Grayscale and Dot-Corrected LED Display Using
TLC5941 and MSP430F427

ABSTRACT

The TLC5941 LED driver uses a serial data interface to receive grayscale and dot correction data. This application report describes the hardware and firmware to drive the TLC5941 with an MSP430F427 microcontroller (MCU).

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1 Introduction

The TLC5941 is a 16-channel LED driver with 12-bit grayscale dimming and 6-bit dot correction capabilities typically used for high-quality LED displays. The 192 bits of grayscale data and 96 bits of dot correction data are entered into the TLC5941 through a serial interface. This application report presents an example of the firmware necessary to drive the TLC5941 with an MSP430F427 MCU.

The serial interface is comprised of a shift register that is controlled by two signals, SLCK and SIN. One bit of serial data is placed on the SIN pin of the TLC5941; then, a positive edge on the SCLK pin shifts the data into the TLC5941 input register. Once all of the 96 or 192 bits have been shifted in, the XLAT pin is pulsed high to latch the data from the input register into the grayscale or dot correction registers.

The TLC5941 also requires a clock signal, GSCLK, for the grayscale PWM function. This clock is used to drive internal counters to derive the 12-bit grayscale dimming function. After 4096 grayscale clocks, the internal counter must be reset to zero by pulsing the BLANK signal high. This clocking function has also been included in the example MSP430F427 firmware to provide a stand-alone solution.
TLC5941 Driver Implementation Using the MSP430F427

Figure 5 and Figure 6 show the schematic of the hardware for the implementation of the circuit with the MSP430F427 and TLC5941. The schematic shows the MSP430F427, the TLC5941, and power circuits needed to implement a complete 16-LED display drive. Additional TLC5941s can be cascaded on the serial communication bus to accommodate any number of LEDs.

The hardware is configured so that the TLC5941 is controlled by six general-purpose I/O (GPIO) pins on the MSP430F427. All six of these GPIO pins are configured as outputs on port one of the MSP430F427. One output pin (P1.1) is configured to be driven by the internal system clock of the MSP430™ MCU. This output pin drives the GSCLK of the TLC5941. The system clock, internal to the MSP430F427, also supplies the clock to a 16-bit counter which also is internal to the MSP430F427. The counter is configured to count from 0 to 4097 with each clock pulse. When the counter reaches 4097, it generates an interrupt. An interrupt routine then pulses the output bit that connects to the BLANK signal of the TLC5941. Figure 1 shows a simplified block diagram of this clocking scheme. This clocking scheme makes the GSCLK and BLANK signal generation transparent to the rest of the software. The firmware only needs to send dot correction and grayscale data to drive the LEDs.

Figure 1. Simplified Block Diagram Of Clocking Scheme

Figure 2 shows a flow chart for the main loop of the firmware. The major portions of the communications firmware resides in three subroutines which makes the main loop very simple. The main loop simply initializes the output port, turns off the watchdog timer and configures the counter. Once these initialization steps are complete, the main loop simply sends all of the dot correction and grayscale data stored in RAM to the TLC5941 and then enters an infinite loop. The main loop ends in an infinite loop instead of halting the processor so that the interrupt routines continue to operate and drive the LEDs.

The GSOUT routine is used to send all of the grayscale data stored in RAM to the TLC5941. The 12-bit grayscale data is stored in RAM as left-justified, 16-bit words. Therefore, the lower four bits of each grayscale data in RAM are ignored by the firmware and are not sent to the TLC5941.

The DCOUT routine is used to send all of the dot correction data stored in RAM to the TLC5941. The 6-bit dot correction data is stored in RAM as left-justified, 8-bit bytes. Therefore, the lower two bits of each dot correction data in RAM are ignored by the firmware and are not sent to the TLC5941. Figure 3 shows the flow charts for the interrupt, GSOUT, and GSOUT routines.
The GSOUT and DOUT routines are similar and could be combined, together with the addition of some flags and conditional statements. This was not done for this example to clarify the difference between grayscale and dot correction communications. Both of these routines determine which byte of data in RAM is to be sent, how many bits of that byte are to be sent, and then passes these two parameters to the SHIFTOUT subroutine. The SHIFTOUT subroutine simply takes the byte of data and drives the bits of the output port that drive the serial communication pins of TLC5941. Figure 4 is the flow chart for the SHIFTOUT subroutine.

Figure 2. Main Loop Flow Chart
Figure 3. Interrupt and Subroutine Flow Charts
SHIFTOUT Start

Store data byte to be shifted out (pointed to by R8) in R10

Set the bit controlling SIN to the value of the most significant bit of data in R10

Shift R10 left one bit

Pulse bit controlling SCLK First high then low

Have all the bits been shifted out?

NO

YES

Return

Figure 4. SHIFTOUT Flow Chart
3  TLC5941 Driver Firmware Code

TLC5941 COMMUNICATIONS FIRMWARE
;
;Scot Lester
;Texas Instruments Incorporated
;February 2008
;
;This firmware was written for the MSP430F427
;
;The hardware is configured to have one general
;purpose I/O port (GPIO) configured as all bits being
;outputs. For this example, 6 bits of port one are used to
;drive the TLC5941. Each of the six used GPIO pins of the MSP430
;are connected as follows:
;
; PIN NAME   TLC5941 FUNCTION
;
P1.0 BLANK
P1.1 GSCLK=2MHz
P1.2 SCLK
P1.3 XLATCH
P1.4 MODE
P1.5 SIN
P1.6 not used
P1.7 not used

#include "msp430x42x.h"

; Definition of named constants

define BLANK (0x01)
define SCLK (0x04)
define XLAT (0x08)
define MODE (0x10)
define SIN (0x20)

;P1OUT is equal to the memory address of output port.

; Dot Correction values are stored sequentially in 8 bit bytes.
The TLC5941 only needs 6 bits of dot correction data so the
dot correction data is stored left justified in the 8 bit byte
the two least significant bits of each 8 bit byte are set
to zero in this example but the firmware ignores these
two bits so they can be any value.
For example, a binary dot correction value of 101010b = 0x2A
is stored as 10101000b = 0xA8

ORG 0200h ; Start of RAM
EVEN ; Align data on even boundary
Dot
DB 0xFC ;CH0
DB 0xFC ;CH1
DB 0xF4 ;CH2
DB 0xF8 ;CH3
DB 0xF8 ;CH4
DB 0xFC ;CH5
DB 0xF4 ;CH6
Grayscale values are stored sequentially in 16 bit words. The TLC5941 only needs 12 bits of grayscale so the grayscale data is stored left justified in the 16 bit word; the four least significant bits of each 16 bit word are set to zero in this example but the firmware ignores these four bits so they can be any value. For example, a hex grayscale value of 0xFFF is stored as 0xFFF0.

Grayscale

```
DB 0xF0 ;CH7
DB 0xF4 ;CH8
DB 0xFC ;CH9
DB 0xFC ;CH10
DB 0xFC ;CH11
DB 0xF8 ;CH12
DB 0xF4 ;CH13
DB 0xF4 ;CH14
DB 0xF8 ;CH15
```

Grayscale values are stored sequentially in 16 bit words. The TLC5941 only needs 12 bits of grayscale so the grayscale data is stored left justified in the 16 bit word; the four least significant bits of each 16 bit word are set to zero in this example but the firmware ignores these four bits so they can be any value. For example, a hex grayscale value of 0xFFF is stored as 0xFFF0.

```
Grayscale
DW 0xAFF0 ;CH0
DW 0xF000 ;CH1
DW 0xF000 ;CH2
DW 0xC000 ;CH3
DW 0xD400 ;CH4
DW 0xE000 ;CH5
DW 0xB000 ;CH6
DW 0xF000 ;CH7
DW 0xFFF0 ;CH8
DW 0x0000 ;CH9
DW 0x0000 ;CH10
DW 0x13F0 ;CH11
DW 0x2380 ;CH12
DW 0xE980 ;CH13
DW 0x0450 ;CH14
DW 0xBA30 ;CH15

;-----------------------------------------------
ORG 0C000h ; Starting Address of Program Space
;-----------------------------------------------
RESET ;reset jump vector jumps to here to start execution.
```

RESET ;reset jump vector jumps to here to start execution.

;Program execution begins here after power up and reset
;Typical start up routines should be located here.
;Routines to initialize the stack pointer, watch dog timers, parallel I/O
;ports etc. etc.
;the General Purpose I/O port (P1) needs to be configured with bits 0:5
;set to outputs. At initialization, all output bits should be cleared to zero.
;this is not shown since it is processor specific.
;Bit P1.1 has a special configuration. The output bit is driven by the
;MSP’s internal oscillator which is set to 2MHz. This drives the
grayscale clock of the TLC5941. Since the output signal is simply the
;system clock, there is no need for the firmware to manipulate this bit.
The grayscale clock will run continuously.

```
MOV.W #600h,SP ;Initialize stack pointer to location 600 hex
MOV.W #WDTPW+WDTHOLD,&WDTCTL ; Stop Watchdog Timer
```
BIS.B #0xFF,&P1DIR ;make all port one GPIO pins outputs
BIS.B #0x02,&P1SEL ;p1.1 = peripheral module output for GSCLK signal.
MOV.B #0x00,&P1OUT ;Initialize all outputs to zero
BIC #GIE,SR ;Turn all interrupts off

;The following commands configure several clocks that are specific to the
;MSP430F427. These commands configure an internal phase locked loop (PLL)
to generate a 2MHz stem clock from a 32.768KHz external crystal.

MOV.B #63,&SCFQCTL ;set MCLK=64*ACLK or 2MHz
MOV.B #FN_2,&SCFI0 ;set DCO range
BIS.B #02,&FLL_CTL1 ;set ACLK/4
BIC.B #01,&FLL_CTL1
BIS.B #XCAP18PF,&FLL_CTL0 ;Set load capacitance for xtal

;The following is a delay loop. This delay is needed to wait until the
crystal oscillator is stable before continuing to execute code. This
step is MSP430 specific.

MOV.W #10000,R15 ;Initial value for a delay loop
Xtal_Wait
DEC R15 ;Delay for 32 kHz crystal to
JNZ Xtal_Wait ;stabilize

;***********************************
;SET UP TIMER TO MAKE BLANK SIGNAL
;***********************************

;This section sets up a 16 bit timer with interrupt capability. The timer
;is configured to count up to the decimal number 4097. The timer clock signal
;is supplied by the system clock which is also the GSCLK. The timer will count 4097
gsclk and then initiate an interrupt. The timer automatically clears to zero
then starts to count again to 4097.
The interrupt routine simply toggles the
;Parallel I/O pin that is connected to the BLANK signal of the TLC5941.
The TLC5941 will receive 4096 GSCLKS and then get a pulse on the BLANK
;pin to reset the internal counters of the TLC5941
;
MOV.W #OUTMOD_3+CCIE,&CCTL0 ;CCR1 toggle/set
MOV.W #4097,&CCRO ;load timer value
MOV.W #TASSEL_2+MC_1,&TACTL ;SMCLK, up mode
BIS.W #GIE,SR ;enable timer interrupt for BLANK signal
 since the grayscale clock run continuously, this timer is used to automatically
;send out BLANK signals to start new display frames.
;This method makes the grayscale clocking transparent to the rest of the
;firmware.

;***********************************
;SEND DC AND GS DATA TO TLC5941
;***********************************

CALL #DCOUT ;call routine to move dot correction
;data to TLC5941
CALL #GSOUT ;call routine to move grayscale
;data to TLC5941

mainloop
NOP
JMP mainloop ;infinite loop when done
; SUBROUTINES

;**************************************************************
; SEND GRAYSCALE DATA TO TLC5941
;**************************************************************

;shift out Grayscale data stored in RAM to TLC5941
;clocks out as MSB of channel 15 first then works down through bytes in memory
;shifts of 12 bits per channel for a total of 192 bits.

;GSOUT

MOV.W #16,R12 ;Register 12 is a loop counter.
;Loop through 16 LEDs.

MOV.W #Grayscale,R13 ;load register 13 with the starting address of the
;grayscale data stored in RAM. R13 will point to the
;byte to shift out.

ADD.W #32,R13 ;Add 32 to the pointer so that R13 points to the byte after
;the last byte in the grayscale table. The first instruction
;in the following loop is a decrement instruction that will
;make R13 point at the last byte in the table.

DEC.W R13 ;decrease the address pointer by one byte

MOV.B #08,R9 ;Load register R9 with the number of bits to shift out
;this value will be passed to the SHIFTOUT subroutine
;R13 points to the MSB first in memory so there are 8 bits to shift out.

MOV.W R13,R8 ;Copy address pointer to R8. The SHIFTOUT routine uses R8 to point to the byte to shift out.

CALL #SHIFTOUT ;call subroutine to shift out data

DEC.W R13 ;decrement pointer one byte to point to LSB byte

MOV.B #0x04,R9 ;load R9 with the number of bits in the second byte
;to shift out. Only four bits remain to be shifted

MOV.W R13,R8 ;Copy address pointer to R8. The SHIFTOUT routine uses R8 to point to the byte to shift out.

CALL #SHIFTOUT ;call subroutine to shift out data

DEC.W R12 ;decrement loop counter by one

JNZ ltadcdt ;jump if not zero to continue looping

BIS.B #XLAT,&P1OUT ;set the I/O pin for XLATCH high to latch
;serial data into the TLC5941

BIC.B #XLAT,&P1OUT ;set XLATCH back to zero

BIS.B #SCLK,&P1OUT ;set the I/O pin for SLCK high to
give SCLK one extra pulse after XLATCH
;this is only required if the previous data sent
;to the TLC5941 was dot correction information

BIS.B #SCLK,&P1OUT ;set I/O pin for SCLK back to zero

RET ;return from subroutine

;**************************************************************
; SEND DOT CORRECTION DATA TO TLC5941
;**************************************************************

;shift out dot correction data stored in ram to TLC5941

;**************************************************************
; SEND DOT CORRECTION DATA TO TLC5941
;**************************************************************


Grayscale and Dot-Corrected LED Display Using TLC5941 and MSP430F427

TLC5941 Driver Firmware Code

;clocks out as MSB of channel 15 first then works down through bytes in memory
;shifts 6 bits per LED channel or 96 bits total.
;This routine is very similar to the Grayscale routine. The DCOUT and GSOUT
;routines could be combined together for some memory space savings by
;using some flags and conditional statements.
DCOUT

BIS.B #MODE,&P1OUT ;set I/O line that is tied to the MODE pin of
;the TLC5941 pin to one to enter DC mode
MOV.W #16,R12 ;Register 12 is a loop counter. Loop through 16 LEDs. MOV.W
#Dot,R13
;load register 13 with the starting address of the
;dot correction data stored in RAM. R13 will point to the
;byte to shift out
ADD.W #16,R13 ;Add 16 to the pointer so that R13 points to the byte after
;the last byte in the dot correction table. The first
;instruction in the following loop is a decrement instruction
;that will make R13 point at the last byte in the table.
ltadcdn
DEC.W R13 ;decrease the address pointer by one byte
MOV.B #06,R9 ;Load register R9 with the number of bits to shift out
;this value will be passed to the SHIFTOUT subroutine
;there are 6 bits to shift out
MOV.W R13,R8 ;Copy address pointer to R8. The SHIFTOUT
;routine uses R8 to point to the byte to shift out.
CALL #SHIFTOUT ;call subroutine to shift out data
DEC.W R12 ;decrement loop counter by one
JNZ ltadcdn ;jump if not zero to continue looping
BIS.B #XLAT,&P1OUT ;set the I/O pin for XLATCH high to latch
;serial data into the TLC5941
BIC.B #XLAT,&P1OUT ;set XLATCH back to zero
BIC.B #10h,&P1OUT ;set the I/O line that is tied to the MODE pin of
;the TLC5941 pin to zero to set back to
;grayscale mode
RET ;return from subroutine

;******************************************************************************
; SHIFT DATA OUT ROUTINE
;******************************************************************************

;clock variable number of bits to TLC5941.
;clocks out as most significant bit first then works down through byte
;r8 = address of byte containing data to shift (word length)
r9 = number of bits 1-8 to shift out (byte length)
r10 used for temporary storage for shifting
;This routine shifts out a variable number of bits from a byte
;stored in the location pointed to by R8. The data to be sent
;is stored left aligned to the most significant bit.
;For example, a 6 bit value of 0x3F would be stored as 0xFC
;with the two least significant bits set to zero.
;Registers R8 and R9 are used to pass parameters to this routine.
;Prior to calling this routine, R8 should contain the address of the
;byte of data to be shifted out. R9 should contain the number of bits
;that need to be shifted out.
;R9 will be used as a loop counter in this routine. The contents of R9
;will not be preserved when returning form this routine.
SHIFTOUT
MOV.B @r8,r10 ;move the byte stored in the memory location pointed to by register 8 into register 10

cbit
  BIC.B #SIN,&P1OUT ;clear the bit controlling SIN to zero
  BIT.B #80h,R10 ;test state of the most significant bit of the data remaining to be shifted out
  ;since we shift the MSB first, the software looks at the MSB of R10 to decide what data to shift out.
  JZ sdateq0 ;if the bit to shift out is a zero then skip ahead
  BIS.B #SIN,&P1OUT ;The data to shift out is a one so set the bit controlling SIN to a one

sdateq0
  BIS.B #SCLK,&P1OUT ;set the bit controlling SCLK to a one
  BIC.B #SCLK,&P1OUT ;clear the bit controlling SCLK to a zero
  RLA.B R10 ;shift the data stored in register 10 one bit left. The LSB of R10 will have a zero shifted in.
  DEC.B R9 ;decrement number of bits to send
  JNZ cbit ;jump if not zero. continue until all bits are sent
  RET ;return from subroutine

;--------------------------------------------------------------
; INTERRUPT ROUTINES
;--------------------------------------------------------------

;--------------------------------------------------------------
;ISR:  Interrupt Service Routine for Timer
;--------------------------------------------------------------

;timer interrupt routine
;when the timer count reaches 4097 it will issue an interrupt. The processor jumps to here to service the interrupt.
;This interrupt routine toggles the bit controlling the BLANK pin of the TLC5941. When the BLANK line of the TLC5941, it resets the internal grayscale counter and starts a new grayscale frame.

  BIS.B #BLANK,&P1OUT ;Toggle bit controlling BLANK
  BIC.B #BLANK,&P1OUT ;signal. First high then low.

  RETI ;Return from ISR

;--------------------------------------------------------------
; Interrupt Vectors
;--------------------------------------------------------------

;this segment is used to define the interrupt vectors in memory

  ORG 0FFFEh ; RESET Vector
  DW RESET 

  ORG 0FFECh ; Timer Interrupt Vector
  DW ISR 

END
4 Modified Blank Signal

The example firmware and flow charts rely on the BLANK signal being manually toggled during a software interrupt. Using an interrupt allows the firmware to know when the BLANK signal is toggled and the end of a frame has been reached. This is useful when the microprocessor and software need to synchronize data transfers to correspond with the end of a display frame. If frame synchronization is not required, then the interrupt can be removed from the code which will free up the interrupt routine for other software functions. The capture and compare functions of the timer can be used to generate the BLANK signal without the need for the interrupt routine. This requires the timer to be configured slightly different than what is shown in the example firmware. The following four lines of code replace the four lines of code listed under the “SET UP TIMER TO MAKE BLANK SIGNAL” header in the code listing.

```
MOV.W #OUTMOD_3+CCIE,&CCTL0 ; CCR1 toggle/set
MOV.W #4098,CCR0
MOV.W #4097,CCR1
MOV.W #TASSEL_2+MC_1,&TACTL ; turn on PWM - SMCLK, up mode
```

This code configures the counter timer to automatically toggle the BLANK line once the counter reaches 4097. With this code, the interrupts can be left disabled if desired.

5 Driving Additional LEDs

The firmware is configured to drive a single TLC5941 with 16 LEDs. However, several TCL5941s can be cascaded or daisy-chained together to drive a large number of LEDs. The TLC5941 data sheet shows how to daisy-chain several TLC5941s together. The loop counters and RAM address calculations of the GSOUT and DCOUT subroutines can be changed to accommodate any number of daisy-chained TLC5941s. The only limitation is the speed of the serial communications versus the desired frame rate of the display and the amount of RAM to store the dot correction and grayscale data.

The firmware example requires little EEPROM space in the MSP430F427. The dot correction and grayscale data tables require 48 bytes of RAM per TLC5941. The MSP430F427 was selected for this example implementation because it has 1KB of RAM available to store the dot correction and grayscale data. The 1KB of RAM is enough to store data for up to 21 TLC5941s or 336 LEDs.

The example implementation uses a 2-MHz system clock. This frequency is generated by the MSP430F427 from an external 32.768-kHz quartz crystal. The selection of a 32.768-kHz crystal and a 2-MHz system clock allow for the possibility of the MSP430F427 to drive an optional LCD display. If an LCD display is not required, then the system clock speed could be increased to 8 MHz which is the highest capability of the MSP430F427. Increasing the clock speed would speed the firmware execution and thus speed the communications between the MSP430F427 and the TLC5941 and thus increase the frame rate.
Figure 5. MSP430F427 Schematic
Figure 6. TLC5941 and Power Schematic
7 Conclusion
The TLC5941 has a simple serial interface to accept grayscale and dot correction data for driving up to 16 LEDs. The simple serial interface can be driven by virtually any microcontroller, FPGA, or digital signal processor. This application report shows one hardware and firmware implementation to drive a display comprised of 16 LEDs.

8 References
1. TLC5941 16 Channel LED Driver w/DOT Correction and Grayscale PWM Control data sheet
2. MSP430F42x Mixed-Signal Controllers data sheet
# Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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