IA611 Rev F Datasheet

IA611

Always On Voice Wake Acoustic Processor

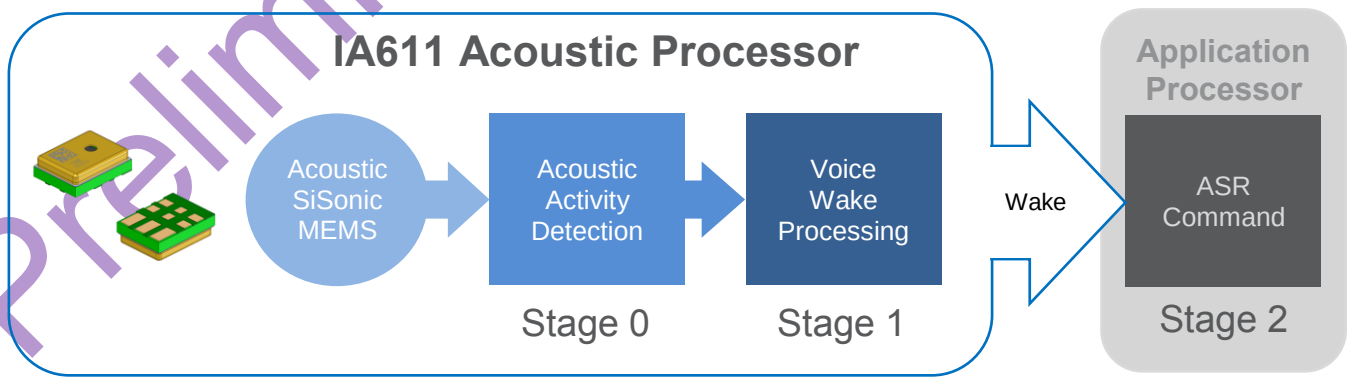
The IA611 is an “always-on” Acoustic Processor featuring Voice Wake and Voice ID keyword detector, a three second buffer, and Knowles’ proven high performance acoustic SiSonic™ MEMS technology in a single, miniature, top-port package. The IA611 offers flexibility by supporting the most relevant audio and data interfaces. Its integrated programmable DSP with 168 kBytes of RAM is available for customer and 3rd party algorithms, enabling unlimited creativity. The solution pushes the system performance to ultra-low power with its custom core design, and accelerates times to market with its unique combined hardware, software and firmware package.

Product Features

- High Accuracy Voice Wake and Voice ID keyword recognition to wake-up any system from a trigger phrase
- Minimum latency when burst out 3 second audio buffer using SPI or SoundWire®
- Ultra-low power “always on” Acoustic Activity Detector (AAD) capable waking the embedded DSP
- Extra flexibility with I²C/UART interfaces
- Interrupt signal to the host processor when a Voice keyword trigger is detected
- Compatible with standard PDM or I²S outputs supporting dual multiplexed channels
- 168 KB RAM, 160 MFLOPS, 40 MHz, 32-bit Complex-Valued Floating-Point ALU, Low Power Open Developer Platform with SDK
- Integrated power tree from a single 1.8V supply voltage
- High Performance Acoustic SiSonic MEMS with ±1 dB matched sensitivity, 65.5 dB SNR and 132.5 dB SPL AOP
- Packaged in SPK 4.00 x 3.00 x 1.25 mm

Typical Applications

- Smartphones
- Wearables
- Tablets
- Small Portable Electronics
- Remote Controllers
- Connected Home Devices



Absolute Maximum Ratings

Parameter	Absolute Maximum Rating	Units
VDD to Ground	-0.3, +2.5	V
Digital Input to Ground	-0.3, VDD+0.3	V
Input Current (any pin)	±5	mA
Temperature	-40 to +100	ºC

Stresses exceeding these "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only. Functional operation at these or any other conditions beyond those indicated under "Microphone Specifications" and "Electrical Characteristics" is not implied. Exposure beyond those indicated under "Microphone Specifications" and "Electrical Characteristics" for extended periods may affect device reliability.

Microphone Specifications

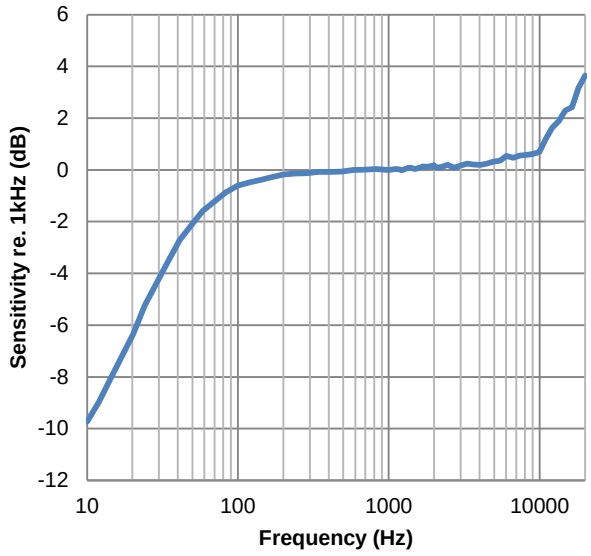
Test Conditions: VDD = 1.8V, No Load, at T_A =25° C, 55±20% R.H., PDM+SPI mode, 3.072MHz clock, unless otherwise specified.

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Supply Voltage	VDD		1.71	1.8	1.98	V
Supply Current[1]	IDD	Deep-Sleep Mode	-	0.13	-	mA
		Voice Wake AAD Mode (stage 0)	-	0.40	-	
		Voice Wake Keyword Detect Mode (stage 1)	-	0.95	-	
		Voice Wake Burst Mode (stage 2)	-	7.0	-	
		Hardware Pass-Through Mode (768kHz Clock)	-	0.87	-	
Power Supply Rejection Ratio	PSRR	200 mVpp sinewave @1 kHz	-	87	-	dBV/FS
Power Supply Rejection	PSR+N	200 mVpp 7/8 duty cycle rectangular waveform @ 217 Hz, A-weighted, BW = 20kHz	-	-99	-	dBFS(A)
Sensitivity[1]	S	94 dB SPL @ 1 kHz	-38	-37	-36	dBFS
DC Output		Fullscale = ±100	-	0	-	% FS
Signal to Noise Ratio	SNR	94 dB SPL @ 1 kHz, A-weighted (20 - 20kHz)	-	65.5	-	dB(A)
Total Harmonic Distortion	THD	94 dB SPL @ 1 kHz, S = Typ	-	0.2	0.5	%
Acoustic Overload Point	AOP	1% THD @ 1 kHz, S = Typ	-	115	-	dB SPL
		10% THD @ 1 kHz, S = Typ	-	132.5	-	
Bandwidth	BW	-3dB relative to 1 kHz	-	50	-	kHz
Directivity			Omnidirectional			
Polarity		Increasing sound pressure	Increasing density of 1's			
Functional Operating Temperature	T_A		-40	25	85	ºC

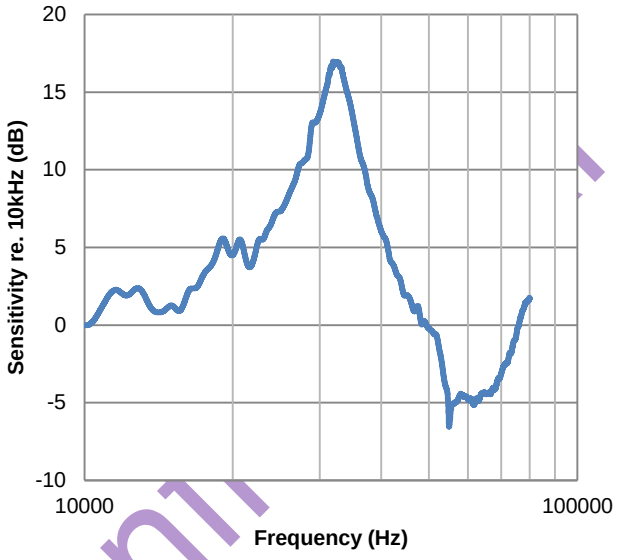
[1] 100% tested.

Performance Curves

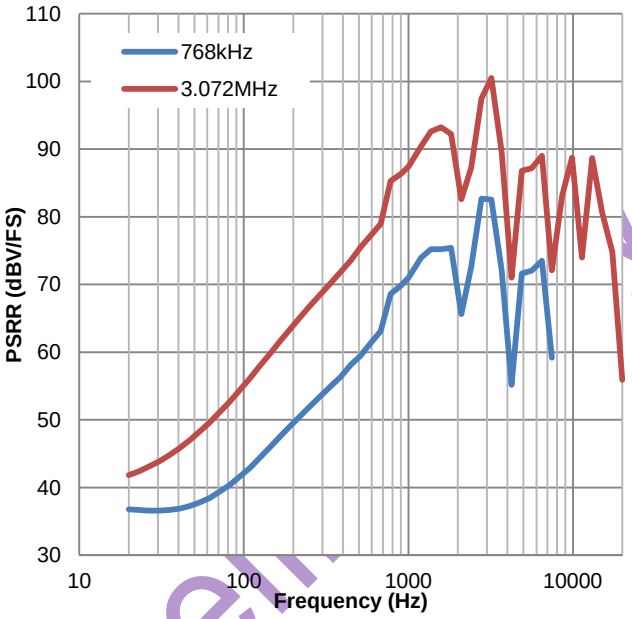
Test Conditions: VDD = 1.8V, No Load, at T_A =25° C, 55±20% R.H., Hardware Pass-Through Mode, unless otherwise specified.



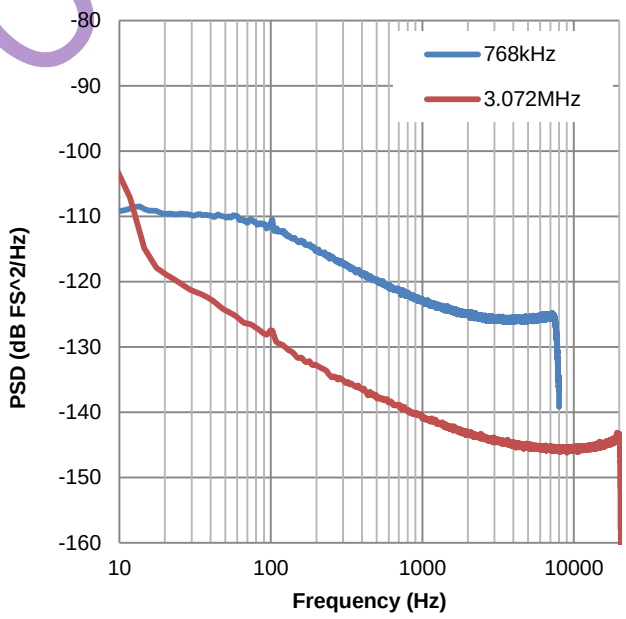
Typical Free Field Response Normalized to 1 kHz



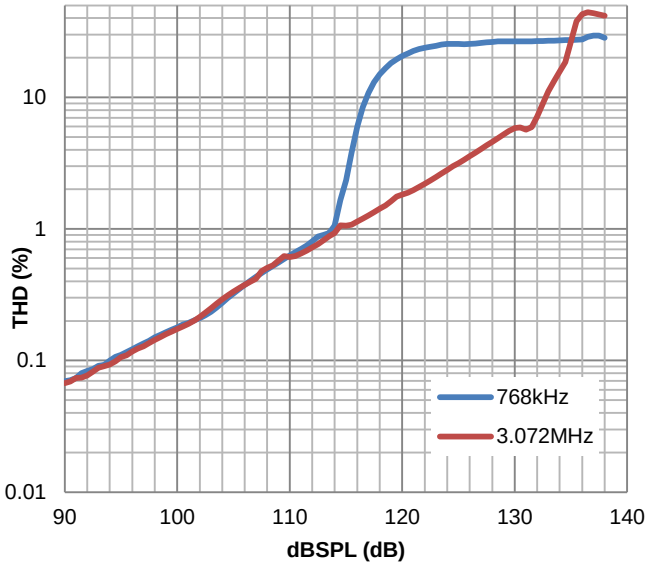
Typical Free Field Response Normalized to 10 kHz



Typical PSR at 768kHz and 3.072MHz



Typical PSD at 768kHz and 3.072MHz



Typical THD vs. SPL

1. Product Description

1.1 Overview

The Knowles IA611 Smart Mic is a flexible, low power, and highly integrated voice and audio processor system targeted toward battery-powered applications. The IA611 includes:

- An advanced Knowles audio-optimized DSP sub-system that has been designed to run compute-intensive audio processing algorithms with very low power consumption, and provide an efficient interface between custom software and the digital audio stream data
- A System Control Unit (SCU) that handles booting, reset, and power management states such as deep-sleep mode, stage 0 and stage 1 Voice Wake activity
- A flexible internal clock generation and routing system
- Integrated interfaces for PDM and I^2S/TDM digital audio data
- A variety of control interfaces including UART, SPI slave, or I^2C slave, all with control interface and audio streaming capability

The IA611 is optimized for low power operation in a wide array of applications including mobile devices.

The IA611 comes with a set of reference drivers for common operating systems and platforms for easy integration and fast time to market. The operating system software is written for the latest Android operating system and supports communication/data transport over the interfaces listed in Table 1.

Table 1 *Android System Interfaces*

Control Messages	Audio Ports	Audio Upload
I^2C	I^2S	I^2S
UART	I^2S	I^2S
SPI	PDM	SPI
UART	PDM	UART
I^2C	PDM	I^2C

Only one of these control interfaces may be used at a time. See section 5 for further details.

1.2 Key Features

Key features of the IA611 processor are:

- Ultra-Low power, Best-in-class Voice Wake: Waits with DSP in sleep mode for acoustic activity before going into Voice Wake Mode
- Voice Wake: Best-in-class Always-on keyword detection in ultra-low power mode. Detection of either pre-programmed (OEM) or user-trained keywords.
- Continuous Voice Wake (CVQ) for seamless transition from Voice Wake to a command phrase that follows.
- SPI Slave interface for fast code download and control
- OpenDSP custom Digital Signal Processing: Low power operation, DSP clock rate up to 40 MHz, with 168 kB available RAM

1.3 Configuration and Firmware Build Tools

Knowles provides AuViD, a comprehensive tool for firmware development and testing, and IA611 system configuration.

1.3.1 AuViD 9.0.0

AuViD provides configuration, debug and design capabilities for engineers. System capabilities include audio streaming, system and route configuration. It can be used offline to define the options in the firmware, or connected to the host directly for run-time debug using a host interface (I^2C, UART, or SPI) or connected using an Android Proxy bridge.

1.4 Typical Application Block Diagrams

The figures below show examples of a typical block diagram for a host system utilizing the IA611. See Table 8 and Table 1 for pin configuration per boot mode.

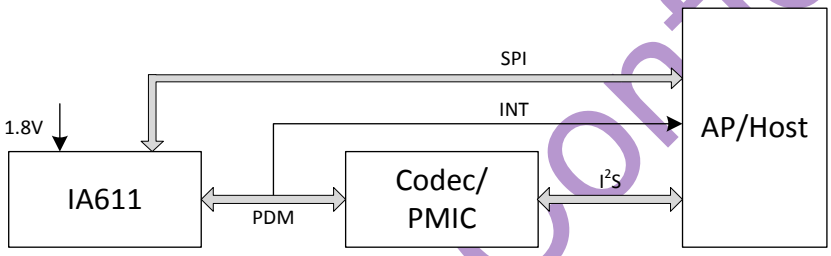


Figure 1 *Application Schematic for a Host System using I^2S with SPI (IA611 only)*

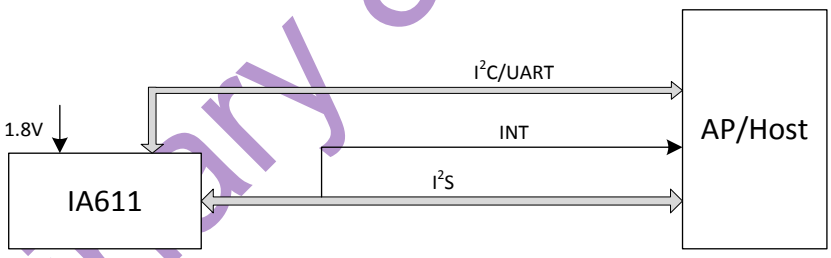


Figure 2 *Application Schematic for a Host System using I^2S and I^2C or UART (IA611 only)*

2. Chip Description

The IA611's major modules (shown in Figure 3) are:

- Low-noise, dual-MEMS transducer microphone element
- Ultra-low power and high-performance DSP sub-system
- Digital Audio Interface module that provides configurable serial digital audio ports, each supporting streaming a wide variety of data formats including PDM, I^2S, or TDM
- SPI, UART, and I^2C Host Interfaces that include
  - Communication with the host
  - A channel for high-speed firmware downloads
  - audio data bursting for Voice Wake or diagnostic purposes
- System Control Unit (SCU) that handles booting, reset, and power management states such as deep-sleep mode
- Internal clock control module which generates internal clock signals and masters output clocks, and locks internal time bases to externally-provided clocks
- System interrupt module which provides
  - Interrupt to host for keyword detection events
  - Event handling to IA611 for wakeup from host

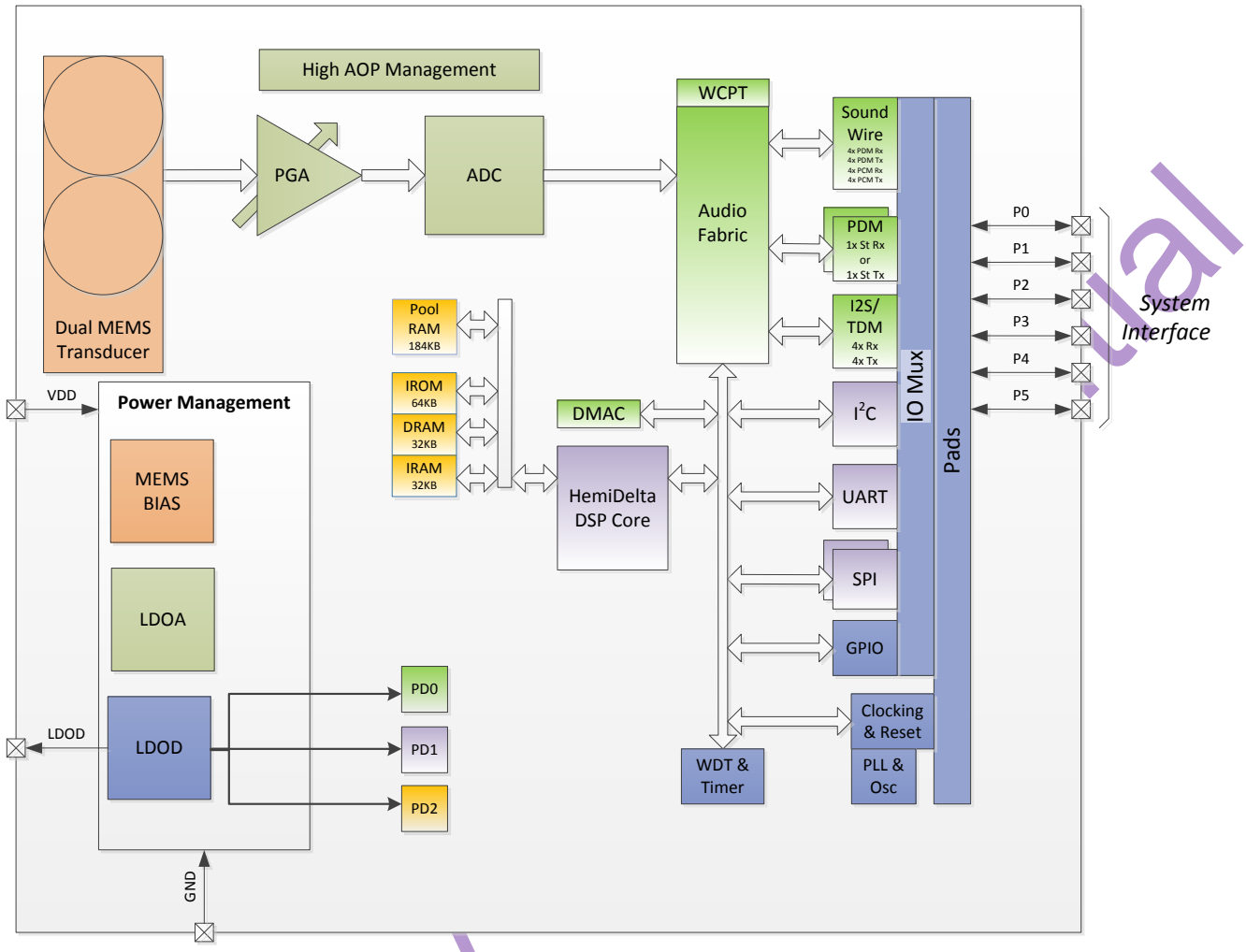


Figure 3 *Block diagram*

2.1 DSP Subsystem

The DSP subsystem is comprised of a HemiDelta (HMD) processor along with digital decimation and interpolation filters, the Audio Fabric, and memory.

2.1.1 Hemi Delta Processor

The HMD is a lower-power digital signal processor that is optimized for frame-based processing. Its features include:

- 64-bit instruction memory access (maximum instruction size: 64 bits)
- 64-bit data memory access (maximum register width: 64 bits)
- Main data type: 32-bit float (AFLOAT)
- Main vector register file: sixteen vector registers (two 32-bit lanes each)
- Permutation registers to support load/store, permute and arithmetic instructions
- Dual issue instruction bundles
- Vector and scalar instructions

- Four MACs (real and complex arithmetic support)
- Nonlinear functions: arc tangent, cosine, sine, log, exponential, inverse, inverse square root, sigmoid (exponential approximation)
- Added acceleration:
  - FFT
  - Peak finding
  - DNNs (eight 8-bit x 8-bit fixed-point MACs)

2.1.2 Digital Filters

IA611 has digital filters to allow use of PDM (Pulse Density Modulation) audio data. There are four receive decimation filter chains and two transmit interpolation filter chains. The decimation filters support 1-bit PDM input oversampled audio data from digital microphones and codec interfaces. The interpolation filters generate 1-bit PDM output oversampled audio data that can go to a speaker or codec.

2.1.3 Audio Fabric

The Audio Fabric is a memory mapped interface that allows any processor to access data efficiently from the various audio interfaces supported by the chip, such as I^2S/TDM, PDM, or SoundWire. Each audio interface converts input data into a common 32-bit integer format; it is synchronized into the processor clock domain from the native audio clock before being multiplexed in the Audio Fabric into generic N-channel logical streams of audio data. Each audio interface similarly can convert 32-bit integer format data into the encoding required for transmission. The audio fabric has support for a low-latency path (for use with the SSP processor); it also has connections to the wall clock/presentation timers unit to allow them to capture “timestamps” of audio data.

2.1.4 Memory

The IA611 has a total of 248 KB of RAM, divided as:

- 64 KB dedicated memory, 32 KB instruction and 32 KB data
- 192 KB of shared memory pool
- Of the total 248 KB memory, 168 KB is reserved for custom algorithm use.

2.1.5 Audio Interfaces

The IA611 audio processor supports the following transfer of audio data:

- Master/Slave I^2S/TDM
- Two PDM output channels

2.1.5.1 Digital Microphone PDM Output Interface

The IA611 has a single PDM Output signal that can be used to transmit two audio channels. The data for one of the two audio channels is transmitted on each clock edge as shown in Figure 4. In PDM output mode, the clock can be configured as input (slave) or output (master). If it is programmed as input, supported frequency ranges are shown in Table 3. If clock is configured as output, the default output frequency is set to 3.072 MHz. For further details see the *IA61x API Guide* for flexibility on using PDM clock as an output.

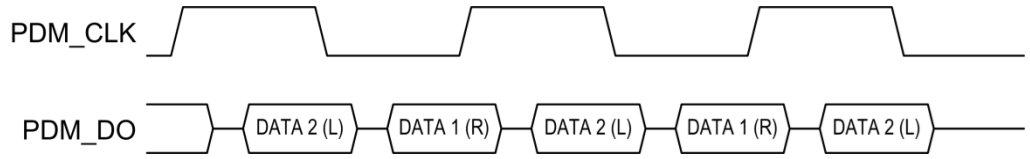


Figure 4 *PDM Two-Channel Output Timing*

2.1.5.2 I²S/TDM Digital Audio Port

When in I²S+ I²C or I²S+UART mode, The IA611 can transfer audio data using the I²S or TDM protocol with an external host or codec device. See Table 8 and Table 1 for more information about pin configuration in these modes. Using API Commands, the IA611 can be configured to operate either in slave or master mode.

I²S transfers have the following features:

- Bit clock (I2S_CLK) up to 24.576 MHz
- Sampling clock (I2S_WS) up to 192 kHz.
- There must be exactly two slots, Left (I2S_WS low) and Right (I2S_WS high).
- There must be an equal number of I2S_CLK periods in each half I2S_WS period.
- Supports from 8 to 32 audio data bits per slot (channel).

Figure 5 shows an example of I²S mode.

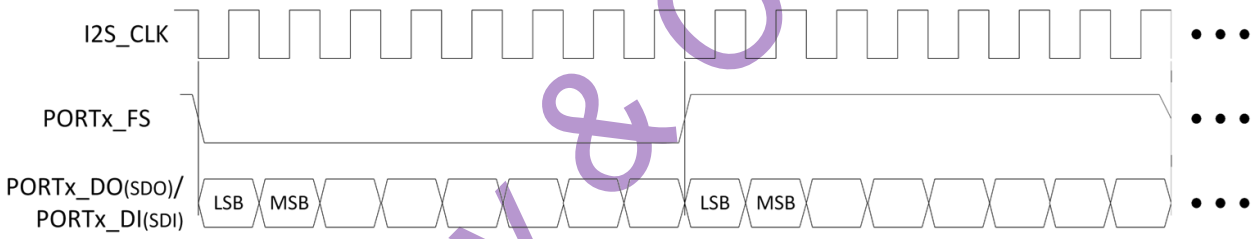


Figure 5 *I²S Mode*

TDM transfers have the following features:

- Bit clock (I2S_CLK) up to 24.576 MHz
- Sampling rates of up to 192 kHz
  - Frame Sync pulse (I2S_WS) must be at least one bit clock wide.
- Supports up to four active slots (channels) out of a maximum of 32. Slots do not need to be contiguous. In master mode, the master clock generator supports up to 256 clocks per frame, but slave TDM operation is not limited by clocks per frame, and will support up to 32 slots with 32 data bits per slot.
- Supports from 8 to 32 audio data bits per slot (channel).
- Supports output transmission on either rising or falling bit clock edge.
- Supports input sampling on either rising or falling bit clock edge.
- Transmitting and sampling edges must be of opposite polarity.
- Support both MSb-first and LSb-first transmission modes.

Figure 6 shows an example of TDM mode.

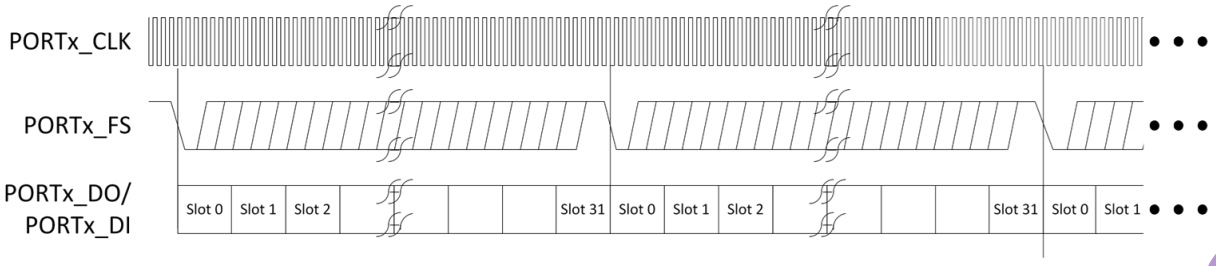


Figure 6 *TDM Mode*

2.1.6 Host Interfaces

2.1.6.1 Firmware download, Command and Control

The IA611 audio processor supports command and control over the following interfaces:

- SPI up to 16 Mbps
- UART up to 2.5 MBaud
- I^2C up to 1 MHz

2.1.6.2 SPI

The IA611 supports a four wire Serial Peripheral Interface (SPI) protocol up to 16 Mbps. The SPI slave port can be used to download a firmware image onto the IA611 and to send API control and data to the IA611.

2.1.6.3 UART

The IA611 supports a two wire UART (UART_SIN, UART_SOUT). The UART can be used to download a firmware image onto the IA611, and a UART connection to the host is required for streaming as alternative to ID tapping. The interface can detect baud rate automatically up to 115kHz and supports baud rates of 0.4608, 0.9216, 1.000, 1.024, 1.152, 2.000, and 2.048 MHz as configured by the host using the Bootloader UART baud rate change API command, or by the firmware after the binary file has been downloaded.

2.1.6.4 I^2C

The IA611 supports a Slave I^2C bus as the host interface with a 7-bit address range. The I^2C address can be set through the data output Latch On Reset (LOR) configuration pin as described in Section 4.1. The I^2C interface can be used to download a firmware image onto the IA611.

2.1.6.5 Debug

The collection of diagnostic data streams is supported on the SPI, UART, I^2C interfaces. This requires the ability to collect synchronized input/output streams using any of the interfaces.

Debug is supported by either a virtual connection over ADB to an Android Proxy running on the host processor, or by a direct physical connection to test-points on the system PCB with no-load resistors connected to the SPI, UART, I^2C I/O pins for the IA611.

2.2 System Control Unit

2.2.1 Boot Control

Upon the supply of power to VDD pin, the IA611 goes through a power up initialization process. During this period of time, the IA611 will not respond to any host requests. The IA611 then enters an Auto-detect mode for control interfaces to determine which pin configuration to use for operation. See Section 4.2 for more information on the Start-up Sequence, and see the *IA61x API Guide* for more information on the auto-detect sequence.

2.2.2 Reset Control

The IA611 has no external reset pin; it generates an internal reset signal on initial power-up, after receipt of a reset command from the host, or on detection of any communication issues through the use of an on-board Watchdog Timer. IA611 has a variety of low power modes it can enter and exit without requiring a reboot and re-download of system firmware (see section 3). For this reason, it is recommended that the IA611 supply voltage be left on all of the time.

2.2.3 Power Management

The block diagram in Figure 3 colors codes the different power domains of the IA611. There are three primary power domains; one to supply the bias of the MEMS element, one to supply the core analog signal path circuitry, and one to supply core DSP subsystem. The DSP core subsystem has three sub power domains that can be independently controlled to optimize power in various use cases. This section provides further details around the primary ASIC power domains.

Table 2 *Power Supply Pins*

Name	Voltage	Max Current	Power Direction	Comment
GND	0 V	25mA	-	
VDD	1.8V	25mA	Input	Main microphone IO supply
LDOD	0.6V to 1.2V	23mA	Output	Primary supply for DSP functions of the microphone

2.2.3.1 GND

This is the common ground pin for all IA611.

2.2.3.2 VDD

This supply provides power to all I/O as well as the power management blocks (LDOs) in the microphone.

2.2.3.3 LDOD

This provides the power output for the DSP subsystem including the processor, memory, Audio Fabric, and core logic. The output can range from 0.6V to 1.2V.

2.2.3.4 LDOA

This provides the power output for the core analog signal path circuitry including programmable gain amplifier (PGA), analog to digital converter (ADC), and all support circuitry that enables high AOP management on IA611.

2.3 Clock Control

2.3.1 Reference Clock Multiplexing

IA611 has one internal PLL (see section 2.3.2), which requires a reference clock. To obtain the reference clock for the PLL, the IA611 can choose from:

- Audio port clock
- Either one of the internal oscillators (see section 2.3.3)

If the audio port clock is chosen as the reference clock, IA611 supports a wide range of input clock frequencies allowing flexibility for the system designer. The below tables summarize supported audio clock rates for both I^2S/TDM and PDM audio configurations.

Table 3 *Supported PDM Clock Rates*

PDM Clock (kHz)	Recommended max bandwidth of audio signal (kHz)
512	5.33
768	8
1024	10.66
1536	16
2048	21.33
3072	32
4608	48

Table 4 *Supported I^2S/TDM Clock and Sampling Rates*

Bit Clock (kHz)	16Bit sampling rate (kHz)	20Bit sampling rate (kHz)	24Bit sampling rate (kHz)	32Bit sampling rate (kHz)
512	16	12.8	10.66666667	8
768	24	19.2	16	12
1024	32	25.6	21.33333333	16
1536	48	38.4	32	24
2048	64	51.2	42.66666667	32
3072	96	76.8	64	48
4608	144	115.2	96	72
6144	192	153.6	128	96

2.3.2 PLL

The IA611 has a high performance integrated Phase Lock Loop (PLL). The PLL is used to provide clocks for the processors, memory and related circuits, and oversampling clocks that drive the serial control communications interfaces. See section 0 for performance details of the PLL.

2.3.3 Internal Oscillators

The IA611 has two integrated silicon oscillators, one optimized for low power and the other optimized for accuracy and system flexibility.

2.3.3.1 Low Power Oscillator

The low power oscillator is calibrated at the factory, and the output frequency is always set to 768kHz. This oscillator is specifically designed for low power voice wake modes.

2.3.3.2 High Performance Oscillator

The high performance oscillator is also calibrated at the factory and the output frequency is set to 43MHz. This output frequency can be divided down by counters within the IA611 for use by various internal modules, or for use as a master output clock. See section 6.3 for performance details of this oscillator.

2.4 Interrupts

The IA611 provides an interrupt request to the host for a keyword detection event through the HOST_IRQ function, as well as a wakeup event from the host through the WAKE function.

The HOST_IRQ and WAKE function maps to a particular pin based on configuration; see Table 8 and Table 1 as well as the *IA61x API Guide* for more information.

3. Operating Modes

IA611 can be in one of the following operating modes:

- Bootloader Auto-Detect Mode – After power up, IA611 is in this mode to detect the host control interface, and waits for firmware download
- Voice Wake Mode – IA611 is in low power mode and can detect keywords spoken
- OpenDSP Mode – IA611 enters this mode to enable third party algorithms
- Software Pass-Through Mode – IA611 can be in software pass-through mode where it acts as a left or right-channel PDM or I^2S mic to the host
- Hardware Pass-Through Mode – IA611 can be in hardware pass-through mode where it acts as a dual-mono PDM mic to the host
- Deep-Sleep Mode

3.1 Bootloader Mode

Upon system power up, or after deep-sleep mode, The IA611 is in Bootloader Mode, and waits for either an API command to determine the host control interface, or a PDM clock to enter HW Bypass Mode. Once the control interface is determined, firmware may be downloaded and the device configured to put the IA611 into one of the other listed modes. See the *IA61x API Guide* for details on auto-detecting the control interface, firmware download, and mode switching.

3.2 Voice Wake

The Voice Wake feature on the IA611 processor allows low power voice wake-up based on detection of either a built-in keyword (OEM keyword), a user trained keyword (user keyword), or a user trained OEM keyword (Voice ID). The host can go into a very low power mode and wait for the IA611 to sense activity and wake it up.

In Voice Wake mode, the IA611 monitors the microphone stream for acoustic activity in an ultra-low power mode. When acoustic activity is detected, the IA611 automatically enters into a slightly higher power mode to analyze the speech utterance for the presence of the wake-up keyword. When a valid keyword is detected, the IA611 asserts an interrupt to the host processor to trigger complete system wake-up. If a keyword is not detected, the device returns to the ultra-low power mode until acoustic activity is detected again. The timeline for this is shown in Figure 7.

Due to its ultra-low-power nature, the Voice Wake feature enables an always-on touchless user interface for mobile device or IoT wake-up.

3.2.1 Intelligent Microphone Wake

In the sleep state, the IA611 wakes up when a falling edge (high to low) is detected on the Wake-up Input pin and transitions to command mode. From the sleep state, the IA611 also wakes up due to acoustic activity and transitions to key word detection mode. After the key word is detected, the IA611 transitions to command mode.

3.2.2 Wake-up Trigger

Voice Wake keeps the mobile device in a low-power, always-on listening mode where the device is listening for the ‘wake-up’ trigger. Once the trigger is detected, the device wakes up and performs the desired action. Voice Wake offers the choice of OEM selectable, user selectable, or user dependent OEM wake-up triggers.

3.2.2.1 OEM Selectable Wake-up Triggers

With this option, OEMs can select their own keyword to wake the device. This wake-up trigger wakes up the mobile device whenever the user says this word. This OEM selectable trigger is speaker independent and does not require user training.

3.2.2.2 User Selectable Wake-up Triggers

With this option, users can personalize their mobile device by selecting their own personal wake-up trigger. In this mode, the user trains the system by speaking the key phrase several times in a relatively quiet environment. The user selectable wake-up trigger can be optionally passed simultaneously during training to the host for storage and analysis.

3.2.2.3 User Dependent OEM Wake-up Triggers

With this option, users can train their device to only wake up to their voice when speaking the OEM keyword. In this mode, the user trains the system by speaking the OEM key phrase several times in a relatively quiet environment. The OEM selectable trigger is then speaker dependent, which means that once a user has trained the system to their voice, the system recognizes and responds only to that user’s voice.

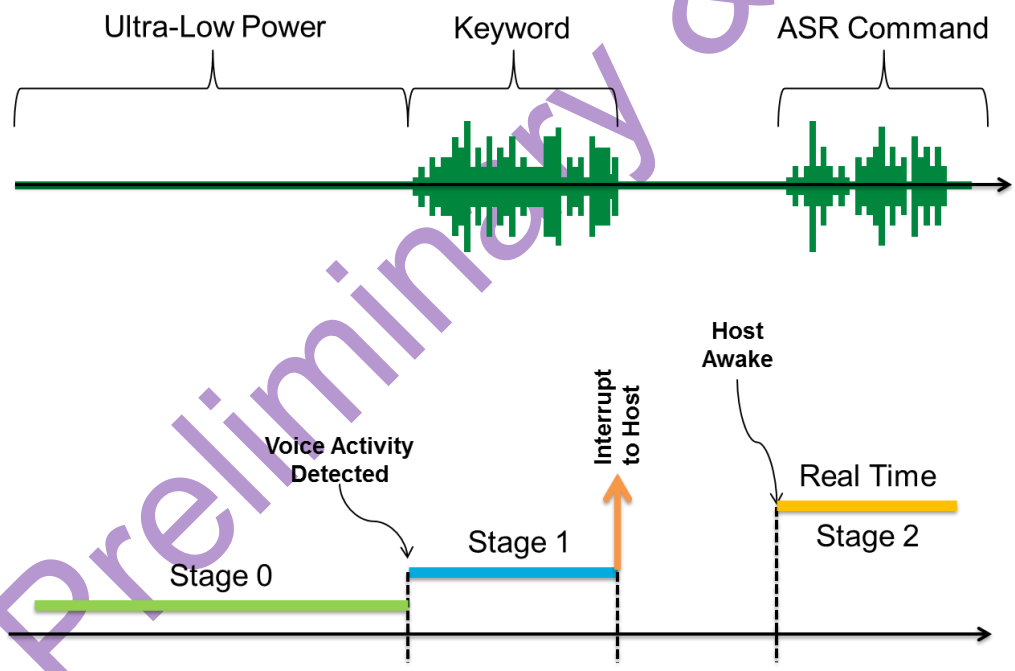


Figure 7 *Timeline in Voice Wake Mode*

3.3 Continuous Voice Wake

The Continuous Voice Wake feature starts where the Voice Wake feature leaves off, and buffers up to three seconds of speech on-chip after receiving the wake-up trigger. It then passes this speech (and optionally also the keyword) to the automated speech recognition (ASR) engine running on the host processor. Continuous Voice Wake allows devices to continuously listen to their surroundings, wake up upon a simple, configurable voice keyphrase, and then act on the instructions that follow.

For example: Hello Voice Q, what is the weather like today?

The IA611 is part of a larger system that includes the Codec, Host Application Processor and Baseband processor along with the peripheral control busses such as UART that connect them. Continuous Voice Wake is performed by the system as a whole in several stages:

Stage 0 (AAD Mode): In Stage0, the IA611 is in ultra-low power mode.

Stage 1 (Keyword Detect Mode): During stage 1, the IA611 is in low power mode and processing inbound microphone samples for the presence of one of the pre-loaded keywords. When a keyword is detected, the IA611 generates an interrupt to the Host and then saves some relevant state information. The IA611 then transitions to stage 2.

Stage 2 (Burst Mode): While the host is waking up, the IA611 continues buffering mic data in a three second circular audio buffer. Once the host is up and running, it can start bursting the audio buffer over SPI/UART/I^2S/I^2C. Once the host decides to stop the capture, it can put the IA611 back into stage 0 (Voice Wake Mode) or Pass-Through Mode. The timeline for this is illustrated in Figure 8.

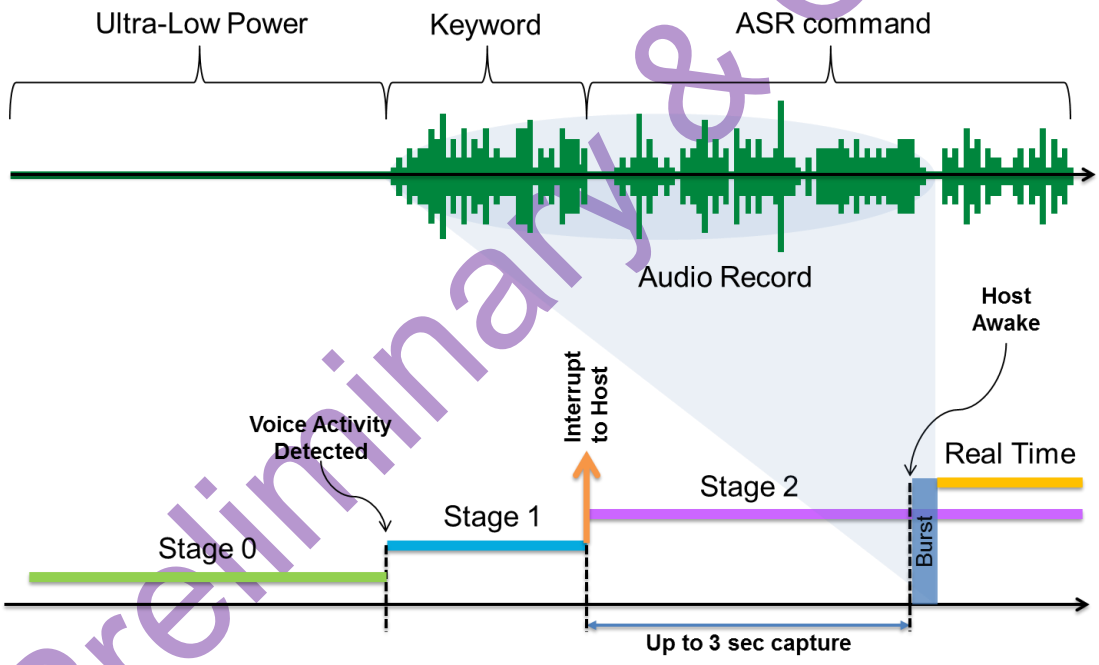


Figure 8 *Continuous Voice Wake System Timeline*

3.3.1 Keyword Preservation

Continuous Voice Wake can be configured to maintain the 16 kHz keyword and pass it to the host with the buffer. This allows for secondary host-based inspection of the keyword as well as ASR channel estimation. Due to the memory needed to keep the keyword, enabling this feature limits the number of available keywords – one OEM keyword and two user-trained keywords.

3.4 OpenDSP

168 kBytes of RAM enables third party algorithms with dynamic audio filtering and keyword detection as examples. Knowles provides a Software Development Kit, to enable third party developers create DSP algorithms on the IA611 Acoustic Processor platform.

Please contact Knowles for access to the SDK and associated Developers Guide.

3.5 Software Pass-Through

IA611 can be in software pass-through mode where it acts as a left or right-channel PDM or I^2S mic to the host. Software Pass-Through mode is supported only after FW download.

3.6 Hardware Pass-Through

Hardware Pass-Through allows the host to put the IA611 in a low-power digital audio pass-through mode to bypass processing. In this mode, the IA611 acts as a dual-mono PDM microphone.

3.7 Deep Sleep Mode

Deep sleep mode should be used only when IA61x operation is not required. It is the lowest power mode of the IA611. Deep Sleep mode is supported only after FW download.

4. Design Considerations

4.1 Latch On Reset Configuration Pins

The IA611 contains two Latch On Reset (LOR) address pins that set the I^2C slave address when in I^2C mode. The state of the address pins is latched when power is on and stable. An internal pull-down resistor pulls the address pins low (0) when unconnected. To set the address pin to a logical value of 1, connect the LOR pin to the same power supply that powers the IA611 with an external 10 kΩ pull-up resistor.

Table 5 shows the configuration of the address pins and the resulting I^2C address.

Table 5 *Latch On Reset Configuration for I^2C Address*

ADDR1	ADDR2	Description
0	0	7 bit, address 0x3E (default)
0	1	7 bit, address 0x38
1	0	7 bit, address 0x3F
1	1	7 bit, address 0x39

4.2 Start-up Sequencing

Figure 9 shows a complete start-up sequence including system power and the host bus.

After Latch On Reset, The IA611 wakes up in the Auto-detect state. In the Auto-detect state, the IA611 determines the control interface and waits for command communication or FW download from the host.

Please note that the host interface pins should be floating or driven to ground during VDD power up so that they are never at a higher voltage than VDD+0.3V.

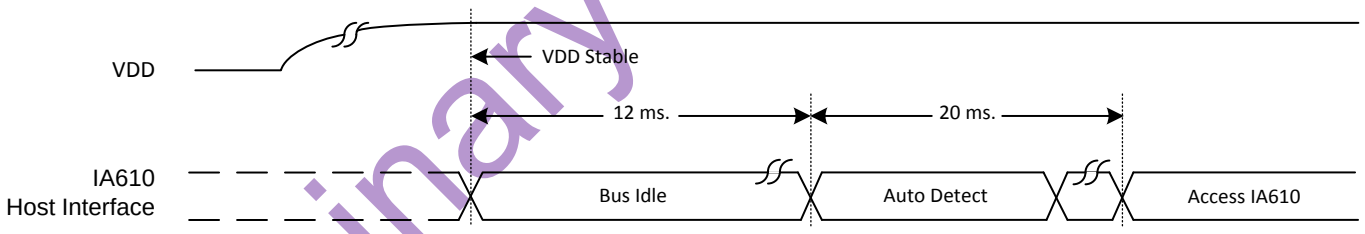


Figure 9 *Start-up Sequence*

The host should follow a defined sequence to download program code into the IA611. The *IA61x API Guide* provides a detailed description of program code download sequences over the various interfaces.

4.3 Sleep and Wake-up Sequence

The IA611 can be placed into an ultra-low power sleep state to minimize power consumption. During sleep the host can continue to access other devices connected to the host interface buses, if any.

Figure 10, Figure 11, and Table 6 provide a general overview of the sleep and wake-up process and process timings. The *IA61x API Guide* provides a detailed description of the sleep and wake-up sequences.

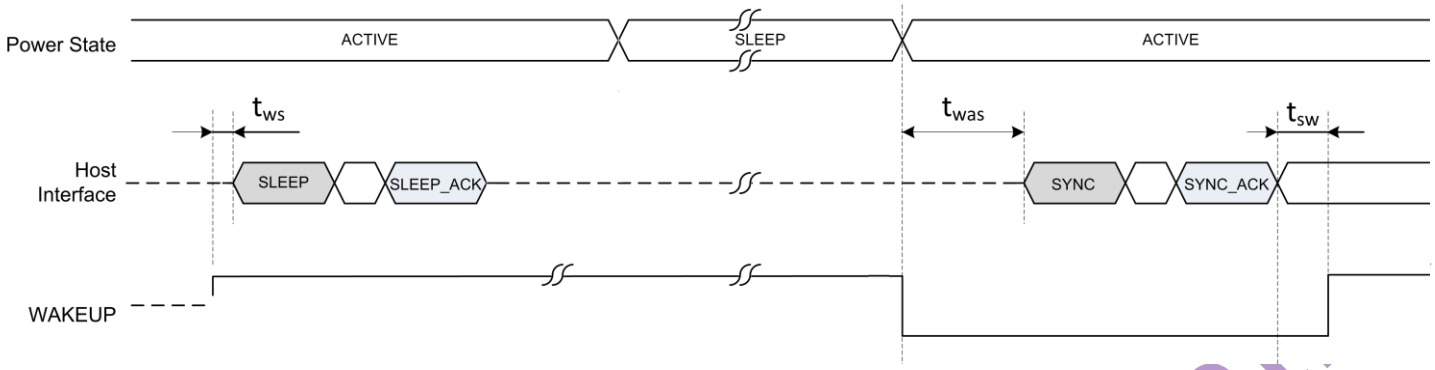


Figure 10 *Sleep and Wake-up Sequence for waking up IA611 using WAKEUP input*

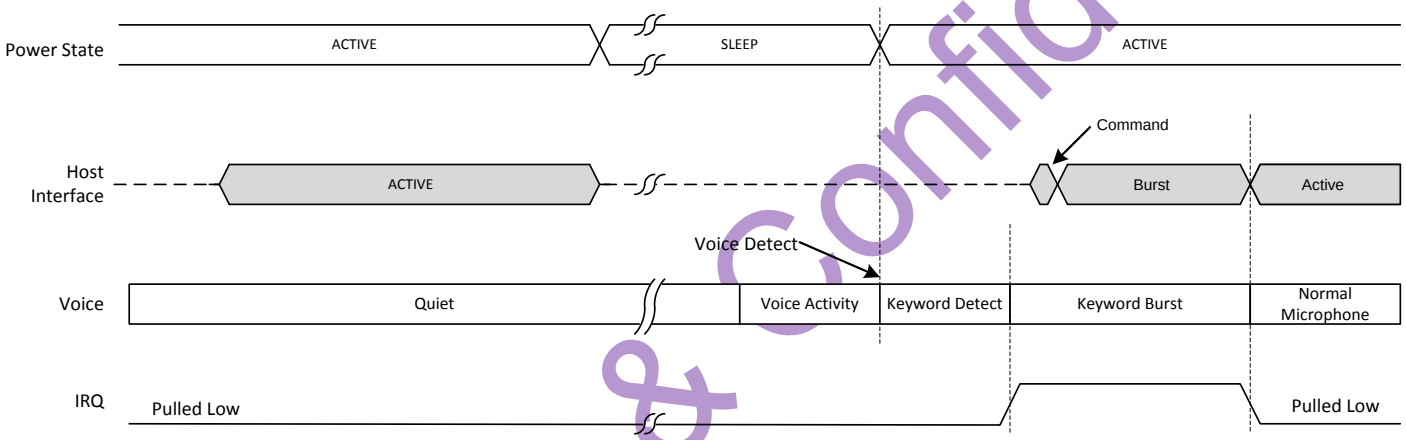


Figure 11 *Sleep and Wake-up Sequence for Voice Wake mode*

Table 6 *Sleep and Wake-up Sequence Timings*

Parameter	Symbol	Min	Typ	Max	Units
Time from WAKEUP deasserted to SLEEP command write	t_{ws}	30	-	-	ms
Time from WAKEUP asserted to SYNC command write	t_{was}	30	-	-	ms
Time from SYNC _ACK read to WAKEUP deasserted	t_{sw}	0	-	-	ms

4.4 Power Down

Do not turn off power to the IA611. The device is intended to be an always-on device and manages power internally for low power use cases (deep-sleep).

5. Pin Descriptions

5.1 Pinout Diagram

Figure 12 shows the pinouts for the IA611 from the bottom view.

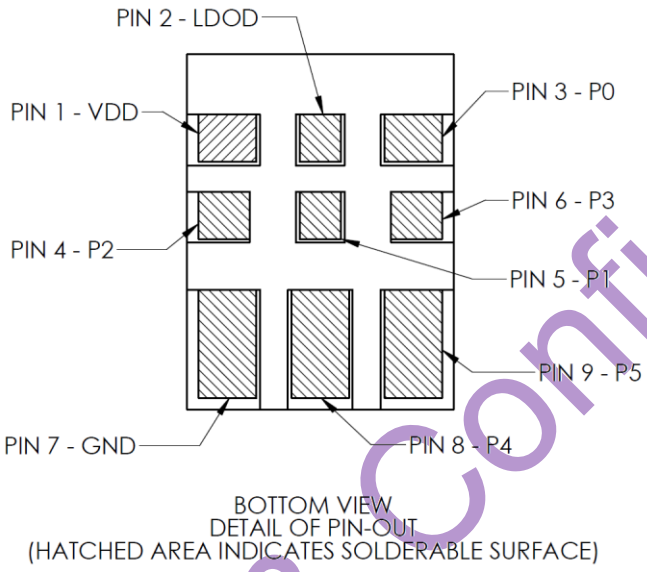


Figure 12 *Pin Assignments (Bottom View)*

5.2 Pinout Table

Table 7 shows a list of the pins and the signals associated with them for the IA611. In active mode, the pin state is set by firmware and differs from mode to mode. Firmware can configure a pin as an input or an output, and can also enable internal pull-ups or pull-downs if available.

Table 7 *Pin Descriptions*

Pin#	Name	Type	Description
1	VDD	Power	Power Supply
2	LDOD	Power	Connect to Bypass Capacitor
3	P0	Digital I/O	P0 I/O
4	P2	Digital I/O	P2 I/O
5	P1	Digital I/O	P1 I/O
6	P3	Digital I/O	P3 I/O
7	GND	Power	Ground
8	P4	Digital I/O	P4 I/O
9	P5	Digital I/O	P5 I/O

Table 8 *Pin Configuration Per Boot Mode*

Mode	P0	P1	P2	P3	P4	P5	IRQ	WAKE
PDM + I2C	PDM_CLK	PDM_SDO	I2C_ADDR1 WAKE	I2C_ADDR2 IRQ	I2C_SCLK	I2C_SDA	P3	P2
PDM + UART	PDM_CLK	PDM_SDO	NA	IRQ	UART_RX WAKE	UART_TX	P3	P4
PDM + SPI	PDM_CLK	PDM_SDO IRQ	SPI_SCLK	SPI_MISO	SPI_SS WAKE	SPI_MOSI	P1	P4
I2S + I2C	I2S_WS	I2S_CLK	I2S_SDI I2C_ADDR1 WAKE	I2S_SDO I2C_ADDR2 IRQ	I2C_SCLK	I2C_SDA	P3	P2
I2S + UART	I2S_WS	I2S_CLK	I2S_SDI	I2S_SDO IRQ*	UART_RX WAKE	UART_TX IRQ*	P3	P4

*IRQ may be configured to be on either the I2S_SDO, or UART_TX, depending on IA611 configuration settings

6. Electrical Characteristics

6.1 General Electrical Characteristics

Test conditions: VDD = 1.8V at T_A =25° C unless otherwise specified.

Parameter	Symbol	Min	Typ	Max	Units
Digital Input High Level Voltage	V_{IH}	0.65*VIO			V
Digital Input Low Level Voltage	V_{IL}	-0.2		0.35*VIO	V
Digital Output High Level Voltage	V_{OH}	0.65*VIO			V
Digital Output Low Level Voltage	V_{OL}			0.35*VIO	V
Programmable Digital Input Internal Pull-Down Resistor		35	61	114	kΩ
Programmable Digital Input Internal Pull-Up Resistor		39	71	138	kΩ
I/O drive strength (default)		7	12	17.5	mA
Capacitance To Ground of I/O Pins	C	9		18	pF

Note: Maximum output current source or sink drive by any I/O pin is programmable in four steps. The default is 12mA nominal. See the *IA61x API Guide* for details and settings.

Note: External I/O loading and drive strength have a direct effect on voltage VIH and VIL transition times. For timing critical signals, the values of any external R and C components connected to the I/O pins need to be adjusted based on the application.

6.2 PLL Characteristics

The PLL has operation parameters shown below. The PLL has two frequency ranges of operation, set through the software API. PFD refers to the Phase-Frequency Detector on the PLL, which receives a divided-down version of the reference clock.

Test conditions: VDD = 1.8V at T_A =25° C unless otherwise specified.

Parameter	Symbol	Conditions	Min	Typical	Max	Units
Reference Frequency	f_{PLL_IN}		0.768		200	MHz
PFD Frequency	f_{PLL_PFD}	Low Range	0.768		$f_{PLL\_VCO} \div 4$	MHz
		High Range	0.768		$f_{PLL\_VCO} \div 8$	MHz
VCO Frequency	f_{PLL_VCO}	Low Range	28		140	MHz
		High Range	120		600	MHz
Output Frequency	f_{PLL_OUT}		0.11		600	MHz
Lock Time	t_{PLL_LOCK}		500		1000	PFD cycles
Feedback Divider	n_{PLL_FBDIV}		4		781	integer
Loop Bandwidth	f_{PLL_BW}			f_{PLL_PFD}/25		MHz
Period Jitter (random)	$t_{PLL\_JIT\_RND}$	f_{PLL_VCO} = 50 MHz		$0.7\ pS \times \sqrt{\frac{600\ MHz}{f_{PLL\_VCO}}} \times \sqrt{\frac{600\ MHz}{f_{PLL\_OUT}}}$	8.4	pS (RMS)
Period Jitter Power Supply Noise Sensitivity	$t_{PLL\_JIT\_PS}$			1.5		pS/mV
Period Jitter from reference spur	$t_{PLL\_JIT\_REF}$			1%		Output clock cycle

Integrated Long-Term Jitter	$t_{PLL\_JIT\_LT}$	Measured on output from 20 kHz to 6.144 MHz. f_{PLL_PFD}=12.288 MHz, f_{PLL_VCO}=125 MHz		$110\ pS \times \sqrt{\frac{6\ MHz}{f_{PLL\_PFD}}} \times \sqrt{\frac{128\ MHz}{f_{PLL\_VCO}}}$	78	pS (RMS)

6.3 Oscillator Characteristics

The on-chip silicon oscillator is calibrated in the factory and has the following characteristics. There are two ranges of operation, set by internal register through the software API.

Test conditions: VDD = 1.8V at T_A =25° C unless otherwise specified.

Parameter	Symbol	Conditions	Min	Typical	Max	Units
Output Frequency	f_{OSC_OUT}	Low Range		43.008		MHz
		High Range		172.032		MHz
Output Frequency Temperature Dependence	Δ_{OSC_T}	0 to 80°C		340	535	ppm/°C
Output Frequency Voltage Dependence	Δ_{OSC_V}	VDDA = 1.0V±5%		7	11.8	ppm/°C
Period Jitter (random)	$t_{OSC\_JIT\_RND}$	Low Range			44	pS (RMS)
		High Range			22	
Period Jitter Power Supply Noise Sensitivity	$t_{OSC\_JIT\_PS}$	Low Range		0.9	2.2	pS/mV

6.4 Audio Port Interface Characteristics

6.4.1 I²S/TDM Interface Slave Timing

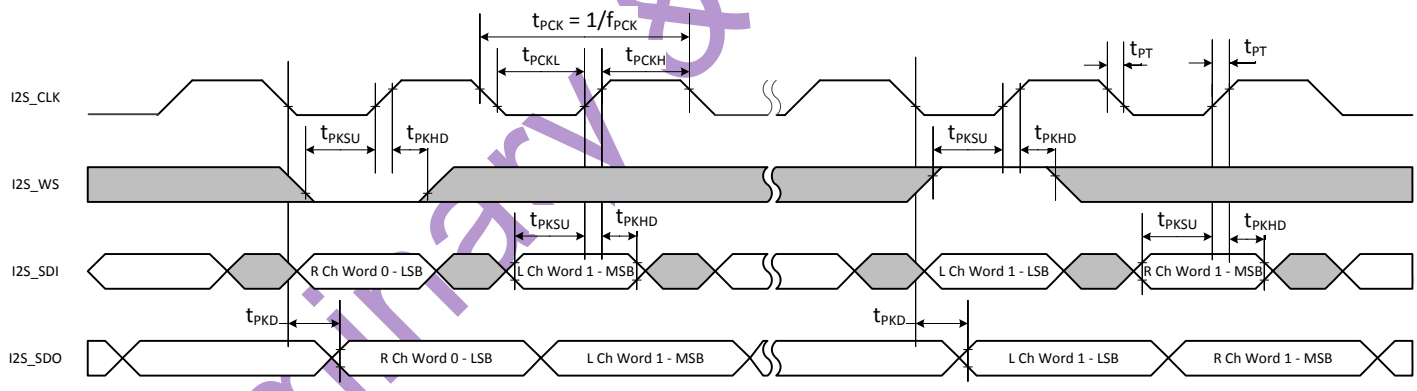


Figure 13 *I²S/TDM Interface Slave Timing*

In Slave Mode, I2S_CLK and I2S_WS are inputs.

Test Conditions: VDD_IO = 1.8V, 10pF Load, at T_A =25° C unless otherwise specified. Measurement levels on waveforms are Vih and Vil. Note 1

Parameter	Symbol	Min	Typ	Max	Units
I2S_CLK Clock Frequency	f_{PCK}			24.576	MHz
I2S_CLK Clock Cycle Time	t_{PCK}		$1/f_{PCK}$		s
I2S_CLK Clock High Pulse Width	t_{PCKH}	35			% t_{PCK}
I2S_CLK Clock Low Pulse Width	t_{PCKL}	35			% t_{PCK}
I2S input transition time	t_{PT}		10		ns
I2S_SDI and I2S_WS Input Setup Time to CLK ↑ Note 2	t_{PKSU}	25			ns
I2S_SDI and I2S_WS Input Hold Time from CLK ↑ Note 2	t_{PKHD}	5.1			ns

Parameter	Symbol	Min	Typ	Max	Units
I2S_SDO Data Output Delay from CLK ↓ Note 3	t_{PKD}	0		15	ns

Note 1: *Timing parameters are guaranteed by design and they are not tested in the final test.*
Note 2: *The I2S_WS and I2S_SDI inputs are set to be sampled at the rising edge of the I2S_CLK.*
Note 3: *The I2S_SDO outputs are set to drive at the falling edge of the I2S_CLK.*

6.4.2 I²S/TDM Interface Master Timing

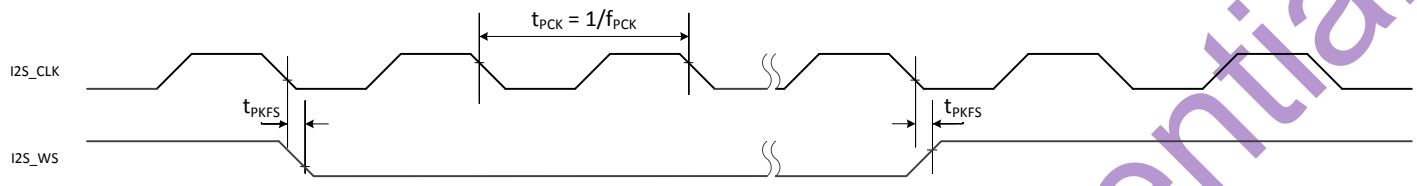


Figure 14 *I²S/TDM Interface Master Timing*

In Master Mode, I2S_CLK and I2S_WS are outputs, but I2S_SDI and I2S_SDO timing with respect to I2S_CLK are identical to that for Slave mode.

Test Conditions: VDD_IO = 1.8V, 10pF Load, at T_A =25° C unless otherwise specified. Measurement levels on waveforms are Vih and Vil. Note 1

Parameter	Symbol	Min	Typ	Max	Units
I2S_WS Output Delay from CLK ↓ Note 2	t_{PKFS}	0		25%	t_{PCK}

Note 1: *Timing parameters are guaranteed by design and they are not tested in the final test.*
Note 2: *The I2S_WS outputs are set to drive at the falling edge of the I2S_CLK. Delay from CLK ↓ to I2S_CLK is determined by an integer number of periods of an internal oversampling clock used to generate both I2S_CLK and I2S_WS.*

6.4.3 Audio Port PDM Interface Characteristics

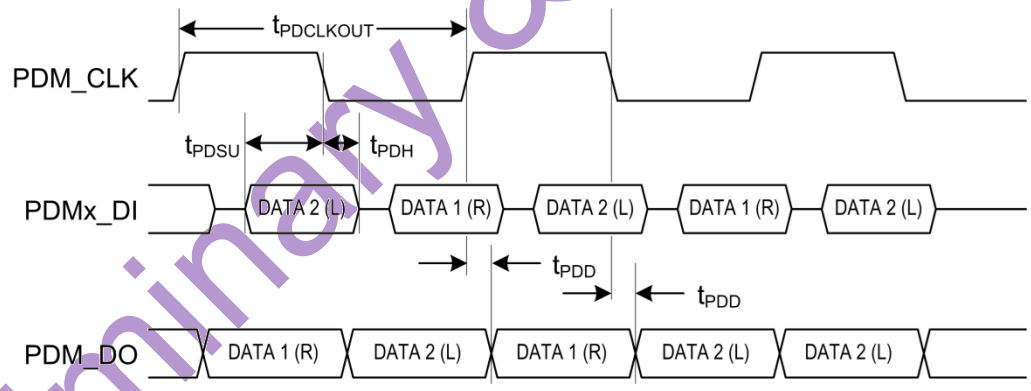


Figure 15 *PDM Interface Timing*

Test Conditions: VDD = 1.8V, 10pF Load, at T_A =25° C unless otherwise specified.

Parameter	Symbol	Min	Typ	Max	Units
PDM_CLK Output Frequency, Operating	$f_{PDCLKOUT}$	0.512	3.072	4.800	MHz
PDM_CLK Output Frequency, Low-power Voice Wake Mode		0.512	0.768 Nominal		MHz
PDM Data Input Setup Time to Clock Edge	t_{PDSU}	25			ns
PDM Data Input Hold Time after Clock Edge	t_{PDH}	3			ns
PDM Data Delay from PDM_CLK Edge [2]	t_{PDD}	6			ns

Note 1: *Timing parameters are guaranteed by design and they are not tested in the final test.*
Note 2: *The edge of the clock on which data is output is programmable.*

6.5 I²C Slave Interface Characteristics

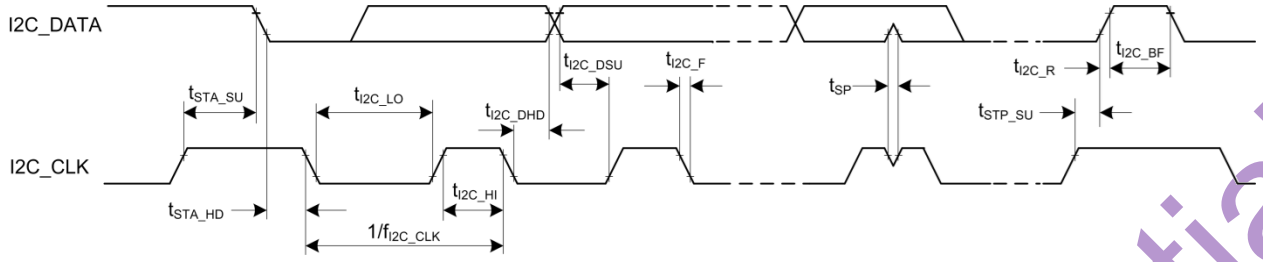


Figure 16 *I²C Slave Interface Timing*

Test Conditions: VDD = 1.8V, Output Load = 20pF; unless otherwise specified.

Parameter	Symbol	Standard Mode		Fast Mode		Fast Mode+ [1]		Units
		Min	Max	Min	Max	Min	Max	
I²C Clock Frequency	f_{I2C_CLK}	0	100	0	400	0	1000	kHz
I²C Clock High Period	t_{I2C_HI}	4.0		0.6		0.26		µs
I²C Clock Low Period	t_{I2C_LO}	4.7		1.3		0.5		µs
Start Condition Setup Time	t_{STA_SU}	4.7		0.6		0.26		µs
Start Condition Hold Time	t_{STA_HD}	4.0		0.6		0.26		µs
Stop Condition Setup Time	t_{STP_SU}	4.0		0.6		0.26		µs
Bus Free Time between Stop and Start Conditions	t_{I2C_BF}	4.7		1.3		0.5		µs
I²C Clock and Data Rise Time	t_{I2C_R}	-	1000	20	300	-	120	ns
I²C Clock and Data Fall Time	t_{I2C_F}		300		300		120	ns
I²C Data Setup Time	t_{I2C_DSU}	250		100		50		ns
I²C Data Hold Time	t_{I2C_DHD}	0	202	0	202	0	-	ns
Spike Suppression Period	t_{SP}	0	0	0	50	0	50	ns

6.6 SPI Interface Specifications

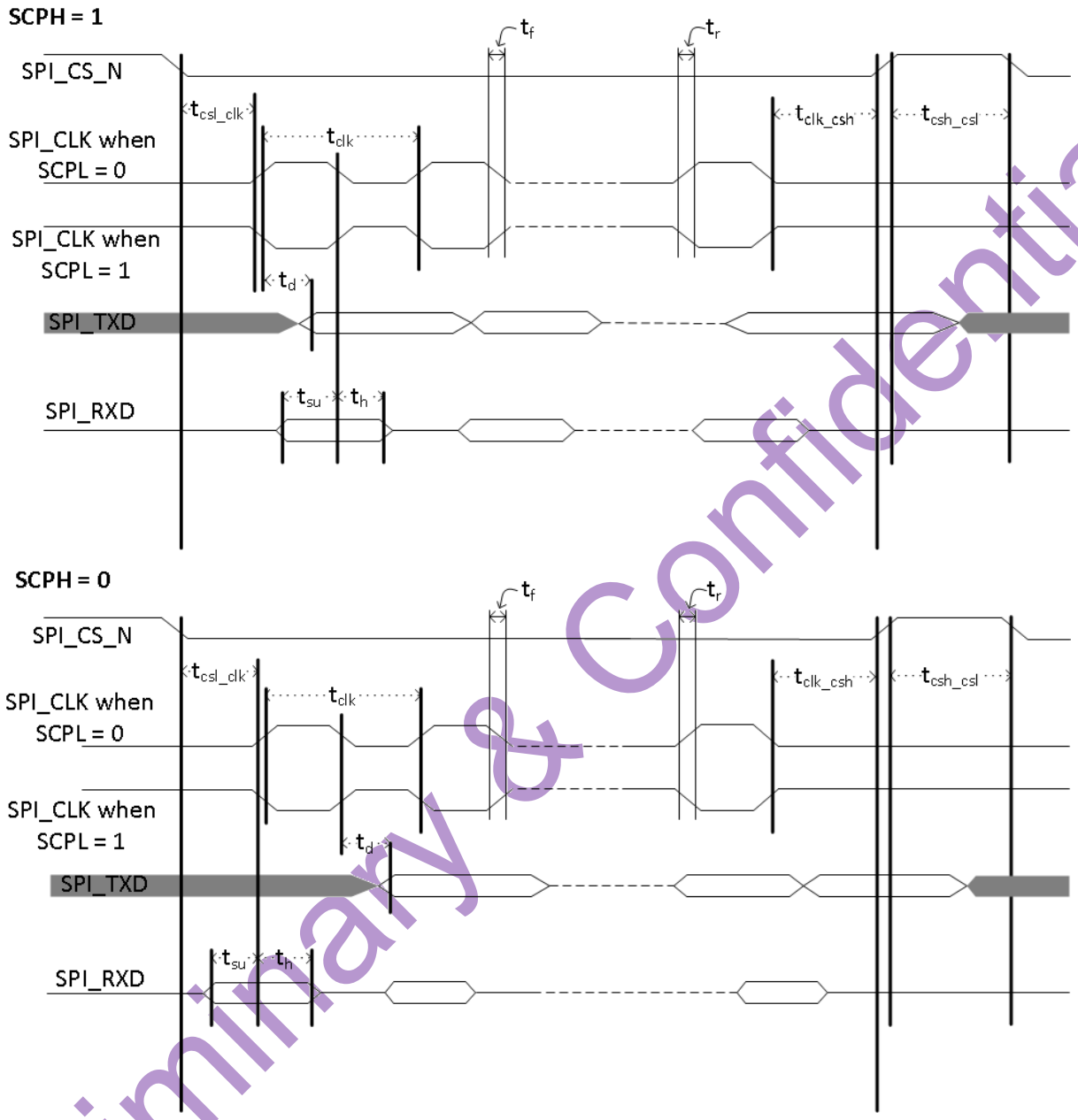


Figure 17 *SPI Interface Timing*

Test Conditions: VDD = 1.8V, >=6x oversampling, 10pF Load, at T_A = 25° C unless otherwise specified.

Parameter	Symbol	Min	Typ	Max	Units
SPI Sample clock frequency	f_{samp}	-		43	MHz
SPI Sample clock period	T_{samp}	23.25		-	ns
SPI Clock Frequency	f_{clk}	-		7.16	MHz
SPI Clock period	t_{clk}	139.67		-	ns
Chip select assert to clock edge	t_{csl_clk}	1		-	t_{clk}
Clock edge to chip select de-assert	t_{clk_csh}	1		-	t_{clk}
Chip select de-assert to chip select assert	t_{csh_csl}	1		-	t_{clk}
Tx Data valid from clock edge	t_d	-		64.125	ns
Rx Data Setup time	t_{su}	0.5		-	t_{samp}

Parameter	Symbol	Min	Typ	Max	Units
Rx Data Hold time	t_h	1.5		-	t_{samp}
SPI Clock rise time	t_r	-		10%	t_{clk}
SPI Clock fall time	t_f	-		10%	t_{clk}

Test Conditions: VDD = 1.8V, <6x oversampling, 10pF Load, at T_A = 25^o C unless otherwise specified.

Parameter	Symbol	Min	Typ	Max	Units
SPI Sample clock frequency	f_{samp}	-		43	MHz
SPI Sample clock period	t_{samp}	23.25		-	ns
SPI Clock Frequency	f_{clk}	7.16		13.56	MHz
SPI Clock period	t_{clk}	73.74		139.67	ns
Chip select assert to clock edge	t_{csl_clk}	1		-	t_{clk}
Clock edge to chip select de-assert	t_{clk_csh}	1		-	t_{clk}
Chip select de-assert to chip select assert	t_{csh_csl}	1		-	t_{clk}
Tx Data valid from clock edge	t_d	12.13		35.38	ns
Rx Data Setup time	t_{su}	0.5		-	t_{samp}
Rx Data Hold time	t_h	1.5		-	t_{samp}
SPI Clock rise time	t_r	-		10%	t_{clk}
SPI Clock fall time	t_f	-		10%	t_{clk}

7. PCB Design & Layout Guidelines

7.1 Power Planes

Power supply noise can have a significant impact on the performance of analog circuitry in the system. Low impedance power planes with decoupling capacitors should be used for the system power supply design.

Ceramic SMT bypass capacitors (1 µF) should be placed next to the IA611 VDD power input pin as well as the LDOD pin (see Figure 18). Additional decoupling capacitors (0.1 µF) may be necessary to reduce the noise on the power pin. Routing traces for the decoupling capacitors should be kept as short as possible. A long trace will have an antenna effect that may introduce additional noise into the power supply, and thus would require additional filtering.

7.2 Digital Signal Routing

PCB layout should follow good design practices by keeping the digital signal traces as short as possible and away from analog and RF signals.

7.3 Typical Application

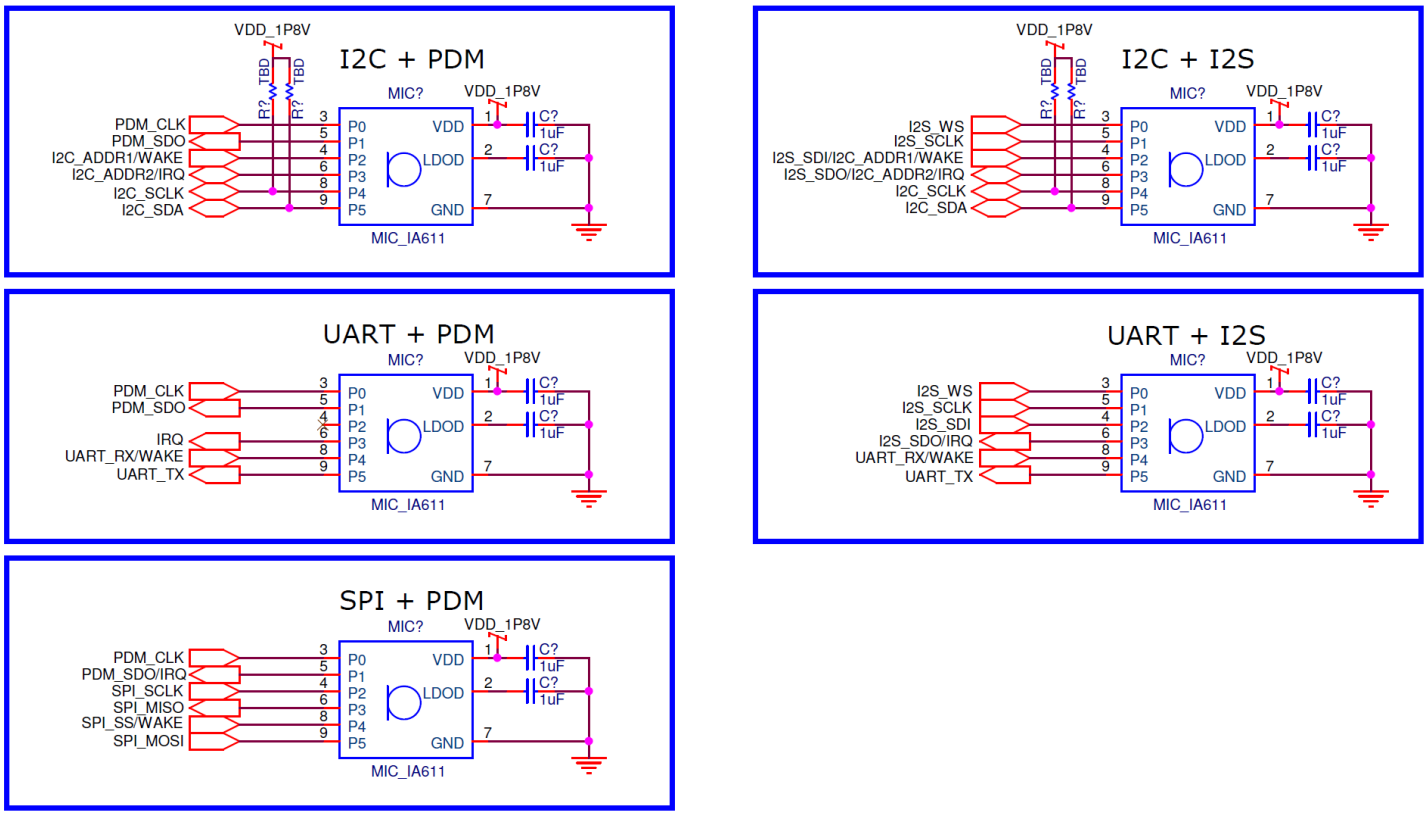
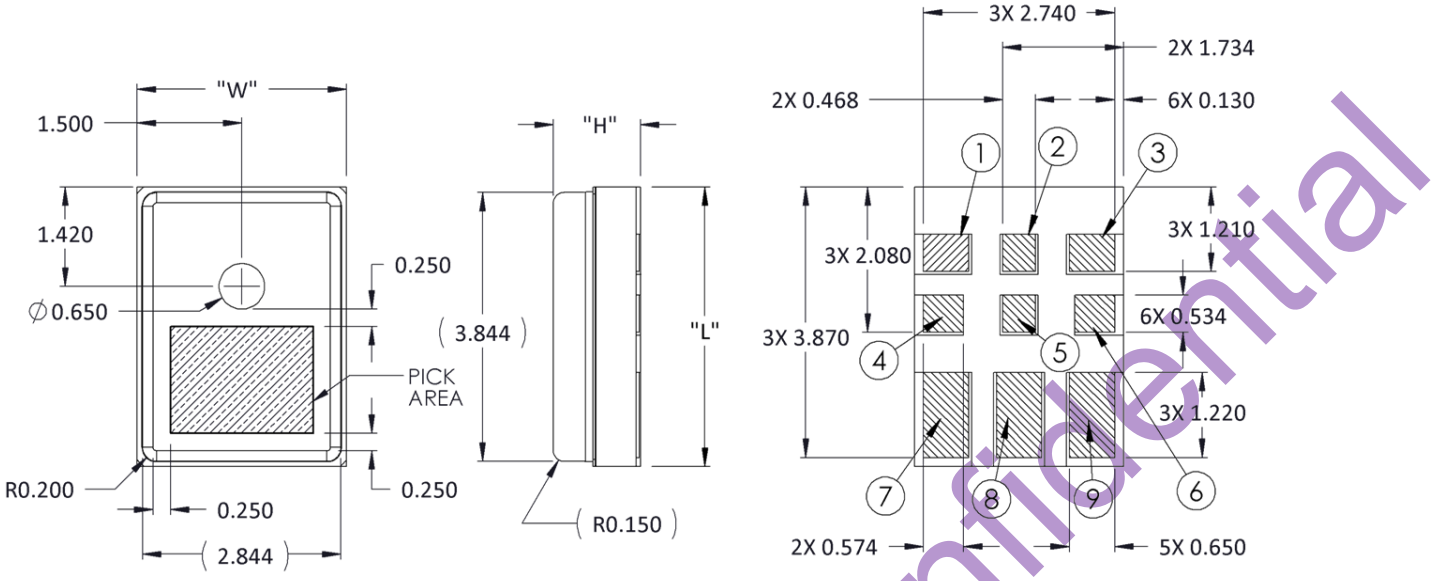


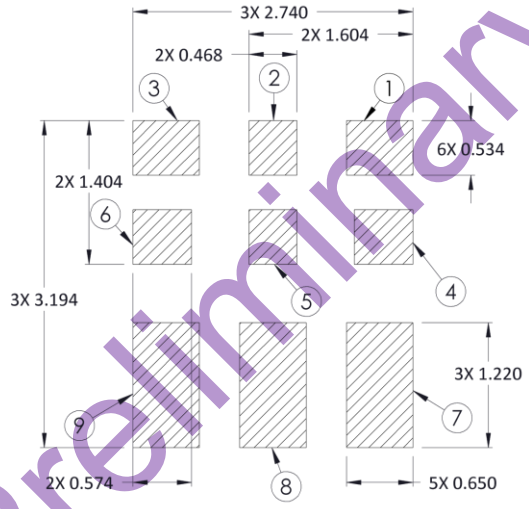
Figure 18 *Schematics showing connection for each of the various interface configurations*

Mechanical Specifications

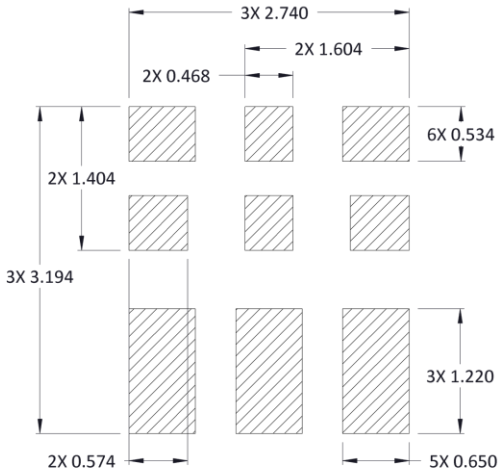


Item	Dimension	Tolerance	Units
Length (L)	4.00	±0.10	mm
Width (W)	3.00	±0.10	mm
Height (H)	1.250	±0.15	mm
Acoustic Port (AP)	0.650	±0.05	mm

Example Land Pattern

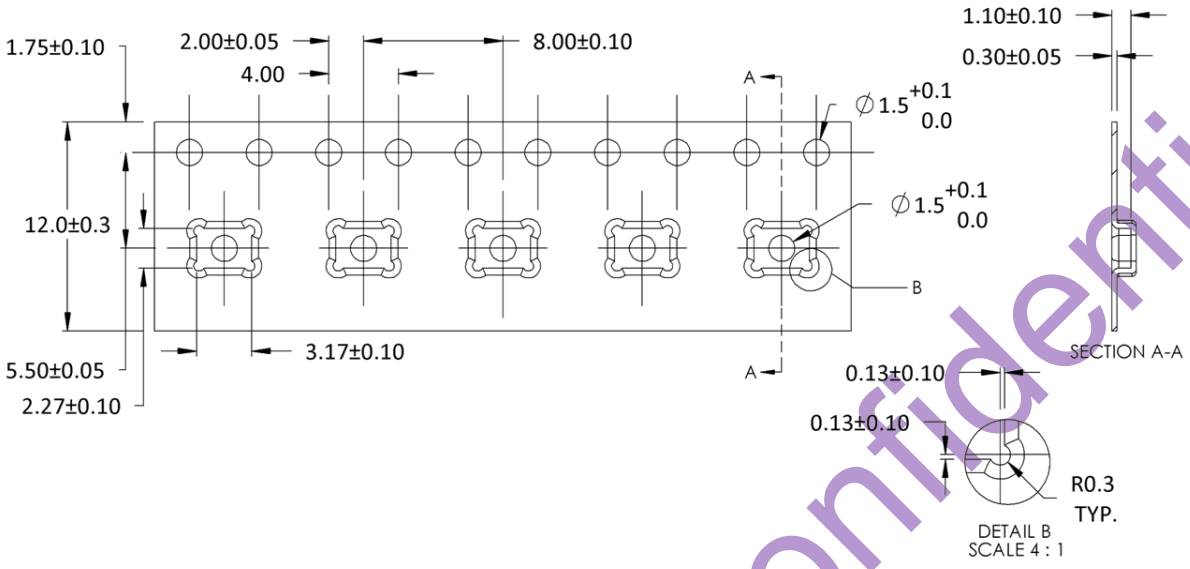


Example Solder Stencil Pattern

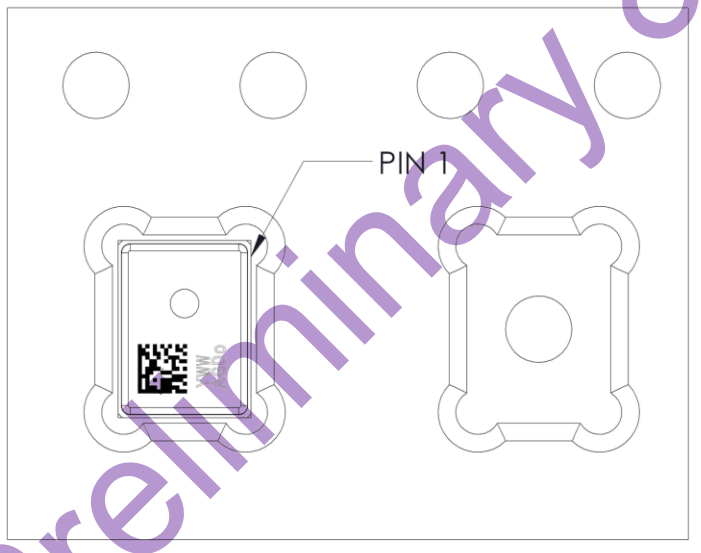


Notes:
Pick Area only extends to 0.25 mm of any edge or hole unless otherwise specified.
Dimensions are in millimeters unless otherwise specified.
Tolerance is ±0.15mm unless otherwise specified
Detailed information on AP size considerations can be found in the latest *SiSonic™ Design Guide* application note.
Further optimizations based on application should be performed.

Packaging & Marking Detail



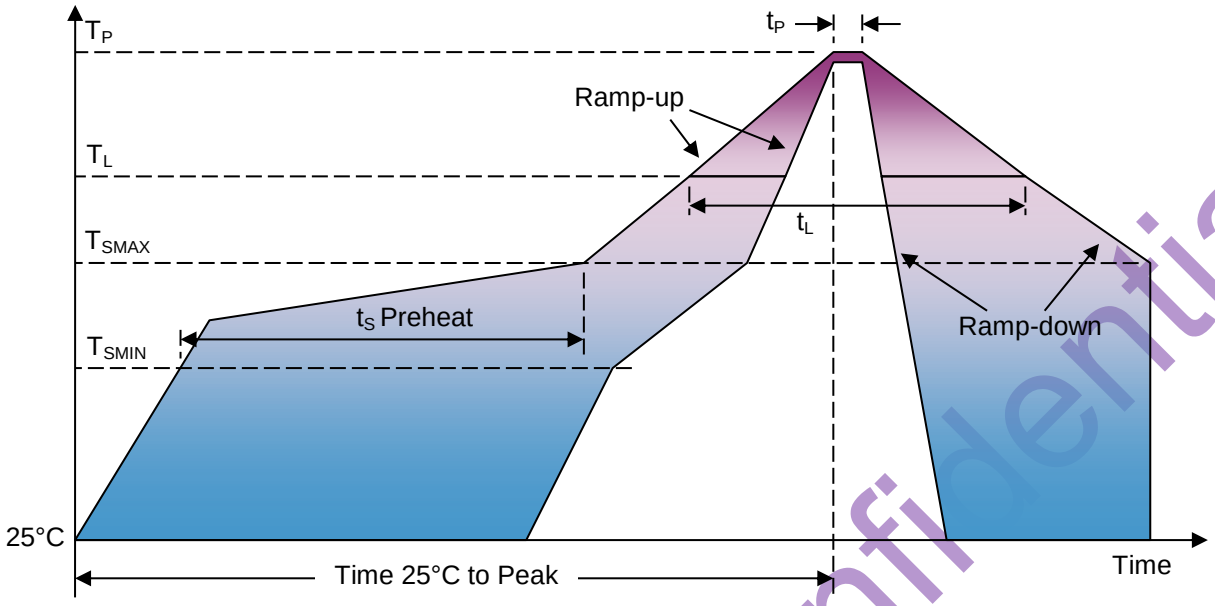
Model Number	Part Number	Quantity Per Reel
IA611	SPK2611HM7H	5,900



2D barcode serial number: PPPYWWDMSSSSAARD
- PPP = Vendor/Facility code
  - KEM = FF9
  - KES = FMV
  - KEI = FF8
- Y = Last digit of current year
- WW = Work week
- D = Day, Sunday is 1 and Saturday is 7
- MSSSS = 5 digit serial code
  - M = Machine ID for laser
  - SSSS = Base 34 serial number (Do not use letter I or O)
- AA = Project name designator
  - AD: Shakira
- R = Revision number
- D = Development Stage
  - E = Engineering Sample
  - P = Prototype Sample
  - M = Mass production

Notes:
1. Dimensions are in millimeters unless otherwise specified.
2. Vacuum pickup only in the pick area indicated in Mechanical Specifications.
3. Tape & reel per EIA-481.
4. Labels applied directly to reel and external package.
5. Shelf life: Twelve (12) months when devices are to be stored in factory supplied, unopened ESD moisture sensitive bag under maximum environmental conditions of 30°C, 70% R.H.

Recommended Reflow Profile



Profile Feature	Pb-Free
Average Ramp-up rate (T_{SMAX} to T_P)	3°C/second max.
Preheat • Temperature Min (T_{SMIN}) • Temperature Max (T_{SMAX}) • Time (T_{SMIN} to T_{SMAX}) (t_S)	 150°C 200°C 60-180 seconds
Time maintained above: • Temperature (T_L) • Time (t_L)	 217°C 60-150 seconds
Peak Temperature (T_P)	260°C
Time within 5°C of actual Peak Temperature (t_P)	20-40 seconds
Ramp-down rate (T_P to T_{SMAX})	6°C/second max
Time 25°C to Peak Temperature	8 minutes max

Notes: Based on IPC/JDEC J-STD-020 Revision C.
All temperatures refer to topside of the package, measured on the package body surface

Additional Notes

(A) MSL (moisture sensitivity level) Class 1.
(B) Maximum of 3 reflow cycles is recommended.
(C) In order to minimize device damage:

- Do not board wash or clean after the reflow process.
- Do not brush board with or without solvents after the reflow process.
- Do not directly expose to ultrasonic processing, welding, or cleaning.
- Do not insert any object in port hole of device at any time.
- Do not apply over 30 psi of air pressure into the port hole.
- Do not pull a vacuum over port hole of the microphone.
- Do not apply a vacuum when repacking into sealed bags at a rate faster than 0.5 atm/sec.

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Materials Statement

Meets the requirements of the European RoHS directive 2011/65/EC as amended.

Meets the requirements of the industry standard IEC 61249-2-21:2003 for halogenated substances and Knowles Green Materials Standards Policy section on Halogen-Free.

Ozone depleting substances are not used in the product or the processes used to make the product, including compounds listed in Annex A, B, and C of the “Montreal Protocol on Substances That Deplete the Ozone Layer.”

Reliability Specifications

Test	Description
Reflow	5 reflow cycles with peak temperature of +260°C
High Temperature Storage	+105°C environment for 1,000 hours (IEC 68-2-2 Test Ba)
Low Temperature Storage	-40°C environment for 1,000 hours (IEC 68-2-1 Test Aa)
High Temperature Bias	+105°C environment while under bias for 1,000 hours (IEC 68-2-2 Test Ba)
Low Temperature Bias	-40°C environment while under bias for 1,000 hours (IEC 68-2-1 Test Aa)
Temperature/Humidity Bias	+85°C/85% R.H. environment while under bias for 1,000 hours (JESD22-A101A-B)
Thermal Shock	100 cycles of air-air thermal shock from -40°C to +125°C with 15 minute soaks (IEC 68-2-4)
Tumble Test	300 Random Drops of Test Box on to Steel Base from 1.0m, 10 Tumbles/Minute
Vibration	16 minutes in each X, Y, Z axis from 20 to 2,000 Hz with peak acceleration of 20 G (MIL 883E, Method 2007.2,A)
Mechanical Shock	3 pulses of 10,000 G in each of the X, Y, and Z directions (IEC 68-2-27 Test Ea)
ESD-HBM	3 discharges of ±2kV direct contact to I/O pins (MIL 883E, Method 3015.7)
ESD-LID/GND	3 discharges of ±8kV direct contact to lid while unit is grounded (IEC 61000-4-2)
ESD-MM	3 discharges of ±200V direct contact to IO pins (ESD STM5.2)

Notes: Microphones must meet all acoustic and electrical specifications before and after reliability testing.
After 3 reflow cycles, the sensitivity of the microphones shall not deviate more than 1 dB from its initial value.

Specification Revisions

Revision	Specification Changes	Date
A	Initial Release	
B	Numerous updates	Sept 29, 2017
C	Numerous updates	Oct 16, 2017
D	I/O drive and capacitance update. PDM max clock update.	Nov 10, 2017
E	Changes to Operating Temperature and I2S address table	Jan 5, 2018
F	Removed Soundwire version	Mar 1, 2018

Knowles Corporation
1151 Maplewood Drive
Itasca, Illinois 60143

Phone: (630) 250-5100
Fax: (630) 250-0575
sales@knowles.com

Model/Reference Number:
SPK2611HM7H