(43)*1000)/16;
cv(3,27)=(x(43)*1000)/16;
cv(4,29)=(x(43)*1000)/16;
cv(5,31)=(x(43)*1000)/16;
cv(6,11)=0;
cv(7,1)=(x(43)*1000)/16;
cv(8,3)=(x(43)*1000)/16;
cv(9,5)=(x(43)*1000)/16;
cv(10,7)=(x(43)*1000)/16;
cv(11,9)=(x(43)*1000)/16;
cv(12,11)=(x(43)*1000)/16;
cv(13,13)=(x(43)*1000)/16;
cv(14,15)=(x(43)*1000)/16;
cv(15,17)=(x(43)*1000)/16;
cv(16,19)=(x(43)*1000)/16;
cv(17,21)=(x(43)*1000)/16;
%msb 29
cv(1,7)=(x(44)*1000)/16;
cv(2,9)=(x(44)*1000)/16;
cv(3,11)=(x(44)*1000)/16;
cv(4,13)=(x(44)*1000)/16;
cv(5,15)=(x(44)*1000)/16;
cv(6,17)=(x(44)*1000)/16;
cv(7,19)=(x(44)*1000)/16;
cv(8,21)=(x(44)*1000)/16;
cv(9,23)=(x(44)*1000)/16;
cv(10,25)=(x(44)*1000)/16;
cv(11,27)=(x(44)*1000)/16;
cv(12,29)=(x(44)*1000)/16;
cv(13,31)=(x(44)*1000)/16;
cv(14,27)=0;
cv(15,1)=(x(44)*1000)/16;
cv(16,3)=(x(44)*1000)/16;
cv(17,5)=(x(44)*1000)/16;
%msb 30
cv(1,15)=(x(45)*1000)/16;
cv(2,17)=(x(45)*1000)/16;
cv(3,19)=(x(45)*1000)/16;
cv(4,21)=(x(45)*1000)/16;
cv(5,23)=(x(45)*1000)/16;
cv(6,25)=(x(45)*1000)/16;
cv(7,27)=(x(45)*1000)/16;

```

```

cv(8,29)=(x(45)*1000)/16;
cv(9,31)=(x(45)*1000)/16;
cv(10,19)=0;
cv(11,1)=(x(45)*1000)/16;
cv(12,3)=(x(45)*1000)/16;
cv(13,5)=(x(45)*1000)/16;
cv(14,7)=(x(45)*1000)/16;
cv(15,9)=(x(45)*1000)/16;
cv(16,11)=(x(45)*1000)/16;
cv(17,13)=(x(45)*1000)/16;
%msb 31
cv(1,31)=(x(46)*1000)/16;
cv(2,3)=0;
cv(3,1)=(x(46)*1000)/16;
cv(4,3)=(x(46)*1000)/16;
cv(5,5)=(x(46)*1000)/16;
cv(6,7)=(x(46)*1000)/16;
cv(7,9)=(x(46)*1000)/16;
cv(8,11)=(x(46)*1000)/16;
cv(9,13)=(x(46)*1000)/16;
cv(10,15)=(x(46)*1000)/16;
cv(11,17)=(x(46)*1000)/16;
cv(12,19)=(x(46)*1000)/16;
cv(13,21)=(x(46)*1000)/16;
cv(14,23)=(x(46)*1000)/16;
cv(15,25)=(x(46)*1000)/16;
cv(16,27)=(x(46)*1000)/16;
cv(17,29)=(x(46)*1000)/16;
cv(18,1)=0;
cv(1,33)=0;
subplot(1.1,1.1,1)
surf(cv)
caxis([1.865,1.92]);
colormap(gray)
view(0,-90)
xlabel('32 Columns of Current Cell Pairs')
ylabel('17 Rows of Current Cell Pairs')
zlabel('Voltage in Millivolts')
title('Figure 7. Voltage Output Contribution of Current
Cell Pairs For DAC #10.')

```

APPENDIX E  
MATLAB<sup>®</sup> CALCULATED MILIVOLTAGE OUTPUT DATA  
FOR  
THS5651IDW DEVICE 10 CURRENT ARRAY

» VOLTS

cv =

Columns 1 through 7

0	1.9025	1.8975	1.8987	1.9006	1.9044	1.8987
0	1.9000	0	1.9025	1.8975	1.8987	1.9006
1.8987	1.9038	0	1.9200	0	1.9025	1.8975
1.8981	1.8994	1.8987	1.9038	0	1.9100	0
1.8981	1.9000	1.8981	1.8994	1.8987	1.9038	0
1.8963	1.9019	1.8981	1.9000	1.8981	1.8994	1.8987
1.9019	1.8981	1.8963	1.9019	1.8981	1.9000	1.8981
1.9038	1.8981	1.9019	1.8981	1.8963	1.9019	1.8981
1.8987	1.9038	1.9038	1.8981	1.9019	1.8981	1.8963
1.8994	1.9012	1.8987	1.9038	1.9038	1.8981	1.9019
1.8981	1.9006	1.8994	1.9012	1.8987	1.9038	1.9038
1.8969	1.9000	1.8981	1.9006	1.8994	1.9012	1.8987
1.8994	1.8987	1.8969	1.9000	1.8981	1.9006	1.8994
1.9038	1.9012	1.8994	1.8987	1.8969	1.9000	1.8981
1.8987	1.9031	1.9038	1.9012	1.8994	1.8987	1.8969
1.9006	1.9044	1.8987	1.9031	1.9038	1.9012	1.8994
1.8975	1.8987	1.9006	1.9044	1.8987	1.9031	1.9038
0	0	0	0	0	0	0

Columns 8 through 14

1.9031	1.9038	1.9012	1.8994	1.8987	1.8969	1.9000
1.9044	1.8987	1.9031	1.9038	1.9012	1.8994	1.8987
1.8987	1.9006	1.9044	1.8987	1.9031	1.9038	1.9012
1.9025	1.8975	1.8987	1.9006	1.9044	1.8987	1.9031
1.9200	0	1.9025	1.8975	1.8987	1.9006	1.9044
1.9038	0	1.9000	0	1.9025	1.8975	1.8987
1.8994	1.8987	1.9038	0	1.9100	0	1.9025
1.9000	1.8981	1.8994	1.8987	1.9038	0	1.8900
1.9019	1.8981	1.9000	1.8981	1.8994	1.8987	1.9038
1.8981	1.8963	1.9019	1.8981	1.9000	1.8981	1.8994
1.8981	1.9019	1.8981	1.8963	1.9019	1.8981	1.9000
1.9038	1.9038	1.8981	1.9019	1.8981	1.8963	1.9019
1.9012	1.8987	1.9038	1.9038	1.8981	1.9019	1.8981
1.9006	1.8994	1.9012	1.8987	1.9038	1.9038	1.8981
1.9000	1.8981	1.9006	1.8994	1.9012	1.8987	1.9038
1.8987	1.8969	1.9000	1.8981	1.9006	1.8994	1.9012
1.9012	1.8994	1.8987	1.8969	1.9000	1.8981	1.9006
0	0	0	0	0	0	0

Columns 15 through 21

1.8981	1.9006	1.8994	1.9012	1.8987	1.9038	1.9038
1.8969	1.9000	1.8981	1.9006	1.8994	1.9012	1.8987
1.8994	1.8987	1.8969	1.9000	1.8981	1.9006	1.8994
1.9038	1.9012	1.8994	1.8987	1.8969	1.9000	1.8981
1.8987	1.9031	1.9038	1.9012	1.8994	1.8987	1.8969
1.9006	1.9044	1.8987	1.9031	1.9038	1.9012	1.8994
1.8975	1.8987	1.9006	1.9044	1.8987	1.9031	1.9038
0	1.9025	1.8975	1.8987	1.9006	1.9044	1.8987
0	1.9000	0	1.9025	1.8975	1.8987	1.9006
1.8987	1.9038	0	1.8800	0	1.9025	1.8975
1.8981	1.8994	1.8987	1.9038	0	1.9100	0
1.8981	1.9000	1.8981	1.8994	1.8987	1.9038	0
1.8963	1.9019	1.8981	1.9000	1.8981	1.8994	1.8987
1.9019	1.8981	1.8963	1.9019	1.8981	1.9000	1.8981
1.9038	1.8981	1.9019	1.8981	1.8963	1.9019	1.8981
1.8987	1.9038	1.9038	1.8981	1.9019	1.8981	1.8963
1.8994	1.9012	1.8987	1.9038	1.9038	1.8981	1.9019
0	0	0	0	0	0	0

Columns 22 through 28

1.8981	1.9019	1.8981	1.8963	1.9019	1.8981	1.9000
1.9038	1.9038	1.8981	1.9019	1.8981	1.8963	1.9019
1.9012	1.8987	1.9038	1.9038	1.8981	1.9019	1.8981
1.9006	1.8994	1.9012	1.8987	1.9038	1.9038	1.8981
1.9000	1.8981	1.9006	1.8994	1.9012	1.8987	1.9038
1.8987	1.8969	1.9000	1.8981	1.9006	1.8994	1.9012
1.9012	1.8994	1.8987	1.8969	1.9000	1.8981	1.9006
1.9031	1.9038	1.9012	1.8994	1.8987	1.8969	1.9000
1.9044	1.8987	1.9031	1.9038	1.9012	1.8994	1.8987
1.8987	1.9006	1.9044	1.8987	1.9031	1.9038	1.9012
1.9025	1.8975	1.8987	1.9006	1.9044	1.8987	1.9031
1.8900	0	1.9025	1.8975	1.8987	1.9006	1.9044
1.9038	0	1.9100	0	1.9025	1.8975	1.8987
1.8994	1.8987	1.9038	0	1.9200	0	1.9025
1.9000	1.8981	1.8994	1.8987	1.9038	0	1.8900
1.9019	1.8981	1.9000	1.8981	1.8994	1.8987	1.9038
1.8981	1.8963	1.9019	1.8981	1.9000	1.8981	1.8994
0	0	0	0	0	0	0

Columns 29 through 33

1.8981	1.8994	1.8987	1.9038	0
1.8981	1.9000	1.8981	1.8994	0
1.8963	1.9019	1.8981	1.9000	0
1.9019	1.8981	1.8963	1.9019	0
1.9038	1.8981	1.9019	1.8981	0
1.8987	1.9038	1.9038	1.8981	0
1.8994	1.9012	1.8987	1.9038	0
1.8981	1.9006	1.8994	1.9012	0
1.8969	1.9000	1.8981	1.9006	0
1.8994	1.8987	1.8969	1.9000	0
1.9038	1.9012	1.8994	1.8987	0
1.8987	1.9031	1.9038	1.9012	0
1.9006	1.9044	1.8987	1.9031	0
1.8975	1.8987	1.9006	1.9044	0
0	1.9025	1.8975	1.8987	0
0	1.9000	0	1.9025	0
1.8987	1.9038	0	0	0
0	0	0	0	0



APPENDIX F  
MATLAB<sup>®</sup> CALCULATED  
AVERAGE MILIVOLTAGE OUTPUT DATA  
FOR  
ALL 36 THS5651IDW CURRENT ARRAYS

VOLTS

cv =

Columns 1 through 7

0	1.8983	1.8966	1.8970	1.8977	1.8985	1.8970
0	1.9075	0	1.8983	1.8966	1.8970	1.8977
1.8954	1.8974	0	1.8997	0	1.8983	1.8966
1.8965	1.8970	1.8954	1.8974	0	1.8967	0
1.8963	1.8977	1.8965	1.8970	1.8954	1.8974	0
1.8979	1.8981	1.8963	1.8977	1.8965	1.8970	1.8954
1.8969	1.8979	1.8979	1.8981	1.8963	1.8977	1.8965
1.8974	1.8982	1.8969	1.8979	1.8979	1.8981	1.8963
1.8980	1.8986	1.8974	1.8982	1.8969	1.8979	1.8979
1.8987	1.8980	1.8980	1.8986	1.8974	1.8982	1.8969
1.8965	1.8988	1.8987	1.8980	1.8980	1.8986	1.8974
1.8975	1.8990	1.8965	1.8988	1.8987	1.8980	1.8980
1.8968	1.8976	1.8975	1.8990	1.8965	1.8988	1.8987
1.8981	1.8989	1.8968	1.8976	1.8975	1.8990	1.8965
1.8970	1.8987	1.8981	1.8989	1.8968	1.8976	1.8975
1.8977	1.8985	1.8970	1.8987	1.8981	1.8989	1.8968
1.8966	1.8970	1.8977	1.8985	1.8970	1.8987	1.8981
0	0	0	0	0	0	0

Columns 8 through 14

1.8987	1.8981	1.8989	1.8968	1.8976	1.8975	1.8990
1.8985	1.8970	1.8987	1.8981	1.8989	1.8968	1.8976
1.8970	1.8977	1.8985	1.8970	1.8987	1.8981	1.8989
1.8983	1.8966	1.8970	1.8977	1.8985	1.8970	1.8987
1.9006	0	1.8983	1.8966	1.8970	1.8977	1.8985
1.8974	0	1.8931	0	1.8983	1.8966	1.8970
1.8970	1.8954	1.8974	0	1.8956	0	1.8983
1.8977	1.8965	1.8970	1.8954	1.8974	0	1.8883
1.8981	1.8963	1.8977	1.8965	1.8970	1.8954	1.8974
1.8979	1.8979	1.8981	1.8963	1.8977	1.8965	1.8970
1.8982	1.8969	1.8979	1.8979	1.8981	1.8963	1.8977
1.8986	1.8974	1.8982	1.8969	1.8979	1.8979	1.8981
1.8980	1.8980	1.8986	1.8974	1.8982	1.8969	1.8979
1.8988	1.8987	1.8980	1.8980	1.8986	1.8974	1.8982
1.8990	1.8965	1.8988	1.8987	1.8980	1.8980	1.8986
1.8976	1.8975	1.8990	1.8965	1.8988	1.8987	1.8980
1.8989	1.8968	1.8976	1.8975	1.8990	1.8965	1.8988
0	0	0	0	0	0	0

Columns 15 through 21

1.8965	1.8988	1.8987	1.8980	1.8980	1.8986	1.8974
1.8975	1.8990	1.8965	1.8988	1.8987	1.8980	1.8980
1.8968	1.8976	1.8975	1.8990	1.8965	1.8988	1.8987
1.8981	1.8989	1.8968	1.8976	1.8975	1.8990	1.8965
1.8970	1.8987	1.8981	1.8989	1.8968	1.8976	1.8975
1.8977	1.8985	1.8970	1.8987	1.8981	1.8989	1.8968
1.8966	1.8970	1.8977	1.8985	1.8970	1.8987	1.8981
0	1.8983	1.8966	1.8970	1.8977	1.8985	1.8970
0	1.9117	0	1.8983	1.8966	1.8970	1.8977
1.8954	1.8974	0	1.8878	0	1.8983	1.8966
1.8965	1.8970	1.8954	1.8974	0	1.8953	0
1.8963	1.8977	1.8965	1.8970	1.8954	1.8974	0
1.8979	1.8981	1.8963	1.8977	1.8965	1.8970	1.8954
1.8969	1.8979	1.8979	1.8981	1.8963	1.8977	1.8965
1.8974	1.8982	1.8969	1.8979	1.8979	1.8981	1.8963
1.8980	1.8986	1.8974	1.8982	1.8969	1.8979	1.8979
1.8987	1.8980	1.8980	1.8986	1.8974	1.8982	1.8969
0	0	0	0	0	0	0

Columns 22 through 28

1.8982	1.8969	1.8979	1.8979	1.8981	1.8963	1.8977
1.8986	1.8974	1.8982	1.8969	1.8979	1.8979	1.8981
1.8980	1.8980	1.8986	1.8974	1.8982	1.8969	1.8979
1.8988	1.8987	1.8980	1.8980	1.8986	1.8974	1.8982
1.8990	1.8965	1.8988	1.8987	1.8980	1.8980	1.8986
1.8976	1.8975	1.8990	1.8965	1.8988	1.8987	1.8980
1.8989	1.8968	1.8976	1.8975	1.8990	1.8965	1.8988
1.8987	1.8981	1.8989	1.8968	1.8976	1.8975	1.8990
1.8985	1.8970	1.8987	1.8981	1.8989	1.8968	1.8976
1.8970	1.8977	1.8985	1.8970	1.8987	1.8981	1.8989
1.8983	1.8966	1.8970	1.8977	1.8985	1.8970	1.8987
1.9014	0	1.8983	1.8966	1.8970	1.8977	1.8985
1.8974	0	1.8967	0	1.8983	1.8966	1.8970
1.8970	1.8954	1.8974	0	1.8950	0	1.8983
1.8977	1.8965	1.8970	1.8954	1.8974	0	1.8964
1.8981	1.8963	1.8977	1.8965	1.8970	1.8954	1.8974
1.8979	1.8979	1.8981	1.8963	1.8977	1.8965	1.8970
0	0	0	0	0	0	0

Columns 29 through 33

1.8965	1.8970	1.8954	1.8974	0
1.8963	1.8977	1.8965	1.8970	0
1.8979	1.8981	1.8963	1.8977	0
1.8969	1.8979	1.8979	1.8981	0
1.8974	1.8982	1.8969	1.8979	0
1.8980	1.8986	1.8974	1.8982	0
1.8987	1.8980	1.8980	1.8986	0
1.8965	1.8988	1.8987	1.8980	0
1.8975	1.8990	1.8965	1.8988	0
1.8968	1.8976	1.8975	1.8990	0
1.8981	1.8989	1.8968	1.8976	0
1.8970	1.8987	1.8981	1.8989	0
1.8977	1.8985	1.8970	1.8987	0
1.8966	1.8970	1.8977	1.8985	0
0	1.8983	1.8966	1.8970	0
0	1.9017	0	1.8983	0
1.8954	1.8974	0	0	0
0	0	0	0	0

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