# Using the VM1010 Wake-on-Sound Microphone and ZeroPower Listening™ Technology

**Application Note**
**Rev1.0**
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# Contents

# Table of Figures

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## List of Tables

# 1 Introduction

## 1.1 Always-on voice-control is (almost) everywhere

Always-on voice-control is already a standard feature in PCs, smartphones and now voice controlled smart speakers which double as home automation hubs. Voice-control does not require a screen, physical contact or a user's full attention, and the only sensor is a microphone or mic array. The on-board processor must recognize a wake-word (Amazon's *Alexa*, Apple's *Hey Siri*, Google's *Hey Google* or Microsoft's *Cortana*, etc.) but all further voice-recognition can be performed in the cloud. By all appearances, it is the ideal way to interact with a new class of omnipresent, unobtrusive, connected devices that are almost everywhere.

Yet they are *almost everywhere* but why not *everywhere*?

Until now, the standby power-consumption of Always-on Voice-control has been too high – it has limited it to devices which are connected to power outlets, or at least frequently charged. This means the devices want to reside by a power outlet for too much of the time to be everywhere. If you examine the architecture of the voice processing, the reason for the high power levels becomes clear.

The microphone and speech processor are always alert, always waiting for the wake-word - even when there is no sound to be heard, or a constant, unremarkable noise floor. This is wasteful and leaves a lot of room for power optimization. How do we put them to sleep when there is nothing of interest to hear? This type of optimization is needed to make battery power feasible for the Always on Voice device.

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## 1.2   Introducing ZeroPower Listening

What is *ZeroPower Listening*<sup>TM</sup> (ZPL)? It is a new power optimized architecture for Always on Voice systems which uses the Vesper Piezoelectric MEMS to operate as an ultra-low power sound detector. When a soundwave hits a piezoelectric cantilever, and makes it move, the motion creates a voltage via the piezoelectric effect. This voltage is sensed by a low current comparator circuit which turns on the microphone circuit and sends a signal to the DSP to turn on. The first product to implement this ZPL architecture is Vesper's VM1010 which has a Wake on Sound (WoS) mode. This application note describes how to use the VM1010 microphone and its WoS mode.

In *Normal* (or "full power") mode, the microphone has a current consumption of 85µA, and acts as a full bandwidth high performance MEMS microphone with a single-ended output. As with all Vesper mics, it has high immunity to dust and water exposure.

In *Wake-on-Sound* mode, the microphone has a current consumption of only 10µA. The analog output is disabled, but the mic is still monitoring the ambient sound level. If a sound is heard which exceeds the (pre-configured) Wake on Sound loudness threshold, the microphone sets the digital output pin high. This single bit digital pin acts as a wake-up signal for a voice-processor, readying it to record and process the incoming sound.

The low current draw and threshold adjustment features of the VM1010 microphone create a configurable, ultra-low-power "acoustic watchdog". While it stays alert, the entire signal chain – voice-processor, preamplifiers & data converters – can go to sleep. And when a sound arrives, the system springs to action.

In many applications, the VM1010 provides this ability with virtually zero power drain. The battery in a smartphone or portable speaker naturally dissipates ~200µA[1], even with no load. A (much smaller) smartwatch battery will drain ~20µA with no load. This battery self-discharge represents the theoretical maximum battery life of a device with zero power consumption. The VM1010's 10µA supply current therefore has minimal impact on this in-built drain, making a "ZeroPower Listening" architecture in terms of product battery life.

Example applications for the VM1010 include:

1.  As the only microphone in an always-on voice-control system – waking the Voice Processor and providing an analog audio signal.
2.  As an "acoustic watchdog" only – waking up the Voice Processor, which then records audio using a separate microphone array.

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[1] ~5%/month self-discharge of a 3000mAh Li-Ion battery (2% leakage + 3% protection-circuits drain)

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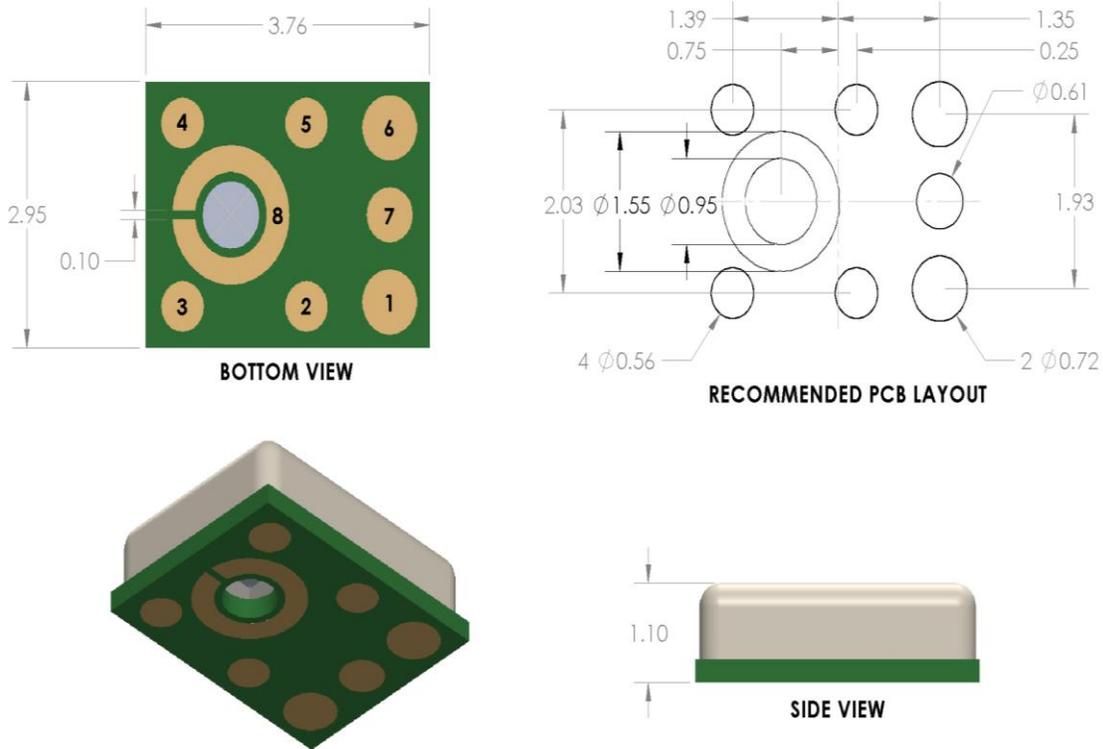77 Summer St, 8th floor
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## 2 Pinout & Pin Description



Figure 1: Mechanical drawing of VM1010 Microphone

| Pin Number | Pin Name | Description |
|---|---|---|
| 1 | $V_{out}$ | Analog Output Voltage |
| 2 | GA2 | Wake-on-Sound Acoustic Threshold Adjust pin 2 |
| 3 | GA1 | Wake-on-Sound Acoustic Threshold Adjust pin 1 |
| 4 | GND | Ground |
| 5 | mode | Mode control *(hi=Wake-on-Sound, lo=Normal-Power)* |
| 6 | $V_{dd}$ | Power Supply *(1.6V to 3.6V)* |

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NOV2018

| 7 | d$_{out}$ | Digital output for Wake-on-Sound trigger |
|---|---|---|
| 8 | GND | Ground |

Table 1: Pin Description for VM1010 Microphone

## 3  Microphone Modes

| mode pin | Mic mode | I$_{dd}$, typ. (µA) | V$_{out}$ pin | d$_{out}$ pin |
|---|---|---|---|---|
| high | Wake-on-Sound | 10 | GND | low, then latches high after first wake-up event |
| low or floating | Normal | 85 | audio output | Tied to GND through low impedance |

Table 2: Effect of mode pin on microphone mode, supply current & output pins

The VM1010 microphone switches between two modes, depending on the *mode* digital input pin. All digital pins use standard CMOS logic levels, scaled to V$_{dd}$.
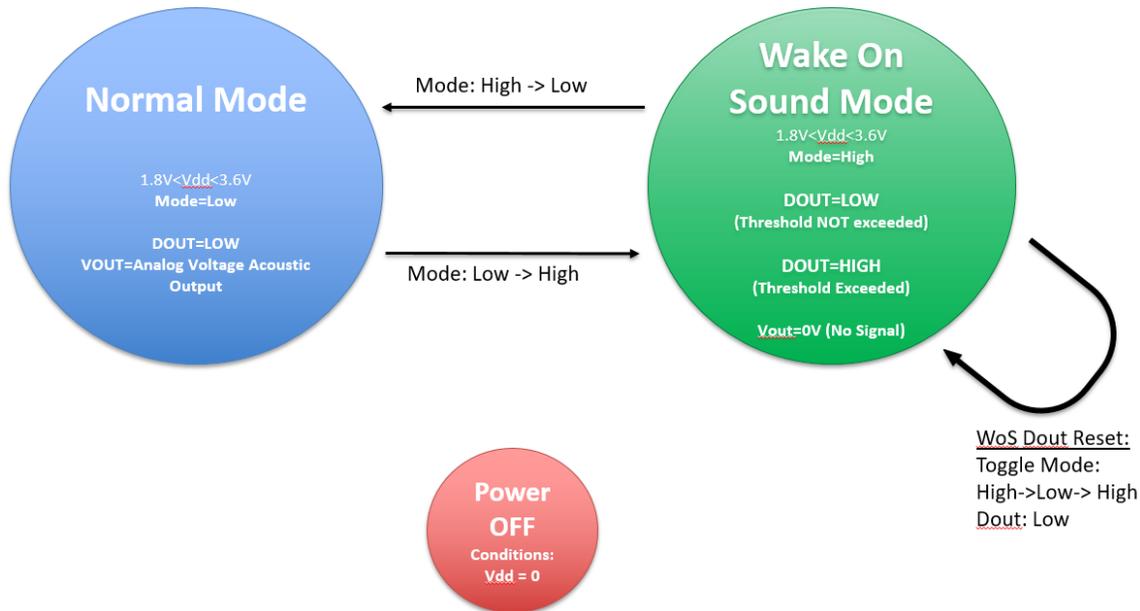
Figure 2: State diagram of VM1010 modes and relevant transitions

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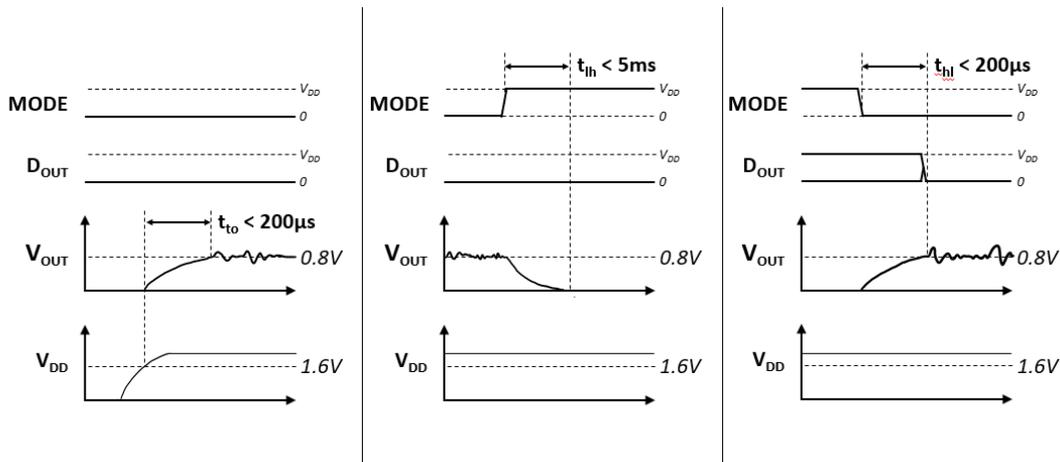Boston, MA - 02110

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Figure 3: Vout DC and Vdd level timing diagrams showing turn-on time (left), transition time into Wake-on-Sound mode (center) & Full-Power mode (right)

We recommend powering up the microphone in Full-Power mode (*mode* pin low), and then entering WoS mode (raising *mode*) as needed.
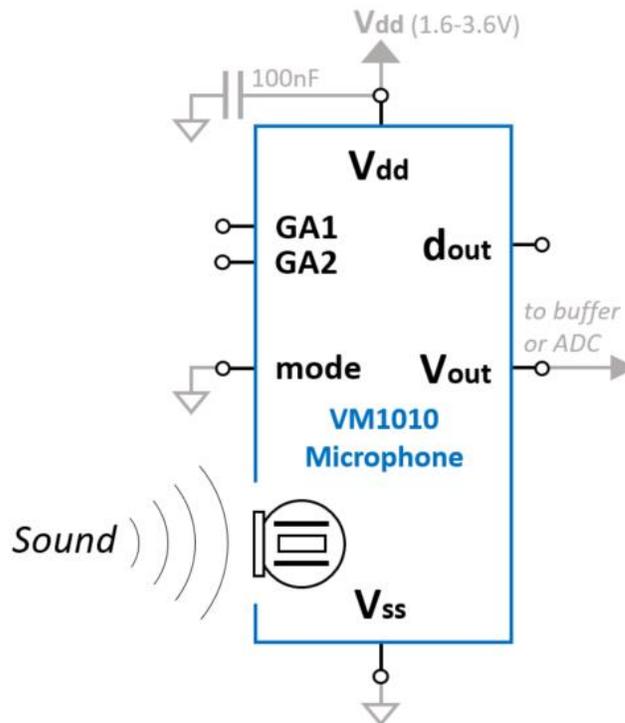
## 3.1   Normal Mode



Figure 4: VM1010 Microphone example circuit in Full-Power mode

With the **mode** pin low, the microphone is in Full-Power mode. It can be used like any other single-ended MEMS microphone.

In Full-Power mode, $V_{out}$ is biased at 0.8V. In Wake-on-Sound mode, $V_{out}$ is grounded. It is recommended to DC couple Vout to the input of the ADC or audio processor to avoid any audio artifacts when Vout goes from 0V to 0.8V.

| Specification | Typical value | Units |
|---|---|---|
| Sensitivity | -38 | dBV/Pa |
| Signal-to-Noise Ratio (20Hz-20kHz) | 60.5 | dB(A) |
| Acoustic Overload Point (10% THD) | 126 | dBSPL |
| Directivity | Omni | |
| Supply Voltage | 1.6 to 3.6 | V |
| Supply Current | 85 | µA |
| Output Impedance | 1 | kΩ |
| Output DC Offset | 0.8 | V |

Table 3: Specifications of VM1010 in Normal mode

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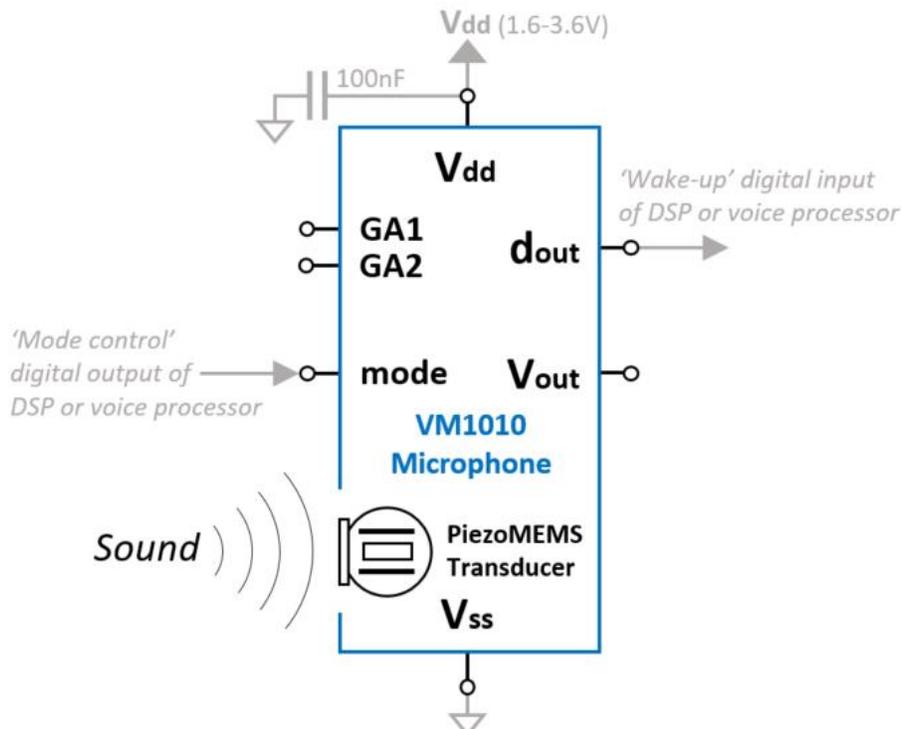NOV2018

## 3.2 Wake-on-Sound Mode



Figure 5: Minimal circuit for VM1010 microphone in Wake-on-Sound mode

With the *mode* pin high, the microphone is in Wake-on-Sound mode.

When first entering WoS mode, the $d_{out}$ pin is set to logic low. If the microphone signal exceeds the WoS threshold, $d_{out}$ latches to logic high.

After latching high, $d_{out}$ remains high until the microphone leaves WoS mode. Hence, the latch can be reset by toggling the *mode* pin to leave and re-enter WoS mode.

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| Specification | Typical value | Units |
|---|---|---|
| Digital logic levels (*mode, d$_{out}$*) | CMOS scaled to V$_{dd}$ | |
| Directivity | Omni | |
| Supply Voltage | 1.6 to 3.6 | V |
| Supply Current | 10 | µA |
| Default WoS threshold High-Z (open) between *GA1* & *GA2* | 89 | dBA |
| WoS minimum threshold 18kΩ between *GA1* & *GA2* | 65 | dBA |
| Max load capacitance at *GA1* | 5 | pF |
| Max load capacitance at *GA2* | 5 | pF |

Table 4: Specifications of VM1010 in WoS mode

In Wake on Sound mode, the microphone has a bandpass frequency response from 250Hz to 6kHz approximately. This allows the system to detect human voice successfully but reject wind noise, HVAC sounds, and other environmental signals and avoid false positives.

The WoS threshold is controlled by the resistance between pins *GA1* and *GA2*. If these pins are not connected (High-Z), the threshold defaults to 89dBSPL. Chapters 3.2.1 and 3.2.2 show how to adjust this threshold.

## 3.2.1 Note on Digital Logic Levels and Level Translation

The digital logic level of the VM1010 tracks Vdd where a Logic high is at least 0.65xVdd, and a logic low is a maximum of 0.35xVdd:

| Parameter | Symbol | Conditions | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|---|
| Logic Input High | | | 0.65*VDD | | 3.6 | V |
| Logic Input Low | | | -0.3 | | 0.35*VDD | V |
| Logic Output High | | $I_{Load}$ = 0.5mA | 0.7*VDD | VDD | | V |
| Logic Output Low | | $I_{Load}$ = 0.5mA | | 0 | 0.3*VDD | V |
| Driving Capability | | | | | 100 | pF |

Table 5: Digital Electrical Interface specification table

If you wish to use VM1010 at a higher voltage such as 3.3V to be compatible with a DSP or microcontroller running at that digital logic level then there is no major power penalty, Idd remains low for both Wake on Sound mode and Normal Mode:
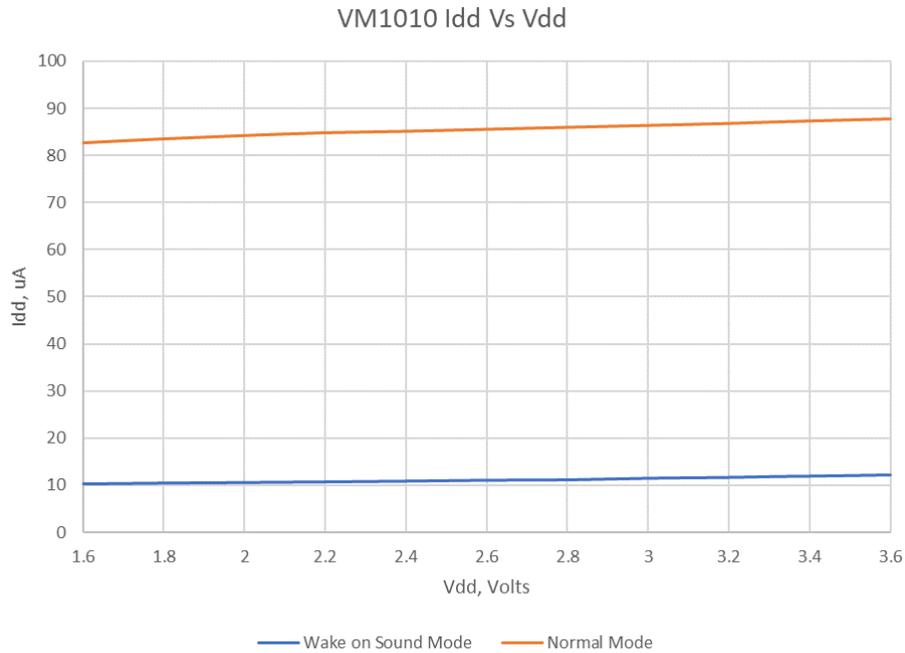
Figure 6: VM1010 Idd Vs Vdd

Correct logic level translation should be only done by using an active logic level translator. A resistor divider circuit to pull up or down voltage will not be a robust solution and may not activate Mode correctly or trigger a system correctly when Dout goes high.

### 3.2.2 Wake-on-Sound Threshold Configuration

The default WoS threshold is 89dBSPL and can adjusted by connecting a resistor between pins *GA1* and *GA2*. As can be seen in Figure 6, these pins provide access to the feedback network of an instrumentation amplifier in the WoS signal path:
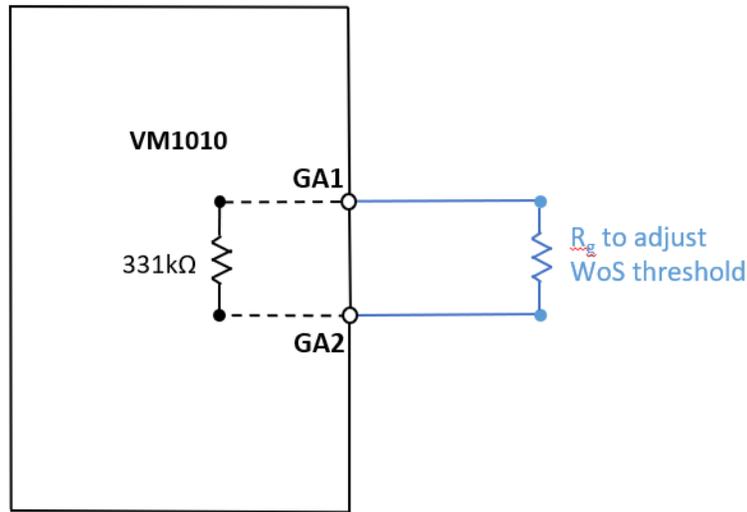
Figure 7: Fixed adjusted WoS threshold, implemented with external resistor (Rg) between GA1 and GA2 pins

The smaller the resistor between *GA1* and *GA2*, the higher the gain of the instrumentation amplifier. The resulting WoS threshold follows this formula:

$$WoS\ threshold = \left[89 - 20 \cdot \log_{10}(1 + \left(\frac{331k\Omega}{Rg}\right))\right] dBSPL$$

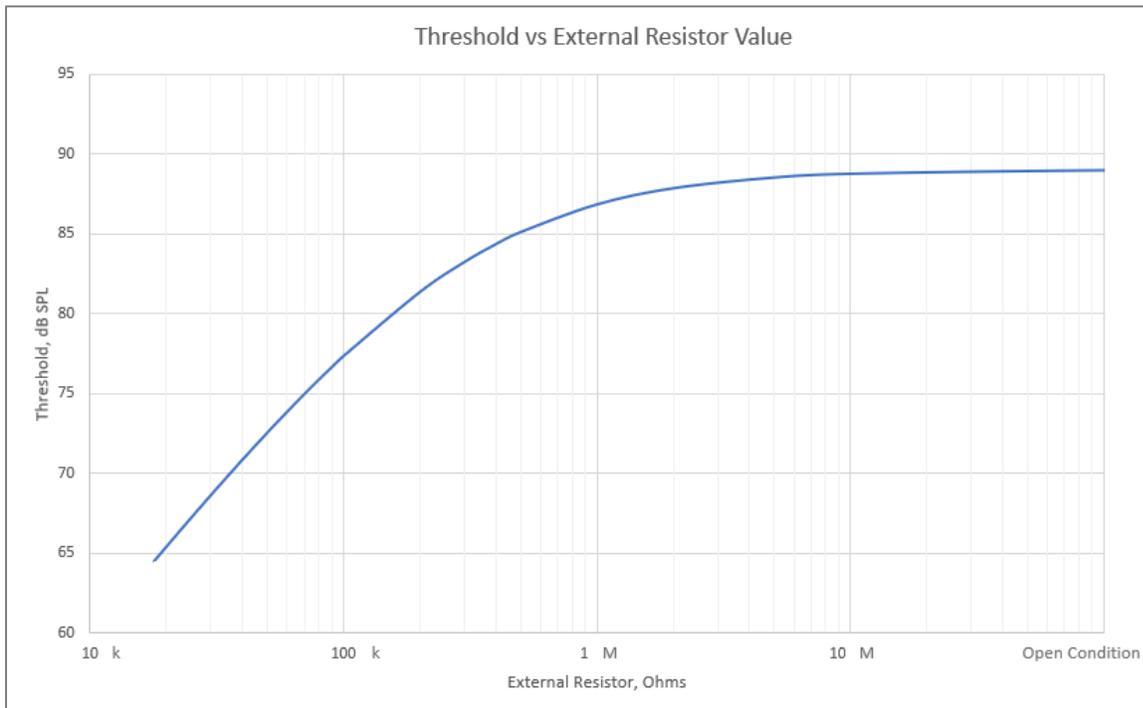This formula holds true to a minimum threshold of 65dBSPL, as shown in Figure 7:

Figure 8: Graph of WoS threshold versus external gain resistor (Rg)

As stated in Table 4, the *GA1* and *GA2* pins can each tolerate a maximum load capacitance of 5pF to GND. Therefore, it is best practice to keep the wires connecting $R_g$ to *GA1* and *GA2* as short as possible.

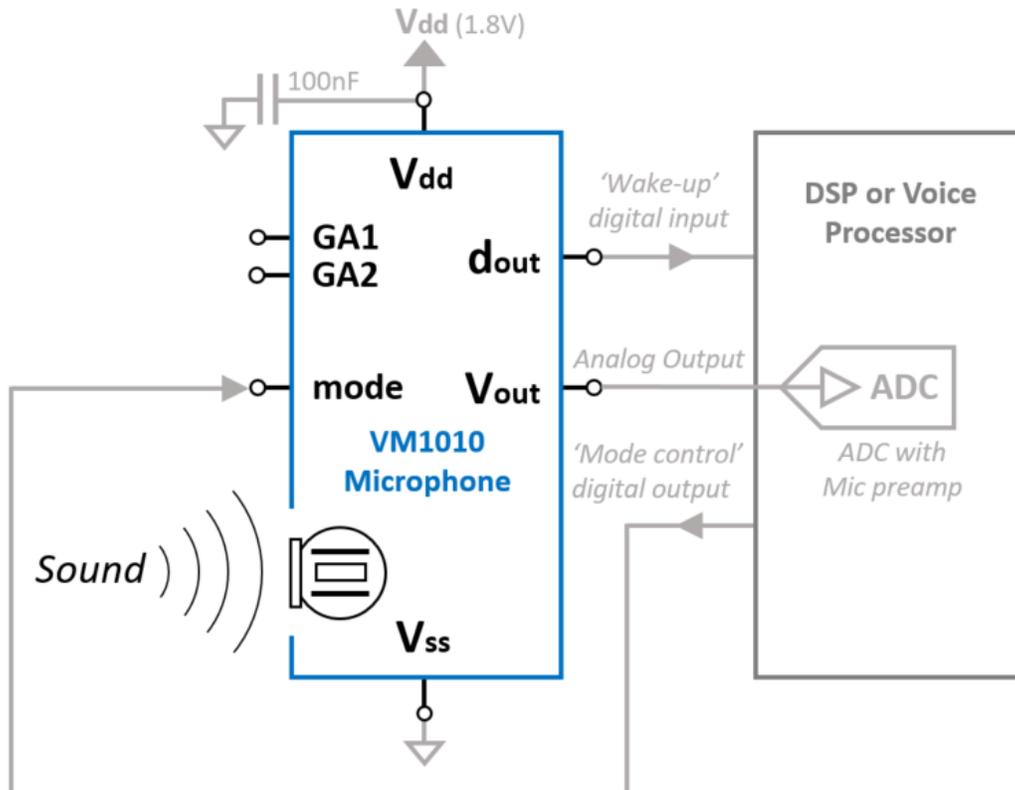# 4 System architecture

## 4.1 Control Loop for Wake-on-Sound



Figure 9: Block diagram of full-featured system built around VM1010 microphone

Figure 8 shows a full-featured system built around the WoS microphone. As the WoS microphone wakes up the system when triggered by sound, the DSP or Voice Processor can be kept in a low-power state when there is no sound to process.
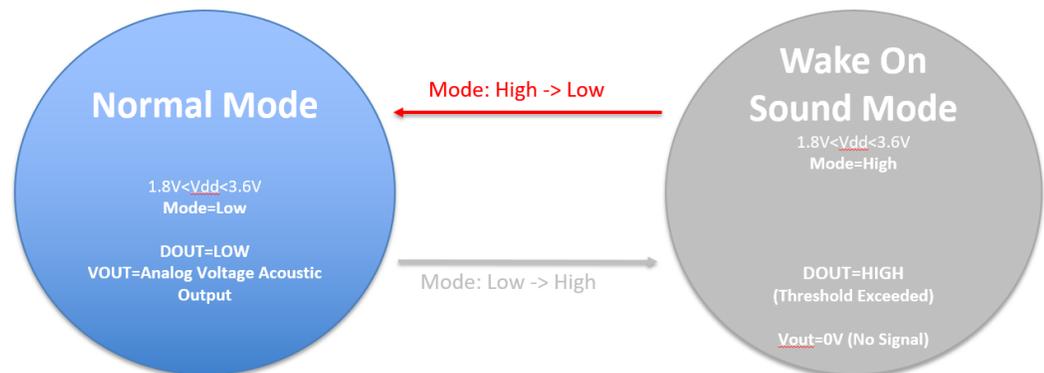
Here is an example control loop which can be built around this system architecture:
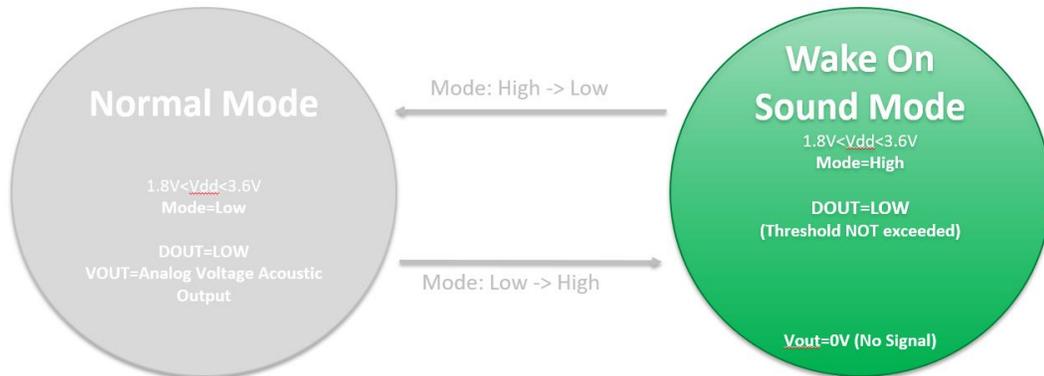
1. Microphone is in WoS mode with *mode* high. Voice Processor is in a low-power state, with $d_{out}$ set up as a hardware interrupt pin.
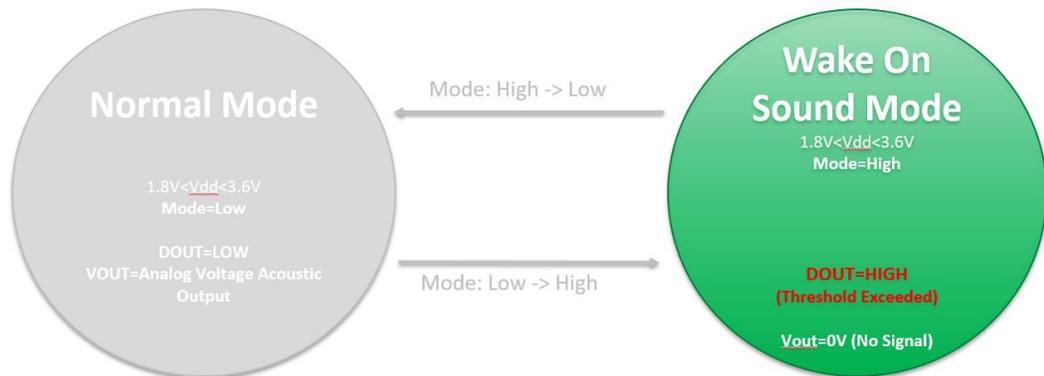


2. A sound is heard above the threshold, **d$_{out}$** transitions from low-to-high, which wakes up the Voice Processor.

3. The Voice Processor pulls the **mode** pin low to enable Normal mode. $V_{out}$ is enabled and it sends analog audio to the ADC. The Voice Processor captures & analyzes this audio for wake-words and responds appropriately.
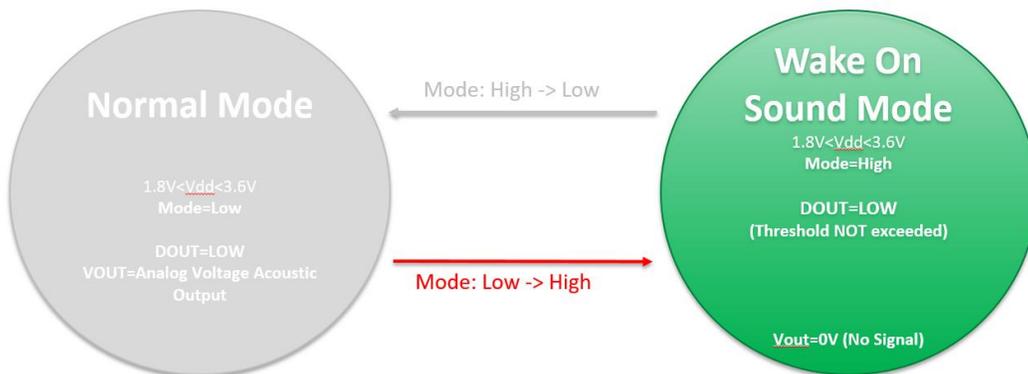


4. The Voice Processor continues responding to sounds until the scene is quiet again. Then the Voice Processor sets the **mode** pin high (putting the mic back into WoS mode) and enters a low-power state.

In a quiet scene, the system will spend most of its time in Step 1, where the Voice Processor is in a low-power state and the microphone is only drawing 10µA. In louder scenes, the Voice Processor can place a larger resistor between **GA1** & **GA2** to raise the WoS threshold above the noise floor. Many use-cases do not require all the blocks in this architecture, such as an ADC with built-in mic preamplifier

The VM1010 can be used as an 'acoustic watchdog' next to an array of other microphones
   o   The other microphones are used for analog capture
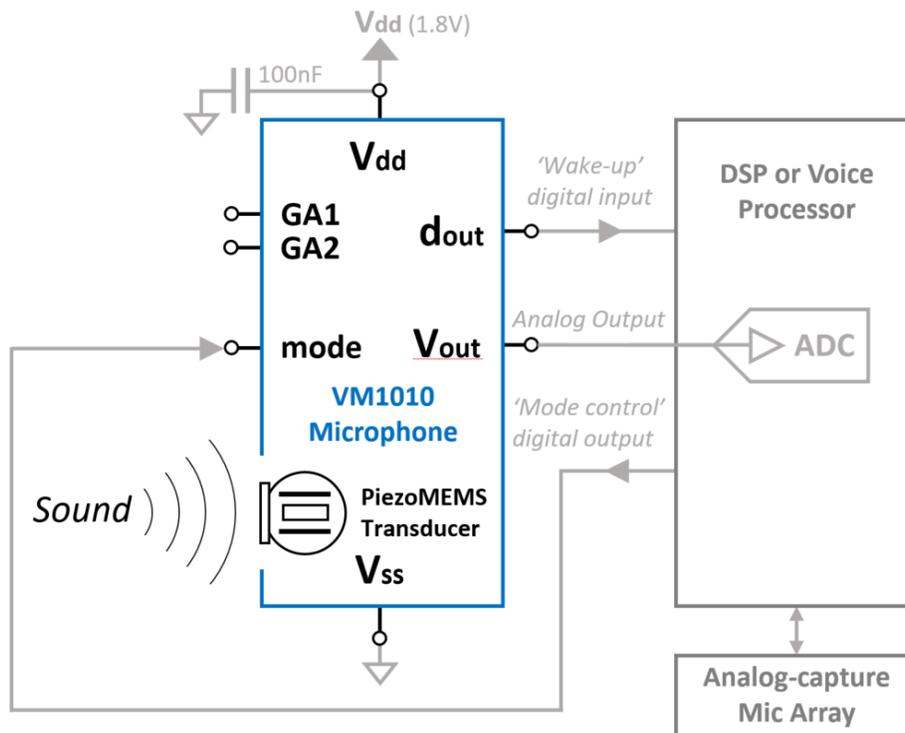   o   WoS microphone only used for waking from sleep

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Figure 10: Block diagram of system using VM1010 microphone as 'acoustic watchdog' only

## 4.2 Vesper Wake on Sound Hardware

Vesper have designed hardware for customers to evaluate Zero Power Listening. There are two types:

- o VM1010 Evaluation PCB
- o VM1010 Zero Power Listening Development Kit

## 4.2.1 VM1010 Evaluation Board

The VM1010 Evaluation board provides the basic circuitry needed to evaluate Zero Power Listening. It has a current monitor chip to allow simple validation of current levels and has different solder options for threshold level.



Figure 11: Vesper's VM1010 Zero Power Evaluation Board (VM1010 microphone seen at the center)

## 4.2.2 VM1010 Zero Power Listening Development Kit

The VM1010 Zero Power Listening Development Kit is a board is built on a DSP Group DBMD6 development platform. It is designed to keep the VM1010 microphone in WoS mode, waiting for an acoustic trigger. Upon triggering, the DBMD6 sets the VM1010 into Normal mode and streams the audio into the processor. The DBMD6 carries out local keyword detect and then can go into a higher performance mode (which in turn can stream audio to the cloud for command processing) or else perform general tasks via the GPIO pins.
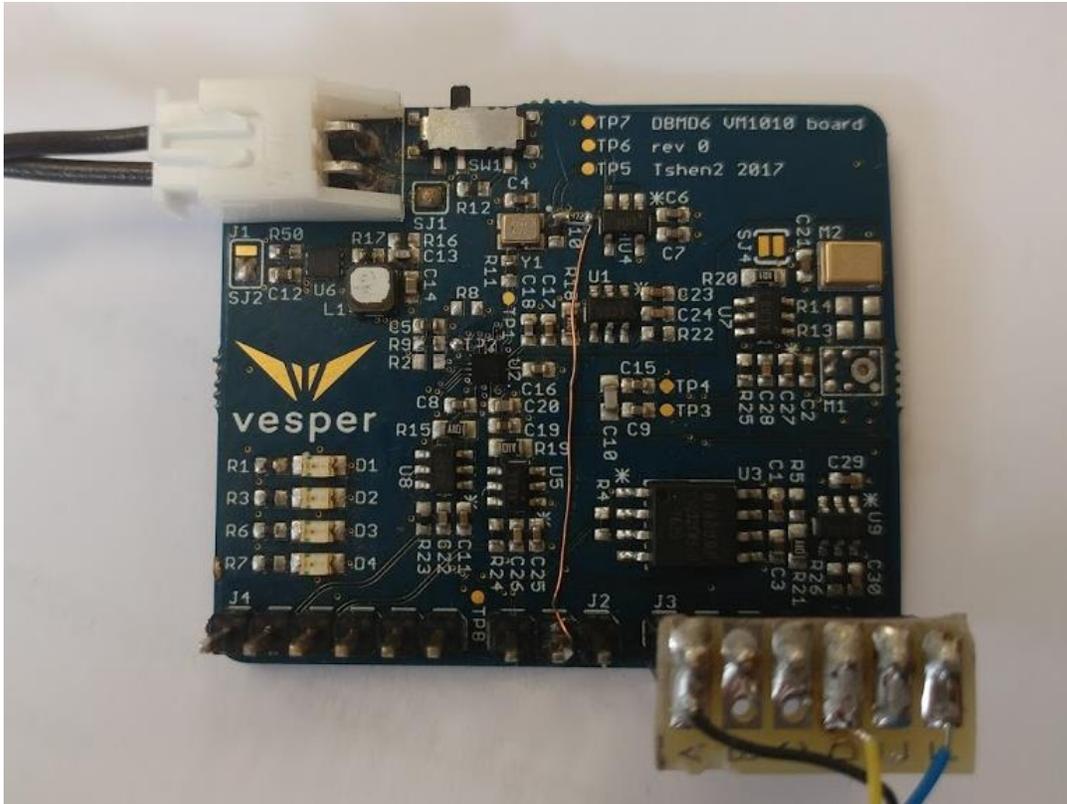
Figure 12: Vesper's VM1010 Zero Power Listening Development board (VM1010 Microphone seen at top right)

For additional information on Vesper's latest roadmap of microphone products, reach out to info@vespermems.com.