P12R.8 SOLAR CALIBRATIONS WITH DUAL POLARIZATION WEATHER RADAR

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1 INTRODUCTION

The calibration of a weather radar includes a determination of the characteristics of four main subsystems: transmitter, antenna, receiver/processor and the waveguide assembly. Each of these contains many different aspects to be considered. As a consequence, the complete calibration of a radar is a complex and laborious task, involving many kinds of laboratory test instruments and setups.

Two main technical developments during recent decades have considerably improved the possibility of achieving an accurate calibration: The adoption of digital techniques in the receivers/signal-processors, and improved electrical stability in the remaining analogue parts of the radar.

On the other hand, use of more complicated techniques, like polarimetry, requires more accuracy and even completely new aspects to be calibrated and monitored. The required accuracy cannot be easily achieved in a straightforward manner by measuring all parts of the signal routes from the transmitter to the antenna and from the antenna to the receiver/processor, and then summing the results. This is because the errors in the individual measurements add up. Another disadvantage of this kind of method is that it is difficult or even impossible to automatize for operational purposes. This has led to different kinds of bulk-calibration methods, such as using the Sun or echoes from precipitation to calibrate the signal routes as a whole.

The Sun cannot be used in transmitter calibration, but it is useful in the calibration of the antenna, the signal route from the antenna to the receiver and to some extent the receiver itself. The Sun has so far mainly been used for calibration of the pointing angles of the antenna (Whiton *et al.*, 1976), (Arnott *et al.*, 2003). In principle it may also be used to determine the half-power beam width of the antenna (Kuz'min & Salomonovich, 1966), (Leskinen *et al.*, 2002), (Frush, 1984) and even the antenna gain (Whiton *et al.*, 1976). The Sun is also important in calibrating or balancing receiving chains from the antenna to the final output of the signal processor as a whole in a multichannel receiver system (Hubbert *et al.*, 2003), (Frush, 1984).

This paper concentrates on using the Sun to study the balance of the dual receiver system, the pointing errors of the antenna and the characteristics of the horizontal and vertical antenna beams.

2 RADAR SETUP

The University of Helsinki radar used in this experiment is a coherent C-band dual polarization Doppler radar, which have been in operation since the end of 2004. This radar transmits simultaneously horizontally and vertically polarized pulses, and also receives simultaneously the corresponding echo signals, obtaining estimates for the horizontal equivalent reflectivity factor Z_e, the differential reflectivity Z_{DR}, the specific differential phase K_{DP} and the co-polar correlation ρ_{hv}. The linear depolarization ratio LDR is estimated by switching the whole power transmitted to the horizontal channel and receiving both the horizontally and vertically-polarized signals.

The radar have a parabolic reflector antenna with a diameter of 4.2 meters equipped with an orthomode feed horn. The half power beamwidths (HPBW) on both channels of the antenna are approximately 1°, corresponding to directivity of 44.6 dBi and the side lobe levels are more than 38 dB below the main lobe maximum.

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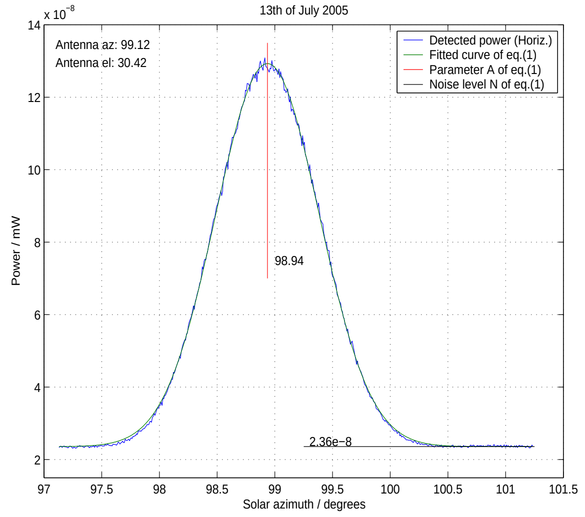

Figure 1: *A sample solar passage with fitted curve and some of the solved parameters.*

3 MEASUREMENTS

The solar measurements were done by holding the radar antenna stationary pointing on one point along the track of the Sun, and recording then the received power as a function of time from both channels, while the Sun was passing the antenna beam.

The received power was measured every two seconds by averaging 15000 recorded samples together. A single solar passage took approximately 19 minutes to complete, during which the Sun traversed a 5° azimuthal distance.

The azimuth and elevation co-ordinates of the Sun were extracted from the Solar Position Calculator (SOLPOS, 2005). These were combined with the power records resulting a plot of received power as a function of solar azimuth (see figure 1).

Totally 49 solar passages were measured between the 12th and 15th of July 2005. Measurements contain passages from early morning (solar azimuth 73°) to late evening (azimuth 288°). These correspond a span of inclination angles between -30° and $+30^\circ$. The inclination angle η is the angle of the solar trajectory with respect to the horizontal line. Excluding few exceptions, There wasn't any clouds blocking the Sun during the measurements.

4 ANALYSIS

As the Sun passes the antenna beam, the signal power obtained is a convolution of the beam pattern and the intensity distribution of the solar disk. With certain simplifications described in (Puhakka *et al.*, 2004), this convolution can be written as

$$\begin{aligned} P =& \frac{I}{2}\sqrt{\frac{\pi}{B}}\left(\operatorname{erf}\left(\sqrt{B}\,(\phi - A + \omega)\right)\right) \\ &- \frac{I}{2}\sqrt{\frac{\pi}{B}}\left(\operatorname{erf}\left(\sqrt{B}\,(\phi - A - \omega)\right)\right) + N, \end{aligned} \tag{1}$$

where I is the intensity of the Sun, B the parameter linked to the half power beam width of the antenna radiation pattern, A the azimuthal position of the peak, ϕ the azimuth of the Sun, ω the angular radius of the Sun and N the noise level of the receiver.

The angular radius ω of the Sun used in the equation (1) is obtained from the optical angular radius r of the Sun by $\omega = 1.07kr$, where the factor 1.07 converts the optical radius into C-band microwave region. The value for r was obtained from U. S. Naval Observatory websites (USNO, 2005). Factor k is

$$k = \frac{|\cos(\eta)|}{\cos(\epsilon)}, \tag{2}$$

where factor $|\cos(\eta)|$ takes into account the inclination angle η of the solar trajectory. Factor $1/\cos(\epsilon)$, where ϵ is the elevation of the Sun, is to convert the solar radius into the horizontal coordinate system (azimuth, elevation) used in equation (1). Using the converting factor k, the half power beam width is calculated from parameter B by $HPBW = \frac{2}{k}\sqrt{\frac{\log(2)}{B}}$.

In this study, equation (1) without the noise N was fitted for both channels into every solar passages using the *fminsearch*-function of the Matlab. The noise level for each passage was solved by averaging ten last measurements of each passage.

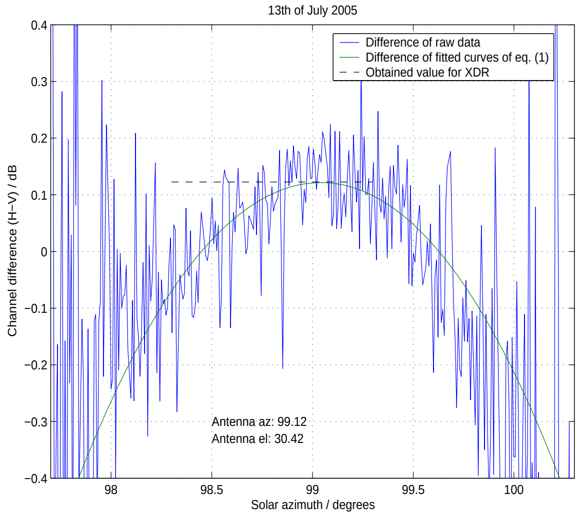

Figure 2: *Differences of received solar signals (blue) and fitted curves (green) in decibels during a single passage. The difference is calculated using equation* (3)*.*

5 PRELIMINARY RESULTS

5.1 CHANNEL BALANCE

Since the solar radiation is supposed to be unpolarized in normal situation, both the horizontal (H) and vertical (V) powers radiated from the Sun can be assumed to be equal. Thus, the imbalance of the H and V channels is directly the difference in signal levels obtained between the channels when measuring the Sun. In this paper, we will abbreviate this imbalance with symbol X_{DR}.

The X_{DR} in decibels was solved from the powers of V and H channels by

$$X_{DR} = 10\log_{10}\left(\frac{P_h - N_h}{P_v - N_v}\right), \tag{3}$$

where P_h and P_v are total detected powers in linear scale on horizontal and vertical channels respectively and N_h and N_v the corresponding noise levels. An example plot of such a subtraction is in figure 2, where one can see the subtraction made for both the raw data and for the fitted curves.

As can be seen, the X_{DR} has a maximum value around the antenna beam peak. This is because the differences between the topologies of the radiation patterns of the H and V channel become more significant as the distance to the beam axis increases. The maximum value of the green line was selected to represent the X_{DR} value of a single passage.

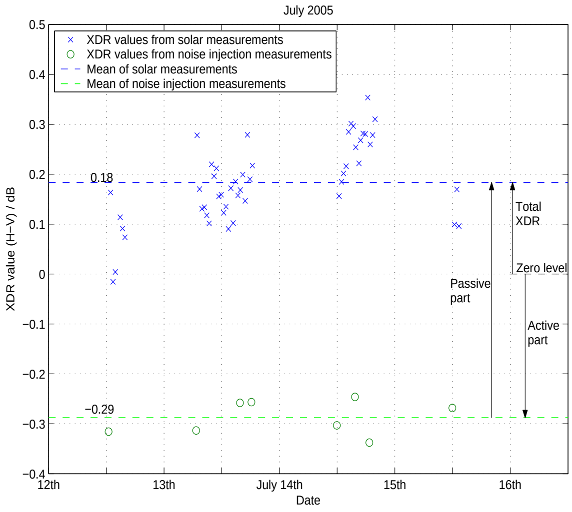

Figure 3: *Channel balance X_{DR} of the receiver as a function of date and time.*

The values of the X_{DR} of every measurement are plotted against the date and time in figure 3. As can be seen, during a single day the X_{DR} varies within an interval of ± 0.1 dB. This is partly explained by random errors caused by the measurements and by the fitting process. However, when plotting the X_{DR} as a function of the solar inclination angle η (figure 4), one can see a slight U-shaped behavior with the minimum value occurring around $\eta = 0°$. The reason for this may be that at high elevations, which correspond to zero inclination, the effect of refraction is at minimum. Since the refraction correction was not taken into account when pointing the antenna towards the solar trajectory, there were indeed some vertical pointing error occurring during the measurements.

Another interesting phenomena in figure 3 is that the X_{DR} seems to variate from day to day. The rising tendency of first three days is followed by a decrease in the fourth day. The first suggestion to this was that the RF electronics part of the system is slightly drifting. In order to monitor this, the integral precision RF noise source of the receiver system was used to inject equal test signal into the RF electronics parts of both channels.

The channel balance obtained via noise injection is plotted in figure 3 with circles. The number of the noise injection measurements seems unfortunately not to be adequate to make any conclusion about the drift of the RF part. However,

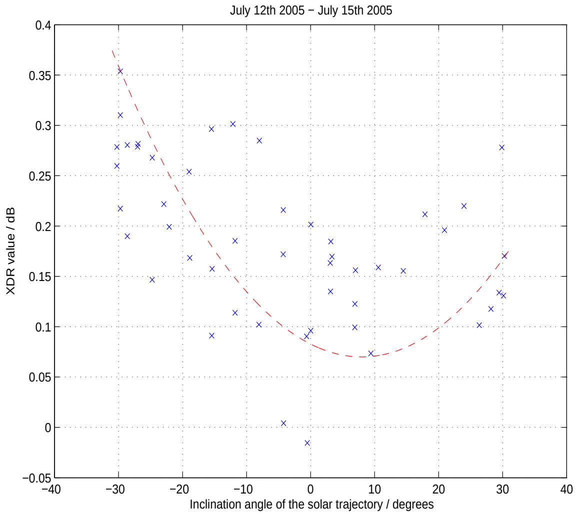

Figure 4: *The behavior of the* X_{DR} *value as a function of the inclination angle* η *of the solar trajectory. The red dashed line demonstrates the systematic behavior of the result points.*

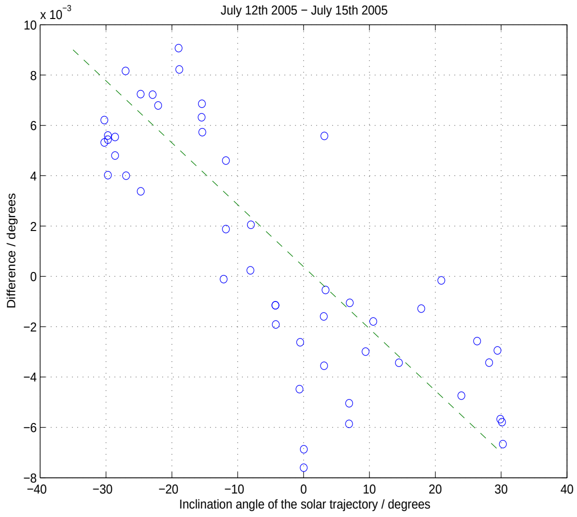

Figure 5: *The difference between the obtained H and V peak locations as a function of the inclination angle* η*. The green dashed line is for demonstrating the systematic behavior of the results.*

it looks like the balance remains more or less constant throughout the measurement campaign. This would mean that either the solar radiation was partly polarized due to variations in the solar activity, or the balance of the antenna or the waveguide assembly before the noise injection points was drifting for some reason.

However, the imbalance of the RF part seems to be approximately -0.3 dB. In other words, V channel have a bit higher gain there. The imbalance of the remaining part is then $+0.5$ dB yielding to total imbalance of $+0.2$ dB as obtained using solar measurements. This budged is sketched also in figure 2.

5.2 ANGULAR POINTING

Besides the channel balance, the solar passages also offer a possibility to study the azimuthal pointing accuracy of the antenna and alignment of the H and V beams with respect to each others.

The azimuthal pointing error can be resolved from the solar passage which had inclination angle of zero, or in other words at noon when the Sun is at its highest elevation. The pointing error is obtained simply by subtracting the antenna azimuth reading from the parameter A in equation (1).

The alignment of the H and V beams can be solved by studying the difference $A_h - A_v$, which is plotted in figure 5 as a function of the inclination angle η for each passage. As can be seen, the beams are very well aligned within an interval of $\pm 0.01°$.

As the Sun do not pass exactly through the beam axes, the azimuths giving the maximum power at each channel do not coincide. This is because the Gaussian radiation patterns of H and V channels are actually slightly elliptical in such way that the main axes of the ellipses are perpendicular. As a consequence of this, the points plotted in figure 5 seems to be oriented along a broad diagonal line from the upper left corner down to the right corner of the plot.

6 CONCLUSIONS

As a conclusion we can say that when trying to define the receiver imbalance with an accuracy of better than 0.2 dB, the solar measurement has to be made in proper way. A single shot by turning the antenna directly towards the Sun is not adequate, as the X_{DR} value obtained might vary within an interval of approximately ± 0.2 dB.

The suggested way to achieve a better accuracy is to measure as described in this paper: a solar passage at noon by keeping the antenna in a constant position at the solar trajectory. The X_{DR} is then obtained at the point where the derivative of the fitted curve in figure 2 is zero. Same measurement then gives also the possible azimuthal pointing error of the antenna. Furthermore, an estimate of the half power beam widths and the alignment of the horizontal and vertical beams can be achieved.

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