Absolute calibration of VHF radars using a calibrated noise source and an ultrasonic delay line

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Introduction

Observations from VHF radars at different locations are often compared on the basis of relative signal strengths or signal-to-noise ratios. This is common as the data acquisition systems of atmospheric coherent scatter radars usually archive the received signal power in units (tpu) based on the A/D converter output . However these parameters are dependent on the individual radar characteristics (transmitting power, antenna gain, and receiver band width) and the experiment configurations (coherent integrations, code, pulse width).

The use of absolutely received echo power instead of e.g. signal-to-noise ratios allows the determination of a system independent parameter like the radar backscatter cross section σ or the volume reflectivity **η**. In order to derive radar reflectivity from the received radar signal it is necessary to determine the system parameters as well as the relation between the received signal in physical units and the digitized data in arbitrary units. The latter procedure is in general called **absolute calibration**.

Volume reflectivity η

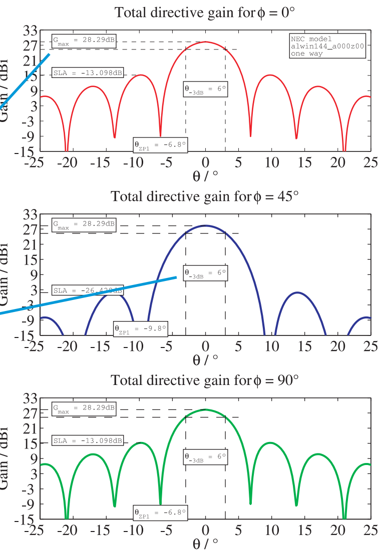
(Hocking and Röttger, *RS*, 1997)

$$\eta_{radar}[m^{-1}] = \frac{P_r \cdot 128 \cdot \pi^2 \cdot 2 \cdot \ln(2) \cdot r^2}{P_t \cdot G_t \cdot G_r \cdot \lambda^2 \cdot e \cdot \Theta^2_{1/2} \cdot c \cdot \tau}$$

P_t	=	transmitted peak power [W]
P_r	=	received signal power [W]
G_t	=	gain of transmit antenna
G_r	=	gain of receive antenna
λ	=	radar wave length
e	=	efficiency
$\Theta_{1/2}$	=	half power half width of transmit antenna
r	=	range to volume center
2 ln(2)	=	beam correction factor
c	=	speed of light
τ	=	pulse width

$$\eta_{radar} = P_r \cdot c_{sys} \cdot r^2$$

Determination of antenna parameters



Most of the system parameters can be measured.

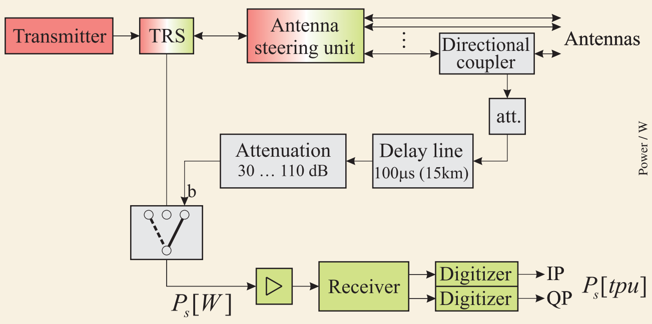
The determination of antenna parameters requires modelling. The Numerical Electromagnetic Code (**NEC**) is used for the analysis:

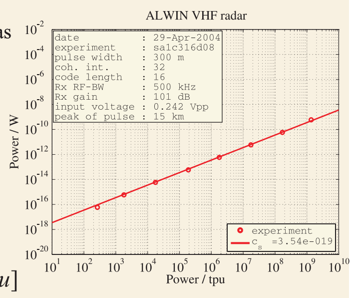
- numerical solution of integral equations for the currents induced on the structure by sources or incident fields
- consideration of material properties of the antenna
- consideration of the soil characteristics of the ground (**Sommerfeld/Norton** approximation).

Calibration with ultrasonic delay line

An acoustic device called *delay line* realizes a delay of 100 µs corresponding to a range of 15 km at 53.5 MHz.

Inserting delayed signals with different amplitudes into the receiver results in a direct proportional output signal.



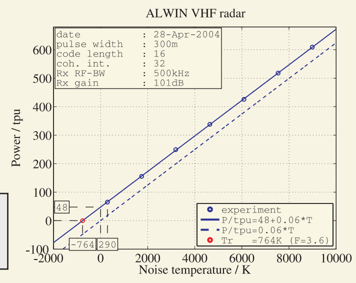


$$P_r[W] = c_s \cdot P_r[tpu]$$

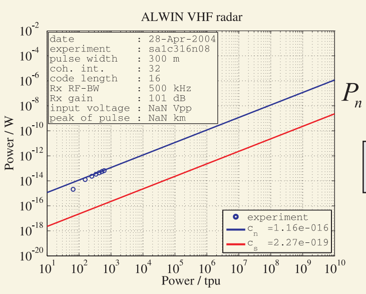
$$c_s = \frac{c_n}{M \cdot N}$$

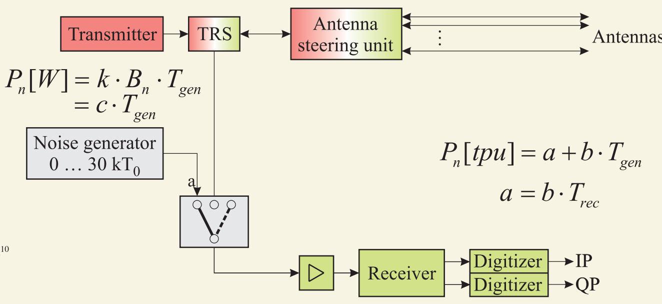
$$c_s = \frac{P_s[W]}{P_s[tpu]} \qquad c_n = \frac{P_n[W]}{(P_n[tpu]-a)} = \frac{c}{b}$$

Calibration with noise source



The noise power fed into the receiver can be described by its equivalent noise temperature T_{gen}. The relation between the inserted noise signal P_n[W] and the noise power P_n[tpu] measured at the receiver output is linear with *T*. The offset at T_{gen}= 0 represents the receiver noise temperature T_{rec}.





$$P_n[W] = k \cdot B_n \cdot T_{gen} = c \cdot T_{gen}$$

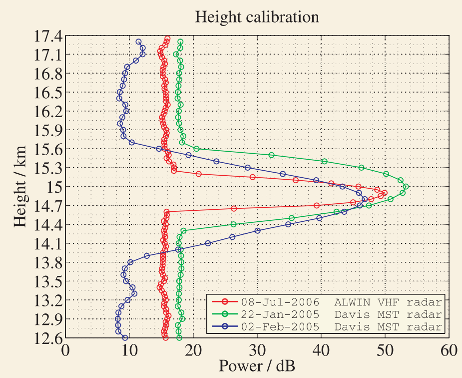
$$P_n[tpu] = a + b \cdot T_{gen}$$

$$a = b \cdot T_{rec}$$

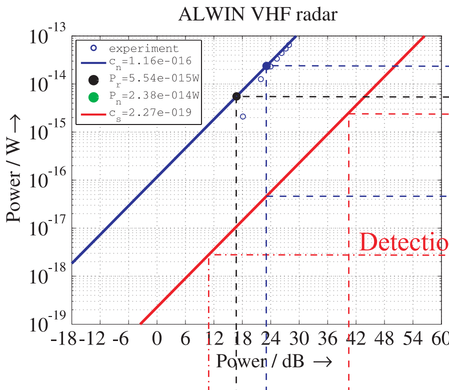
Height calibration

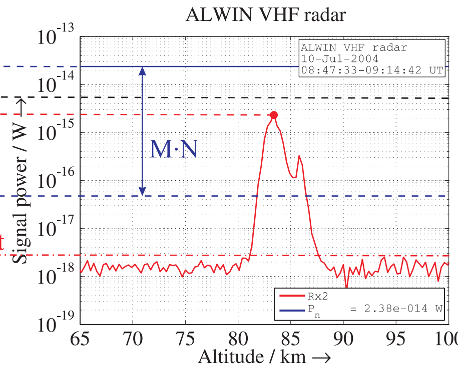
The calibration setup with delay line allows also a comfortable and very accurate determination of the system's *zero delay.*

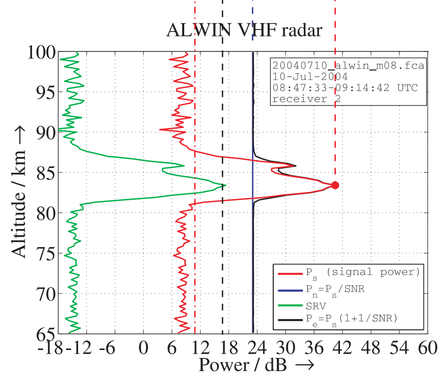
The maximum of the received pulse has to peak some meters below 15 km corresponding to the electrical length of the antenna feeding cables. The figure shows the results of the height calibration of the Davis VHF radar before (green) and after (blue) zero delay correction. The height calibration profile of the ALWIN VHF radar is shown in red.



Noise power P_n, receiver noise power P_r singal-to-noise ratio and signal power P_s







$$SNR = \frac{P_s[tpu]}{P_n[tpu]} = (M \cdot N) \cdot \frac{P_s[W]}{P_n[W]}$$

$$P_s[W] = P_n[tpu] \cdot c_n \cdot \frac{SNR}{M \cdot N} = P_n[W] \cdot \frac{SNR}{M \cdot N}$$

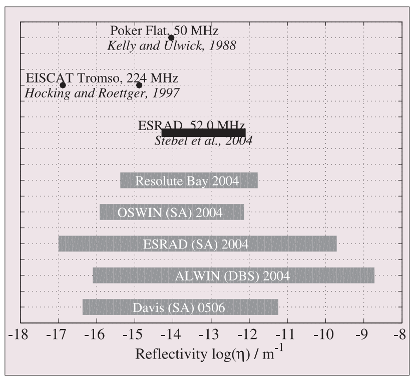
$$P_s[W] = c_s \cdot P_s[tpu]$$

M = total number of coherent interations
N = number of code elements

Range of volume reflectivity estimates based on PMSE observations from calibrated VHF radars at various locations

VHF radars at Andenes/Norway, Kiruna/Sweden, Resolute Bay/Canada, Kühlungsborn/Germany and Davis/Antarctica have undergone absolute calibration using both methods and identical equipment. The table below shows the system parameters and experiment configurations used for PMSE observations which results in different system and signal calibration factors. Especially the product ***M·N*** has an important impact on the minimum detection limit of radar volume reflectivity. The figure shows estimated radar reflectivities of Polar Mesosphere Summer Echoes observed at Resolute Bay, Kühlungsborn, Kiruna, Andenes and Davis in recent years in comparison with data from other radars.

Radar	ALWIN	ESRAD	OSWIN	VHF-Radar	VHF-Radar
Site	Andenes	Kiruna	Kborn	David	RS-Bay
Coordinates	69°N; 16°E	68°N; 21°E	54°N; 11°E	69°S,78°E	75°N; 95°E
System parameter					
Radar wavelength	5.6 m	5.8 m	5.6 m	5.5 m	5.8 m
Peak power	36 kW	72 kW	60 kW	41 kW	12 kW
Gain of main antenna array	28.3 dBi	31.5 dBi	28.3 dBi	28.9 dBi	24.0 dBi
Half-power beam width	6°	4.2°	6°	6°	4°
Gain of SA receiving antenna array	20.6 dBi	23.8 dBi	20.6 dBi	21.0 dBi	
Efficiency	0.58	0.57	0.58	0.49	0.09
Effective Pulse width	300 m	600 m	300 m	450 m	750 m
SA system factor c_{sys}	**2.1E-08**	**2.3E-09**	**1.3E-08**	**1.8E-08**	
DBS system factor c_{sys}	**3.6E-09**	**3.8E-10**	**2.1E-09**	**3.0E-09**	**4.3E-07**
Experiment paramter					
Number of coherent integrations *M*	32	256	20	104	16
Number of code elementes *N*	16	8	16	8	1
M N	512	2048	320	832	16
Receiver gain / dB	101	110	67	80.5	122
Receiver bandwidth / kHz	500	250	506	280	140
SA signal power factor c_s	**2.3E-19**	**9.1E-20**	**2.9E-21**	**1.5E-20**	
DBS signal power factor c_s	**3.8E-20**	**1.5E-20**	**4.8E-22**	**4.8E-22**	**4.5E-22**



Summary

Absolute calibration of VHF radars is necessary for comparison of results obtained with different radars. **The use of an independent calibrated noise source or a delayed transmitted signal for absolute calibration gives very accurate and convertible results** which might be more reliable than a method using cosmic noise.

Five VHF radars from different locations in the northern and southern hemisphere have been absolutely calibrated with identical technical equipment using both methods. A minimum detectable radar reflectivity has been derived for all radars.