REMOTE ACOUSTIC URBAN SENSING - 04/03/17

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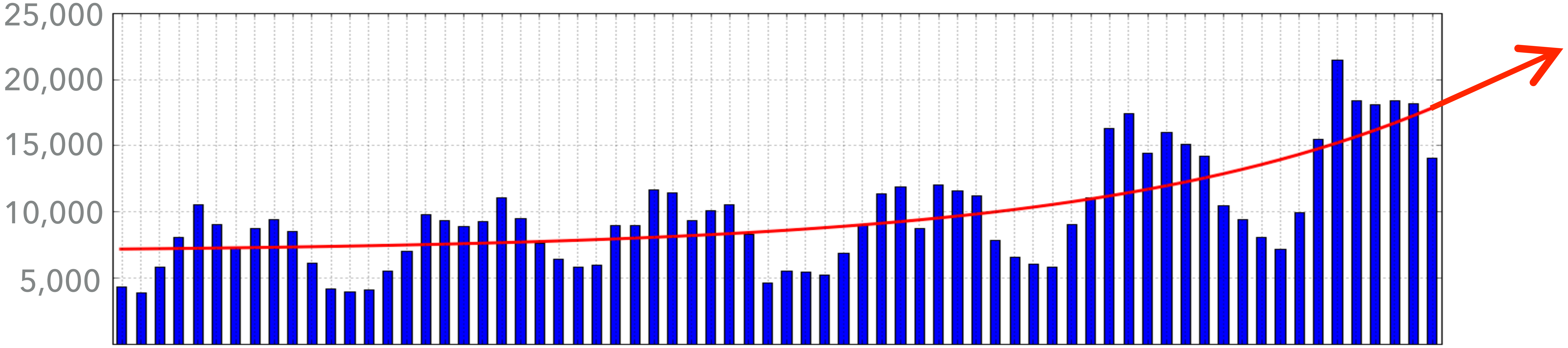
- **Noise monitoring** - why noise? sounds of new york city
- **Sensing sound** - what can we use? what are we sensing? what are the metrics?
- **Calibration** - how do we collect accurate data? what happens over time?
- **Sampling** - how do we digitize sound data?
- **Frequency** - what frequencies matter? how do we hear?
- **Analysis** - how do we handle sound data?

WHY NOISE?

Estimated 9 of 10 adults in NYC exposed to HARMFUL levels of NOISE

Over 3.4 MILLION complaints since 2003 [based on 311 data]



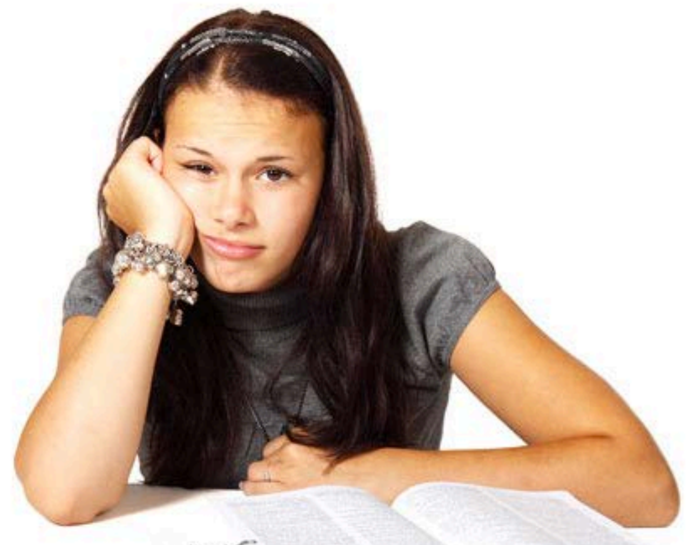
Complaints per month since 2010

SLEEP LOSS

HEARING LOSS

PRODUCTIVITY

LEARNING IMPAIRMENT



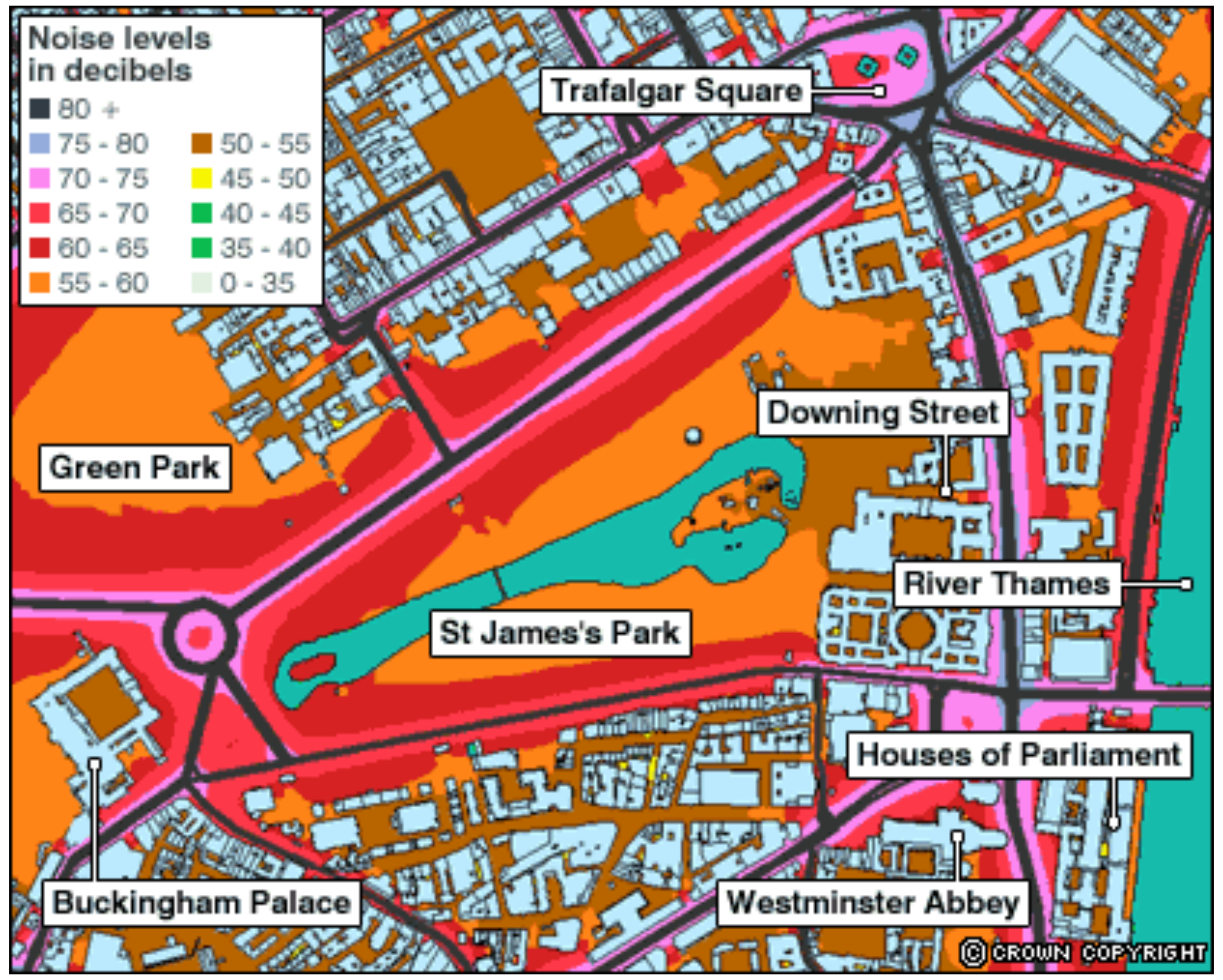
STRESS

NOISE SURVEYING

NOISE SURVEYING

Expensive equipment

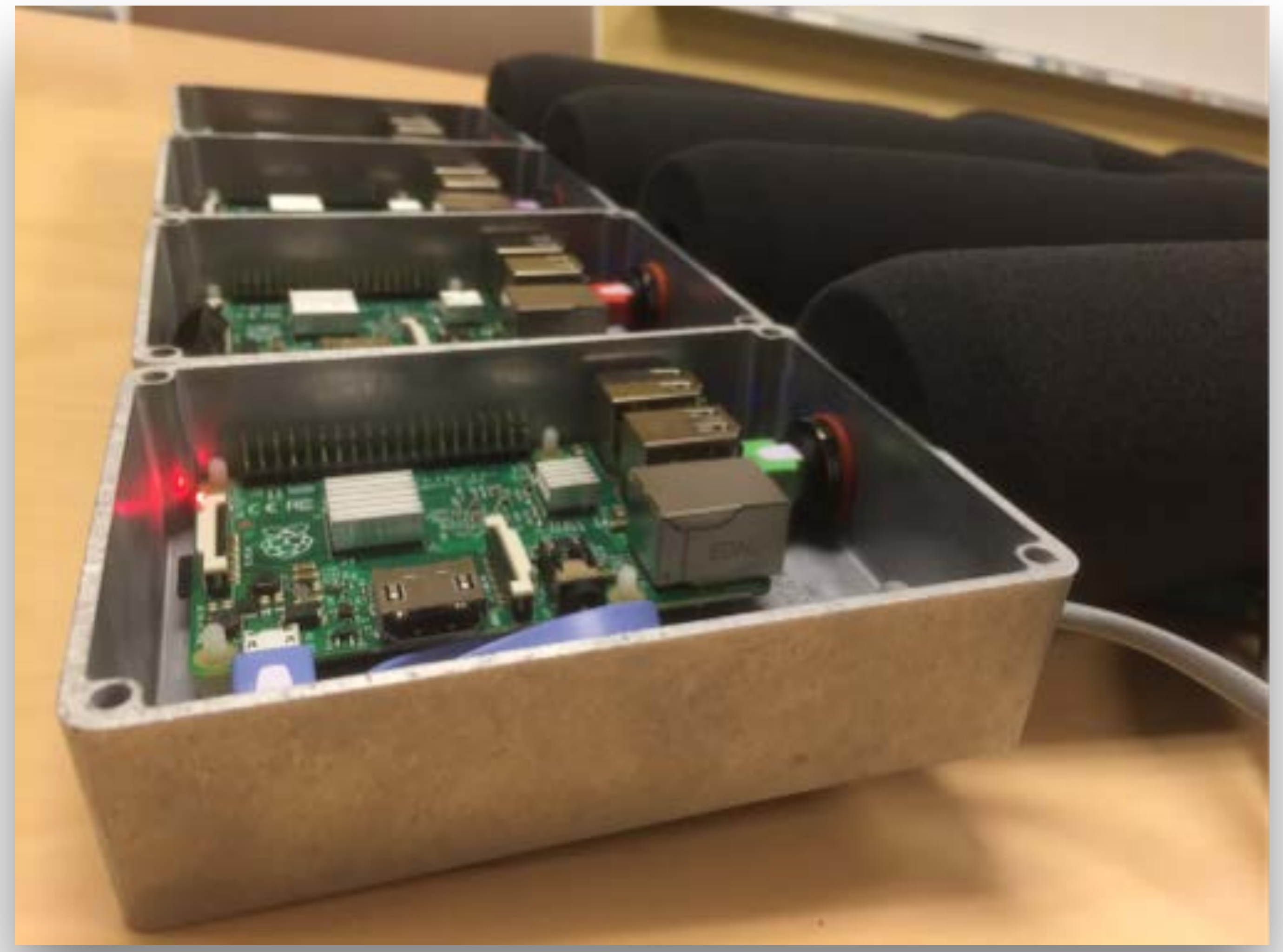
Expensive people



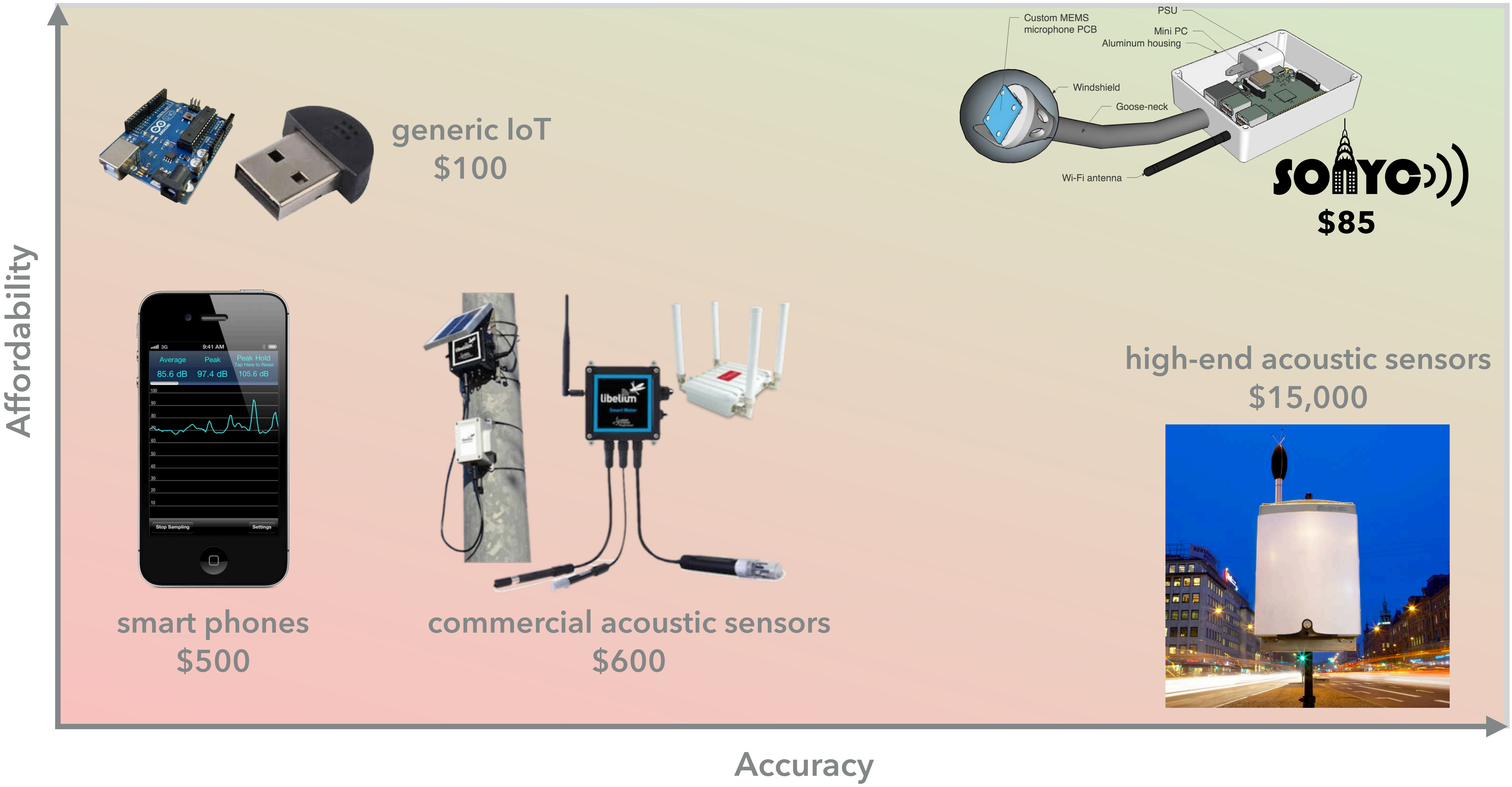
Inadequate data

SONYC — ACOUSTIC SENSING DEVICES

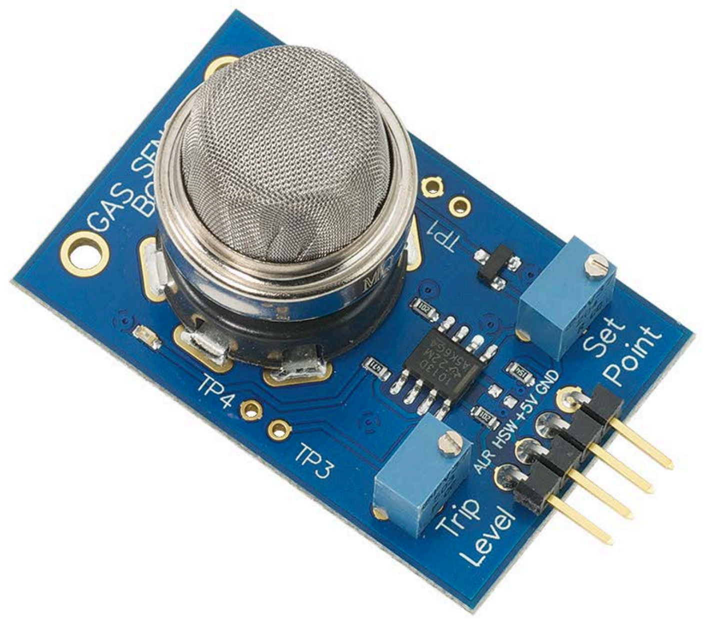
- Design focussed on:
  - Accuracy
  - Low cost
  - Resilience
  - Scalability

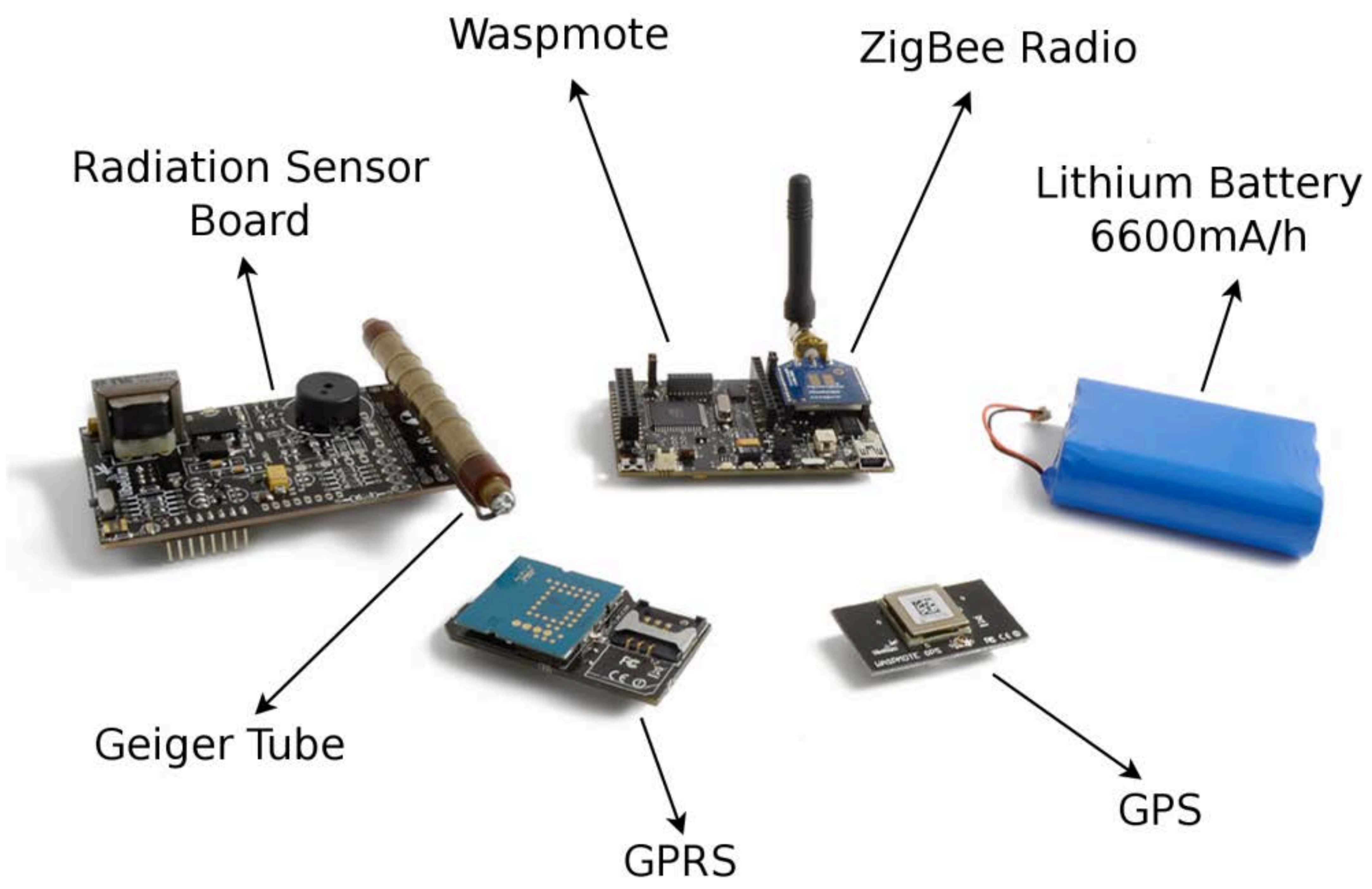


SONYC — ACOUSTIC SENSING DEVICES

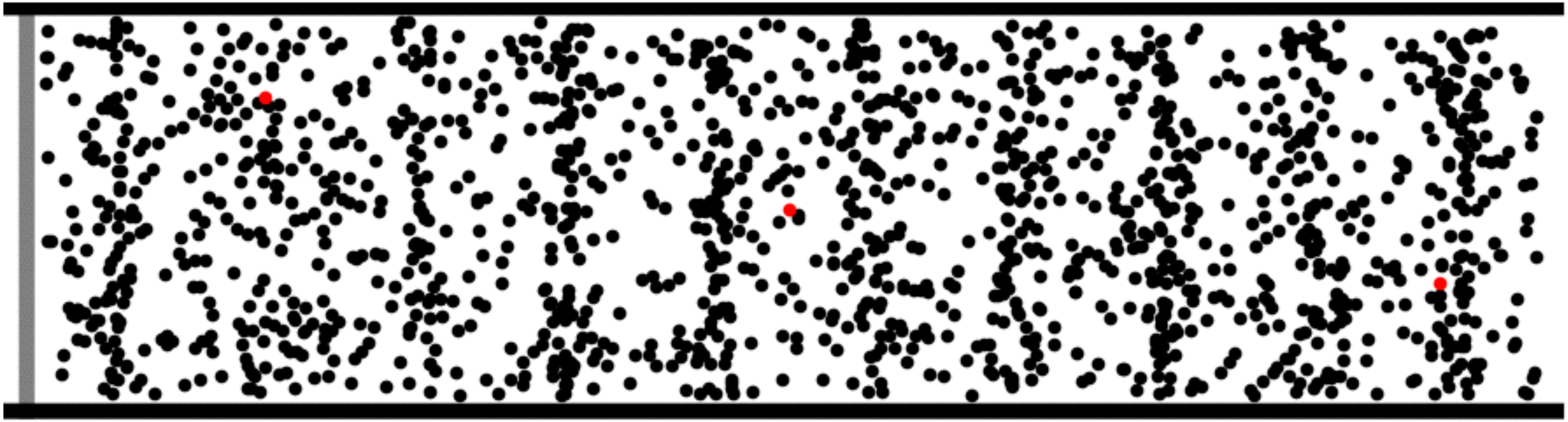


- **Sensor** - a device that converts some physical phenomenon into an electrical signal
- **Transducer** - a component that converts one type of energy into another type of energy





Sound is the energy transferred when something vibrates in a medium



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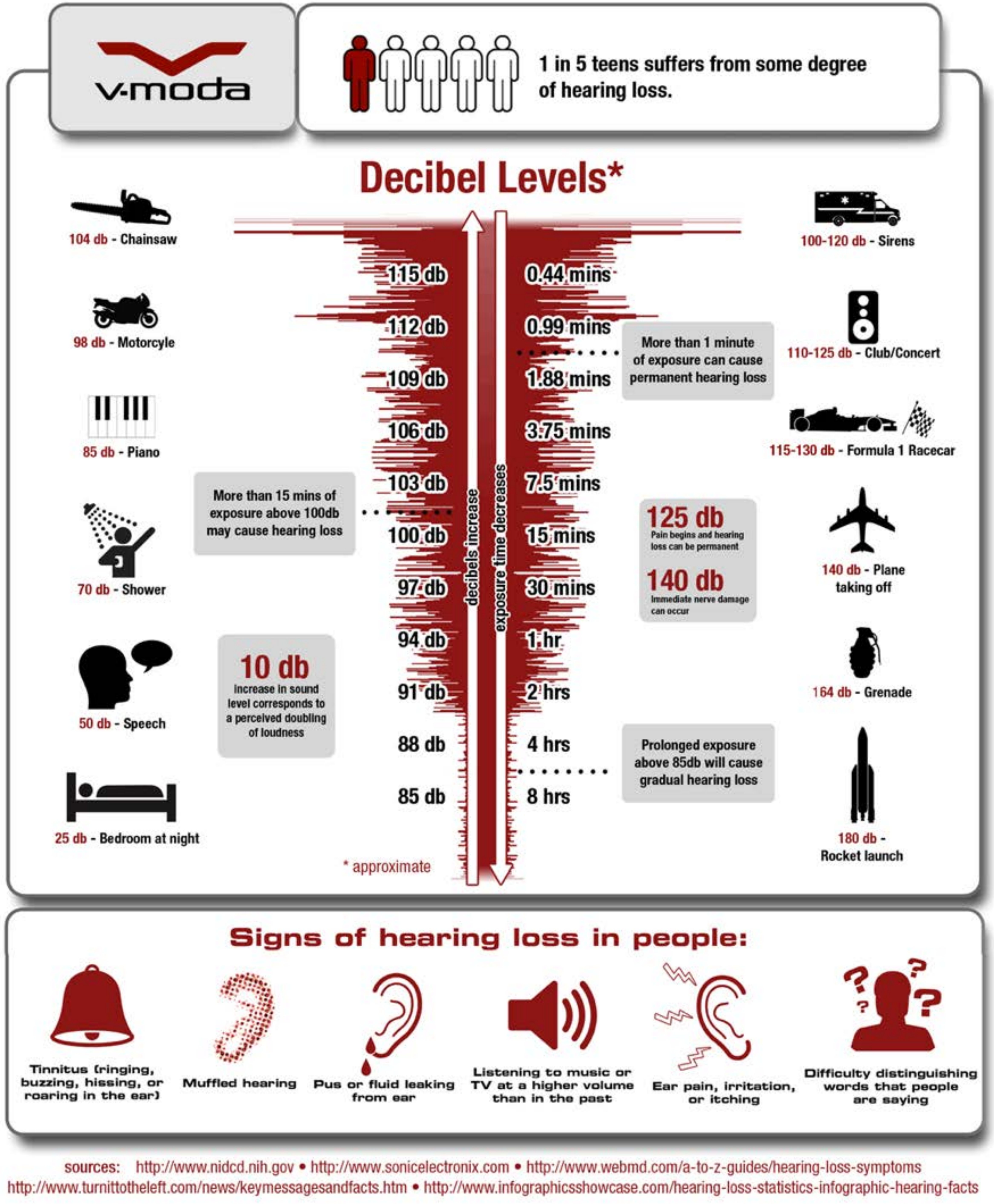
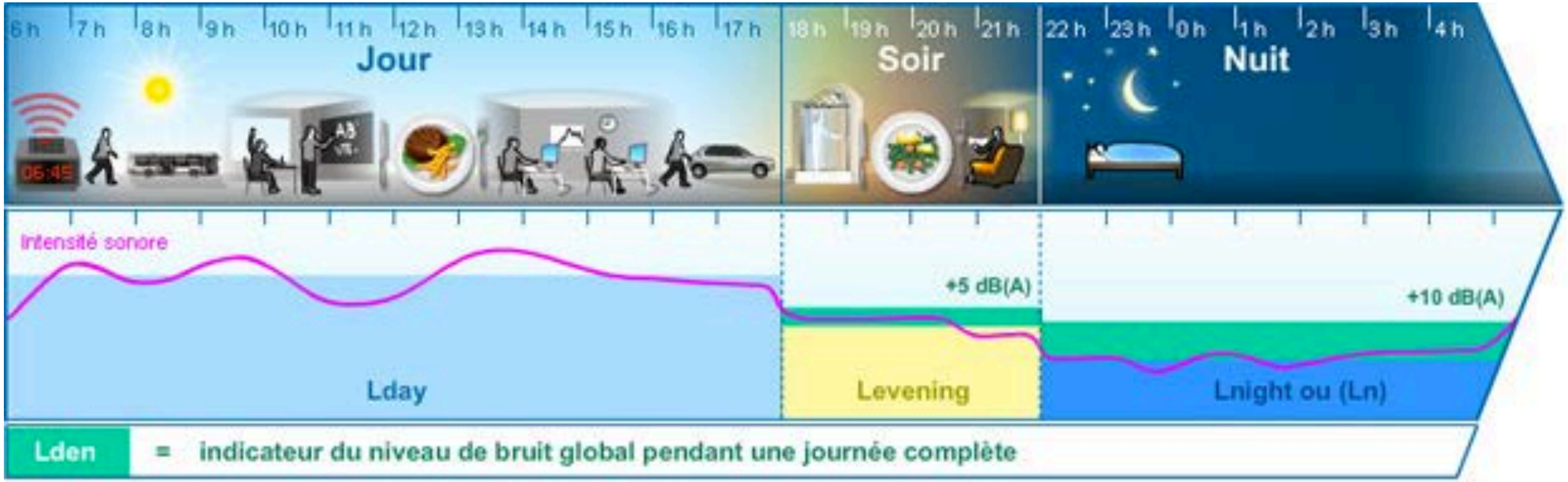
SOUND PRESSURE LEVEL

- Our ears response to sound pressure is ~log10
- A 3dB increase doubles sound intensity
- For example:
  - 10dB is x10 more intense than 1dB
  - 20dB is x100 more intense than 1dB
- Sound pressure level in dB is a log10 ratio relative to the threshold of hearing:

$$20 \log_{10} \left(\frac{p}{p_0} \right) \text{ dB}$$

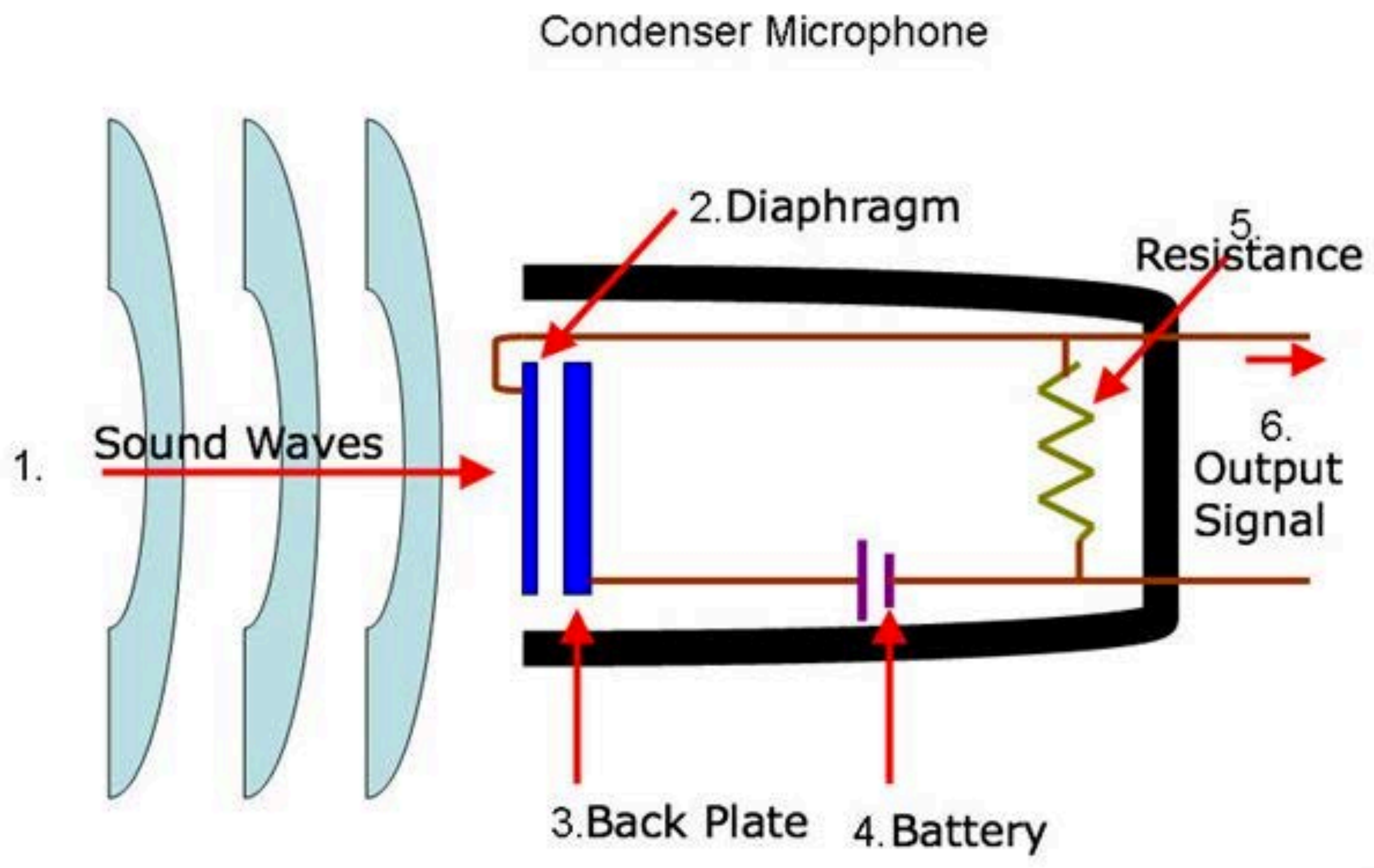


- Average equivalent sound pressure level over a 24 hour period
- Penalty added to reflect the increased impact of noise at different times of the day
- 5dB(A) added during the evening hours of 18:00 – 22:00
- 10dB(A) added during the nighttime hours of 22:00 – 07:00



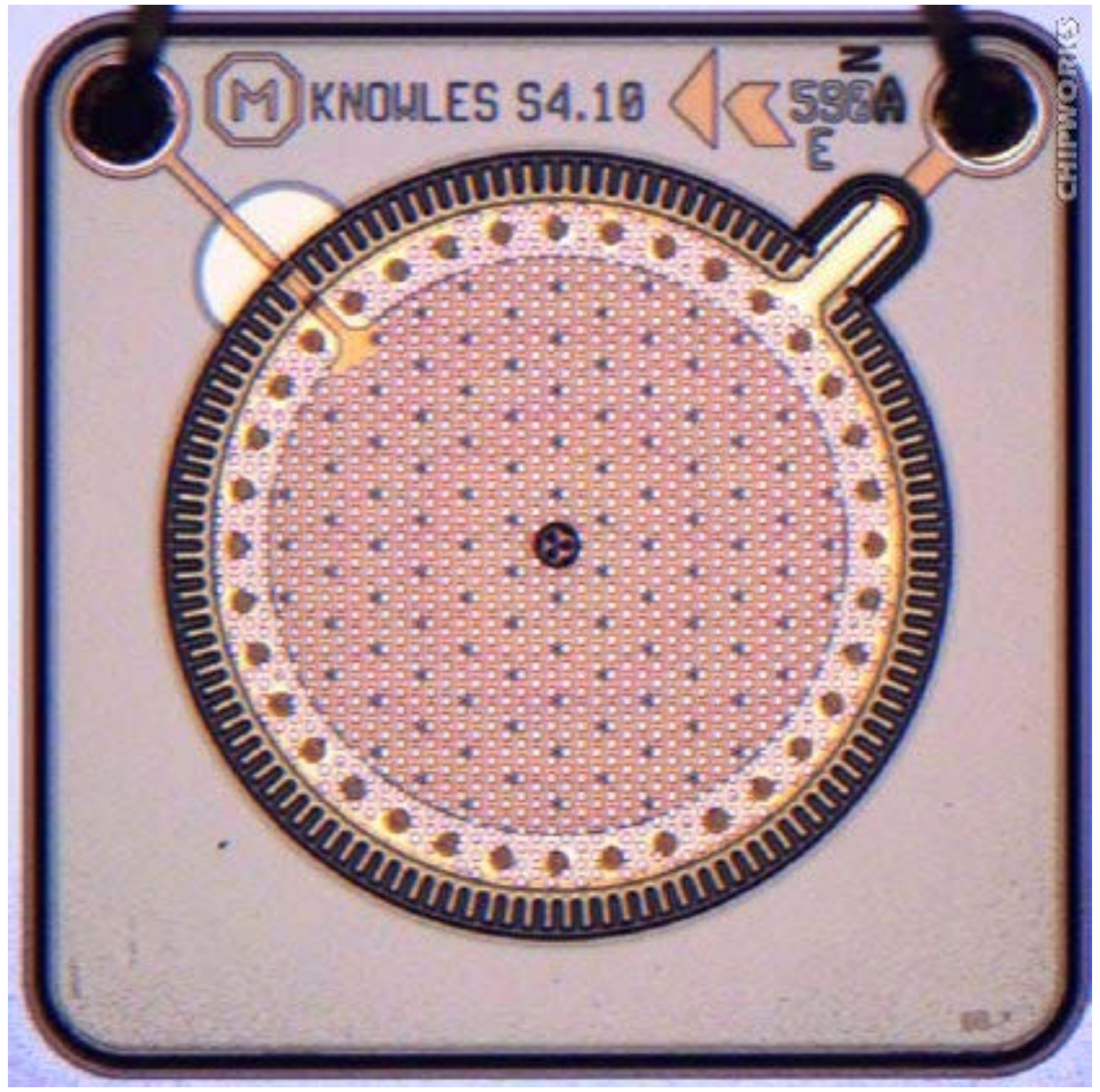
- The microphone diaphragm acts as a capacitor
- As the diaphragm vibrates a varying voltage is generated
- This varying voltage (±1.0) is the audio signal
- Linear relationship between sound pressure and voltage
- You can convert to **uncalibrated** decibels using the formula below, where p = instantaneous voltage and p_0 = the reference voltage of 1.0

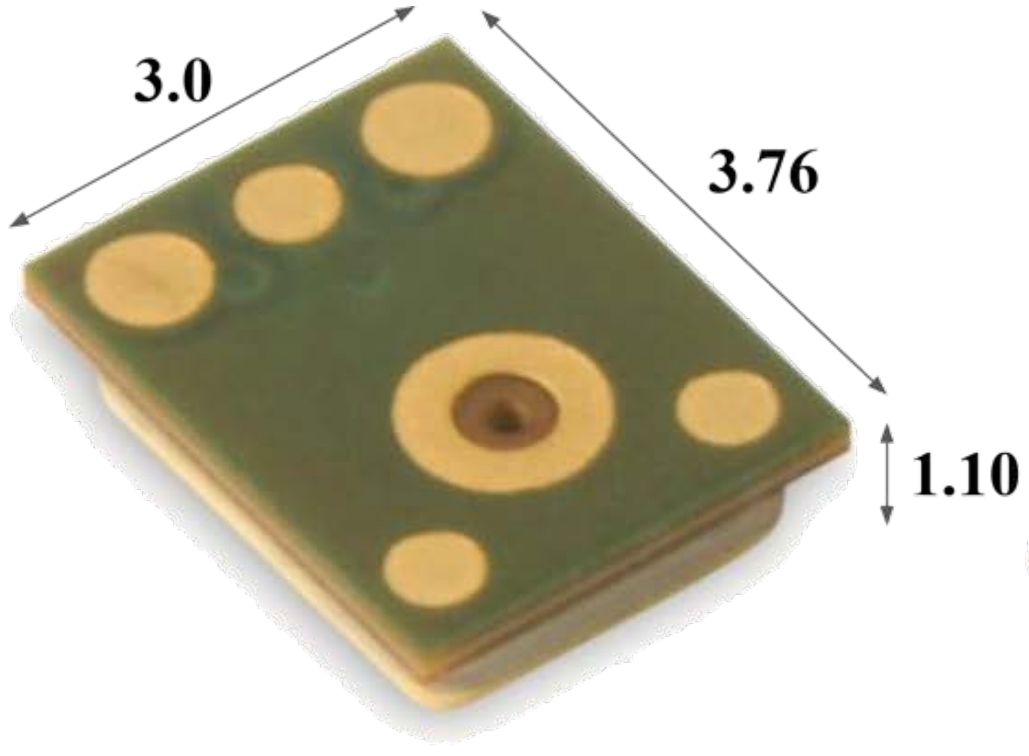
$$20 \log_{10} \left(\frac{p}{p_0} \right) \text{ dB}$$

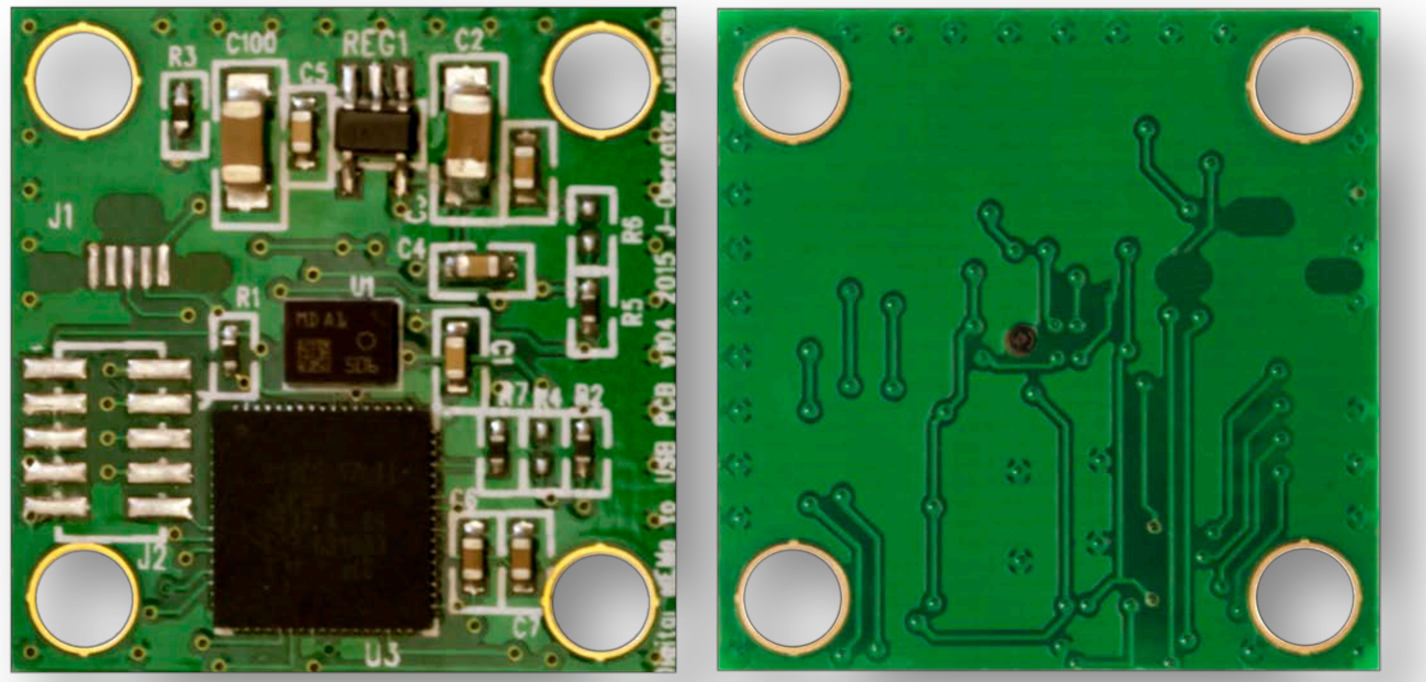


MEMS MICROPHONES

- Diaphragm is etched directly onto a silicon chip using Micro Electro Mechanical System techniques
- Variant of the condenser microphone type
- Extremely small
- Very rugged
- Very high part to part consistency

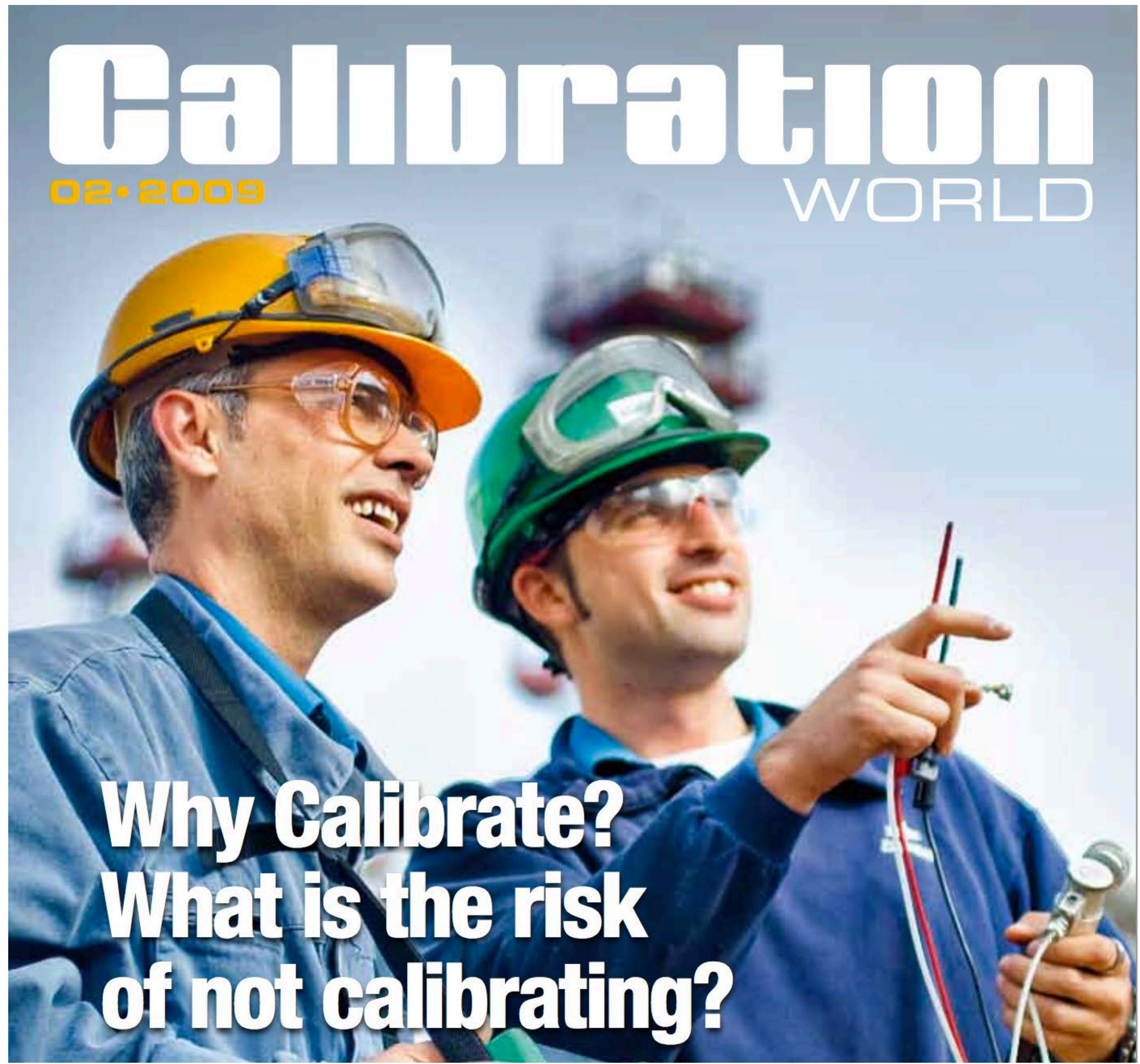




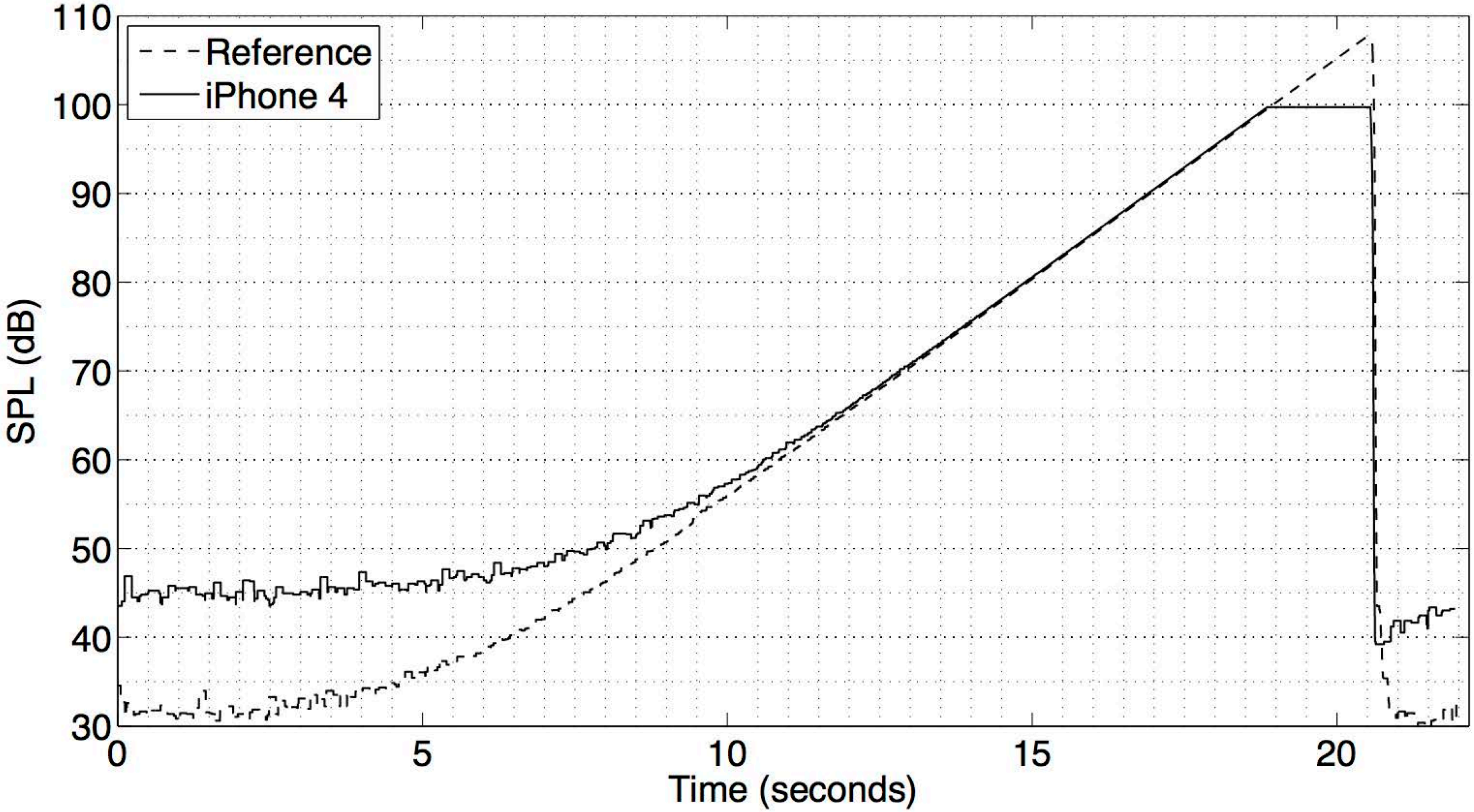


WHY DO WE NEED CALIBRATED SPL DATA?

- Need to be sure of the accuracy of a set of measurements
- American National Standards Institute (ANSI) specify 3 classes for SPL measurements:
  - 0 = laboratory grade (±<1dB)
  - 1 = precision field measurement grade (±1dB)
  - 2 = general purpose measurement grade(±2dB)
- Involves the generation of a known SPL in comparison to a reference device such as a class 1 sound level meter (SLM)

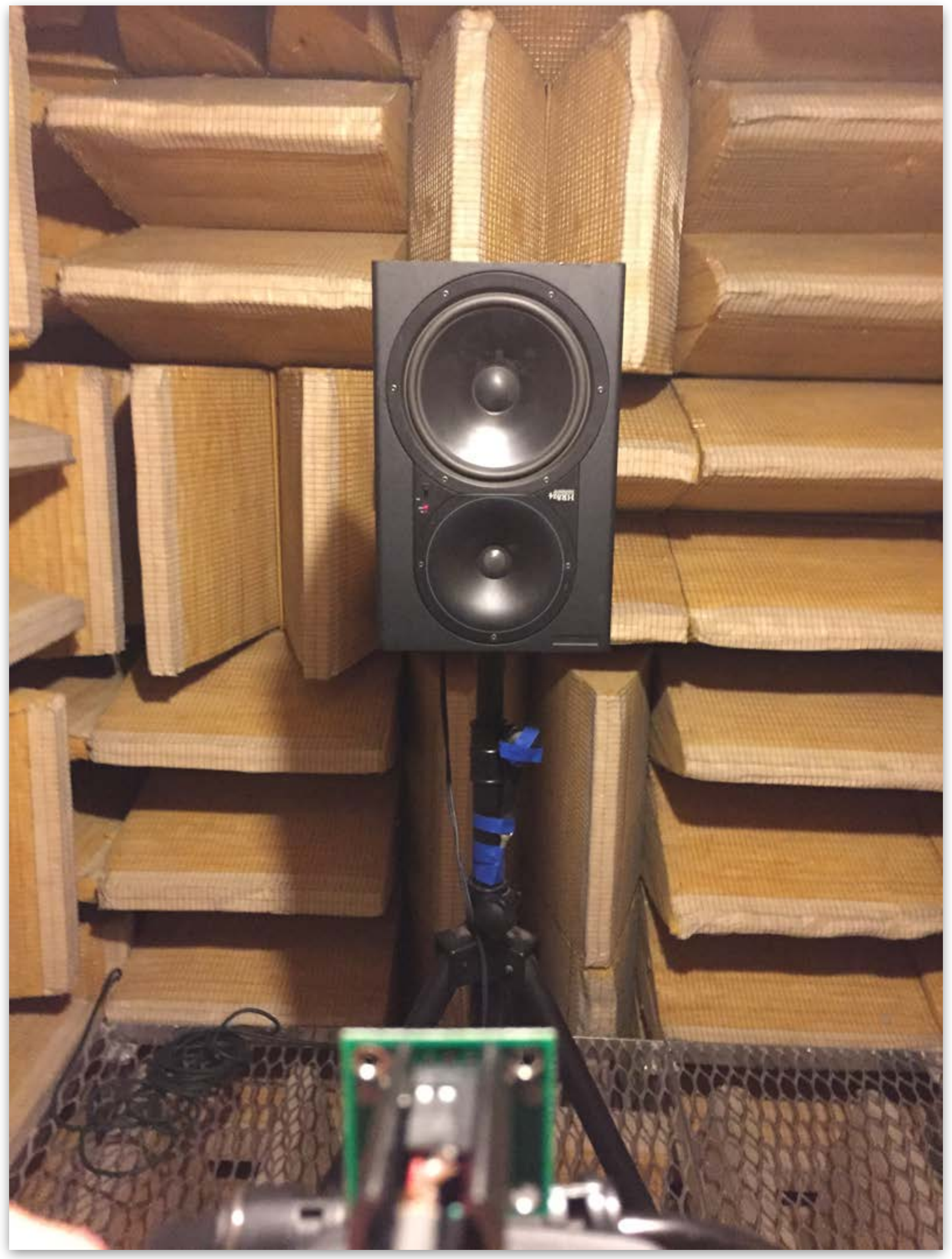


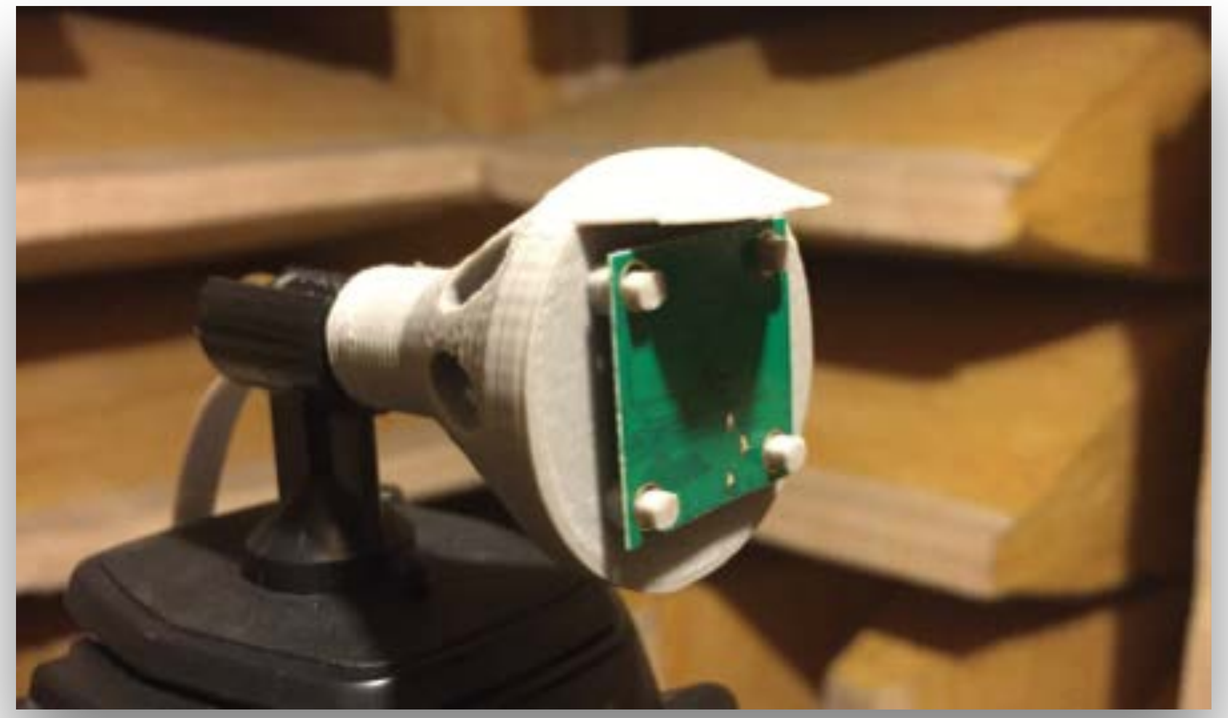
COMPARISON TO A CALIBRATED DEVICE



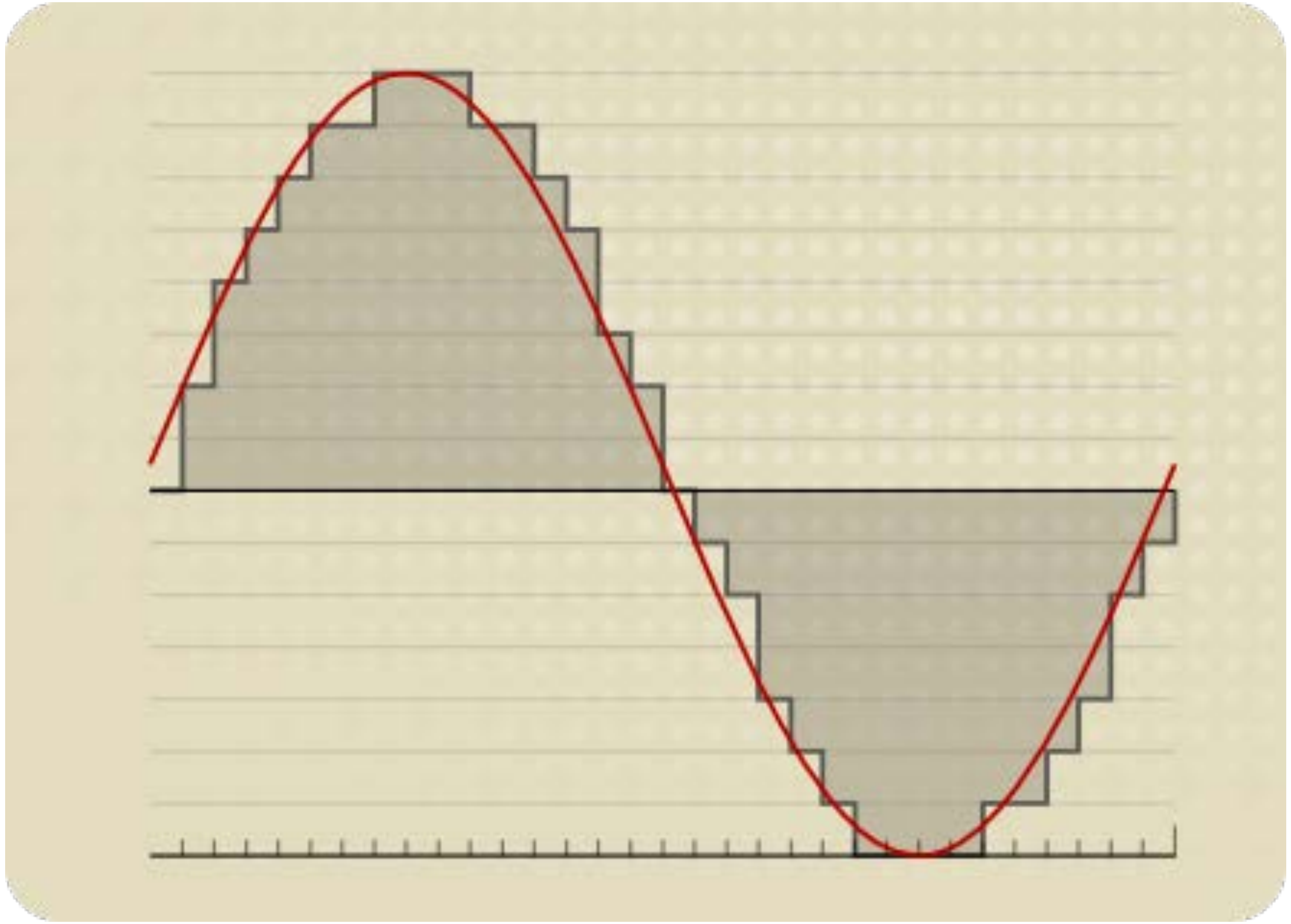
ACOUSTIC SENSOR CALIBRATION

- Repeat measurements using ref. meter & device under test (DUT)
- Determine dB offset
- Use of MEMS microphone simplifies network calibration
- Noise floor of the system
- How does the microphone perform after 6 months in the field?



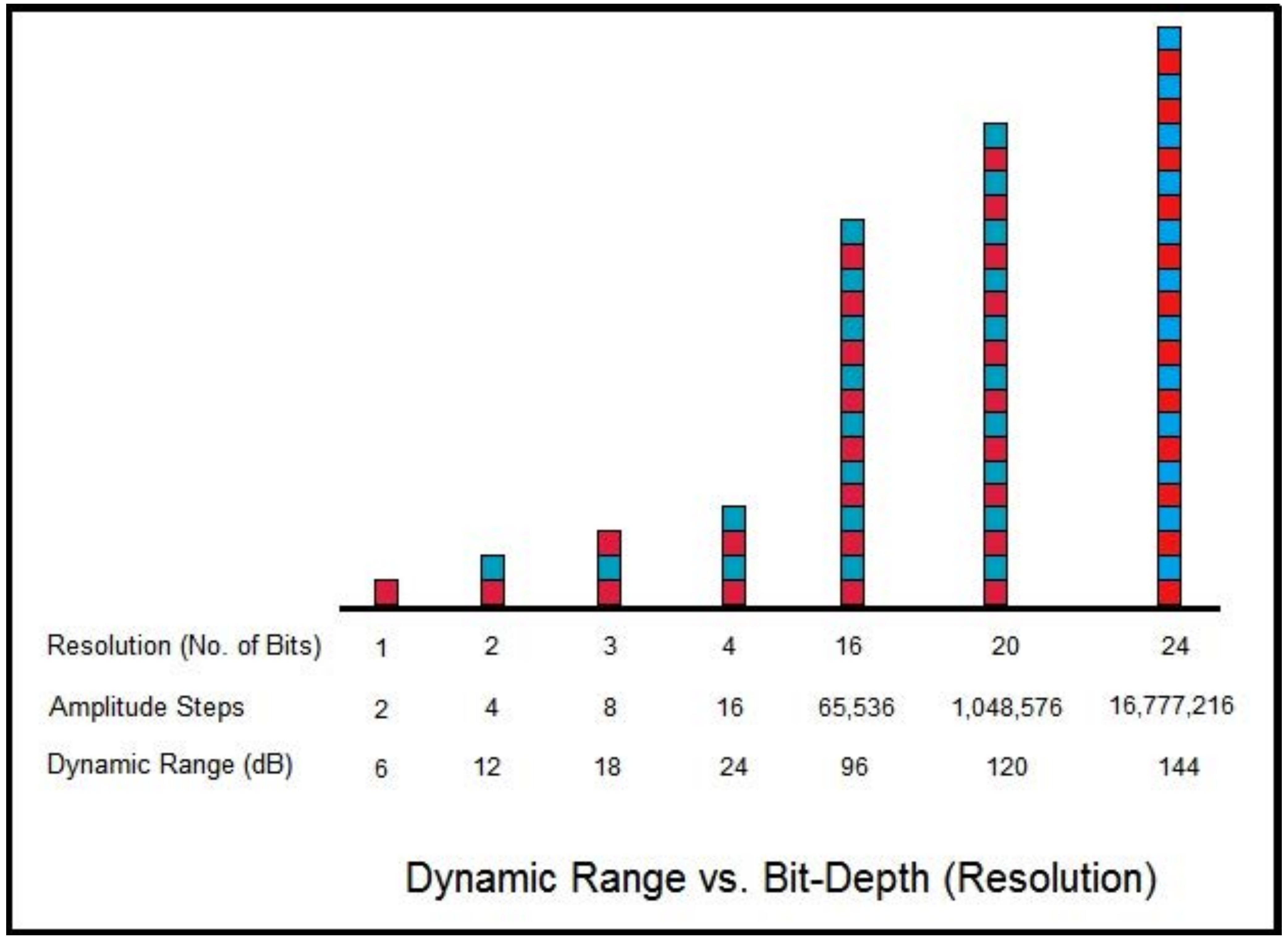


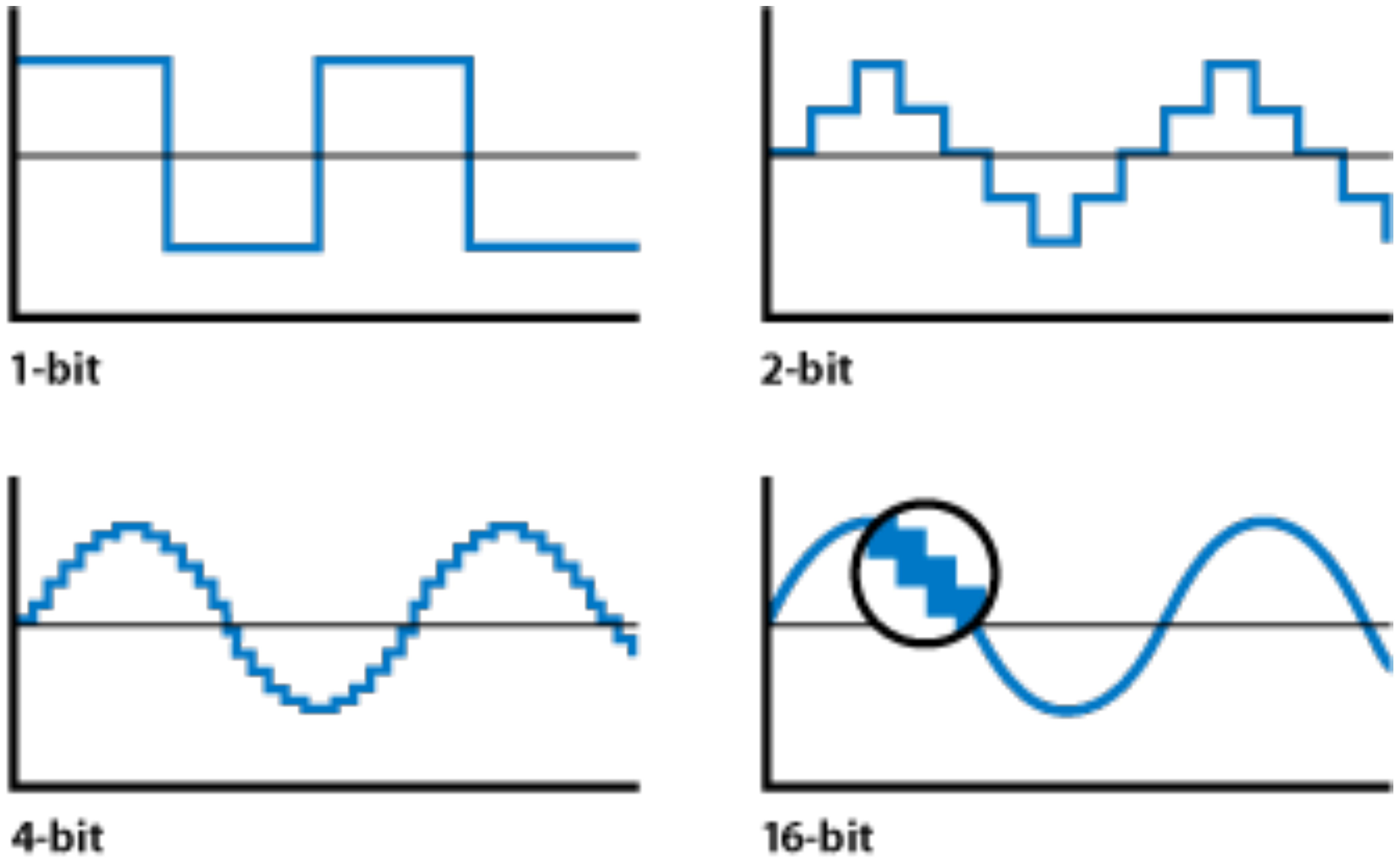
- The reduction of a continuous signal to a discrete signal (sequence of samples)
- A sample represents an amplitude in time
- The sample rate determines how often a sample is measured in time
- CD quality audio is sampled at 44,100 times per second (Hz)



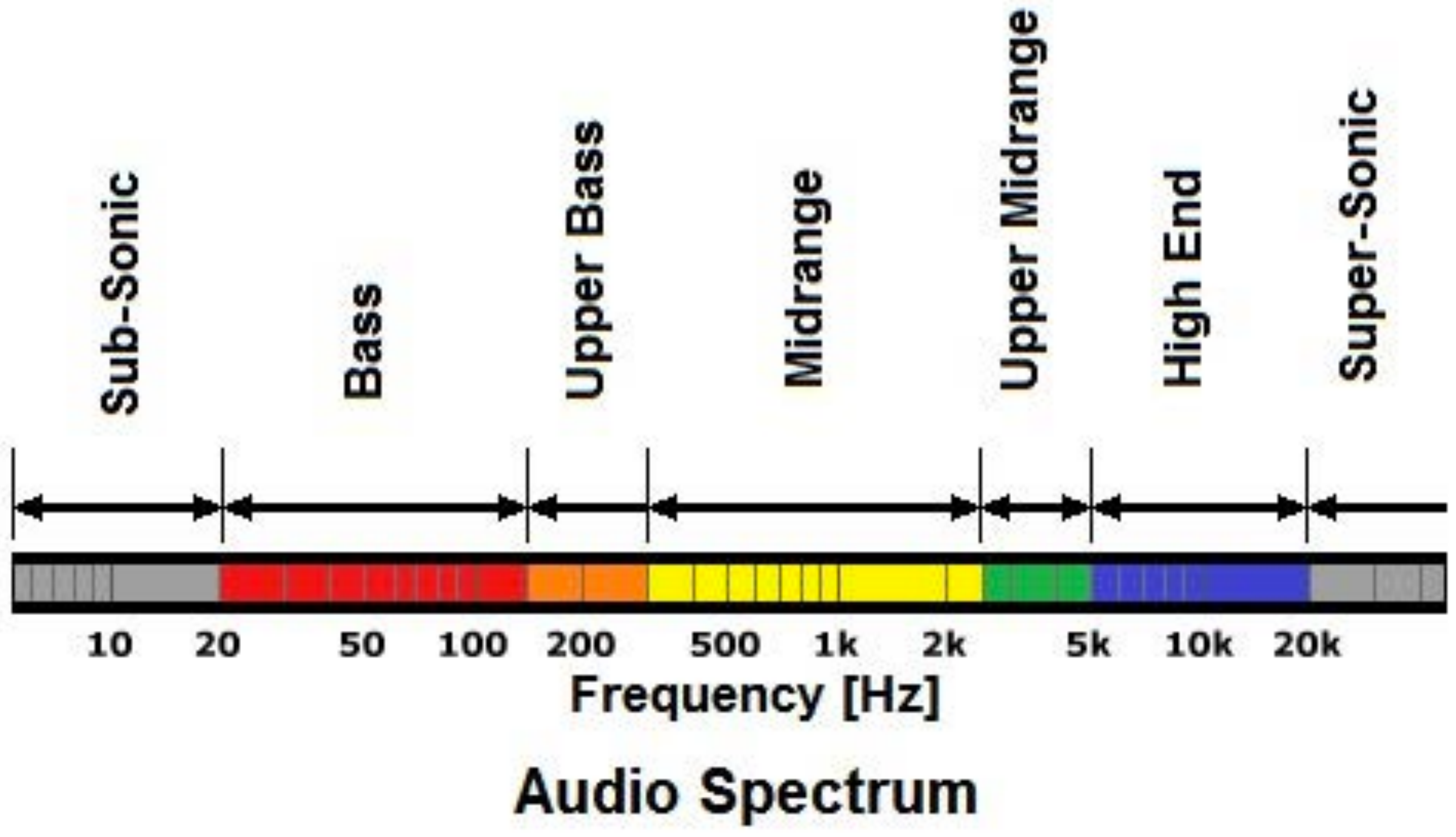
DIGITAL AUDIO SAMPLING (ADC)

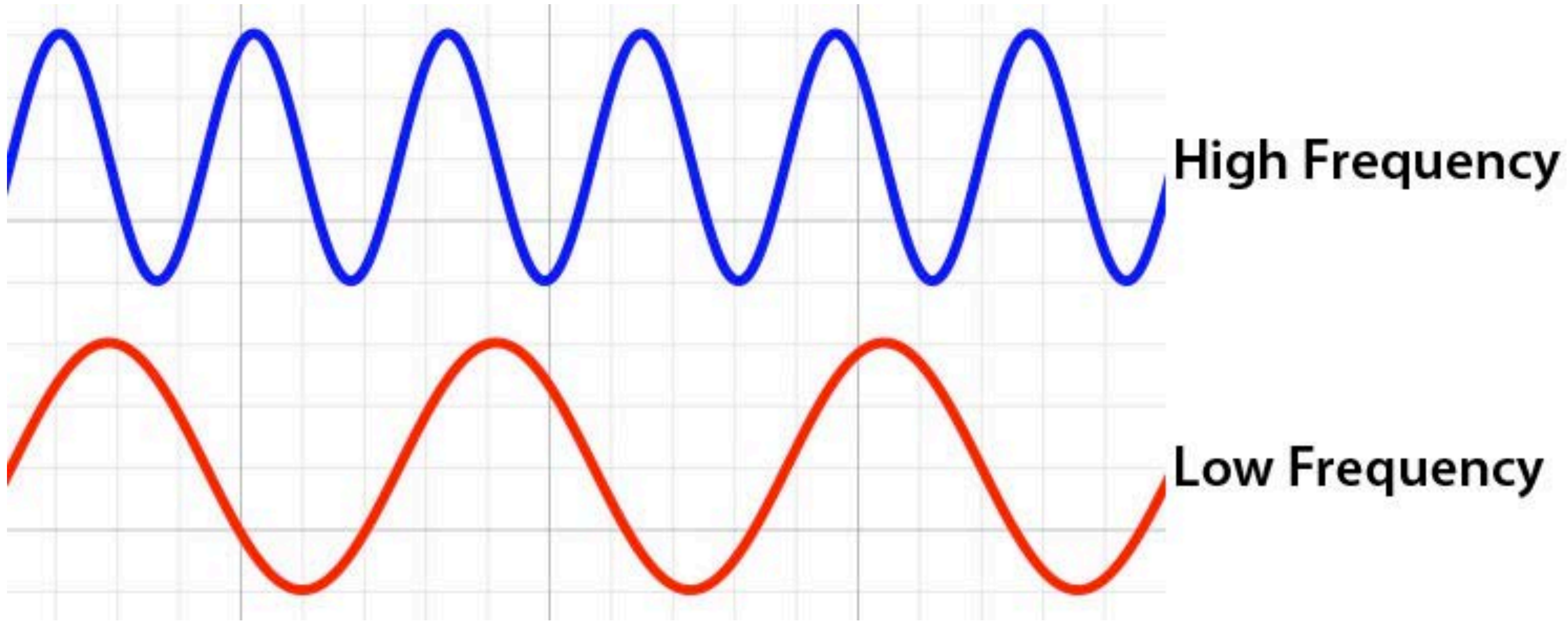
- The number of bits of information used to represent each audio sample
- CD quality audio uses 16 bits of information per audio sample (0±32768)
- Lower bit depths reduce the signal to noise ratio

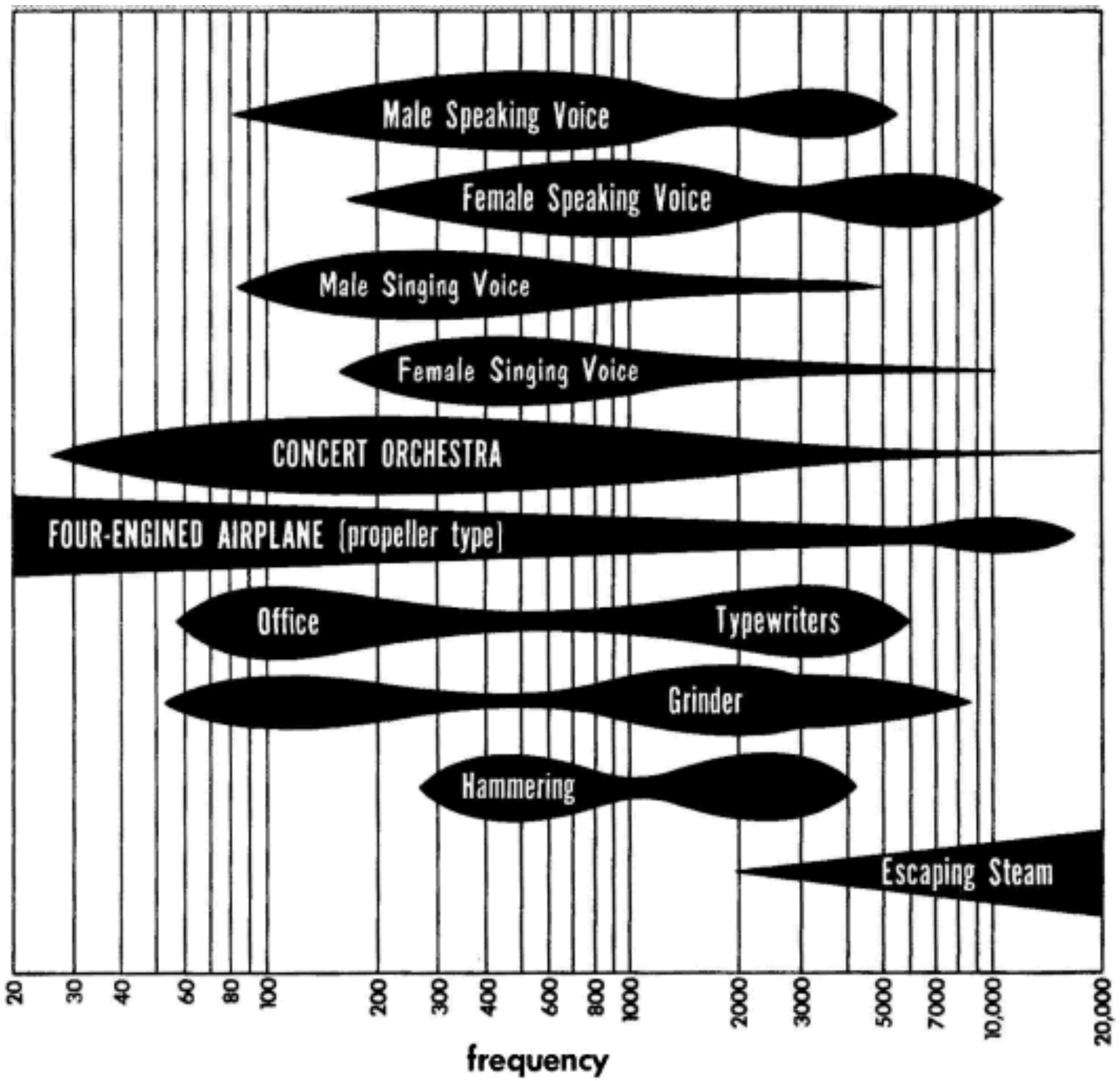




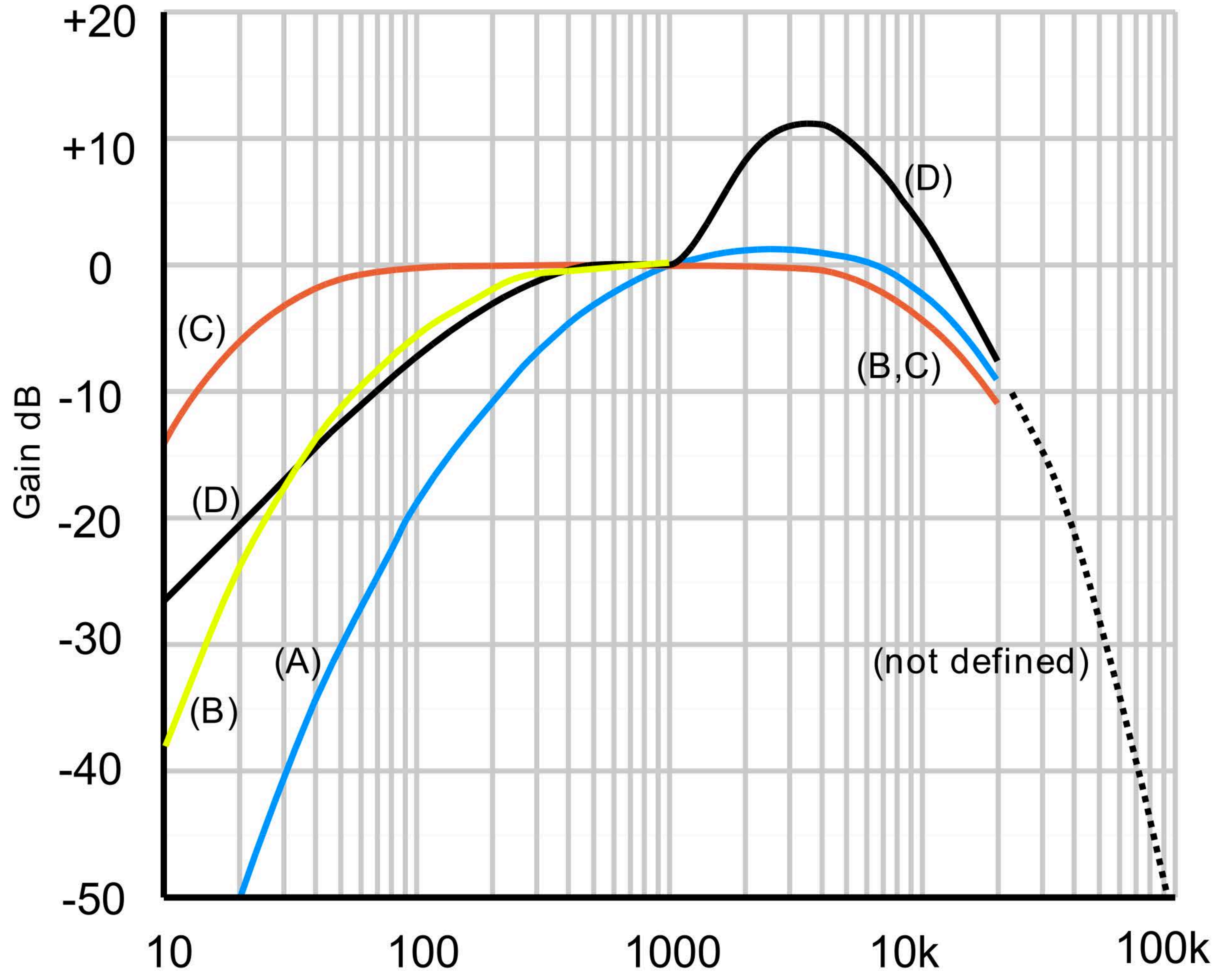
AUDIBLE FREQUENCY RANGE





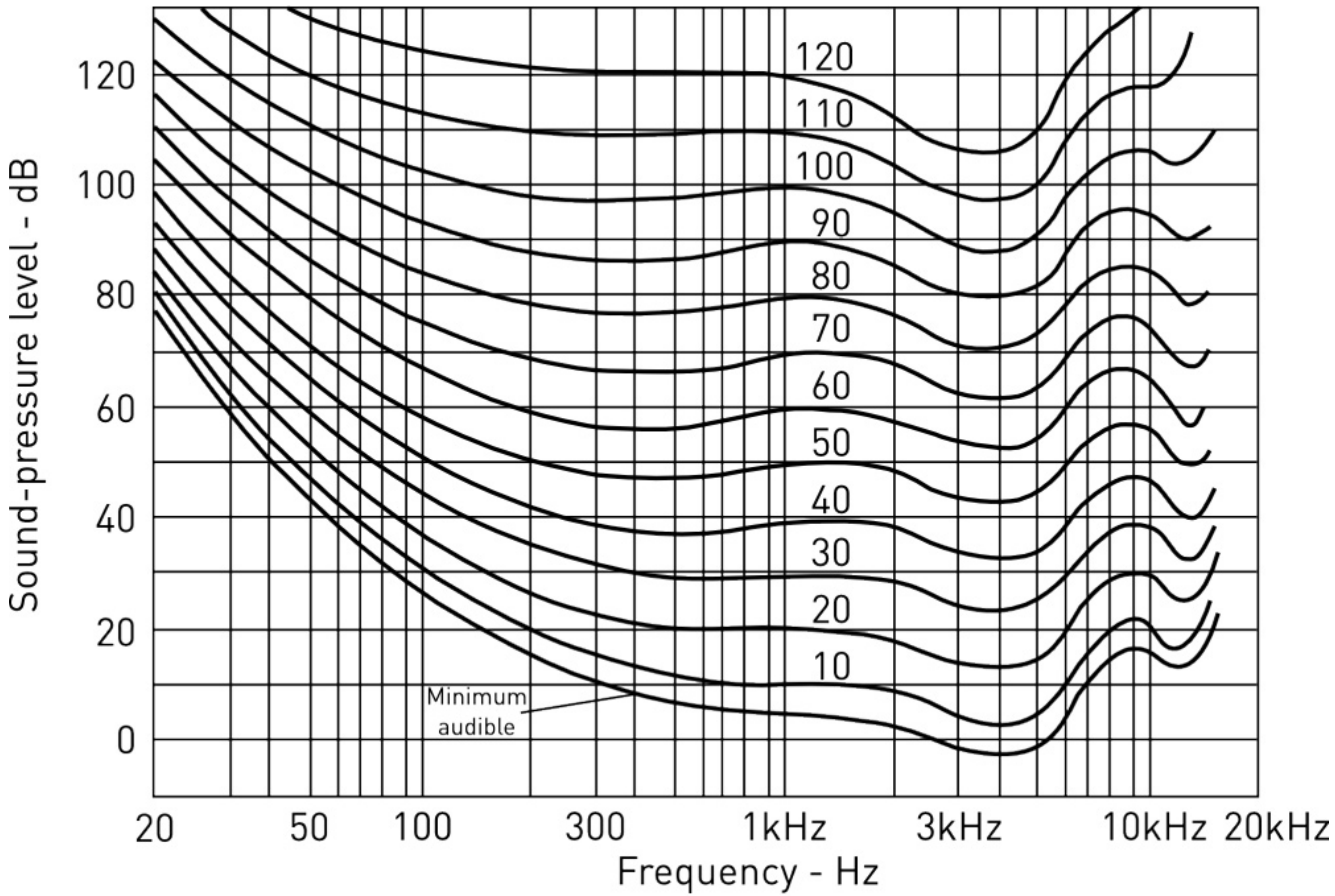


- Human ear more sensitive to frequencies between 500Hz – 8kHz
- Urban noise policies rely on the use of A weighted sound pressure level
- Approximates the response of the human auditory system
- Dated standard
- Low frequency noise annoyance isn't accounted for – wind turbine noise



A-weighting (blue), B (yellow), C (red), and D-weighting (blk)

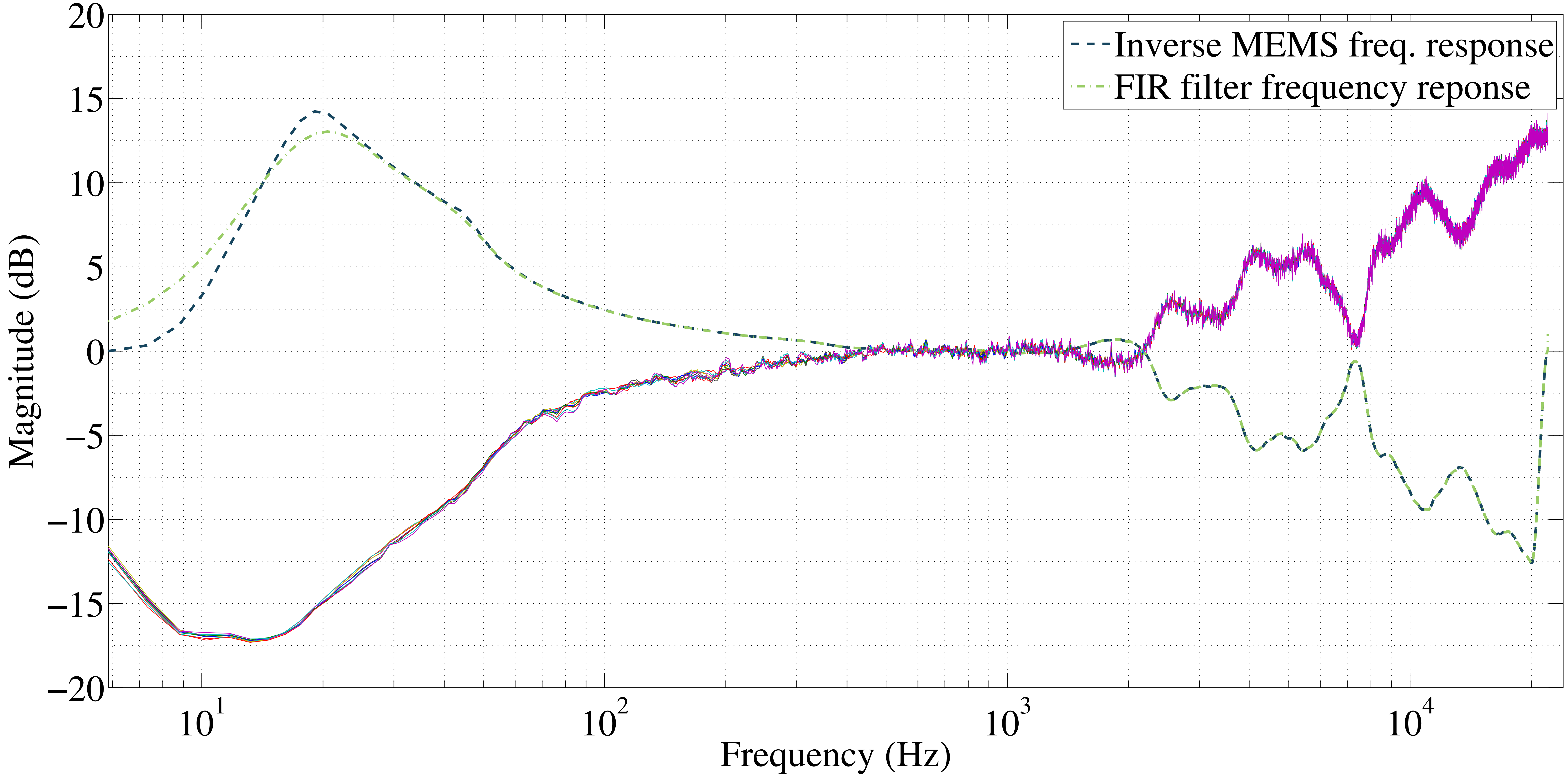
EQUAL LOUDNESS CONTOURS



Robinson and Dadson curves (1956)

MICROPHONE FREQUENCY RESPONSE

- Characterizes a microphone's sensitivity/output level across the audible frequency range
- Accurate sensing requires as close to a "flat" response as possible



PRESBYCUSIS - AGE RELATED HEARING LOSS

- The auditory system's sensitivity to high frequency sound degrades over time
- Hearing damage also results in high frequency losses
- The evil mosquito anti loitering device
- How young are your ears…

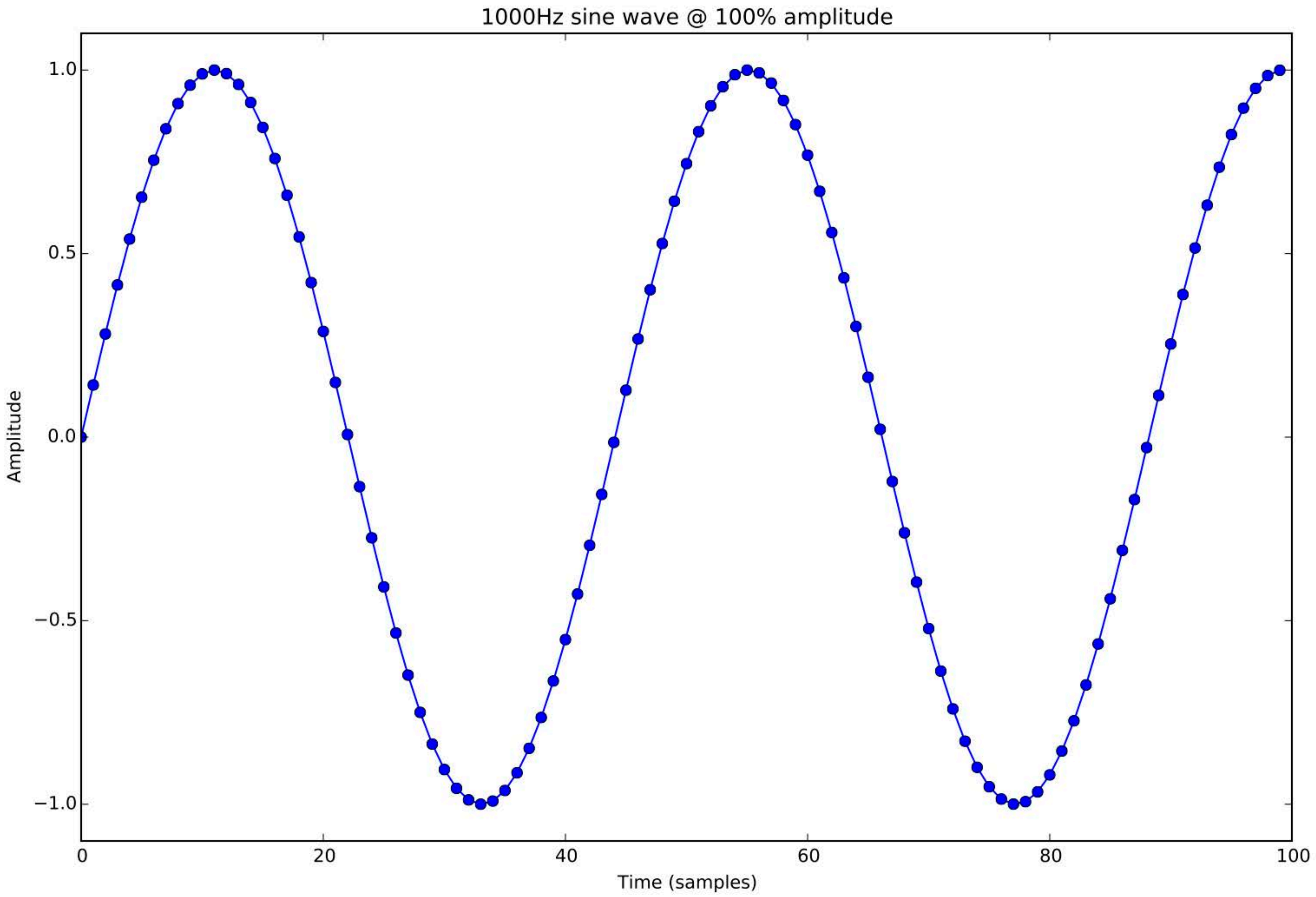
- In 1807, Jean Baptiste Joseph Fourier, a French mathematician and physicist stated that:

  Any *periodic function can be rewritten as a weighted sum of* ***sines*** *and* ***cosines*** *of different frequencies*

- *This was called Fourier Series and is one of the most important tools in science*

- According to Fourier we can recreate any complex waveform using a weighted combination of the most fundamental audio components:

$$A\sin(2\pi fT+\phi)$$



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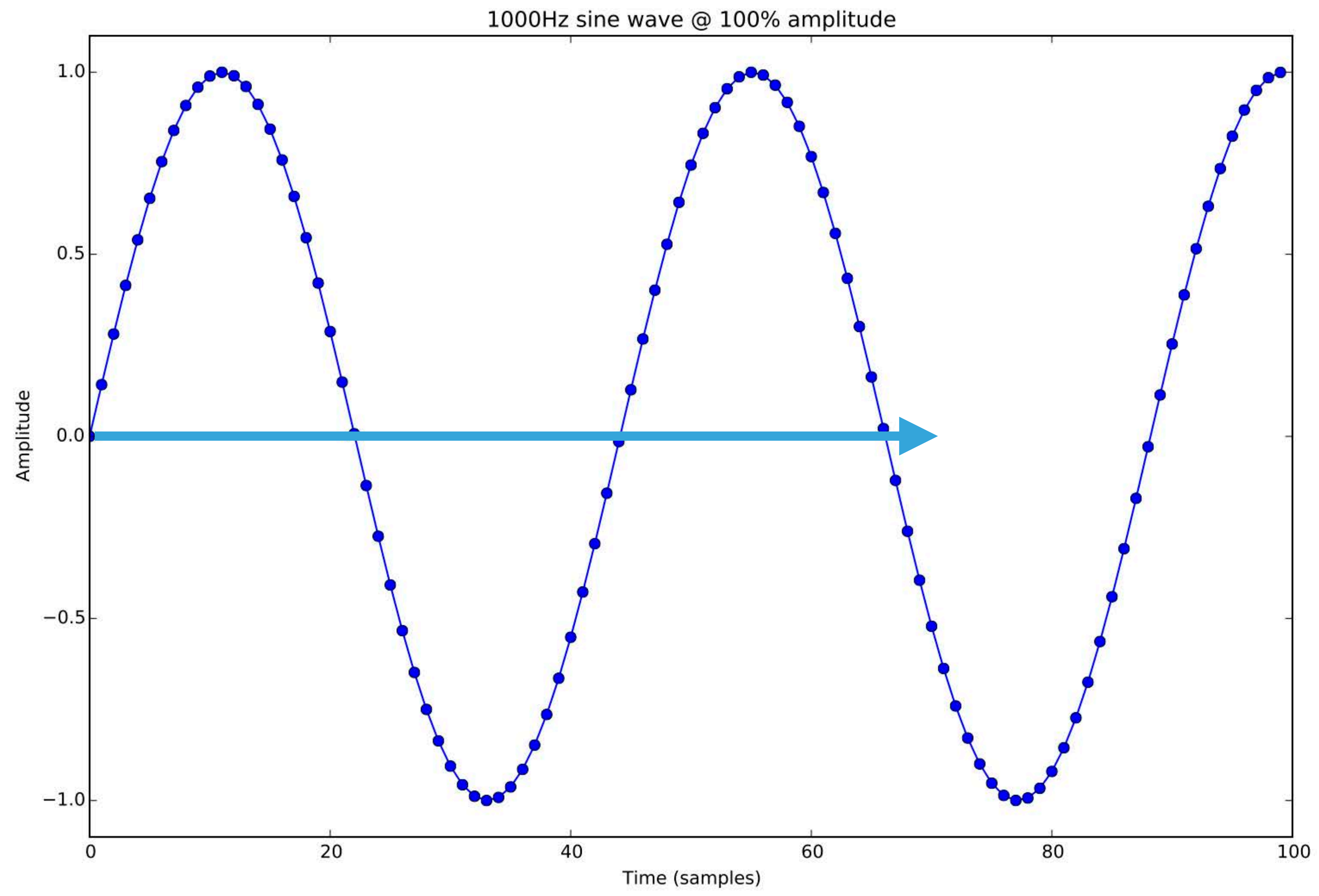
$$A\sin(2\pi fT + \phi)$$

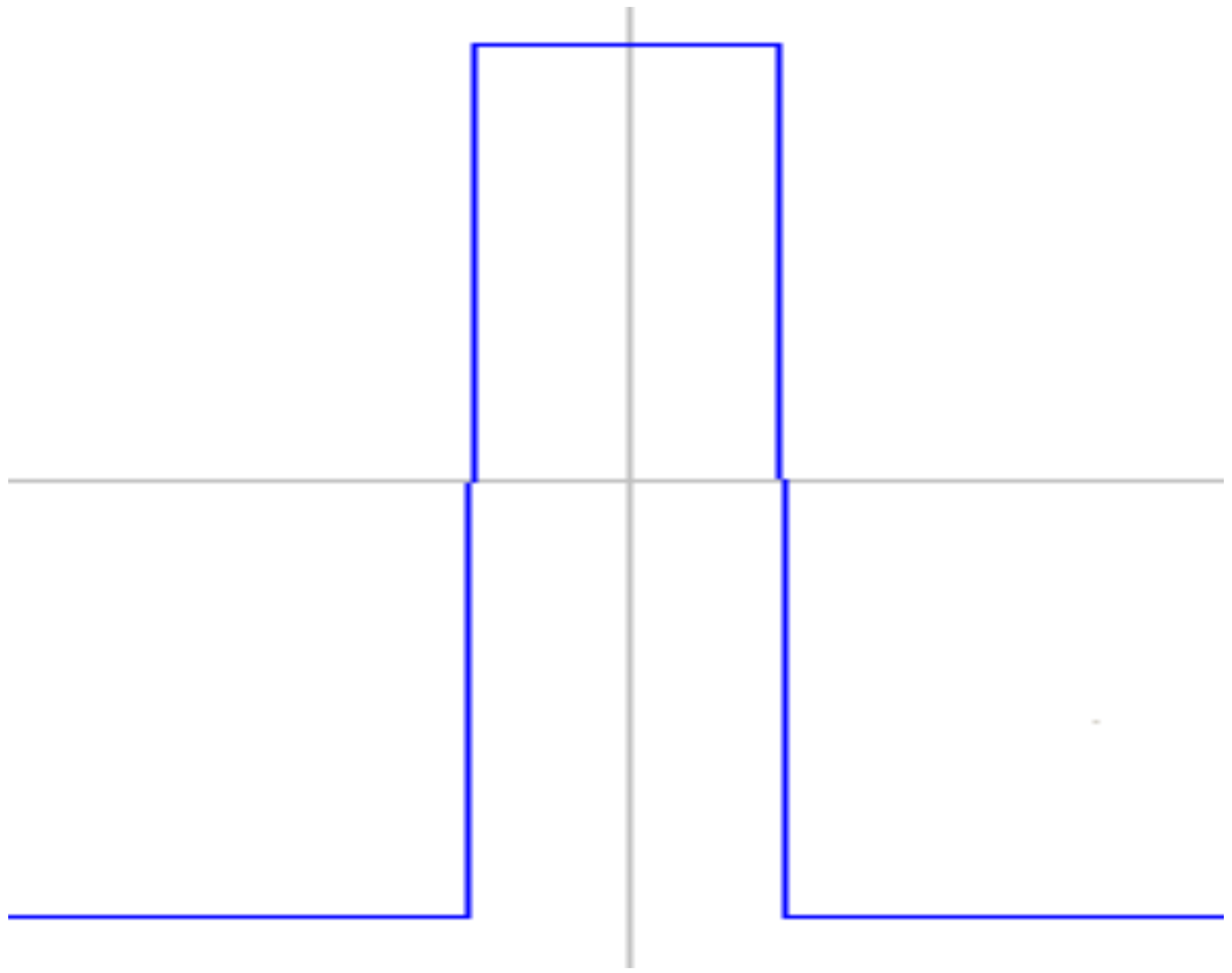
phase component

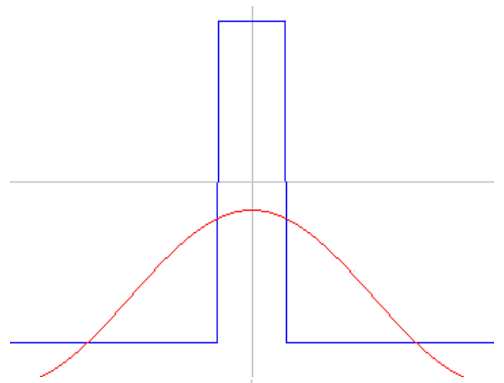



```
for i in range(sample_len):
    sine_samples[i] = A * np.sin(2 * np.pi * freq * T[i])
```

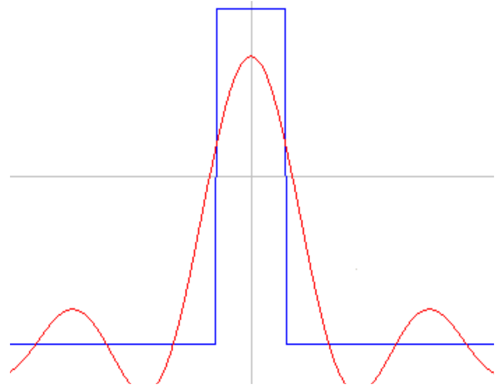
FREQUENCY DOMAIN ANALYSIS

- If you sum an infinite number of weighted sine and cosine waves, you can recreate any complex waveform, such as: human speech, car horn, siren, music, urban soundscapes, etc., etc., etc…

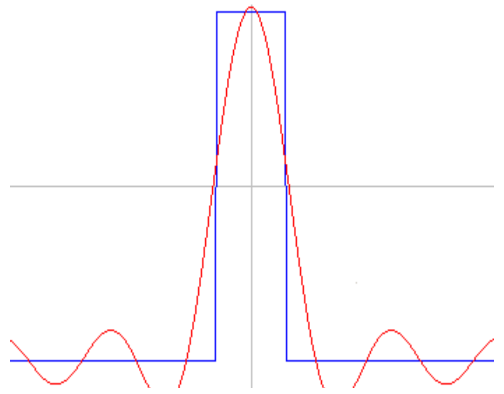




$$a_0 + a_1 \cos(x)$$

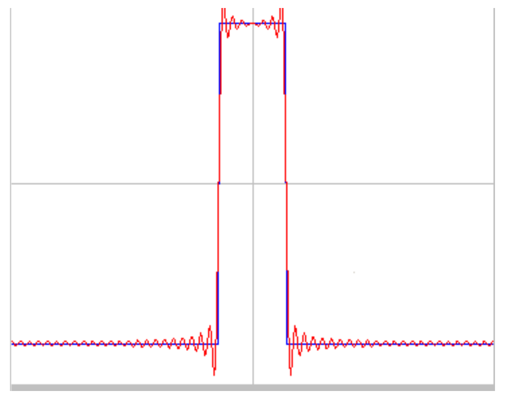


$$\ldots + a_2 \cos(2x)$$



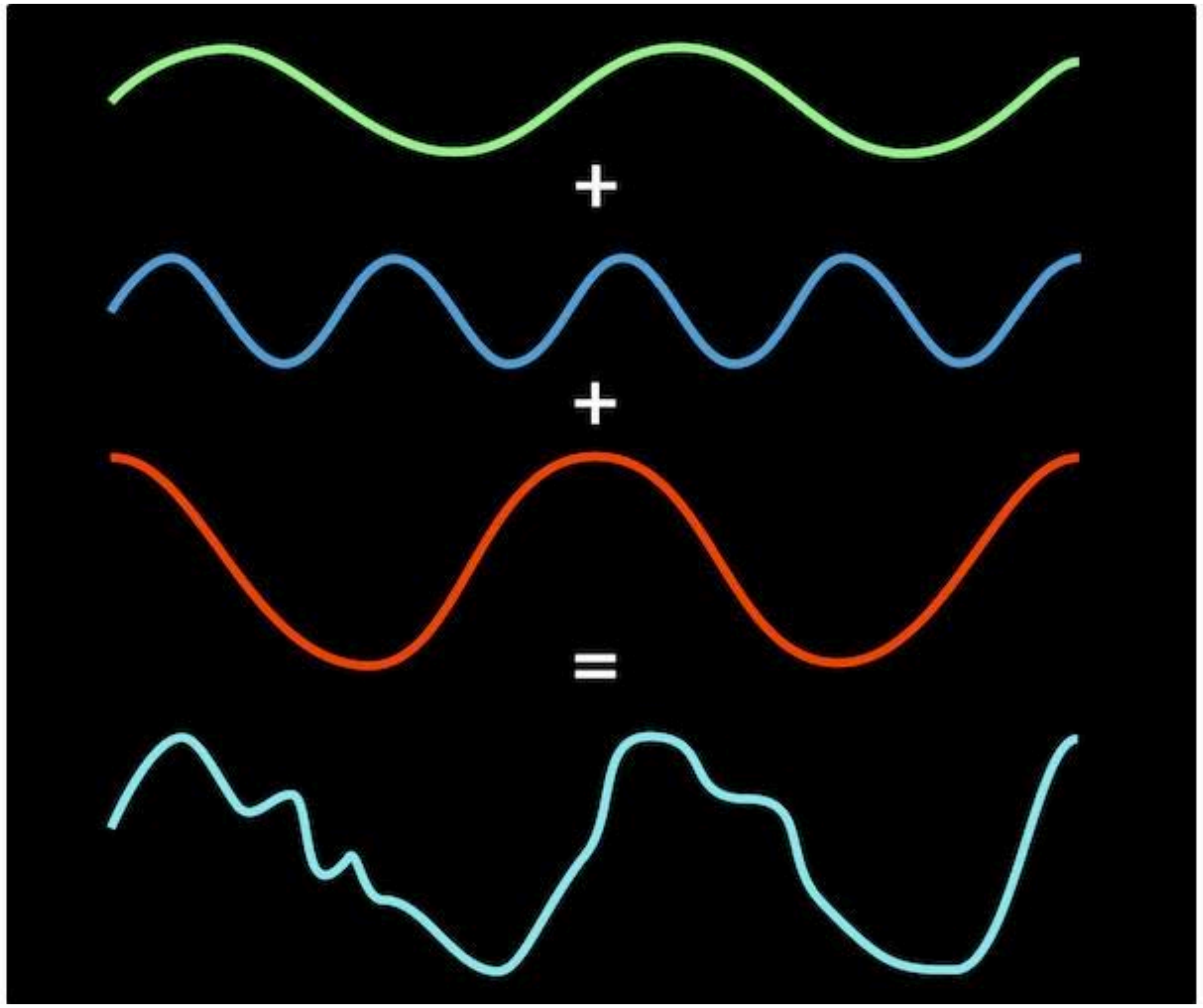
$$\ldots + a_3 \cos(3x)$$

…



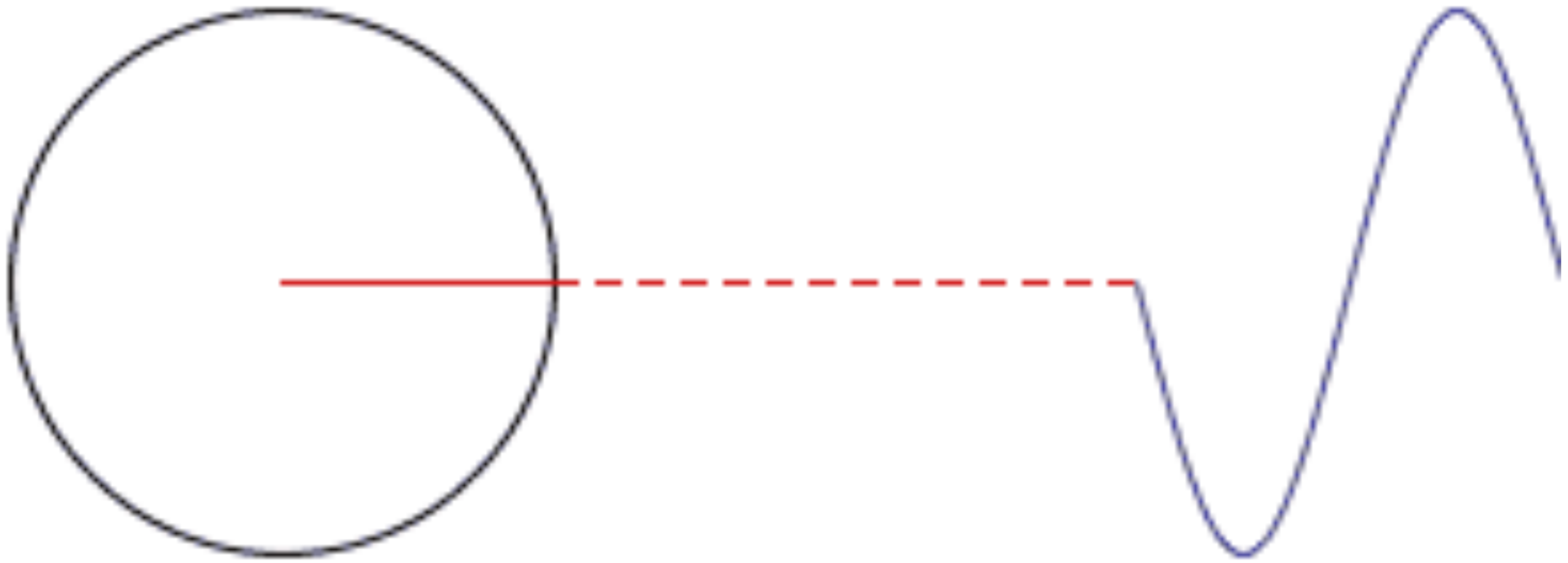
$$\ldots + a_n \cos(nx) + \ldots$$

- The sound wave generated by a piano note may look complex, but it is simply a combination of a number of sine waves



- Take a look at this gif showing the decomposition (and Fourier transform) of a square wave:

- Thought of in another way, the combination of simple sinusoids can be represented as a set of rotating circles of different sizes, where:
  - Its size = the sinusoids amplitude
  - Its rotational speed = the sinusoids frequency



- Download the free audio software Audacity: audacityteam.org
- Have a go at recording some audio and inspecting it in the time domain…
- Now switch over to the frequency domain…