Analysis of Polarization Data of Wideband Feed

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CHAPTER : 1

INTRODUCTION

1.1 GMRT

NCRA has set up a unique facility for radio astronomical research using the meter wavelengths range of the radio spectrum, known as the Giant Meterwave Radio Telescope (GMRT), it is located at a site about 80 km north of Pune. GMRT consists of 30 fully steerable gigantic parabolic dishes of 45m diameter each spread over distances of up to 25 km. GMRT is one of the most challenging experimental programmes in basic sciences undertaken by Indian scientists and engineers.

Antenna configuration and Specifications: The number and configuration of the dishes was optimized to meet the principal astrophysical objectives which require sensitivity at high angular resolution as well as ability to image radio emission from diffuse extended regions. Fourteen of the thirty dishes are located more or less randomly in a compact central array in a region of about 1 sq. km. The remaining sixteen dishes are spread out along the 3 arms of an approximately `Y'-shaped configuration over a much larger region, with the longest interferometric baseline of about 25 km.

The highest angular resolution achievable will range from about 60 arc sec at the lowest frequencies to about 2 arc sec at 1.4 GHz.

Electronic Frontends and Backends : Apart from the novel low-cost design of the parabolic dishes, the instrument has state-of-the-art electronics systems developed indigenously and consisting of the following main sub units.

- Antenna feeds at six different frequency bands between 50 MHz and 1500 MHz, having good polarization characteristics as well as simultaneous multiband operation.
- Low-noise amplifiers, local oscillator synthesizers, mixers, IF amplifiers.
- Optical fibers linking the entire array with the CEB (Central Electronics Building). These are used both for the telemetry signals and local oscillator phase reference communication between the CEB and each antenna base.
- A software based FX-type real time correlator providing up to 512 spectral channels and covering a maximum bandwidth of 32 MHz.

1.2 Polarization Capability of GMRT

GMRT is composed of sophisticated chain of electronic subsystem which carries two polarization signals (linear and circular) from feed to correlator. As the signals travels through the systems, it acquires unequal gains for two polarization signal. As a result, a change in state of signal occurs. Apart from this effect, there can be chances of one polarization signal getting leaked into other polarization signal in electronics due to poor isolation between them. This kind of leakage shows significant cross-correlation between orthogonal polarization signal.

GMRT is being upgraded to have a frequency coverage from 100 – 1500 MHz using different kind of feeds. Under current project, we are testing polarization behavior of one such antenna where a feed covering frequency from 250 – 500 MHz is already installed and is in testing phase.

1.3 Observation

Currently GSB is a default observatory backend. We are carrying out testing using GSB. However, GSB is designed to process bandwidth of 33.33 MHz. The new upgraded frontend is offering about 200 MHz bandwidth. So, for such testing, in future, wideband correlator like GPU (Graphic Processing Unit) correlator, PoBe (FPGA based Pocket Correlator Beamformer) correlator which are under development can be used.

CHAPTER 2
PULSAR AND POLARIZATION

2.1 THEORY

Pulsars are rotating neutron stars born from collapse of Type II supernova. Periods of pulsars range from 1.5msec to 8sec with average period of about 1 sec. Pulsars are seen to slow down at a steady rate. Pulsars are seen to slow down at a steady rate. Pulsar Magnetic fields vary from 10^8 to 10^{13} gauss. Pulsar emits pulsed radiation across the whole electromagnetic spectrum. Pulsars are very weak source of radio and can range from miliJansky to few Jansky. The radiation can only be observed when the beam of emission is pointing towards the Earth. This is called Lighthouse Effect and gives rise to the pulsed nature that gives pulsars their name. Because neutron stars are very dense objects, the rotation period and thus the interval between observed pulses are very regular. For most of pulsar, the radio pulse occurs during a small fraction of its period, approximately 5^0 to 20^0 of the pulse phase. The pulse is formed by a beam of radiation that sweeps across the observer's line of sight. The beam is radiated by high energy particles constrained to move along the field lines over a magnetic pole, so that the beam is rigidly attached to the solid surface of the neutron star. The radio beam originate in regions some tens of stellar radii above the surface, lower the radio frequency, further from the surface is the emitting region.

The individual radio pulses are often very highly polarized and can give up to 100% polarized radiation. When the integrated pulse profile is formed by adding many pulses, and the polarized components are also added suitably, a high average polarization may be seen. This often shows a remarkably simple behavior. The position angle of the linear component swings monotonically through the integrated pulse by an angle up to 180^0. A circular component is also seen, usually close to center of the pulse. The simple nature of polarization indicates that the origin of the radio beam is above a magnetic pole. The swing of position angle is then related to the radio emitting regions whose radiation is polarized along the direction of the field lines.

2.2 Actual Observation

- Source : B0329+54
- Observing mode : Full Polar Mode
- Observation Date : 22/June/2012

The parameters such as RF, LO1, LO5 are set through a series of software (editing required files and setting requires values) in Control Room. The RF, LO1 and LO5 values are mentioned below for sub bands covered under this project.

RF(L)	RF(R)	LO1(L)	LO1(R)	LO5(L)	LO5(R)
270	270	219	219	51	51
322	322	271	271	51	51
348	348	297	297	51	51
449	449	500	500	51	51

A 32 MHz filter is placed in IF(Intermediate Frequency).
If the RF>LO1, the total frequency coverage will be 'frequency of CH0+BW (33.33MHz)'.
If the RF<LO1, the total frequency coverage will be 'frequency of CH0-BW (33.33MHz)'.

2.3 Data Acquisition:

Antenna (C06) set to track source (B0329+54) continuously and data recorded by the GSB with sampling interval 0.24576msec. For each set of RF frequency listed above, data was recorded for 10 minutes each. Source B0329+54 is a strong pulsar having about 15% linear polarization. Hence, single antenna observation can give sufficient detection of linear polarization which is essential for polarization calibration of antenna.

2.4 Data Reduction:

The raw data is recorded in computer disk files which contains the raw voltages squared and cross multiplied, giving output in four channels(stream) viz. RR*, LL*, Re(RL*) and Im(RL*). This raw data is passed through series of offline software to obtain the 'Observed Stokes Parameters' for given observation. For full polarization calibration, a series of observations is needed, but under this project we are not carrying out full polarization calibration but producing uncalibrated single profile.

The signal received in two polarizations measured at input of sampler of correlator shows different power levels as it may have subjected to unequal gains in receiver chain. The stokes parameter are very sensitive to the difference in two powers, viz. RR* and LL*, which for the case of circular polarization receiver, as in GMRT, quantify amount of circular polarization. Hence the spurious power can get added to the true polarization power due to uncalibrated gains.

Since we receive voltage products from GSB, we use co- and cross-polar voltage products rather than voltage signals to determine amplitude scaling factor. Initially self and cross voltage products, (viz. RR*, LL*, Re (RL*) and Im (RL*)) are averaged over observation duration. While averaging the ranges of bad spectral channels are taken as input from user, and are excluded from determining scale factors. These averaged voltage products, along with the spectral channel selection, are written to text file.

2.5 Conversion to Stokes Parameter:

The scaling factor application, and conversion of voltage self/cross products to the stokes parameters are obtained by using following formulae.

$$I = \frac{RR^*}{RR^*_{Avg}/Max} + \frac{LL^*}{LL^*_{Avg}/Max}$$

$$V = \frac{RR^*}{RR^*_{Avg}/Max} - \frac{LL^*}{LL^*_{Avg}/Max}$$

$$Q = 2 * \frac{Re(RL^*)}{\sqrt{\frac{RR^*_{Avg}}{Max} * \frac{LL^*_{Avg}}{Max}}}$$

$$U = 2 * \frac{Im(RL^*)}{\sqrt{\frac{RR^*_{Avg}}{Max} * \frac{LL^*_{Avg}}{Max}}}$$

Each of the parameter is written to separate data file for further processing.

In radio telescope, uncorrected signal transmission delay between two polarization channels reflects as constant phase ramp (across band) for voltage cross products. As an effect summing the stokes-L across band becomes incoherent. In order the stokes-L to add coherently, time integrated (or folded) profiles, one per each channel, of Stokes-L are obtained and off pulse mean power is subtracted from all the profiles of Stokes-I to suppress the off pulse noise to zero. The folded profiles of stokes-I, -L, & -V are averaged across the band and plotted. A pulse bin, which has a smooth curve of position angle passing through, is selected. A straight line is fitted to obtain the slope of phase ramp across the band. Correction of phase ramp slope followed by coherent addition of stokes-L across all frequency channels give the final linear Stokes profile.

A single profile is obtained by integrating one observing scan of few minutes. In process of integrating, the dispersion of pulse across frequency is corrected. Integrated (folded) pulse profile in time, in each of 256 spectral channels is written to another data file. This procedure is repeated for all stokes parameters.

The software tools used for all of this processes and procedure of using the software is mentioned below:

1) **Psr_mon**: is a pulsar monitoring tool. This program shows online display of time series, spectrum, current averaged profile over a short duration and cumulative profile folded using the given parameter of DM (Dispersion Measure), period by user via a startup file. The user has to take care of whether the RF value, USB/LSB bit and reference channel are correct or not. The user has to observe carefully and decide whether the data recorded is a good data or bad data and choose to advance for further procedure.

2) **Make_gains**: This program averages whole data available in file, separately for each co- or cross products. User input is taken for selecting the range of channels to be flagged (bad data channels). A file all_gains.dat is written to the disk which is being used later by ‘split_iquv’ program.

3) **Split_iquv**: By running this program, the four stokes mentioned above are deduced from the data by the formulae. This four stokes are stored in four separate files and made ready for calibration.

4) **Psr_dsp_fold_mch.lin :** This program reads the raw data file and fold it with the period of rotation and write folded profile into another ASCII files with 256 channels after dispersion application. Repeat this with all Stokes files generated out from split_iquv.

   Keep the list of all files in order of I, U, Q & V in text files say ‘file.list’.

5) **Calibrate**: This program reads the four files in ‘file.list’. In calibration, we have to select a bin (specifically choose the bin in the highest power region) and a straight line is fitted for the data points in the chosen bin to combine all of the four stokes for better profile generation.

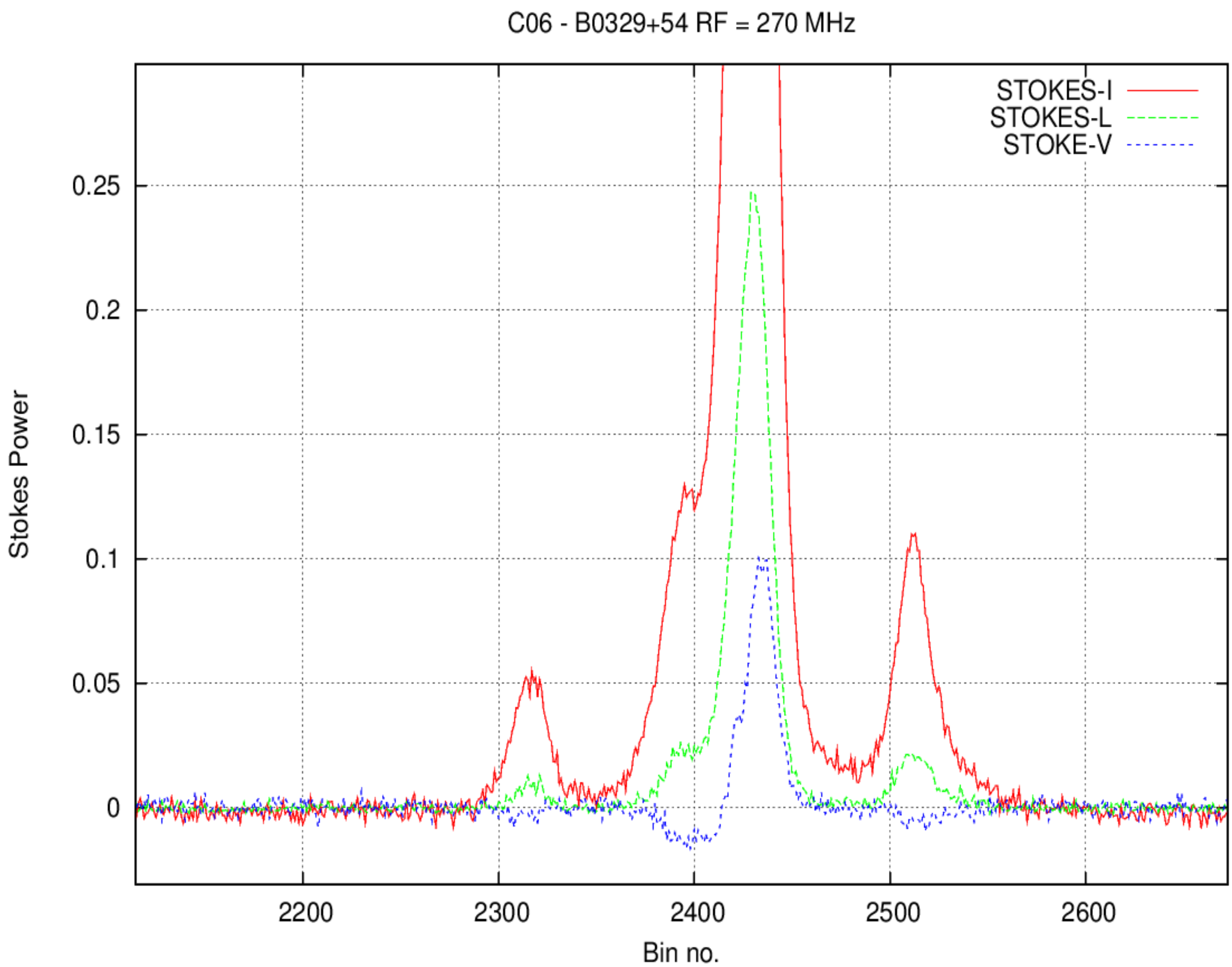
At the end of this procedure a profile is generated and compared with a reference EPN profile.

CHAPTER 3

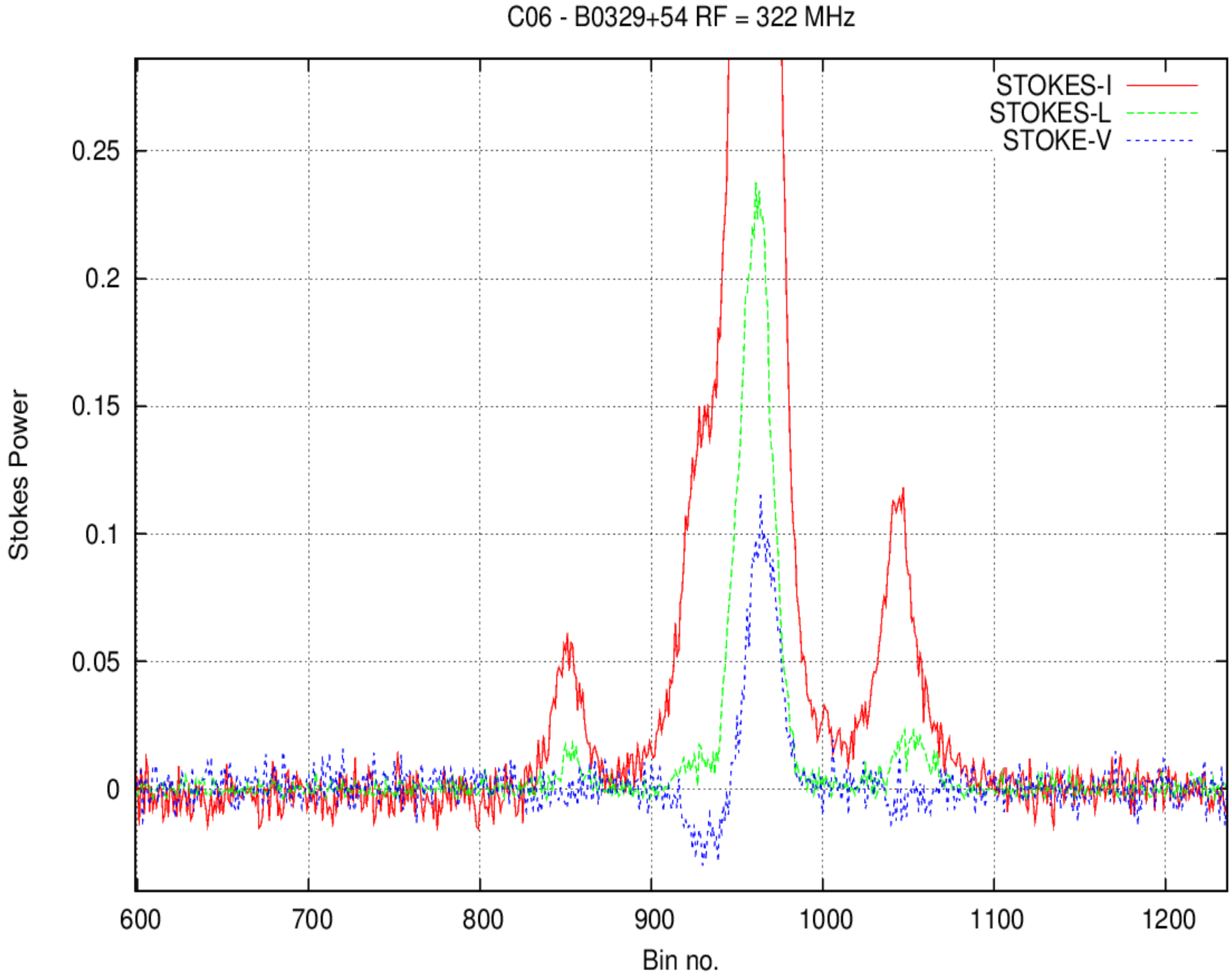
RESULT AND CONCLUSION

The data analysis done by procedure as described in earlier chapter. Profile generated for RF's 270MHz, 322MHz, 348MHz and 449MHz. The profiles are shown in following figures:

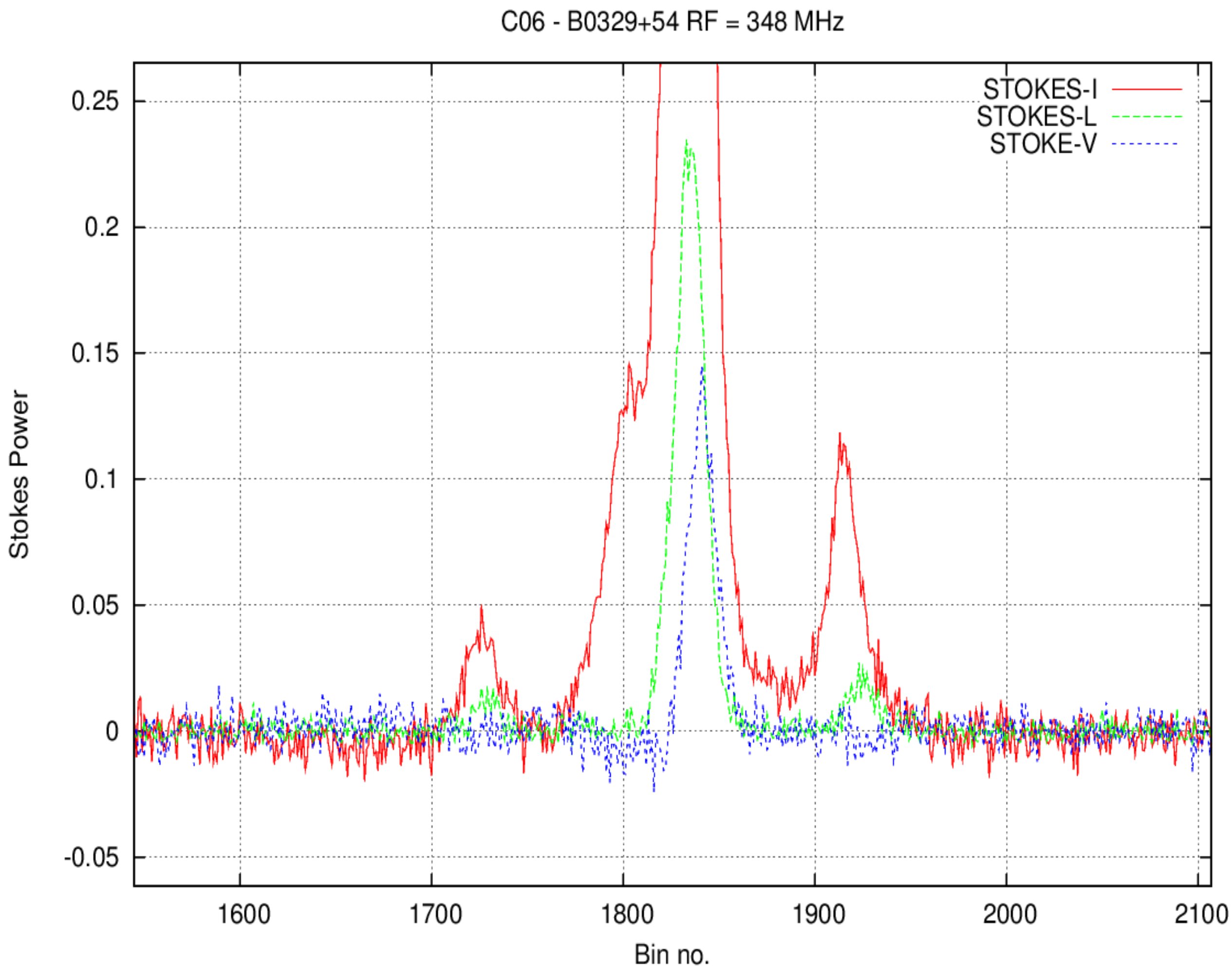
3.1 Profile at 270MHz RF:



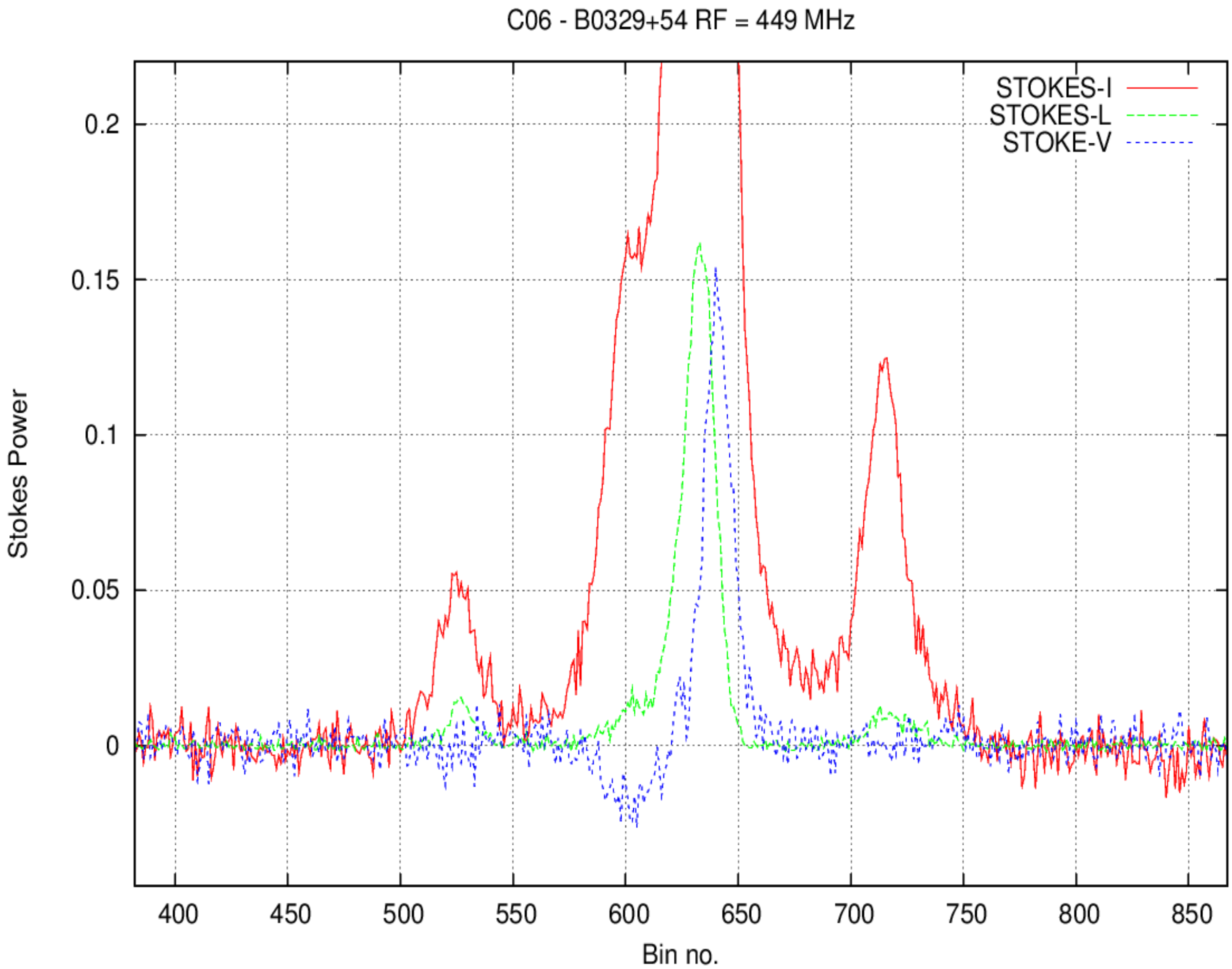
3.2 Profile at 322MHz RF:



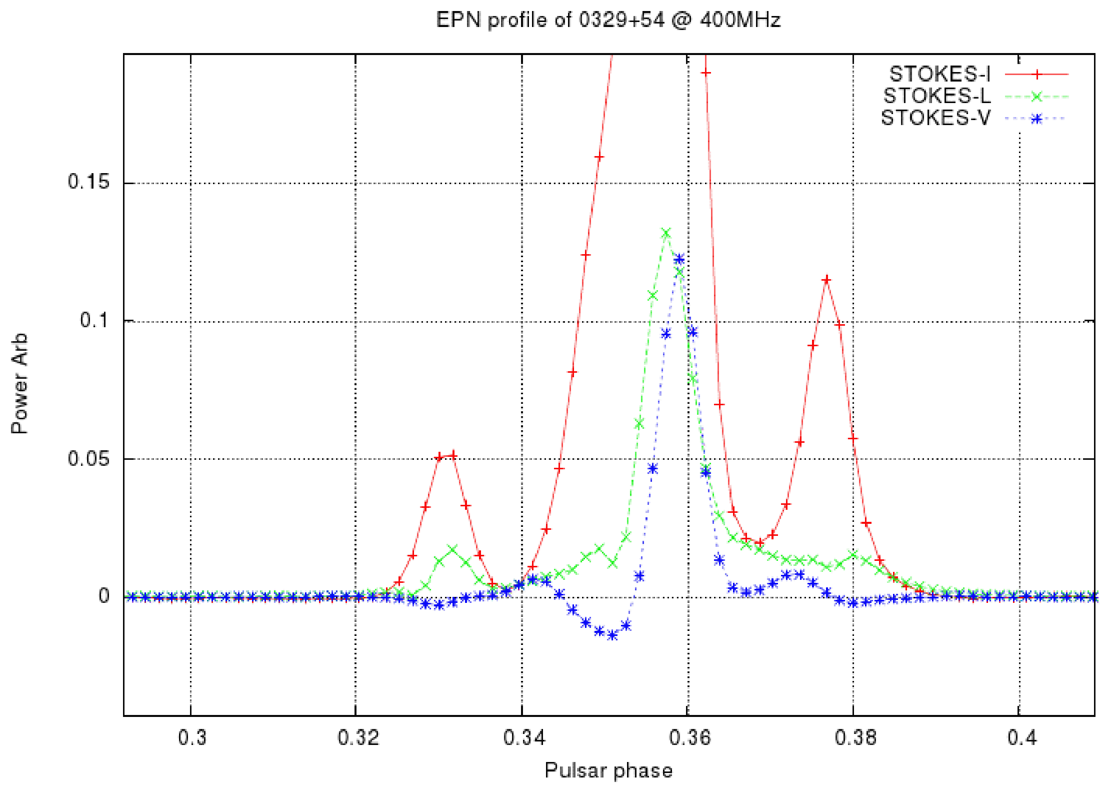
3.3 Profile at 348MHz RF:



3.4 Profile at 449MHz RF:



3.5 Reference EPN Profile at 400 MHz (for comparison):



3.6 Conclusions:

- The profile at 449 MHz is closely matching with the reference EPN profile at 400 MHz.
- All the profiles with RF's 270, 322, 348, 449 MHz are also matching with each other.
- Hence, the polarization response of C06 Broadband feed is comparable across full wideband and with reference.

3.7 Future Work:

1) Fitting a polynomial across a RL* phase.

   In current scenario, it's fitted with a straight line. However the phase response of whole electronic chain is changing residual phase as a function of frequency from just pure phase ramp. Hence, straight line fitting leaves uncorrected phases. This can be eliminated by fitting and estimating phase correction by using polynomial fit, resulting in better estimate of Stokes-L.

   Software 'calibrate.c' is carrying out estimation of phase correction across frequency by fitting a straight line across observed phases of RL*. We have modified this software for polynomial fit by replacing 'fit' routine by 'lfit' routine. However we couldn't finish thorough checking of routine. This is a standard Numerical Recipes routine and need to be taken ahead. At larger bandwidth, which will be observed by PoBe and GPU correlator, fitting of phase data with polynomial is highly essential in order to add linear stokes coherently across large bandwidth. The so far developed code is kept in /home/rammurthy/code folder path in astro5 machine.

2) Repeat the test to check the repeatability of the profile generated at given RF

3) Compare with GPU and PoBe correlator.