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VS1003 - MP3/WMA AUDIO CODEC

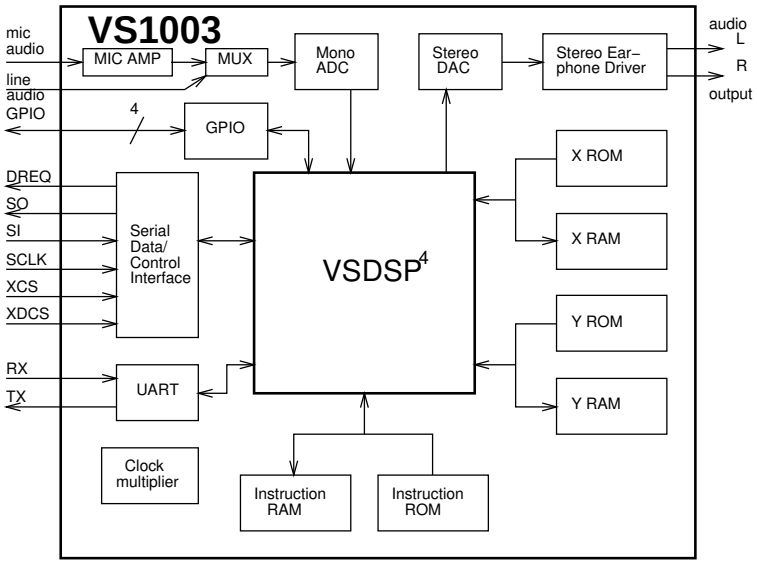
Features

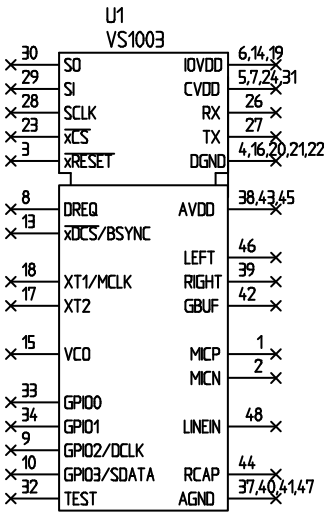
- Decodes MPEG 1 & 2 audio layer III (CBR +VBR +ABR); WMA 4.0/4.1/7/8/9 all profiles (5-384kbit/s); WAV (PCM + IMA ADPCM); General MIDI / SP-MIDI files
- Encodes IMA ADPCM from microphone or line input
- Streaming support for MP3 and WAV
- Bass and treble controls
- Operates with a single 12..13 MHz clock
- Internal PLL clock multiplier
- Low-power operation
- High-quality on-chip stereo DAC with no phase error between channels
- Stereo earphone driver capable of driving a 30Ω load
- Separate operating voltages for analog, digital and I/O
- 5.5 KiB On-chip RAM for user code / data
- Serial control and data interfaces
- Can be used as a slave co-processor
- SPI flash boot for special applications
- UART for debugging purposes
- New functions may be added with software and 4 GPIO pins

Description

VS1003 is a single-chip MP3/WMA/MIDI audio decoder and ADPCM encoder. It contains a high-performance, proprietary low-power DSP processor core VS_DSP^4, working data memory, 5 KiB instruction RAM and 0.5 KiB data RAM for user applications, serial control and input data interfaces, 4 general purpose I/O pins, an UART, as well as a high-quality variable-sample-rate mono ADC and stereo DAC, followed by an earphone amplifier and a common buffer.

VS1003 receives its input bitstream through a serial input bus, which it listens to as a system slave. The input stream is decoded and passed through a digital volume control to an 18-bit oversampling, multi-bit, sigma-delta DAC. The decoding is controlled via a serial control bus. In addition to the basic decoding, it is possible to add application specific features, like DSP effects, to the user RAM memory.





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1 Licenses

MPEG Layer-3 audio decoding technology licensed from Fraunhofer IIS and Thomson.

VS1003 contains WMA decoding technology from Microsoft.
This product is protected by certain intellectual property rights of Microsoft and cannot be used or further distributed without a license from Microsoft.

2 Disclaimer

All properties and figures are subject to change.

3 Definitions

B Byte, 8 bits.

b Bit.

Ki "Kibi" = 2^{10} = 1024 (IEC 60027-2).

Mi "Mebi" = 2^{20} = 1048576 (IEC 60027-2).

VS_DSP VLSI Solution's DSP core.

W Word. In VS_DSP, instruction words are 32-bit and data words are 16-bit wide.

4 Characteristics & Specifications

4.1 Absolute Maximum Ratings

Parameter	Symbol	Min	Max	Unit
Analog Positive Supply	AVDD	-0.3	2.85	V
Digital Positive Supply	CVDD	-0.3	2.7	V
I/O Positive Supply	IOVDD	-0.3	3.6	V
Current at Any Digital Output			±50	mA
Voltage at Any Digital Input		-0.3	IOVDD+0.3[1]	V
Operating Temperature		-40	+85	°C
Storage Temperature		-65	+150	°C

[1] Must not exceed 3.6 V

4.2 Recommended Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit
Ambient Operating Temperature		-40		+85	°C
Analog and Digital Ground [1]	AGND DGND		0.0		V
Positive Analog	AVDD	2.6	2.8	2.85	V
Positive Digital	CVDD	2.4	2.5	2.7	V
I/O Voltage	IOVDD	CVDD-0.6V	2.8	3.6	V
Input Clock Frequency[2]	XTALI	12	12.288	13	MHz
Internal Clock Frequency	CLKI	12	36.864	52.0[4]	MHz
Internal Clock Multiplier[3]		1.0×	3.0×	4.5×[4]	
Master Clock Duty Cycle		40	50	60	%

[1] Must be connected together as close the device as possible for latch-up immunity.
[2] The maximum sample rate that can be played with correct speed is XTALI/256.
Thus, XTALI must be at least 12.288 MHz to be able to play 48 kHz at correct speed.
[3] Reset value is 1.0×. Recommended SC_MULT=3.0×, SC_ADD=1.0× (SCI_CLOCKF=0x9000).
[4] 52.0 MHz is the maximum clock for the full CVDD range.
(4.0 × 12.288 MHz=49.152 MHz or 4.0 × 13.0 MHz=52.0 MHz)

4.3 Analog Characteristics

Unless otherwise noted: AVDD=2.85V, CVDD=2.5V, IOVDD=-2.8V, TA=-25..+70°C, XTALI=12.288MHz, DAC tested with 1307.894 Hz full-scale output sinewave, measurement bandwidth 20..20000 Hz, analog output load: LEFT to GBUF 30Ω, RIGHT to GBUF 30Ω. Microphone test amplitude 50 mVpp, f=1 kHz, Line input test amplitude 2.2 Vpp, f=1 kHz.

Parameter	Symbol	Min	Typ	Max	Unit
DAC Resolution			18		bits
Total Harmonic Distortion	THD		0.1	0.3	%
Dynamic Range (DAC unmuted, A-weighted)	IDR		>90		dB
S/N Ratio (full scale signal)	SNR	70[5]	83[4]		dB
Interchannel Isolation (Cross Talk)		50	75		dB
Interchannel Isolation (Cross Talk), with GBUF			40		dB
Interchannel Gain Mismatch		-0.5	±0.2	0.5	dB
Frequency Response		-0.1		0.1	dB
Full Scale Output Voltage (Peak-to-peak)		1.3	1.5[1]	1.7	Vpp
Deviation from Linear Phase				5	°
Analog Output Load Resistance	AOLR	16	30[2]		Ω
Analog Output Load Capacitance				100	pF
Microphone input amplifier gain	MICG		26		dB
Microphone input amplitude			50	140[3]	mVpp AC
Microphone Total Harmonic Distortion	MTHD		0.02	0.10	%
Microphone S/N Ratio	MSNR	50[5]	68		dB
Line input amplitude			2200	2800[3]	mVpp AC
Line input Total Harmonic Distortion	LTHD		0.015	0.10	%
Line input S/N Ratio	LSNR	60[5]	86		dB
Line and Microphone input impedances			100		kΩ

Typical values are measured of about 5000 devices of Lot 4234011, Week Code 0452.
[1] 3.0 volts can be achieved with +-to-+ wiring for mono difference sound.
[2] AOLR may be much lower, but below *Typical* distortion performance may be compromised.
[3] Above typical amplitude the Harmonic Distortion increases.
[4] Unweighted, A-weighted is about 3 dB better.
[5] Limit low due to noise level of production tester.

4.4 Power Consumption

Tested with an MPEG 1.0 Layer-3 128 kbit/s sample and generated sine. Output at full volume. XTALI 12.288 MHz. Internal clock multiplier $3.0\times$. CVDD = 2.5 V, AVDD = 2.8 V.

Parameter	Min	Typ	Max	Unit
Power Supply Consumption AVDD, Reset		0.6	5.0	μA
Power Supply Consumption CVDD, Reset, +25°C		3.7	40.0	μA
Power Supply Consumption CVDD, Reset, +85°C			200.0	μA
Power Supply Consumption AVDD, sine test, 30Ω + GBUF		36.9		mA
Power Supply Consumption CVDD, sine test		12.4		mA
Power Supply Consumption AVDD, no load		7.0		mA
Power Supply Consumption AVDD, output load 30Ω		10.9		mA
Power Supply Consumption AVDD, 30Ω + GBUF		16.1		mA
Power Supply Consumption CVDD		17.5		mA

4.5 Digital Characteristics

Parameter	Symbol	Min	Typ	Max	Unit
High-Level Input Voltage		0.7×IOVDD		IOVDD+0.3[1]	V
Low-Level Input Voltage		-0.2		0.3×IOVDD	V
High-Level Output Voltage at I_O = -1.0 mA		0.7×IOVDD			V
Low-Level Output Voltage at I_O = 1.0 mA				0.3×IOVDD	V
Input Leakage Current		-1.0		1.0	μA
SPI Input Clock Frequency [2]				$\frac{CLKI}{7}$	MHz
Rise time of all output pins, load = 50 pF				50	ns

[1] Must not exceed 3.6V
[2] Value for SCI reads. SCI and SDI writes allow $\frac{CLKI}{4}$.

4.6 Switching Characteristics - Boot Initialization

Parameter	Symbol	Min	Max	Unit
XRESET active time		2		XTALI
XRESET inactive to software ready		16600	50000[1]	XTALI
Power on reset, rise time to CVDD		10		V/s

[1] DREQ rises when initialization is complete. You should not send any data or commands before that.

4.7 Typical characteristics

4.7.1 Line input ADC

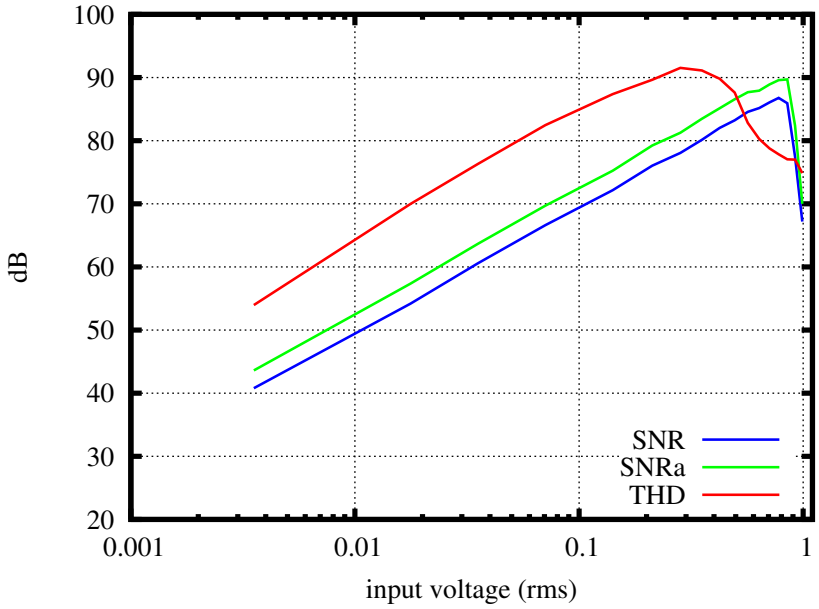

Figure 1: Measured ADC performance of the LINEIN pin. X-axis is rms amplitude of 1 kHz sine input. Curves are unweighted signal-to-noise ratio (blue), A-weighted signal-to-noise ratio (green), and unweighted signal-to-distortion ratio (red). Sampling rate of ADC is 48 kHz (master clock 12.288 MHz), noise calculated from 0 to 20 kHz.

4.7.2 Microphone input ADC

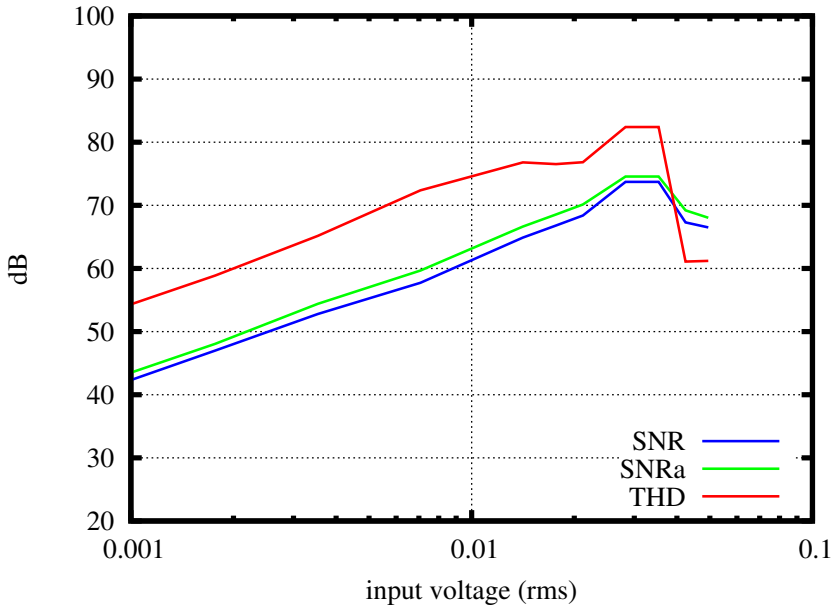

Figure 2: Measured ADC performance of the MIC pins (differential). Other settings same as in Fig. 1.

4.7.3 RIGHT and LEFT outputs

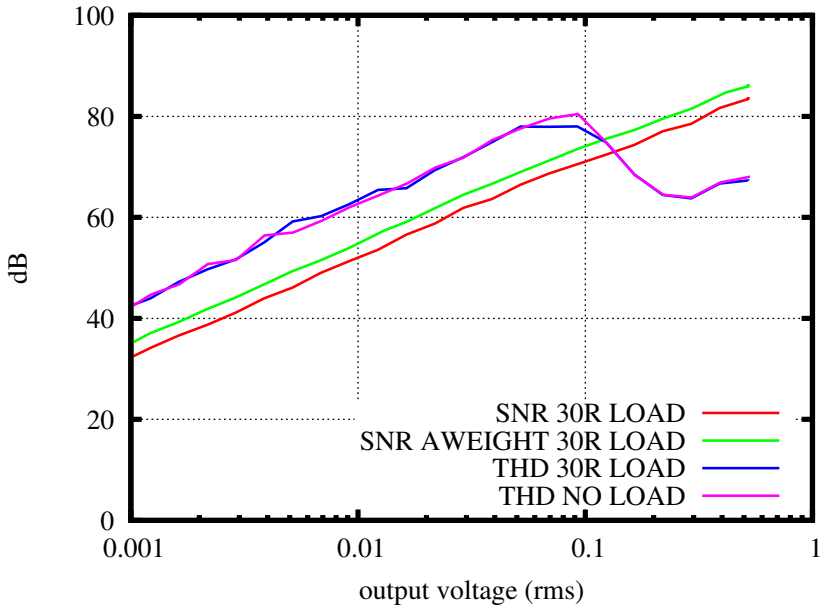

Figure 3: Measured performance of RIGHT (or LEFT) output with 1 kHz generated sine. Sampling rate of DAC is 48 kHz (master clock 12.288 MHz), noise calculated from 0 to 20 kHz.

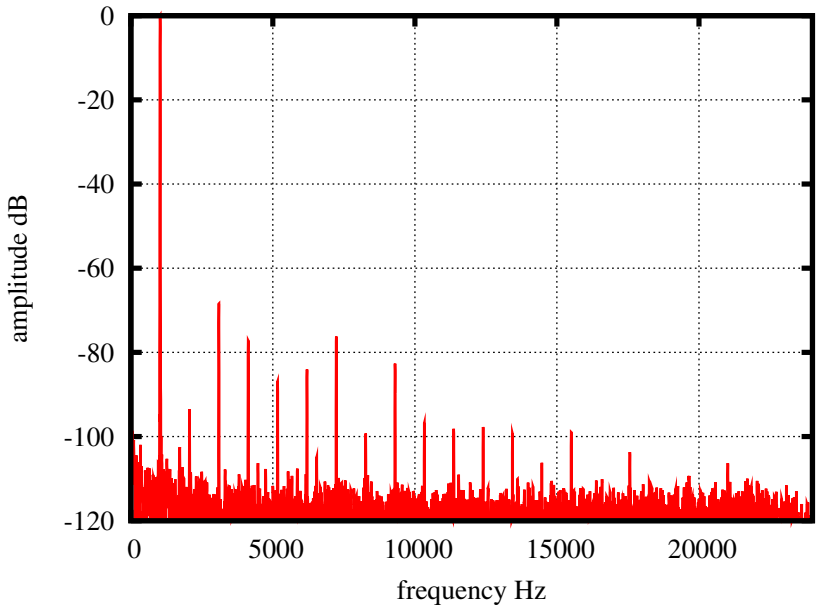

Figure 4: Typical spectrum of RIGHT (or LEFT) output with maximum level and 30 Ohm load. Setup is the same is in Fig. 3.

5 Packages and Pin Descriptions

5.1 Packages

Both LPQFP-48 and BGA-49 are lead (Pb) free and also RoHS compliant packages. RoHS is a short name of *Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment*.

5.1.1 LQFP-48

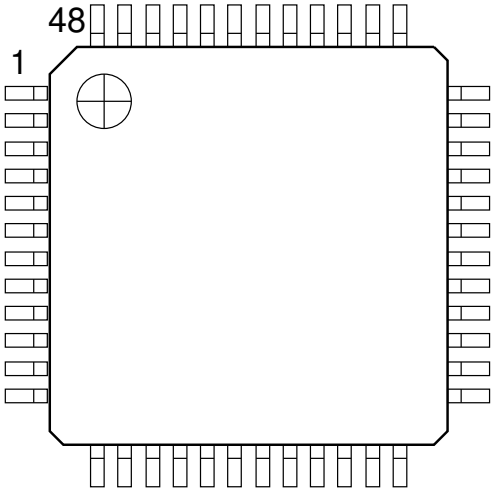

Figure 5: Pin Configuration, LQFP-48.

LQFP-48 package dimensions are at *http://www.vlsi.fi/* .

5.1.2 BGA-49

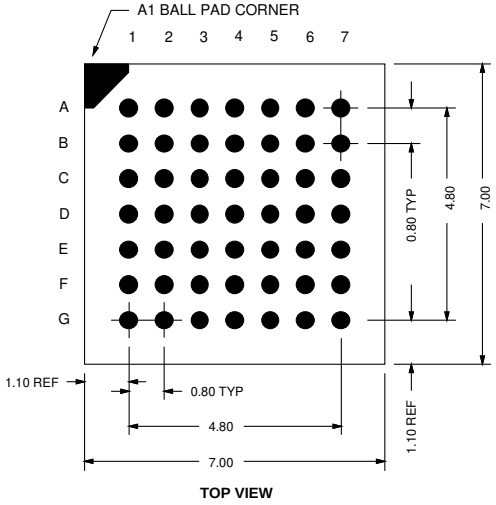

Figure 6: Pin Configuration, BGA-49.

BGA-49 package dimensions are at *http://www.vlsi.fi/* .

5.2 LQFP-48 and BGA-49 Pin Descriptions

Pin Name	LQFP-48 Pin	BGA49 Ball	Pin Type	Function
MICP	1	C3	AI	Positive differential microphone input, self-biasing
MICN	2	C2	AI	Negative differential microphone input, self-biasing
XRESET	3	B1	DI	Active low asynchronous reset
DGND0	4	D2	DGND	Core & I/O ground
CVDD0	5	C1	CPWR	Core power supply
IOVDD0	6	D3	IOPWR	I/O power supply
CVDD1	7	D1	CPWR	Core power supply
DREQ	8	E2	DO	Data request, input bus
GPIO2 / DCLK[1]	9	E1	DIO	General purpose IO 2 / serial input data bus clock
GPIO3 / SDATA[1]	10	F2	DIO	General purpose IO 3 / serial data input
XDCS / BSYNC[1]	13	E3	DI	Data chip select / byte sync
IOVDD1	14	F3	IOPWR	I/O power supply
VCO	15	G2	DO	For testing only (Clock VCO output)
DGND1	16	F4	DGND	Core & I/O ground
XTALO	17	G3	AO	Crystal output
XTALI	18	E4	AI	Crystal input
IOVDD2	19	G4	IOPWR	I/O power supply
IOVDD3		F5	IOPWR	I/O power supply
DGND2	20		DGND	Core & I/O ground
DGND3	21	G5	DGND	Core & I/O ground
DGND4	22	F6	DGND	Core & I/O ground
XCS	23	G6	DI	Chip select input (active low)
CVDD2	24	G7	CPWR	Core power supply
RX	26	E6	DI	UART receive, connect to IOVDD if not used
TX	27	F7	DO	UART transmit
SCLK	28	D6	DI	Clock for serial bus
SI	29	E7	DI	Serial input
SO	30	D5	DO3	Serial output
CVDD3	31	D7	CPWR	Core power supply
TEST	32	C6	DI	Reserved for test, connect to IOVDD
GPIO0 / SPIBOOT	33	C7	DIO	General purpose IO 0 / SPIBOOT, use 100 kΩ pull-down resistor[2]
GPIO1	34	B6	DIO	General purpose IO 1
AGND0	37	C5	APWR	Analog ground, low-noise reference
AVDD0	38	B5	APWR	Analog power supply
RIGHT	39	A6	AO	Right channel output
AGND1	40	B4	APWR	Analog ground
AGND2	41	A5	APWR	Analog ground
GBUF	42	C4	AO	Common buffer for headphones
AVDD1	43	A4	APWR	Analog power supply
RCAP	44	B3	AIO	Filtering capacitance for reference
AVDD2	45	A3	APWR	Analog power supply
LEFT	46	B2	AO	Left channel output
AGND3	47	A2	APWR	Analog ground
LINEIN	48	A1	AI	Line input

[1] First pin function is active in New Mode, latter in Compatibility Mode.

[2] Unless pull-down resistor is used, SPI Boot is tried. See Chapter 9.5 for details.

Pin types:

Type	Description
DI	Digital input, CMOS Input Pad
DO	Digital output, CMOS Input Pad
DIO	Digital input/output
DO3	Digital output, CMOS Tri-stated Output Pad
AI	Analog input

Type	Description
AO	Analog output
AIO	Analog input/output
APWR	Analog power supply pin
DGND	Core or I/O ground pin
CPWR	Core power supply pin
IOPWR	I/O power supply pin

In BGA-49, no-connect balls are A7, B7, D4, E5, F1, G1.
In LQFP-48, no-connect pins are 11, 12, 25, 35, 36.

6 Connection Diagram, LQFP-48

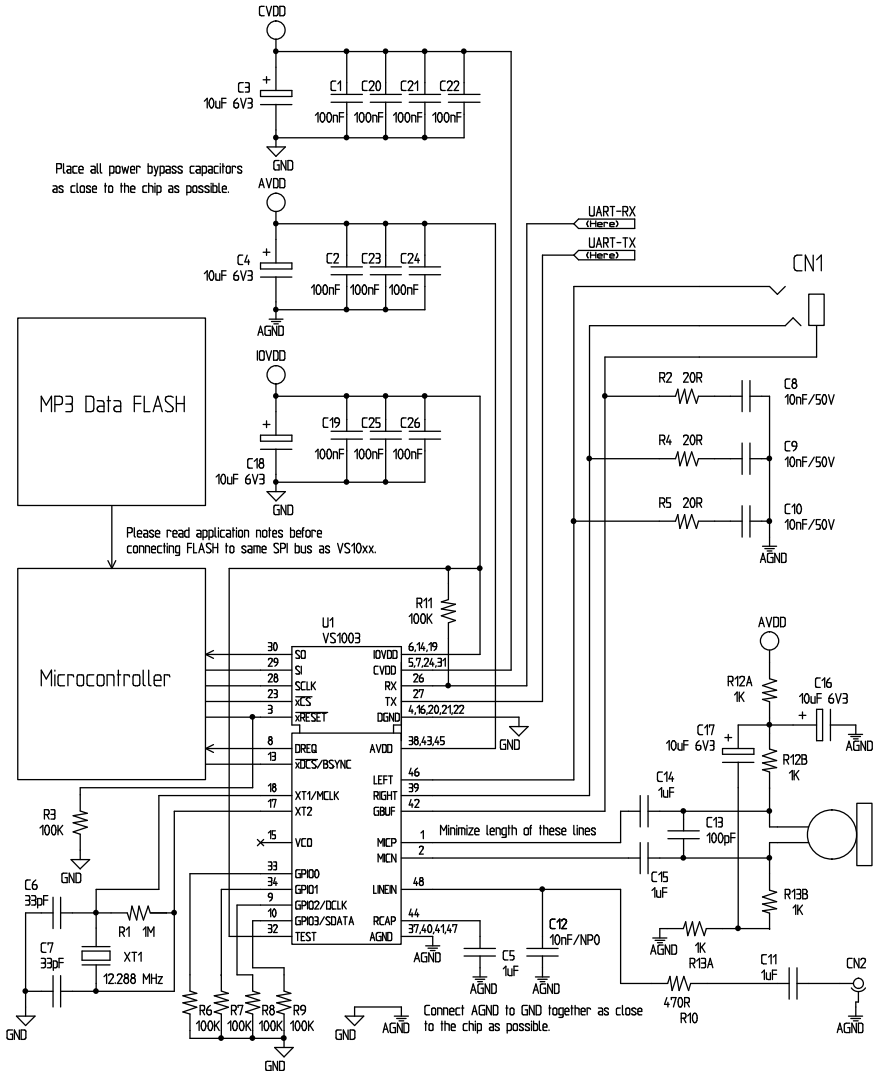

Figure 7: Typical Connection Diagram Using LQFP-48.

The common buffer GBUF can be used for common voltage (1.24 V) for earphones. This will eliminate the need for large isolation capacitors on line outputs, and thus the audio output pins from VS1003 may be connected directly to the earphone connector.

GBUF must NOT be connected to ground under any circumstances. If GBUF is not used, LEFT and RIGHT must be provided with coupling capacitors. To keep GBUF stable, you should always have the resistor and capacitor even when GBUF is not used. See application notes for details.

Unused GPIO pins should have a pull-down resistor.

If UART is not used, RX should be connected to IOVDD and TX be unconnected.

Do not connect any external load to XTALO.

Note: This connection assumes SM_SDINEW is active (see Chapter 8.6.1). If also SM_SDISHARE is used, xDCS should be tied low or high (see Chapter 7.2.1).

7 SPI Buses

7.1 General

The SPI Bus - that was originally used in some Motorola devices - has been used for both VS1003's Serial Data Interface SDI (Chapters 7.4 and 8.4) and Serial Control Interface SCI (Chapters 7.5 and 8.5).

7.2 SPI Bus Pin Descriptions

7.2.1 VS1002 Native Modes (New Mode)

These modes are active on VS1003 when SM_SDINEW is set to 1 (default at startup). DCLK and SDATA are not used for data transfer and they can be used as general-purpose I/O pins (GPIO2 and GPIO3). BSYNC function changes to data interface chip select (XDCS).

SDI Pin	SCI Pin	Description
XDCS	XCS	Active low chip select input. A high level forces the serial interface into standby mode, ending the current operation. A high level also forces serial output (SO) to high impedance state. If SM_SDISHARE is 1, pin XDCS is not used, but the signal is generated internally by inverting XCS.
SCK		Serial clock input. The serial clock is also used internally as the master clock for the register interface. SCK can be gated or continuous. In either case, the first rising clock edge after XCS has gone low marks the first bit to be written.
SI		Serial input. If a chip select is active, SI is sampled on the rising CLK edge.
-	SO	Serial output. In reads, data is shifted out on the falling SCK edge. In writes SO is at a high impedance state.

7.2.2 VS1001 Compatibility Mode

This mode is active when SM_SDINEW is set to 0. In this mode, DCLK, SDATA and BSYNC are active.

SDI Pin	SCI Pin	Description
-	XCS	Active low chip select input. A high level forces the serial interface into standby mode, ending the current operation. A high level also forces serial output (SO) to high impedance state.
BSYNC	-	SDI data is synchronized with a rising edge of BSYNC.
DCLK	SCK	Serial clock input. The serial clock is also used internally as the master clock for the register interface. SCK can be gated or continuous. In either case, the first rising clock edge after XCS has gone low marks the first bit to be written.
SDATA	SI	Serial input. SI is sampled on the rising SCK edge, if XCS is low.
-	SO	Serial output. In reads, data is shifted out on the falling SCK edge. In writes SO is at a high impedance state.

7.3 Data Request Pin DREQ

The DREQ pin/signal is used to signal if VS1003's FIFO is capable of receiving data. If DREQ is high, VS1003 can take at least 32 bytes of SDI data or one SCI command. When these criteria are not met, DREQ is turned low, and the sender should stop transferring new data.

Because of the 32-byte safety area, the sender may send upto 32 bytes of SDI data at a time without checking the status of DREQ, making controlling VS1003 easier for low-speed microcontrollers.

Note: DREQ may turn low or high at any time, even during a byte transmission. Thus, DREQ should only be used to decide whether to send more bytes. It should not abort a transmission that has already started.

Note: In VS10XX products upto VS1002, DREQ was only used for SDI. In VS1003 DREQ is also used to tell the status of SCI.

There are cases when you still want to send SCI commands when DREQ is low. Because DREQ is shared between SDI and SCI, you can not determine if a SCI command has been executed if SDI is not ready to receive. In this case you need a long enough delay after every SCI command to make certain none of them is missed. The SCI Registers table in section 8.6 gives the worst-case handling time for each SCI register write.

7.4 Serial Protocol for Serial Data Interface (SDI)

7.4.1 General

The serial data interface operates in slave mode so DCLK signal must be generated by an external circuit.

Data (SDATA signal) can be clocked in at either the rising or falling edge of DCLK (Chapter 8.6).

VS1003 assumes its data input to be byte-sychronized. SDI bytes may be transmitted either MSb or LSb first, depending of contents of SCI_MODE (Chapter 8.6.1).

The firmware is able to accept the maximum bitrate the SDI supports.

7.4.2 SDI in VS1002 Native Modes (New Mode)

In VS1002 native modes (SM_NEWMODE is 1), byte synchronization is achieved by XDCS. The state of XDCS may not change while a data byte transfer is in progress. To always maintain data synchronization even if there may be glitches in the boards using VS1003, it is recommended to turn XDCS every now and then, for instance once after every flash data block or a few kilobytes, just to keep sure the host and VS1003 are in sync.

If SM_SDISHARE is 1, the XDCS signal is internally generated by inverting the XCS input.

For new designs, using VS1002 native modes are recommended.

7.4.3 SDI in VS1001 Compatibility Mode

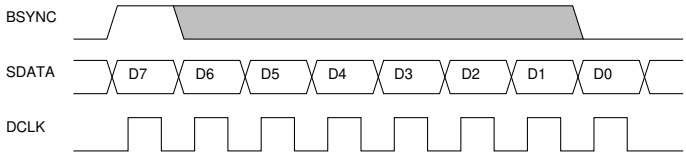

Figure 8: BSYNC Signal - one byte transfer.

When VS1003 is running in VS1001 compatibility mode, a BSYNC signal must be generated to ensure correct bit-alignment of the input bitstream. The first DCLK sampling edge (rising or falling, depending on selected polarity), during which the BSYNC is high, marks the first bit of a byte (LSB, if LSB-first order is used, MSB, if MSB-first order is used). If BSYNC is '1' when the last bit is received, the receiver stays active and next 8 bits are also received.

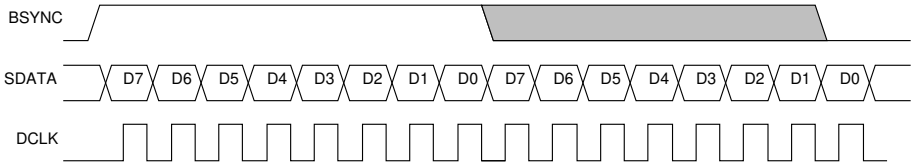

Figure 9: BSYNC Signal - two byte transfer.

7.4.4 Passive SDI Mode

If SM_NEWMODE is 0 and SM_SDISHARE is 1, the operation is otherwise like the VS1001 compatibility mode, but bits are only received while the BSYNC signal is '1'. Rising edge of BSYNC is still used for synchronization.

7.5 Serial Protocol for Serial Command Interface (SCI)

7.5.1 General

The serial bus protocol for the Serial Command Interface SCI (Chapter 8.5) consists of an instruction byte, address byte and one 16-bit data word. Each read or write operation can read or write a single register. Data bits are read at the rising edge, so the user should update data at the falling edge. Bytes are always send MSb first. XCS should be low for the full duration of the operation, but you can have pauses between bits if needed.

The operation is specified by an 8-bit instruction opcode. The supported instructions are read and write. See table below.

Instruction		
Name	Opcode	Operation
READ	0b0000 0011	Read data
WRITE	0b0000 0010	Write data

Note: VS1003 sets DREQ low after each SCI operation. The duration depends on the operation. It is not allowed to start a new SCI/SDI operation before DREQ is high again.

7.5.2 SCI Read

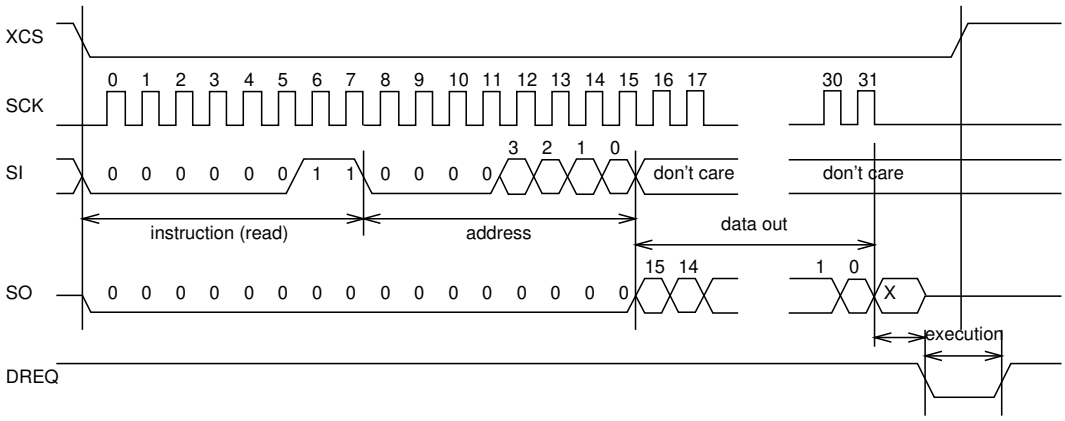

Figure 10: SCI Word Read

VS1003 registers are read from using the following sequence, as shown in Figure 10. First, XCS line is pulled low to select the device. Then the READ opcode (0x3) is transmitted via the SI line followed by an 8-bit word address. After the address has been read in, any further data on SI is ignored by the chip. The 16-bit data corresponding to the received address will be shifted out onto the SO line.

XCS should be driven high after data has been shifted out.

DREQ is driven low for a short while when in a read operation by the chip. This is a very short time and doesn't require special user attention.

7.5.3 SCI Write

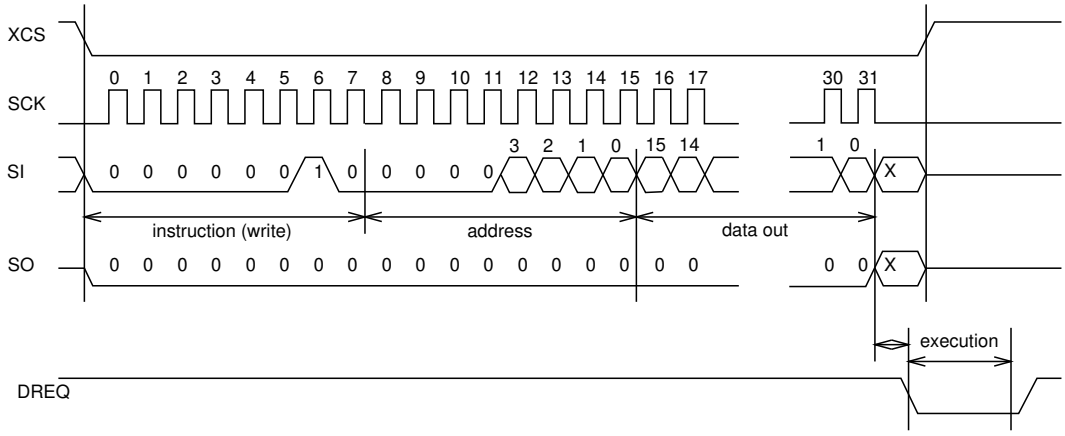

Figure 11: SCI Word Write

VS1003 registers are written from using the following sequence, as shown in Figure 11. First, XCS line is pulled low to select the device. Then the WRITE opcode (0x2) is transmitted via the SI line followed by an 8-bit word address.

After the word has been shifted in and the last clock has been sent, XCS should be pulled high to end the WRITE sequence.

After the last bit has been sent, DREQ is driven low for the duration of the register update, marked "execution" in the figure. The time varies depending on the register and its contents (see table in Chapter 8.6 for details). If the maximum time is longer than what it takes from the microcontroller to feed the next SCI command or SDI byte, it is not allowed to finish a new SCI/SDI operation before DREQ has risen up again.

7.6 SPI Timing Diagram

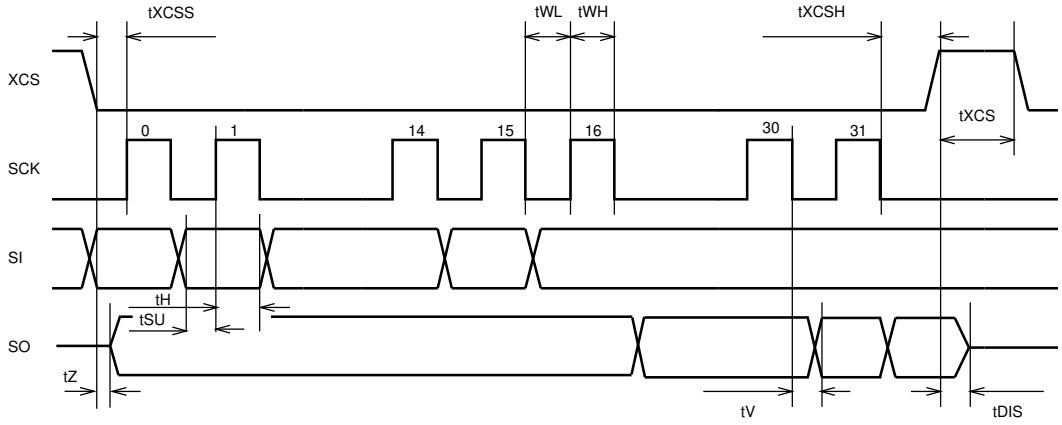

Figure 12: SPI Timing Diagram.

Symbol	Min	Max	Unit
tXCSS	5		ns
tSU	0		ns
tH	2		CLKI cycles
tZ	0		ns
tWL	2		CLKI cycles
tWH	2		CLKI cycles
tV	2 (+ 25ns[1])		CLKI cycles
tXCSH	1		CLKI
tXCS	2		CLKI cycles
tDIS		10	ns

[1] 25ns is when pin loaded with 100pF capacitance. The time is shorter with lower capacitance.

Note: As tWL and tWH, as well as tH require at least 2 clock cycles, the maximum speed for the SPI bus that can easily be used with asynchronous clocks is 1/7 of VS1003's internal clock speed CLKI.

Note: Although the timing is derived from the internal clock CLKI, the system always starts up in $1.0\times$ mode, thus CLKI=XTALI.

7.7 SPI Examples with SM_SDINEW and SM_SDISHARED set

7.7.1 Two SCI Writes

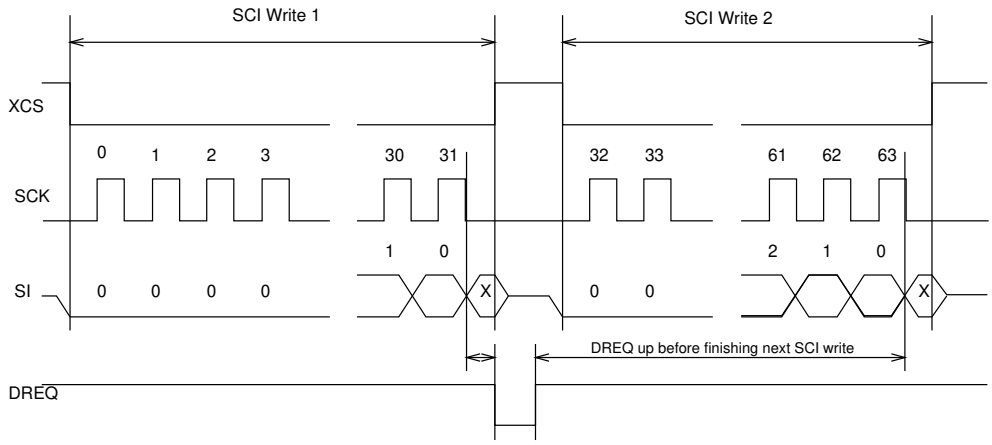

Figure 13: Two SCI Operations.

Figure 13 shows two consecutive SCI operations. Note that xCS *must* be raised to inactive state between the writes. Also DREQ must be respected as shown in the figure.

7.7.2 Two SDI Bytes

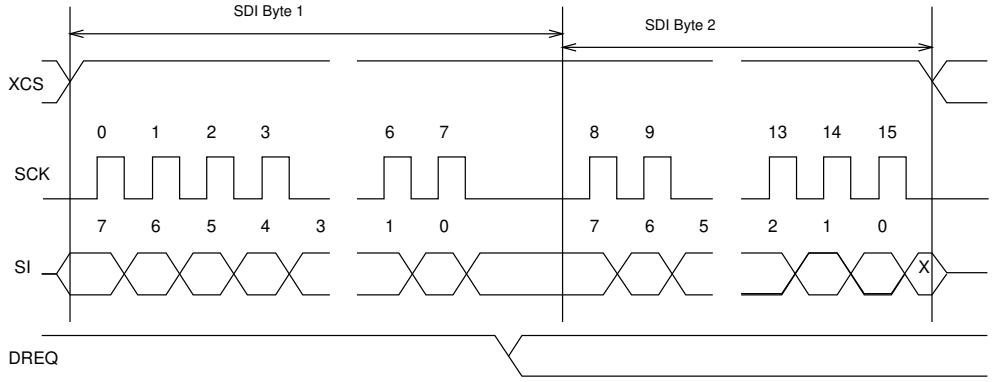

Figure 14: Two SDI Bytes.

SDI data is synchronized with a raising edge of xCS as shown in Figure 14. However, every byte doesn't need separate synchronization.

7.7.3 SCI Operation in Middle of Two SDI Bytes

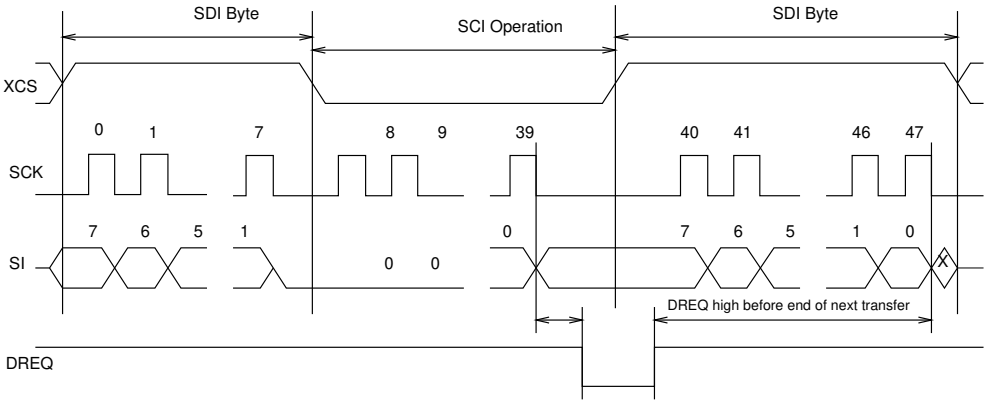

Figure 15: Two SDI Bytes Separated By an SCI Operation.

Figure 15 shows how an SCI operation is embedded in between SDI operations. xCS edges are used to synchronize both SDI and SCI. Remember to respect DREQ as shown in the figure.