Ridge Gap Waveguide based band pass filter for Ku-band Application

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Abstract. This paper describes a simple, low loss, compact tuneable band pass filter based on ridge gap waveguide (RGW) technology for the Ku-band applications. This is achieved by keeping the height of the air gap in the gap guide structure equal to the thickness of the substrate or base of the structure. The resonant frequency and electromagnetic (EM) field distribution of the structure is investigated. This filter is designed by inserting the proposed ridge in the cut-off region of the gap waveguide. The frequency of tuning has been carried out using the slot created on ridge, which generates capacitive effect. Experimental results of the manufactured structure show an insertion loss of approximately 0.15 dB and a return loss of 16.38 dB over 4.5% relative bandwidth in Ku-band. The structure, put forwarded here, has been designed and optimized in the CST microwave studio environment and simulated results are validated by experimental results. The size of the structure is 64.65 mm x 64.65 mm x 7 mm.

Keywords. Dispersion Diagram, Insertion Loss, Kurtz band application, Return Loss, Ridge Gap Waveguide Technology.

1. Introduction
Now days, it is expected to have a high-density technique with substantial process of fabrication at lower cost, which offers widespread solutions for future millimetre wave applications. To meet this expectation, an extensive research in this area has been carrying out in antenna/propagation/microwave communities. Techniques started providing the improved results, kicked off with SIW technology [1], followed by one of the famous low loss TFMS - thin film microstrip line [2], Low Temperature Co-Fired Ceramic [3] and many more. These methods have their own pros and cons. However, as market has not been sticking at a single point, a gap waveguide technology is booming now-a-days designing the various high frequencies components or devices. This is the concept of a structure, contains metallic base, pins and a lid. This periodic structure of pins creates artificial magnetic conductor – predominately provides high impedance, which helps preventing the electromagnetic wave propagations for particular frequency region. This historic theory is presented in [4] with reference to the simulations. On later stage, based on the experimental results, idea was confirmed in [5]. Aforementioned literature validates the electromagnetic band gap characteristic of the structure, which can be advantageous for the application at high frequencies.
This technology provides us the promising results in an absence of dielectric material in any form, diminishing losses pertaining to the radiation & dielectric material, which are associated predominately with microstrip based/SIW structures [15].
The point that makes the structure an easy and straightforward is – no electric contact between two plates. It is the main pros in fabricating the components at millimetre waves compared to conventional tech designs. In [6], three different types of gap waveguides are demonstrated viz. – Ridge Gap Waveguide, Groove Gap Waveguide and microstrip Gap Waveguide.
In the year of 2009[7], Kildal has given the concept of ridge gap waveguide to the microwave researcher’s community. Three-dimensional view of the structure is shown in the Fig. 1. To have an internal view of the structure, upper lid is removed. This concept is an early extension of the concept of hard and soft surfaces. PMC surface can be felt by arranging the nails of quarter wavelength with two-dimensional placement. Upper lid made up of the same material as the ground plane, covers the structure. Ridge is place in between the columns of nails, behaves as PEC which allows signal to be guided along with it [8-10]. Surrounding nails behave like PMC surface, which prevent leakages from the sides of the structure. This is the proof of existence of the band gap, which prohibiting wave propagation inside the periodic cells. Researchers are exploring higher frequency bands to design the microwave components, and gap waveguide is the best suited guiding structures to meet the design expectations.

![Figure 1. Three-dimensional view of the structure providing Insights of the periodic structure](image)

These guiding structures are well known for carrying microwave signals specifically in the form of quasi-TEM mode [11, 12]. Even if time lapsed, post announcement this, it is still being snatching the focus of the communities due to its own advantages. Blockage of side leakage is the substantial pros of the artificial PMC surroundings over the micro strip lines. Key part of designing is to construct the smallest part of structure – a unit cell, which acts as the PMC surface. Structure of this unit cell characterizes the operating bandwidth, by forming the artificial magnetic conductor surfaces. Discussions have been depicted on the proposed unit cell in the subsequent sections of this paper. Dispersion diagram – one of the key aspects, connected with this unit cell, has also been illustrated. People are putting rigorous efforts in this area, exploring various shapes of unit cells to achieve good bandwidth ratio, exploring the ways for a transition between the standard connecters and ridge gap waveguide [13, 14].

Here, a proof of concept of tuneable band pass filter based on ridge gap waveguide technology is put forward. Started with unit cell first, band stop region is identified and post that whole structure is simulated in CST microwave studio. The same structure is also fabricated and results are compared in Simulations & Results section. Agreement between simulated and measured results confirms the validity of all simulated results. At this point, the scope of this paper is to demonstrate the capability and manufacturing flexibility of the proposed ridge gap waveguide filter only.

2. Unit cell & stop band

Unit Cell: The desired filter is implemented using Gap Waveguide technique; hence, gap waveguide structure must be designed first. Aforesaid structure is designed in such a way that the frequency band gap incorporates the operating frequency band of the filter. This two-dimensional structure provides us the stop band for the electromagnetic waves.

By examining a part of the structure – called a unit cell with periodic boundary conditions, stop band can be calculated between different modes of frequencies. Unit cell structure is shown in the Fig. 2.
Various parameters viz. – width of pins \((a)\), height of pins \((h)\), distance of upper plates from pins i.e., airgap \((a_g)\), period of alignment of pins \((p)\) – are the crucial to consider while designing the structure, as they control the frequencies of operation, size of band, impedance and so on. Band gap can be defined by the upper and lower bounds of frequencies and respectively, can be controlled by varying the height of pins and air gap distance – distance of lid/upper plate from pins. For the proposed design, appropriate dimensions of the structure are calculated to create required band gap, based on parametric study.

**Figure 2.** The dispersion diagram for several different modes \((p=6.5 \text{ mm, } h=4.5 \text{ mm, } a=3 \text{ mm, } g=1 \text{ mm})\).

With reference to the Fig. 2, the band gap frequency range is from 14.5-19 GHz and its relative bandwidth of \((f_{\text{max}}/f_{\text{min}}) \approx 2.24\). By introducing the proper defects within the structure, filter is designed by developing apt sized ridge.

Such a structure electrically represented as the resonant parallel LC circuit, which has impedance equal to the impedance of the parallel LC circuit. Generally, impedance of parallel LC circuit hit the peak if the frequency of structure reached at resonant frequency.

### 3. Simulation Results

Based on discussions in previous section, RGW structure is designed. Table 1 contains the parametric view of the same. The proposed structure has been constructed in Computer Simulation Technology (CST) microwave studio software as shown in Figure 3. The same software is used for simulation purpose. The electric field distribution inside the proposed stricter is shown in Figure 4. The scattering parameters are shown in Figure 7. They show that over the expected bandwidth, return loss observed better than 15 dB, and the insertion loss is better than 1 dB for almost the same bandwidth.

| Pin Height \((h)\) | Period \((p)\) | width \((a)\) | Air gap \((g)\) | Thickness of base | Thickness of upper metal lid | Desired Stop Band |
|------------------|----------------|--------------|----------------|-------------------|----------------------------|------------------|
| \(\lambda/4\)    | \(\lambda/3\)  | \(\lambda/6\) | \(\lambda/20\) | \(\lambda/2\)    | \(\lambda/20\)            | 14.5-19 GHz       |

**Figure 3.** Perspective view of the complete geometry including bed of nails underneath.

**Figure 4.** The E-field distribution in ridge gap waveguide filter.
Second part of the design is to explore tuning capability of the structure. By introducing the slot on the ridge, gives us the capability to fine-tune the filter in the operating frequency band(s), keeping the scattering parameters almost similar. Figure 5 shows the structure with a slot on a ridge of the gap waveguide structure. Figure 6 shows the field distribution inside the structure which is confine to the ridge at the desired frequencies and structure will not let the flux to leakage from the sides. Figure 7 shows the comparison between the simulated results of the structure without a slot on a ridge and with a slot on a ridge of the proposed structure. Figure 8 is the measurement setup of the fabricated filter. The
optimized response of the filter is plotted in Figure 9 along with the measured results. The measured results in Figure 9 show an acceptable agreement with the analyses in general as a first prototype trial. Some additional loss are observed in the measurements due to the possible presence of additional airgap between the layers.

4. Conclusion
This paper has been proposed the structure, purely based on the concept of perfect magnetic conductor, having a symmetric geometry, and is realized using gap waveguide technology. This geometry causes considerably less fringing fields around the ridge located in the centre. This structure contains fewer numbers of periodic cells on the both sides of the ridge, which reduces the structure size. Simulation results confirmed the theoretically expected band obtained via the Eigen mode solver in CST. The simulated results for the filter are capable to meet the stringent commercial specifications. However, fabrication tolerance associated with commonly used manufacturing techniques is to be investigated more in depth. At last, structure is fabricated, tested, and observed good agreement between measured and simulation results.

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