Air-borne and tissue-borne sensitivities of skin-radiation acoustic sensors

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Skin surface measurements

- Monitoring and diagnosis of body systems:
  - Respiratory
  - Cardiac & Circulatory
  - Gastrointestinal
  - Phonatory

- Most common skin-radiation acoustic sensors:
  - Light-weight accelerometers
  - Air-coupled microphones

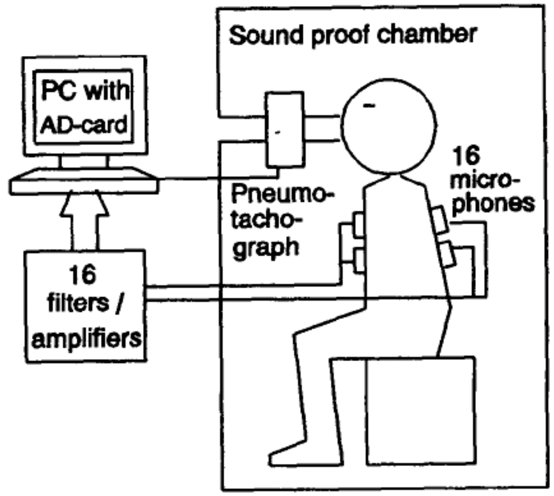
Skin surface measurements: background noise

- Effects of background noise can be significant
- Background noise sources:
  - Environment (uncorrelated),
  - Instrumentation (uncorrelated),
  - Subject’s respiration or voice (correlated)
- What is the response of the sensor to the noise?
  - Different approaches to discard uncorrelated sources
  - Correlated sources are challenging
  - Noise effects are often neglected or not quantified

Some approaches for correlated sources

Provide passive acoustic protection around the sensor

Separate source and noise by altering the environment.



Air-borne and tissue-borne sensitivities

- Define response of the sensors to each pathway
- May help to discriminate the response of the sensor and effectiveness of acoustic isolation methods

- Useful references: ISO 5347 Parts 11 & 15
- Limitations of these guidelines
  - Designed for industrial applications
  - Behavior of sensors on soft-tissue can change
  - Generally not included in specifications of sensors
  - Many sensors are custom-made
  - Methods need to change for soft-tissue vibration

Study objectives

Overall aim

- Quantify the response of the sensors to tissue-borne and air-borne excitations

Specific aims

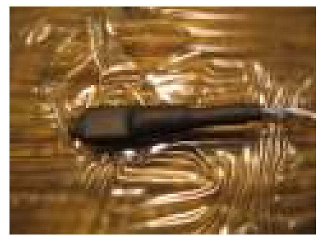
- Propose methods to quantify air-borne and tissue-borne sensitivities of sensors
- Report the sensitivities of commonly-used sensors
- Evaluate effectiveness of acoustic isolation methods
- Use sensitivities to discriminate response of the sensors to each excitation pathway

Sensors & transducers

Sensors under evaluation

Air-coupled mic
Sony ECM-77B

Knowles accel
BU-7135



Siemens accel
EMT25C

Reference sensors

B&K hand-held
analyzer (Type 2250)

B&K mic
(Type 4191)

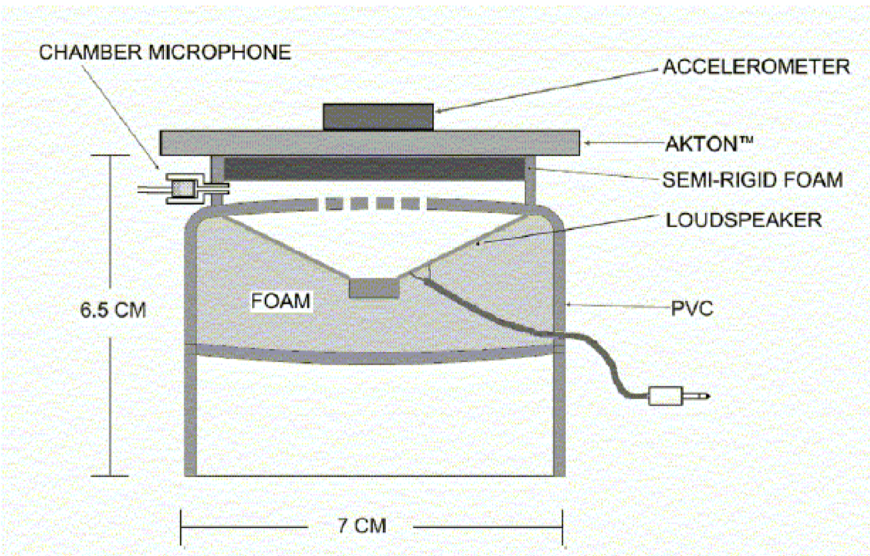
Near Skin mic
Sony ECM-77B

PCB accel
(A353B17)

Polytec laser vibrometer

Tissue-borne sensitivity: Methods

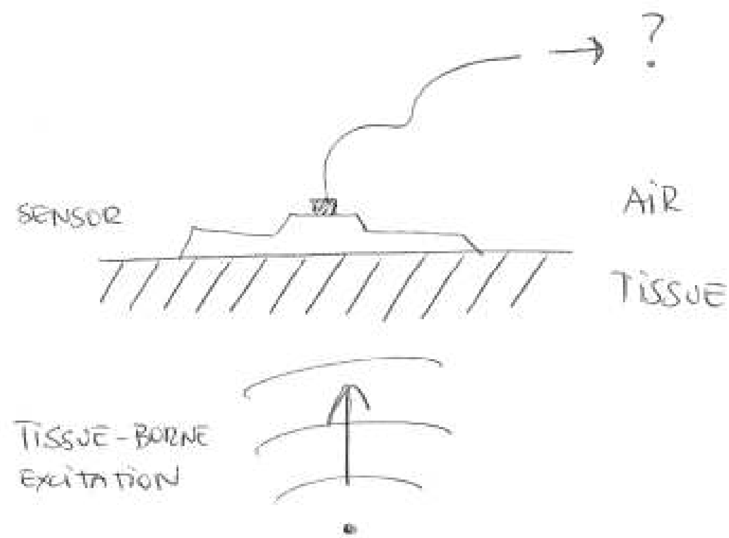
- Bioacoustic Transducer Tester (BATT)
  - Design mimics soft tissue vibration
  - High transverse vibration & low noise
  - New scaled versions: (2:1 and 4:1)



Kraman *et al.*, 2006 IEEE.

Tissue-borne sensitivity: Methods

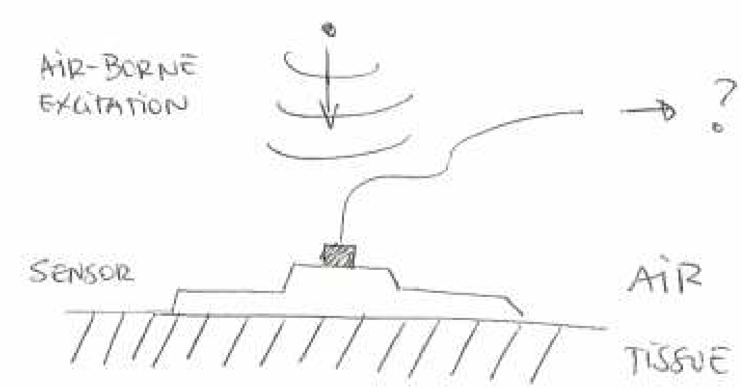
- Pink noise excitation
- Compensated BATT transfer functions
- 80 Hz to 8 kHz ±2dB in 1/3 octave
- Amplitude: As speech at sternal notch
- Best sensor for calibration: Knowles accelerometer



- Recordings: sound proof chamber model (IAC 102871).
- Low background noise (room and BATTs)
- DAQ: 16 bits, 96 kHz sampling with anti-aliasing filters

Air-borne sensitivity: Methods

- In vitro: sensors on artificial skin
- In vivo: sensor on human subjects
  - Subjects seated at breath hold
  - 5 human subjects (3M, 2F)
  - Sensors on chest wall (RUL) and 3 other locations

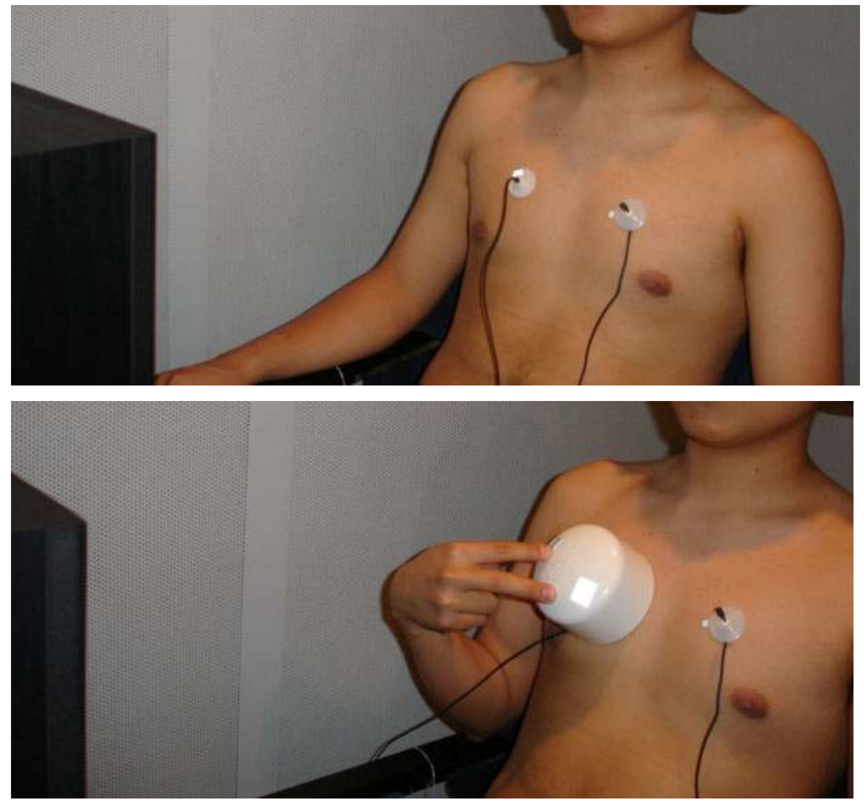


- Speaker at 26” (~66 cm) at desired SPL
- Amplitude: As speech near the sternal notch: 85 dBZ
- Source signal, conditioning and calibration as before
- Best sensor for calibration: Near-skin mic

Air-borne sensitivity: In-vitro setup

Air-borne sensitivity: In-vivo setup

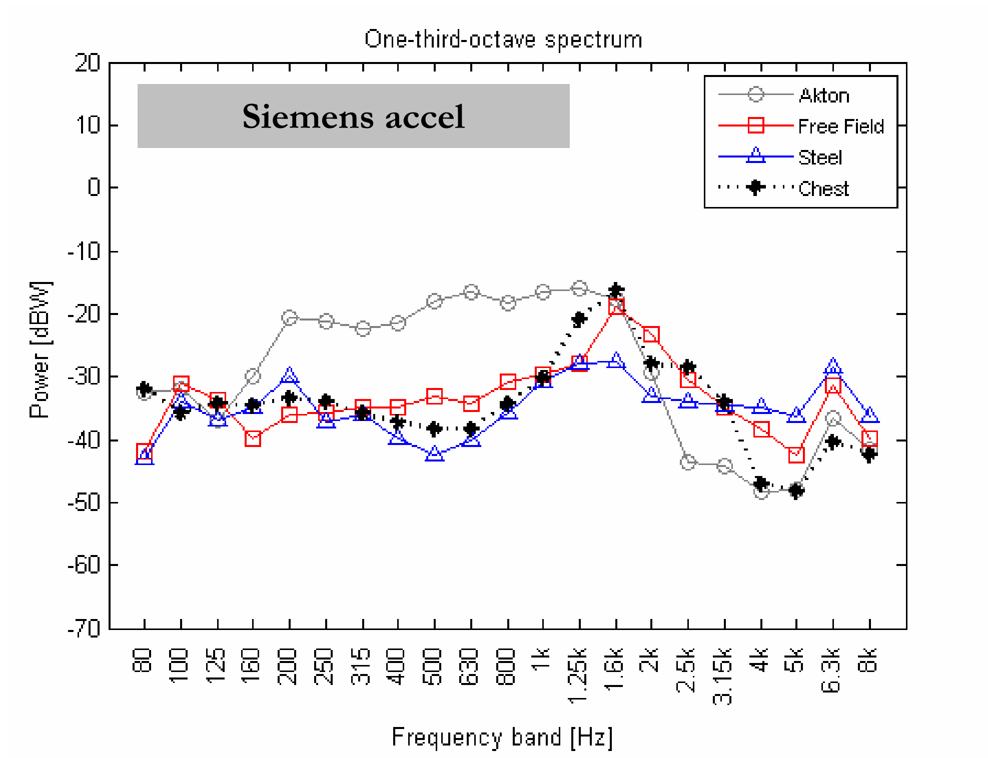
Near-skin mic (right) and SLM are used for calibration



Effects of acoustic protectors were evaluated

Results: Effect of mounting surfaces

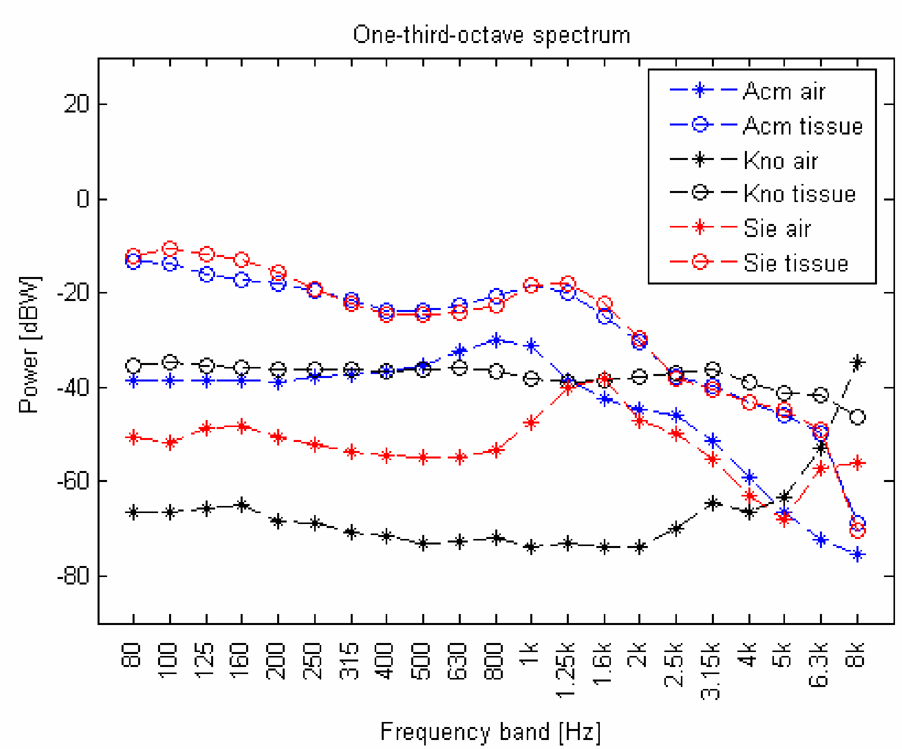
- Tested mounting surfaces: Akton, free field, steel, human skin (chest wall)
- Air-borne sensitivity is a function of mounting surface
- No other surface fully resembles skin for all sensors
- Air-borne sensitivity requires in-vivo tests only



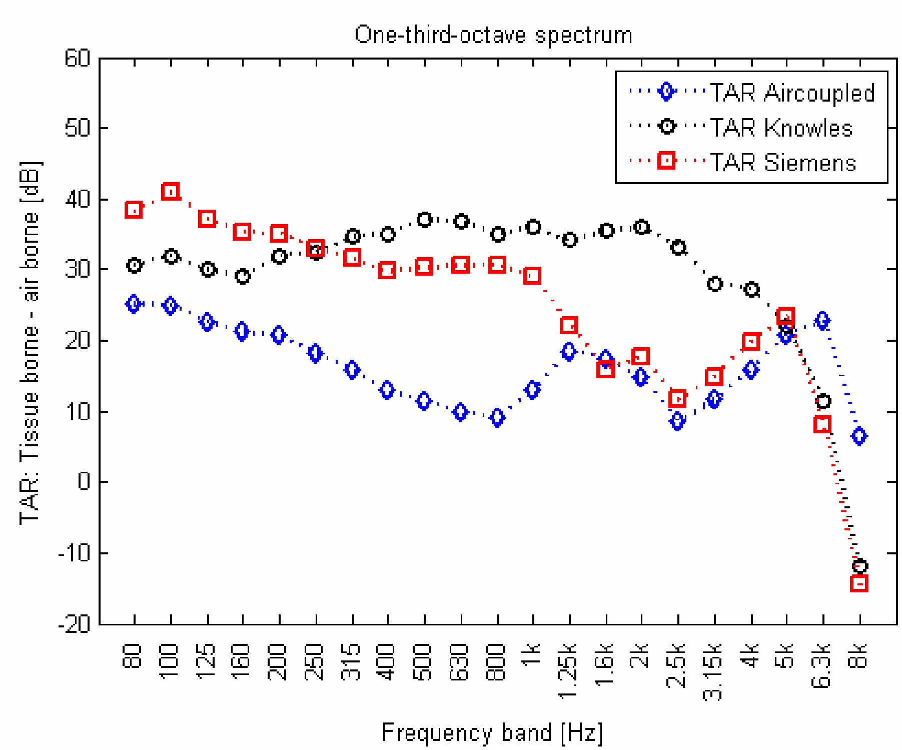
Air-borne sensitivity vs mounting

Results: sensitivity and TAR curves

Tissue-borne (o) & Air-borne (*) sensitivities



Tissue-to-Air-Ratio (TAR) curves



Results: Effect of passive protectors

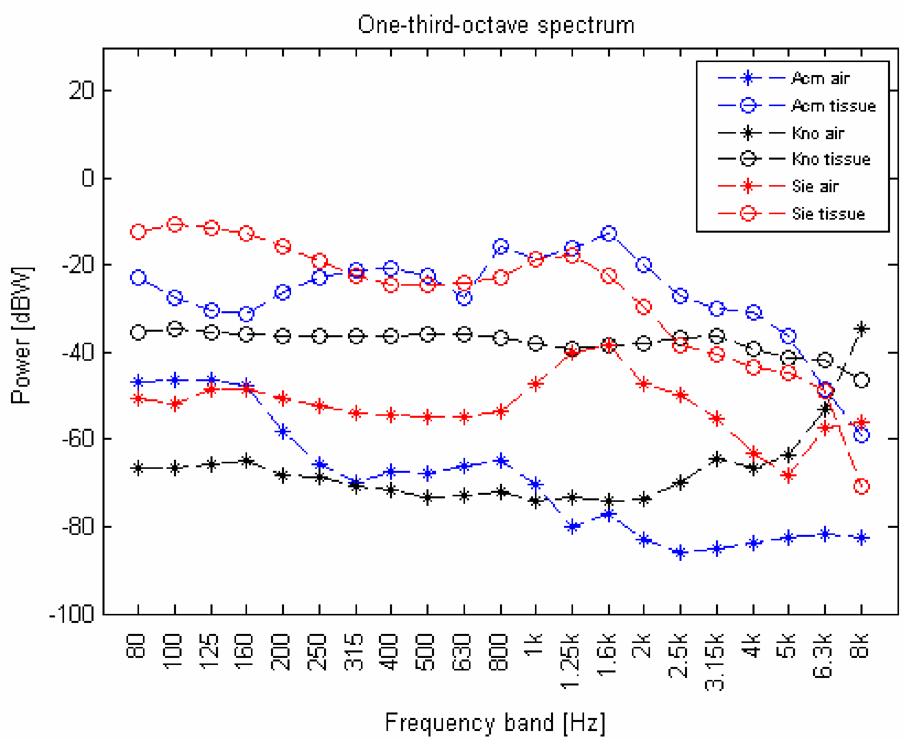
- BioAcoustic Insulator (BAI) surrounding the sensors
- A number of loading conditions and BAIs were tested
- NRR 30 and NRR 33, and a 3” diameter PVC cap

<u>Effects of using a BAI:</u>

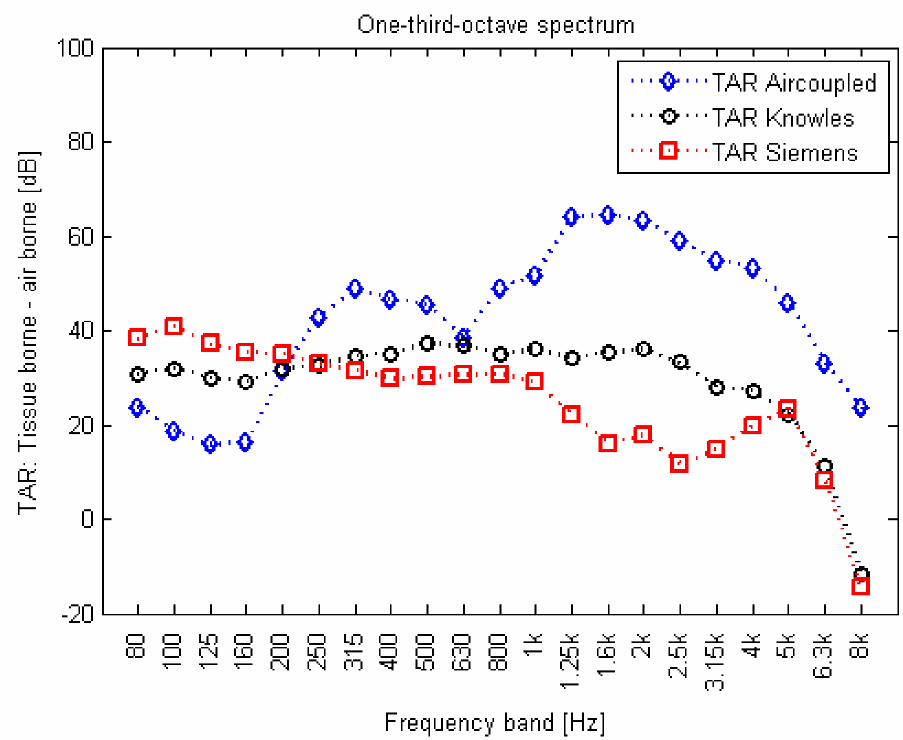
- Increases low frequency “body noise”
- Reduces air-borne sensitivity in air-coupled mic
- Introduces undesired perturbations in accelerometers
- Only useful for air-coupled mic (mid-high frequencies)

Results: Effect of passive acoustic protection

Tissue-borne (o) & Air-borne (*) sensitivities



Tissue-to-Air-Ratio (TAR) curves



- Blue curves: new sensitivities for the air-coupled mic. Others as before

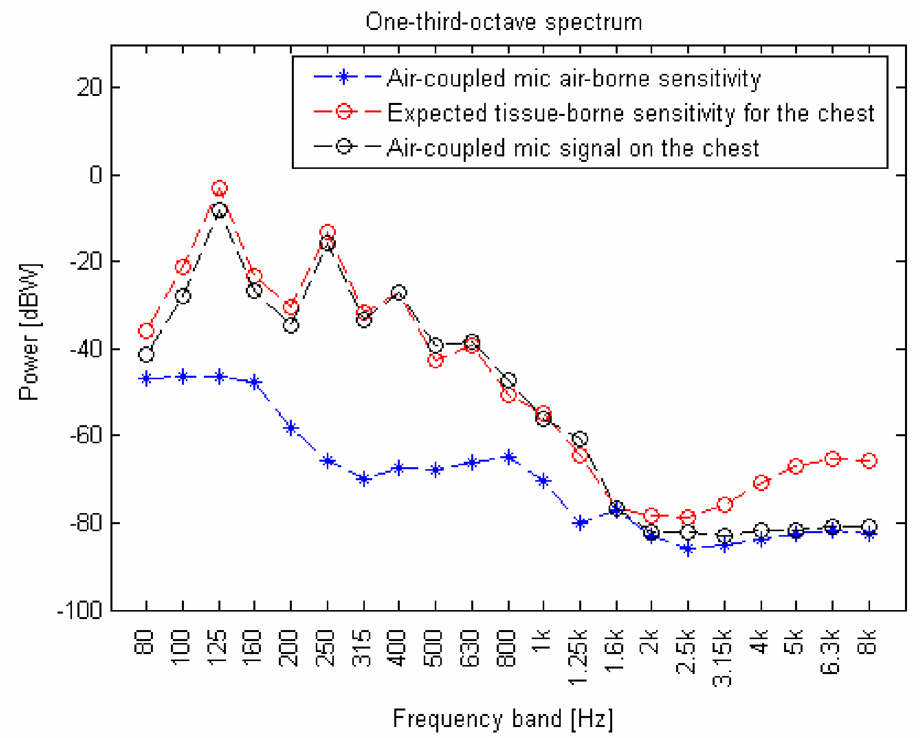
Application note: Discriminating tissue-borne and air-borne signal components

- Energy based discrimination of components using curves
- The sensitivities and TAR curves can be translated :
  - Need to measure the associated amplitudes
  - Need to measure body noise
- Given a certain measurement condition:
  - Translate and use air-borne sensitivity as threshold
  - Consider the effect of body background noise
  - Translate tissue-borne curve to predict component

Discriminating components: Example

- Recording of speech on the chest wall
- Sensor: Air-coupled mic with BAI (PCV 3")
- Sensitivity curve includes the effect of background noise
- Curves were translated to account for the expected new levels

Discrimination of tissue-borne component



Conclusions

- Air-borne components affect skin surface measurements, particularly for speech sounds
- The proposed methods allow comparing the complete response of bioacoustic sensors
- The curves aid the selection of bioacoustic sensors for specific applications
- The proposed curves allow energy based discrimination of the excitation route
- Translation of these approaches to other bioacoustic measurements is possible