Improved PMC Packaging Design by Using Novel Pin Geometries

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Abstract— Nowadays, microwave systems have gained more interest in wireless communications due to the need both for higher data rates and greater bandwidth. Nevertheless, electromagnetic compatibility (EMC) problems on circuit components is one of the significant problems to be overcome in these systems. High electromagnetic isolation must be ensured in neighboring microwave circuits or between critical components and undesirable electromagnetic interference (EMI) must be suppressed. Recently, new structures that the microwave circuits are located in metal enclosures containing three-dimensional periodic metal pin arrays called as perfect magnetic conductor (PMC) packaging are proposed to solve these problems. In this study six different novel pin geometries as helical shaped models containing one, two, three and four helices, pyramidal shaped model and inverted pyramidal shaped model are suggested. Pinned cover models are designed with all proposed pin shapes and the obtained simulation results are represented by comparing with the square cross-sectioned ones. The band gap of the stop band region obtained by the proposed pinned covers are shifted to the lower frequencies according to the band gap of the pinned cover with square cross-sectioned pins. The suggested pin geometries can contribute to the compactness of the covers by their lighter, smaller and requiring less material features.

1. INTRODUCTION

The irrepressible growth in wireless communication application necessitate the engineers and the researchers to develop next generation wireless systems which have higher data rates, greater bandwidth and enable high level of integration besides being smaller, lighter and more compact. On the other hand, in the microwave systems including RF circuits, the unwanted electromagnetic noise emission by the connecting cables and signal paths since they act as antennas is a known fact. Thus, the noise coupling, signal integrity, cross-talk between RF/Digital components and unwanted electromagnetic interference (EMI) on neighboring circuit elements cause malfunctions in the microwave systems which are also the essential parts of wireless communication applications. Therefore, dealing with these problems is one of the most important tasks of today's engineers.

A new shielding method based on gap waveguide (GW) known as a perfect magnetic conductor (PMC) packaging technology has been widely studied in recent years [1–5]. This technology consists of two parallel plates, a bottom perfect electric conductor (PEC) layer and a top artificial magnetic conductors (AMC) layer that contains an array of periodic metal pins which provides PMC surface effect. When the literature is examined, it can be seen that the metal pins of the PMC periodic constructions have generally square cross section. However, this can be accomplished by smaller, lighter, requiring less material pin geometries and they can contribute to the compactness of the systems besides the isolation. This paper focused on novel different pin geometries and configurations to provide enhancements in electrical performance or advantages in physical structure. For this purpose, six different pin geometries are suggested here that four of them have mainly helical and the other two pyramidal shapes. The impact of the different pin geometries on the electrical performance of the novel PMC packaging is numerically investigated. The numerical modeling and simulations are performed by using the commercial full-wave electromagnetic simulation software CST Microwave Studio [6]. The results are represented by comparing with the PMC packaging including square cross sectioned pins.

2. SYNTHESIS PROCEDURE AND ANALYZES

In the PMC packaging technology, an enclosure with two parallel plates is designed by considering several design limitations. In the enclosure the ground layer of the circuit board forms the PEC layer while the pinned cover with periodic pin array behaves like PMC layer and the revealed PEC-PMC structure provides significant improvements in system performance by suppressing all unwanted cavity modes, substrate modes, EMI and scattering. In these applications, the space between the parallel plates should be less than quarter wavelength and the height of the pins are about a quarter wavelength to suppress the unwanted electromagnetic waves in the cavity [1, 2, 4]. On the other hand, design parameters such as pin height, pin width, distance between the pins effect the electrical performance of the PMC packaging.

In this study novel different pin geometries and configurations are investigated to design covers with pins that have smaller dimensions, lighter and requiring less material. For this purpose, all of the design parameters of the cover are kept constant but only the pin geometries are changed for investigating the effect of the pin shapes. Initially a pinned cover model made by 5×5 array of pin with square cross section is designed for 10 GHz–20 GHz frequency band and used as a reference model for the comparison with the novel covers having different pin shapes. The reference cover model and its design parameters which are significant in the design procedure are shown in Figure 1 and listed in Table 1.

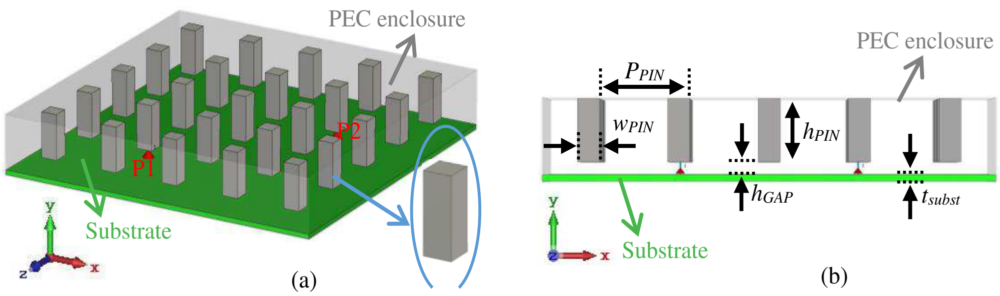

Figure 1: Pinned cover with square cross section model (a) perspective view and (b) side view.

Table 1: Pinned cover with square cross section model design parameter values.

p_{PIN}	w_{PIN}	h_{PIN}	h_{GAP}	t_{subst}	ε_r
7.5 mm	1.82 mm	5 mm	1 mm	0.5 mm	3.66

The numerical modelling and simulations are performed for the reference model and the obtained transmission characteristics are given in Figure 2. A forbidden propagation region is obtained between 10.61 GHz and 20.45 GHz that corresponds to X, Ku and K bands with 9.84 GHz bandwidth.

The study is continued with the novel pin model designs. To accomplish examining the effect of the pin geometries the designs are done by great care. The novel pin shapes and their design parameters have been chosen to fit the new pins into the volume of the reference pin model as shown in Figure 3. The cross section of the bases of the three-dimensional pin geometries are common for the reference and the proposed designs. So that, the novel design parameters the pin width w_{PIN}, the width of the unit cell p_{PIN} and the pin height h_{PIN} remain constant.

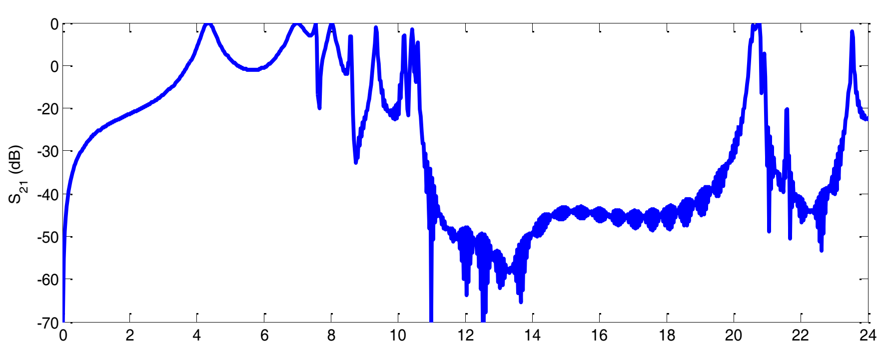

Figure 2: Frequency dependent S_{21} simulation results of the pinned cover with square cross section.

The novel pin geometries investigated in this study can be introduced mainly in two classes; helical shapes and pyramidal shapes. The helical shapes are constituted by increasing the number

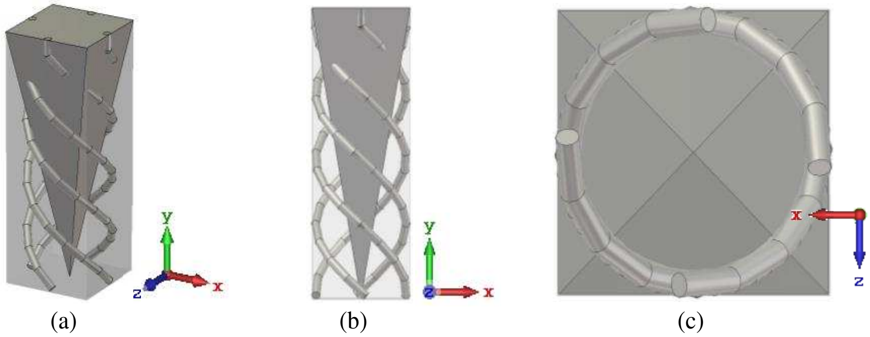

Figure 3: Comparison of the unit elements (a) perspective view, (b) side view and (c) bottom view.

of helices included in the unit element of the structure. In this sense four helical pin models are studied including one, two, three and four helices. The rest two models are the one with pyramidal shape and the other formed by inverting the pyramidal unit element. The locations of the new shaped pins in the 5×5 array configuration are kept unchanged, so that the outer dimensions of the pinned covers remain the same with the reference one. The pinned covers with helical shaped pins containing one, two, three and four helices in its unit elements are shown in Figure 4 and the frequency dependent transmission characteristics for the covers are given in Figure 5.

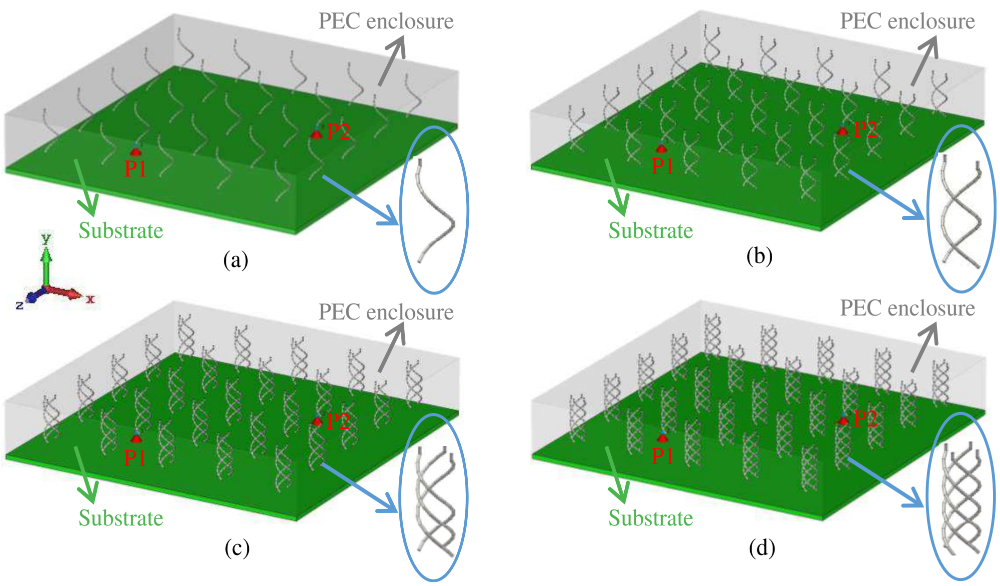

Figure 4: Helical pinned cover models with (a) 1 helix, (b) 2 helices, (c) 3 helices and (d) 4 helices.

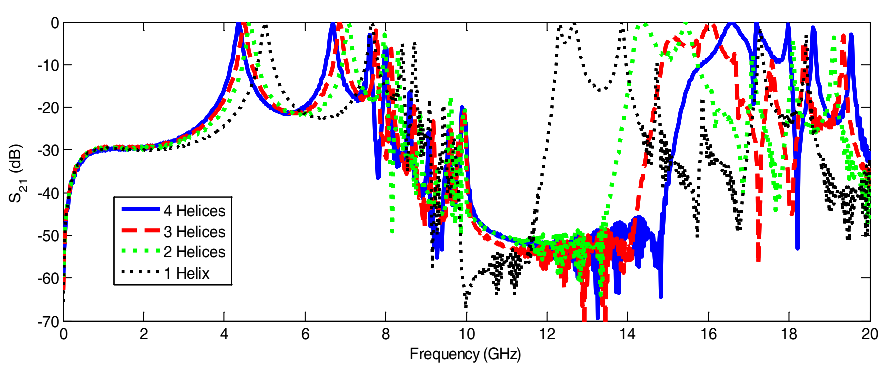

Figure 5: Frequency dependent S_{21} simulation results of the helical pinned cover models.

It can be easily seen that the addition of the helix into the unit cell increases the bandwidth towards the higher frequency region. The observed bandgap limits (f_{low} and f_{high}) for the helical pinned cover model with one helix are 8.74 GHz and 12.22 GHz with 3.48 GHz bandwidth. When the number of helices is increased one by one the bandwidth of the stop band is increased to the 5.76 GHz ($f_{low} = 8.34$ GHz and $f_{high} = 14.10$ GHz), 6.70 GHz ($f_{low} = 8.15$ GHz and $f_{high} = 14.85$ GHz) and 7.81 GHz ($f_{low} = 8.02$ GHz and $f_{high} = 15.83$ GHz), respectively.

Subsequently, the pyramidal pinned covers with pyramidal shaped pins and inverted pyramidal shaped pins are designed and analyzed. The pinned covers with pyramidal shaped pins and the simulated frequency dependent transmission characteristics of these covers are given in Figure 6 and Figure 7, respectively.

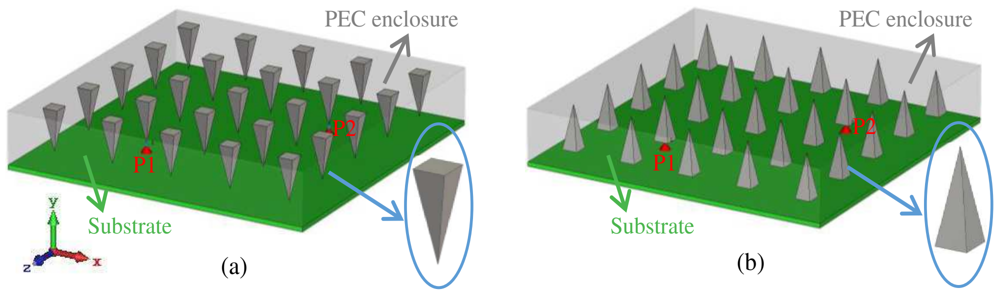

Figure 6: Pyramidal pinned cover models with (a) pyramidal and (b) inverted pyramidal shaped pins.

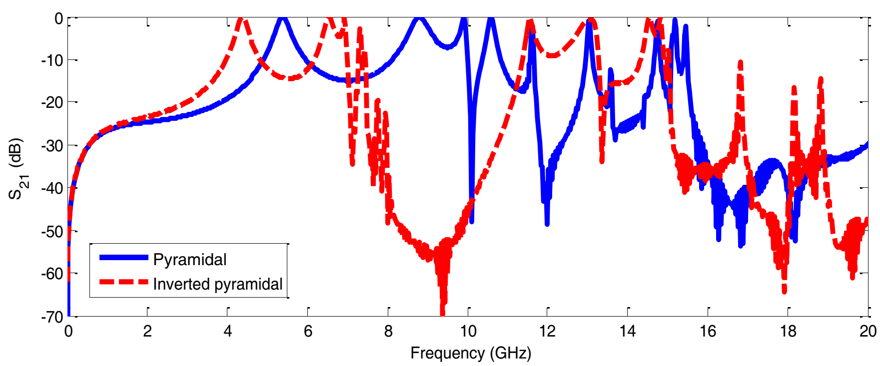

Figure 7: Frequency dependent S_{21} simulation results of the pyramidal pinned covers.

When the obtained transmission characteristics depending on the frequency for the pinned cover model with pyramidal shaped pins is investigated, a discontinuous stop band region between 10.01 GHz and 14.67 GHz with four notches can observed. However, this does not meet the broad band gap expectations. On the other hand, the transmission characteristics of the pinned cover model with inverted pyramidal shaped pins has a continuous band gap between 7.01 GHz and 11.37 GHz. This band gap nearly corresponds to the total stop band bandwidths of the discontinuous notches of the pinned cover model with pyramidal shaped pins but shifted to the lower frequencies.

Finally, the reference pinned cover and the selected two novel pinned covers, one is helical pinned cover with four helices and the other is pyramidal pinned cover with inverted pyramidal shaped pins, are compared. Figure 8 represents the frequency dependent transmission characteristics of these covers. Additionally, the lower and higher frequency limit values are given in Table 2.

Table 2: Cutoff frequencies and bandwidths of the models compared in Figure 8.

Model	f_{low} **(GHz)**	f_{high} **(GHz)**	**BW (GHz)**
Pinned cover with square cross sectioned pins	10.61	20.45	9.84
Helical pinned cover model with four helices	8.02	15.83	7.81
Pinned cover model with inverted pyramidal shaped pins	7.01	11.37	4.36

When compared results are examined it is observed that helical pinned cover with four helices gives a forbidden propagation zone with 7.81 GHz bandwidth in X and Ku bands. The pinned

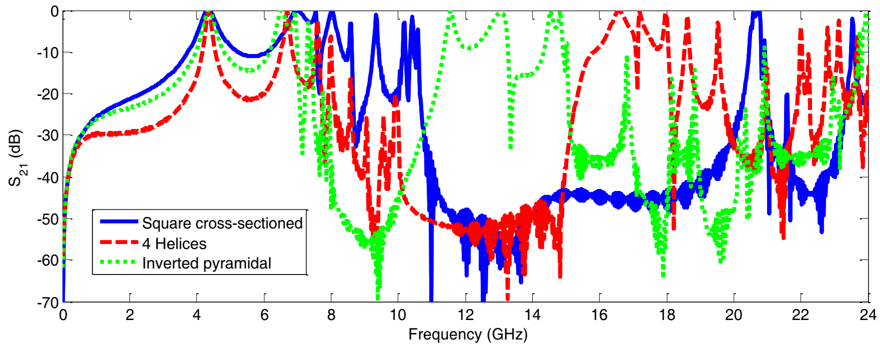

Figure 8: Comparison of the frequency dependent S_{21} simulation results.

cover model with inverted pyramidal shaped pins is also has a band gap in X band with 4.36 GHz bandwidth. Consequently, it is observed from the simulation results that both the electrical lengths and the shapes of the pins have significant effect on the operation frequency of the pinned covers.

3. CONCLUSIONS

This paper presents a study that investigates the effect of the pin geometries on the electromagnetic isolation of the pinned covers used in the PMC packaging technology. For this purpose, six novel pin geometries are suggested which are manufacturable but lighter and requiring less material. The designs suggested in this study are done without any changes in design parameters since the focus of the study is to investigate the effect of the pin geometries only. All of the proposed pined covers are simulated, and the transmission characteristics are obtained in the frequency range of interest. Then two models, the helical pinned cover model with four helices and the pinned cover model with inverted pyramidal shaped pins, that have largest band gaps are chosen and compared with the reference square cross-sectioned pinned cover. An electromagnetic isolation in the 8.74 GHz–12.22 GHz frequency band is observed by pinned cover model with pins including one helix and the band is broadened to 8.02 GHz–15.83 GHz by increasing the number of helices to four in the pin. On the other hand, the pinned cover with inverted pyramidal shaped pins succeeded an isolation band between 7.01 GHz and 11.37 GHz.

As a result, it can be concluded that the proposed pin geometries can contribute to the compactness of the systems with their smaller and lighter structural features. The weights of the PMC packages including proposed pins can reduce according to the pinned covers with square cross sectioned pins. The proposed pin geometries could provide desired stop band regions and better isolation by different arrangements and optimization of the design parameters.

ACKNOWLEDGMENT

This study was supported by TUBITAK — The Scientific and Technological Research Council of Turkey — (Project number: EEEAG-117E807).

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