Connecting an I²S-Compatible Audio DAC to the AT91x40 Series Microcontrollers

Introduction

The purpose of this Application Note is to provide the procedure to construct the interface between a stereo audio digital-to-analog converter (DAC) and an AT91x40 Series Microcontroller (DocRef. 2).

The stereo audio DAC of choice for this example, is the Micronas® DAC 3550A device. The digital interface of such a device is usually I²S standard compliant. As the AT91x40 Series microcontrollers do not embed such a serial peripheral, a parallel to I²S serial interface has to be set up with a programmable logic device. This has been achieved with an ATMEL ATF1508ASV 128 Macrocells CPLD (DocRef. 3).

This class of DAC embeds audio configuration registers that are accessible through a serial link. Because this peripheral is not embedded in the AT91x40 Series Microcontrollers, the protocol must be established by software through Parallel Input/Output (PIO) lines (DocRef. 4).

References

The following sources contributed information to this Application Note

1. ATMEL AT91 ARM Thumb Microcontrollers AT91x40 Series Full Data-Sheet, Rev. 1354C-07/01
2. ATMEL High-performance EE PLD ATF1508ASV/ATF1508ASVL, Rev. 1408E-09/00
3. AT91 TWI Drivers for AT24C512 Serial E²PROM, Rev. 1742A-04/01

AT91 ARM® Thumb® Microcontrollers

Application Note

Rev. 2646A–ATARM–05-02

Serialization

The I^2S (Inter-IC Sound) standard is based on a three-wire bus (DocRef. 1):

- a continuous serial clock (sck),
- a word select signal (ws)
- a serial data line (sd)

The device generating sck and ws (ie the CPLD in our application) is the master.

The serial data (sd) is driven out from the master on the trailing edge of the serial clock (sck) and sampled by the audio DAC on the sck leading edge. The word select signal (ws) indicates the channel being transmitted:

- ws = 0; left channel,
- ws = 1; right channel.

The access to the serializer is established through the AT91 External Bus Interface (EBI) peripheral. An interrupt signal is provided by this device to the microcontroller in order to alert the software that it must write the next audio data.

To view the adopted I^2S hardware configuration, please refer to the illustration in Figure 1 on page 3. The hardware connections are illustrated in Figure 3 on page 4. In this application example, the 6.144MHz Quartz Crystal Oscillator sets the audio data sample rate to 48KHz.

I²S Hardware Block Diagram

Figure 1. I²S Hardware Interface Block Diagram

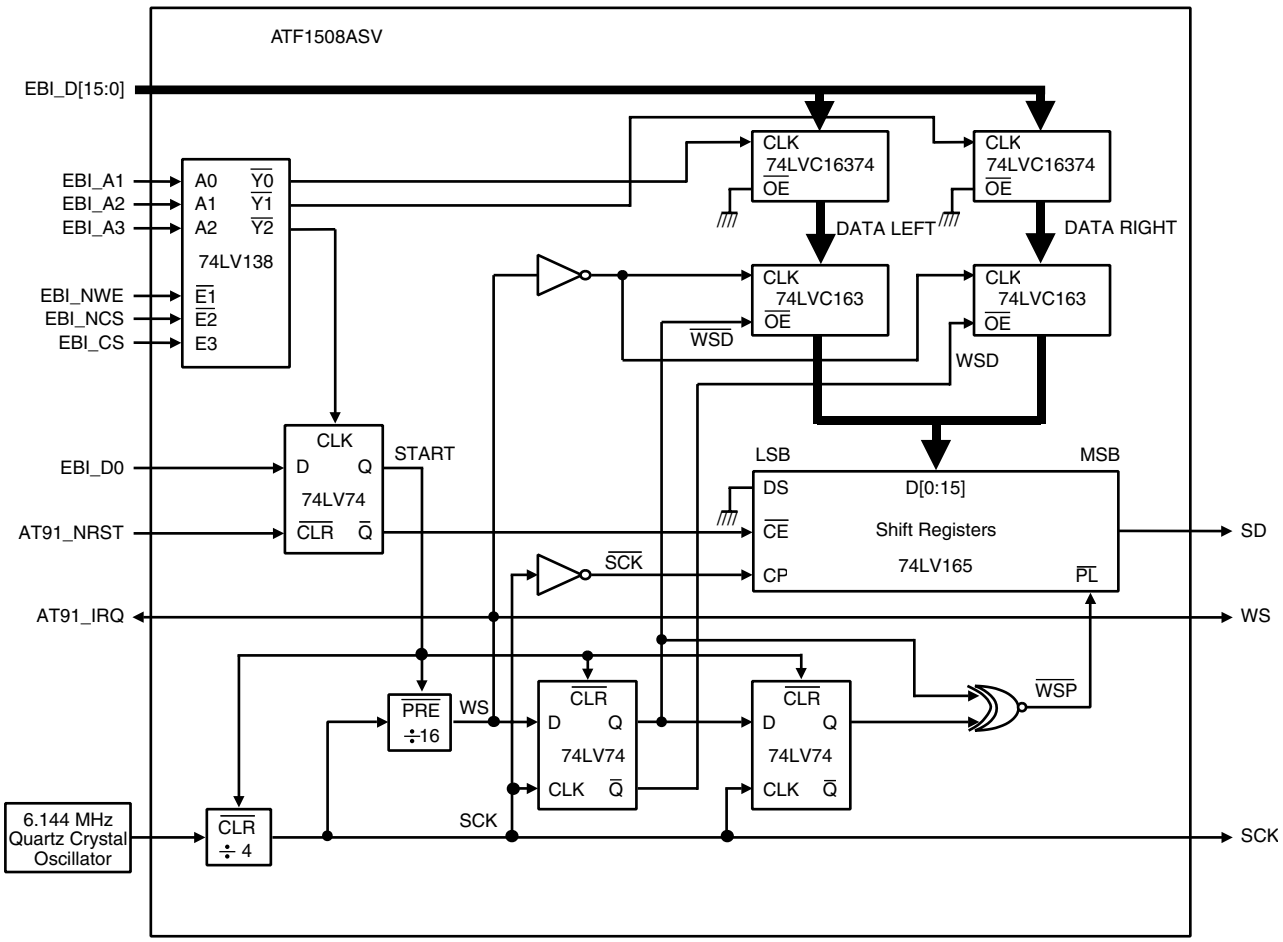


Figure 2. Timing Diagram

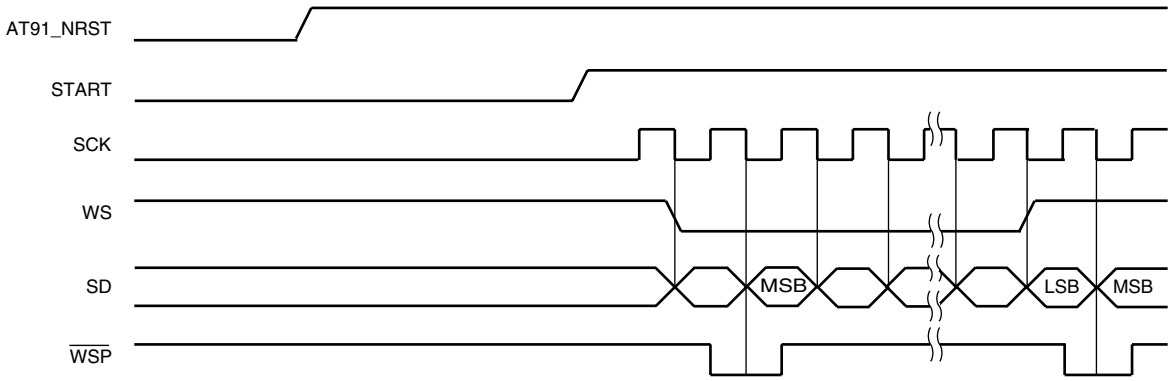
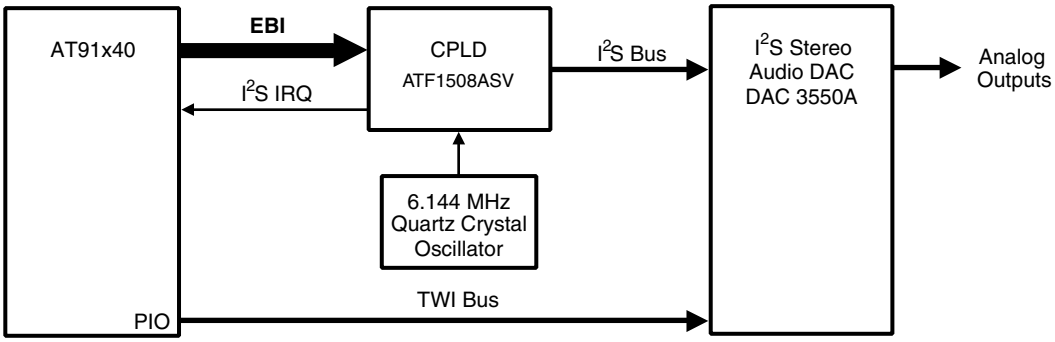


Figure 3. I^2S Hardware Connections



AT71508ASV CPLD VHDL Code

The related CPLD VHDL Code is the following:

```
-- ATMEL Microcontroller Software Support  -  ROUSSET  -
-- AT91 Audio Extension Card I2S Interface
-- 1.0- 11/10/01- ED
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

library IEEE ;
use IEEE.std_logic_1164.all ;

--------------------------------------------------------------------------------
-- Entity Section
--------------------------------------------------------------------------------

entity i2s_interface is

port (
       data: in std_logic_vector(15 downto 0);   -- Data Bus
       address: in std_logic_vector(3 downto 1 ;  -- Address Bus
       nrst,                                      -- AT91 Reset Signal
       ncs,                                       -- AT91 Chip Select Signal
       cs,                                        -- AT91 Chip Select Signal
       nwe,                                       -- AT91 Write Control Signal
       clock : in std_logic ;                     -- 6.144MHz Clock Input

       irq,                                       -- AT91 Interrupt Signal
       dai,                                       -- I2S Serial Data
       wsi,                                       -- I2S Channel Word Select
       cli: out std_logic                         -- I2S Serial Clock
   ) ;
end i2s_interface ;

--------------------------------------------------------------------------------
-- I2S Architecture Section
--------------------------------------------------------------------------------

architecture i2s of i2s_interface is

signal left_data_select,           -- left data chip select signal
    right_data_select,             -- right data chip select signal
    run_command_select,           -- start/stop command chip select
    start,                         -- Start/Stop Serializing Data
    sck,                           -- primary clock (6.144MHz)
                                   -- divided by 4 (1.536MHz)
    clk_int_sck,                  -- intermediate clock variable
    sck_1,                        -- left data register output enable command
    sck_2,                         -- right data register output enable command
```

```
    ws,                                         -- primary clock (6.144MHz)
                                                -- divided by 32 (96KHz)
    wsp                                         -- shift register load command
: std_logic ;

signal  left_data_1,                            -- left data from software interface
        right_data_1,                           -- right data from software interface
    left_data_2,                                -- left data ready to be serialized
    right_data_2,                               -- right data ready to be serialized
    parallel_data,                               -- parallel data to be loaded into
                                                 -- the shift register
    loaded_data                                  -- parallel data to be serialized
: std_logic_vector(15 downto 0) ;
signal         clk_int_ws                       -- intermediate clock variable
: integer range 0 to 31 ;

begin

  i2s_selection : process(nrst, cs, ncs, nwe, address)
  begin
    if ((nrst = '0') or ((cs = '0') and (ncs = '1')) or (nwe = '1')) then
      left_data_select <= '1' ;                   -- select signals are deactivated
      right_data_select <= '1' ;                 -- in case of reset assertion
      run_command_select <= '1' ;                 -- and no area selection
    elsif ((cs = '1') and (ncs = '0') and (nwe = '0')) then
      case address is
        when b"000" =>
          left_data_select <= '0' ;               -- if area selection,
          right_data_select <= '1' ;              -- one select signal
          run_command_select <= '1' ;             -- activated
        when b"001" =>
          left_data_select <= '1' ;              -- depending on
          right_data_select <= '0' ;               -- the address code
          run_command_select <= '1' ;
        when b"010" =>
          left_data_select <= '1' ;
          right_data_select <= '1' ;
          run_command_select <= '0' ;
        when others =>
          left_data_select <= '1' ;
          right_data_select <= '1' ;
          run_command_select <= '1' ;
      end case ;
    else
      left_data_select <= '1' ;                   -- else, all select signals
      right_data_select <= '1' ;                   -- deactivated
      run_command_select <= '1' ;
    end if ;
  end process ;
```

```
left_data_1(15 downto 0) <= data(15 downto 0) when rising_edge(left_data_select) ;

-- left data registered (first registration stage) in case of related select signal activation

right_data_1(15 downto 0) <= data(15 downto 0) when rising_edge(right_data_select) ;

-- right data registered (first registration stage) in case of related select signal activation

start <= '0' when nrst = '0' else data(0) when rising_edge(run_command_select) ;

-- start/stop command registered in case of related select signal activation

clk_int_sck <= '0' when start = '0' else not clk_int_sck when rising_edge(clock) ;
sck <= '0' when start = '0' else not sck when rising_edge(clk_int_sck) ;

-- I2S Serial Clock

sck_div : process(nrst, start, sck)
begin
  if ((nrst = '0') or (start = '0')) then
    clk_int_ws <= 31 ;
  elsif falling_edge(sck) then                    -- clk_int_ws = sck
    clk_int_ws <= (clk_int_ws + 1) mod 32 ;            -- divided 5 times
  end if ;
end process ;

ws_assert : process(nrst, start, clk_int_ws)
begin
  if ((nrst = '0') or (start = '0')) then
    ws <= '1' ;
  elsif ((clk_int_ws >= 0) and (clk_int_ws <= 15)) then
    ws <= '0' ;                                  -- ws toggles each
  else                                                  -- sck divided 4
    ws <= '1' ;                                        -- times toggling
  end if ;
end process ;

-- I2S Channel Word Select

data_load_signals : process(start, ws, sck)
begin
  if (start = '0') then
    sck_1 <= '0' ;
    sck_2 <= '0' ;
  elsif rising_edge(sck) then
    sck_1 <= ws ;
    sck_2 <= sck_1 ;
  end if ;
end process ;
```

```
  -- parallel data to be loaded into the shift register output enable signal
  -- signal to generate the load of the shift register in combination with the sck_1 signal

  wsp <= not (sck_1 xor sck_2) ;                      -- shift register load signal

  registered_data : process(nrst, start, ws)          -- data second registration stage
  begin
    if ((nrst = '0') or (start = '0')) then
      left_data_2(15 downto 0) <= x"0000" ;
      right_data_2(15 downto 0) <= x"0000" ;
    elsif falling_edge(ws) then
      left_data_2(15 downto 0) <= left_data_1(15 downto 0) ;
      right_data_2(15 downto 0) <= right_data_1(15 downto 0) ;
    end if ;
  end process ;

  parallel_data(15 downto 0) <= left_data_2(15 downto 0) when sck_1 = '0' else right_data_2(15 downto 0) ;

  -- registered data release to the shift register input

  shifter : process
  begin
    wait until falling_edge(sck) ;
    if (wsp = '0') then
      loaded_data(15 downto 0) <= parallel_data(15 downto 0) ;
      -- loading of the released data into the shift register
    elsif (wsp = '1') then
      loaded_data(15 downto 1) <= loaded_data(14 downto 0) ;
      loaded_data(0) <= '0' ;
      -- loaded data shifted with sck
    end if ;
  end process ;

  serial_data : process(nrst, start, loaded_data(15))
  begin
    if ((nrst = '0') or (start = '0')) then
      dai <= '0' ;
    else
      dai <= loaded_data(15) ;                    -- output serial data
    end if ;
  end process ;

  cli <= sck ;                                     -- I2S Serial Clock

  wsi <= ws ;                                     -- I2S Channel Word Select

  irq <= ws ;                                     -- AT91 Interrupt Signal

end i2s ;
```

Software Interface Description

The corresponding software interface is made up of 3 16-bit registers to write the right and left channel data and to start and stop the serialization process.

The I^2S registers are accessed through an AT91 Chip Select line and the sub-addresses are decoded by the CPLD.

Offset to Base Address	Operation
0x0	Load input latch left channel
0x2	Load input latch right channel
0x4	Start (Write 1)/Stop (Write 0: Reset State)

Schematics

The schematics shown in Figure 4 on page 10 and Figure 5 on page 11, illustrate a concrete example of the principle set out in this Application Note.

Figure 4. Schematics Board: Audio Extension Card Decode CPLD

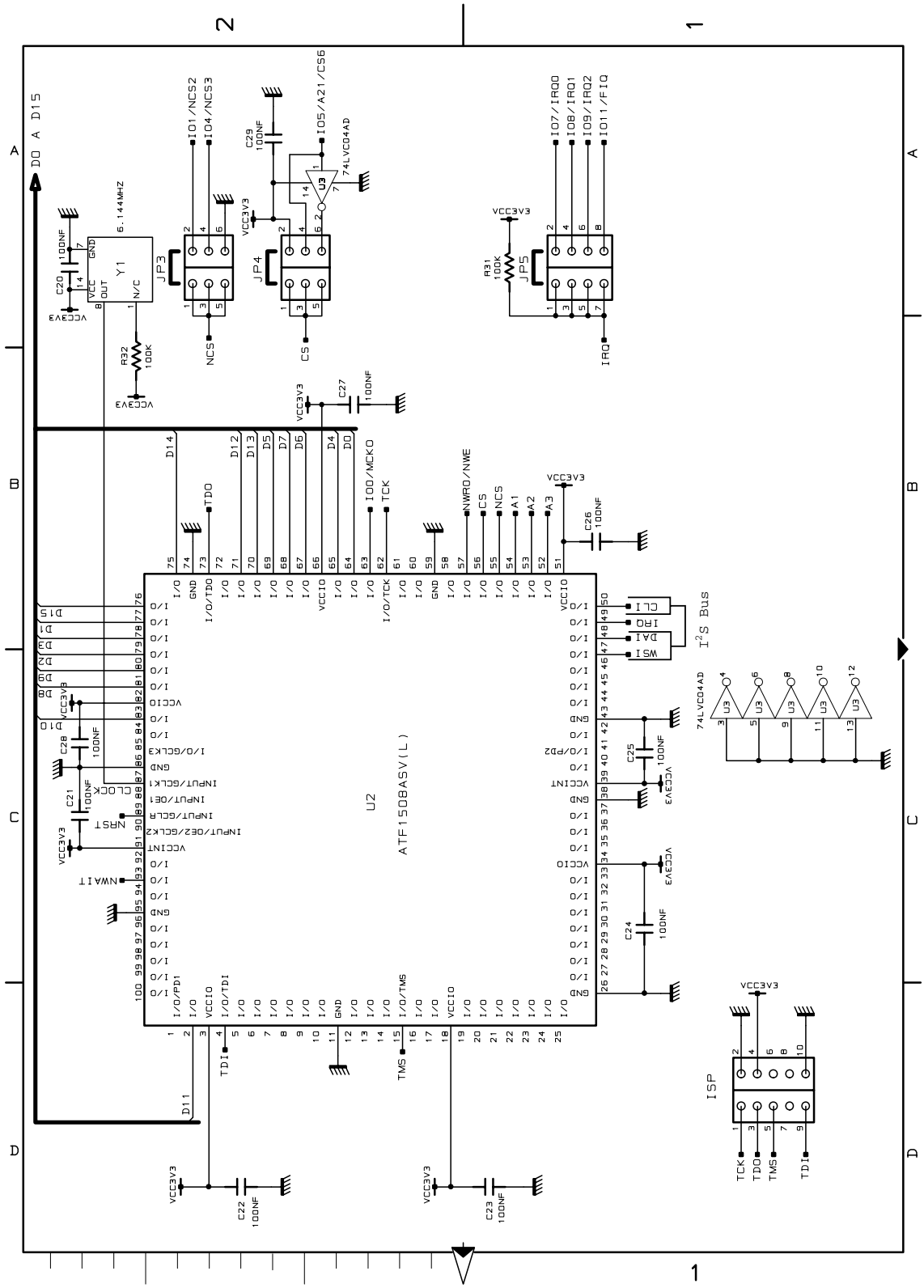
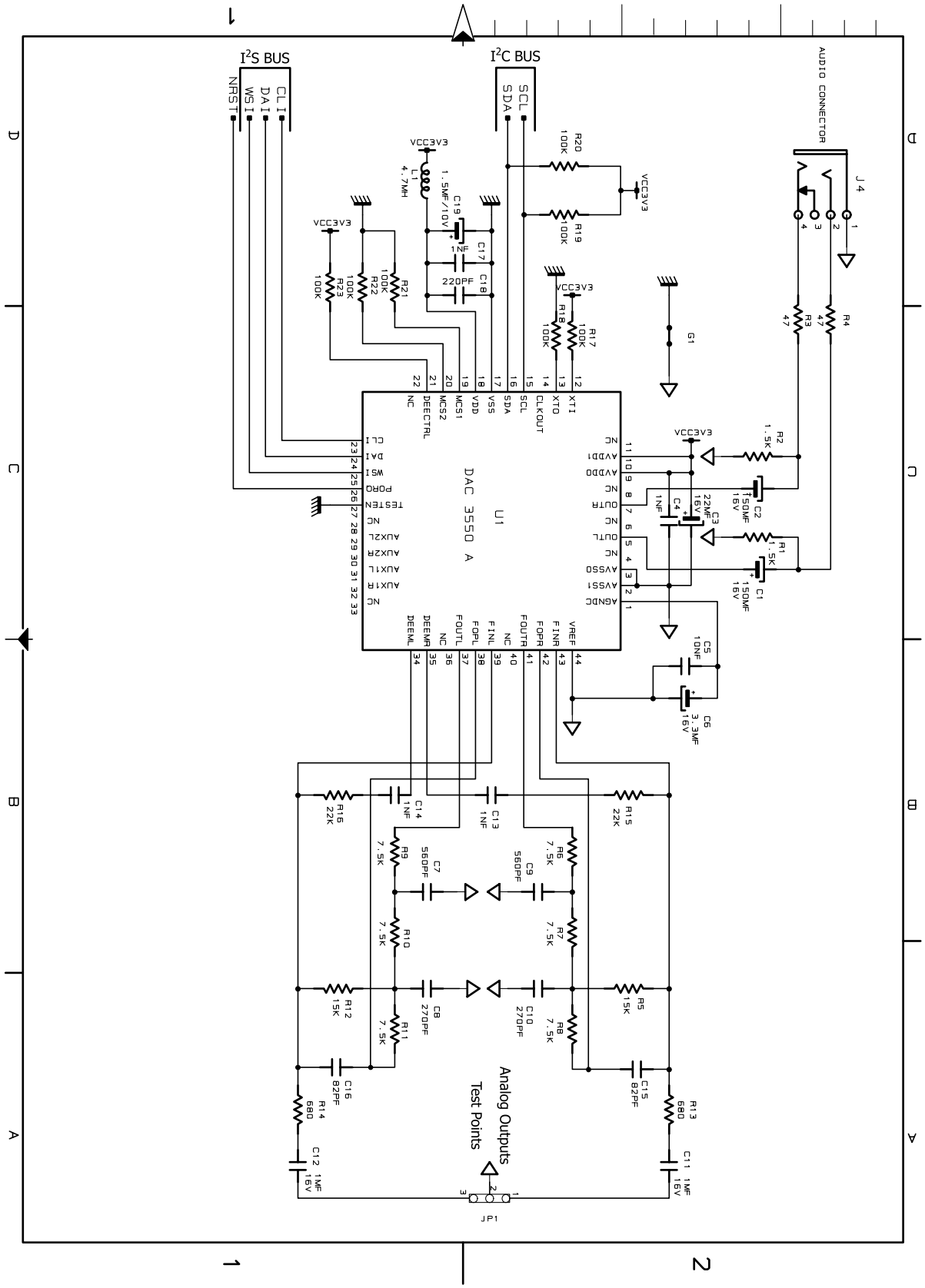


Figure 5. Audio Extension Card Audio DAC



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Atmel Headquarters

Corporate Headquarters
2325 Orchard Parkway
San Jose, CA 95131
TEL 1(408) 441-0311
FAX 1(408) 487-2600

Europe
Atmel Sarl
Route des Arsenaux 41
Case Postale 80
CH-1705 Fribourg
Switzerland
TEL (41) 26-426-5555
FAX (41) 26-426-5500

Asia
Room 1219
Chinachem Golden Plaza
77 Mody Road Tsimhatsui
East Kowloon
Hong Kong
TEL (852) 2721-9778
FAX (852) 2722-1369

Japan
9F, Tonetsu Shinkawa Bldg.
1-24-8 Shinkawa
Chuo-ku, Tokyo 104-0033
Japan
TEL (81) 3-3523-3551
FAX (81) 3-3523-7581

Atmel Operations

Memory
2325 Orchard Parkway
San Jose, CA 95131
TEL 1(408) 441-0311
FAX 1(408) 436-4314

Microcontrollers
2325 Orchard Parkway
San Jose, CA 95131
TEL 1(408) 441-0311
FAX 1(408) 436-4314

La Chantrerie
BP 70602
44306 Nantes Cedex 3, France
TEL (33) 2-40-18-18-18
FAX (33) 2-40-18-19-60

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FAX (44) 1355-242-743

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Theresienstrasse 2
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74025 Heilbronn, Germany
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FAX (49) 71-31-67-2340

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e-mail
literature@atmel.com

Web Site
http://www.atmel.com

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