Using MATLAB® And LabView® Software To Determine Current Array Outputs Of A Segmented Current Steering Digital To Analog Converter

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Abstract

This paper describes MATLAB® software, LabView® software, instrumentation, acquisition of test data and calculations to determine the output of each current cell pair in the current array of the THS5651IDW digital to analog converter (DAC), a prototype of the future Texas Instruments TLV5651, 10-bit, 125 MHz communication DAC. The THS5651IDW is a 5-4-1 segmented current steering DAC. Data was collected at the Texas Instruments' facility on Forest Lane, Dallas Texas. LabView® software was used for instrument control and data acquisition. MATLAB® software was used to process data, to calculate current cell pair outputs, and to plot the results to determine if there were major problem areas in the current array. Plots showed no problem areas.

I. Introduction

Texas Instruments invited the author to learn about the THS5651IDW, a new high-speed digital to analog converter (DAC), being designed at their facility on Forest Lane, Dallas Texas. This knowledge is being passed on to students in the Electronic Engineering Technology program at the University of North Texas. The THS5651IDW DAC is a prototype of the future Texas Instruments TLV5651, 10-bit, 125 MHz communications DAC. This high-speed DAC will be used in cellular telephone base stations to assist in reducing saturation of base station circuits during peak periods. The THS5651IDW DAC has a diagonal pattern for its segmented current array. The author made a study of this pattern to determine if there were major problem areas associated with using a diagonal pattern to overcome output differences in adjacent current cells. Texas Instruments provided 36 THS5651IDW DACs and the use of their laboratory facility. LabView® software was used for instrument control and data acquisition. MATLAB® software was used for calculations and plotting data. Calculations were made for all 36 DACs. Texas Instruments required a gray-scale plot of DAC 10 data and the average data of all 36 DACs.

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 resister ladders, current steering circuits, and switched capacitors[1]. This paper discusses the conversion method used by Texas Instruments' THS5651IDW segmented current steering DAC.

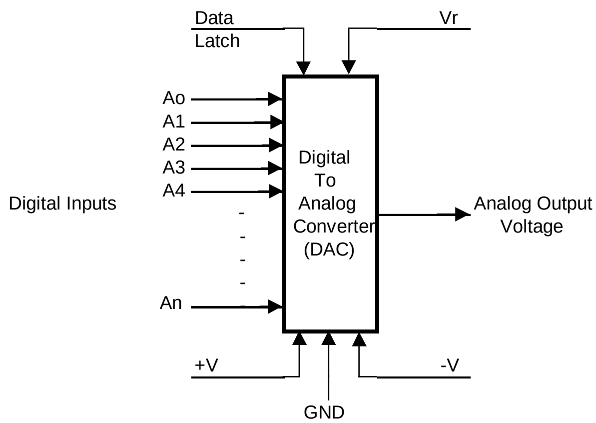

Figure 1. Generic DAC diagram[2]

II. 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 2 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[3].

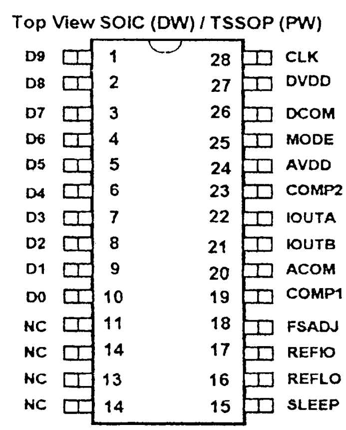

Figure 2. Top view of the THS5651IDW DAC[3].

A block diagram of the THS5651IDW DAC is shown in Figure 3. The THS5651IDW has 20 mA current outputs with greater than 100 kΩ 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. IOUTA goes from 0 to full scale when all digital inputs are ones. IOUTB goes from full scale to 0 when all digital inputs are ones (complementary to IOUTA). IOUTA was used for this research project[3].

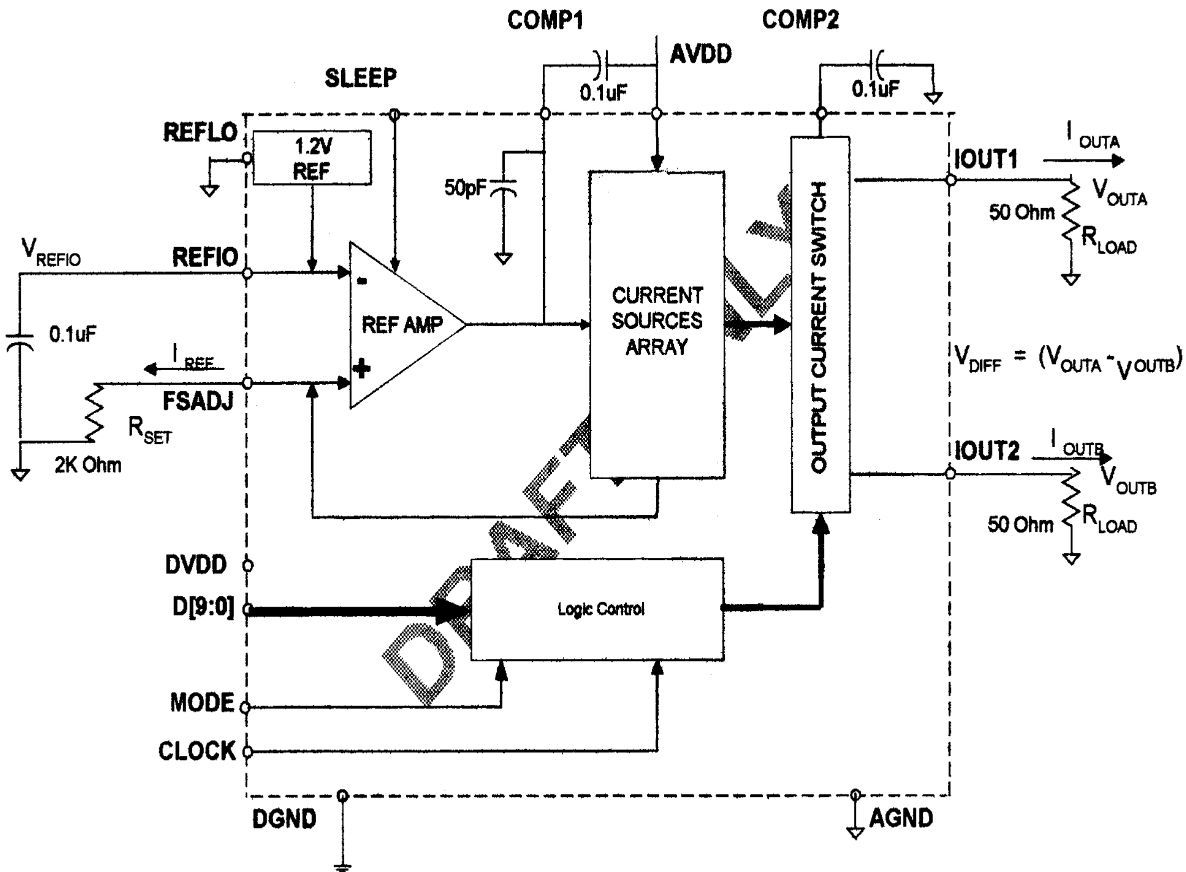

Figure 3. Block diagram of the THS5651IDW DAC[3].

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* (decimal 3) 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[4]. The THS5651IDW is divided into three segments (5-4-1), which are most significant bits (MSBs), mid-bit (MID), and least significant bit 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[5]. The number of current cells in each *N-bit* segment is 2^N - 1.

Table II shows the 5-4 segmentation of the 17 x 32 current array in more detail. In the MID segment, there are 15 separate MID unit current cell groups that are located down the center diagonal of the 17 x 32 current array. In the MSB segment, there are 31 separate current cell groups. Each MSB current cell group consists of 16 unit current cell pairs connected in a diagonal pattern. Each segment is like a separate DAC[6]

A generic current cell is shown in Figure 4. 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 IOUTB and no analog voltage is developed at IOUT. A digital input of *1* at the input turns off transistor M3 and turns on transistor M2. Thus, an analog voltage is present at IOUT and none at IOUTB. In a 10-bit DAC all 1024 M2 transistors are connected to IOUT and all 1024 M3 transistors are connected to IOUTB. When all digital inputs are *0s*, IOUTB has full-scale voltage and IOUT has zero voltage. When all digital inputs are *1s*, IOUT has full-scale voltage and IOUTB has zero voltage[6].

	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	1
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	2
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	3
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	4
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	5
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	6
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	7
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	8
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	9
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	10
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	11
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	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	13
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	14
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	15
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	16
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			17
	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	

Table II. Segmented current cell array pattern for THS5651IDW DAC[6].

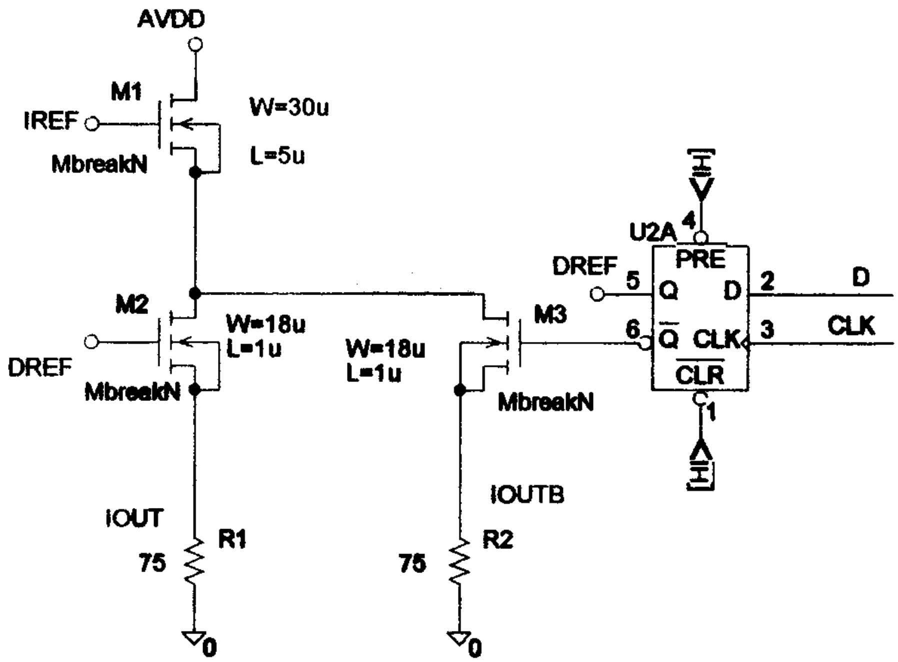

Figure 4. A generic current cell[6].

III. Equipment

Texas Instruments provided the test equipment used in this project. Figure 5 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 **G**eneral **P**urpose **I**nterface **B**us (GPIB) or Institute of Electrical and Electronic Engineers Standard 488-1975[7] port on the power supply[8]. The Tektronix 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[9]. 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[10]. 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[11]. Equipment settings were 1 analog volt maximum output, 40 µ seconds between samples, and 1024 samples. Data was collected at IoutA shown in Figure 3.

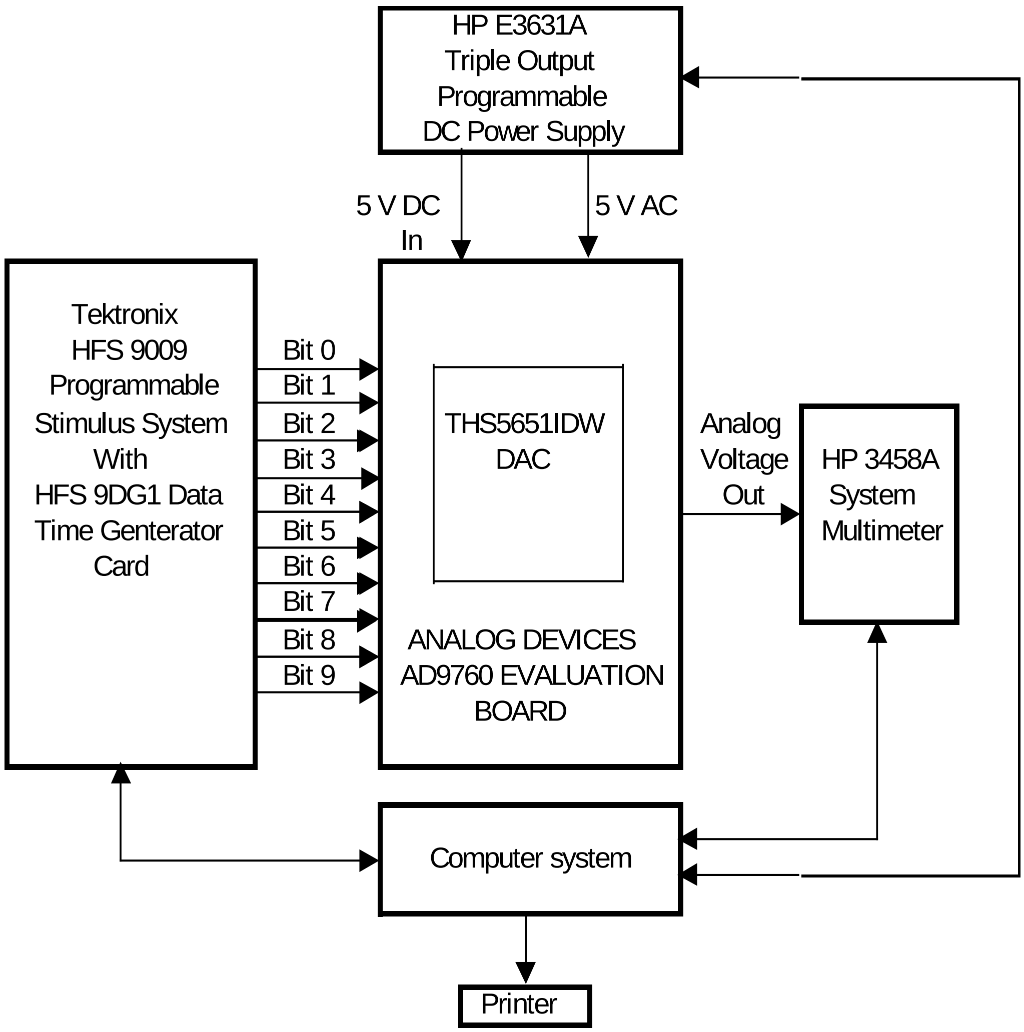

Figure 5. Block diagram of test equipment.

IV. LabView® Software

A LabView® software program (The complete program is Texas Instruments' proprietary information.) was used for data acquisition, and instrument control. LabView® (**Lab**oratory **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[7]. The front panel of this software program is shown in Figure 6.

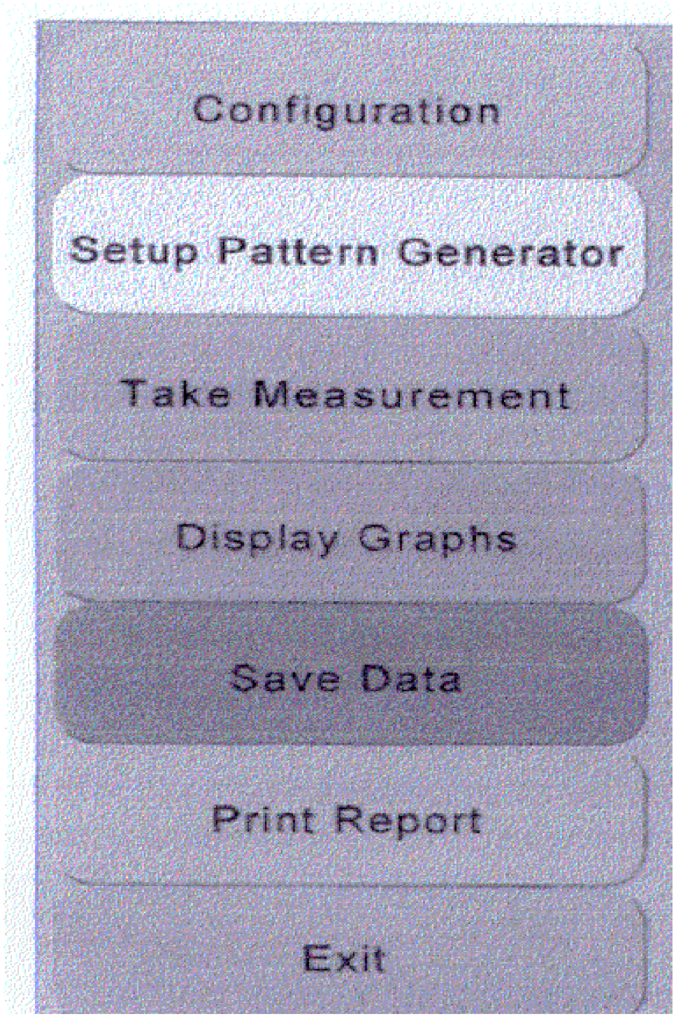

Figure 6. Front panel of LabVIEW® software program[12].

A DAC was inserted into a socket on the test board in Figure 5. The **Take Measurement** switch in Figure 6 was selected. Voltage outputs of the DAC were acquired for 1024 input codes. The **Save Data** switch was selected and data was saved to a disk. This was repeated for all 36 DACs. Data for all 1024 input codes for each DAC were printed using Microsoft Excel, 21 pages per DAC for a total of 756.

V. Mid-Bits

A Microsoft Excel program, using Equations 1 below, was used to locate MIDs in data acquired by the LabView® software program. Table III shows the MIDs for DAC 10 and Table IV shows the average MIDs for all 36 DACs.

$$\text{MID-n} = [\text{Volts}_{(i+2)} - \text{Volts}_{(i)}] \quad (1)$$

For i = code 2, 4, 6,…..30

n = 2,3,4, ….. 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 III. 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 IV. Average MIDs for 36 DACs.

VI. Most Significant Bits

A Microsoft Excel program, using Equations 2 below, was used to locate MSBs in data acquired by the LabView® software program. Table V shows the MSBs for DAC 10 and Table VI shows the average MSBs for all 36 DACs. .

$$\text{MSB-n} = [\text{Volts}_{(i+32)} - \text{Volts}_{(i)}] \text{ volts} \quad (2)$$

For i = code 32, 64, 128, ….. 992

n = 2,3,4, …..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

Table V. MSBs for DAC 10.

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. Average MSBs for 36 DAC.

VII. MATLAB® Software Program

MATLAB® software has become popular in engineering fields and can be considered the world standard for simulation and analysis of linear and nonlinear dynamic systems[13]. A MATLAB® program 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. The MATLAB® program also used these calculations to plot overhead views shown in Figure 7 and Figure 8. The white color represents unused current cell pairs. Shades of gray represent equal millivolt values.

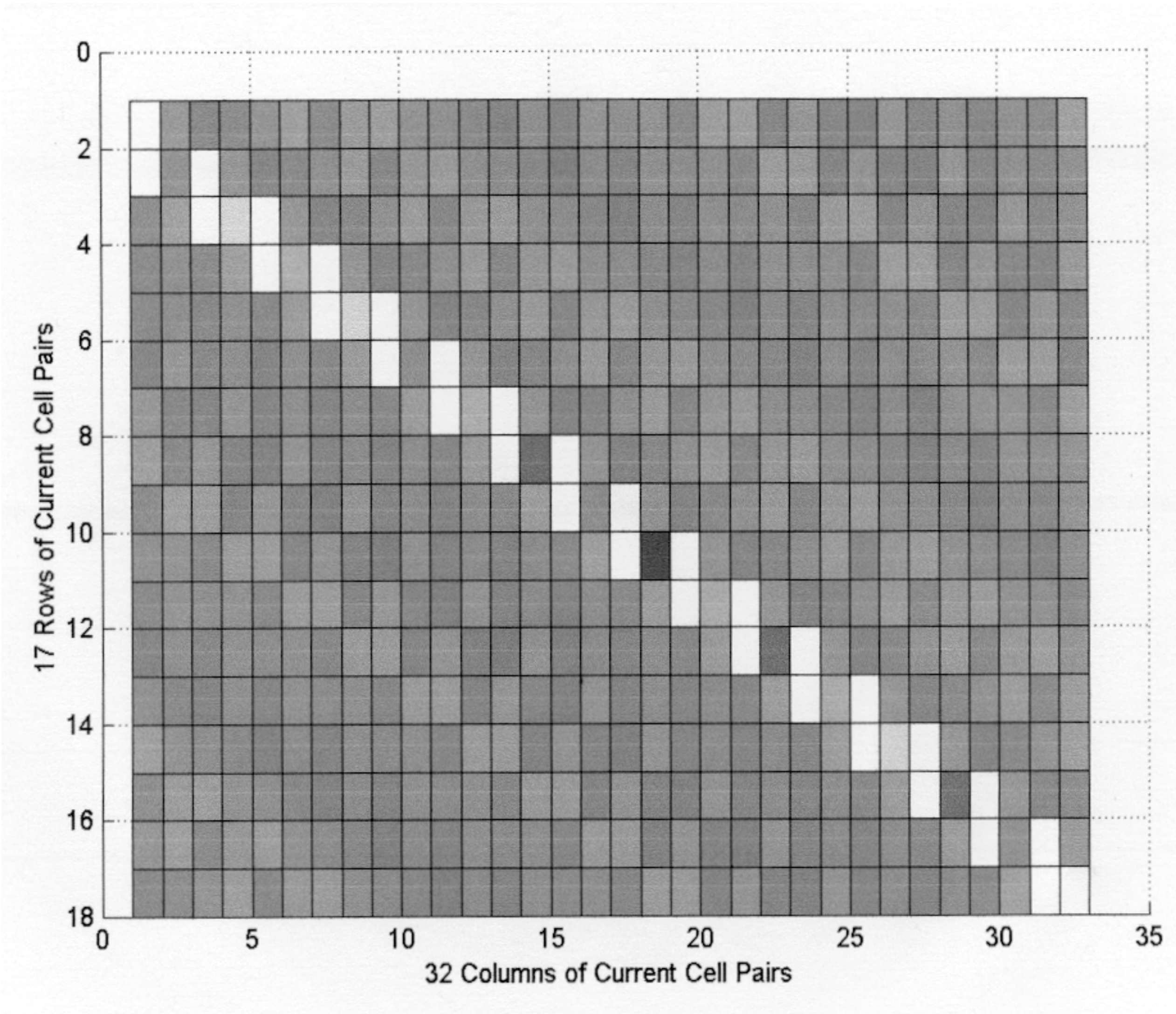

Figure 7. Voltage output of current cell pairs for DAC 10.

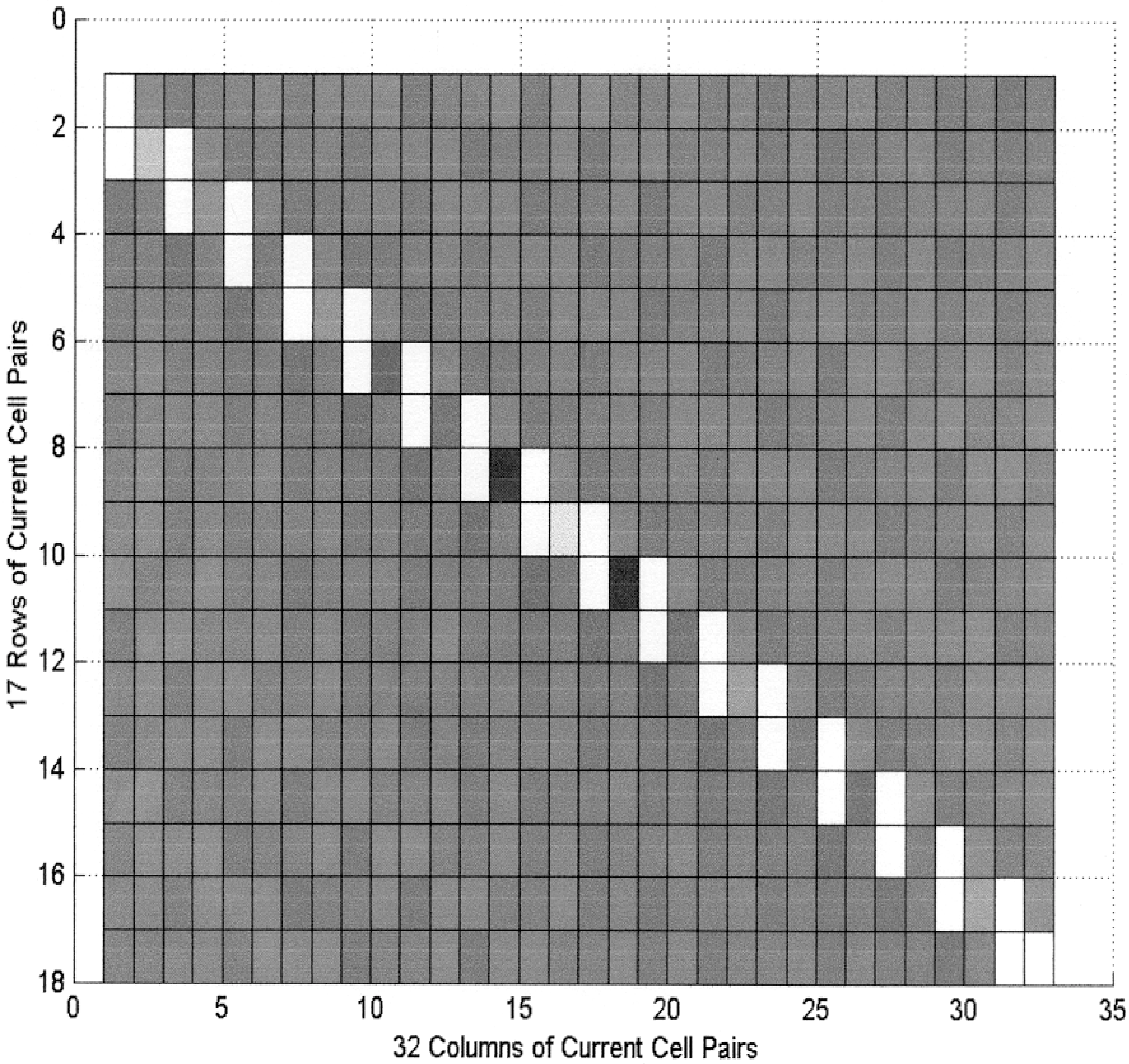

Figure 8. Average voltage output of current cell pairs for all 36 DACs.

VIII. Current Array Patterns

The best current array pattern for all DACs is unknown at this time. Patterns such as checker board, random, vertical and horizontal squares have been used. A diagonal pattern is being used for the THS5651IDW DAC. The current array pattern affects the monotonicity of DACs with greater than 8-bits because the LSB of these DACS become smaller and smaller. The difference in current cell outputs becomes relevant when compared to the LSB of these DACs. This difference is caused by imperfections in making the current array. The DAC could become non-monotonic[5]. The THS5651IDW DAC was determined to be monotonic in a previous study[14].

IX. Conclusion

Since the THS5651IDW DAC was determined to be monotonic in a previous study[14] and analysis of gray-scale plots showed no problem areas in current arrays, it can be concluded that a diagonal pattern for a 10-bit segmented current array will overcome output differences in adjacent current cells.

X. Recommendations

Recommend the segmented current steering DAC be included in Electronics II courses. The text book, *Electronic Devices and Circuits* by Bogart[15], is used for the Electronics II course in the electronic engineering technology program. Chapter 17 of this book covers all types of DACs except the segmented current steering DAC. The segmented current steering DAC is included in the course at this time.

XI. Acknowledgments

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XII. References

1. Razavi, B. *Principles of Data Conversion System Design*, IEEE Press, 445 Hoes Lane, Piscataway, NY 08855, pp. 45-51, 1995.
2. Johnson, C. *Process Control Instrumentation Technology*, Sixth Edition, Prentice Hall, Upper Saddle River, New Jersey 07458, pp. 126, 2000.
3. McGlothlin, R. *Production Defintion: TLV5651, 2.7V-5.5V, 10-bit, 125MHZ, Communication DAC*, Texas Instruments Inc., Dallas, Texas, June 11, 1998.
4. Chen, W. *The Circuits and Filters Handbook*, CRC Press, Inc., 2000 Corporate Blvd., N. M., Boca Raton, Florida 33431, pp. 2072–2075, 1995.
5. Soenen, E. *The THS5651IDW, 10-BIT, 125 MHz, Segmented Current Steering DAC*, Lecture, Texas Instruments Corporation, Dallas Texas, Jan. 4, 1999.

6. Chaudhry, I. *The THS5651IDW, 10-BIT, 125 MHz, Segmented Current Steering DAC,* Lecture, Texas Instruments Corporation, Dallas Texas, July 10, 1998.
7. Bishop, R. *Learning with LabVIEW®*, Addison Wesley Longman, Inc., 2725 Sand Hill Road, Menlo Park, California 94025, pp. 5 & 331, 1998.
8. Hewlett-Packard, *HP E3631A Triple Output Power Supply*, Hewlett-Packard Co., 23 Inverness Way East, Englewood, Co. 80112, pp. 17, 1996.
9. Tektronix, Inc.(1998), *Programmable Stimulus System*, Available: http://www.tek.com/measurement/products/catalog/nfs/index/html.
10. Hewlett-Packard (1999), *HP 3458A System Multimeter*, Available: http://www.tmo.hp.com/datasheets/english/HP345
11. Odom, B. (1998), *AN-420 Application Note: Using the AD9708/AD9760/ad9762/ad9764-EB Evaluation Board*, Available: http://www.analog.com/products/descriptions/1989-0.html
12. McGlothlin, R. *The THS5651IDW, 10-BIT, 125 MHz, Segmented Current Steering DAC*, Lecture, Texas Instruments Corporation, Dallas Texas, Jan. 4, 1999.
13. Cavallo A. et al, *Using MATLAB, Simulink, and Control System Toolbox*, Prentice Hall, Englewood Cliffs, NJ 07632, pp. 1, 1996.
14. Bittle,C. *Linearity and Monotonicity of a 10-Bit, 125MHz, Segmented Current Steering Digital to Analog Converter*, 2001 ASEE Annual Conference & Exposition, June 26, 2001
15. Bogart, T. et al, *Electronic Devices and Circuits*, , Fifth Edition, Prentice Hall, Upper Saddle River, New Jersey 07458, pp 659-672, 2001.

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