CHALMERS – Space, Earth and Environment

RRY100 – Satellite Communications – 2024 – LAB-3

Antenna exercise

1 Introduction

Antennas are a crucial part of any satellite communication system. Since distances are large and signal levels weak, often directive antennas are used. This lab exercise aims at studying some of the properties of directive antennas. It makes use of a small antenna system at the Onsala Space Observatory. The antenna is called Such A Lovely Small Antenna (SALSA)[1] and has a parabolic reflector with diameter 2.3 m. The SALSA system has been developed for educational purposes, with a focus on radio astronomy observations. There are actually three SALSA antennas, which in theory can observe radio waves in the approximate range of 800 MHz to 2300 MHz. SALSA is optimized for atomic hydrogen (1420 MHz), but can also observe e.g. GNSS satellite systems (e.g. 1575 MHz). In this exercise we use SALSA to measure radiation from the Sun at about 1.4 GHz.

Expected learning outcome:

- Measure the FWHM, often called θ_{3dB}, of the SALSA antennas.
- Determine the antenna gain.
- Investigate potential pointing errors.
- Investigate the impact of ground noise pick-up and /or side lobes
- Analyse the data and present the results, preferably during the lab time.
- Report your results and main lessons learned in the combined ”lab report”.

2 Theoretical background

A parabolic reflector has maximum gain (send/receives maximum power) in the direction the reflector is pointing. Antennas do, however, also have gain in other directions. The antenna gain pattern is often described as a ”main lobe”, centered in the pointing direction, and ”side lobes” (with much smaller gain) directed away from the pointing centre; see Figure 1. Detailed descriptions of antenna gain patterns are very complex. In this exercise we introduce fundamental concepts often used in every-day discussions of antennas and antenna performance.

[1]See the SALSA webpage at http://salsa.oso.chalmers.se.

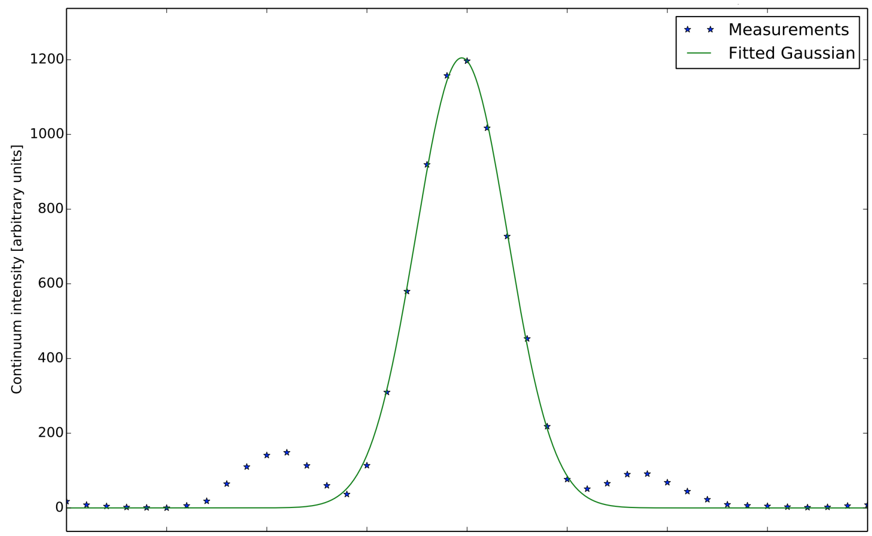

Figure 1: Measurement of the SALSA beam at 1410 MHz around the Sun; data taken 2014-10-03. Vertical scale is power in arbitrary units, horizontal scale is pointing offset relative to the Sun. The units on the horizontal axis have been removed, since one goal of this exercise is to reproduce this figure. A Gaussian distribution has been fitted to the main lobe. Side lobes are also visible, about 2 FWHM from the pointing centre.

2.1 The antenna main lobe and FWHM

The main lobe is often approximated as a Gaussian function (see Figure 1), where the gain peaks at the pointing direction and falls off away the further we are from the pointing centre. We are often interested in the angular *width* of this Gaussian function. For easy comparison, we usually characterise the antenna main lobe width at one specific gain level: the full-width half-maximum (FWHM). This is twice (because it is the width, edge to edge) the angular distance we have to go away from the pointing centre before the gain falls to half its peak value. A reduction by 50 % is, in a logarithmic scale such as dB, equal to a reduction of 10*log(0.5)=3 dB. Therefore, the FWHM is often denoted $\theta_{\rm 3dB}$. The FWHM is usually approximated, in radians, as

$$\theta_{\rm 3dB} \approx 1.2\,\frac{\lambda}{D} \tag{1}$$

where λ is the wavelength and D is the diameter of the antenna aperture. (The factor 1.2 comes from detailed derivations not covered in this exercise.)

2.2 The antenna gain

The gain G of an antenna is related to the FWHM via the expression

$$G = \eta\left(\frac{\pi\cdot 70^{\rm o}}{\theta_{\rm 3dB}}\right)^2 \tag{2}$$

where η is the aperture efficiency, a measure of the antenna performance, which you can assume to be 0.5 for SALSA around 1.4 GHz.

2.3 Pointing errors

SALSA moves around two axes: up/down from $0^\circ - 90^\circ$ is called "Altitude" (or Elevation), and "rotate around" from 0° (North) and 360° around is called "Azimuth". An ideal antenna system will point exactly where you tell it to. However, in reality antennas are not perfect and they may have errors in their pointing in one or more axes. Errors can be software/model related, where the software/models are not good enough, or hardware errors - where e.g. some deformation of the antenna structure has changed the alignment. To a first approximation, we can say that the antenna pointing is good if the pointing error is smaller than the half the FWHM. This means we still get at most 50 % reduction in received antenna power if observing objects in the sky.

2.4 Ground noise and side lobes

Anything with a temperature (e.g. anything warmer than 0 K) will emit some radio waves. These can be picked up by the antenna and disturb us when we want to observe other signals. The ground is about 273 K and will therefore contribute with radio emission. If we are pointing we close to the ground, we will pick up ground noise in the antenna main lobe. However, even if we are further away, we can still pick up ground noise in the antenna side lobes. By observing the antenna power at various separations from the ground, it is possible to estimate the impact of ground noise - leaking into main lobes or side lobes - on observations. Note that also other signals than ground noise may cause disturbances (in main lobe and side lobes), such as natural and artificial radio emitters which happen (probably without you knowledge and without you planning for it) to be close to your antenna pointing direction.

3 Observing with SALSA

SALSA is relatively easy to use and may be used by anyone remotely for free, by following the documentation available via the SALSA website. However, because we have limited time in this exercise, the lab supervisor will guide you through the SALSA setup procedure in detail. Therefore, these exercise instructions do not cover any details on how to use the telescope. Below we describe briefly how to achieve the goals of the exercise. The plan is for you to work out the details, together with the lab supervisor.

3.1 Measure the SALSA beam

The beam can be determined by measuring the total power received at various angles from a strong and compact radio source. We will use the Sun which is a very strong radio source. The Sun emits continuum radiation, meaning it emits power at all frequencies. The angular diameter of the Sun (about $0.5°$) is significantly smaller than the SALSA FWHM. Therefore, we assume in this exercise that the Sun is a point-source. You should confirm this assumption by estimating the theoretical SALSA FWHM using Equation 1.

The theoretical SALSA FWHM at 1.4 GHz is: ________________ degrees.

3.1.1 Stepping through elevation

We will tell the antenna to point with different elevation *offsets* relative to the Sun. We observe the range of offsets between $\pm 12°$ in steps of $1°$. For each offset value, we get a total power measurement. (This is in arbitrary units, because SALSA is not calibrated for absolute power measurements, but you can think of this as Watts if you want). We have prepared Table 1 for you below which you can use to enter your measured values. However, perhaps it is more convenient if you log directly enter your values in a spreadsheet where you can do calculations.

Table 1:

Offset [degrees]	Measured power [arbitrary units]
-12 °	
-11 °	
-10 °	
-9 °	
-8 °	
-7 °	
-6 °	
-5 °	
-4 °	
-3 °	
-2 °	
-1 °	
0 °	
1 °	
2 °	
3 °	
4 °	
5 °	
6 °	
7 °	
8 °	
9 °	
10 °	
11 °	
12 °	

3.1.2 Subtracting the zero-level

The ”Half-Max” in FWHM refers only to the power we measure from the Sun. We also measure a background noise from other sources (receiver system, atmosphere etc.). To calculate the FWHM, we first need to subtract the background level (assumed to be constant) from all our power measurements. What is (approximatively) the zero-level you find from Table 1?

The zero-level is: ________________.

If we plot our measurements of power vs offset, after subtracting the zero-level, we should obtain something similar to Figure 1 (again: note that we use arbitrary power values, so yours may differ).

3.2 Calculating the FWHM

After subtracting your zero-level, you can obtain the FWHM from your measurements. What is the measured FWHM?

The measured FWHM is: ________________ degrees. Does this agree with your theoretical estimate?

(If doing this exercise in azimuth: Be aware that the antenna moves by $AZ \cdot \cos(EL)$ when selecting offsets in azimuth; hence your FWHM calculation need to account for this.)

3.3 Calculating the antenna gain

Using the FWHM, we can estimate the antenna gain from Equation 2. Note, however, that gain values are usually expressed in dBi. What is the gain of SALSA in dBi ? ________________

3.4 Check for a pointing error

If the antenna has a pointing offset, it means the peak power is not received at offset $0°$ (towards the Sun).

At what offset do you find the peak power: ________________? Is this offset significant?

3.5 Ground noise and side lobes

Discuss the possible impact of ground noise on your measurements.

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Also, can you see any evidence for side lobes in your data?

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4 Feed back

Comments and suggestions for improving this lab exercise are much appreciated and can be sent to:
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Rüdiger Haas (`rudiger.haas at chalmers.se`)