

24-bit Audio CODEC

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Outline

- Introduction to Audio Signal
- Architecture Overview
- Device Initialization
- Device Operation

Introduction to Audio Signal

Introduction

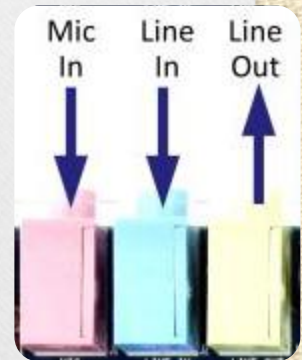
- An audio signal is a representation of sound, typically as an **electrical voltage**.
- Audio signals have frequencies in the audio frequency range of roughly **20 to 20,000 Hz**.
- Audio signals may be **synthesized** directly, or may originate at a transducer such as a **microphone**.
- **Loudspeakers** or **headphones** convert an electrical audio signal into sound.

// Line Level (1/2)

- Line level is the **specified strength** of an audio signal used to transmit analog sound between audio components.
- As opposed to line level, there are **weaker** audio signals, such as those from **microphones**, and **stronger** signals, such as those used to drive headphones and loudspeakers.

Line Level (2/2)

- Consumer electronic devices concerned with audio (for example sound cards) often have a connector labeled "line in" and/or "line out."
- The line in/out connections on a consumer-oriented computer sound card are unbalanced, with a 3.5 mm (1/8") 3-conductor TRS minijack connector providing ground, left channel, and right channel.
- Professional equipment commonly uses balanced connections on 6.35 mm (1/4") phone jacks or XLR connectors.



Line In V.S. Mic In

- A line input level signal typically has a voltage ranging from 0.3 to 2 Volts.
- A microphone input level signal is more often in the range from 5 to 50 mV (millivolts).
 - Need microphone input level boost.



// Phone Connector (1/3)

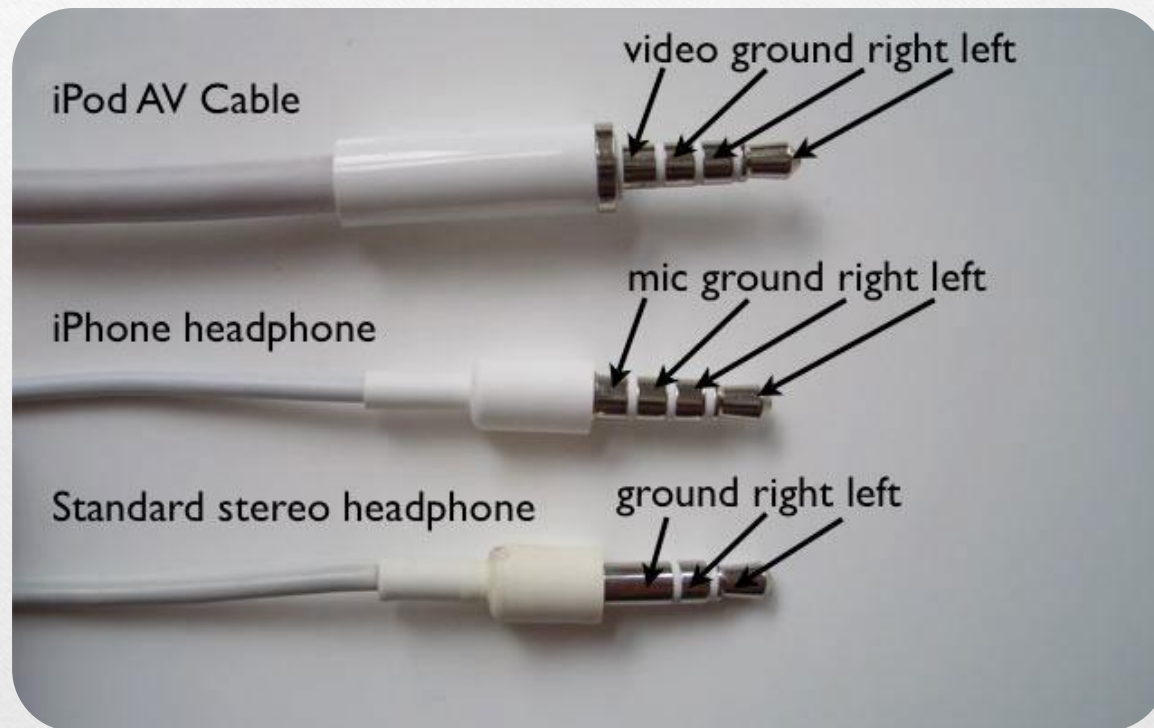
- In electronics, a phone connector is a common family of connector typically used for analog signals, primarily **audio**.
 - It is also termed an **audio jack**, **phone jack**, etc.
- It is cylindrical in shape, typically with **two**, **three** or **four** contacts.
- Three-contact versions are known as **TRS connectors**, where T stands for "**tip**", R stands for "**ring**" and S stands for "**sleeve**".
- Similarly, two- and four-contact versions are called **TS** and **TRRS** connectors respectively.

// Phone Connector (2/3)

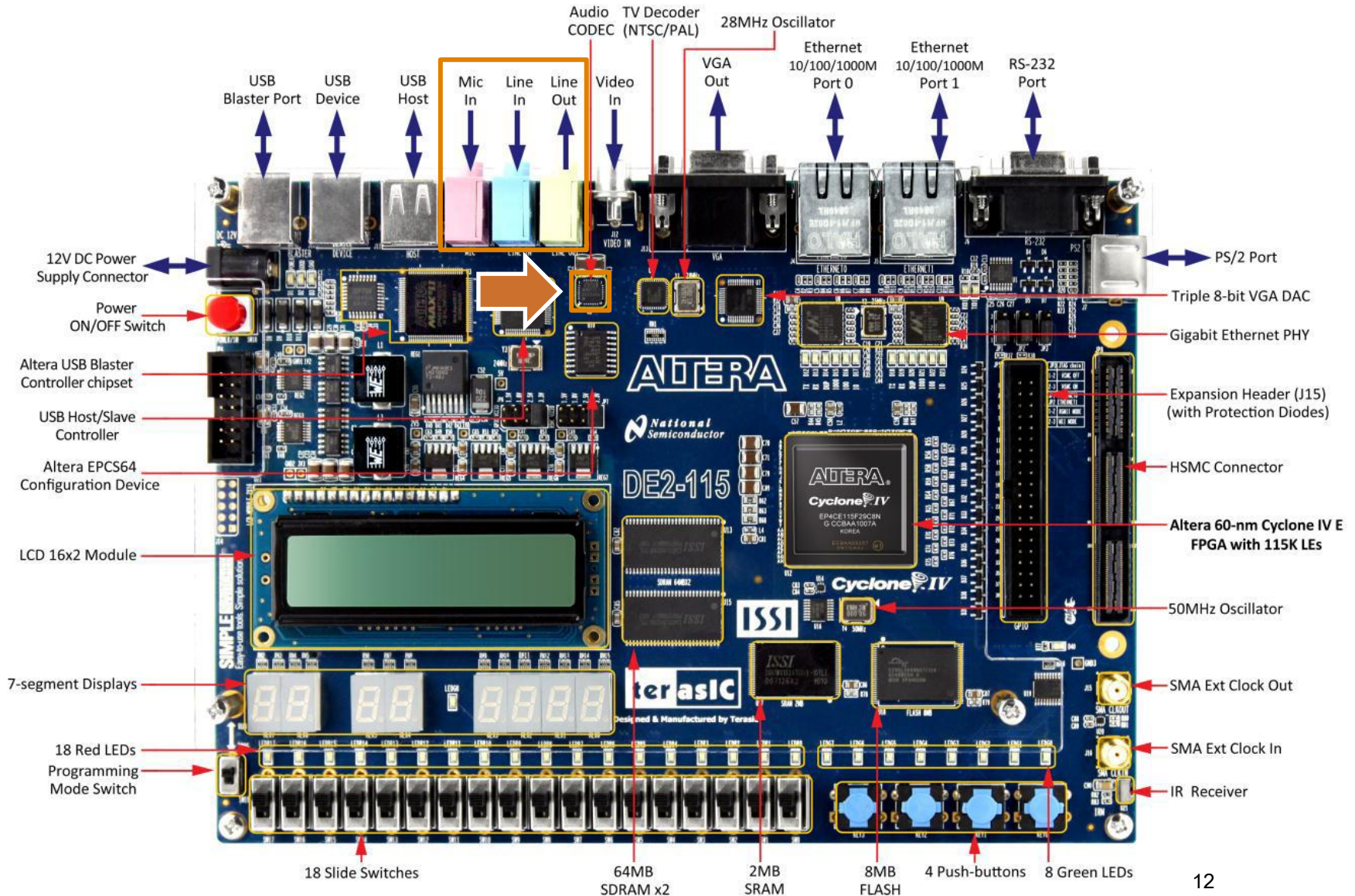
- Modern phone connectors are available in **three** standard sizes.
 - 2.5 mm mono (TS)
 - 3.5 mm mono (TS)
 - 3.5 mm stereo (TRS)
 - 6.35 mm (1/4 in) (TRS)



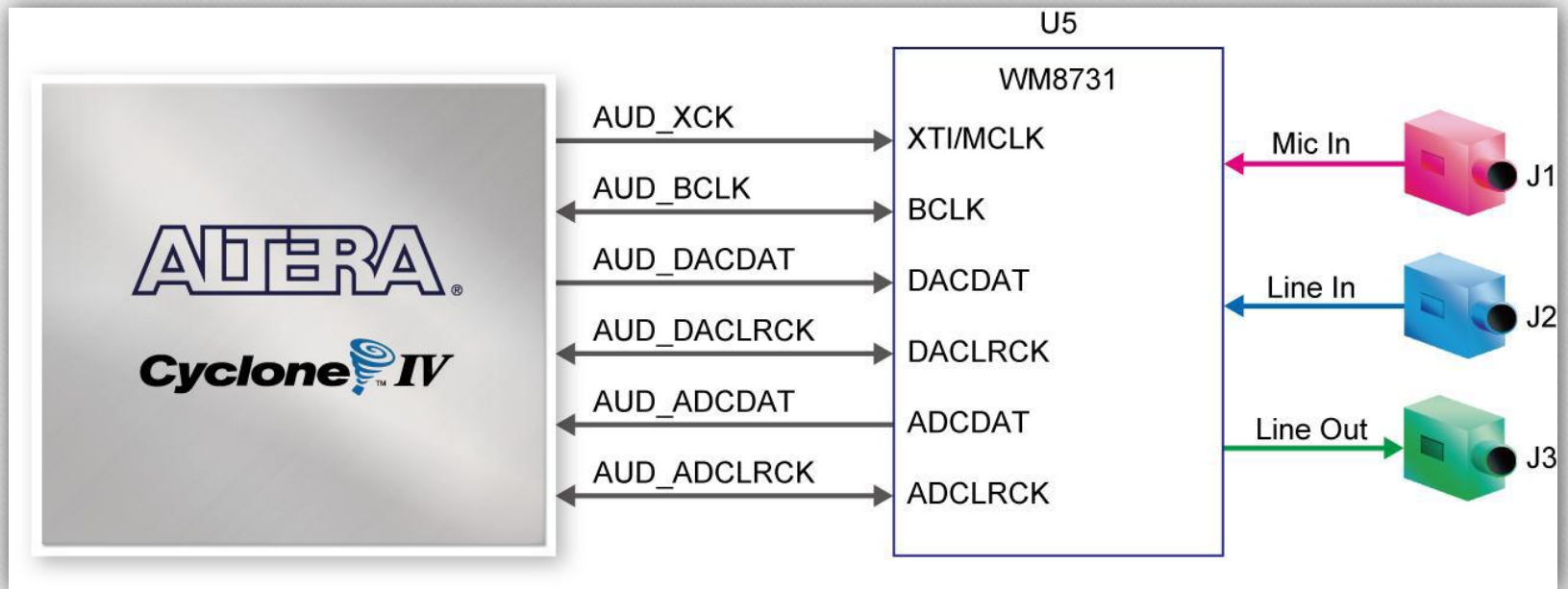
Phone Connector (3/3)



Architecture Overview



Schematic Diagram

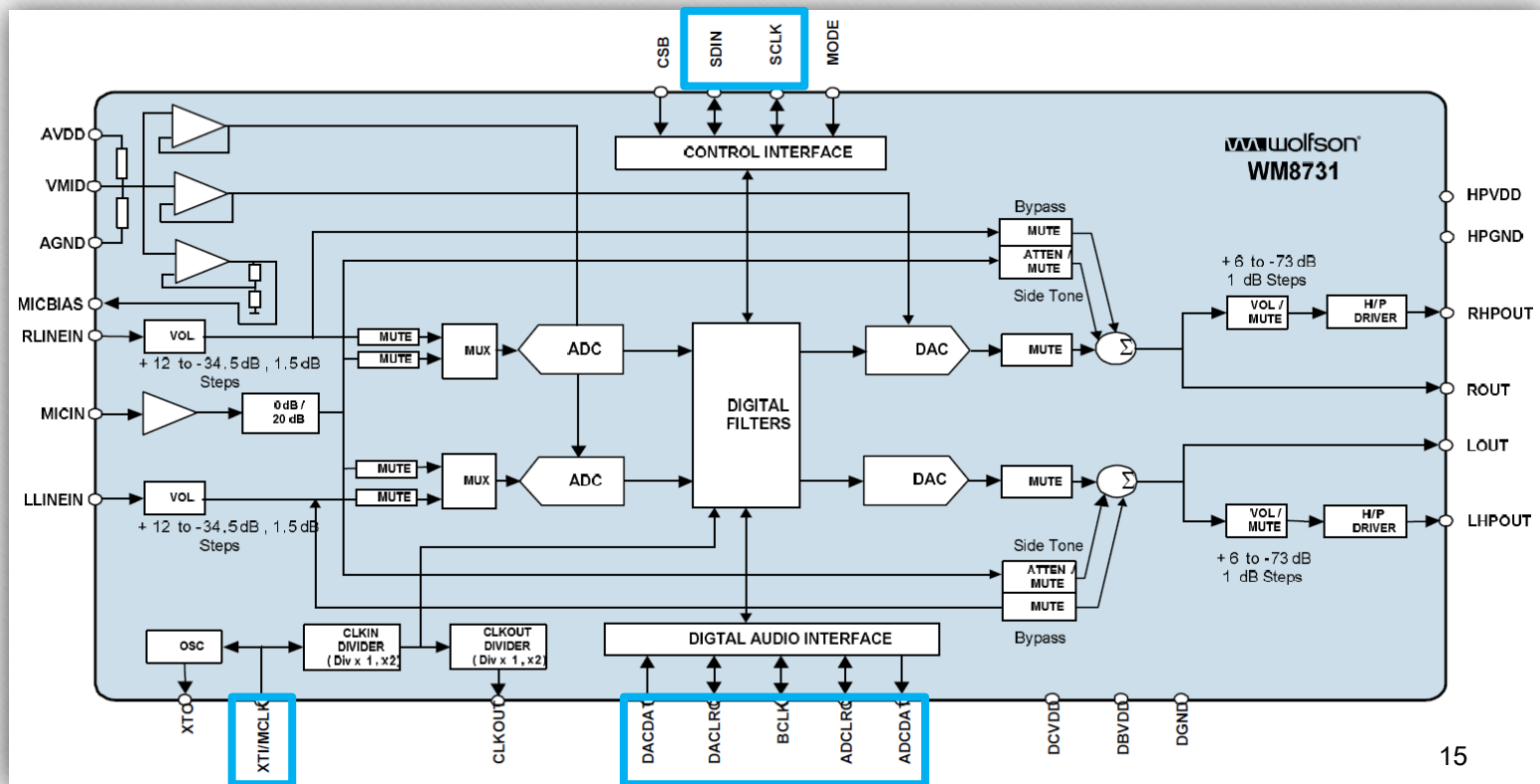


Audio CODEC Pin Assignments

Signal Name	FPGA Pin No.	Description
I2C_SCLK	PIN_B7	I2C Clock
I2C_SDAT	PIN_A8	I2C Data
AUD_XCK	PIN_E1	Audio CODEC Chip Clock
AUD_BCLK	PIN_F2	Audio CODEC Bit-Stream Clock
AUD_ADCLRCK	PIN_C2	Audio CODEC ADC LR Clock
AUD_ADCDAT	PIN_D2	Audio CODEC ADC Data
AUD_DACLK	PIN_E3	Audio CODEC DAC LR Clock
AUD_DACDAT	PIN_D1	Audio CODEC DAC Data

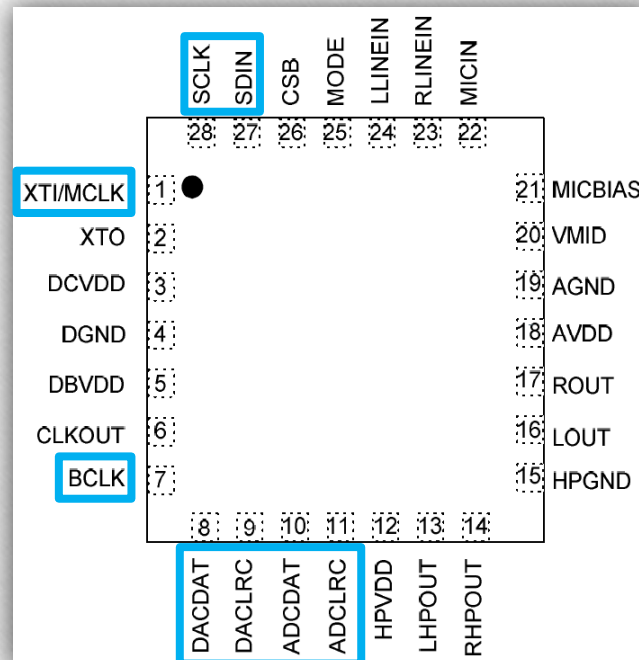
Audio chip and TV decoder chip share one I2C bus

WM8731 Block Diagram



WM8731 Pin Configuration

- Top view of 28 pin QFN



How to Use WM8731?

1. Initialize the device by setting the registers via I2C bus interface.
2. After correct initialization, we can receive or transmit audio data via digital audio interface.

Device Initialization

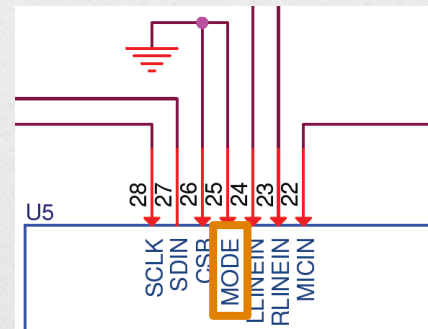
Software Control Interface (1/2)

- Different modes can be configured under software control.
 - Input to ADC: Microphone
 - Sampling rate: 32kHz
 - Input audio data bit length: 16 bits
 - etc.

Software Control Interface (2/2)

- Selection of serial control mode
 - The serial control interface may be selected to operate in either 2 or 3-wire modes. This is achieved by setting the state of the **MODE** pin.

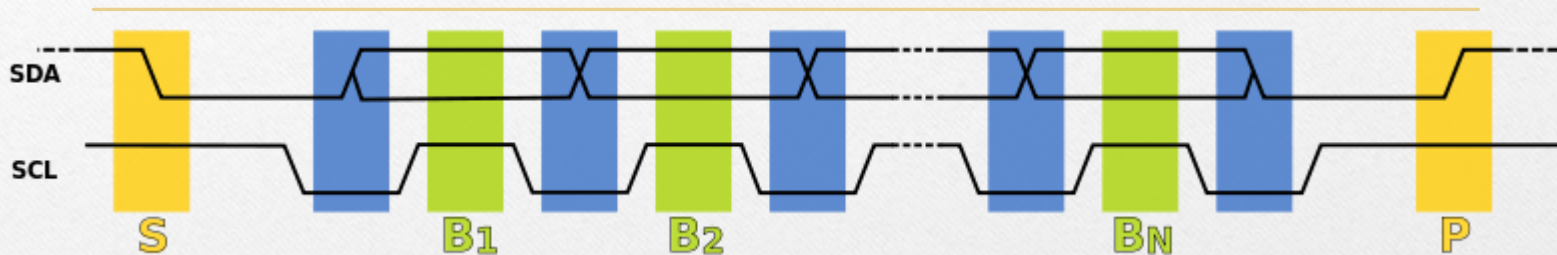
MODE	INTERFACE FORMAT
0	2 wire
1	3 wire



// 2-Wire Serial Control Mode

- The WM8731/L supports a 2-wire MPU (Microprocessor unit) interface, which is compatible with I²C protocol.
 - I²C (Inter-Integrated Circuit, referred to as I-squared-C) uses only two bidirectional open-drain lines, Serial Data Line (SDA) and Serial Clock (SCL).

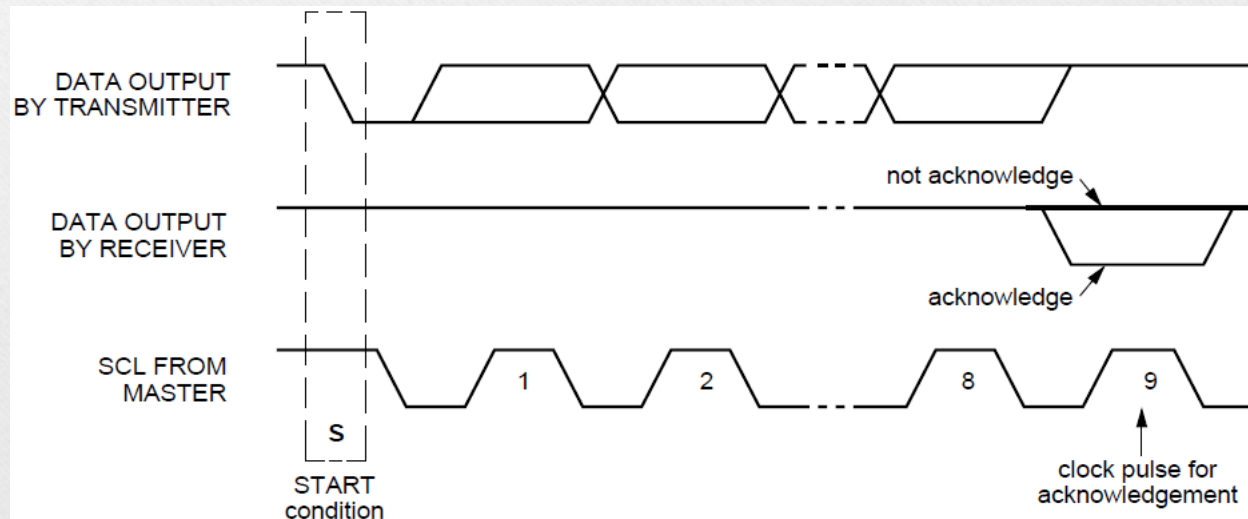
I²C protocol (1/3)



- First, SDA ↓ then SCL ↓.
- The data is transmitted with SCL is 1.
- Finally, SCL ↑ then SDA ↑.
- Principle: When transmitting bits, never change SDA near by high-level SCL.

I²C protocol (2/3)

- After every 8 data bits in one direction, an "acknowledge" bit (0) is transmitted in the other direction.



I²C protocol (3/3)

- You will need inout port:

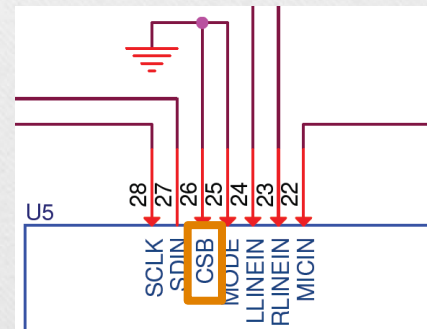
```
module inout_port(oe, clk, SDA)
input oe; // output enable
inout io;
logic i, o;
// You should have learnt what z means last year
assign io = oe? o: 1'bz;

// And you can use i whenever you need it.
```

2-Wire Interface (1/2)

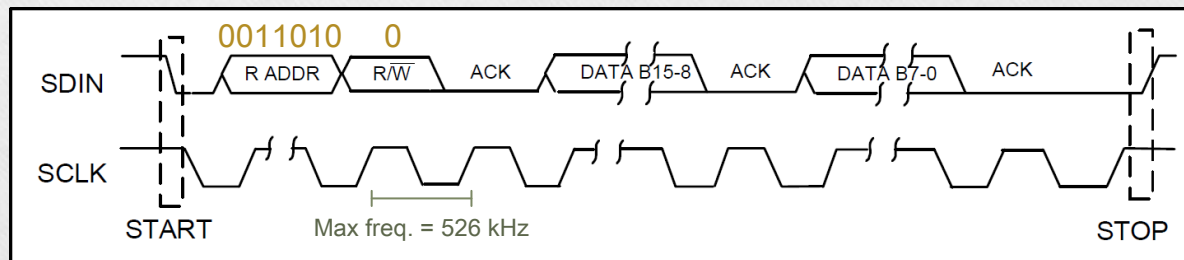
- The device operates as a **slave device** only.
- The WM8731/L has one of two slave address that are selected by setting the state of the **CSB** pin.

CSB STATE	ADDRESS
0	0011010
1	0011011



2-Wire Interface (2/2)

- 2-wire serial interface
 - ADDR[6:0] (7 bits) are Slave Address Bits
 - R/W is '0', indicating a write
 - B[15:9] (7 bits) are Register Address Bits
 - B[8:0] (9 bits) are Register Data Bits



Register Map

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R0 (00h) Left Line In	LRINBOTH	LINMUTE	0	0	LINVOL[4:0]					0_1001_0111
R1 (01h) Right Line In	RLINBOTH	RINMUTE	0	0	RINVOL[4:0]					0_1001_0111
R2 (02h) Left Headphone Out	LRHPBOTH	LZCEN	LHPVOL[6:0]						0_0111_1001	
R1 (01h) Right Headphone Out	RLHPBOTH	RZCEN	RHPVOL[6:0]						0_0111_1001	
R4 (04h) Analogue Audio Path Control	0	SIDEATT[1:0]		SIDETONE	DACSEL	BYPASS	INSEL	MUTEMIC	MICBOOST	0_0000_1010
R5 (05h) Digital Audio Path Control	0	0	0	0	HPOR	DACMU	DEEMPH[1:0]		ADCHPD	0_0000_1000
R6 (06h) Power Down Control	0	POWEROFF	CLKOUTPD	OSCPD	OUTPD	DACPD	ADCPD	MICPD	LINEINPD	0_1001_1111
R7 (07h) Digital Audio Interface Format	0	BCLKINV	MS	LRSWAP	LRP	IWL[1:0]		FORMAT[1:0]		0_1001_1111
R8 (08h) Sampling Control	0	CLKODIV2	CLKIDIV2	SR[3:0]				BOSR	USB/ NORMAL	0_0000_0000
R9 (09h) Active Control	0	0	0	0	0	0	0	0	Active	0_0000_0000
R15 (0Fh) Reset	RESET[8:0]									not reset

Left Line In

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R0 (00h) Left Line In	LRINBOTH	LINMUTE	0	0	LINVOL[4:0]					0_1001_0111

- Just use the default setting if we do not use the line input.
 - 000_0000_0_1001_0111

Right Line In

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R1 (01h) Right Line In	RLINBOTH	RINMUTE	0	0	RINVOL[4:0]					0_1001_0111

- Just use the default setting if we do not use the line input.
 - 000_0001_0_1001_0111

Left Headphone Out

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R2 (02h) Left Headphone Out	LRHPBOTH	LZCEN	LHPVOL[6:0]							0_0111_1001

- Here we can just use the default setting.
 - 000_0010_0_0111_1001

Right Headphone Out

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R3 (03h) Right Headphone Out	RLHPBOTH	RZCEN	RHPVOL[6:0]							0_0111_1001

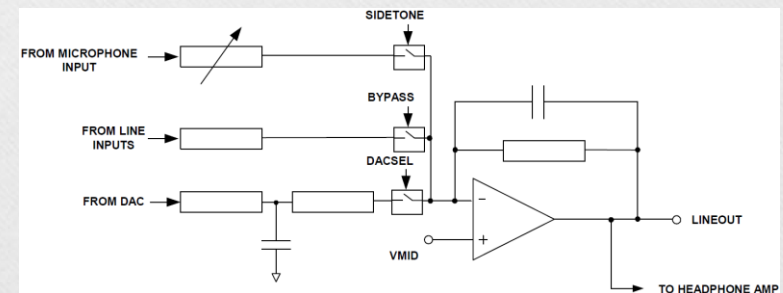
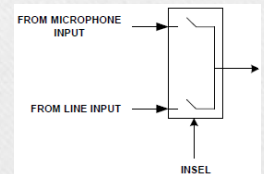
- Here we can just use the default setting.
 - 000_00111_0_0111_1001

Analogue Audio Path Control

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R4 (04h) Analogue Audio Path Control	0	SIDEATT[1:0]		SIDETONE	DACSEL	BYPASS	INSEL	MUTEMIC	MICBOOST	0_0000_1010

- Enable boost, disable mute, choose microphone input, disable bypass, and select DAC.

- 000_0100_0_0001_0101



Digital Audio Path Control

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R5 (05h) Digital Audio Path Control	0	0	0	0	HPOR	DACMU	DEEMPH[1:0]		ADCHPD	0_0000_1000

- Disable soft mute
 - 000_0101_0_0000_0000

Power Down Control

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R6 (06h) Power Down Control	0	POWER OFF	CLKOUTPD	OSCPD	OUTPD	DACPD	ADCPD	MICPD	LINEINPD	0_1001_1111

- Choose power on and disable all the power down options.
 - 000_0110_0_0000_0000

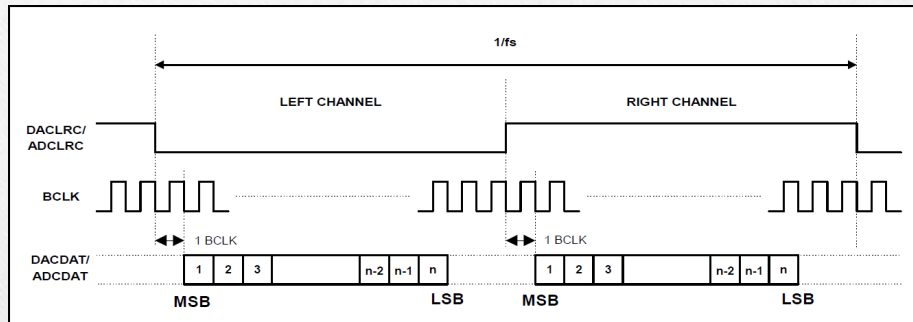
Digital Audio Interface Format (1/2)

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R7 (07h) Digital Audio Interface Format	0	BCLKIVE	MS	LRSWAP	LRP	IWL[[1:0]		FORMAT[1:0]		0_0000_1010

- Choose I²S format, 16-bit length, and master mode.
 - 000_0111_0_0100_0010

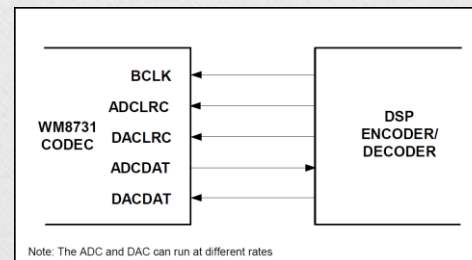
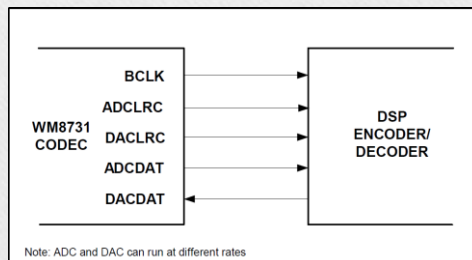
Digital Audio Interface Format (2/2)

- I²S format



➤ 16-bit length

- Master mode v.s. Slave mode



Sampling Control (1/2)

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R8 (08h) Sampling Control	0	CLKODIV2	CLKIDIV2	SR[3:0]				BOSR	USB/ Normal	0_0000_0000

- Choose USB mode (fixed MCLK 12MHz) and sampling rate = 32 kHz, BOSR = 0.
 - 000_1000_0_0001_1001

Sampling Control (2/2)

SAMPLING RATE		MCLK FREQUENCY	SAMPLE RATE REGISTER SETTINGS					DIGITAL FILTER TYPE
ADC	DAC							
kHz	kHz	MHz	BOSR	SR3	SR2	SR1	SR0	
48	48	12.000	0	0	0	0	0	0
44.1 (Note 2)	44.1 (Note 2)	12.000	1	1	0	0	0	1
48	8	12.000	0	0	0	0	1	0
44.1 (Note 2)	8 (Note 1)	12.000	1	1	0	0	1	1
8	48	12.000	0	0	0	1	0	0
8 (Note 1)	44.1 (Note 2)	12.000	1	1	0	1	0	1
8	8	12.000	0	0	0	1	1	0
8 (Note 1)	8 (Note 1)	12.000	1	1	0	1	1	1
32	32	12.000	0	0	1	1	0	0
96	96	12.000	0	0	1	1	1	3
88.2 (Note 3)	88.2 (Note 3)	12.000	1	1	1	1	1	2

Use PLL to get 12MHz (11.2896MHz) clock!

Active Control

REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R9 (09h) Active Control	0	0	0	0	0	0	0	0	Active	0_0000_0000

- Activate interface
 - 000_1001_0_0000_0001

Reset Register

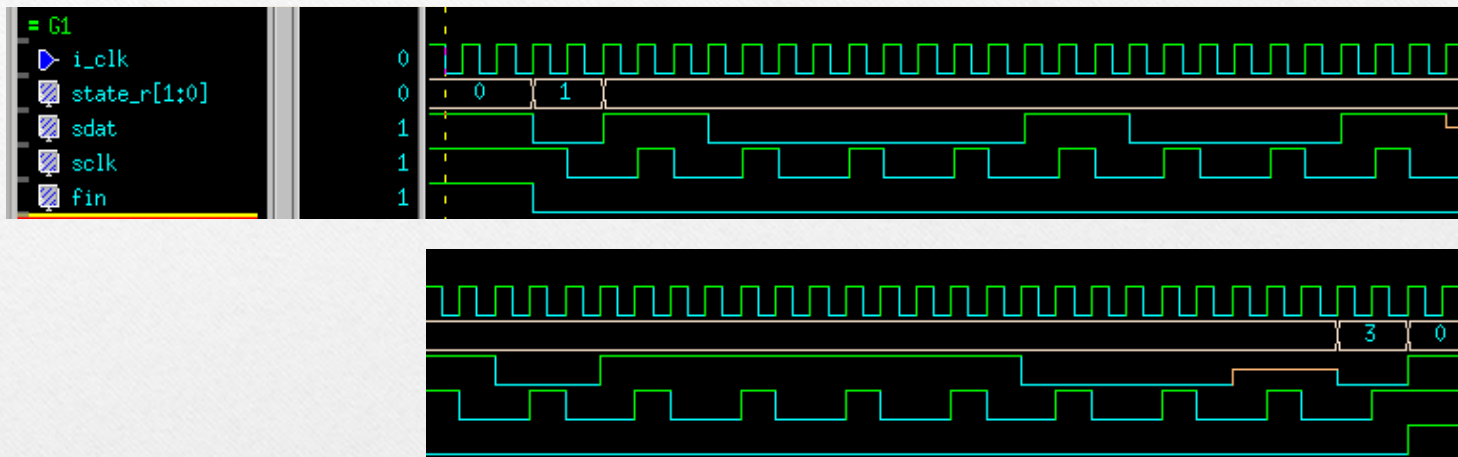
REGISTER	BIT[8]	BIT[7]	BIT[6]	BIT[5]	BIT[4]	BIT[3]	BIT[2]	BIT[1]	BIT[0]	DEFAULT
R15 (15h) Active Control	RESET[8:0]									not reset

- You can try to reset the device to a known (?) state.
 - 000_1111_0_0000_0000 (?)

Recommended settings

Left Line In	000_0000_0_1001_0111
Right Line In	000_0001_0_1001_0111
Left Headphone Out	000_0010_0_0111_1001
Right Headphone Out	000_0011_0_0111_1001
Analogue Audio Path Control	000_0100_0_0001_0101
Digital Audio Path Control	000_0101_0_0000_0000
Power Down Control	000_0110_0_0000_0000
Digital Audio Interface Format	000_0111_0_0100_0010
Sampling Control	000_1000_0_0001_1001
Active Control	000_1001_0_0000_0001

Check the Waveform

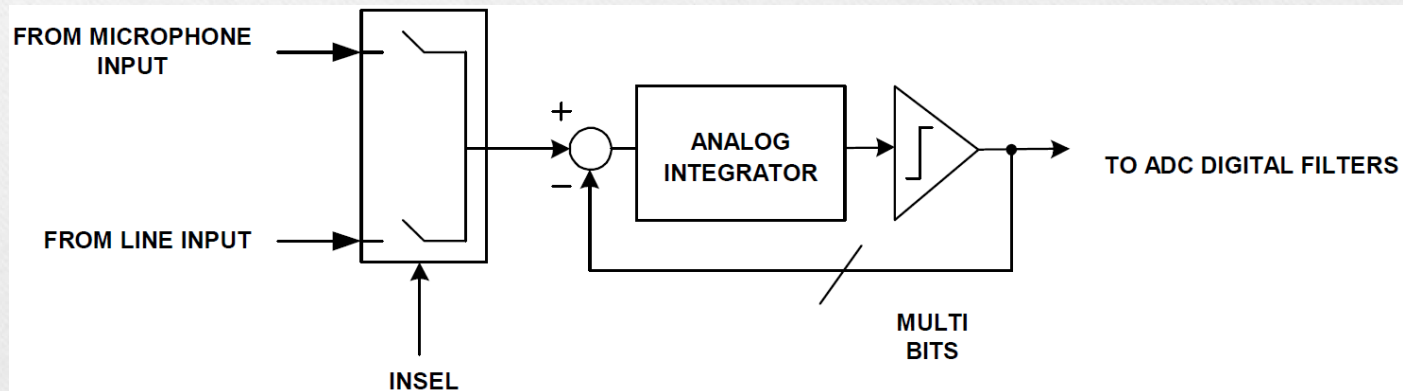


- 24'h890abc (3 bytes).
- How fast should the clock be (see the spec)?
- How will you design your FSM?
 - Possible: 2 clocks for begin and end, and 3 clocks per bit.
- I have provide a testbench and the interface is similar to lab2.

Device Operation

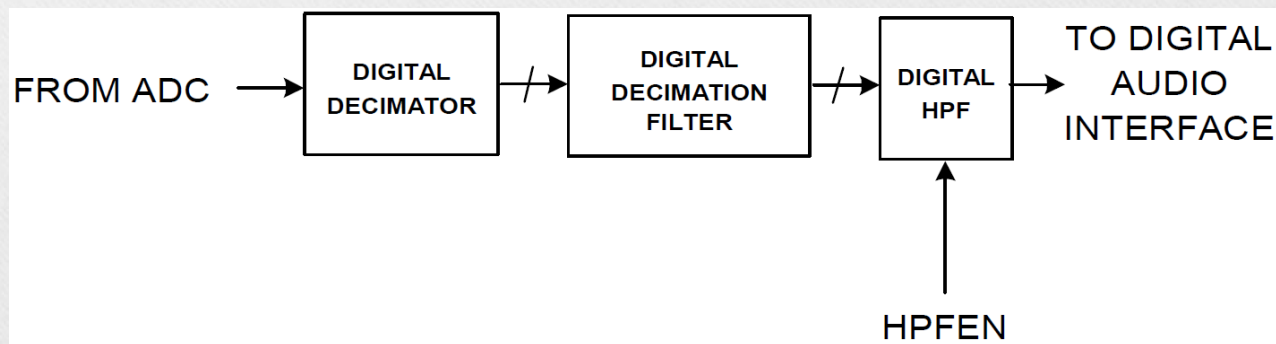
ADC

- The WM8731/L uses a multi-bit oversampled sigma-delta ADC. A single channel of the ADC is illustrated below.



ADC Filters

- The ADC filters perform true **24 bit signal processing** to convert the raw multi-bit oversampled data from the ADC to the correct sampling frequency to be output on the **digital audio interface**.



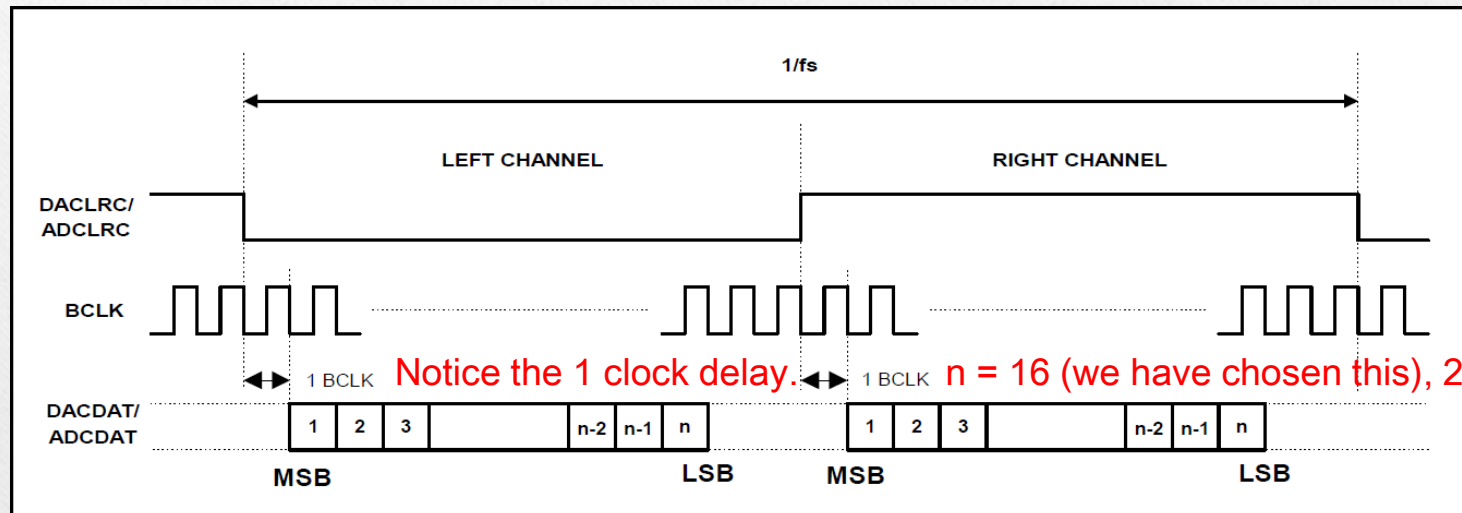
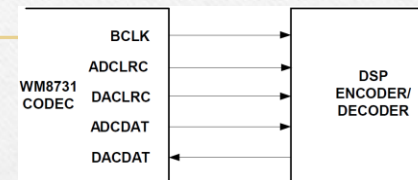
Digital Audio Interfaces (1/5)

- WM8731/L may be operated in either one of the 4 offered audio interface modes. These are:
 - Right justified
 - Left justified
 - I²S (We have chosen this.)
 - DSP mode
- All four of these modes are MSB first and operate with data 16 to 32 bits.

Digital Audio Interfaces (2/5)

- I²S mode

Master mode



... in USB mode where BCLK always 12MHz.

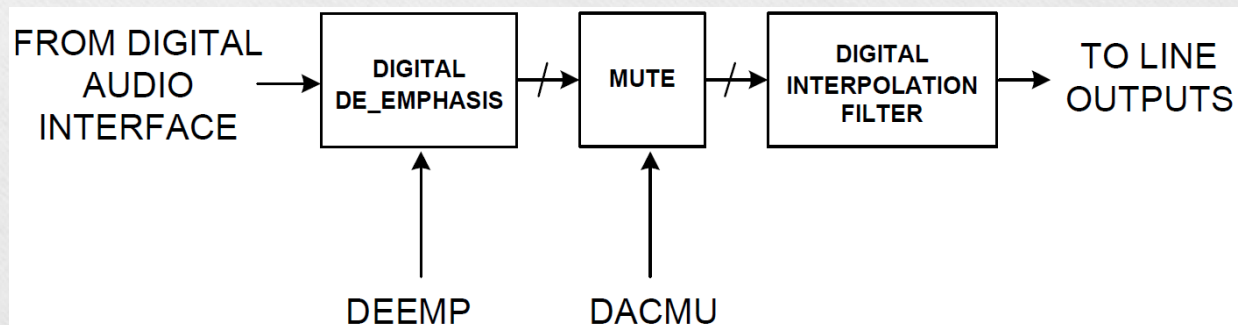
... for example, in 12MHz/32k ... DACLRC and ADCLRC outputs will have a mark space ratio of 187:188.

Digital Audio Interfaces (5/5)

- The length of the digital audio data is programmable at 16/20/24 or 32 bits.
- The data is signed 2's complement.
 - If the ADC is programmed to output 16 or 20 bit data then it strips the LSBs from the 24 bit data.
 - If the ADC is programmed to output 32 bits then it packs the LSBs with zeros.
 - Similar adjustments in DAC.

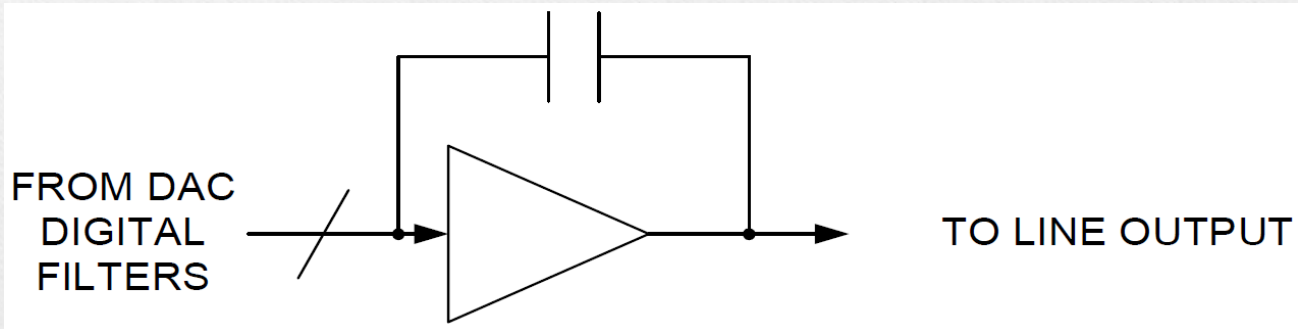
DAC Filters

- The DAC filters perform true **24 bit signal processing** to convert the incoming digital audio data from the digital audio interface at the specified sample rate to multi-bit oversampled data for processing by the analogue DAC.

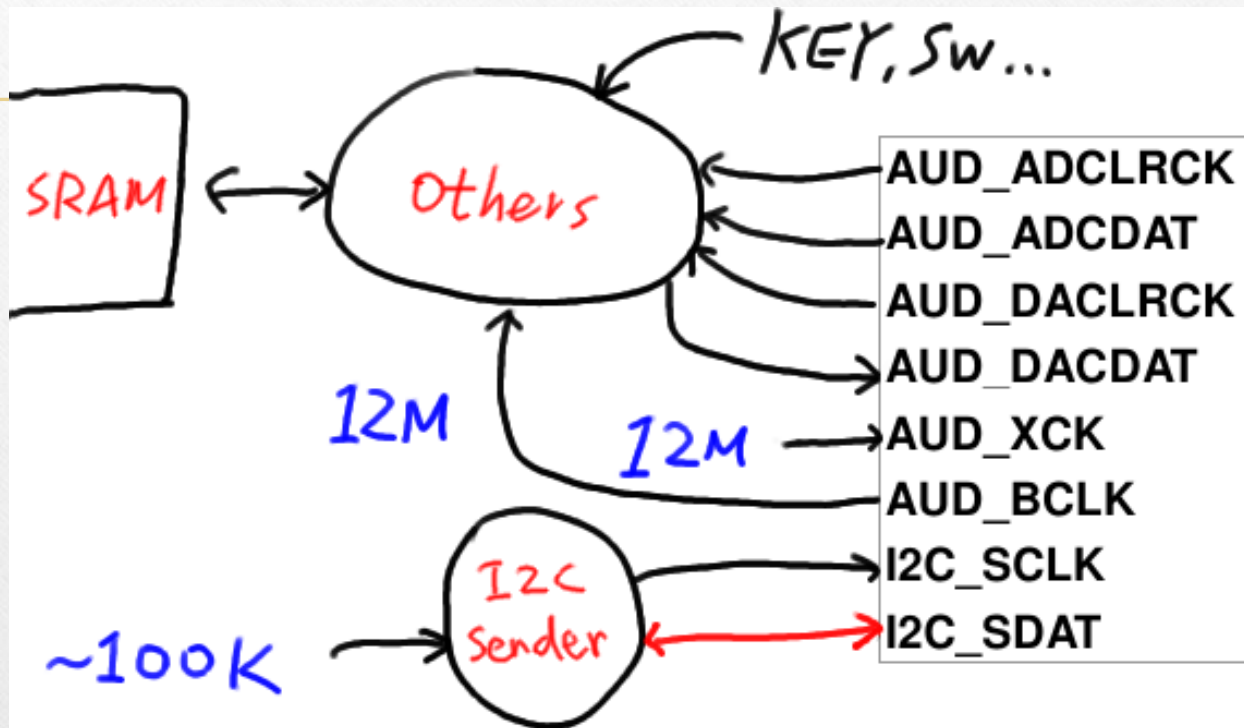


DAC

- The WM8731/L employs a multi-bit sigma delta oversampling digital to analogue converter.



Possible Architecture



- You have to use PLL.
- Clock crossing is difficult, so we just use the 12MHz clock (What's new in the sdc file of lab3?).
- I2C_SDAT is inout!

The End.

Any question?

Reference

1. http://en.wikipedia.org/wiki/Audio_signal
2. <http://en.wikipedia.org/wiki/I%C2%B2C>
3. "THE I 2C-BUS SPECIFICATION VERSION 2.1" by Philips.
4. "DE2-115 User Manual" by Terasic.
5. "DE2-115_MB.pdf" by Terasic.
6. "WM8731.pdf" by Wolfson Microelectronics.