ATMOS

Delft University of Technology

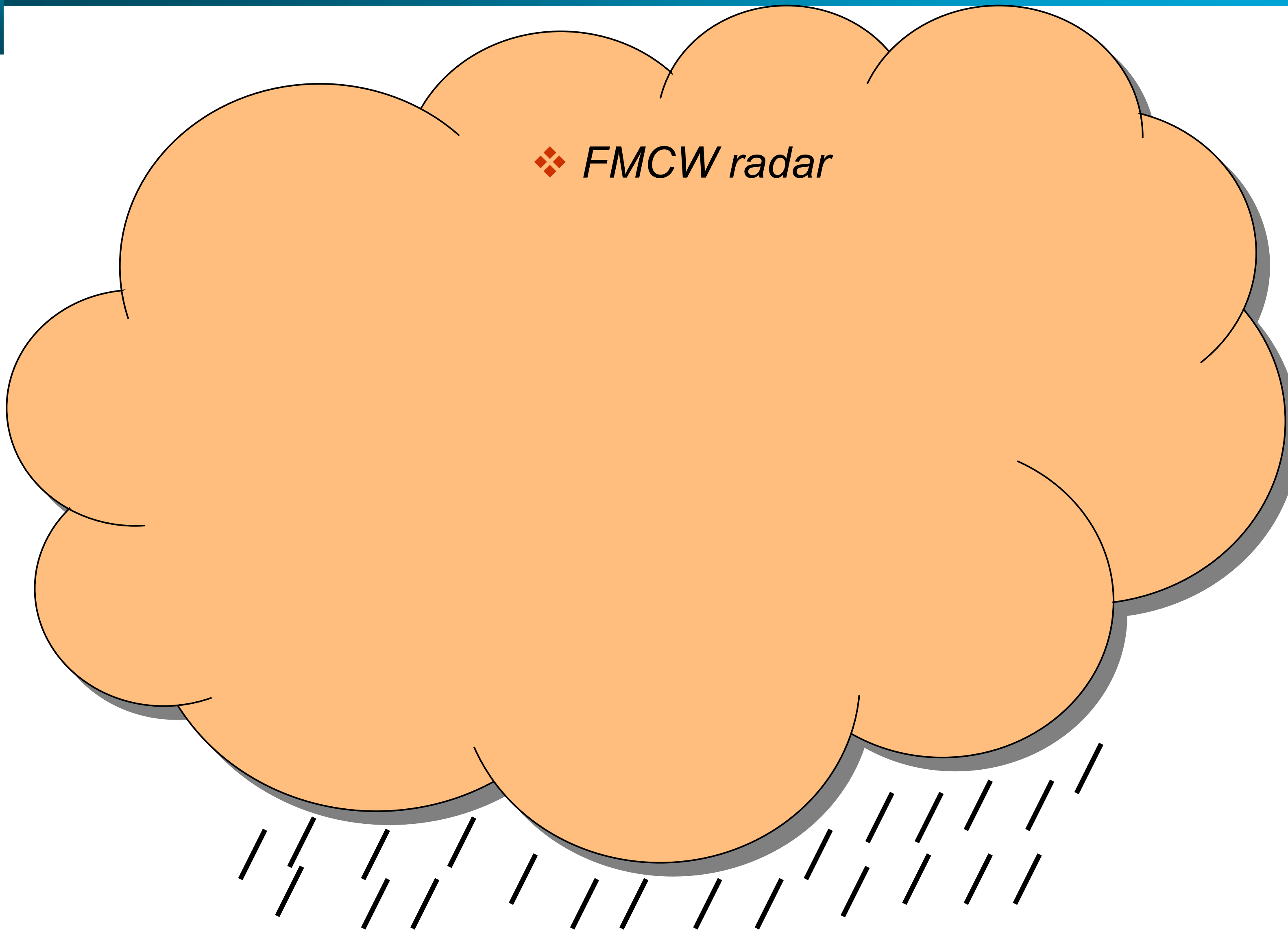
Weather/atmospheric radar signal processing techniques

RPG Cloud Radar Calibration

Christine Unal

Contents

- FMCW radar
- Receiver absolute calibration (liquid nitrogen)
- Receiver absolute calibration (clear sky)
- Dicke switch
- Check and prevention
- Transmit power monitoring


FMCW radar

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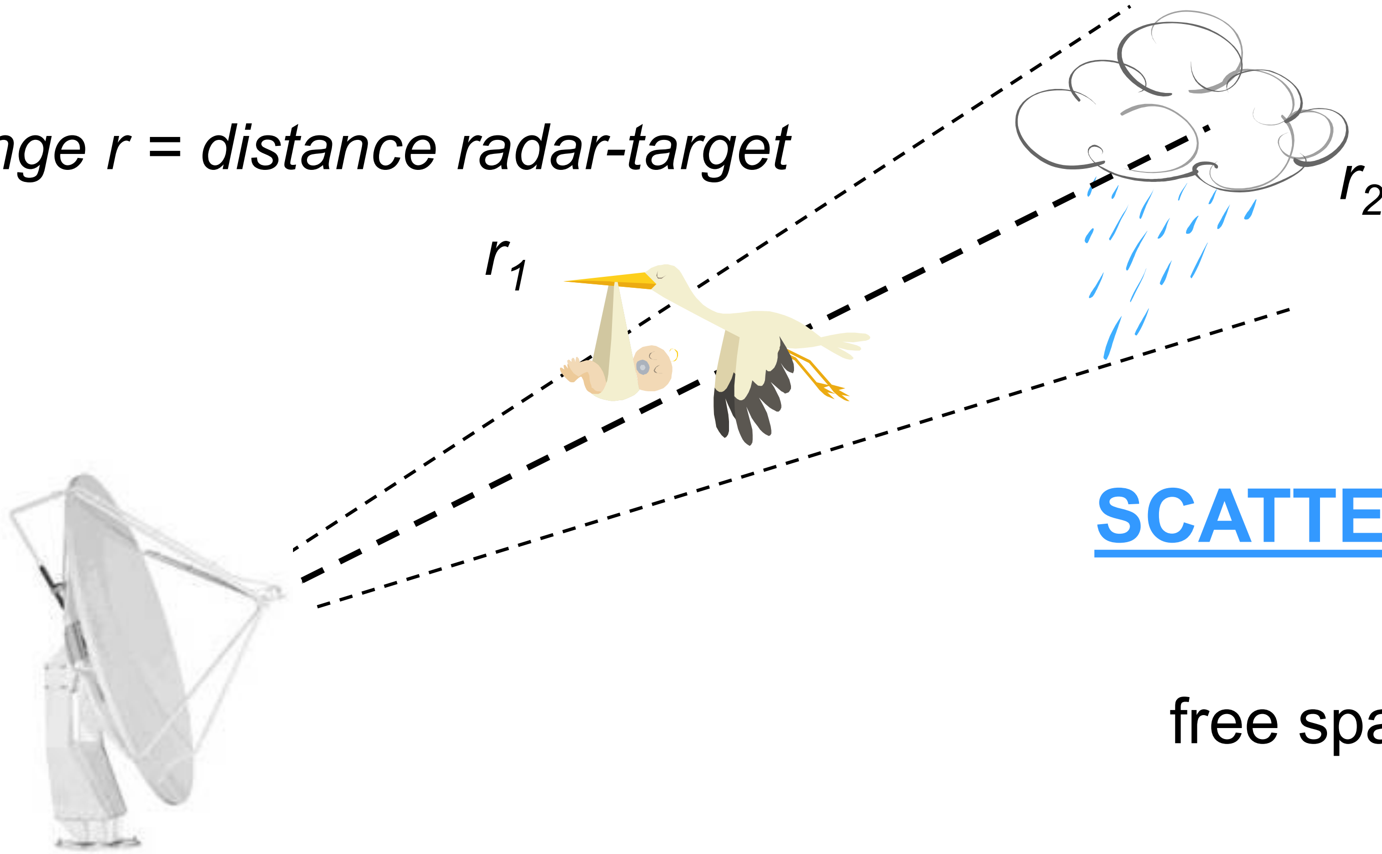
Radar: Radio Detection and Ranging

Range r = distance radar-target



SCATTERING

free space

electromagnetic waves

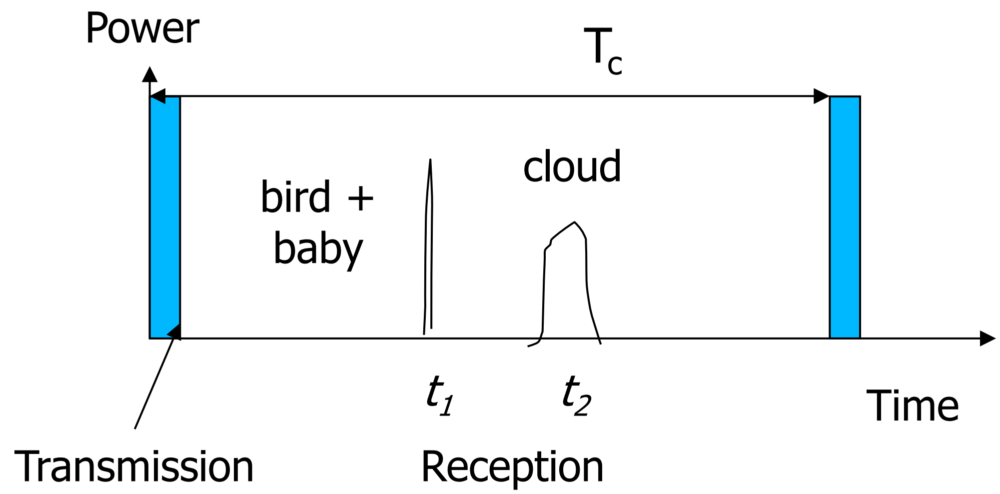
$$\lambda = \frac{c}{f_c}$$

C = 3 10^8 m s^{-1}

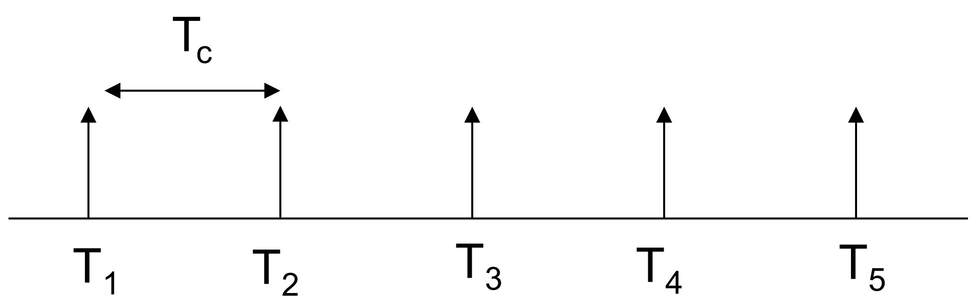
Radar: Radio Detection and Ranging

The ranges of objects (targets) are measured

$$\boxed{R = \frac{ct}{2}}$$



T_c pulse repetition time



Large $T_{c:}$ large R_{max}

$$R_{\max} = \frac{cT_c}{2}$$

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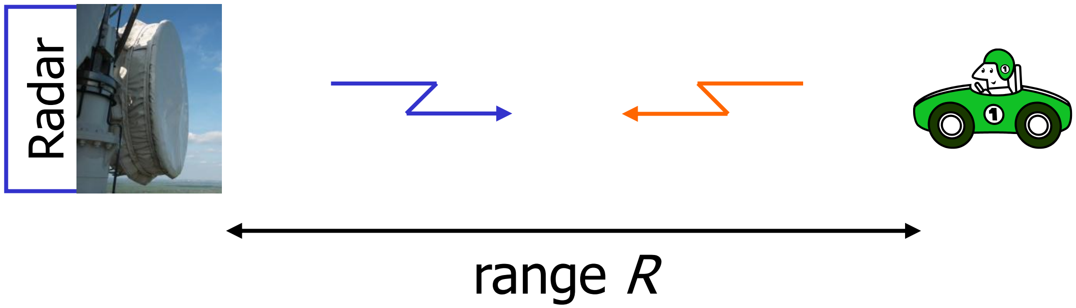
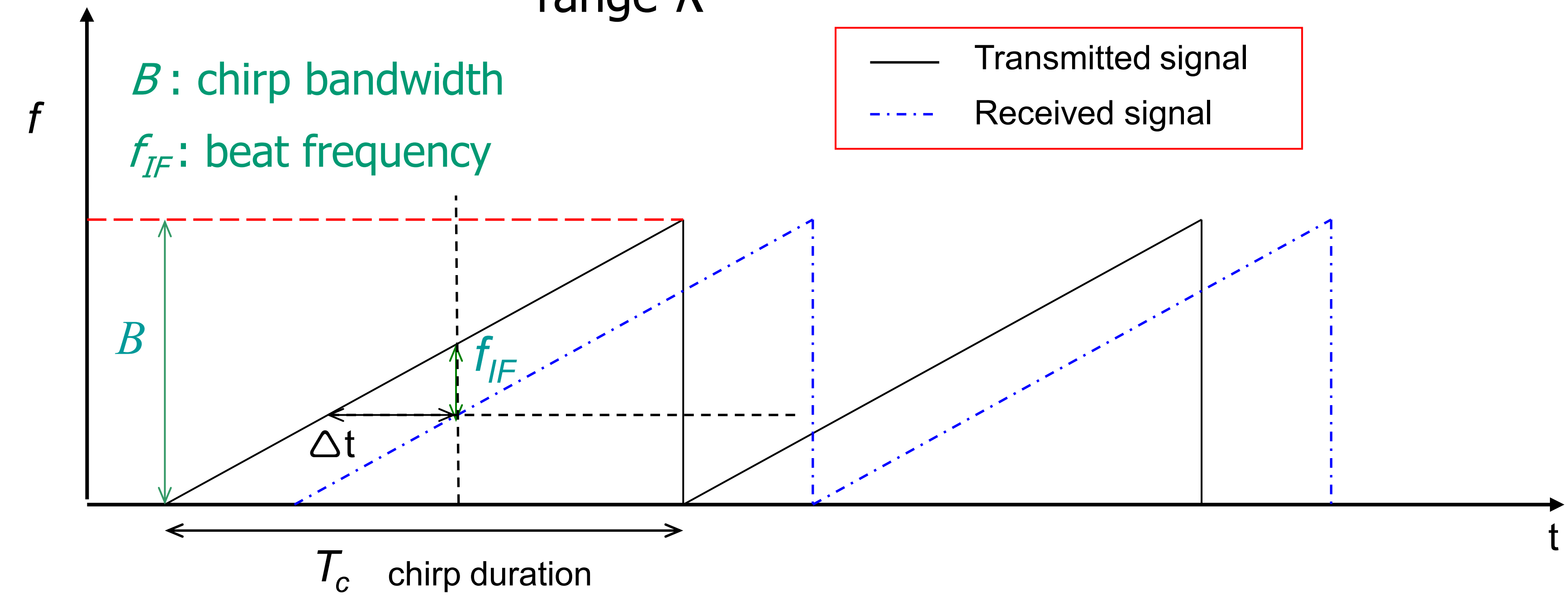
Single target: parked car

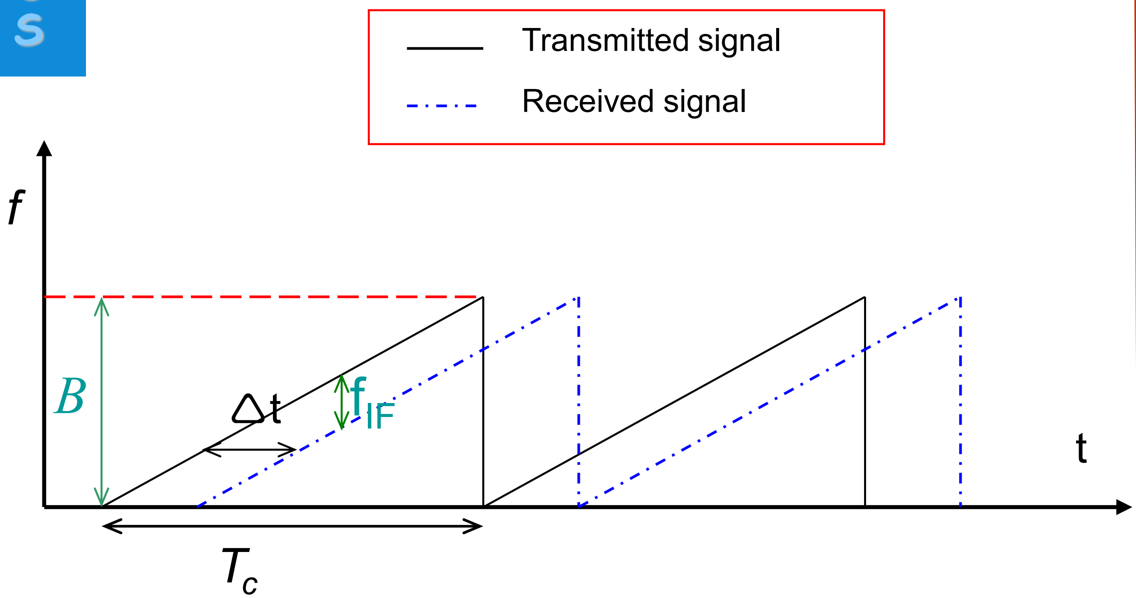


FMCW radar



S : chirp ramp slope $\quad S = \dfrac{f_{IF}}{\Delta t} = \dfrac{B}{T_c}$ and $\Delta t = \dfrac{2R}{c}$ $\Rightarrow$ measured $\boxed{f_{IF} = S\,\dfrac{2R}{c}}$

FMCW radar (Frequency Modulated Continuous Wave)



Mixer

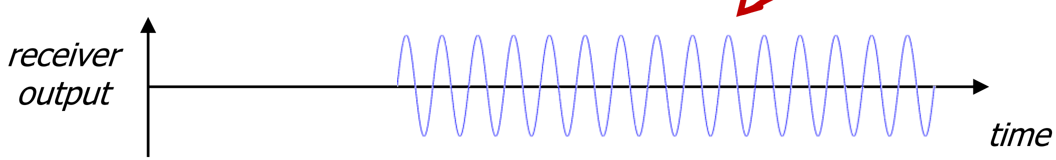
$$\cos\left(2\pi ft\right)\cdot\cos\left(2\pi(f+f_{IF})t\right)$$

received [GHz] *transmitted* [GHz]

$$\cos\left(2\pi f_{IF}t\right) + \cancel{\cos\left(2\pi(2f+f_{IF})t\right)}$$

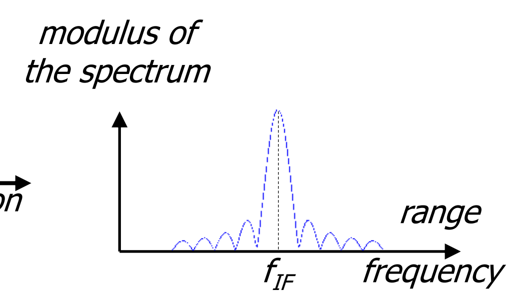
[MHz] [GHz]

Low-pass filter



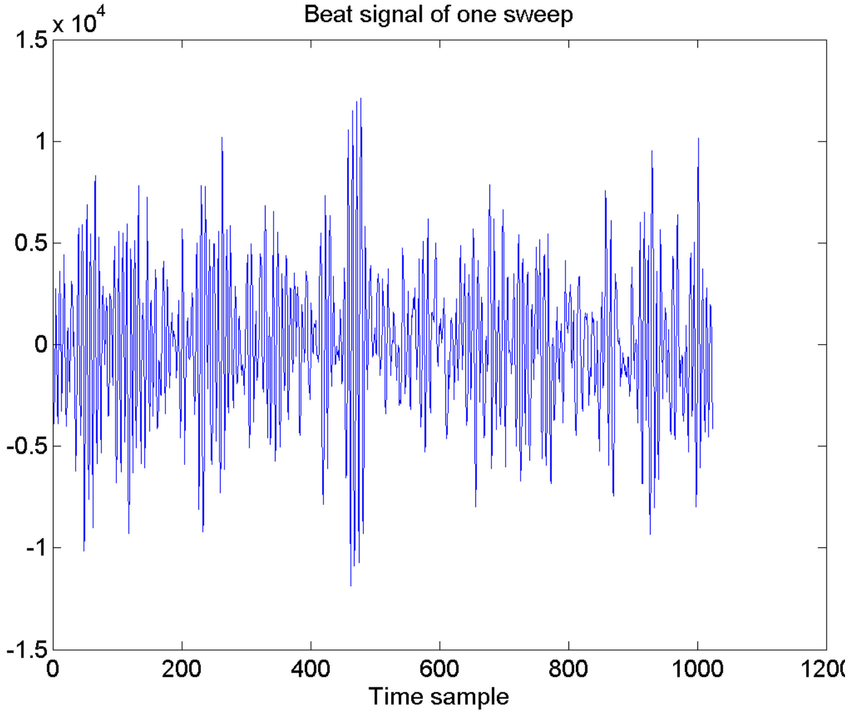
Sampling the signal per chirp

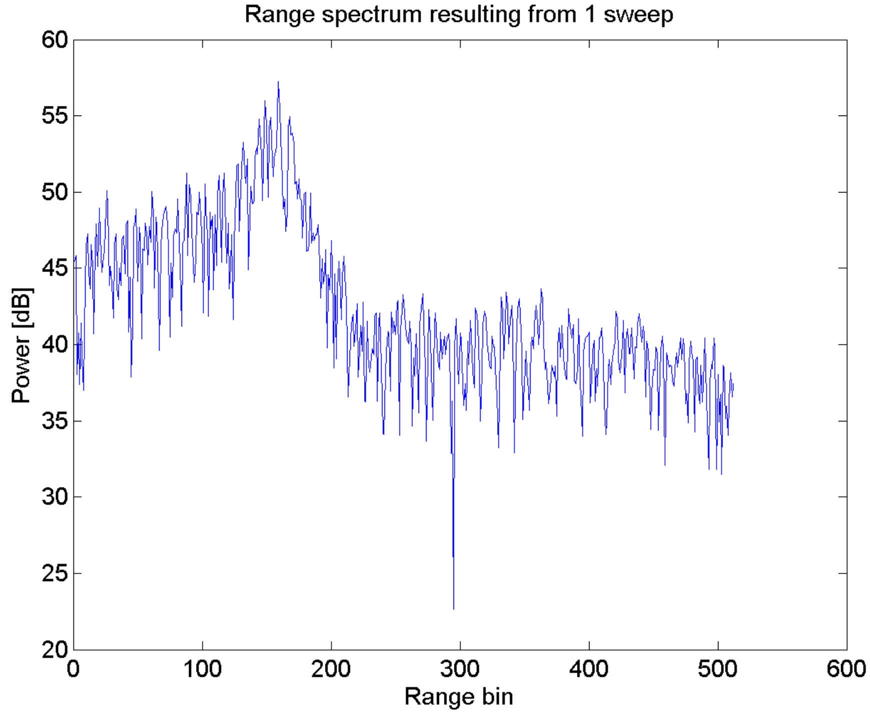
Fourier transformation



One chirp (0.5 ms) – several hydrometeors

real **TARA S-band** *complex*





FFT + | |^2

1024 samples → range spectrum of 512 range bins

$$\sum_i A_i \cos\left(2\pi f_i t + \varphi_i\right)$$

$$P_r\left(f_i\right) \rightarrow P_r\left(R_i\right)$$

Equation for weather/cloud radar

Compact form of the equation – Far range – Linear values

Receive power [W]

$$P_r(R_i) = C_r P_t \frac{\delta R}{R_i^2} Z_e^{att}(R_i)$$

Range resolution [m]

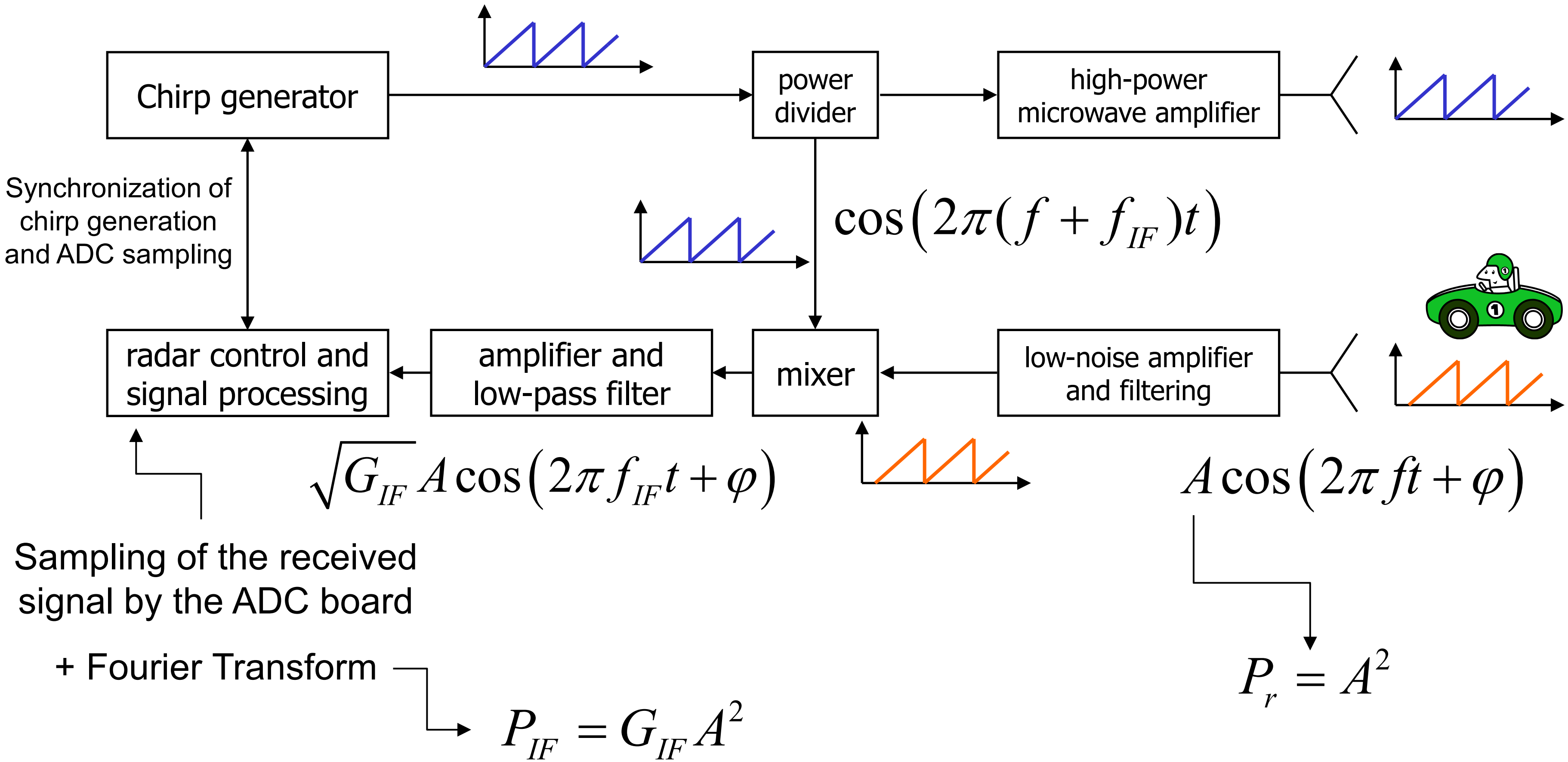
Transmit power [W]

Equivalent reflectivity factor (attenuated) [mm^6 m^{-3}]

$$Z_e^{att}(R_i) = Z_e(R_i)\exp\left[-2\tau(R_i)\right]$$

Total one-way path attenuation [Np]

General block diagram of a FM-CW radar



- Receiver absolute calibration (recommended twice a year) with liquid nitrogen or clear sky

Receiver absolute calibration

$$f_i = S\frac{2R_i}{c}$$

Power obtained after FFT related to the beat frequency f_i

Measured

$$P_r(R_i) = C_r P_t \frac{\delta R}{R_i^2} Z_e^{att}(R_i) = P_{ri} = \frac{P_i}{G_{ri}}$$

Receiver calibration → knowledge of the gains G_{ri}

Receiver + antenna gain: all gains and losses ?

Measured $\boxed{P_i = G_{ri} P_{ri}}$ Known values needed

<u>Question 1</u>

Noise estimation

reflectivity noise

$$P_r(R_i) = P_{ri} + P_{ri}^n = \frac{P_i}{G_{ri}} + \frac{P_i^n}{G_{ri}}$$

The radar noise level is required

<u>Question 2</u>

Measured $P_i^n = G_i T_i$ Unknown

T_i: radar receiver system noise temperatures

G_i: gain factors linking temperature to power

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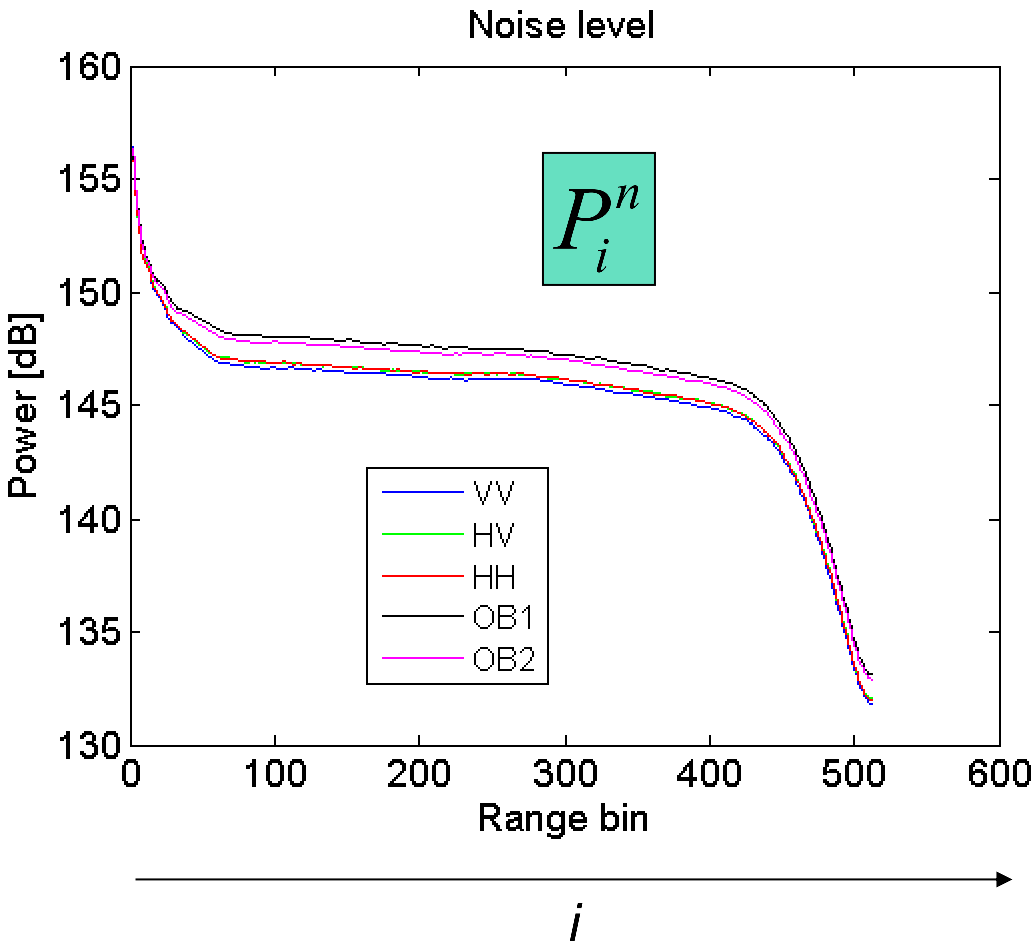
Receiver calibration: noise processor

Daily: 30 s of noise measurement



TARA S-band

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Technique based on temperature for calibration and noise estimation

The transmission of power is stopped

Target at fixed brightness temperature T

k_B: Boltzmann constant ($1.38\ 10^{-23}$ J K^{-1})

Known value

$$\boxed{P_r^T = k_B B_c T}$$

$$B_c = \frac{1}{T_c}$$ radar receiver bandwidth

G_{ri}

What we measure:

$$\boxed{P_i^T = G_i\left(T_i + T\right)}$$

2 unknowns (G_i and T_i)

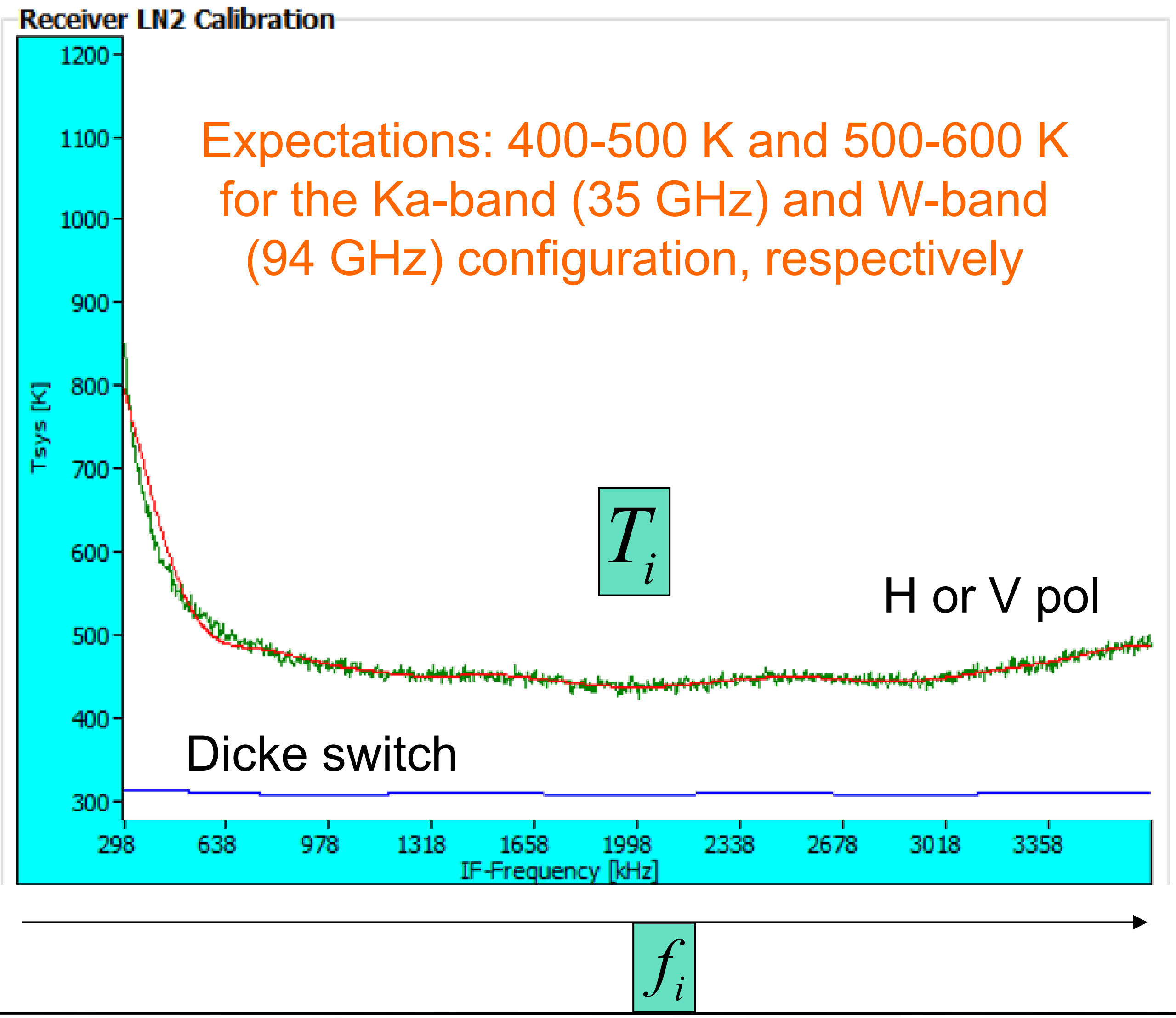
2 brightness temperatures needed: hot (T_H) and cold (T_C)

Question 2 solved

$$\begin{cases} P_i^{T_H} = G_i\left(T_i + T_H\right) \\ P_i^{T_C} = G_i\left(T_i + T_C\right) \end{cases}$$

G_i and T_i depend on the radar frequency and polarization channel

Receiver noise temperature versus beat frequency



Ref: RPG FMCW Operation and Software Manual

$$f_i = S\frac{2R_i}{c}$$

Receiver calibration (including receiving antenna)

The transmission of power is stopped

Target at fixed brightness temperature *T*

Input signal

$$P_r^T = k_B B_c T$$

G_{ri}

Measured

$$P_i^T = G_i T_i + G_i T$$

Receiver noise offset

Response to input signal

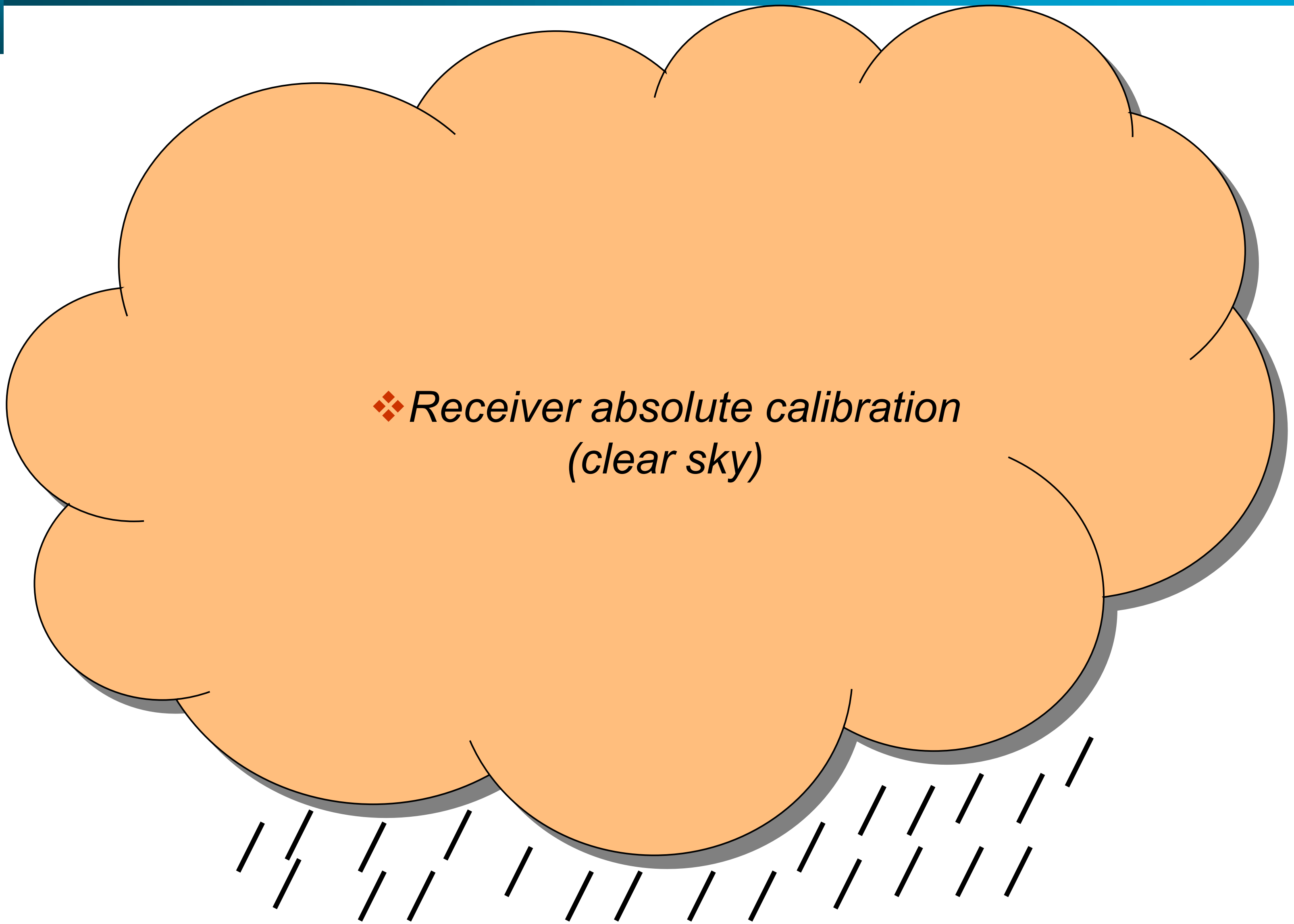
$$G_{ri} = \frac{\text{Response to input signal}}{\text{Input signal}}$$

$$\boxed{G_{ri} = \frac{G_i}{k_B B_c}}$$

<u>Question 1 solved</u>

We can relate measured power after FFT to incident power on the antenna: receiver calibration done

For reflectivity measurements, chirp tables with different B_c will be used. The radar changes the G_{ri} accordingly


Receiver absolute calibration
(clear sky)

Technique based on temperature for calibration and noise estimation

The transmission of power is stopped

Target at fixed brightness temperature *T*

k_B: Boltzmann constant ($1.38\ 10^{-23}$ J K^{-1})

$$B_c = \frac{1}{T_c}$$ radar receiver bandwidth

Known value

$$P_r^T = k_B B_c T$$

G_{ri}

What we measure:

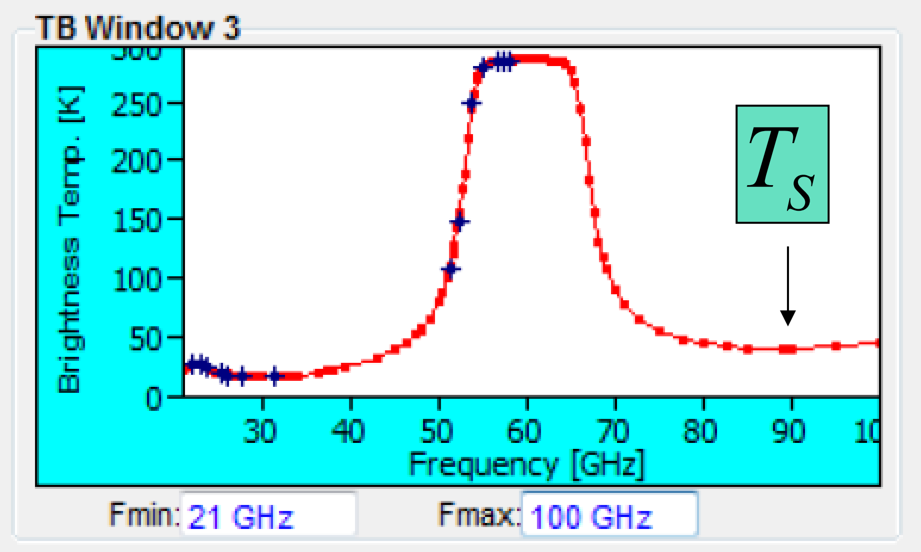
$$P_i^T = G_i \left(T_i + T \right)$$

2 unknowns (G_i and T_i)

2 brightness temperatures needed: hot (T_H) and cold (sky, T_S)

~~2 brightness temperatures needed: hot (Dicke, T_D) and cold (sky, T_S)~~

Sky brightness temperature

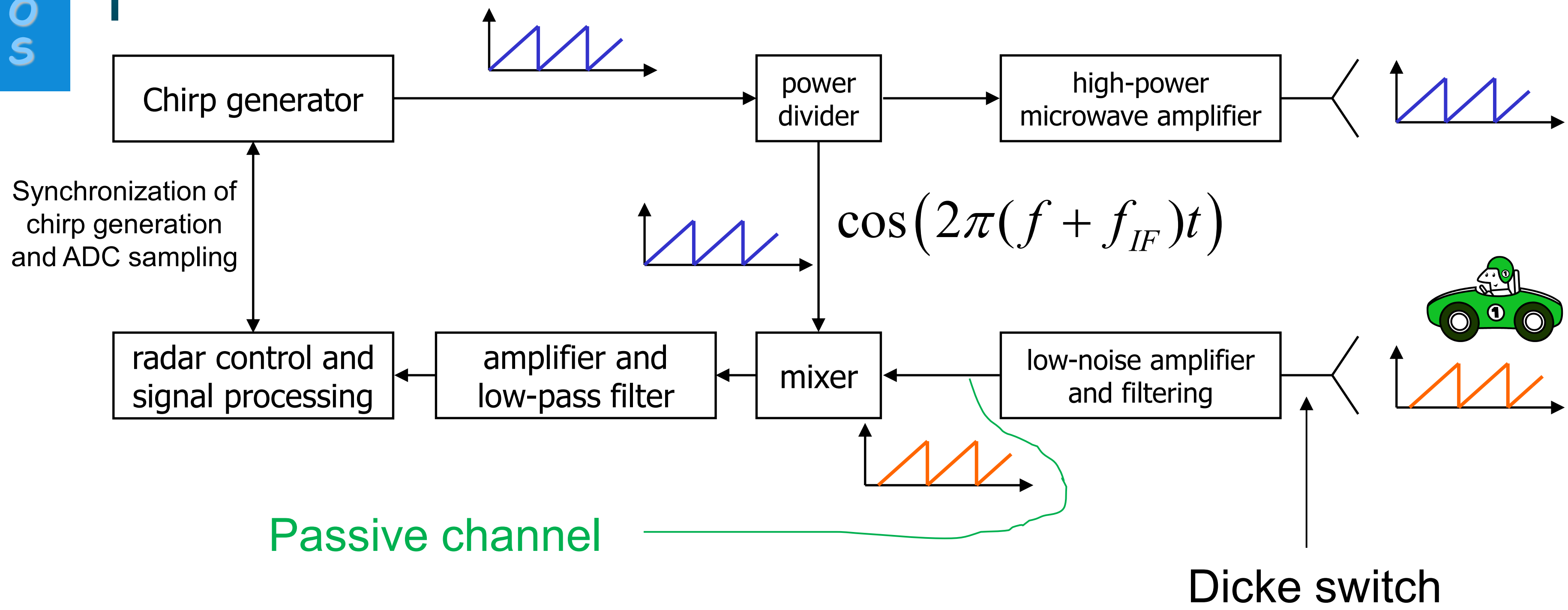


Ref: RPG FMCW Operation and Software Manual

Spectrum retrieval output (red curve) of a RPG-HATPRO radiometer for the frequency range [20 GHz, ... , 100 GHz]. The 90 GHz brightness temperature can be used to calibrate the RPG-FMCW-94 cloud radar.

- *Dicke switch (internal calibration)*

Dicke switching: monitoring the absolute calibration



The transmission of power is stopped

Internal black body standard at temperature T_D

Recommended every 1000 s

Adjust the receiver gain factors

Dicke switching: monitoring the absolute calibration

The transmission of power is stopped

Internal black body standard at temperature T_D

Known value

$$P_r^{T_D} = k_B B_c T_D$$

We carry out the receiver calibration excluding the antenna

$$G_{ri}^{'}$$

What we measure:

$$P_i^{T_D} = G_i^{'}\left(T_i + T_D\right)$$

T_i are assumed constant, estimation of $G_i^{'}$

Antenna loss: L_A

estimation of $$G_{ri}^{'} = \frac{G_i^{'}}{k_B B_c}$$

estimation of $$G_{ri} = \frac{G_{ri}^{'}}{L_A}$$

Absolute calibration of the receiver

During the absolute calibration of the receiver using hot and cold brightness temperatures:

1) Hot target (ambient target)
2) Cold target (LN2 or clear sky)
3) Dicke switch

$G_i \; T_i \; G_{ri}$

$G_i' \; G_{ri}'$

Calibration time: T_0
(every six months)

During the Dicke internal calibration every 1000 s

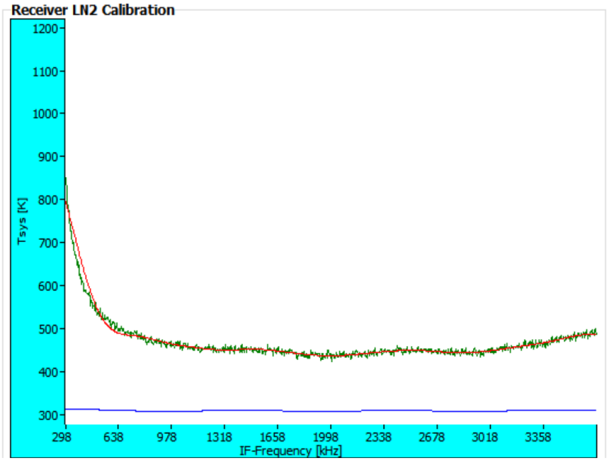
$$G_{ri} = \frac{G'_{ri}}{L_A} = G'_{ri} \frac{G_{ri}\left(T_0\right)}{G'_{ri}\left(T_0\right)}$$

Adjustment of gains

Contents

- *Check and prevention*

How to check the receiver calibration



Communication Alexander Myagkov (RPG):

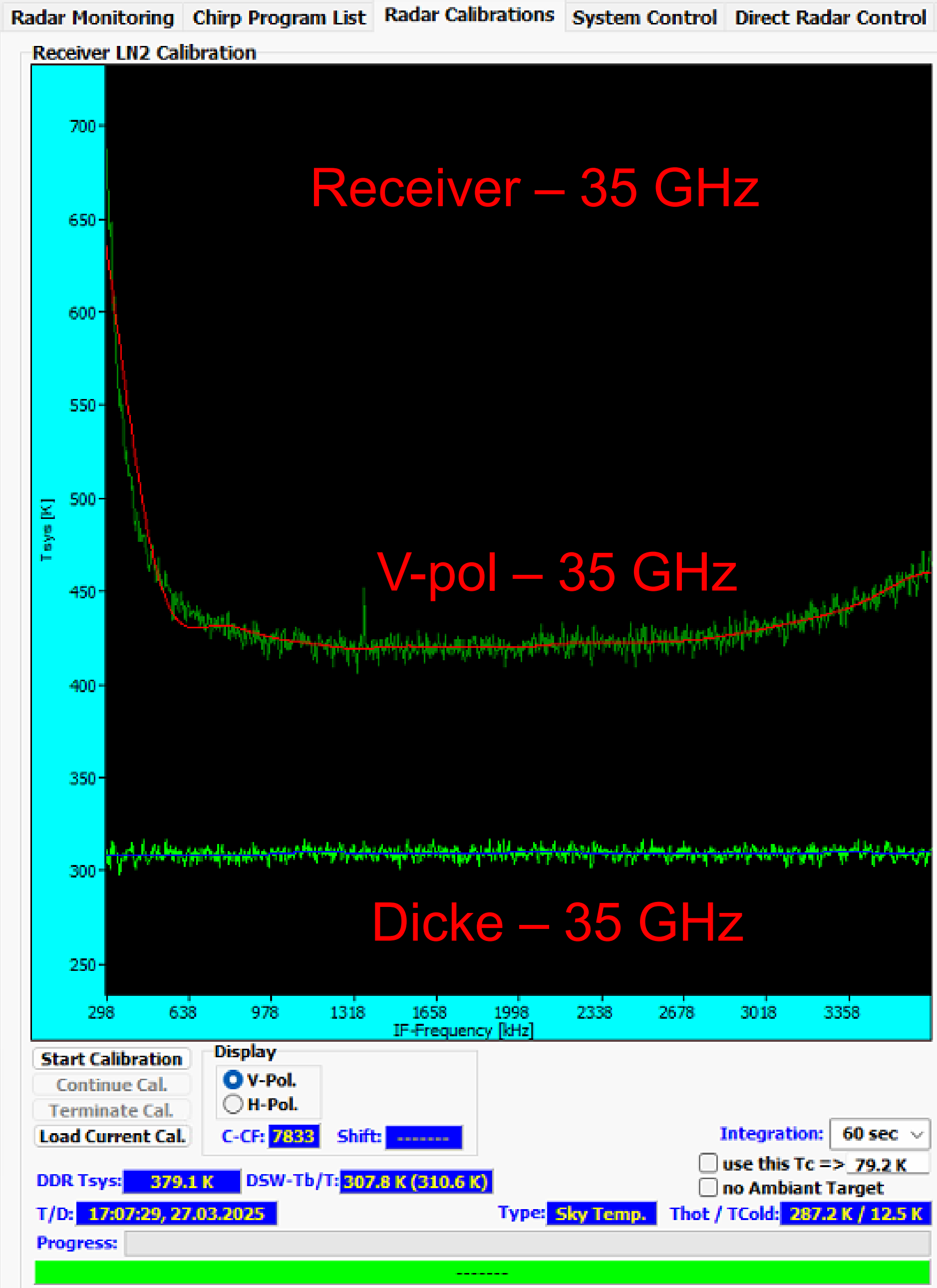
1) The TSYS curve should be mainly monotonic with small ripple. Large spikes/jumps should not occur.

2) The TSYS curve should be consistent with previous results, there should not be deviations of let's say 100 K or more. For this check of course you need to take screenshots of the previous calibration manually.

3) Always check results of both polarimetric channels.

4) Also check TSYS of the passive channel (box DD-Rec. Tsys)

In case you see any abovementioned issues, I would recommend to repeat the calibration.



ABSCAL.LOG (radar computer, CALIB directory)

DD Tsys: 379.1239 K (passive channel- 31.4 GHz)

V-Polarisation:

Radar Fmid Tsys: 410.7191 K

Radar Fmid Dicke SW Tb: 304.4391 K

H-Polarisation:

Radar Fmid Tsys: 362.3948 K

Radar Fmid Dicke SW Tb: 302.5341 K

How to prevent the failure of the receiver calibration

Communication Alexander Myagkov (RPG) and Stefan Kneifel (LMU)

1) Please note, that since recently I highly recommend to cover the transmitter antenna with the absorber during observation on the cold target (both LN2 target and sky).

2) If there is another radar (same frequency) at the site, it must be switched off during the clear-sky calibration.

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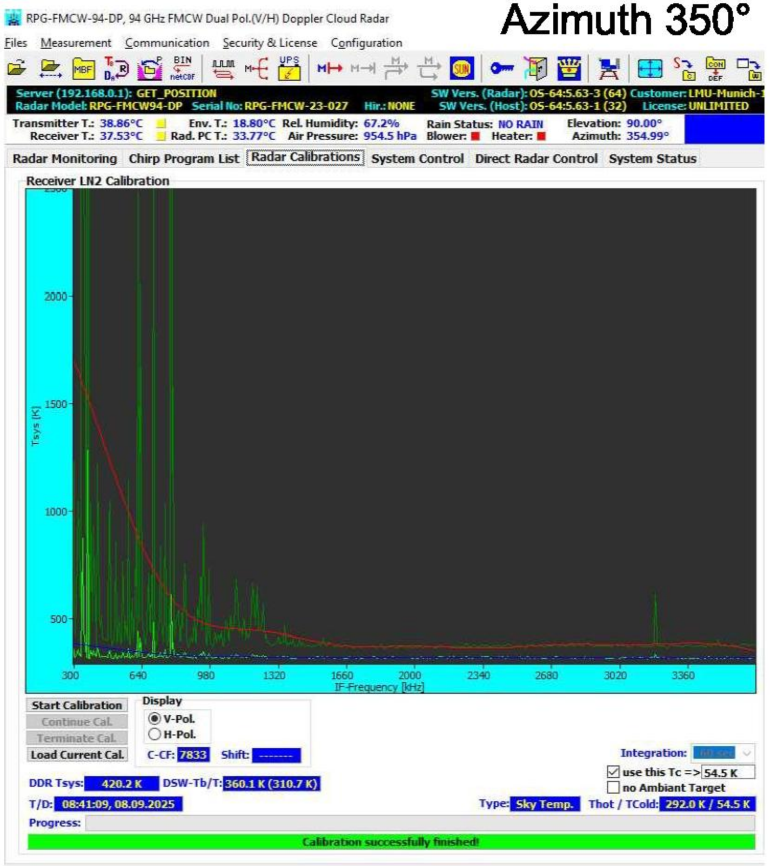
Some examples of failure of the receiver calibration

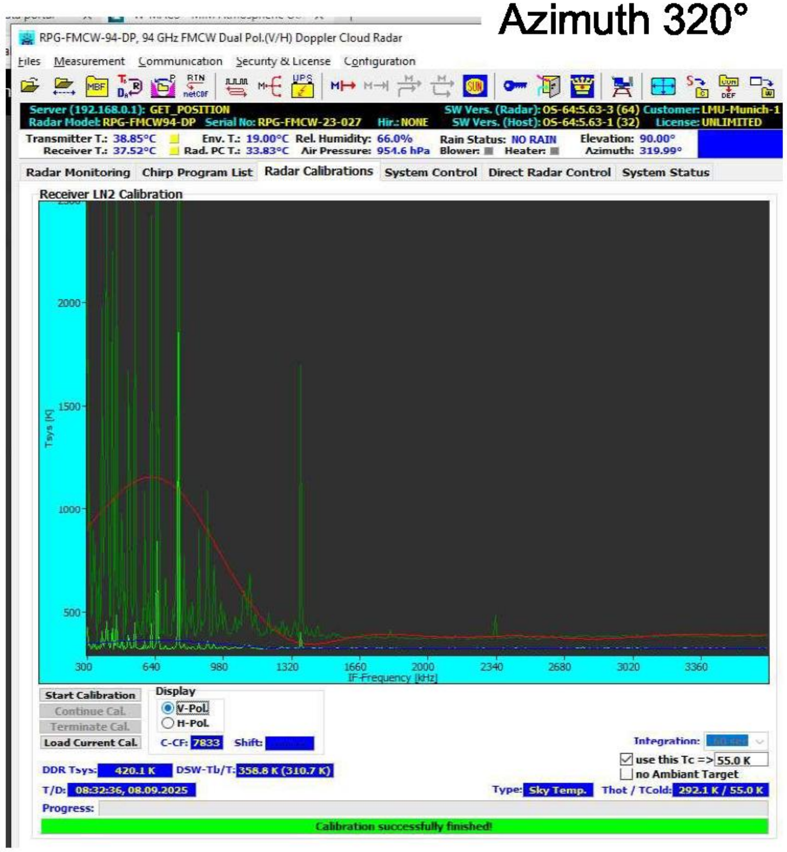
Courtesy: Stefan Kneifel (LMU)

wmacs calibration with HatPro (clear-sky) on 04/09/2025

Azimuth 350°



Azimuth 320°



Contents

❖ *Transmit power monitoring*

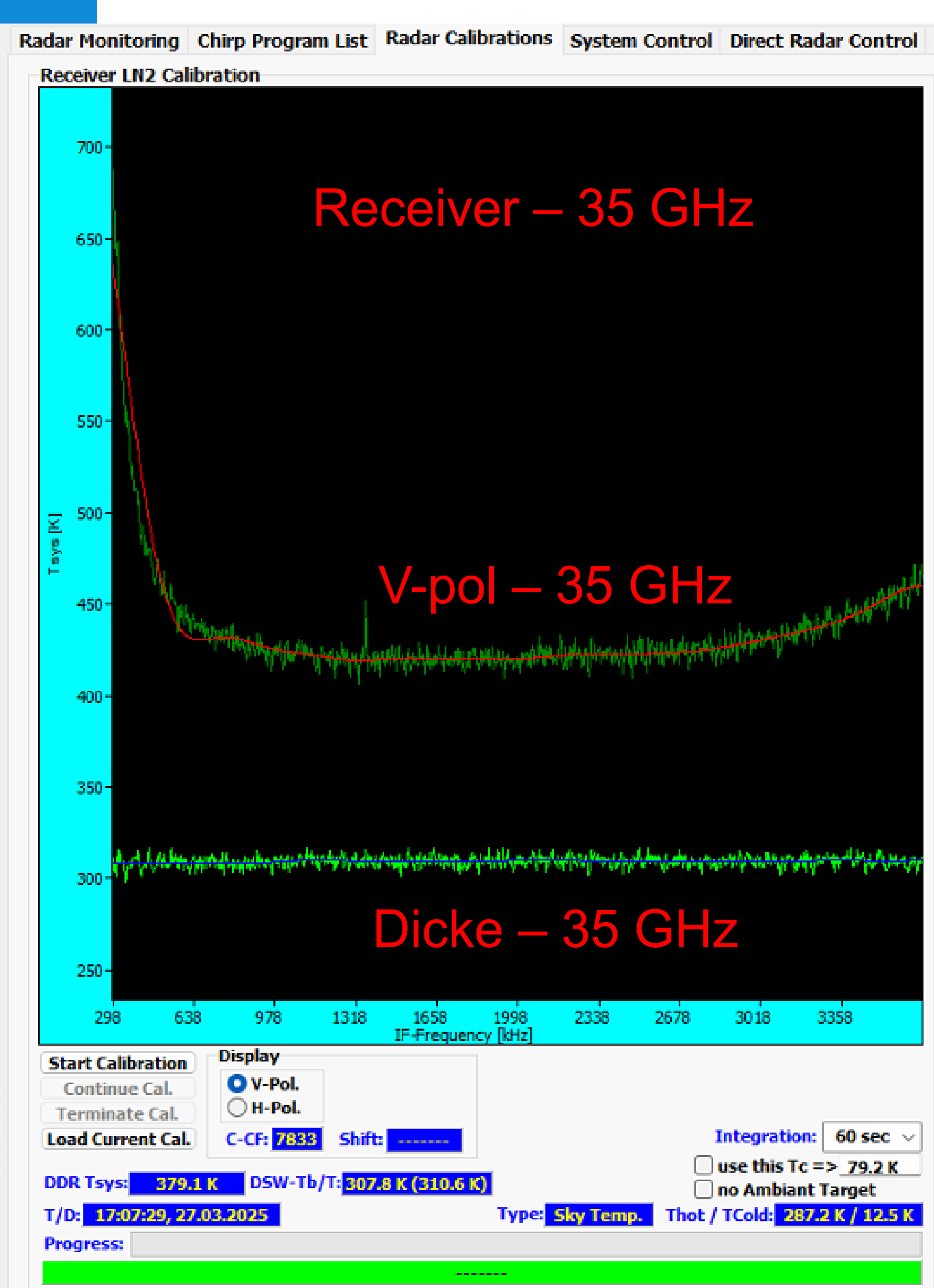
Communication Christine Unal (TU-Delft)

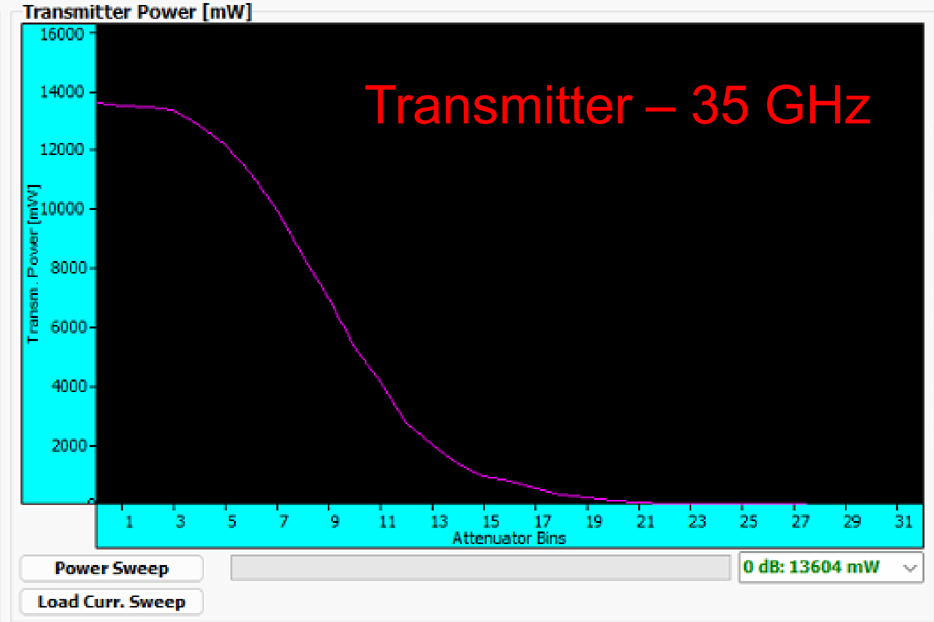
Nothing to do with the absolute calibration of the receiver

BUT

Check the transmit power!

If the transmit power decreases, the weather/cloud radar equation is adjusted to estimate correctly the equivalent reflectivity factor. However, sensitivity may decrease





P_t: transmit power [mW]

35 GHz: 10000 mW

94 GHz: 1500 mW

Backup slides

Clear sky calibration possible failure

TU-Delft experience

A beautiful blue sky BUT………

Missed clear sky calibration attributed to the presence of "insects" (echo's) in the first 200m – 300m. The calibration has then worked when we retried after sunset.