SALSA project documentation: Antenna response using the Sun

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Abstract

SALSA-Onsala ("Such A Lovely Small Antenna") is a 2.3 m diameter radio telescope built at Onsala Space Observatory, Sweden, to introduce pupils, students and teachers to the marvels of radio astronomy. The sensitive receiver makes it possible to detect radio emission from atomic hydrogen far away in our galaxy. From these measurements we can learn about the kinematics and distribution of gas in our galaxy, the Milky Way. One can also use the antenna for other projects which does not involve hydrogen. In this document we describe how you can measure the antenna response function, also called the *beam*, of the SALSA telescope by observing the total power received from the Sun.

First we review some basic concepts of how radio telescopes work and what the antenna reponse function for SALSA is expected to look like. Then we describe how to use the SALSA control program to observe the Sun to learn about the beam of SALSA.

Please note that this document is focused on understanding the antenna response and only briefly describes the telescope control program. Instructions for operating the SALSA telescope can be found in the document entitled *SALSA users manual* available at the SALSA website.

Coverimage: The SALSA telescopes in Onsala.

Chapter 1

The reponse function of a radio telescope

1.1 The concept of angular resolution

1.2 The response of a circular aperture

Chapter 2

Measuring the antenna response of SALSA by observing the Sun

In this chapter we describe how you can measure the antenna response of SALSA by observing the Sun. The Sun is a bright radio source and a small angular size compared to the angular resolution of SALSA. By measuring the total power received by the telescope at different angular separations from the Sun we get the reponse function of the SALSA antenna. Note that in this project we are only interested in measuring the relative response in different directions, i.e. we do not require an absolute flux scale calibration of the antenna.

2.1 When is a good time to observe?

In this project we need the Sun to be up, i.e. it has to be daytime in Onsala. To avoid disturbing radio emisson from the Earth itself it is good to observe when the Sun is as high above the horizon as possible. This means that it is good to observe around noon in Sweden, i.e. 11 UT, but also earlier or later times are fine (in particular during the long Swedish summer days). To find out exactly where the Sun is at a specific time you may use the free planetarium software Stellarium. This software is described briefly in the *SALSA user manual* available via the SALSA website.

2.2 Tracking positions relative to the Sun

To observe the Sun we must know where to point the telescope at a given time. Finding the celestial coordinates of the Sun can be tricky since it is not stationary in the common Glactic or Equatorial coordinate systems (because of the Earth's movement around the Sun). The SALSA control program can however calculate the position of the Sun at any given time automatically. To track the Sun, select *The Sun* as desired target (instead of the default *Galactic*) in the control program. The program will now automatically calculate where the Sun is right now.

However, to measure the antenna response it is not enough to measure on the Sun itself, we also want to measure at different angular separations relative to the Sun. Conveniently, the SALSA control program can also automatically track positions relative to the Sun by specifying local horizontal (altitude, azimuth) offsets. For example, to track a point on the sky which is

always 3 degrees offset in azimuth angle from the Sun, chose the Sun as the target and enter an azimuth offset of 3 in the control program, then press the button *Track*. To switch to another relative position you have to first press *Stop* to be able to input new offets, and then track the new position.

2.3 Measuring total power from the Sun

The SALSA control program, as described in the *SALSA user manual*, was developed to measure radio emission from neutral hydrogen. When observing hydrogen it is crucial to find out how the emission changes with different frequencies close to 1420 MHz, and therfore the program was developed primarily to measure spectra, i.e. a plot of the radio emission as a function of frequency within a specific frequency range. However, when observing the Sun to measure the antenna response function, we are only interested in the total power received by the antenna in some frequency range.

Since the SALSA receiver works best around 1420 MHz we will observe the Sun at this or a nearby frequency. To be sure not to include any hydrogen emission from the galaxy (which may be in the background of the Sun) we chose 1410 MHz as center frequency for our observations. This is done in the tab *Advanced* in the *Receiver control* part of the control program. This frequency is close enough for the receiver to work well, but far enough from 1420 MHz to not include any emission from galactic hydrogen. The default bandwidth does not need to be changed.

By default, the program will observe in *Switched* mode, which is used for spectral line observations of hydrogen. This mode removes disturbances from the receiver on the signal, but will also remove much of the total power received from the final spectrum. Since we want the total power, we need to change the mode of SALSA from *Switched* to *Signal*, also in the tab *Advanced* in the *Receiver control* part.

Once we have specified the frequency and the signal-mode we are ready to measure. Make sure you are tracking a desired position relative to the Sun (using offsets) and press *Measure*. The default integration time of 10 seconds is enough to detect the Sun, it is very bright also in radio emission.

When the measurement has finished we need to extract the total power measured. This is done by lookin in the terminal you used to start SALSA. After your measurement has finished you will see output similar to the line

```
SPECTRUM INFO: Offset_alt=0.0 deg. Offset_az=1.5 deg. Total power = 670.0
```

assuming you selected an azimutal offset of 1.5 degrees relative to the Sun.

Note the offset numbers and the total power measured, for example in a spreadsheet (e.g. using the free software Libre Office Calc available via www.libreoffice.org).

2.4 Plotting the antenna response function

Using your measurements you may now plot the antenna response function relative to the Sun. If you plot the total power as a function of azimutal offset, it should look similar to Fig. 2.1.

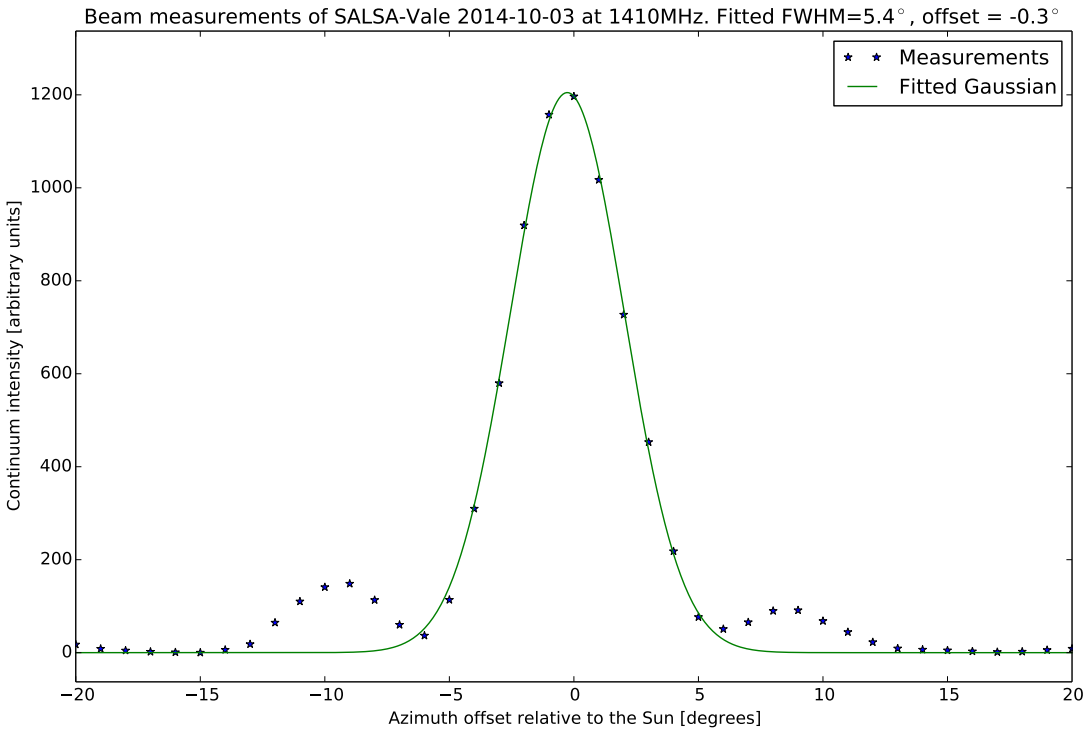

Figure 2.1: The beam of Vale measured using the Sun at 1410 MHz. A Gaussian fit gives the FWHM=5.4°. The sidelobes of the Sinc-function are clearly visible, as expected for a circular aperture.