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Microwave Cavity Filters Design Upto 60 GHz

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ABSTRACT: This paper presents design of microwave cavity 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.

KEYWORDS: Microwave filter, Cavity Filter, Insertion Loss(IL), Quality Factor, TE_{101} Mode

I.INTRODUCTION

Filters with high-frequency selectivity, low insertion loss, and robust temperature stability are key building blocks for microwave and millimeter-wave systems. Cavity filters become more practical in terms of size and a significantly higher quality factor. In microwave Cavity filters are widely useful in space communication, radar and broadcasting systems. There has been an increasing demand for wireless communication systems with broadband and high data rate(>2Gb/s) transmission characteristics to accommodate applications such as gigabit Ethernet and high speed internet, automotive and radar sensing, real time video streaming and high –definition television. The recently released unlicensed 60GHz frequency zone of v-band (50-75GHz) is well suited for these applications because of the advantages of wide bandwidth, increased resolution, compact integration and reduced interference that is enabled by the high attenuation of oxygen at those frequencies[5]. As the use of the adjacent channel becomes more common, filters are required to have high-frequency selectivity and temperature stability in order to satisfy the demands of the whole system. Over the past years, a great deal of efforts has been devoted to the design of cavity filters[2]. The performance of high frequency selectivity can be achieved by multiple selections, multiple modes and cross couplings[3]. A good filter should have not only sharp selectivity, but also high temperature stability.
Paper presents a cavity filter design model for frequency Up to 60GHz is reliable, affordable wireless solution with the highest performance and best reliability with a purchase price of less than half of the prevailing gigabit wireless market. License-free 60GHz radios have unique characteristics that make them significantly different from traditional 2.4GHz or 5GHZ license-free radio and from licensed-band millimeter-wave radios[11][8]. For every wireless communication application, a band pass filter is a crucial and mass-used component to allow signals and suppress noise in specific frequencies. In particular, wireless communication in the 60GHz band, an unlicensed spectrum centered at 60GHz with a bandwidth exceeding 7GHz (regulated in the US by the Federal Communication Commission, FCC), provides a higher transmission rate than other wireless techniques such as WI-Fi(2Mbps) and Bluetooth(11Mbps) and can even transmit uncompressed high-definition cinema data[8][9].

II.CONCEPT OF MICROWAVE CAVITY FITERS

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[8]. 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.

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Physically a cavity filter is a resonator inside a conducting "box" with coupling loops at the input and output[9]. 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[3]. 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.

The Resonant frequency of the TE101 [2]mode can be found as-

Resonance frequency (fres) = $\frac{C}{2\pi\sqrt{\epsilon r}} * \sqrt{(\frac{m\pi}{L})^2 + (\frac{n\pi}{H})^2 + (\frac{p\pi}{W})^2}$

Where, C= speed of light, ϵr= relative dielectric constant, L, H, W is the cavity of Length, Height and .Width respectively. Note that the higher order parallel-plate modes of the structure perpendicular to the boards occur far above the operating frequency range of the fabricated cavity; hence they do not contribute to the performance of the cavity. The integers of m, n, and p represent the numbers of half-sing-wave variations in the x, y and z directions respectively.

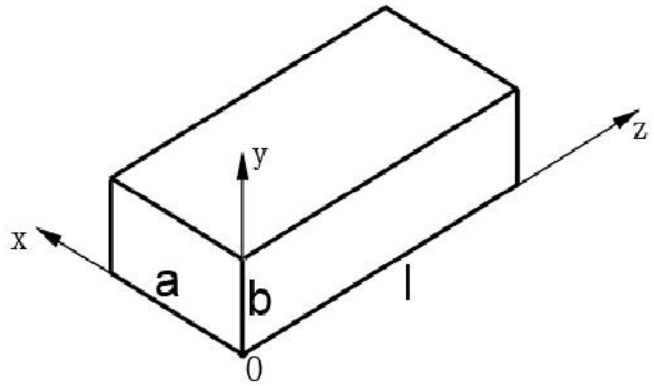

Fig.1 Rectangular waveguide resonant cavity[7]

For TE101 dominant mode with simple indexing→ m=1, n=0, p=1, Initial value assume that according to the reference papers[2], just for experiments that's value is- l=L=1.95mm, b= H=0.3mm, a=W=1.275mm and that's result of quality factor Qu is 367 and the insertion loss is 1.67 dB at the frequency is 59.8 GHz Qu is 372 at 60 GHz.[2] But now in this paper value of insertion loss is -1.0861dB with quality factor 661 at the resonance frequency is 50 GHz. Insertion loss -1.0361dB with quality factor 585 at 60GHz

III.PROPOSED MODEL

In this paper cavity band pass filter is designed to decreases the insertion loss. The objective of this design is to obtain the 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 defined-

$$Qu = (\frac{1}{Qcond} + \frac{1}{Qdiele} + \frac{1}{Qrad})^{-1}$$

Where Qcond, Qdielec and Qrad take into account the conductor loss from the horizontal plates (the metal loss of the horizontal 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.

So, $Qu = (\frac{1}{Qcond} + \frac{1}{Qdielec})^{-1}$

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

$Qcond = \frac{(kWL)*H\eta}{2\pi^2 Rm(2W^3L+2L^3H+W^3L+L^3W)}$ and $Qdielec = \frac{1}{\tan(\delta)}$

Where $\tan(\delta)$ is the tangant loss = 0.0015 for the LTCC[2]. 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 keep the 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 η is the Intrinsic wave impedance of the (medium) LTCC resonator filling.

$k = \frac{2\pi fres\sqrt{\epsilon r}}{c}$, and $Rm = \sqrt{\frac{\pi fres\mu}{2\sigma}}$, and $\eta = \sqrt{\frac{\mu 0}{\epsilon 0 \epsilon r}}$

Where μ_0 *and* ϵ_0 are the magnetic permeability and electric permittivity in a vacuum respectively

$\epsilon_0 = 8.854 * 10^{-12} F/m,\ \mu_0 = 4\pi * 10^{-7} w/m,$ Where, $\epsilon_r = 5.5,\ \sigma = 5$(conductivity)[2],

The conductivity and relative permittivity of the LTCC materials because of this interesting properties of the ceramics and flexibility of the technology. 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[6][2][7].

At first to get the result we have to input the parameters of cavity length, width and height and also we take input operating 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.

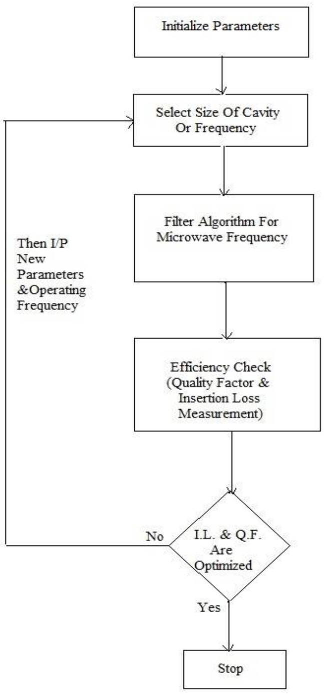

Fig.2 Flow Chart Of Microwave Cavity Filter Design

Then through algorithm for this particular program determines the output values. The output values are such like efficiency insertion loss and quality factor. If this output are not our desired values then we have get input new values

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of 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.

IV. EXPERIMENTAL RESULTS

The value of the unloaded quality factor (Qu) was extracted from the measured External quality factor (Qext) and the loaded quality factor (Ql) and the Insertion loss(I.L.) with the following equations:-

$Ql = \frac{fres}{\Delta f}$ and $Qu = (\frac{1}{Ql} - \frac{1}{Qext})^{-1}$ Then, $Qext = \frac{Qu*Ql}{(Qu-Ql)}$

Where, Δf is the bandwidth, and

$S_{21} = 20log_{10}(\frac{Ql}{Qext})$

Since, $I.L.(loss) = -20log|S_{21}|$

The measured insertion loss is - 1.0361 dB with 3-dB bandwidth. The center frequency is 60 GHz. and an unloaded Q of 585. The insertion loss changes from -1.0021 dB at the lowest frequency state to -1.0361 dB at the highest frequency state. This change is the variation of the cavity size and is due to the decrease in the size of cavity and decreases insertion loss as well as the increases in *Qu*.

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 at operating frequency is 60GHz. This paper has observed the best performance of parameters as a low insertion loss and high quality factor . Firstly take size of cavity[2] 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

S.No.	Size Of Cavity[L*H*W(mm)]	Quality Factor	Insertion Loss(dB)
1	0.95*0.2*0.275	661	-1.0864
2	1*0.2*1	640	-1.0511
3	1.95*0.3*1.275	585	-1.0361
4	2.95*0.6*2.275	540	-1.0231
5	3.95*0.8*3.275	520	-1.0132

In view of these constraints, filter design at microwave frequencies needed to develop its own theory. To vary the size of the cavity at 60GHz frequency pay important role in the microwave frequency range. We have got the accurate size (1) with low insertion loss and high quality factor at 60GHz. The low insertion loss -1.0864dB and high quality factor 661.

B. FREQUENCY VARIATION AND QUALITY FACTOR & INSERTION LOSS

Band pass filter is proposed so considering frequency range from 50GHz to 60GHz. This paper calculate the insertion loss and quality factor at different frequencies. The frequency change of the rectangular cavity with a TE_{101} mode (the volume of the cavity is 1.95mm*0.3mm*1.275mm). This paper present vary the frequency and observed the best performance of the result low insertion loss and high quality factor at 60GHz.

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

S.No.	Different Frequencies(GHz)	Quality Factor	Insertion Loss(dB)
1	50	564	-1.0021
2	52	567	-1.0135
3	54	572	-1.0229
4	56	577	-1.0274
5	58	580	-1.0322
6	60	585	-1.0361

For experimental analysis the operating frequency is changed from 50GHz to 60GHz than quality factor and insertion loss will be observed like insertion loss -1.0021dB with quality factor 564 at 50 GHz and insertion loss -1.0361dB with quality factor 585 at 60GHz . If we will increases the operating frequency than quality factor will be increasing and insertion loss will be decreases. The purpose of this work is to overcome the insertion losses and develop band pass filter with wide pass band to cover the various microwave frequency band. But in this paper a particular frequency like 60GHz. It takes the frequency ranges from 50GHz to 60GHz than low insertion loss get the higher frequency at 60GHz.

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 refers to a particular kind of physical structure, and filter design is solving the physical dimensions of a structure. The whole design process entails other stages upon which the task of finding out dimensions is built. This cavity size is same as [2] 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 60GHz

S.No.	Filter	Cavity Size[L*H*W(mm)]	Q.F.	I.L.(dB)
1	Proposed Cavity Filter	1.95*0.3*1.275	585	-1.0361dB
2	LTCC Cavity Filter[2]	1.95*0.3*1.275	426	0.84dB

In [2] for comparison same value of frequency and size of cavity in[2] is considered then observed that insertion loss and 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[4]. From a mechanical point of view, weight and volume can be critical depending on the target system.

In high-performance systems, each stage is key when it comes to producing a design that meets the given specifications. In fact, each of those stages has such complexity that it is considered a different area of expertise. Only after studying and gathering all the information it was possible to develop a based of software. Finally, it must be reinforced the idea that although it was used a specific example of a rectangular waveguide filter with low loss to show how scaling works, this explanation can be applied to any kind of structure. Furthermore, this kind of reasoning can be applied likewise to move the band pass of a filter into another frequency without having to do a different design (if the fractional bandwidth is preserved and the design is not taking into account the filter losses). However, filter design of microwave cavity filters should avoid problems with a large number of variables, since full-wave responses are very time consuming and demand a lot of ram in the computer.

V.CONCLUSION

In this paper microwave cavity filters up to 60GHz is successfully designed. The proposed cavity filter structures have been design in the frequency range from 50GHz to 60GHz. It has been observed that the cavity band pass filter has insertion loss of about(-1.0021dB) with quality factor 564 at 50GHz and -1.0361dB insertion loss with quality factor

585 at 60GHz. To reduce the overall size of the filter achieving optimized performance. In this system, initially promoted by the necessity for improved filter performance, and also for increased efficiency of design. An efficient design process is required in a competitive commercial environment, the cavity also show better result in terms of insertion loss because the shielded and is less affected by moisture. This characteristic makes the cavity structure of choice to design microwave system working in hostile environment with high humidity.

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