Technical/Astrosupport Note

Working towards a Pointing Model for GMRT antennas - I

By Nimisha G. Kantharia for the pointing group.
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1 Why do we need a pointing model ?

Pointing in the desired direction leads to better images. However, most telescopes have pointing imperfections which need to be corrected. For a single dish telescope, pointing errors $< HPBW/10$ are sufficient to limit the axial gain loss to a few percent However, for interferometry, pointing errors should be less than $HPBW/20$ (Napier 1998) at the highest operating frequency to limit the intensity fluctuations at the peak to less than 1%. Even with such a pointing accuracy the intensity fluctuations at the half power point will be about 12.5%. As expected this will be worse for sources located further out in the beam. As the pointing accuracy degrades, the reliability and dynamic range of the images also degrade. Thus a pointing model which corrects for pointing offsets as a function of elevation and azimuth is required to minimise the variation in pointing offsets due to various instrumental effects.

At GMRT, typical pointing errors of 1' for each of the elevation and azimuth axes are tolerated when updating the antenna pointing. This translates to a rms pointing error of about 1.4' when the errors along both the axes are combined. This degrades as a function of elevation giving a total variation of 3'-6' for most antennas especially in the pointing of the antenna along the elevation as the source moves across the sky. We need to reduce the instantaneous pointing errors to 30"$-1'$ to be able to make high dynamic range images at L band. The technical specification of the servo system seems to indicate pointing accuracies of 1' for wind speeds less than 20 kms^{-1}. Since many users have noticed a systematic variation in pointing offset of 3'-6' in almost all GMRT antennas, it should be possible to remove this variation using a pointing model and improve the pointing accuracy.

We list the expected variation in the source strength at the peak and half power points for the L band assuming a range in pointing errors, many of them typical of GMRT antennas (see Table 1). As is obvious, pointing offset variation will especially affect the sources at half power points and further out.

For a two-element interferometer, a pointing offset of 3' in both antennas will lead to a drop in the correlation coefficient of 7% while a pointing offset of 4' in both antennas will lead to a drop of 12% for a source at the pointing centre. On the other hand, a pointing offset of 10' in one antenna and 3' in the other will cause the correlation coefficient of a source at the pointing centre to drop by a whopping 36%. Thus it is necessary to model the variation in pointing offsets as a

Pointing error ’	source at peak %	source at half power point %
0.5	0.1	5.3
1.2	0.6	12.5
2	1.6	20.6
3	3.7	30.1
5	9.8	47.1
10	33.8	77.3

function of elevation and azimuth for the alt-azimuth mounted GMRT antennas and reduce their effect on the final product.

This note addresses two points: 1. the need for reducing the variation in pointing offsets and finding and applying a model 2. suggesting that the functional form of the pointing model for GMRT antennas is likely to be similar to that used on mm-wave antennas which is derived based on instrumental problems.

In most experiments conducted by different users, it has been noted that the pointing offset varies with elevation/hour angle. A change of about $3' - 6'$ is observed from hour angle ~ -4 hours to transit and to $\sim +4$ hours at L band. Beyond 4 hours, a steep drop in the correlation coefficient of almost 30% (Private communication: Dipanjan Mitra, Ishwar Chandra) has been observed. While the reason for the abrupt drop at hour angles larger than 4 hours is not clear and its repeatability has to be investigated, the change observed within ±4 hours is repeatable and is likely to be due to the changing pointing offsets. This can easily be corrected by using a pointing model. If this effect is taken out, the residual rms pointing error will be $\leq 1'$.

This note is the first step towards obtaining and implementing a pointing model. For the pointing model (PM), we need to obtain sufficient pointing measurements to be able to determine all the coefficients in the model which is in common use on mm wave antennas (e.g. Greve et al. 1996). As the next step, the relevant pointing offsets for a given elevation and azimuth need to be incorporated to test the efficacy of the PM. If this is found to be satisfactory, then the PM should be incorporated in the control software, ONLINE at GMRT. Lastly the PM will have to be regularly checked and updated, if required. The astro-support group comprising of myself, Vasant Kulkarni and Rajaram Nityananda are working on obtaining a pointing model for GMRT antennas.

Pointing offset is defined as the offset between the encoder/target position and the actual pointing position. At GMRT, pointing offsets are generally obtained by taking a scan across the source and noting the offset of the peak from the expected time. The difference, when converted to minutes of arc, gives the pointing offset. At GMRT, the convention is to attribute a positive pointing offset if the peak leads the expected time and a negative offset if it lags the expected time. Since $A(encoder) = A(actual) + \delta A$ and $E(encoder) = E(actual) + \delta E$ where δA and δE are the pointing offsets, the offsets are positive if the encoder values are larger than the actual values and negative if the encoder values are less than the actual pointing center. These offsets often vary with time due to various reasons outlined in the following section.

2 Why do pointing offsets change with time ?

Pointing offsets can result from several reasons, majority of which are instrumental. Errors like setting the wrong declination of the source will also mimic pointing errors. However these are user-dependent and hence transitory in nature and are not required to be incorporated in the pointing model. However instrumental effects need to be taken into account in a pointing model. Some of these effects are the non-orthogonality of the azimuth and elevation axis, the orientation of the tilt of the azimuth axis, encoder offsets for both elevation and azimuth encoders, errors in the feed positioning system and gravitational deformation; most of which change as a function of elevation and/or azimuth. Ulich (1981) (following Stumpff 1972) has given the necessary corrections required to be included while positioning an alt-azimuth mount telescope to account for all the above effects. The model applies for small corrections since it includes only first order terms and all the higher order terms are neglected. We suggest that the same functions might work well at GMRT and present these equations for GMRT antennas in the following section.

3 Functional form of the Pointing Model for GMRT antennas

If the azimuth (A) and elevation (E) of a source set by the control system are in error by δA and δE, then the pointing errors in the vertical and horizontal directions will be:
$\delta v = \delta E$
$\delta h = \delta A cos(E)$

Ulich (1981), Greve et al. (1996) (following Stumff 1972, Meeks 1968) have presented the equations for determining δh and δv. Since the peak-to-peak variation in the pointing offsets at GMRT for most antennas range from $3' - 6'$, the linear pointing model specified by Ulich (1981), Greve et al. (1996) should be applicable to GMRT antennas. Moreover, the model is mainly based on pointing errors arising from axes mis-alignment and gravitational bending which are common to any dish antenna. A term, specific to GMRT is the error introduced by the feed positioning system. Since the prime focus feeds at GMRT are mounted on a turret which is rotated to focus the frequency of interest at any give time, it is likely to introduce an error in the elevation pointing offset. However this error will be a constant term in the elevation pointing offset and hence can be integrated into the existing constant term in the equation. The standard pointing model which can be examined for GMRT antennas as taken from Greve et al. (1996) is:

$$\delta \mathrm{h} = \mathrm{P_1 cosE} + \mathrm{P_2} + \mathrm{P_3 sinE} + \mathrm{P_4 sinEcosA} + \mathrm{P_5 sinAsinE} \quad (1)$$

$$\delta \mathrm{v} = -\mathrm{P_4 sinA} + \mathrm{P_5 cosA} + \mathrm{P_6} + \mathrm{P_7 cosE} + \mathrm{P_8 sinE} \quad (2)$$

where the P_i are the coefficients to be determined and each of which correspond to a mechanical imperfection in the antenna. P_1 quantifies the zero-offset of the azimuth encoder, P_2 gives the collimation error between the prime focus feed and the antenna dish, P_3 estimates the inclination of the elevation axis, if any, P_4 quantifies the error in the inclination in the azimuth axis along the NS direction whereas P_5 quantifies the error in the EW direction. P_6 gives the zero-offset of the elevation encoder whereas P_7 and P_8 quantify the gravitational bending of the antenna.

Since P_6 is a constant in determining the elevation pointing error, any error in the FPS system at GMRT will be included in this coefficient and there is no need to introduce a separate term. After conducting experiments to determine the model using the above equations, the need for any extra terms peculiar to GMRT antennas can be examined from the residual pointing errors. If it is found that the above model does not work inspite of introducing terms peculiar to GMRT, then a different treatment of the problem will be required.

4 Implementation of pointing models on a couple of other telescopes

Although pointing models are implemented on all telescopes, they are crucially required at telescopes operating at very small radio wavelengths (such as millimetre waves). Here we very briefly summarize the models implemented at IRAM and SMA.

4.1 IRAM

Greve et al. (1996) have used the equations in Ulich to obtain a satisfactory pointing model for the IRAM. Using this they obtain a nine-parameter model which gives them a rms pointing accuracy of 3.5". They find that their model degrades over two weeks and hence a new model (ie new coefficients) have to be determined and the model updated. However the incremental changes are minor and the user corrects for this using referenced pointing while observing. They also find that a six-parameter model is sufficient to take care of the variation in the pointing offsets.

Additionally Greve et al (1996) find seasonal and temperature variation in some of the coefficients especially those related to the azimuth axis tilt.

4.2 SMA

Patel & Sridharan (2004) find a 19 parameter pointing model which corrects for the SMA pointing imperfections. The model gives a pointing accuracy of 1" at the highest operating frequency of 690 GHz where the FWHM of the primary beam is 12". This model is based on the standard model with several extra terms added to it which are specific to the SMA antennas.

5 Summary

The need for a pointing model for GMRT antennas is explained in this note. The standard pointing model used on mm-wave telescopes is suggested as a possible one and the functional form taken from Greve et al. (1996) which is based on Stumpf (1972) and Ulich (1972) is presented. Elevation pointing offsets for most antennas at GMRT are seen to show a systematic variation of 3'-6' for a rise-to-set track of a source. The offsets vary due to various instrumental effects and limit the dynamic range of the final images. The degradation is most pronounced at the highest GMRT frequencies as expected. A pointing model is required which would correct the pointing offsets as a function of azimuth and elevation as the source moves in the sky. Here we present a functional form for the pointing model for GMRT which includes errors in the orientation of the elevation and azimuth axis, encoder zero offsets, FPS errors and gravitational deformation and is the standard model used on mm-wave antennas. Data has to be obtained and software developed for checking this model before it can be implemented at GMRT. After implementation, the model will need to be regularly updated and also long-term variations determined. The astrosupport group comprising myself, Vasant Kulkarni and Rajaram Nityananda are working on finding this model and Part II of this work will report the results.

6 References

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