National Centre for Radio Astrophysics

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Internal Technical Report
GMRT/Jan 2013/

Internal Technical Report on Band Pass Filter 250-500 MHz.

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Objective: To improve the Bandwidth of the 250-500 MHz Frontend Box.

Revision	Date	Modification/ Change
Ver. 1	Jan 2013	Initial Version

Acknowledgement

I am thankful to our Group Coordinator Mr. S. Sureshkumar, who has assigned me to assemble and tune Band Pass Filter 250-500 MHz and implement the same in the Frontend Box. I am very much thankful for his guidance, constant encouragement, supervision, and motivation & help in preparation of this report.

I am thankful to Mr. Bhalerao who has designed this Band Pass Filter for 250-500 MHz broadband frequency range and made it possible to increase the Bandwidth of the 327 MHz Frontend Box.

I am also greatly indepted to Prof. Yashwant Gupta, Dean, GMRT and Prof. S. K. Ghosh, Center Director, GMRT for their encouragement.

I also greatly acknowledge the support from Mr. Anil Raut and his suggestion in preparing this report & motivation.

I am especially grateful to our colleagues Gaurav Parikh, Hanumant Rao, Sougata Chattergee, Vishal Temkar, S. Ramesh, Santosh Bhor, K T Thorat, & Barkund who helped me in different ways to complete this work.

I take this opportunity to thank all our GMRT staff that has directly or indirectly helped in our work.

Abstract

The purpose of this project is to improve the bandwidth of the 327 MHz Front End System. Presently, system bandwidth is 40 MHz, limited by the LNA and Band Pass Filter. The existing Kildal Feed has been replaced by Cone Dipole Feed (CDF) for broader frequency coverage from 250 - 500 MHz. The 327 MHz Front-End box was modified with low Loss Sage Lab Quadrature Hybrid, Wide Band Low Noise Amplifier and Broad Band Filter to give 250-500 MHz overall broadband bandpass response with good stability. The broadband feed and front end system is mounted on C06, C10, S02 and W01 antennas. They are tested extensively and are found to perform satisfactorily. This report covers the description of the Broadband Bandpass Filter 250-500 MHz used in the upgraded 327 MHz Front-end Box.

Contents

1. Introduction to Filters:

Electronic filters are electronic circuits which perform signal processing functions, specifically to remove unwanted frequency components from the signal, to enhance wanted ones, or both. Filters are used to pass a particular frequency or band of frequency and reject the unwanted ones. Depending on these function filters can be classified as low pass filter, high pass filter, band pass filter, band stop filter, and notch filter.

Low pass filters are used to pass low frequency bands (i.e. they are used to pass the frequency from 0 Hz to a certain break frequency or cut off frequency fc Hz) and reject the remaining band of frequency.

High pass filters as name indicates are used to pass the high band of frequency (i.e. they are used to pass all the frequency components higher than the cut off frequency fc Hz).

Band pass filter and Band stop filters are used to pass or stop a certain band of frequency respectively and reject the remaining frequency components.

Notch filters are those which are used to reject only a particular frequency components and pass the remaining ones.

2. Types of Filters Design:

There are basically three types of filters:

1. Butterworth Filter.
2. Chebyshev Filter.
3. Elliptical Filter.

2.1 Butterworth Filter:

The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the passband. It is also referred to as a maximally flat magnitude filter.

The frequency response of the Butterworth filter is maximally flat (i.e. has no ripples) in the passband and rolls off towards zero in the stopband. When viewed on a logarithmic Bode plot the response slopes off linearly towards negative infinity. A first-order filter's response rolls off at −6 dB per octave (−20 dB per decade) (all first-order lowpass filters have the same normalized frequency response). A second-order filter decreases at −12 dB per octave, a third-order at −18 dB and so on. Butterworth filters have a monotonically changing magnitude function with ω, unlike other filter types that have non-monotonic ripple in the passband and/or the stopband.

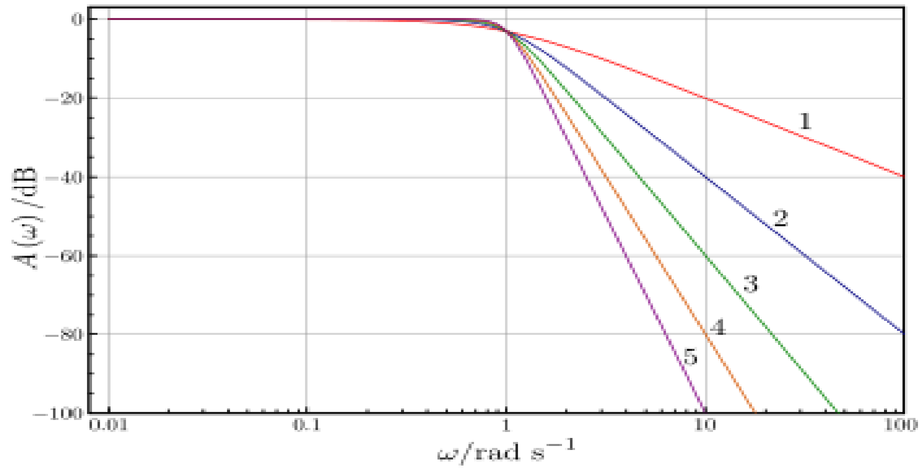


Fig. 1 Plot of the gain of Butterworth low-pass filters of orders 1 through 5, with cutoff frequency ω_o=1.

The gain response as a function of angular frequency ω of the nth-order Butterworth low pass filter is

$$G_n^2(\omega) = |H_n(j\omega)|^2 = \frac{G_O^2}{1 + (\frac{\omega}{\omega_C})^{2n}}$$

where

n => Order of filter,

ω_C => Cutoff frequency (approximately the -3dB frequency),

G_O => DC gain.

2.2 Chebyshev Filter:

Chebyshev filters are analogue or digital filters having a steeper roll-off and more passband ripple (type I) or stopband ripple (type II) than Butterworth filters. Chebyshev filters have the property that they minimize the error between the idealized and the actual filter characteristic over the range of the filter, but with ripples in the passband. Because of the passband ripple inherent in Chebyshev filters, the ones that have a smoother response in the passband but a more irregular response in the stopband are preferred for some applications.

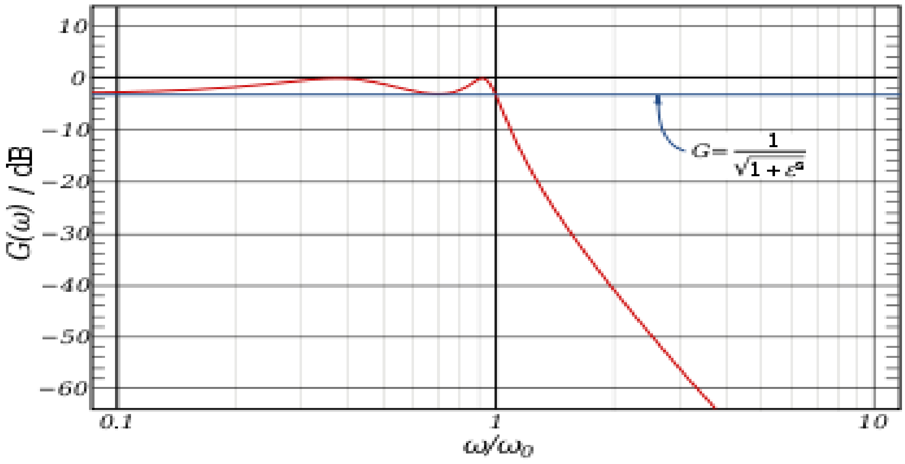


Fig. 2 The frequency response of a fourth-order type I Chebyshev low-pass filter with Ɛ=1.

The gain response as a function of angular frequency ω of the nth-order Chebyshev low pass filter is

$$G_n(\omega) = |H_n(j\omega)| = \frac{1}{\sqrt{1+\ \varepsilon^2 T_n^2(\frac{\omega}{\omega_O})}}$$

Where
ε => Ripple factor,
ω_O => Cutoff frequency,
T_n => Chebyshev polynomial of the nth order.

2.3 Elliptical Filter:

An elliptic filter (also known as a Cauer filter, named after Wilhelm Cauer) is a signal processing filter with equalized ripple (equiripple) behavior in both the passband and the stopband. The amount of ripple in each band is independently adjustable, and no other filter of equal order can have a faster transition in gain between the passband and the stopband, for the given values of ripple (whether the ripple is equalized or not). Alternatively, one may give up the ability to independently adjust the passband and stopband ripple, and instead design a filter which is maximally insensitive to component variations.

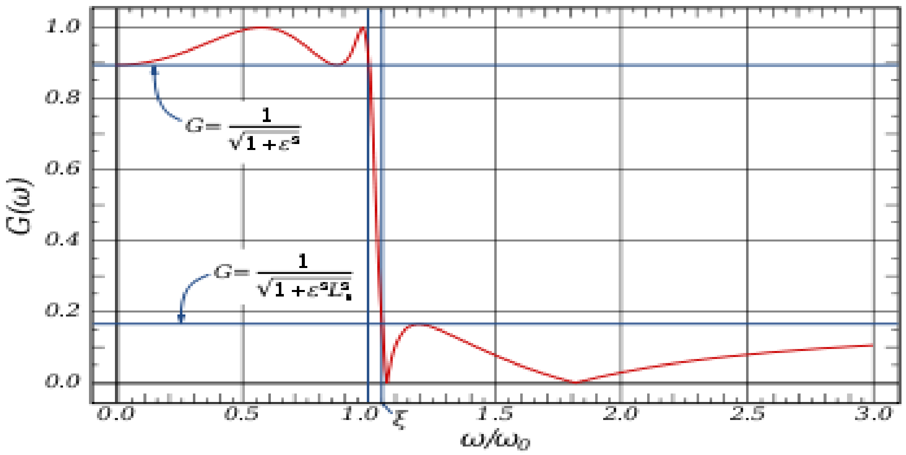


Fig. 3 The frequency response of a fourth-order elliptic low-pass filter with ε=0.5 and ξ =1.05.

As the ripple in the stopband approaches zero, the filter becomes a type I Chebyshev filter. As the ripple in the passband approaches zero, the filter becomes a type II Chebyshev filter and finally, as both ripple values approach zero, the filter becomes a Butterworth filter.

The gain of a lowpass elliptic filter as a function of angular frequency ω is given by:

$$G_n^2(\omega) = |H_n(j\omega)|^2 = \frac{1}{1 + \mathcal{E}^2 \mathrm{R}_\mathrm{n}^2\,(\xi, \frac{\omega}{\omega_0})}$$

Where

R_n is the *n*th-order elliptic rational function (sometimes known as a Chebyshev rational function),

ω_o => cutoff frequency,

$\mathcal{E}$ => ripple factor,

ξ => selectivity factor.

3. Band-pass Filter for GMRT:

The 250-500 MHz filter is designed by Mr. Bhalerao for the broadband 327 MHz front end system. Later this was also simulated in AWR and the simulated results are included along with the measured results. An Elliptical filter design technique was used as it provides a very fast transition in gain between passband and stopband. For large bandwidth it is preferable to have low pass filter and high pass filter combined as Wideband Band Pass Filter. Therefore a high pass filter having cut off frequency of 250 MHz is cascaded with a low pass filter having cut off frequency of 500 MHz to form a Bandpass filter of 250 MHz bandwidth. With this kind of configuration it is possible to tune the response characteristics of an individual filter without affecting the response of another filter.

The fig. 4 shows a pictorial view of BPF 250-500 MHz along with chassis.

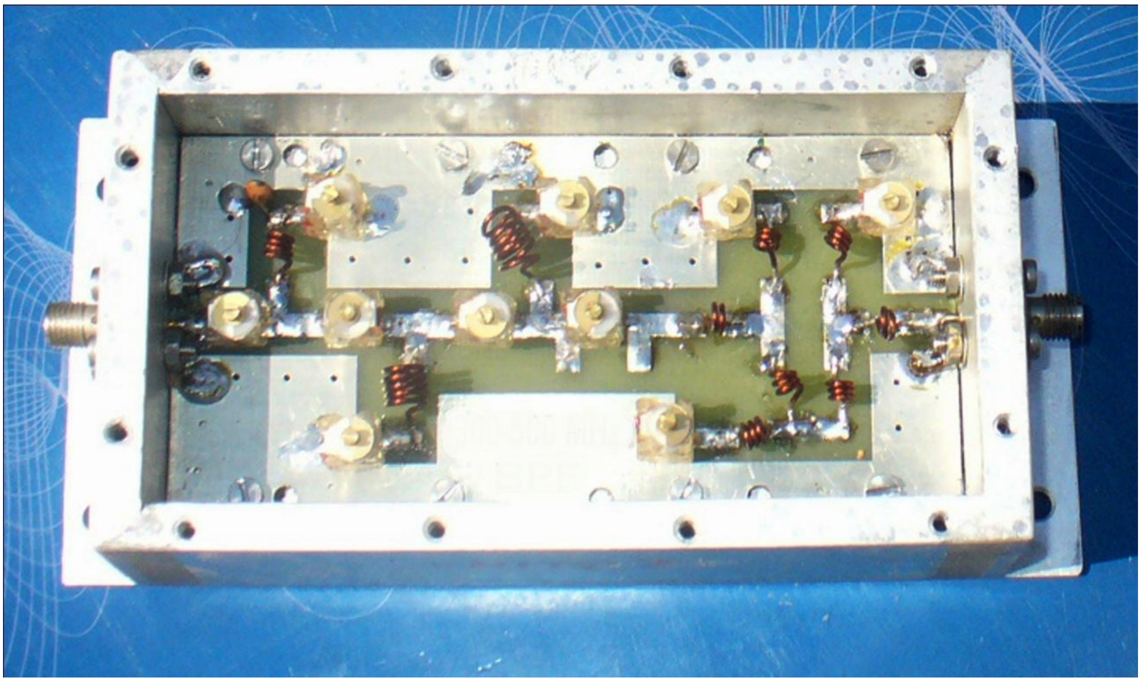
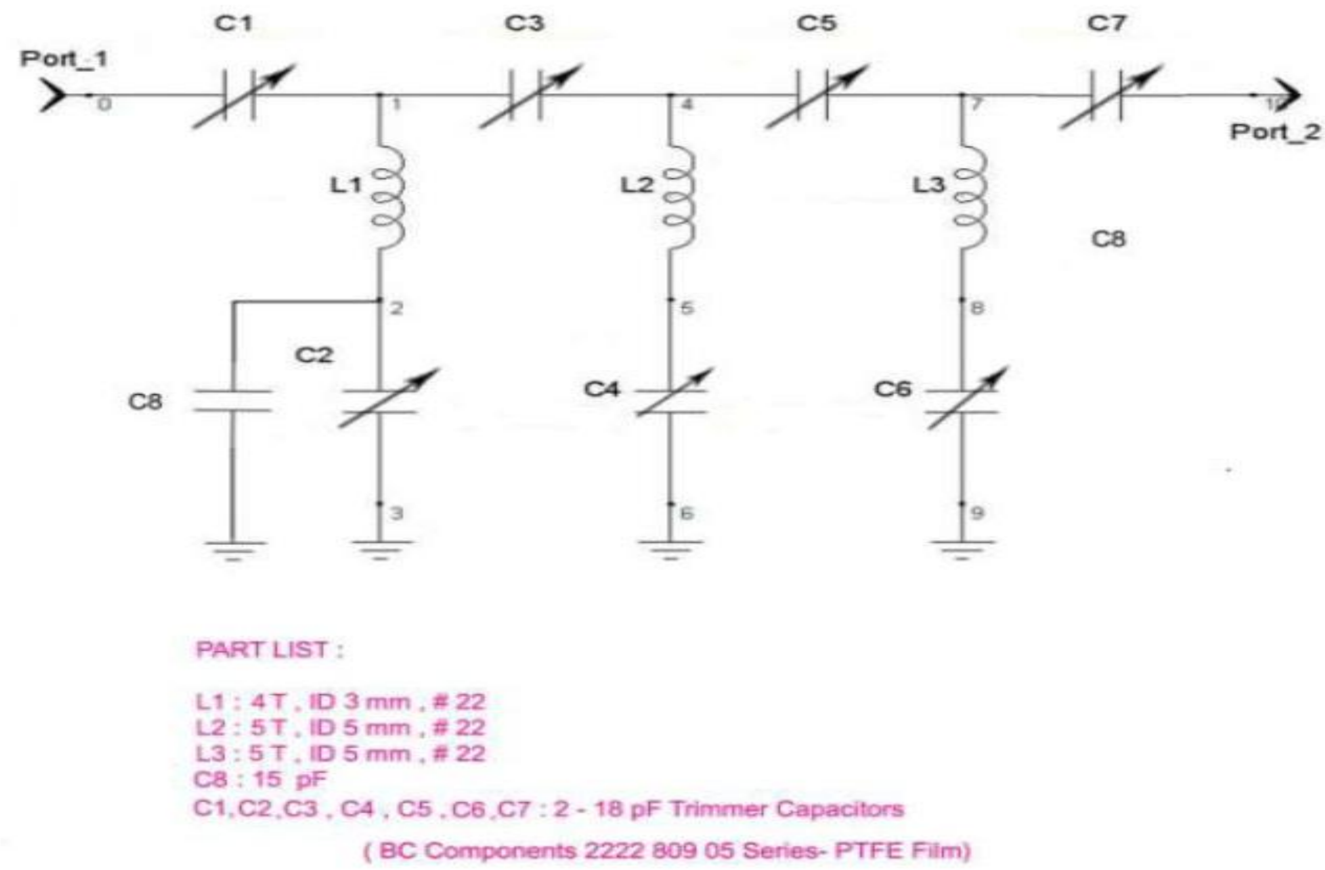


Fig. 4 Pictorial view of the BPF.

4. Schematic Circuit of the BPF 250-500 MHz:

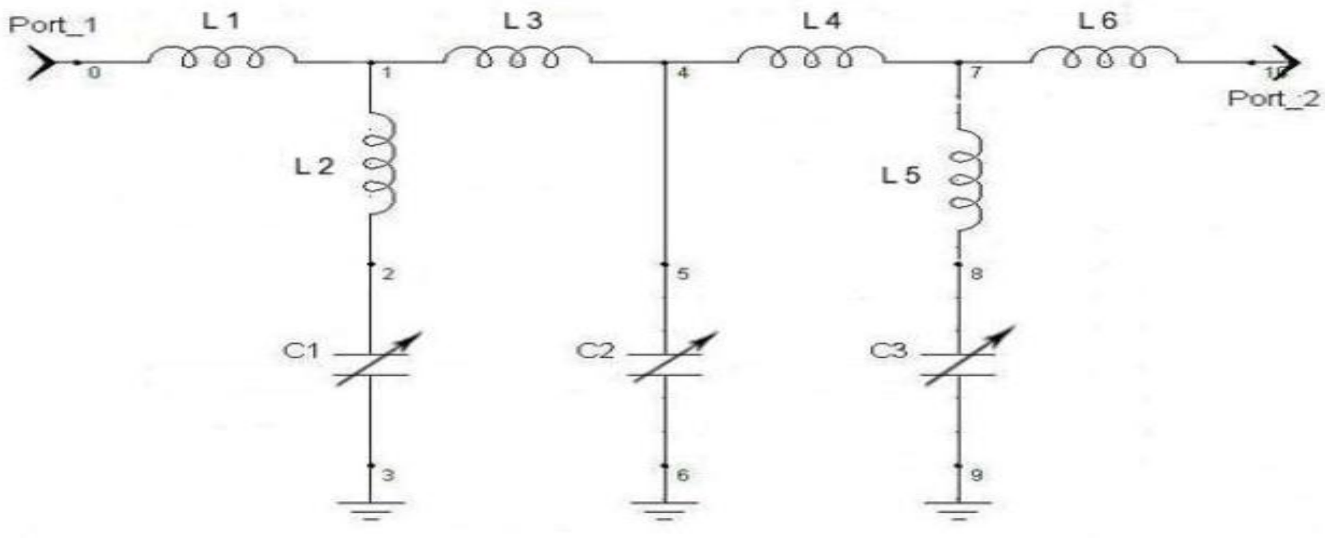
The BPF 250-500 MHz filter is formed by cascading the 7th order elliptic type high pass filter followed by a 7th order elliptic type low pass filter having 250 MHz and 500 MHz as 3 dB cut off frequency respectively. The circuit diagram for the high pass filter and low pass filter is shown in the fig. given below.



PART LIST :

L1 : 4 T , ID 3 mm , # 22
L2 : 5 T , ID 5 mm , # 22
L3 : 5 T , ID 5 mm , # 22
C8 : 15 pF
C1, C2, C3 , C4 , C5 , C6 ,C7 : 2 - 18 pF Trimmer Capacitors
(BC Components 2222 809 05 Series- PTFE Film)

Fig. 5 Schematic diagram of 7th order elliptic type 250 MHz High Pass Filter.



PART LIST :

L1 , L2 , L5 , L6 : 2T , ID 3 mm , # 22

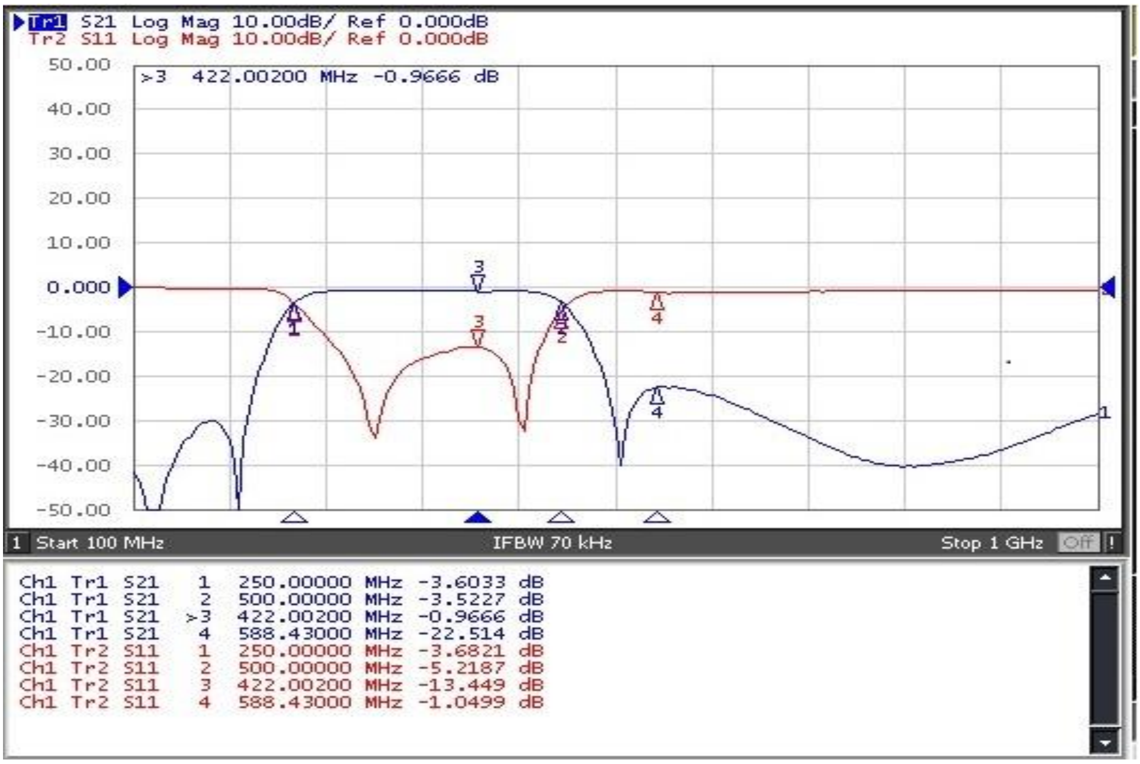
L3 , L4 : 3 T , ID 3 mm , # 22

C1 , C2 , C3 : 2 - 18 pF Trimmer Capacitors
(BC Components 2222 809 05 Series- PTFE Film)

Fig. 6 Schematic diagram of 7th order elliptic type 500 MHz Low Pass Filter.

5. Plot showing the response of the BPF 250-500 MHz:

The S-parameter measurements were done on the filter units using the network analyser in Front-end lab. The following plot shows the measurement response for a filter. The insetion loss (S21) of the filter over the desired band was found to be -1 dB and the return loss (S11) was found to be well below -10 dB over the desired BW. The BPF ensures around -20 dB rejection of the TV band operating at 540 MHz.



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Tr1 S21 Log Mag 10.00dB/ Ref 0.000dB
Tr2 S11 Log Mag 10.00dB/ Ref 0.000dB
>3  422.00200 MHz -0.9666 dB
1 Start 100 MHz          IFBW 70 kHz          Stop 1 GHz

Ch1 Tr1 S21   1  250.00000 MHz -3.6033 dB
Ch1 Tr1 S21   2  500.00000 MHz -3.5227 dB
Ch1 Tr1 S21  >3  422.00200 MHz -0.9666 dB
Ch1 Tr1 S21   4  588.43000 MHz -22.514 dB
Ch1 Tr2 S11   1  250.00000 MHz -3.6821 dB
Ch1 Tr2 S11   2  500.00000 MHz -5.2187 dB
Ch1 Tr2 S11   3  422.00200 MHz -13.449 dB
Ch1 Tr2 S11   4  588.43000 MHz -1.0499 dB
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Fig. 7 The plot showing the response of the BPF 250-500 MHz.

6. Simulated Circuit and response of the BPF 250-500 MHz:

The BPF designed for GMRT 250-500 MHz Frontend Box is the combination of high pass and low pass filter. Therefore the combined circuit is made and simulated in AWR to find the exact value of the capacitors and inductors for which the system is tuning for the 250-500 MHz band. The schematic and the simulated response of the BPF are shown in the figures given below.

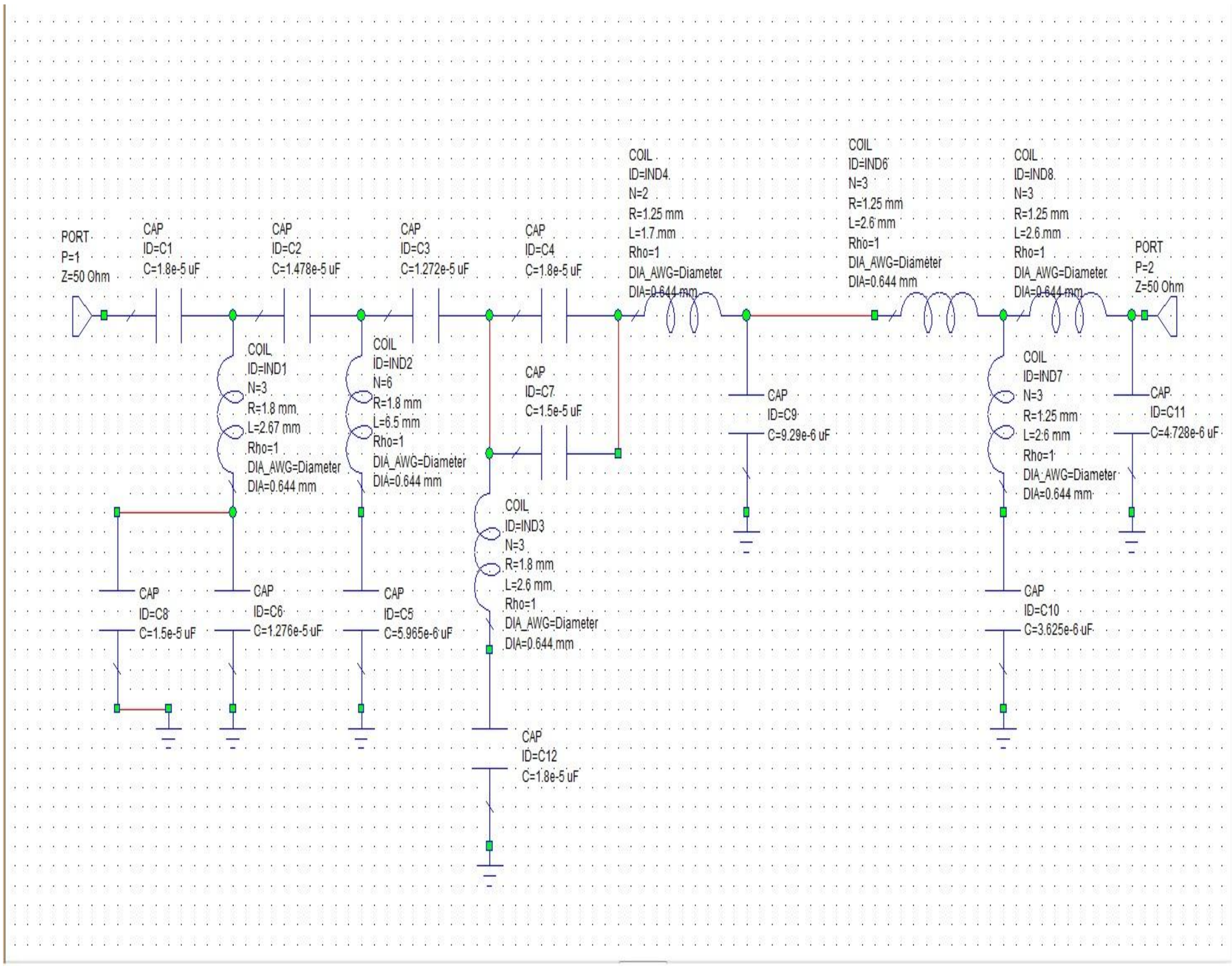

Fig. 8 Showing the Schematic diagram of the BPF 250-500 MHz.

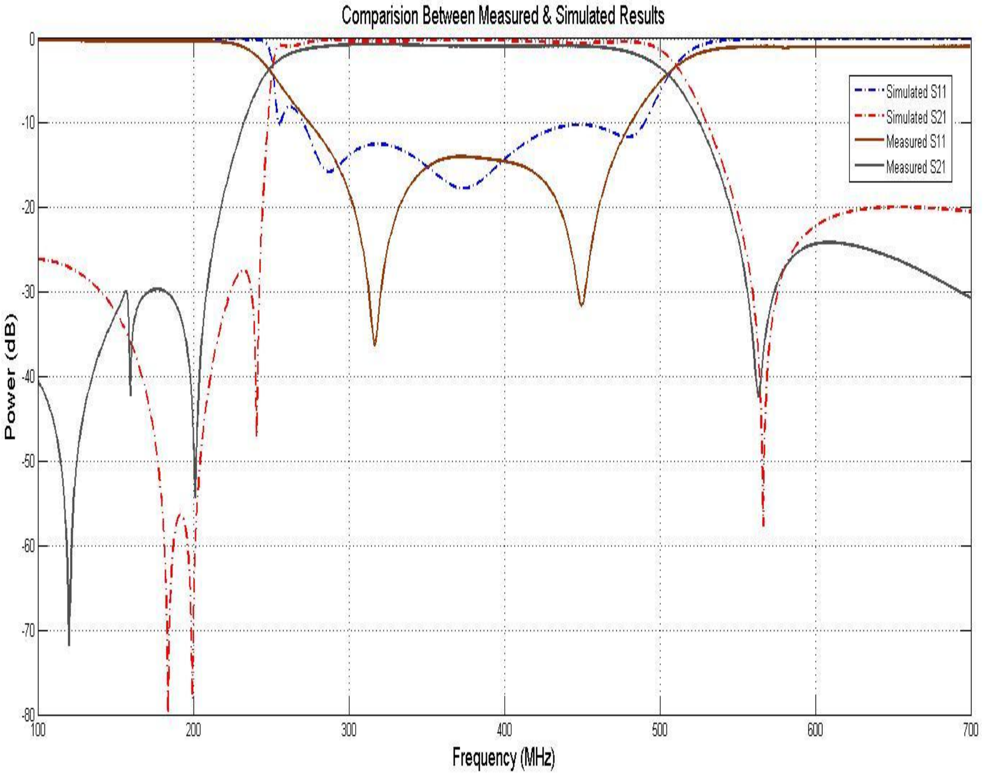

Fig. 9 Graph showing the comparision of Measured and Simulated Results of the BPF 250-500 MHz.

7. Plots showing repeatability of the response of BPF 250-500 MHz:

The Bandpass filter designed for the upgradation can easily be tuned for the given frequency. The repeatability of the filter was found to be excellent. The following plots show the repeatability of the 9 filter units.

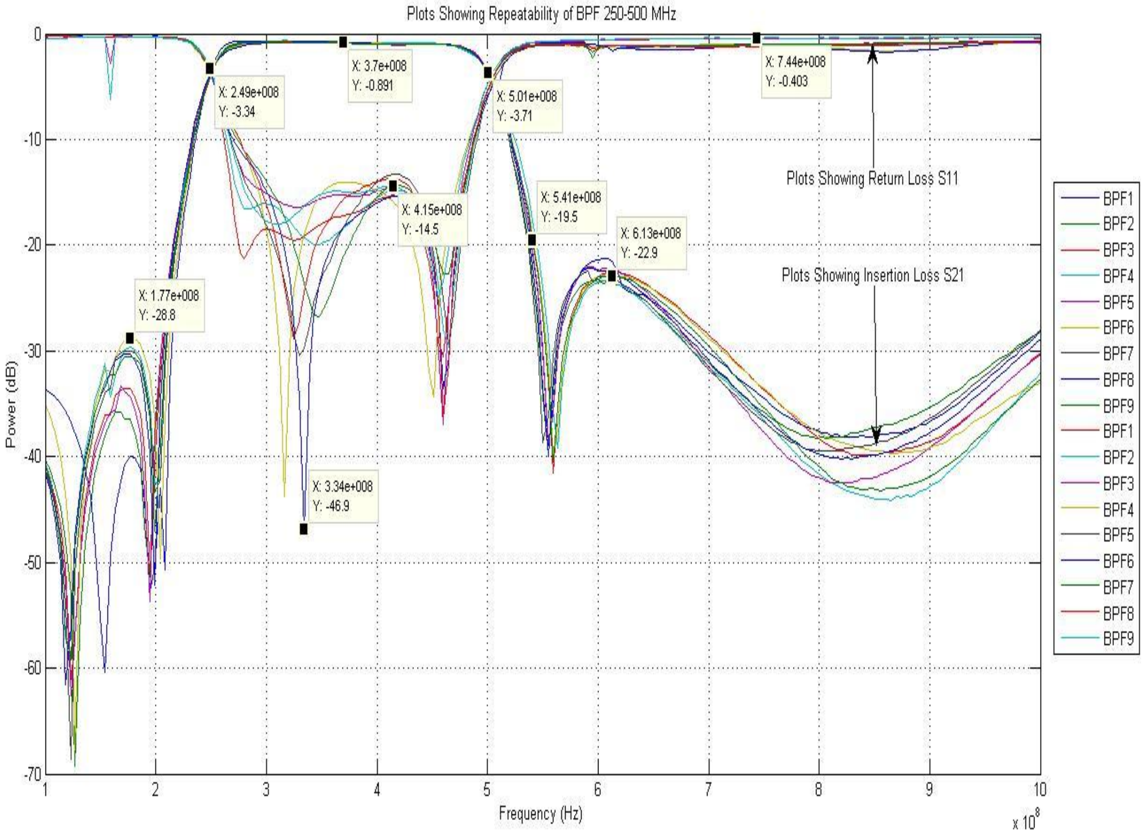

Fig. 10 Plots showing the repeatability of the BPF 250-500 MHz.

8. Conclusion:

The filter is found to have an insertion loss (S21) of -1 dB and return loss (S11) of better than -10 dB over the desired frequency range of 250-500 MHz band. It also offers rejection of around -20 dB to a TV signal at 540 MHz. Total 9 nos. Of filter units are assembled and the repeatability of the performance parameters was found to be excellent. The simulated results using AWR and the measured results are very much matched. The filters have already been integrated in upgraded 327 MHz front end box and are installed successfully on four GMRT antennas. The mass production of these filters is under process so that they can be installed on all the remaining antennas. We have plans to incorporate four sub-band filters along with the BPF in the upgraded Front-End Box in near future.

9. Reference:

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2. Aarti Sandikar, Manisha Parate & V.B. Bhalerao, “Upgraded Broadband 300-500 MHz Front-End System.
3. Vinod Toshniwal, “RFI Rejection Filter At 150 MHz”, STP project report.
4. Bhalerao V. B., 2010,Wide Bandpass filter for 327 MHz Front-End GMRT Reciever.
5. Wikipedia.