A Geometric Study of Tunable Planar Groove Gap Waveguide Cavities

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Abstract.
A comparative simulation-based study of tunable Planar Groove Gap Waveguide (PGGWG) cavities is presented. All cavities employ a simple biasing scheme to control the resonance of the cavity electronically. This is done by exploiting the DC isolation of the Planar Groove Gap Waveguide geometry for device biasing. Results obtained show that a higher tuning range (1.4%) is obtained with a rectangular PGGWG cavity as opposed to square and circular cavities. A higher unloaded Q-factor is obtained for the square cavity, which is more variable over the tuning range as compared to the circular and rectangular cavities.

1. Introduction
Planar integration media such as Substrate Integrated Waveguide (SIW) provide numerous advantages over hollow metallic waveguide, including low production cost and small size [1]. It is widely used in microwave systems where compact and moderately low-loss requirements are important [2]. Frequency-agile front-end filters are commonly implemented in SIW [3], [4]. However, due to the lack of DC isolation between the top and bottom conducting planes of SIW, bridging wires [5] or multi-layer routing [4] is required to connect the DC bias lines to the active device.

An alternative planar waveguide is the Planar Groove Gap Waveguide (PGGWG)[6]. PGGWG is an implementation of the Groove Gap Waveguide [7] in planar form. It is derived by replacing the electric sidewall with an artificial Perfect Magnetic Conductor (PMC) realised through an Electromagnetic Band Gap (EBG) structure [8]. This provides the advantage of DC isolation between the top and bottom plate, making the biasing of active device easier [9].

In this paper, we explore different tunable resonant cavity geometries in PGGWG using the biasing scheme as presented in [9] and compare them with respect to the achievable tuning range as well as the unloaded quality factor.

2. Planar Groove Gap Waveguide
The PGGWG structure is implemented on multilayer PCB, as shown in figure 1. The structure is formed by placing three rows of blind vias (diameter $v_d$), each capped by a catch pad at either
Multiple dielectric layers

Figure 1. Cross-section of the Planar Groove Gap Waveguide. From [6].

side of a groove gap of width $w$. The blind vias and catch pads form an electromagnetic bandgap (EBG) structure.

The resonant frequency of the unit cell is determined by the capacitance between the catch pad and the bottom perfect electromagnetic conductor (PEC) plane, the capacitance between the catch pad and the top conductive plane, as well as the inductance of the blind via. By changing the size of the catch pad, the height and the width of the via, the bandgap that the EBG creates can be designed and shifted. This is demonstrated in figure 2 for the round top pad and square patch. Through appropriate choices of $h$ and $h_a$, an artificial magnetic conductor (AMC) sidewall is created either side of the groove of width $w$. The medium then supports a $TE_{10}$ propagating mode, similar to that of GGWG [10], in the EBG.

Figure 2. Magnitude of $S_{21}$ for the different embedded EBG structures in parallel planes showing the effect of different pad and patch sizes. The insert is the EBG unit cell for round and square mushroom-type EBG where $p_d$ is the diameter of the round pad and $p_w$ the width of the square patch.

3. Geometry

3.1. Basic cavity

Various cavity arrangements, each formed with square and round EBG cells, of the PGGWG resonant cavity are explored. Figure 3(a), 3(b) and 3(c) show the rectangular, square and round resonant cavities with the corresponding electric field distribution of the fundamental resonant mode. Note the vias are topped by catch pads as detailed in figure 1.

The PGGWG cavity is excited using the CPW feed (Figure 3(d)) through weak input and output coupling in order to determine $Q_0$ of the resonant cavity while maintaining DC isolation between the two planes. The resonant frequency of the rectangular and square cavity is determined by the length of the cavity $L_g$ while the coupling to the cavity, set by the iris width $C_g$, is intentionally chosen as a low value in this case, to minimize loading effects. The resonant frequency of the circular cavity is determined by its radius $C_r$. 
Park Electrochemical Mercurywave 9350 low-cost substrate with \( \varepsilon_r = 3.5 \) is used in a three-layer stack-up. The dimensions of the waveguide as presented in Figure 1 are \( h = 0.5 \text{ mm} \), \( h_a = 0.1 \text{ mm} \), \( v_d = 0.3 \text{ mm} \), pad diameter \( p_d = 0.7 \text{ mm} \) (round pad EBG), \( p_w = 0.7 \text{ mm} \) and \( p = 0.85 \text{ mm} \). In the case of the rectangular cavity, \( w = 5.08 \text{ mm} \) and \( L_g = 3.67 \text{ mm} \); for the square cavity, \( L_g = w = 3.86 \text{ mm} \), and for the circular cavity the radius is \( C_r = 1.4 \text{ mm} \).

![Figure 3. Electric field distribution for different resonant cavity arrangements. (a) Rectangular cavity. (b) Square cavity. (c) Circular cavity. (d) PGGWG structure with top and bottom view showing the connection of the varactor diode [9].](image)

### 3.2. Varactor inclusion

A simple biasing scheme is applied as a result of the beneficial DC isolation between the top and bottom conducting plates of the PGGWG. As shown in figure 3(d), the DC bias line can be applied directly to the top metal plate of the PGGWG. This is done by etching a groove \( (P_g = 0.15 \text{ mm}) \) around the square patch \( (P_L = 0.75 \text{ mm}) \) in the center of the cavity. The patch is subsequently grounded to the lower conductor by a metallic via of diameter \( 0.3 \text{ mm} \), which creates an effective capacitive load on the resonant cavity at the local resonant E-field maximum. By varying the capacitance across the gap, the resonant frequency of the cavity is varied. To this end, a reverse biased varactor diode is connected across the gap, to electrically vary the gap capacitance. This approach is applied to all cavities.

### 4. Simulation result

To verify the achievable tuning range, a hybrid EM-circuit co-simulation is performed in CST Microwave Studio with the Spice model of a Macom 46600 series varactor diode. By varying the reverse bias voltage 0 - 30 V (corresponding to 0.13 - 0.25 pF) the results in Table 1 are obtained. Figure 4 shows the simulated S-parameters (insert shows the interface of the 3D model to DC bias line and varactor diode).

It is observed that the unloaded Q-factor is higher for square cavity than the rectangular cavity at the expense of lower achievable tuning range. On the other hand, the circular cavity has the least tuning range at 0.3% but with a fairly high and constant unloaded Q-factor.

### 5. Conclusion

A comparison between different electronically tunable resonant PGGWG cavity is presented using a simple biasing network. This simplified biasing scheme is a direct result of the PGGWGs unique property of DC isolated conducting planes. It is found that the unloaded Q-factor is fairly constant over the tuning range. Future work will investigate other cavity arrangements, and aim to increase the tuning range.
Figure 4. S-parameter of rectangular PGGWG cavity for different values of varactor capacitance

Table 1. Q-factor comparison between different resonant cavities

|                      | $f_0$ (GHz)       | $Q_u$ (GHz) | Tuning range % |
|----------------------|-------------------|-------------|----------------|
| Rectangular Cavity, Round EBG | 31.54 - 31.95 | 152 - 160 | 1.4            |
| Rectangular Cavity, Square EBG | 38.48 - 38.81 | 136 - 137 | 1              |
| Square Cavity, Round EBG | 33.02 - 33.43 | 173 - 222 | 1.36           |
| Circular Cavity, Round EBG | 38.76 - 38.83 | 193 - 194 | 0.3            |

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References
[1] Bozzi M, Georgiadis A, Wu K. Review of substrate-integrated waveguide circuits and antennas. IET Microwaves, Antennas Propagation. 2011 June;5(8):909–920.
[2] Tao Y, Hong W, Tang H. Design of A Ka-Band Bandpass Filter Based on High Order Mode SIW Resonator. In: 7th International Symposium on Antennas, Propagation EM Theory; 2006. p. 1–3.
[3] Entesari K, Saghati AP, Sekar V, Armendariz M. Tunable SIW Structures: Antennas, VCOs, and Filters. IEEE Microwave Magazine. 2015 Jun;16(5):34–54.
[4] Sirci S, Martinez JD, Taroncher M, Boria VE. Varactor-loaded continuously tunable SIW resonator for reconfigurable filter design. In: 41st European Microwave Conference; 2011. p. 436–439.
[5] He F, Chen XP, Wu K, Hong W. Electrically tunable substrate integrated waveguide reflective cavity resonator. In: Asia Pacific Microwave Conference; 2009. p. 119–122.
[6] Oyedokun T, Geschke R, Stander T. Experimental characterization of Planar Groove Gap Waveguide and Cavity. In: Proceedings of the 47th European Microwave Conference; 2017. p. 436 – 439.
[7] Rajo-Iglesias E, Kildal PS. Groove gap waveguide: A rectangular waveguide between contactless metal plates enabled by parallel-plate cut-off. In: Proceedings of the 4th European Conference on Antennas and Propagation; 2010. p. 1–4.
[8] Sievenpiper D, Zhang L, Broas RFJ, Alexopolous NG, Yablonovitch E. High-impedance electromagnetic surfaces with a forbidden frequency band. IEEE Transactions on Microwave Theory and Techniques. 1999 Nov;47(11):2059–2074.
[9] Oyedokun T, Geschke R, Stander T. A Ka Band Tunable Planar Groove Gap Waveguide Cavity. In: IEEE Radio and Antenna Days of the Indian Ocean (RADIO); 2017. p. 1–4.
[10] Berenguier A, Fusco V, Zelenchuk DE, Sanchez-Escudero D, Baquero-Escudero M, Boria-Esbert VE. Propagation Characteristics of Groove Gap Waveguide Below and Above Cutoff. IEEE Transactions on Microwave Theory and Techniques. 2016 Jan;64(1):27–36.