GUI-Based Utility For Post-Processing Of FPA
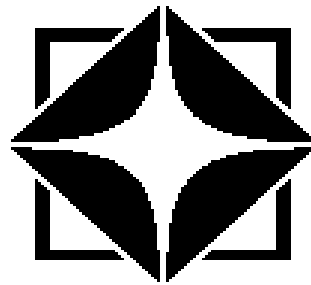
STUDENT PROJECT

By
Shailly Meherwal
Sonalisa Sahu

Electrical & Electronics Communication Engineering
Vellore Institute of Technology
Chennai Campus

Under the guidance of

Mr. Kaushal Buch

NCRA • TIFR

GIANT METREWAVE RADIO TELESCOPE
NATIONAL CENTRE FOR RADIO ASTROPHYSICS
TATA INSTITUTE OF FUNDAMENTAL RESEARCH
KHODAD, DIST. PUNE - 410 504
MAHARASHTRA, INDIA

DECEMBER 2015

Abstract

The focal plane array (FPA) work as a multi-pixel feed , to improve the field of view single pixel feed . FPA is used to form multiple beams in field of view. We have developed a tool (MATLAB based GUI) and 'C 'code for testing coupling between the elements of the FPA feed.

Acknowledgements

GUI-Based Utility For Post-Processing Of FPA

CHAPTER 1

INTRODUCTION

1.1 Introduction to GMRT: The Giant Metrewave Radio Telescope, located near Pune in India, is the world's largest array of radio telescopes at metre wavelengths. It is operated by the National Centre for Radio Astrophysics, a part of the Tata Institute of Fundamental Research, Mumbai.

Fig. 1. Antennas at Khodad pointed towards a source

The GMRT contains 30 fully steerable telescopes, each 45 metres in diameter with the reflector made of wire rope stretched between metal struts in a parabolic configuration. This configuration works _ne as the telescope operates at long wavelengths (21 cm and above). Every antenna has four different receivers mounted at the focus. Each individual receiver assembly can rotate,

GUI-Based Utility For Post-Processing Of FPA

enabling the user to select any of them for the observation. GMRT antennas operate in five frequency bands, centered at 153, 233, 327,610, and 1420 MHz[1].

Out of the 30 telescopes at GMRT, fourteen telescopes are randomly arranged in the central square of 1 km by 1 km in size. Rest sixteen telescopes are arranged in three arms of a nearly "Y"-shaped array each having a length of 14 km from the array center. Therefore GMRT can act as an interferometer which uses a technique known as aperture synthesis to make images of radio sources. The maximum baseline in the array gives the telescope an angular resolution (the smallest angular scale that can be distinguished) of about 1 arc-second, at the frequency of neutral hydrogen.(i.e 1420MHz)

PROJECT INTRODUCTION:

The aim of this project is to design and implement a beamforming post processing utility for focal plane array(FPA) data. Beamforming is a standard signal processing technique used to control the directivity of the reception or transmission of a signal. Beamforming hardware was implemented using the Center for Astronomy Signal Processing and Electronics Research (CASPER) tool flow. It is implemented on FPGA based ROACH board. In this case the output of beamformer is coherent sum of voltages from different elements of the FPA .This post processing tool processes coherent sum from each beam to obtain stoke parameters(I,Q,U,V).

In diagnostics part , each element of FPA feed is checked for power level and mutual coupling using autocorrelation and cross correlation outputs of elements.

GUI-Based Utility For Post-Processing Of FPA

CHAPTER 2
THEORETICAL CONCEPTS

2.1Focal plan array:

Focal plane array are arrays of receivers placed at the focus of a radio-telescope. Traditional radio-telescopes have only one receiver at the focus. but radio-telescopes are now starting to be equipped with focal plane arrays.

Fig2:Focal plan array feed

2.1.1 Advantage of focal plane array feed over single feed:

- **Improved Antenna Efficiency**: The maximum aperture efficiency of a reflector is achieved when the feed matches the focal plane field generated from an incoming plane wave on the reflector.

- **Field of View (FoV):** Discrete FPAs can greatly increase the FoV of an antenna system by placing multiple beams on the sky but the FoV is not contiguous and to fully sample the sky four or more interleaved pointing's are required . Dense FPAs however can fill in these gaps, providing near constant and smoothly varying efficiency and sensitivity across the FoV .

- **Reducing baseline ripple:** Reflections between the focal plane and the reflector can set up a standing wave. The impedance variation introduces a ripple in the antenna gain and hence the baseline for detecting radio astronomy spectra. Dense FPAs are able to reduce this.

GUI-Based Utility For Post-Processing Of FPA

- **Interference cancellation:** The flexibility that beamforming an FPA allows nulls to be established in directions of an interference.

- **Re-configurability:** Dense FPAs lend themselves to electronic beamforming and so offer the flexibility to adapt the element weighting to changing demands and environments. the weighting can be adjusted to balance them for specific purposes. For example in a radio telescope a balance may be selected between maximizing sensitivity and pattern control or interference mitigation and pattern control.

2.2 Beamforming

In its essence, beamforming combines different signals, received from many antennas, and to form a single coherent signal, called a beam. It provides directionality to an array of non-directional antennas. Beamforming application in radio astronomy is mainly used for pulsar research. A pulsar is a rapidly rotating, highly magnetized neutron star, which emits electromagnetic radiation from its poles. Similar to the behavior of a lighthouse, the radiation is visible to us only if one of the poles points towards the Earth, and appears to us as a very regular series of pulses, with a period being as low as milliseconds. Pulsars are weak radio sources, and their individual pulses often do not rise above the background noise that flowers our universe Beamforming is the standard signal processing approach for their study. There are two types of techniques that are required for phased arrays: incoherent and coherent beam-forming [4].

1.Incoherent Beamforming:

- Power Signal from N dishes are combined to give final signal
- $\sqrt{N}$ times improvement in sensitivity
- Beamwidth equivalent that of a single dish
- Application in large scale pulsar search

GUI-Based Utility For Post-Processing Of FPA

- The mathematical expression for incoherent beamforming is as shown:

$$B_i = \sum_{k=1}^{N} V_1{}^2 + V_2{}^2 + \ldots \ldots V_N{}^2$$

where V is the voltage of an antenna, N is the number of antennas and B_i is the average power of the antennas or the incoherent beamformed output.

2. Coherent Beamforming:

- Voltage signal from N dishes are added to get final signal
- Requires proper phasing of array to compensate for the delay and phases
- N times improvement in sensitivity
- Beam-width is much narrower than that of a single dish,
- Application in studying individual pulsar, polarimetry etc.
- The mathematical expression for coherent beamforming is as shown:

$$B_c = \sum_{k=1}^{N} (V_1 + V_2 + \ldots \ldots V_N)^2$$

where ,V is the voltage of an antenna, N is the number of antennas and B_c is the average power of the antennas or coherent beamformed output.

2.3 POLARIZATION AND STOKES PARAMETERS

2.3.1 POLARIZATION:

Polarization is orientation of lines of electric flux in electromagnetic field

Various types of polarization of electromagnetic waves are:

i) Linear Polarization.

ii)Circular Polarization.

iii) Elliptical Polarization

2.3.2 Stokes parameters: By using four Stokes parameters, we can fully describe a polarized wave.[2]

☐ *X*-amplitude

GUI-Based Utility For Post-Processing Of FPA

- *Y*-amplitude
- Phase angle φ between them
- Polarization fraction Π

i)Stokes I: total intensity: Stokes I represents the total power in the incoming radiation.

ii) Stokes Q U: linear polarization: Q and U fully describe linear polarization**.** linear polarization, you need to find both an amplitude and a position angle.

iii) Stokes V: circular polarization: Stokes V deals with circular polarization

iv) Polarization fraction: The total fraction of polarized light is calculated in the following way

$$II = \frac{\sqrt{Q^2+U^2+V^2}}{I}$$

$$II \le 1$$

Measurement of Polarization: Dual-polarization receivers generally comprise either crossed linear or crossed circular feeds. Using the voltages detected by those orthogonal feeds, you can get all four Stokes parameters by calculating the following products:

$$I = E_x E_x^* + E_y E_y^*$$
$$Q = E_x E_x^* - E_y E_y^*$$
$$U = E_x E_y^* + E_y E_x^*$$
$$iV = E_x E_y^* - E_y E_x^*$$

GUI-Based Utility For Post-Processing Of FPA

CHAPTER 3
POST-PROCESSING TOOL

3.1Post Processing:

FPA feed: Focal plane array is multi-pixel feed which contains nearly 8 x 9 elements with two polarizations.

Analog system: Signal coming from FPA feed is very weak there for amplification needed.The analog system amplifies and convert RF signal in to base band signal.
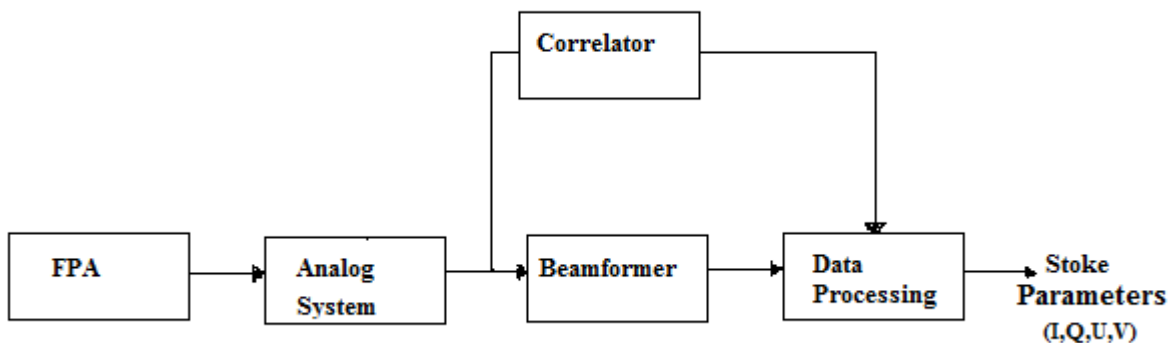
Fig3: Post-processing block diagram

Beamformer and correlator: Base band signal is analog signal in this block first convert analog signal in to the digital.In digital domain geometric and fine delay correction perform .Output of correlator contain visibility information in the form of cross and self correlation of element signals. Beamformer output is coherent sum of all element signals .

Data processing: For Data processing we design GUI in MATLAB .which contain two parts

i) Stokes

ii) Diagnostics

GUI-Based Utility For Post-Processing Of FPA

Input to this GUI is number of input spectral channels ,base integration and final integration as shown in fig. output of this tool is stock parameters(I,Q,U,V) of each beam and correlation between two antennas.
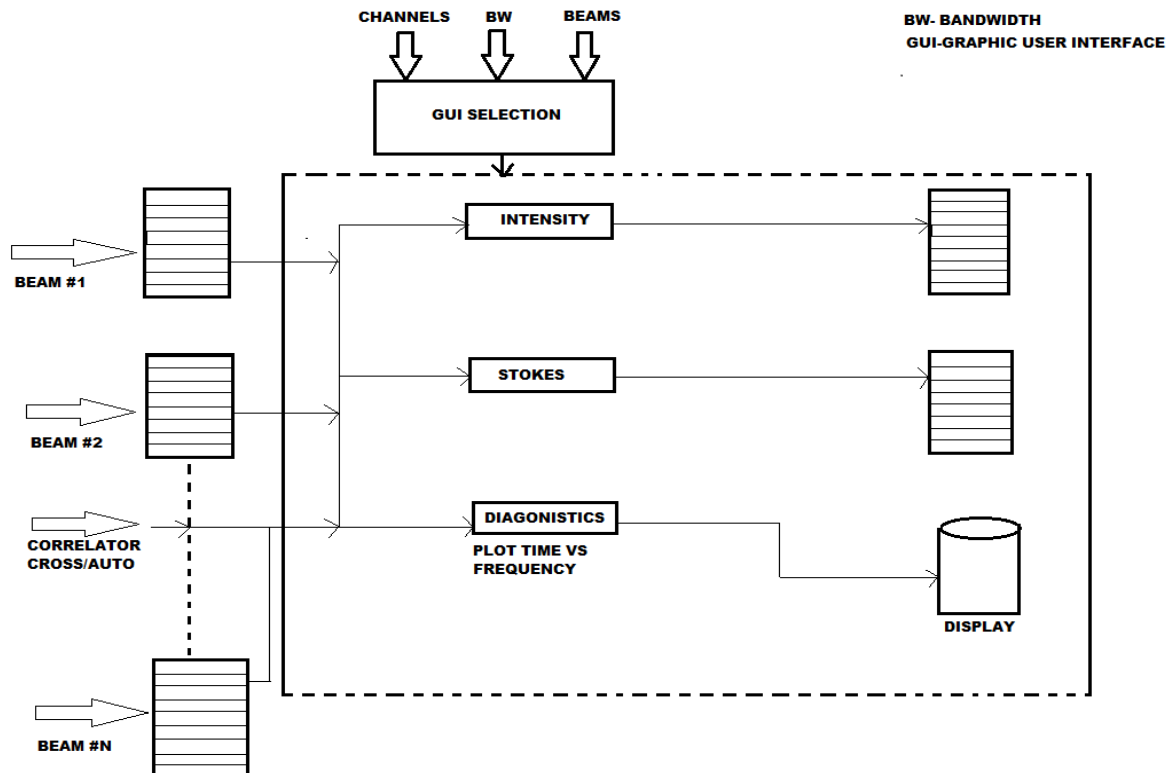
Fig4:Post processing GUI layout

Stokes: Stoke parameters are different for linear and circular polarization .Output of beamformer is coherent sum, and hence we get two files for real and imaginary values. From this data ,we compute stokes parameters .

ii) Diagnostics: Different elements of the feed are checked by changing threshold value of and comparing autocorrelation spectrum (self power) of element with threshold ,if self power above threshold then it is working and cross correlation spectrum help in understanding the coupling the elements.

GUI-Based Utility For Post-Processing Of FPA

3.2 Tool Flow: GUI –based utility for post-processing for focal plane array contain two parts

    3.2.1 Stoke tool flow:

```
                        ┌──────────────┐
                        │    Start     │
                        └──────────────┘
                               │
                               ▼
              ╱─────────────────────────────────╲
             ╱ Inputs                            ╲
            ╱  Number of spectral channels(C)     ╲
            ╲  Base  integration(n)               ╱
             ╲ Total integration (m)             ╱
              ╲ Real and Imaginary beamformer   ╱
               ╲        data                   ╱
                ╲─────────────────────────────╱
                               │
                               ▼
              ┌───────────────────────────────────┐
              │ Number of integrations (Int=m/n)  │
              └───────────────────────────────────┘
                               │
                               ▼
              ┌───────────────────────────────────┐
              │ Read beamformer data (Real and    │
              │ imaginary files)                  │
              └───────────────────────────────────┘
                               │
                               ▼
                        ◇──────────────◇    Linear polarization
                       ╱  Select        ╲───────────────────┐
                       ╲ polarization   ╱                   │
                        ◇──────────────◇                    ▼
     Circular polarization   │          ┌──────────────────────────┐
                             │          │ Stokes                   │
                             │          │ I=Ex^2+Ey^2              │
                             ▼          │ Q=Ex^2-Ey^2             │
              ┌──────────────────────┐  │ U=2*Real(ExEy)          │
              │ Stokes               │  │ V=0                     │
              │ I=Ex^2+Ey^2         │  └──────────────────────────┘
              │ Q=Ex^2-Ey^2        │
              │ V=2*Real(ExEy)      │        Ex and Ey are two
              │ U=2Img(ExEy)        │        polarized components of
              └──────────────────────┘        decomposed electric field
                             │
                             ▼
              ┌──────────────────────────┐
              │ Integration and plotting │◄──────────┘
              └──────────────────────────┘
                             │
                             ▼
                        ┌──────────┐
                        │   End    │
                        └──────────┘
```

GUI –based utility for post-processing, stoke part compute I,Q,U and V stoke parameters. Inputs to this part are number of spectral channels this value depends on beam-former output, base integration and total integration. For example we want to compute intensity(I), inputs through GUI are
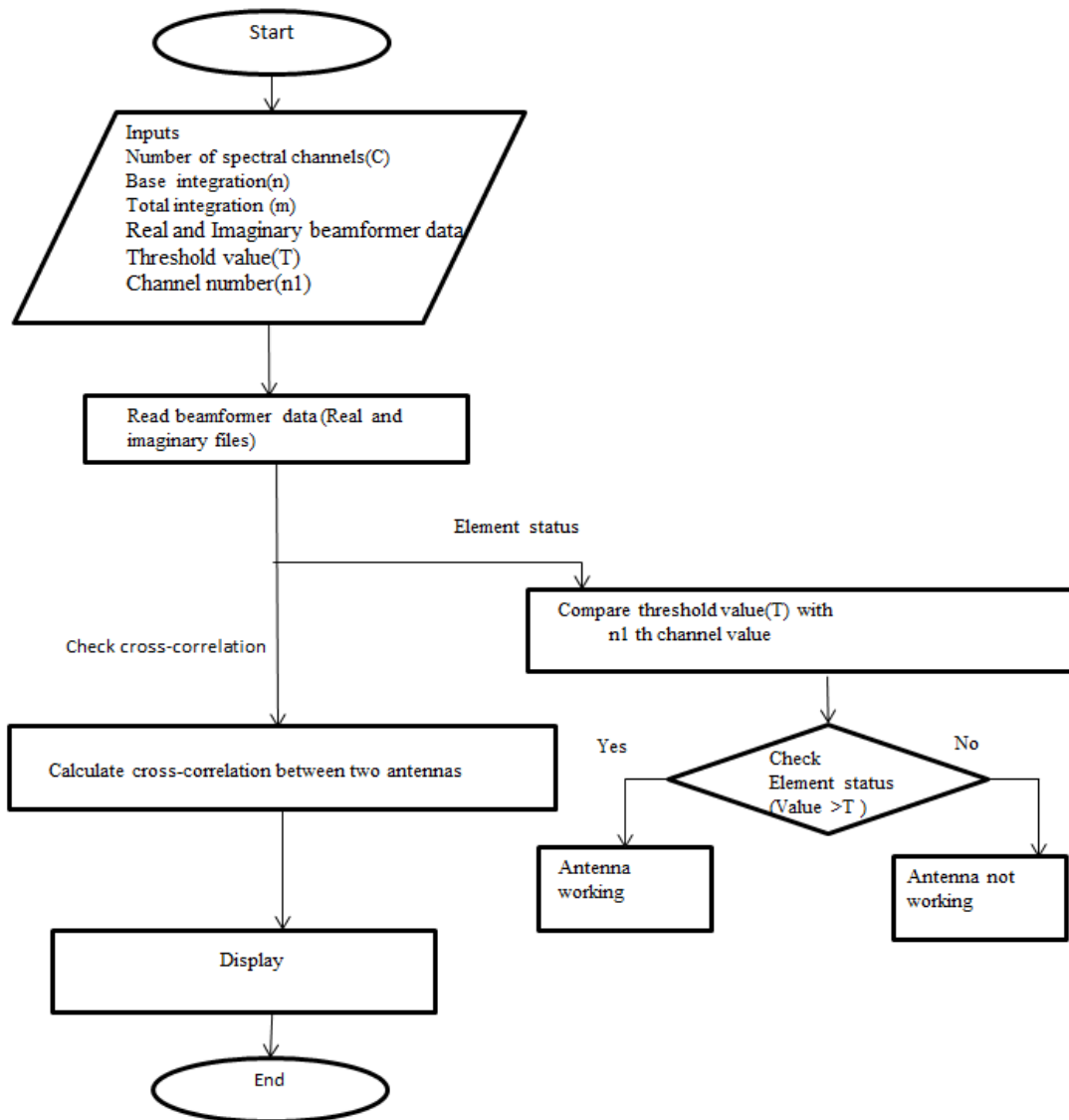
spectral channels=256

base integration=1(m)

total integration=100(n)

GUI-Based Utility For Post-Processing Of FPA

number of integration(m/n)=(100/1)

$$=100$$

Read real and imaginary coherent sum files and stored in to the variable R and L respectively.

Select polarization linear or circular. Select intensity stoke .

Then compute I,I1=R*R +L*L i.e intensity without integration .We get total intensity by Integrating I1 hundred times

Similarly for other stoke parameters.

3.2.2 Diagnostics tool flow:

GUI-Based Utility For Post-Processing Of FPA

In diagnostics part , each element of FPA feed is checked for power level and mutual coupling using autocorrelation and cross correlation outputs of elements. . Inputs to this part are number of spectral channels this value depends on beam-former output, base integration ,total integration and threshold value. For example we want to check FPA elements ,inputs through GUI are

spectral channels=256

base integration=1(m)

total integration=100(n)

number of integration(m/n)=(100/1)

$$=100$$

Threshold value=200

Channel no=150

Select two element to check mutual coupling =one and two

Red color indicates antenna elements not working as shown in fig.
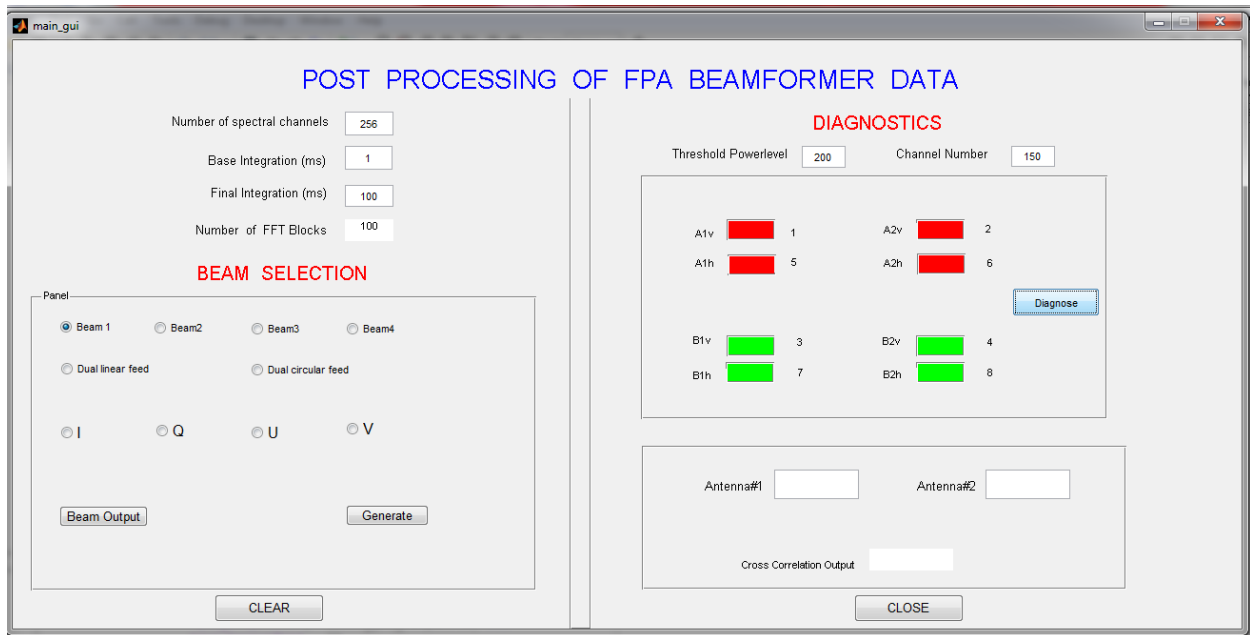
Fig : Diagnostics part of GUI snapshot

GUI-Based Utility For Post-Processing Of FPA

CHAPTER 4
Conclusion and Evaluation

4.1Results:

    4.1.1)Check GUI MATLAB and 'C'code for stokes: To check MATLAB GUI and C code we write MATLAB code ,in which two random signals are generated ,i e behaves like uncorrelated noise signal from this   we compute stokes .then apply same input(uncorrelated noise) to the MAT LAB GUI and C code and compare results. Comparison of results as shown bellowi
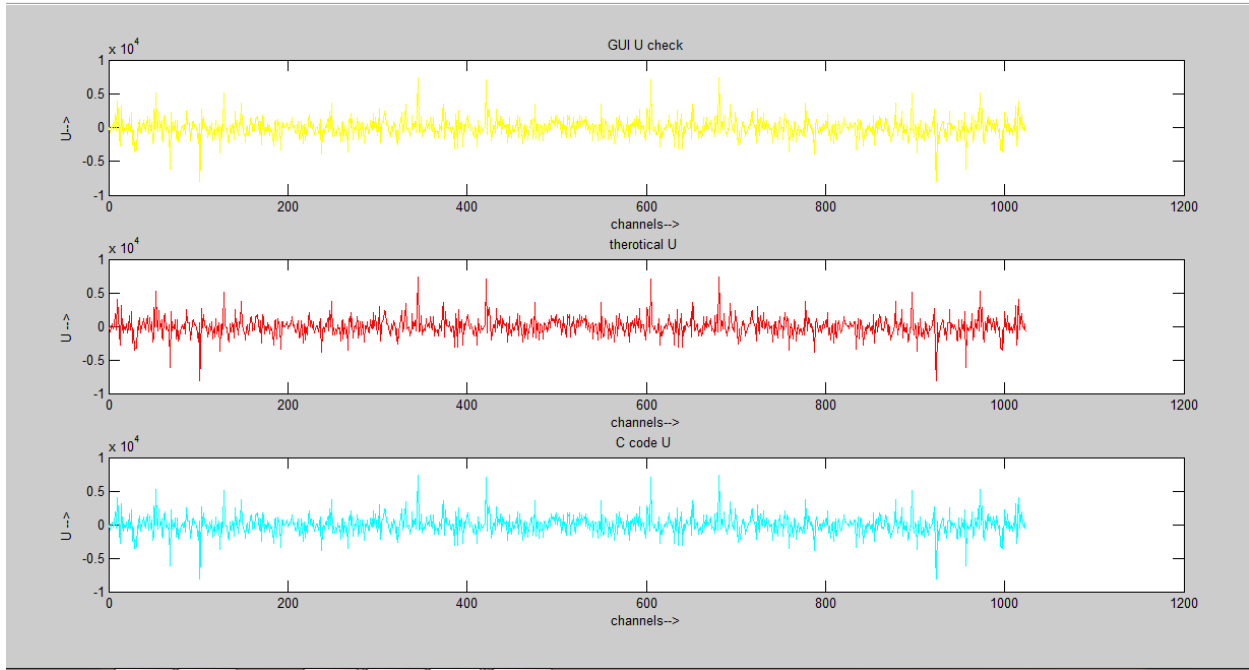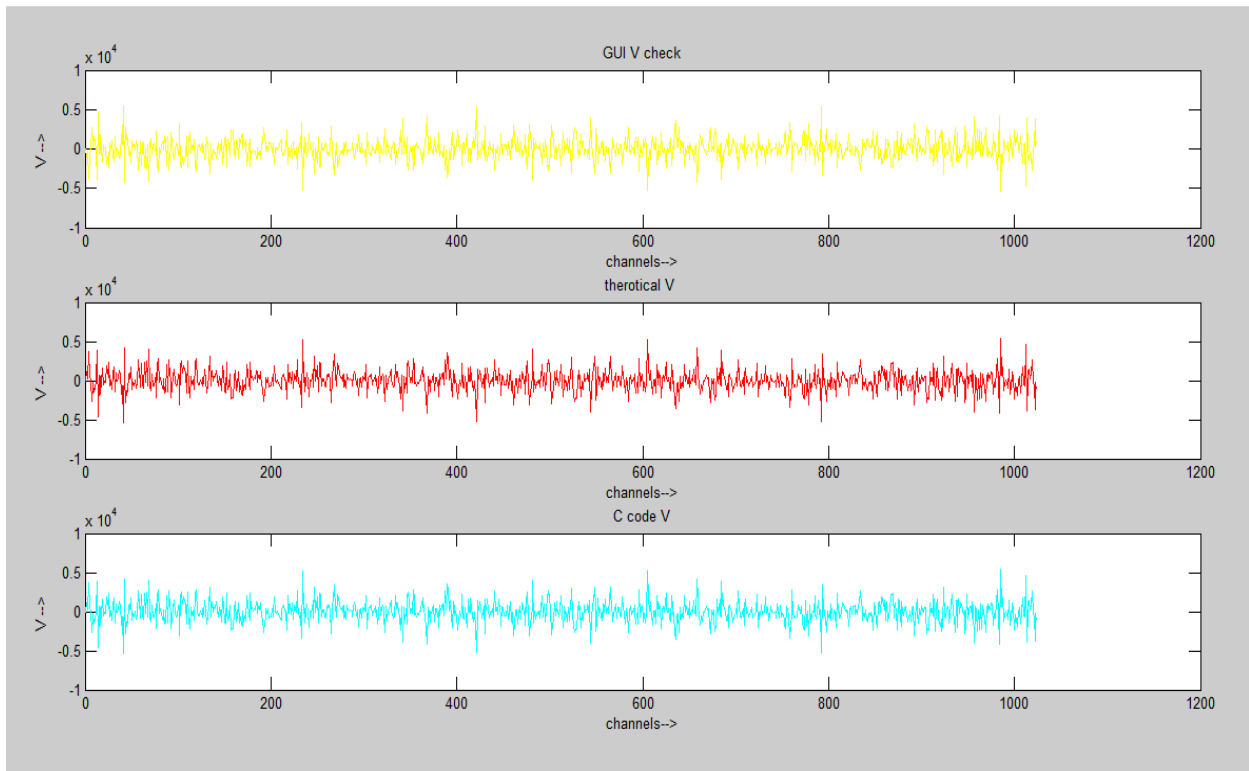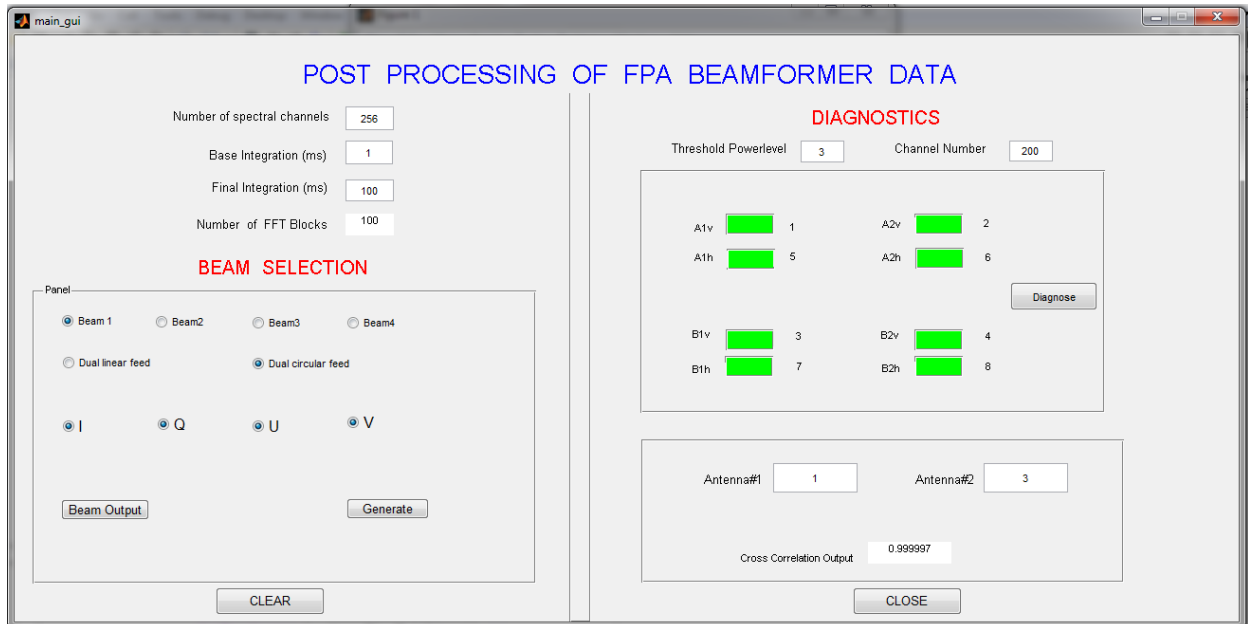
i)Intensity
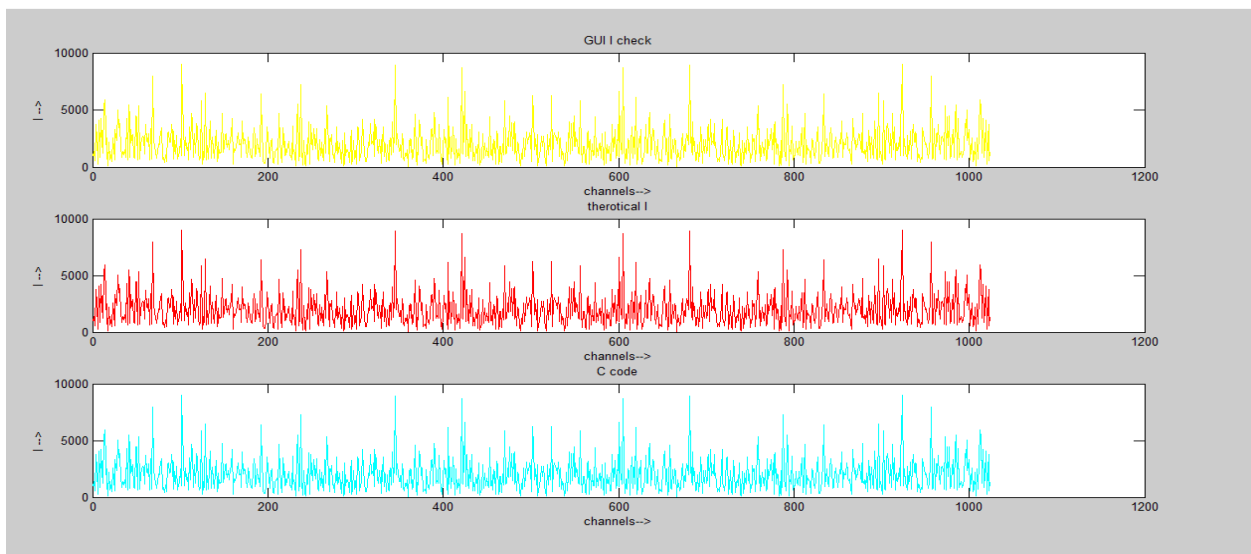
ii)stoke Q:

iii)U stoke :

iv)V stoke

GUI-Based Utility For Post-Processing Of FPA
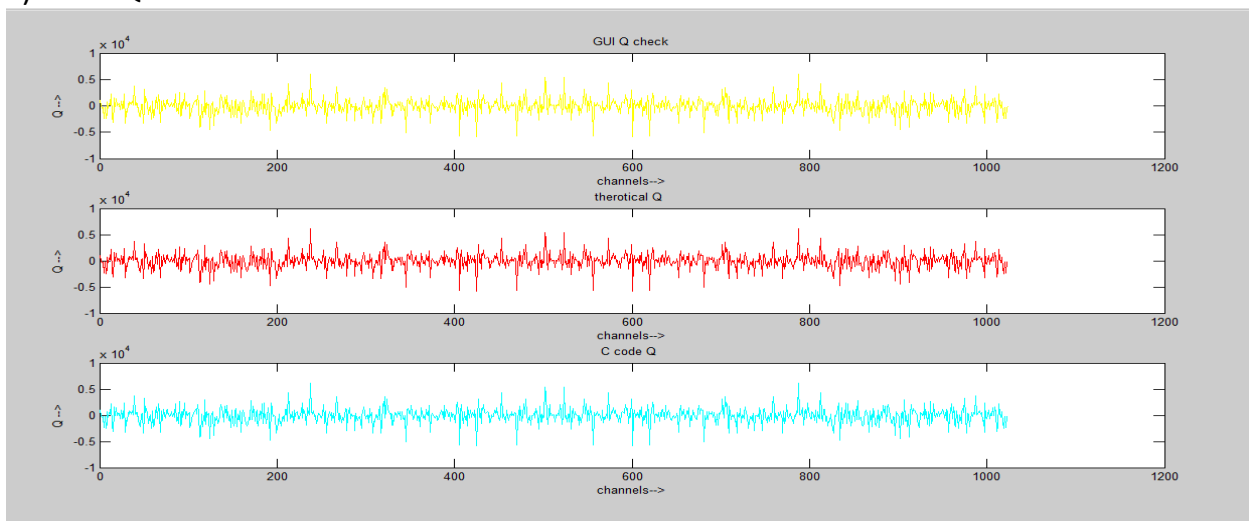
4.12) Diagnostic
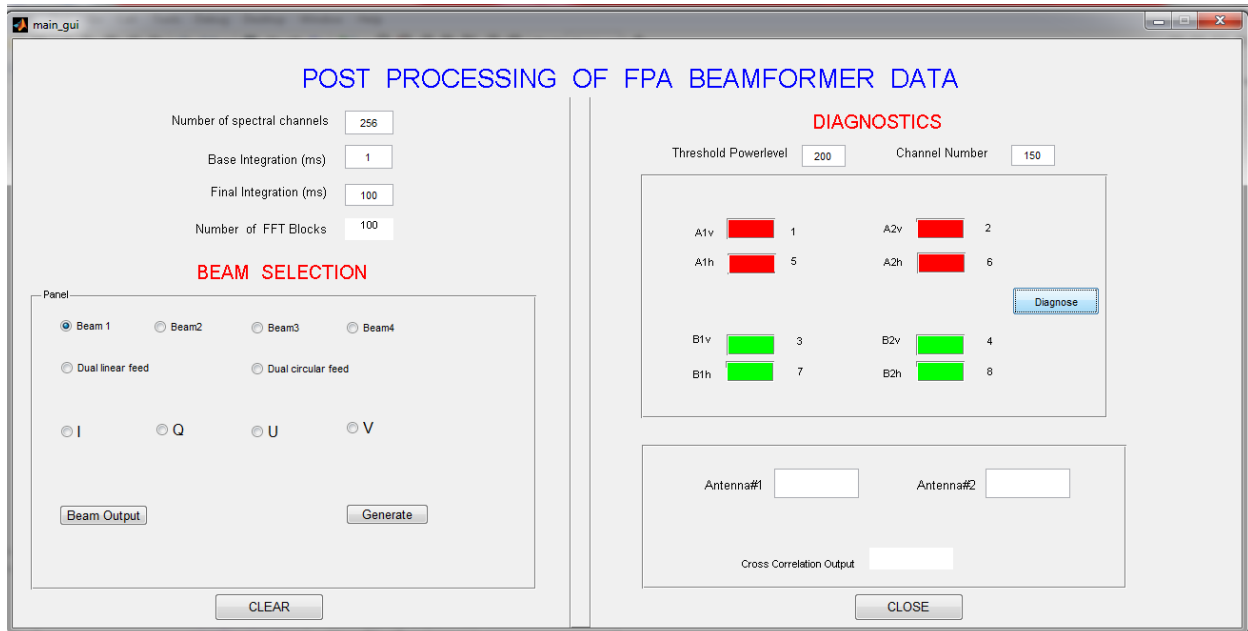
i)All four elements are working: Threshold value=3

Channel number=200

ii)Two elements are working: Threshold value=200

Channel number=150

GUI-Based Utility For Post-Processing Of FPA

4.2 Conclusion and future scope: This section will put forth the advantages of FPA post processing utility and also suggest future scope for the further development .

Advantages:

i)Due to this offline data processing tool less number of FPGA resources required

for coherent beam forming

ii) This is a useful tool that can be used for focal plane array element testing

Future scope: This MAT LAB GUI to accommodate for a more realistic situation processes four element two beam data, can be extended for more number of elements and more beams .

In conclusion, the post processing of FPA data usable tool for computing stoke parameters and from autocorrelation spectrum (self power) check elements ,cross correlation spectrum help in understanding the coupling the elements.

GUI-Based Utility For Post-Processing Of FPA

References:

[1] GMRT Website - http://gmrt.ncra.tifr.res.in/

[2]https://casper.berkeley.edu/astrobaki/index.php/Polarization#Stokes_Q_U:_linear_polarization

[3]http://www.gmrt.ncra.tifr.res.in/~joardar/lecHtmlPages/lectures/03-Polarimetry.pdf

[4]Jayaram N Chengalur, Yashwant Gupta, KS Dwarakanath "Low Frequency Radio Astronomy"
– 3rd Edition, NCRA, Pune, 2007

GUI-Based Utility For Post-Processing Of FPA