Design Of L Band Cavity Filter For GPS Receiver

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***Abstract*—Filters play a critical role in RF and Microwave systems and the type used depends on the application. It is used in the receiver front end to improve selectivity and in transmitter for spurious /harmonic rejection where low insertion loss and narrow bandwidth are the major requirements.**

This paper, deals with the design of a narrow band cavity filter in L band with centre frequency of 1575.42 MHz. It is planned to use at the front end of a GPS receiver where the system has to withstand the harsh environment of launch vehicle. The cavity filter is designed for the required specification, simulated and optimized using the software Advanced Design System (ADS) and ElectroMagnetic Professional (EMPro).

***Index Terms*— Cavity filter, ADS, EMPro, GPS receiver.**

I. Introduction

GPS is a satellite based radio navigation system by the US Department of Defense in which the L1 carrier (1575.42 MHz) is available for public domain. GPS receiver will provide location and time in all weather, day and night at anywhere in the world. For launch vehicle application this is used for tracking the vehicle with better accuracy and the system has to work in the harsh environment. The signal received in the launch vehicle from GPS satellite is around -125 dB in which strong spurious signal near the carrier can desensitize the receiver. To avoid this, a filter with high Q and low insertion loss is required at the front end of the LNA in the receiver maintaining over all system noise figure low.

Microwave filters are of different types based on frequency, Q value, insertion loss and shape factor. Lumped element filters, Ceramic filters, SAW filters, Crystal filters and Cavity filters are some examples of such microwave filters. For high Q value filter applications, lumped component filters are not suitable. SAW filters and Crystal filters have high Q value but have large insertion loss, very difficult to tune and have extremely low power handling capability. Ceramic filters have low power handling capability, unstable at higher temperatures and also produce vibration related issues. Cavity filters having high Q with sharp stop band rejection, low insertion loss, high power handling ability and narrow bandwidth is suitable for this application.

This paper discusses about the design and development of cavity filter in L band with centre frequency of 1575.42 MHz. The simulation work is performed using ADS and EMPro software.

The paper is organized as follows. Section II describes about cavity filter, important types and the reason for selection of particular type for this application. Section III discusses about the design of cavity filter. Section IV describes about the simulation works, section V the results and finally conclusion in section VI.

II. Cavity Filter

It is a mechanical filter which employs mechanical structure to pass a certain range of frequencies with very narrow bandwidth and to reject all other unwanted frequencies by bouncing back to the source of the signal. Cavity filter is made with series of resonators that are mounted in the cavity to act as L and C. The resonators are shorted at one end and have distributed capacitances at the other end. The distance between resonator and distributed capacitance act as capacitor where the distance between two resonators acts as inductor. Cavity filter provides very high Q in the range of 1500-3000. The structure of resonator affects the frequency response in large and the equivalent circuit of cavity filter is shown in figure.1. Shunt inductor and capacitor pairs represents individual resonant elements and the series inductors represent the magnetic coupling between resonators.

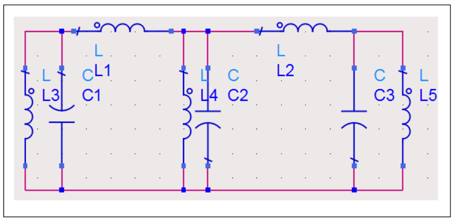

Fig. 1. Equivalent circuit of cavity filter

Different types of cavity filters exist and are selected according to the specific application with better results. Some of the important types of cavity filters generally used are explained below.

A. Combline Cavity Filter

This type of filter is used for wider band width applications, up to 15% of centre frequency. These filters are extensively used in mobile and satellite communication systems because of the advantages like low loss, high rejection, compact size, simple structure, wide tuning range and higher power handling capability.

The design structure with three resonators is shown in figure.2. It consists of long cylinders (resonators) and buckets (lumped capacitance). The long solid cylinders are connected to the top of the cavity, the buckets are connected to the bottom of the cavity. The resonators don't extend to the bottom. With the lumped capacitors the resonator lines will be less than λ/4 long at resonance, and the coupling between resonators is predominantly magnetic in nature. If the capacitors were not present the resonator lines would be a full λ/4 long at resonance. In this kind of filter the walls of the cavity, the long cylinders, the buckets under the cylinders and the disk shaped objects near the first and last cylinders are all made of metal. The disk shaped objects near the first and last resonator are connected to the input and output transmission lines and provide the necessary coupling to the source and the load, are known as pan antennas. The cylinder-bucket combination act as a resonating structure. The number of resonators required depends on the filter specifications.

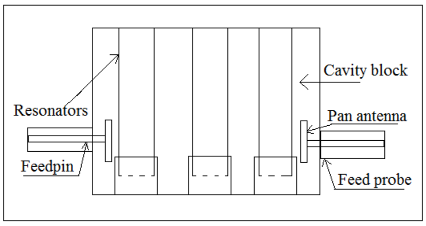

Fig. 2. Structure of combline cavity filter

B. Iris Coupled Cavity Filter

Iris coupled filter is widely used for narrow band (less than 1% of centre frequency) applications with low insertion loss. Similar to combline cavity filter, this also has cavity block, resonators, cover plate and coupling screws. Each cavity is coupled to its adjacent cavity through a narrow rectangular opening called iris. In iris coupled cavity filter, the resonators are mounted in the cavity with one end grounded and distributed capacitor is placed at the other free end. By adjusting coupling screws, the filter provides coupling between cavities.

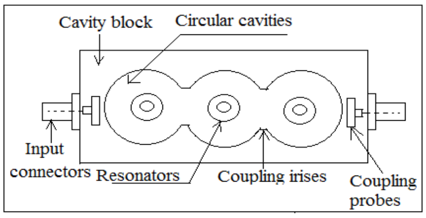

Fig. 3. Structure of iris coupled cavity filter

Iris coupled filter is bigger in size than that of the combline, milling operation of cavities is expensive and achieving wider bandwidth is also difficult. The structure of iris coupled cavity filter is shown in figure.3.

C. Interdigital Filter

In this filter, the resonators are grounded at alternate ends for reducing the coupling between the resonators, walls are not present between the individual resonators. Resonators used are of λ/4 length. Figure.4. shows the structure of interdigital filter.

Interdigital filter normally has bandwidth less than 10% of centre frequency. This is widely used for frequencies below 300 MHz and often used as a diplexer in mobile radio transceiver.

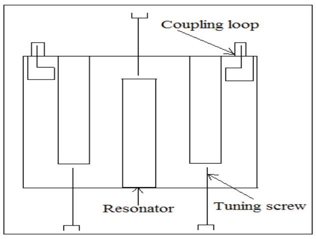

Fig. 4. Structure of interdigital filter

III. Design Of L Band Cavity Filter

The objective of this paper is to design and develop cavity band pass filter at 1575.42 MHz frequency. For this application insertion loss, bandwidth and size are the major considerations and combline cavity filter is selected. The structure consists of cavity block, resonators and cover plate. λ/8 length resonators are used to reduce the size of the structure and to obtain very narrow bandwidth. The important specifications of the filter are listed in Table I.

TABLE I. Filter Specification

Parameter	Value
Center frequency	1575.42± 2MHz
1 dB Bandwidth	10 MHz(min)
3 dB Bandwidth	35±2 MHz
Pass Band Ripple	0.2 dB max
Insertion loss at centre frequency	1.3 dB (max)
Rejection at (f_0±100 MHz)	40 dB (min)
Rejection at (f_0±140 MHz)	50 dB (min)
Shape factor	8
Out of band rejection	>60 dB

Design

The cavity filter design basically will emphasize on selection of an appropriate number of resonators and coupling structure. The center frequency of the filter is mainly determined by the resonance frequency of resonator where coupling structure determines the bandwidth of the filter.

Cavity filter design involves converting the electrical specifications into the mechanical dimensions of the parts of the filter. Design dimensions of cavity band pass filter are shown in figure.5.

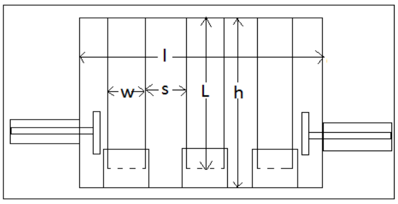

Fig.5. Design dimensions of cavity band pass filter

The mechanical dimensions that need to be computed are:
b, the width of the cavity.
l, the length of the cavity.
h, the height of the cavity.
L, the length of the resonator.
w, the width and t, thickness of the resonator.
s, the spacing between the resonators.

Once the essential parameters are selected, the next step in the design is to specify the dimensions of a cavity filter. There are several design equations that need to be considered to configure the length, height and width of the cavity, as well as the dimensions of resonators such as width and length of resonators.

Computational Steps for Combline Filter

The filter design involves intermediate computations for determining the values of mechanical design parameters. The steps in the computations are:

Step 1. Determine the number of filter sections

(a) Calculate ω, ratio of bandwidth to centre frequency

(b) Calculate ω'/ω_1', low pass to band pass transformation factor

(c) Calculate ε

i. $\varepsilon = [\text{antilog10}\ (L_{Ar}/10)] - 1$ (1)

ii. L_{Ar} is the ripple in pass band

(d) Determine the number of filter sections, n

L_A rejection at upper rejection frequency,

$n=\cosh^{-1}[\text{SQRT}\{(10^\wedge(L_A/10)-1/\varepsilon\}]/\cosh^{-1}(\omega'/\omega_1')$ (2)

n is rounded up to the next higher integer.

Step 2. Calculate resonator length

λ/8 resonators are used in combline filters.

Step 3.Calculate the width and thickness of rectangular resonators.

(a) Compute g-values

(b) Compute G_T/Y_A and $J_{j,j+1}/Y_A$

(c) Compute normalized capacitance/unit length (line and ground)

(d) Compute normalized capacitance/unit length (adjacent resonators)

(e) Obtain (s/b) and $(C'_{fe}/\ \varepsilon)$ from graphs.

(f) Calculate the normalized width of resonators.

Step 4. Decide the width of cavity

The width of the cavity places a relevant role in determining size of the filter. Higher width results in large sized filter with lower insertion loss. Here 14mm width is assumed.

Step 5. Approximate rectangular resonators to cylindrical resonators.

The diameter of the cylindrical resonators are calculated as

$$\Pi d_j = 2(w_j+t)$$

Step 6. Determine the spacing between resonators.

Spacing between resonators= $(s_{j,j+1}/b)*b$

Where b is the width of the cavity

Step 7. Determine the length of cavity.

The length of cavity is calculated from the diameter of the resonators and the spacing between the resonators. Further, a gap of 5 mm is required to couple the end resonators (Resonator-I and Resonator-III) to the input/output coaxial connectors.

Cavity length,'l'= 2* end gap + 3* resonator diameter + sum of spacing.

Step 8. Calculate the capacitance C_j^s, for tuning resonators

Step 9. Calculate the height of cavity.

The height of a combline filter is decided by the length of resonator and the air gap to realize the distributed capacitance. Hence, 1mm gap between the resonators and the wall of the cavity block is assumed.

Height of the cavity,'h' = 1mm + length of resonators

After completing each step of the design procedure, the mechanical dimensions of cavity filter are obtained. The obtained mechanical dimensions for the required L Band cavity filter is tabulated in table 2.

TABLE II. PARAMETERS AND ITS VALUES OF CAVITY FILTER

Mechanical design parameter	Value
The width of the cavity, 'b'	14 mm
The length of the cavity, 'l'	55.51mm
The height of the cavity, 'h'	24.80 mm
The length of the cylindrical resonator, 'L'	23.80 mm
Diameter of cylindrical resonator, 'd'	6.304 mm
Number of resonators	3
The spacing between the resonators	$S_{1,2}$=13.3mm $S_{2,3}$=13.3 mm

Surface finishing of cavity and resonators is also important. For cavity filter, the most commonly used coating metals are silver and gold. Gold plating provides greater advantages for frequency greater than 300 GHz, it needs Cr or Ni adhesion layer and are also costly. Silver coating provides better conductivity than gold and is cheaper also but will corrode much more easily. In this design Silver coating is selected for the inner and mating surfaces for better conductivity, external surfaces are black anodized to prevent corrosion.

IV. SIMULATION USING ADS AND EMPRO SOFTWARE

After completing the design procedure, the design is simulated using ADS and EMPRO software. Using ADS, the prototype design is carried out and the results are verified for the specification. EMPro is a 3D modeling and simulation tool for analyzing the 3D electromagnetic effects of high speed RF/ microwave components. It provides three different types of EM simulation technologies such as MoM, FEM, and FDTD. Parameterization capability, full scripting, integration with ADS, importing of existing CAD files and HFSS files are also possible in EMPRO software. FEM simulation technology is used for the 3D simulation. The various steps involved in the simulation for designing cavity filter is shown in figure 6.

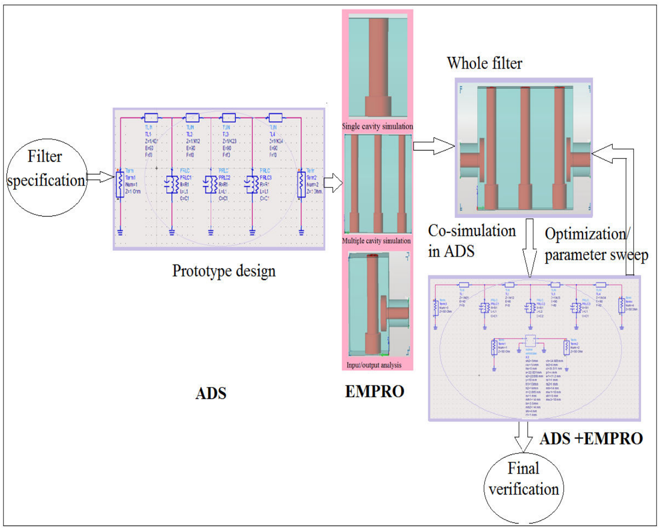

Fig.6. Flow chart of cavity filter design using ADS EMPro

Cavity filter simulation consists of mainly four steps.

Step 1: Create a prototype design of that designed cavity filter using ADS.

Step 2: Draw the 3D structure of cavity filter in EMPRO.

Step 3: Perform co-simulation of EMPro file in ADS.

Step 4: Observe the obtained frequency response with the required filter specifications.

The first step of prototype design is the creation of equivalent circuit for cavity filter of 3[rd] order Chebyshev in ADS. The initial design goal should provide enough design margin so that the final realized filter can be easily tuned for good performance. Figure.7 shows the designed prototype. Parameter tuning is necessary if the output waveform of prototype design does not match with the required filter response. The corrected prototype design waveform is shown in figure.7.

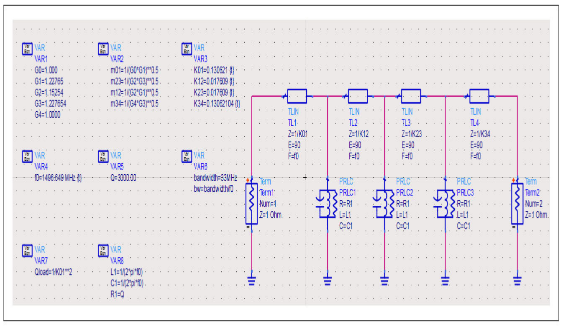

Fig.7. Prototype design

The next step is to determine the geometry structure for cavity filter. Structures that need to be determined are:

1. Single cavity size.
2. Multiple cavity structure.
3. Couple structure for the input and output

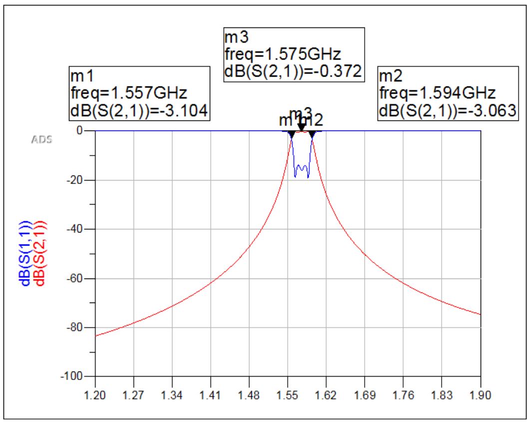

Fig.8.Output of prototype design

By using ADS and EMPro software, each steps are analyzed. After completing all the four steps, the complete 3D structure of cavity filter is obtained and it is shown in figure.9. In that cavity filter structure, three resonators are mounted on the cavity in the perpendicular direction. Similarly, an input coupling and output coupling are provided in the first and last resonators respectively. When the dimensions of the input/output coupling are changed, the bandwidth of the frequency response is affected. The number of resonators determine the shape factor of the filter. The obtained waveform is shown in figure 10.

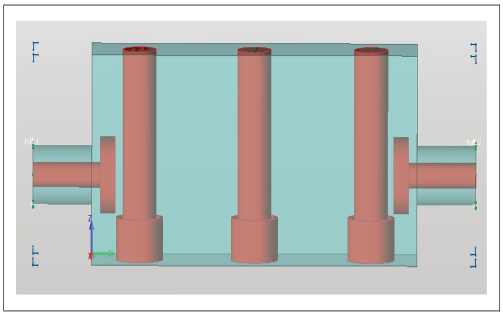

Fig.9. Simulated structure of cavity filter

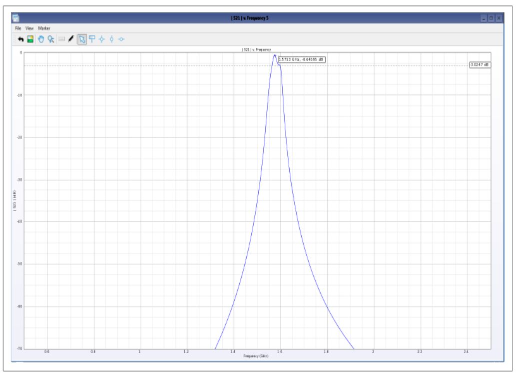

Fig.10. Output waveform of filter using EMPRO software

After designing the cavity filter in EMPro software, it is necessary to analyze the structure using co-simulation of

EMPro file into ADS. The schematic diagram of co-simulation is shown in Figure.11. On comparing the obtained co-simulation results with the filter requirements, if any variation is noticed optimization needs to be performed to obtain the required frequency response. The output waveform of cavity filter after optimization is shown in figure.12.

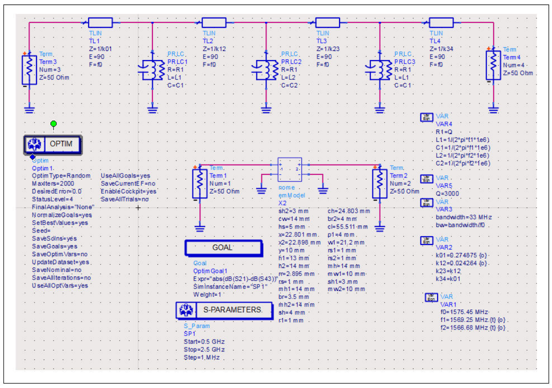

Fig.11. Schematic diagram of co-simulation

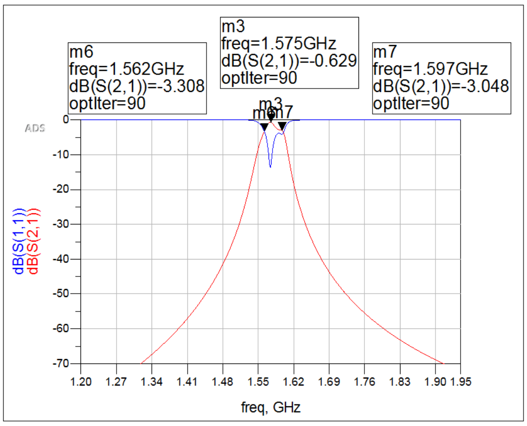

Fig.12. Output waveform of co-simulation

Hardware implementation

The designed cavity filter parameters such as length, height, width and spacing are used to make mechanical drawing for housing and assembly. The structure drawing was created using AutoCAD and is shown in figure 13.

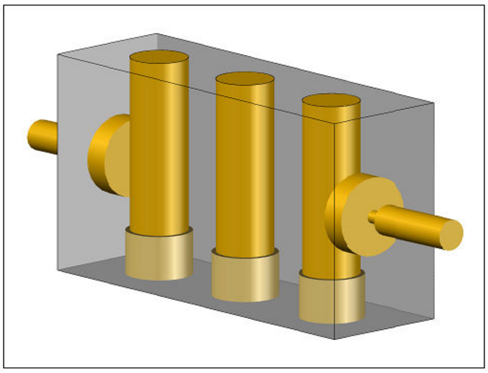

Fig.13. AutoCAD drawing of cavity filter

Then the designed filter model was fabricated using CNC machine using aluminum as base material and Flange mount receptacle connectors as input /output coupling connectors. The filter surface is plated with silver material. After that, the fabricated filter is tested using vector network analyzer. The tested waveform of the filter is shown in figure 14. The measured S parameters of the cavity filter shows a good agreement for the frequency behavior between simulated and measured values. The measured center frequency is 1576.33 MHz with bandwidth about 31.460 MHz. The decrease in the bandwidth is caused by the tolerance in fabrication. The minimum insertion loss of the cavity band pass filter is 0.8679 dB at center frequency 1576.33 MHz which is slightly higher than the simulated value.

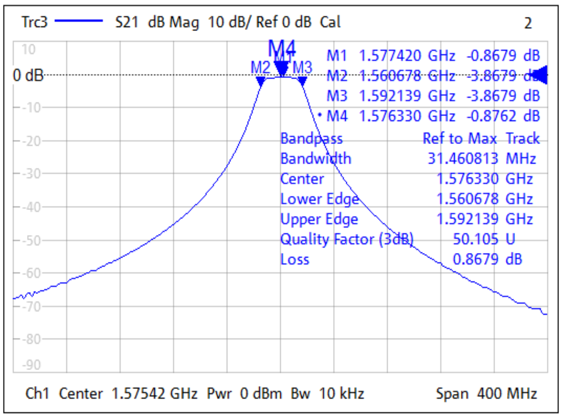

Fig.14. Output waveform of the fabricated filter

V. Results

Cavity filter is designed using the basic filter design equations, then prototype design is created in ADS software and the 3D structure of the cavity filter is simulated in EMPRO software. Co-simulation is performed in ADS software as the next step. The manually calculated values do not provide the most optimum performances and therefore there is a need to change the component values. The resonant frequency is determined by the length of the resonators. Bandwidth of the frequency response is determined by the coupling structure. Thus the design of resonators and coupling structures makes a crucial role in filter performance. The required frequency response is obtained by performing optimization. Design goal and obtained EM simulation results are tabulated in table.3.

TABLE III. Complete Filter Simulation Result

Filter specification	Design Goal	Simulated Result
Center frequency (MHz)	1575.42±2	1575
1 dB Bandwidth (MHz min)	10	11
3 dB Bandwidth (MHz)	35±2	35
Insertion loss (dB max)	1.3	0.629
Rejection @ (f_0±100MHz)	40 dB	42 dB
Rejection at (f_0±140 MHz)	50 dB	51 dB
Shape factor	8	8
Out of band rejection	>60 dB	>65 dB

VI. CONCLUSION

A combline cavity band pass filter operating at L band with a centre frequency of 1.575 GHz and bandwidth about 35 MHz is designed with high Q value, narrow bandwidth, low insertion loss, and high power handling capability. ADS and EMPro software is used to simulate the designed cavity filter. Parameter tuning is performed to obtain the desired frequency response.

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