Acoustic Modules for IceCube-Gen2

Calibration Workshop

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GEFÖRDERT VOM

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IceCube Upgrade

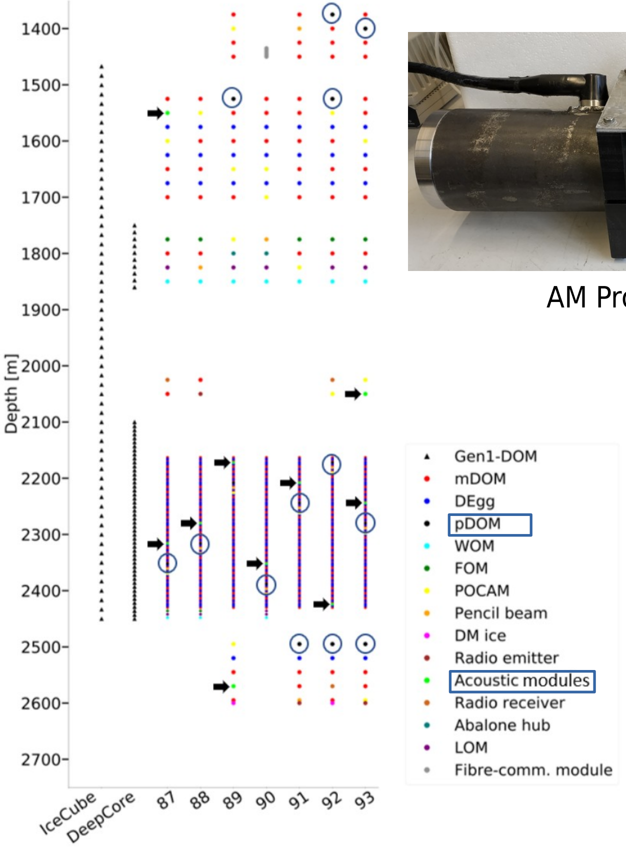
Physics Institute III B

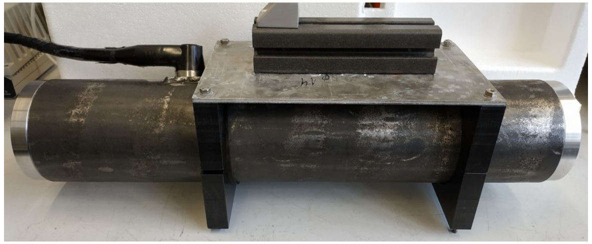
RWTH Aachen University

IceCube Upgrade Acoustic System Overview

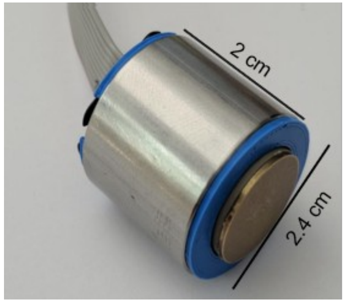
Acoustic Modules (AMs)

- 10 AMs are planned for the upgrade
  (7 in physics region, 2 above, 1 below)
- At least one on each string (87-93)
- AMs equipped with acoustic emitter and receiver; pDOMs equipped with acoustic sensors (measurement of travel time + trilateration)
- Geometry calibration using trilateration of acoustic signals to determine the positions of pDOMs/Ams (10 cm accuracy over >100m)
- Glaciological measurements of ice properties (ice movement, acoustical properties)
- Based on experience from EnEx-RANGE





AM Prototype rev1



Acoustic Sensor

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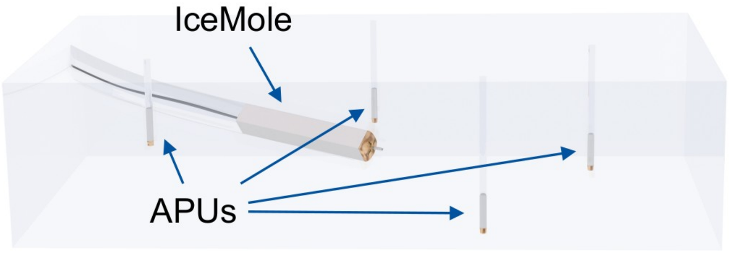
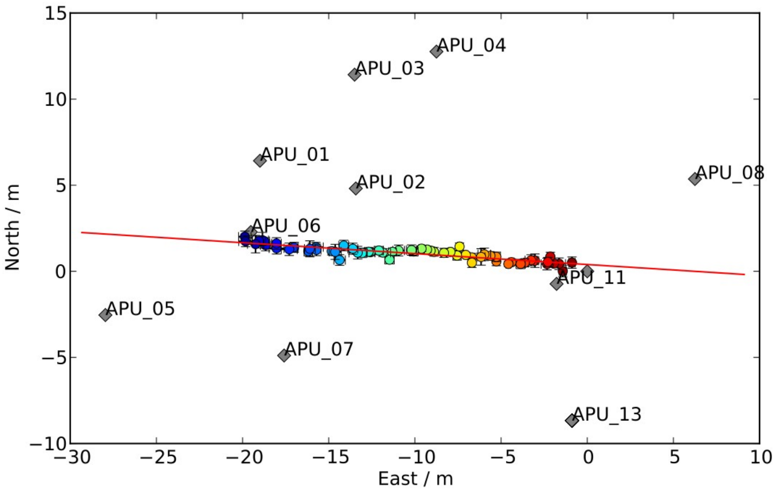
EnEx-RANGE

- **Goal:** robust localization of a maneuverable melting probe (IceMole) in instrumented ice volume
- Development of 13 melting probes with acoustic instrumentation (APUs)
- Achieved accuracy of 0.32 m for moving object in 30 m x 40 m x 10 m volume of glacial ice with $\lambda_{att} = 8.7\,m$
- With cold ice in IceCube ($\lambda_{att} = 300\,m$)* larger distances at same accuracy possible ($d > 300\,m$)

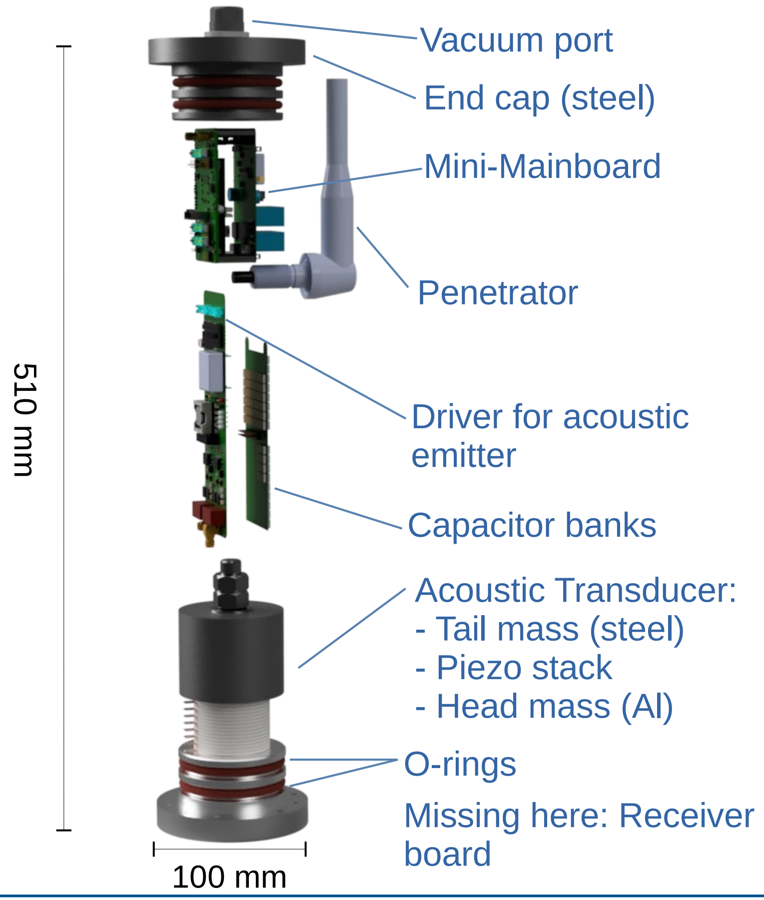


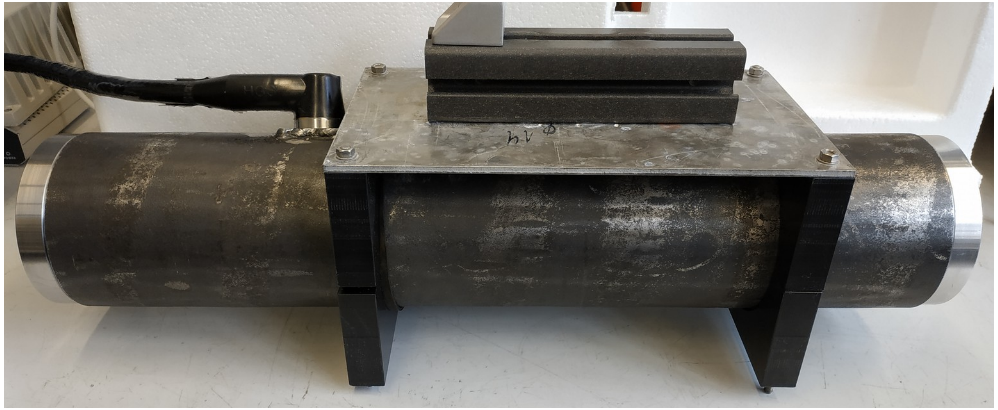
[Source: Dmitry Eliseev]



*Abbasi et. al., “Measurement of Acoustic Attenuation in South Pole Ice”, DOI:10.1016/j.astropartphys.2010.10.003

Acoustic Module Technical Design

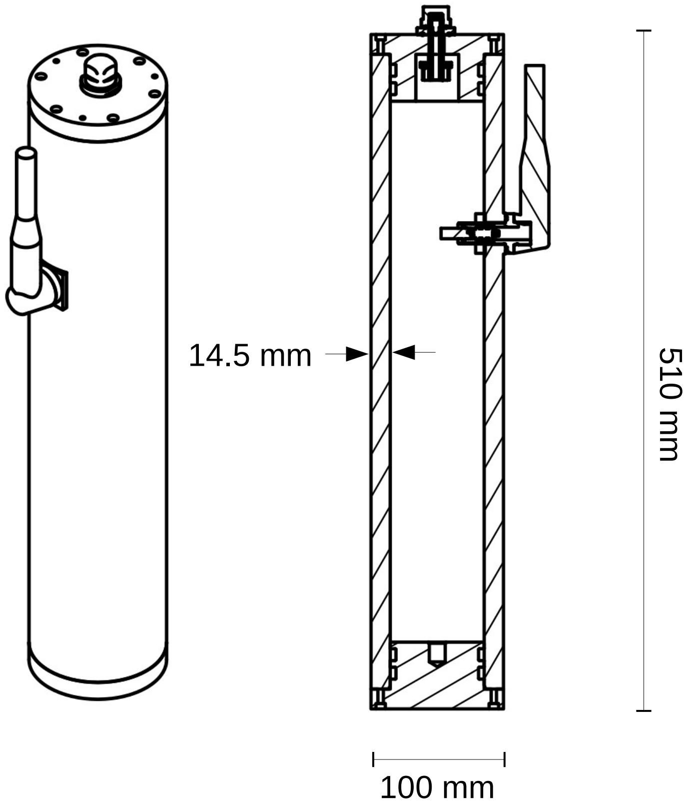




AM Prototype rev1

Pressure Housing

- Housing made of contruction steel S355
  (UTS = 355 MPa)
- Designed for pressure resistance up to 70 MPa
- Vacuum port allows reducing/balancing pressure in the housing
- Penetrator cable assembly at the side
- Total weight ~22kg

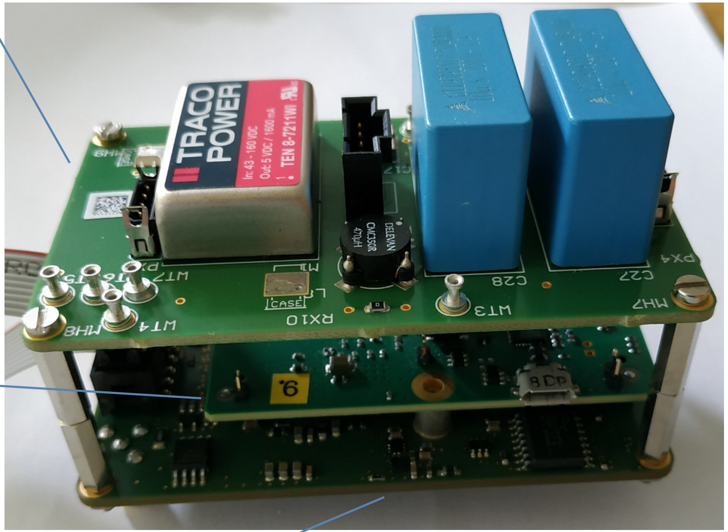


Electronics: Mini-Mainboard (MMB)

- Used by many different new Upgrade devices (Acoustic module, pencil beam and POCAM, ..)
- Developed in Aachen together with Madison
- Stack of 3 boards (5 x 8.5 x 6 cm³):
  - **MMB Power Board**
    - Filters signals from surface
    - Provides power supply for other electronics
  - **MMB Controller Board**
    - STM32 H743ZIT microcontroller
    - 30 GPIOs, 2x I2C, 2x SPI, 2x UART
    - Slow control: Magnetometer, accelerometer, pressure sensor
  - **ICM** (Ice Comms Module)
    - Communication with surface
    - Provide timestamps to in-ice devices

MMB power board

ICM

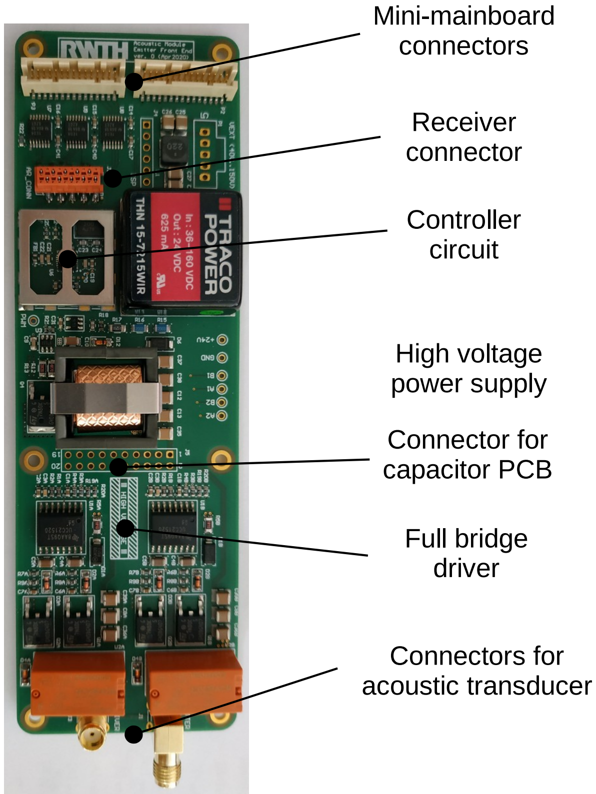


MMB controller board

Prototype rev1

Electronics: Acoustic Emitter Driver

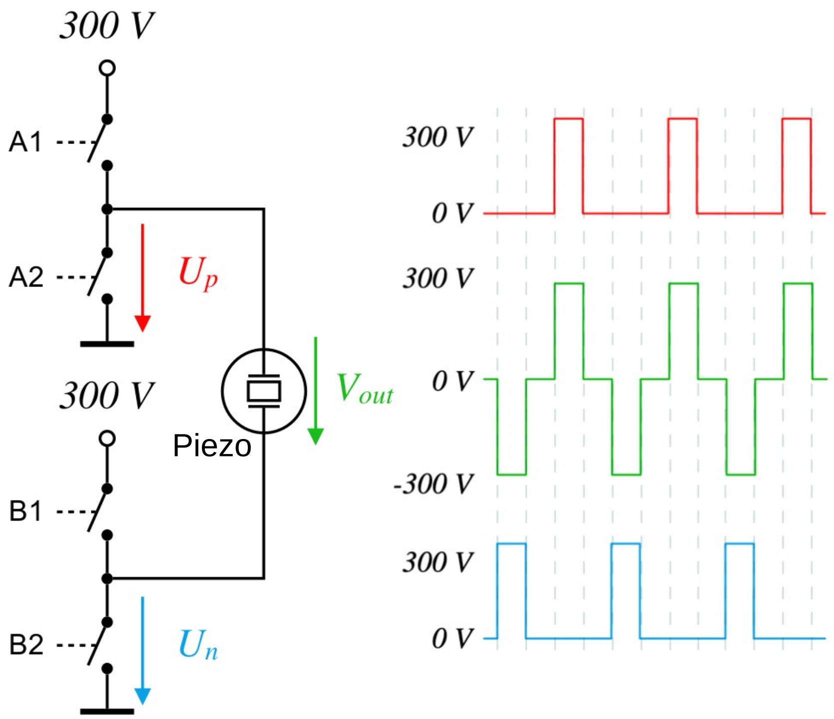
- **High voltage power supply** generates 300 V to charge capacitors
- **Storage capacitors** (stacked PCB) provide high power for short periods during emission
- **Full bridge driver** generates high voltage bipolar rectangular pulses to drive the acoustic transducer
- **Controller circuit** regulates high voltage power supply, generates waveform and controls full bridge driver
- Connected to Mini-Mainboard (SPI, 7 GPIOs, low voltage supplies, WP_P/N)



Prototype rev0

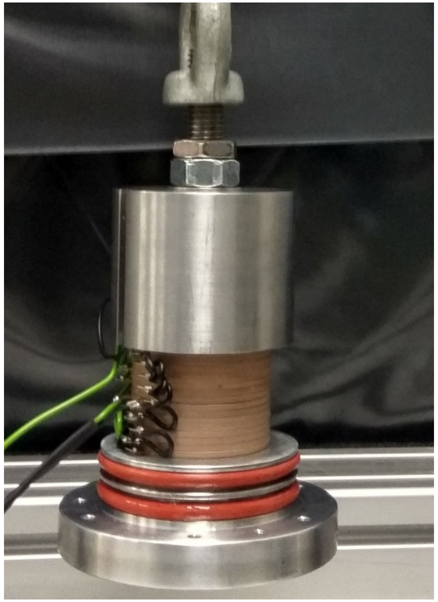
Backup: Signal Generation

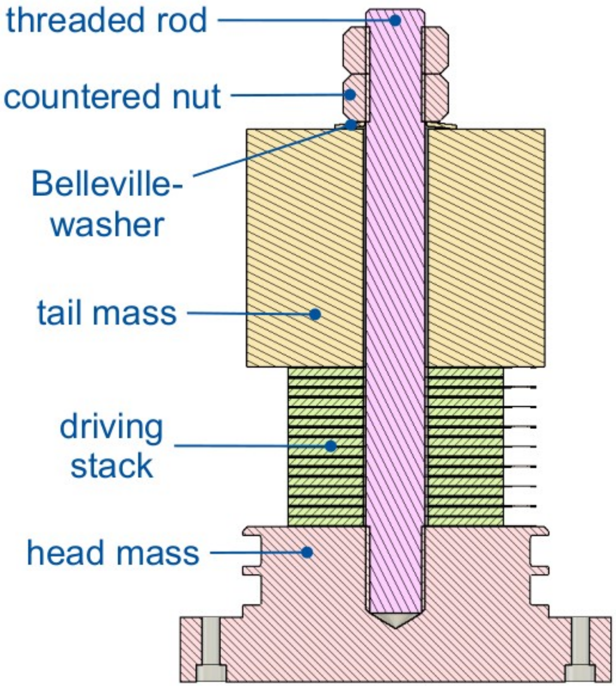
- Outputs bipolar rectangular pulses with three possible states +300V, 0V, -300V
- Steep rising/falling edges $t_{rise/fall} = 100\,ns$
- High sampling rate $f_s = 2\,MSps$
- Arbitrary waveform (chirp) possible as a series of output states +300V, 0V, -300V and state duration $\Delta_{tick} = 0.5..300\,\mu s$



Acoustic Transducer

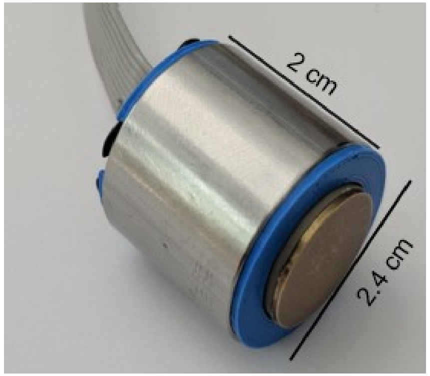
- Tonpilz-style piezoelectric transducer
- Driving stack with 16 piezoelectric discs (Sonox P4, $r_o = 50\,mm, r_i = 15\,mm, h = 2\,mm$)
- Aluminium head mass (0.635 kg)
- Steel Tailmass (1.36 kg)
- Improved head-to-tail-ratio ($M_H : M_T \approx 1:2$)
- Resonance frequency ~10 kHz
- Based on EnEx-RANGE design; tested on alpine glaciers

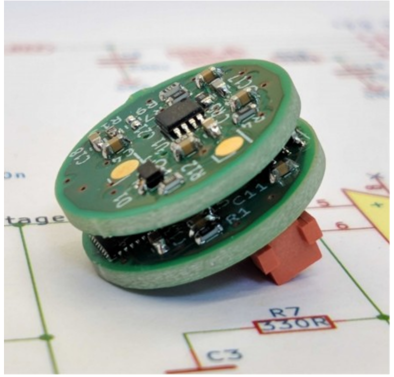




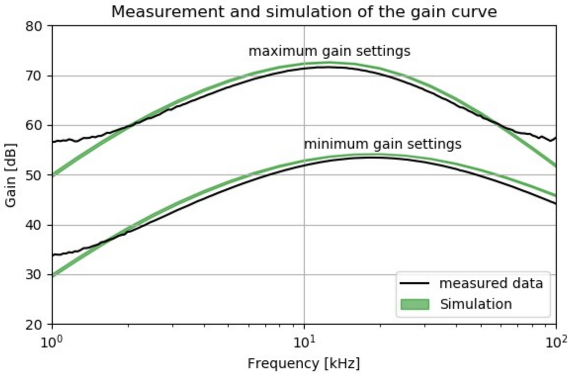
Acoustic Receiver

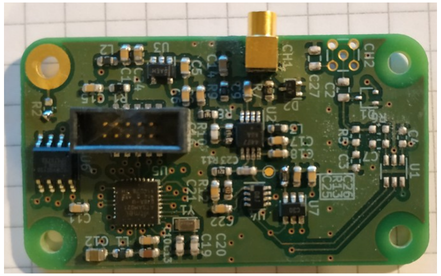
- Modified schematic design based on EnEx(-RANGE) project (Simon Zierke)
- Digitizes acoustic signals from acoustic transducer
- Variable gain to match unkown enviromental noise
- Bandwidth (-3dB):
  - 7,8 kHz - 45 kHz @ 53dB
  - 5,8 kHz - 25 kHz @ 72 dB
- Full functioning acoustic sensor ready to be integrated to DOM-sphere





Acoustic sensor prototype rev1

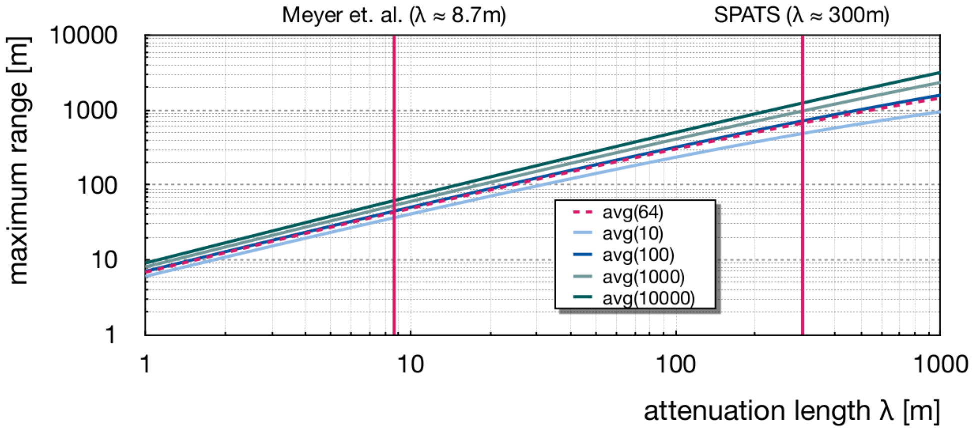




Single PCB sensor rev1.2, 4,9 x 2,8 cm

Performance Estimation

- Measured attenuation length in glacial (warm) ice: 8.7 m (Meyer et. al., EnEx-RANGE)
- Measured attenuation length in shallow antarctic (cold) ice: 300 m (SPATS)
- We expect the attenuation length to be smaller than measured by SPATS
  (ice is slightly warmer at larger depths)
- By extrapolating EnEx data of a glacier measurement, the range in antarctic ice can be estimated
- For an attenuation length of 100 m a range of ~300 m is expected



Extrapolation of EnEx-RANGE data (old transducer design) in glacial ice (att. length $\lambda \approx 8.7\ m$) to antarctic ice ($\lambda \approx 300\ m$) for $SNR = 5{:}1$ results in maximum ranges $> 100\ m$

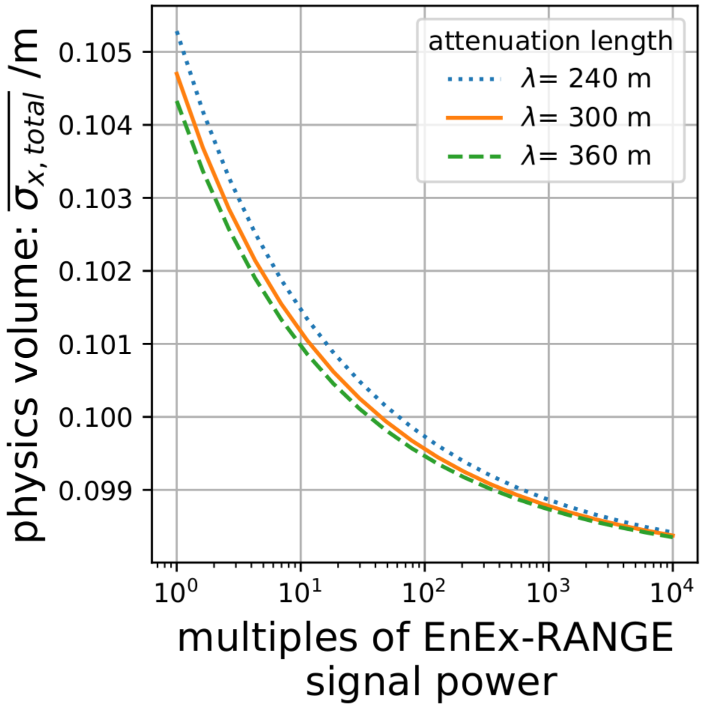
SPATS: South Pole Acoustic Test Setup

Performance Estimation

- Simulations of the acoustic signal propagation for the Upgrade configuration have been carried out
- The simulations indicate a resolution of ~10 cm for different attenuation lengths and signal powers
- Master thesis by Maximilian Scharf

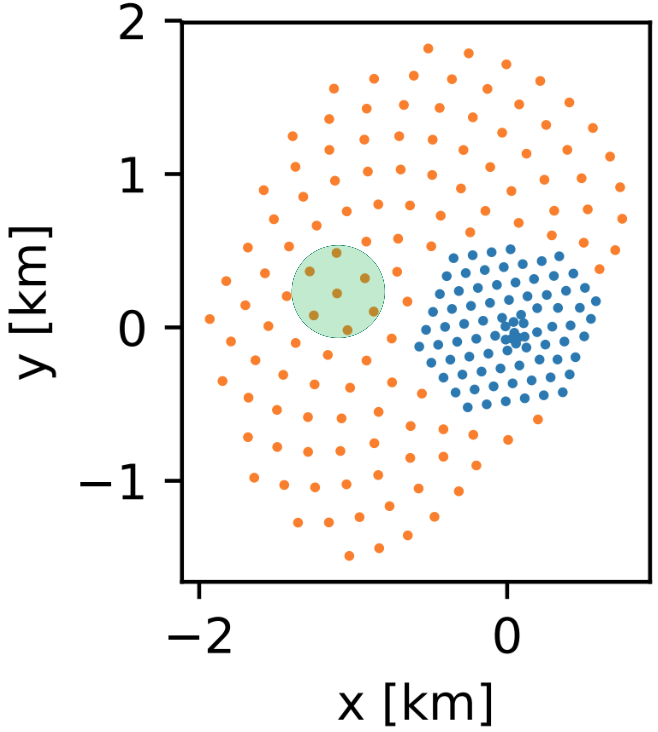
Table 4.1.: Assumptions of Simulation

σ_{spatial}	12.8 μs
$\sigma_{\text{synchronization}}$	5.0 μs
σ_{Shannon}	given by SNR(λ, n)
λ	300 m[3]
signal power n	10 x EnEx-RANGE Power (which used 64 averages [48])
constant speed of sound in ice	3900.0 m/s[2]



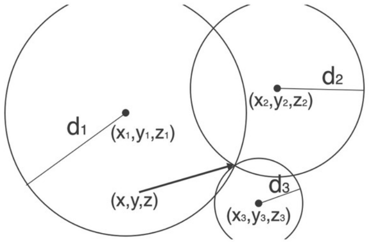
Strategies for Gen2

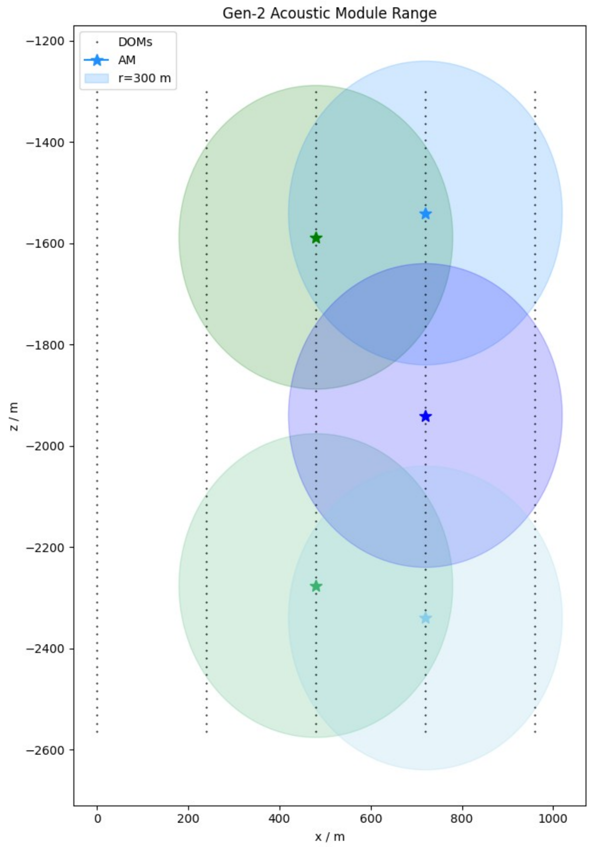
- **Gen-2 geometry:**
  - Sunflower geometry
  - String spacing: ~240 m
  - Module spacing: 16 m
  - Depth: 1.3 – 2.6 km
- **Acoustic Module:**
  - Range: ~300 m
  - ~6 strings within range (up to 175 DOMs)



Strategies for Gen2

- At least 3 transient times are required to locate a DOM
- **Two possible approaches:**
  - Determine the position of every DOM
    (~2-3 AMs per string, receivers in every DOM)
  - Determine only the end positions of strings and interpolate DOM locations
    (~1-2 AMs per string, receivers in some DOMs)
- Exact attenuation length needs to be measured in the Upgrade to determine the required number of AMs
- For non-spherical response more AMs might be required





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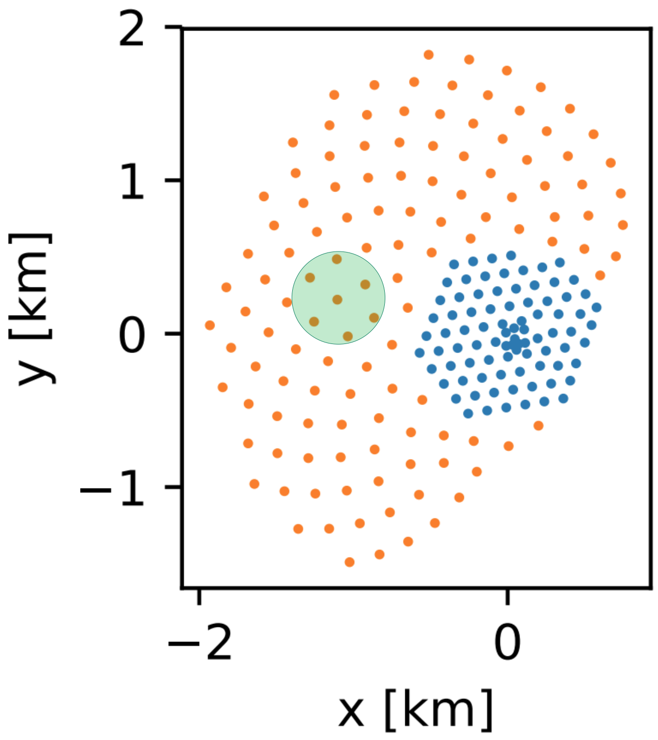
Conclusion / Discussion

- The Acoustic Module is a promising candidate for the geometry calibration of the upcoming IceCube Upgrade and IceCube Gen2 detector
- Using trilateration, the acoustic system aims for a resolution of ~10 cm of the DOM positions over a range ~300 m
- Range highly dependent on attenuation length → need to measure this in the Upgrade
- Which calibration strategy is favourable for Gen2?
- How can acoustic and optical calibration be combined?



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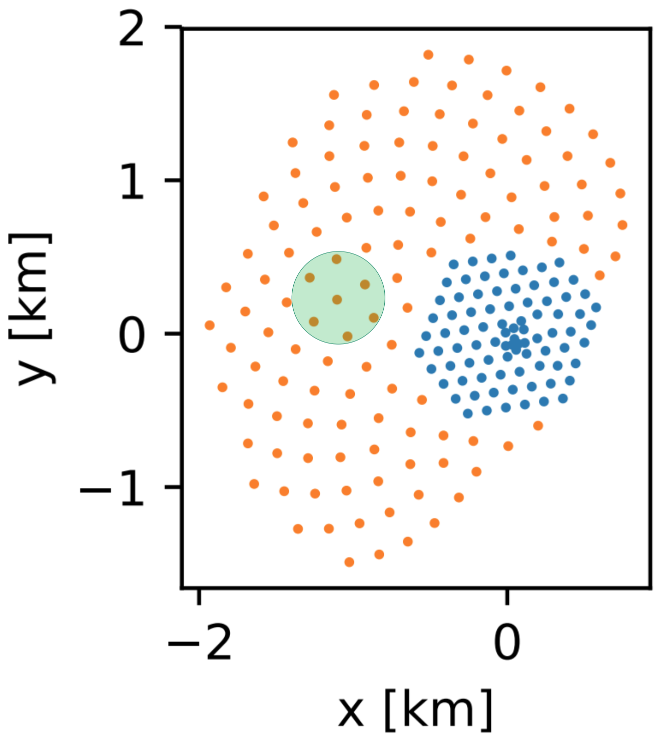

Thank you for your attention!