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AD9880 Color Space Converter User's Guide

by Del Jones

COLOR SPACE CONVERSION MATRIX

The color space conversion matrix (CSC) in the AD9880 is a 3 × 3 matrix with full programmability of all coefficients in the matrix. Each coefficient is 12 bits wide to ensure that signal integrity is maintained. The CSC is designed to run at speeds of up to 150 MHz supporting 1080 p @ 60 Hz rates. With the "any-to-any" color space support, formats such as RGB, YUV, YCrCb, and others are supported by the CSC.

The CSC contains three identical processing channels, one of which is shown in Figure 1. The main inputs, In_A, In_B, and In_C, come from 8-bit outputs of each ADC or DVI channel. Each input to the individual channels to the CSC is multiplied by a separate coefficient for each channel. In Figure 1 these coefficients are marked A1, A2, and A3. The variable in the figure labelled A4 is used as an offset control for Channel A in the CSC. The functional diagram for a single channel in the CSC is repeated for the other two remaining Channels B and C. The coefficients for these channels are called B1, B2, B3, B4, C1, C2, C3, and C4.

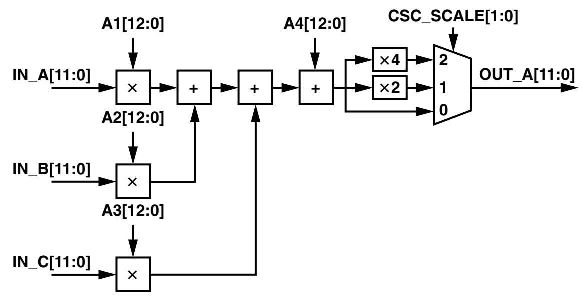

Figure 1. Single CSC Channel

The coefficients are detailed in Table I with their default I^2C power-on reset values.

Table I. CSC Coefficients

Bit	AD9880 Register	Default Value	Description
CSC_scale[1:0]	0x35 bits 6:5	1	Scaling for CSC formula
A1[12:0] A2[12:0] A3[12:0]	0x35 – 0x36 0x37 – 0x39 0x39 – 0x3A	3154 2048 0	Coefficients for Channel A
B1[12:0] B2[12:0] B3[12:0]	0x3D – 0x3E 0x3F – 0x40 0x41 – 0x42	–940 2048 –375	Coefficients for Channel B
C1[12:0] C2[12:0] C3[12:0]	0x45 – 0x46 0x47 – 0x48 0x49 – 0x4A	0 2048 3719	Coefficients for Channel C
A4[12:0] B4[12:0] C4[12:0]	0x3B – 0x3C 0x43 – 0x44 0x4B – 0x4C	–1577 658 –1859	Offsets for the three channels

PROGRAMMING THE CSC

The equations performed by the CSC are as follows:

CSC Channel A

$$Out\_A = [In\_A \times \frac{A1}{4096} + B\frac{A2}{4096} + In\_C \times \frac{A3}{4096} + A4] \times 2^{CSC\_scale} \quad (1)$$

CSC Channel B

$$Out\_B = [In\_A \times \frac{B1}{4096} + B\frac{B2}{4096} + In\_C \times \frac{B3}{4096} + B4] \times 2^{CSC\_scale} \quad (2)$$

CSC Channel C

$$Out\_C = [In\_A \times \frac{C1}{4096} + B\frac{C2}{4096} + In\_C \times \frac{C3}{4096} + C4] \times 2^{CSC\_scale} \quad (3)$$

As Equations 1, 2, and 3 show, the A1 – A3, B1 – B3, and C1 – C3 coefficients are used to scale the primary inputs. The values of A4, B4, and C4 are then added as offsets. The CSC_scale bits allow the user to implement conversion formulas in which the conversion coefficients are ≥ 1. In other words, if an equation is being implemented whose coefficients are ≥ 1, the CSC_scale bits can be used to ensure that the resulting output code does not exceed the 12-bit limit of 4095. Table II describes the conditions under which each CSC_scale setting should be used. Note that if any coefficient in any of the three CSC equations requires scaling (CSC_scale $\neq$ 0), then all coefficients, including the offset values, are scaled as indicated by Equations 1, 2, and 3. The values of A1 – A4, B1 – B4 , and C1 – C4 will equal the coefficients from the desired conversion formula multiplied by $4096/2^{CSC\_scale}$.

Table II. CSC_scale Settings

CSC_scale	Conversion Coefficient
0	N < 1
1	1 ≤ N < 2
2	2 ≤ N < 4

Note that for the CSC to operate properly, the channel mapping shown in Table III must be followed.

Table III. CSC Port Mapping

Channel	AD9980 Input (analog)	CSC Channel
Red/Pr	R_{AIN}	A
Green/Y	G_{AIN}	B
Blue/Pb	B_{AIN}	C

Output mapping depends on the output format. Refer to the AD9880 data sheet for details.

Programming Steps

To arrive at programming values from typical formulas, the following steps must be performed:

1. Check the value of each coefficient.

   The coefficients can only be programmed in the range of [–0.999... +0.999]. To support larger coefficients, the CSC_scale function should be used (see Table II).

   Determine the setting for CSC_scale and adjust coefficients (if necessary).

2. Program the coefficient values.

   Convert the float point coefficients into 12-bit fixed decimal format by multiplying them by $[4096/2^{CSC\_scale}]$. Convert into binary format, using twos complement for negative values.

   Program A1 – A3, B1 – B3, and C1 – C3

3. Progam the offset values.

   Depending on the type of color space, conversion offsets may have to be used.

   Program A4, B4, and C4.

CSC EXAMPLE

The following sets of equations give an example of a conversion from an HDTV YCbCr to RGB (12 bits):

$R = Y + 1.540(Cr - 2048) = Y + 1.540 \times Cr - 3154$

$G = Y - 0.459(Cr - 2048) - 0.183(Cb - 2048) =$
$Y - 0.459 \times Cr - 0.183 \times Cb + 1315$

$B = Y + 1.816(Cb - 2048) = Y + 1.816 \times Cb - 3719$

The original equations give offset values of 128 for the Pr and Pb components. The value of 128 equates to half the range on an 8-bit system. It must be noted that the CSC of the AD9880 operates on a 12-bit range. The offsets therefore must be changed from 128 to half the range of a 12-bit system, which is 2048.

Check the Value of Each Coefficient

The maximum value for each coefficient on its own can only be within the range of –4095/4096 to 4095/4096 which equals [–0.999755859375 .. 0.999755859375]. Values outside this range do not fit into the 12-bit fixed point format used to program the coefficients.

If the value of one or more coefficients exceeds the supported coefficient range, the CSC needs to be scaled using the CSC_scale bits.

With the CSC_scale set to "1," *all* coefficients must be scaled by half, which makes them fit into the given coefficient range. The overall outputs of the CSC are then increased by a fixed value of two, thus compensating for the scaled down coefficients.

In the example, the biggest coefficient is 1.816, so the CSC_scale bits would be set to "01."

1. To achieve a coefficient value of 1.0 for any given coefficient, the CSC_scale bits should be set to "1" and the coefficient should actually be programmed to a value of 0.5. Otherwise the largest value would be 4095/4096 = 0.9997, which is not exactly 1. While this value could be interpreted as a 1, it is recommended to use the value of 0.5 and the CSC_scale bit for maximum accuracy.
2. For very large coefficient values (e.g., 2.58), the CSC_scale must be set to "2" and all coefficients must be scaled by one-quarter, which makes them fit into the given coefficient range. The overall outputs of the CSC are then gained up by a fixed value of four, thus compensating for the scaled down coefficients.

Program the coefficient values as follows:

$$R = 1.540 \times Cr + 0 \times Cb + 1 \times Y - 3154$$

$$G = -0459 \times Cr - 0.183 \times Cb + 1 \times Y + 1315$$

$$B = 0 \times Cr + 1.816 \times Cb + 1 \times Y - 3719$$

- The coefficient values are programmed with 12-bit accuracy in a fixed point format.
- To translate the float point coefficients, they must be multiplied by 2^{12} (4096) and then rounded to 12 bits.
- Twos complement notation should be used for negative numbers.

In_A carries the Pr or R components, In_B contains the Y or G components, and In_C delivers the Pb or B components. Similarly, Out_A = Pr or R, Out_B + Y or G, and Out_C = Pb or B.

Program the Offset Values

When programming the offset values (A4, B4, C4) the CSC_scale is set to 1 so the offset value from the original equation must be divided by 2.

Table IV. Example Offset Values

Equation	Original Offset	Adjusted Offset*	Register	Hex Value (13-bit, twos complement)
Red	–3154	–1577	A4[12:0]	0x19D7
Green	1315	657	B4[12:0]	0x0291
Blue	–3719	–1859	C4[12:0]	0x18BD

*Since the CSC_scale is set to 1, the calculated coefficient is divided by 2 (2^{CSC_scale}).

Table V. Example Coefficient Calculations

Equation	Equation Coefficients		Calculation*	Rounded Result ($-4096 \leq N < 4096$)	Register	Hex Value (Twos complement)
Red	Cr	1.54	1.54 × 4096/2	3154	A1[12:0]	0x0C52
	Y	1	1 × 4096/2	2048	A2[12:0]	0x0800
	Cb	0	0 × 4096/2	0	A3[12:0]	0x0000
Green	Cr	–0.459	0.459 × 4096/2	–940	B1[12:0]	0x1C54
	Y	1	1 × 4096/2	2048	B2[12:0]	0x0800
	Cb	–0.183	0.183 × 4096/2	–375	B3[12:0]	0x3E89
Blue	Cr	0	0 × 4096/2	0	C1[12:0]	0x000
	Y	1	1 × 4096/2	2048	C2[12:0]	0x0800
	Cb	1.816	1.816 × 4096/2	3719	C3[12:0]	0x0E87

*Since the CSC_scale is set to 1, the calculated coefficient is divided by 2.

REGISTER SETTINGS FOR CSC EXAMPLE

For the CSC example, the I^{2}C registers of the AD9880 must be programmed with the values shown in Table VI.

Table VI. Color Space Conversion and Decimation Filters

Register	Address	Bit Description and Values								Hex Value
Red/Cr Coeff. 1	0x35	unused	CSC_scale[1:0]		A1.12	A1.11	A1.10	A1.9	A1.8	0x0C
		*	0	1	0	1	1	0	0	
	0x36	A1.7	A1.6	A1.5	A1.4	A1.3	A1.2	A1.1	A1.0	0x52
		0	1	0	1	0	0	1	0	
Red/Cr Coeff. 2	0x37	unused	unused	unused	A2.12	A2.11	A2.10	A2.9	A2.8	0x08
		*	*	*	0	0	0	0	0	
	0x38	A2.7	A2.6	A2.5	A2.4	A2.3	A2.2	A2.1	A2.0	0x00
		0	0	0	0	0	0	0	0	
Red/Cr Coeff. 3	0x39	unused	unused	unused	A3.12	A3.11	A3.10	A3.9	A3.8	0x00
		*	*	*	0	0	0	0	0	
	0x3A	A3.7	A3.6	A3.5	A3.4	A3.3	A3.2	A3.1	A3.0	0x00
		*	*	*	0	0	0	0	0	
Red/Cr Offset	0x3B	unused	unused	unused	A4.12	A4.11	A4.10	A4.9	A4.8	0x19
		*	*	*	1	1	0	0	1	
	0x3C	A4.7	A4.6	A4.5	A4.4	A4.3	A4.2	A4.1	A4.0	0xD7
		1	1	0	1	0	1	1	1	
Green/Y Coeff. 1	0x3D	unused	unused	unused	B1.12	B1.11	B1.10	B1.9	B1.8	0x1C
		*	*	*	1	1	1	0	0	
	0x3E	B1.7	B1.6	B1.5	B1.4	B1.3	B1.2	B1.1	B1.0	0x54
		0	1	0	1	0	1	0	0	
Green/Y Coeff. 2	0x3F	unused	unused	unused	B2.12	B2.11	B2.10	B2.9	B2.8	0x08
		*	*	*	0	1	0	0	0	
	0x40	B2.7	B2.6	B2.5	B2.4	B2.3	B2.2	B2.1	B2.0	0x00
		0	0	0	0	0	0	0	0	
Green/Y Coeff. 3	0x41	unused	unused	unused	B3.12	B3.11	B3.10	B3.9	B3.8	0x3E
		*	*	*	1	1	1	1	0	
	0x42	B3.7	B3.6	B3.5	B3.4	B3.3	B3.2	B3.1	B3.0	0x89
		1	0	0	0	1	0	0	1	
Green/Y Coeff. 4	0x43	unused	unused	unused	B4.12	B4.11	B4.10	B4.9	B4.8	0x02
		*	*	*	0	0	0	1	0	
	0x44	B4.7	B4.6	B4.5	B4.4	B4.3	B4.2	B4.1	B4.0	0x91
		1	0	0	1	0	0	0	1	
Blue/Cb Coeff. 1	0x45	unused	unused	unused	C1.12	C1.11	C1.10	C1.9	C1.8	0x00
		*	*	*	0	0	0	0	0	
	0x46	C1.7	C1.6	C1.5	C1.4	C1.3	C1.2	C1.1	C1.0	0x00
		0	0	0	0	0	0	0	0	
Blue/Cb Coeff. 2	0x47	unused	unused	unused	C2.12	C2.11	C2.10	C2.9	C2.8	0x08
		*	*	*	0	1	0	0	0	
	0x48	C2.7	C2.6	C2.5	C2.4	C2.3	C2.2	C2.1	C2.0	0x00
		0	0	0	0	0	0	0	0	
Blue/Cb Coeff. 3	0x49	unused	unused	unused	C3.12	C3.11	C3.10	C3.9	C3.8	0x0E
		*	*	*	0	1	1	1	0	
	0x4A	C3.7	C3.6	C3.5	C3.4	C3.3	C3.2	C3.1	C3.0	0x87
		1	0	0	0	0	1	1	1	
Blue/Cb Offset	0x4B	unused	unused	unused	C4.12	C4.11	C4.10	C4.9	C4.8	0x18
		*	*	*	1	1	0	0	0	
	0x4C	C4.7	C4.6	C4.5	C4.4	C4.3	C4.2	C4.1	C4.0	0xBD
		1	0	1	1	1	1	0	1	

Legend: ■ Bit name as per register table ■ Example bit value ■ Example register value

APPENDIX

Register Settings for Standard Color Space Conversions

Table VII. HDTV YCrCb (0 – 255) to RGB (0 – 255)*

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x0C 0x52
Red/Cr Coeff. 2	0x37 0x38	0x08 0x00
Red/Cr Coeff. 3	0x39 0x3A	0x00 0x00
Red/Cr Coeff. Offset	0x3B 0x3C	0x19 0xD7
Green/Y Coeff. 1	0x3D 0x3E	0x1C 0x54
Green/Y Coeff. 2	0x3F 0x40	0x08 0x00
Green/Y Coeff. 3	0x41 0x42	0x3E 0x89
Green/Y Coeff. Offset	0x43 0x44	0x02 0x91
Blue/Cb Coeff. 1	0x45 0x46	0x00 0x00
Blue/Cb Coeff. 2	0x47 0x48	0x08 0x00
Blue/Cb Coeff. 3	0x49 0x4A	0x0E 0x87
Blue/Cb Coeff. Offset	0x4B 0x4C	0x18 0xBD

*This is the same conversion as the example. The coeficients are the default settings for the AD9880.

Table VIII. HDTV YCrCb (16 – 235) to RGB (0 – 255)

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x47 0x2C
Red/Cr Coeff. 2	0x37 0x38	0x04 0xA8
Red/Cr Coeff. 3	0x39 0x3A	0x00 0x00
Red/Cr Coeff. Offset	0x3B 0x3C	0x1C 0x1F
Green/Y Coeff. 1	0x3D 0x3E	0x1D 0xDD
Green/Y Coeff. 2	0x3F 0x40	0x04 0xA8
Green/Y Coeff. 3	0x41 0x42	0x1F 0x26
Green/Y Coeff. Offset	0x43 0x44	0x01 0x34
Blue/Cb Coeff. 1	0x45 0x46	0x00 0x00
Blue/Cb Coeff. 2	0x47 0x48	0x04 0xA8
Blue/Cb Coeff. 3	0x49 0x4A	0x08 0x75
Blue/Cb Coeff. Offset	0x4B 0x4C	0x1B 0x7D

Table IX. SDTV YCrCb (0 – 255) to RGB (0 – 255)

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x2A 0xFA
Red/Cr Coeff. 2	0x37 0x38	0x08 0x00
Red/Cr Coeff. 3	0x39 0x3A	0x00 0x00
Red/Cr Coeff. Offset	0x3B 0x3C	0x1A 0x84
Green/Y Coeff. 1	0x3D 0x3E	0x1A 0x6A
Green/Y Coeff. 2	0x3F 0x40	0x08 0x00
Green/Y Coeff. 3	0x41 0x42	0x1D 0x50
Green/Y Coeff. Offset	0x43 0x44	0x04 0x23
Blue/Cb Coeff. 1	0x45 0x46	0x00 0x00
Blue/Cb Coeff. 2	0x47 0x48	0x08 0x00
Blue/Cb Coeff. 3	0x49 0x4A	0x0D 0xDB
Blue/Cb Coeff. Offset	0x4B 0x4C	0x19 0x12

Table X. SDTV YCrCb (16 – 235) to RGB (0 – 255)

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x46 0x63
Red/Cr Coeff. 2	0x37 0x38	0x04 0xA8
Red/Cr Coeff. 3	0x39 0x3A	0x00 0x00
Red/Cr Coeff. Offset	0x3B 0x3C	0x1C 0x84
Green/Y Coeff. 1	0x3D 0x3E	0x1C 0xC0
Green/Y Coeff. 2	0x3F 0x40	0x04 0xA8
Green/Y Coeff. 3	0x41 0x42	0x1E 0x6F
Green/Y Coeff. Offset	0x43 0x44	0x02 0x1E
Blue/Cb Coeff. 1	0x45 0x46	0x00 0x00
Blue/Cb Coeff. 2	0x47 0x48	0x04 0xA8
Blue/Cb Coeff. 3	0x49 0x4A	0x08 0x11
Blue/Cb Coeff. Offset	0x4B 0x4C	0x1B 0xAD

Table XI. RGB (0 – 255) to HDTV YCrCb (0 – 255)

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x08 0x2D
Red/Cr Coeff. 2	0x37 0x38	0x18 0x93
Red/Cr Coeff. 3	0x39 0x3A	0x1F 0x3F
Red/Cr Coeff. Offset	0x3B 0x3C	0x08 0x00
Green/Y Coeff. 1	0x3D 0x3E	0x03 0x68
Green/Y Coeff. 2	0x3F 0x40	0x0B 0x71
Green/Y Coeff. 3	0x41 0x42	0x01 0x27
Green/Y Coeff. Offset	0x43 0x44	0x00 0x00
Blue/Cb Coeff. 1	0x45 0x46	0x1E 0x21
Blue/Cb Coeff. 2	0x47 0x48	0x19 0xB2
Blue/Cb Coeff. 3	0x49 0x4A	0x08 0x2D
Blue/Cb Coeff. Offset	0x4B 0x4C	0x08 0x00

Table XII. RGB (0 – 255) to HDTV YCrCb (16 – 235)

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x07 0x06
Red/Cr Coeff. 2	0x37 0x38	0x19 0xA0
Red/Cr Coeff. 3	0x39 0x3A	0x1F 0x5B
Red/Cr Coeff. Offset	0x3B 0x3C	0x08 0x00
Green/Y Coeff. 1	0x3D 0x3E	0x02 0xED
Green/Y Coeff. 2	0x3F 0x40	0x09 0xD3
Green/Y Coeff. 3	0x41 0x42	0x00 0xFD
Green/Y Coeff. Offset	0x43 0x44	0x01 0x00
Blue/Cb Coeff. 1	0x45 0x46	0x1E 0x64
Blue/Cb Coeff. 2	0x47 0x48	0x1A 0x96
Blue/Cb Coeff. 3	0x49 0x4A	0x07 0x06
Blue/Cb Coeff. Offset	0x4B 0x4C	0x08 0x00

Table XIII. RGB (0 – 255) to HDTV YCrCb (0 – 255)

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x08 0x2D
Red/Cr Coeff. 2	0x37 0x38	0x19 0x27
Red/Cr Coeff. 3	0x39 0x3A	0x1E 0xAC
Red/Cr Coeff. Offset	0x3B 0x3C	0x08 0x00
Green/Y Coeff. 1	0x3D 0x3E	0x04 0xC9
Green/Y Coeff. 2	0x3F 0x40	0x09 0x64
Green/Y Coeff. 3	0x41 0x42	0x01 0xD3
Green/Y Coeff. Offset	0x43 0x44	0x00 0x00
Blue/Cb Coeff. 1	0x45 0x46	0x1D 0x3F
Blue/Cb Coeff. 2	0x47 0x48	0x1A 0x93
Blue/Cb Coeff. 3	0x49 0x4A	0x08 0x2D
Blue/Cb Coeff. Offset	0x4B 0x4C	0x08 0x00

Table XIV. RGB (0 – 255) to HDTV YCrCb (16 – 235)

Register	Address	Value
Red/Cr Coeff. 1	0x35 0x36	0x07 0x06
Red/Cr Coeff. 2	0x37 0x38	0x1A 0x1E
Red/Cr Coeff. 3	0x39 0x3A	0x1E 0xDC
Red/Cr Coeff. Offset	0x3B 0x3C	0x08 0x00
Green/Y Coeff. 1	0x3D 0x3E	0x04 0x1C
Green/Y Coeff. 2	0x3F 0x40	0x08 0x11
Green/Y Coeff. 3	0x41 0x42	0x01 0x91
Green/Y Coeff. Offset	0x43 0x44	0x01 0x00
Blue/Cb Coeff. 1	0x45 0x46	0x1D 0xA3
Blue/Cb Coeff. 2	0x47 0x48	0x1B 0x57
Blue/Cb Coeff. 3	0x49 0x4A	0x07 0x06
Blue/Cb Coeff. Offset	0x4B 0x4C	0x08 0x00

AN05556–0–5/05(0)