RESEARCH ARTICLE OPEN ACCESS

Design of Microwave Cavity Bandpass Filter from 25GHz TO 60GHz

*Ashna Shaiba[1], Dr. Agya Mishra[2]
[1]*Department of Electronics & Telecommunication Engineering, Jabalpur Engineering College , Jabalpur Madhya Pradesh, Pin- 482011 India*
[2]*Department of Electronics & Telecommunication Engineering, Jabalpur Engineering College , Jabalpur Madhya Pradesh, Pin- 482011 India*
Corresponding Author: Ashna Shaiba[1]

ABSTRACT

This paper presents the design of microwave cavity band pass filter and analyzes the quality factor and insertion loss upto 60GHz .This paper discusses the performance of a cavity filter for different size of cavity at different frequencies upto 60GHz with calculation of quality factor and insertion loss. This type of microwave cavity filter will be useful in any microwave system wherein low insertion loss and high frequency selectivity are crucial, such as in base station, radar and broadcasting system. It is shown that the basis for much fundamental microwave filter theory lies in the realm of cavity filters, which indeed are actually used directly for many applications at microwave frequencies as high as 60 GHz. Many types of algorithm are discussed and compared with the object of pointing out the most useful references, especially for a researcher to the field.

Keywords: Microwave cavity filters, band pass filter(BPF), quality factor, s-parameter, insertion loss, TE_{101} mode.

Date of Submission: 05-09-2017 Date of acceptance: 21-09-2017

I. INTRODUCTION

A filter is an electronic device used to select a particular pass band range. Signals with in that range are allowed to pass while the signals outside that range are disallowed. Also, it is very important to reduce the losses like insertion loss and return loss in various communications. The rapid developments of wireless communications challenge RF/microwave filter with ever more stringent requirements—higher performance, smaller size, lower cost, and lighter weight. For the microwave systems, cavity filters are an attractive option because of the relatively high quality factor (Q) compared to stripline / microstrip or lumped element type filters. But traditional cavity filters filled with air is not easy to integrate for the big size of resonate cavity.

With the fast development of wideband wireless communication, BPF with characteristics of high performance, low-cost, low insertion loss(IL) and compact BPF are highly desirable.

The purpose of this paper is to present the theories of cavity filters, and then focus on the simple way to design cavity band-pass filters with these cavity theories. At first, we discuss the determine of the single rectangular cavity resonator, then we show how to achieve the desired external quality factor(Qext), with the variation in frequency and also to calculate the s-parameter and the losses within it.

II. CONCEPTS OF MICROWAVE CAVITY FILTER

Cavities are often grouped in series with each other to increases filter effectiveness by making the pass band dipper with respect to surrounding frequencies. Cavity is the hollow or sinus with in the body or sizeable hole(usually in the ground) and also space that is surrounded by something. The cavity bandpass filter at microwave frequencies with small size and low insertion loss plays a crucial role in the microwave communication system, especially in the transmitting and receiving systems to the identify and transmit the desired signals. This can be very useful when ham repeaters are situated very close to other spectrum users such as pager whose unwanted signals can interfere with the ham equipment. Cavity filter are very effective way to create a notch at the repeater frequencies.

Physically a cavity filter is a resonator inside a conducting "box" with coupling loops at the input and output. Cavity Filters are known for low insertion loss and higher power handling ability. API Technologies engineers researched the suppression of inter modulation products in low loss, high power cavity designs and through careful process control and component selection devised specialized design techniques to satisfy our customers’ unique requirements. These type of filters are typically found in the front-end of high-frequency transceivers of diverse systems such as radar, satellite TV or microwave links.

Because of the multi-player structure of LTCCtechnologies, it's hard to design a rectangular cavity with 6metal walls. But we utilize via fenses as side walls andconducting planes as horizontal walls, this structure is shownin Fig. 1

.

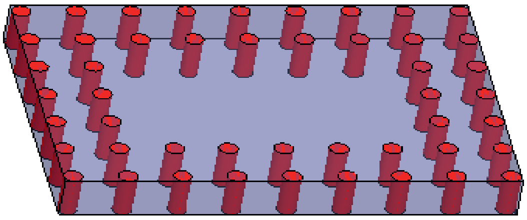

Figure 1.LTCC cavity with via fenses.

The Resonant frequency of the TE$_{101}$mode can be found as-

$$f_{res} = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{(\frac{m\pi}{L})^2 + (\frac{n\pi}{H})^2 + (\frac{l\pi}{W})^2} \quad ....(1)$$

Where, ε_r is the dielectric constant, c is the speed of light, *L* isthe length of cavity, *W* is the width of cavity, and *H* is theheight of the cavity. The relative permittivity of the substrate is5.75, and we use five layers of ceramic for the thickness ofeach layer is 0.1 mm. So, ε_r = 5.75 and *H* = 0.5 mm. Thedominate mode is TE_{101}, so m = 1, n = 0 and l = 1. Finally weachieve the dimensions of the cavity with perfect conductingwalls by (1). But these dimensions are not absolutely right for the cavitywith via fences as side conducting walls. We must design theLTCC cavity and take these dimensions as the initialdimensions.
The via diameter is 170 micrometer and the spacing between viarows must be more than the minimum via pitch (400um) andthe gap between the via fences must be less than $\lambda/2$ at 36.1GHz. λ can be figured out by

$$\lambda = \frac{c}{f_0\sqrt{\varepsilon_r}} \quad ....(2)$$

Then, the initial dimensions are optimized with a full-waveelectromagnetic simulator. Finally, the dimensions are shownin Fig. 2

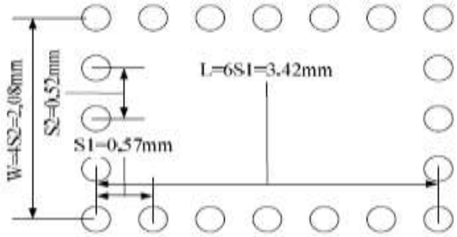

Figure 2.The dimensions of the LTCC cavity.

III. PROPOSED MODEL

In this paper cavity band pass filter is designed to decreases the insertion loss. The objective of this design is to obtainthe high performance band pass filter having low insertion loss and high selectivity. Its choice pursues three main goals: to have the resonance frequency at f_0, to achieve insertion loss, and to reach a high unloaded quality factor (which is a ratio between the stored energy and the losses).

In the case of low external coupling, the unloaded quality factor (Qu), is controlled by three loss mechanisms and is defined by-

$$Qu = \left(\frac{1}{Qcond} + \frac{1}{Qdielec} + \frac{1}{Qrad}\right)^{-1} \quad ....(3)$$

where Q$_{cond}$, Q$_{dielec}$ and Q$_{rad}$ take into account the conductor loss from the horizontal plates (the metal loss of thehorizontal plates dominates especially for a thin substrate such as 0.3mm), the dielectric loss from the filling substrates, and the leakage loss through the via walls, respectively. Since the gap between the via posts is less than $\frac{\lambda g}{2}$ at the highest frequency of interest as mentioned. The leakage (radiation) loss can be negligible as mentioned above and the individual quantity of two other quality factors can be obtained.

$$Qu = \left(\frac{1}{Qcond} + \frac{1}{Qdielec}\right)^{-1} \quad ....(4)$$

Then, the quality factors Qcond and Qdielec can be determined, respectively from the following relations as,

$$Qcond = \frac{(KWL)*H\eta}{2\pi^2 Rm(2W^3L + 2L^3H + W^3L + L^3W)} \quad ..(5)$$

$$Qdiec = \frac{1}{\tan(\delta)} \quad ....(6)$$

Where tan (δ) is the tangent loss = 0.0015 for the LTCC. The fabrication process of LTCC system is simple, fast and inexpensive. Cost of investment is much lower than in silicon or thin-film industry. Short production series are profitable. The technology is suitable for small and medium enterprise[6]. The idea is to use LTCC materials to keepthe size of the cavity as unchanged as possible when the temperature varies it means high temperature stability[3][7].

Where k is the wave number in the resonator, Rm is the surface resistance and n is the Intrinsic wave impedance of the (medium) LTCC resonator filling.

$$k = \frac{2\pi fres\sqrt{\varepsilon_r}}{c}$$

$$Rm = \sqrt{\frac{\pi fres\ \mu}{2\sigma}}$$

$$\eta = \sqrt{\frac{\mu o}{\varepsilon o\, \varepsilon r}} \quad \text{……..………………..…..(7)}$$

Whereμo, εo are the magnetic permeability and electric permittivity in a vacuum respectively
εo = 8.854 $*10^{-12}$ F/m, μo= $4*3.14*10^{-7}$wb/m, where, εr = 5.5, σ = 5(conductivity),

The conductivity and relative permittivity of the LTCC materials because of this interesting properties of the ceramicsand flexibility of the µtechnology. The following advantages of the LTCC ceramic are responsible for a success in the market:- good electrical and mechanical parameters, high reliability and stability, possibility of making three dimensional microstructures with Cavities and channels, high level of integration(sensors, actuators, heating, cooling, micro fluidic, electronics and photonic systems in one LTCC module), very good properties at high voltage, high pressure and high vacuumed.

At first to get the result we have to input the parameters of cavity length, width and height and also we take inputoperating frequency to the filter. Now we initializes same values of the given input parameters. So that the program should start on that given value. Flowchart of the overall process of the cavity filter design and tuning to verify theory is included below.

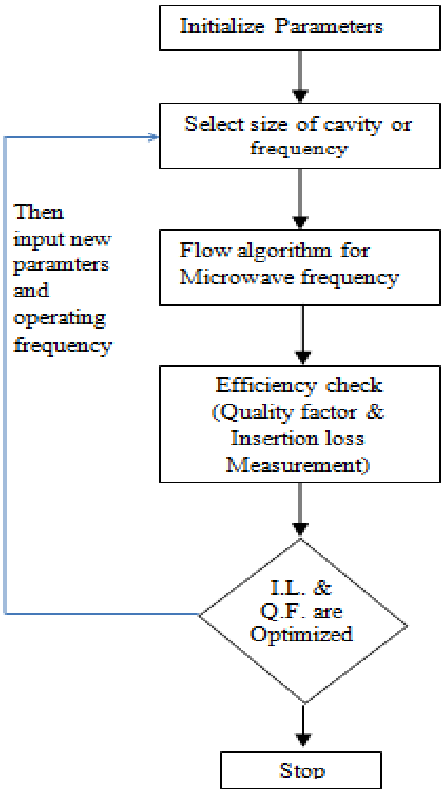

Fig.3. Flowchart of Microwave cavity filter.

Then through algorithm for this particular program determines the output values. The output values are such likeefficiency insertion loss and quality factor. If this output are not our desired values then we have get input new valuesof operating frequency manually. Then in this new given operating frequency the program should continues and we get new values of insertion loss and quality factor and if it does not our desired values then repeat this process. At last when we get the desired parameter value then we quit the program. For the band pass filter analysis using the response curves of losses.

At first, we design the external slots for the desired inputand output *Q*ext. *Q*ext is defined by

$$Q_{ext} = \frac{g_i g_{i+1} f_{res}}{BW} \quad \text{……………………..(8)}$$

where*gi* is the element values of the low pass prototype, *f*resisthe resonant frequency, and *BW* is the bandwidth of the filter.

We define g_0 = 1, g_1= 1.0316 for the Chebyshevlowpassprototype filters with passband ripple *L*Ar = 0.1 dB, *f*res= 35.85GHz and *BW* = .5 GHz. Finally the input and output *Qext*were calculated to be 73.97. Some characteristics are shown by the Chebyshevfilters [5].

- Peak error minimized in the pass band.
- It provides Equiripple magnitude response in the pass band.
- It provides monotonically decreasing magnitude response in the stop band.
- Sharper roll off than Butterworth filters.

The transfer function H(s) of chebyshev low passfilter is given by-

$$H(s) = \frac{1}{|S_{21}\ (\Omega)|^2} \quad \text{…………….…… (9)}$$

$$|S_{21}(\Omega)|^2 = \frac{1}{1+k^2\, T_N^2\left(\frac{\Omega}{\Omega_C}\right)} \quad \text{………………..(10)}$$

Here, the ripple constant k is related to a given passband ripple LAr in dB by:

$$K = \sqrt{10^{\frac{L_{Ar}}{10}} - 1} \quad \text{………….………..(11)}$$

$T_N(x)$ is the Nth- order chebyshev polynomial defined as

$$T_N\ (x) = 2xT_{N-1}\ (x) - T_{N-2}\ (x) \quad \text{…………..(12)}$$

where, $x = \frac{\Omega}{\Omega c}$ for a low pass filter

The high pass and band pass filters transferfunctions are derived from the low pass response only.

- Band-pass Filter

If a high-pass filter and a low-pass filter arecascaded, a band pass filter is created. The band passfilter passes a band of frequencies between a lowercutoff frequency and upper cutoff frequency. Theequations for obtaining element values of commonlyused band pass prototype filter are given by thefollowing relation.

For the elements in Series

$$L_K' = \frac{L_K\ Z_0}{\omega_0\ \Delta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

$$C_K' = \frac{\Delta}{\omega_0\ L_K\ Z_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(14)$$

For the elements in parallel

$$L_K' = \frac{\Delta\ Z_0}{\omega_0\ C_K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

$$C_K' = \frac{C_K}{\omega_0\ \Delta\ Z_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

where, $\Delta = \frac{\omega_2 - \omega_1}{\omega_0}$ $w_1$is the lower cutoff frequency, w_2 is the uppercutoff frequency and wo is given the expression

$$\omega_0 = \sqrt{\omega_1\ \omega_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(17)$$

L_K and C_K are the element values for two port network. The transfer function for high pass filter canbe obtained by replacing the variable x in equation (4)by

$$x = \frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots..(18)$$

- . Band-passfilter analysis

A band-pass filter is a device that passes frequencieswithin a certain range and rejects (attenuates)frequencies outside that range. The Lumped-element band-pass filter circuit is shown in Fig. 4.

Theoretical Analysis

For the analysis of BPF using, a MATLAB code we have calculated the lumped element values $C_k$and$L_k$ofbandpass filter by the following Equations

For the elements in Series

$$L_K' = \frac{L_K\ Z_0}{\omega_0\ \Delta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

$$C_K' = \frac{\Delta}{\omega_0\ L_K\ Z_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(20)$$

For the elements in parallel

$$L_K' = \frac{\Delta\ Z_0}{\omega_0\ C_K} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(21)$$

$$C_K' = \frac{C_K}{\omega_0\ \Delta\ Z_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(22)$$

Where, $\Delta = \frac{\omega_2 - \omega_1}{\omega_0}$

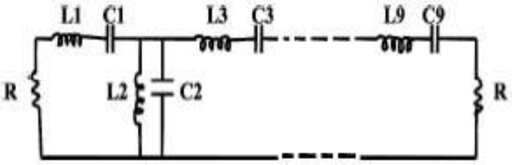

Fig.4. Lumped-element Bandpass filter circuit.

$w_1$is the lower cutoff frequency, $w_2$is the uppercutoff frequency and $w_o$is given the expression

$$\omega_0 = \sqrt{\omega_1\ \omega_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(23)$$

L_K and C_K are the element values of lowpassfilterprototype. The calculated values oflumped elements andthe corresponding S-parameter graph obtained from MATLAB which is the theoretical response.

In order to extract the external quality factor from the frequency response of the I/O resonator, we consider anequivalent circuit for thiscoupling structure and then obtain arelationship as follows-

$$Q_{ext} = \frac{\omega_\circ}{\Delta\omega_{\pm 90^\circ}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(24)$$

where $\Delta\omega_{\pm 90^\circ}$ is the frequency difference between ±90° phaseresponse of S11, and w_o is the resonant frequency. Finally the phasechart of S11 is shown in Fig. 5.

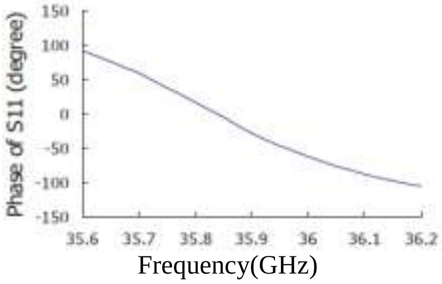

Fig.5. Phase response of S11 for the internal coupling structure.

We have finished the design of the cavity resonant and theexternal coupling structure, the last step is to achieve the internal coupling structure dimensions for the desired inter-resonant coupling coefficients ($k$jj+1).

$$k_{jj+1} = \frac{BW}{f_{res}}\sqrt{\frac{1}{g_j g_{j+1}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(25)$$

where$g$jj+1 (j = 1 or 2) are the element values of the low passprototype, $f$res is the resonant frequency, and BW is the bandwidth of the filter. On the other hand, we can figure out the kjj+1 for any coupling structure dimensions by

$$k_{jj+1} = \frac{f_{p2}^2 - f_{p1}^2}{f_{p2}^2 + f_{p1}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(26)$$

where$f$p1 and fp2 are the characteristic frequencies, which arethe frequencies of the peaks for *S21* (or *S12*) when an electricwall or magnetic wall is inserted in the symmetrical plane. What's more, it's not aneasy work to insert the electric wall and the magnetic wall, andwe may not find the desired BW when the whole filter issimulated by HFSS. So we don't focus on how to achieve thedesired $k$jj+1but just optimized thevariables that determine the $k$jj+1.

IV. EXPERIMENTAL RESULTS

A. CAVITY SIZE VARIATION ANDINSERTION LOSS & QUALITY FACTOR

We have calculated and measured the insertion loss and quality factor for rectangular cavity of different sizes up to the operating frequency of about 60GHz. This paper has observed the best performance of parameters as a low insertion loss and high quality factor. Firstly take size of cavity and calculate the result than we observed the our result is low insertion loss and high quality factor. So this paper vary the size of cavity (increases the size of cavity & decreases the size of cavity). And observed the result is best.

Table No.01 Variation Of Insertion Loss & Quality Factor With Cavity Size

Size of cavity	S-parameter	Quality factor	Insertion loss
1.95*1.275*0.3	1.217	575	-1.705
2.20*1.275*0.5	1.207	522	-1.637
2.20*1.35*0.5	1.215	492	-1.693
2.40*1.50*0.5	1.213	400	-1.677
2.80*1.65*0.5	1.196	303	-1.556
3.20*1.95*0.5	1.19	216	-1.511
3.42*2.08*0.5	1.184	108	-1.466

In view of these constraints, filter design at microwave frequencies needed to develop its own theory. To vary the sizeof the cavity at 60GHz frequency play an important role in the microwave frequency range. We have got the accurate size with low insertion loss and high quality factor at 60GHz. The low insertion loss -1.466dB and high quality factor575.

B.VARIATION OF QUALITY FACTOR & INSERTION LOSS WITH FREQUENCY VARIATION

Band pass filter is proposed so considering frequency range from 30GHz to 60GHz. This paper calculate the insertionloss and quality factor at different frequencies. The frequency change of the rectangular cavity with a TE_{101}mode (thevolume of the cavity is 3.42mm*2.08mm*0.5mm). This paper present vary the frequency and observed the bestperformance of the result low insertion loss and high quality factor.

Table No.02 Insertion Loss & Quality factor Variation with Microwave Frequency

Frequency range	S-parameter	Quality factor	Insertion loss
25	-19.81	51.58	-2.853
30	-11.70	77.37	-2.35
35	-6.511	100.3	-1.79
36	-6.00	103.16	-1.704
37	-5.5	108.89	-1.611
38	-4.866	114.62	-1.512
40	-3.840	140.67	-1.286
45	-11.701	180.22	-2.350
50	-19.810	230.45	-2.853
55	-22.526	260	-2.975
60	-20.141	294.67	-2.869

For experimental analysis the operating frequency is from 25GHz to 60GHz than quality factor and insertionloss will be observed like insertion loss -1.512 with quality factor 115 at about40GHz and insertion loss -2.86dB with quality factor 295 at 60GHz . If we calculate the s-parameter and insertion loss below 25GHz we observe that both the parameters are high which is undesired also for frequency above 60GHz range quality factor will be increasing but the insertion loss and s-parameters are high which is also undesirable as shown in the plot.

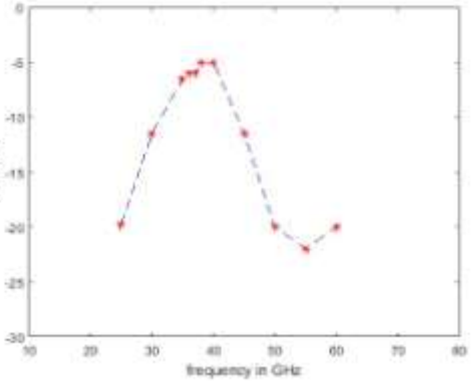

Figure 6. The simulated results of the filter.

The purpose of this work is to overcome the insertion losses and develop band passfilter with wide pass band to cover the various microwave frequency band. In this paper the frequency ranges from 25GHz to 60GHz than the low insertion loss get the frequency at about 40GHz.

C.COMPARISION BETWEEN PROPOSED MODEL WITH EXSTING FILTER

The comparison between the proposed model with existing filter reported is discussed in table. This work is entitled"Filter design in low Loss cavities" as it aims at designing a cavity band pass filter. However, this technical term refersto a particular kind of physical structure, and filter design is solving the physical dimensions of a structure. The wholedesign process entails other stages upon which the task of finding out dimensions is built. This cavity size is same but low insertion loss and high quality factor has observed.

Table No.03 The table with Comparison Proposed Model and LTCC Cavity Filter at frequency up to 60GHz

S. No	Filter	Cavity size [L*H*W(mm)]	Q.F.	I.L.(dB)
1	Proposed Cavity Filter	3.42*2.08*0.5	108	-1.46dB
2	LTCC Cavity Filter	3.42*2.08*0.5	77	-1.5dB

In this for comparison same value of frequency and size of cavity is considered then observed that insertion lossand quality factor of proposed model is better. These systems are usually subject to very restrictive specifications,demanding high-performance filters. From the electrical point of view, the desirable features can be summarized as:high selectivity, low insertion losses in the pass band, wide free-spurious window, and good power handling capability. From a mechanical point of view, weight and volume can be critical depending on the target system..

V. CONCLUSION

In this paper, an approach for designing the microwave cavity band pass filters up to 60GHz is discussed. The proposed cavity filter structures havebeen design in the frequency range from 25GHz to 60GHz. It has been observed that the cavity band pass filter hasinsertion loss of about -2.35dB with quality factor of about 77.37dB at 30GHz and -1.512dB insertion loss with quality factor of about 114.62 at 38GHz and -2.869dB insertion loss with quality factor ofabout 294 at 60GHz . To reduce the overall size of the filter achieving optimized performance. In this system, initiallypromoted by the necessity for improved filter performance, and also for increased efficiency of design. An efficientdesign process is required in a competitive commercial environment, the cavity also show better result in terms ofinsertion loss because the shielded and is less affected by moisture. This characteristic makes the cavity structure ofchoice to design microwave system working in hostile environment with high humidity.

REFERENCES

[1]. Cheng Quen, ZiqiangXu, Tian Li, Wei Tang, ZhiyiZeng, “A Ka-Band Cavity Bandpass Filter Using LTCC Technology”, IEEE conference, China,September 25-27, 2009.

[2]. SantoshUikey, Dr. Agyamishra, “Microwave Filters Design up to 60 GHz”, IJAREEIE- International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering , VOL. 05, Issue 08, August 2016.

[3]. BahramYassini, “A Ka-Band Fully Tunable Cavity Filter”, IEEE Transactions on Microwave Theory And Techniques, VOL. 60, NO. 12, DEC. 2012.

[4]. JonhHoon Lee, IEEE, StephanePinel, Member, IEEE, Joy Laskar, Senior member, IEEE and Manos M. Tentzeris, senior member, IEEE, “Low Loss LTCC Cavity Filters Using System-On-Package Technology At 60 GHz” , IEEE Transactions On Microwave Theory And Techniques, SEP. 2011.

[5]. YashikaSaini, Mithilesh Kumar, “Performance Analysis of 9th Order Chebyshev Filter at Microwave Frequency”, IEEE- International conference on Advances in Engineering and Technology Research, August, 2014.

[6]. DimitraPsychogiou, DimitriosPeroulis, Yunjia Li, Christian Hafner, “V-Band Band pass Filter With Continuously Variable Center Frequency”, IET Microwave, Antennas & Propagation, April 2013.

[7]. SantoshUikey, Dr. Agya Mishra, “Cavity Filters For Microwave Application A Literature Review”, IJSRD- International Journal for Scientific Research And Development, VOL. 03, Issue 04, 2015.

[8]. Ta-Jen Yen, Yi-Juchiang, Tsung-YuHuang, and Ai-ping Yen, “Toward a Bandpass Filter For 60 GHz Wireless Communications”, SPIE newsroom 10.1117/2.1201108.003752,SPIE 2011.

[9]. Yidong Wang and Qiang Sui, “A New temperature Compensation Method of Rectangular Waveguide Resonant Cavities”, APMC IEEE, 2005.

[10]. DimitraPsychogiou, DimitriosPeroulis, Yunjia Li, Christian Hafner, “V-Band Band pass Filter With Continuously Variable Center Frequency”, IET Microwave, Antennas & Propagation, April 2013.

[11]. TarekDjerafi, Ke Wu, “A Temperature-Compensation Technique For Substrate Integrated Waveguide Cavities And Filters”, IEEE Transactions On Microwave Theory And Techniques, VOL. 60, NO. 8, AUG. 2012.

[12]. L.J. Golonka, “Technology And Applications Of Low Temperature Co-fired Ceramic(LTCC) Based Sensors And Microsystems”, Bulletin Of The Polish Academy of Sciences, Technical Sciences, Vol.54, No.2, 2006.

[13]. Microwaves IOI, “Insertion Loss”The worlds Microwave Information Resource Since 2001.

[14]. AnuradhaGoyal, AmarpreetKaur, “Analysis And Design Of MicrostripBandpass Filter”, Department Of ECE, Ludhiyana College Of Engineering & Technology, PTU, Ludhiyana, Panjab, India, IJESC, Feb. 2015

.

International Journal of Engineering Research and Applications (IJERA) is **UGC approved** Journal with Sl. No. 4525, Journal no. 47088. Indexed in Cross Ref, Index Copernicus (ICV 80.82), NASA, Ads, Researcher Id Thomson Reuters. DOAJ.

Ashna Shaiba. “Design of Microwave Cavity Bandpass Filter from 25GHz TO 60GHz.” International Journal of Engineering Research and Applications (IJERA) , vol. 7, no. 9, 2017, pp. 64–69.