Low-Power Analog Front End with DSP Microcomputer

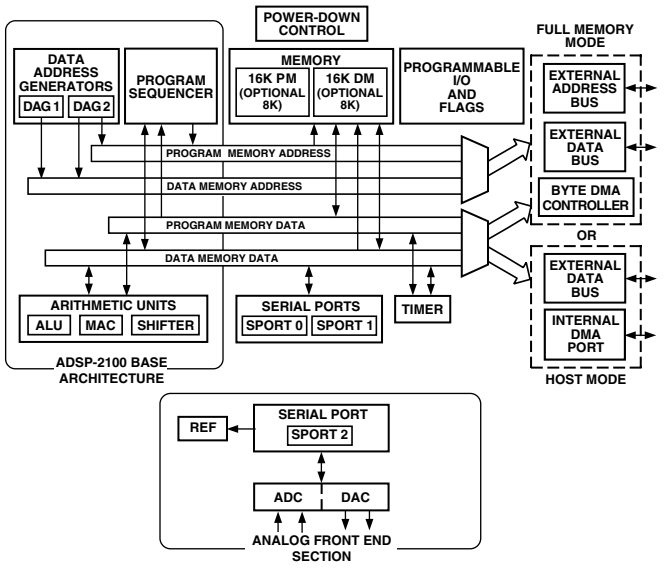
AD73411

FEATURES

AFE PERFORMANCE
16-Bit A/D Converter
16-Bit D/A Converter
Programmable Input/Output Sample Rates
76 dB ADC SNR
77 dB DAC SNR
64 kS/s Maximum Sample Rate
–90 dB Crosstalk
Low Group Delay (25 μs Typ per ADC Channel, 50 μs Typ per DAC Channel)
Programmable Input/Output Gain
On-Chip Reference

DSP PERFORMANCE
19 ns Instruction Cycle Time @ 3.3 V, 52 MIPS Sustained Performance
AD73411-80
80K Bytes of On-Chip RAM, Configured as 16K Words Program Memory RAM and 16K Words Data Memory RAM
AD73411-40
40K Bytes of On-Chip RAM, Configured as 8K Words Program Memory RAM and 8K Words Data Memory RAM

FUNCTIONAL BLOCK DIAGRAM



GENERAL DESCRIPTION

The AD73411 is a single device incorporating a single analog front end (AFE) and a microcomputer optimized for digital signal processing (DSP) and other high-speed numeric processing applications.

The AD73411's analog front end (AFE) section is suitable for general-purpose applications including speech and telephony. The AFE section features a 16-bit A/D converter and a 16-bit D/A converter. Each converter provides 76 dB signal-to-noise ratio over a voiceband signal bandwidth.

The AD73411 is particularly suitable for a variety of applications in the speech and telephony area, including low bit rate, high-quality compression, speech enhancement, recognition, and synthesis. The low group delay characteristic of the AFE makes it suitable for single or multichannel active control applications. The A/D and D/A conversion channels feature programmable input/output gains with ranges of 38 dB and 21 dB respectively. An on-chip reference voltage is included to allow single supply operation.

The sampling rate of the AFE is programmable with four separate settings offering 64, 32, 16, and 8 kHz sampling rates (from a master clock of 16.384 MHz) while the serial port (SPORT2) allows easy expansion of the number of I/O channels by cascading extra AFEs external to the AD73411.

The AD73411's DSP engine combines the ADSP-2100 family base architecture (three computational units, data address generators, and a program sequencer) with two serial ports, a 16-bit internal DMA port, a byte DMA port, a programmable timer, Flag I/O, extensive interrupt capabilities, and on-chip program and data memory.

The AD73411-80 integrates 80K bytes of on-chip memory configured as 16K words (24-bit) of program RAM, and 16K words (16-bit) of data RAM. The AD73411-40 integrates 40K bytes of on-chip memory configured as 8K words (24-bit) of program RAM, and 8K words (16-bit) of data RAM. Power-down circuitry is also provided to meet the low power needs of battery-operated portable equipment. The AD73411 is available in a 119-ball PBGA package.

REV. 0

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AD73411–SPECIFICATIONS[1]

(AVDD = DVDD = 3.0 V to 3.6 V; DGND = AGND = 0 V, f_{MCLK} = 16.384 MHz, f_{SAMP} = 64 kHz; T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
AFE SECTION					
REFERENCE					
REFCAP					
Absolute Voltage, V_{REFCAP}	1.08	1.2	1.32	V	
REFCAP TC		50		ppm/°C	0.1 µF Capacitor Required from
REFOUT					REFCAP to AGND2
Typical Output Impedance		145		Ω	
Absolute Voltage, V_{REFOUT}	1.08	1.2	1.32	V	Unloaded
ADC SPECIFICATIONS					
Maximum Input Range at VIN[2, 3]		1.578		V p-p	Measured Differentially
		–2.85		dBm	Max Input = (1.578/1.2) × V_{REFCAP}
Nominal Reference Level at VIN		1.0954		V p-p	Measured Differentially
(0 dBm0)		–6.02		dBm	
Absolute Gain					
PGA = 0 dB	–2.2	–0.6	+1.0	dB	1.0 kHz, 0 dBm0
PGA = 38 dB		–1.0		dB	1.0 kHz, 0 dBm0
Gain Tracking Error		±0.1		dB	1.0 kHz, +3 dBm0 to –50 dBm0
Signal to (Noise + Distortion)					Refer to Figure ?
PGA = 0 dB	71	76		dB	300 Hz to 3400 Hz;
	70	74		dB	0 Hz to f_{SAMP}/2
		72		dB	300 Hz to 3400 Hz; f_{SAMP} = 64 kHz
		56		dB	0 Hz to f_{SAMP}/2; f_{SAMP} = 64 kHz
PGA = 38 dB		60		dB	300 Hz to 3400 Hz;
		59		dB	0 Hz to f_{SAMP}/2
Total Harmonic Distortion					
PGA = 0 dB		–85	–75	dB	300 Hz to 3400 Hz
PGA = 38 dB		–85		dB	300 Hz to 3400 Hz
Intermodulation Distortion		–82		dB	PGA = 0 dB
Idle Channel Noise		–76		dBm0	PGA = 0 dB
Crosstalk		–100		dB	ADC Input Signal Level: 1.0 kHz, 0 dBm0
					DAC Input at Idle
DC Offset	–20	+2	+25	mV	PGA = 0 dB
Power Supply Rejection		–84		dB	Input Signal Level at AVDD and DVDD
					Pins 1.0 kHz, 100 mV p-p Sine Wave
Group Delay[4, 5]		25		µs	f_{SAMP} = 64 kHz
Input Resistance at PGA[2, 4, 6]		45		kΩ	DMCLK = 16.384 MHz
DAC SPECIFICATIONS					
Maximum Voltage Output Swing[2]					
Single-Ended		1.578		V p-p	PGA = 6 dB
		–2.85		dBm	Max Output = (1.578/1.2) × V_{REFCAP}
Differential		3.156		V p-p	PGA = 6 dB
		3.17		dBm	Max Output = 2 × ((1.578/1.2) × V_{REFCAP}
Nominal Voltage Output Swing (0 dBm0)					
Single-Ended		1.0954		V p-p	PGA = 6 dB
		–6.02		dBm	
Differential		2.1909		V p-p	PGA = 6 dB
		0		dBm	
Output Bias Voltage[4]	1.08	1.2	1.32	V	REFOUT Unloaded
Absolute Gain	–1.8	–0.7	+0.4	dB	1.0 kHz, 0 dBm0; Unloaded
Gain Tracking Error		±0.1		dB	1.0 kHz, +3 dBm0 to –50 dBm0
Signal to (Noise + Distortion)					
PGA = 0 dB	70	77		dB	300 Hz to 3400 Hz
		76		dB	300 Hz to 3400 Hz; f_{SAMP} = 64 kHz
PGA = 6 dB		77		dB	300 Hz to 3400 Hz
		77		dB	300 Hz to 3400 Hz; f_{SAMP} = 64 kHz
Total Harmonic Distortion at 0 dBm0					
PGA = 0 dB		–80	–70	dB	
PGA = 6 dB		–80		dB	
Intermodulation Distortion		–76		dB	PGA = 0 dB
Idle Channel Noise		–82		dBm0	PGA = 0 dB
Crosstalk		–100		dB	ADC Input Signal Level: AGND; DAC
					Output Signal Level: 1.0 kHz, 0 dBm0

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
DAC SPECIFICATIONS (Continued)					
Power Supply Rejection		–81		dB	Input Signal Level at AVDD and DVDD Pins: 1.0 kHz, 100 mV p-p Sine Wave
Group Delay[4, 5]		25		µs	f_{SAMP} = 64 kHz; Interpolator Bypassed
		50		µs	f_{SAMP} = 64 kHz
Output DC Offset[2, 7]	–30	+5	+50	mV	PGA = 6 dB
LOGIC INPUTS					
V_{INH}, Input High Voltage	DVDD – 0.8		DVDD	V	
V_{INL}, Input Low Voltage	0		0.8	V	
I_{IH}, Input Current	–10		+10	µA	
LOGIC OUTPUT					
V_{OH}, Output High Voltage	DVDD – 0.4		DVDD	V	|IOUT| ≤ 100 µA
V_{OL}, Output Low Voltage	0		0.4	V	|IOUT| ≤ 100 µA
Three-State Leakage Current	–10		+10	µA	
POWER SUPPLIES					
AVDD	3.0		3.6	V	
DVDD	3.0		3.6	V	
I_{DD}[9]					See Table I

NOTES
[1]Operating temperature range is as follows: –20°C to +85°C. Therefore, T_{MIN} = –20°C and T_{MAX} = +85°C.
[2]Test conditions: Input PGA set for 0 dB gain, Output PGA set for 6 dB gain, no load on analog outputs (unless otherwise noted).
[3]At input to sigma-delta modulator of ADC.
[4]Guaranteed by design.
[5]Overall group delay will be affected by the sample rate and the external digital filtering.
[6]The ADC's input impedance is inversely proportional to DMCLK and is approximated by: (3.3×10^{11})/DMCLK.
[7]Between VOUTP and VOUTN.
[8]At VOUT output.
[9]Test Conditions: no load on digital inputs, analog inputs ac-coupled to ground, no load on analog outputs.

Specifications subject to change without notice.

AD73411–SPECIFICATIONS (AVDD = DVDD = VDD = 3.0 V to 3.6 V; DGND = AGND = 0 V, f_{MCLK} = 16.384 MHz, f_{SAMP} = 64 kHz; $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.)

Parameter		Test Conditions	Min	Typ	Max	Unit
DSP SECTION						
V_{IH}	Hi-Level Input Voltage[1, 2]	@ VDD = max	2.0			V
V_{IH}	Hi-Level CLKIN Voltage	@ VDD = max	2.2			V
V_{IL}	Lo-Level Input Voltage[1, 3]	@ VDD = min			0.8	V
V_{OH}	Hi-Level Output Voltage[1, 4, 5]	@ VDD = min				
		I_{OH} = –0.5 mA	2.4			V
		@ VDD = min				
		I_{OH} = –100 μA[6]	VDD – 0.3			V
V_{OL}	Lo-Level Output Voltage[1, 4, 5]	@ VDD = min				
		I_{OL} = 2 mA			0.4	V
I_{IH}	Hi-Level Input Current[3]	@ VDD = max				
		V_{IN} = VDD max			10	μA
I_{IL}	Lo-Level Input Current[3]	@ VDD = max				
		V_{IN} = 0 V			10	μA
I_{OZH}	Three-State Leakage Current[7]	@ VDD = max				
		V_{IN} = VDD max[8]			10	μA
I_{OZL}	Three-State Leakage Current[7]	@ VDD = max				
		V_{IN} = 0 V[8]			10	μA
I_{DD}	Supply Current (Idle)[9]	@ VDD = 3.3				
		t_{CK} = 19 ns[10]		12		mA
		t_{CK} = 25 ns[10]		11		mA
		t_{CK} = 30 ns[10]		10		mA
I_{DD}	Supply Current (Dynamic)[11]	@ VDD = 3.3				
		T_{AMB} = 25°C				
		t_{CK} = 19 ns[10]		45		mA
		t_{CK} = 25 ns[10]		43		mA
		t_{CK} = 30 ns[10]		36		mA
C_I	Input Pin Capacitance[3, 6, 12]	@ V_{IN} = 2.5 V				
		f_{IN} = 1.0 MHz				
		T_{AMB} = 25°C		8		pF
C_O	Output Pin Capacitance[6, 7, 12, 13]	@ V_{IN} = 2.5 V				
		f_{IN} = 1.0 MHz				
		T_{AMB} = 25°C		8		pF

NOTES

[1] Bidirectional pins: D0–D23, RFS0, RFS1, SCLK0, SCLK1, TFS0, TFS1, A1–A13, PF0–PF7.

[2] Input only pins: $\overline{\text{RESET}}$, $\overline{\text{BR}}$, DR0, DR1, $\overline{\text{PWD}}$.

[3] Input only pins: CLKIN, $\overline{\text{RESET}}$, BR, DR0, DR1, $\overline{\text{PWD}}$.

[4] Output pins: $\overline{\text{BG}}$, $\overline{\text{PMS}}$, $\overline{\text{DMS}}$, $\overline{\text{BMS}}$, $\overline{\text{IOMS}}$, $\overline{\text{CMS}}$, $\overline{\text{RD}}$, $\overline{\text{WR}}$, PWDACK, A0, DT0, DT1, CLKOUT, FL2–0, $\overline{\text{BGH}}$.

[5] Although specified for TTL outputs, all AD73411 outputs are CMOS-compatible and will drive to VDD and GND, assuming no dc loads.

[6] Guaranteed but not tested.

[7] Three-statable pins: A0–A13, D0–D23, $\overline{\text{PMS}}$, $\overline{\text{DMS}}$, $\overline{\text{BMS}}$, $\overline{\text{IOMS}}$, $\overline{\text{CMS}}$, $\overline{\text{RD}}$, $\overline{\text{WR}}$, DT0, DT1, SCLK0, SCLK1, TFS0, TFS1, RFS0, RFS1, PF0–PF7.

[8] 0 V on $\overline{\text{BR}}$.

[9] Idle refers to AD73411 state of operation during execution of IDLE instruction. Deasserted pins are driven to either VDD or GND.

[10] V_{IN} = 0 V and 3 V. For typical figures for supply currents, refer to Power Dissipation section.

[11] I_{DD} measurement taken with all instructions executing from internal memory. 50% of the instructions are multifunction (Types 1, 4, 5, 12, 13, 14), 30% are Type 2 and Type 6, and 20% are idle instructions.

[12] Applies to PBGA package type.

[13] Output pin capacitance is the capacitive load for any three-stated output pin.

Specifications subject to change without notice.

POWER CONSUMPTION

Parameter	Typ	Max	SE	MCLK On	Test Conditions
AFE SECTION					
ADC Only On	7	8	1	Yes	REFOUT Disabled
ADC and DAC On	11	12.5	1	Yes	REFOUT Disabled
REFCAP Only On	0.65	1.00	0	No	REFOUT Disabled
REFCAP and REFOUT Only On	2.7	3.8	0	No	
All AFE Sections Off	0.6	0.75	0	Yes	MCLK Active Levels Equal to 0 V and DVDD
All AFE Sections Off	5 μA	30 μA	0	No	Digital Inputs Static and Equal to 0 V or DVDD
DSP SECTION					
Idle Mode	6.4				
Dynamic	43				

NOTES
The above values are in mA and are typical values unless otherwise noted.
Specifications subject to change without notice.

TIMING CHARACTERISTICS–AFE SECTION

Parameter	Limit	Unit	Description
Clock Signals			See Figure 1
t_1	61	ns min	16.384 MHz AMCLK Period
t_2	24.4	ns min	MCLK Width High
t_3	24.4	ns min	MCLK Width Low
Serial Port			See Figures ? and ?
t_4	t_1	ns min	SCLK Period (SCLK = AMCLK)
t_5	$0.4 \times t_1$	ns min	SCLK Width High
t_6	$0.4 \times t_1$	ns min	SCLK Width Low
t_7	20	ns min	SDI/SDIFS Setup Before SCLK Low
t_8	0	ns min	SDI/SDIFS Hold After SCLK Low
t_9	10	ns max	SDOFS Delay from SCLK High
t_{10}	10	ns min	SDOFS Hold After SCLK High
t_{11}	10	ns min	SDO Hold After SCLK High
t_{12}	10	ns max	SDO Delay from SCLK High
t_{13}	30	ns max	SCLK Delay from MCLK

Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS*
(T_A = +25°C unless otherwise noted)

AVDD, DVDD to GND . . . . . –0.3 V to +4.6 V
AGND to DGND . . . . . –0.3 V to +0.3 V
Digital I/O Voltage to DGND . . . . . –0.3 V to DVDD + 0.3 V
Analog I/O Voltage to AGND . . . . . –0.3 V to AVDD + 0.3 V
Operating Temperature Range
Industrial (B Version) . . . . . –20°C to +85°C
Storage Temperature Range . . . . . –40°C to +125°C
Maximum Junction Temperature . . . . . 150°C
PBGA, θ_{JA} Thermal Impedance . . . . . 25°C/W
Reflow Soldering
Maximum Temperature . . . . . 225°C
Time at Maximum Temperature . . . . . 15 sec
Maximum Temperature Ramp Rate . . . . . 1.3°C/sec

*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
AD73411BB-80	–20°C to +85°C	119-Ball Plastic Ball Grid Array	B-119
AD73411BB-40	–20°C to +85°C	119-Ball Plastic Ball Grid Array	B-119

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the AD73411 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

PBGA BALL CONFIGURATION

	1	2	3	4	5	6	7
A	$\overline{\text{IRQE}}$/PF4	$\overline{\text{DMS}}$	VDD (INT)	CLKIN	A11/IAD10	A7/IAD6	A4/IAD3
B	$\overline{\text{IRQL0}}$/PF5	$\overline{\text{PMS}}$	$\overline{\text{WR}}$	XTAL	A12/IAD11	A8/IAD7	A5/IAD4
C	$\overline{\text{IRQL1}}$/PF6	$\overline{\text{IOMS}}$	$\overline{\text{RD}}$	VDD (EXT)	A13/IAD12	A9/IAD8	GND
D	$\overline{\text{IRQ2}}$/PF7	$\overline{\text{CMS}}$	$\overline{\text{BMS}}$	CLKOUT	GND	A10/IAD9	A6/IAD5
E	DT0	TFS0	RFS0	A3/IAD2	A2/IAD1	A1/IAD0	A0
F	DR0	SCLK0	DT1/F0	PWDACK	$\overline{\text{BGH}}$	MODE A/PF0	MODE B/PF1
G	TFS1/$\overline{\text{IRQ1}}$	RFS1/$\overline{\text{IRQ0}}$	DR1/FI	GND	$\overline{\text{PWD}}$	VDD (EXT)	MODE C/PF2
H	SCLK1	$\overline{\text{ERESET}}$	$\overline{\text{RESET}}$	PF3	FL0	FL1	FL2
J	$\overline{\text{EMS}}$	EE	ECLK	D23	D22	D21	D20
K	ELOUT	ELIN	$\overline{\text{EINT}}$	D19	D18	D17	D16
L	$\overline{\text{BG}}$	D3/$\overline{\text{IACK}}$	D5/IAL	D8	D9	D12	D15
M	$\overline{\text{EBG}}$	D2/IAD15	D4/$\overline{\text{IS}}$	D7/$\overline{\text{IWR}}$	VDD (EXT)	D11	D14
N	$\overline{\text{BR}}$	D1/IAD14	VDD (INT)	D6/$\overline{\text{IRD}}$	GND	D10	D13
P	$\overline{\text{EBR}}$	D0/IAD13	DVDD	DGND	$\overline{\text{ARESET}}$	SCLK2	AMCLK
R	SDO	SDOFS	SDIFS	SDI	SE	REFCAP	REFOUT
T	VINP	NC	VINN	NC	NC	NC	NC
U	AGND	AVDD	NC	NC	VOUTP	VOUTN	NC

TOP VIEW

NOTES:
VDD (INT) – DSP CORE SUPPLY
VDD (EXT) – DSP I/O DRIVER SUPPLY
BOTH VDD (INT) AND VDD (EXT) SHOULD BE POWERED FROM THE SAME SUPPLY.

PBGA BALL FUNCTION DESCRIPTIONS

Mnemonic	BGA Location	Function
VINP	T1	This pin allows direct access to the positive input of the sigma-delta modulator.
VINN	T3	This pin allows direct access to the negative input of the sigma-delta modulator.
REFOUT	R7	Buffered Reference Output, which has a nominal value of 1.2 V.
REFCAP	R6	A Bypass Capacitor to AGND of 0.1 μF is required for the on-chip reference. The capacitor should be fixed to this pin.
DGND	P4	AFE Digital Ground/Substrate Connection.
DVDD	P3	AFE Digital Power Supply Connection.
$\overline{\text{ARESET}}$	P5	Active Low Reset Signal. This input resets the entire analog front end, resetting the control registers and clearing the digital circuitry.
SCLK2	P6	Output Serial Clock whose rate determines the serial transfer rate to/from the codec. It is used to clock data or control information to and from the serial port (SPORT2). The frequency of SCLK is equal to the frequency of the master clock (AMCLK) divided by an integer number—this integer number being the product of the external master clock rate divider and the serial clock rate divider.
AMCLK	P7	AFE Master Clock Input. AMCLK is driven from an external clock signal. If it is required to run the DSP and AFE sections from a common clock crystal, AMCLK should be connected to the XTAL pin of the DSP section.
SDO	R1	Serial Data Output of the Codec. Both data and control information may be output on this pin and is clocked on the positive edge of SCLK. SDO is in three-state when no information is being transmitted and when SE is low.
SDOFS	R2	Framing Signal Output for SDO Serial Transfers. The frame sync is one bit wide and is active one SCLK period before the first bit (MSB) of each output word. SDOFS is referenced to the positive edge of SCLK. SDOFS is in three-state when SE is low.
SDIFS	R3	Framing Signal Input for SDI Serial Transfers. The frame sync is one bit wide and is valid one SCLK period before the first bit (MSB) of each input word. SDIFS is sampled on the negative edge of SCLK and is ignored when SE is low.
SDI	R4	Serial Data Input of the Codec. Both data and control information may be input on this pin and are clocked on the negative edge of SCLK. SDI is ignored when SE is low.
SE	R5	SPORT2 Enable. Asynchronous input enable pin for SPORT2. When SE is set low by the DSP, the output pins of SPORT2 are three-stated and the input pins are ignored. SCLK2 is also disabled internally in order to decrease power dissipation. When SE is brought high, the control and data registers of SPORT2 are at their original values (before SE was brought low), however the timing counters and other internal registers are at their reset values.
AGND	U1	AFE Analog Ground/Substrate Connection.
AVDD	U2	AFE Analog Power Supply Connection.
VOUTP	U5	Analog Output from the Positive Terminal of the Output.
VOUTN	U6	Analog Output from the Negative Terminal of the Output.
$\overline{\text{RESET}}$	H3	(Input) Processor Reset Input.
$\overline{\text{BR}}$	N1	(Input) Bus Request Input.
$\overline{\text{BG}}$	L1	(Output) Bus Grant Output.
$\overline{\text{BGH}}$	F5	(Output) Bus Grant Hung Output.
$\overline{\text{DMS}}$	A2	(Output) Data Memory Select Output.
$\overline{\text{PMS}}$	B2	(Output) Program Memory Select Output.
$\overline{\text{IOMS}}$	C2	(Output) Memory Select Output.
$\overline{\text{BMS}}$	D3	(Output) Byte Memory Select Output.
$\overline{\text{CMS}}$	D2	(Output) Combined Memory Select Output.
$\overline{\text{RD}}$	C3	(Output) Memory Read Enable Output.
$\overline{\text{WR}}$	B3	(Output) Memory Write Enable Output.
$\overline{\text{IRQ2}}$/		(Input) Edge- or Level-Sensitive Interrupt Request[1].
PF7	D1	(Input/Output) Programmable I/O Pin.
$\overline{\text{IRQL1}}$/		(Input) Level-Sensitive Interrupt Requests[1].
PF6	C1	(Input/Output) Programmable I/O Pin.

PBGA BALL FUNCTION DESCRIPTIONS (Continued)

Mnemonic	BGA Location	Function
IRQL0/		(Input) Level-Sensitive Interrupt Requests[1].
PF5	B1	(Input/Output) Programmable I/O Pin.
IRQE/		(Input) Edge-Sensitive Interrupt Requests[1].
PF4	A1	(Input/Output) Programmable I/O Pin.
PF3	H4	(Input/Output) Programmable I/O Pin During Normal Operation.
Mode C/		(Input) Mode Select Input—Checked Only During RESET.
PF2	G7	(Input/Output) Programmable I/O Pin During Normal Operation.
Mode B/		(Input) Mode Select Input—Checked Only During RESET.
PF1	F7	(Input/Output) Programmable I/O Pin During Normal Operation.
Mode A/		(Input) Mode Select Input—Checked Only During RESET.
PF0	F6	(Input/Output) Programmable I/O Pin During Normal Operation.
CLKIN	A4	(Inputs) Clock or Quartz Crystal Input. The CLKIN input cannot be halted or changed during operation
XTAL	B4	nor operated below 10 MHz during normal operation.
CLKOUT	D4	(Output) Processor Clock Output.
SPORT0		
TFS0	E2	(Input/Output) SPORT0 Transmit Frame Sync.
RFS0	E3	(Input/Output) SPORT0 Receive Frame Sync.
DT0	E1	(Output) SPORT0 Transmit Data.
DR0	F1	(Input) SPORT0 Receive Data.
SCLK0	F2	(Input/Output) SPORT0 Serial Clock.
SPORT1		
TFS1/		(Input/Output) SPORT1 Transmit Frame Sync.
IRQ1	G1	(Input) Edge or Level Sensitive Interrupt.
RFS1		(Input/Output) SPORT1 Receive Frame Sync.
IRQ0	G2	(Input) Edge or Level Sensitive Interrupt.
DT1/		(Output) SPORT1 Transmit Data.
FO	F3	(Output) Flag Out[2].
DR1/		(Input) SPORT1 Receive Data.
FI	G3	(Input) Flag In[2].
SCLK1	H1	(Input/Output) SPORT1 Serial Clock.
FL0	H5	(Output) Flag 0.
FL1	H6	(Output) Flag 1.
FL2	H7	(Output) Flag 2.
VDD(INT)	A3	(Input) DSP Core Supply.
	N3	
VDD(EXT)	C4	(Input) DSP I/O Interface Supply.
	G6	
	M5	
GND	C7	DSP Ground.
	D5	
	G4	
	N5	
EZ-ICE Port		
ERESET	H2	
EMS	J1	
EE	J2	
ECLK	J3	
ELOUT	K1	
ELIN	K2	
EINT	K3	
EBR	P1	
EBG	M1	
Address Bus	A0–E7; A1/IAD0–E6; A2/IAD1–E5; A3/IAD2–E4; A4/IAD3–A7; A5/IAD4–B7; A6/IAD5–D7; A7/IAD6–A6; A8/IAD7–B6; A9/IAD8–C6; A10/IAD9–D6; A11/IAD10–A5; A12/IAD11–B5; A13/IAD12–C5	
Data Bus	D0/IAD13–P2; D1/IAD14–N2; D2/IAD15–M2; D3/IACK–L2; D4/IS–M3; D5/IAL–L3; D6/IRD–N4; D7/IWR–M4; D8–L4; D9–L5; D10–N6; D11–M6; D12–L6; D13–N7; D14–M7; D15–L7; D16–K7; D17–K6; D18–K5; D19–K4; D20–J7; D21–J6; D22–J5; D23–J4	

NOTES

[1]Interrupt/Flag pins retain both functions concurrently. If IMASK is set to enable the corresponding interrupts, then the DSP will vector to the appropriate interrupt vector address when the pin is asserted, either by external devices, or set as a programmable flag.

[2]SPORT configuration determined by the DSP System Control Register. Software configurable.

ARCHITECTURE OVERVIEW

The AD73411 instruction set provides flexible data moves and multifunction (one or two data moves with a computation) instructions. Every instruction can be executed in a single processor cycle. The AD73411 assembly language uses an algebraic syntax for ease of coding and readability. A comprehensive set of development tools supports program development.

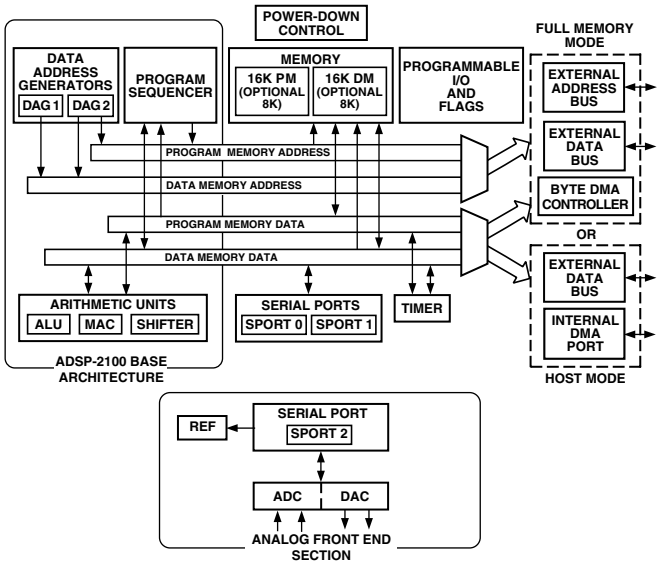


Figure 1. Functional Block Diagram

Figure 1 is an overall block diagram of the AD73411. The processor section contains three independent computational units: the ALU, the multiplier/accumulator (MAC) and the shifter. The computational units directly process 16-bit data and have provisions to support multiprecision computations. The ALU performs a standard set of arithmetic and logic operations; division primitives are also supported. The MAC performs single-cycle multiply, multiply/add and multiply/subtract operations with 40 bits of accumulation. The shifter performs logical and arithmetic shifts, normalization, denormalization, and derive exponent operations.

The internal result (R) bus connects the computational units so that the output of any unit may be the input of any unit on the next cycle.

A powerful program sequencer and two dedicated data address generators ensure efficient delivery of operands to these computational units. The sequencer supports conditional jumps, subroutine calls and returns in a single cycle. With internal loop counters and loop stacks, the AD73411 executes looped code with zero overhead; no explicit jump instructions are required to maintain loops.

Two data address generators (DAGs) provide addresses for simultaneous dual operand fetches (from data memory and program memory). Each DAG maintains and updates four address pointers. Whenever the pointer is used to access data (indirect addressing), it is post-modified by the value of one of four possible modify registers. A length value may be associated with each pointer to implement automatic modulo addressing for circular buffers.

The two address buses (PMA and DMA) share a single external address bus, allowing memory to be expanded off-chip, and the two data buses (PMD and DMD) share a single external data bus. Byte memory space and I/O memory space also share the external buses.

An interface to low-cost byte-wide memory is provided by the Byte DMA port (BDMA port). The BDMA port is bidirectional and can directly address up to four megabytes of external RAM or ROM for off-chip storage of program overlays or data tables.

The AD73411 can respond to eleven interrupts. There can be up to six external interrupts (one edge-sensitive, two level-sensitive, and three configurable), and seven internal interrupts generated by the timer, the serial ports (SPORTs), the Byte DMA port and the power-down circuitry. There is also a master $\overline{\text{RESET}}$ signal. The two serial ports provide a complete synchronous serial interface with optional companding in hardware and a wide variety of framed or frameless data transmit and receive modes of operation.

Each port can generate an internal programmable serial clock or accept an external serial clock.

The AD73411 provides up to 13 general-purpose flag pins. The data input and output pins on SPORT1 can be alternatively configured as an input flag and an output flag. In addition, eight flags are programmable as inputs or outputs and three flags are always outputs.

A programmable interval timer generates periodic interrupts. A 16-bit count register (TCOUNT) is decremented every *n* processor cycle, where *n* is a scaling value stored in an 8-bit register (TSCALE). When the value of the count register reaches zero, an interrupt is generated and the count register is reloaded from a 16-bit period register (TPERIOD).

Analog Front End

The AFE section is configured as a separate block that is normally connected to either SPORT0 or SPORT1 of the DSP section. As it is not hardwired to either SPORT, users have total flexibility in how they wish to allocate system resources to support the AFE. It is also possible to further expand the number of analog I/O channels connected to the SPORT by cascading other single or dual channel AFEs (AD73311 or AD73322) external to the AD73411.

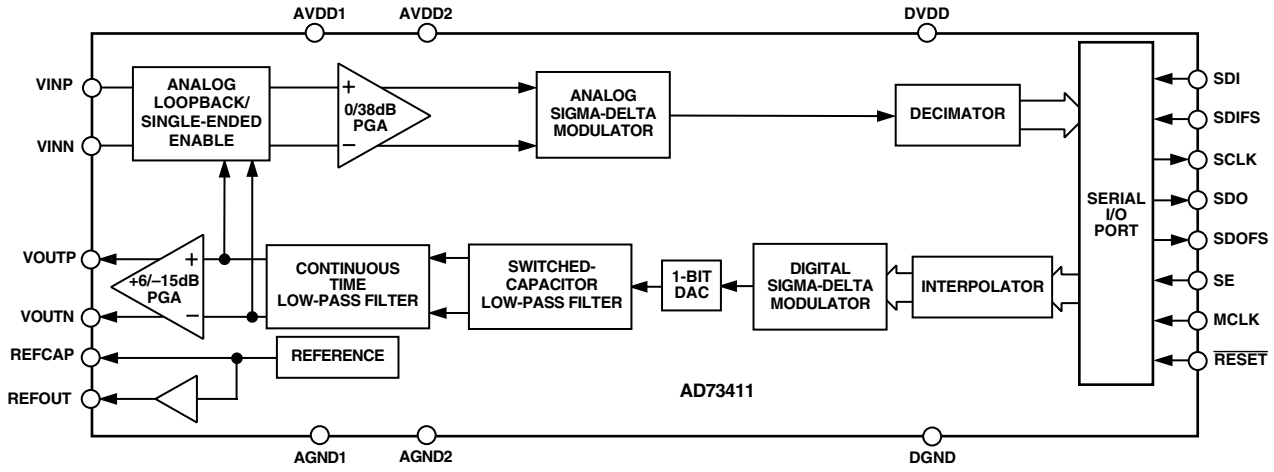


Figure 2. Functional Block Diagram of Analog Front End Section

The AFE is configured as a single I/O channel (similar to that of the discrete AD73311L; refer to the AD73311L data sheet for more details) having a 16-bit sigma-delta-based ADC and DAC. Both ADC and DAC share a common reference whose nominal value is 1.2 V. Figure 2 shows a block diagram of the AFE section of the AD73411. It shows an ADC and DAC as well as a common reference. Communication to both channels is handled by the SPORT2 block which interfaces to either SPORT0 or SPORT1 of the DSP section.

The I/O channel features fully differential inputs and outputs. The input section allows direct connection to the internal Programmable Gain Amplifier at the input of the sigma-delta ADC section. The input section also features programmable differential channel inversion and configuration of the differential input as two separate single-ended inputs. The ADC features a second order sigma-delta modulator which samples at MCLK/8. Its bitstream output is filtered and decimated by a Sinc-cubed decimator to provide a sample rate selectable from 64 kHz, 32 kHz, 16 kHz or 8 kHz (based on an MCLK of 16.384 MHz).

The DAC channel features a Sinc-cubed interpolator which increases the sample rate from the selected rate to the digital sigma-delta modulator rate of MCLK/8. The digital sigma-delta modulator's output bitstream is fed to a single-bit DAC whose output is reconstructed/filtered by two stages of low-pass filtering (switched capacitor and continuous time) before being applied to the differential output driver.

FUNCTIONAL DESCRIPTION

Encoder Channel

The encoder channel consists of an input configuration block, a switched capacitor PGA and a sigma-delta analog-to-digital converter (ADC). An on-board digital filter, which forms part of the sigma-delta ADC, also performs critical system-level filtering. Due to the high level of oversampling, the input antialias requirements are reduced such that a simple single pole RC stage is sufficient to give adequate attenuation in the band of interest.

Input Configuration Block

The input configuration block consists of a multiplexing arrangement that allows selection of various input configurations. This includes ADC input selection from either the VINP, VINN pins or from the DAC output via the Analog Loop-Back (ALB) arrangement. Differential inputs can be inverted and it is also possible to use the device in single-ended mode, which allows the option of using the VINP, VINN pins as two separate single-ended inputs, either of which can be selected under software control.

Programmable Gain Amplifier

The encoder section's analog front end comprises a switched capacitor PGA that also forms part of the sigma-delta modulator. The SC sampling frequency is DMCLK/8. The PGA, whose programmable gain settings are shown in Table I, may be used to increase the signal level applied to the ADC from low output sources such as microphones, and can be used to avoid placing external amplifiers in the circuit. The input signal level to the sigma-delta modulator should not exceed the maximum input voltage permitted.

The PGA gain is set by bits IGS0, IGS1 and IGS2 (CRD:0–2) in Control Register D.

Table I. PGA Settings for the Encoder Channel

IGS2	IGS1	IGS0	Gain (dB)
0	0	0	0
0	0	1	6
0	1	0	12
0	1	1	18
1	0	0	20
1	0	1	26
1	1	0	32
1	1	1	38

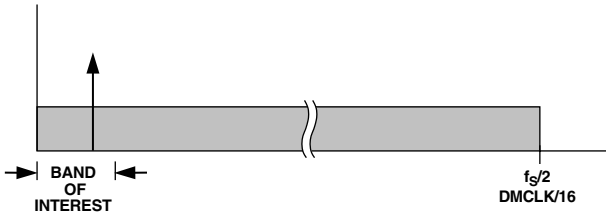
ADC

The ADC consists of an analog sigma-delta modulator and a digital antialiasing decimation filter. The sigma-delta modulator noise-shapes the signal and produces 1-bit samples at a DMCLK/8 rate. This bitstream, representing the analog input signal, is input to the antialiasing decimation filter. The decimation filter reduces the sample rate and increases the resolution.

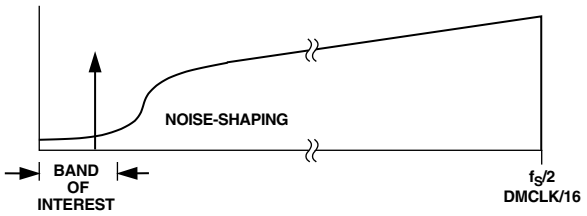
Analog Sigma-Delta Modulator

The AD73411 input channel employs a sigma-delta conversion technique, which provides a high resolution 16-bit output with system filtering being implemented on-chip.

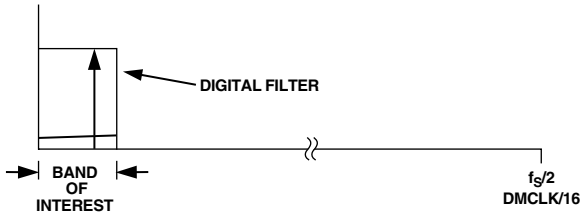
Sigma-delta converters employ a technique known as oversampling, where the sampling rate is many times the highest frequency of interest. In the case of the AD73411, the initial sampling rate of the sigma-delta modulator is DMCLK/8. The main effect of oversampling is that the quantization noise is spread over a very wide bandwidth, up to $f_S/2$ = DMCLK/16 (Figure 3a). This means that the noise in the band of interest is much reduced. Another complementary feature of sigma-delta converters is the use of a technique called noise-shaping. This technique has the effect of pushing the noise from the band of interest to an out-of-band position (Figure 3b). The combination of these techniques, followed by the application of a digital filter, sufficiently reduces the noise in band to ensure good dynamic performance from the part (Figure 3c).



a.



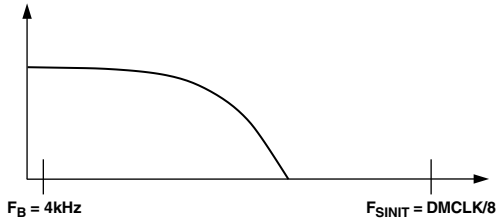
b.



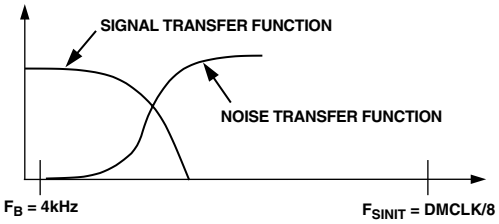
c.

Figure 3. Sigma-Delta Noise Reduction

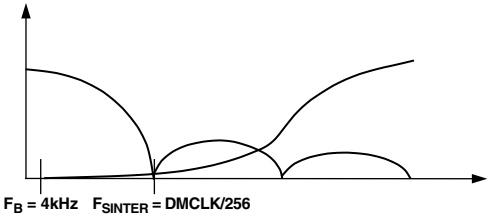
Figure 4 shows the various stages of filtering that are employed in a typical AD73411 application. In Figure 4a we see the transfer function of the external analog antialias filter. Even though it is a single RC pole, its cutoff frequency is sufficiently far away from the initial sampling frequency (DMCLK/8) that it takes care of any signals that could be aliased by the sampling frequency. This also shows the major difference between the initial oversampling rate and the bandwidth of interest. In Figure 4b, the signal and noise-shaping responses of the sigma-delta modulator are shown. The signal response provides further rejection of any high frequency signals while the noise-shaping will push the inherent quantization noise to an out-of-band position. The detail of Figure 4c shows the response of the digital decimation filter (Sinc-cubed response) with nulls every multiple of DMCLK/256, which is the decimation filter update rate. The final detail in Figure 4d shows the application of a final antialias filter in the DSP engine. This has the advantage of being implemented according to the user's requirements and available MIPS. The filtering in Figures 4a through 4c is implemented in the AD73411.



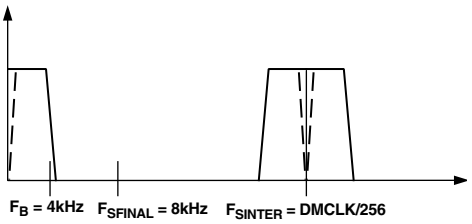
a. Analog Antialias Filter Transfer Function



b. Analog Sigma-Delta Modulator Transfer Function



c. Digital Decimator Transfer Function



d. Final Filter LPF (HPF) Transfer Function

Figure 4. AD73411 ADC Frequency Responses

Decimation Filter

The digital filter used in the AD73411 carries out two important functions. Firstly, it removes the out-of-band quantization noise, which is shaped by the analog modulator and secondly, it decimates the high-frequency bitstream to a lower rate 15-bit word.

The antialiasing decimation filter is a sinc-cubed digital filter that reduces the sampling rate from DMCLK/8 at the modulator to an output rate at the SPORT of DMCLK/M (where M depends on the sample rate setting—M = 256 @ 64 kHz; M = 512 @ 32 kHz, M = 1024 @ 16 kHz, M = 2048 @ 8 kHz), and increases the resolution from a single bit to 15 bits. Its Z transform is given as: $[(1–Z^{–N})/(1–Z^{–1})]^3$ where N is determined by the sampling rate (N = 32 @ 64 kHz, N = 64 @ 32 kHz, N = 128 @ 16 kHz, N = 256 @ 8 kHz). This ensures a minimal group delay of 25 μs at the 64 kHz sampling rate.

ADC Coding
The ADC coding scheme is in twos complement format (see Figure 5). The output words are formed by the decimation filter, which grows the word length from the single-bit output of the sigma-delta modulator to a 15-bit word, which is the 16-bit transfer being used as a flag bit to indicate either control or data in the frame.

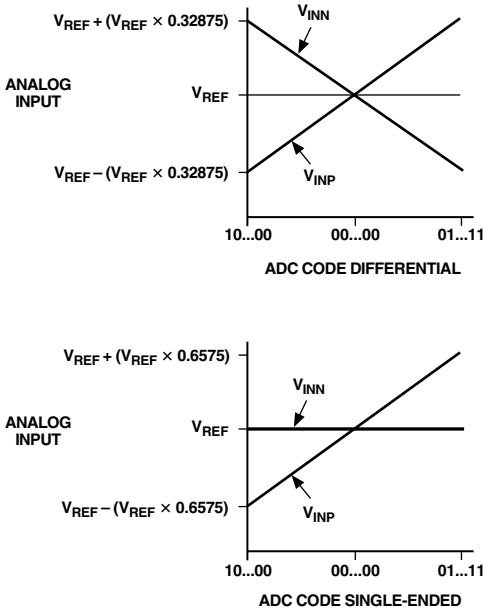


Figure 5. ADC Transfer Function

Decoder Channel
The decoder channel consists of a digital interpolator, digital sigma-delta modulator, a single bit digital-to-analog converter (DAC), an analog smoothing filter and a programmable gain amplifier with differential output.

DAC Coding
The DAC coding scheme is in twos complement format with 0x7FFF being full-scale positive and 0x8000 being full-scale negative.

Interpolation Filter
The anti-imaging interpolation filter is a sinc-cubed digital filter which upsamples the 16-bit input words from the SPORT input rate of DMCLK/M (where M depends on the sample rate setting (M = 256 @ 64 kHz; M = 512 @ 32 kHz, M = 1024 @ 16 kHz, M = 2048 @ 8 kHz), to a rate of DMCLK/8 while filtering to attenuate images produced by the interpolation process. Its Z transform is given as: $[(1–Z^{–N})/(1–Z^{–1})]^3$ where N is determined by the sampling rate (N = 32 @ 64 kHz, N = 64 @ 32 kHz, N = 128 @ 16 kHz, N = 256 @ 8 kHz). The DAC receives 16-bit samples from the host DSP processor at a rate of DMCLK/M. If the host processor fails to write a new value to the serial port, the existing (previous) data is read again. The data stream is filtered by the anti-imaging interpolation filter, but there is an option to bypass the interpolator for the minimum group delay configuration by setting the IBYP bit (CRE:5) of Control Register E. The interpolation filter has the same characteristics as the ADC's antialiasing decimation filter.

The output of the interpolation filter is fed to the DAC's digital sigma-delta modulator, which converts the 16-bit data to 1-bit samples at a rate of DMCLK/8. The modulator noise-shapes the signal so that errors inherent to the process are minimized in the passband of the converter. The bitstream output of the sigma-delta modulator is fed to the single bit DAC where it is converted to an analog voltage.

Analog Smoothing Filter and PGA
The output of the single-bit DAC is sampled at DMCLK/8, therefore it is necessary to filter the output to reconstruct the low frequency signal. The decoder's analog smoothing filter consists of a continuous-time filter preceded by a third-order switched-capacitor filter. The continuous-time filter forms part of the output programmable gain amplifier (PGA). The PGA can be used to adjust the output signal level from –15 dB to +6 dB in 3 dB steps, as shown in Table II. The PGA gain is set by bits OGS0, OGS1 and OGS2 (CRD:4-6) in Control Register D.

Table II. PGA Settings for the Decoder Channel

OGS2	OGS1	OGS0	Gain (dB)
0	0	0	6
0	0	1	3
0	1	0	0
0	1	1	–3
1	0	0	–6
1	0	1	–9
1	1	0	–12
1	1	1	–15

Differential Output Amplifiers
The decoder has a differential analog output pair (VOUTP and VOUTN). The output channel can be muted by setting the MUTE bit (CRD:7) in Control Register D. The output signal is dc-biased to the codec's on-chip voltage reference.

Voltage Reference
The AD73411 reference, REFCAP, is a bandgap reference that provides a low noise, temperature-compensated reference to the DAC and ADC. A buffered version of the reference is also made available on the REFOUT pin and can be used to bias other external analog circuitry. The reference has a default nominal value of 1.2 V.

The reference output (REFOUT) can be enabled for biasing external circuitry by setting the RU bit (CRC:6) of CRC.

AFE Serial Port (SPORT2)
The AFE section communicates with the DSP section via its bidirectional synchronous serial port (SPORT2), which interfaces to either SPORT0 or SPORT1 of the DSP section. SPORT2 is used to transmit and receive digital data and control information. This allows other single or dual codec devices to be cascaded together (up to a limit of eight codec units).

In both transmit and receive modes, data is transferred at the serial clock (SCLK2) rate with the MSB being transferred first. Communications between the AFE section and the DSP section must always be initiated by the AFE section (AFE is in master mode—DSP SPORT is in slave mode). This ensures that there is no collision between input data and output samples.

SPORT2 Overview

SPORT2 is a flexible, full-duplex, synchronous serial port whose protocol has been designed to allow extra AFE devices (AD733xx series), up to a maximum of eight I/O channels, to be connected in cascade to a DSP SPORT (0 or 1). It has a very flexible architecture that can be configured by programming two of the internal control registers. SPORT2 has three distinct modes of operation: Control Mode, Data Mode and Mixed Control/Data Mode.

In Control Mode (CRA:0 = 0), the device's internal configuration can be programmed by writing to the five internal control registers. In this mode, control information can be written to or read from the codec. In Data Mode (CRA:0 = 1), information that is sent to the device is used to update the decoder section (DAC), while the encoder section (ADC) data is read from the device. In this mode, only DAC and ADC data is written to or read from the device. Mixed mode (CRA:0 = 1 and CRA:1 = 1) allows the user to choose whether the information being sent to the device contains either control information or DAC data. This is achieved by using the MSB of the 16-bit frame as a flag bit. Mixed mode reduces the resolution to 15 bits, with the MSB being used to indicate whether the information in the 16-bit frame is control information or DAC/ADC data.

The SPORT features a single 16-bit serial register that is used for both input and output data transfers. As the input and output data must share the same register some precautions must be observed. The primary precaution is that no information be written to the SPORT without reference to an output sample event, which is when the serial register will be overwritten with the latest ADC sample word. Once the SPORT starts to output the latest ADC word, it is safe for the DSP to write new control or data words to the codec. In certain configurations, data can be written to the device to coincide with the output sample being shifted out of the serial register—see section on interfacing devices. The serial clock rate (CRB:2–3) defines how many 16-bit words can be written to a device before the next output sample event will happen.

The SPORT block diagram, shown in Figure 6, details the six control registers (A–F), external MCLK to internal DMCLK divider, and serial clock divider. The divider rates are controlled by the setting of Control Register B. The AD73411 features a master clock divider that allows users the flexibility of dividing externally available high-frequency DSP or CPU clocks to generate a lower frequency master clock internally in the codec which may be more suitable for either serial transfer or sampling rate requirements. The master clock divider has five divider options (÷1 default condition, ÷2, ÷3, ÷4, ÷5) that are set by loading the master clock divider field in Register B with the appropriate code. Once the internal device master clock (DMCLK) has been set using the master clock divider, the sample rate and serial clock settings are derived from DMCLK.

The SPORT can work at four different serial clock (SCLK) rates: chosen from DMCLK, DMCLK/2, DMCLK/4, or DMCLK/8, where DMCLK is the internal or device master clock resulting from the external or pin master clock being divided by the master clock divider. When working at the lower SCLK rate of DMCLK/8, which is intended for interfacing with slower DSPs, the SPORT will support a maximum of two devices in cascade with the sample rate of DMCLK/256.

SPORT2 Register Maps

There are two register banks for the AD73411: the control register bank and the data register bank. The control register bank consists of six read/write registers, each eight bits wide. Table VII shows the control register map for the AD73411. The first two control registers, CRA and CRB, are reserved for controlling the SPORT. They hold settings for parameters such as bit rate, internal master clock rate, and device count (used when more than one AFE is connected in cascade from a single SPORT). The other three registers; CRC, CRD, and CRE are used to hold control settings for the ADC, DAC, Reference, and Power Control sections of the device. Control registers are written to on the negative edge of SCLK. The data register bank consists of two 16-bit registers that are the DAC and ADC registers.

Master Clock Divider

The AD73411 features a programmable master clock divider that allows the user to reduce an externally available master clock, at pin MCLK, by one of the ratios 1, 2, 3, 4, or 5, to produce an internal master clock signal (DMCLK) that is used to calculate the sampling and serial clock rates. The master clock divider is programmable by setting CRB:4–6. Table III shows the division ratio corresponding to the various bit settings. The default divider ratio is divide-by-one.

Table III. DMCLK (Internal) Rate Divider Settings

MCD2	MCD1	MCD0	DMCLK Rate
0	0	0	MCLK
0	0	1	MCLK/2
0	1	0	MCLK/3
0	1	1	MCLK/4
1	0	0	MCLK/5
1	0	1	MCLK
1	1	0	MCLK
1	1	1	MCLK

Serial Clock Rate Divider

The AD73411 features a programmable serial clock divider that allows users to match the serial clock (SCLK) rate of the data to that of the DSP engine or host processor. The maximum SCLK rate available is DMCLK and the other available rates are: DMCLK/2, DMCLK/4, and DMCLK/8. The slowest rate (DMCLK/8) is the default SCLK rate. The serial clock divider is programmable by setting bits CRB:2–3. Table IV shows the serial clock rate corresponding to the various bit settings.

Table IV. SCLK Rate Divider Settings

SCD1	SCD0	SCLK Rate
0	0	DMCLK/8
0	1	DMCLK/4
1	0	DMCLK/2
1	1	DMCLK

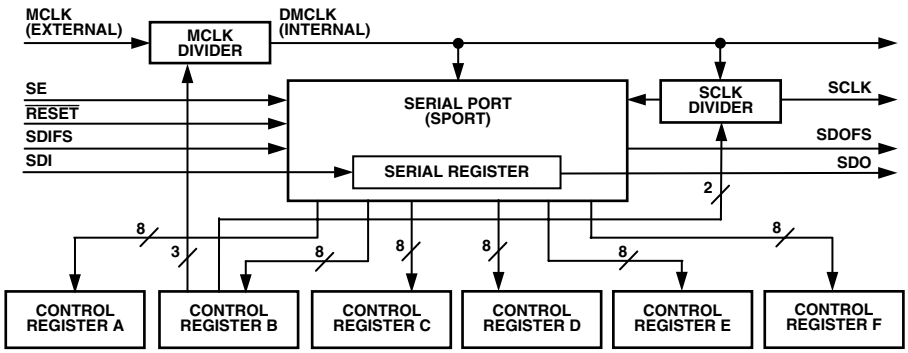


Figure 6. SPORT Block Diagram

Sample Rate Divider

The AD73411 features a programmable sample rate divider that allows users flexibility in matching the codec's ADC and DAC sample rates to the needs of the DSP software. The maximum sample rate available is DMCLK/256, which offers the lowest conversion group delay, while the other available rates are: DMCLK/512, DMCLK/1024, and DMCLK/2048. The slowest rate (DMCLK/2048) is the default sample rate. The sample rate divider is programmable by setting bits CRB:0–1. Table V shows the sample rate corresponding to the various bit settings.

Table V. Sample Rate Divider Settings

DIR1	DIR0	SCLK Rate
0	0	DMCLK/2048
0	1	DMCLK/1024
1	0	DMCLK/512
1	1	DMCLK/256

DAC Advance Register

The loading of the DAC is internally synchronized with the unloading of the ADC data in each sampling interval. The default DAC load event happens one SCLK cycle before the SDOFS flag is raised by the ADC data being ready. However, this DAC load position can be advanced before this time by modifying the contents of the DAC Advance field in Control Register E (CRE:0–4). The field is five bits wide, allowing 31 increments of weight 1/(DMCLK/8); see Table VI. In certain circumstances this can reduce the group delay when the ADC and DAC are used to process data in series.

Note: The DAC advance register should be changed before the DAC section is powered up.

Table VI. DAC Timing Control

DA4	DA3	DA2	DA1	DA0	Time Advance*
0	0	0	0	0	0 ns
0	0	0	0	1	488.2 ns
0	0	0	1	0	976.5 ns
—	—	—	—	—	—
1	1	1	1	0	14.64 µs
1	1	1	1	1	15.13 µs

*DMCLK = 16.384 MHz.

OPERATION

Resetting the AFE Section of the AD73411

The $\overline{\text{RESET}}$ pin resets all the control registers. All registers are reset to zero, indicating that the default SCLK rate (DMCLK/8) and sample rate (DMCLK/2048) are at a minimum to ensure that slow speed DSP engines can communicate effectively. As well as resetting the control registers using the $\overline{\text{RESET}}$ pin, the device can be reset using the $\overline{\text{RESET}}$ bit (CRA:7) in Control Register A. Both hardware and software resets require four DMCLK cycles. On reset, DATA/$\overline{\text{PGM}}$ (CRA:0) is set to 0 (default condition) thus enabling Program Mode. The reset conditions ensure that the device must be programmed to the correct settings after power-up or reset. Following a reset, the SDOFS will be asserted 2048 DMCLK cycles after $\overline{\text{RESET}}$ going high. The data that is output following $\overline{\text{RESET}}$ and during Program Mode is random and contains no valid information until either Data or Mixed Mode is set.

Power Management

The individual functional blocks of the AFE can be enabled separately by programming the power control register CRC. It allows certain sections to be powered down if not required, which adds to the device's flexibility in that the user need not incur the penalty of having to provide power for a certain section if it is not necessary to their design. The power control register provides individual control settings for the major functional blocks and also a global override that allows all sections to be powered up by setting the bit. Using this method the user could, for example, individually enable a certain section, such as the reference (CRC:5), and disable all others. The global power-up (CRC:0) can be used to enable all sections but if power-down is required using the global control, the reference will still be enabled, in this case, because its individual bit is set. Refer to Table XI for details of the settings of CRC.

Table VII. Control Register Map

Address (Binary)	Name	Description	Type	Width	Reset Setting (Hex)
000	CRA	Control Register A	R/$\overline{W}$	8	0x00
001	CRB	Control Register B	R/$\overline{W}$	8	0x00
010	CRC	Control Register C	R/$\overline{W}$	8	0x00
011	CRD	Control Register D	R/$\overline{W}$	8	0x00
100	CRE	Control Register E	R/$\overline{W}$	8	0x00
101	CRF	Control Register F	R/$\overline{W}$	8	0x00
110 to 111		Reserved			

Table VIII. Control Word Description

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C/$\overline{D}$	R/$\overline{W}$	Device Address			Register Address			Register Data							

Control	Frame	Description
Bit 15	Control/$\overline{Data}$	When set high, it signifies a control word in Program or Mixed Program/Data Modes. When set low, it signifies a data word in Mixed Program/Data Mode or an invalid control word in Program Mode.
Bit 14	Read/$\overline{Write}$	When set low, it tells the device that the data field is to be written to the register selected by the register field setting provided the address field is zero. When set high, it tells the device that the selected register is to be written to the data field in the input serial register and that the new control word is to be output from the device via the serial output.
Bits 13–11	Device Address	This 3-bit field holds the address information. Only when this field is zero is a device selected. If the address is not zero, it is decremented and the control word is passed out of the device via the serial output.
Bits 10–8	Register Address	This 3-bit field is used to select one of the five control registers on the AD73411.
Bits 7–0	Register Data	This 8-bit field holds the data that is to be written to or read from the selected register provided the address field is zero.

Table IX. Control Register A Description

CONTROL REGISTER A

7	6	5	4	3	2	1	0
$\overline{RESET}$	**DC2**	**DC1**	**DC0**	**SLB**	**DLB**	**MM**	**DATA/$\overline{PGM}$**

Bit	Name	Description
0	DATA/$\overline{PGM}$	Operating Mode (0 = Program; 1 = Data Mode)
1	MM	Mixed Mode (0 = Off; 1 = Enabled)
2	DLB	Digital Loop-Back Mode (0 = Off; 1 = Enabled)
3	SLB	SPORT Loop-Back Mode (0 = Off; 1 = Enabled)
4	DC0	Device Count (Bit 0)
5	DC1	Device Count (Bit 1)
6	DC2	Device Count (Bit 2)
7	$\overline{RESET}$	Software Reset (0 = Off; 1 = Initiates Reset)

Table X. Control Register B Description

CONTROL REGISTER B

7	6	5	4	3	2	1	0
CEE	MCD2	MCD1	MCD0	SCD1	SCD0	DIR1	DIR0

Bit	Name	Description
0	DIR0	Decimation/Interpolation Rate (Bit 0)
1	DIR1	Decimation/Interpolation Rate (Bit 1)
2	SCD0	Serial Clock Divider (Bit 0)
3	SCD1	Serial Clock Divider (Bit 1)
4	MCD0	Master Clock Divider (Bit 0)
5	MCD1	Master Clock Divider (Bit 1)
6	MCD2	Master Clock Divider (Bit 2)
7	CEE	Control Echo Enable (0 = Off; 1 = Enabled)

Table XI. Control Register C Description

CONTROL REGISTER C

7	6	5	4	3	2	1	0
RES	RU	PUREF	PUDAC	PUADC	RES	RES	PU

Bit	Name	Description
0	PU	Power-Up Device (0 = Power Down; 1 = Power-On)
1	Reserved	Must Be Programmed to Zero (0)
2	Reserved	Must Be Programmed to Zero (0)
3	PUADC	ADC Power (0 = Power Down; 1 = Power On)
4	PUDAC	DAC Power (0 = Power Down; 1 = Power On)
5	PUREF	REF Power (0 = Power Down; 1 = Power On)
6	RU	REFOUT Use (0 = Disable REFOUT; 1 = Enable REFOUT)
7	Reserved	Must Be Programmed to Zero (0)

Table XII. Control Register D Description

CONTROL REGISTER D

7	6	5	4	3	2	1	0
MUTE	OGS2	OGS1	OGS0	RMOD	IGS2	IGS1	IGS0

Bit	Name	Description
0	IGS0	Input Gain Select (Bit 0)
1	IGS1	Input Gain Select (Bit 1)
2	IGS2	Input Gain Select (Bit 2)
3	RMOD	Reset ADC Modulator (0 = Off; 1 = Reset Enabled)
4	OGS0	Output Gain Select (Bit 0)
5	OGS1	Output Gain Select (Bit 1)
6	OGS2	Output Gain Select (Bit 2)
7	MUTE	Output Mute (0 = Mute Off; 1 = Mute Enabled)

Table XIII. Control Register E Description

CONTROL REGISTER E

7	6	5	4	3	2	1	0
RES	**RES**	**IBYP**	**DA4**	**DA3**	**DA2**	**DA1**	**DA0**

Bit	Name	Description
0	DA0	DAC Advance Setting (Bit 0)
1	DA1	DAC Advance Setting (Bit 1)
2	DA2	DAC Advance Setting (Bit 2)
3	DA3	DAC Advance Setting (Bit 3)
4	DA4	DAC Advance Setting (Bit 4)
5	IBYP	Interpolator Bypass (0 = Bypass Disabled; 1 = Bypass Enabled)
6	Reserved	Must Be Programmed to Zero (0)
7	Reserved	Must Be Programmed to Zero (0)

Table XIV. Control Register F Description

CONTROL REGISTER F

7	6	5	4	3	2	1	0
ALB	**INV**	**SEEN**	**RES**	**RES**	**RES**	**RES**	**RES**

Bit	Name	Description
0	Reserved	Must Be Programmed to Zero (0)
1	Reserved	Must Be Programmed to Zero (0)
2	Reserved	Must Be Programmed to Zero (0)
3	Reserved	Must Be Programmed to Zero (0)
4	Reserved	Must Be Programmed to Zero (0)
5	SEEN	Single-Ended Enable (0 = Disabled; 1 = Enabled)
6	INV	Input Invert (0 = Disabled; 1 = Enabled)
7	ALB	Analog Loopback of Output to Input (0 = Disabled; 1 = Enabled)

AFE Operating Modes

Five operating modes are available on the AFE. Two of these—Digital Loop-Back and Sport Loop-Back—are provided as diagnostic modes with the other three, Program, Data and Mixed Program/Data, being available for general-purpose use. The device configuration—register settings—can be changed only in Program, and Mixed Program/Data Modes. In all modes, transfers of information to or from the device occur in 16-bit packets, therefore the DSP engine's SPORT will be programmed for 16-bit transfers.

Program (Control) Mode

In Program Mode, CRA:0 = 0, the user writes to the control registers to set up the device for desired operation—SPORT operation, cascade length, power management, input/output gain, etc. In this mode, the 16-bit information packet sent to the device by the DSP engine is interpreted as a control word whose format is shown in Table VIII. In this mode, the user must address the device to be programmed using the address field of the control word. This field is read by the device and if it is zero (000 bin), the device recognizes the word as being addressed to it. If the address field is not zero, it is then decremented and the control word is passed out of the device—either to the next device in a cascade or back to the DSP engine. This 3-bit address format allows the user to uniquely address any one of up to eight devices in a cascade; please note that this addressing scheme is valid only in sending control information to the device—a different format is used to send DAC data to the device(s). In a single codec configuration, all control word addresses must be zero, otherwise they will not be recognized; in a multicodec configuration all addresses from zero to N-1 (where *N* = number of devices in cascade) are valid.

Following reset, when the SE pin is enabled, the codec responds by raising the SDOFS pin to indicate that an output sample event has occurred. Control words can be written to the device to coincide with the data being sent out of the SPORT, as shown in Figure 7, or they can lag the output words by a time interval that should not exceed the sample interval. After reset, output frame sync pulses will occur at a slower default sample rate, which is DMCLK/2048, until Control Register B is programmed, after which the SDOFS pulses will occur at a rate set by the DIR0–1 bits of CRB. This is to allow slow controller devices to establish communication with the AFE. During Program Mode, the data output by the device is random and should not be interpreted as ADC data.

Data Mode

Once the device has been configured by programming the correct settings to the various control registers, the device may exit Program Mode and enter Data Mode. This is done by programming the DATA/$\overline{\text{PGM}}$ (CRA:0) bit to a 1 and MM (CRA:1) to 0. Once the device is in Data Mode, the 16-bit input data frame is now interpreted as DAC data rather than a control frame. This data is therefore loaded directly to the DAC register. In Data Mode, as the entire input data frame contains DAC data, the device relies on counting the number of input frame syncs received at the SDIFS pin. When that number equals the device count stored in the device count field of CRA, the device knows that the present data frame being received is its own DAC update data. When the device is in normal Data Mode (i.e., mixed mode disabled), it must receive a hardware reset to reprogram any of the control register settings. In a single codec configuration, each 16-bit data frame sent from the DSP to the device is interpreted as DAC data. The default device count is 1, therefore each input frame sync will cause the 16-bit data frame to be loaded to the DAC register.

Mixed Program/Data Mode

This mode allows the user to send control words to the device along with the DAC data. This permits adaptive control of the device whereby control of the input/output gains can be affected by interleaving control words along with the normal flow of DAC data. The standard data frame remains 16 bits, but now the MSB is used as a flag bit to indicate whether the remaining 15 bits of the frame represent DAC data or control information. In the case of DAC data, the 15 bits are loaded with MSB justification and LSB set to 0 to the DAC register. Mixed Mode is enabled by setting the MM bit (CRA:1) to 1 and the DATA/$\overline{\text{PGM}}$ bit (CRA:0) to 1. In the case where control setting changes will be required during normal operation, this mode allows the ability to load both control and data information with the slight inconvenience of formatting the data. Note that the output samples from the ADC will also have the MSB set to zero to indicate it is a data word.

Digital Loop-Back

This mode can be used for diagnostic purposes and allows the user to feed the ADC samples from the ADC register directly to the DAC register. This forms a loop-back of the analog input to the analog output by reconstructing the encoded signal using the decoder channel. The serial interface will continue to work, which allows the user to control gain settings, etc. Only when DLB is enabled with Mixed Mode operation can the user disable the DLB, otherwise the device must be reset.

Sport Loop-Back

This mode allows the user to verify the DSP interfacing and connection by writing words to the SPORT of the device and have them returned back unchanged at the next sample interval. The frame sync and data word that are sent to the device are returned via the output port. Again, SLB mode can only be disabled when used in conjunction with mixed mode, otherwise the device must be reset.

Analog Loop-Back

In Analog Loop-Back mode, the differential DAC output is connected, via a loop-back switch, to the ADC input (see Figure 9). This mode allows the ADC channel to check functionality of the DAC channel as the reconstructed output signal can be monitored using the ADC as a sampler. Analog Loop-Back is enabled by setting the ALB bit (CRF:7).

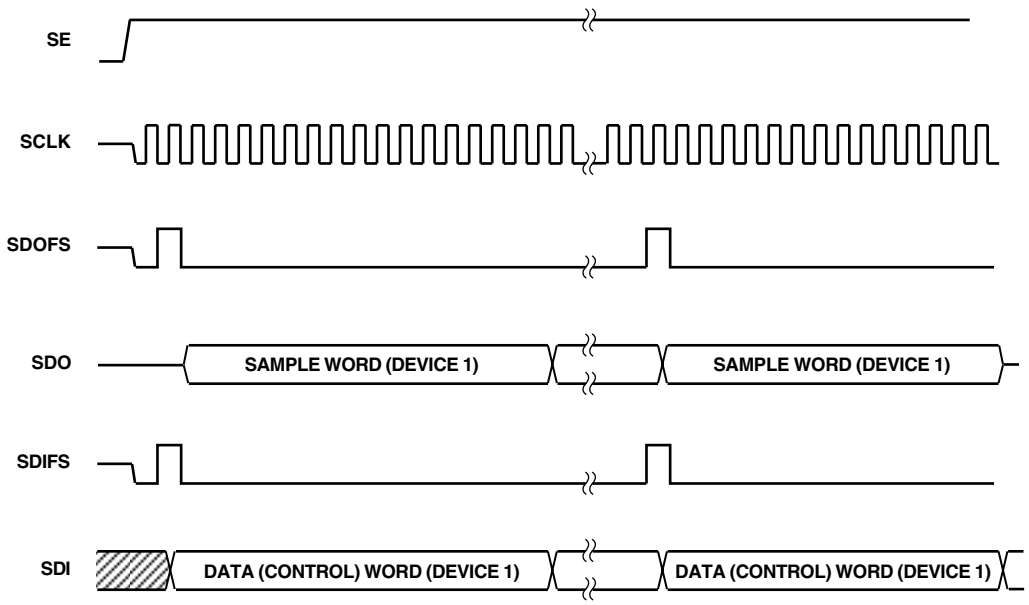


Figure 7. Interface Signal Timing for Single Device Operation

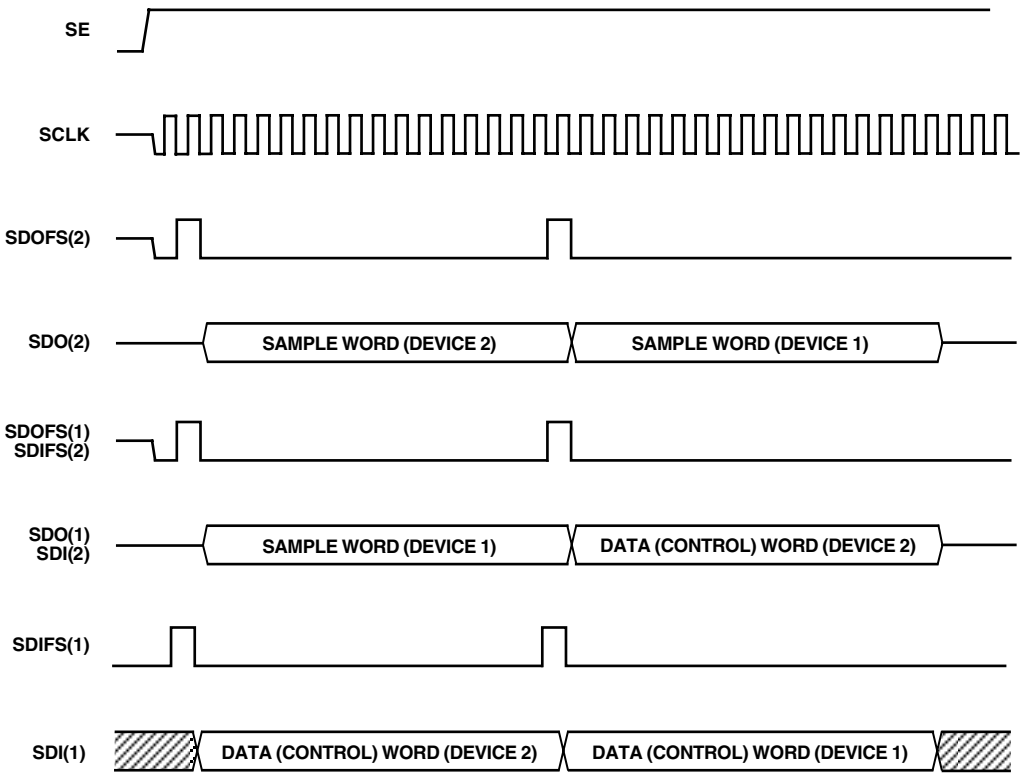


Figure 8. Interface Signal Timing for Cascade of Two Devices

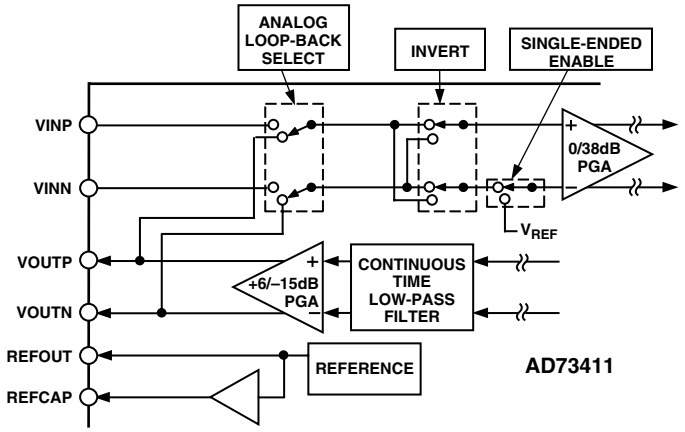


Figure 9. Analog Loop-Back Connectivity

AFE Interfacing

The AFE section SPORT (SPORT2) can be interfaced to either SPORT0 or SPORT1 of the DSP section. Both serial input and output data use an accompanying frame synchronization signal which is active high one clock cycle before the start of the 16-bit word or during the last bit of the previous word if transmission is continuous. The serial clock (SCLK) is an output from the codec and is used to define the serial transfer rate to the DSP's Tx and Rx ports. Two primary configurations can be used: the first is shown in Figure 10 where the DSP's Tx data, Tx Frame Sync, Rx data and Rx Frame Sync are connected to the codec's SDI, SDIFS, SDO and SDOFS respectively. This configuration, referred to as indirectly coupled or nonframe sync loop-back, has the effect of decoupling the transmission of input data from the receipt of output data. The delay between receipt of codec output data and transmission of input data for the codec is determined by the DSP's software latency. When programming the DSP serial port for this configuration, it is necessary to set the Rx Frame Sync as an input and the Tx Frame Sync as an output generated by the DSP. This configuration is most useful when operating in mixed mode, as the DSP has the ability to decide how many words (either DAC or control) can be sent to the codecs. This means that full control can be implemented over the device configuration as well as updating the DAC in a given sample interval. The second configuration (shown in Figure 11) has the DSP's Tx data and Rx data connected to the codec's SDI and SDO, respectively while the DSP's Tx and Rx frame syncs are connected to the codec's SDIFS and SDOFS. In this configuration, referred to as directly coupled or frame sync loop-back, the frame sync signals are connected together and the input data to the codec is forced to be synchronous with the output data from the codec. The DSP must be programmed so that both the Tx Frame Sync and Rx Frame Sync are inputs as the codec SDOFS will be input to both. This configuration guarantees that input and output events occur simultaneously and is the simplest configuration for operation in normal Data Mode. Note that when programming the DSP in this configuration it is advisable to preload the Tx register with the first control word to be sent before the codec is taken out of reset. This ensures that this word will be transmitted to coincide with the first output word from the device(s).

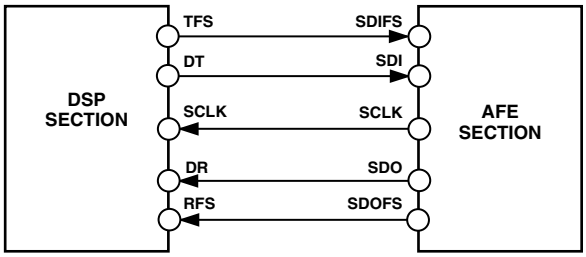


Figure 10. Indirectly Coupled or Nonframe Sync Loop-Back Configuration

Cascade Operation

The AD73411 has been designed to support up to eight codecs in a cascade connected to a single serial port. The SPORT interface protocol has been designed so that device addressing is built into the packet of information sent to the device. This allows the cascade to be formed with no extra hardware overhead for control signals or addressing. A cascade can be formed in either of the two modes previously discussed.

There may be some restrictions in cascade operation due to the number of devices configured in the cascade and the serial clock rate chosen. Table XV details the requirements for SCLK rate for cascade lengths from 1 to 8 devices. This assumes a directly coupled frame sync arrangement as shown in Figure 11.

Table XV. Cascade Options

	Number of Devices in Cascade							
SCLK	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
DMCLK	✓	✓	✓	✓	✓	✓	✓	✓
DMCLK/2	✓	✓	✓	✓	✓	✓	✓	✓
DMCLK/4	✓	✓	✓	✓	X	X	X	X
DMCLK/8	✓	✓	X	X	X	X	X	X

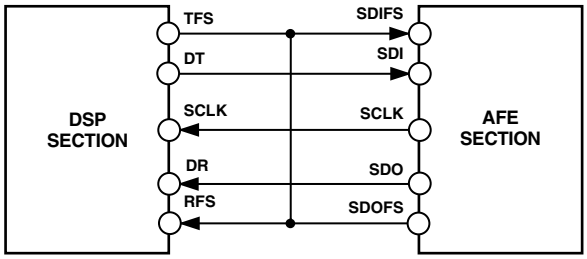


Figure 11. Directly Coupled or Frame Sync Loop-Back Configuration

When using the indirectly coupled frame sync configuration in cascaded operation it is necessary to be aware of the restrictions in sending data to all devices in the cascade. Effectively, the time allowed is given by the sampling interval (256/DMCLK) which is 15.625 µs for a sample rate of 64 kHz. In this interval, the DSP must transfer N × 16 bits of information where N is the number of devices in the cascade. Each bit will take 1/SCLK and, allowing for any latency between the receipt of the Rx interrupt and the transmission of the Tx data, the relationship for successful operation is given by:

$$256/DMCLK > ((N \times 16/SCLK) + T_{INTERRUPT\ LATENCY})$$

The interrupt latency will include the time between the ADC sampling event and the Rx interrupt being generated in the DSP—this should be 16 SCLK cycles.

In Cascade Mode, each device must know the number of devices in the cascade because the Data and Mixed modes use a method of counting input frame sync pulses to decide when they should update the DAC register from the serial input register. Control Register A contains a 3-bit field (DC0–2) that is programmed by the DSP during the programming phase. The default condition is that the field contains 000b, which is equivalent to a single device in cascade (see Table XVI). For cascade operation, however this field must contain a binary value that is one less than the number of devices in the cascade.

Table XVI. Device Count Settings

DC2	DC1	DC0	Cascade Length
0	0	0	1
0	0	1	2
0	1	0	3
0	1	1	4
1	0	0	5
1	0	1	6
1	1	0	7
1	1	1	8

FUNCTIONAL DESCRIPTION—DSP

The AD73411 instruction set provides flexible data moves and multifunction (one or two data moves with a computation) instructions. Every instruction can be executed in a single processor cycle. The AD73411 assembly language uses an algebraic syntax for ease of coding and readability. A comprehensive set of development tools supports program development.

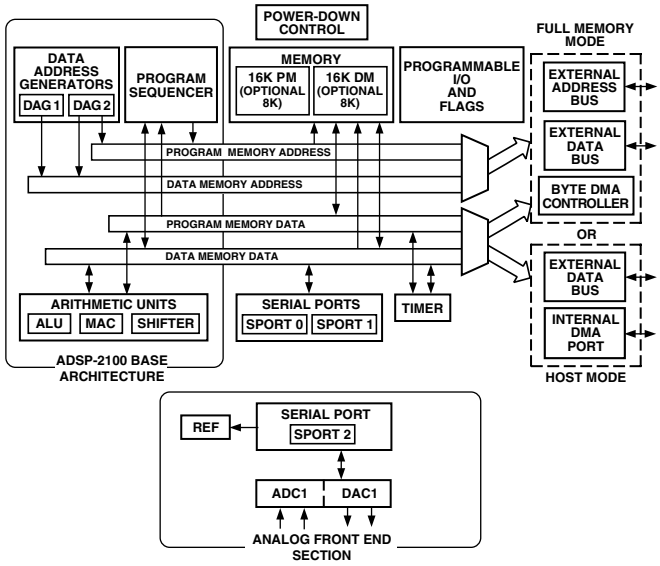


Figure 12. Functional Block Diagram

Figure 12 is an overall block diagram of the AD73411. The processor contains three independent computational units: the ALU, the multiplier/accumulator (MAC) and the shifter. The computational units process 16-bit data directly and have provisions to support multiprecision computations. The ALU performs a standard set of arithmetic and logic operations; division primitives are also supported. The MAC performs single-cycle multiply, multiply/add and multiply/subtract operations with 40 bits of accumulation. The shifter performs logical and arithmetic shifts, normalization, denormalization and derive exponent operations.

The shifter can be used to efficiently implement numeric format control including multiword and block floating-point representations.

The internal result (R) bus connects the computational units so that the output of any unit may be the input of any unit on the next cycle.

A powerful program sequencer and two dedicated data address generators ensure efficient delivery of operands to these computational units. The sequencer supports conditional jumps, subroutine calls and returns in a single cycle. With internal loop counters and loop stacks, the AD73411 executes looped code with zero overhead; no explicit jump instructions are required to maintain loops.

Two data address generators (DAGs) provide addresses for simultaneous dual operand fetches (from data memory and program memory). Each DAG maintains and updates four address pointers. Whenever the pointer is used to access data (indirect addressing), it is post-modified by the value of one of four possible modify registers. A length value may be associated with each pointer to implement automatic modulo addressing for circular buffers.

Efficient data transfer is achieved with the use of five internal buses:

- Program Memory Address (PMA) Bus
- Program Memory Data (PMD) Bus
- Data Memory Address (DMA) Bus
- Data Memory Data (DMD) Bus
- Result (R) Bus

The two address buses (PMA and DMA) share a single external address bus, allowing memory to be expanded off-chip, and the two data buses (PMD and DMD) share a single external data bus. Byte memory space and I/O memory space also share the external buses.

Program memory can store both instructions and data, permitting the AD73411 to fetch two operands in a single cycle, one from program memory and one from data memory. The AD73411 can fetch an operand from program memory and the next instruction in the same cycle.

In lieu of the address and data bus for external memory connection, the AD73411 may be configured for 16-bit Internal DMA port (IDMA port) connection to external systems. The IDMA port is made up of 16 data/address pins and five control pins. The IDMA port provides transparent, direct access to the DSPs on-chip program and data RAM.

An interface to low-cost byte-wide memory is provided by the Byte DMA port (BDMA port). The BDMA port is bidirectional and can directly address up to four megabytes of external RAM or ROM for off-chip storage of program overlays or data tables.

The byte memory and I/O memory space interface supports slow memories and I/O memory-mapped peripherals with programmable wait state generation. External devices can gain control of external buses with bus request/grant signals ($\overline{BR}$, $\overline{BGH}$, and $\overline{BG}$). One execution mode (Go Mode) allows the AD73411 to continue running from on-chip memory. Normal execution mode requires the processor to halt while buses are granted.

The AD73411 can respond to eleven interrupts. There can be up to six external interrupts (one edge-sensitive, two level-sensitive and three configurable) and seven internal interrupts generated by the timer, the serial ports (SPORTs), the Byte DMA port and the power-down circuitry. There is also a master RESET signal. The two serial ports provide a complete synchronous serial interface with optional companding in hardware and a wide variety of framed or frameless data transmit and receive modes of operation.

Each port can generate an internal programmable serial clock or accept an external serial clock.

The AD73411 provides up to 13 general-purpose flag pins. The data input and output pins on SPORT1 can be alternatively configured as an input flag and an output flag. In addition, eight flags are programmable as inputs or outputs and three flags are always outputs.

A programmable interval timer generates periodic interrupts. A 16-bit count register (TCOUNT) is decremented every *n* processor cycle, where *n* is a scaling value stored in an 8-bit register (TSCALE). When the value of the count register reaches zero, an interrupt is generated and the count register is reloaded from a 16-bit period register (TPERIOD).

Serial Ports

The DSP section incorporates two complete synchronous serial ports (SPORT0 and SPORT1) for serial communications and multiprocessor communication.

Following is a brief list of the capabilities of the SPORTs. For additional information on Serial Ports, refer to the *ADSP-2100 Family User's Manual*, Third Edition.

- SPORTs are bidirectional and have a separate, double-buffered transmit and receive section.
- SPORTs can use an external serial clock or generate their own serial clock internally.
- SPORTs have independent framing for the receive and transmit sections. Sections run in a frameless mode or with frame synchronization signals internally or externally generated. Frame sync signals are active high or inverted, with either of two pulsewidths and timings.
- SPORTs support serial data word lengths from 3 to 16 bits and provide optional A-law and μ-law companding according to CCITT recommendation G.711.
- SPORT receive and transmit sections can generate unique interrupts on completing a data word transfer.
- SPORTs can receive and transmit an entire circular buffer of data with only one overhead cycle per data word. An interrupt is generated after a data buffer transfer.
- SPORT0 has a multichannel interface to selectively receive and transmit a 24- or 32-word, time-division multiplexed, serial bitstream.
- SPORT1 can be configured to have two external interrupts (IRQ0 and IRQ1) and the Flag In and Flag Out signals. The internally generated serial clock may still be used in this configuration.

DSP SECTION PIN DESCRIPTIONS

The AD73411 is available in a 119-ball PBGA package. In order to maintain maximum functionality and reduce package size and pin count, some serial port, programmable flag, interrupt, and external bus pins have dual, multiplexed functionality. The external bus pins are configured during RESET only, while serial port pins are software configurable during program execution. Flag and interrupt functionality is retained concurrently on multiplexed pins. In cases where pin functionality is reconfigurable, the default state is shown in plain text; alternate functionality is shown in italics. See Pin Function Descriptions section.

Memory Interface Pins

The AD73411 processor can be used in one of two modes, Full Memory Mode, which allows BDMA operation with full external overlay memory and I/O capability, or Host Mode, which allows IDMA operation with limited external addressing capabilities. The operating mode is determined by the state of the Mode C pin during RESET and cannot be changed while the processor is running. See Full Memory Mode Pins and Host Mode Pins charts for descriptions.

Full Memory Mode Pins (Mode C = 0)

Pin Name(s)	# of Pins	Input/ Output	Function
A13:0	14	O	Address Output Pins for Program, Data, Byte, and I/O Spaces
D23:0	24	I/O	Data I/O Pins for Program, Data, Byte, and I/O Spaces (8 MSBs are also used as Byte Memory addresses)

Host Mode Pins (Mode C = 1)

Pin Name(s)	# of Pins	Input/ Output	Function
IAD15:0	16	I/O	IDMA Port Address/Data Bus
A0	1	O	Address Pin for External I/O, Program, Data, or Byte Access
D23:8	16	I/O	Data I/O Pins for Program, Data Byte and I/O Spaces
IWR	1	I	IDMA Write Enable
IRD	1	I	IDMA Read Enable
IAL	1	I	IDMA Address Latch Pin
IS	1	I	IDMA Select
IACK	1	O	IDMA Port Acknowledge

NOTE
In Host Mode, external peripheral addresses can be decoded using the A0, CMS, PMS, DMS, and IOMS signals.

Terminating Unused Pin

The following chart shows the recommendations for terminating unused pins.

Pin Terminations

Pin Name	I/O 3-State (Z)	Reset State	Hi-Z* Caused By	Unused Configuration
XTAL	I	I		Float
CLKOUT	O	O		Float
A13:1 or	O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
IAD12:0	I/O (Z)	Hi-Z	$\overline{IS}$	Float
A0	O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
D23:8	I/O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
D7 or	I/O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{IWR}$	I	I		High (Inactive)
D6 or	I/O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{IRD}$	I	I	$\overline{BR}$, $\overline{EBR}$	High (Inactive)
D5 or	I/O (Z)	Hi-Z		Float
IAL	I	I		Low (Inactive)
D4 or	I/O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{IS}$	I	I		High (Inactive)
D3 or	I/O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{IACK}$				Float
D2:0 or	I/O (Z)	Hi-Z	$\overline{BR}$, $\overline{EBR}$	Float
IAD15:13	I/O (Z)	Hi-Z	$\overline{IS}$	Float
$\overline{PMS}$	O (Z)	O	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{DMS}$	O (Z)	O	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{BMS}$	O (Z)	O	$\overline{BR}$, $\overline{EBR}$	Float
IOMS	O (Z)	O	BR, EBR	Float
$\overline{CMS}$	O (Z)	O	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{RD}$	O (Z)	O	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{WR}$	O (Z)	O	$\overline{BR}$, $\overline{EBR}$	Float
$\overline{BR}$	I	I		High (Inactive)
$\overline{BG}$	O (Z)	O	EE	Float
$\overline{BGH}$	O	O		Float
$\overline{IRQ2}$/*PF7*	I/O (Z)	I		Input = High (Inactive) or Program as Output, Set to 1, Let Float
$\overline{IRQL1}$/*PF6*	I/O (Z)	I		Input = High (Inactive) or Program as Output, Set to 1, Let Float
$\overline{IRQL0}$/*PF5*	I/O (Z)	I		Input = High (Inactive) or Program as Output, Set to 1, Let Float
$\overline{IRQE}$/*PF4*	I/O (Z)	I		Input = High (Inactive) or Program as Output, Set to 1, Let Float
SCLK0	I/O	I		Input = High or Low, Output = Float
RFS0	I/O	I		High or Low
DR0	I	I		High or Low
TFS0	I/O	O		High or Low
DT0	O	O		Float
SCLK1	I/O	I		Input = High or Low, Output = Float
RFS1/$\overline{IRQ0}$	I/O	I		High or Low
DR1/FI	I	I		High or Low
TFS1/$\overline{IRQ1}$	I/O	O		High or Low
DT1/FO	O	O		Float
$\overline{EE}$	I	I		
$\overline{EBR}$	I	I		
$\overline{EBG}$	O	O		
$\overline{ERESET}$	I	I		
$\overline{EMS}$	O	O		
$\overline{EINT}$	I	I		
ECLK	I	I		
ELIN	I	I		
ELOUT	O	O		

NOTES

*Hi-Z = High Impedance.

1. If the CLKOUT pin is not used, turn it OFF.
2. If the Interrupt/Programmable Flag pins are not used, there are two options:
   Option 1: When these pins are configured as INPUTS at reset and function as interrupts and input flag pins, pull the pins High (inactive).
   Option 2: Program the unused pins as OUTPUTS, set them to 1, and let them float.
3. All bidirectional pins have three-stated outputs. When the pins is configured as an output, the output is Hi-Z (high impedance) when inactive.
4. CLKIN, $\overline{RESET}$, and PF3:0 are not included in the table because these pins must be used.

Interrupts

The interrupt controller allows the processor to respond to the eleven possible interrupts and $\overline{RESET}$ with minimum overhead. The AD73411 provides four dedicated external interrupt input pins, $\overline{IRQ2}$, $\overline{IRQL0}$, $\overline{IRQL1}$, and $\overline{IRQE}$. In addition, SPORT1 may be reconfigured for $\overline{IRQ0}$, $\overline{IRQ1}$, FLAG_IN, and FLAG_OUT, for a total of six external interrupts. The AD73411 also supports internal interrupts from the timer, the byte DMA port, the two serial ports, software, and the power-down control circuit. The interrupt levels are internally prioritized and individually maskable (except power-down and reset). The $\overline{IRQ2}$, $\overline{IRQ0}$, and $\overline{IRQ1}$ input pins can be programmed to be either level- or edge-sensitive. $\overline{IRQL0}$ and $\overline{IRQL1}$ are level-sensitive and $\overline{IRQE}$ is edge-sensitive. The priorities and vector addresses of all interrupts are shown in Table XVII.

Table XVII. Interrupt Priority and Interrupt Vector Addresses

Source of Interrupt	Interrupt Vector Address (Hex)
$\overline{RESET}$ (or Power-Up with PUCR = 1)	0000 (*Highest Priority*)
Power-Down (Nonmaskable)	002C
$\overline{IRQ2}$	0004
$\overline{IRQL1}$	0008
$\overline{IRQL0}$	000C
SPORT0 Transmit	0010
SPORT0 Receive	0014
$\overline{IRQE}$	0018
BDMA Interrupt	001C
SPORT1 Transmit or $\overline{IRQ1}$	0020
SPORT1 Receive or $\overline{IRQ0}$	0024
Timer	0028 (*Lowest Priority*)

Interrupt routines can either be nested, with higher priority interrupts taking precedence, or processed sequentially. Interrupts can be masked or unmasked with the IMASK register. Individual interrupt requests are logically ANDed with the bits in IMASK; the highest priority unmasked interrupt is then selected. The power-down interrupt is nonmaskable.

The AD73411 masks all interrupts for one instruction cycle following the execution of an instruction that modifies the IMASK register. This does not affect serial port autobuffering or DMA transfers.

The interrupt control register, ICNTL, controls interrupt nesting and defines the $\overline{IRQ0}$, $\overline{IRQ1}$, and $\overline{IRQ2}$ external interrupts to be either edge- or level-sensitive. The $\overline{IRQE}$ pin is an external edge-sensitive interrupt and can be forced and cleared. The $\overline{IRQL0}$ and $\overline{IRQL1}$ pins are external level-sensitive interrupts.

The IFC register is a write-only register used to force and clear interrupts. On-chip stacks preserve the processor status and are automatically maintained during interrupt handling. The stacks

are twelve levels deep to allow interrupt, loop, and subroutine nesting. The following instructions allow global enable or disable servicing of the interrupts (including power-down), regardless of the state of IMASK. Disabling the interrupts does not affect serial port autobuffering or DMA.

ENA INTS;
DIS INTS;

When the processor is reset, interrupt servicing is enabled.

LOW-POWER OPERATION

The AD73411 has three low-power modes that significantly reduce the power dissipation when the device operates under standby conditions. These modes are:

- Power-Down
- Idle
- Slow Idle

The CLKOUT pin may also be disabled to reduce external power dissipation.

Power-Down

The AD73411 processor has a low-power feature that lets the processor enter a very low-power dormant state through hardware or software control. Here is a brief list of power-down features. Refer to the *ADSP-2100 Family User's Manual*, Third Edition, "System Interface" chapter, for detailed information about the power-down feature.

- Quick recovery from power-down. The processor begins executing instructions in as few as 400 CLKIN cycles.
- Support for an externally generated TTL or CMOS processor clock. The external clock can continue running during power-down without affecting the 400 CLKIN cycle recovery.
- Support for crystal operation includes disabling the oscillator to save power (the processor automatically waits 4096 CLKIN cycles for the crystal oscillator to start and stabilize), and letting the oscillator run to allow 400 CLKIN cycle startup.
- Power-down is initiated by either the power-down pin ($\overline{\text{PWD}}$) or the software power-down force bit. Interrupt support allows an unlimited number of instructions to be executed before optionally powering down. The power-down interrupt also can be used as a nonmaskable, edge-sensitive interrupt.
- Context clear/save control allows the processor to continue where it left off or start with a clean context when leaving the power-down state.
- The $\overline{\text{RESET}}$ pin also can be used to terminate power-down.
- Power-down acknowledge pin indicates when the processor has entered power-down.

Idle

When the AD73411 is in the Idle Mode, the processor waits indefinitely in a low power state until an interrupt occurs. When an unmasked interrupt occurs, it is serviced; execution then continues with the instruction following the IDLE instruction. In Idle Mode IDMA, BDMA, and Autobuffer Cycle steals still occur.

Slow Idle

The IDLE instruction on the AD73411 slows the processor's internal clock signal, further reducing power consumption. The reduced clock frequency, a programmable fraction of the normal clock rate, is specified by a selectable divisor given in the IDLE instruction. The format of the instruction is

IDLE (n);

where n = 16, 32, 64, or 128. This instruction keeps the processor fully functional, but operating at the slower clock rate. While it is in this state, the processor's other internal clock signals, such as SCLK, CLKOUT, and Timer Clock, are reduced by the same ratio. The default form of the instruction, when no clock divisor is given, is the standard IDLE instruction.

When the IDLE *(n)* instruction is used, it effectively slows down the processor's internal clock and thus its response time to incoming interrupts. The one-cycle response time of the standard idle state is increased by n, the clock divisor. When an enabled interrupt is received, the AD73411 will remain in the idle state for up to a maximum of n processor cycles (n = 16, 32, 64, or 128) before resuming normal operation.

When the IDLE (n) instruction is used in systems that have an externally generated serial clock (SCLK), the serial clock rate may be faster than the processor's reduced internal clock rate. Under these conditions, interrupts must not be generated at a rate faster than can be serviced, due to the additional time the processor takes to come out of the idle state (a maximum of n processor cycles).

SYSTEM INTERFACE

Figure 13 shows a typical basic system configuration with the AD73411, two serial devices, a byte-wide EPROM, and optional external program and data overlay memories (mode selectable). Programmable wait state generation allows the processor to connect easily to slow peripheral devices. The AD73411 also provides four external interrupts and two serial ports or six external interrupts and one serial port. Host Memory Mode allows access to the full external data bus, but limits addressing to a single address bit (A0). Additional system peripherals can be added in this mode through the use of external hardware to generate and latch address signals.

Clock Signals

The AD73411 can be clocked by either a crystal or a TTL-compatible clock signal.

The CLKIN input cannot be halted, changed during operation, or operated below the specified frequency during normal operation. The only exception is while the processor is in the power-down state. For detailed information on this power-down feature, refer to Chapter 9, *ADSP-2100 Family User's Manual,* Third Edition.

If an external clock is used, it should be a TTL-compatible signal running at half the instruction rate. The signal is connected to the processor's CLKIN input. When an external clock is used, the XTAL input must be left unconnected.

The AD73411 uses an input clock with a frequency equal to half the instruction rate; a 26.00 MHz input clock yields a 19 ns processor cycle (which is equivalent to 52 MHz). Normally, instructions are executed in a single processor cycle. All device timing is relative to the internal instruction clock rate, which is indicated by the CLKOUT signal when enabled.

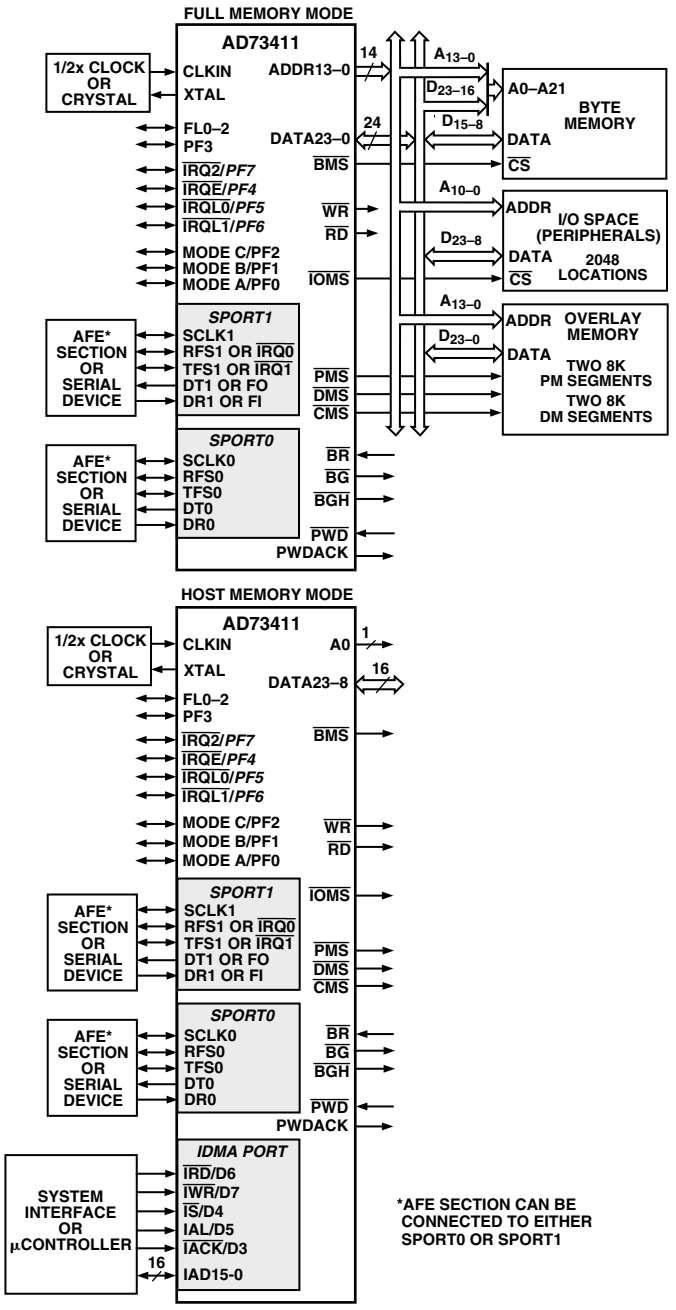


Figure 13. Basic System Configuration

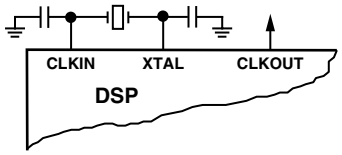


Figure 14. External Crystal Connections

Because the AD73411 includes an on-chip oscillator circuit, an external crystal may be used. The crystal should be connected across the CLKIN and XTAL pins, with two capacitors connected as shown in Figure 14. Capacitor values are dependent on crystal type and should be specified by the crystal manufacturer. A parallel-resonant, fundamental frequency, microprocessor-grade crystal should be used.

A clock output (CLKOUT) signal is generated by the processor at the processor's cycle rate. This can be enabled and disabled by the CLK0DIS bit in the SPORT0 Autobuffer Control Register.

Reset

The $\overline{\text{RESET}}$ signal initiates a master reset of the DSP section of the AD73411. The $\overline{\text{RESET}}$ signal must be asserted during the power-up sequence to assure proper initialization. $\overline{\text{RESET}}$ during initial power-up must be held long enough to allow the internal clock to stabilize. If $\overline{\text{RESET}}$ is activated any time after power-up, the clock continues to run and does not require stabilization time.

The power-up sequence is defined as the total time required for the crystal oscillator circuit to stabilize after a valid V_{DD} is applied to the processor, and for the internal phase-locked loop (PLL) to lock onto the specific crystal frequency. A minimum of 2000 CLKIN cycles ensures that the PLL has locked, but does not include the crystal oscillator start-up time. During this power-up sequence the $\overline{\text{RESET}}$ signal should be held low. On any subsequent resets, the $\overline{\text{RESET}}$ signal must meet the minimum pulsewidth specification, t_{RSP}.

The $\overline{\text{RESET}}$ input contains some hysteresis; however, if an RC circuit is used to generate the $\overline{\text{RESET}}$ signal, an external Schmitt trigger is recommended.

The master reset sets all internal stack pointers to the empty stack condition, masks all interrupts, and clears the MSTAT register. When $\overline{\text{RESET}}$ is released, if there is no pending bus request and the chip is configured for booting, the boot-loading sequence is performed. Once boot loading completes, the first instruction is fetched from on-chip program memory location 0x0000.

MODES OF OPERATION

Table XVII summarizes the AD73411 memory modes.

Setting Memory Mode

Memory Mode selection for the AD73411 is made during chip reset through the use of the Mode C pin. This pin is multiplexed with the DSP's PF2 pin, so care must be taken in how the mode selection is made. The two methods for selecting the value of Mode C are active and passive.

Passive Configuration involves the use a pull-up or pull-down resistor connected to the Mode C pin. To minimize power consumption, or if the PF2 pin is to be used as an output in the DSP application, a weak pull-up or pull-down, on the order of 100 kΩ, can be used. This value should be sufficient to pull the pin to the desired level and still allow the pin to operate as a programmable flag output without undue strain on the processor's output driver. For minimum power consumption during power-down, reconfigure PF2 to be an input, as the pull-up or pull-down will hold the pin in a known state and will not switch.

Active Configuration involves the use of a three-statable external driver connected to the Mode C pin. A driver's output enable should be connected to the DSP's $\overline{\text{RESET}}$ signal such that it only drives the PF2 pin when $\overline{\text{RESET}}$ is active (low). When $\overline{\text{RESET}}$ is deasserted, the driver should three-state, thus allowing full use of the PF2 pin as either an input or output. To minimize power consumption during power-down, configure the programmable flag as an output when connected to a three-stated buffer. This ensures that the pin will be held at a constant level and not oscillate should the three-state driver's level hover around the logic switching point.

Table XVIII. Modes of Operations[1]

MODE C[2]	MODE B[3]	MODE A[4]	Booting Method
0	0	0	BDMA feature is used to load the first 32 program memory words from the byte memory space. Program execution is held off until all 32 words have been loaded. Chip is configured in Full Memory Mode.[5]
0	1	0	No automatic boot operations occur. Program execution starts at external memory location 0. Chip is configured in Full Memory Mode. BDMA can still be used, but the processor does not automatically use or wait for these operations.
1	0	0	BDMA feature is used to load the first 32 program memory words from the byte memory space. Program execution is held off until all 32 words have been loaded. Chip is configured in Host Mode.[6]
1	0	1	IDMA feature is used to load any internal memory as desired. Program execution is held off until internal program memory location 0 is written to. Chip is configured in Host Mode.[5]

NOTES
[1]All mode pins are recognized while $\overline{\text{RESET}}$ is active (low).
[2]When Mode C = 0, Full Memory enabled. When Mode C = 1, Host Memory Mode enabled.
[3]When Mode B = 0, Autobooting enabled. When Mode B = 1, no Autobooting.
[4]When Mode A = 0, BDMA enabled. When Mode A = 1, IDMA enabled.
[5]Considered as standard operating settings. Using these configurations allows for easier design and better memory management.
[6]Requires additional hardware.

MEMORY ARCHITECTURE

The AD73411 provides a variety of memory and peripheral interface options. The key functional groups are Program Memory, Data Memory, Byte Memory, and I/O. Refer to the following figures and tables for PM and DM memory allocations in the AD73411.

PROGRAM MEMORY

Program Memory (Full Memory Mode) is a 24-bit-wide space for storing both instruction op codes and data. The AD73411-80 has 16K words of Program Memory RAM on chip (the AD73411-40 has 8K words of Program Memory RAM on chip), and the capability of accessing up to two 8K external memory overlay spaces using the external data bus.

Program Memory (Host Mode) allows access to all internal memory. External overlay access is limited by a single external address line (A0). External program execution is not available in host mode due to a restricted data bus that is only 16 bits wide.

Table XIX. PMOVLAY Bits

PMOVLAY	Memory	A13	A12:0
0	Internal	Not Applicable	Not Applicable
1	External Overlay 1	0	13 LSBs of Address Between 0x2000 and 0x3FFF
2	External Overlay 2	1	13 LSBs of Address Between 0x2000 and 0x3FFF

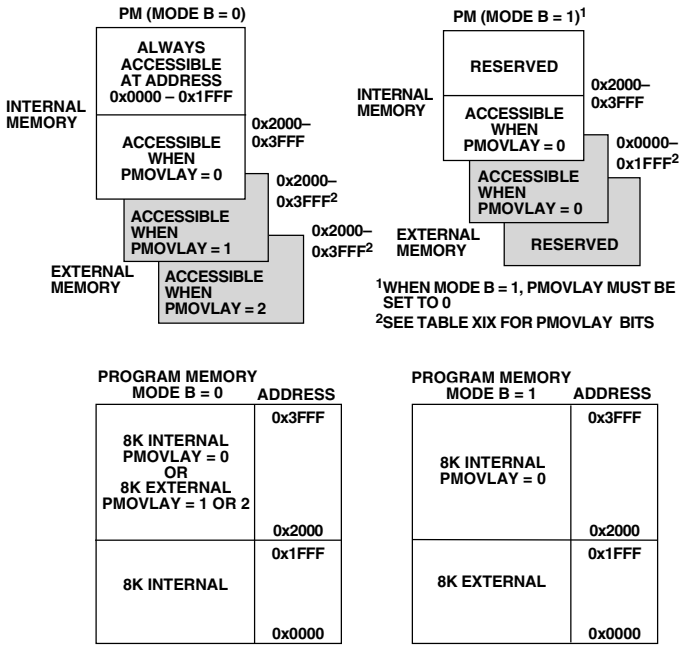


Figure 15. Program Memory Map

DATA MEMORY

Data Memory (Full Memory Mode) is a 16-bit-wide space used for the storage of data variables and for memory-mapped control registers. The AD73411-80 has 16K words on Data Memory RAM on-chip (the AD73411-40 has 8K words on Data Memory RAM on-chip), consisting of 16,352 user-accessible locations in the case of the AD73411-80 (8,160 user-accessible locations in the case of the AD73411-40) and 32 memory-mapped registers. Support also exists for up to two 8K external memory overlay spaces through the external data bus. All internal accesses complete in one cycle. Accesses to external memory are timed using the wait states specified by the DWAIT register.

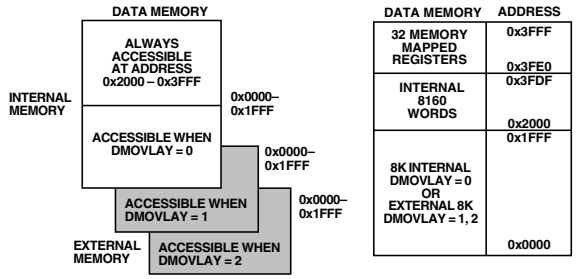


Figure 16. Data Memory Map

Data Memory (Host Mode) allows access to all internal memory. External overlay access is limited by a single external address line (A0). The DMOVLAY bits are defined in Table XX.

Table XX. DMOVLAY Bits

DMOVLAY	Memory	A13	A12:0
0	Internal	Not Applicable	Not Applicable
1	External Overlay 1	0	13 LSBs of Address Between 0x2000 and 0x3FFF
2	External Overlay 2	1	13 LSBs of Address Between 0x2000 and 0x3FFF

I/O Space (Full Memory Mode)

The AD73411 supports an additional external memory space called I/O space. This space is designed to support simple connections to peripherals (such as data converters and external registers) or to bus interface ASIC data registers. I/O space supports 2048 locations of 16-bit-wide data. The lower 11-bits of the external address bus are used; the upper three bits are undefined. Two instructions were added to the core ADSP-2100 Family Instruction Set to read from and write to I/O memory space. The I/O space also has four dedicated 3-bit wait state registers, IOWAIT0-3, that specify up to seven wait states to be automatically generated for each of four regions. The wait states act on address ranges as shown in Table XXI.

Table XXI. Wait States

Address Range	Wait State Register
0x000–0x1FF	IOWAIT0
0x200–0x3FF	IOWAIT1
0x400–0x5FF	IOWAIT2
0x600–0x7FF	IOWAIT3

Composite Memory Select ($\overline{\text{CMS}}$)

The AD73411 has a programmable memory select signal that is useful for generating memory select signals for memories mapped to more than one space. The $\overline{\text{CMS}}$ signal is generated to have the same timing as each of the individual memory select signals ($\overline{\text{PMS}}$, $\overline{\text{DMS}}$, $\overline{\text{BMS}}$, $\overline{\text{IOMS}}$) but can combine their functionality.

Each bit in the CMSSEL register, when set, causes the $\overline{\text{CMS}}$ signal to be asserted when the selected memory select is asserted. For example, to use a 32K word memory to act as both program and data memory, set the $\overline{\text{PMS}}$ and $\overline{\text{DMS}}$ bits in the CMSSEL register and use the $\overline{\text{CMS}}$ pin to drive the chip select of the memory; use either $\overline{\text{DMS}}$ or $\overline{\text{PMS}}$ as the additional address bit.

The $\overline{\text{CMS}}$ pin functions like the other memory select signals, with the same timing and bus request logic. A 1 in the enable bit causes the assertion of the $\overline{\text{CMS}}$ signal at the same time as the selected memory select signal. All enable bits default to 1 at reset, except the $\overline{\text{BMS}}$ bit.

Boot Memory Select ($\overline{\text{BMS}}$) Disable

The AD73411 also lets you boot the processor from one external memory space while using a different external memory space for BDMA transfers during normal operation. You can use the $\overline{\text{CMS}}$ to select the first external memory space for BDMA transfers and $\overline{\text{BMS}}$ to select the second external memory space for booting. The $\overline{\text{BMS}}$ signal can be disabled by setting Bit 3 of the System Control Register to 1. The System Control Register is illustrated in Figure 17.

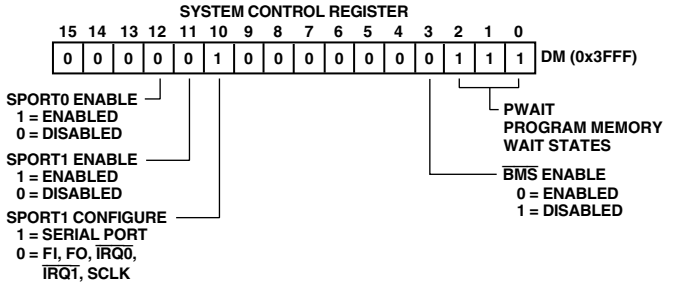


Figure 17. System Control Register

Byte Memory

The byte memory space is a bidirectional, 8-bit-wide, external memory space used to store programs and data. Byte memory is accessed using the BDMA feature. The BDMA Control Register is shown in Figure 18. The byte memory space consists of 256 pages, each of which is 16K × 8.

The byte memory space on the AD73411 supports read and write operations as well as four different data formats. The byte memory uses data bits 15:8 for data. The byte memory uses data bits 23:16 and address bits 13:0 to create a 22-bit address. This allows up to a 4 meg × 8 (32 megabit) ROM or RAM to be used without glue logic. All byte memory accesses are timed by the BMWAIT register.

Byte Memory DMA (BDMA, Full Memory Mode)

The Byte memory DMA controller allows loading and storing of program instructions and data using the byte memory space. The BDMA circuit is able to access the byte memory space while the processor is operating normally, and steals only one DSP cycle per 8-, 16-, or 24-bit word transferred.

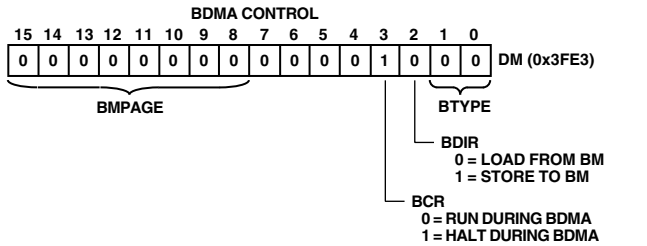


Figure 18. BDMA Control Register

The BDMA circuit supports four different data formats that are selected by the BTYPE register field. The appropriate number of 8-bit accesses are done from the byte memory space to build the word size selected. Table XXII shows the data formats supported by the BDMA circuit.

Table XXII. Data Formats

BTYPE	Internal Memory Space	Word Size	Alignment
00	Program Memory	24	Full Word
01	Data Memory	16	Full Word
10	Data Memory	8	MSBs
11	Data Memory	8	LSBs

Unused bits in the 8-bit data memory formats are filled with 0s. The BIAD register field is used to specify the starting address for the on-chip memory involved with the transfer. The 14-bit BEAD register specifies the starting address for the external byte memory space. The 8-bit BMPAGE register specifies the starting page for the external byte memory space. The BDIR register field selects the direction of the transfer. Finally the 14-bit BWCOUNT register specifies the number of DSP words to transfer and initiates the BDMA circuit transfers.

BDMA accesses can cross page boundaries during sequential addressing. A BDMA interrupt is generated on the completion of the number of transfers specified by the BWCOUNT register.

The BWCOUNT register is updated after each transfer so it can be used to check the status of the transfers. When it reaches zero, the transfers have finished and a BDMA interrupt is generated. The BMPAGE and BEAD registers must not be accessed by the DSP during BDMA operations.

The source or destination of a BDMA transfer will always be on-chip program or data memory.

When the BWCOUNT register is written with a nonzero value, the BDMA circuit starts executing byte memory accesses with wait states set by BMWAIT. These accesses continue until the count reaches zero. When enough accesses have occurred to create a destination word, it is transferred to or from on-chip memory. The transfer takes one DSP cycle. DSP accesses to external memory have priority over BDMA byte memory accesses.

The BDMA Context Reset bit (BCR) controls whether or not the processor is held off while the BDMA accesses are occurring. Setting the BCR bit to 0 allows the processor to continue operations. Setting the BCR bit to 1 causes the processor to stop execution while the BDMA accesses are occurring, to clear the context of the processor and start execution at address 0 when the BDMA accesses have completed.

The BDMA overlay bits specify the OVLAY memory blocks to be accessed for internal memory.

Internal Memory DMA Port (IDMA Port; Host Memory Mode)

The IDMA Port provides an efficient means of communication between a host system and the AD73411. The port is used to access the on-chip program memory and data memory of the DSP with only one DSP cycle per word overhead. The IDMA port cannot be used, however, to write to the DSP's memory-mapped control registers. A typical IDMA transfer process is described as follows:

1. Host starts IDMA transfer.
2. Host checks $\overline{\text{IACK}}$ control line to see if the DSP is busy.
3. Host uses $\overline{\text{IS}}$ and IAL control lines to latch the DMA starting address (IDMAA) into the DSP's IDMA control registers. IAD[15] must be set = 0.
4. Host uses $\overline{\text{IS}}$ and $\overline{\text{IRD}}$ (or $\overline{\text{IWR}}$) to read (or write) DSP internal memory (PM or DM).
5. Host checks $\overline{\text{IACK}}$ line to see if the DSP has completed the previous IDMA operation.
6. Host ends IDMA transfer.

The IDMA port has a 16-bit multiplexed address and data bus and supports 24-bit program memory. The IDMA port is completely asynchronous and can be written to while the AD73411 is operating at full speed.

The DSP memory address is latched and then automatically incremented after each IDMA transaction. An external device can therefore access a block of sequentially addressed memory by specifying only the starting address of the block. This increases throughput as the address does not have to be sent for each memory access.

IDMA Port access occurs in two phases. The first is the IDMA Address Latch cycle. When the acknowledge is asserted, a 14-bit address and 1-bit destination type can be driven onto the bus by an external device. The address specifies an on-chip memory location; the destination type specifies whether it is a DM or PM access. The falling edge of the address latch signal latches this value into the IDMAA register.

Once the address is stored, data can either be read from or written to the AD73411's on-chip memory. Asserting the select line ($\overline{\text{IS}}$) and the appropriate read or write line ($\overline{\text{IRD}}$ and $\overline{\text{IWR}}$ respectively) signals the AD73411 that a particular transaction is required. In either case, there is a one-processor-cycle delay for synchronization. The memory access consumes one additional processor cycle.

Once an access has occurred, the latched address is automatically incremented and another access can occur.

Through the IDMAA register, the DSP can also specify the starting address and data format for DMA operation. Asserting the IDMA port select (IS) and address latch enable (IAL) directs the AD73411 to write the address onto the IAD0–14 bus into the IDMA Control Register. The IDMAA register, shown below, is memory mapped at address DM (0x3FE0). Note that the latched address (IDMAA) cannot be read back by the host. See Figure 19 for more information on IDMA and DMA memory maps.

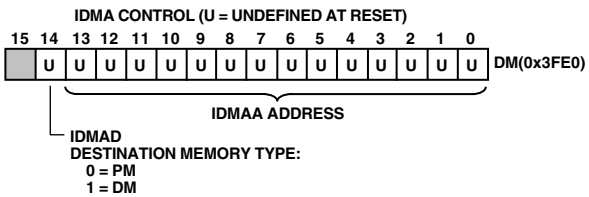


Figure 19. IDMA Control/OVLAY Registers

Bootstrap Loading (Booting)

The AD73411 has two mechanisms to allow automatic loading of the internal program memory after reset. The method for booting after reset is controlled by the Mode A, B and C configuration bits.

When the mode pins specify BDMA booting, the AD73411 initiates a BDMA boot sequence when reset is released.

When BDMA booting is specified, the BDMA interface is set up during reset to the following defaults: the BDIR, BMPAGE, BIAD and BEAD registers are set to 0, the BTYPE register is set to 0 to specify program memory 24-bit words, and the BWCOUNT register is set to 32. This causes 32 words of on-chip program memory to be loaded from byte memory. These 32 words are used to set up the BDMA to load in the remaining program code. The BCR bit is also set to 1, which causes program execution to be held off until all 32 words are loaded into on-chip program memory. Execution then begins at address 0.

The ADSP-2100 Family Development Software (Revision 5.02 and later) fully supports the BDMA booting feature and can generate byte memory-space-compatible boot code.

The IDLE instruction can also be used to allow the processor to hold off execution while booting continues through the BDMA interface. For BDMA accesses while in Host Mode, the addresses to boot memory must be constructed externally to the AD73411. A0 is the only memory address bit provided by the processor.

IDMA Port Booting

The AD73411 can also boot programs through its Internal DMA port. If Mode C = 1, Mode B = 0 and Mode A = 1, the AD73411 boots from the IDMA port. IDMA feature can load as much on-chip memory as desired. Program execution is held off until on-chip program memory location 0 is written to.

Bus Request and Bus Grant (Full Memory Mode)

The AD73411 can relinquish control of the data and address buses to an external device. When the external device requires access to memory, it asserts the bus request (BR) signal. If the AD73411 is not performing an external memory access, it responds to the active BR input in the following processor cycle by:

- Three-stating the data and address buses and the $\overline{\text{PMS}}$, $\overline{\text{DMS}}$, $\overline{\text{BMS}}$, $\overline{\text{CMS}}$, $\overline{\text{IOMS}}$, $\overline{\text{RD}}$, $\overline{\text{WR}}$ output drivers
- Asserting the bus grant ($\overline{\text{BG}}$) signal
- Halting program execution

If Go Mode is enabled, the AD73411 will not halt program execution until it encounters an instruction that requires an external memory access.

If the AD73411 is performing an external memory access when the external device asserts the $\overline{\text{BR}}$ signal, it will not three-state the memory interfaces or assert the $\overline{\text{BG}}$ signal until the processor cycle after the access completes. The instruction does not need to be completed when the bus is granted. If a single instruction requires two external memory accesses, the bus will be granted between the two accesses.

When the $\overline{\text{BR}}$ signal is released, the processor releases the $\overline{\text{BG}}$ signal, reenables the output drivers and continues program execution from the point at which it stopped.

The bus request feature operates at all times, including when the processor is booting and when $\overline{\text{RESET}}$ is active.

The $\overline{\text{BGH}}$ pin is asserted when the AD73411 is ready to execute an instruction, but is stopped because the external bus is already granted to another device. The other device can release the bus by deasserting bus request. Once the bus is released, the AD73411 deasserts $\overline{\text{BG}}$ and $\overline{\text{BGH}}$ and executes the external memory access.

Flag I/O Pins

The AD73411 has eight general-purpose programmable input/output flag pins. They are controlled by two memory-mapped registers. The PFTYPE register determines the direction, 1 = output and 0 = input. The PFDATA register is used to read and write the values on the pins. Data being read from a pin configured as an input is synchronized to the AD73411's clock. Bits that are programmed as outputs will read the value being output. The PF pins default to input during reset.

In addition to the programmable flags, the AD73411 has five fixed-mode flags, FLAG_IN, FLAG_OUT, FL0, FL1, and FL2. FL0–FL2 are dedicated output flags; FLAG_IN and FLAG_OUT are available as an alternate configuration of SPORT1.

Note: Pins PF0, PF1, PF2, and PF3 are also used for device configuration during reset.

INSTRUCTION SET DESCRIPTION

The AD73411 assembly language instruction set has an algebraic syntax that was designed for ease of coding and readability. The assembly language, which takes full advantage of the processor's unique architecture, offers the following benefits:

- The algebraic syntax eliminates the need to remember cryptic assembler mnemonics. For example, a typical arithmetic add instruction, such as AR = AX0 + AY0, resembles a simple equation.
- Every instruction assembles into a single, 24-bit word that can execute in a single instruction cycle.
- The syntax is a superset ADSP-2100 Family assembly language and is completely source-and object-code-compatible with other family members. Programs may need to be relocated to utilize on-chip memory and conform to the AD73411's interrupt vector and reset vector map.
- Sixteen condition codes are available. For conditional jump, call, return, or arithmetic instructions, the condition can be checked and the operation executed in the same instruction cycle.
- Multifunction instructions allow parallel execution of an arithmetic instruction with up to two fetches or one write to processor memory space during a single instruction cycle.

DESIGNING AN EZ-ICE®-COMPATIBLE SYSTEM

The AD73411 has on-chip emulation support and an ICE-Port, a special set of pins that interface to the EZ-ICE. These features allow in-circuit emulation without replacing the target system processor by using only a 14-pin connection from the target system to the EZ-ICE. Target systems must have a 14-pin connector to accept the EZ-ICE's in-circuit probe, a 14-pin plug. See the ADSP-2100 Family EZ-Tools™ data sheet for complete information on ICE products.

Issuing the chip reset command during emulation causes the DSP to perform a full chip reset, including a reset of its memory mode. Therefore, it is vital that the mode pins are set correctly *prior* to issuing a chip reset command from the emulator user interface. If you are using a passive method of maintaining mode information (as discussed in Setting Memory Modes), it does not matter that the mode information is latched by an emulator reset. However, if using the $\overline{\text{RESET}}$ pin as a method

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EZ-Tools™ registered trademark of Analog Devices.

of setting the value of the mode pins, the effects of an emulator reset must be taken into consideration.

One method of ensuring that the values located on the mode pins are those desired, is to construct a circuit like the one shown in Figure 20. This circuit forces the value located on the Mode A pin to logic high; regardless if it is latched via the $\overline{\text{RESET}}$ or $\overline{\text{ERESET}}$ pin.

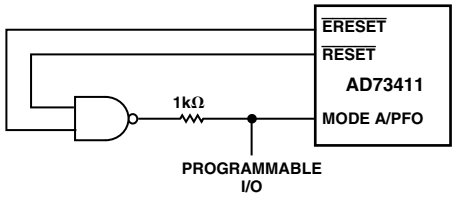


Figure 20. Mode A Pin/EZ-ICE Circuit

The ICE-Port interface consists of the following AD73411 pins:

$\overline{\text{EBR}}$	$\overline{\text{EBG}}$	$\overline{\text{ERESET}}$
$\overline{\text{EMS}}$	$\overline{\text{EINT}}$	ECLK
ELIN	ELOUT	EE

These AD73411 pins must be connected *only* to the EZ-ICE connector in the target system. These pins have no function except during emulation, and do not require pull-up or pull-down resistors. The traces for these signals between the AD73411 and the connector must be kept as short as possible, no longer than three inches.

The following pins are also used by the EZ-ICE:

$\overline{\text{BR}}$	$\overline{\text{BG}}$
$\overline{\text{RESET}}$	GND

The EZ-ICE uses the EE (emulator enable) signal to take control of the AD73411 in the target system. This causes the processor to use its $\overline{\text{ERESET}}$, $\overline{\text{EBR}}$, and $\overline{\text{EBG}}$ pins instead of the $\overline{\text{RESET}}$, $\overline{\text{BR}}$, and $\overline{\text{BG}}$ pins. The $\overline{\text{BG}}$ output is three-stated. These signals do not need to be jumper-isolated in your system.

The EZ-ICE connects to your target system via a ribbon cable and a 14-pin female plug. The ribbon cable is 10 inches in length with one end fixed to the EZ-ICE. The female plug is plugged onto the 14-pin connector (a pin strip header) on the target board.

Target Board Connector for EZ-ICE Probe

The EZ-ICE connector (a standard pin strip header) is shown in Figure 21. You must add this connector to your target board design if you intend to use the EZ-ICE. Be sure to allow enough room in your system to fit the EZ-ICE probe onto the 14-pin connector.

The 14-pin, 2-row pin strip header is keyed at the Pin 7 location—you must remove Pin 7 from the header. The pins must be 0.025 inch square and at least 0.20 inch in length. Pin spacing should be 0.1 × 0.1 inches. The pin strip header must have at least 0.15 inch clearance on all sides to accept the EZ-ICE probe plug.

Pin strip headers are available from vendors such as 3M, McKenzie, and Samtec.

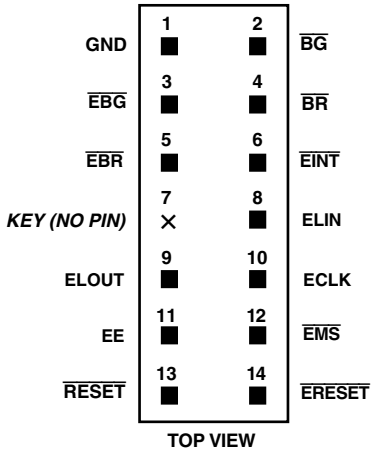


Figure 21. Target Board Connector for EZ-ICE

Target Memory Interface

For your target system to be compatible with the EZ-ICE emulator, it must comply with the memory interface guidelines listed below.

PM, DM, BM, IOM and CM

Design your Program Memory (PM), Data Memory (DM), Byte Memory (BM), I/O Memory (IOM) and Composite Memory (CM) external interfaces to comply with worst-case device timing requirements and switching characteristics as specified in the DSP's data sheet. The performance of the EZ-ICE may approach published worst case specification for some memory access timing requirements and switching characteristics.

Note: If your target does not meet the worst-case chip specification for memory access parameters, you may not be able to emulate your circuitry at the desired CLKIN frequency. Depending on the severity of the specification violation, you may have trouble manufacturing your system as DSP components statistically vary in switching characteristic and timing requirements within published limits.

Restriction: All memory strobe signals on the AD73411 ($\overline{\text{RD}}$, $\overline{\text{WR}}$, $\overline{\text{PMS}}$, $\overline{\text{DMS}}$, $\overline{\text{BMS}}$, $\overline{\text{CMS}}$, and $\overline{\text{IOMS}}$) used in your target system must have 10 kΩ pull-up resistors connected when the EZ-ICE is being used. The pull-up resistors are necessary because there are no internal pull-ups to guarantee their state during prolonged three-state conditions resulting from typical EZ-ICE debugging sessions. These resistors may be removed at your option when the EZ-ICE is not being used.

Target System Interface Signals
When the EZ-ICE board is installed, the performance on some system signals changes. Design your system to be compatible with the following system interface signal changes introduced by the EZ-ICE board:

- EZ-ICE emulation introduces an 8 ns propagation delay between your target circuitry and the DSP on the $\overline{\text{RESET}}$ signal.
- EZ-ICE emulation introduces an 8 ns propagation delay between your target circuitry and the DSP on the $\overline{\text{BR}}$ signal.
- EZ-ICE emulation ignores $\overline{\text{RESET}}$ and $\overline{\text{BR}}$ when single-stepping.
- EZ-ICE emulation ignores $\overline{\text{RESET}}$ and $\overline{\text{BR}}$ when in Emulator Space (DSP halted).
- EZ-ICE emulation ignores the state of target $\overline{\text{BR}}$ in certain modes. As a result, the target system may take control of the DSP's external memory bus only if bus grant ($\overline{\text{BG}}$) is asserted by the EZ-ICE board's DSP.

ANALOG FRONT END (AFE) INTERFACING

The AFE section of the AD73411 features a voiceband input/output channel, each with 16-bit linear resolution. Connectivity to the AFE section from the DSP is uncommitted, thus allowing the user the flexibility of connecting in the mode or configuration of their choice. This section will detail several configurations—with no extra AFE channels configured and with two extra AFE channels configured (using an external AD73322 dual AFE).

DSP SPORT to AFE Interfacing
The SCLK, SDO, SDOFS, SDI and SDIFS pins of SPORT2 must be connected to the Serial Clock, Receive Data, Receive Data Frame Sync, Transmit Data, and Transmit Data Frame Sync pins respectively of either SPORT0 or SPORT1. The SE pin may be controlled from a parallel output pin or flag pin such as FL0–2 or, where SPORT2 power-down is not required, it can be permanently strapped high using a suitable pull-up resistor. The $\overline{\text{ARESET}}$ pin may be connected to the system hardware reset structure or it may also be controlled using a dedicated control line. In the event of tying it to the global system reset, it is advisable to operate the device in mixed mode, which allows a software reset, otherwise there is no convenient way of resetting the AFE section.

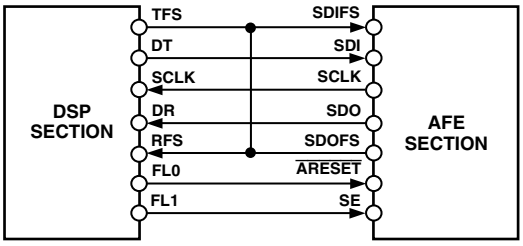


Figure 22. AD73411 AFE to DSP Connection

Cascade Operation
Where it is required to configure extra analog I/O channels to the existing two channels on the AD73411, it is possible to cascade up to seven more channels (using single channel AD73311 or dual channel AD73322 AFEs) by using the scheme described in Figure 24. It is necessary, however, to ensure that the timing of the SE and $\overline{\text{ARESET}}$ signals is synchronized at each device in the cascade. A simple D-type flip-flop is sufficient to sync each signal to the master clock AMCLK, as in Figure 23.

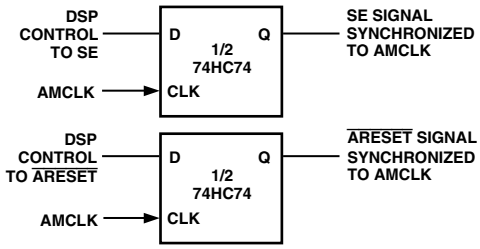


Figure 23. SE and $\overline{\text{ARESET}}$ Sync Circuit for Cascaded Operation

Connection of a cascade of devices to a DSP, as shown in Figure 24, is no more complicated than connecting a single device. Instead of connecting the SDO and SDOFS to the DSP's Rx port, these are now daisy-chained to the SDI and SDIFS of the next device in the cascade. The SDO and SDOFS of the final device in the cascade are connected to the DSP section's Rx port to complete the cascade. SE and $\overline{\text{ARESET}}$ on all devices are fed from the signals that were synchronized with the AMCLK using the circuit as described above. The SCLK from only one device need be connected to the DSP section's SCLK input(s) as all devices will be running at the same SCLK frequency and phase.

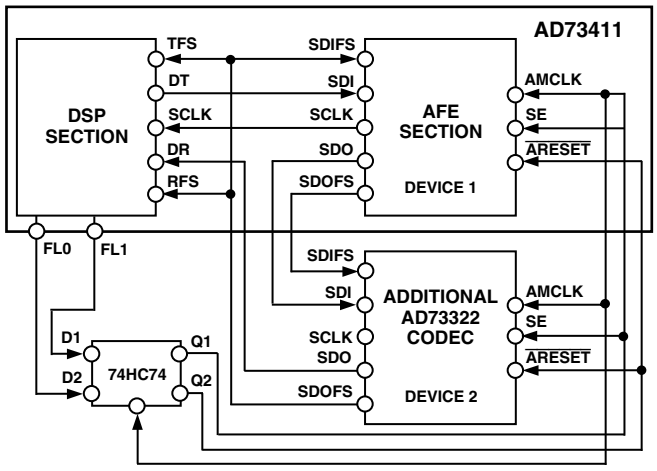


Figure 24. Connection of an AD73322 Cascaded to AD73411

Interfacing to the AFE's Analog Inputs and Outputs
The AFE section of the AD73411 offers a flexible interface for microphone pickups, line level signals, or PSTN line interfaces. This section will detail some of the configurations that can be used with the input and output sections.

The AD73411 features both differential inputs and outputs to provide optimal performance and avoid common-mode noise. It is also possible to interface either inputs or outputs in single-ended mode. This section details the choice of input and output configurations and also gives some tips toward successful configuration of the analog interface sections.

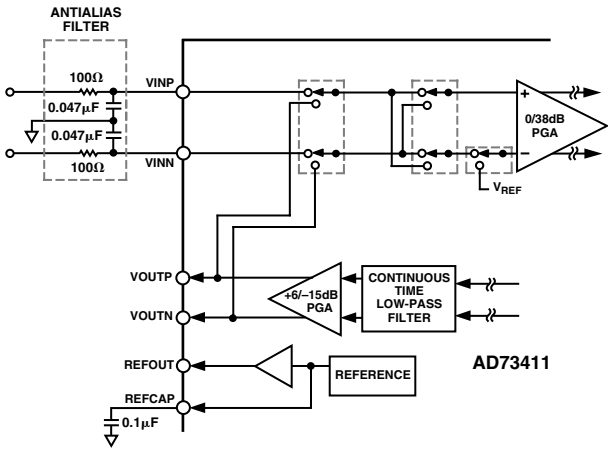


Figure 25. Analog Input (DC-Coupled)

Analog Inputs

The analog input (encoder) section of the AD73411 can be interfaced to external circuitry in either ac-coupled or dc-coupled modes.

It is also possible to drive the ADC in either differential or single-ended modes. If the single-ended mode is chosen it is possible, using software control, to multiplex between two single-ended inputs connected to the positive and negative input pins.

The primary concerns in interfacing to the ADC are to provide adequate antialias filtering and to ensure that the signal source will drive the switched-capacitor input of the ADC correctly. The sigma-delta design of the ADC and its oversampling characteristics simplify the antialias requirements, but it must be remembered that the single-pole RC filter is primarily intended to eliminate aliasing of frequencies above the Nyquist frequency of the sigma-delta modulator's sampling rate (typically 2.048 MHz). It may still require a more specific digital filter implementation in the DSP to provide the final signal frequency response characteristics. It is recommended that for optimum performance the capacitors used for the antialiasing filter be of high quality dielectric (NPO). The second issue mentioned above is interfacing the signal source to the ADC's switched capacitor input load. The SC input presents a complex dynamic load to a signal source, therefore, it is important to understand that the slew rate characteristic is an important consideration when choosing external buffers for use with the AD73411.

The AD73411's on-chip 38 dB preamplifier can be enabled when there is not enough gain in the input circuit; the preamplifier is configured by bits IGS0–2 of CRD. The total gain must be configured to ensure that a full-scale input signal produces a signal level at the input to the sigma-delta modulator of the ADC that does not exceed the maximum input range.

The dc biasing of the analog input signal is accomplished with an on-chip voltage reference. If the input signal is not biased at the internal reference level (via REFOUT), it must be ac-coupled with external coupling capacitors. C_{IN} should be 0.1 μF or larger. The dc biasing of the input can then be accomplished using resistors to REFOUT as in Figures 27 through 29.

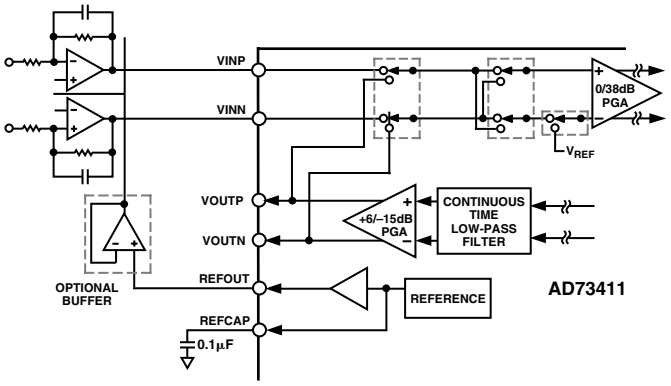


Figure 26. Analog Input (DC-Coupled) Using External Amplifiers

The AD73411's ADC inputs are biased about the internal reference level (REFCAP level), therefore, it may be necessary to bias external signals to this level using the buffered REFOUT level as the reference. This is applicable in either dc- or ac-coupled configurations. In the case of dc coupling, the signal (biased to REFOUT) may be applied directly to the inputs as shown in Figure 25, or it may be conditioned in an external op amp where it can also be biased to the reference level using the buffered REFOUT signal as shown in Figure 26.

In the case of ac-coupling, a capacitor is used to couple the signal to the input of the ADC. The ADC input must be biased to the internal reference (REFCAP) level, which is done by connecting the input to the REFOUT pin through a 10 kΩ resistor as shown in Figure 27.

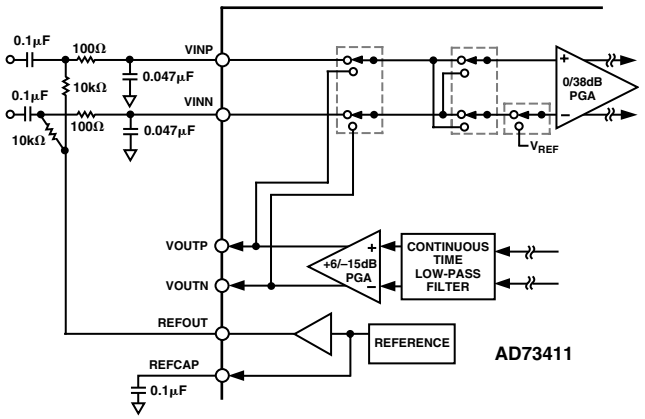


Figure 27. Analog Input (AC-Coupled) Differential

If the ADC is being connected in single-ended mode, the AD73411 should be programmed for single-ended mode using the SEEN and INV bits of CRF, and the inputs connected as shown in Figure 28. When operated in single-ended input mode, the AD73411 can multiplex one of the two inputs to the ADC input, as shown in Figures 28 and 29.

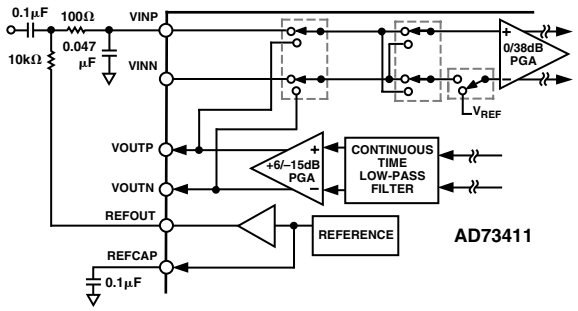


Figure 28. Analog Input (AC-Coupled) Single-Ended

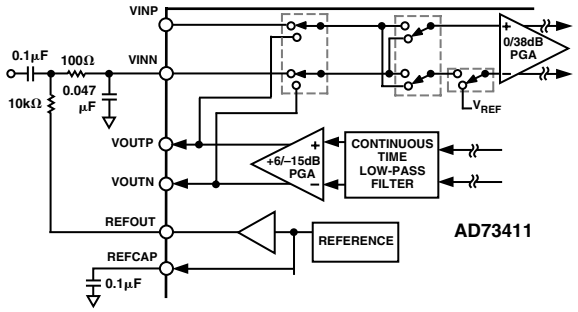


Figure 29. Analog Input (AC-Coupled) Single-Ended (Alternate Input)

Interfacing to an Electret Microphone

Figure 30 details an interface for an electret microphone which may be used in some voice applications. Electret microphones typically feature a FET amplifier whose output is accessed on the same lead that supplies power to the microphone; therefore, this output signal must be capacitively coupled to remove the power supply (dc) component. In this circuit the AD73411 input channel is being used in single-ended mode where the inverting amplifier provides suitable gain to scale the input signal relative to the ADC's full-scale input range. The buffered internal reference level at REFOUT is used via an external buffer to provide power to the electret microphone. This provides a quiet, stable supply for the microphone. If this is not a concern, the microphone can be powered from the system power supply.

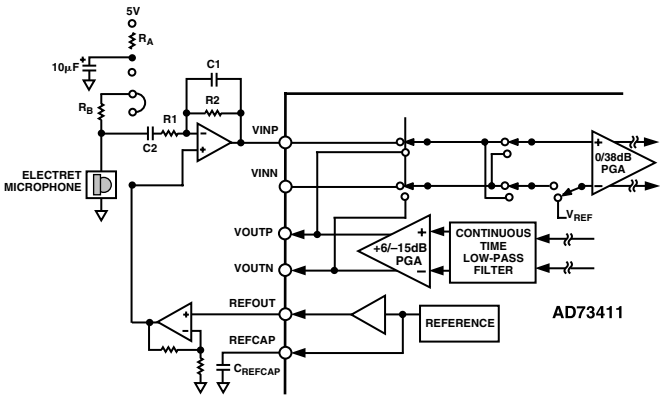


Figure 30. Electret Microphone Interface Circuit

Analog Output

The AD73411's differential analog output (VOUT) is produced by an on-chip differential amplifier. The differential output can be ac-coupled or dc-coupled directly to a load that can be a headset or the input of an external amplifier. It is possible to connect the outputs in either a differential or a single-ended configuration, but please note that the effective maximum output voltage swing (peak-to-peak) is halved in the case of single-ended connection. Figure 31 shows a simple circuit providing a differential output with ac coupling. The capacitors in this circuit (C_{OUT}) are optional; if used, their value can be chosen as follows:

$$C_{OUT} = \frac{1}{2\ \pi\ f_C\ R_{LOAD}}$$

where f_C = desired cutoff frequency.

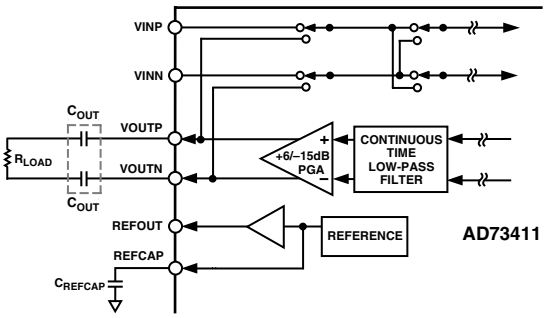


Figure 31. Example Circuit for Differential Output

Figure 32 shows an example circuit for providing a single-ended output with ac coupling. The capacitor of this circuit (C_{OUT}) is not optional if dc current drain is to be avoided.

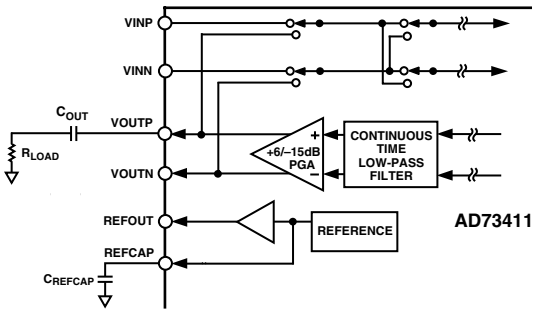


Figure 32. Example Circuit for Single-Ended Output

Differential-to-Single-Ended Output

In some applications it may be desirable to convert the full differential output of the decoder channel to a single-ended signal. The circuit of Figure 33 shows a scheme for doing this.

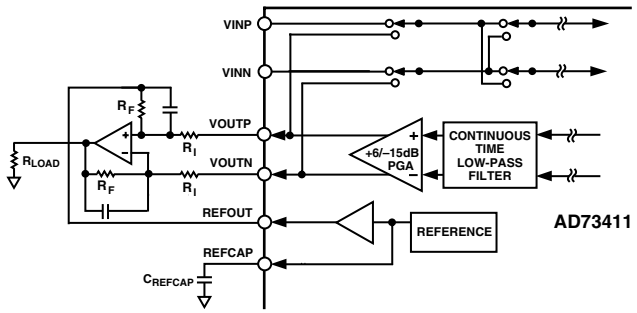


Figure 33. Example Circuit for Differential-to-Single-Ended Output Conversion

Grounding and Layout

As the analog inputs to the AD73411's AFE section are differential, most of the voltages in the analog modulator are common-mode voltages. The excellent common-mode rejection of the part will remove common-mode noise on these inputs. The analog and digital supplies of the AD73411 are independent and separately pinned out to minimize coupling between analog and digital sections of the device. The digital filters on the encoder section will provide rejection of broadband noise on the power supplies, except at integer multiples of the modulator sampling frequency. The digital filters also remove noise from the analog inputs provided the noise source does not saturate the analog modulator. However, because the resolution of the AD73411's ADC is high, and the noise levels from the AD73411 are so low, care must be taken with regard to grounding and layout.

The printed circuit board that houses the AD73411 should be designed so the analog and digital sections are separated and confined to certain sections of the board. The AD73411 ball-out configuration offers a major advantage in that its analog interfaces are confined to the last three rows of the package. This facilitates the use of ground planes that can be easily separated, as shown in Figure 34. A minimum etch technique is generally best for ground planes as it gives the best shielding. Digital and analog ground planes should be joined in only one place. If this connection is close to the device, it is recommended to use a ferrite bead inductor.

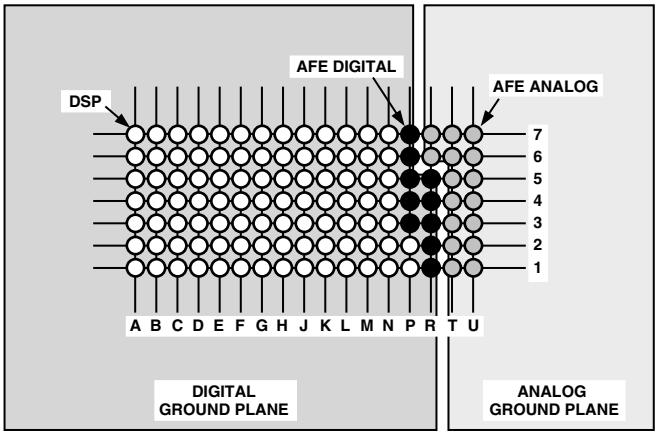


Figure 34. Ground Plane Layout

Avoid running digital lines under the AFE section of the device for they will couple noise onto the die. The analog ground plane should be allowed to run under the AD73411's AFE section to avoid noise coupling (see Figure 34). The power supply lines to the AD73411 should use as large a trace as possible to provide low impedance paths and reduce the effects of glitches on the power supply lines. Fast switching signals such as clocks should be shielded with digital ground to avoid radiating noise to other sections of the board, and clock signals should never be run near the analog inputs. Traces on opposite sides of the board should run at right angles to each other. This will reduce the effects of feedthrough through the board. A microstrip technique is by far the best but is not always possible with a double-sided board. In this technique, the component side of the board is dedicated to ground planes while signals are placed on the other side.

Good decoupling is important when using high-speed devices. On the AD73411 both the reference (REFCAP) and supplies need to be decoupled. It is recommended that the decoupling capacitors used on both REFCAP and the supplies, be placed as close as possible to their respective ball connections to ensure high performance from the device. All analog and digital supplies should be decoupled to AGND and DGND respectively, with 0.1 µF ceramic capacitors in parallel with 10 µF tantalum capacitors. The AFE's digital section supply (DVDD) should be connected to the digital supply that feeds the DSP's VDD(Ext) connections while the AFE's digital ground DGND should be returned to the digital ground plane.

TABLE OF CONTENTS

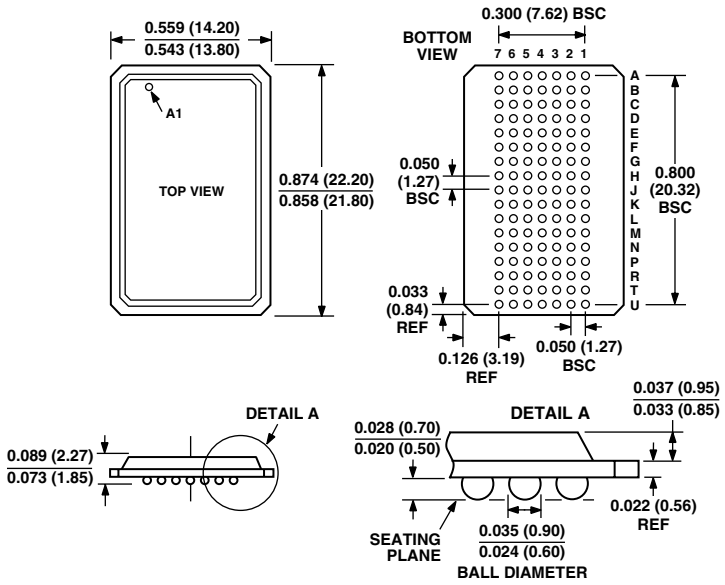
Topic	Page
FEATURES	1
FUNCTIONAL BLOCK DIAGRAM	1
GENERAL DESCRIPTION	1
SPECIFICATIONS	2
POWER CONSUMPTION	5
TIMING CHARACTERISTICS—AFE SECTION	5
ABSOLUTE MAXIMUM RATINGS	6
ORDERING GUIDE	6
PBGA BALL CONFIGURATIONS	6
PBGA BALL FUNCTION DESCRIPTIONS	7
ARCHITECTURE OVERVIEW	9
Analog Front End	9
FUNCTIONAL DESCRIPTION	10
Encoder Channel	10
Input Configuration Block	10
Programmable Gain Amplifier	10
ADC	10
Analog Sigma-Delta Modulator	11
Decimation Filter	11
ADC Coding	12
Decoder Channel	12
DAC Coding	12
Interpolation Filter	12
Analog Smoothing Filter and PGA	12
Differential Output Amplifiers	12
Voltage Reference	12
AFE Serial Port (SPORT2)	12
SPORT2 Overview	13
SPORT2 Register Maps	13
Master Clock Divider	13
Serial Clock Rate Divider	13
Sample Rate Divider	14
DAC Advance Register	14
OPERATION	14
Resetting the AFE Section of the AD73411	14
Power Management	14
AFE Operating Modes	18
Program (Control) Mode	18
Data Mode	18
Mixed Program/Data Mode	18
Digital Loop-Back	18
Sport Loop-Back	18
Analog Loop-Back	18
AFE Interfacing	20
Cascade Operation	20
FUNCTIONAL DESCRIPTION—DSP	21
Serial Ports	22
DSP SECTION PIN DESCRIPTIONS	22
Memory Interface Pins	22
Terminating Unused Pin	23
Interrupts	23

Topic	Page
LOW-POWER OPERATION	24
Power-Down	24
Idle	24
Slow Idle	24
SYSTEM INTERFACE	24
Clock Signals	24
Reset	25
MODES OF OPERATION	25
Setting Memory Mode	25
MEMORY ARCHITECTURE	26
PROGRAM MEMORY	26
Program Memory (Full Memory Mode)	26
Program Memory (Host Mode)	26
DATA MEMORY	26
Data Memory (Full Memory Mode)	26
I/O Space (Full Memory Mode)	27
Composite Memory Select ($\overline{\text{CMS}}$)	27
Boot Memory Select ($\overline{\text{BMS}}$) Disable	27
Byte Memory	27
Byte Memory DMA (BDMA, Full Memory Mode)	27
Internal Memory DMA Port (IDMA Port; Host Memory Mode)	28
Bootstrap Loading (Booting)	29
IDMA Port Booting	29
Bus Request and Bus Grant (Full Memory Mode)	29
Flag I/O Pins	29
INSTRUCTION SET DESCRIPTION	29
DESIGNING AN EZ-ICE®-COMPATIBLE SYSTEM	29
Target Board Connector for EZ-ICE Probe	30
Target Memory Interface	30
PM, DM, BM, IOM, and CM	30
Target Systems Interface Signals	30
ANALOG FRONT END (AFE) INTERFACING	31
DSP SPORT to AFE Interfacing	31
Cascade Operation	31
Interfacing to the AFE's Analog Inputs and Outputs	31
Analog Inputs	32
Interfacing to an Electret Microphone	33
Analog Output	33
Differential-to-Single-Ended Output	34
Grounding and Layout	34
OUTLINE DIMENSIONS	36

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

119-Ball Plastic Ball Grid Array (PBGA)
B-119



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