IceCube-Gen2 Radio Array Surface Calibration: Opportunities from Unique Transmitter and Receiver Systems

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Outline

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1. RF Channel Calibration
   - Surface transmitter measurements
     1.1 Heartbeat calibration pulsers and Δt_{off}
     1.2 In situ calibration measurements
   - Drone borne transmitters
     1.1 θ and ϕ in situ variation (radiation patterns)
     1.2 R (gain calibration)
2. Constraining Ice Effects
   - Attenuation length $\lambda(\nu)$, $\lambda(\nu, z)$
   - Drone borne transmitters, receivers, and $\lambda(\nu, x, y)$
   - Drone borne transmitters, receivers, and birefringence

RF Channel Calibration

RF Channel Calibration - fixed transmitter

Heartbeat calibration pulsers: on-station, calibration of x and y axes

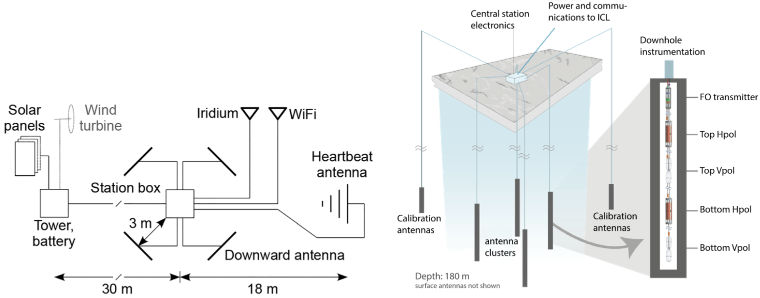

Figure 1: Examples of heartbeat designs in ARIANNA (left) and ARA (right) prototypes. (See talks by K. Hughes, S. Barwick for more details). (S.A. Kleinfelder *et al* (2015), P. Allison *et al* (2016)).

RF Channel Calibration - fixed transmitter

Heartbeat calibration pulsers: on-station, calibration of x and y axes

1. Calibration of the *x-axis:* timing offsets.

$$\Delta t_{\mathrm{obs}} = \Delta t_{\mathrm{phys}} - \Delta t_{\mathrm{off}} \tag{1}$$

   The Δt_{phys} are associated with detector geometry, and Δt_{off} arise from systematic offsets in cable delays, RF antenna location, etc.

2. Calibration of the *y-axis: in situ* gain calibration, accounting for $c \to c/n(z)$, identical TX,RX

$$\frac{P_r}{P_t} = D_t R_r \left(\frac{\lambda}{4\pi r}\right)^2 \tag{2}$$

RF Channel Calibration - fixed transmitter

Long-baseline calibration measurements: performed by people or from fixed installations. Offers calibration of timing offsets and gain in the extreme far field, can trigger multiple stations at once.

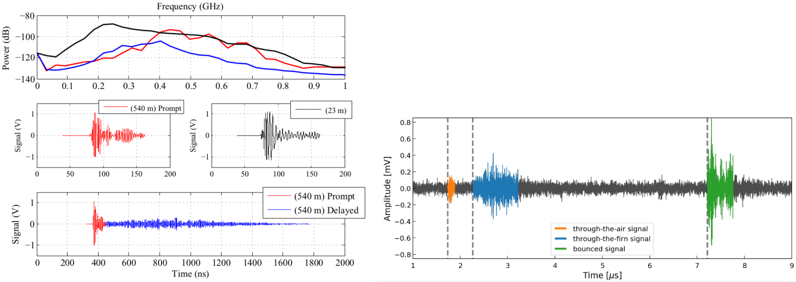

Figure 2: Examples of long-baseline measurements revealing horizontal propagation. (J. C. Hanson (2015), S. W. Barwick *et al* (2018)).

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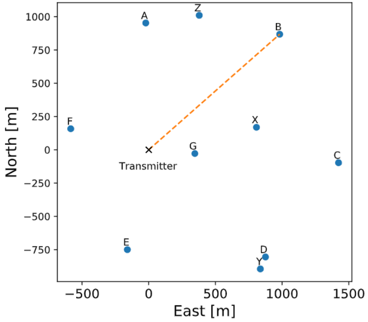


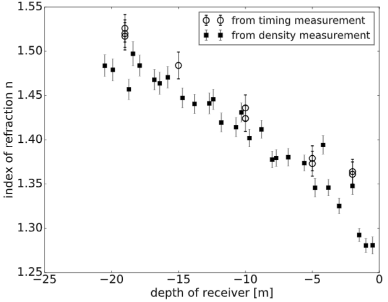


Figure 3: (Left) Multiple stations triggered by a single transmitter. (Right) Cross-check of *in situ* index of refraction. (S. W. Barwick *et al* (2018))

RF Channel Calibration - drone borne

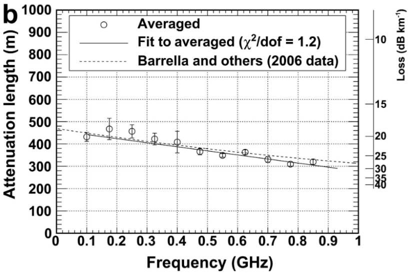
Drone-borne calibration measurements: lightweight transmitter carried by RC drone. Offers (θ, ϕ) calibration (timing), and R calibration (gain). Working prototype built at Whittier College.

Figure 4: Example of a 3D printed drone with ≈ 1.0 kg payload, 11.1 V, 3C LiPo battery, quad-rotor configuration. Technical consideration: cold-temp Li battery, altitude of Pole.

Constraining Ice Effects

Constraining Ice Effects - drone borne

Drone-borne calibration measurements: RF attenuation length $\lambda(\nu)$, $\lambda(\nu, z)$ have been already measured.



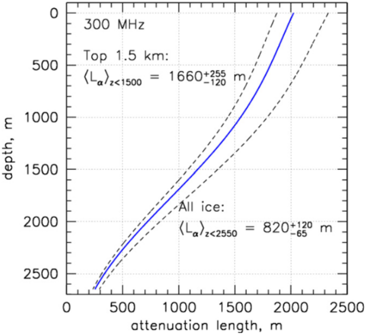


Figure 5: Examples of of Antarctic $\lambda(\nu)$ and $\lambda(\nu, z)$ measurements for Askaryan-class detectors. (J. C. Hanson *et al* (2015), P. Allison *et al* (2012)).

Constraining Ice Effects - drone borne

Drone-borne calibration measurements: RF attenuation length $\lambda(\nu, x, y)$ has not been measured (CReSIS effort already exists at University of Kansas). Birefringence: drones can rotate independently.

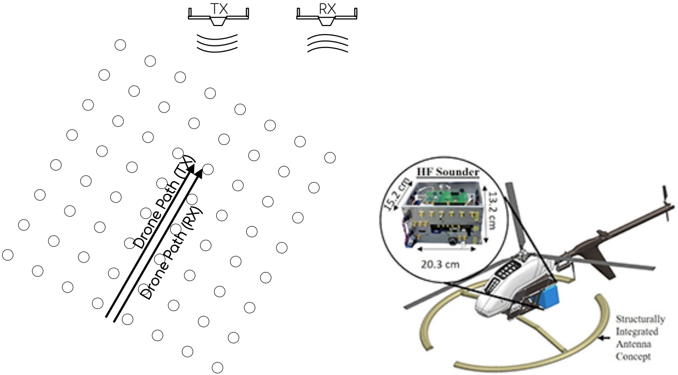


Figure 6: Drone ice calibration of $\lambda(\nu, x, y)$ (alternative: go in person).

Conclusion

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