National Centre for Radio Astrophysics

Fitting Beamwidths for Broadband Feeds

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Objective: To describe the usage and some useful details of the procedure developed to fit beamshapes using spectrum analyzer data captured at antenna base.

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Ver. 1	September 3, 2012	Initial Version	

1 Introduction

GMRT is under going a massive upgrade of it's electronic systems. New broadband feeds are being installed on GMRT antennas as a part of this upgrade. There is hence a need to characterize all these new feeds. To make it easier to perform this task on a large number of antennas in a consistent manner, it is desirable to automate as many aspects of feed characterization as possible.

This is a first step towards this larger goal. The objective of this particular exercise is to characterize the beam-width of the new feeds. It uses the data captured using a spectrum analyzer at the antenna base. Not needing the GSB will make the task of characterizing the performance of individual feeds substantially easier, and will be helpful in our present phase of the upgrade.

This report presents some useful details about the procedure and the approach used to fit beam-shapes.

In a nutshell, the approach is to scan in AZ/EL across a strong source and fit a Gaussian to the obtained data to estimate the beam-width.

2 Procedure

For data, we take scan across strong source (CASA/CYGA/CRAB/HYDRA) with a known fixed rate in EL/AZ axis and the data is recorded using spectrum analyzer at the antenna base. The data is recorded in units of **dB** and for the period of the scan and for the entire bandwidth of the feed with a sufficient frequency resolution and time.

2.1 Data Format

First few columns of the data gives the information about the time and rest columns gives the information about the power measured (in the units of dB) at that particular time. For a typical nun, if we record data for the scan period of 20 minutes and for a bandwidth of 400 MHz say from 200 to 600 MHz, there will be 406 columns (5 columns for the time information and 401 columns for the power measured for the band) and there will be 401 rows at the typical time resolution of 3 seconds.

3 Beam Fitting

Even though the beam shape is not truly Gaussian, for our present purposes, a Gaussian is an adequate representation of the beam shape. This is a comparatively coarse measurement meant to check for gross features.

The data measures the power in the unit of dB, and we had to convert it to linear units before using Gaussian fitting algorithm.

Internally, this program fits a Gaussian + a constant to the beam shape (using program *mynlsfit*, provided by Prof. J. N. Chengalur, which in turn uses Numerical Recipes functions).

For this fitting program we need to provide initial guesses for the values of peak/amplitude of the Gaussian, it's position and the width of the beam.

For the initial guesses, we find out the peak/amplitude and it's position and for the width of the Gaussian, it's $\sqrt{2} * \sigma$, where σ is the standard deviation of the Gaussian.

3.1 Corrections applied

- The Gaussian equation implemented in the fitting program is

$$G(x) = Ae^{-((x-B)/c)^2} \tag{1}$$

  But the usual equation for the Gaussian is

$$G(x) = Ae^{-(x-B)^2/2\sigma^2} \tag{2}$$

  so from above two equations, we apply correction of **(1/sqrt(2))** for the calculation of beam-width.

- We need to translate from the scan rate of the antennas in El/Az to an angular displacement on the sky. For example, for a scan rate of 50 arc-min per min leads to a multiplicative correction factor of **50/60 arc-min**.

- We apply a correction of value - **2.3548**, to convert from σ of a Gaussian to its HPBW.

- For the azimuth scans, we apply the correction of cos(**El**). The program calculates the elevation of the source for the epoch of observation. This program also does the precession of the source co-ordinates for the epoch of observation for calculating elevation of the source.

Apart from the parameters of best fit Gaussian to the beam-shape (amplitude, position and width of the Gaussian), the fitting program also provides normalized χ^2 for the fit. For a 'good' fit normalized $\chi^2 < 1$. We also provide formal error on the beam-width based on the quality of the fit.

4 Removing Bad Data

The data are often seen to have spikes in time domain. It is assumed that these are due to time variable RFI. In order to make the fits robust against spikes in the data, we try to identify spikes in the data and remove them.

This is a two step process. In the first step we fit the Gaussian to the beam-shape. We then compute the difference between the Gaussian fitted data and the actual data. and calculate the standard deviation of this difference values. In the second step, if this value is greater or less than 3 × standard deviation, then that actual data is omitted for the next Gaussian fit.

We see some improvement in the value of χ^2 in the second Gaussian fit after removing the bad data.

5 Beam Width Estimates

Here we present few example plots for the beam-width we calculated using the program.

1. The figure **??** gives estimated beam-width (arc-min) vs frequency (MHz) for the antenna S02. The scan was done along the **Elevation axis**, at the scan rate of 50 arc-min/min. The figure also plots the expected (theoretical) HPBW. The function we use for plotting expected HPBW for GMRT dishes of diameter **D=45m** is

$$f(x) = (1.22 * (3E + 8)/(x * (1E + 6) * D)) * 180 * (60/3.1415) \quad (3)$$
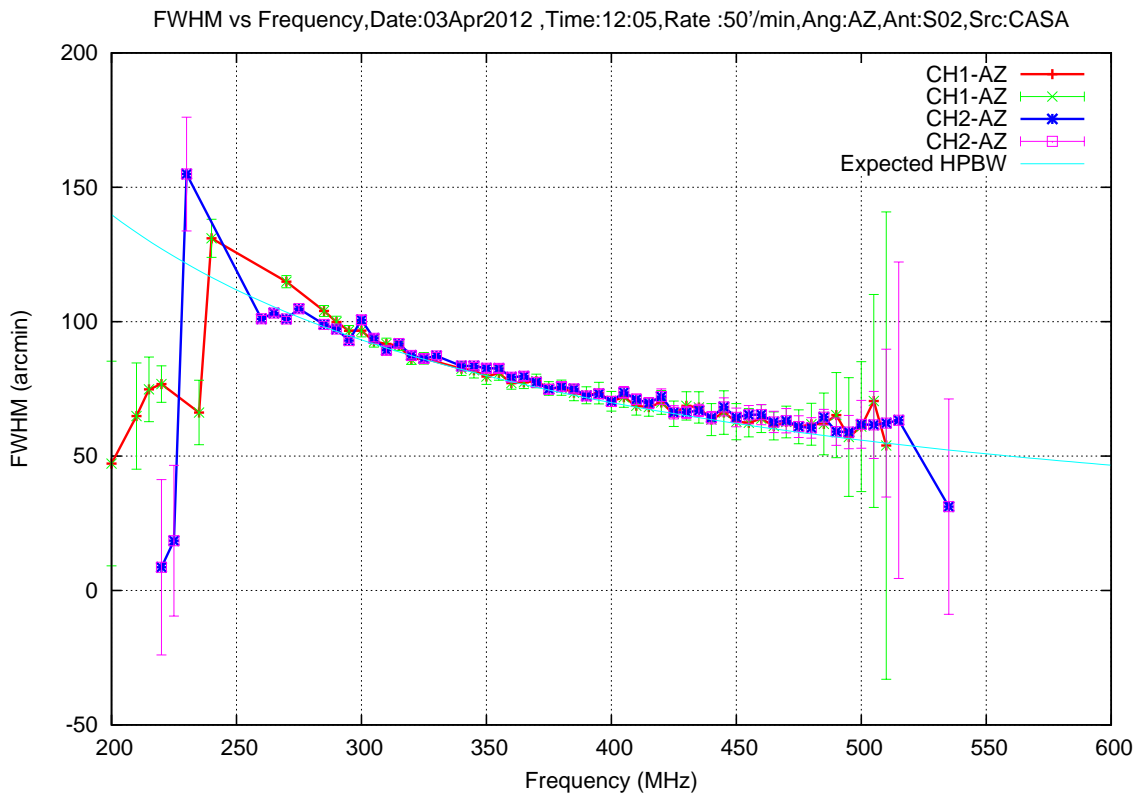
Where x is the observing frequency in MHz.
It also shows the error on the beam-width based on the quality of the fit.

FWHM vs Frequency,Date:03Apr2012 ,Time:10:51,Rate :50'/min,Ang:EL,Ant:S02,Src:CASA
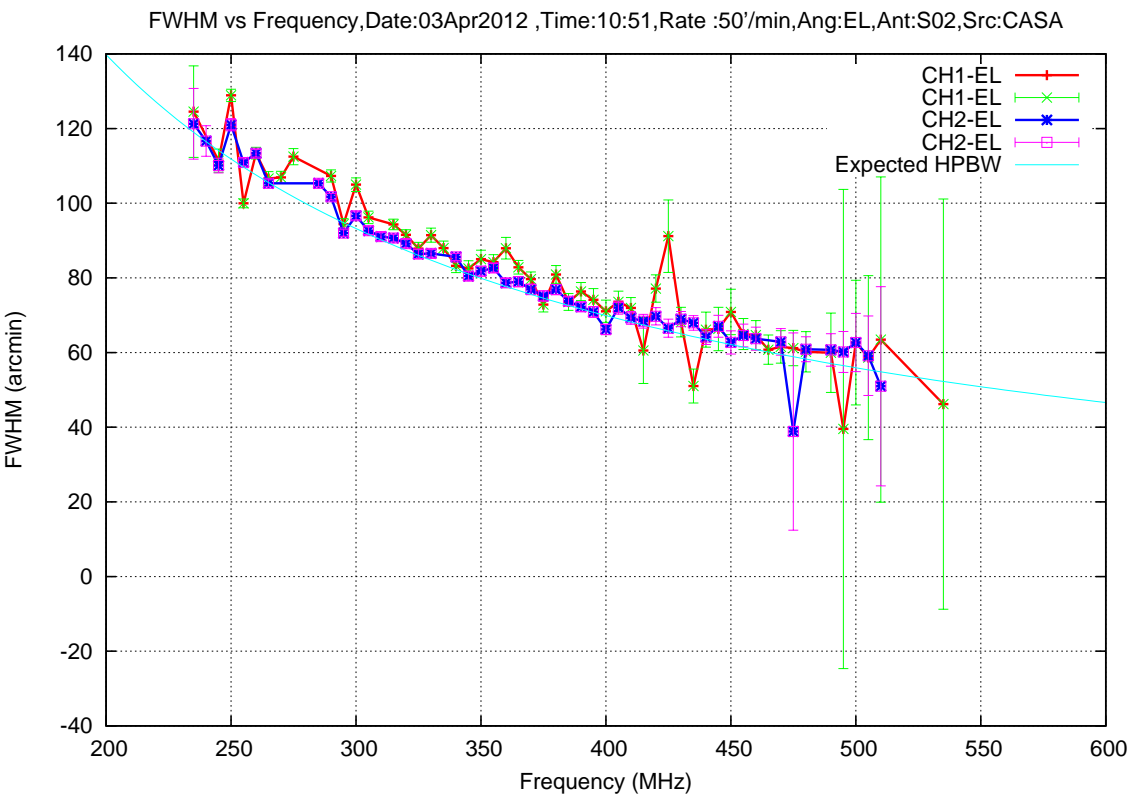
Plot of
FWHM vs Frequency for antenna S02 for **Elevation** for the source
CASA.

2. The figure 2 gives estimated band-width (arc-min) vs frequency (MHz) for the antenna S02. The data corresponds to the scan along the **Az-imuth axis**, at the scan rate of 50 arc-min/min., and it also plots the expected (theoretical) HPBW. Here we have applied the correction of cos of elevation of the source at the epoch of observation. We also plot

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the error on the beam-width based on the quality of the fit.

FWHM vs Frequency for antenna S02 for **Azimuth** for the source CASA.

Plot of

FWHM vs Frequency,Date:03Apr2012 ,Time:12:05,Rate :50'/min,Ang:AZ,Ant:S02,Src:CASA

- CH1-AZ
- CH1-AZ
- CH2-AZ
- CH2-AZ
- Expected HPBW

FWHM (arcmin)

Frequency (MHz)

6   Example Command Lines

Here we list the parameters which a user can supply on the command line and the default values which are used by the program. This program is expected to serve the needs for different broad band feeds by allowing the initial frequency, frequency step and bandwidth the be user defined parameters. Usage of the program is,

```
Usage : ./fit_beamwidth.pl [options]

* options :
-h  # This help Message
-f  # File Name
-s  # Frequency Step (MHz)
-i  # Initial Frequency of the data (MHz)
-b  # Bandwidth (MHz)
-a  # Scan Angle (AZ/EL)
-r  # Scan Rate ('/min)
-S  # Source Name.
-n  # Antenna Name.
```

The default values are

- Frequency step : 5 MHz

- Initial Frequency of the data : 200 MHz

- Bandwidth : 400 MHz

- Scan Angle : EL

- Scan Rate : 50 arc-min/min.

- Source Name : CASA

- Antenna Name : S02

```
### Example

fit_beamwidth.pl -f s02el.txt -s 5 -i 200 -b 400 -a EL -r 50
-S CASA -n S02
```

The program above can be used for single channel file, and if you want to plot for both channels, then another script can be used

```
Usage : ./fit_beamwidth_2pol.pl [options]

* options :
-h  # This help Message
-F  # CH1 File Name
-f  # CH2 File Name
-s  # Frequency Step (MHz)
-i  # Initial Frequency of data (MHz)
-b  # Bandwidth (MHz)
-a  # Scan Angle (AZ/EL)
-r  # Scan Rate ('/min)
-S  # Source Name. (Default : CASA)
-n  # Antenna Name. (Default : S02)

### Example

fit_beamwidth_2pol.pl -F s02el1.txt -f s02el2.txt -s 5 -i 200 -b 400
-a EL -r 50 -S CASA -n S02
```

This script runs the program fit-beamwidth.pl twice for each channel and then plots bandwidths for both channel in single plot.

7   Future Improvements

For getting a better fit for the beam-shape, we can fit a Gaussian + constant + slope to account for slow variations in the sky brightness distribution as we scan across the source. The fitting program can be modified for the same.

8   Acknowledgments

References

[1] Secondary Beam Pattern Measurements for Broadband feeds for the GMRT., NCRA internal technical report, March 2012.