

## Low-power, Multi-channel Decimation Filter

### Features

- 1- to 4-channel Digital Decimation Filter
  - ♦ Multiple On-chip FIR and IIR Coefficient Sets
  - ♦ Programmable Coefficients for Custom Filters
  - ♦ Synchronous Operation
- Selectable Output Word Rate
  - ♦ 4000, 2000, 1000, 500, 333, 250 SPS
  - ♦ 200, 125, 100, 50, 40, 25, 20, 10, 5, 1 SPS
- Digital Gain and Offset Corrections
- Test DAC Bit Stream Generator
  - ♦ Sine Wave or Impulse Output Mode
- Time Break Controller, General Purpose I/O
- Secondary SPI™ Port, Boundary Scan JTAG
- Microcontroller or EEPROM Configuration
- Small-footprint, 64-pin TQFP Package
- Low Power Consumption
  - ♦ 9 mW per Channel at 500 SPS
- Flexible Power Supplies
  - ♦ I/O Interface: 3.3 V or 5.0 V
  - ♦ Digital Logic Core: 3.0 V, 3.3 V or 5.0 V

### Description

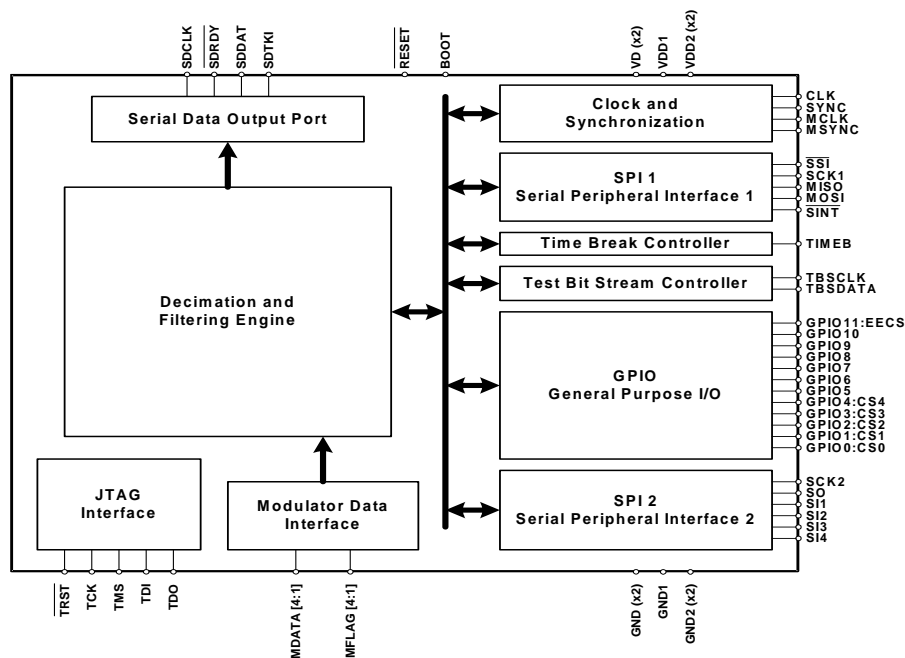
The CS5376A is a multi-function digital filter utilizing a low-power signal processing architecture to achieve efficient filtering for up to four  $\Delta\Sigma$  modulators. By combining the CS5376A with CS3301/02 differential amplifiers, CS5371/72  $\Delta\Sigma$  modulators, and the CS4373A  $\Delta\Sigma$  test DAC a synchronous, high-resolution, self-testing, multi-channel measurement system can be designed quickly and easily.

Digital filter coefficients for the CS5376A FIR and IIR filters are included on-chip for a simple setup, or they can be programmed for custom applications. Selectable digital filter decimation ratios produce output word rates from 4000 SPS to 1 SPS, resulting in measurement bandwidths ranging from 1600 Hz down to 400 mHz when using the on-chip coefficient sets.

The CS5376A includes integrated peripherals to simplify system design: offset and gain corrections, a test DAC bit stream generator, a time-break controller, 12 general-purpose I/O pins, a secondary SPI port, and a boundary scan JTAG port.

### ORDERING INFORMATION

See [page 107](#).



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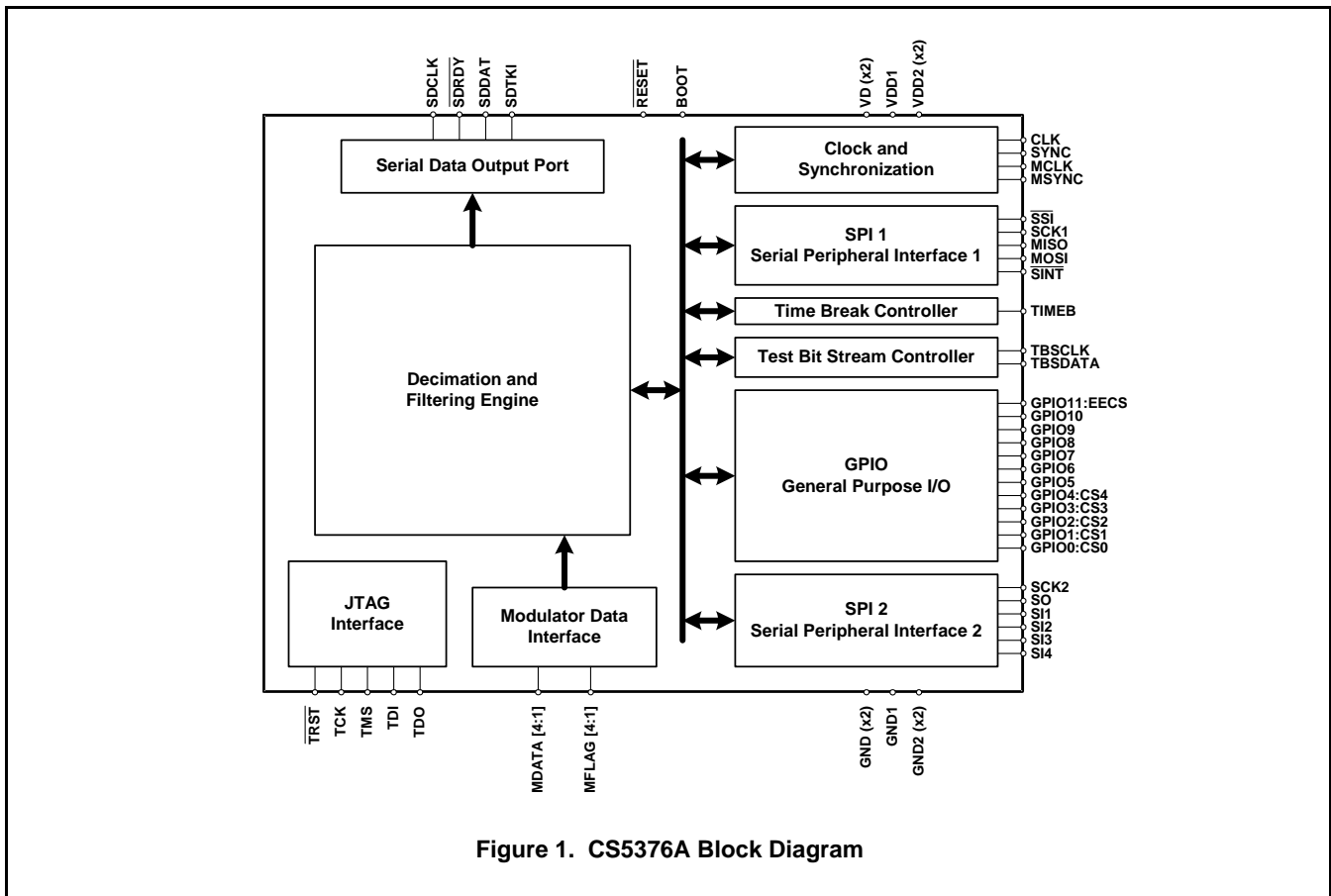


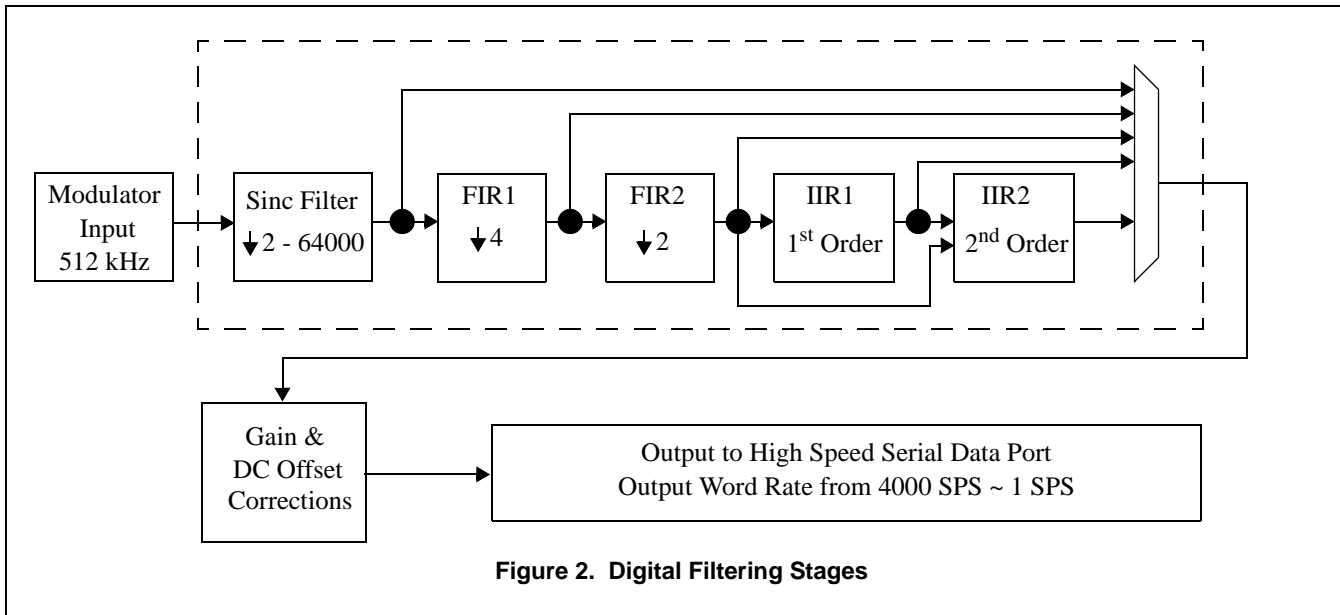
Figure 1. CS5376A Block Diagram

## 1. GENERAL DESCRIPTION

The CS5376A is a multi-channel digital filter with integrated system peripherals. Figure 1 illustrates a simplified block diagram of the CS5376A.

### 1.1 Digital Filter Features

- Multi-channel decimation filter for CS5371/72  $\Delta\Sigma$  modulators.
  - 1, 2, 3, or 4 channel concurrent operation.
- Synchronous operation for simultaneous sampling in multi-sensor systems.
  - Internal synchronization of digital filter phase to an external SYNC signal.
- Multiple output word rates, including low bandwidth rates.
  - Standard output rates: 4000, 2000, 1000, 500, 333, 250 SPS.
- Low bandwidth rates: 200, 125, 100, 50, 40, 25, 20, 10, 5, 1 SPS.
- Flexible digital filter configuration. (See Figure 2)
  - Cascaded SINC, FIR, and IIR filters with selectable output stage.
  - Linear and minimum phase FIR low-pass filter coefficients included.
  - 3 Hz Butterworth IIR high-pass filter coefficients included.
  - FIR and IIR coefficients are programmable to create a custom filter response.
- Digital gain correction.
  - Individual channel gain correction to normalize signal amplitudes.



- Digital offset correction and calibration.
    - Individual channel offset correction to remove measurement offsets.
    - Calibration engine for automatic calculation of offset correction factors.
  - Programmable waveform data for custom test signal generation.
  - Time break controller to record system timing information.
    - Dedicated TB status bit in the output data stream.
    - Programmable output delay to match system group delay.
  - Additional hardware peripherals simplify system design.
    - 12 General Purpose I/O (GPIO) pins for local hardware control.
    - Secondary SPI 2 serial port to control local serial peripherals.
    - JTAG port for boundary scan (IEEE 1149.1 compliant).
- ## 1.2 Integrated Peripheral Features
- Synchronous operation for simultaneous sampling in multi-sensor systems.
    - MCLK / MSYNC output signals to synchronize external components.
  - High speed serial data output port (SD port).
    - Asynchronous operation to 4 MHz for direct connection to system telemetry.
    - Internal 8-deep data FIFO for flexible output timing.
  - Digital test bit stream signal generator suitable for CS4373A  $\Delta\Sigma$  test DAC.
    - Sine wave output mode for testing total harmonic distortion.
    - Impulse output mode for transfer function characterization.
- ## 1.3 System Level Features
- Flexible configuration options.
    - Configuration 'on-the-fly' via microcontroller or system telemetry.
    - Fixed configuration via stand-alone boot



## EEPROM.

- Low power consumption.
  - 37 mW for 4-channel operation at 500 SPS (9.25 mW/channel).
  - 40  $\mu$ W standby mode.
- Flexible power supply configurations.
  - Separate digital logic core, telemetry I/O, and modulator I/O power supplies.
  - Telemetry I/O and modulator I/O interfaces operate from 3.3 V or 5 V.
  - Digital logic core operates from 3.0 V, 3.3 V or 5 V.
- Small 64-pin TQFP package.
  - Total footprint 12 mm x 12 mm plus five bypass capacitors.

## 1.4 Configuration Interface

- Configuration from microcontroller or stand-alone boot EEPROM.
  - Microcontroller boot permits reconfiguration during operation.
  - EEPROM boot sets a fixed operational configuration.
- Configuration commands written through Serial Peripheral Interface 1. (See Table 1)
  - Standardized microcontroller interface using SPI 1 registers. (See Table 3)
  - Commands write digital filter registers, filter coefficients, and test bit stream data.
  - Digital filter registers set hardware configuration options.

### Microcontroller Boot Configuration Commands

| Name                   | CMD<br>24-bit | DAT1<br>24-bit           | DAT2<br>24-bit           | Description                       |
|------------------------|---------------|--------------------------|--------------------------|-----------------------------------|
| NOP                    | 000000        | -                        | -                        | No Operation                      |
| WRITE DF REGISTER      | 000001        | REG                      | DATA                     | Write Digital Filter Register     |
| READ DF REGISTER       | 000002        | REG<br>[DATA]            | -<br>-                   | Read Digital Filter Register      |
| WRITE FIR COEFFICIENTS | 000003        | NUM FIR1<br>(FIR COEF)   | NUM FIR2<br>(FIR COEF)   | Write Custom FIR Coefficients     |
| WRITE IIR COEFFICIENTS | 000004        | a11<br>b11<br>a22<br>b21 | b10<br>a21<br>b20<br>b22 | Write Custom IIR Coefficients     |
| WRITE ROM COEFFICIENTS | 000005        | COEF SEL                 | -                        | Use On-Chip Coefficients          |
| WRITE TBS DATA         | 000006        | NUM TBS<br>(TBS DATA)    | -<br>(TBS DATA)          | Write Custom Test Bit Stream Data |
| WRITE ROM TBS          | 000007        | -                        | -                        | Use On-Chip TBS Data              |
| FILTER START           | 000008        | -                        | -                        | Start Digital Filter Operation    |
| FILTER STOP            | 000009        | -                        | -                        | Stop Digital Filter Operation     |

### EEPROM Boot Configuration Commands

| Name                   | CMD<br>8-bit | DATA<br>24-bit                                       | Description                       |
|------------------------|--------------|--|-----------------------------------|
| NOP                    | 00           | -  | No Operation                      |
| WRITE DF REGISTER      | 01           | REG<br>DATA  | Write Digital Filter Register     |
| WRITE FIR COEFFICIENTS | 02           | NUM FIR1<br>NUM FIR2<br>(FIR COEF)                   | Write Custom FIR Coefficients     |
| WRITE IIR COEFFICIENTS | 03           | a11<br>b10<br>b11<br>a21<br>a22<br>b20<br>b21<br>b22 | Write Custom IIR Coefficients     |
| WRITE ROM COEFFICIENTS | 04           | COEF SEL   | Use On-Chip Coefficients          |
| WRITE TBS DATA         | 05           | NUM TBS<br>(TBS DATA)                                | Write Custom Test Bit Stream Data |
| WRITE ROM TBS          | 06           | -  | Use On-Chip TBS Data              |
| FILTER START           | 07           | -  | Start Digital Filter Operation    |

[DATA] indicates data word returned from digital filter.

(DATA) indicates multiple words of this type are to be written.

**Table 1. Microcontroller and EEPROM Configuration Commands**

| Bits      | 23:20 | 19:16 | 15:12 | 11:8 | 7:4  | 3:0  |
|-----------|-------|-------|-------|------|------|------|
| Selection | 0000  | 0000  | IIR2  | IIR1 | FIR2 | FIR1 |

| Bits 15:12 | IIR2 Coefficients |
|------------|-------------------|
| 0000       | 3 Hz @ 2000 SPS   |
| 0001       | 3 Hz @ 1000 SPS   |
| 0010       | 3 Hz @ 500 SPS    |
| 0011       | 3 Hz @ 333 SPS    |
| 0100       | 3 Hz @ 250 SPS    |

| Bits 11:8 | IIR1 Coefficients |
|-----------|-------------------|
| 0000      | 3 Hz @ 2000 SPS   |
| 0001      | 3 Hz @ 1000 SPS   |
| 0010      | 3 Hz @ 500 SPS    |
| 0011      | 3 Hz @ 333 SPS    |
| 0100      | 3 Hz @ 250 SPS    |

| Bits 3:0 | FIR1 Coefficients |
|----------|-------------------|
| 0000     | Linear Phase      |
| 0001     | Minimum Phase     |

| Bits 7:4 | FIR2 Coefficients |
|----------|-------------------|
| 0000     | Linear Phase      |
| 0001     | Minimum Phase     |

**Figure 3. FIR and IIR Coefficient Set Selection Word**

**Test Bit Stream Characteristic Equation:**

$$(Signal\ Freq) * (\#\ TBS\ Data) * (Interpolation + 1) = Output\ Rate$$

**Example:**  $(31.25\ Hz) * (1024) * (0x07 + 1) = 256\ kHz$

| Signal Frequency (TBSDATA) | Output Rate (TBSCLK) | Output Rate Selection (RATE) | Interpolation Selection (INTP) |
|----------------------------|----------------------|------------------------------|--------------------------------|
| 10.00 Hz                   | 256 kHz              | 0x4                          | 0x18                           |
| 10.00 Hz                   | 512 kHz              | 0x5                          | 0x31                           |
| 25.00 Hz                   | 256 kHz              | 0x4                          | 0x09                           |
| 25.00 Hz                   | 512 kHz              | 0x5                          | 0x13                           |
| 31.25 Hz                   | 256 kHz              | 0x4                          | 0x07                           |
| 31.25 Hz                   | 512 kHz              | 0x5                          | 0x0F                           |
| 50.00 Hz                   | 256 kHz              | 0x4                          | 0x04                           |
| 50.00 Hz                   | 512 kHz              | 0x5                          | 0x09                           |
| 125.00 Hz                  | 256 kHz              | 0x4                          | 0x01                           |
| 125.00 Hz                  | 512 kHz              | 0x5                          | 0x03                           |

**Table 2. TBS Configurations Using On-Chip Data**

### SPI 1 Registers

| Name     | Addr.   | Type | # Bits  | Description   |
|----------|---------|------|---------|---------------|
| SPI1CTRL | 00 - 02 | R/W  | 8, 8, 8 | SPI 1 Control |
| SPI1CMD  | 03 - 05 | R/W  | 8, 8, 8 | SPI 1 Command |
| SPI1DAT1 | 06 - 08 | R/W  | 8, 8, 8 | SPI 1 Data 1  |
| SPI1DAT2 | 09 - 0B | R/W  | 8, 8, 8 | SPI 1 Data 2  |

### Digital Filter Registers

| Name     | Addr. | Type | # Bits | Description                                    |
|----------|-------|------|--------|--|
| CONFIG   | 00    | R/W  | 24     | Hardware Configuration                         |
| RESERVED | 01-0D | R/W  | 24     | Reserved                                       |
| GPCFG0   | 0E    | R/W  | 24     | GPIO[7:0] Direction, Pull-up Enable, and Data  |
| GPCFG1   | 0F    | R/W  | 24     | GPIO[11:8] Direction, Pull-up Enable, and Data |
| SPI2CTRL | 10    | R/W  | 24     | SPI 2 Control                                  |
| SPI2CMD  | 11    | R/W  | 16     | SPI 2 Command                                  |
| SPI2DAT  | 12    | R/W  | 24     | SPI 2 Data                                     |
| RESERVED | 13-1F | R/W  | 24     | Reserved                                       |
| FILTCFG  | 20    | R/W  | 24     | Digital Filter Configuration                   |
| GAIN1    | 21    | R/W  | 24     | Gain Correction Channel 1                      |
| GAIN2    | 22    | R/W  | 24     | Gain Correction Channel 2                      |
| GAIN3    | 23    | R/W  | 24     | Gain Correction Channel 3                      |
| GAIN4    | 24    | R/W  | 24     | Gain Correction Channel 4                      |
| OFFSET1  | 25    | R/W  | 24     | Offset Correction Channel 1                    |
| OFFSET2  | 26    | R/W  | 24     | Offset Correction Channel 2                    |
| OFFSET3  | 27    | R/W  | 24     | Offset Correction Channel 3                    |
| OFFSET4  | 28    | R/W  | 24     | Offset Correction Channel 4                    |
| TIMEBRK  | 29    | R/W  | 24     | Time Break Delay                               |
| TBSCFG   | 2A    | R/W  | 24     | Test Bit Stream Configuration                  |
| TBSGAIN  | 2B    | R/W  | 24     | Test Bit Stream Gain                           |
| SYSTEM1  | 2C    | R/W  | 24     | User Defined System Register 1                 |
| SYSTEM2  | 2D    | R/W  | 24     | User Defined System Register 2                 |
| VERSION  | 2E    | R/W  | 24     | Hardware Version ID                            |
| SELFTST  | 2F    | R/W  | 24     | Self-Test Result Code                          |

**Table 3. SPI 1 and Digital Filter Registers**

## 2. CHARACTERISTICS AND SPECIFICATIONS

- Min / Max characteristics and specifications are guaranteed over the Specified Operating Conditions.
- Typical performance characteristics and specifications are derived from measurements taken at nominal supply voltages and  $T_A = 25^\circ\text{C}$ .
- GND, GND1, GND2 = 0 V, all voltages with respect to 0 V.

### SPECIFIED OPERATING CONDITIONS

| Parameter                              | Symbol | Min   | Nom | Max  | Unit             |
|--|--------|-------|-----|------|------------------|
| Logic Core Power Supply                | VD     | 2.85  | 3.0 | 5.25 | V                |
| Microcontroller Interface Power Supply | VDD1   | 3.135 | 3.3 | 5.25 | V                |
| Modulator Interface Power Supply       | VDD2   | 3.135 | 3.3 | 5.25 | V                |
| Ambient Operating Temperature          | $T_A$  | -40   | -   | 85   | $^\circ\text{C}$ |

### ABSOLUTE MAXIMUM RATINGS

| Parameter                                     | Symbol                            | Min  | Max      | Units            |
|---|-----------------------------------|------|----------|------------------|
| DC Power Supplies                             | Logic Core<br>VD                  | -0.3 | 6.0      | V                |
|   | Microcontroller Interface<br>VDD1 | -0.3 | 6.0      | V                |
|   | Modulator Interface<br>VDD2       | -0.3 | 6.0      | V                |
| Input Current, Any Pin Except Supplies        | (Note 1)<br>$I_{IN}$              | -    | $\pm 10$ | mA               |
| Input Current, Power Supplies                 | (Note 1)<br>$I_{IN}$              | -    | $\pm 50$ | mA               |
| Output Current                                | (Note 1)<br>$I_{OUT}$             | -    | $\pm 25$ | mA               |
| Power Dissipation                             | $P_{DN}$                          | -    | 500      | mW               |
| Digital Input Voltages                        | $V_{IND}$                         | -0.5 | VDD+0.5  | V                |
| Ambient Operating Temperature (Power Applied) | $T_A$                             | -40  | 85       | $^\circ\text{C}$ |
| Storage Temperature Range                     | $T_{STG}$                         | -65  | 150      | $^\circ\text{C}$ |

1. Transient currents up to 100 mA will not cause SCR latch-up.

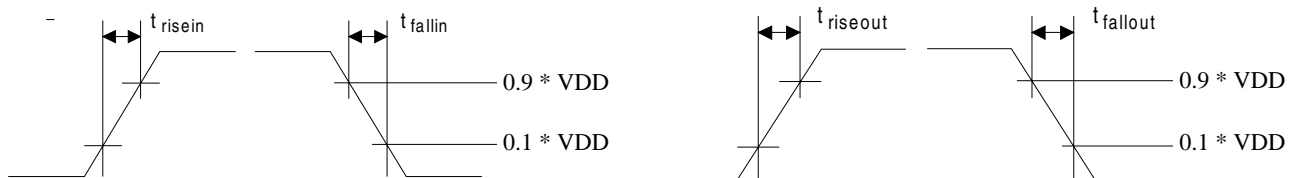
## THERMAL CHARACTERISTICS

| Parameter                                     | Symbol        | Min | Typ | Max | Unit   |
|---|---------------|-----|-----|-----|--------|
| Allowable Junction Temperature                | $T_J$         | -   | -   | 135 | °C     |
| Junction to Ambient Thermal Impedance         | $\Theta_{JA}$ | -   | 65  |     | °C / W |
| Ambient Operating Temperature (Power Applied) | $T_A$         | -40 | -   | +85 | °C     |

## DIGITAL CHARACTERISTICS

| Parameter  | Symbol     | Min       | Typ     | Max      | Unit    |
|--|------------|-----------|---------|----------|---------|
| High-Level Input Drive Voltage                           | $V_{IH}$   | 0.6 * VDD | -       | VDD      | V       |
| Low-Level Input Drive Voltage                            | $V_{IL}$   | 0.0       | -       | 0.8      | V       |
| High-Level Output Drive Voltage<br>$I_{out} = -40 \mu A$ | $V_{OH}$   | VDD - 0.3 | -       | VDD      | V       |
| Low-Level Output Drive Voltage<br>$I_{out} = +40 \mu A$  | $V_{OL}$   | 0.0       | -       | 0.3      | V       |
| Rise Times, Digital Inputs                               | $t_{RISE}$ | -         | -       | 100      | ns      |
| Fall Times, Digital Inputs                               | $t_{FALL}$ | -         | -       | 100      | ns      |
| Rise Times, Digital Outputs                              | $t_{RISE}$ | -         | -       | 100      | ns      |
| Fall Times, Digital Outputs                              | $t_{FALL}$ | -         | -       | 100      | ns      |
| Input Leakage Current (Note 2)                           | $I_{IN}$   | -         | $\pm 1$ | $\pm 10$ | $\mu A$ |
| 3-State Leakage Current                                  | $I_{OZ}$   | -         | -       | $\pm 10$ | $\mu A$ |
| Digital Input Capacitance                                | $C_{IN}$   | -         | 9       | -        | pF      |
| Digital Output Pin Capacitance                           | $C_{OUT}$  | -         | 9       | -        | pF      |

Notes: 2. Max leakage for pins with pull-up resistors ( $\overline{TRST}$ , TMS, TDI,  $\overline{SS1}$ , GPIO, MOSI, SCK1) is  $\pm 250 \mu A$ .



## POWER CONSUMPTION

| Parameter                                   | Symbol     | Min | Typ | Max | Unit    |
|---|------------|-----|-----|-----|---------|
| <b>Operational Power Consumption</b>        |            |     |     |     |         |
| 1.024 MHz Digital Filter Clock              | $PWR_1$    | -   | 21  | -   | mW      |
| 2.048 MHz Digital Filter Clock              | $PWR_2$    | -   | 26  | -   | mW      |
| 4.096 MHz Digital Filter Clock              | $PWR_4$    | -   | 37  | -   | mW      |
| 8.192 MHz Digital Filter Clock              | $PWR_8$    | -   | 57  | -   | mW      |
| 16.384 MHz Digital Filter Clock             | $PWR_{16}$ | -   | 85  | -   | mW      |
| <b>Standby Power Consumption</b>            |            |     |     |     |         |
| 32 kHz Digital Filter Clock, Filter Stopped | $PWR_S$    | -   | 40  | -   | $\mu W$ |

## SWITCHING CHARACTERISTICS

### SPI 1 Interface Timing (External Master)

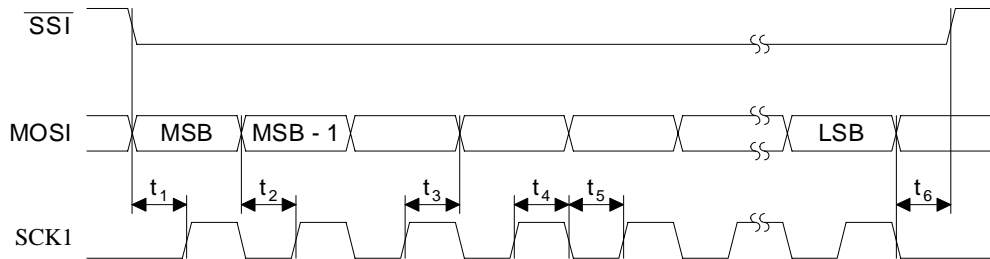


Figure 4. MOSI Write Timing in SPI Slave Mode

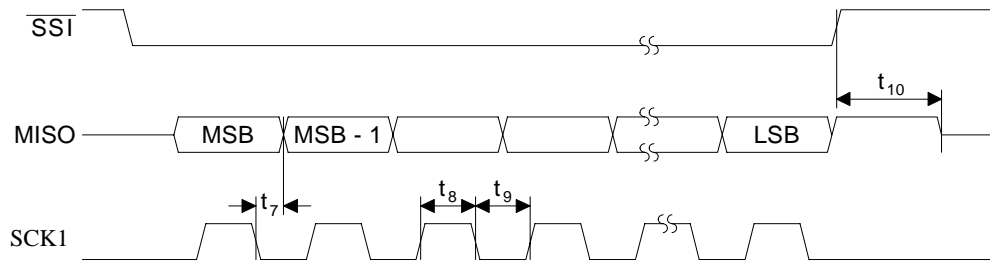


Figure 5. MISO Read Timing in SPI Slave Mode

| Parameter                             | Symbol   | Min | Typ | Max | Unit |
|---------------------------------------|----------|-----|-----|-----|------|
| <b>MOSI Write Timing</b>              |          |     |     |     |      |
| SS1 Enable to Valid Latch Clock       | $t_1$    | 60  | -   | -   | ns   |
| Data Set-up Time Prior to SCK1 Rising | $t_2$    | 60  | -   | -   | ns   |
| Data Hold Time After SCK1 Rising      | $t_3$    | 120 | -   | -   | ns   |
| SCK1 High Time                        | $t_4$    | 120 | -   | -   | ns   |
| SCK1 Low Time                         | $t_5$    | 120 | -   | -   | ns   |
| SCK1 Falling Prior to SS1 Disable     | $t_6$    | 60  | -   | -   | ns   |
| <b>MISO Read Timing</b>               |          |     |     |     |      |
| SCK1 Falling to New Data Bit          | $t_7$    | -   | -   | 200 | ns   |
| SCK1 High Time                        | $t_8$    | 120 | -   | -   | ns   |
| SCK1 Low Time                         | $t_9$    | 120 | -   | -   | ns   |
| SS1 Rising to MISO Hi-Z               | $t_{10}$ | -   | -   | 150 | ns   |

## SWITCHING CHARACTERISTICS

### Serial Data Port (SD Port)

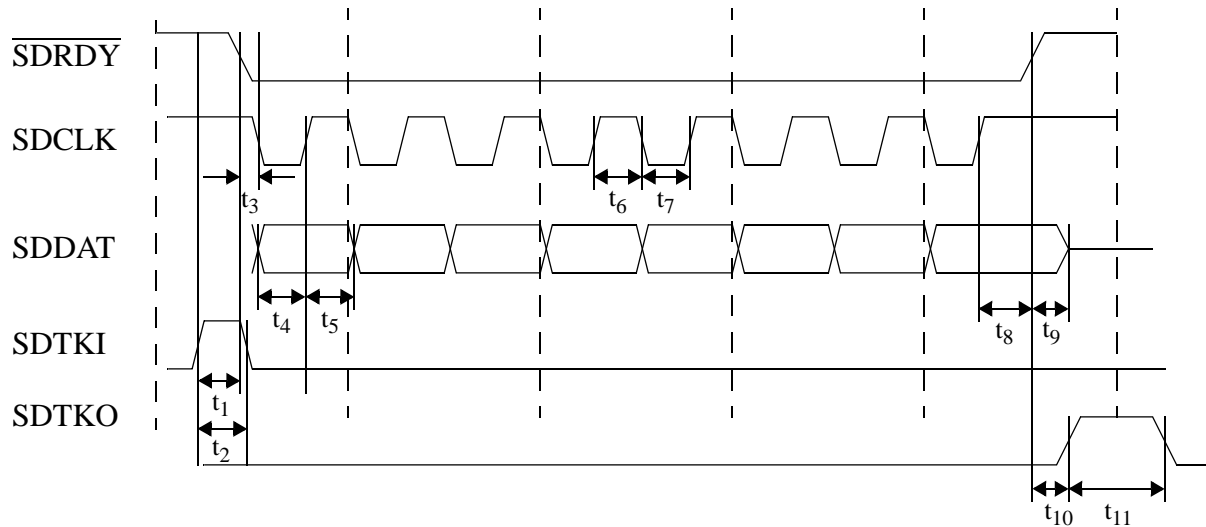


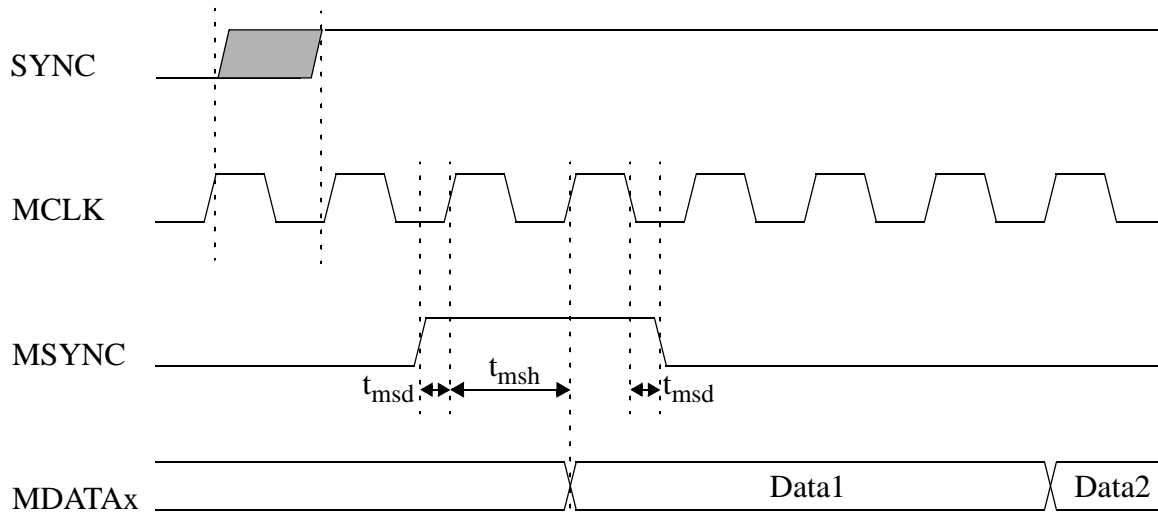
Figure 6. SD Port Read Timing

| Parameter                                | Symbol   | Min | Typ | Max  | Unit |
|--|----------|-----|-----|------|------|
| SDTKI to SDRDY Falling Edge              | $t_1$    | 60  | -   | -    | ns   |
| SDTKI High Time Width                    | $t_2$    | 60  | -   | 1000 | ns   |
| SDRDY Falling Edge to SDCLK Falling Edge | $t_3$    | 50  | -   | -    | ns   |
| Data Setup Time Prior to SDCLK Rising    | $t_4$    | 60  | -   | -    | ns   |
| Data Hold Time After SDCLK Rising        | $t_5$    | 60  | -   | -    | ns   |
| SDCLK High Time                          | $t_6$    | 120 | -   | -    | ns   |
| SDCLK Low Time                           | $t_7$    | 120 | -   | -    | ns   |
| SDCLK Rising to SDRDY Rising             | $t_8$    | 60  | -   | -    | ns   |
| Data Hold Time After SDRDY Rising        | $t_9$    | -   | -   | 150  | ns   |
| SDRDY High to SDTKO Rising Edge          | $t_{10}$ | -   | -   | 60   | ns   |
| SDTKO High Time                          | $t_{11}$ | 90  | -   | -    | ns   |



## SWITCHING CHARACTERISTICS

*CLK, SYNC, MCLK, MSYNC, and MDATAx*



Note: SYNC input latched on MCLK rising edge. MSYNC output triggered by MCLK falling edge.

| $f_{MCLK}$               | 2.048 MHz          | 1.024 MHz          |
|--------------------------|--------------------|--------------------|
| $t_{msd} = T_{MCLK} / 4$ | $t_{msd} = 122$ ns | $t_{msd} = 244$ ns |
| $t_{msh} = T_{MCLK}$     | $t_{msh} = 488$ ns | $t_{msh} = 976$ ns |

**Figure 7. SYNC, MCLK, MSYNC, MDATA Interface Timing**

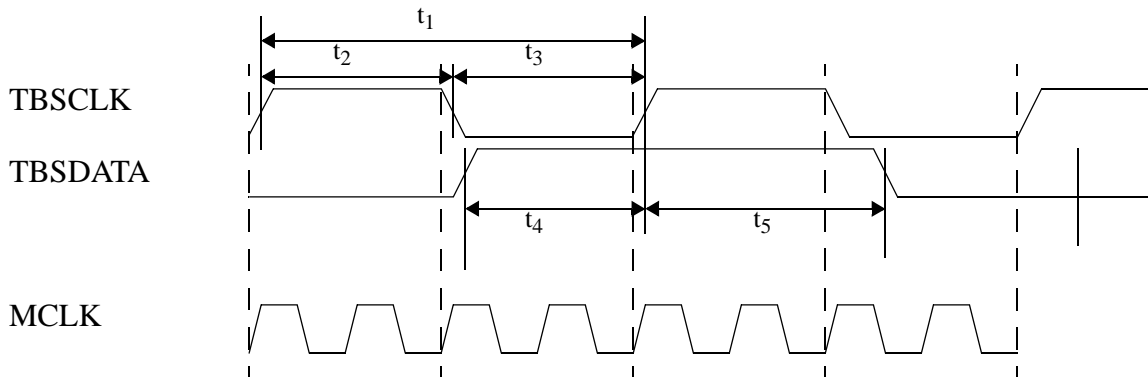
| Parameter                                  | Symbol     | Min | Typ    | Max | Unit    |
|--|------------|-----|--------|-----|---------|
| Master Clock Frequency (Note 3)            | CLK        | 32  | 32.768 | 33  | MHz     |
| Master Clock Duty Cycle                    | DTY        | 40  | -      | 60  | %       |
| Master Clock Rise Time                     | $t_{RISE}$ | -   | -      | 20  | ns      |
| Master Clock Fall Time                     | $t_{FALL}$ | -   | -      | 20  | ns      |
| Master Clock Jitter                        | JTR        | -   | -      | 300 | ps      |
| Synchronization after SYNC rising (Note 4) | SYNC       | -2  | -      | 2   | $\mu$ s |
| MSYNC Setup Time to MCLK rising            | $t_{msr}$  | 20  | -      | -   | ns      |
| MCLK rising to Valid MDATA                 | $t_{mdv}$  | -   | -      | 75  | ns      |
| MSYNC falling to MCLK rising               | $t_{msf}$  | 20  | -      | -   | ns      |

Notes: 3. Master clock frequencies above or below 32.768 MHz will affect generated clock frequencies.

4. Sampling synchronization between multiple CS5376A devices receiving identical SYNC signals.

## SWITCHING CHARACTERISTICS

### Test Bit Stream (TBS)

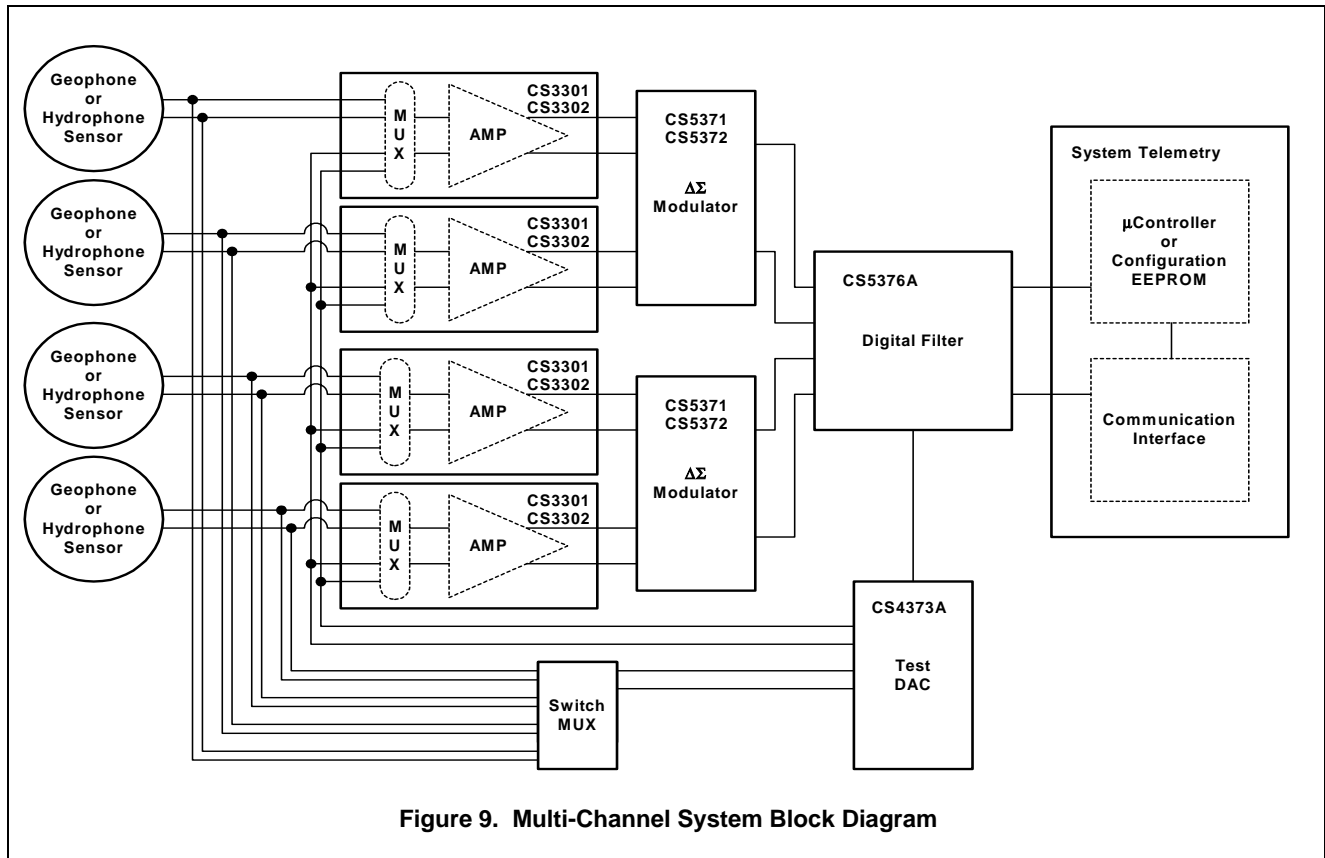


Note: Example timing shown for a 256 kHz output rate and no programmable delays.

**Figure 8. TBS Output Clock and Data Timing**

| Parameter   | Symbol | Min | Typ   | Max | Unit          |
|---|--------|-----|-------|-----|---------------|
| <b>TBS Clock Timing</b>                                 |        |     |       |     |               |
| TBS Clock Period  | $t_1$  | -   | 3.906 | -   | $\mu\text{s}$ |
| TBS Clock High Time (Note 5)                            | $t_2$  | 40  | -     | 60  | %             |
| TBS Clock Low Time                                      | $t_3$  | 40  | -     | 60  | %             |
| <b>TBS Data Output Timing</b>                           |        |     |       |     |               |
| TBS Data Bit Rate                                       |        | -   | 256   | -   | kbps          |
| TBS Data Rising to TBS Clock Rising Setup Time          | $t_4$  | 60  | -     | -   | ns            |
| TBS Clock Rising to TBS Data Falling Hold Time (Note 6) | $t_5$  | 60  | -     | -   | ns            |

5. TBSCLK phase can be delayed in 1/8 increments. The timing diagram shows no TBSCLK delay.
6. TBSDATA can be delayed from 0 to 63 full bit periods. The timing diagram shows no TBSDATA delay.



### 3. SYSTEM DESIGN WITH CS5376A

Figure 9 illustrates a simplified block diagram of the CS5376A in a multi-channel measurement system.

Up to four differential sensors are connected through CS3301/02 differential amplifiers to the CS5371/72  $\Delta\Sigma$  modulators, where analog to digital conversion occurs. Each modulators 1-bit output connects to a CS5376A MDATA input, where the oversampled  $\Delta\Sigma$  data is decimated and filtered to 24-bit output samples at a programmed output rate. These output samples are buffered in an 8-deep data FIFO and passed to the system telemetry on command.

System self tests are performed by connecting the CS5376A test bit stream (TBS) generator to the CS4373A test DAC. Analog tests drive differential signals from the CS4373A test DAC into the multiplexed inputs of the CS3301/02 amplifiers or di-

rectly to the sensors through external analog switches. Digital loopback tests internally connect the TBS digital output directly to the CS5376A modulator inputs.

#### 3.1 Power Supplies

The multi-channel system shown in Figure 9 typically operates from a  $\pm 2.5$  V analog power supply and a 3.3 V digital power supply. The CS5376A logic core can be powered from 3 V to minimize power consumption, if required.

#### 3.2 Reset Control

System reset is required only for the CS5376A device, and is a standard active low signal that can be generated by a power supply monitor or microcontroller. Other system devices default to a power-down state when the CS5376A is reset.

### 3.3 Clock Generation

A single 32.768 MHz low-jitter clock input, which can be generated from a VCXO based PLL, is required to drive the CS5376A device. Clock inputs for other system devices are driven by clock outputs from the CS5376A.

### 3.4 Synchronization

Digital filter phase and analog sample timing of the four  $\Delta\Sigma$  modulators connected to the CS5376A are synchronized by a rising edge on the SYNC pin. If a synchronization signal is received identically by all CS5376A devices in a measurement network, synchronous sampling across the network is guaranteed.

### 3.5 System Configuration

Through the SPI 1 serial port, filter coefficients and digital filter register settings can either be programmed by a microcontroller or automatically loaded from an external EEPROM after reset. System configuration is only required for the CS5376A device, as other devices are configured via the CS5376A General Purpose I/O pins.

Two registers in the digital filter, SYSTEM1 and SYSTEM2 (0x2C, 0x2D), are provided for user defined system information. These are general purpose registers that will hold any 24-bit data values written to them.

### 3.6 Digital Filter Operation

After analog to digital conversion occurs in the modulators, the oversampled 1-bit  $\Delta\Sigma$  data is read into the CS5376A through the MDATA pins. The digital filter then processes data through the enabled filter stages, decimating it to 24-bit words at a programmed output word rate. The final 24-bit samples are concatenated with 8-bit status words and placed into an output FIFO.

### 3.7 Data Collection

Data is collected from the CS5376A through the Serial Data port (SD port). Automatically or upon request, depending how the SDTKI pin is connected, the SD port initiates serial transactions to transfer 32-bit data from the output FIFO to the system telemetry. The output FIFO has eight data locations to permit latency in data collection.

### 3.8 Integrated peripherals

#### ***Test Bit Stream (TBS)***

A digital signal generator built into the CS5376A produces a 1-bit  $\Delta\Sigma$  sine wave or impulse function. This digital test bit stream can be connected to the CS4373A test DAC to create high quality analog test signals or it can be internally looped back to the CS5376A MDATA inputs to test the digital filter and data collection circuitry.

#### ***Time Break***

Timing information is recorded during data collection by strobing the TIMEB pin. A dedicated flag in the sample status bits, TB, is set high to indicate over which measurement the timing event occurred.

#### ***General Purpose I/O (GPIO)***

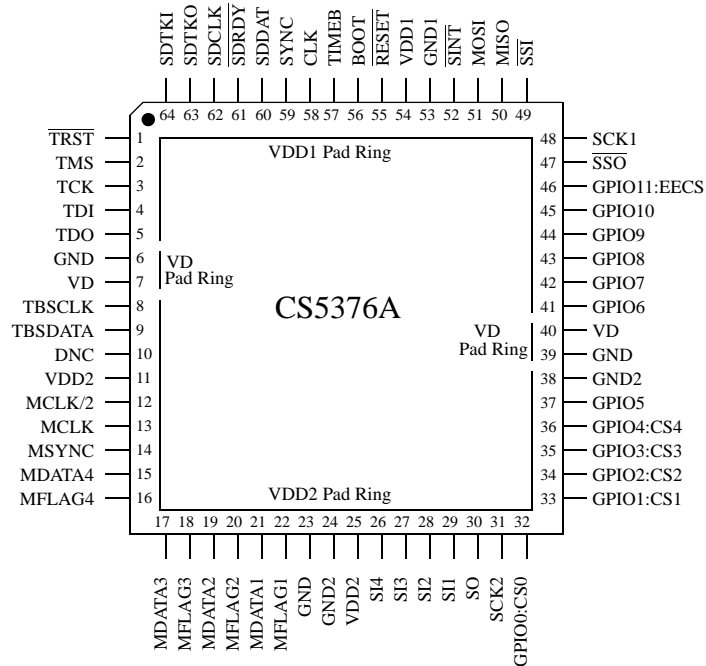
Twelve general purpose pins are available on the CS5376A for system control. Each pin can be set as input or output, high or low, with an internal pull-up enabled or disabled. The CS3301/02, CS5371/72 and CS4373A devices in Figure 9 are configured by simple pin settings controlled through the CS5376A GPIO pins.

#### ***Serial Peripheral Interface 2 (SPI 2)***

A secondary master mode serial port to communicate with external serial peripherals.

#### ***JTAG Port***

Boundary scan JTAG is IEEE 1149.1 compliant.



**Figure 10. Power Supply Block Diagram**

## 4. POWER SUPPLIES

The CS5376A has three sets of power supply inputs. Two sets supply power to the I/O pins of the device (VDD1, VDD2), and the third supplies power to the logic core (VD). The I/O pin power supplies determine the maximum input and output voltages when interfacing to peripherals, and the logic core power supply largely determines the power consumption of the CS5376A.

### 4.1 Pin Descriptions

#### **VDD1, GND1 - Pins 54,53**

Sets the interface voltage to a microcontroller and system telemetry. Can be driven with voltages from 3.3 V to 5 V.

VDD1 powers pins 1-5 and 41-64:

$\overline{\text{TRST}}$ , TMS, TCK, TDI, TDO

GPIO6 - GPIO11:EECS

$\overline{\text{SSO}}$ , SCK1,  $\overline{\text{SSI}}$ , MISO, MOSI,  $\overline{\text{SINT}}$ ,

$\overline{\text{RESET}}$ , BOOT, TIMEB, CLK, SYNC

SDDAT,  $\overline{\text{SDRDY}}$ , SDCLK, SDTKO, SDTKI

#### **VDD2, GND2 - Pins 11, 25, 24, 38**

Sets the interface voltage to the modulators, test DAC, and serial peripherals. Can be driven with voltages from 3.3 V to 5 V.

VDD2 powers pins 8-37:

TBSCLK, TBSDATA

MCLK/2, MCLK, MSYNC

MDATA1 - MDATA4

MFLAG1 - MFLAG4

SI1 - SI4, SO, SCK2

GPIO0:CS0 - GPIO5

**VD, GND - Pins 7, 40, 6, 23, 39**

Sets the operational voltage of the CS5376A logic core. Can be driven with voltages from 3 V to 5 V. A 3 V supply minimizes total power consumption.

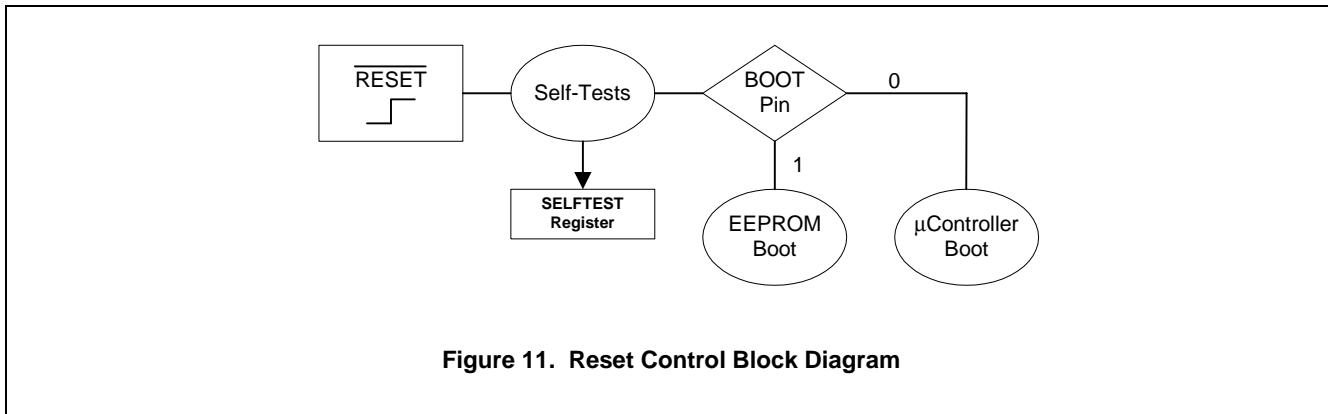
**4.2 Bypass Capacitors**

Each power supply pin should be bypassed with parallel 1  $\mu$ F and 0.01  $\mu$ F caps, or by a single 0.1  $\mu$ F cap, placed as close as possible to the CS5376A. Bypass capacitors should be ceramic

(X7R, C0G), tantalum, or other good quality dielectric type.

**4.3 Power Consumption**

Power consumption of the CS5376A depends primarily on the power supply voltage of the logic core (VD) and the programmed digital filter clock rate. Digital filter clock rates are selected based on the required output word rate as explained in “Digital Filter Initialization” on page 41.



**Figure 11. Reset Control Block Diagram**

## 5. RESET CONTROL

The CS5376A reset signal is active low. When released, a series of self-tests are performed and the device either actively boots from an external EEPROM or enters an idle state waiting for microcontroller configuration.

### 5.1 Pin Descriptions

#### **RESET - Pin 55**

Reset input, active low.

#### **BOOT - Pin 56**

Boot mode select, latched following a **RESET** rising edge.

BOOT = 1 = EEPROM boot

BOOT = 0 = Microcontroller boot

### 5.2 Reset Self-Tests

After **RESET** is released but before booting, a series of digital filter self-tests are run. Results are

| Self-Test Type | Pass Code | Fail Code |
|----------------|-----------|-----------|
| Program ROM    | 0x00000A  | 0x00000F  |
| Data ROM       | 0x0000A0  | 0x0000F0  |
| Program RAM    | 0x000A00  | 0x000F00  |
| Data RAM       | 0x00A000  | 0x00F000  |
| Execution Unit | 0x0A0000  | 0x0F0000  |

combined into the SELFTEST register (0x2F), with 0x0AAAAA indicating all passed. Self-tests require 60 ms to complete, after which configuration commands are serviced.

### 5.3 Boot Configurations

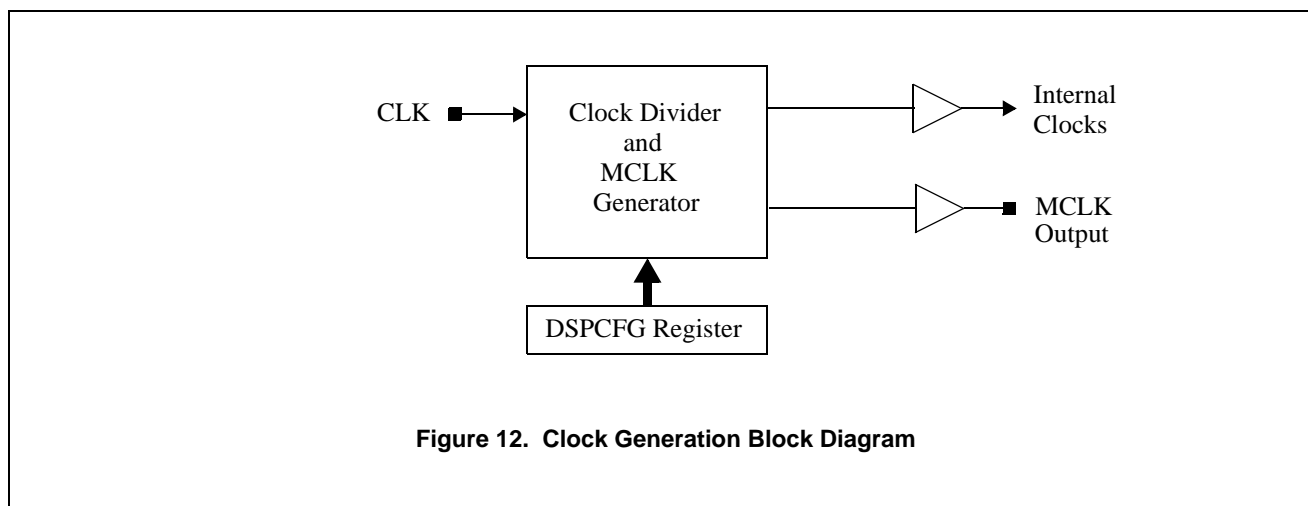
The logic state of the BOOT pin after reset determines if the CS5376A actively reads configuration information from EEPROM or enters an idle state waiting for a microcontroller to write configuration commands.

#### **EEPROM Boot**

When the BOOT pin is high after reset, the CS5376A actively reads data from an external serial EEPROM and then begins operation in the specified configuration. Configuration commands and data are encoded in the EEPROM as specified in the 'Configuration By EEPROM' section of this data sheet, starting on page 26.

#### **Microcontroller Boot**

When the BOOT pin is low after reset, the CS5376A enters an idle state waiting for a microcontroller to write configuration commands and initialize filter operation. Configuration commands and data are written as specified in the 'Configuration By Microcontroller' section of this data sheet, starting on page 32.



**Figure 12. Clock Generation Block Diagram**

## 6. CLOCK GENERATION

The CS5376A requires a 32.768 MHz master clock input, which is used to generate internal digital filter clocks and external modulator clocks.

### 6.1 Pin Description

#### **CLK - Pin 58**

Clock input, nominal frequency 32.768 MHz.

### 6.2 Synchronous Clocking

To guarantee synchronous measurements throughout a sensor network, the CS5376A master clock should be distributed to arrive at all nodes in phase. The 32.768 MHz master clock can either be directly distributed through the system telemetry, or reconstructed locally using a VCXO based PLL. To

ensure recovered clocks have identical phase, system PLL designs should use a phase/frequency detector architecture.

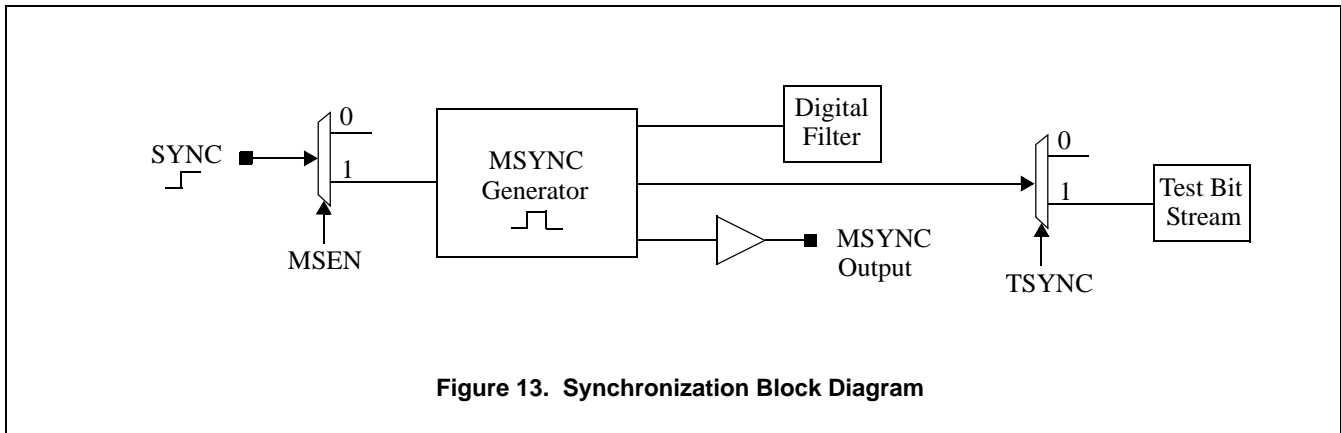
### 6.3 Master Clock Jitter and Skew

Care must be taken to minimize jitter and skew in the received master clock as both parameters affect measurement performance.

Jitter in the master clock causes jitter in the generated modulator clocks, resulting in sample timing errors and increased noise.

Skew in the master clock from node to node creates a sample timing offset, resulting in systematic measurement errors in the reconstructed signal.





**Figure 13. Synchronization Block Diagram**

## 7. SYNCHRONIZATION

The CS5376A has a dedicated SYNC input that aligns the internal digital filter phase and generates an external signal for synchronizing modulator analog sampling. By providing simultaneous rising edges to the SYNC pins of multiple CS5376A devices, synchronous sampling across a network can be guaranteed.

### 7.1 Pin Description

#### **SYNC - Pin 59**

Synchronization input, rising edge triggered.

### 7.2 MSYNC Generation

The SYNC signal rising edge is used to generate a retimed synchronization signal, MSYNC. The MSYNC signal reinitializes internal digital filter phase and is driven onto the MSYNC output pin to phase align modulator analog sampling.

The MSEN bit in the digital filter CONFIG register (0x00) enables MSYNC generation. See “Modulator Interface” on page 39 for more information about MSYNC.

### 7.3 Digital Filter Synchronization

The internal MSYNC signal resets the digital filter state machine to establish a known digital filter

phase. Filter convolutions restart, and the next output word is available one full sample period later.

Repetitive synchronization is supported when SYNC events occur at exactly the selected output word rate. In this case, re-synchronization occurs at the start of a convolution cycle when the digital filter state machine is already reset.

### 7.4 Modulator Synchronization

The external MSYNC signal phase aligns modulator analog sampling when connected to the CS5371/72 MSYNC input. This ensures synchronous analog sampling relative to MCLK.

Repetitive synchronization of the modulators is supported when SYNC events occur at exactly the selected output word rate. In this case, synchronization will occur at the start of analog sampling.

### 7.5 Test Bit Stream Synchronization

When the test bit stream generator is enabled, an MSYNC signal can reset the internal data pointer. This restarts the test bit stream from the first data point to establish a known output signal phase.

The TSYNC bit in the digital filter TBSCFG register (0x2A) enables synchronization of the test bit stream by MSYNC. When TSYNC is disabled, the test bit stream phase is not affected by MSYNC.

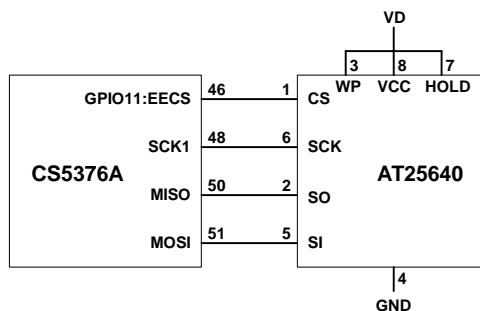


Figure 14. EEPROM Configuration Block Diagram

## 8. CONFIGURATION BY EEPROM

After reset, the CS5376A reads the state of the BOOT pin to determine a source for configuration commands. If BOOT is high, the CS5376A initiates serial transactions through the SPI 1 port to read configuration information from an external EEPROM.

### 8.1 Pin Descriptions

Pins required for EEPROM boot are listed here, other SPI 1 pins are inactive.

#### ***GPIO11:EECS - Pin 46***

EEPROM chip select output, active low.

#### ***SCK1 - Pin 48***

Serial clock output, nominally 1.024 MHz.

#### ***MOSI - Pin 51***

Serial data output pin. Valid on rising edge of SCK1, transition on falling edge.

#### ***MISO - Pin 50***

Serial data input pin. Valid on rising edge of SCK1, transition on falling edge.

### 8.2 EEPROM Hardware Interface

When booting from EEPROM the CS5376A SPI 1 port actively performs serial transactions, as shown

in Figure 15, to read configuration commands and data. 8-bit SPI opcodes and 16-bit addresses are combined to read back 8-bit configuration commands and 24-bit configuration data.

System design should include a connection to the configuration EEPROM for in-circuit reprogramming. The CS5376A SPI 1 pins go high impedance when inactive to support external connections to the serial bus.

### 8.3 EEPROM Organization

The boot EEPROM holds the 8-bit commands and 24-bit data required to initialize the CS5376A into an operational state. Configuration information starts at memory location 0x10, with addresses 0x00 to 0x0F free for use as manufacturing header information.

The first serial transaction reads a 1-byte command from memory location 0x10 and then, depending on the command type, reads multiple 3-byte data words to complete the command. Command and data reads continue until the ‘Filter Start’ command is recognized.

The maximum number of bytes that can be written for a single configuration is approximately

| Instruction | Opcode | Address    | Definition  |
|-------------|--------|------------|---|
| Read        | 0x03   | ADDR[15:0] | Read data beginning at the address given in ADDR. |

### SPI 1 Read from EEPROM

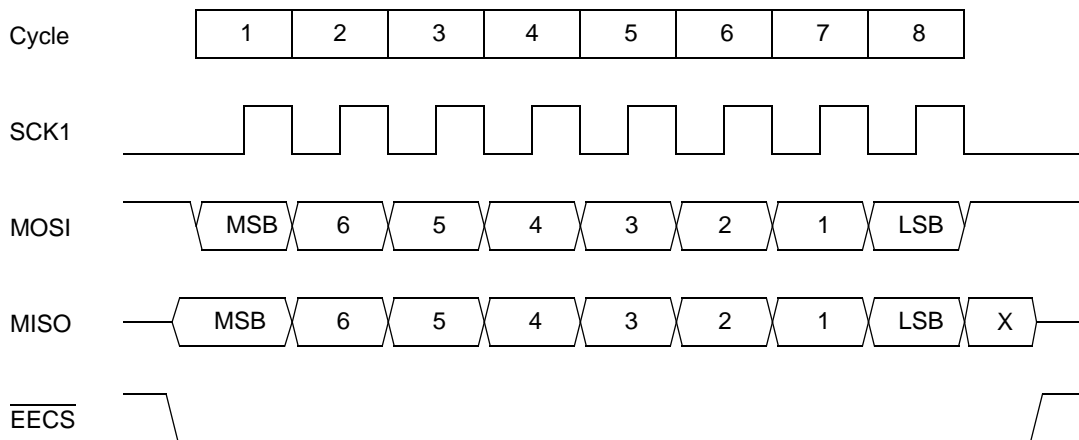
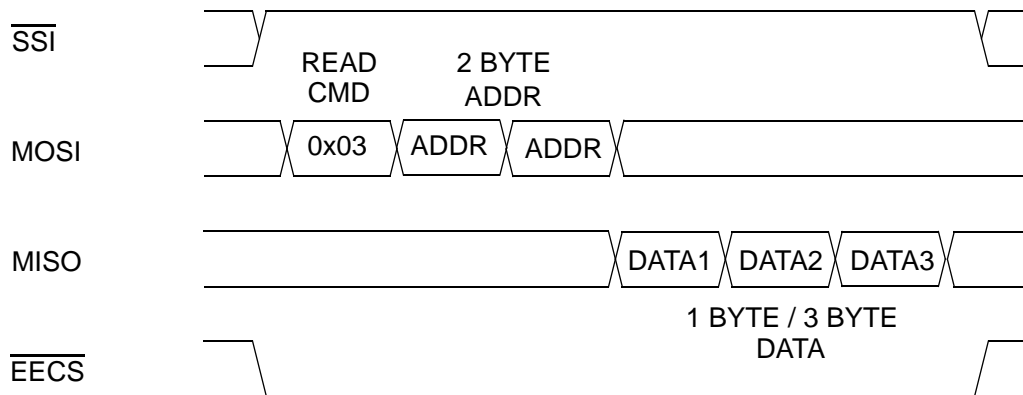
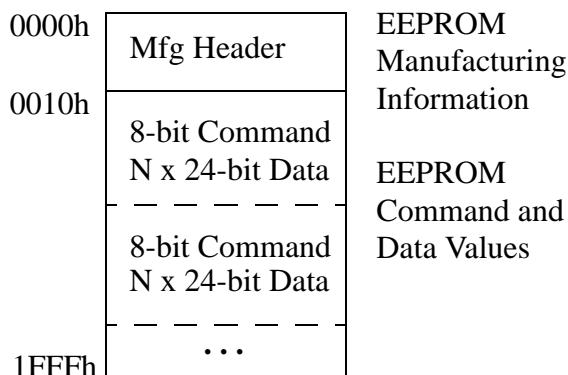


Figure 15. SPI 1 EEPROM Read Transactions



**Figure 16. 8 Kbyte EEPROM Memory Organization**

5 KByte (40 Kbit), which includes command overhead:

| Memory Requirement            | Bytes       |
|-------------------------------|-------------|
| Digital Filter Registers (22) | 154         |
| FIR Coefficients (255+255)    | 1537        |
| IIR Coefficients (3+5)        | 25          |
| Test Bit Stream Data (1024)   | 3076        |
| 'Filter Start' Command        | 1           |
| <b>Total Bytes</b>            | <b>4793</b> |

**Table 4. Maximum EEPROM Configuration**

Supported serial configuration EEPROMs are SPI mode 0 (0,0) compatible, 16-bit addresses, 8-bit data, larger than 5 KByte (40 Kbit). ATMEL AT25640, AT25128, or similar serial EEPROMs are recommended.

## 8.4 EEPROM Configuration Commands

A summary of available EEPROM commands is shown in Table 5.

### Write DF Register - 0x01

This EEPROM command writes a data value to the specified digital filter register. Digital filter registers control hardware peripherals and filtering functions. See “Digital Filter Registers” on page 87 for the bit definitions of the digital filter registers.

#### Sample Command:

Write digital filter register 0x00 with data value 0x070431. Then write 0x20 with data 0x000240.

```
01 00 00 00 07 04 31
```

```
01 00 00 20 00 02 40
```

### Write FIR Coefficients - 0x02

This EEPROM command writes custom coefficients for the FIR1 and FIR2 filters. The first two data words set the number of FIR1 and FIR2 coefficients to be written. The remaining data words are the concatenated FIR1 and FIR2 coefficients.

A maximum of 255 coefficients can be written for each FIR filter, though the available digital filter computation cycles will limit their practical size. See “FIR Filter” on page 47 for more information about FIR filter coefficients.

#### Sample Command:

Write FIR1 coefficients 0x00022E, 0x000771 then FIR2 coefficients 0xFFFFB9, 0xFFFE8D.

```
02 00 00 02 00 00 02
```

```
00 02 2E 00 07 71 FF FF B9 FF FE 8D
```

### Write IIR Coefficients - 0x03

This EEPROM command writes custom coefficients for the two stage IIR filter. The IIR architecture and number of coefficients is fixed, so eight data words containing coefficient values always immediately follow the command byte. The IIR coefficient write order is: a11, b10, b11, a21, a22, b20, b21, and b22. See “IIR Filter” on page 55 for more information about IIR filter coefficients.

**Sample Command:**

Write IIR1 coefficients 0x84BC9D, 0x7DA1B1, 0x825E4F, and IIR2 coefficients 0x83694F, 0x3CAD5F, 0x3E5104, 0x835DF8, 0x3E5104.

03

84 BC 9D 7D A1 B1 82 5E 4F 83 69 4F

3C AD 5F 3E 51 04 83 5D F8 3E 51 04

**Write ROM Coefficients - 0x04**

This EEPROM command selects the on-chip coefficients for the FIR1, FIR2, IIR 1st order, and IIR 2nd order filters for use by the digital filter. One data word is required to select which internal coefficient sets to use. See “Filter Coefficient Selection” on page 41 for information about selecting on-chip FIR and IIR coefficient sets.

**Sample Command:**

Select IIR1 and IIR2 3 Hz @ 500 SPS low-cut coefficients, with FIR1 and FIR2 linear phase high-cut coefficients. Data word 0x002200.

04 00 22 00

**Write TBS Data - 0x05**

This EEPROM command writes a custom data set for the test bit stream (TBS) generator. This command, along with the ability to program the test bit stream generator interpolation and clock rate, can create custom frequency test signals.

The first data word sets the number of TBS data to be written and the remaining data words are the TBS data values. See “Test Bit Stream Generator” on page 64 for information about using custom test bit stream data sets.

| Name                   | CMD 8-bit | DATA 24-bit  | Description                       |
|------------------------|-----------|--|-----------------------------------|
| NOP                    | 00        | -  | No Operation                      |
| WRITE DF REGISTER      | 01        | REG DATA   | Write Digital Filter Register     |
| WRITE FIR COEFFICIENTS | 02        | NUM FIR1<br>NUM FIR2<br>(FIR COEF)                   | Write Custom FIR Coefficients     |
| WRITE IIR COEFFICIENTS | 03        | a11<br>b10<br>b11<br>a21<br>a22<br>b20<br>b21<br>b22 | Write Custom IIR Coefficients     |
| WRITE ROM COEFFICIENTS | 04        | COEF SEL   | Use On-Chip Coefficients          |
| WRITE TBS DATA         | 05        | NUM TBS<br>(TBS DATA)                                | Write Custom Test Bit Stream Data |
| WRITE ROM TBS          | 06        | -  | Use On-Chip TBS Data              |
| FILTER START           | 07        | -  | Start Digital Filter Operation    |

(DATA) indicates multiple words of this type are to be written.

**Table 5. EEPROM Boot Configuration Commands**

**Sample Command:**

Write test bit stream data 0x000000, 0x0007DA, 0x000FB5, 0x00178F.

05 00 00 04

00 00 00 00 07 DA 00 0F B5 00 17 8F

**Write TBS ROM Data - 0x06**

This EEPROM command selects the on-chip test bit stream (TBS) data for use by the TBS generator. No data words are required for this EEPROM command. See “Test Bit Stream Generator” on page 64 for more information about the on-chip test bit stream data set.

**Sample Command:**

06

**Filter Start - 0x07**

This EEPROM command initializes and starts the digital filter. Measurement data becomes available one full sample period after this command is received. No data words are required for this EEPROM command.

**Sample Command:**

07

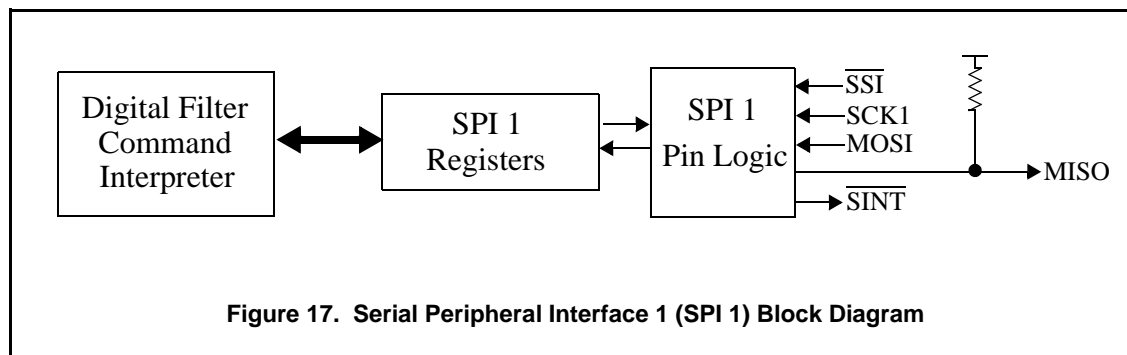
## 8.5 Example EEPROM Configuration

Table 6 shows an example EEPROM file for a minimal CS5376A configuration.

| Addr | Data | Description            |
|------|------|------------------------|
| 00   | 00   | Mfg header             |
| 01   | 00   |                        |
| 02   | 00   |                        |
| 03   | 00   |                        |
| 04   | 00   |                        |
| 05   | 00   |                        |
| 06   | 00   |                        |
| 07   | 00   |                        |
| 08   | 00   |                        |
| 09   | 00   |                        |
| 0A   | 00   |                        |
| 0B   | 00   |                        |
| 0C   | 00   |                        |
| 0D   | 00   |                        |
| 0E   | 00   |                        |
| 0F   | 00   |                        |
| 10   | 04   | Write ROM Coefficients |
| 11   | 00   |                        |
| 12   | 22   |                        |
| 13   | 00   |                        |
| 14   | 06   | Write TBS ROM Data     |
| 15   | 01   | Write CONFIG Register  |
| 16   | 00   |                        |
| 17   | 00   |                        |
| 18   | 00   |                        |
| 19   | 07   |                        |
| 1A   | 04   |                        |
| 1B   | 31   |                        |
| 1C   | 01   | Write FILTCFG Register |
| 1D   | 00   |                        |
| 1E   | 00   |                        |
| 1F   | 20   |                        |

| Addr | Data | Description            |
|------|------|------------------------|
| 20   | 00   |                        |
| 21   | 02   |                        |
| 22   | 40   |                        |
| 23   | 01   | Write TBSCFG Register  |
| 24   | 00   |                        |
| 25   | 00   |                        |
| 26   | 2A   |                        |
| 27   | 07   |                        |
| 28   | 40   |                        |
| 29   | 40   |                        |
| 2A   | 01   | Write TBSGAIN Register |
| 2B   | 00   |                        |
| 2C   | 00   |                        |
| 2D   | 2B   |                        |
| 2E   | 04   |                        |
| 2F   | B0   |                        |
| 30   | 00   |                        |
| 31   | 07   | Filter Start           |

**Table 6. Example EEPROM File**



## 9. CONFIGURATION BY MICROCONTROLLER

After reset, the CS5376A reads the state of the BOOT pin to determine a source for configuration commands. If BOOT is low, the CS5376A receives configuration commands from a microcontroller.

### 9.1 Pin Descriptions

Pins required for microcontroller boot are listed here, other SPI 1 pins are inactive.

#### ***SSI - Pin 49***

Slave select input pin, active low. Serial chip select input from a microcontroller.

#### ***SCK1 - Pin 48***

Serial clock input pin. Serial clock input from microcontroller, maximum 4.096 MHz.

#### ***MOSI - Pin 51***

Serial data input pin. Valid on rising edge of SCK1, transition on falling edge.

#### ***MISO - Pin 50***

Serial data output pin. Valid on rising edge of SCK1, transition on falling edge. Open drain output requiring a 10 kΩ pull-up resistor.

#### ***SINT - Pin 52***

Serial interrupt output pin, active low. 1 uS active low pulse output when ready for next serial transaction.

### 9.2 Microcontroller Hardware Interface

When booting from a microcontroller the CS5376A SPI 1 port receives configuration commands and configuration data through serial transactions, as shown in Figure 18. 8-bit SPI opcodes and 8-bit addresses are combined to read and write 24-bit configuration commands and data.

Microcontroller serial transactions require toggling the  $\overline{SSI}$  pin as the CS5376A chip select and writing a serial clock to the SCK1 input. Serial data is input to the CS5376A on the MOSI pin, and output from the CS5376A on the MISO pin.

### 9.3 Microcontroller Serial Transactions

Microcontroller configuration commands are written to the digital filter through the SPI 1 registers. A 24-bit command and two 24-bit data words can be written to the SPI 1 registers in any single serial transaction. Some commands require additional data words through additional serial transactions to complete.

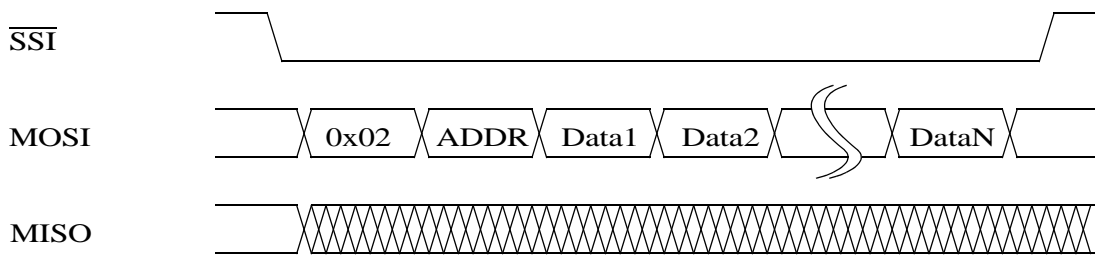
#### 9.3.1 SPI opcodes

A microcontroller communicates with the CS5376A SPI 1 port using standard 8-bit SPI opcodes and an 8-bit SPI address. The standard SPI ‘Read’ and ‘Write’ opcodes are listed in Figure 18.

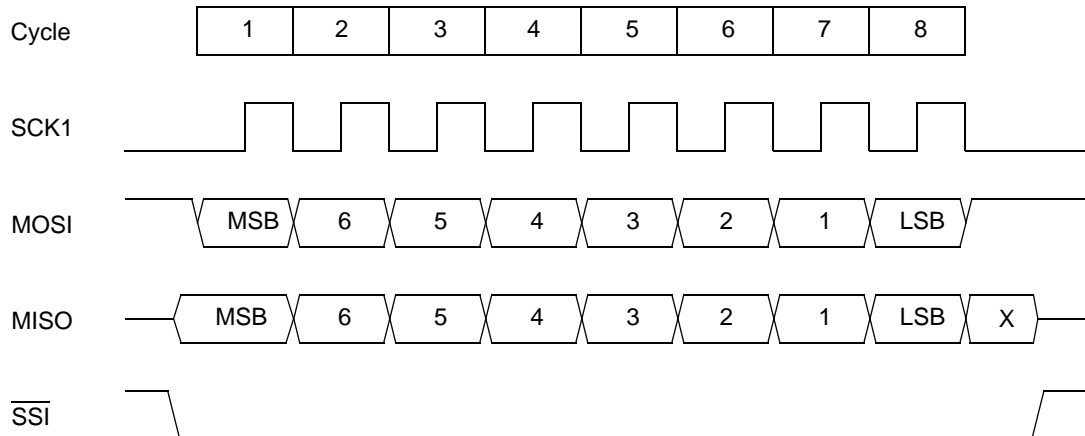
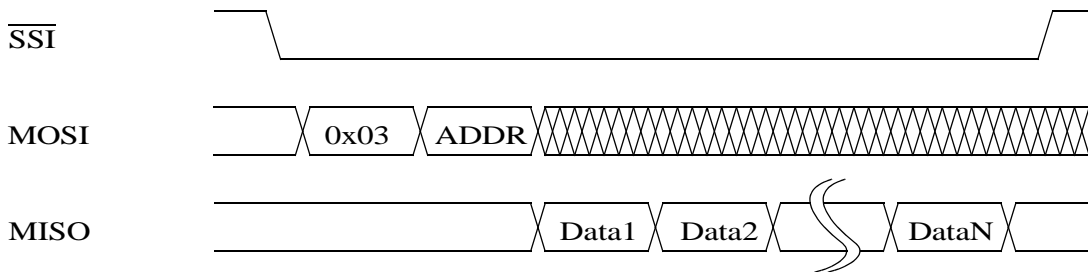


| Instruction | Opcode | Address   | Definition  |
|-------------|--------|-----------|---|
| Write       | 0x02   | ADDR[7:0] | Write SPI 1 registers beginning at the address in ADDR. |
| Read        | 0x03   | ADDR[7:0] | Read SPI 1 registers beginning at the address in ADDR.  |

### Microcontroller Write to SPI 1



### Microcontroller Read from SPI 1



**Figure 18. Microcontroller Serial Transactions**

### 9.3.2 SPI 1 registers

The SPI 1 registers are shown in Figure 19 and are 24-bit registers mapped into an 8-bit register space as high, mid, and low bytes. See “SPI 1 Registers” on page 82 for the bit definitions of the SPI 1 registers.

### 9.3.3 SPI 1 transactions

A serial transaction to the SPI 1 registers starts with an SPI opcode, followed by an address, and then some number of data bytes written or read starting at that address.

Typical serial write transactions require sending groups of 5, 8, or 11 total bytes to the SPI1CMD or SPI1DAT1 registers.

Example 5-byte write transaction to SPI1CMD

02 03 12 34 56

Example 5-byte write transaction to SPI1DAT1

02 06 12 34 56

Example 8-byte write transaction to SPI1CMD

02 03 12 34 56 AB CD EF

Example 8-byte write transaction to SPI1DAT1

02 06 12 34 56 AB CD EF

Example 11-byte write transaction to SPI1CMD

02 03 12 34 56 AB CD EF 65 43 21

Typical serial read transactions require groups of 3 or 5 bytes, split between writing into MOSI and reading from MISO.

3-byte read transaction of mid-byte of SPI1CTRL

MOSI: 03 01 00

MISO: xx xx 12

5-byte read transaction of SPI1DAT1

MOSI: 03 06 00 00 00

MISO: xx xx 12 34 56

### 9.3.4 Multiple serial transactions

Some configuration commands require multiple serial transactions to complete. There must be a small delay between transactions for the CS5376A to process the incoming data. Three methods can be used to ensure the CS5376A is ready to receive the next configuration command.

- 1) Delay a fixed 1 ms period to guarantee enough time for the command to be completed.
- 2) Monitor the  $\overline{\text{SINT}}$  pin for a 1 us active low pulse. This pulse output occurs once the CS5376A completes processing the current command.
- 3) Verify the status of the E2DREQ bit by reading the SPI1CTRL register. When low, the CS5376A is ready for the next command.

### 9.3.5 Polling E2DREQ

One transaction type that can always be performed no matter the delay from the previous configuration command is reading E2DREQ in the mid-byte of the SPI1CTRL register. A 3-byte read transaction.

MOSI: 03 01 00

MISO: xx xx 01 <- E2DREQ bit high

MISO: xx xx 00 <- E2DREQ bit low

| Name     | Addr.   | Type | # Bits  | Description   |
|----------|---------|------|---------|---------------|
| SPI1CTRL | 00 - 02 | R/W  | 8, 8, 8 | SPI 1 Control |
| SPI1CMD  | 03 - 05 | R/W  | 8, 8, 8 | SPI 1 Command |
| SPI1DAT1 | 06 - 08 | R/W  | 8, 8, 8 | SPI 1 Data 1  |
| SPI1DAT2 | 09 - 0B | R/W  | 8, 8, 8 | SPI 1 Data 2  |

Figure 19. SPI 1 Registers

The E2DREQ bit reads high while a configuration command is being processed. When low, the digital filter is ready to receive a new configuration command.

## 9.4 Microcontroller Configuration Commands

A summary of available microcontroller configuration commands is listed in Table 7.

### Write DF Register - 0x01

This configuration command writes a specified digital filter register. Digital filter registers control hardware peripherals and filtering functions. See “Digital Filter Registers” on page 87 for the bit definitions of the digital filter registers.

Sample Command:

Write digital filter register 0x00 with data value 0x070431. Then write 0x20 with data 0x000240.

02 03 00 00 01 00 00 00 07 04 31

Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

02 03 00 00 01 00 00 20 00 02 40

Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

### Read DF Register - 0x02

This command reads a specified digital filter register. The register value is requested in the first SPI transaction, with the register value copied to SPI1DAT1 and read in a subsequent SPI transaction.

Sample Command:

Read digital filter registers 0x00 and 0x20.

02 03 00 00 02 00 00 00

| Name                   | CMD 24-bit | DAT1 24-bit              | DAT2 24-bit              | Description                       |
|------------------------|------------|--------------------------|--------------------------|-----------------------------------|
| NOP                    | 000000     | -                        | -                        | No Operation                      |
| WRITE DF REGISTER      | 000001     | REG                      | DATA                     | Write Digital Filter Register     |
| READ DF REGISTER       | 000002     | REG<br>[DATA]            | -<br>-                   | Read Digital Filter Register      |
| WRITE FIR COEFFICIENTS | 000003     | NUM FIR1<br>(FIR COEF)   | NUM FIR2<br>(FIR COEF)   | Write Custom FIR Coefficients     |
| WRITE IIR COEFFICIENTS | 000004     | a11<br>b11<br>a22<br>b21 | b10<br>a21<br>b20<br>b22 | Write Custom IIR Coefficients     |
| WRITE ROM COEFFICIENTS | 000005     | COEF SEL                 | -                        | Use On-Chip Coefficients          |
| WRITE TBS DATA         | 000006     | NUM TBS<br>(TBS DATA)    | -<br>(TBS DATA)          | Write Custom Test Bit Stream Data |
| WRITE ROM TBS          | 000007     | -                        | -                        | Use On-Chip TBS Data              |
| FILTER START           | 000008     | -                        | -                        | Start Digital Filter Operation    |
| FILTER STOP            | 000009     | -                        | -                        | Stop Digital Filter Operation     |

[DATA] indicates data word returned from digital filter.

(DATA) indicates multiple words of this type are to be written.

Table 7. Microcontroller Boot Configuration Commands

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

MOSI: 03 06 00 00 00

MISO: xx xx 07 04 31

02 03 00 00 02 00 00 20

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

MOSI: 03 06 00 00 00

MISO: xx xx 00 02 40

### **Write FIR Coefficients - 0x03**

This command writes custom coefficients for the FIR1 and FIR2 filters. The first two data words set the number of FIR1 and FIR2 coefficients to be written. The remaining data words are the concatenated FIR1 and FIR2 coefficients.

A maximum of 255 coefficients can be written for each FIR filter, though the available digital filter computation cycles will limit their practical size. See “FIR Filter” on page 47 for more information about FIR filter coefficients.

Sample Command:

Write FIR1 coefficients 0x00022E, 0x000771 then FIR2 coefficients 0xFFFFB9, 0xFFFFE8D.

02 03 00 00 03 00 00 02 00 00 02

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

02 06 00 02 2E 00 07 71

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

02 06 FF FF B9 FF FE 8D

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

### **Write IIR Coefficients - 0x04**

This command writes custom coefficients for the two stage IIR filter. The IIR architecture and number of coefficients is fixed, so eight coefficient values immediately follow this command. The IIR coefficient write order is: a11, b10, b11, a21, a22, b20, b21, and b22. See “IIR Filter” on page 55 for more information about IIR filter coefficients.

Sample Command:

Write IIR1 coefficients 0x84BC9D, 0x7DA1B1, 0x825E4F, and IIR2 coefficients 0x83694F, 0x3CAD5F, 0x3E5104, 0x835DF8, 0x3E5104.

02 03 00 00 04 84 BC 9D 7D A1 B1

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

02 06 82 5E 4F 83 69 4F

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

02 06 3C AD 5F 3E 51 04

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

02 06 83 5D F8 3E 51 04

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

### **Write ROM Coefficients - 0x05**

This configuration command selects the on-chip coefficients for FIR1, FIR2, IIR 1st order, and IIR 2nd order filters for use by the digital filter. One data word is required to select which internal coefficient sets to use. See “Filter Coefficient Selection” on page 41 for information about selecting on-chip FIR and IIR coefficient sets.

Sample Command:

Select IIR1 and IIR2 3 Hz @ 500 SPS low-cut coefficients, with FIR1 and FIR2 linear phase high-cut coefficients. Data word 0x002200.

02 03 00 00 05 00 22 00

Delay 1 ms, monitor  $\overline{SINT}$ , or poll E2DREQ

### **Write TBS Data - 0x06**

This command writes a custom data set for the test bit stream (TBS) generator. This command, along with the ability to program the test bit stream generator interpolation and clock rate, can create custom frequency test signals.

The first data word sets the number of TBS data to be written and the remaining data words are the TBS data values. See “Test Bit Stream Generator”

on page 64 for information about using custom test bit stream data sets.

**Sample Command:**

Write test bit stream data 0x000000, 0x0007DA, 0x000FB5, 0x00178F.

02 03 00 00 06 00 00 04

Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

02 06 00 00 00 00 07 DA

Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

02 06 00 0F B5 00 17 8F

Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

**Write TBS ROM Data - 0x07**

This command selects the on-chip test bit stream (TBS) data for use by the TBS generator. No data words are required for this configuration command. See “Test Bit Stream Generator” on page 64 for information about the on-chip test bit stream data set.

**Sample Command:**

02 03 00 00 07

Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

**Filter Start - 0x08**

This command initializes and starts the digital filter. Measurement data becomes available one full sample period after this command is issued. No data words are required for this configuration command.

**Sample Command:**

02 03 00 00 08

Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

**Filter Stop - 0x09**

This command disables the digital filter. Measurement data output stops immediately after this command is issued. No data words are required for this configuration command.

**Sample Command:**

02 03 00 00 09

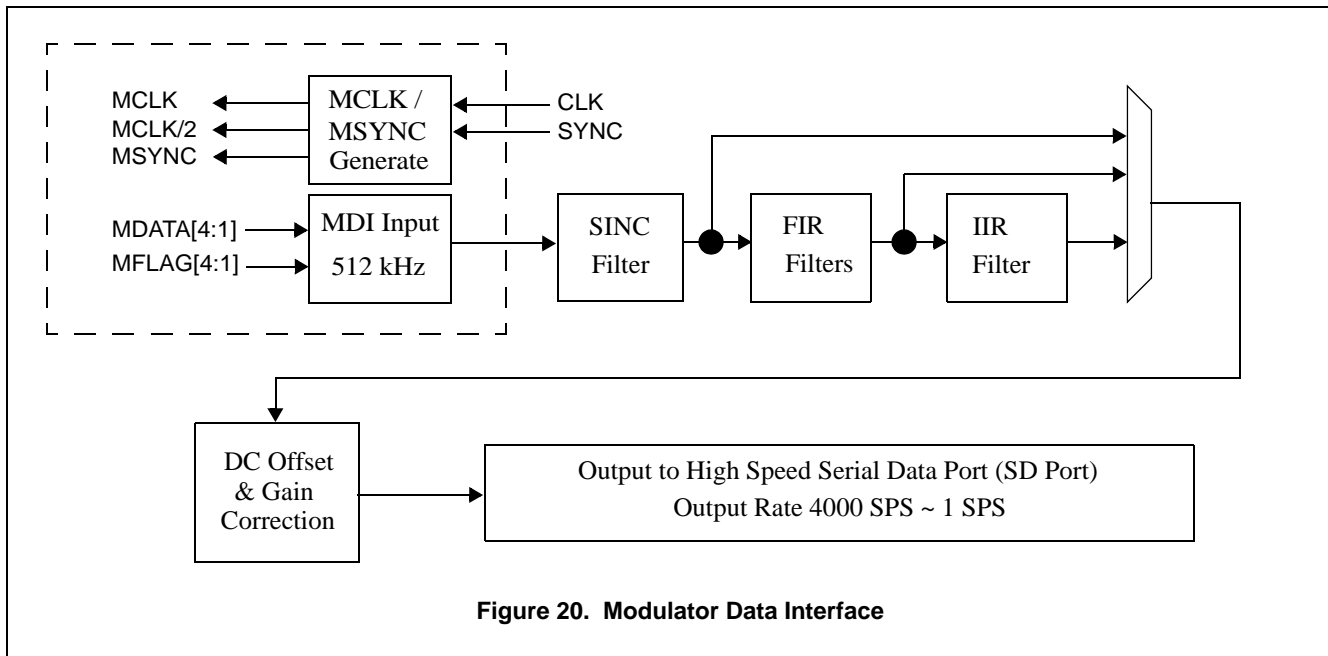
Delay 1 ms, monitor  $\overline{\text{SINT}}$ , or poll E2DREQ

## 9.5 Example Microcontroller Configuration

Table 6 shows example microcontroller transactions for a minimal CS5376A configuration.

| Transaction | SPI Data  | Description            |
|-------------|---|------------------------|
| 01          | 02 03 00 00 05 00 22 00                               | Write ROM coefficients |
| 02          | Delay 1ms, monitor $\overline{SINT}$ , or poll E2DREQ |                        |
| 03          | 02 03 00 00 07  | Write ROM TBS Data     |
| 04          | Delay 1ms, monitor $\overline{SINT}$ , or poll E2DREQ |                        |
| 05          | 02 03 00 00 01 00 00 00 07 04 31                      | Write CONFIG Register  |
| 06          | Delay 1ms, monitor $\overline{SINT}$ , or poll E2DREQ |                        |
| 07          | 02 03 00 00 01 00 00 20 00 02 40                      | Write FILTCFG Register |
| 08          | Delay 1ms, monitor $\overline{SINT}$ , or poll E2DREQ |                        |
| 09          | 02 03 00 00 01 00 00 2A 07 40 40                      | Write TBSCFG Register  |
| 10          | Delay 1ms, monitor $\overline{SINT}$ , or poll E2DREQ |                        |
| 11          | 02 03 00 00 01 00 00 2B 04 B0 00                      | Write TBSGAIN Register |
| 12          | Delay 1ms, monitor $\overline{SINT}$ , or poll E2DREQ |                        |
| 13          | 02 03 00 00 08  | Filter Start           |

**Table 8. Example Microcontroller Configuration**



## 10. MODULATOR INTERFACE

The CS5376A performs digital filtering for up to four  $\Delta\Sigma$  modulators. Signals from the modulators are connected through the modulator data interface (MDI).

### 10.1 Pin Descriptions

#### ***MCLK, MCLK/2 - Pins 13, 12***

Modulator clock outputs. Nominally 2.048 MHz and 1.024 MHz.

#### ***MSYNC - Pin 14***

Modulator synchronization signal output. Generated from the SYNC input.

#### ***MDATA1 - MDATA4 - Pins 15, 17, 19, 21***

Modulator data inputs, nominally 512 kbit/s.

#### ***MFLAG1 - MFLAG4 - Pins 16, 18, 20, 22***

Modulator flag inputs. Driven high when modulator is unstable due to an analog over-range signal.

### 10.2 Modulator Clock Generation

The MCLK and MCLK/2 outputs are low-jitter, low-skew modulator clocks generated from the 32.768 MHz master clock.

MCLK typically operates at 2.048 MHz unless analog low-power modes require a 1.024 MHz modulator clock. MCLK/2 always produces a clock at half the selected MCLK rate.

The MCLK rate is selected and the MCLK and MCLK/2 outputs are enabled by bits in the digital filter CONFIG register (0x00). By default MCLK and MCLK/2 are disabled and driven low.

### 10.3 Modulator Synchronization

The MSYNC output signal follows an input on the SYNC pin. MSYNC phase aligns the modulator sampling instant to guarantee synchronous analog sampling across a measurement network.

MSYNC is enabled by a bit in the CONFIG register (0x00). By default SYNC inputs do not cause an MSYNC output.

### 10.4 Modulator Data Inputs

The MDATA input expects 1-bit  $\Delta\Sigma$  data at a 512 kHz or 256 kHz rate. The input rate is selected by a bit in the CONFIG register (0x00). By default, MDATA is expected at 512 kHz.

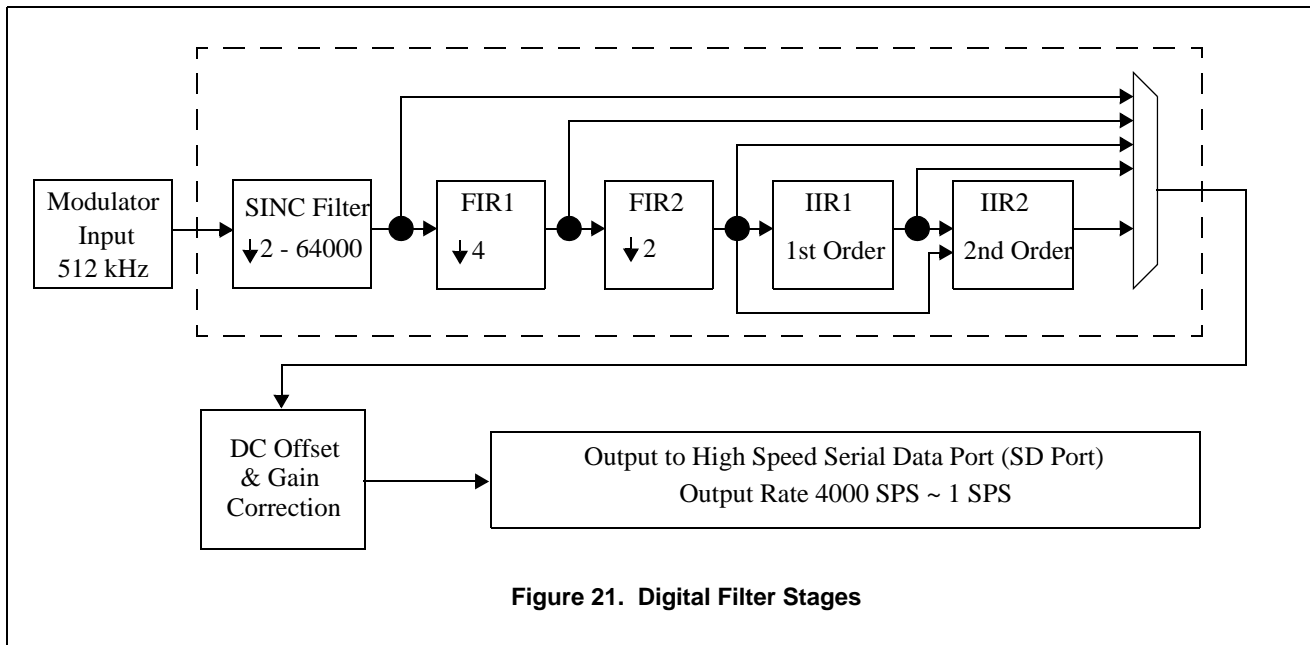
The MDATA input one's density is designed for full scale positive at 86% and full scale negative at 14%, with absolute maximum over-range capability to 93% and 7%. These raw  $\Delta\Sigma$  inputs are decimated and filtered by the digital filter to create 24-bit samples at the output rate.

### 10.5 Modulator Flag Inputs

A high MFLAG input signal indicates the corresponding  $\Delta\Sigma$  modulator has become unstable due to an analog over-range input signal. Once the over-range signal is reduced, the modulator recovers stability and the MFLAG signal is cleared.

The MFLAG inputs are mapped to status bits in the SD port, and are associated with each sample when written. See “Serial Data Port” on page 61 for more information on the MFLAG error bits in the SD port status byte.





**Figure 21. Digital Filter Stages**

## 11. DIGITAL FILTER INITIALIZATION

The CS5376A digital filter consists of three multi-stage sections: a three stage SINC filter, a two stage FIR filter, and a two stage IIR filter.

To initialize the digital filter, FIR and IIR coefficient sets are selected using configuration commands, and the FILTCFG register (0x20) is written to select the output filter stage, the output word rate, and the number of enabled channels. The digital filter clock rate is selected by writing the CONFIG register (0x00).

### 11.1 Filter Coefficient Selection

Selection of SINC filter coefficients is not required as they are selected automatically based on the programmed output word rate.

Digital filter FIR and IIR coefficients are selected using the ‘Write FIR Coefficients’ and ‘Write IIR Coefficients’, or the ‘Write ROM Coefficients’ configuration commands. When writing the FIR and IIR coefficients from ROM, a data word selects an on-chip coefficient set for each filter stage. Figure 22 shows the format of the coefficient selection

word, and the available coefficient sets for each selection.

Characteristics of the on-chip digital filter coefficients are discussed in the ‘SINC Filter’, ‘FIR Filter’, and ‘IIR Filter’ sections of this data sheet.

### 11.2 Filter Configuration Options

Digital filter parameters are selected by bits in the FILTCFG register (0x20), and the digital filter clock rate is selected by bits in the CONFIG register (0x00).

#### 11.2.1 Output Filter Stage

The digital filter can output data following any stage in the filter chain. The output filter stage is selected by the FSEL bits in the FILTCFG register.

Taking data from the SINC or FIR1 filter stages reduces the overall decimation of the filter chain and increases the output rate, as discussed in the following section. Taking data from FIR2, IIR1, IIR2, or IIR3 results in data at the selected rate.

| Bits      | 23:20 | 19:16 | 15:12 | 11:8 | 7:4  | 3:0  |
|-----------|-------|-------|-------|------|------|------|
| Selection | 0000  | 0000  | IIR2  | IIR1 | FIR2 | FIR1 |

| Bits 15:12 | IIR2 Coefficients |
|------------|-------------------|
| 0000       | 3 Hz @ 2000 SPS   |
| 0001       | 3 Hz @ 1000 SPS   |
| 0010       | 3 Hz @ 500 SPS    |
| 0011       | 3 Hz @ 333 SPS    |
| 0100       | 3 Hz @ 250 SPS    |

| Bits 11:8 | IIR1 Coefficients |
|-----------|-------------------|
| 0000      | 3 Hz @ 2000 SPS   |
| 0001      | 3 Hz @ 1000 SPS   |
| 0010      | 3 Hz @ 500 SPS    |
| 0011      | 3 Hz @ 333 SPS    |
| 0100      | 3 Hz @ 250 SPS    |

| Bits 3:0 | FIR1 Coefficients |
|----------|-------------------|
| 0000     | Linear Phase      |
| 0001     | Minimum Phase     |

| Bits 7:4 | FIR2 Coefficients |
|----------|-------------------|
| 0000     | Linear Phase      |
| 0001     | Minimum Phase     |

**Figure 22. FIR and IIR Coefficient Set Selection Word**

### 11.2.2 Output Word Rate

The CS5376A digital filter supports output word rates (OWRs) between 4000 SPS and 1 SPS. The output word rate is selected by the DEC bits in the FILTCFG register.

When taking data directly from the SINC filter, the decimation of the FIR1 and FIR2 stages is bypassed and the actual output word rate is multiplied by a factor of eight compared with the register selection. When taking data directly from FIR1, the decimation of the FIR2 stage is bypassed and the actual output word rate is multiplied by a factor of two. Data taken from the FIR2, IIR1, IIR2, or IIR3 filtering stages is output at the selected rate.

### 11.2.3 Channel Enable

Digital filtering can be performed simultaneously for up to four  $\Delta\Sigma$  modulators. The number of enabled channels is selected by the CH bits in the FILTCFG register.

Channels are enabled sequentially. Selecting one channel operation enables channel 1 only, selecting two channel operation enables channels 1 and 2, se-

lecting three channel operation enables channels 1, 2, and 3, and selecting four channel operation enables all four channels.

### 11.2.4 Digital Filter Clock

The digital filter clock rate is programmable between 16.384 MHz and 32 kHz by bits in the CONFIG register.

### Computation Cycles

The minimum digital filter clock rate for a configuration depends on the computation cycles required to complete digital filter convolutions at the selected output word rate. All configurations work for a maximum digital filter clock, but lower clock rates consume less power.

### Standby Mode

The CS5376A can be placed in a low-power standby mode by sending the 'Filter Stop' configuration command and programming the digital filter clock to 32 kHz. In this mode the digital filter idles, consuming minimal power until re-enabled by later configuration commands.

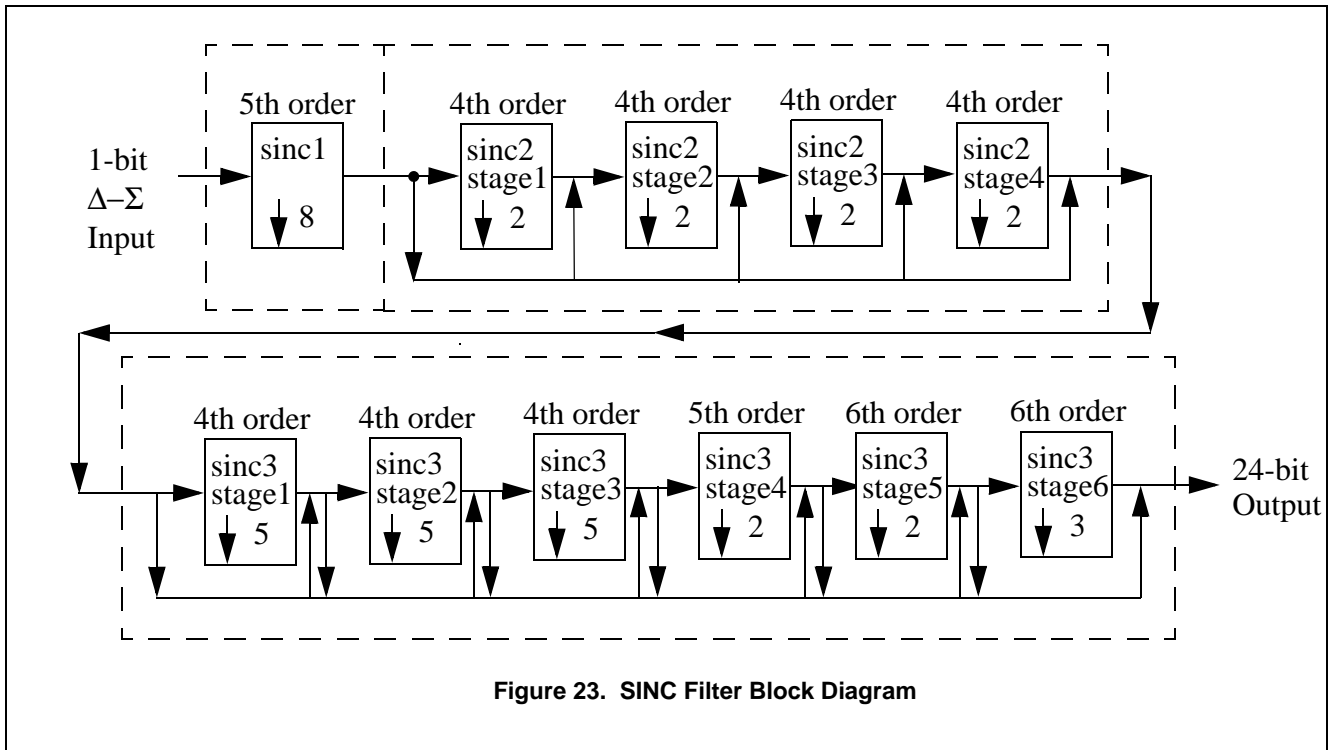


Figure 23. SINC Filter Block Diagram

## 12. SINC FILTER

The SINC filters primary purpose is to attenuate out-of-band noise components from the  $\Delta\Sigma$  modulators. While doing so, they decimate 1-bit  $\Delta\Sigma$  data into lower frequency 24-bit data suitable for the FIR and IIR filters.

The SINC filter has three cascaded sections, SINC1, SINC2, and SINC3, which are each made up of the smaller stages shown in Figure 23.

The selected output word rate in the FILTCFG register automatically determines the coefficients and decimation ratios selected for the SINC filters. Once the SINC filter configuration is set, all enabled channels are filtered and decimated using an identical hardware algorithm.

### 12.1 SINC1 Filter

The first section is SINC1, a single stage 5th order fixed decimate by 8 SINC filter. This SINC filter decimates the incoming 1-bit  $\Delta\Sigma$  bit stream from the modulators down to a 64 kHz rate.

### 12.2 SINC2 Filter

The second section is SINC2, a multi-stage, variable order, variable decimation SINC filter. Depending on the selected output word rate in the FILTCFG register, different cascaded SINC2 stages are enabled, as shown in Table 9.

### 12.3 SINC3 Filter

The last section is SINC3, a flexible multi-stage variable order, variable decimation SINC filter. Depending on the selected output word rate in the FILTCFG register, different SINC3 stages are enabled, as shown in Table 9.

### 12.4 SINC Filter Synchronization

The SINC filter is synchronized to the external system by the MSYNC signal, which is generated from the SYNC input. The MSYNC signal sets a reference time (time 0) for all filter operations, and the SINC filter is restarted to phase align with this reference time.

**SINC1 - Single stage, fixed decimate by 8**

5<sup>th</sup> order decimate by 8, 36 coefficients

**SINC2 - Multi-stage, variable decimation**

Stage 1: 4<sup>th</sup> order decimate by 2, 5 coefficients

Stage 2: 4<sup>th</sup> order decimate by 2, 5 coefficients

Stage 3: 5<sup>th</sup> order decimate by 2, 6 coefficients

Stage 4: 6<sup>th</sup> order decimate by 2, 7 coefficients

**SINC3 - Multi-stage, variable decimation**

Stage 1: 4<sup>th</sup> order decimate by 5, 17 coefficients

Stage 2: 4<sup>th</sup> order decimate by 5, 17 coefficients

Stage 3: 4<sup>th</sup> order decimate by 5, 17 coefficients

Stage 4: 5<sup>th</sup> order decimate by 2, 6 coefficients

Stage 5: 6<sup>th</sup> order decimate by 2, 7 coefficients

Stage 6: 6<sup>th</sup> order decimate by 3, 13 coefficients

**Figure 24. SINC Filter Stages**

**SINC filters**

| FIR2 Output Word Rate | DEC Bit Setting | SINC1 Decimation | SINC2 Decimation | SINC2 Stages | SINC3 Decimation | SINC3 Stages |
|-----------------------|-----------------|------------------|------------------|--------------|------------------|--------------|
| 4000                  | 0111            | 8                | 2                | 4            | -                | -            |
| 2000                  | 0110            | 8                | 4                | 3,4          | -                | -            |
| 1000                  | 0101            | 8                | 8                | 2,3,4        | -                | -            |
| 500                   | 0100            | 8                | 16               | 1,2,3,4      | -                | -            |
| 333                   | 0011            | 8                | 8                | 2,3,4        | 3                | 6            |
| 250                   | 0010            | 8                | 16               | 1,2,3,4      | 2                | 5            |
| 200                   | 0001            | 8                | 2                | 4            | 20               | 3,4,5        |
| 125                   | 0000            | 8                | 16               | 1,2,3,4      | 4                | 4,5          |
| 100                   | 1111            | 8                | 4                | 3,4          | 20               | 3,4,5        |
| 50                    | 1110            | 8                | 8                | 2,3,4        | 20               | 3,4,5        |
| 40                    | 1101            | 8                | 2                | 4            | 100              | 2,3,4,5      |
| 25                    | 1100            | 8                | 16               | 1,2,3,4      | 20               | 3,4,5        |
| 20                    | 1011            | 8                | 4                | 3,4          | 100              | 2,3,4,5      |
| 10                    | 1010            | 8                | 8                | 2,3,4        | 100              | 2,3,4,5      |
| 5                     | 1001            | 8                | 16               | 1,2,3,4      | 100              | 2,3,4,5      |
| 1                     | 1000            | 8                | 16               | 1,2,3,4      | 500              | 1,2,3,4,5    |

**Table 9. SINC Filter Configurations**

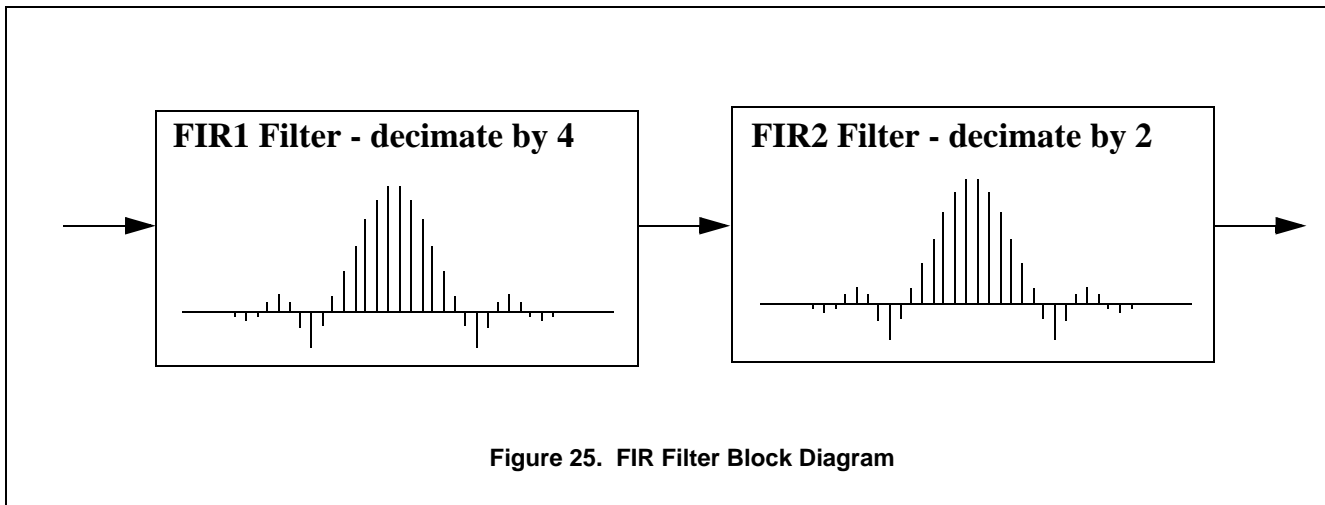
| Filter Type   | System Function   | Filter Coefficients  |
|---|---|--|
| SINC1<br>5 <sup>th</sup> order decimate by 8<br>36 coefficients | $H(z) = \left( \frac{1 - z^{-8}}{1 - z^{-1}} \right)^5$ | $h_0 = 1$ $h_{18} = 2460$<br>$h_1 = 5$ $h_{19} = 2380$<br>$h_2 = 15$ $h_{20} = 2226$<br>$h_3 = 35$ $h_{21} = 2010$<br>$h_4 = 70$ $h_{22} = 1750$<br>$h_5 = 126$ $h_{23} = 1470$<br>$h_6 = 210$ $h_{24} = 1190$<br>$h_7 = 330$ $h_{25} = 926$<br>$h_8 = 490$ $h_{26} = 690$<br>$h_9 = 690$ $h_{27} = 490$<br>$h_{10} = 926$ $h_{28} = 330$<br>$h_{11} = 1190$ $h_{29} = 210$<br>$h_{12} = 1470$ $h_{30} = 126$<br>$h_{13} = 1750$ $h_{31} = 70$<br>$h_{14} = 2010$ $h_{32} = 35$<br>$h_{15} = 2226$ $h_{33} = 15$<br>$h_{16} = 2380$ $h_{34} = 5$<br>$h_{17} = 2460$ $h_{35} = 1$ |

| Filter Type   | System Function   | Filter Coefficients  |
|---|---|--|
| SINC2 (Stage 1)<br>SINC2 (Stage 2)<br>4 <sup>th</sup> order decimate by 2<br>5 coefficients | $H(z) = \left( \frac{1 - z^{-2}}{1 - z^{-1}} \right)^4$ | $h_0 = 1$<br>$h_1 = 4$<br>$h_2 = 6$<br>$h_3 = 4$<br>$h_4 = 1$                              |
| SINC2 (Stage 3)<br>5 <sup>th</sup> order decimate by 2<br>6 coefficients                    | $H(z) = \left( \frac{1 - z^{-2}}{1 - z^{-1}} \right)^5$ | $h_0 = 1$<br>$h_1 = 5$<br>$h_2 = 10$<br>$h_3 = 10$<br>$h_4 = 5$<br>$h_5 = 1$               |
| SINC2 (Stage 4)<br>6 <sup>th</sup> order decimate by 2<br>7 coefficients                    | $H(z) = \left( \frac{1 - z^{-2}}{1 - z^{-1}} \right)^6$ | $h_0 = 1$<br>$h_1 = 6$<br>$h_2 = 15$<br>$h_3 = 20$<br>$h_4 = 15$<br>$h_5 = 6$<br>$h_6 = 1$ |

**Table 10. SINC1 and SINC2 Filter Coefficients**

| Filter Type   | System Function   | Filter Coefficients  |
|---|---|--|
| SINC3 (Stage 1)<br>SINC3 (Stage 2)<br>SINC3 (Stage 3)<br>4 <sup>th</sup> order decimate by 5<br>17 coefficients | $H(z) = \left( \frac{1 - z^{-5}}{1 - z^{-1}} \right)^4$ | h <sub>0</sub> = 1<br>h <sub>1</sub> = 4<br>h <sub>2</sub> = 10<br>h <sub>3</sub> = 20<br>h <sub>4</sub> = 35<br>h <sub>5</sub> = 52<br>h <sub>6</sub> = 68<br>h <sub>7</sub> = 80<br>h <sub>8</sub> = 85<br>h <sub>9</sub> = 80<br>h <sub>10</sub> = 68<br>h <sub>11</sub> = 52<br>h <sub>12</sub> = 35<br>h <sub>13</sub> = 20<br>h <sub>14</sub> = 10<br>h <sub>15</sub> = 4<br>h <sub>16</sub> = 1 |
| SINC3 (Stage 4)<br>5 <sup>th</sup> order decimate by 2<br>6 coefficients  | $H(z) = \left( \frac{1 - z^{-2}}{1 - z^{-1}} \right)^5$ | h <sub>0</sub> = 1<br>h <sub>1</sub> = 5<br>h <sub>2</sub> = 10<br>h <sub>3</sub> = 10<br>h <sub>4</sub> = 5<br>h <sub>5</sub> = 1   |
| SINC3 (Stage 5)<br>6 <sup>th</sup> order decimate by 2<br>7 coefficients  | $H(z) = \left( \frac{1 - z^{-2}}{1 - z^{-1}} \right)^6$ | h <sub>0</sub> = 1<br>h <sub>1</sub> = 6<br>h <sub>2</sub> = 15<br>h <sub>3</sub> = 20<br>h <sub>4</sub> = 15<br>h <sub>5</sub> = 6<br>h <sub>6</sub> = 1  |
| SINC3 (Stage 6)<br>6 <sup>th</sup> order decimate by 3<br>13 coefficients                                       | $H(z) = \left( \frac{1 - z^{-3}}{1 - z^{-1}} \right)^6$ | h <sub>0</sub> = 1<br>h <sub>1</sub> = 6<br>h <sub>2</sub> = 21<br>h <sub>3</sub> = 50<br>h <sub>4</sub> = 90<br>h <sub>5</sub> = 126<br>h <sub>6</sub> = 141<br>h <sub>7</sub> = 126<br>h <sub>8</sub> = 90<br>h <sub>9</sub> = 50<br>h <sub>10</sub> = 21<br>h <sub>11</sub> = 6<br>h <sub>12</sub> = 1  |

**Table 11. SINC3 Filter Coefficients**



## 13. FIR FILTER

The finite impulse response (FIR) filter block consists of two cascaded stages, FIR1 and FIR2. It compensates for SINC filter droop and creates a low-pass corner to block aliased components of the input signal.

On-chip linear phase or minimum phase coefficients can be selected using a configuration command, or the coefficients can be programmed for a custom filter response.

### 13.1 FIR1 Filter

The FIR1 filter stage has a decimate by four architecture. It compensates for SINC filter droop and flattens the magnitude response of the pass band.

The on-chip linear and minimum phase coefficient sets are 48-tap, with a maximum 255 programmable coefficients. All coefficients are normalized to 24-bit two's complement full scale, 0x7FFFFFFF.

The characteristic equation for FIR1 is a convolution of the input values,  $X(n)$ , and the filter coefficients,  $h(k)$ , to produce an output value,  $Y$ .

$$Y = [h(k)*X(n-k)] + [h(k+1)*X(n-(k+1))] + \dots$$

### 13.2 FIR2 Filter

The FIR2 filter stage has a decimate by two architecture. It creates a low-pass brick wall filter to block aliased components of the input signal.

The on-chip linear and minimum phase coefficient sets are 126-tap, with a maximum 255 programmable coefficients. All coefficients are normalized to 24-bit two's complement full scale, 0x7FFFFFFF.

The characteristic equation for FIR2 is a convolution of the input values,  $X(n)$ , and the filter coefficients,  $h(k)$ , to produce an output value,  $Y$ .

$$Y = [h(k)*X(n-k)] + [h(k+1)*X(n-(k+1))] + \dots$$

### 13.3 On-Chip FIR Coefficients

Two sets of on-chip linear phase and minimum phase coefficients are available for FIR1 and FIR2. Performance of the on-chip coefficient sets is very good, with excellent ripple and stop band characteristics as described in Figure 26 and Table 12.

Which on-chip coefficient set to use is selected by a data word following the 'Write ROM Coefficients' configuration command. See "Filter Coefficient Selection" on page 41 for information about selecting on-chip coefficient sets.

### 13.4 Programmable FIR Coefficients

A maximum of 255 + 255 coefficients can be programmed into FIR1 and FIR2 to create a custom filter response. The total number of coefficients for the FIR filter is fundamentally limited by the available computation cycles in the digital filter, which itself is determined by the digital filter clock rate.

Custom filter sets should normalize the maximum coefficient value to 24-bit two's complement full scale, 0x7FFFFFFF, and scale all other coefficients accordingly. To maintain maximum internal dynamic range, the CS5376A FIR filter performs double precision calculations with an automatic gain correction to scale the final output.

Custom FIR coefficients are uploaded using the 'Write FIR Coefficients' configuration command. See "EEPROM Configuration Commands" on page 28 or "Microcontroller Configuration Commands" on page 35 for information about writing custom FIR coefficients.

### 13.5 FIR Filter Synchronization

The FIR1 and FIR2 filters are synchronized to the external system by the MSYNC signal, which is generated from the SYNC input. The MSYNC signal sets a reference time (time 0) for all filter operations, and the FIR filters are restarted to phase align with this reference time.



**FIR1 - Single stage, fixed decimate by 4**

Coefficient set 0: linear phase decimate by 4, 48 coefficients  
 Coefficient set 1: minimum phase decimate by 4, 48 coefficients  
 SINC droop compensation filter

**FIR2 - Single stage, fixed decimate by 2**

Coefficient set 0: linear phase decimate by 2, 126 coefficients  
 Coefficient set 1: minimum phase decimate by 2, 126 coefficients  
 Brick wall low-pass filter, flat to 40%  $f_s$

**Combined SINC + FIR digital filter specifications**

Passband ripple less than +/- 0.01 dB below 40%  $f_s$   
 Transition band -3 dB frequency at 42.89%  $f_s$   
 Stopband attenuation greater than 130 dB above 50%  $f_s$

**Figure 26. FIR Filter Stages**
**SINC + FIR filters**

| FIR2 Output Word Rate | SINC Decimation | FIR1 Decimation | FIR2 Decimation | Total Decimation | Passband Ripple ( $\pm$ dB) | Stopband Attenuation (dB) |
|-----------------------|-----------------|-----------------|-----------------|------------------|-----------------------------|---------------------------|
| 4000                  | 16              | 4               | 2               | 128              | 0.0042                      | 130.38                    |
| 2000                  | 32              | 4               | 2               | 256              | 0.0045                      | 130.38                    |
| 1000                  | 64              | 4               | 2               | 512              | 0.0040                      | 130.42                    |
| 500                   | 128             | 4               | 2               | 1024             | 0.0041                      | 130.42                    |
| 333                   | 192             | 4               | 2               | 1536             | 0.0080                      | 130.45                    |
| 250                   | 256             | 4               | 2               | 2048             | 0.0064                      | 130.43                    |
| 200                   | 320             | 4               | 2               | 2560             | 0.0041                      | 130.43                    |
| 125                   | 512             | 4               | 2               | 4096             | 0.0046                      | 130.42                    |
| 100                   | 640             | 4               | 2               | 5120             | 0.0040                      | 130.43                    |
| 50                    | 1280            | 4               | 2               | 10240            | 0.0040                      | 130.43                    |
| 40                    | 1600            | 4               | 2               | 12800            | 0.0036                      | 130.43                    |
| 25                    | 2560            | 4               | 2               | 20480            | 0.0040                      | 132.98                    |
| 20                    | 3200            | 4               | 2               | 25600            | 0.0036                      | 130.43                    |
| 10                    | 6400            | 4               | 2               | 51200            | 0.0036                      | 130.43                    |
| 5                     | 12800           | 4               | 2               | 102400           | 0.0036                      | 130.43                    |
| 1                     | 64000           | 4               | 2               | 512000           | 0.0029                      | 134.31                    |

**Table 12. FIR Filter Characteristics**

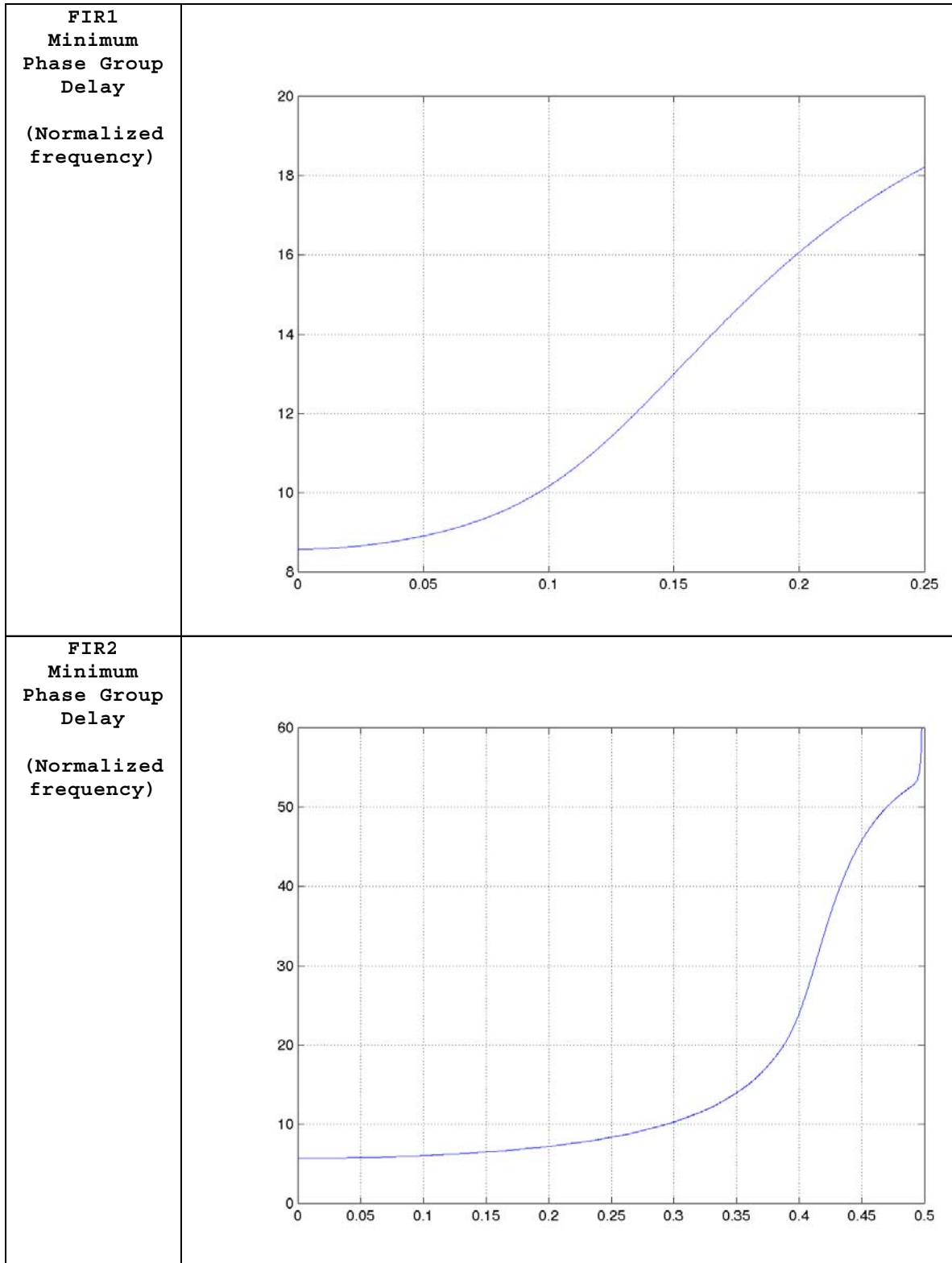
**Individual filter stage group delay (no IIR)**

|                   | Decimation Ratios | Number of Coefficients | Group Delay (Filter Stage Input Rate) |
|-------------------|-------------------|------------------------|---------------------------------------|
| <b>SINC1</b>      | 8                 | 36                     | 17.5                                  |
| <b>SINC2</b>      |                   |                        |                                       |
| Stage 4           | 2                 | 7                      | 3.0                                   |
| Stages 3,4        | 2,2               | 6,7                    | 8.5                                   |
| Stages 2,3,4      | 2,2,2             | 5,6,7                  | 19.0                                  |
| Stages 1,2,3,4    | 2,2,2,2           | 5,5,6,7                | 40.0                                  |
| <b>SINC3</b>      |                   |                        |                                       |
| Stage 6           | 3                 | 13                     | 6.0                                   |
| Stage 5           | 2                 | 7                      | 3.0                                   |
| Stages 4,5        | 2,2               | 6,7                    | 8.5                                   |
| Stages 3,4,5      | 5,2,2             | 17,6,7                 | 50.5                                  |
| Stages 2,3,4,5    | 5,5,2,2           | 17,17,6,7              | 260.5                                 |
| Stages 1,2,3,4,5  | 5,5,5,2,2         | 17,17,17,6,7           | 1310.5                                |
| <b>FIR1</b>       |                   |                        |                                       |
| Coefficient Set 0 | 4                 | 48                     | 23.5                                  |
| Coefficient Set 1 | 4                 | 48                     | See Figure                            |
| <b>FIR2</b>       |                   |                        |                                       |
| Coefficient Set 0 | 2                 | 126                    | 62.5                                  |
| Coefficient Set 1 | 2                 | 126                    | See Figure                            |

**Cumulative linear phase group delay (no IIR)**

| FIR2 Output Word Rate | SINC Output Group Delay (SINC Filter Input Rate) | FIR1 Output Group Delay (SINC Filter Input Rate) | FIR2 Output Group Delay (SINC Filter Input Rate) | FIR2 Output Group Delay (FIR2 Output Word Rate) |
|-----------------------|--|--|--|---|
| 4000                  | 41.5   | 417.5  | 4417.5   | 34.5117   |
| 2000                  | 85.5   | 837.5  | 8837.5   | 34.5215   |
| 1000                  | 169.5  | 1673.5   | 17673.5  | 34.5186   |
| 500                   | 337.5  | 3345.5   | 35345.5  | 34.5171   |
| 333                   | 553.5  | 5065.5   | 53065.5  | 34.5479   |
| 250                   | 721.5  | 6737.5   | 70737.5  | 34.5398   |
| 200                   | 849.5  | 8369.5   | 88369.5  | 34.5193   |
| 125                   | 1425.5   | 13457.5  | 141457.5   | 34.5355   |
| 100                   | 1701.5   | 16741.5  | 176741.5   | 34.5198   |
| 50                    | 3401.5   | 33481.5  | 353481.5   | 34.5197   |
| 40                    | 4209.5   | 41809.5  | 441809.5   | 34.5164   |
| 25                    | 6801.5   | 66961.5  | 706961.5   | 34.5196   |
| 20                    | 8421.5   | 83621.5  | 883621.5   | 34.5165   |
| 10                    | 16841.5  | 167241.5   | 1767241.5  | 34.5164   |
| 5                     | 33681.5  | 334481.5   | 3534481.5  | 34.5164   |
| 1                     | 168081.5   | 1672081.5  | 17672081.5                                       | 34.5158   |

**Table 13. SINC + FIR Group Delay**

**Minimum phase group delay**

**Figure 27. Minimum Phase Group Delay**

| Filter Type   | Filter Coefficients<br>(normalized 24-bit)  |   |
|---|---|---|
| FIR1 (Coefficient set 0)<br>Low pass, SINC compensation<br>Linear phase decimate by 4<br>48 coefficients  | $h_0 = 558$<br>$h_1 = 1905$<br>$h_2 = 3834$<br>$h_3 = 5118$<br>$h_4 = 365$<br>$h_5 = -14518$<br>$h_6 = -39787$<br>$h_7 = -67365$<br>$h_8 = -69909$<br>$h_9 = -19450$<br>$h_{10} = 97434$<br>$h_{11} = 258881$<br>$h_{12} = 375562$<br>$h_{13} = 332367$<br>$h_{14} = 39864$<br>$h_{15} = -496361$<br>$h_{16} = -1084130$<br>$h_{17} = -1392827$<br>$h_{18} = -1053303$<br>$h_{19} = 189436$<br>$h_{20} = 2266428$<br>$h_{21} = 4768946$<br>$h_{22} = 7042723$<br>$h_{23} = 8388607$                       | $h_{24} = 8388607$<br>$h_{25} = 7042723$<br>$h_{26} = 4768946$<br>$h_{27} = 2266428$<br>$h_{28} = 189436$<br>$h_{29} = -1053303$<br>$h_{30} = -1392827$<br>$h_{31} = -1084130$<br>$h_{32} = -496361$<br>$h_{33} = 39864$<br>$h_{34} = 332367$<br>$h_{35} = 375562$<br>$h_{36} = 258881$<br>$h_{37} = 97434$<br>$h_{38} = -19450$<br>$h_{39} = -69909$<br>$h_{40} = -67365$<br>$h_{41} = -39787$<br>$h_{42} = -14518$<br>$h_{43} = 365$<br>$h_{44} = 5118$<br>$h_{45} = 3834$<br>$h_{46} = 1905$<br>$h_{47} = 558$ |
| FIR1 (Coefficient set 1)<br>Low pass, SINC compensation<br>Minimum phase decimate by 4<br>48 coefficients | $h_0 = 3337$<br>$h_1 = 22258$<br>$h_2 = 88284$<br>$h_3 = 266742$<br>$h_4 = 655747$<br>$h_5 = 1371455$<br>$h_6 = 2502684$<br>$h_7 = 4031988$<br>$h_8 = 5783129$<br>$h_9 = 7396359$<br>$h_{10} = 8388607$<br>$h_{11} = 8325707$<br>$h_{12} = 6988887$<br>$h_{13} = 4531706$<br>$h_{14} = 1507479$<br>$h_{15} = -1319126$<br>$h_{16} = -3207750$<br>$h_{17} = -3736028$<br>$h_{18} = -2980701$<br>$h_{19} = -1421498$<br>$h_{20} = 237307$<br>$h_{21} = 1373654$<br>$h_{22} = 1711919$<br>$h_{23} = 1322371$ | $h_{24} = 555919$<br>$h_{25} = -165441$<br>$h_{26} = -581479$<br>$h_{27} = -617500$<br>$h_{28} = -388985$<br>$h_{29} = -99112$<br>$h_{30} = 114761$<br>$h_{31} = 186557$<br>$h_{32} = 141374$<br>$h_{33} = 58582$<br>$h_{34} = -12664$<br>$h_{35} = -42821$<br>$h_{36} = -35055$<br>$h_{37} = -16792$<br>$h_{38} = 367$<br>$h_{39} = 7929$<br>$h_{40} = 5926$<br>$h_{41} = 2892$<br>$h_{42} = 23$<br>$h_{43} = -1164$<br>$h_{44} = -538$<br>$h_{45} = -238$<br>$h_{46} = 18$<br>$h_{47} = 113$                    |

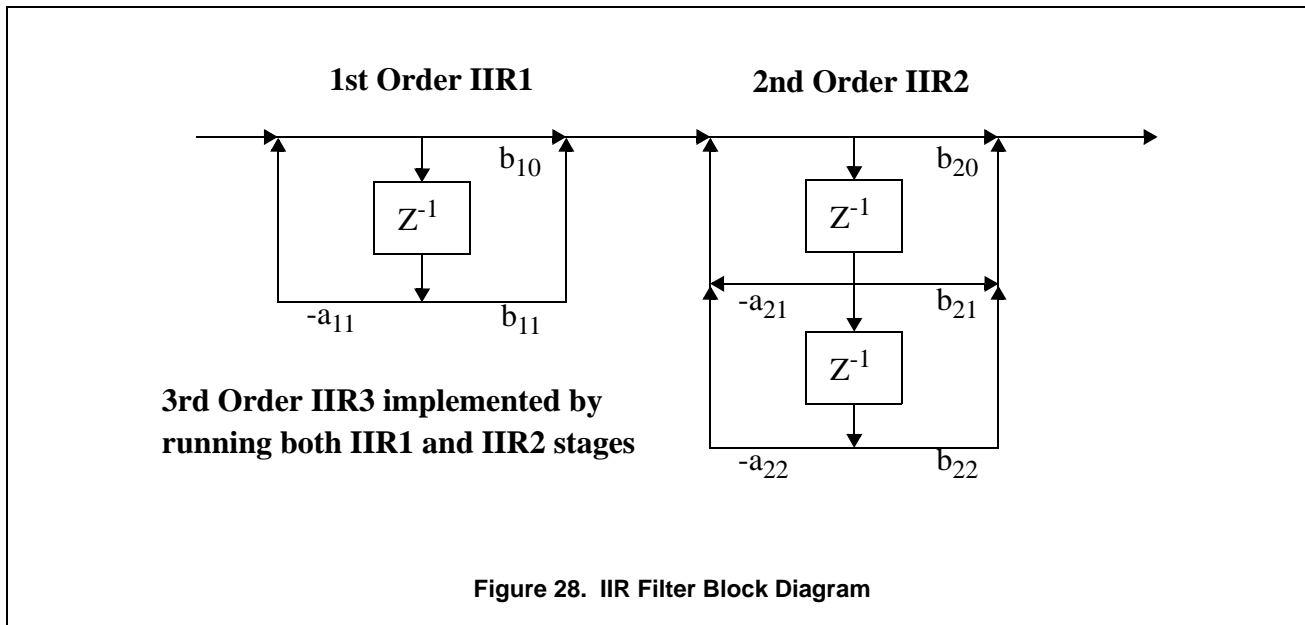
**Table 14. FIR1 Coefficients**

| Filter Type   | Filter Coefficients<br>(normalized 24-bit)   |  |
|---|--|--|
| FIR2 (Coefficient set 0)<br>Low pass, passband to 40% $f_s$<br>Linear phase decimate by 2<br>126 coefficients | $h_0 = -71$<br>$h_1 = -371$<br>$h_2 = -870$<br>$h_3 = -986$<br>$h_4 = 34$<br>$h_5 = 1786$<br>$h_6 = 2291$<br>$h_7 = 291$<br>$h_8 = -2036$<br>$h_9 = -943$<br>$h_{10} = 2985$<br>$h_{11} = 3784$<br>$h_{12} = -1458$<br>$h_{13} = -5808$<br>$h_{14} = -1007$<br>$h_{15} = 7756$<br>$h_{16} = 5935$<br>$h_{17} = -7135$<br>$h_{18} = -11691$<br>$h_{19} = 3531$<br>$h_{20} = 17500$<br>$h_{21} = 4388$<br>$h_{22} = -20661$<br>$h_{23} = -15960$<br>$h_{24} = 18930$<br>$h_{25} = 29808$<br>$h_{26} = -9795$<br>$h_{27} = -42573$<br>$h_{28} = -7745$<br>$h_{29} = 49994$<br>$h_{30} = 33021$<br>$h_{31} = -47092$<br>$h_{32} = -62651$<br>$h_{33} = 29702$<br>$h_{34} = 90744$<br>$h_{35} = 4436$<br>$h_{36} = -109189$<br>$h_{37} = -54172$<br>$h_{38} = 109009$<br>$h_{39} = 114154$<br>$h_{40} = -81993$<br>$h_{41} = -174452$<br>$h_{42} = 22850$<br>$h_{43} = 221211$<br>$h_{44} = 68863$<br>$h_{45} = -238025$<br>$h_{46} = -187141$<br>$h_{47} = 208018$<br>$h_{48} = 318763$<br>$h_{49} = -116005$<br>$h_{50} = -443272$<br>$h_{51} = -49958$<br>$h_{52} = 533334$<br>$h_{53} = 298975$<br>$h_{54} = -553873$<br>$h_{55} = -642475$<br>$h_{56} = 454990$<br>$h_{57} = 1113788$<br>$h_{58} = -137179$<br>$h_{59} = -1854336$<br>$h_{60} = -766230$<br>$h_{61} = 3875315$<br>$h_{62} = 8388607$ | $h_{63} = 8388607$<br>$h_{64} = 3875315$<br>$h_{65} = -766230$<br>$h_{66} = -1854336$<br>$h_{67} = -137179$<br>$h_{68} = 1113788$<br>$h_{69} = 454990$<br>$h_{70} = -642475$<br>$h_{71} = -553873$<br>$h_{72} = 298975$<br>$h_{73} = 533334$<br>$h_{74} = -49958$<br>$h_{75} = -443272$<br>$h_{76} = -116005$<br>$h_{77} = 318763$<br>$h_{78} = 208018$<br>$h_{79} = -187141$<br>$h_{80} = -238025$<br>$h_{81} = 68863$<br>$h_{82} = 221211$<br>$h_{83} = 22850$<br>$h_{84} = -174452$<br>$h_{85} = -81993$<br>$h_{86} = 114154$<br>$h_{87} = 109009$<br>$h_{88} = -54172$<br>$h_{89} = -109189$<br>$h_{90} = 4436$<br>$h_{91} = 90744$<br>$h_{92} = 29702$<br>$h_{93} = -62651$<br>$h_{94} = -47092$<br>$h_{95} = 33021$<br>$h_{96} = 49994$<br>$h_{97} = -7745$<br>$h_{98} = -42573$<br>$h_{99} = -9795$<br>$h_{100} = 29808$<br>$h_{101} = 18930$<br>$h_{102} = -15960$<br>$h_{103} = -20661$<br>$h_{104} = 4388$<br>$h_{105} = 17500$<br>$h_{106} = 3531$<br>$h_{107} = -11691$<br>$h_{108} = -7135$<br>$h_{109} = 5935$<br>$h_{110} = 7756$<br>$h_{111} = -1007$<br>$h_{112} = -5808$<br>$h_{113} = -1458$<br>$h_{114} = 3784$<br>$h_{115} = 2985$<br>$h_{116} = -943$<br>$h_{117} = -2036$<br>$h_{118} = 291$<br>$h_{119} = 2291$<br>$h_{120} = 1786$<br>$h_{121} = 34$<br>$h_{122} = -986$<br>$h_{123} = -870$<br>$h_{124} = -371$<br>$h_{125} = -71$ |

**Table 15. FIR2 Linear Phase Coefficients**

| Filter Type  | Filter Coefficients<br>(normalized 24-bit) |                    |
|--|--|--------------------|
| FIR2 (Coefficient set 1)<br>Low pass, passband to 40% $f_s$<br>Minimum phase decimate by 2<br>126 coefficients | $h_0 = 4019$                               | $h_{63} = 67863$   |
|  | $h_1 = 43275$                              | $h_{64} = -190800$ |
|  | $h_2 = 235427$                             | $h_{65} = -128546$ |
|  | $h_3 = 848528$                             | $h_{66} = 114197$  |
|  | $h_4 = 2240207$                            | $h_{67} = 147750$  |
|  | $h_5 = 4525758$                            | $h_{68} = -46352$  |
|  | $h_6 = 7077833$                            | $h_{69} = -143269$ |
|  | $h_7 = 8388607$                            | $h_{70} = -13290$  |
|  | $h_8 = 6885673$                            | $h_{71} = 114721$  |
|  | $h_9 = 2483461$                            | $h_{72} = 51933$   |
|  | $h_{10} = -2538963$                        | $h_{73} = -75952$  |
|  | $h_{11} = -4800543$                        | $h_{74} = -68746$  |
|  | $h_{12} = -2761696$                        | $h_{75} = 38171$   |
|  | $h_{13} = 1426109$                         | $h_{76} = 68492$   |
|  | $h_{14} = 3624338$                         | $h_{77} = -7856$   |
|  | $h_{15} = 1820814$                         | $h_{78} = -57526$  |
|  | $h_{16} = -1695825$                        | $h_{79} = -12540$  |
|  | $h_{17} = -2885148$                        | $h_{80} = 41717$   |
|  | $h_{18} = -605252$                         | $h_{81} = 23334$   |
|  | $h_{19} = 2135021$                         | $h_{82} = -25516$  |
|  | $h_{20} = 1974197$                         | $h_{83} = -26409$  |
|  | $h_{21} = -630111$                         | $h_{84} = 11717$   |
|  | $h_{22} = -2168177$                        | $h_{85} = 24246$   |
|  | $h_{23} = -750147$                         | $h_{86} = -1620$   |
|  | $h_{24} = 1516192$                         | $h_{87} = -19248$  |
|  | $h_{25} = 1550127$                         | $h_{88} = -4610$   |
|  | $h_{26} = -508445$                         | $h_{89} = 13356$   |
|  | $h_{27} = -1686937$                        | $h_{90} = 7526$    |
|  | $h_{28} = -437822$                         | $h_{91} = -7887$   |
|  | $h_{29} = 1308705$                         | $h_{92} = -8016$   |
|  | $h_{30} = 1069556$                         | $h_{93} = 3559$    |
|  | $h_{31} = -657282$                         | $h_{94} = 7023$    |
|  | $h_{32} = -1301014$                        | $h_{95} = -598$    |
|  | $h_{33} = -30654$                          | $h_{96} = -5350$   |
|  | $h_{34} = 1173754$                         | $h_{97} = -1097$   |
|  | $h_{35} = 579643$                          | $h_{98} = 3579$    |
|  | $h_{36} = -803111$                         | $h_{99} = 1806$    |
|  | $h_{37} = -895851$                         | $h_{100} = -2058$  |
|  | $h_{38} = 328399$                          | $h_{101} = -1859$  |
|  | $h_{39} = 962522$                          | $h_{102} = 936$    |
|  | $h_{40} = 124678$                          | $h_{103} = 1558$   |
|  | $h_{41} = -820948$                         | $h_{104} = -224$   |
|  | $h_{42} = -466657$                         | $h_{105} = -1129$  |
|  | $h_{43} = 545674$                          | $h_{106} = -152$   |
|  | $h_{44} = 652827$                          | $h_{107} = 718$    |
|  | $h_{45} = -220448$                         | $h_{108} = 290$    |
|  | $h_{46} = -680495$                         | $h_{109} = -395$   |
|  | $h_{47} = -80886$                          | $h_{110} = -290$   |
|  | $h_{48} = 578844$                          | $h_{111} = 178$    |
|  | $h_{49} = 306445$                          | $h_{112} = 227$    |
|  | $h_{50} = -395302$                         | $h_{113} = -53$    |
|  | $h_{51} = -431004$                         | $h_{114} = -151$   |
|  | $h_{52} = 181900$                          | $h_{115} = -5$     |
|  | $h_{53} = 454403$                          | $h_{116} = 86$     |
|  | $h_{54} = 15856$                           | $h_{117} = 23$     |
|  | $h_{55} = -395525$                         | $h_{118} = -42$    |
|  | $h_{56} = -166123$                         | $h_{119} = -22$    |
|  | $h_{57} = 284099$                          | $h_{120} = 17$     |
|  | $h_{58} = 253485$                          | $h_{121} = 14$     |
|  | $h_{59} = -152407$                         | $h_{122} = -5$     |
|  | $h_{60} = -277888$                         | $h_{123} = -7$     |
|  | $h_{61} = 28526$                           | $h_{124} = 1$      |
|  | $h_{62} = 250843$                          | $h_{125} = 3$      |

**Table 16. FIR2 Minimum Phase Coefficients**



## 14. IIR FILTER

The infinite impulse response (IIR) filter block consists of two cascaded stages, IIR1 and IIR2. It creates a high-pass corner to block very low-frequency and DC components of the input signal.

On-chip IIR1 and IIR2 coefficients can be selected using a configuration command, or the coefficients can be programmed for a custom filter response.

### 14.1 IIR Architecture

The architecture of the IIR filter is automatically determined when the output filter stage is selected in the FILTCFG register. Selecting the 1st order IIR1 filter bypasses the 2nd order stage, while selecting the 2nd order IIR2 filter bypasses the 1st order stage. Selection of the 3rd order IIR3 filter enables both the 1st and 2nd order stages.

### 14.2 IIR1 Filter

The 1st order IIR filter stage is a direct form filter with three coefficients:  $a_{11}$ ,  $b_{10}$ , and  $b_{11}$ . Coefficients of a 1st order IIR are inherently normalized to one, and should be scaled to 24-bit two's complement full scale, 0x7FFFFFFF.

The characteristic equations for the 1st order IIR include an input value,  $X$ , an output value,  $Y$ , and two intermediate values,  $W1$  and  $W2$ , separated by a delay element ( $z^{-1}$ ).

$$W2 = W1$$

$$W1 = X + (-a_{11} * W2)$$

$$Y = (W1 * b_{10}) + (W2 * b_{11})$$

### 14.3 IIR2 Filter

The 2nd order IIR filter stage is a direct form filter with five coefficients:  $a_{21}$ ,  $a_{22}$ ,  $b_{20}$ ,  $b_{21}$ , and  $b_{22}$ . Coefficients of a 2nd order IIR are inherently normalized to two, and should be scaled to 24-bit two's complement full scale, 0x7FFFFFFF. Normalization effectively divides the 2nd order coefficients in half relative to the input, and requires modification of the characteristic equations.

The characteristic equations for the 2nd order IIR include an input value,  $X$ , an output value,  $Y$ , and three intermediate values,  $W3$ ,  $W4$ , and  $W5$ , each separated by a delay element ( $z^{-1}$ ). The following

characteristic equations model the operation of the 2nd order IIR filter with unnormalized coefficients.

$$W5 = W4$$

$$W4 = W3$$

$$W3 = X + (-a21 * W4) + (-a22 * W5)$$

$$Y = (W3 * b20) + (W4 * b21) + (W5 * b22)$$

Internally, the CS5376A uses normalized coefficients to perform the 2nd order IIR filter calculation, which changes the algorithm slightly. The following characteristic equations model the operation of the 2nd order IIR filter when using normalized coefficients.

$$W5 = W4$$

$$W4 = W3$$

$$W3 = 2 * [(X / 2) + (-a21 * W4) + (-a22 * W5)]$$

$$Y = 2 * [(W3 * b20) + (W4 * b21) + (W5 * b22)]$$

#### 14.4 IIR3 Filter

The 3rd order IIR filter is implemented by running both the 1st order and 2nd order IIR filter stages. It can be modeled by cascading the characteristic equations of the 1st order and 2nd order IIR stages.

#### 14.5 On-Chip IIR Coefficients

Five sets of on-chip coefficients are available for IIR1 and IIR2, each providing a 3 Hz high-pass Butterworth response at different output word rates. Characteristics of the on-chip coefficient sets are described in Figure 29 and Table 17.

Which on-chip coefficient set to use is selected by a data word following the ‘Write ROM Coefficients’ configuration command. See ‘Filter Coefficient Selection’ on page 41 for information about selecting on-chip coefficient sets.

#### 14.6 Programmable IIR Coefficients

A maximum of 3 + 5 coefficients can be programmed into IIR1 and IIR2 to create a custom filter response. Custom filter sets should normalize the coefficients to 24-bit two’s complement full scale, 0x7FFFFFFF. To maintain maximum internal dynamic range, the CS5376A IIR filter performs double precision calculations with an automatic gain correction to scale the final output.

Custom IIR coefficients are uploaded using the ‘Write IIR Coefficients’ configuration command. See ‘EEPROM Configuration Commands’ on page 28 or ‘Microcontroller Configuration Commands’ on page 35 for information about writing custom IIR coefficients.

#### 14.7 IIR Filter Synchronization

The IIR filter is not synchronized to the external system directly, only indirectly through the synchronization of the SINC and FIR filters. Because IIR filters have ‘infinite’ memory, a discontinuity in the input data stream from a synchronization event can require significant time to settle out. The exact settling time depends on the size of the discontinuity and the filter coefficient characteristics.



**IIR1 - Single stage, no decimation**

1<sup>st</sup> order no decimation, 3 coefficients

Coefficient set 0: high-pass, corner 0.15%  $f_s$  (3 Hz at 2000 SPS)  
 Coefficient set 1: high-pass, corner 0.30%  $f_s$  (3 Hz at 1000 SPS)  
 Coefficient set 2: high-pass, corner 0.60%  $f_s$  (3 Hz at 500 SPS)  
 Coefficient set 3: high-pass, corner 0.90%  $f_s$  (3 Hz at 333 SPS)  
 Coefficient set 4: high-pass, corner 1.20%  $f_s$  (3 Hz at 250 SPS)

**IIR2 - Single stage, no decimation**

2<sup>nd</sup> order no decimation, 5 coefficients

Coefficient set 0: high-pass, corner 0.15%  $f_s$  (3 Hz at 2000 SPS)  
 Coefficient set 1: high-pass, corner 0.30%  $f_s$  (3 Hz at 1000 SPS)  
 Coefficient set 2: high-pass, corner 0.60%  $f_s$  (3 Hz at 500 SPS)  
 Coefficient set 3: high-pass, corner 0.90%  $f_s$  (3 Hz at 333 SPS)  
 Coefficient set 4: high-pass, corner 1.20%  $f_s$  (3 Hz at 250 SPS)

**IIR3 - Two stage, no decimation**

3<sup>rd</sup> order no decimation, 8 coefficients  
 (Combined IIR1 and IIR2 filter responses)

Coefficient set 0,0: high-pass, corner 0.20%  $f_s$  (4 Hz at 2000 SPS)  
 Coefficient set 1,1: high-pass, corner 0.41%  $f_s$  (4 Hz at 1000 SPS)  
 Coefficient set 2,2: high-pass, corner 0.82%  $f_s$  (4 Hz at 500 SPS)  
 Coefficient set 3,3: high-pass, corner 1.22%  $f_s$  (4 Hz at 333 SPS)  
 Coefficient set 4,4: high-pass, corner 1.63%  $f_s$  (4 Hz at 250 SPS)

**Figure 29. IIR Filter Stages**

**IIR filters**

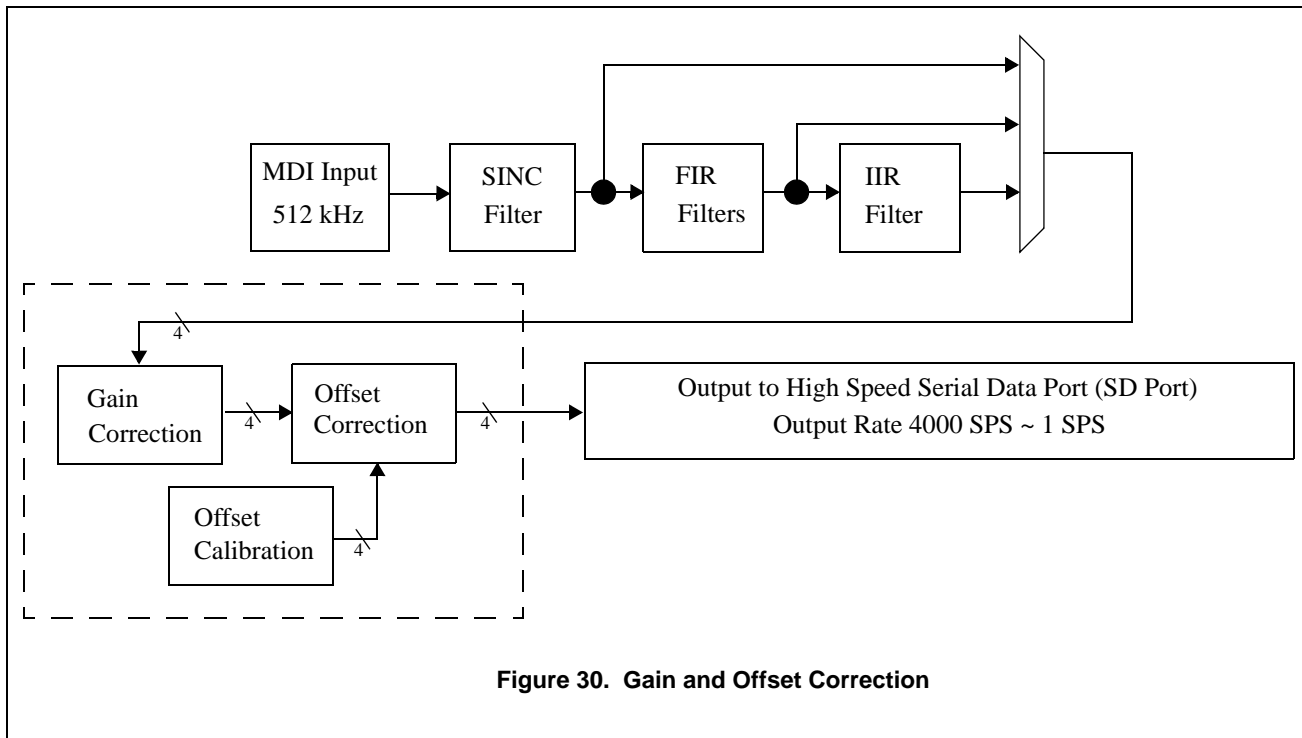
| IIR1 Coeff Selection | IIR1 Corner Frequency | IIR2 Coeff Selection | IIR2 Corner Frequency | IIR3 Coeff Selection | IIR3 Corner Frequency |
|----------------------|-----------------------|----------------------|-----------------------|----------------------|-----------------------|
| 0                    | 0.15% $f_s$           | 0                    | 0.15% $f_s$           | 0,0                  | 0.2041% $f_s$         |
| 1                    | 0.30% $f_s$           | 1                    | 0.30% $f_s$           | 1,1                  | 0.4074% $f_s$         |
| 2                    | 0.60% $f_s$           | 2                    | 0.60% $f_s$           | 2,2                  | 0.8152% $f_s$         |
| 3                    | 0.90% $f_s$           | 3                    | 0.90% $f_s$           | 3,3                  | 1.2222% $f_s$         |
| 4                    | 1.20% $f_s$           | 4                    | 1.20% $f_s$           | 4,4                  | 1.6293% $f_s$         |

**Table 17. IIR Filter Characteristics**

| Filter Type   | System Function  | Filter Coefficients<br>(normalized 24-bit)                       |
|---|--|--|
| IIR1 (Coefficient set 0)<br>1 <sup>st</sup> order, high pass<br>Corner at 0.15% $f_s$<br>3 coefficients | $H(z) = \left( \frac{b_{10} + b_{11}z^{-1}}{1 + a_{11}z^{-1}} \right)$ | $a_{11} = -8309916$<br>$b_{10} = 8349262$<br>$b_{11} = -8349262$ |
| IIR1 (Coefficient set 1)<br>1 <sup>st</sup> order, high pass<br>Corner at 0.30% $f_s$<br>3 coefficients | $H(z) = \left( \frac{b_{10} + b_{11}z^{-1}}{1 + a_{11}z^{-1}} \right)$ | $a_{11} = -8231957$<br>$b_{10} = 8310282$<br>$b_{11} = -8310282$ |
| IIR1 (Coefficient set 2)<br>1 <sup>st</sup> order, high pass<br>Corner at 0.60% $f_s$<br>3 coefficients | $H(z) = \left( \frac{b_{10} + b_{11}z^{-1}}{1 + a_{11}z^{-1}} \right)$ | $a_{11} = -8078179$<br>$b_{10} = 8233393$<br>$b_{11} = -8233393$ |
| IIR1 (Coefficient set 3)<br>1 <sup>st</sup> order, high pass<br>Corner at 0.90% $f_s$<br>3 coefficients | $H(z) = \left( \frac{b_{10} + b_{11}z^{-1}}{1 + a_{11}z^{-1}} \right)$ | $a_{11} = -7927166$<br>$b_{10} = 8157887$<br>$b_{11} = -8157887$ |
| IIR1 (Coefficient set 4)<br>1 <sup>st</sup> order, high pass<br>Corner at 1.20% $f_s$<br>3 coefficients | $H(z) = \left( \frac{b_{10} + b_{11}z^{-1}}{1 + a_{11}z^{-1}} \right)$ | $a_{11} = -7778820$<br>$b_{10} = 8083714$<br>$b_{11} = -8083714$ |

| Filter Type   | System Function  | Filter Coefficients<br>(normalized 24-bit)   |
|---|--|--|
| IIR2 (Coefficient set 0)<br>2 <sup>nd</sup> order, high pass<br>Corner at 0.15% $f_s$<br>5 coefficients | $H(z) = \left( \frac{b_{20} + b_{21}z^{-1} + b_{22}z^{-2}}{1 + a_{21}z^{-1} + a_{22}z^{-2}} \right)$ | $a_{21} = -8332704$<br>$a_{22} = 4138771$<br>$b_{20} = 4166445$<br>$b_{21} = -8332890$<br>$b_{22} = 4166445$ |
| IIR2 (Coefficient set 1)<br>2 <sup>nd</sup> order, high pass<br>Corner at 0.30% $f_s$<br>5 coefficients | $H(z) = \left( \frac{b_{20} + b_{21}z^{-1} + b_{22}z^{-2}}{1 + a_{21}z^{-1} + a_{22}z^{-2}} \right)$ | $a_{21} = -8276806$<br>$a_{22} = 4083972$<br>$b_{20} = 4138770$<br>$b_{21} = -8277540$<br>$b_{22} = 4138770$ |
| IIR2 (Coefficient set 2)<br>2 <sup>nd</sup> order, high pass<br>Corner at 0.60% $f_s$<br>5 coefficients | $H(z) = \left( \frac{b_{20} + b_{21}z^{-1} + b_{22}z^{-2}}{1 + a_{21}z^{-1} + a_{22}z^{-2}} \right)$ | $a_{21} = -8165041$<br>$a_{22} = 3976543$<br>$b_{20} = 4083972$<br>$b_{21} = -8167944$<br>$b_{22} = 4083972$ |
| IIR2 (Coefficient set 3)<br>2 <sup>nd</sup> Order, high pass<br>Corner at 0.90% $f_s$<br>5 coefficients | $H(z) = \left( \frac{b_{20} + b_{21}z^{-1} + b_{22}z^{-2}}{1 + a_{21}z^{-1} + a_{22}z^{-2}} \right)$ | $a_{21} = -8053350$<br>$a_{22} = 3871939$<br>$b_{20} = 4029898$<br>$b_{21} = -8059796$<br>$b_{22} = 4029898$ |
| IIR2 (Coefficient set 4)<br>2 <sup>nd</sup> order, high pass<br>Corner at 1.20% $f_s$<br>5 coefficients | $H(z) = \left( \frac{b_{20} + b_{21}z^{-1} + b_{22}z^{-2}}{1 + a_{21}z^{-1} + a_{22}z^{-2}} \right)$ | $a_{21} = -7941764$<br>$a_{22} = 3770088$<br>$b_{20} = 3976539$<br>$b_{21} = -7953078$<br>$b_{22} = 3976539$ |

**Table 18. IIR Filter Coefficients**



**Figure 30. Gain and Offset Correction**

## 15.GAIN AND OFFSET CORRECTION

The CS5376A digital filter can apply independent gain and offset corrections to the data of each measurement channel. Also, an offset calibration algorithm can automatically calculate offset correction values for each channel.

Gain correction values are written to the GAINx registers (0x21-0x24), while offset correction values are written to the OFFSETx registers (0x25-0x28). Gain and offset corrections are enabled by the USEGR and USEOR bits in the FILTCFG register (0x20).

When enabled, the offset calibration algorithm will automatically calculate offset correction values for each channel and write them into the OFFSETx registers. Offset calibration is enabled by writing the EXP and ORCAL bits in FILTCFG.

### 15.1 Gain Correction

Gain correction in the CS5376A normalizes sensor gains in multi-sensor networks. It requires exter-

nally calculated correction values to be written into the GAINx registers (0x21-0x24).

Gain correction values are 24-bit two's complement with unity gain defined as full scale, 0x7FFFFFFF. Gain correction always scales to a fractional value, and can never gain the digital filter data greater than one.

$$\text{Output Value} = \text{Data} * (\text{GAIN} / 0x7FFFFFFF)$$

$$\text{Unity Gain: GAIN} = 0x7FFFFFFF$$

$$\text{50\% Gain: GAIN} = 0x3FFFFFFF$$

$$\text{Zero Gain: GAIN} = 0x000000$$

Once the GAIN registers are written, the USEGR bit in the FILTCFG register enables gain correction.

### 15.2 Offset Correction

Offset correction in the CS5376A cancels the DC bias of a measurement channel by subtracting the

value in the OFFSETx registers (0x25-0x28) from the digital filter output data word.

Offset correction values are 24-bit two's complement with a maximum positive value of 0x7FFFFFFF, and a maximum negative value of 0x800000. If applying an offset correction causes the final result to exceed a 24-bit two's complement maximum, the output data will saturate to that maximum value.

$$\text{Output Data} = \text{Input Data} - \text{Offset Correction}$$

$$\text{Max Positive Output Value} = 0x7FFFFFFF$$

$$\text{Max Negative Output Value} = 0x800000$$

Once the OFFSET registers are written, the USE-OR bit in the FILTCFG register enables offset correction.

### 15.3 Offset Calibration

An offset calibration algorithm in the CS5376A can automatically calculate offset correction values. When using the offset calibration algorithm, background noise data should be used as the basis for calculating the offset value of each measurement channel.

The offset calibration algorithm is an exponential averaging function that places increased weight on

more recent digital filter data. The exponential weighting factor is set by the EXP bits in the FILTCFG register, with larger exponent values producing a smoother averaging function that requires a longer settling time, and smaller values producing a noisier averaging function that requires a shorter settling time. Typical exponential values range from 0x05 to 0x0F, depending on the available settling time.

The characteristic equations of the offset calibration algorithm include an input value, X, an output value, Y, a summation value, YSUM, a sample index, n, and an exponential value, EXP.

$$Y(n) = X(n) - [YSUM(n-1) \gg \text{EXP}]$$

$$YSUM(n) = Y(n) + YSUM(n-1)$$

$$\text{Offset Correction} = YSUM \gg \text{EXP}$$

Once the EXP bits are written, the ORCAL bit in the FILTCFG register is set to enable offset calibration. When enabled, updated offset correction values are automatically written to the OFFSETx registers. When the offset calibration algorithm is fully settled, the ORCAL bit is cleared to maintain the final values in the OFFSETx registers.

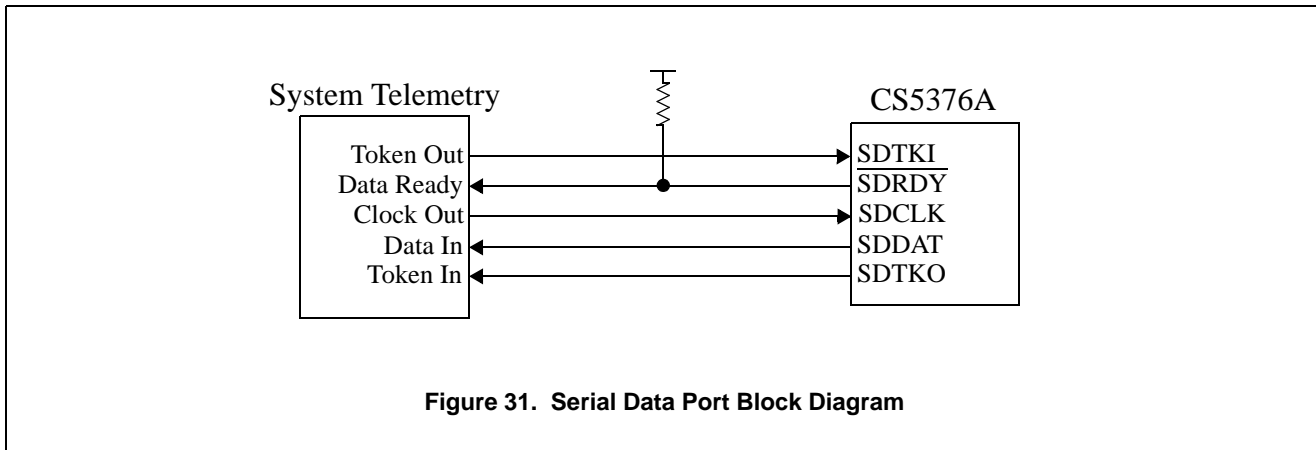


Figure 31. Serial Data Port Block Diagram

## 16. SERIAL DATA PORT

Once digital filtering is complete, each 24-bit output sample is combined with an 8-bit status byte. These 32-bit data words are written to an 8-deep FIFO buffer and then transmitted to the communications channel through a high speed serial data port (SD port).

### 16.1 Pin Descriptions

#### ***SDTKI - Pin 64***

Token input, requests an SD port transaction.

#### ***SDRDY - Pin 61***

Data ready output signal, active low. Open drain output requiring a 10 kΩ pull-up resistor.

#### ***SDCLK - Pin 62***

Serial clock input.

#### ***SDDAT - Pin 60***

Serial data output. Data valid on rising edge of SDCLK, transition on falling edge.

#### ***SDTKO - Pin 63***

Token output, ends an SD port transaction. Passes through the SDTKI signal when no data is available in the SD port output FIFO.

### 16.2 SD Port Data Format

Serial data transactions transfer 32-bit words. Each word consists of an 8-bit status byte followed by a 24-bit output sample. The status byte, shown in Figure 32, has an MFLAG bit, channel bits, a time break bit, and a FIFO overflow bit.

#### ***MFLAG Bit - MFLAG***

The MFLAG bit is set when an MFLAG signal is received on the MFLAG1-MFLAG4 pins. When received, that channel MFLAG bit is set in the next output word. See “Modulator Interface” on page 39 for more information about MFLAG.

#### ***Channel Bits - CH[1:0]***

Channel bits indicate from which conversion channel the data word is from. The channel number, CH[1:0], is zero based.

CH[1:0] = 00 = Channel 1

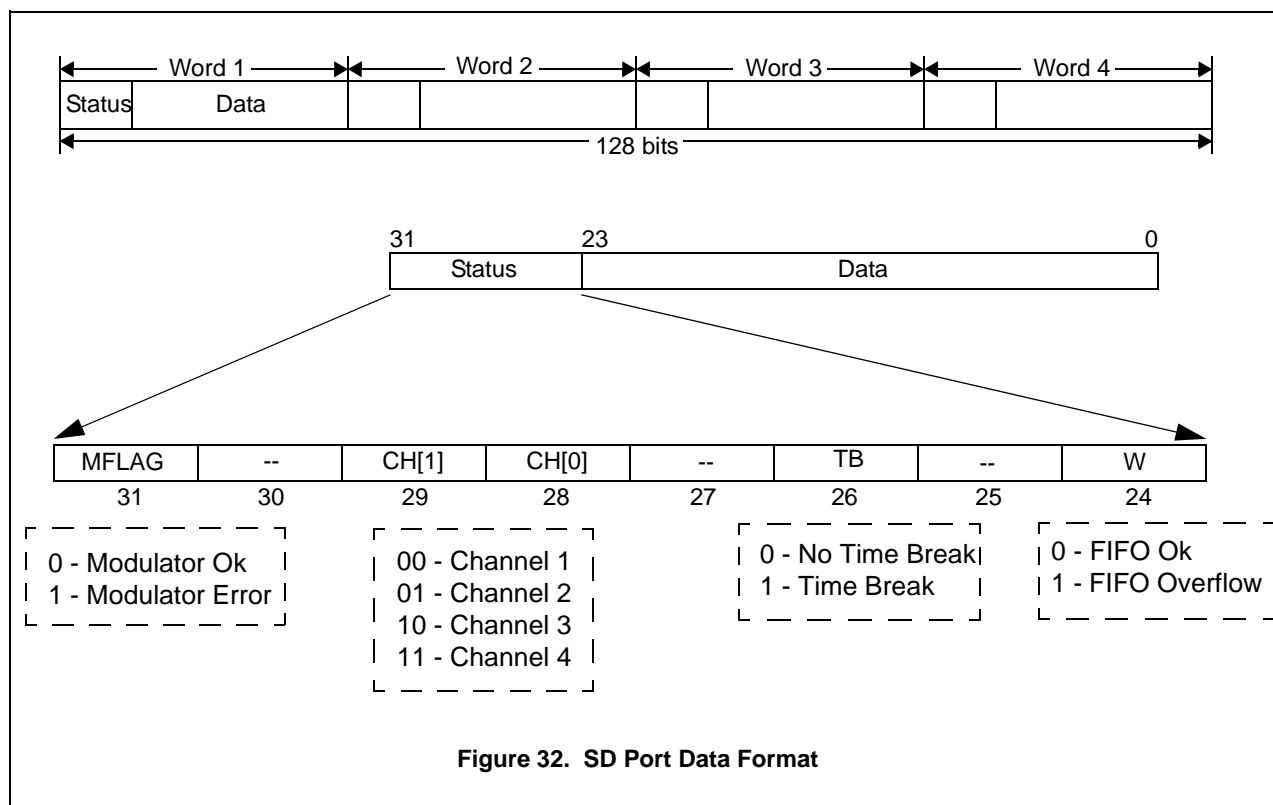
CH[1:0] = 01 = Channel 2

CH[1:0] = 10 = Channel 3

CH[1:0] = 11 = Channel 4

#### ***Time Break Bit - TB***

The time break bit marks a timing reference based on a rising edge into the TIMEB pin. After a programmed delay, the TB bit in the status byte is set for one output sample in all channels. The TIME-



BRK digital filter register (0x29) programs the sample delay for the TB bit output. See “Time Break Controller” on page 68 for more information about time break.

### **FIFO Overflow Bit - W**

The FIFO overflow bit indicates an error condition in the SD port data FIFO, and is set if new digital filter data overwrites a FIFO location containing data which has not yet been sent.

The W bit is sticky, meaning it persists indefinitely once set. Clearing the W bit requires sending the ‘Filter Stop’ and ‘Filter Start’ configuration commands to reinitialize the data FIFO.

### **Conversion Data Word**

The lower 24-bits of the SD port output data word is the conversion sample for the specified channel. Conversion data is 24-bit two’s complement format.

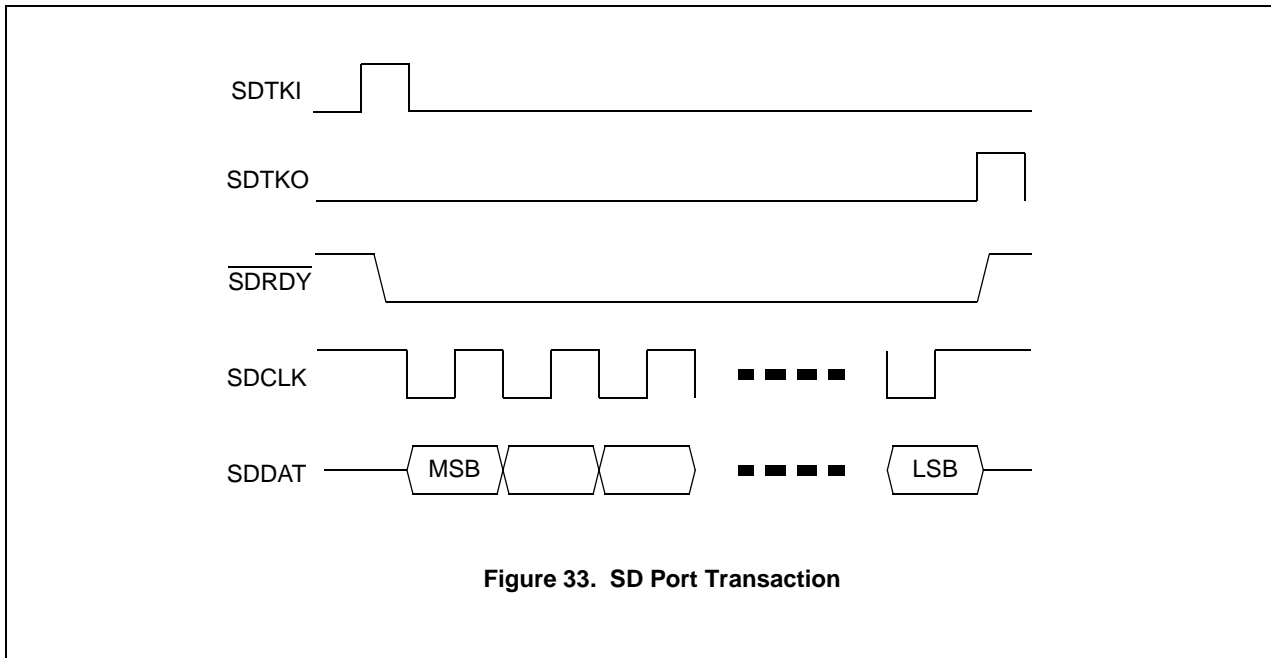
## **16.3 SD Port Transactions**

The SD port can operate in two modes depending how the SDTKI pin is connected: request mode where data is output when requested by the communications channel, or continuous mode where data is output immediately when ready.

### **16.3.1 Request Mode**

To initiate SD port transactions on request, SDTKI is connected to an active high polling signal from the communications channel. A rising edge into SDTKI when new data is available in the SD port FIFO causes the CS5376A to initiate an SD port transaction by driving SDRDY low. If data is not yet available in the SD port FIFO, the SDTKI signal is passed through to the SDTKO output.

Once an SD port transaction is initiated, serial clocks into SDCLK cause data to be output to SDDAT, as shown in Figure 33. When all available



**Figure 33. SD Port Transaction**

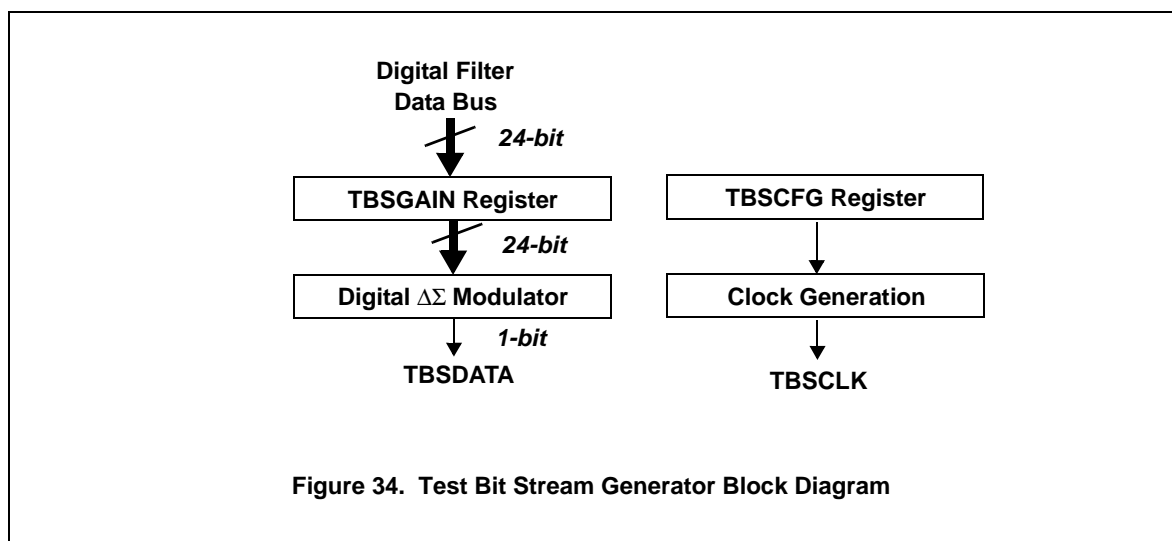
data is read from the SD port data FIFO,  $\overline{\text{SDRDY}}$  is released and SDTKO is pulsed high for 100 nS.

### 16.3.2 Continuous Mode

To have the CS5376A automatically initiate SD port transactions whenever data becomes available, connect SDTKI to a 4 MHz or slower clock source such as MCLK/2. The first rising edge into SDTKI after data becomes available in the SD port FIFO

causes the CS5376A to initiate an SD port transaction by driving  $\overline{\text{SDRDY}}$  low. If data is not available in the SD port FIFO, the SDTKI signal is passed through to the SDTKO output.

Once an SD port transaction is initiated, serial clocks into SDCLK cause data to be output to SDDAT, as shown in Figure 33. When all available data is read from the SD port data FIFO,  $\overline{\text{SDRDY}}$  is released and SDTKO is pulsed high for 100 nS.



## 17. TEST BIT STREAM GENERATOR

The CS5376A test bit stream (TBS) generator creates sine wave or impulse  $\Delta\Sigma$  bit stream data to drive an external test DAC. The TBS digital output can also be internally connected to the MDATA inputs for loopback testing of the digital filter.

### 17.1 Pin Descriptions

#### **TBSDATA - Pin 9**

Test bit stream 1-bit  $\Delta\Sigma$  data output.

#### **TBSCLK - Pin 8**

Test bit stream clock output. Not used by the CS4373A test DAC.

### 17.2 TBS Architecture

The test bit stream generator consists of a data interpolator and a digital  $\Delta\Sigma$  modulator. It receives periodic 24-bit data from the digital filter to create a 1-bit  $\Delta\Sigma$  data output on the TBSDATA pin. It also creates a clock signal at the data rate, output to the TBSCLK pin.

The TBS input data from the digital filter is scaled by the TBSGAIN register (0x2B). Maximum stable amplitude is 0x04FFFF, with 0x04B8F2 approximately full scale for the CS4373A test DAC. The full scale 1-bit  $\Delta\Sigma$  output from the TBS generator is

defined as 25% minimum and 75% maximum one's density.

### 17.3 TBS Configuration

Configuration options for the TBS generator are set through the TBSCFG register (0x2A). Gain scaling of the TBS generator output is set by the TBSGAIN register (0x2B).

#### **Interpolation Factor - INTP[7:0]**

Selects how many times the interpolator uses a data point when generating the output bit stream. Interpolation is zero based and represents one greater than the programmed register value.

#### **Operational Mode - TMODE**

Selects between sine wave or impulse output mode.

#### **Clock Rate - RATE[2:0]**

Selects the TBSDATA and TBSCLK output rate.

#### **Synchronization - TSYNC**

Enables synchronization of the TBS output phase to the MSYNC signal.

#### **Clock Delay - CDLY[2:0]**

Programs a fractional delay for TBSCLK with a 1/8 clock period resolution.



**Test Bit Stream Characteristic Equation:**

$$(Signal\ Freq) * (\#\ TBS\ Data) * (Interpolation + 1) = Output\ Rate$$

**Example:**  $(31.25\ Hz) * (1024) * (0x07 + 1) = 256\ kHz$

| Signal Frequency (TBSDATA) | Output Rate (TBSCLK) | Output Rate Selection (RATE) | Interpolation Selection (INTP) |
|----------------------------|----------------------|------------------------------|--------------------------------|
| 10.00 Hz                   | 256 kHz              | 0x4                          | 0x18                           |
| 10.00 Hz                   | 512 kHz              | 0x5                          | 0x31                           |
| 25.00 Hz                   | 256 kHz              | 0x4                          | 0x09                           |
| 25.00 Hz                   | 512 kHz              | 0x5                          | 0x13                           |
| 31.25 Hz                   | 256 kHz              | 0x4                          | 0x07                           |
| 31.25 Hz                   | 512 kHz              | 0x5                          | 0x0F                           |
| 50.00 Hz                   | 256 kHz              | 0x4                          | 0x04                           |
| 50.00 Hz                   | 512 kHz              | 0x5                          | 0x09                           |
| 125.00 Hz                  | 256 kHz              | 0x4                          | 0x01                           |
| 125.00 Hz                  | 512 kHz              | 0x5                          | 0x03                           |

**Table 19. TBS Configurations Using On-chip Data**

**Loopback - LOOP**

Enables digital loopback from the TBS output to the MDATA inputs.

**Run - RUN**

Enables the test bit stream generator.

**Data Delay - DDLY[5:0]**

Programs full period delays for TBSDATA, up to a maximum of 63 bits.

**Gain - TBSGAIN[23:0]**

Scales the amplitude of the sine wave output and generated impulse. Maximum 0x04FFFF, nominal 0x04B8F2.

**17.4 TBS Data Source**

Data to create test signals is loaded into digital filter memory by configuration commands. The on-

chip sine wave data is suitable for most tests, though custom data is required to support custom signal frequencies. See “EEPROM Configuration Commands” on page 28 or “Microcontroller Configuration Commands” on page 35 for information about programming TBS data.

**TBS ROM Data**

An on-chip 24-bit 1024 point digital sine wave is stored on the CS5376A. When selected by the ‘Write TBS ROM Data’ configuration command, the TBS generator can produce the test signal frequencies listed in Table 19. Additional discrete test frequencies and output rates can be programmed with the on-chip data by varying the interpolation factor and output rate.

**Test Bit Stream Impulse Characteristics:**

| Interpolation Selection (INTP) | Output Rate Selection (RATE) | Pulse Width from CS4373A | Gain Scale Factor (TBSGAIN) | Pulse Height from CS4373A |
|--------------------------------|------------------------------|--------------------------|-----------------------------|---------------------------|
| 0xFF                           | 0x5                          | 500 $\mu$ s              | 0x04B8F2                    | 860 mV                    |
| 0xFF                           | 0x4                          | 1 ms                     | 0x04B8F2                    | 820 mV                    |
| 0xFF                           | 0x3                          | 2 ms                     | 0x04B8F2                    | 820 mV                    |
| 0x7F                           | 0x5                          | 250 $\mu$ s              | 0x04B8F2                    | 820 mV                    |
| 0x7F                           | 0x4                          | 500 $\mu$ s              | 0x04B8F2                    | 820 mV                    |
| 0x7F                           | 0x3                          | 1 ms                     | 0x04B8F2                    | 820 mV                    |

**Table 20. TBS Impulse Characteristics**
**Custom TBS Data**

If a required test frequency cannot be generated using the on-chip test bit stream data, a custom data set can be written into the CS5376A. The number of data points to write, up to a maximum of 1024, depends on the required test signal frequency, output rate, and available interpolation factors. Custom data sets must be continuous on the ends; i.e. when copied end-to-end the data set must produce a smooth curve.

**17.5 TBS Sine Wave Output**

When the TMODE bit in the TBSCFG register is low, the TBS generator operates in sine wave mode. In this mode, sine wave data from digital filter memory is used to create a sine wave test signal that can drive a test DAC. Sine wave frequency and output data rate are calculated as shown by the characteristic equation of Table 19.

The sine wave maximum  $\Delta\Sigma$  one's density output from the TBS generator is set by the TBSGAIN register. TBSGAIN can be programmed up to a maximum of 0x04FFFF, with the TBS generator unstable for higher amplitudes. For the CS4373A test DAC, a gain value of 0x04B8F2 produces an approximately full scale sine wave output ( $5 V_{pp}$  differential).

**17.6 TBS Impulse Output**

If the TMODE bit in TBSCFG is set high, the TBS generator operates in impulse mode. In this mode, the value in TBSGAIN sets the amplitude of the generated impulse. Impulse amplitude and period are calculated as shown in Table 20.

To create a -20 dB impulse from the TBS generator, the TBSGAIN register should be set to maximum 0x0078E5, and the INTP bits in TBSCFG should also be set to maximum 0xFF. The RATE bits should be set to produce data at the correct rate for the test DAC.

A rising edge on the TIMEB pin triggers the impulse output. When impulse mode is enabled but no TIMEB input is received, the TBS generator uses a negated TBSGAIN register as a repetitive input value. When a rising edge is recognized on the TIMEB pin, a single positive TBSGAIN value is written to the TBS generator to create the impulse.

**17.7 TBS Loopback Testing**

Included as part of the CS5376A test bit stream generator is a feedback path to the digital filter MDATA inputs. This loopback mode provides a fully digital signal path to test the TBS generator, digital filter, and data collection interface. Digital

loopback testing expects 512 kHz  $\Delta\Sigma$  data for the MDATA inputs.

A mismatch of the TBS generator full scale output and the MDATA full scale input results in an amplitude mismatch when testing in loopback mode. The TBS generator outputs a 75% maximum one's density, while the MDATA inputs expect an 86% maximum one's density from a  $\Delta\Sigma$  modulator, resulting in a measured full scale error of -3.6 dB.

### 17.8 TBS Synchronization

When the TSYNC bit is set in the TBSCFG register, the MSYNC signal resets the sine wave data pointer and phase aligns the TBS signal output. Once the digital filter is settled, all CS5376A devices receiving the SYNC signal will have identical TBS signal phase. See "Synchronization" on page 25 for more information about the SYNC and MSYNC signals.

If TSYNC is clear, MSYNC has no effect on the TBS data pointer and no change in the TBS output phase will occur during synchronization.

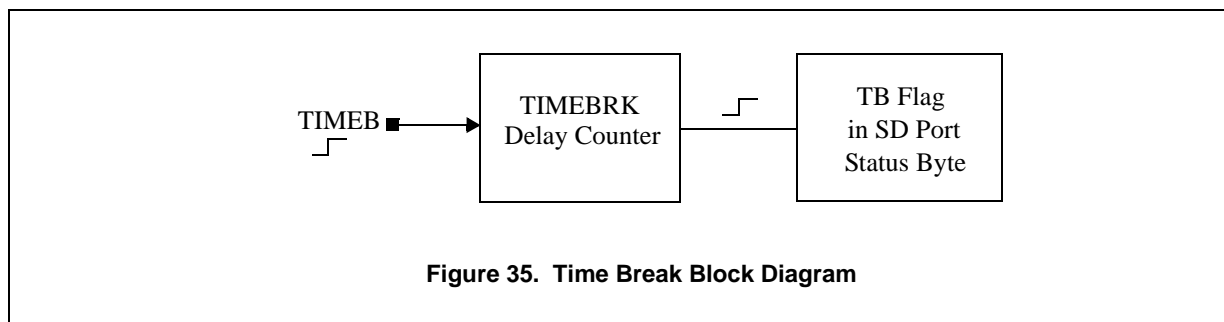


Figure 35. Time Break Block Diagram

## 18. TIME BREAK CONTROLLER

A time break signal is used to mark timing events that occur during measurement. An external signal sets a flag in the status byte of an output sample to mark when the external event occurred.

A rising edge input to the TIMEB pin causes the TB timing reference flag to be set in the SD port status byte. When set, the TB flag appears for only one output sample in the status byte of all enabled channels. The TB flag output can be delayed by programming a sample delay value into the TIMEBRK digital filter register.

### 18.1 Pin Description

#### **TIMEB - Pin 57**

Time break input pin, rising edge triggered.

### 18.2 Time Break Operation

An externally generated timing reference signal applied to the TIMEB pin initiates an internal sample counter. After a number of output samples have passed, programmed in the TIMEBRK digital filter register (0x29), the TB flag is set in the status byte of the SD port output word for all enabled channels. The TB flag is automatically cleared for subsequent data words, and appears for only one output sample in each channel.

### 18.3 Time Break Delay

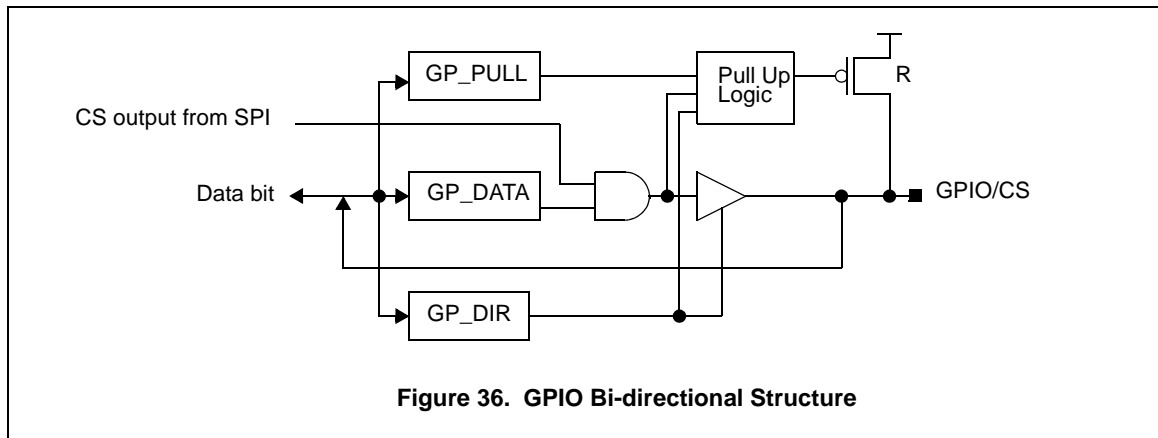
The TIMEBRK register (0x29) sets a sample delay between a received rising edge on the TIMEB pin and writing the TB flag into the SD port status byte.

The programmable sample counter can compensate for group delay through the digital filters. When the proper group delay value is programmed into the TIMEBRK register, the TB flag will be set in the status byte of the measurement sample taken when the timing reference signal was received.

#### **18.3.1 Step Input and Group Delay**

A simple method to empirically measure the step response and group delay of a CS5376A measurement channel is to use the time break signal as both a timing reference input and an analog step input.

When a rising edge is received on the TIMEB pin with no delay programmed into the TIMEBRK register, the TB flag is set in the next SD port status byte. The same rising edge can act as a step input to the analog channel, propagating through the digital filter to appear as a rising edge in the measurement data. By comparing the timing of the TB status flag output and the rising edge in the measurement data, the measurement channel group delay can be determined.



## 19. GENERAL PURPOSE I/O

The General Purpose I/O (GPIO) block provides 12 general purpose pins to interface with external hardware.

### 19.1 Pin Descriptions

#### ***GPIO[4:0]:CS[4:0] - Pins 32 - 36***

Standard GPIO pins also used as SPI 2 chip selects.

#### ***GPIO[5:10] - Pins 37, 41 - 45***

Standard GPIO pins.

#### ***GPIO11:EECS - Pin 46***

Standard GPIO pin also used as an SPI 1 chip select when booting from an external EEPROM.

### 19.2 GPIO Architecture

Each GPIO pin can be configured as input or output, high or low, with a weak (~200 kΩ) internal pull-up resistor enabled or disabled. Several GPIO pins also double as chip selects for the SPI 1 and SPI 2 serial ports. Figure 36 shows the structure of a bi-directional GPIO pin with SPI chip select functionality.

When the CS5376A is used as an SPI master, either when booting from EEPROM using SPI 1 or performing master mode transactions using SPI 2, the chip select signals from SPI 1 and SPI 2 are logically AND-ed with the GPIO data bit. The corre-

sponding GPIO pin should be initialized as output mode and logical 1 to produce the chip select falling edge.

### 19.3 GPIO Registers

When used as standard GPIO pins, settings are programmed in the GPCFG0 and GPCFG1 registers. GP\_DIR bits set the input/output mode, GP\_PULL bits enable/disable the internal pull-up resistor, and GP\_DATA bits set the output data value. After reset, GPIO pins default as inputs with pull-up resistors enabled.

### 19.4 GPIO Input Mode

When reading a value from the GP\_DATA bits, the returned data reports the current state of the pins. If a pin is externally driven high it reads a logical 1, if externally driven low it reads a logical 0. When a GPIO pin is used as an input, the pull-up resistor should be disabled to save power if it isn't required.

### 19.5 GPIO Output Mode

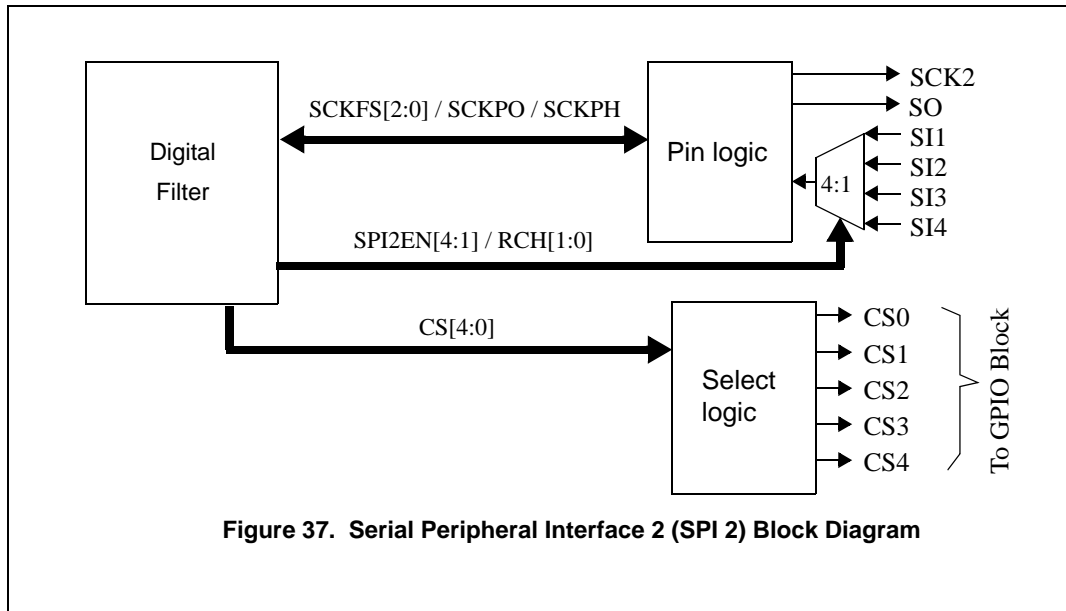
When a GPIO pin is programmed as an output with a data value of 0, the pin is driven low and the internal pull-up resistor is automatically disabled. When programmed as an output with a data value of 1, the pin is driven high and the pull-up resistor is inconsequential.

Any GPIO pin can be used as an open-drain output by setting the data value to 0, enabling the pull-up, and using the GP\_DIR direction bits to control the pin value. This open-drain output configuration uses the internal pull-up resistor to hold the pin high when GP\_DIR is set as an input, and drives the pin low when GP\_DIR is set as an output.

#### **19.5.1 GPIO Reads in Output Mode**

When reading GPIO pins the GP\_DATA register value always reports the current state of the pins, so

a value written in output mode does not necessarily read back the same value. If a pin in output mode is written as a logical 1, the CS5376A attempts to drive the pin high. If an external device forces the pin low, the read value reflects the pin state and returns a logical 0. Similarly, if an output pin is written as a logical 0 but forced high externally, the read value reflects the pin state and returns a logical 1. In both cases the CS5376A is in contention with the external device resulting in increased power consumption.



**Figure 37. Serial Peripheral Interface 2 (SPI 2) Block Diagram**

## 20. SERIAL PERIPHERAL INTERFACE 2

The Serial Peripheral Interface 2 (SPI 2) port is a master mode SPI port designed to interface with serial peripherals. By writing the SPI2 digital filter registers, multiple serial slave devices can be controlled through the CS5376A.

### 20.1 Pin Descriptions

#### **CS[4:0] - Pins 32 - 36**

Serial chip selects. Multiplexed with GPIO pins.

#### **SCK2 - Pin 31**

Serial clock output, common to all channels.

#### **SO - Pin 30**

Serial data output, common to all channels.

#### **SI[4:1] - Pins 26 - 29**

Serial data inputs.

### 20.2 SPI 2 Architecture

The SPI 2 pin interface has multiple chip selects and serial data inputs, but a common serial clock and serial data output. Which chip select and serial input to use for a particular slave serial transaction

is selected by bits in the SPI2CTRL digital filter register.

SPI 2 chip select outputs are multiplexed with GPIO pins, which cannot perform both functions simultaneously. When used as a chip select, the GPIO output must be programmed high to permit the chip select to operate as an active low signal. See “General Purpose I/O” on page 69 for information about programming the GPIO pins.

The SPI 2 interface transfers data from the SPI 2 registers to a slave serial device and back through a bi-directional 8-bit shift register. Serial transactions are automatic once control, command, and data values are written into the SPI 2 digital filter registers.

### 20.3 SPI 2 Registers

SPI 2 transactions are initiated by first writing command, address, and data values to the SPI2CMD and SPI2DAT digital filter registers, and then writing the SPI2CTRL register to set the D2SREQ bit. The D2SREQ bit initiates a serial transaction using the programmed SPI2CTRL configuration.

### 20.3.1 SPI 2 Control Register

The SPI 2 hardware is configured by the SPI2CTRL digital filter register (0x10).

Bits in this register select the serial input pin and chip select pin used for a transaction, set the total number of bytes in a transaction, initiate a serial transaction, and report status information about a transaction. Other bits in SPI2CTRL set hardware configuration options such as the serial clock rate, the SPI mode, and the state of internal pull-up resistors.

#### **Chip Select Enable - CS[4:0]**

The chip select pin to use during a transaction is selected by the CS0, CS1, CS2, CS3, and CS4 bits. Multiple chip selects can be enabled to send a transaction to more than one serial peripheral.

#### **Serial Input Select - SPI2EN[4:1], RCH[1:0]**

Which serial input pin will receive data is selected using the SPI2EN bits and the RCH bits. The SPI2EN bits enable the serial input, while the RCH bits select it for the SPI 2 transaction.

A channel's SPI2EN bit should always be enabled, even when transactions do not expect to receive data from the slave device.

#### **Transaction Bytes - DNUM[2:0]**

DNUM bits specify the total number of bytes to transfer during a serial transaction, including command and address bytes. DNUM is zero based and represents one greater than the number programmed.

#### **Serial Clock Rate - SCKFS[2:0]**

The serial clock rate output from the SCK2 pin is selected by the SCKFS bits. Serial clock rates range from 32 kHz to 4.096 MHz.

#### **SPI Mode - SCKPO, SCKPH**

The serial mode used for a transaction depends on the SCKPO and SCKPH bits. The SPI 2 port sup-

ports all four SPI modes, with mode 0 and mode 3 the most commonly used. Supported modes are:

SPI Mode 0 (0,0): SCKPO = 0, SCKPH = 0

SPI Mode 1 (0,1): SCKPO = 0, SCKPH = 1

SPI Mode 2 (1,0): SCKPO = 1, SCKPH = 0

SPI Mode 3 (1,1): SCKPO = 1, SCKPH = 1

#### **Wired-Or Mode - WOM**

The SPI 2 pins can operate in two modes depending on the WOM bit. A default push-pull configuration drives output signals both high and low. Wired-Or mode only drives low, relying on a weak internal pull-up resistor to pull the output high. Wired-Or mode permits multiple serial controllers to access the same bus without contention.

#### **Initiating Serial Transactions - D2SREQ**

Writing the D2SREQ bit starts an SPI 2 serial transaction. When complete, the D2SREQ bit is automatically cleared by the SPI 2 hardware.

#### **Status and Error Bits - D2SOP, SWEF, TM**

Three bits in the SPI2CTRL register report status and error information.

D2SOP is set when the SPI 2 port is busy performing a transaction. It is automatically cleared when the transaction is completed.

SWEF is set if a request to initiate a new transaction occurs during the current transaction. This flag is latched and must be cleared manually.

TM is set to indicate the SPI 2 port timed out on the requested transaction. This flag is latched and must be cleared manually.

### 20.3.2 SPI 2 Command Register

The SPI2CMD register (0x11) is a 16-bit digital filter register with the high byte designated as an SPI command and the low byte designated as an address. The high byte holds an 8-bit SPI 'write' or 'read' opcode, as shown in Figure 38, and the low byte holds an 8-bit serial address.



During a transaction, bits in SPI2CMD are output MSB first, with data in SPI2DAT written or read following.

### 20.3.3 SPI 2 Data Register

The SPI2DAT register (0x12) is a 24-bit digital filter register containing three SPI data bytes. Data in SPI2DAT is always LSB aligned, with 1-byte data written or received using the low byte, 2-byte data written or received using the middle and low bytes, and 3-byte data written or received using all three bytes.

Data in SPI2DAT is written or read after writing the command and address bytes from the SPI2CMD register.

## 20.4 SPI 2 Transactions

The SPI 2 port operates as an SPI master to perform write and read transactions with serial slave peripherals. The exact format of the SPI transactions depends on the SPI mode, selected using the SCKPO and SCKPH bits in the SPI2CTRL register.

### Write Transactions

Write transactions start by writing an SPI ‘write’ (0x02) opcode and an 8-bit destination address into the SPI2CMD register and the output data value to the SPI2DAT register. Writing the D2SREQ bit in the SPI2CTRL register initiates the SPI 2 transaction based on the SPI2CTRL configuration.

A write transaction outputs 1 or 2 bytes from the SPI2CMD register followed by 1, 2, or 3 bytes from the SPI2DAT register. Write transactions are therefore a minimum of 1 byte (DNUM = 0) and a maximum of 5 bytes (DNUM = 4). The SPI 2 port uses the DNUM bits in the SPI2CTRL register to determine the total number of bytes to send during a write transaction.

Write transactions are not required to use standard SPI commands. If serial peripherals use non-

standard write commands they can be written into SPI2CMD and SPI2DAT as required.

### Read Transactions

Read transactions start by writing an SPI ‘read’ (0x03) opcode and an 8-bit source address to the SPI2CMD register. Writing the D2SREQ bit in the SPI2CTRL register initiates the SPI 2 transaction based on the SPI2CTRL configuration, with the data value automatically received into the SPI2DAT register.

A read transaction outputs 2 bytes from the SPI2CMD register and can receive 1, 2, or 3 bytes into the SPI2DAT register. Read transactions are a minimum of 3 bytes (DNUM = 2) and a maximum of 5 bytes (DNUM = 4). The SPI 2 port uses the DNUM bits in the SPI2CTRL register to determine the total number of bytes to send and receive during a read transaction.

Read transactions are not required to use standard SPI commands. If serial peripherals use non-standard read commands they can be written to the SPI2CMD register, as long as they conform to the format of 2 bytes out with 1, 2, or 3 bytes in.

### SPI Modes

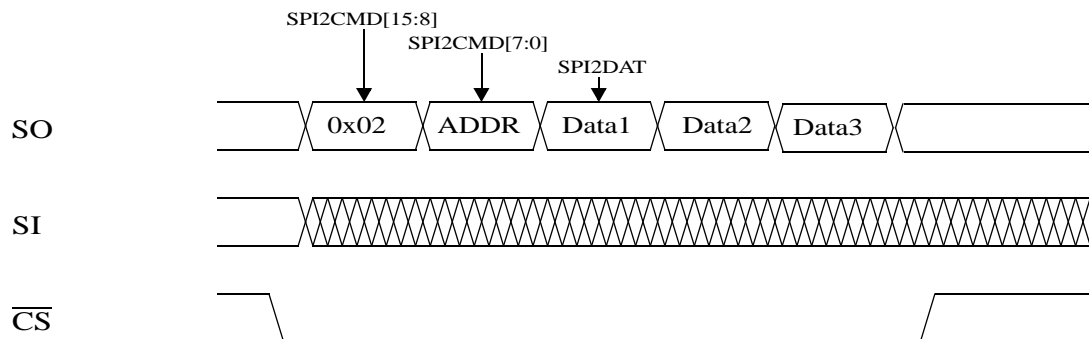
The SPI mode for the SPI 2 port is selected in the SPI2CTRL register using the SCKPO and SCKPH bits. The most commonly used SPI modes are mode 0 and mode 3, both of which define the serial clock with data valid on rising edges and transitioning on falling edges.

In SPI mode 0, the SCK2 serial clock is defined initially in a low state. Output data on the SO pin is valid immediately after the chip select pin goes low, and the first rising edge of SCK2 latches valid data.

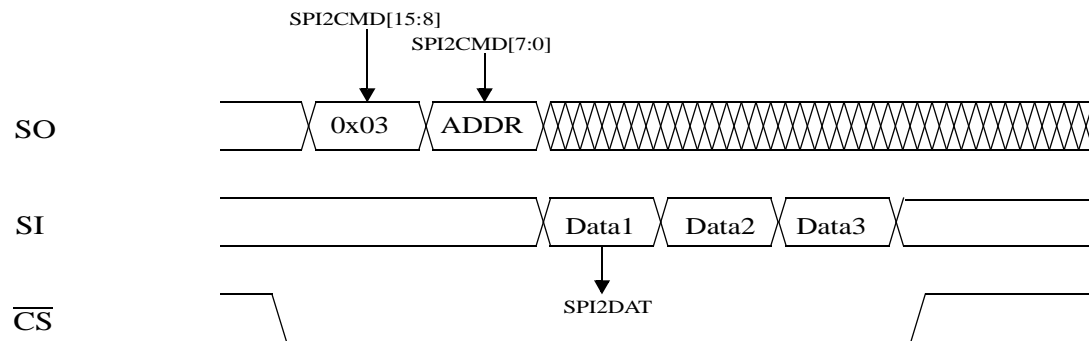
In SPI mode 3, the SCK2 serial clock is defined initially in a high state. Output data on the SO pin is invalid until the initial falling edge of SCK2, and the first rising edge of SCK2 latches valid data.

| Instruction | Opcode | Address      | Definition  |
|-------------|--------|--------------|---|
| Write       | 0x02   | SPI2CMD[7:0] | Write serial peripheral beginning at the address given in SPI2CMD[7:0]. |
| Read        | 0x03   | SPI2CMD[7:0] | Read serial peripheral beginning at the address given in SPI2CMD[7:0].  |

### SPI 2 Write to External Slave

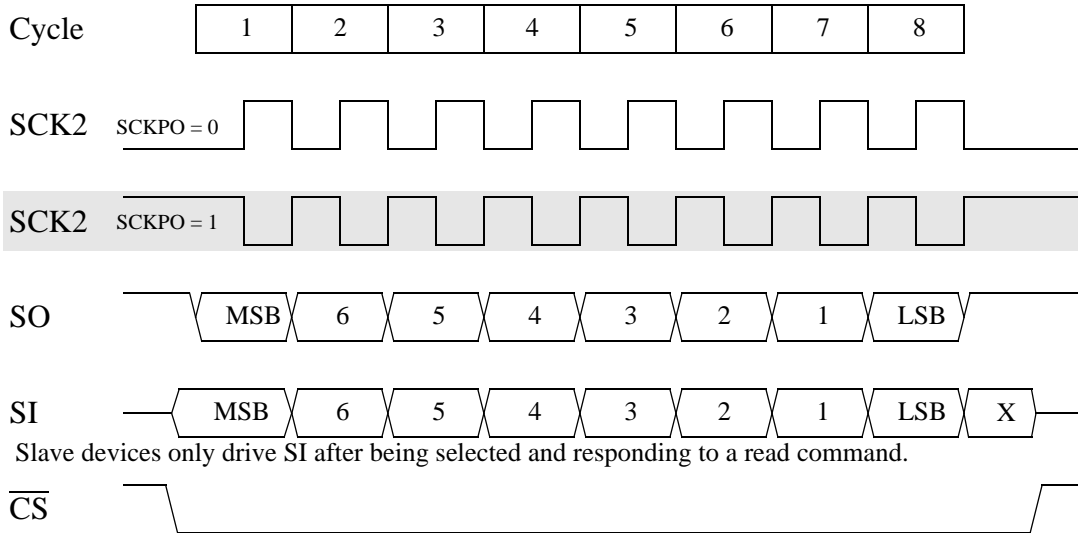
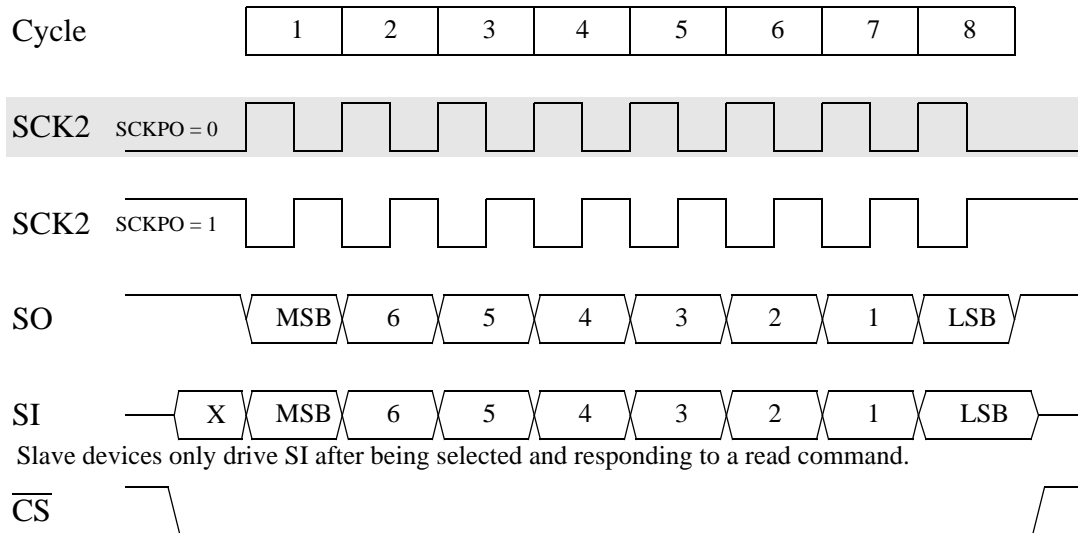


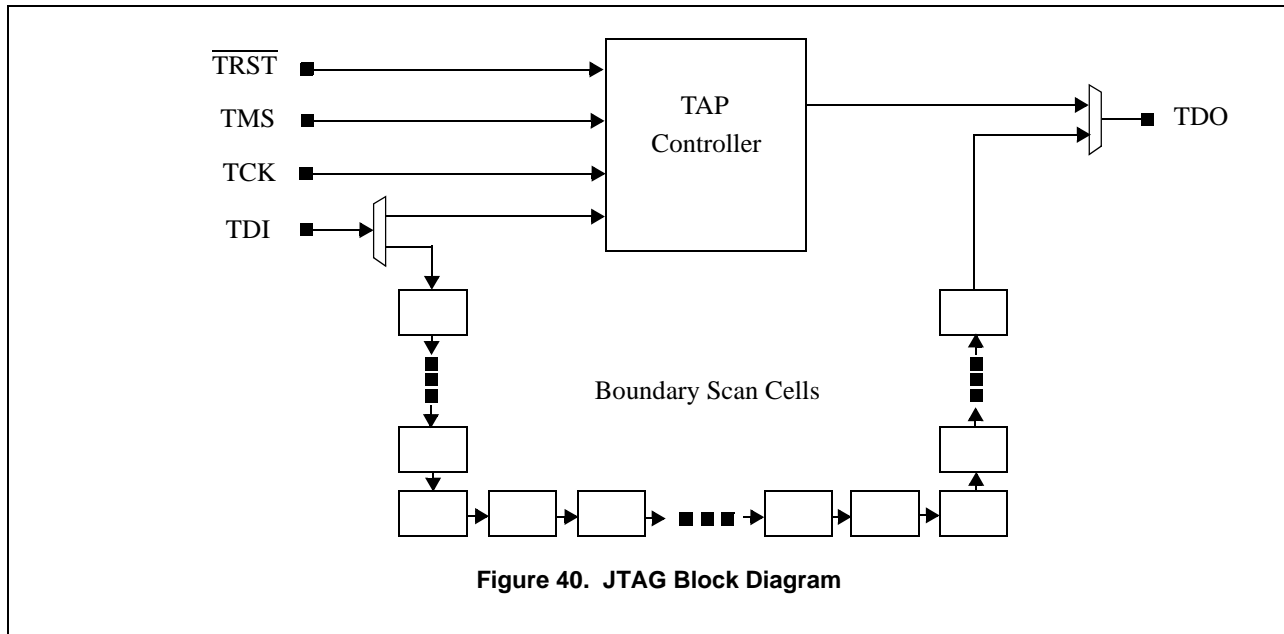
### SPI 2 Read from External Slave



**Figure 38. SPI 2 Master Mode Transactions**

SPI modes 1 and 4 work similarly to modes 0 and 3, with the serial clock defined to have data valid on falling edges and transitioning on rising edges.

**SPI 2 Transaction with SCKPH=0**

**SPI 2 Transaction with SCKPH=1**

**Figure 39. SPI 2 Transaction Details**



## 21. BOUNDARY SCAN JTAG

The CS5376A includes an IEEE 1149.1 boundary scan JTAG port to test PCB interconnections. Refer to the IEEE 1149.1 specification for more information about boundary scan testing.

### 21.1 Pin Descriptions

#### ***TRST*** - Pin 1

Reset input for the test access port (TAP) controller and all boundary scan cells, active low. Connect to GND to disable the JTAG port.

#### ***TMS*** - Pin 2

Serial input to select the JTAG test mode.

#### ***TCK*** - Pin 3

Clock input to the TAP controller.

#### ***TDI*** - Pin 4

Serial input to the scan chain or TAP controller.

#### ***TDO*** - Pin 5

Serial output from the scan chain or TAP controller.

### 21.2 JTAG Architecture

The JTAG test circuitry consists of a test access port (TAP) controller and boundary scan cells connected to each pin. The boundary scan cells are linked together to create a scan chain around the CS5376A.

#### 21.2.1 JTAG Reset

As required by the IEEE 1149.1 specification, the JTAG  $\overline{TRST}$  signal is independent of the CS5376A  $\overline{RESET}$  signal. In systems not using the JTAG port,  $\overline{TRST}$  should be connected to ground. In systems using the JTAG port,  $\overline{TRST}$  and  $\overline{RESET}$  should be independently driven to provide reset capability during boundary scan.

#### 21.2.2 TAP Controller

The test access port (TAP) controller manages commands and data through the boundary scan chain. It supports the four JTAG instructions and contains the IDCODE listed in Table 21.

The TAP controller also implements the 16 JTAG state assignments from the IEEE 1149.1 specification, which are sequenced using TMS and TCK.

| JTAG Instructions | Encoding |
|-------------------|----------|
| BYPASS            | 11       |
| EXTEST            | 00       |
| IDCODE            | 01       |
| SAMPLE / PRELOAD  | 10       |

| JTAG IDCODE Components | Encoding          |
|------------------------|-------------------|
| Revision               | 0x10000000        |
| Device ID              | 0x05376000        |
| Manufacturer ID        | 0x000000C9        |
| <b>CS5376A IDCODE</b>  | <b>0x153760C9</b> |

Table 21. JTAG Instructions and IDCODE

### 21.2.3 Boundary Scan Cells

The CS5376A JTAG test port provides access to all device pins via internal boundary scan cells. When the JTAG port is disabled, boundary scan cells are transparent and do not affect CS5376A operation. When the JTAG port is enabled, boundary scan cells can write and read each pin independent of CS5376A operation.

Boundary scan cells are serially linked to create a scan chain around the CS5376A controlled by the TAP controller. Table 22 lists the scan cell mapping of the CS5376A.

| BRC | Pin     | Function      | BRC           | Pin    | Function      | BRC           | Pin                | Function      |               |
|-----|---------|---------------|---------------|--------|---------------|---------------|--------------------|---------------|---------------|
| 1   | TBSCLK  | data out      | 36            | GPIO3  | data in       | 68            | GPIO11             | data in       |               |
| 2   | TBSDATA | data out      | 37            |        | data out      | 69            |                    | data out      |               |
| 3   | DNC     | data out      | 38            |        | output enable | 70            |                    | output enable |               |
| 4   | MCLK/2  | data out      | 39            |        | pullup        | 71            |                    | pullup        |               |
| 5   | MCLK    | data out      | 40            | GPIO4  | data in       | 72            | $\overline{SSO}$   | data out      |               |
| 6   | MSYNC   | data out      | 41            |        | data out      | 73            |                    | output enable |               |
| 7   | MDATA4  | data in       | 42            |        | output enable | 74            |                    | WOM           |               |
| 8   | MFLAG4  | data in       | 43            |        | pullup        | 75            | SCK1               | data in       |               |
| 9   | MDATA3  | data in       | 44            | GPIO5  | data in       | 76            |                    | data out      |               |
| 10  | MFLAG3  | data in       | 45            |        | data out      | 77            |                    | output enable |               |
| 11  | MDATA2  | data in       | 46            |        | output enable | 78            |                    | WOM           |               |
| 12  | MFLAG2  | data in       | 47            |        | pullup        | 79            | pullup             |               |               |
| 13  | MDATA1  | data in       | 48            | GPIO6  | data in       | 80            | $\overline{SSI}$   | data in       |               |
| 14  | MFLAG1  | data in       | 49            |        | data out      | 81            |                    | MISO          | data in       |
| 15  | GND     | data in       | 50            |        | output enable | 82            |                    |               | data out      |
| 16  | SI4     | data in       | 51            |        | pullup        | 83            |                    |               | output enable |
| 17  | SI3     | data in       | 52            | GPIO7  | data in       | 84            | MOSI               |               | WOM           |
| 18  | SI2     | data in       | 53            |        | data out      | 85            |                    | pullup        |               |
| 19  | SI1     | data in       | 54            |        | output enable | 86            |                    | data in       |               |
| 20  | SO      | data out      | 55            |        | pullup        | 87            |                    | data out      |               |
| 21  |         | WOM           | 56            | GPIO8  | data in       | 88            | output enable      |               |               |
| 22  | SCK2    | data out      | 57            |        | data out      | 89            | WOM                |               |               |
| 23  |         | WOM           | 58            |        | output enable | 90            | pullup             |               |               |
| 24  | GPIO0   | data in       | 59            |        | pullup        | 91            | $\overline{SINT}$  | data out      |               |
| 25  |         | data out      | 60            | GPIO9  | data in       | 92            | $\overline{RESET}$ | data in       |               |
| 26  |         | output enable | 61            |        | data out      | 93            | BOOT               | data in       |               |
| 27  |         | pullup        | 62            |        | output enable | 94            | TIMEB              | data in       |               |
| 28  | GPIO1   | data in       | 63            |        | pullup        | 95            | CLK                | data in       |               |
| 29  |         | data out      | 64            | GPIO10 | data in       | 96            | SYNC               | data in       |               |
| 30  |         | output enable | 65            |        | data out      | 97            | SDDAT              | data out      |               |
| 31  | pullup  | 66            | output enable |        | 98            | output enable |                    |               |               |
| 32  | GPIO2   | data in       | 67            |        | pullup        | 99            | $\overline{SDRDY}$ | data out      |               |
| 33  |         | data out      |               |        | 100           | SDCLK         | data in            |               |               |
| 34  |         | output enable |               |        | 101           | SDTKO         | data out           |               |               |
| 35  |         | pullup        |               |        | 102           | SDTKI         | data in            |               |               |

**Table 22. JTAG Scan Cell Mapping**

## 22.DEVICE REVISION HISTORY

The CS5376A is a pin compatible upgrade to the CS5376. The part family has had three revisions:

**CS5376 rev A**

**CS5376 rev B**

**CS5376A rev A**

The part number change for CS5376A reflects additional functionality built into the device.

### 22.1 Changes from CS5376 rev A to CS5376 rev B

#### ***New Sinc Filter, SINC3***

Added a new sinc filter, SINC3, between the previous sinc filters and FIR1. Will permit higher decimation rates for seismology applications. Not used for 0.25 ms, 0.5 ms, 1 ms, or 2 ms output rates to maintain backward compatibility.

#### ***Added FIR1 Coefficients***

Included an improved FIR1 filter to compensate for sinc filter droop. Previous filter had stop band frequency components up to -100 dB not removed by the FIR2 brick wall filter. Required stop band attenuation is 130 dB minimum. Previous FIR1 filter coefficients still included to maintain backwards compatibility.

#### ***Added IIR Coefficients***

Included 3 Hz IIR1 and IIR2 filter coefficients for the 0.5 ms, 1 ms, 2 ms, 3 ms, and 4 ms configurations (5 sets IIR1, 5 sets IIR2). Previous 2 Hz @ 1 ms coefficient set was removed.

#### ***Modified Output Word Rate Selection***

Changed the DEC bit settings in the FILTCFG register used to select an output word rate. Re-numbered to include the new 120 Hz, 60 Hz, 30 Hz, 15 Hz, and 7.5 Hz output rates. Other settings the same for backward compatibility.

#### ***Modified ROM Coefficient Selection Method***

Changed the ROM coefficient selection routines (SPI and EEPROM) to require a 24 bit data word. Previously no data word was required, only the command byte. The data word is parsed to select the FIR1, FIR2, IIR1, and IIR2 coefficient sets.

#### ***Modified ROM TBS Data Selection Method***

Changed the ROM test bit stream selection routine (SPI and EEPROM) to require a 24 bit data word. Previously no data word was required, only the command byte. The data word scales the ROM test bit stream data to a user selected amplitude.

#### ***Modified SPI port to strobe SINT pin***

The SPI port now pulses the SINT pin whenever data is received. Can be used by a microcontroller to trigger additional data writes. Eliminates the need to poll the e2dreq bit.

#### ***Fixed continuous synchronization operation***

The synchronization operation was modified to permit continuous re-sync. The SD port FIFO is no longer reset by the SYNC interrupt.

#### ***Corrected EEPROM loader bug***

The EEPROM loader bug is fixed. A preamble to write required constants into memory is no longer required.

### 22.2 Changes from CS5376 rev B to CS5376A rev A

#### ***Fixed synchronization repeatability bug***

Identical synchronization signals previously caused different impulse responses from multiple devices. Synchronization is now repeatable.

**Modified SINC2 filter to correct gain and timing errors**

Corrected SINC2 decimate by 2 gain error which affected 4000 SPS operation. Also modified SINC2 decimate by 16 output timing to match output of other SINC2 rates. Previous SINC2 decimate by 16 output was one sample later than expected.

**Corrected gain error of 333 SPS output rate**

SINC architecture was modified to correct gain error in SINC2 decimate by 12 by moving decimate by 3 stage into SINC3.

**Modified SINC3 filter for new low bandwidth rates.**

Newly supported output word rates are 200, 125, 100, 50, 40, 25, 20, 10, 5, 1 SPS. Older low bandwidth rates of 120, 60, 30, 15, 7.5 SPS were removed. No changes to 4000, 2000, 1000, 500, 333, 250 SPS rates for backwards compatibility to CS5376 revision A/B.

**Added minimum phase FIR coefficients**

Minimum phase FIR1 coefficient set 1 and FIR2 coefficient set 1 are newly available as selections for the SPI and EEPROM 'Write ROM Coefficients' command.

**Corrected IIR2/IIR3 channels 2, 3, 4 bug**

When selecting IIR2 or IIR3 output, data from channels 2, 3, and 4 were corrupted. IIR2 and IIR3 now operate correctly for these channels.

**Corrected IIR2 coefficient DC offset**

IIR2 coefficient sets 0, 1, and 3 did not perfectly cancel DC due to coefficient b20, b21, b22 mismatch. New b21 IIR2 coefficients correct this offset error.

**Removed gain scale factor from 'Write TBS ROM' command**

TBS data was previously scaled during configuration by a data word following the 'Write TBS ROM' command. Added a new TBSGAIN register (0x2B, replacing WD\_CFG) that scales the TBS amplitude and can be modified during normal operation.

**Removed watchdog timer**

The watchdog timer was removed. Replaced WD\_CFG register (0x2B) with TBSGAIN register.

**Set GPIO11 as tri-state when EEPROM boot completed**

After stand-alone boot from EEPROM, GPIO11 (acting as EEPROM chip select) was previously driven high. This pin now tri-states with an internal pull-up to hold it high.

**Modified Test Bit Stream (TBS) to disable loopback when TBS disabled.**

If TBS loopback mode was enabled, the external MDATA inputs were disconnected from the SINC filter even if the TBS was disabled. Now when the TBS is disabled, loopback mode is automatically disabled also.

**Added Test Bit Stream (TBS) impulse mode.**

TBS can now operate in sine wave or impulse mode, depending on bit 15 in the TBSCFG register. When impulse mode is enabled (TBSCFG bit 15 = 1), a rising edge on the TIMEB pin causes the TBS to output an impulse bitstream. When sine wave mode is enabled (TBSCFG bit 15 = 0), operation is identical to CS5376 revision A/B.



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***Added Test Bit Stream (TBS) synchronization in sine wave mode.***

The TBS sine wave phase will reset if bit 11 of the TBSCFG register is set (TBSCFG bit 11 = 1) and a rising edge is received on the SYNC pin. When TBSCFG bit 11 is set low (TBSCFG bit 11 = 0), TBS phase is unaffected by the SYNC input similar to CS5376 revision A/B.

***Modified Time Break delay function.***

The timing delay between receiving a rising

edge on the TIMEB pin and asserting the TIMEB flag in the output word status bits is corrected. In CS5376 revision A/B a '0' value in the TIMEBREAK register (0x29) disabled the TIMEB status bit write, and a '1' value set the status bit in the current output word. Now, a '0' value sets the TIMEB status bit in the current output word, and a '1' value delays until the following word.

## 23. REGISTER SUMMARY

### 23.1 SPI 1 Registers

The CS5376A SPI 1 registers interface the serial port to the digital filter.

| Name       | Addr. | Type | # Bits | Description                         |
|------------|-------|------|--------|-------------------------------------|
| SPI1CTRLH  | 00    | R/W  | 8      | SPI 1 Control Register, High Byte   |
| SPI1CTRLM  | 01    | R/W  | 8      | SPI 1 Control Register, Middle Byte |
| SPI1CTRL L | 02    | R/W  | 8      | SPI 1 Control Register, Low Byte    |
| SPI1CMDH   | 03    | R/W  | 8      | SPI 1 Command, High Byte            |
| SPI1CMDM   | 04    | R/W  | 8      | SPI 1 Command, Middle Byte          |
| SPI1CMDL   | 05    | R/W  | 8      | SPI 1 Command, Low Byte             |
| SPI1DAT1H  | 06    | R/W  | 8      | SPI 1 Data 1, High Byte             |
| SPI1DAT1M  | 07    | R/W  | 8      | SPI 1 Data 1, Middle Byte           |
| SPI1DAT1L  | 08    | R/W  | 8      | SPI 1 Data 1, Low Byte              |
| SPI1DAT2H  | 09    | R/W  | 8      | SPI 1 Data 2, High Byte             |
| SPI1DAT2M  | 0A    | R/W  | 8      | SPI 1 Data 2, Middle Byte           |
| SPI1DAT2L  | 0B    | R/W  | 8      | SPI 1 Data 2, Low Byte              |

**23.1.1 SPI1CTRL : 0x00, 0x01, 0x02**
**Figure 41. SPI 1 Control Register SPI1CTRL**

|          |      |     |     |     |     |     |     |
|----------|------|-----|-----|-----|-----|-----|-----|
| (MSB) 23 | 22   | 21  | 20  | 19  | 18  | 17  | 16  |
| --       | --   | --  | --  | --  | --  | --  | --  |
| R/W      | R/W1 | R/W | R/W | R/W | R/W | R/W | R/W |
| 0        | 0    | 0   | 0   | 1   | 0   | 1   | 1   |

|       |     |    |      |      |     |     |        |
|-------|-----|----|------|------|-----|-----|--------|
| 15    | 14  | 13 | 12   | 11   | 10  | 9   | 8      |
| SMODF | --  | -- | EMOP | SWEF | --  | --  | E2DREQ |
| R     | R/W | R  | R    | R    | R/W | R/W | R/W    |
| 0     | 0   | 0  | 0    | 0    | 0   | 1   | 0      |

|     |     |     |     |     |     |     |         |
|-----|-----|-----|-----|-----|-----|-----|---------|
| 7   | 6   | 5   | 4   | 3   | 2   | 1   | (LSB) 0 |
| --  | --  | --  | --  | --  | --  | --  | --      |
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W     |
| 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0       |

**SPI 1 Address: 0x00  
0x01  
0x02**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |    |          |       |        |   |     |    |          |
|-------|----|----------|-------|--------|---|-----|----|----------|
| 23:16 | -- | reserved | 15    | SMODF  | SPI 1 mode fault flag                               | 7:0 | -- | reserved |
|       |    |          | 14:13 | --     | reserved  |     |    |          |
|       |    |          | 12    | EMOP   | External master to SPI 1 operation in progress flag |     |    |          |
|       |    |          | 11    | SWEF   | SPI 1 write collision error flag                    |     |    |          |
|       |    |          | 10:9  | --     | reserved  |     |    |          |
|       |    |          | 8     | E2DREQ | External master to digital filter request flag      |     |    |          |

**23.1.2 SPI1CMD : 0x03, 0x04, 0x05**
**Figure 42. SPI 1 Command Register SPI1CMD**

|          |         |         |         |         |         |         |         |
|----------|---------|---------|---------|---------|---------|---------|---------|
| (MSB) 23 | 22      | 21      | 20      | 19      | 18      | 17      | 16      |
| S1CMD23  | S1CMD22 | S1CMD21 | S1CMD20 | S1CMD19 | S1CMD18 | S1CMD17 | S1CMD16 |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| 15       | 14      | 13      | 12      | 11      | 10      | 9       | 8       |
| S1CMD15  | S1CMD14 | S1CMD13 | S1CMD12 | S1CMD11 | S1CMD10 | S1CMD9  | S1CMD8  |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| 7        | 6       | 5       | 4       | 3       | 2       | 1       | (LSB) 0 |
| S1CMD7   | S1CMD6  | S1CMD5  | S1CMD4  | S1CMD3  | S1CMD2  | S1CMD1  | S1CMD0  |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |

**SPI 1 Address: 0x03  
0x04  
0x05**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|  |  |  |
|--|--|--|
| 23:16 S1CMD[23:16] SPI 1 Command High Byte | 15:8 S1CMD[15:8] SPI 1 Command Middle Byte | 15:8 S1CMD[7:0] SPI 1 Command Low Byte |
|--|--|--|

**23.1.3 SPI1DAT1 : 0x06, 0x07, 0x08**
**Figure 43. SPI 1 Data Register SPI1DAT1**

|          |         |         |         |         |         |         |         |
|----------|---------|---------|---------|---------|---------|---------|---------|
| (MSB) 23 | 22      | 21      | 20      | 19      | 18      | 17      | 16      |
| S1DAT23  | S1DAT22 | S1DAT21 | S1DAT20 | S1DAT19 | S1DAT18 | S1DAT17 | S1DAT16 |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| 15       | 14      | 13      | 12      | 11      | 10      | 9       | 8       |
| S1DAT15  | S1DAT14 | S1DAT13 | S1DAT12 | S1DAT11 | S1DAT10 | S1DAT9  | S1DAT8  |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
| 7        | 6       | 5       | 4       | 3       | 2       | 1       | (LSB) 0 |
| S1DAT7   | S1DAT6  | S1DAT5  | S1DAT4  | S1DAT3  | S1DAT2  | S1DAT1  | S1DAT0  |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |

**SPI 1 Address: 0x06  
0x07  
0x08**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|  |  |  |
|--|--|--|
| 23:16 S1DAT[23:16] SPI 1 Data<br>High Byte | 15:8 S1DAT[15:8] SPI 1 Data<br>Middle Byte | 15:8 S1DAT[7:0] SPI 1 Data<br>Low Byte |
|--|--|--|

**23.1.4 SPI1DAT2 : 0x09, 0x0A, 0x0B**
**Figure 44. SPI 1 Data Register SPI1DAT2**

|          |         |         |         |         |         |         |         |
|----------|---------|---------|---------|---------|---------|---------|---------|
| (MSB) 23 | 22      | 21      | 20      | 19      | 18      | 17      | 16      |
| S1DAT23  | S1DAT22 | S1DAT21 | S1DAT20 | S1DAT19 | S1DAT18 | S1DAT17 | S1DAT16 |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
|          |         |         |         |         |         |         |         |
| 15       | 14      | 13      | 12      | 11      | 10      | 9       | 8       |
| S1DAT15  | S1DAT14 | S1DAT13 | S1DAT12 | S1DAT11 | S1DAT10 | S1DAT9  | S1DAT8  |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |
|          |         |         |         |         |         |         |         |
| 7        | 6       | 5       | 4       | 3       | 2       | 1       | (LSB) 0 |
| S1DAT7   | S1DAT6  | S1DAT5  | S1DAT4  | S1DAT3  | S1DAT2  | S1DAT1  | S1DAT0  |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |

**SPI 1 Address: 0x09  
0x0A  
0x0B**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |              |                         |      |             |                           |     |            |                        |
|-------|--------------|-------------------------|------|-------------|---------------------------|-----|------------|------------------------|
| 23:16 | S1DAT[23:16] | SPI 1 Data<br>High Byte | 15:8 | S1DAT[15:8] | SPI 1 Data<br>Middle Byte | 7:0 | S1DAT[7:0] | SPI 1 Data<br>Low Byte |
|-------|--------------|-------------------------|------|-------------|---------------------------|-----|------------|------------------------|

## 23.2 Digital Filter Registers

The CS5376A digital filter registers control hardware peripherals and filtering functions.

| Name     | Addr. | Type | # Bits | Description                                    |
|----------|-------|------|--------|--|
| CONFIG   | 00    | R/W  | 24     | Hardware Configuration                         |
| RESERVED | 01-0D | R/W  | 24     | Reserved                                       |
| GPCFG0   | 0E    | R/W  | 24     | GPIO[7:0] Direction, Pull-Up Enable, and Data  |
| GPCFG1   | 0F    | R/W  | 24     | GPIO[11:8] Direction, Pull-Up Enable, and Data |
| SPI2CTRL | 10    | R/W  | 24     | SPI2 Control                                   |
| SPI2CMD  | 11    | R/W  | 16     | SPI2 Command                                   |
| SPI2DAT  | 12    | R/W  | 24     | SPI2 Data                                      |
| RESERVED | 13-1F | R/W  | 24     | Reserved                                       |
| FILTCFG  | 20    | R/W  | 24     | Digital Filter Configuration                   |
| GAIN1    | 21    | R/W  | 24     | Gain Correction Channel 1                      |
| GAIN2    | 22    | R/W  | 24     | Gain Correction Channel 2                      |
| GAIN3    | 23    | R/W  | 24     | Gain Correction Channel 3                      |
| GAIN4    | 24    | R/W  | 24     | Gain Correction Channel 4                      |
| OFFSET1  | 25    | R/W  | 24     | Offset Correction Channel 1                    |
| OFFSET2  | 26    | R/W  | 24     | Offset Correction Channel 2                    |
| OFFSET3  | 27    | R/W  | 24     | Offset Correction Channel 3                    |
| OFFSET4  | 28    | R/W  | 24     | Offset Correction Channel 4                    |
| TIMEBRK  | 29    | R/W  | 24     | Time Break Delay                               |
| TBSCFG   | 2A    | R/W  | 24     | Test Bit Stream Configuration                  |
| TBSGAIN  | 2B    | R/W  | 24     | Test Bit Stream Gain                           |
| SYSTEM1  | 2C    | R/W  | 24     | User Defined System Register 1                 |
| SYSTEM2  | 2D    | R/W  | 24     | User Defined System Register 2                 |
| VERSION  | 2E    | R/W  | 24     | Hardware Version ID                            |
| SELFTEST | 2F    | R/W  | 24     | Self-Test Result Code                          |

**23.2.1 CONFIG : 0x00**
**Figure 45. Hardware Configuration Register CONFIG**

|         |     |     |     |     |      |      |      |
|---------|-----|-----|-----|-----|------|------|------|
| (MSB)23 | 22  | 21  | 20  | 19  | 18   | 17   | 16   |
| --      | --  | --  | --  | --  | DFS2 | DFS1 | DFS0 |
| R/W     | R/W | R/W | R/W | R/W | R/W  | R/W  | R/W  |
| 0       | 0   | 0   | 0   | 0   | 1    | 0    | 1    |

|     |     |     |     |     |        |        |        |
|-----|-----|-----|-----|-----|--------|--------|--------|
| 15  | 14  | 13  | 12  | 11  | 10     | 9      | 8      |
| --  | --  | --  | --  | --  | MCKFS2 | MCKFS1 | MCKFS0 |
| R/W | R/W | R/W | R/W | R/W | R/W    | R/W    | R/W    |
| 0   | 0   | 0   | 0   | 0   | 1      | 0      | 0      |

|     |     |        |       |       |     |      |        |
|-----|-----|--------|-------|-------|-----|------|--------|
| 7   | 6   | 5      | 4     | 3     | 2   | 1    | (LSB)0 |
| --  | --  | MCKEN2 | MCKEN | MDIFS | --  | BOOT | MSEN   |
| R/W | R/W | R/W    | R/W   | R/W   | R/W | R    | R/W    |
| 0   | 0   | 0      | 0     | 0     | 0   | 0    | 1      |

**DF Address: 0x00**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |              |  |       |                |   |     |        |  |
|-------|--------------|--|-------|----------------|---|-----|--------|--|
| 23:19 | --           | reserved   | 15:11 | --             | reserved  | 7:6 | --     | reserved   |
| 18:16 | DFS<br>[2:0] | Digital filter<br>frequency select<br>111: 16.384 MHz<br>110: 8.192 MHz<br>101: 4.096 MHz<br>100: 2.048 MHz<br>011: 1.024 MHz<br>010: 512 kHz<br>001: 256 kHz<br>000: 32 kHz | 10:8  | MCKFS<br>[2:0] | MCLK frequency select<br>111: reserved<br>110: reserved<br>101: 4.096 MHz<br>100: 2.048 MHz<br>011: 1.024 MHz<br>010: 512 kHz<br>001: reserved<br>000: reserved | 5   | MCKEN2 | MCLK/2 output enable<br>1: Enabled<br>0: Disabled                      |
|       |              |  |       |                |   | 4   | MCKEN  | MCLK output enable<br>1: Enabled<br>0: Disabled                        |
|       |              |  |       |                |   | 3   | MDIFS  | MDATA input frequency<br>select<br>1: 256 kHz<br>0: 512 kHz            |
|       |              |  |       |                |   | 2   | --     | reserved   |
|       |              |  |       |                |   | 1   | BOOT   | Boot source indicator<br>1: Booted from EEPROM<br>0: Booted from Micro |
|       |              |  |       |                |   | 0   | MSEN   | MSYNC enable<br>1: MSYNC generated<br>0: MSYNC remains low             |



**23.2.2 GPCFG0 : 0x0E**
**Figure 46. GPIO Configuration Register GPCFG0**

|          |         |         |         |         |         |         |         |
|----------|---------|---------|---------|---------|---------|---------|---------|
| (MSB) 23 | 22      | 21      | 20      | 19      | 18      | 17      | 16      |
| GP_DIR7  | GP_DIR6 | GP_DIR5 | GP_DIR4 | GP_DIR3 | GP_DIR2 | GP_DIR1 | GP_DIR0 |
| R/W      | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     | R/W     |
| 0        | 0       | 0       | 0       | 0       | 0       | 0       | 0       |

|          |          |          |          |          |          |          |          |
|----------|----------|----------|----------|----------|----------|----------|----------|
| 15       | 14       | 13       | 12       | 11       | 10       | 9        | 8        |
| GP_PULL7 | GP_PULL6 | GP_PULL5 | GP_PULL4 | GP_PULL3 | GP_PULL2 | GP_PULL1 | GP_PULL0 |
| R/W      | R/W      | R/W      | R/W      | R/W      | R/W      | R/W      | R/W      |
| 1        | 1        | 1        | 1        | 1        | 1        | 1        | 1        |

|          |          |          |          |          |          |          |          |
|----------|----------|----------|----------|----------|----------|----------|----------|
| 7        | 6        | 5        | 4        | 3        | 2        | 1        | (LSB) 0  |
| GP_DATA7 | GP_DATA6 | GP_DATA5 | GP_DATA4 | GP_DATA3 | GP_DATA2 | GP_DATA1 | GP_DATA0 |
| R/W      | R/W      | R/W      | R/W      | R/W      | R/W      | R/W      | R/W      |
| 1        | 1        | 1        | 1        | 1        | 1        | 1        | 1        |

**DF Address: 0x0E**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |              |   |      |               |   |     |               |                                     |
|-------|--------------|---|------|---------------|---|-----|---------------|-------------------------------------|
| 23:16 | GP_DIR [7:0] | GPIO pin direction<br>1: Output<br>0: Input | 15:8 | GP_PULL [7:0] | GPIO pullup resistor<br>1: Enabled<br>0: Disabled | 7:0 | GP_DATA [7:0] | GPIO data value<br>1: VDD<br>0: GND |
|-------|--------------|---|------|---------------|---|-----|---------------|-------------------------------------|

Note: GPIO[4:0] also used as SPI 2 chip selects CS[4:0].

**23.2.3 GPCFG1 : 0x0F**
**Figure 47. GPIO Configuration Register GPCFG1**

|          |     |     |     |           |           |          |          |
|----------|-----|-----|-----|-----------|-----------|----------|----------|
| (MSB) 23 | 22  | 21  | 20  | 19        | 18        | 17       | 16       |
| --       | --  | --  | --  | GP_DIR11  | GP_DIR10  | GP_DIR9  | GP_DIR8  |
| R/W      | R/W | R/W | R/W | R/W       | R/W       | R/W      | R/W      |
| 0        | 0   | 0   | 0   | 0         | 0         | 0        | 0        |
|          |     |     |     |           |           |          |          |
| 15       | 14  | 13  | 12  | 11        | 10        | 9        | 8        |
| --       | --  | --  | --  | GP_PULL11 | GP_PULL10 | GP_PULL9 | GP_PULL8 |
| R/W      | R/W | R/W | R/W | R/W       | R/W       | R/W      | R/W      |
| 0        | 0   | 0   | 0   | 1         | 1         | 1        | 1        |
|          |     |     |     |           |           |          |          |
| 7        | 6   | 5   | 4   | 3         | 2         | 1        | (LSB) 0  |
| --       | --  | --  | --  | GP_DATA11 | GP_DATA10 | GP_DATA9 | GP_DATA8 |
| R/W      | R/W | R/W | R/W | R/W       | R/W       | R/W      | R/W      |
| 0        | 0   | 0   | 0   | 1         | 1         | 1        | 1        |

**DF Address: 0x0F**

-- Not defined; read as 0

R Readable

W Writable

R/W Readable and Writable

Bits in bottom rows are reset condition

Bit definitions:

|       |               |   |       |                |   |     |                |                                     |
|-------|---------------|---|-------|----------------|---|-----|----------------|-------------------------------------|
| 23:20 | --            | reserved                                    | 15:12 | --             | reserved  | 7:4 | --             | reserved                            |
| 19:16 | GP_DIR [11:8] | GPIO pin direction<br>1: Output<br>0: Input | 11:8  | GP_PULL [11:8] | GPIO pullup resistor<br>1: Enabled<br>0: Disabled | 3:0 | GP_DATA [11:8] | GPIO data value<br>1: VDD<br>0: GND |

Note: GPIO11 also used as boot EEPROM chip select EECS.

**23.2.4 SPI2CTRL : 0x10**
**Figure 48. SPI 2 Control Register SPI2CTRL**

|          |        |        |        |         |         |         |         |
|----------|--------|--------|--------|---------|---------|---------|---------|
| (MSB) 23 | 22     | 21     | 20     | 19      | 18      | 17      | 16      |
| WOM      | SCKFS2 | SCKFS1 | SCKFS0 | SPI2EN3 | SPI2EN2 | SPI2EN1 | SPI2EN0 |
| R/W      | R/W    | R/W    | R/W    | R/W     | R/W     | R/W     | R/W     |
| 0        | 0      | 1      | 1      | 1       | 1       | 1       | 1       |

|      |      |       |       |      |       |     |        |
|------|------|-------|-------|------|-------|-----|--------|
| 15   | 14   | 13    | 12    | 11   | 10    | 9   | 8      |
| RCH1 | RCH0 | D2SOP | SCKPH | SWEF | SCKPO | TM  | D2SREQ |
| R/W  | R/W  | R     | R/W   | R/W  | R/W   | R/W | R/W    |
| 0    | 0    | 0     | 0     | 0    | 0     | 0   | 0      |

|       |       |       |     |     |     |     |         |
|-------|-------|-------|-----|-----|-----|-----|---------|
| 7     | 6     | 5     | 4   | 3   | 2   | 1   | (LSB) 0 |
| DNUM2 | DNUM1 | DNUM0 | CS4 | CS3 | CS2 | CS1 | CS0     |
| R/W   | R/W   | R/W   | R/W | R/W | R/W | R/W | R/W     |
| 1     | 1     | 1     | 0   | 0   | 0   | 0   | 0       |

**DF Address: 0x10**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable  
and Writable

Bits in bottom rows  
are reset condition.

Bit definitions:

|       |                 |  |       |              |  |     |               |  |
|-------|-----------------|--|-------|--------------|--|-----|---------------|--|
| 23    | WOM             | Wired-or mode<br>1: Enabled (open drain)<br>0: Disabled (push-pull)  | 15:14 | RCH<br>[1:0] | Read channel<br>11: SI4<br>10: SI3<br>01: SI2<br>00: SI1   | 7:5 | DNUM<br>[2:0] | Number of bytes in<br>serial transaction |
| 22:20 | SCKFS<br>[2:0]  | SCK2 frequency select<br>111: reserved<br>110: reserved<br>101: 4.096 MHz<br>100: 2.048 MHz<br>011: 1.024 MHz<br>010: 512 kHz<br>001: 128 kHz<br>000: 32 kHz | 13    | D2SOP        | Digital filter to SPI2<br>operation in progress<br>flag  | 4   | CS4           | Chip Select 4 Enable                     |
|       |                 |  | 12    | SCKPH        | SO output timing<br>1: Data becomes valid<br>on first SCK2 edge<br>0: Data becomes valid<br>before first SCK2 edge                     | 3   | CS3           | Chip Select 3 Enable                     |
|       |                 |  |       |              |  | 2   | CS2           | Chip Select 2 Enable                     |
|       |                 |  | 11    | SWEF         | SPI2 write collision flag  | 1   | CS1           | Chip Select 1 Enable                     |
| 19:16 | SPI2EN<br>[3:0] | SI[4:1] input enable<br>1111: All enabled<br>0000: All disabled  | 10    | SCKPO        | SCK2 data polarity<br>1: Valid on falling edge,<br>transition on rising edge<br>0: Valid on rising edge,<br>transition on falling edge | 0   | CS0           | Chip Select 0 Enable                     |
|       |                 |  | 9     | TM           | SPI2 timeout flag<br>1: SPI2 timed out<br>0: not timed out   |     |               |  |
|       |                 |  | 8     | D2SREQ       | Digital filter to SPI2<br>serial transaction request<br>1: Request operation<br>0: Operation complete<br>(cleared by hardware)         |     |               |  |

**23.2.5 SPI2CMD : 0x11**
**Figure 49. SPI 2 Command Register SPI2CMD**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| (MSB) 23 | 22  | 21  | 20  | 19  | 18  | 17  | 16  |
| --       | --  | --  | --  | --  | --  | --  | --  |
| R/W      | R/W | R/W | R/W | R/W | R/W | R/W | R/W |
| 0        | 0   | 0   | 0   | 0   | 0   | 0   | 0   |

|        |        |        |        |        |        |       |       |
|--------|--------|--------|--------|--------|--------|-------|-------|
| 15     | 14     | 13     | 12     | 11     | 10     | 9     | 8     |
| SCMD15 | SCMD14 | SCMD13 | SCMD12 | SCMD11 | SCMD10 | SCMD9 | SCMD8 |
| R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W   | R/W   |
| 0      | 0      | 0      | 0      | 0      | 0      | 0     | 0     |

|       |       |       |       |       |       |       |         |
|-------|-------|-------|-------|-------|-------|-------|---------|
| 7     | 6     | 5     | 4     | 3     | 2     | 1     | (LSB) 0 |
| SCMD7 | SCMD6 | SCMD5 | SCMD4 | SCMD3 | SCMD2 | SCMD1 | SCMD0   |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0       |

|  |                           |
|--|---------------------------|
| <b>DF Address: 0x11</b>                    |                           |
| --   | Not defined;<br>read as 0 |
| R  | Readable                  |
| W  | Writable                  |
| R/W  | Readable and<br>Writable  |
| Bits in bottom rows<br>are reset condition |                           |

Bit definitions:

|       |    |          |      |            |                            |      |           |                            |
|-------|----|----------|------|------------|----------------------------|------|-----------|----------------------------|
| 23:16 | -- | reserved | 15:8 | SCMD[15:8] | SPI2 Upper Command<br>Byte | 15:8 | SCMD[7:0] | SPI2 Lower Command<br>Byte |
|-------|----|----------|------|------------|----------------------------|------|-----------|----------------------------|

**23.2.6 SPI2DAT : 0x12**
**Figure 50. SPI 2 Data Register SPI2DAT**

|          |        |        |        |        |        |        |        |
|----------|--------|--------|--------|--------|--------|--------|--------|
| (MSB) 23 | 22     | 21     | 20     | 19     | 18     | 17     | 16     |
| SDAT23   | SDAT22 | SDAT21 | SDAT20 | SDAT19 | SDAT18 | SDAT17 | SDAT16 |
| R/W      | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    |
| 0        | 0      | 0      | 0      | 0      | 0      | 0      | 0      |

|        |        |        |        |        |        |       |       |
|--------|--------|--------|--------|--------|--------|-------|-------|
| 15     | 14     | 13     | 12     | 11     | 10     | 9     | 8     |
| SDAT15 | SDAT14 | SDAT13 | SDAT12 | SDAT11 | SDAT10 | SDAT9 | SDAT8 |
| R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W   | R/W   |
| 0      | 0      | 0      | 0      | 0      | 0      | 0     | 0     |

|       |       |       |       |       |       |       |         |
|-------|-------|-------|-------|-------|-------|-------|---------|
| 7     | 6     | 5     | 4     | 3     | 2     | 1     | (LSB) 0 |
| SDAT7 | SDAT6 | SDAT5 | SDAT4 | SDAT3 | SDAT2 | SDAT1 | SDAT0   |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0       |

**DF Address: 0x12**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |             |                         |      |            |                          |      |           |                         |
|-------|-------------|-------------------------|------|------------|--------------------------|------|-----------|-------------------------|
| 23:16 | SDAT[23:16] | SPI2 Upper Data<br>Byte | 15:8 | SDAT[15:8] | SPI2 Middle Data<br>Byte | 15:8 | SDAT[7:0] | SPI2 Lower Data<br>Byte |
|-------|-------------|-------------------------|------|------------|--------------------------|------|-----------|-------------------------|

**23.2.7 FILTCFG : 0x20**
**Figure 51. Filter Configuration Register FILTCFG**

|          |       |       |       |      |       |       |         |
|----------|-------|-------|-------|------|-------|-------|---------|
| (MSB) 23 | 22    | 21    | 20    | 19   | 18    | 17    | 16      |
| --       | --    | --    | EXP4  | EXP3 | EXP2  | EXP1  | EXP0    |
| R/W      | R/W   | R/W   | R/W   | R/W  | R/W   | R/W   | R/W     |
| 0        | 0     | 0     | 0     | 0    | 0     | 0     | 0       |
| 15       | 14    | 13    | 12    | 11   | 10    | 9     | 8       |
| --       | ORCAL | USEOR | USEGR | --   | FSEL2 | FSEL1 | FSEL0   |
| R/W      | R/W   | R/W   | R/W   | R/W  | R/W   | R/W   | R/W     |
| 0        | 0     | 0     | 0     | 0    | 0     | 0     | 0       |
| 7        | 6     | 5     | 4     | 3    | 2     | 1     | (LSB) 0 |
| DEC3     | DEC2  | DEC1  | DEC0  | --   | --    | CH1   | CH0     |
| R/W      | R/W   | R/W   | R/W   | R/W  | R/W   | R/W   | R/W     |
| 0        | 0     | 0     | 0     | 0    | 0     | 0     | 0       |

**DF Address: 0x20**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |          |                                |      |           |  |     |          |  |
|-------|----------|--------------------------------|------|-----------|--|-----|----------|--|
| 23:21 | --       | reserved                       | 15   | --        | reserved   | 7:4 | DEC[3:0] | Decimation selection<br>(Output word rate)   |
| 20:16 | EXP[4:0] | OFFSET calibration<br>exponent | 14   | ORCAL     | Run OFFSET calibration<br>1: Enable<br>0: Disable  |     |          | 0111: 4000 SPS<br>0110: 2000 SPS<br>0101: 1000 SPS<br>0100: 500 SPS<br>0011: 333 SPS<br>0010: 250 SPS<br>0001: 200 SPS<br>0000: 125 SPS<br>1111: 100 SPS<br>1110: 50 SPS<br>1101: 40 SPS<br>1100: 25 SPS<br>1011: 20 SPS<br>1010: 10 SPS<br>1001: 5 SPS<br>1000: 1 SPS |
|       |          |                                | 13   | USEOR     | Use OFFSET correction<br>1: Enable<br>0: Disable   |     |          |  |
|       |          |                                | 12   | USEGR     | Use GAIN correction<br>1: Enable<br>0: Disable   |     |          |  |
|       |          |                                | 11   | --        | reserved   | 3:2 | --       | reserved   |
|       |          |                                | 10:8 | FSEL[2:0] | Output filter stage select<br>111: reserved<br>110: reserved<br>101: IIR 3rd Order<br>100: IIR 2nd Order<br>011: IIR 1st Order<br>010: FIR2 Output<br>001: FIR1 Output<br>000: SINC Output | 1:0 | CH[1:0]  | Channel Enable<br>11: 3 Channel (1, 2, 3)<br>10: 2 Channel (1, 2)<br>01: 1 Channel (1 only)<br>00: 4 Channel (1, 2, 3, 4)  |

**23.2.8 GAIN1 - GAIN4 : 0x21 - 0x24**
**Figure 52. Gain Correction Register GAIN1**

|          |        |        |        |        |        |        |        |
|----------|--------|--------|--------|--------|--------|--------|--------|
| (MSB) 23 | 22     | 21     | 20     | 19     | 18     | 17     | 16     |
| GAIN23   | GAIN22 | GAIN21 | GAIN20 | GAIN19 | GAIN18 | GAIN17 | GAIN16 |
| R/W      | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    |
| 0        | 0      | 0      | 0      | 0      | 0      | 0      | 0      |

|        |        |        |        |        |        |       |       |
|--------|--------|--------|--------|--------|--------|-------|-------|
| 15     | 14     | 13     | 12     | 11     | 10     | 9     | 8     |
| GAIN15 | GAIN14 | GAIN13 | GAIN12 | GAIN11 | GAIN10 | GAIN9 | GAIN8 |
| R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W   | R/W   |
| 0      | 0      | 0      | 0      | 0      | 0      | 0     | 0     |

|       |       |       |       |       |       |       |         |
|-------|-------|-------|-------|-------|-------|-------|---------|
| 7     | 6     | 5     | 4     | 3     | 2     | 1     | (LSB) 0 |
| GAIN7 | GAIN6 | GAIN5 | GAIN4 | GAIN3 | GAIN2 | GAIN1 | GAIN0   |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0       |

**DF Address: 0x21**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |             |                               |      |            |                                |      |           |                               |
|-------|-------------|-------------------------------|------|------------|--------------------------------|------|-----------|-------------------------------|
| 23:16 | GAIN[23:16] | Gain Correction<br>Upper Byte | 15:8 | GAIN[15:8] | Gain Correction<br>Middle Byte | 15:8 | GAIN[7:0] | Gain Correction<br>Lower Byte |
|-------|-------------|-------------------------------|------|------------|--------------------------------|------|-----------|-------------------------------|

**23.2.9 OFFSET1 - OFFSET4 : 0x25 - 0x28**
**Figure 53. Offset Correction Register OFFSET1**

|          |        |        |        |        |        |        |        |
|----------|--------|--------|--------|--------|--------|--------|--------|
| (MSB) 23 | 22     | 21     | 20     | 19     | 18     | 17     | 16     |
| OFST23   | OFST22 | OFST21 | OFST20 | OFST19 | OFST18 | OFST17 | OFST16 |
| R/W      | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    |
| 0        | 0      | 0      | 0      | 0      | 0      | 0      | 0      |

|        |        |        |        |        |        |       |       |
|--------|--------|--------|--------|--------|--------|-------|-------|
| 15     | 14     | 13     | 12     | 11     | 10     | 9     | 8     |
| OFST15 | OFST14 | OFST13 | OFST12 | OFST11 | OFST10 | OFST9 | OFST8 |
| R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W   | R/W   |
| 0      | 0      | 0      | 0      | 0      | 0      | 0     | 0     |

|       |       |       |       |       |       |       |         |
|-------|-------|-------|-------|-------|-------|-------|---------|
| 7     | 6     | 5     | 4     | 3     | 2     | 1     | (LSB) 0 |
| OFST7 | OFST6 | OFST5 | OFST4 | OFST3 | OFST2 | OFST1 | OFST0   |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0       |

|  |                           |
|--|---------------------------|
| <b>DF Address: 0x25</b>                    |                           |
| --   | Not defined;<br>read as 0 |
| R  | Readable                  |
| W  | Writable                  |
| R/W  | Readable and<br>Writable  |
| Bits in bottom rows<br>are reset condition |                           |

Bit definitions:

|       |             |                                 |      |            |                                  |      |           |                                 |
|-------|-------------|---------------------------------|------|------------|----------------------------------|------|-----------|---------------------------------|
| 23:16 | OFST[23:16] | Offset Correction<br>Upper Byte | 15:8 | OFST[15:8] | Offset Correction<br>Middle Byte | 15:8 | OFST[7:0] | Offset Correction<br>Lower Byte |
|-------|-------------|---------------------------------|------|------------|----------------------------------|------|-----------|---------------------------------|



**23.2.10 TIMEBRK : 0x29**
**Figure 54. Time Break Counter Register TIMEBRK**

|          |        |        |        |        |        |        |        |
|----------|--------|--------|--------|--------|--------|--------|--------|
| (MSB) 23 | 22     | 21     | 20     | 19     | 18     | 17     | 16     |
| TBRK23   | TBRK22 | TBRK21 | TBRK20 | TBRK19 | TBRK18 | TBRK17 | TBRK16 |
| R/W      | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W    |
| 0        | 0      | 0      | 0      | 0      | 0      | 0      | 0      |

|        |        |        |        |        |        |       |       |
|--------|--------|--------|--------|--------|--------|-------|-------|
| 15     | 14     | 13     | 12     | 11     | 10     | 9     | 8     |
| TBRK15 | TBRK14 | TBRK13 | TBRK12 | TBRK11 | TBRK10 | TBRK9 | TBRK8 |
| R/W    | R/W    | R/W    | R/W    | R/W    | R/W    | R/W   | R/W   |
| 0      | 0      | 0      | 0      | 0      | 0      | 0     | 0     |

|       |       |       |       |       |       |       |         |
|-------|-------|-------|-------|-------|-------|-------|---------|
| 7     | 6     | 5     | 4     | 3     | 2     | 1     | (LSB) 0 |
| TBRK7 | TBRK6 | TBRK5 | TBRK4 | TBRK3 | TBRK2 | TBRK1 | TBRK0   |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0       |

**DF Address: 0x29**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |             |                                  |      |            |                                   |     |           |                                  |
|-------|-------------|----------------------------------|------|------------|-----------------------------------|-----|-----------|----------------------------------|
| 23:16 | TBRK[23:16] | Time Break Counter<br>Upper Byte | 15:8 | TBRK[15:8] | Time Break Counter<br>Middle Byte | 7:0 | TBRK[7:0] | Time Break Counter<br>Lower Byte |
|-------|-------------|----------------------------------|------|------------|-----------------------------------|-----|-----------|----------------------------------|

**23.2.11 TBSCFG : 0x2A**
**Figure 55. Test Bit Stream Configuration Register TBSCFG**

|          |       |       |       |       |       |       |         |
|----------|-------|-------|-------|-------|-------|-------|---------|
| (MSB) 23 | 22    | 21    | 20    | 19    | 18    | 17    | 16      |
| INTP7    | INTP6 | INTP5 | INTP4 | INTP3 | INTP2 | INTP1 | INTP0   |
| R/W      | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0        | 0     | 0     | 0     | 0     | 0     | 0     | 0       |
| 15       | 14    | 13    | 12    | 11    | 10    | 9     | 8       |
| TMODE    | RATE2 | RATE1 | RATE0 | TSYNC | CDLY2 | CDLY1 | CDLY0   |
| R/W      | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0        | 0     | 0     | 0     | 0     | 0     | 0     | 0       |
| 7        | 6     | 5     | 4     | 3     | 2     | 1     | (LSB) 0 |
| LOOP     | RUN   | DDLY5 | DDLY4 | DDLY3 | DDLY2 | DDLY1 | DDLY0   |
| R/W      | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 0        | 0     | 0     | 0     | 0     | 0     | 0     | 0       |

**DF Address: 0x2A**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |           |  |       |           |   |     |           |   |
|-------|-----------|--|-------|-----------|---|-----|-----------|---|
| 23:16 | INTP[7:0] | Interpolation factor<br>0xFF: 256<br>0xFE: 255<br>...<br>0x01: 2<br>0x00: 1 (use once) | 15    | TMODE     | Operational mode<br>1: Impulse mode<br>0: Sine Mode   | 7   | LOOP      | Loopback<br>TBSDATA output<br>to MDATA inputs<br>1: Enabled<br>0: Disabled                                    |
|       |           |  | 14:12 | RATE[2:0] | TBSDATA and<br>TBSCCLK output<br>rate.<br>111: 2.048 MHz<br>110: 1.024 MHz<br>101: 512 kHz<br>100: 256 kHz<br>011: 128 kHz<br>010: 64 kHz<br>001: 32 kHz<br>000: 4 kHz          | 6   | RUN       | Run Test Bit Stream<br>1: Enabled<br>0: Disabled  |
|       |           |  | 11    | TSYNC     | Synchronization<br>1: Sync enabled<br>0: No sync  |     |           |   |
|       |           |  | 10:8  | CDLY[2:0] | TBSCCLK output<br>phase delay<br>111: 7/8 period<br>110: 3/4 period<br>101: 5/8 period<br>100: 1/2 period<br>011: 3/8 period<br>010: 1/4 period<br>001: 1/8 period<br>000: none | 5:0 | DDLY[5:0] | TBSDATA output<br>delay<br>0x3F: 63 bits<br>0x3E: 62 bits<br>...<br>0x01: 1 bit<br>0x00: 0 bits (no<br>delay) |

**23.2.12 TBSGAIN : 0x2B**
**Figure 56. Test Bit Stream Gain Register TBSGAIN**

|                 |           |           |           |           |           |           |           |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| <b>(MSB) 23</b> | <b>22</b> | <b>21</b> | <b>20</b> | <b>19</b> | <b>18</b> | <b>17</b> | <b>16</b> |
| TGAIN23         | TGAIN22   | TGAIN21   | TGAIN20   | TGAIN19   | TGAIN18   | TGAIN17   | TGAIN16   |
| R/W             | R/W       | R/W       | R/W       | R/W       | R/W       | R/W       | R/W       |
| 0               | 0         | 0         | 0         | 0         | 0         | 0         | 0         |

|           |           |           |           |           |           |          |          |
|-----------|-----------|-----------|-----------|-----------|-----------|----------|----------|
| <b>15</b> | <b>14</b> | <b>13</b> | <b>12</b> | <b>11</b> | <b>10</b> | <b>9</b> | <b>8</b> |
| TGAIN15   | TGAIN14   | TGAIN13   | TGAIN12   | TGAIN11   | TGAIN10   | TGAIN9   | TGAIN8   |
| R/W       | R/W       | R/W       | R/W       | R/W       | R/W       | R/W      | R/W      |
| 0         | 0         | 0         | 0         | 0         | 0         | 0        | 0        |

|          |          |          |          |          |          |          |                |
|----------|----------|----------|----------|----------|----------|----------|----------------|
| <b>7</b> | <b>6</b> | <b>5</b> | <b>4</b> | <b>3</b> | <b>2</b> | <b>1</b> | <b>(LSB) 0</b> |
| TGAIN7   | TGAIN6   | TGAIN5   | TGAIN4   | TGAIN3   | TGAIN2   | TGAIN1   | TGAIN0         |
| R/W      | R/W      | R/W      | R/W      | R/W      | R/W      | R/W      | R/W            |
| 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0              |

|  |                           |
|--|---------------------------|
| <b>DF Address: 0x2B</b>                    |                           |
| --   | Not defined;<br>read as 0 |
| R  | Readable                  |
| W  | Writable                  |
| R/W  | Readable and<br>Writable  |
| Bits in bottom rows<br>are reset condition |                           |

Bit definitions:

|       |              |                                    |      |             |                                     |     |            |                                    |
|-------|--------------|------------------------------------|------|-------------|-------------------------------------|-----|------------|------------------------------------|
| 23:16 | TGAIN[23:16] | Test Bit Stream Gain<br>Upper Byte | 15:8 | TGAIN[15:8] | Test Bit Stream<br>Gain Middle Byte | 7:0 | TGAIN[7:0] | Test Bit Stream<br>Gain Lower Byte |
|-------|--------------|------------------------------------|------|-------------|-------------------------------------|-----|------------|------------------------------------|

**23.2.13 SYSTEM1, SYSTEM2 : 0x2C, 0x2D**
**Figure 57. User Defined System Register SYSTEM1**

|          |       |       |       |       |       |       |       |
|----------|-------|-------|-------|-------|-------|-------|-------|
| (MSB) 23 | 22    | 21    | 20    | 19    | 18    | 17    | 16    |
| SYS23    | SYS22 | SYS21 | SYS20 | SYS19 | SYS18 | SYS17 | SYS16 |
| R/W      | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   |
| 0        | 0     | 0     | 0     | 0     | 0     | 0     | 0     |

|       |       |       |       |       |       |      |      |
|-------|-------|-------|-------|-------|-------|------|------|
| 15    | 14    | 13    | 12    | 11    | 10    | 9    | 8    |
| SYS15 | SYS14 | SYS13 | SYS12 | SYS11 | SYS10 | SYS9 | SYS8 |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W  | R/W  |
| 0     | 0     | 0     | 0     | 0     | 0     | 0    | 0    |

|      |      |      |      |      |      |      |         |
|------|------|------|------|------|------|------|---------|
| 7    | 6    | 5    | 4    | 3    | 2    | 1    | (LSB) 0 |
| SYS7 | SYS6 | SYS5 | SYS4 | SYS3 | SYS2 | SYS1 | SYS0    |
| R/W  | R/W  | R/W  | R/W  | R/W  | R/W  | R/W  | R/W     |
| 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0       |

|  |                           |
|--|---------------------------|
| <b>DF Address: 0x2C</b>                    |                           |
| --   | Not defined;<br>read as 0 |
| R  | Readable                  |
| W  | Writable                  |
| R/W  | Readable and<br>Writable  |
| Bits in bottom rows<br>are reset condition |                           |

Bit definitions:

|       |            |                               |      |           |                                |      |          |                               |
|-------|------------|-------------------------------|------|-----------|--------------------------------|------|----------|-------------------------------|
| 23:16 | SYS[23:16] | System Register<br>Upper Byte | 15:8 | SYS[15:8] | System Register<br>Middle Byte | 15:8 | SYS[7:0] | System Register<br>Lower Byte |
|-------|------------|-------------------------------|------|-----------|--------------------------------|------|----------|-------------------------------|

**23.2.14 VERSION : 0x2E**
**Figure 58. Hardware Version ID Register VERSION**

|          |       |       |       |       |       |       |       |
|----------|-------|-------|-------|-------|-------|-------|-------|
| (MSB) 23 | 22    | 21    | 20    | 19    | 18    | 17    | 16    |
| TYPE7    | TYPE6 | TYPE5 | TYPE4 | TYPE3 | TYPE2 | TYPE1 | TYPE0 |
| R/W      | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   |
| 0        | 1     | 1     | 1     | 0     | 1     | 1     | 0     |

|     |     |     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 15  | 14  | 13  | 12  | 11  | 10  | 9   | 8   |
| HW7 | HW6 | HW5 | HW4 | HW3 | HW2 | HW1 | HW0 |
| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W |
| 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   |

|      |      |      |      |      |      |      |         |
|------|------|------|------|------|------|------|---------|
| 7    | 6    | 5    | 4    | 3    | 2    | 1    | (LSB) 0 |
| ROM7 | ROM6 | ROM5 | ROM4 | ROM3 | ROM2 | ROM1 | ROM0    |
| R/W  | R/W  | R/W  | R/W  | R/W  | R/W  | R/W  | R/W     |
| 0    | 0    | 0    | 0    | 0    | 0    | 0    | 1       |

**DF Address: 0x2E**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

|       |      |                      |       |    |  |       |     |  |
|-------|------|----------------------|-------|----|--|-------|-----|--|
| 23:16 | TYPE | Chip Type            | 15:8  | HW | Hardware Revision  | 7:4   | ROM | ROM Version                                  |
| [7:0] |      | 76 - CS5376, CS5376A | [7:0] |    | 01 - CS5376 Rev A<br>02 - CS5376 Rev B<br>03 - CS5376A Rev A | [7:0] |     | 01 - Ver 1.0<br>02 - Ver 2.0<br>03 - Ver 3.0 |

**23.2.15 SELFTEST : 0x2F**
**Figure 59. Self Test Result Register SELFTEST**

|          |     |     |     |     |     |     |     |
|----------|-----|-----|-----|-----|-----|-----|-----|
| (MSB) 23 | 22  | 21  | 20  | 19  | 18  | 17  | 16  |
| --       | --  | --  | --  | EU3 | EU2 | EU1 | EU0 |
| R/W      | R/W | R/W | R/W | R/W | R/W | R/W | R/W |
| 0        | 0   | 0   | 0   | 1   | 0   | 1   | 0   |

|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 15    | 14    | 13    | 12    | 11    | 10    | 9     | 8     |
| DRAM3 | DRAM2 | DRAM1 | DRAM0 | PRAM3 | PRAM2 | PRAM1 | PRAM0 |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   |
| 1     | 0     | 1     | 0     | 1     | 0     | 1     | 0     |

|       |       |       |       |       |       |       |         |
|-------|-------|-------|-------|-------|-------|-------|---------|
| 7     | 6     | 5     | 4     | 3     | 2     | 1     | (LSB) 0 |
| DROM3 | DROM2 | DROM1 | DROM0 | PROM3 | PROM2 | PROM1 | PROM0   |
| R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W   | R/W     |
| 1     | 0     | 1     | 0     | 1     | 0     | 1     | 0       |

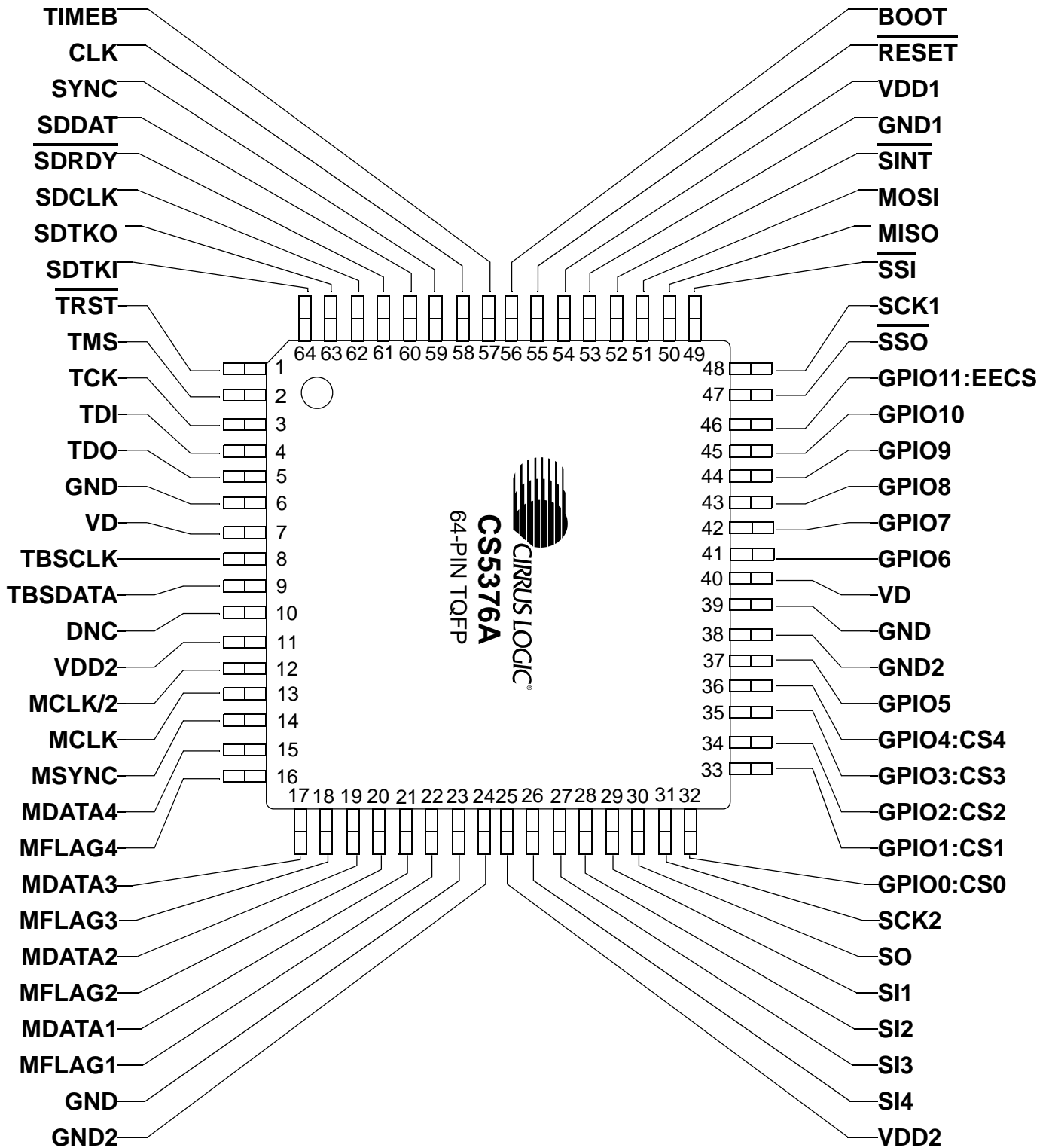
**DF Address: 0x2F**

-- Not defined;  
read as 0  
R Readable  
W Writable  
R/W Readable and  
Writable

Bits in bottom rows  
are reset condition

Bit definitions:

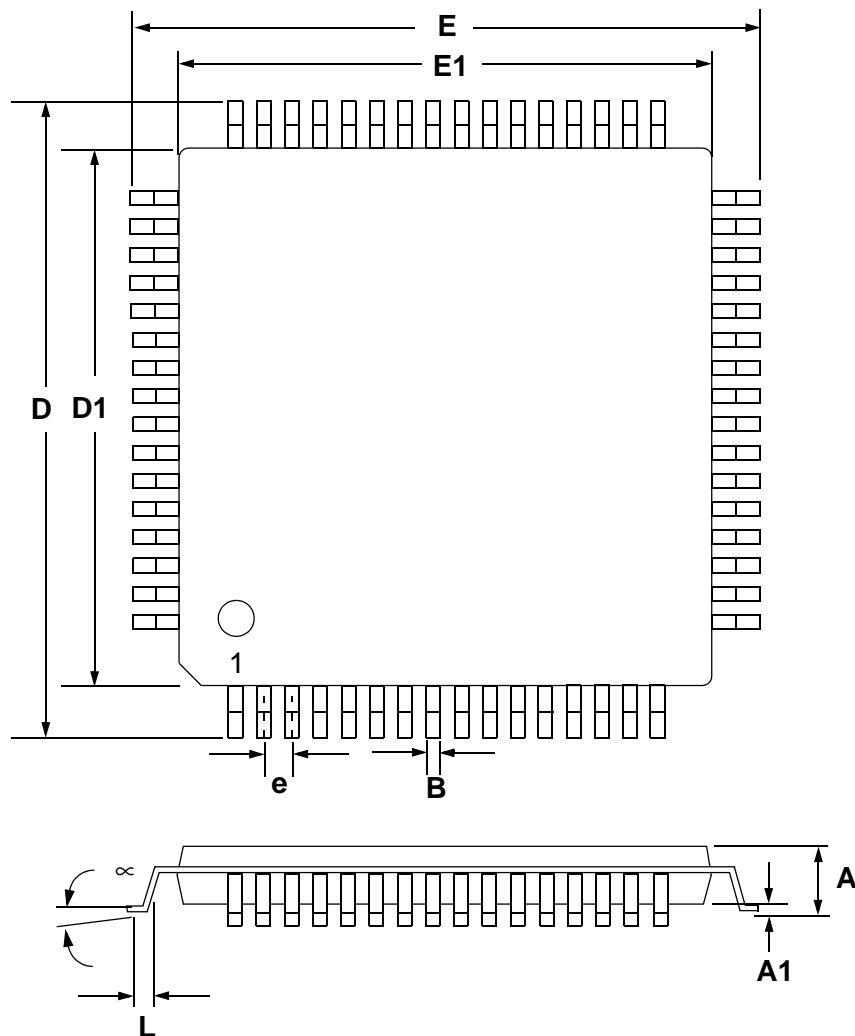
|       |             |   |       |               |  |     |               |  |
|-------|-------------|---|-------|---------------|--|-----|---------------|--|
| 23:20 | --          | reserved                                      | 15:12 | DRAM<br>[3:0] | Data RAM Test<br>'A': Pass<br>'F': Fail    | 7:4 | DROM<br>[3:0] | Data ROM Test<br>'A': Pass<br>'F': Fail    |
| 19:16 | EU<br>[3:0] | Execution Unit Test<br>'A': Pass<br>'F': Fail | 11:8  | PRAM<br>[3:0] | Program RAM Test<br>'A': Pass<br>'F': Fail | 3:0 | PROM<br>[3:0] | Program ROM Test<br>'A': Pass<br>'F': Fail |

**24. PIN DESCRIPTIONS**


| Pin Name                              | Pin Number             | Pin Type       | Pin Description  |
|---------------------------------------|------------------------|----------------|--|
| <b>JTAG port</b>                      |                        |                |  |
| $\overline{\text{TRST}}$              | 1                      | Input          | JTAG reset, active low.<br>Connect to GND if JTAG is not used.                             |
| TMS                                   | 2                      | Input          | JTAG test mode select.   |
| TCK                                   | 3                      | Input          | JTAG clock input.  |
| TDI                                   | 4                      | Input          | JTAG data input.   |
| TDO                                   | 5                      | Output         | JTAG data output.  |
| <b>Test Bit Stream</b>                |                        |                |  |
| TBSCLK                                | 8                      | Output         | Test bit stream clock output.  |
| TBSDATA                               | 9                      | Output         | Test bit stream data output.   |
| <b>No Connect</b>                     |                        |                |  |
| DNC                                   | 10                     | N/A            | Do not connect.  |
| <b>Modulator Interface</b>            |                        |                |  |
| MCLK/2                                | 12                     | Output         | Modulator clock output, half rate.   |
| MCLK                                  | 13                     | Output         | Modulator clock output, full rate.   |
| MSYNC                                 | 14                     | Output         | Modulator sync output.   |
| MDATA[4:1]                            | 15, 17, 19, 21         | Input          | Modulator data inputs.   |
| MFLAG[4:1]                            | 16, 18, 20, 22         | Input          | Modulator flag inputs.   |
| <b>Serial Peripheral Interface 2</b>  |                        |                |  |
| SI[4:1]                               | 26, 27, 28, 29         | Input          | SPI 2 data inputs.   |
| SO                                    | 30                     | Output         | SPI 2 data output.   |
| SCK2                                  | 31                     | Output         | SPI 2 clock output.  |
| <b>General Purpose Input / Output</b> |                        |                |  |
| GPIO[0:4]:CS[0:4]                     | 32, 33, 34, 35, 36     | Input / Output | General Purpose I/O with SPI 2 chip selects.   |
| GPIO[5:10]                            | 37, 41, 42, 43, 44, 45 | Input / Output | General Purpose I/O.   |
| GPIO11:EECS                           | 46                     | Input / Output | General Purpose I/O with boot EEPROM chip select.  |
| <b>Serial Peripheral Interface 1</b>  |                        |                |  |
| $\overline{\text{SSO}}$               | 47                     | Output         | SPI 1 slave select output, active low.   |
| SCK1                                  | 48                     | Input / Output | SPI 1 serial clock input / output.   |
| $\overline{\text{SSI}}$               | 49                     | Input          | SPI 1 slave select input, active low.  |
| MISO                                  | 50                     | Input / Output | SPI 1 data, master in / slave out.<br>Open drain output requiring a 10 k $\Omega$ pull-up. |
| MOSI                                  | 51                     | Input / Output | SPI 1 data, master out / slave in.   |
| $\overline{\text{SINT}}$              | 52                     | Output         | SPI 1 serial interrupt output, active low.   |
| <b>Reset Control</b>                  |                        |                |  |
| $\overline{\text{RESET}}$             | 55                     | Input          | Reset, active low.   |
| BOOT                                  | 56                     | Input          | Boot mode select.  |
| <b>Time Break</b>                     |                        |                |  |
| TIMEB                                 | 57                     | Input          | Time break input.  |



| Pin Name                         | Pin Number               | Pin Type | Pin Description   |
|----------------------------------|--------------------------|----------|---|
| <b>Clock and Synchronization</b> |                          |          |   |
| CLK                              | 58                       | Input    | Clock input, nominal 32.768 MHz.  |
| SYNC                             | 59                       | Input    | Sync input.   |
| <b>Serial Data Port</b>          |                          |          |   |
| SDDAT                            | 60                       | Output   | SD port data output.  |
| $\overline{\text{SDRDY}}$        | 61                       | Output   | SD port data ready, active low.<br>Open drain output requiring a 10 k $\Omega$ pull-up. |
| SDCLK                            | 62                       | Input    | SD port clock input.  |
| SDTKO                            | 63                       | Output   | SD port token output.   |
| SDTKI                            | 64                       | Input    | SD port token input.  |
| <b>Power Supplies</b>            |                          |          |   |
| VDD1                             | 54                       | Supply   | Pin power supply for pins 1 - 5 and 41 - 64.  |
| VDD2                             | 11, 25                   | Supply   | Pin power supplies for pins 8 - 37.   |
| VD                               | 7, 40                    | Supply   | Logic core power supplies.  |
| GND1, GND2, GND                  | 6, 23, 24,<br>38, 39, 53 | Supply   | Digital grounds.  |

**25.PACKAGE DIMENSIONS**
**64L TQFP PACKAGE DRAWING**


| DIM | INCHES |        | MILLIMETERS |       |
|-----|--------|--------|-------------|-------|
|     | MIN    | MAX    | MIN         | MAX   |
| A   | ---    | 0.063  | ---         | 1.60  |
| A1  | 0.002  | 0.006  | 0.05        | 0.15  |
| B   | 0.007  | 0.011  | 0.17        | 0.27  |
| D   | 0.461  | 0.484  | 11.70       | 12.30 |
| D1  | 0.390  | 0.398  | 9.90        | 10.10 |
| E   | 0.461  | 0.484  | 11.70       | 12.30 |
| E1  | 0.390  | 0.398  | 9.90        | 10.10 |
| e*  | 0.016  | 0.024  | 0.40        | 0.60  |
| L   | 0.018  | 0.030  | 0.45        | 0.75  |
| μ   | 0.000° | 7.000° | 0.00°       | 7.00° |

\* Nominal pin pitch is 0.50 mm  
 Controlling dimension is mm.  
 JEDEC Designation: MS026

## 26. ORDERING INFORMATION

| Model                 | Temperature   | Package     |
|-----------------------|---------------|-------------|
| CS5376A-IQ            | -40 to +85 °C | 64-pin TQFP |
| CS5376A-IQZ Lead Free |               |             |

## 27. ENVIRONMENTAL, MANUFACTURING, & HANDLING INFORMATION

| Model Number          | Peak Reflow Temp | MSL Rating* | Max Floor Life |
|-----------------------|------------------|-------------|----------------|
| CS5376A-IQ            | 240 °C           | 3           | 7 Days         |
| CS5376A-IQZ Lead Free | 250 °C           |             |                |

\* MSL (Moisture Sensitivity Level) as specified by IPC/JEDEC J-STD-020.

## 28. REVISION HISTORY

| Revision | Date     | Changes   |
|----------|----------|---|
| PP1      | SEP 2003 | Initial "Preliminary Product" release.  |
| F1       | FEB 2004 | Update group delay on page 50, power consumption on page 14 and MISO read timing on page 15. Add TBS impulse data on page 66 and MOSI pull-up on page 32. |
| F2       | AUG 2005 | Updated ordering information. Added MSL data.   |
| F3       | SEP 2005 | Added lead-free device ordering information.  |

## Contacting Cirrus Logic Support

For all product questions and inquiries contact a Cirrus Logic Sales Representative.

To find the one nearest to you go to [www.cirrus.com](http://www.cirrus.com)

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