PALINDROME
REMOTE SENSING

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

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WMO CIMO TECO, 8.10.2018, Amsterdam

Swiss Confederation
Commission for Technology and Innovation CTI

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

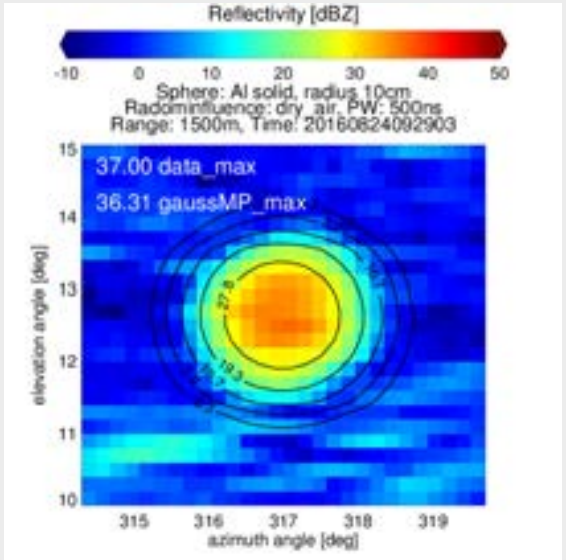
METAS
Federal Office of Metrology

NTB
Interstaatliche Hochschule für Technik Buchs
FHO Fachhochschule Ostschweiz

Stiftung für Innovation, Entwicklung und Forschung Graubünden

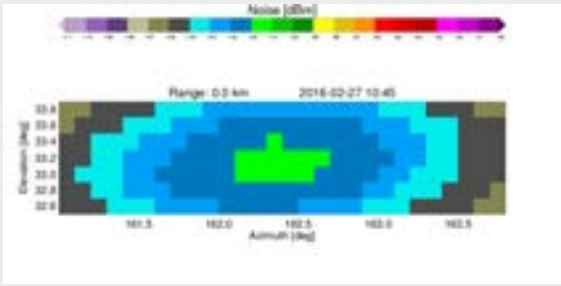
# Radar calibration is difficult

## Sphere calibration

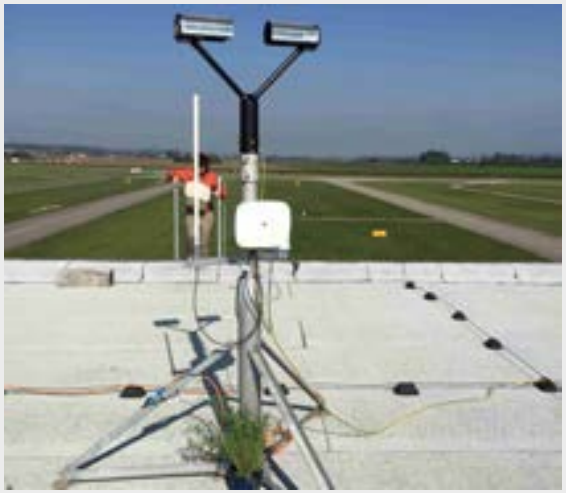



## Manual maintenance

## Sun calibration

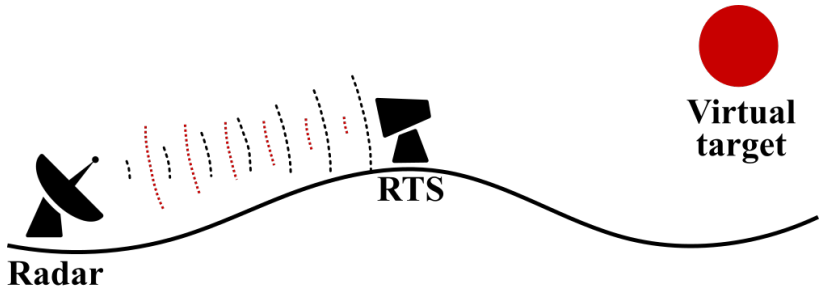


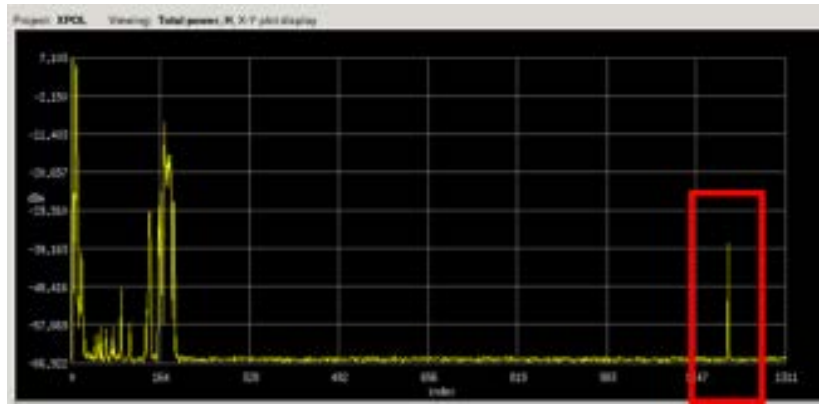

## Ground truth



# Palindrome Radar Target Simulator (RTS)

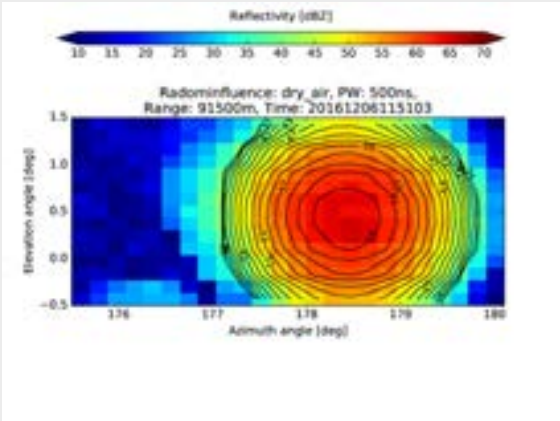
- Generates a calibrated, virtual radar target
- Receives incoming radar pulses
- Every individual pulse is sampled and stored
- Pulses are sent back with predefined amplitude, Doppler shift and time delay



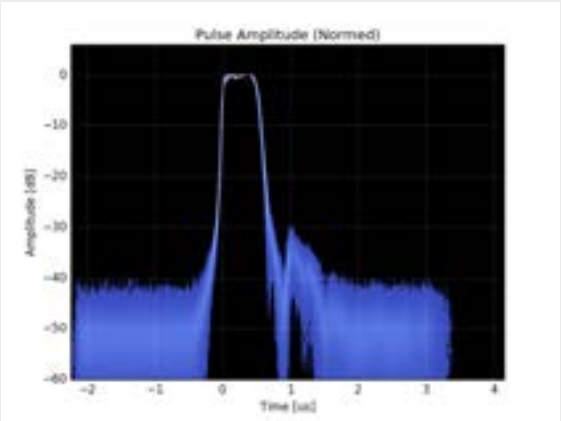



# Measurement capabilities

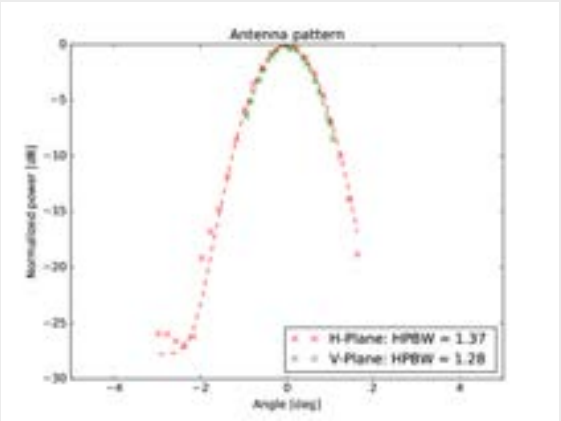
## Reflectivity



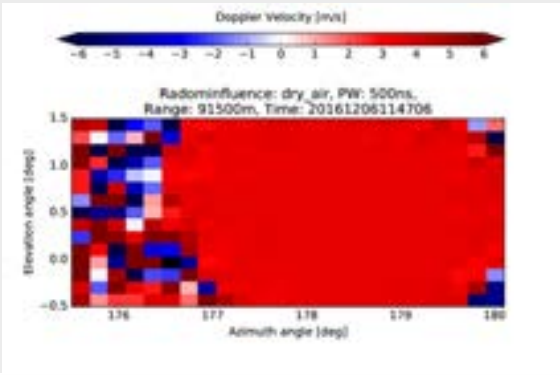

## Pulse Amplitude



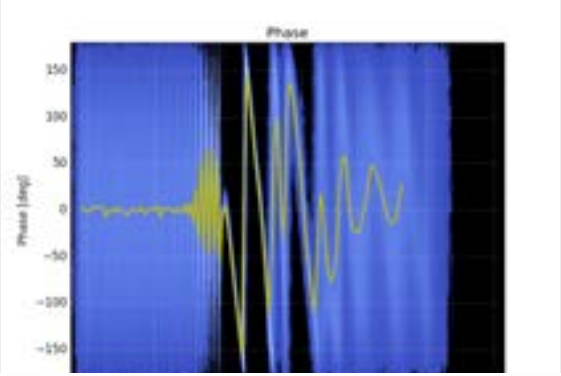

## Antenna pattern




## Doppler




## Pulse Phase




## Pulse Frequency

# 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 outging and incoming power is known, the RCS $\sigma_b$ of a target is known precisely

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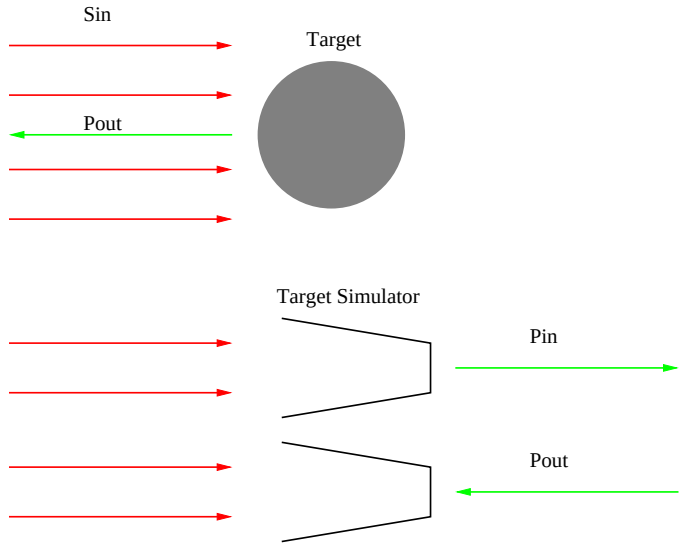


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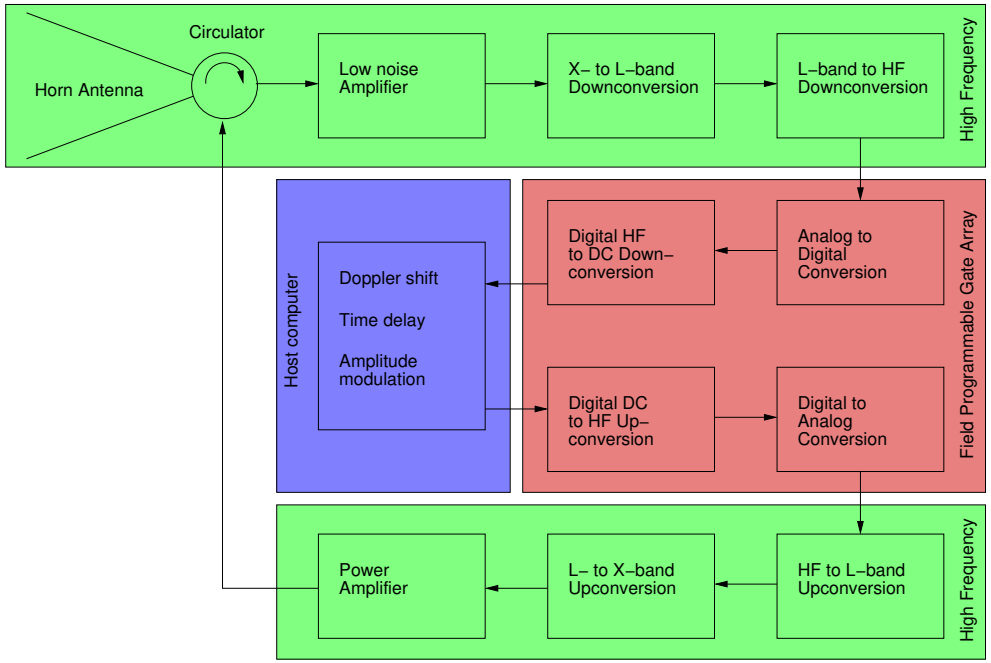
# Calibration with a target simulator



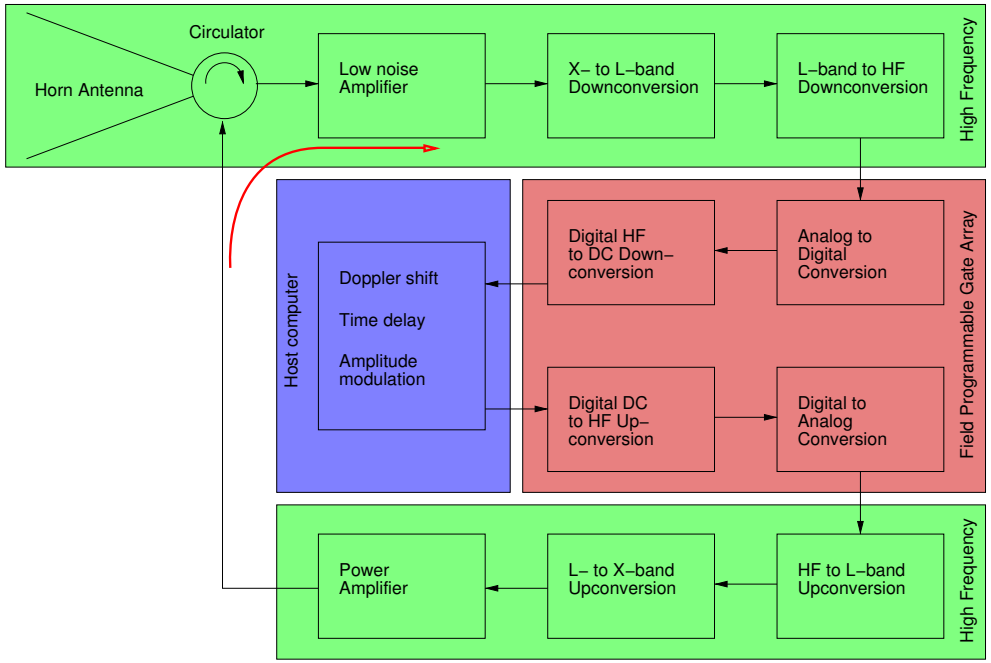

Analog up- / down-conversion, amplification

Analog $\rightleftharpoons$ digital conversion

Digital up- / down-conversion

Signal processing

# Calibration with a target simulator




Feedback loop with gain $G_f$

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

$\rightarrow G_f$ needs to be determined precisely.

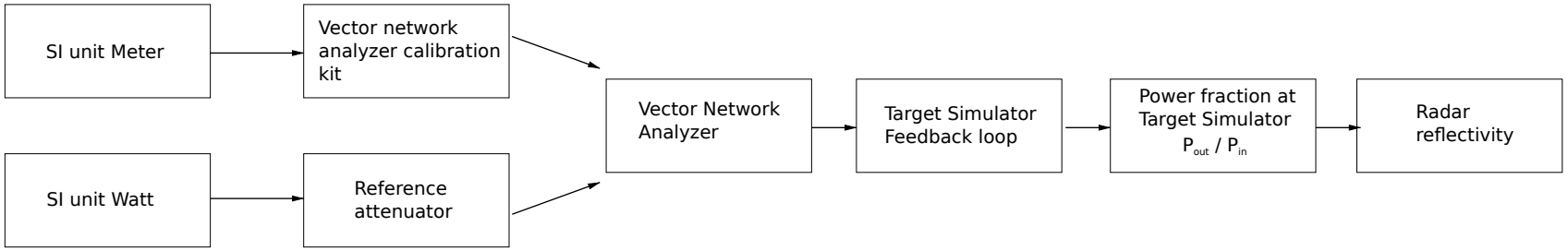
Analog up- / down-conversion, amplification

Analog $\rightleftharpoons$ digital conversion

Digital up- / down-conversion

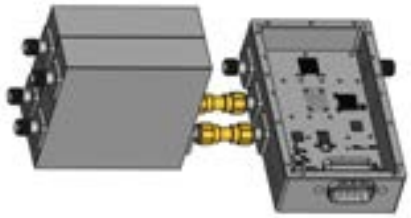
Signal processing

# Traceability to SI units



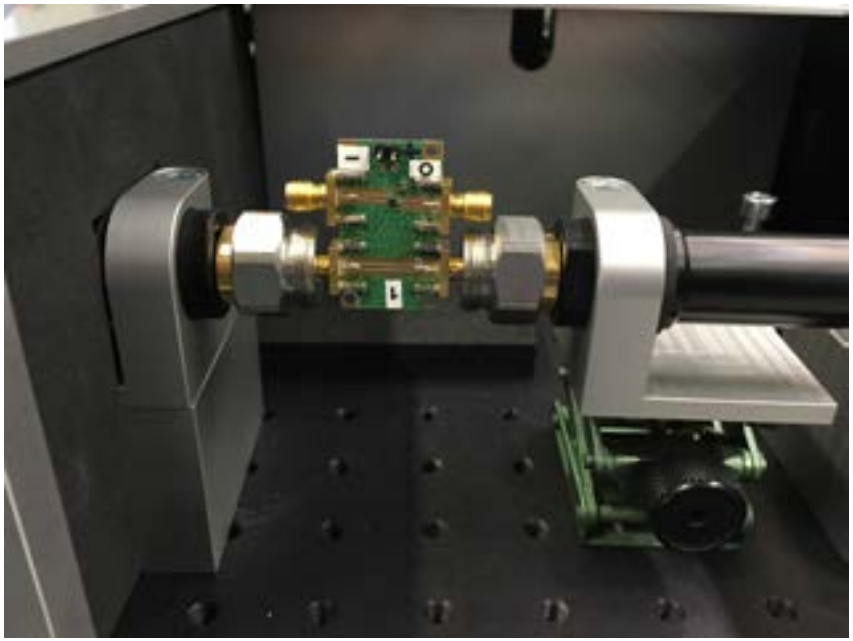

Calibration Kit

VNA measurements



Target simulator calibration unit

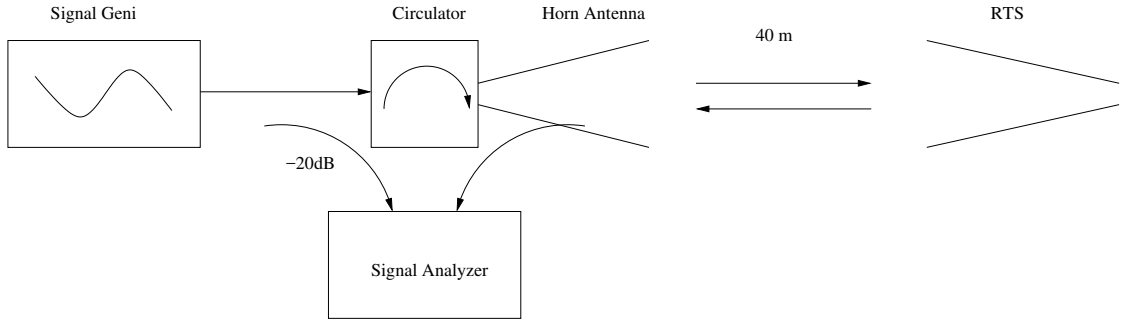
# Network analyzer measurements



- 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

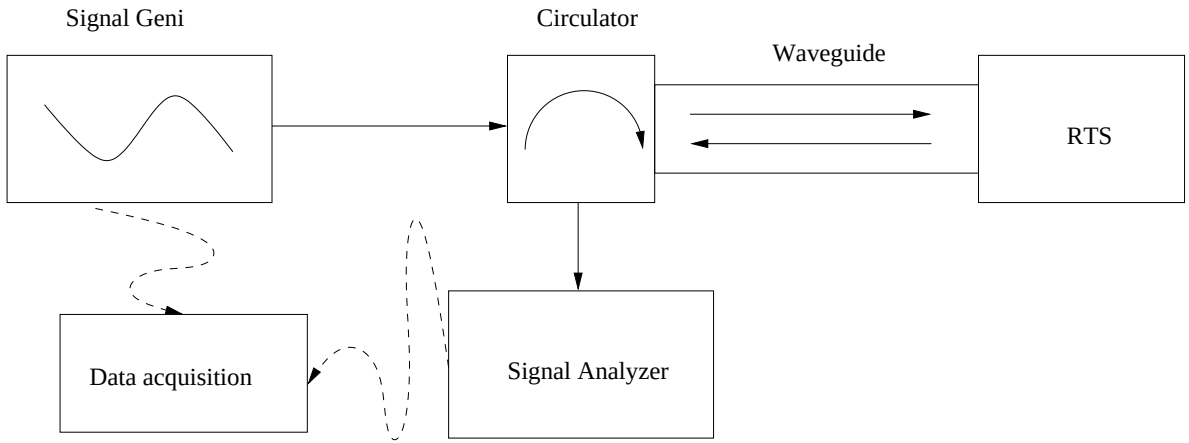
METAS
Federal Office of Metrology

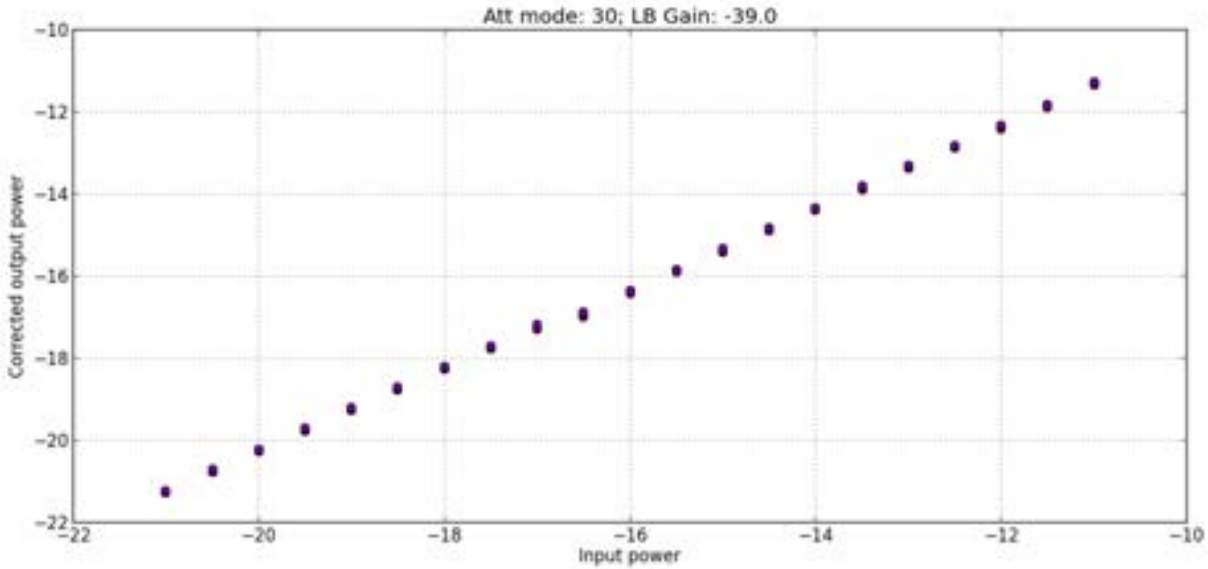
# Outdoor verification with Antennas




Measurement of the difference between the outgoing and incoming pulse power $\Delta P$

# Laboratory verification without antennas



# Measurements during Olympics 2018

## 60DX calibration

- Distance: 2.1 km
- $\Delta h$: 100 m
- 3 observation days
- window scans

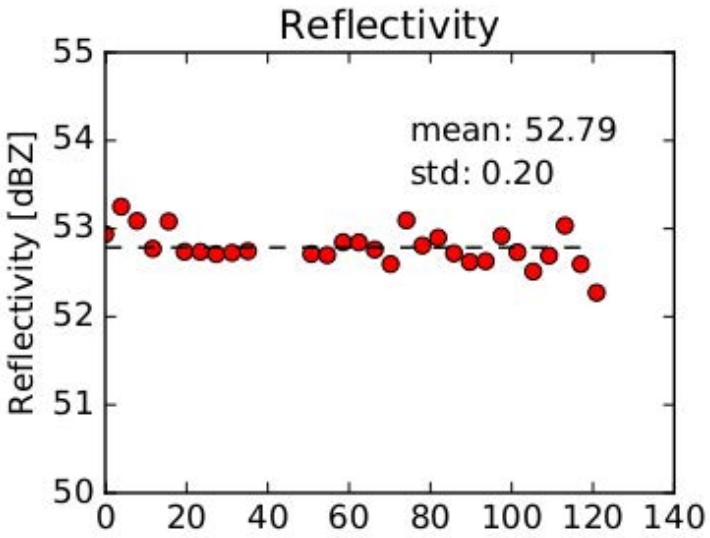
## Long-term measurements with MXPol

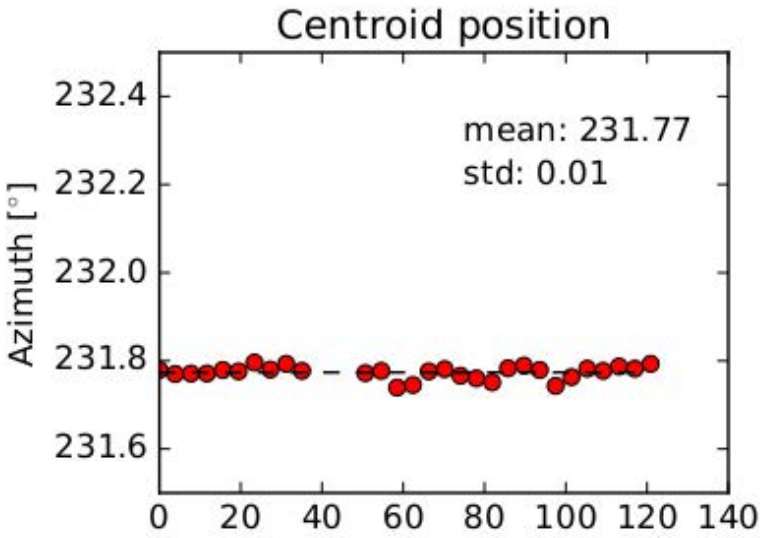
- Distance: 13 km
- $\Delta h$: 700 m
- 40 observation days
- RHI scans

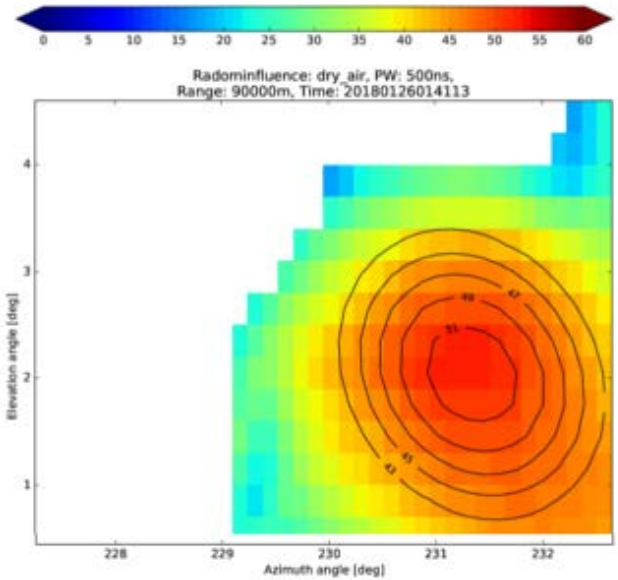
## MXPol test measurements

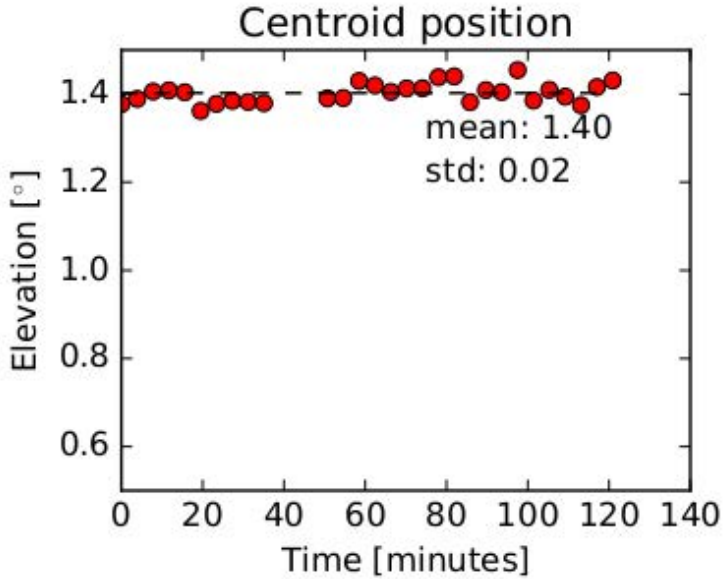
- Distance: 5 km
- $\Delta h$: 0 m
- 1 observation day
- window scans

# 60DX calibration with 50 dBZ target



# 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

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