Implementing the Gamma Correction Algorithm Using the TMS320C2xx DSP

APPLICATION REPORT: SPRA361

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Contents

Examples

Table

.

Implementing the Gamma Correction Algorithm Using the TMS320C2xx DSP

Abstract

A nonlinear effect of signal transfer exists between an electrical and an optical device. For example, the transfer function of a cathode-ray picture tube (CRT) produces an output intensity proportional to some power (usually about 2.2 and referred to as the *gamma factor*) of the signal voltage. The nonlinear effect distorts the color displayed by the CRT. To compensate for the nonlinear effect, a *gamma correction* is applied to the video signal before the CRT displays it to make the intensity output of the CRT linear.

The gamma correction is an image-processing algorithm that compensates for the nonlinear effect of signal transfer between electrical and optical devices. The image processing performed by video applications, such as CRTs, digital cameras, color printers, and scanners, includes a gamma correction for the output. Although a PC may implement image-processing algorithms for its peripheral equipment, digital signal processors (DSPs), such as the Texas Instruments (TI™) TMS320C2xx ('C2xx) DSP, are essential in implementing the image-processing algorithms for stand-alone systems.

This application note describes how to implement the gamma correction algorithm included with the 'C2xx DSP software. The document includes two main parts: the basic gamma correction theory and formula, and the 'C2xx gamma correction software description. Appendixes A through D present the assembly source code.

Product Support on the World Wide Web

TI's World Wide Web site at www.ti.com contains the most up-to-date product information, revisions, and additions. New users must register with TI&ME before they can access the data sheet archive. TI&ME allows users to build custom information pages and receive new product updates automatically via email.

Gamma Correction Theory and Formula

The following transformation equation uses a gamma factor of 2.2, which is typical in the consumer video environment.

$$R_{display} = R_{received}{}^{2.2}$$
$$G_{display} = G_{received}{}^{2.2} \qquad \text{(equation 1)}$$
$$B_{display} = B_{received}{}^{2.2}$$

where R, G, B values are normalized to the range of [0,1].

To compensate for the nonlinear processing of the display, the linear RGB data is gamma-corrected as follows:

$$R_{transmit} = R_{received}{}^{0.45}$$
$$G_{transmit} = G_{received}{}^{0.45} \qquad \text{(equation 2)}$$
$$B_{transmit} = B_{received}{}^{0.45}$$

where the R, G, B values are normalized to the range of [0,1].

Therefore, the displayed signals become linear to the receive signals.

$$R_{display} = R_{transmit}{}^{2.2} = (R_{received}{}^{0.45})^{2.2} = R_{received}$$
$$G_{display} = G_{transmit}{}^{2.2} = (G_{received}{}^{0.45})^{2.2} = G_{received}$$
$$B_{display} = B_{transmit}{}^{2.2} = (B_{received}{}^{0.45})^{2.2} = B_{received}$$

This application report assumes that the input digital signal is 8 bits wide; that is, the range of the input digital signal is within range [0, 255]. The compensate gamma factor is 0.45. Therefore, the gamma correction formula is

$$R_{transmit} = 255 \times \left(\frac{R_{received}}{256} \right)^{0.45}$$
$$G_{transmit} = 255 \times \left(\frac{G_{received}}{256} \right)^{0.45} \qquad \text{(equation 3)}$$
$$B_{transmit} = 255 \times \left(\frac{B_{received}}{256} \right)^{0.45}$$

The TMS320C2xx assembly language code described in this application report implements the gamma correction formula shown in equation (3).

Software Description

The gamma correction software contains three parts:

- The first part creates a look-up table, which is the most efficient way to obtain the corrected output data.
- The second part declares the variables and initializes the coefficients and tables used in the main program.
- The third part is the main program, which derives the corrected data from the original signal.

Creating the Gamma Correction Look-Up Table

The gamma correction look-up table avoids the complicated calculation of power. Data is related to the original input as generated by equation 3 (see Table 1).

Table 1. Creating the Gamma Correction Look-Up Table

(R,G,B)received (hex)	00	01	02	03	04	05	....
(R,G,B)transmit (hex)	00	15	1D	22	27	2B	....

TABLES.ASM defines the look-up table (see Appendix B).

Variable Declaration and Initial Values

Two blocks of memory space are declared in the program:

GAMMA_TABLE Defines the gamma correction look-up table as shown in Table 1.

GAMMA_BLOCK Image signal data array

Both blocks are declared in C2xx assembly language code as shown in Example 1.

Example 1. Memory Blocks Declared in ’C2xx Assembly Language Code

```
;-------------------------------------------------------------------------
;      Define variables & data blocks
;-------------------------------------------------------------------------
GAMMA_TABLE        .usect  ".gma_tbl", 256
GAMMA_BLOCK        .usect  ".gma_blk", IMAGE_SIZE
```

Example 2 shows the GAMMA_TABLE initialization based on constants defined in TABLES.ASM.

Example 2. Gamma Correction Table Initialization

```
;---------------------------------------------------------------------------
;       GAMMA CORRECTION TABLE INITIALIZATION
;---------------------------------------------------------------------------
GAMMA_INIT:
        LAR                 AR2, #GAMMA_TABLE
        MAR                 *, AR2
        RPT                 #255
        BLPD        #GTBL0, *+

        SPM                 0
        SETC        SXM
        CLRC        OVM
        RET
```

Gamma Correction Using the Look-Up Table

The program shown in Example 3 assigns four auxiliary registers.

Example 3. Auxiliary Register Assignment

```
;------------------------------------------------------------------------------------------
;       AR assignment:
;       AR0 =  #GAMMA_TABLE                 ; address of GAMMA_TABLE
;       AR2 -> GAMMA_BLOCK                  ; data array
;       AR3 -> pointer for look-up table    ; look-up table
;       AR7 -> counter
;------------------------------------------------------------------------------------------
        LAR                 AR0, #GAMMA_TABLE
        LAR                 AR2, #GAMMA_BLOCK
        LAR                 AR7, #IMAGE_SIZE-1
        MAR                 *, AR2
```

The program shown in Example 4 shows how to obtain the corrected results from the table.

Example 4. Look-Up Table Results

```
GAMMA_LOOP:
        LAR                 AR3, *, AR3     ; AR3 = content of AR2
        MAR                 *0+             ; AR3 = AR3 + #GAMMA_TABLE
        LACC        *, 0, AR2
        SACL        *+, 0, AR7
        BANZ        GAMMA_LOOP, *-, AR2
```

The original data is replaced by the corrected data. The complete program is named GAMMA.ASM. Appendixes A through D contain all of the source code and linker command files.

Summary

The gamma correction algorithm included in the TMS320C2xx software compensates for the nonlinear effect of signal transfer that exists between electrical and optical devices.

The gamma correction software uses the look-up table to obtain the corrected output data and avoid the complicated and time-consuming calculation of power. The look-up table is very effective, although it requires extra memory, must be calculated in advance, and is fixed. In the example code used in this application report, data needs only five cycles to complete the gamma correction operation. The program control, BANZ, needs four extra cycles but is optional.

Reference

Video Demystified, A Handbook for the Digital Engineer, Second Edition, pp58-61, Keith Jack, HighText Interactive, Inc., San Diego, 1996.

Appendix A. gamma.asm

```
;--------------------------------------------------------------------
;     Filename:           GAMMA.ASM
;     Description:        GAMMA CORRECTION
;     Author:             Vivian Shao
;     Date:      04/02/1997
;--------------------------------------------------------------------
           .def   start
           .def   GAMMA_INIT, GAMMA_CORRECTION
           .ref   GTBL0

;------------------------------------------------------------------
;     Define variables & data blocks
;------------------------------------------------------------------
IMAGE_SIZE              .set    16*16
GAMMA_TABLE             .usect  ".gma_tbl", 256
GAMMA_BLOCK             .usect  ".gma_blk", IMAGE_SIZE

           .text
start:
     CALL       GAMMA_INIT
     CALL       GAMMA_CORRECTION
     B          start

;-----------------------------------------------------------------------------
;     GAMMA CORRECTION TABLE INITIALIZATION
;-----------------------------------------------------------------------------
GAMMA_INIT:
     LAR        AR2, #GAMMA_TABLE
     MAR        *, AR2
     RPT        #255
     BLPD       #GTBL0, *+

     SPM        0
     SETC       SXM
     CLRC       OVM
     RET

;-----------------------------------------------------------------------------
;     GAMMA CORRECTION MAIN
;-----------------------------------------------------------------------------
GAMMA_CORRECTION:
;---------------------------------------------------------
;     AR assignment:
;     AR0 =  #GAMMA_TABLE
;     AR2 -> GAMMA_BLOCK
;     AR3 -> pointer for look-up table
;     AR7 -> counter
;---------------------------------------------------------
     LAR        AR0, #GAMMA_TABLE
     LAR        AR2, #GAMMA_BLOCK
     LAR        AR7, #IMAGE_SIZE-1
     MAR        *, AR2

;---------------------------------------------------------
```

```
;       GAMMA CORRECTION FORMULA:
;                                   original data      0.45
;       corrected data = 255 * ( -------------------- )
;                                        256
;----------------------------------------------------------
GAMMA_LOOP:
        LAR     AR3, *, AR3             ; AR3 = content of AR2
        MAR     *0+                     ; AR3 = AR3 + #GAMMA_TABLE
        LACC    *, 0, AR2
        SACL    *+, 0, AR7
        BANZ    GAMMA_LOOP, *-, AR2

        RET
```

Appendix B. tables.asm

```
;-------------------------------------------------------------------------------------------------
;       Filename:       TABLES.ASM
;       Description:    INITIAL VALUES OF GAMMA CORRECTION TABLE
;       Author:         Vivian Shao
;       Date:           04/02/1997
;-------------------------------------------------------------------------------------------------
        .def    GTBL0
        .data
GTBL0:
        .word   0h,     15h,    1dh,    22h,    27h,    2bh,    2fh,    32h
        .word   36h,    39h,    3bh,    3eh,    40h,    43h,    45h,    47h
        .word   49h,    4bh,    4dh,    4fh,    51h,    53h,    55h,    56h
        .word   58h,    5ah,    5bh,    5dh,    5eh,    60h,    61h,    63h
        .word   64h,    65h,    67h,    68h,    69h,    6bh,    6ch,    6dh
        .word   6fh,    70h,    71h,    72h,    73h,    75h,    76h,    77h
        .word   78h,    79h,    7ah,    7bh,    7ch,    7eh,    7fh,    80h
        .word   81h,    82h,    83h,    84h,    85h,    86h,    87h,    88h
        .word   89h,    8ah,    8bh,    8bh,    8ch,    8dh,    8eh,    8fh
        .word   90h,    91h,    92h,    93h,    94h,    95h,    95h,    96h
        .word   97h,    98h,    99h,    9ah,    9ah,    9bh,    9ch,    9dh
        .word   9eh,    9fh,    9fh,    0a0h,   0a1h,   0a2h,   0a2h,   0a3h
        .word   0a4h,   0a5h,   0a6h,   0a6h,   0a7h,   0a8h,   0a9h,   0a9h
        .word   0aah,   0abh,   0abh,   0ach,   0adh,   0aeh,   0aeh,   0afh
        .word   0b0h,   0b0h,   0b1h,   0b2h,   0b3h,   0b3h,   0b4h,   0b5h
        .word   0b5h,   0b6h,   0b7h,   0b7h,   0b8h,   0b9h,   0b9h,   0bah
        .word   0bbh,   0bbh,   0bch,   0bdh,   0bdh,   0beh,   0bfh,   0bfh
        .word   0c0h,   0c0h,   0c1h,   0c2h,   0c2h,   0c3h,   0c4h,   0c4h
        .word   0c5h,   0c5h,   0c6h,   0c7h,   0c7h,   0c8h,   0c8h,   0c9h
        .word   0cah,   0cah,   0cbh,   0cbh,   0cch,   0cdh,   0cdh,   0ceh
        .word   0ceh,   0cfh,   0d0h,   0d0h,   0d1h,   0d1h,   0d2h,   0d2h
        .word   0d3h,   0d4h,   0d4h,   0d5h,   0d5h,   0d6h,   0d6h,   0d7h
        .word   0d7h,   0d8h,   0d9h,   0d9h,   0dah,   0dah,   0dbh,   0dbh
        .word   0dch,   0dch,   0ddh,   0ddh,   0deh,   0deh,   0dfh,   0e0h
        .word   0e0h,   0e1h,   0e1h,   0e2h,   0e2h,   0e3h,   0e3h,   0e4h
        .word   0e4h,   0e5h,   0e5h,   0e6h,   0e6h,   0e7h,   0e7h,   0e8h
        .word   0e8h,   0e9h,   0e9h,   0eah,   0eah,   0ebh,   0ebh,   0ech
        .word   0ech,   0edh,   0edh,   0eeh,   0eeh,   0efh,   0efh,   0f0h
        .word   0f0h,   0f1h,   0f1h,   0f2h,   0f2h,   0f3h,   0f3h,   0f3h
        .word   0f4h,   0f4h,   0f5h,   0f5h,   0f6h,   0f6h,   0f7h,   0f7h
        .word   0f8h,   0f8h,   0f9h,   0f9h,   0fah,   0fah,   0fah,   0fbh
        .word   0fbh,   0fch,   0fch,   0fdh,   0fdh,   0feh,   0feh,   0ffh
```

Appendix C. vectors.asm

```
;--------------------------------------------------------------------
;       Filename:               VECTORS.ASM
;       Description:            Define Vector Table
;       Author:                 Vivian Shao
;       Date:                   11/15/1996
;--------------------------------------------------------------------
        .def            reset
        .ref            start

        .sect           "vectors"
reset:  B               start
```

Appendix D. gamma.cmd

```
/*********************************************************************************************/
/*                                                                                          */
/*    Usage:      dsplnk <obj files...> -o <out file> -m <map file> lab.cmd                 */
/*                                                                             */
/*********************************************************************************************/
vectors.obj
tables.obj
gamma.obj
-v0
-m gamma.map
-o gamma.out

MEMORY
{
            /* Program Space */
   PAGE 0 :     VECS    : origin =    0h , length =   040h          /* Vectors */
                PROG    : origin =  040h , length =  0FC0h          /* 4K ROM */

            /* Data Space */
   PAGE 1 :     MMREGS  : origin =    0h , length =    60h          /* MMRS    */
                B2      : origin =  060h , length =   020h  /* On-chip DARAM B2 */
                B0      : origin = 0200h , length =  0100h          /* B0  */
                B1      : origin = 0300h , length =  0100h          /* B1 */
                SARAM   : origin = 1000h , length =  1000h          /* Internal RAM */
}

/*--------------------------------------------------------------------------------*/
/* SECTIONS ALLOCATION                                                             */
/*--------------------------------------------------------------------------------*/
SECTIONS
{
   vectors :     { } > VECS      PAGE 0        /* INTERRUPT VECTOR TABLE       */
   .text   :     { } > PROG      PAGE 0        /* CODE                    */
   .data   :     { } > PROG      PAGE 0        /* INITIALIZATION DATA TABLES   */
   .bss    :     { } > B2        PAGE 1        /* UNINITIALIZED DATA          */
   .gma_blk:     { } > SARAM     PAGE 1        /* GAMMA correction data buffer */
   .gma_tbl:     { } > B0        PAGE 1        /* GAMMA correction look-up table */
}
```