Traceability and Calibration of Weather Radar Reflectivity Measurements by Means of a Target Simulator

M. Schneebeli\textsuperscript{1}, A. Leuenberger\textsuperscript{1}, E. Tas\textsuperscript{2}, O. Schreiber\textsuperscript{3}, T. Pittorino\textsuperscript{3}

\textsuperscript{1}Palindrome Remote Sensing GmbH, Landquart, Switzerland
\textsuperscript{2}Swiss Federal Institute of Metrology METAS, Wabern, Switzerland
\textsuperscript{3}NTB Interstate Applied University of Technology Buchs, Buchs, Switzerland

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Radar calibration is difficult

**Sphere calibration**

**Manual maintenance**

**Sun calibration**

**Ground truth**

Radar calibration with an RTS
Palindrome Radar Target Simulator (RTS)

- Generates a calibrated, virtual radar target
- Receives incoming radar pulses
- Every individual pulse is sampled and stored
- Pulses are sent back with predefined amplitude, Doppler shift and time delay
Measurement capabilities

**Reflectivity**

**Pulse Amplitude**

**Antenna pattern**

**Doppler**

**Pulse Phase**

**Pulse Frequency**

Radar calibration with an RTS
Calibration theory

\[ Z_e = f(\sigma_b, \lambda, \theta, r) \]

- \( Z_e \): radar reflectivity
- \( \sigma_b \): radar cross section
- \( \lambda \): wavelength
- \( \theta \): half power beam width of radar antenna
- \( r \): distance to target

\[
\sigma_b = \frac{P_{\text{out}}}{S_{\text{in}}} = \frac{P_{\text{out}}A_{\text{eff}}}{P_{\text{in}}} = \frac{P_{\text{out}}G\lambda^2}{P_{\text{in}}4\pi}
\]

- \( S_{\text{in}} \): incoming power density on target
- \( P_{\text{out}} \): reflected power
- \( A_{\text{eff}} \): Effective antenna area
- \( G \): antenna gain

If the fraction between outgoing and incoming power is known, the RCS \( \sigma_b \) of a target is known precisely.
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Calibration with a target simulator

Analog up- / down-conversion, amplification
Analog ⇔ digital conversion
Digital up- / down-conversion
Signal processing
Calibration with a target simulator

Feedback loop with gain $G_f$

$\frac{P_{\text{out}}}{P_{\text{in}}} = f(G_f)$

$G_f$ needs to be determined precisely.

Analog up- / down-conversion, amplification

Analog ⇔ digital conversion

Digital up- / down-conversion

Signal processing
Traceability to SI units

Vector network analyzer calibration kit → Vector Network Analyzer → Target Simulator Feedback loop → Power fraction at Target Simulator $\frac{P_{\text{out}}}{P_{\text{in}}}$ → Radar reflectivity

SI unit Meter
SI unit Watt
Reference attenuator

Calibration Kit
VNA measurements
Target simulator calibration unit
Network analyzer measurements

- High-precision measurements of feedback gain $G_f$
- Accuracy: below 0.1 dB
- Measurement of antenna gains in anechoic chambers
- Swiss Metrology Institution METAS is responsible for the calibration and traceability
Outdoor verification with Antennas

Measurement of the difference between the outgoing and incoming pulse power $\Delta P$
Laboratory verification without antennas

Radar calibration with an RTS
Measurements during Olympics 2018

**60DX calibration**
- Distance: 2.1 km
- \( \Delta h: 100 \) m
- 3 observation days
- window scans

**Long-term measurements with MXPol**
- Distance: 13 km
- \( \Delta h: 700 \) m
- 40 observation days
- RHI scans

**MXPol test measurements**
- Distance: 5 km
- \( \Delta h: 0 \) m
- 1 observation day
- window scans
60DX calibration with 50 dBZ target

Reflectivity

- mean: 52.79
- std: 0.20

Centroid position

- mean: 231.77
- std: 0.01

Elevation [°]

- mean: 1.40
- std: 0.02

Time [minutes]
Conclusion

A target simulator provides a mean to calibrate and trace weather radar reflectivity measurements back to SI units.

Accuracy depends on the measurement precision of the feedback gain.

Outlook

- Certified commercial instrument available in 2019 for X- and C-band
- Extensive tests will be performed

Booth 9070