An Open-source Noise Dosimeter for Evaluating Exposure Metrics

Christopher Smalt, Chip Audette, Aaron Rodriguez
Bioengineering Systems and Technologies

8 June, 2021

This research is sponsored by ONR under United States Air Force Contract #FA8721-05-C-0002. Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government or the Department of the Navy.

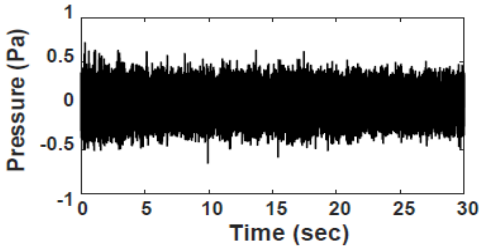
Disclaimer

This material is based upon work supported by the Department of the Navy under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of the Navy.

Industrial Noise Types and Measurement Considerations

Continuous

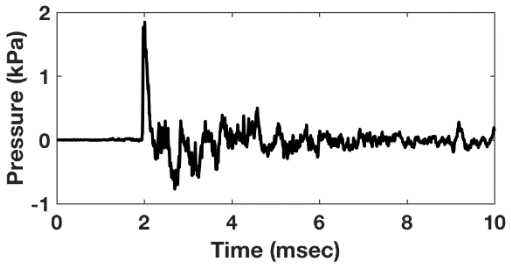
Continuous engine or machine noise



Peak Levels ~ 120-130 dB
Frequency Range ~ 4 kHz

Impulse

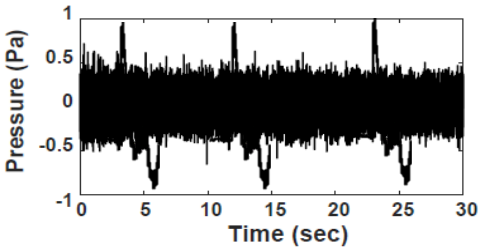
Industrial Impact Noise



Peak Levels ~ 150 dB SPL
Max Frequency: 50+ kHz

Complex

Mixture of* Impulse *and Continuous Noise



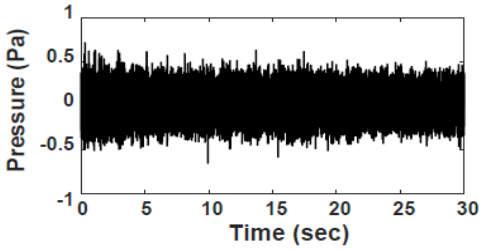
Levels: 90 – 130 dB SPL
Frequency Range: 50+ kHz

Equal-Energy Hypothesis (LAeq8hr) may be under-predict damage from complex, nonGuassian noise (Hamernik et al., 2003)

Military Noise Types and Measurement Considerations

Continuous

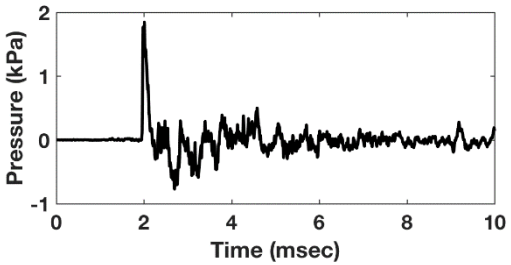
Continuous engine or machine noise



Level ~ 88dBA at 55 MPH
Frequency Range ~ 4 kHz

Impulse

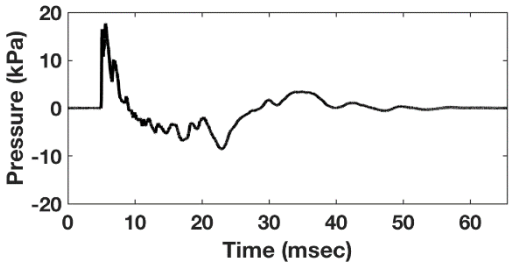
Small weapons fire



Peak Levels ~ 160 dB SPL
Max Frequency: 50+ kHz

Blast

Grenades, TNT, large-caliber weapons



Peak Levels ~ 185+ dB SPL
Frequency Range: 50+ kHz

Noise environments can vary widely, creating challenging measurement requirements with extreme sound pressure levels

Noise Dosimetry Spectrum

Sound Pressure Level (dB)

Up to 140 | **130-185** | **>185**

- **Continuous Noise**
  - Large selection of wearable COTS devices available

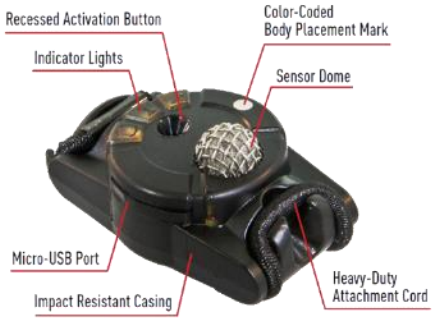
- **Impulse Noise**
  - Few COTS options, typically large, stationary systems

Stationary recording systems

SPL Meter with high SPL ¼" microphone

MIT LL Augmented COTS Recorder

- **Blast**
  - Wearable COTS exist
  - Only sensitive to large blasts
  - Does not capture impulses



COTS: Commercial off the Shelf

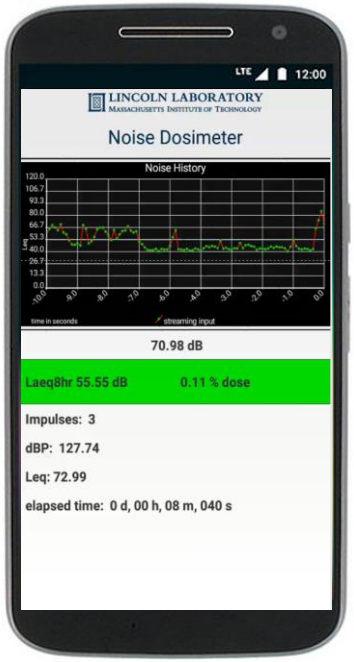
Low-Cost Open-Source Noise Dosimeter

Approximate Dimensions: 3.5” x 1.5” x 1”

- 2-channel audio
- Teensy 3.6 processor
- 96 kHz sample rate
- MicroSD card
- Battery life ~ 8h
- Cost: ~$150 ea

Bluetooth Retrieval

Smartphone App



Low-cost, flexible solution for noise dosimetry in continuous and complex noise environments where peak noise is are below 130 dBSPL

Tympan RevC Open-Source Audio Platform

https://tympan.org

- **Tympan is a powerful open-source audio development platform**
  - **2017 release, designed by Creare**
  - **Teensy 3.6 processor**
- **Well-suited for wearable applications**
- **Supports real-time extraction of standard or custom noise exposure metrics**
- **Limited capability for military impulse noise**
  - **Lacks circuitry to power high-SPL external microphones**

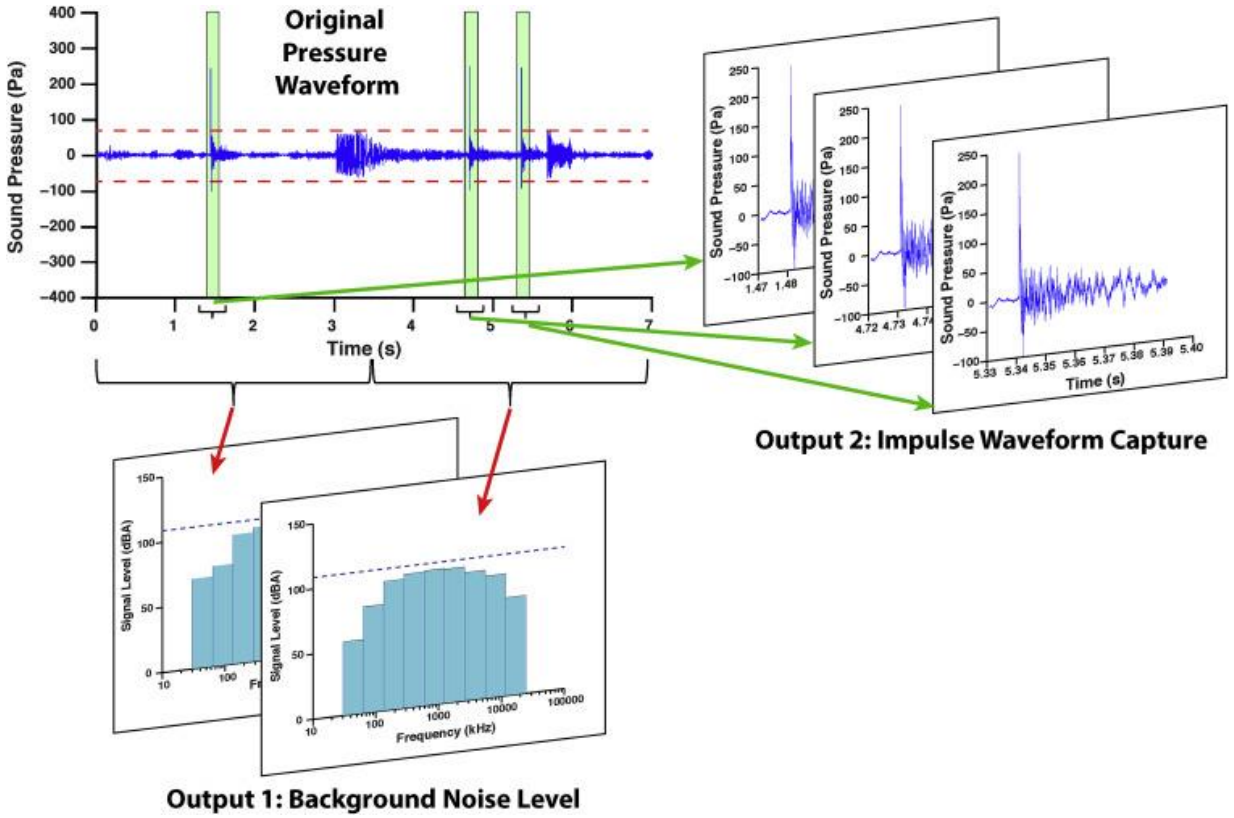
Compatible with 1/8" external microphones

Microphones used in Evaluation of Smartphone SPL Meter Apps (Kardous and Shaw, 2016)

Device Comparison	Tympan RevC	Tascam DR-100mkIII
Maximum Sample Rate	96 kHz	192 kHz
Programmable On-Board Processing	Yes	No
Approximate Cost	$150	$400
Num. Audio Channels	2	2
Phantom Power	No	Yes
Remote Data Retrieval	Bluetooth	No
Approximate Size	~5 in^3	~27 in^3

Noise Dosimetry Data Processing

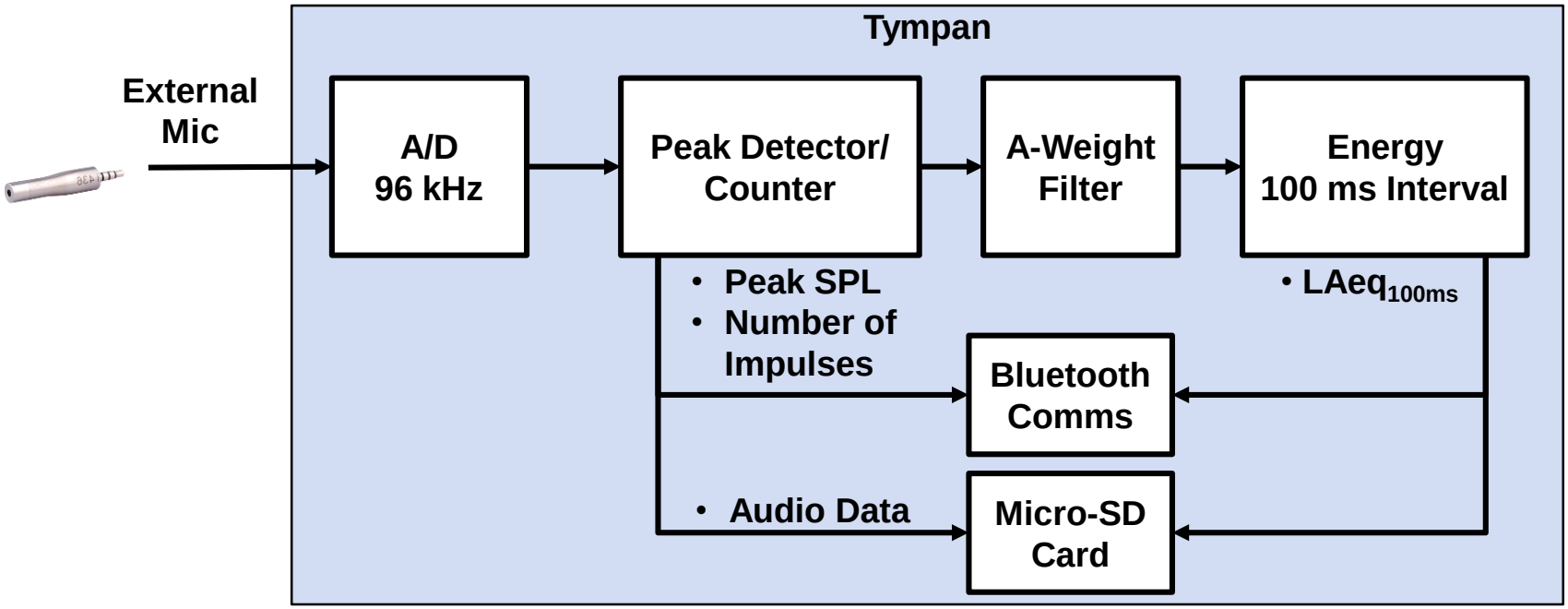
- **Goal is to retain information necessary for noise exposure research**



U.S. Patent No. 9,478,229, 10,074,397

Noise Dosimetry Data Processing

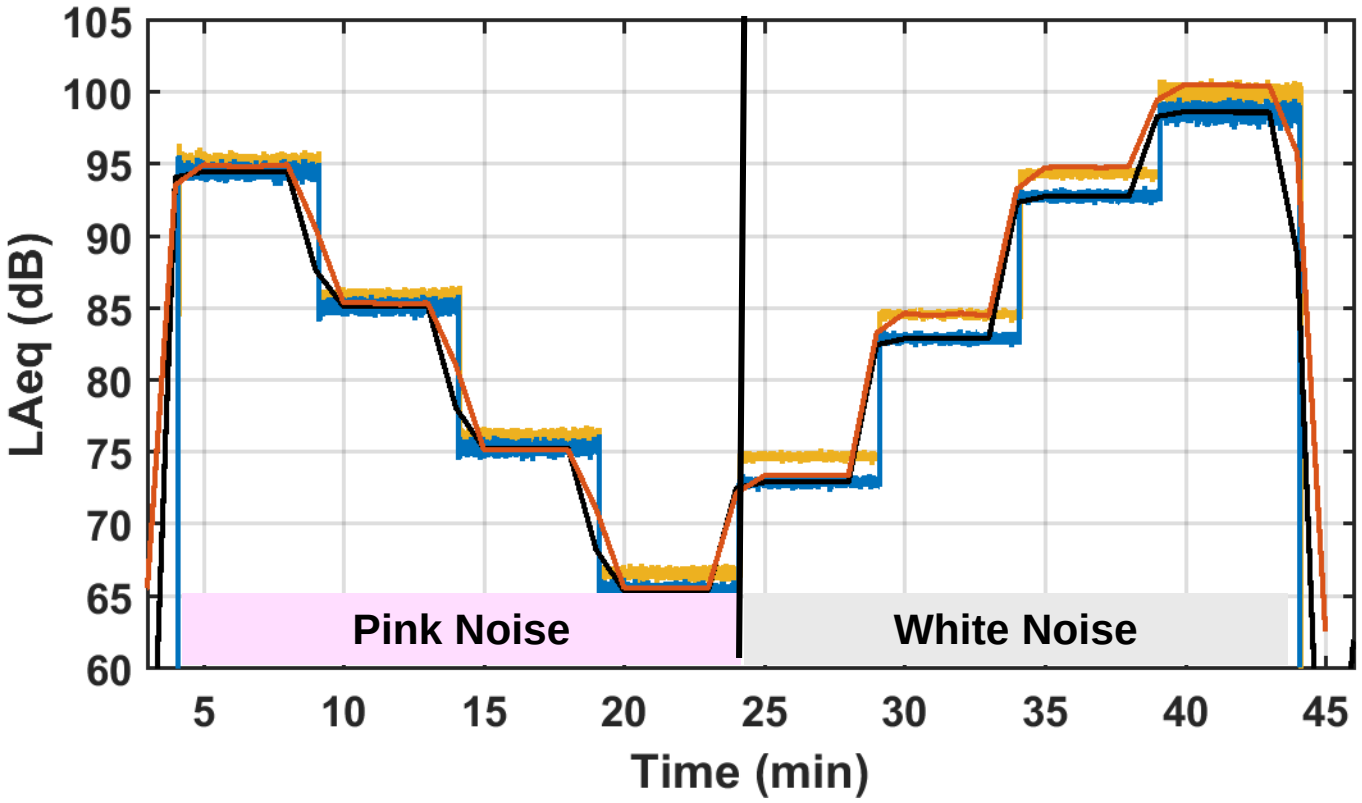
Basic Noise Exposure Metrics



Noise exposure logged to disk for off-line analysis and available for real-time monitoring via Bluetooth

Laboratory Validation

Measured noise levels for three co-located dosimeters



Augmented Tascam DR100
100 ms updates

Tympan Rev C

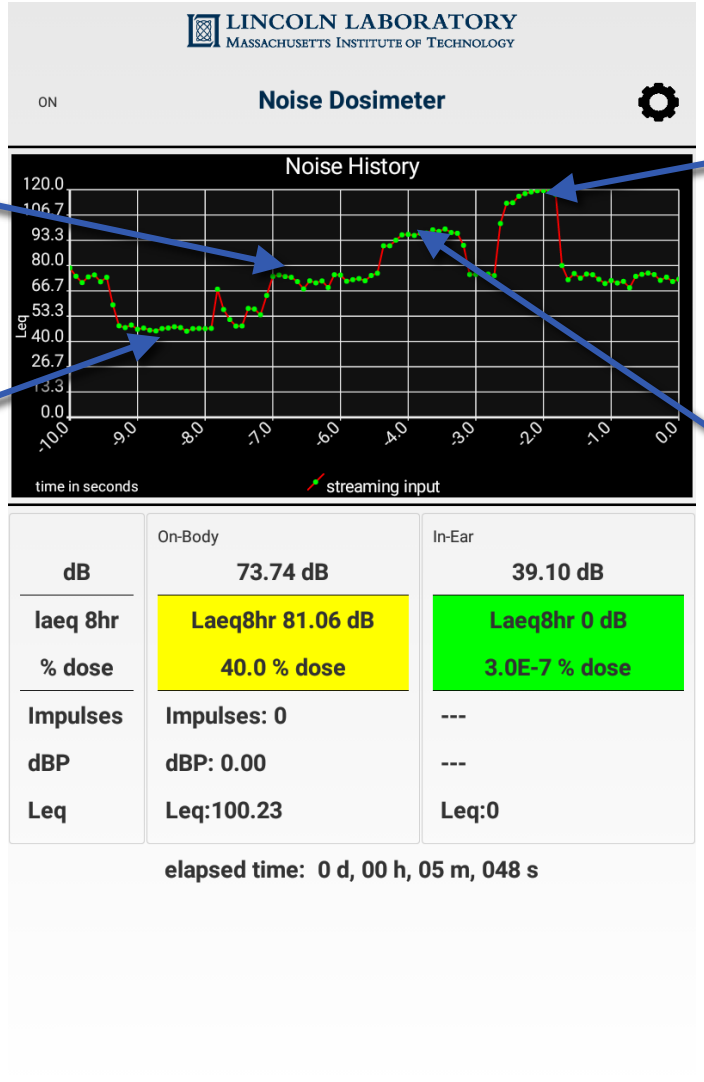
100 ms

60 s

doseBadge CR110
60 s updates

Tympan exposure levels are within 2 dB of other dosimetry systems.
Fast data logging allows dynamic noise exposure to be captured.

Noise Dosimeter App



Stereo System

Background Level

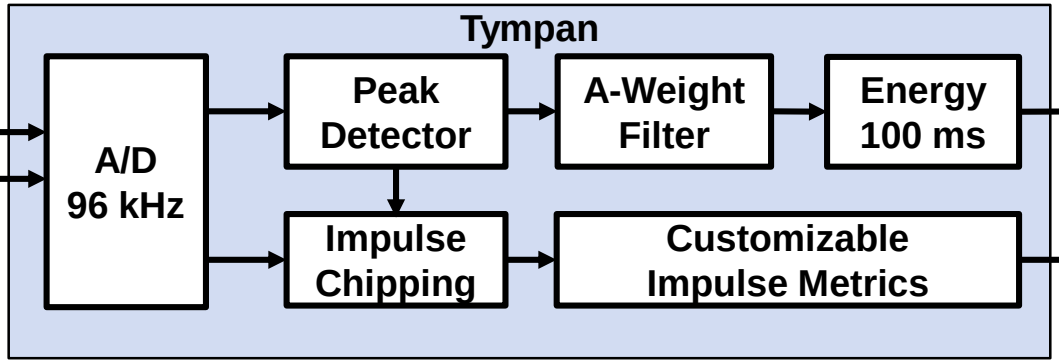
Chris's Trumpet at 1m

Chris's Trumpet across the room

mNOISE Dosimeter Prototype

- **Concept: Modify Tympan to support military impulse noise research**
- **Augment with dual-channel high-SPL microphones**
  - **Circuit modifications required to power mics**
- **Leverage existing MIT LL custom assemblies for in-ear and on-body measurements**
- **COTS microphone cost: ~$3500 / pair**

Smartphone App



- **$LAeq_{100ms}$**
- **Peak SPL**
- **AHAAH**
- **$LIAeq_{8h}$**
- **HPD attenuation rating**
- **Kurtosis**
- **Impulse waveform**
- ***etc*.**

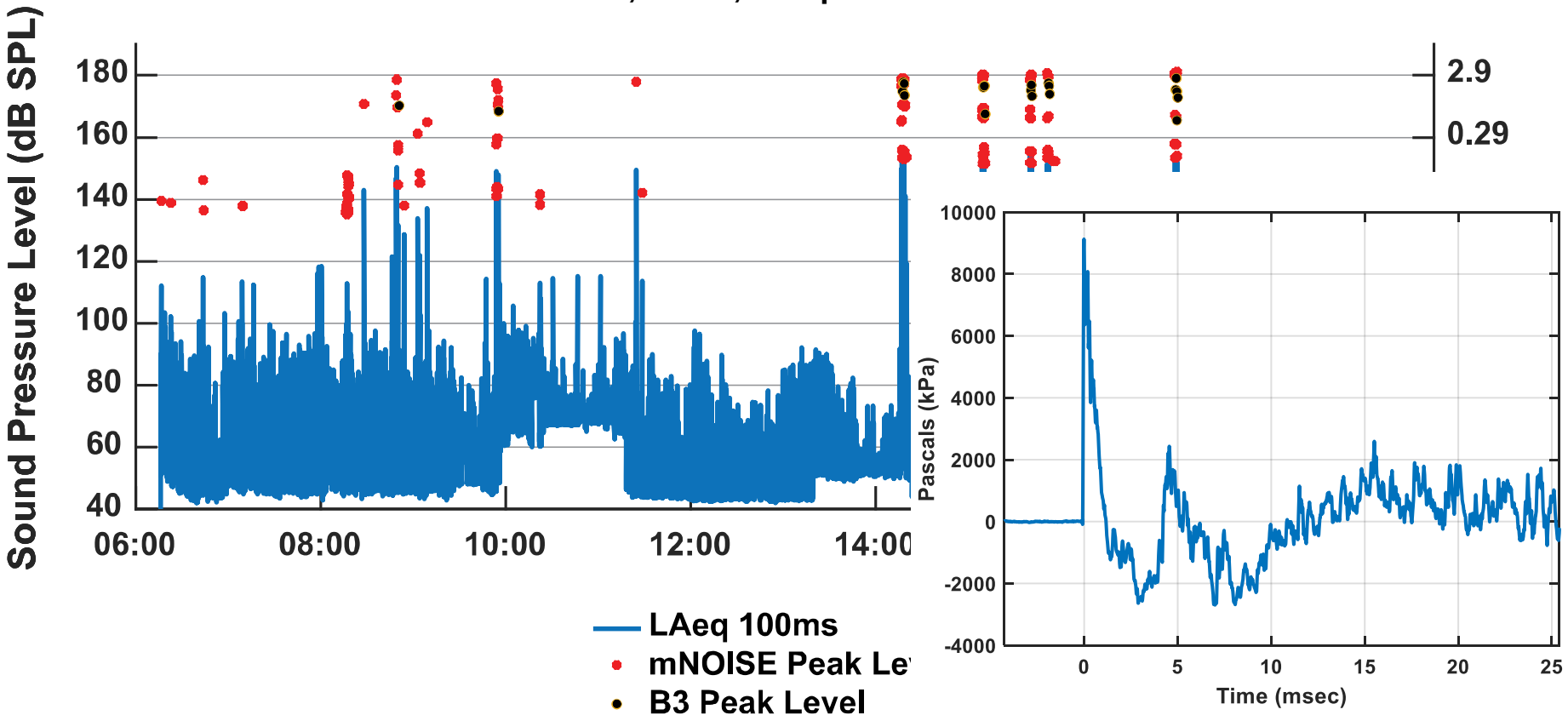
Walter Reed National Military Medical Center

Fort Bragg

DEPARTMENT OF DEFENSE HEARING CENTER OF EXCELLENCE

M777 Charge 3&4 Rolling Thunder, Fort Bragg

181 dBP, ~3PSI, LAeq8hr = 113.6



Slide re-used from NHCA 2021 presentation

Pros and Cons for Tympan-Based Noise Dosimetry

Pros

- Open source
  - Low cost
  - Customize processing on Arduino
    - Easy to program; Large body of open-source libraries and code
    - Supports research: record raw audio or non-standard metrics
- Wireless retrieval
  - Real-time monitoring or alerts
- Supports up to 2 external microphones
  - Simultaneous in-ear and on-body could enable hearing protection fit estimates

Cons

- Lacks circuitry to power high-SPL microphones
- Limited memory and processing
- Not ruggedized for outdoor use
  - Vulnerable to dust, rain, impact, etc

Summary

- **Tympan supports comparable audio and offers the flexibility of on-board, real-time processing**
  - **Open-source dosimetry Arduino and Android app developed to monitor conventional noise metrics: LAeq, number of impulses, peak SPL**

- **New customized version developed (phantom power shield for additional microphone types)**

https://github.com/Tympan/Tympan_Library/tree/master/examples/02-Utility/SDWriting_02_RemoteControlled

https://github.com/Tympan/Tympan_Library/tree/master/examples/02-Utility/SoundLevelMeter_2Chan

Acknowledgements

- MIT LL
  - Paula Collins
  - Shakti Davis
  - Nick Malyska
  - Thomas Quatieri
  - Aaron Rodriguez
  - Chris Smalt
  - Lawrence Thul

- Sponsors
  - Office of Naval Research (ONR)
  - U.S. Military Operational Medicine Research Program (MOMRP)
  - Marine Expeditionary Rifle Squad (MERS)
  - U.S. Army Research Institute of Environmental Medicine (USARIEM)
  - U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC)

- Collaborators
  - DoD Hearing Center of Excellence
  - Walter Reed National Military Medical Center (Doug Brungart)
  - National Institute for Occupational Safety and Health (NIOSH) - Bill Murphy and Chucri Kardous
  - Creare LLC - Chip Audette, Eric Yuan, Odile Clavier