MATLAB-BASED TOOL FOR FPA RAW VOLTAGE TIME-SERIES ANALYSIS

Student Project

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Rohan Dhankani

ABSTRACT

The Expanded GMRT (eGMRT) proposes new antennas and equipping existing antennas with Focal Plane Array (FPA) feeds having a bandwidth of 300 MHz. The purpose of this project is to develop a tool for analyzing the raw voltage of the FPA beamformer input. The overall aim is to check the quality of data and to obtain offline correlation and to generate the necessary weights for the beamformer. The time domain analysis of raw voltage data was done and signal quality was tested by plotting the histogram of a particular ADC channel. The correlation chain was implemented in MATLAB and the correlation matrix was generated for the digitized data obtained at the input of beamformer by radiation and with direct input from signal generator. The correlation domain analysis included observing normalized correlation matrix, correlation phase matrix, 2D Fast Fourier Transform (FFT) of correlation matrix for signals with different power level and by physically steering the radiating antenna

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Chapter 1

GMRT : Introduction

1.1 Overview

Giant Metrewave Radio Telescope is an observatory which explores the metre wavelength range of the radio spectrum. It is set up by the National centre for Radio Astrophysics (NCRA). GMRT consists of 30 fully steerable gigantic parabolic dishes of 45m diameter which are spread over distances of upto 25 km. The site was selected because it fulfills following important criteria such as
1) Low man-made radio noise.
2) Low wind speed.
3) It has a geographical latitude which is sufficiently north of the geomagnetic equator in order to have a reasonably quiet ionosphere and yet be able to observe a good part of the southern sky as well.

In the electromagnetic spectrum the metre wavelength range of spectrum has been particularly chosen for study with GMRT because man-made radio interference is quite less in this part of the spectrum in India and there are many outstanding astrophysical phenomenon which are best studied at metre wavelengths [1].

Figure 1.1: One of the Antennas at GMRT

1.2 GMRT Receiver

GMRT antennas(following the recent upgrade) operate in four frequency bands 120-240 MHz, 250-500 MHz, 550-850 MHz and 1000-1450 MHz with maximum processing bandwidth of 400 MHz. The feeds at the focus convert EM signal to electrical signal and they are followed by low noise amplifiers which amplify the incoming signal. The optical fibre transmitter converts the electrical signal into light signal and the signal is transported to the central station with the help of fibre optic cables. The fibre optic receiver converts the light signal into electrical signal and then the RF signal is down-converted to base-band frequency in the analog back-end. The signals are then digitized in the digital back-end where they undergo a process of correlation and beamforming and later the data is recorded in the digital back-end [2].

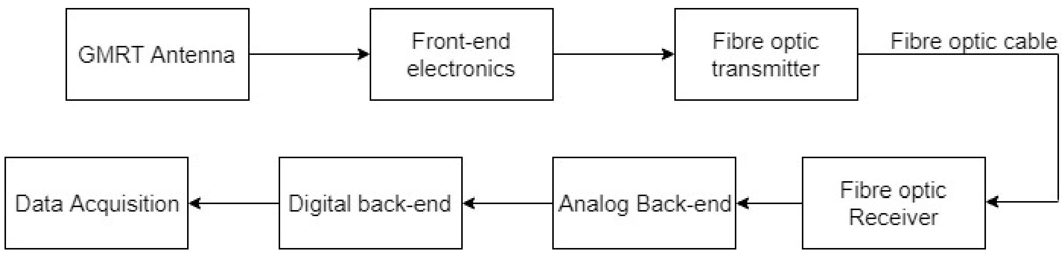

Figure 1.2: Typical Receiver signal chain

1.3 The Expanded GMRT (eGMRT)

The expanded GMRT (eGMRT) is mainly aimed to
1) Increase the GMRT sensitivity
2) Increase its angular resolution
3) Increasing the field of view with the addition of new antennas and using Focal Plane Array (FPA) feeds.

The eGMRT proposal aims at installing low-frequency focal plane arrays (FPA) along with a factor of 5 increase in the angular resolution, by installing new antennas on baselines extending to 100 km. In order to improve sensitivity to extend radio emission, new antennas will be installed at very short baselines, at spacing much lower than 1 km. To achieve a larger field of view the single receiver element at the focus of each GMRT parabolic dish can be replaced with an array of receiver elements at the focal plane of each dish, i.e. a focal plane array (FPA). Such an FPA is designed so that each of its elements receives signals from a different direction, and thus sees a different part of the sky. The field of view of each element would be the same as the present GMRT field of view, with a single receiver element. The total field of view of such an FPA would be the sum of the fields of view of the individual elements [3].

Chapter 2

TIME DOMAIN DATA ANALYSIS

2.1 Procedure of the tests conducted

The tests on Focal Plane Array (FPA) were carried out in the FPA Lab. The parabolic dish antenna is used to radiate the RF signal that is received by the Focal plane array (FPA) which is an array of 8*9 Vivaldi elements. The basic block diagram of the system is shown in the Fig. 2.1.

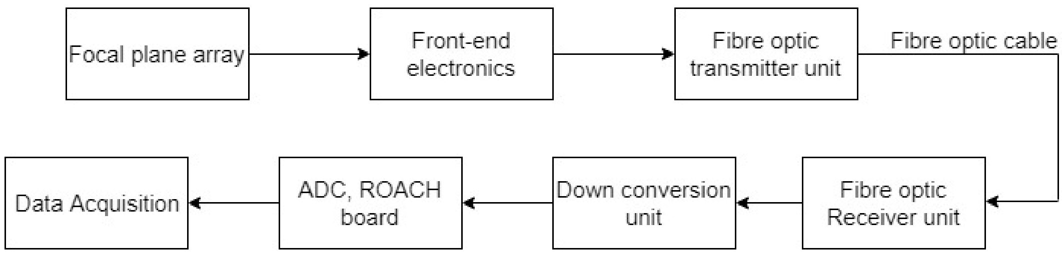

Figure 2.1: FPA signal chain

There are two ways in which the tests are conducted

1) Without radiation
There is a RF signal generator in the FPA lab which generates the signal and its spectrum is observed on the spectrum analyzer. We can generate single frequency sinusoidal signal with the help of this generator. Similarly, RF noise generator is used to generate noise signals. They are provided to an ADC which digitizes the signal and which goes as input to the ROACH board. The digitized output files are used for further analysis.

2) With Radiation
The steps followed to carry out the tests are

1. The RF signal (1 to 1.7 GHz) is generated by a signal generator in receiver

room and it is radiated using the antenna and received by the FPA.
2. The EM signal is converted into electrical signal by the receiving elements.
3. The electric signal is converted into light signal using fibre optic transmitter which is transmitted using an optical fibre to the FPA lab.
4. The light signal is converted to electrical signal by the fibre optic receiver in the FPA lab and the signal is down converted to a baseband frequency signal (double down conversion)
5. The signal is digitized using ADC connected to the ROACH board (Reconfigurable Open Architecture Computing Hardware). The binary data is transferred to the data acquisition PC through a 10 GB ethernet cable. The data is converted to ASCII file and is used for further processing.

2.2 Histogram of the input signals

The histogram of a raw voltage data of a receiver element was observed to check the signal quality and number of ADC bits used to represent the amplitude values. The noise data that was obtained by radiation with central frequency 1.3 GHz with a low pass filter with cut-off frequency of 22MHz, noise power -26dBm/32MHz. Histogram of the 1st ADC channel is shown in the Fig. 2.2, The *histfit* function in MATLAB is used to plot the histogram. This function fits with a normal density function indicated by the red line in the figure. The function plots the histogram with input argument as column matrix and number of bins of to be displayed. The vertical lines indicate the $+3\sigma$ and -3σ values of the Gaussian distribution curve. The values within $+3\sigma$ and -3σ alongside mean contain 99.7 percent of the given data. The histogram is used to indicate the signal quality and the number of bits of ADC required to represent the amplitude values. It is determined by considering the maximum value of the amplitude which is less than or equal to 2^n then n is the number of bits of ADC required. The noise data was acquired through direct input from the signal generator and the power levels of the signal generated were attenuated. The table 2.2 shows the number of ADC bits used to represent signals with corresponding attenuation. The Figs. 2.3,2.4, 2.5 indicate the histogram of noise data with attenuation corresponding to the table

Type of Attenuation	Number of ADC bits used
Signal without attenuation	7
Signal with -6dBm attenuation	6
Signal with -12dBm attenuation	5

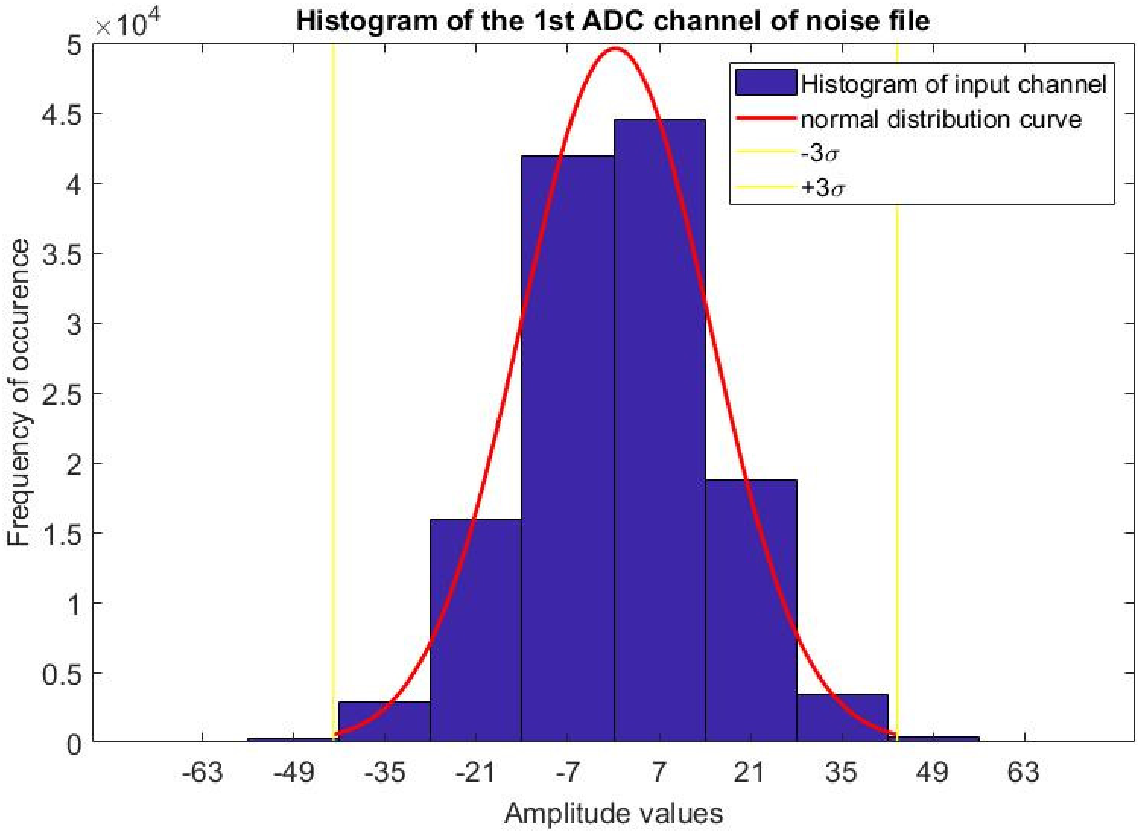

Figure 2.2: Histogram of 1st channel of noise file with normal distribution curve

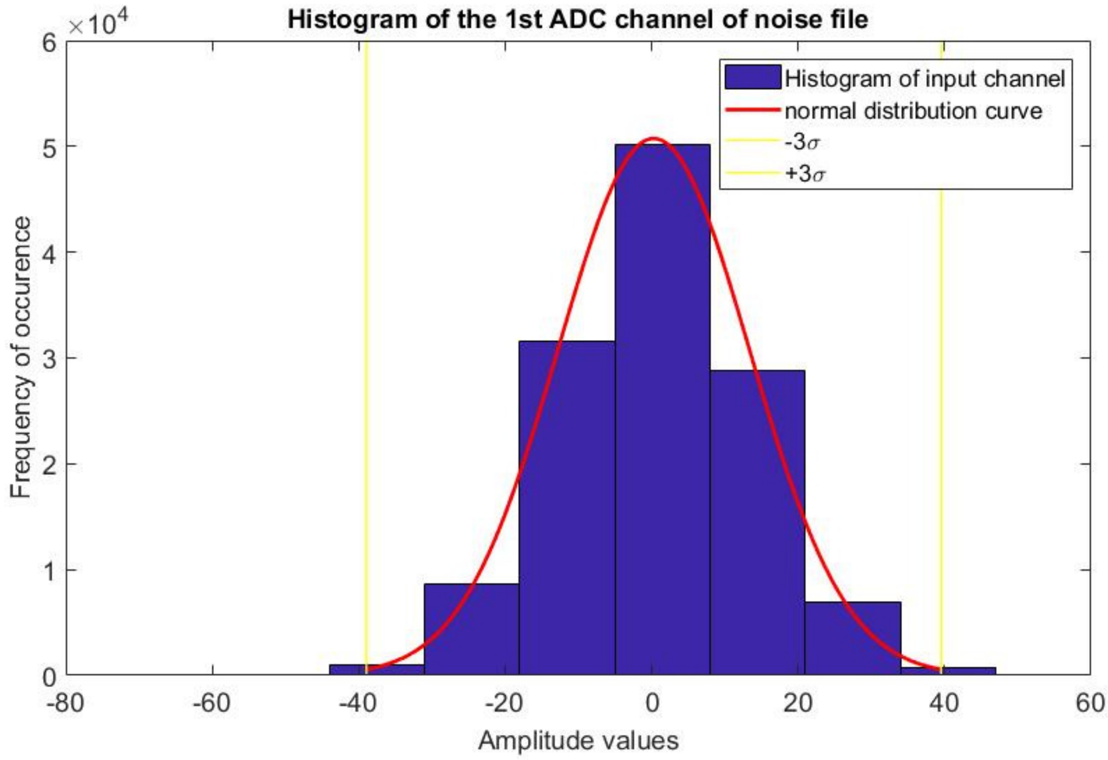

Figure 2.3: Histogram of 1st channel of noise file without attenuation

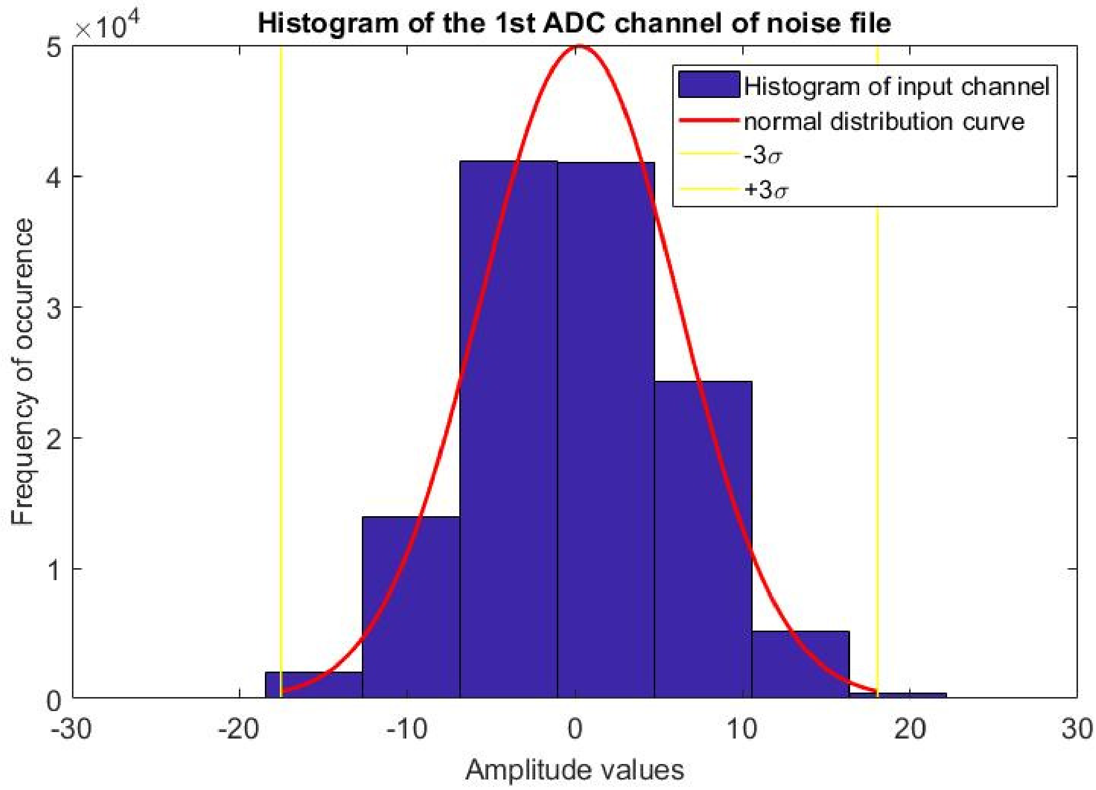

Figure 2.4: Histogram of 1st channel of noise file with -6dBm attenuation

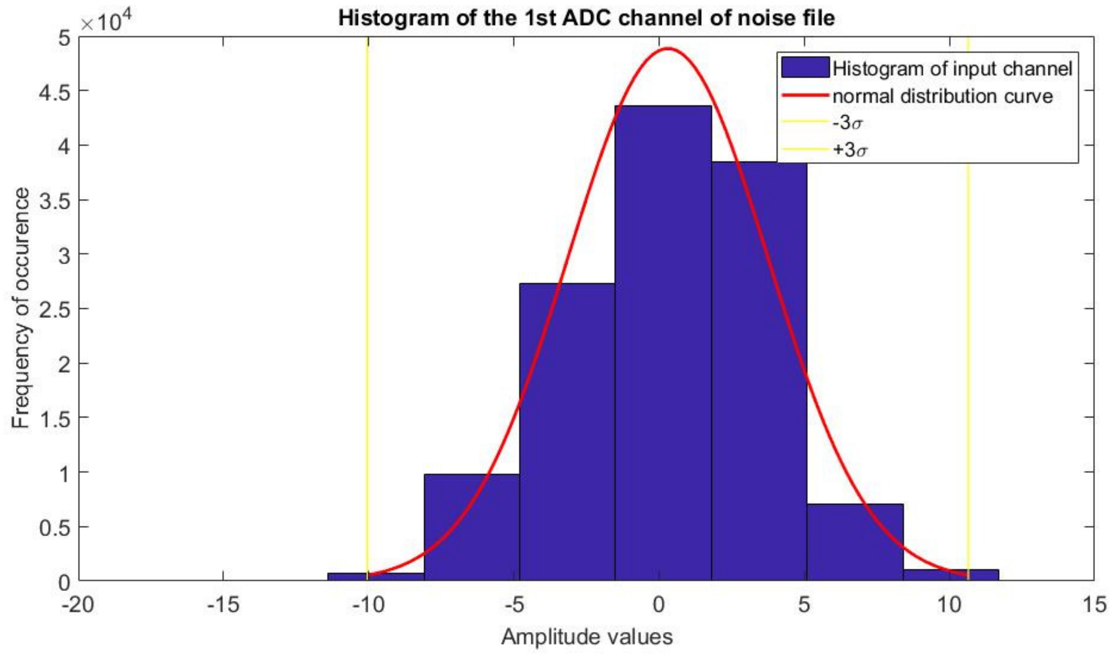

Figure 2.5: Histogram of 1st channel of noise file with -12dBm attenuation

2.3 Test to determine presence of Radio Frequency Interference(RFI) in the signal

The test was performed to check the presence of Radio Frequency Interference of the received signal. In order to determine the presence of RFI in the signal, we consider a noise signal without RFI which was obtained through radiation experiment. The noise signal has central frequency 1.3 GHz and a bandwidth of 22MHz, noise power -26dBm/32MHz and sampling frequency 64 MHz. The column matrix is reshaped which depend on the number of blocks in which the data is divided(varies from 1 to 100). The variance of every block is evaluated and value of normalized variance for a fixed number of blocks is calculated which is given by:

$$v_1/(\sum_{i=1}^{n} v_i)$$

where,

v_1 = variance of the first block
v_i = variance of the ith block
n = number of blocks

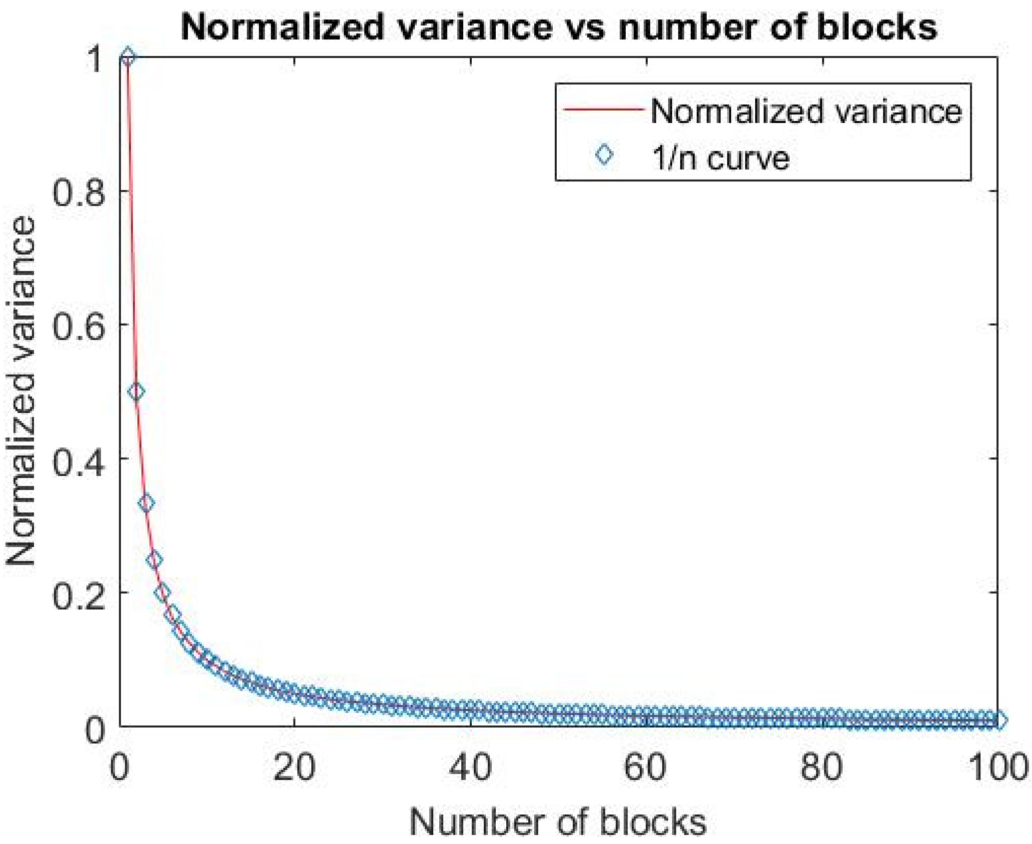

Figure 2.6: Normalized variance for signal without RFI

The variation of normalized variance with number of blocks is plotted with 1/n curve is overlaid as shown in the Fig. 2.6.

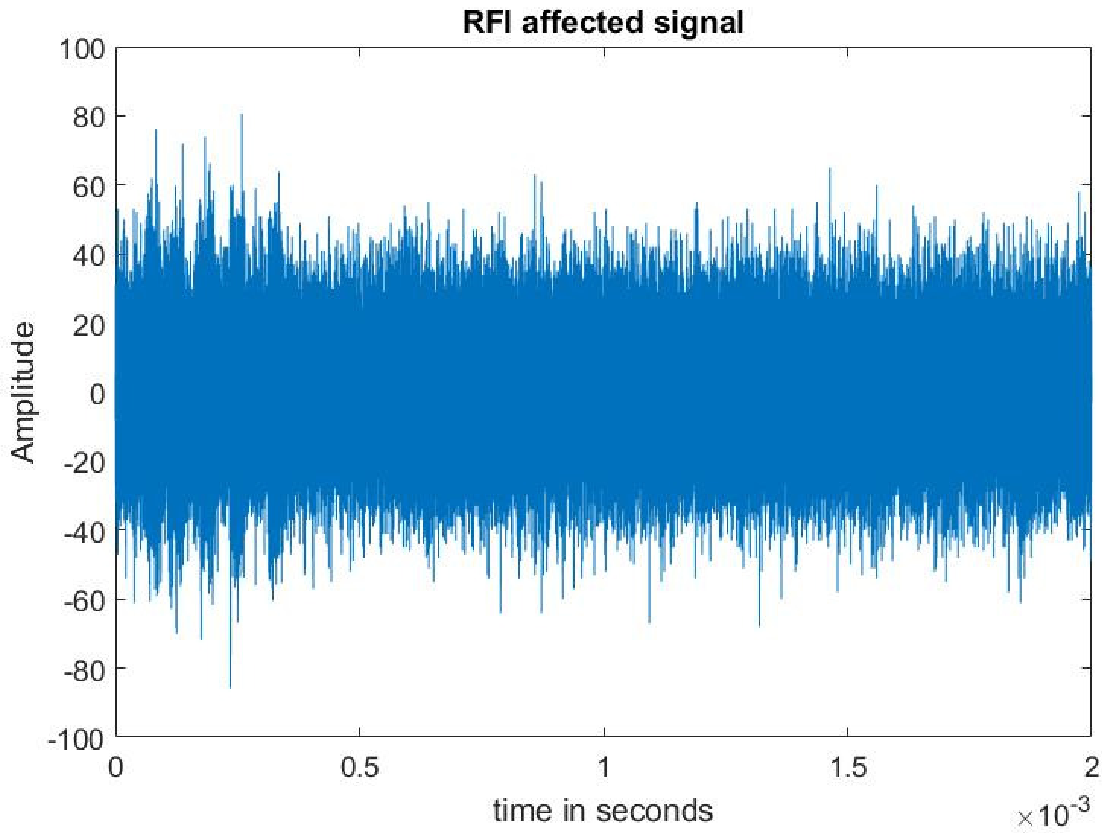

Figure 2.7: RFI affected signal

The above radiated noise signal is taken and a larger variance of noise(generated using *randn* function) is added to it at some intervals of the signal so that it can be approximated as a signal affected by RFI as shown in the Fig. 2.7. The normalized variance of this signal is computed similar to the signal without RFI. The plot of normalized variance versus number of blocks with 1/n curve is overlaid as shown in the Fig. 2.8.

It can be seen that the normalized variance versus the number of blocks coincides with the 1/n curve for the signal which is not affected with RFI and it will not coincide with 1/n curve for signal which is affected by RFI, hence we can check the presence of RFI(non randomness in the data) in a signal with the help of this test.

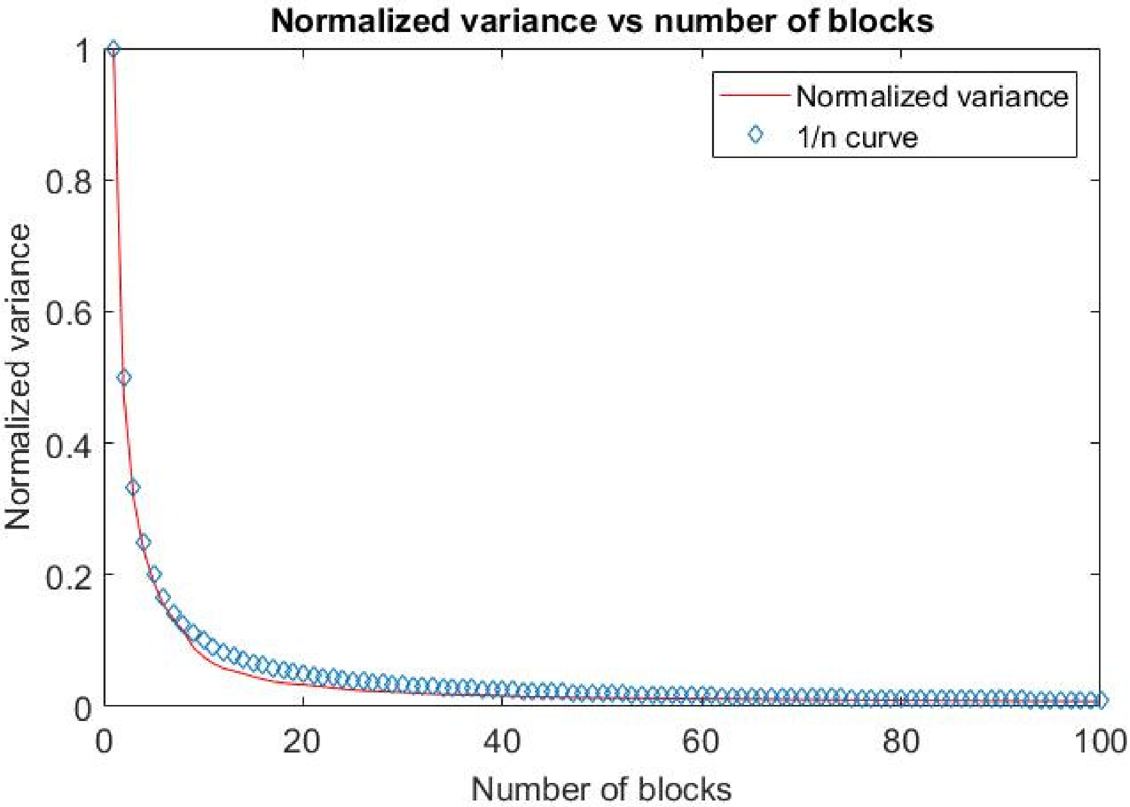

Figure 2.8: Normalized variance for signal with RFI

Chapter 3

CORRELATION DOMAIN DATA ANALYSIS

3.1 CORRELATION MATRIX

The files are fed from the data packetizer. The analog to digital converter embedded on the ROACH board is used to acquire data on the machine. The code takes input the sampling frequency, number of multiply and accumulate(MAC) cycles, number of FFT points, spectral channel for which correlation is to be observed, number of MAC blocks in which data is to be divided and plots the correlation matrix for 8 or 16 inputs for a particular block of the data which is also user programmable. However, the code can be extended for more elements as well.

The following steps are followed to generate a correlation matrix

1) The digitized files for the user input MAC block are taken as the input, and according to the number of elements entered the time series data for 2 elements is extracted.

2) The data is reshaped according to the number of FFT points and MAC.

3) The FFT is computed for the data after reshaping it because it is easier to calculate correlation in the frequency domain.

4) The correlation for two elements is evaluated by multiplying the signals(channel-wise) in frequency domain.

5) If there are 'n' elements as the input $n*(n-1)/2$ cross correlation values and 'n' autocorrelation values of the input elements are obtained.

6) After each MAC cycle, the correlation value is accumulated and stored. Finally we get an accumulated correlation matrix for the two signals and we take the absolute value of the correlation matrix is computed.

7) Depending on the spectral channel entered by the user we get the corresponding

value of correlation which is normalized by dividing it with number of FFT points and MAC and the value is stored in the form of a matrix and displayed as a MATLAB figure.
The same procedure is repeated for all the combinations of input elements and correlation matrix figure is generated.

The correlation matrix helps us to know the signal similarity between different antenna elements and by knowing the phase lag between the elements, the phase can be corrected so that the signals have zero phase difference and a coherently generated beam pattern can be observed. The data is reshaped according to MAC because signal averaging results in increasing the signal to noise ratio.

The noise data was obtained by radiation at central frequency 1.3 GHz and bandwidth of 22MHz, noise power -26dBm/32MHz and with sampling frequency of 64MHz, Number of points of FFT 1024, number of MAC= 10, spectral channel= 150. The correlation was computed and the absolute value of cross correlation was observed and is displayed in the Fig. 3.1.

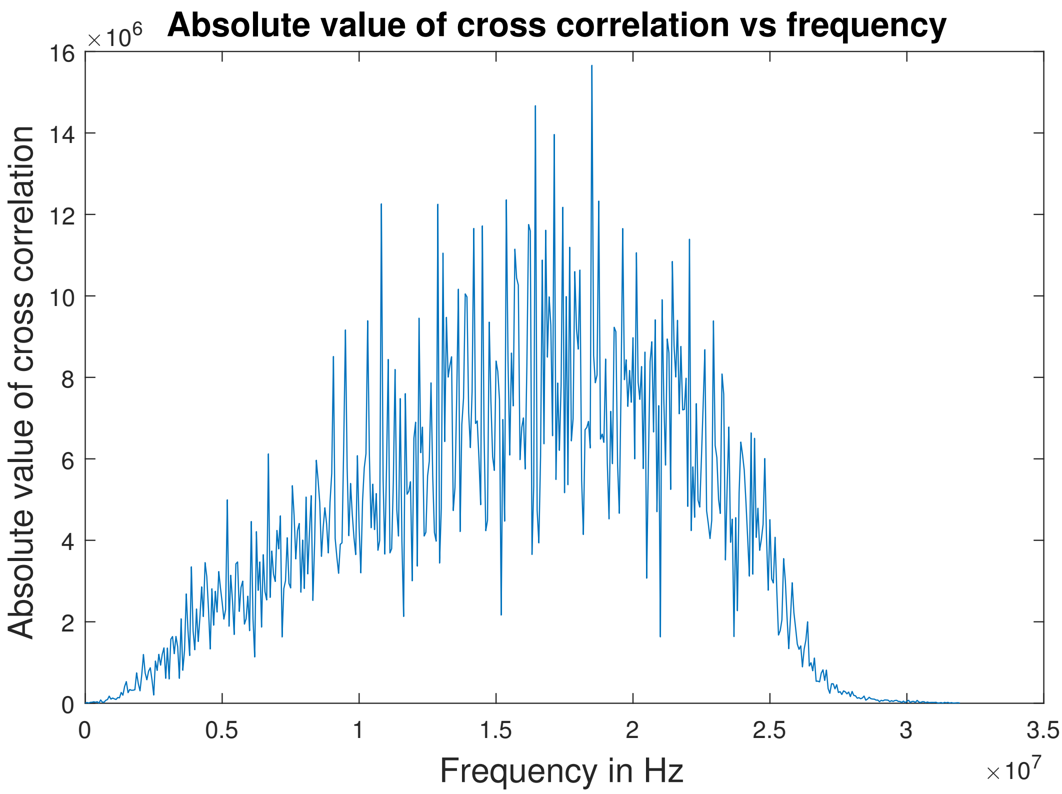

Figure 3.1: Absolute value of cross correlation

The correlation matrix of 8 elements for same data as mentioned before was generated as a matrix[4]. The auto and cross correlation values are normalized by dividing with a product of number of FFT points and Multiply and accumulate cycles. The auto correlation values of the elements is displayed in the diagonal in red colour while the other values are cross correlation values which are displayed in blue colour in the Fig. 3.2. The x-axis and y-axis represent the FPA element number.

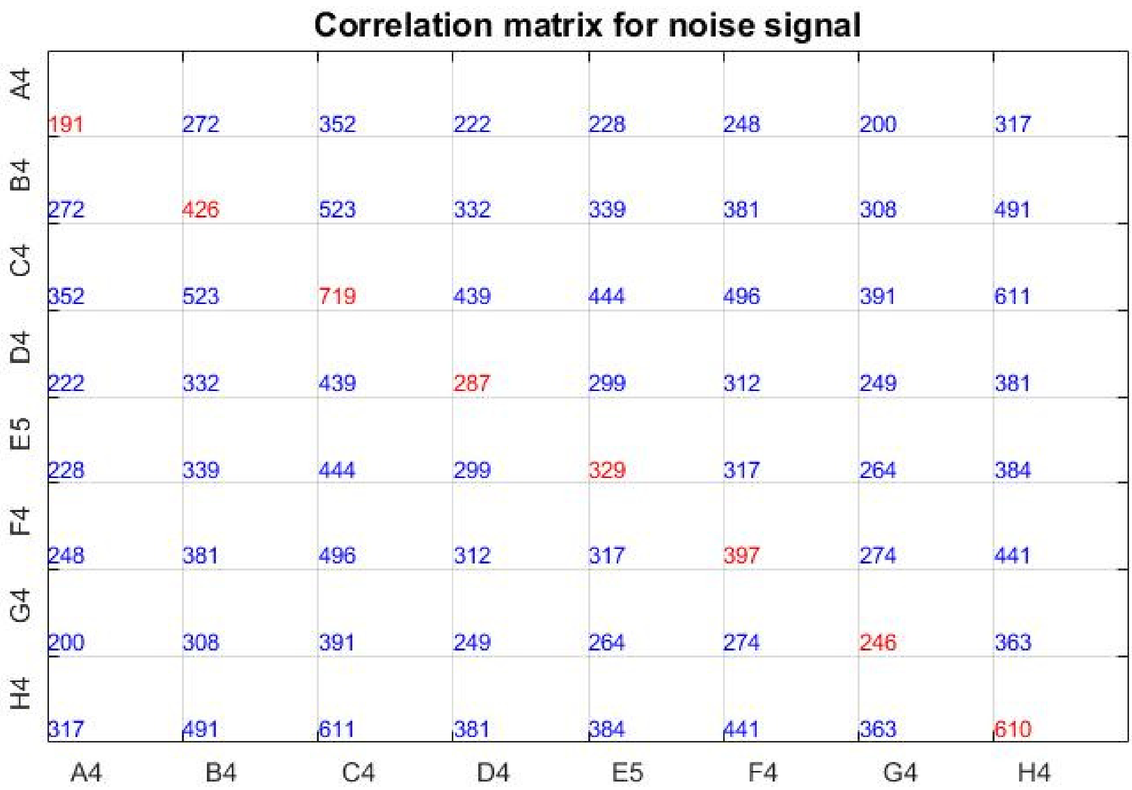

Figure 3.2: Correlation matrix

The correlation matrix is further used to generate normalized correlation matrix, the correlation phase and two dimensional Fast Fourier transform.

3.1.1 Absolute value of correlation for blocks of the data

The test was conducted to observe variation in absolute value of correlation for different blocks of data. The digitized data which is acquired is divided into number of blocks. We follow the same procedure for all the blocks as mentioned in the section 3.1. We get the absolute value of cross correlation for a particular spectral channel for all the blocks and then we plot that value vs different blocks of the data. We consider the same noise data as in the section 3.1 and plot a bar chart for absolute value of cross correlation vs blocks number it appears to be nearly same for all the blocks. the Fig.3.3 displays absolute value of cross correlation for the spectral channel for different blocks of the data of a noise signal.

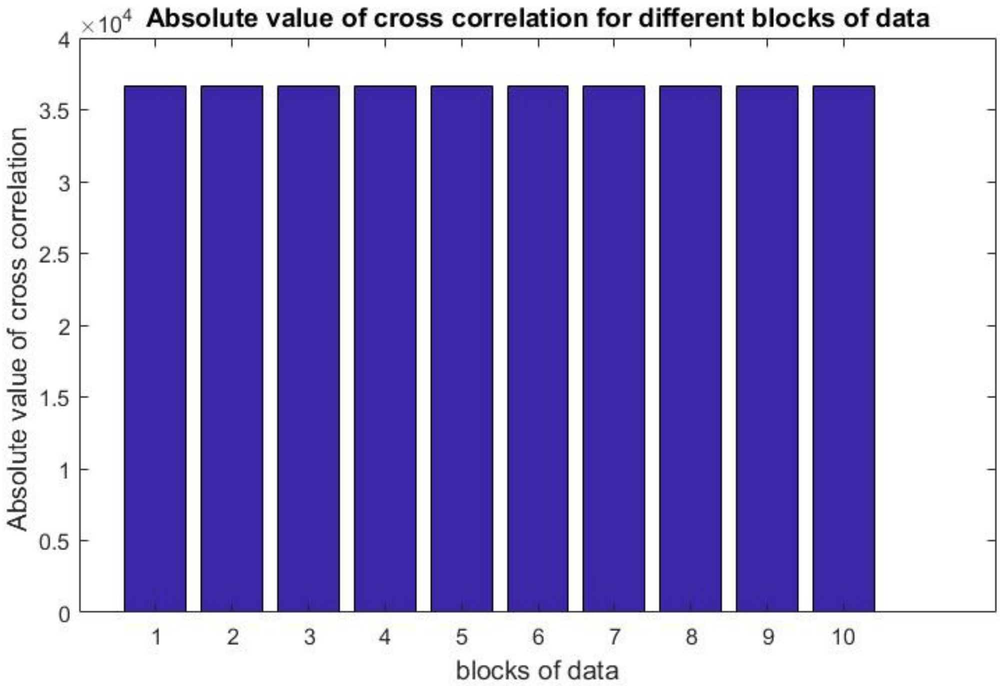

Figure 3.3: Absolute value of cross correlation for different blocks of data

3.1.2 Normalized correlation matrix

For every combination of elements the normalized correlation which is given by

$$cc/(\sqrt{(}ac_1 * ac_2))$$

where,

cc = cross correlation of the two elements.
ac_1 = auto correlation of one element.
ac_2 = auto correlation of the other element.

The value of normalized correlation always lies between 0 and 1 because of the Cauchy Schwarz inequality which states that the product of auto correlation of two signals must be greater than or equal to the cross correlation between them. The normalized correlation for all the combination of elements is evaluated and then the normalized correlation matrix is formed similar to the correlation matrix.

The normalized correlation matrix tells us the percentage of correlation between elements and also takes into consideration the auto correlation of the elements. It helps us to determine whether an element is faulty or not in a proper working condition. The *imagesc* function in MATLAB is used to display the values as variation of colours which is another representation to extract some useful information known as waterfall plot. The waterfall plot of a signal for different elements was observed for the same noise data as in section 3.1, the variation of normalized correlation matrix between various elements is seen in the waterfall plot as shown in the Fig. 3.4

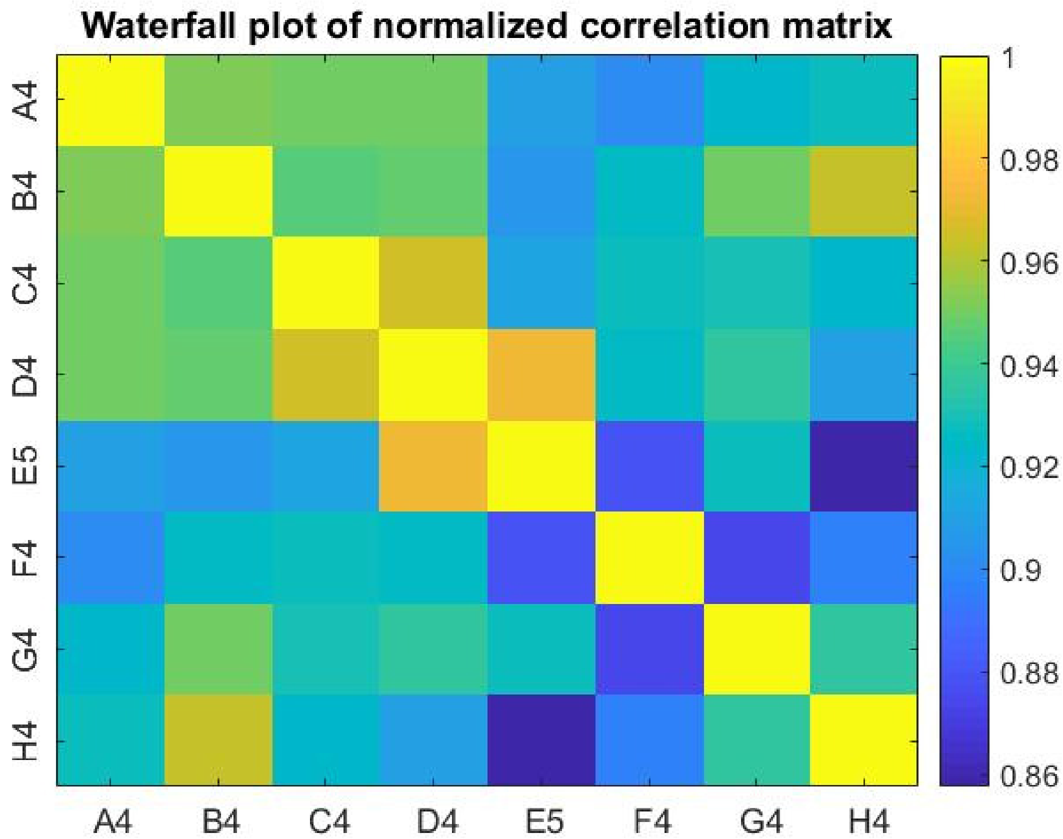

Figure 3.4: Waterfall plot of normalized correlation matrix

3.1.3 Correlation phase

The accumulated correlation matrix obtained in step 6 in the section 3.1. Correlation values are complex; the phase is calculated with help of *angle* function in MATLAB and we observe the phase of correlation between the elements for a particular spectral channel. The variation in phase can be observed and the phase difference between the signals received by different elements can be determined. The phase spectrum is noisy due to fact that the inverse tangents are computed from the ratio of imaginary part to real part of the FFT result. Even a small floating rounding off error will amplify the result and manifest incorrectly as useful phase information. Therefore we employ threshold method by making the correlation value as zero if the magnitude or absolute value of the correlation is less than or equal to small threshold.[5] By doing this we get phase value for correlation values which are significant. For example, consider the same noise data as in section 3.1 we observe the correlation phase for different elements. The Fig. 3.5 displays the phase difference between different elements for a particular spectral channel. The phase difference for the signals that arrive at different elements can be seen.

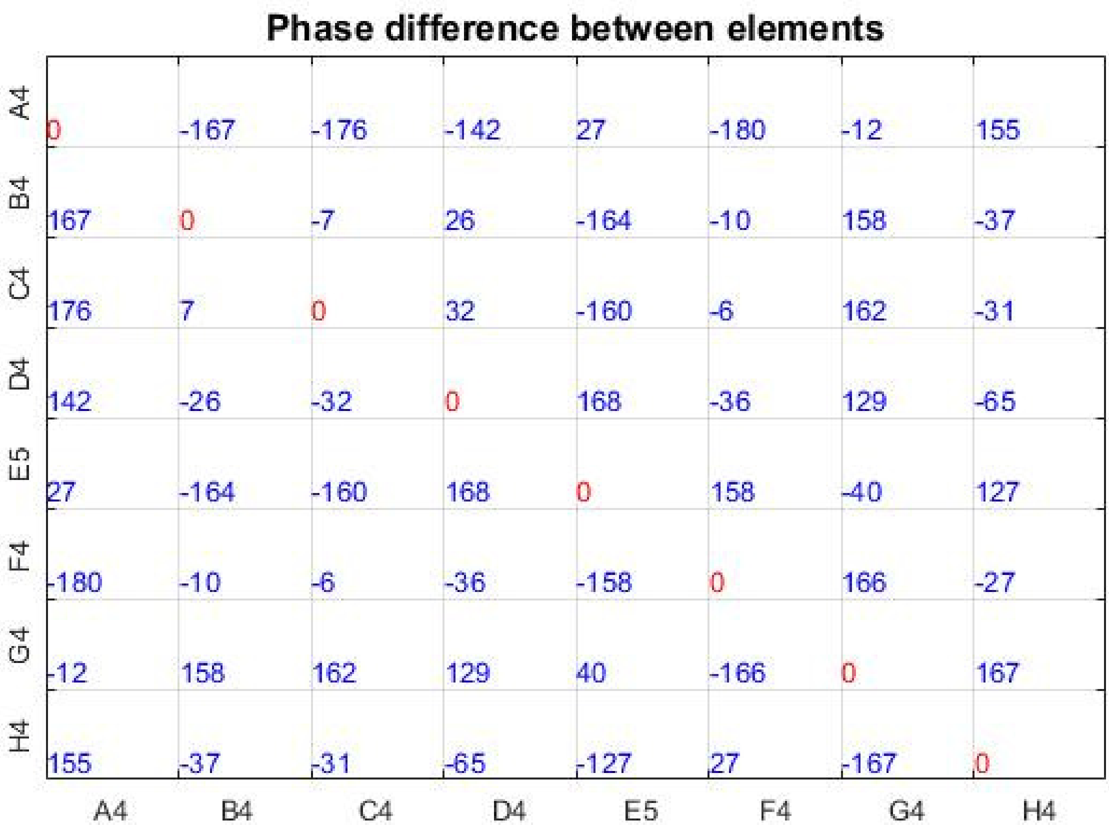

Figure 3.5: Correlation phase matrix

3.1.4 Steering the radiating antenna at an angle

The test was conducted to observe the correlation between elements when the radiating antenna is steered. The parabolic dish antenna which is used for testing the FPA, was physically steered at an angle of 45 degree from the centre position with respect to FPA in both the directions and we also conducted a test keeping the antenna at the center the position with respect to FPA. We observed the normalized correlation matrix for all the three cases. The Fig. 3.6 indicates the images of antenna which is at center position and steered at an angle. The antenna image at top left indicates rotation in anticlockwise direction while the antenna image at top right indicates the rotation in clockwise direction. The aim was to observe the difference between normalized correlation matrix for all the three cases. The signals were radiated by

Figure 3.6: Images of antenna at center position and steered at an angle

steering the antenna at 45 degree in both clockwise and anti-clockwise direction and also at center position. The noise data with a central frequency 1.3 GHz and bandwidth 22 MHz, noise power -26dBm/32MHz and the code variables are sampling frequency 64 MHz, number of FFT points 1024, number of MAC 10 and spectral channel 150. The Figs. 3.7, 3.8, 3.9 display the waterfall plot of normalized correlation matrix for the three cases 0 degree, 45 degree(antenna steered in clockwise direction from the centre) and -45 degree(antenna steered in the anticlockwise direction from the centre). We observe that the correlation values decreases for elements do not receive signal as the antenna is rotated in a direction away from the element. For the case when antenna was not rotated we conclude that there is maximum correlation between the elements but as we rotate the antenna the normalized correlation between the elements decreases.

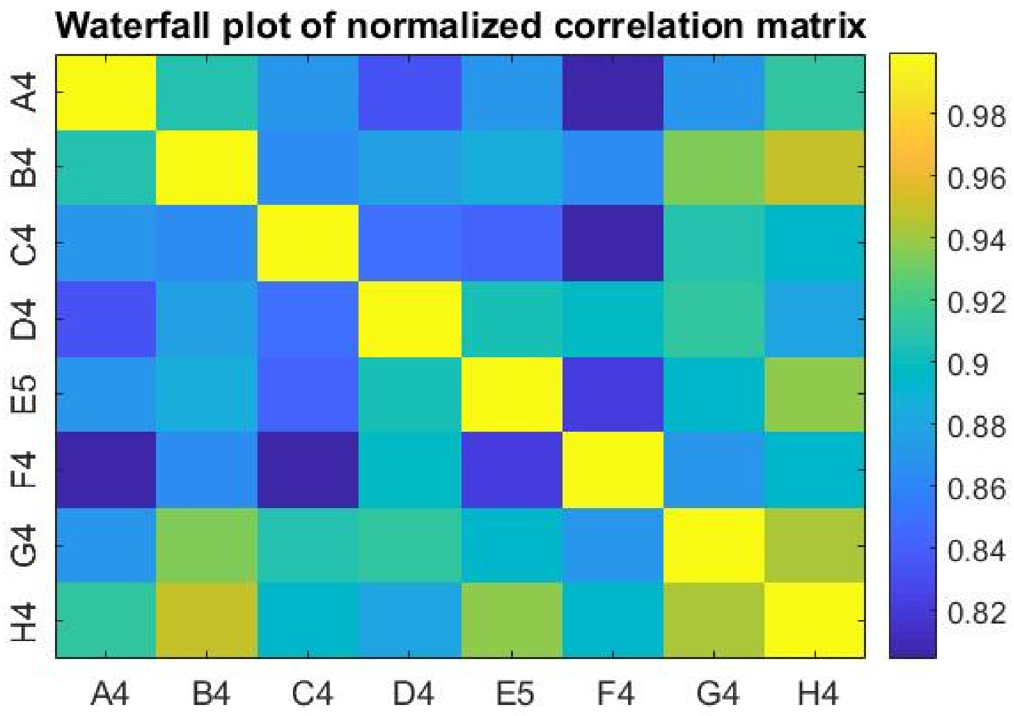

Figure 3.7: Waterfall plot of normalized correlation matrix for antenna at center position

3.1.5 2D FFT of correlation matrix

The correlation values(complex) were computed and the correlation values(real and imaginary) between elements which are similar in spatial domain were summed, we get an array of complex values whose FFT was taken and the magnitude of the FFT was computed the it was plotted The Fig. 3.10 displays the FFT of the array which was obtained. The work is going on generating a 2D array of correlation by arranging elements and computing its 2D FFT so that the beam pattern can be observed.

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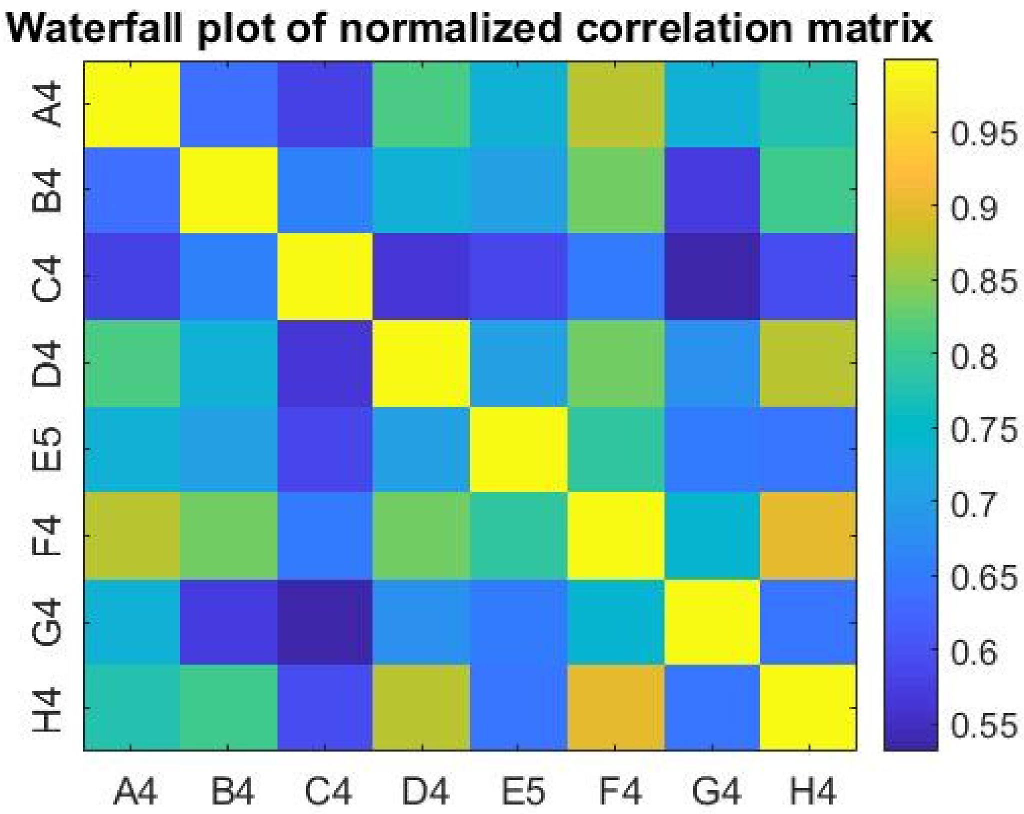

Figure 3.8: Waterfall plot of normalized correlation matrix for antenna rotated at 45 degree in clockwise direction

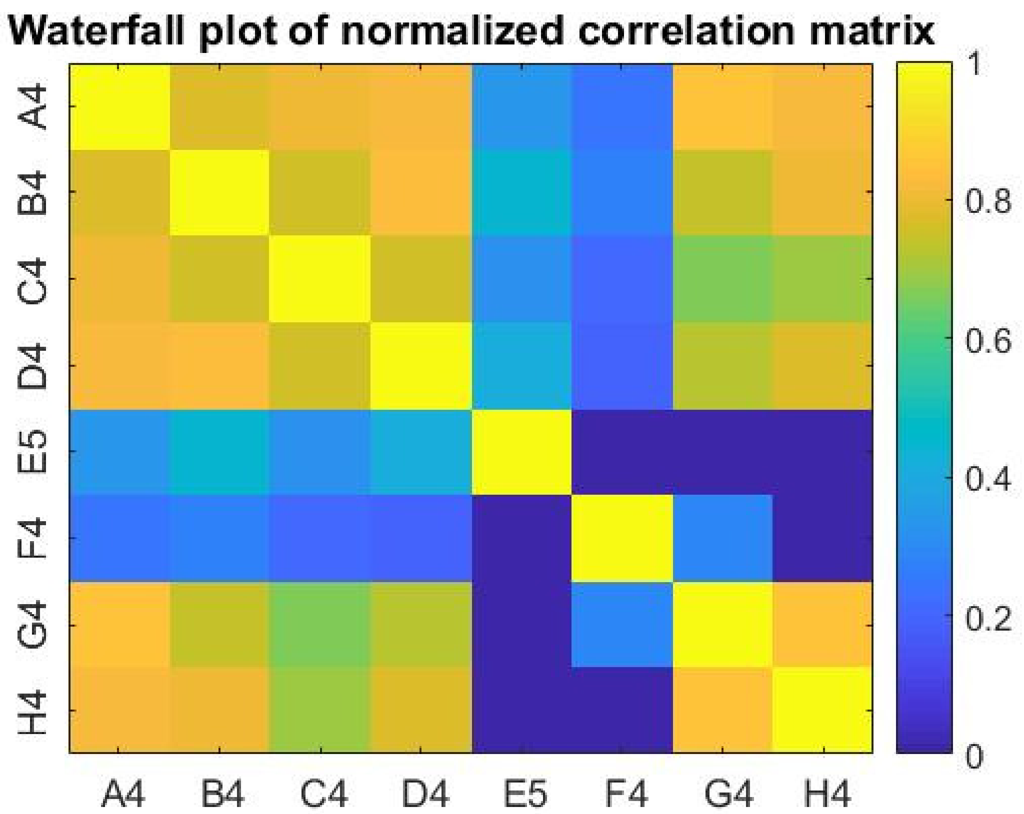

Figure 3.9: Waterfall plot of normalized correlation matrix for antenna rotated at 45 degree in the anticlockwise direction

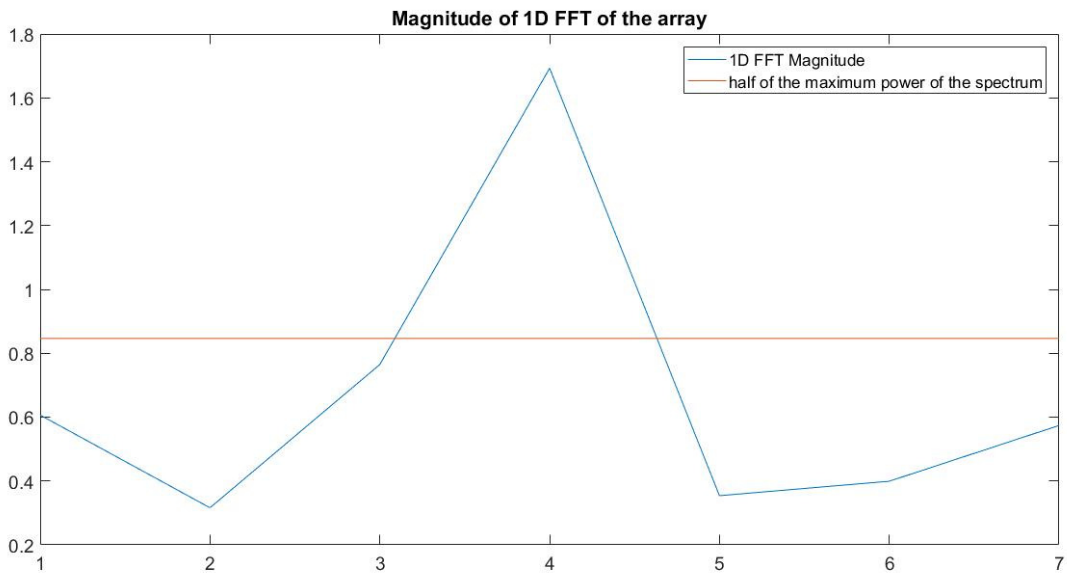

Figure 3.10: 1D FFT

Chapter 4

FEATURES OF THE TOOL

The MATLAB-based tool was developed for performing time domain and correlation domain analysis of the signal received by the FPA. The code is user programmable with options to select from for analyzing in time domain and correlation domain. It inputs the required variables and displays the corresponding plot mentioned. The Fig. 4.1 displays the command window when we execute the code it has the given options to select from, and there are two options to go with default value which are displayed if user selects to default, another option is user input values.

```
enter 1 - histogram plot of the channel
      2 - correlation matrix figure
      3- waterfall plot of 2D FFT of the correlation matrix
      4- waterfall plot of correlation matrix
      5- waterfall plot of normalized correlation matrix
      6- phase spectrum of correlation matrix
      7- waterfall plot of phase of correlation
      8- waterfall plot (on source - off source) correlation matrix
      9- Test for RFI
6
enter 0 to enter default values and 1 to enter the values manually
0
sampling frequency= 64e6, number of pts of FFT= 1024
number of Multiply and accumulate cycles= 10, spectral channel = 150
 number of MAC blocks= 10, 1st MAC correlation matrix
```

Figure 4.1: Command window that appears when the code is executed

The Fig.4.2 displays the flow chart of the MATLAB program.

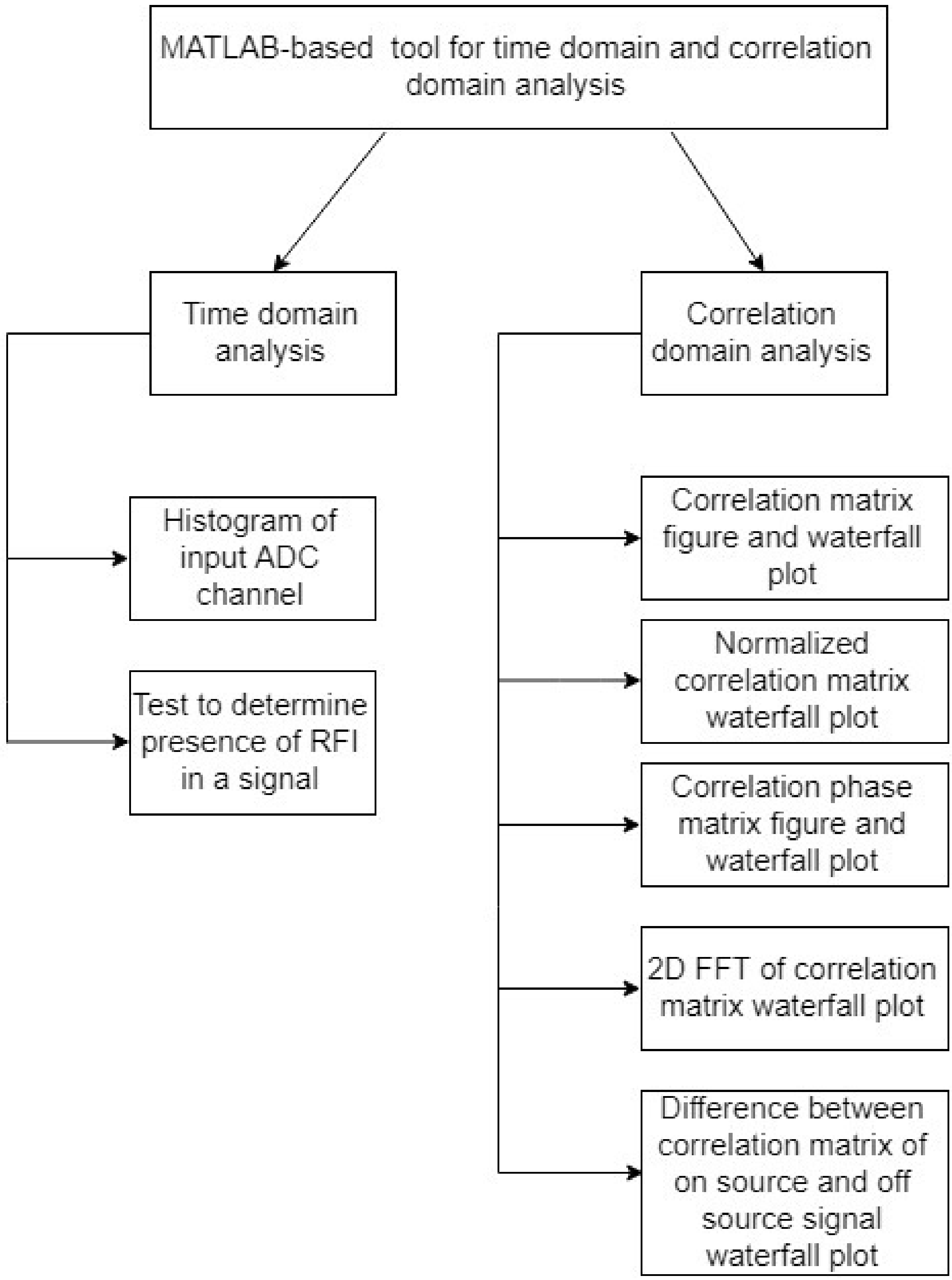

Figure 4.2: The flowchart of code features

Chapter 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The MATLAB tool is developed to analyze the data which is recorded by radiation and by direct input to the FPA beamformer. The data recorded is analyzed in time domain as well as correlation domain. The time domain analysis includes checking the signal quality and presence of Radio Frequency Interference in the signal. The correlation domain analysis includes observing the correlation matrix, normalized correlation matrix, correlation phase matrix and 2D FFT of the correlation matrix and extracting some useful information from the data.

5.2 Future Scope

1. The tool is developed for 8 and 16 elements however, it can be extended for more elements as well.

2. A graphical user interface (GUI) or an application using app designer in MATLAB can be created for the code which is developed.

3. Use of parallel computing toolox(PCT) can be made to reduce the computing time.

References

[1] https://en.wikipedia.org/wiki/Giant_Metrewave_Radio_Telescope

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abcentral/answers/95255-how-do-i-display-a-matrix-in-a-figure-window