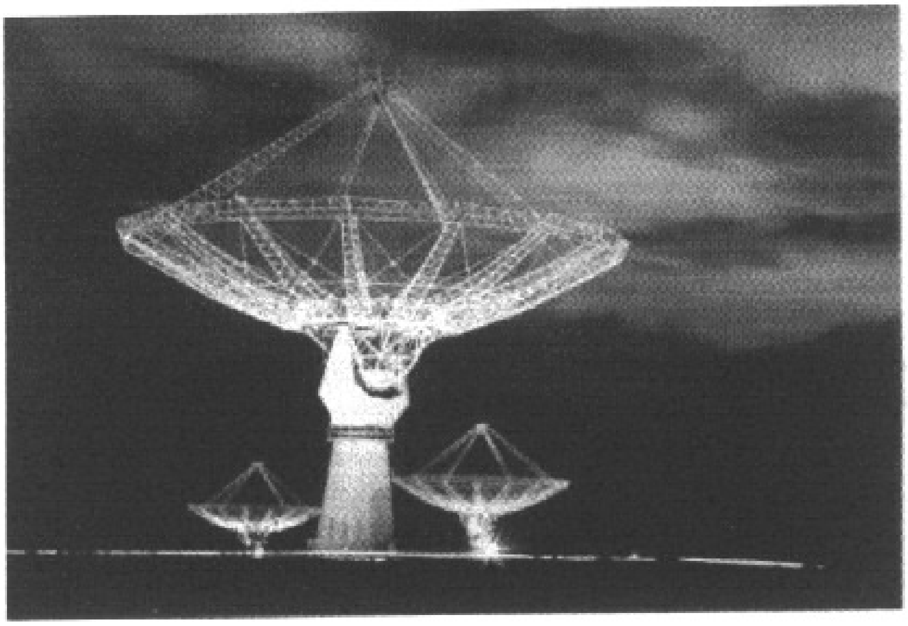
PROJECT REPORT

RFI REJECTION FILTERS AT 150 MHz



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Stp 2003.

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ABSTRACT-

150 MHz is one of the main frequency band of operation for the GMRT. Observations at 150 MHz are severely affected by the strong men-made interfering near the frequency band of operation. As part of the project the suitable filters have been designed to remove the strong interfering lines. The filters developed include a Low-Pass Filter, a High-Pass Filter and a Band Stop Filter. This report describes the design and development of these filters and the response of the wired filters.

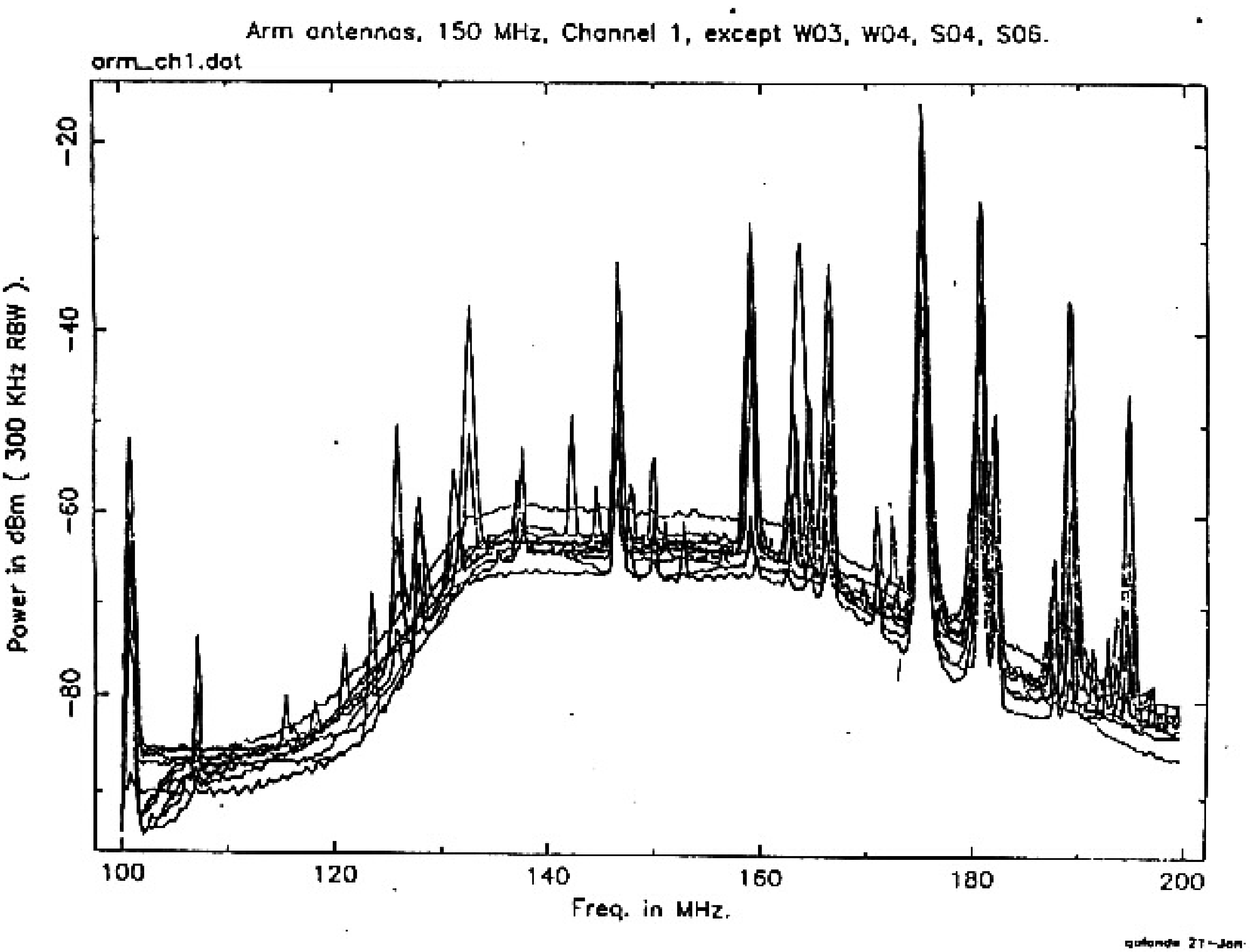
The Difficulties Faced At 150 MHz -

A summary of Front End Electronics is given in annexture1.

As mentioned above the GMRT system has been designed to operate at a frequency band centered roughly at 150 MHz corresponding to the allocated band of 152-155 MHz for radio astronomy. However, with the broad band coverage of the existing system of pagers, MARR (Multiple Access Rural Radio) system, T.V. Transmission, police wireless and civil aviation communication the 150 MHz band is subjected to high levels of interferences. The plot of POWER vs FREQUENCY at 150 MHz is given in figure 1.

And the frequency at which the interferences occurs are given below.

1.	MARR	-	121, 127, 132.3, 137.8, and 144.3 MHz.	
2.	Pager	-	146 MHz.	
3.	Police wireless	-	159.5, 163 , 164.3 MHz.	
4.	T.V. communication	-	Picture	Audio
	(1) Channel 5		172.25 MHZ	180.75 MHz
	(2) Channel 6		182.25 MHZ	187.25 MHz
	(3) Channel 7		189.25 MHz	194.75 MHz



* 101 MHz : Pune FM Radio
* 130 MHz : Aviation
* 146 MHz : Pager
* 159 MHz : Communication
* 163 MHz : Rural Police
* 175 MHz : Pune TV Video
* 181 MHz : Pune TV Audio

The receiver system must essentially remain linear over a reasonable level of interferences signals and should not produce Inter Modulation Distortion [IMD] products above a certain limit, acceptable for astronomical observations .

Proposed Upgradation -

Now to take observations at 150 MHz it is necessary to cut all the interference signals so that we can proceed with the actual astronomical signals. So we can think for the band stop notch filters for these interfering frequencies according to their frequency with the minimum bandwidth possible and to place them in place of solitary existing Band-Pass filter. So that observations at 150 MHz frequency can be taken away with quite easier way.

Based on the spectrum at 150 MHz given above we can see that the useful band for the 150 MHz range is between 120 MHz to 160 MHz because below 120MHz and above 160MHz there are too many interfering lines. So aim of the project is to have High Pass filter having 3-dB cut-off at 120MHz and with maximum attenuation at FM radio frequency, Low Pass filter having 3-dB cut-off at 160MHz and with maximum attention at 175 MHz that is T.V. Transmission frequency. Both of these lines are strong interfering lines and they need to be eliminated. In addition to this we need to have notch filters to remove some of the interfering lines in the band of 120MHz –150MHz.

Filter Designing -

We have to design three filters named as
1.Low-Pass Filter
2.High-Pass Filter
3.Band-Stop Filter

Low-Pass Filter should have minimum insertion loss and 3 dB point at greater than 160MHz and maximum rejection of 40 dB at 175MHz that is Pune T.V. Filter should be elliptic type and 5^{th} order and tuned at required frequency. This was designed as given in the filter designing handbook by Williams.

High-Pass Filter should also have minimum insertion loss and 3 dB point at 120 MHz and maximum rejection of around 40 dB at 101 MHz that is FM radio frequency. Filter should be elliptic type and 5^{th} order and tuned at required frequency. This was also designed by the procedure given in the same handbook.

Band Stop Filter should also have minimum insertion loss and notches of minimum band-width possible at 133.5 MHz, 146.5 MHz. and 159 MHz. These are the main interfering lines in the band of 150 MHz. These signals are found to be narrow band so notch filter have been planned. These 3rd order elliptic filter have been designed to provide more than 30 dB of isolation.

Here we should not that these all interfering lines are not constant lines that remains always in the 150 MHz band. As these lines comes and disappears according to the frequency allocated to them and their use. So It is not fix that these lines remains constant.

After calculating values for all these filters including Low Pass, High Pass and Band Stop filter as given in the handbook on filter design by Williams the values for designing were obtained and that are listed below.

Table 1.

1. Low Pass Filter -

SR. No.	*Components*	*Value*	*Source*
1	Inductor L1	59 nH	In Lab.
2	Inductor L2	30 nH	In Lab.
3	Inductor L3	35 nH	In Lab.
4	Capacitor C1	20 pF	From Market
5	Capacitor C2	4.8 pF	From Market
6	Capacitor C3	26 pF	From Market
7	Capacitor C4	26 pF	From Market
8	Capacitor C5	21 pF	From Market
9	Capacitor C6	19 pF	From Market
10	Capacitor C7	127 pF	From Market

LOW PASS FILTER

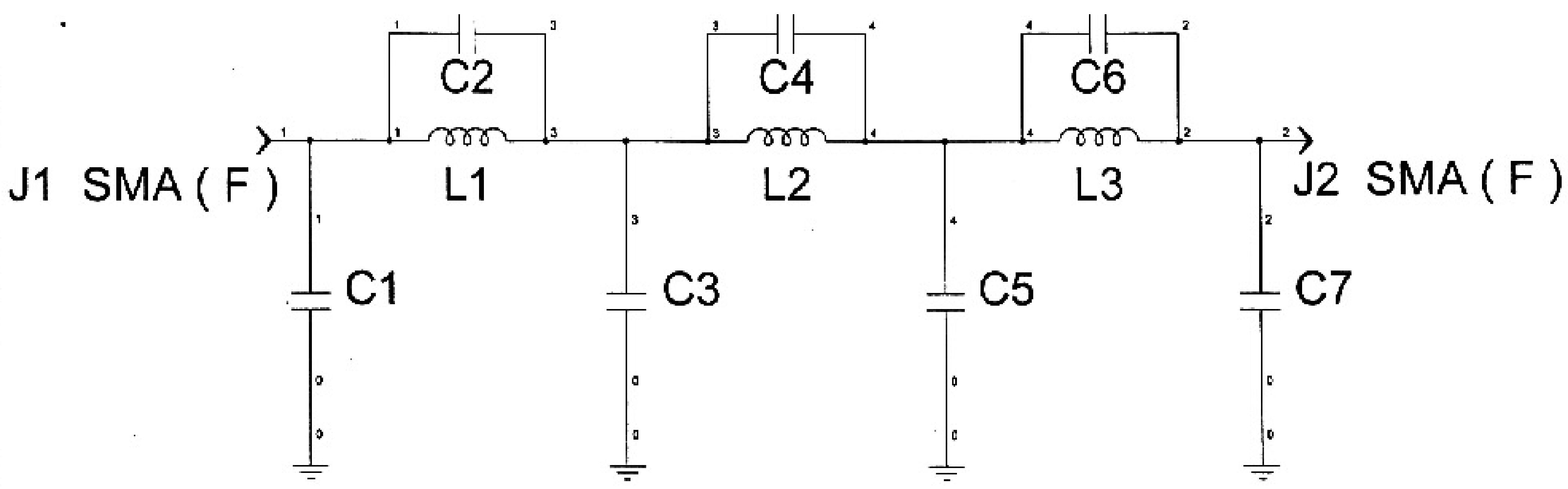


Table 2.

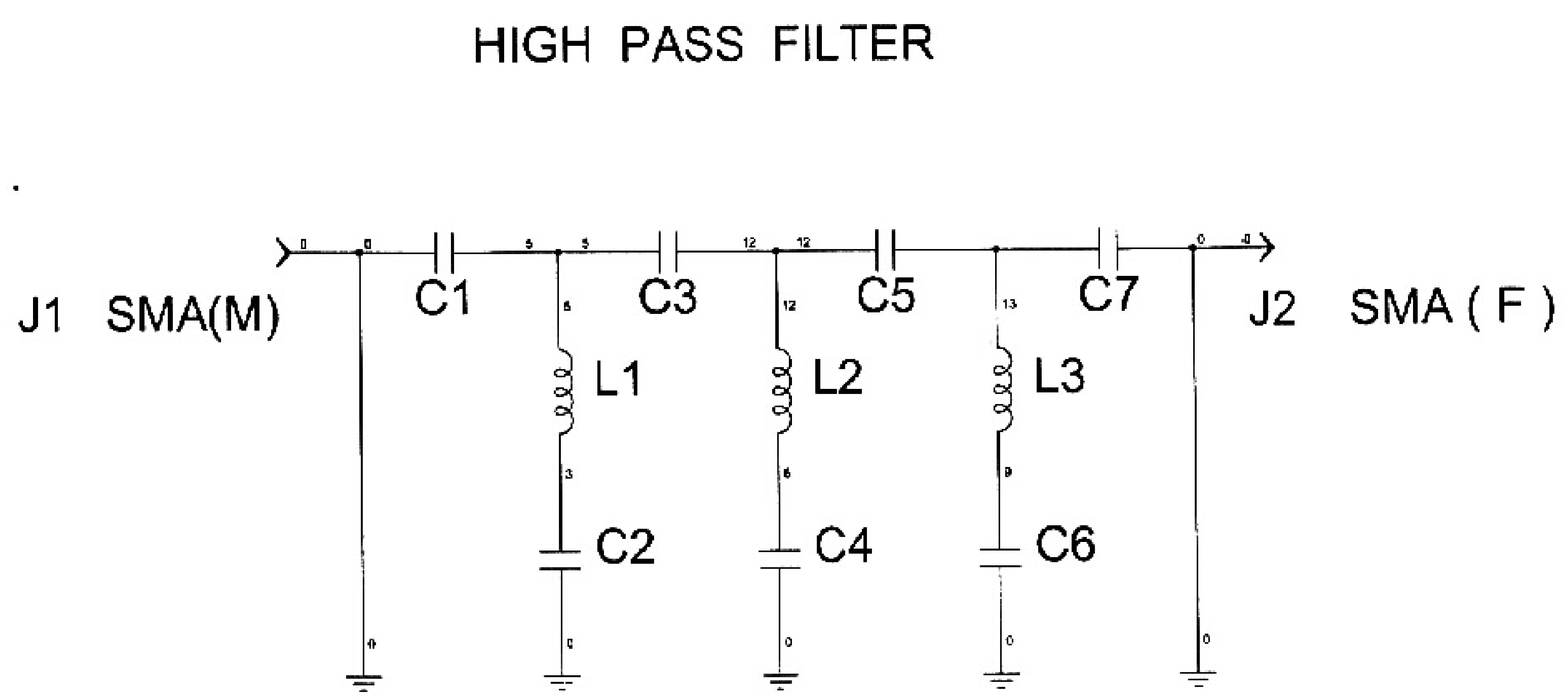
2. High Pass Filter -

Sr. No.	*Components*	*Value*	*Source*
1	Inductor L1	49.2 nH	In Lab.
2	Inductor L2	75.5 nH	In Lab.
3	Inductor L3	71.2 nH	In Lab.
4	Capacitor C1	23.4 pF	From Market
5	Capacitor C2	146.8 pF	From Market
6	Capacitor C3	16.6 pF	From Market
7	Capacitor C4	28.8 pF	From Market
8	Capacitor C5	19.3 pF	From Market
9	Capacitor C6	39.9 pF	From Market
10	Capacitor C7	33 pF	From Market

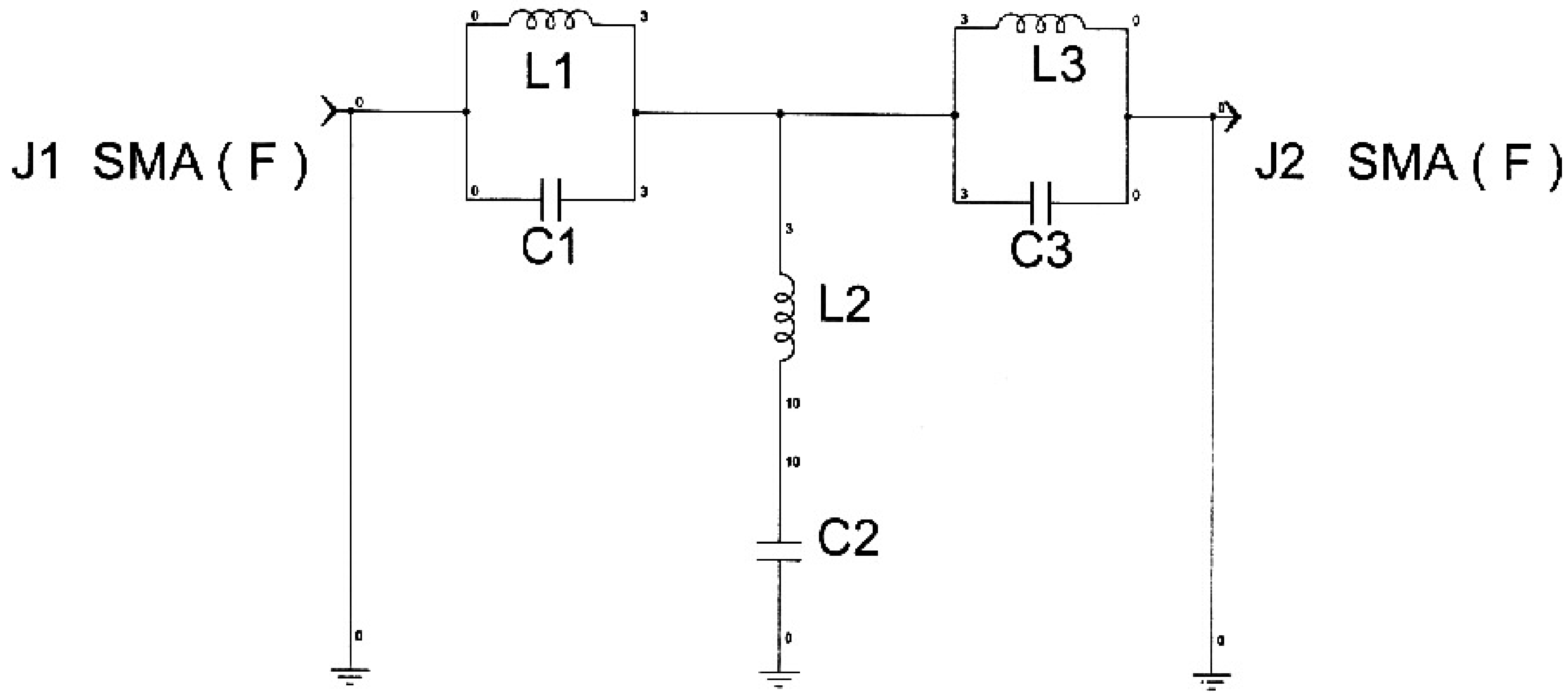
Table 3.

3. Band Stop Filter -

Sr. No.	*Component*	*Value*	*Source*
1	Inductor ($L_1 = L_3$)	0.507 nH	In Lab
2	Inductor (L_2)	4.99 µH	In Lab
3	Capacitor ($C_1 = C_3$)	2.22 kpF	Market
4	Capacitor (C_2)	0.225 kpF	Market


HIGH PASS FILTER
J1 SMA(M)
C1
C3
C5
C7
J2 SMA (F)
L1
L2
L3
C2
C4
C6

BAND STOP FILTER



Now the problem with the values of components for the notch filter was that they were not realizable. So to make them realizable some transformation had to done and after that transformation the values obtained are as given.

This technique is called "interleaving" and because of this it was possible to have the values that we can design in the lab.

Table 4.

4. Transformed Notch Filter -

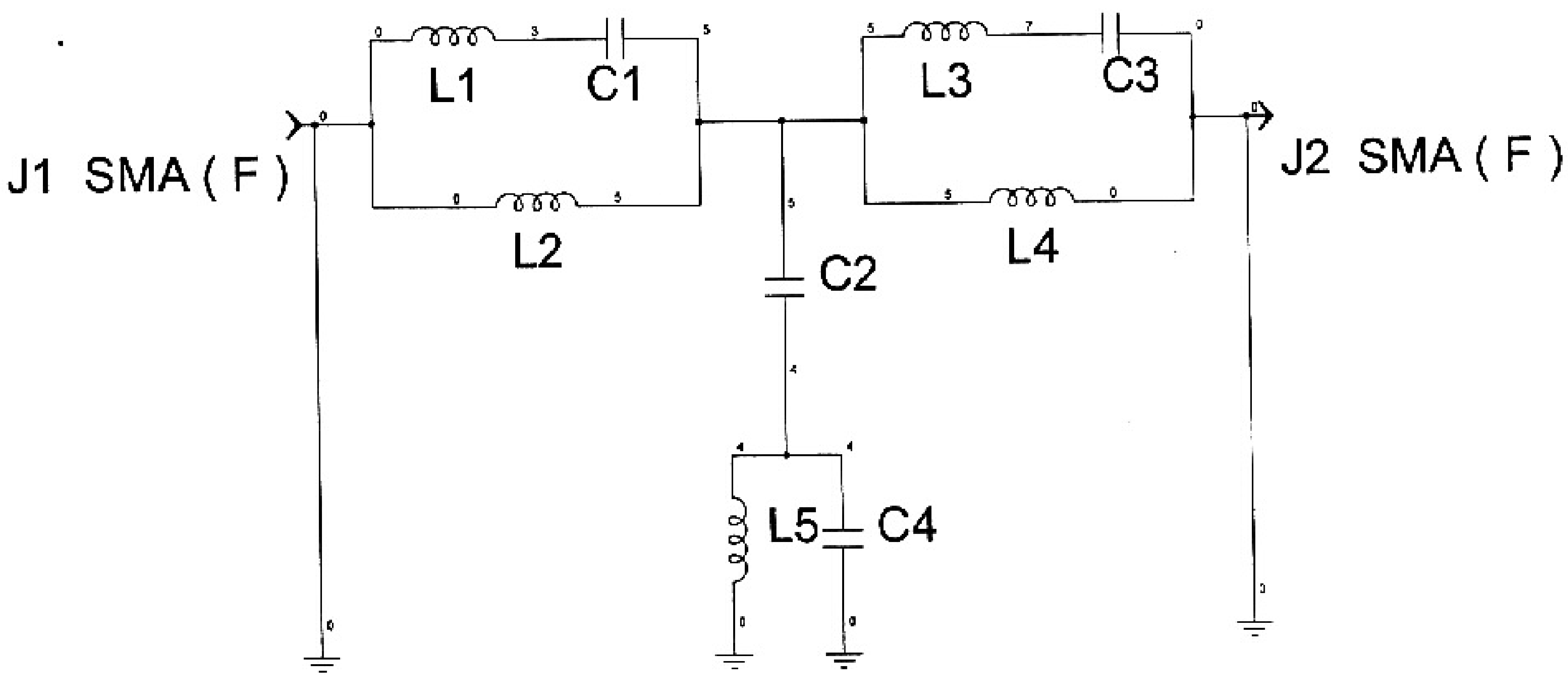
Sr. No.	*Components*	*Value*	*Source*
1	Inductor L1 = L3	267.7 nH	In Lab.
2	Inductor L2 = L4	11.9 nH	In Lab.
3	Inductor L5	9.62 nH	In Lab.
4	Capacitor C1= C3	4.024 pF	Market
5	Capacitor C2	5.125 pF	Market
6	Capacitor C5	111.6 pF	Market

Circuit Diagrams for the filters are given in figure 2, 3, 4, & 5.

PCB Considerations for filters (Layout and Artwork) -

As stated, we have considered surface mount technology for the PCB design . Though, the design principles are totally applicable to the switches PCBs. For such a high frequency circuits tracks on PCBs are to be considered as transmission lines along with their respective parameters and characteristics. These include characteristic impedance, cut-off frequency, attenuation characteristics, reflection losses etc. So while designing the track for PCB, we have to consider all these parameters . The design include track width , track length, and minimum separation between two tracks. The

TRASFORMED BAND STOP FILTER



matching of the tracks is also necessary with the characteristic impedance of the RF system we are concerned with to avoid the reflection losses. In our case the termination is 50 ohm .The width of track has to be done with the frequency of the RF signal it is passing . We are dealing with 150 MHz band so the design will be accordingly.

Another important point to be considered in the PCB design is the high frequency noise suppression. The noise in high frequency circuits is due to the fast varying signals . In this scenario we have to keep the ground line as a constant potential irrespective off the other lines . So in order to achieve this , it is recommended that the ground tracks should be as broad as possible (Rather they should have larger surface area) .

Implementation And Testing -

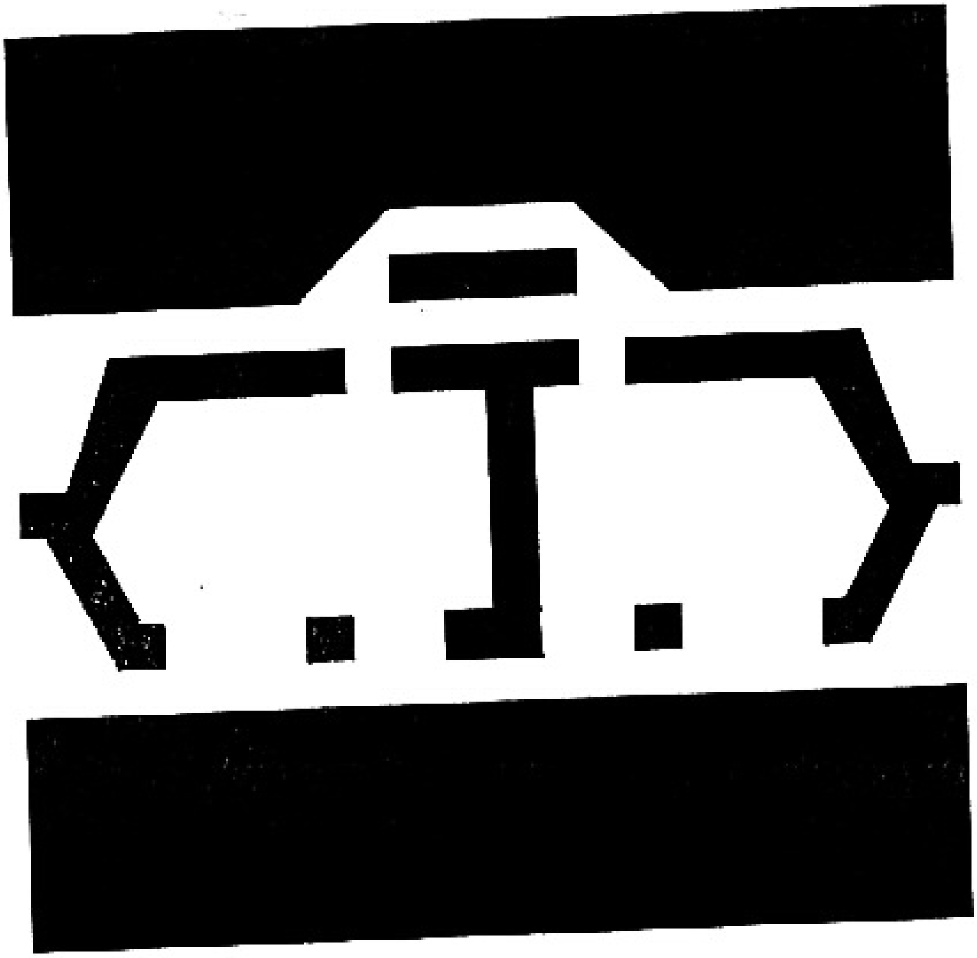
The equipments that were used during the making and testing of Filter Bank are listed Below.

1. Network Analyzer (HP 8714C).
2. Impedance phase gain meter (4194 A).
3. Spectrum Analyzer (8590L).
4. Noise figure meter (N8973A).

To design the Filter Bank First PCB layout was designed on a copper clad sheet using Bishop's tape. The PCB etching was done by using $FeCl_3$ solution. Now the PCB was wired and was placed in a suitable chassis. The components used were inductor and capacitor. The inductors were made in the lab. using copper wire and circular rode of suitable gage. The inductors value were checked on IMPEDANCE/GAIN-PHASE ANALYZER. The capacitors were taken directly available in the market.

The Chassis Dimension for band stop filter was 50 x 150 mm. In a single chassis three PCB were placed to have three separate notches at required frequency. And for Low Pass Filter and High Pass Filter Chassis used were of 50 x 50 mm. Filters were connected in a sequence and tuned as per the requirement.

The Chassis diagram for the filter is given in figure 6. This diagram shows the Front view, Elevation, & Plan for the chassis.



PCB DIAGRAM.

notch filter.pcb - Mon Jul 28 13:35:59 2003

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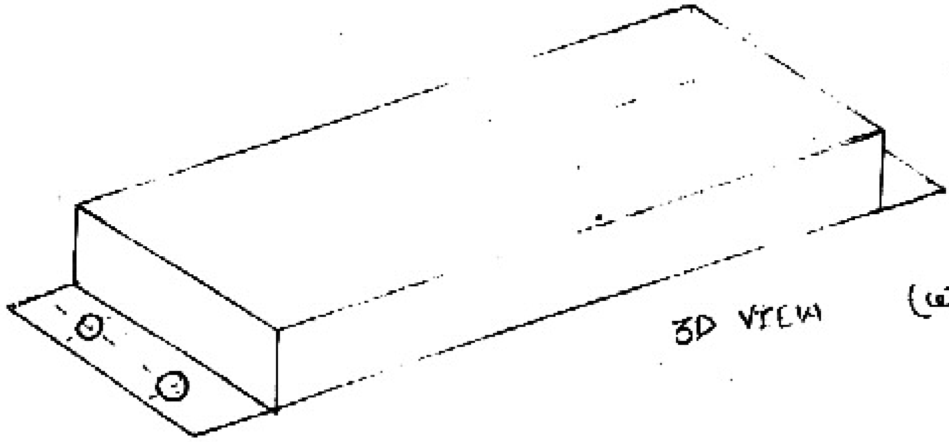

3D VIEW (without scale)

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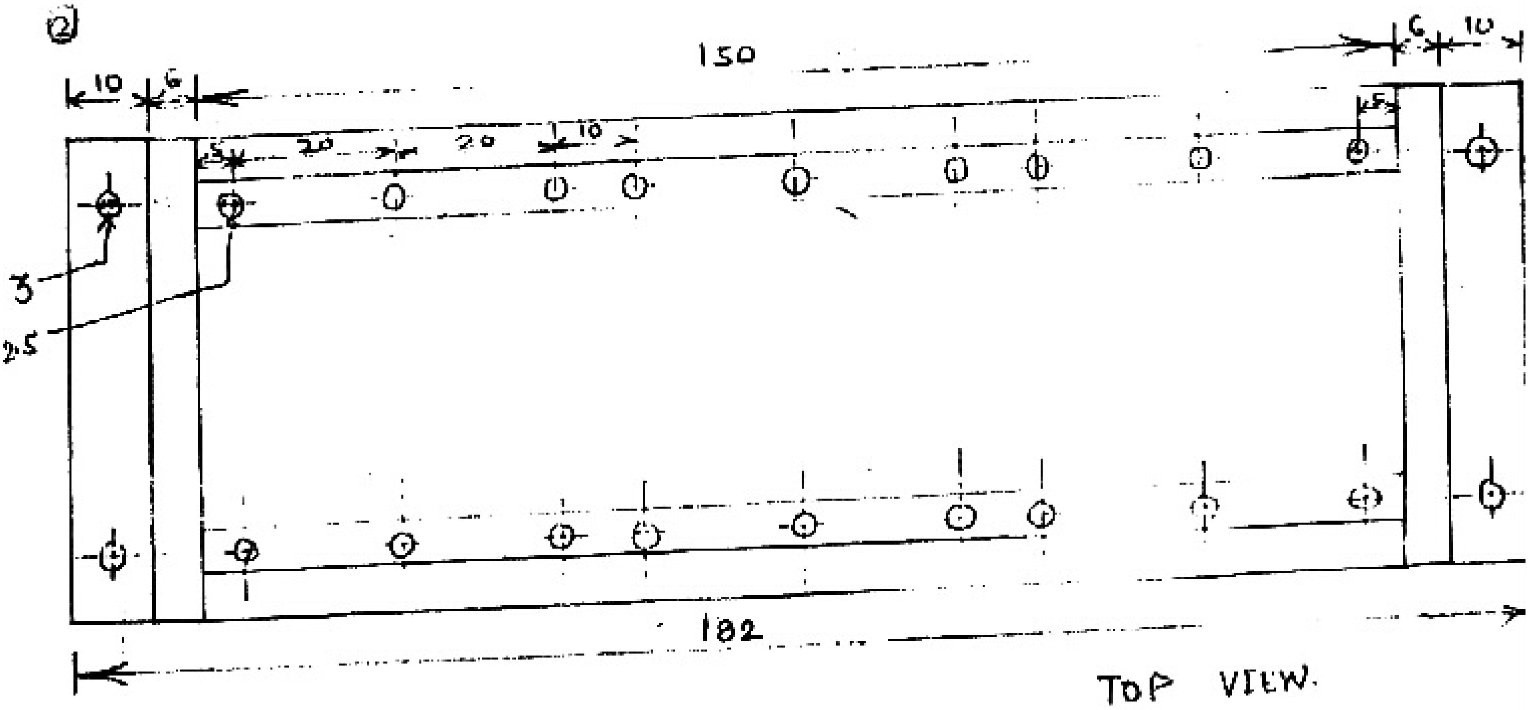

TOP VIEW.

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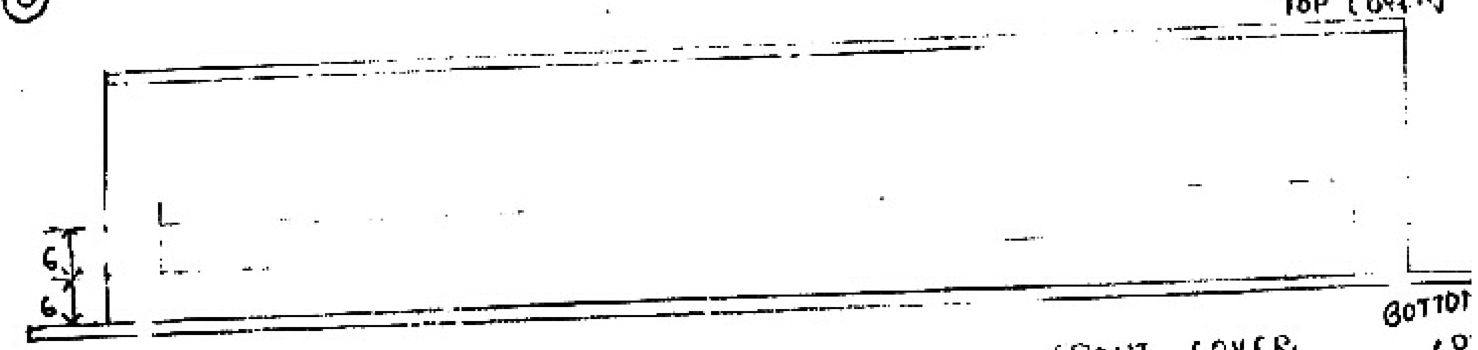

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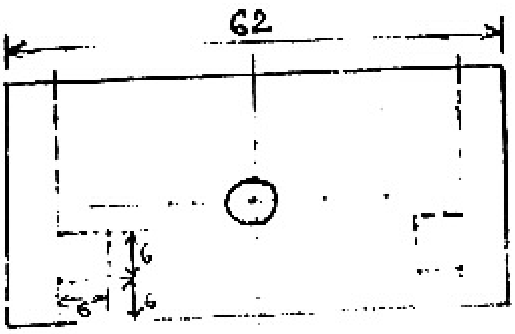


TNC CONNECTOR

SIDE VIEW.

NOTE →
ALL DIMENSIONS ARE IN mm.

The set-up to check the filter's response is given below.

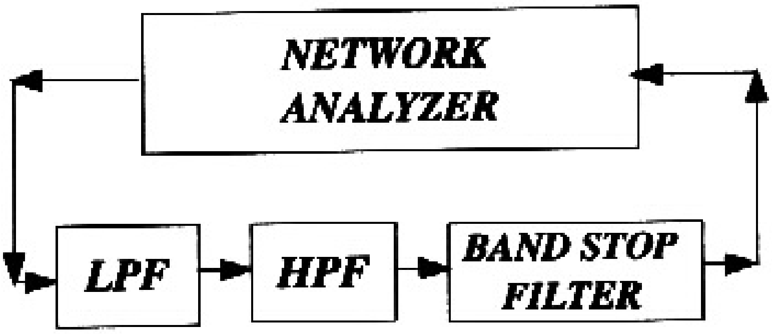


Fig 7. Block diagram of filter checking

When filter was placed between spectrum analyzer and front end output the diagram look likes as given below.

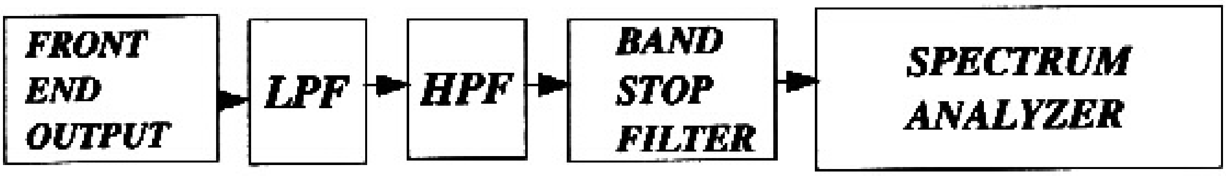


Fig 8. Block diagram of testing

When filter is not placed between them then it looks like.

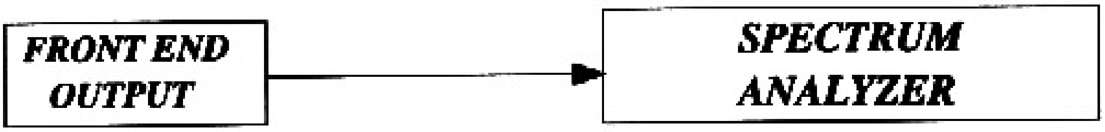
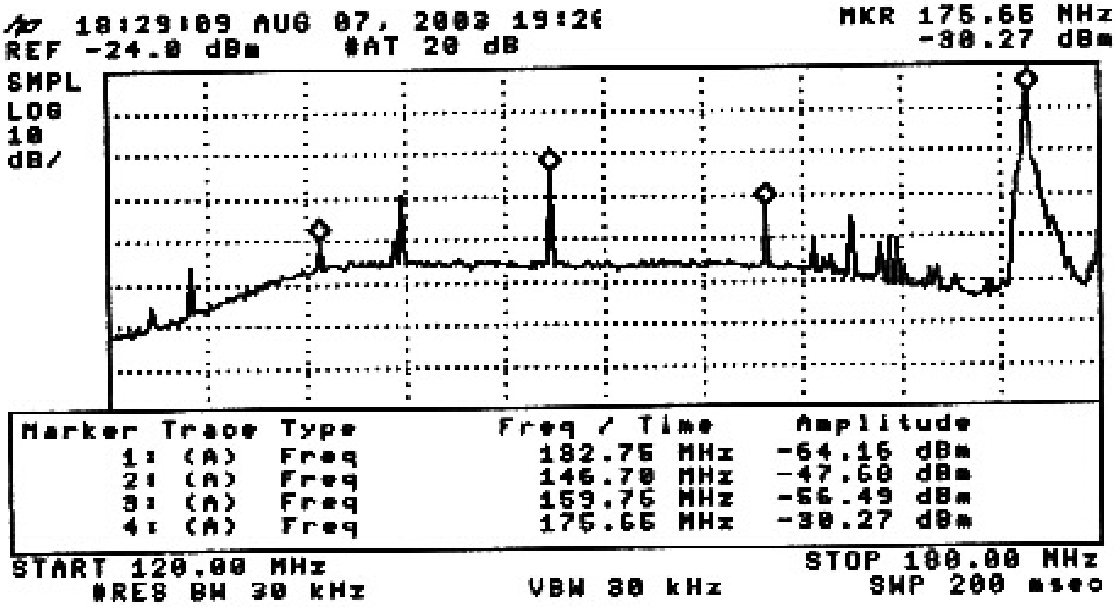
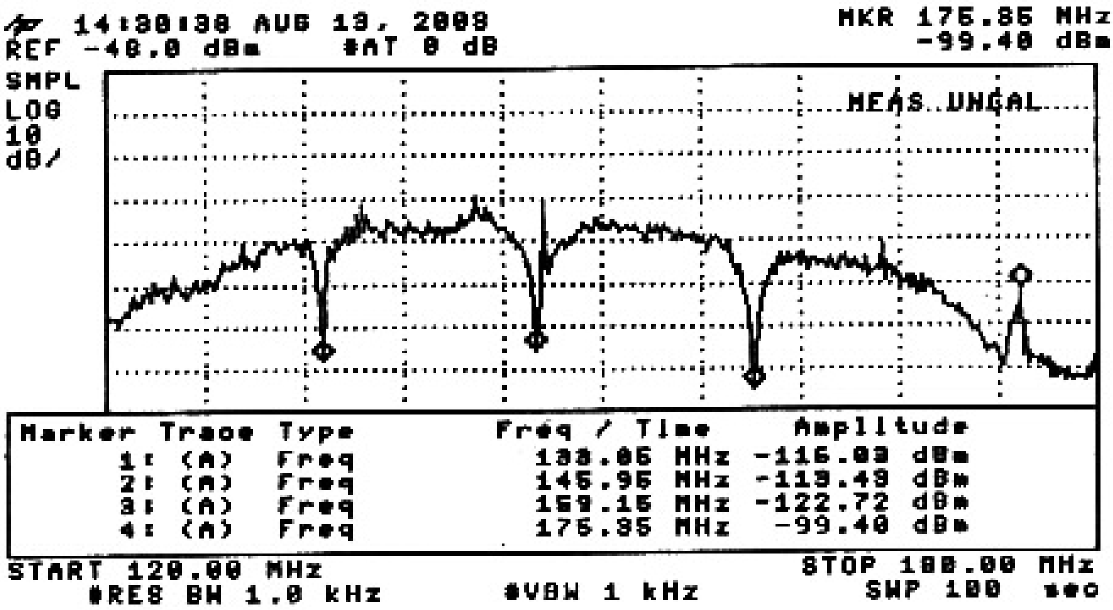


Fig 9. Block diagram of testing

The Filter was tested at the antenna base and the two spectrum were obtained for the 150 MHz band . One before inserting the Filter Bank and second one after inserting Filter Bank.



Spectrum at 150 MHz without inserting Filter Bank



Spectrum at 150 MHz after inserting Filter Bank

Conclusion-

In this way the project was completed successfully and the minimum bandwidth that is possible with the components having low Q value compare to directly available in the market was achieved. The filter bank was tested and required results were obtained .

The spectrum obtained clearly shows that interfering lines at 133 MHz and 159 MHz were suppressed by Filter Bank while At 146.7 MHz it need some tuning of Filter Bank.

We, thus, hereby conclude the report with the fond hope that the work done during this project will, in future, be of help to astronomers using GMRT at Khodad, Pune.

Future Scope -

Any system, however meticulously designed, always has scope of improvement and upradation. This fact, but naturally, applies to our system also. So we thus suggest some upgradations which could be implemented with advantage in this project.

By this filter bank the minimum bandwidth that was achieved is around 2.5 MHz, so we can think new ideas to reduce this to a low level. For this most plausible area of improvement is to increase the order of filters as the order taken in this filter with LPF and HPF is 5th while in case of Notch Filter it is 3rd. As by increasing the order bandwidth will be reduced and rejection will increase. The same effect will be seen if the components having high value of Q is used that are available in the market.

We can plan to make the filter by using micro-strip lines as in case of micro-strips low values of capacitance and inductance can be realized easily and that will not require any transformation as we have done in it.

The resonating cavities can also be considered as they have a very narrow band of rejection. So we can think to make the Band Stop by this also.

Some study is also required to find out the correct position of filter bank i.e. whether it has to be in antenna base or in front-end box and the way in which this will be placed with LNA as it was not considered here.

Acknowledgment -

I would like to give hearty thanks to Mr. *Prof. S. Ananthakrishnan*, observatory director, GMRT to give me a chance to work here in GMRT as an STP. I would also like to express thanks to Mr. A.B Joshi.

I am indebted to my project guide Mr. Ajith Kumar B.,without whose valuable guidance this project would not have been possible. I express my deep gratitude to him for his constant encouragement and support throughout the course of the project. I thank him for his immense help in successful completion of the project.

I would like to express sincere gratitude towards Mr. Jyanto Roy for keenly following up my progress in the project. I owe thanks to Mr. Prakash Hande, and Mr. Sandeep Parakhi, for being a guiding force behind all efforts. I also express thanks to Mr. Pravin Kumar who also guided me time to time.

I highly acknowledge the help of Mr. Ramdas, without whose help, the project would not have been implemented satisfactorily, in the stipulated time.
I would also like to give thanks all the staff members of the E-Lab with whom I could completed my project.In the last but not least thanks I wish to thank all the staff members of GMRT project site, for making my work here a memorable one.

References -

1. Arthur B. Williams and Fred J. Taylor, "Electronic Filter Design Handbook".

2. Phillip R. Geffe, "Novel Designs For Elliptic Band Stop Filters" RF Design Journal,P 75-76,Y February 1999.

Web sites-

1. www.sigtech.com
2. www.rfdesign.com

Annexure 1.

Existing Front End System -

The existing front end (FE) system for the 150 MHz band gets its input from two orthogonal pairs of folded thick dipoles at spacing of approximately half wavelength placed in a quad formation over a plane reflector. The response VSWR vs. FREQUENCY of these is shown in figure 1.

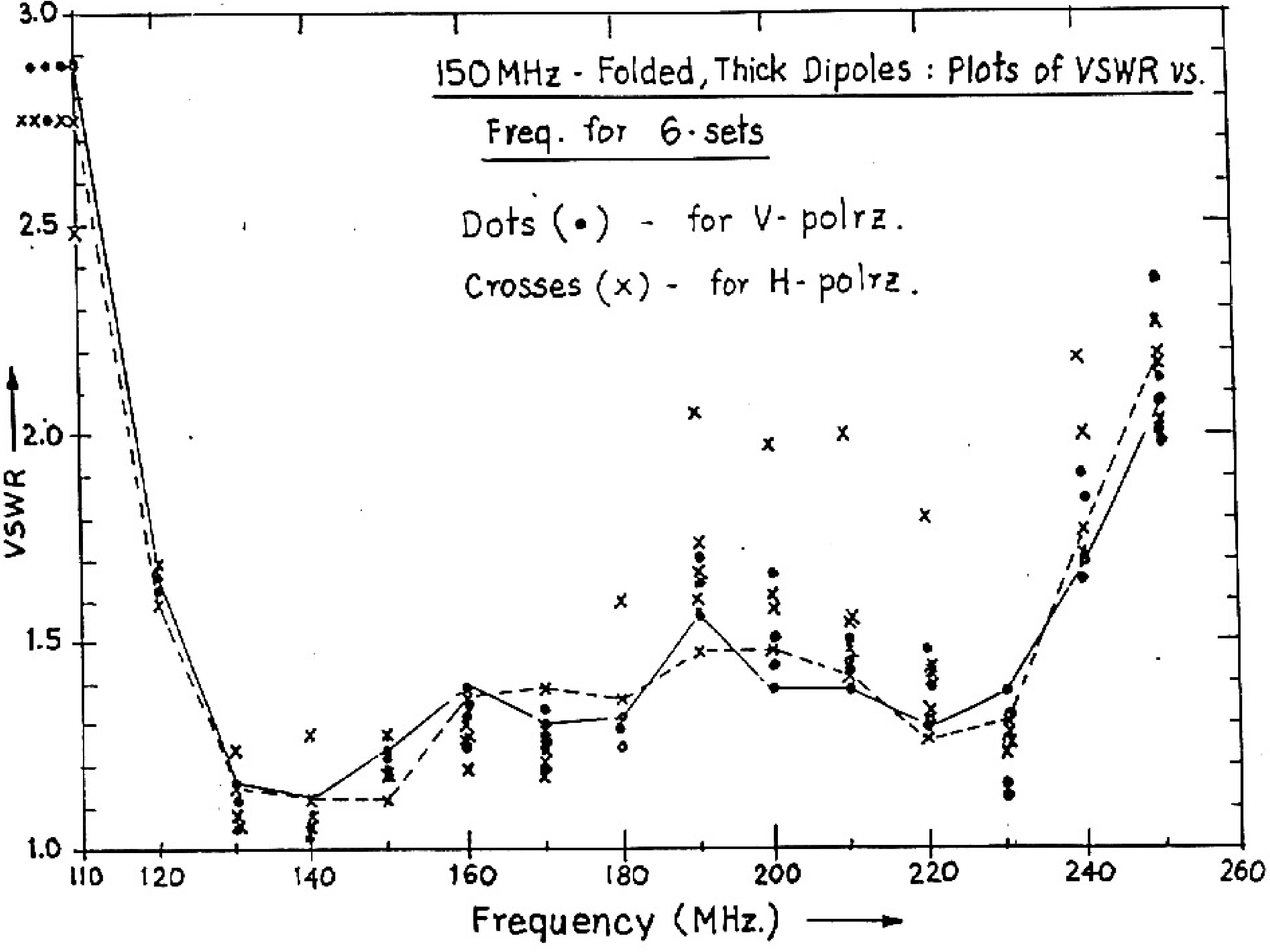
Figure 1.

This plot shows that the present useful range for this feed extends from 120 MHz to 240MHz, i.e. VSWR<2.

The inputs from the pair is processed by the combiner (one per channel) and the polarizer . The noise output is then coupled to both the channel using directional couplers. The signal is then amplified by the LNA's which have a gain of 32 dB and a bandwidth in excess of 100MHz .Next ,the signal is band limited by using bandpass filters (one per channel).These BPF's are centered at 150MHz and a 3-dB rejection at 150 ± 50 MHz. The insertion loss is less than 0.5 dB in the pass band . The signal is then amplified by the post amplifier . Hereafter , the signal is modulated with Walsh function using the phase switching to reduce the effect of coupling between the different channels .

The RF on/off facility is also provided for connecting or disconnecting a channel by means of RF switch. The signal is then sent to the common box which incorporates the band-selector and the solar attenuator. The entire FE box electronics is controlled by the Radio Frequency Control and Monitor (RFCM) card. The RFCM card gets its controls from the MCM cards via the MCM interface card. The RFCM card provides the noise generator bias , the LNA bias , the post amplifier bias ,the level shifted Walsh functional signals. It also provides for the RF on/off and the noise generator controls. The filter selection bits are also provided for which are, at present, unused.

An additional card gets the control data from the MCM interface card and in turn from the MCM 2 which provides the Walsh function signals , noise on/off , MCM on / off (for MCM 5). The power supply is derived from FE power supply of ± 17 volts.


150 MHz - Folded, Thick Dipoles : Plots of VSWR vs. Freq. for 6-sets
Dots (•) - for V-polrz.
Crosses (x) - for H-polrz.
VSWR
3.0
2.5
2.0
1.5
1.0
110
120
140
160
180
200
220
240
260
Frequency (MHz.)

Anexture 2.

Filter Basics-

1. Filters -

Filters are necessarily reactive circuits that will pass desired band of frequencies while almost totally rejecting or suppressing the other band of frequencies. In receiving system the first task happens to be the selection of the band of interest from the wide spectrum of the wide spectrum of the feed of the receiving antenna. This selection is invariably done using bandpass filters. This has to be done before any further processing i.e.just after the feed of the receiving antenna. This filtering principally serves to limit the total unwanted signal of excessive amplitude . In the GMRT receiving chain , they are located in between the LNA and the post amplifier and the phase switch circuitry .Thus , as mentioned all ideal filters s
should pass all the frequencies in a given band without reduction in magnitude called pass band and totally suppressing all other frequencies called stop band. However , such ideal performance is not possible but can be approached with complex designs , if the need warrants. In this light, many filter approximations have been suggested .

2.Types of Filters -

Electronic filters can be classified on the basis of the type of components/ devices used, the band of frequencies they select , and the exact nature of the transfer funcion which tries to approximate the ideal characteristic.
The filters are classified according to the type of components / devices into active and passive filters .A number of limitations and factors must be considered before choosing to use either of two . Some of these are given below :

1.Frequency limitations : At sub-audio frequencies LC filter require high values inductance and capacitance along with their associated bulk. Active filters are more practical because they can be designed at higher
impedance levels so that capacitor magnitudes are reduced . But above 50 KHz , most commercial grade operational amplifiers have insufficient open loop gain for the active filter requirement . LC filters , In contrast , are practical at frequencies up to few hundred MHz . However beyond this range , filters become impractical to be

built in lumped form , and so distributed parameter techniques are used .

2. Ease of adjustment : In critical LC filters , tuned circuits require adjustment to specific resonances . Capacitor cannot be made variable unless they are below a few hundred picofarads . Inductors , however can be easily adjusted , since most all coil structures provides a mean for tuning . On the other hand , the active filter circuits are not easily adjustable so they may contain RC sections wherein two or more resistors which have to be varied simultaneously.

3. Economics and ease of manufacture : LC filters generally cost more than active filters because they use inductors. High quality coils require efficient magnetic cores . Sometimes special coil winding techniques and skills are required . Active filters have the distinct advantage that they can be easily assembled using of the shelf components with ease . Furthermore , active filters , by virtue of having no inductors can easily integrated on a single chip using microelectronics technology . Apart from miniaturizations , this ensures reliable replication of circuits in case of mass production.

Based upon the band of frequencies selected the filters are classified into Low-Pass , High-Pass,Band-pass, and Band-Stop filters.

Principally , the different filters are classified on the basis of the nature of their transfer functions i.e. the frequency and the phase response in the pass band and the rate of roll-off in the stop band . Modern network theory has provided us with many different shapes of frequency responses which have been analytically various restrictions on transfer functions.
The major categories of these are :

1. Buterworth .
2. Chebshev .
3. Bessel(Linear phase) .
4. Transitional .
5. Synchronously tuned .
6. 6.Elliptic function.

The Butterworth approximation to an ideal low pass filter is based upon on the assumptions that a flat response at zero frequencies is more important than response at other frequencies . This approximation results in a class of filters which have moderate attenuation steepness and acceptable transient characterestics. their element values are more practical and less critical than those of most other filters. The rounding of the frequency response in the vicinity of cutt- off make these filters undesirable where a sharp cut-off is required ; nevertheless they are recommended wherever possible b because of their favourable characteristics.

The Chebshev approximation to an ideal filter has much more rectangular frequency response near the cut-off than the Butterworth family of filters. This is accomplished at the expense of allowing ripples in the pass band . Chebshev filters have more delay variation in their pass-band . As the pass band ripple is made larger , the rate of rol-off increases ,but the transient properties rapidly deteriorate . If no ripples are permitted , the Chebshev filter degenerates of Butterworth. The Chebshev function is particularly useful where frequency response is the major consideration . It provides the maximum theoretical rate of roll-off any pole transfer function for a given order . Odd order Chebshev LC filters have zero relative attenuation at DC ; even order filters , however have a loss at DC equal to the pass-band ripple. As a result , the even order filters must operate between unequal source and load resistances ,whereas for the odd ordered ones the source and the load may be equal.

The Bessel transfer function has been optimized to obtain a linear phase , i.e. maximally flat delay. The step response has no overshoot or ringing and the impulse response lacks oscillatory behavior . However the frequency response is much less selective than other filter types . This restricts the use of these filters where transient properties are the major consideration.

Transitional filters have a near linear shift and a smooth amplitude roll-off in the passband . Outside the pass-band , a sharp break in the amplitude characteristic occurs. Beyond this breakout the attenuation increases quite abruptly as compared to

Bessel filters especially for higher orders. Synchronously tuned are the most basic filter type and are the easiest to construct and align. They consist the most multiple poles . The transient properties are near optimum . The step response shows no overshoot at all and the impulse response lacks oscillatory behavior . But , the poor selectivity of these filters limits their application to circuits requiring modest attenuation steepness and simplicity of alignment.

Component Consideration -

In our design ,we have designed passive filters for our requirement . Since the operating frequency of these filters is very high,component specifications ,as well as PCB design need special attention.

1. Inductor Considerations -

In the design and selection of the inductors the following specifications of inductors are considered :

1. Core material
2. Area of core
3. Gage of metal wire used for winding
4. Number of turns of winding

The type of core material to be used depends primarily upon the frequency of operation and the value of the inductor to be realized . For low frequencies , ferrite or iron cores can be used . But , for radio frequencies ,which are of particular concern to our filters , these core materials cannot be used ,because these materials introduce large losses at thses high frequencies . The losses are mainly due to the eddy currents which are set up inside the core .
As the signal energy is not of much significance we can neglect the losses due to the hysteresis effect. The eddy current losses become severe , particularly at high frequencies . Air core inductors are thus recommended for high frequency applications, as these inductors do not saturate (since relative permeability of air is unity).

The second and important reason for using air core inductors is the range of values of inductors are to be realized . Inductors of very small values , of the order of nanohenries can be realized only by using air as their core.
In our case the design values of inductors are of the order of nanohenries , which are to operate in radio frequency
range . So , but obviously , air core inductors emerge to be the best choice of our design. Copper wire is generally used for winding purpose . The brass rodes of different diameters (4.5 mm ,4 mm ,3.5 mm , 2.5 mm) are used in order to wind the copper wire. The exact formula for designing the air core inductor is as given below -

$$L = N^2 r^2/(9r + 10\,l)$$

Where

L = Inductance in micro henries .
N = Number of turns .
r = Radius of core in inches .
l = Length of coil in inches .

By choosing proper core size and gage number of the wire for the given value of the inductor , number of turns can be decided . For maximum coupling , we assume

l = NR where R = wire diameter.

Though the method seems straight forward , in practical case there is a lot of trial and error approach that is to be applied while tuning for the filters . So the theoritical and practical designs may differ to great extent . This disparity is due to stray inductance present in the tracks of the filter PCBs , antenna effect present in the designed inductors , mutual inductance present between two inductors and also that between PCB track and the designed inductors . Due to these factors practical designs deviate from the theoritical.

Capacitor considerations -

The capacitor to be selected are in the range of picofarads. The selected capacitors should be high frequency capacitors . The chip capacitors are the best option for such applications . For the fine tuning of the filters , these chip capacitors along with variables capacitors are used.The reason for using the chip capacitors is due to their leadless form. Because the lead may show an antenna effect at such a high frequency . So the design may go wrong. The chip capacitors are necessarily surface mount devices . So PCB design for filters is done confirming to these devices. The variable capacitors are in the range of 2 - 18 pF.

Annuxure 3.

Plots For Filters -

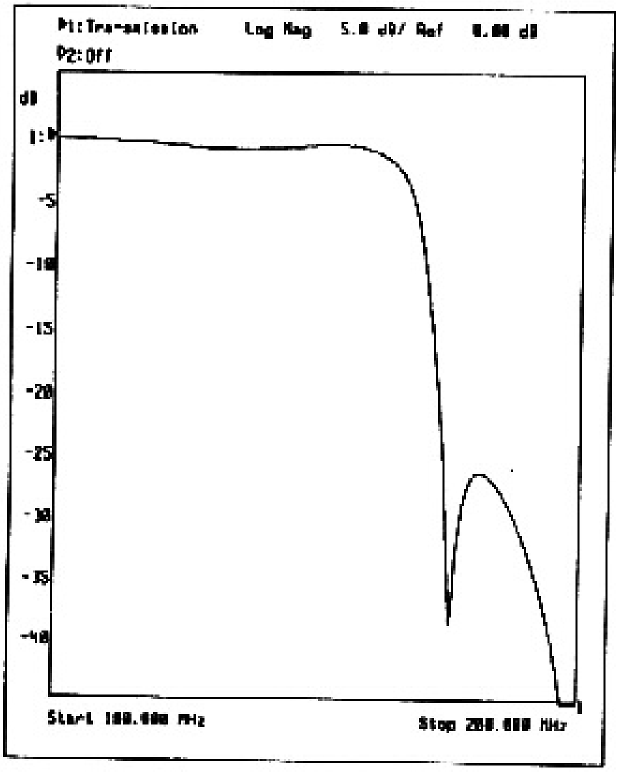
Here plots obatined during checking the response of filters are attached. The plots are for Low Pass, High Pass, Band Stop & Transformed Band Stop filters. Every plot has information about the following characteristics.

1. Insertion Loss.
2. Group Delay.
3. Return Loss.
4. SWR.

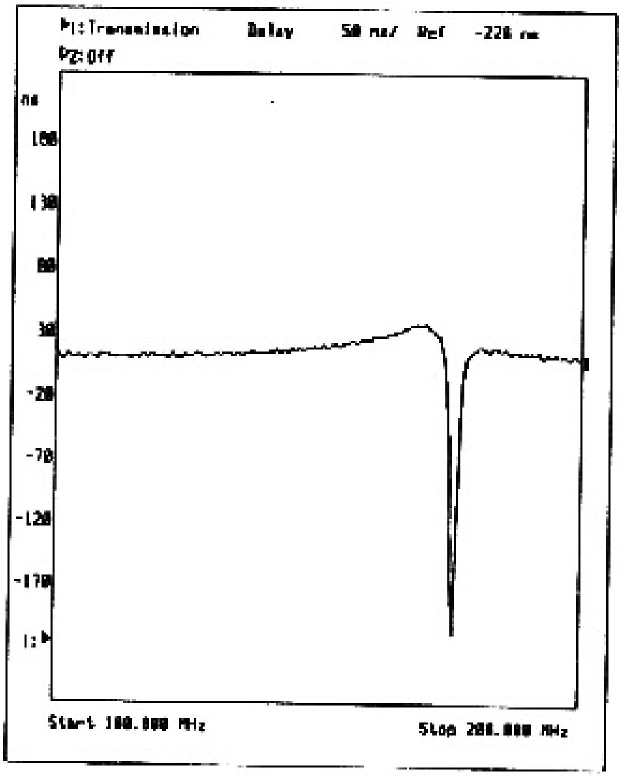
These characteristics fully explains the nature of filters.

LOW PASS FILTER RESPONSE

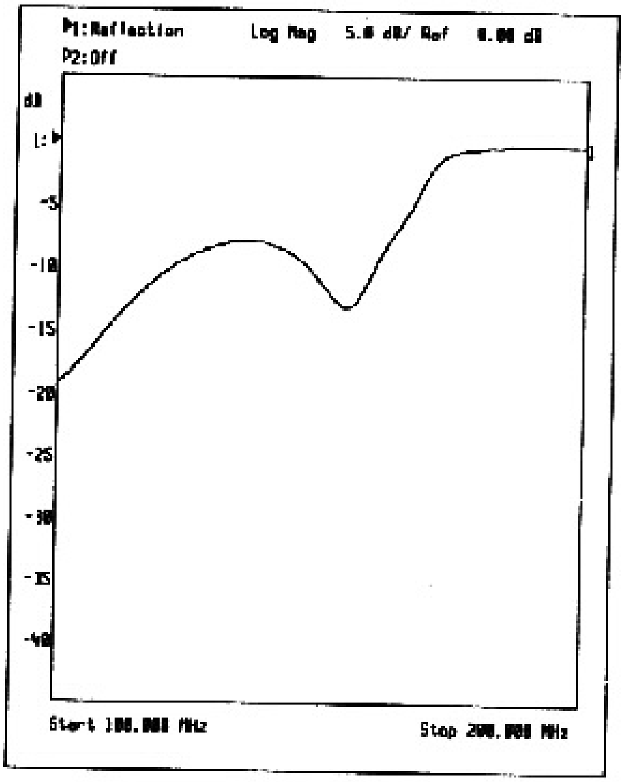
Unit No. 002



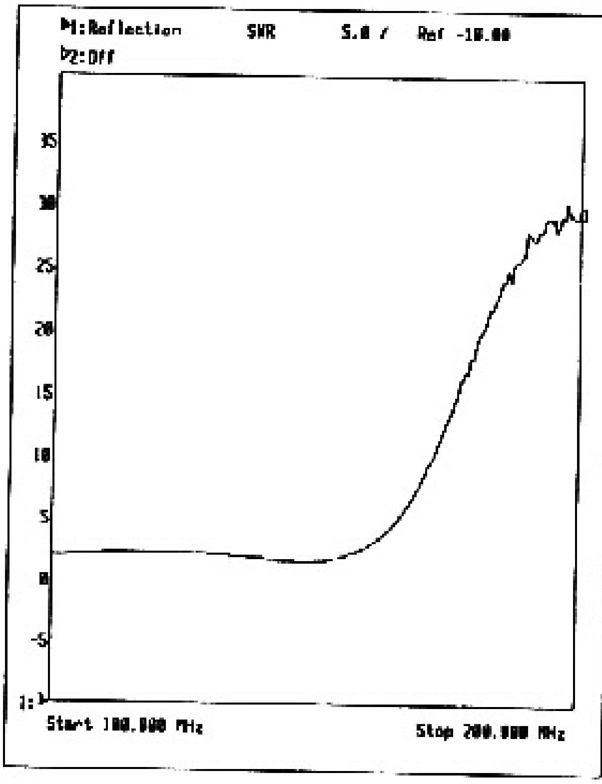
Insertion Loss



Group Delay



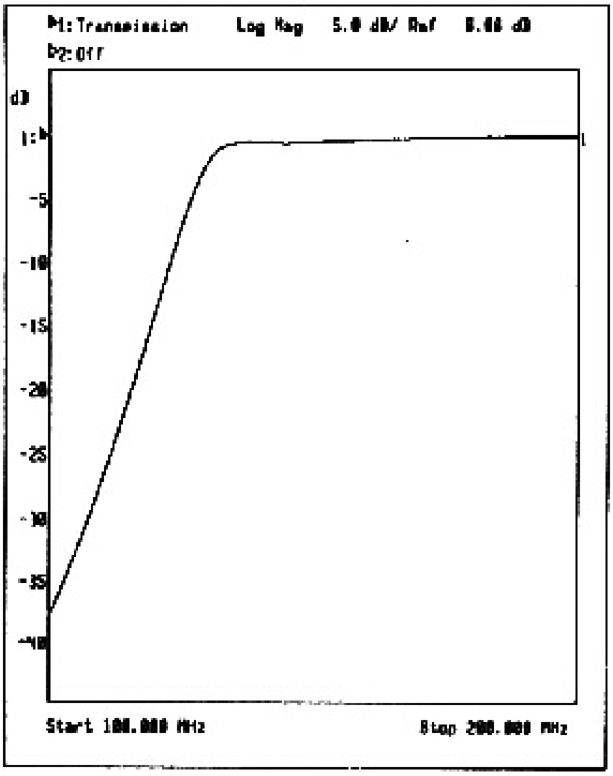
Return Loss



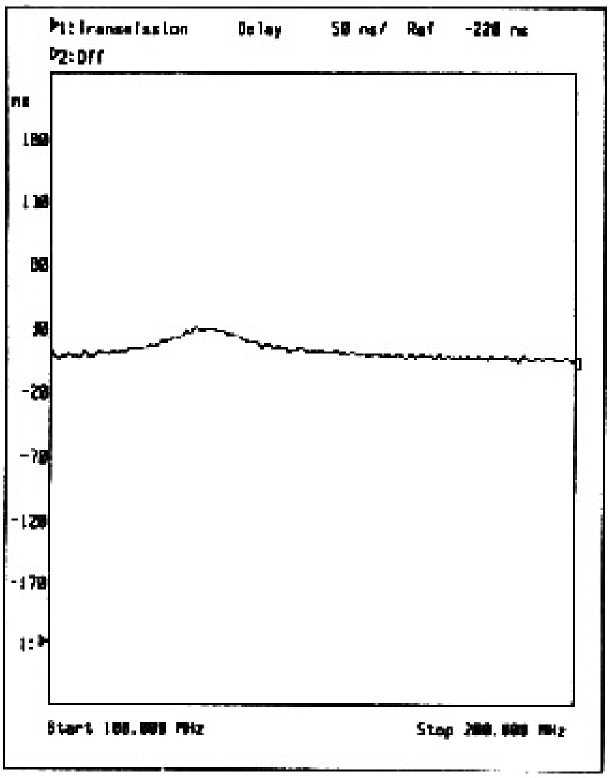
SWR

HIGH PASS FILTER RESPONSE

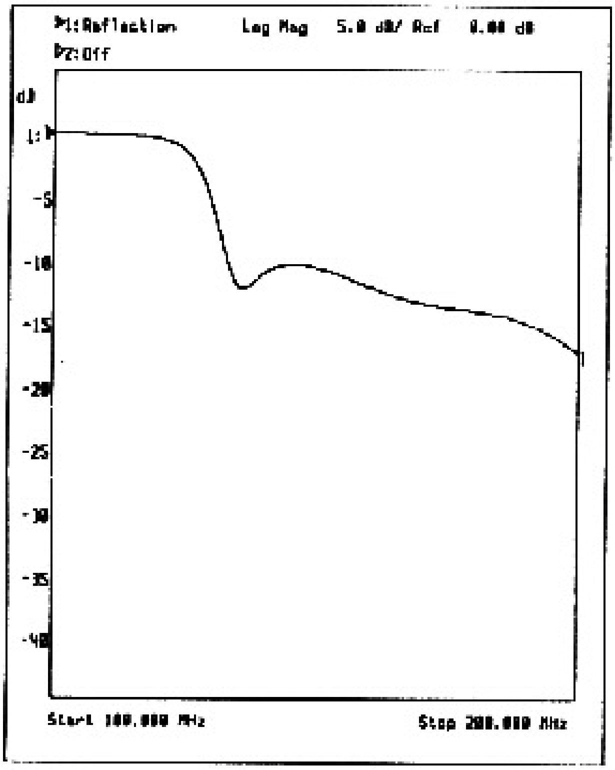
Unit No. 002



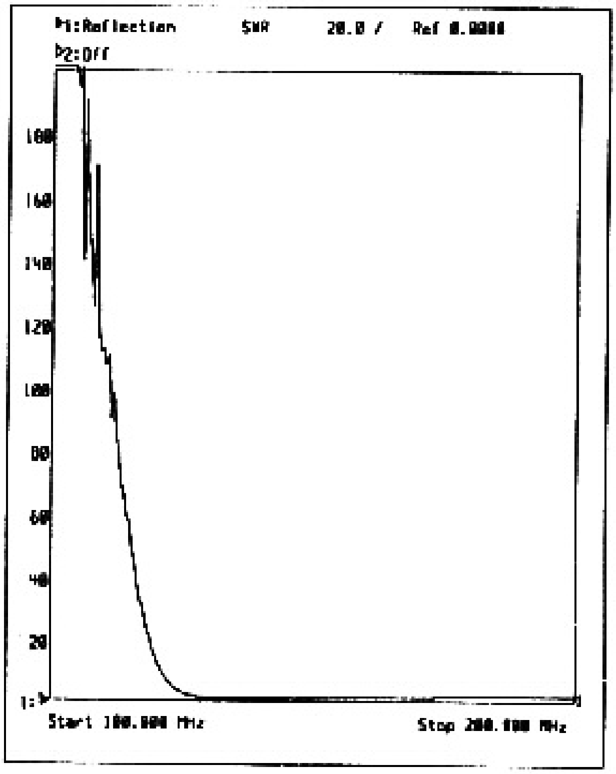
Insertion Loss



Group Delay



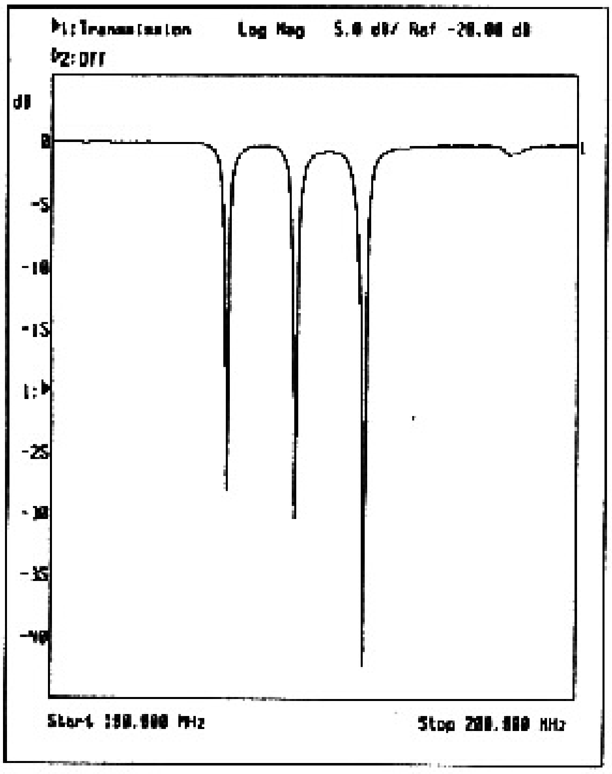
Return Loss



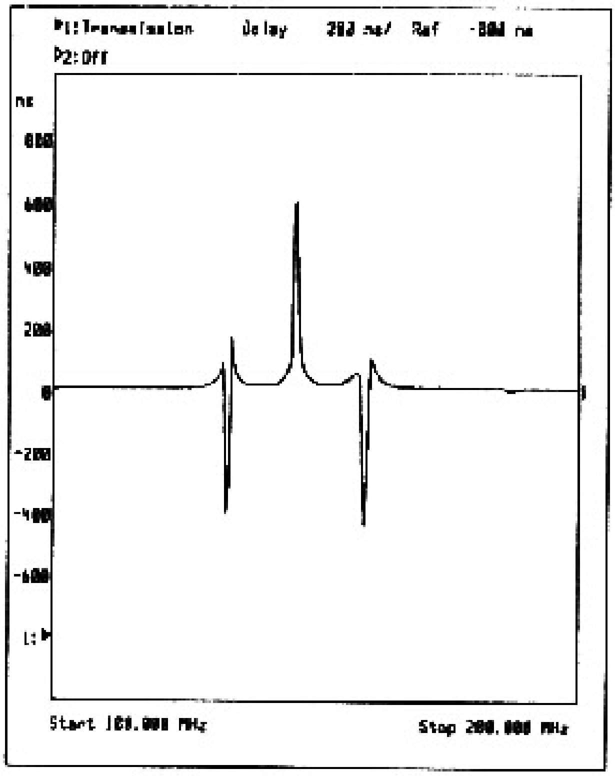
SWR

BAND STOP FILTER RESPONSE

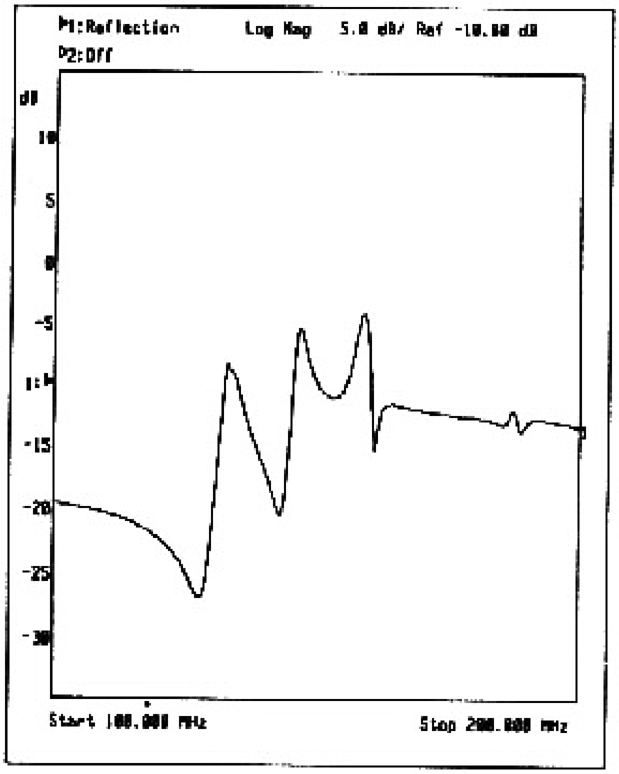
Unit No. 002



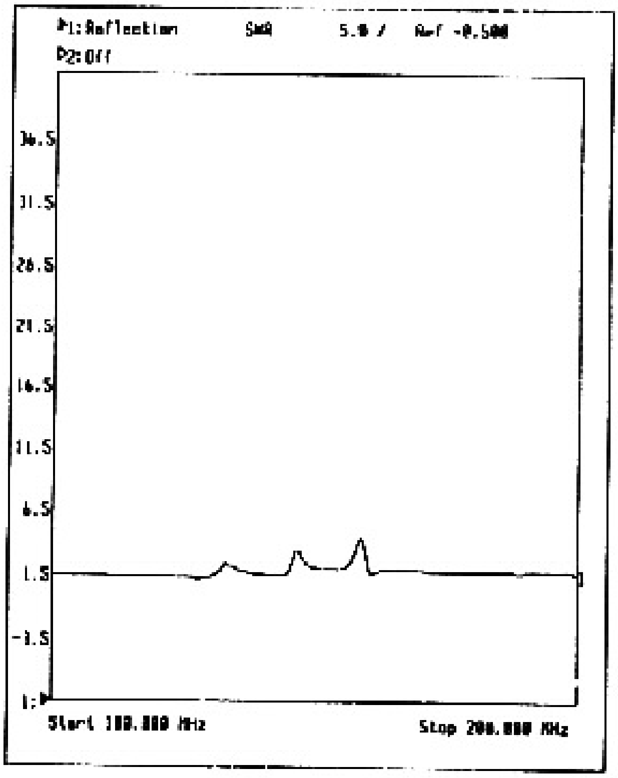
Insertion Loss



Group Delay



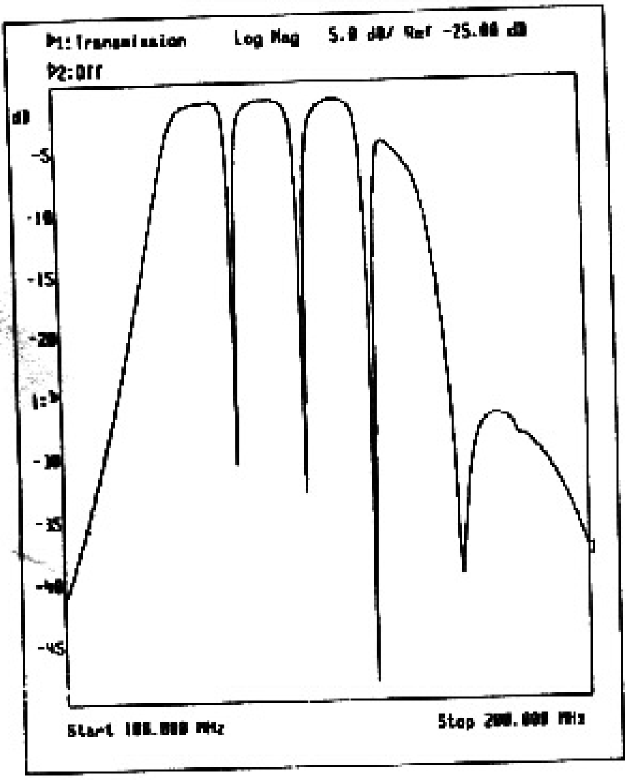
Return Loss



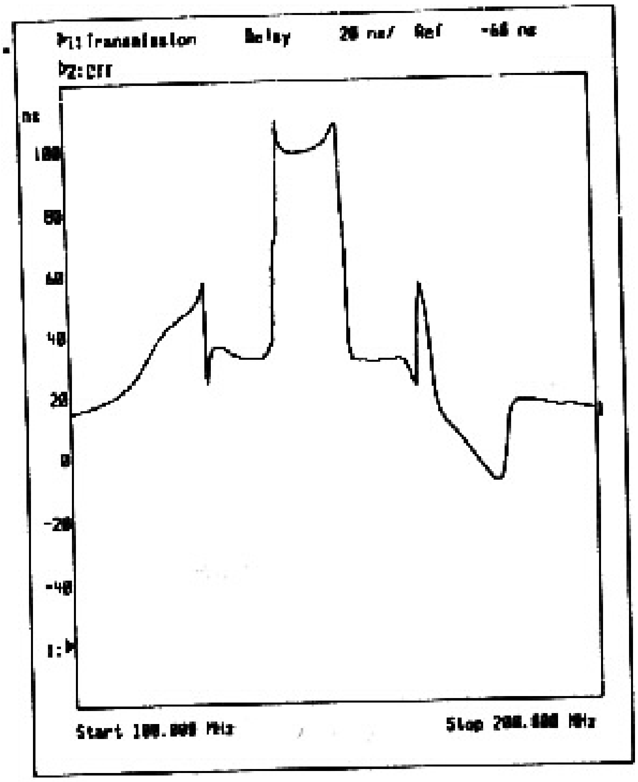
SWR

FILTER BANK RESPONSE

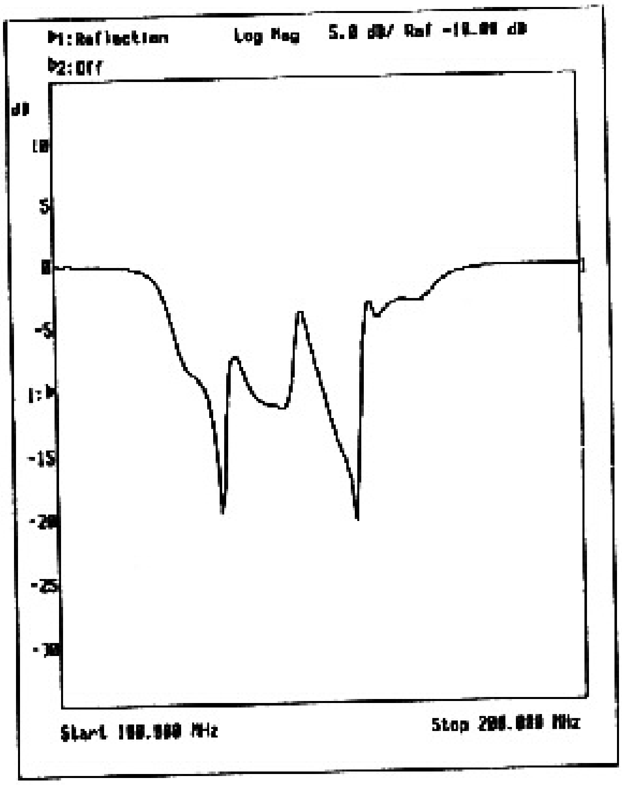
Unit No. 002



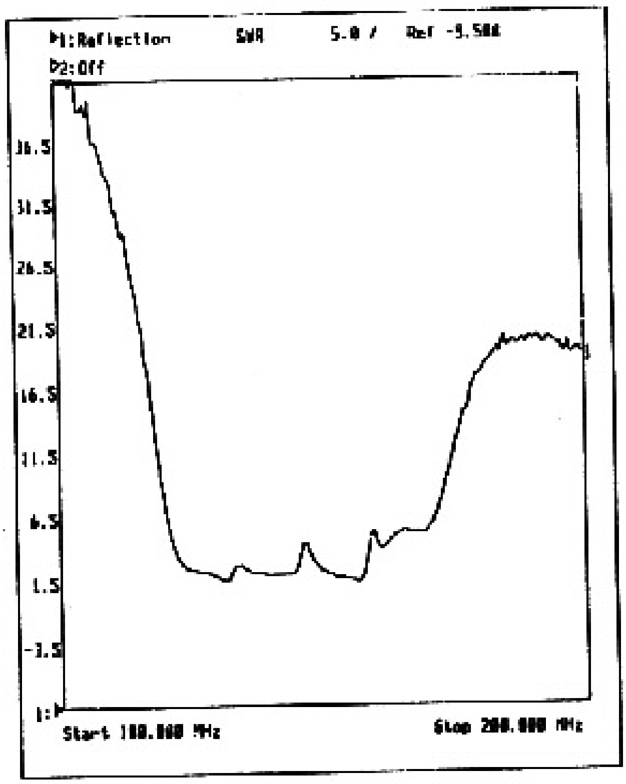
Insertion Loss



Group Delay



Return Loss



SWR