



# Audio Sensor Enabled Devices & Use Cases

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#### Introduction



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- InvenSense: Microphone Product Applications Engineer
- Analog Devices: Microphone, SigmaDSP Applications Engineer

#### Education

- Completing MEng in Acoustics from Penn State University
- BSEE from Penn State University



### Agenda



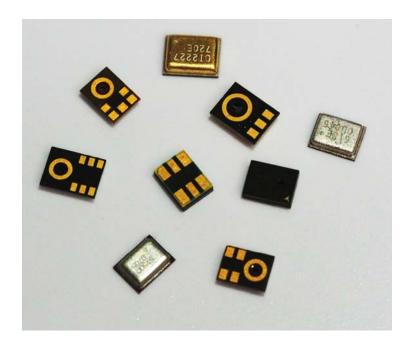
Cover the technical aspects of microphone-based applications, including voice control, microphone arrays, and unique use cases

- Emergence of Voice Control
- Designing with Microphone Arrays
- Specific Microphone Use Cases

### **Ubiquitous microphones**



- Capture voice from anywhere
  - From across the room
  - On your remote control
  - On your wrist
  - In your car
- Listen to the environment
  - Fault detection
  - Occupancy sensing
  - Noise reduction/cancellation



### **Ubiquitous voice control**

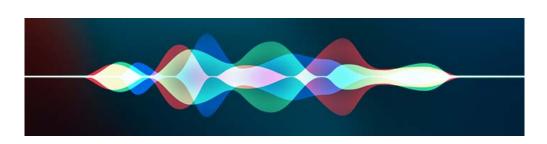


Voice control is becoming ubiquitous in IoT/Smart home devices











### Microphones for voice control



### Arrays of omnidirectional mics are used for many voice control applications

- Enable directional pickup
- Beamforming/beamsteering

### The best mics in these arrays feature:

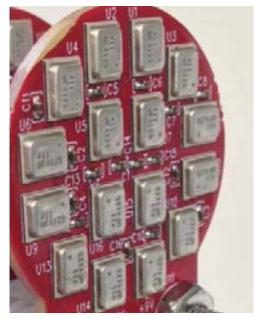
- High SNR
- Tight sensitivity matching



### **High SNR: Summing Omni Mics**



- Mic Summing = higher SNR, still omni (mostly)
  - Every doubling of mics of same SNR provide additional ~3dB SNR when used in an array
  - Example: 2 x 65 dB SNR Mics = Mic Array with 68 dB SNR
- High SNR mic arrays yields even better
  - Example: 2 x 65dB SNR Mics = Mic array with 68dB SNR!
- If better SNR is main goal, mics are placed as closely together as possible
- High SNR array stays omnidirectional





Omnidirectional Mic Polar Response

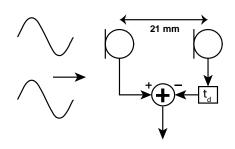
### **High SNR Array: Beamforming**



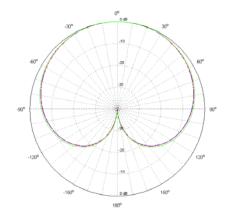
- Beamforming
  - To achieve directionality, beamforming uses multiple mics to "shape" area of highest response from mic



- Cardioid response pattern
- Reduces gain of sound picked up from behind mic – effective increase in SNR!
- Beamforming benefits from highest SNR mics available
  - Beamforming reduces measured SNR but increases directional gain



2-mic endfire array

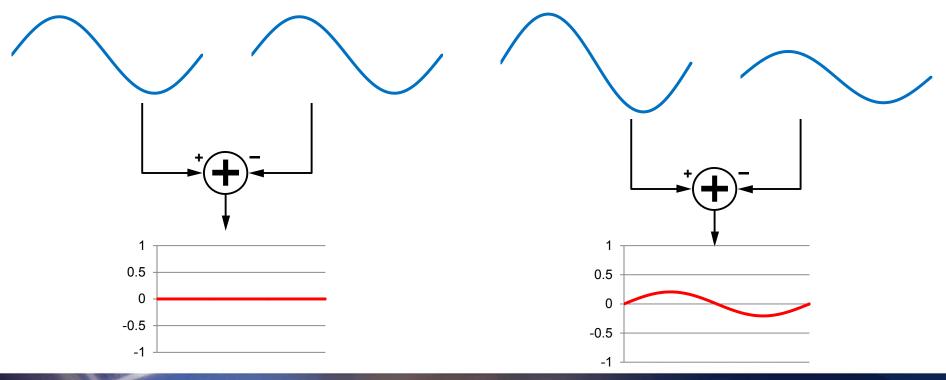


Directional array response

## **Sensitivity Tolerance & Microphone Arrays**



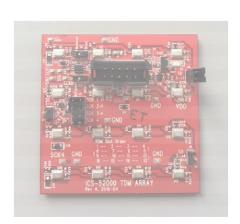
- Sensitivity Tolerance
  - The variation from the nominal sensitivity that will be seen across all mics
  - ±3 dB was common, but most new mics have a ±1 dB tolerance
- Tighter sensitivity matching leads to better beamforming array performance
- Algorithms perform best when all mics in an array have identical sensitivity and response



### **TDM Microphone Arrays**

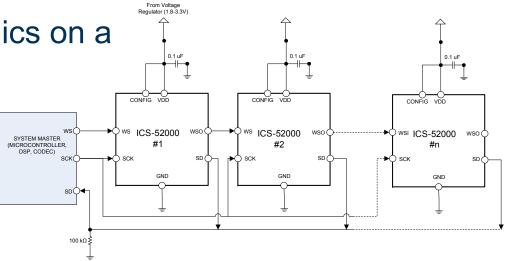


- Enable high-performance beamforming arrays
  - Ease of system design no discrete ADCs needed
  - Acoustic capture is completely synchronized



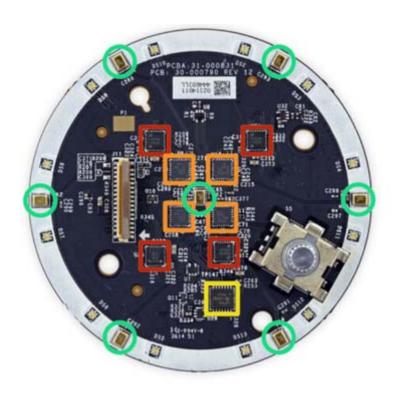
16x ICS-52000 demo board

- ICS-52000
  - Daisy-chain up to 16 mics on a common TDM bus
  - 65 dB SNR



#### System Optimization with TDM



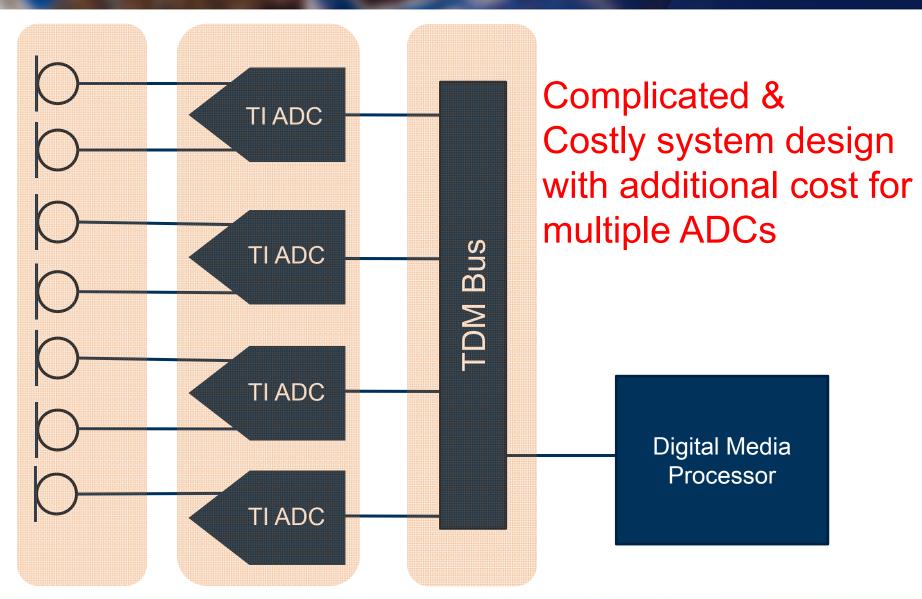


- Texas Instruments LP55231 Programmable
   9-Output LED Driver (x4)
- Texas Instruments TLV320ADC3101 92dB
   SNR Low-Power Stereo ADC (x4)
- Texas Instruments SN74LVC74A Dual
   Positive-Edge-Triggered D-Type Flip-Flops
- \$1053 0090 V6 Microphone (x7)
- Texas Instruments DM3725CUS100
   Digital Media Processor

Amazon Echo Teardown

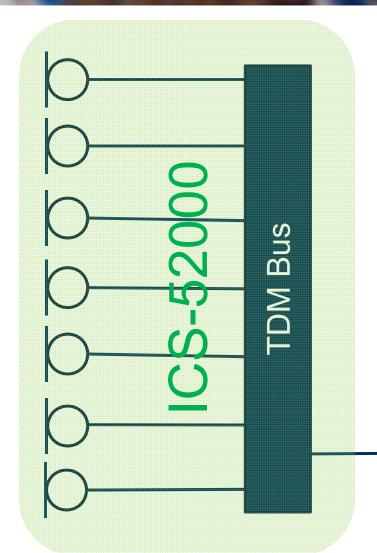
#### System design without ICS-52000





### System Optimization with ICS-52000





#### **Optimized Configuration**

- No additional cost for ADCs
- Simplest system design
- Single interface to host
- 100% synchronized data sampling

Digital Media
Processor

### **Microphone Applications**



- Voice/Keyword detection
- Far Field Speech recognition
- IoT Home Appliance
- Photoacoustic Gas Sensor
- Acoustic Activity Detection
- Active Noise Cancellation
- Drones

### Application: Voice/Keyword Detection



- A microphone can wake up the system based on voice detection or recognizing a specific keyword
- Main processor and radios can be put to sleep until the keyword is detected



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### Application: Voice/Keyword Detection



- Key specs:
  - Low power
  - Low noise & distortion for best performance of speech recognition
- ICS-40618, ICS-41350, ICS-43434 have high SNR and low-power modes to enable always-on operation



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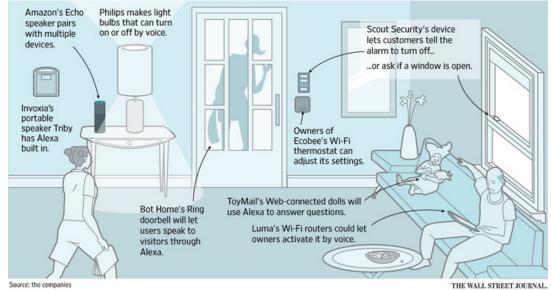
### Application: Far Field Speech Recognition



Home voice assistant appliances, like Google
Home and Amazon Echo, use microphone arrays to
accurately recognize voice commands from
anywhere in a room

#### 'Alexa, Can You Please...'

Amazon's voice-recognition software works with several household devices.

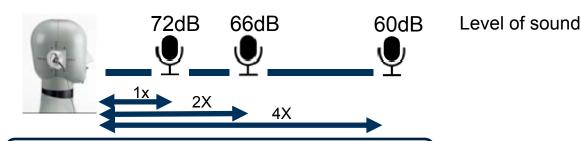




WSJ, May 16, 2016

### Far Field Voice Capture





6 dB of SPL drops when distance doubles

Higher input gain is needed to compensate for softer input signal – raising the noise floor

High SNR microphone keeps noise level low to enable pleasant communication



Lower SNR microphone noise level boosted and create unpleasant communication experience



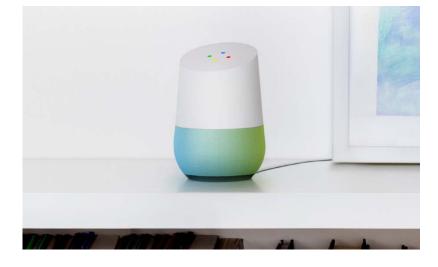
### Application: Far Field Speech Recognition



- Key specs:
  - Low noise/high SNR
  - Tight matching of sensitivity and response between mics
- ICS-40720 is the highest-SNR (70 dB) MEMS mic on the market, enabling far-field voice control

ICS-52000 enables large high-performance arrays

of microphones



### **Application: IoT Home Appliance**



- IoT devices use mics for voice control, recording, security
  - Thermostats
  - Home cameras
  - Lightswitches/bulbs
  - Home security
  - Glass break detection







### **Application: IoT Home Appliance**



- Key specs:
  - Simple interface to system processor these applications often are listen-only
  - Low power (if battery-powered)
- ICS-43434 is the lowest-power I<sup>2</sup>S mic, enabling long battery life, and can interface directly to the digital system processor without an audio codec





### **Application: Photoacoustic Gas Detection**



- Why?
  - Monitoring levels of certain gasses (i.e, CO<sub>2</sub>) in a room can help a smart home to decide whether to circulate air
- What does this have to do with microphones?
  - Specific gasses have an acoustic signature when excited with certain frequencies of light

Listening for these acoustic signatures indicate the

presence of specific gasses

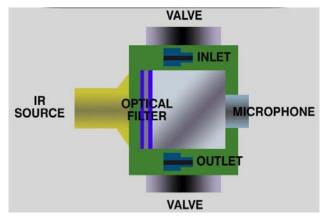


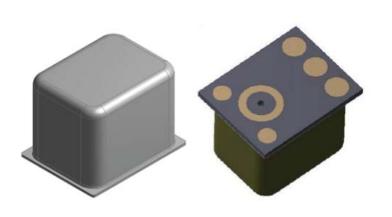
Diagram by MSA

### **Application: Photoacoustic Gas Detection**



#### Key Specs:

- Low noise the detected signals are not loud
- Good low-frequency response the acoustic signature of many of these gasses is sub-sonic (<20 Hz)</li>
- Recommended mics
  - The ICS-40300 has a low frequency corner of 6 Hz and a 63 dB SNR



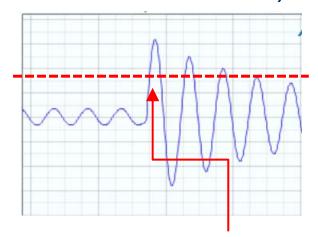


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### **Application: Acoustic Activity Detection**



- Environmental acoustic activity can be used as a trigger to wake up the rest of the system
- How with mics?
  - When the mic's output level exceeds a certain threshold in a specific frequency band, the always-on part of the system can trigger the rest of the system (main processor, Wi-Fi/BT radios) to wake up.



System wakes up

### **Application: Acoustic Activity Detection**



- Key specs:
  - Low power for Always-On operation
- Recommended microphones with low-power modes
  - Analog: ICS-40618/9, 55 μΑ
  - PDM: ICS-41350, **185** μA
  - I<sup>2</sup>S: ICS-43434, **230** μA

### **Application: Active Noise Cancellation**



#### Headphones

 Many ANC headphones use at least 4 mics (2 in ear cup, 2 external) for noise cancelling

#### Automotive

- Reduces road & engine noise for in-cabin comfort
- Enables more accurate in-cabin voice control





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### **Application: Active Noise Cancellation**



- Key specs:
  - Well-matched response (gain & phase) from mic to mic enables higher levels of noise reduction gain
  - Low noise, especially at low frequencies

 ICS-40618/9 have 67 dB SNR and ±1 dB sensitivity tolerance



### **Application: Drones**



- Many drone controllers are including microphones for recording voice over the video recording
- Mics on a drone is a very challenging acoustic environment





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### **Application: Drones**



- Key specs:
  - Well-matched response from mic to mic
    - Enable array processing for clear far-field capture
    - Higher-order beamforming is necessary to reduce drone noise in recordings
  - High AOP to prevent clipping from wind noise and loud motors

 ICS-40618/9 (analog), INMP621 (PDM) have high AOP (>130 dB SPL)



#### Conclusion



- Voice and Audio is emerging as an ubiquitous interface for controlling devices
- High performance microphones enable these applications
  - High SNR
  - Low Power
  - Wide Dynamic Range



### **Thank You**

