Designing components containing photonic bandgap structures using time domain field solvers

Arbitrary passive 3D structures are becoming increasingly complex, requiring ever faster and more efficient field solvers. Due to economical use of computer resources and run-time, the time domain code the technique has been gaining in importance over the last few years. This paper describes the application of metallo-dielectric resonant structures at microwave frequencies incorporated into realistic devices by using a 3D field simulator based on the time domain technique.

ZUSAMMENFASSUNG

Die Entwicklung von Komponenten mit photonischen Bandabstands-Strukturen mit Lösungen im Zeitbereich

Passive 3D-Strukturen werden immer komplexer und benötigen immer schnellere und effizientere Lösungen im Zeitbereich. Wegen der ökonomischen Nutzung der Computer-Ressourcen und der Laufzeit, haben Verfahren im Zeitbereich in den letzten Jahren Bedeutung gewonnen. Dieser Beitrag beschreibt die Anwendung von metallisch-dielektrischen Resonanz-Strukturen bei Mikrowellen in realistischen Bauteilen durch Anwendung eines 3D-Feld-Simulators nach dem Zeitbereichs-Verfahren.

SOMMAIRE

Conception de composants contenant des structures PBG (photonic band gap) en utilisant des méthodes de calcul de champ dans le domaine temps

Les structures 3D passives arbitraires deviennent de plus en plus complexes, exigeant des logiciels toujours plus rapides et efficaces. Pour économiser les ressources informatiques et raccourcir le temps d'exécution, la technique de résolution dans le domaine temps a pris de l'importance au cours des dernières années. Cet article décrit l'application aux structures résonantes métallo-diélectriques à des fréquences micro-ondes incorporées à des dispositifs réalistes, en utilisant un simulateur de champ 3D basé sur la technique dans le domaine temps.

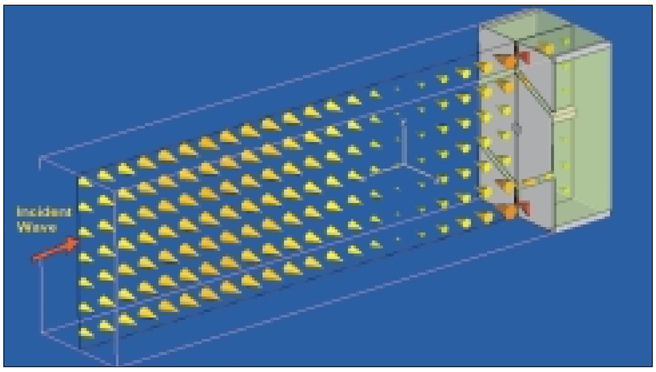


Figure 1: Model set-up of the hexagonal structure

In this paper various methods are presented as to how to compute and optimise the frequency bandgaps (BPG) of photonic bandgap structures for given metal textures. Several useful applications are then examined including a wire antenna over ground and a patch antenna, both demonstrating an improvement in radiation efficiency, concluded by a waveguide bandpass filter using stacked PBG-material.

Why PGBs?

The high frequency community is currently demonstrating growing interest in a new type of metallic structure [1] which offers fascinating electromagnetic properties. Although it is made of conductive material, it behaves, for a certain frequency band, as an isolator while maintaining dc currents. Within this gap propagating surface waves are not supported, and image currents are in phase rather than phase reversed. Although PBGs were developed originally for the optical range, they are applicable to a wide range of frequencies, including microwave, therefore the terminology of crystal band structures is used.

The concept of suppressing surface waves has been used for many years in geometries such as corrugated slabs and bumps, but is now applied to thin 2D-structures described by band structure concepts. The repetitive structure consists mainly of 2D slabs such as patches and vias; they are often called met-

Figure 2: Typical reflection phase diagram for the given hexagonal lattice

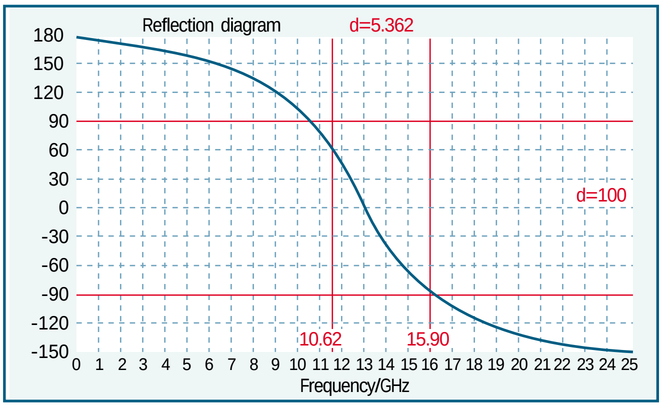
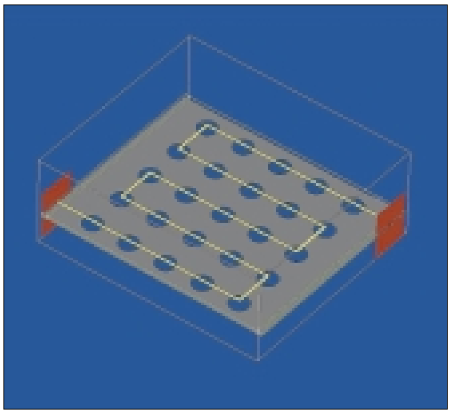
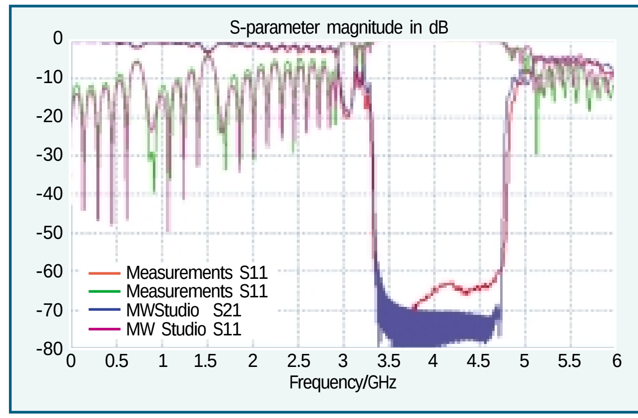


Figure 3a (right): Model representation of the compact PBG microstrip band rejection structure.
Figure 3b (far right): Simulated and measured S-parameters for the compact PBG microstrip using a fine mesh discretisation





allo-dielectric PBGs. Embedded in a substrate, they are inexpensive to fabricate.

PBG modelling concepts

The behaviour of PBGs can be summarised in a single parameter, namely the surface impedance. For a smooth conducting plate it is quite low, but with a special texture the surface impedance may become very high. It can be shown that TM waves occur on an inductive surface whereas TE waves can exist on capacitive surfaces. If characterised by an equivalent LC-circuit, the surface impedance is extremely high around the resonance frequency band and therefore the waves are not bound to the surface anymore.

Reflection phase analysis method

Since the surface impedance varies, the reflection phase changes from a perfect metal reflection which is 180º (electric node at the surface) down to -180º for a perfect magnetic conductor (node for H-field). The reflection phase is zero at the resonance frequency band. The typical set-up for a model in order to predict the reflection phase is to determine the phase difference between an incident wave illuminating the structure and the reflected wave at a certain position above a unit cell model with appropriate periodic boundary conditions at the side walls of the cell. Figure 1 demonstrates a unit cell model set-up containing a hexagonal lattice structure backed up by a perfect electric conductor (PEC). Applying a field probe detecting the signals in magnitude and phase, the reflected signal is computed by signal calculator thereby adding another 180º phase shift to account for a reference phase of a pure metal. The reflection phase diagram is shown in Figure 2. The model itself is very simple and takes approximately 1 min CPU time for a broad band of frequencies. Since the run-time is very low, optimisation loops can be performed to achieve the desired resonant frequency by varying, for example, the patch-size, via diameter and periodicity.

Direct transmission analysis method

As PBGs inside the resonance regime do not conduct waves bound to the surface, a transmission of energy through the structure is low and is thus visible in the transmission S-parameters. A typical measurement set-up would be such that vertical and/or horizontal orientated monopole probes are positioned at some distance apart, coupled only by the PBG surface. The equivalent analysis set-up consists simply of either two discrete ports or two waveguide ports with the appropriate excitation mode.

The insertion loss parameter S_{21} indicates that no energy is transported through the device. This curve can be minimised broadband by varying the distance and size of the dielectric posts. Since run-time is extremely short (27s per run) the optimised solution for a desired centre frequency of 9GHz was found by the CST MICROWAVE STUDIO built-in optimiser within 18 minutes performing 20 runs for two variables: periodicity and rod-size. It should be mentioned that normally the structures are highly resonant, and it may take a while for the time signals to converge but through the use of robust built-in auto regressive filters (AR-filters) run-time is reduced dramatically.

Application Examples

High performance microstrip band rejection filter

One of the greatest advances in the development of PBG structures in the microwave range, has been their implementation in microstrip technology. The simplest and most effective way is to etch the periodic pattern

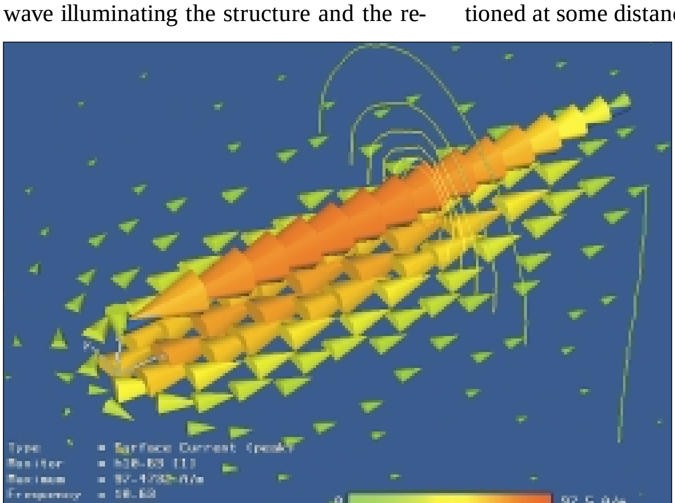


Figure 4: Current distribution for a simple monopole over ground

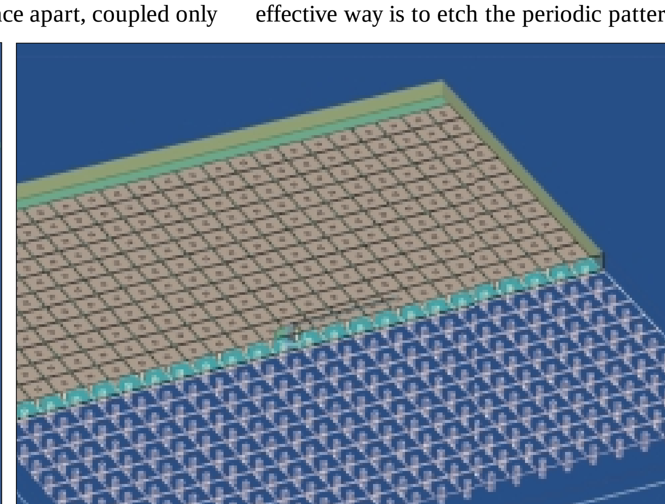


Figure 5: Wire antenna over a PGB structure

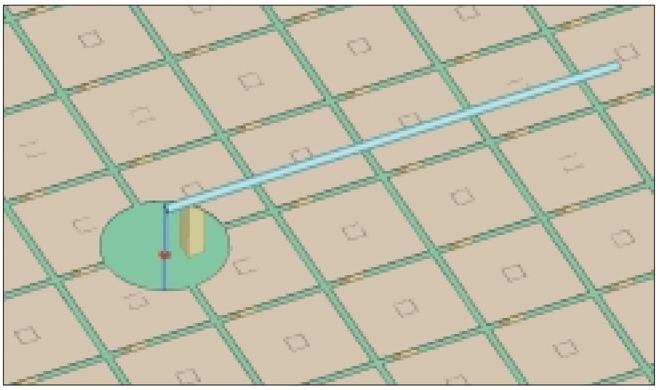


Figure 6: Close up look at the feed including source and the cut away hole of the PBG.

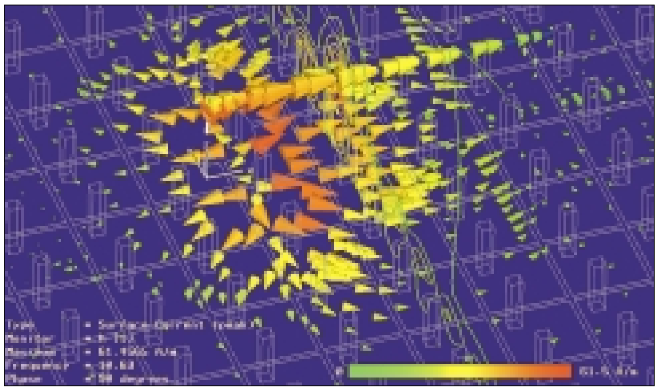


Figure 7: Arrow plot of the current density for the reinforced set-up including PBG

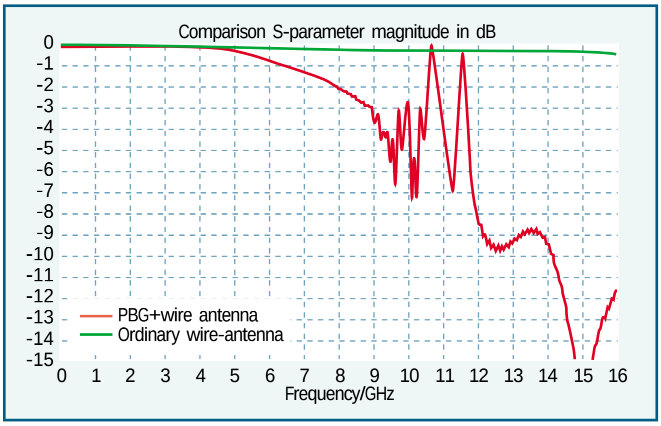
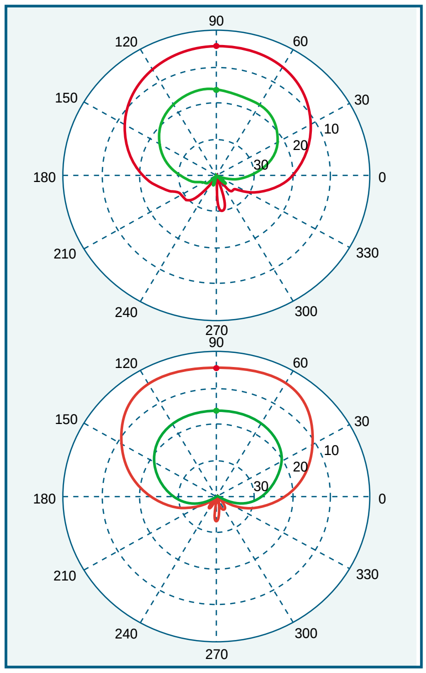


Figure 8 (left): Return loss of the horizontal antenna on two different ground planes

Figure 9 (right): E-Plane and H-Plane of the radiation pattern

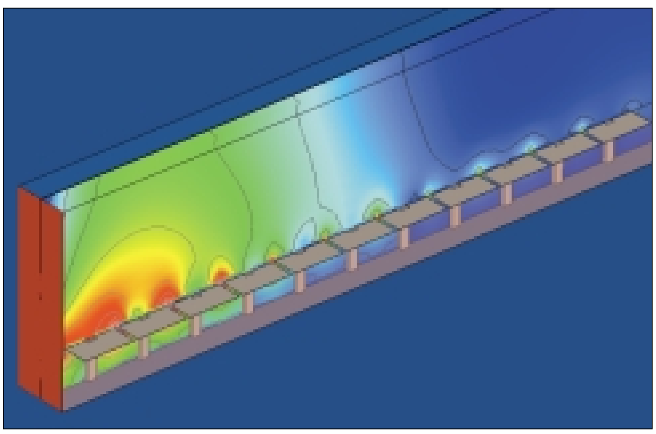


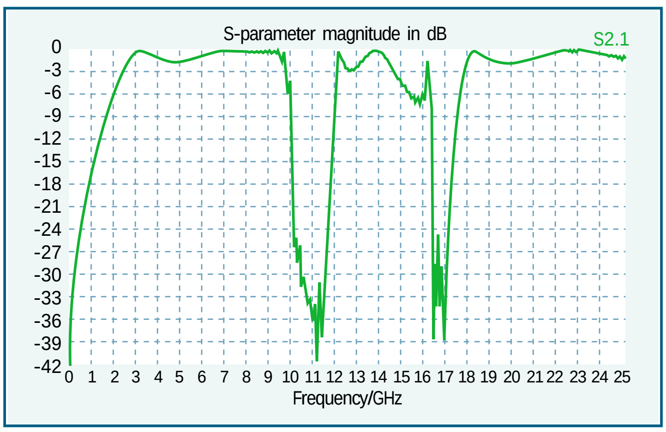
in the ground plane of the microstrip line, generating a band of frequencies in which electromagnetic propagation is not allowed. Certain applications in microstrip technology, such as high performance filters, require high rejection values in the stop-bands and sharp cut-offs. To obtain these high rejection values it is necessary to include a large number of periods in the structure [4]. To solve the problem of getting large longitudinal dimensions, a new compact 2D-PBG configuration has been proposed [3], in which the microstrip line presents multiple bends, following a similar structure to that of a meander line, shown in Figure 3a.

The simulation results, taking into account dielectric and metallic surface losses, are in excellent agreement with measurements. A variation of the typical dimensions such as holeradius, structure period, and linewidth within a tolerance of ±10% has hardly any impact with respect to the S-parameter performance, whereas a variation of the dielectric constant by ±10% results in a shift of the cut-off frequencies by 5%. Two model set-ups were generated: coarse and fine.

Figure 10 (below left): Squared PBG structure operating at 11GHz
Figure 12 (below right):Insertion loss S_{21} for the squared patch PBG with a designed band-gap of 10 – 12GHz

A coarse model applying default mesh-settings containing 43000 cells was simulated on a Pentium III, 800MHz, 512MB RAM, with a total CPU-time of 19 minute by applying online AR-filtering. The upper cut-off frequency was lower than the measured one by 3%, the lower one agreed very well with measurements.





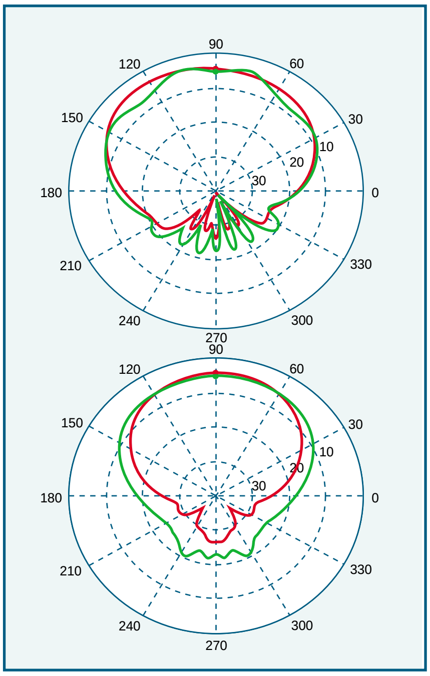


Figure 13: E- and H-Plane pattern of the patch on the two different ground planes

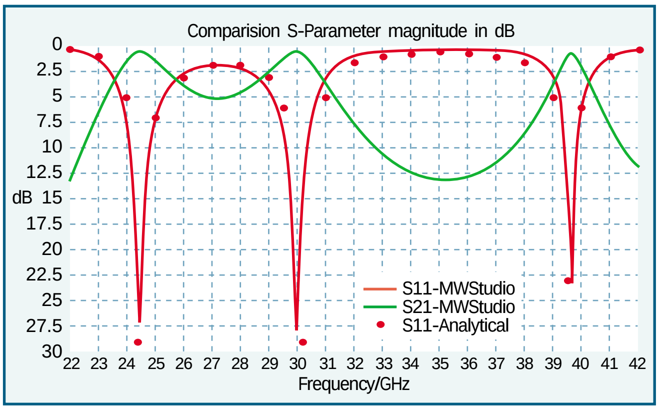


Figure 14: Geometry set-up and S-parameters for two stacked layers

In a second model, with a denser mesh over the dielectric and across the micro-strip, cut-off frequencies were spot on with measurements as shown in Figure 3b. The overall number of mesh-cells was 307020 and the required RAM to run in core was approximately 20MB with a run-time of 3 hours and 6 min.

Horizontal wire antenna

One important property of the PBGs can easily be demonstrated with this simple example of a wire antenna orientated parallel to a ground plane. The image currents at ground are in phase rather than out of phase with the antenna current if PBGs are applied. A horizontal wire antenna radiates poorly on ordinary metal because the image current at ground cancels currents in the antenna.

Figure 4 shows the image current on a normal metal surface and adds destructively to the radiation pattern. The antenna is fed by a discrete port acting as an ideal current source with a given source impedance.

The wire antenna resonates at 11GHz and the length is approximately half a wavelength. The wire antenna is now mounted above a PBG Structure maintaining the same distance to the PBG as to the previously used simple metal ground. A PBG structure was designed to have a bandgap of 10 - 12GHz, illustrated in Figure 11, by applying the transmission line method to a unit cell model. At band centre there is no transmission and the rejection of the waves entering the transmission line can be seen quite clearly Figure 10 excited by a waveguide port to the left. The antenna image currents at ground are reinforcing the radiation and are in phase with the currents in the antenna.

Waveguide filter

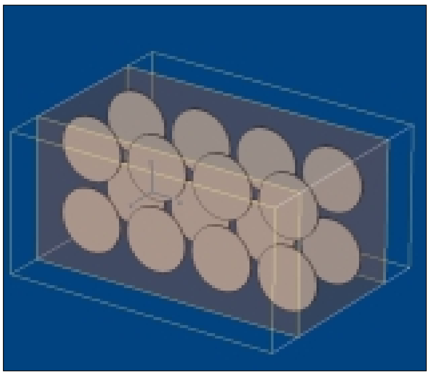
The filter presented here consists of N dielectric layers imprinted with a transverse lattice of planar metallic scatterers, stacked monolithically along the longitudinal direction of a rectangular waveguide [2].

The number of layers is varied and compared to theory given in [2]. As a reference for the accuracy a layer number N of 2 was chosen as shown in Figure 14 and results given by CST MICROWAVE STUDIO are in excellent agreement with the plot given in [2] (Figure 7 a, b). The CPU time of 2 min 32 sec achieved by AR-filtering of time signals is extremely fast compared to the days of CPU time required by a referenced finite element model in [2].

If the thickness of the substrate layers is reduced, thereby increasing the interaction of the printed layers, we observe the beginning of the formation of a passband. Critical mesh areas are regions around gaps between two adjacent disks and disk to metal face. Both problematic regimes are excellently meshed by the expert database supported mesher finding critical areas. Through the use of the PBA technique there is no need for a fine mesh resolution along curved surfaces – often resulting in a tiny stair case mesh ruining performance - since they are considered as curved without any polynomial approximation. Figure 15 shows the details of this meshing technique. Nevertheless, adaptive meshing is also available. The S-parameter results are illustrated in Figure 17, again with excellent agreement to [2], (Figure 9 a, b). Applying online AR-filtering, the run-time was 11 min.

Finally presented here is the challenging task of computing a N=12 layer bandpass, as shown in Figure 18. The slope of the filter again shows an excellent agreement with theory given in [2],with respect to slope and frequency bandwidth, all within a reasonable CPU time of 1h 54 min.

Figure 17 also shows the influence of the lossy dielectric with a reduction of the insertion loss by –1.5dB, compared to -0.25 dB for the lossless case. The filter is



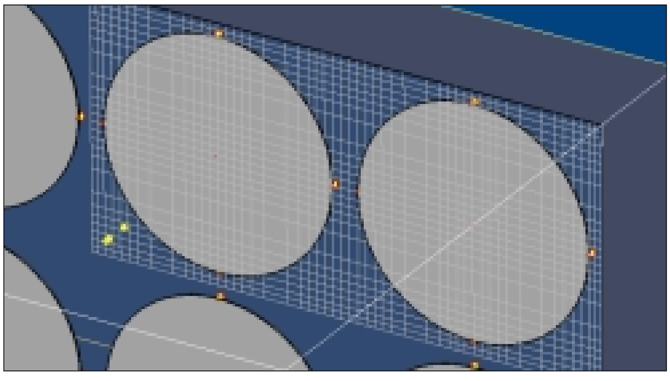


Figure 15: Geometry set-up and mesh details of the 2 layer bandpass. The use of the PBA technique avoids the need for a fine mesh resolution along curved surfaces and speeds up run-time by orders of magnitude

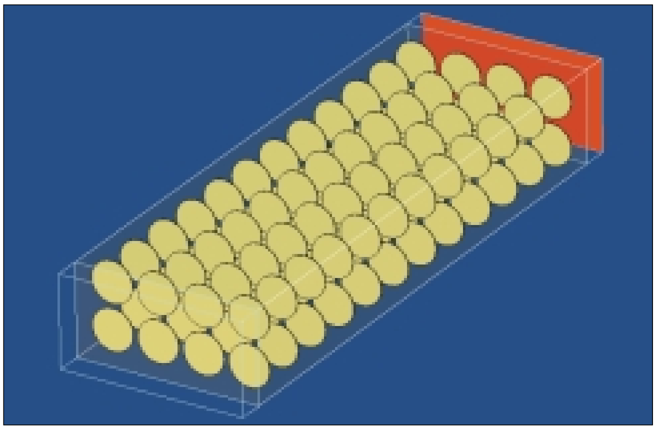


Figure 16: Layer arrangement of the 12 layer bandpass filter

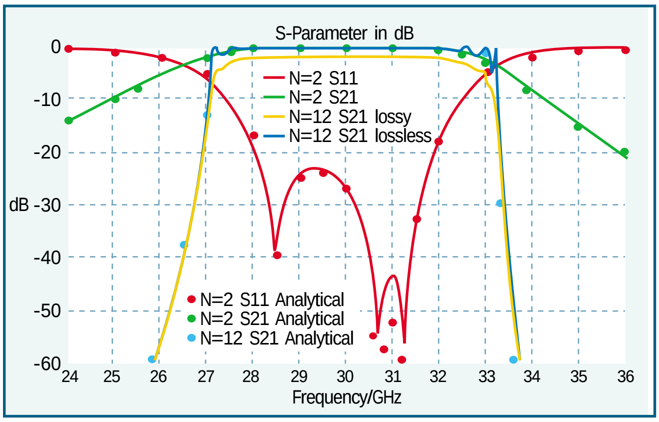


Figure 17: Passband filter characteristic for 2 and 12 layers

sensitive with respect to metallisation thickness, and this has to be taken into account in the model in order to achieve accurate results. A thickness of 35m was assumed. The shift of the lower frequency band was approximately 0.25GHz per 10m.

Conclusion

Using efficient time domain codes such as CST MICROWAVE STUDIO, even electrically large and high Q-factor models can be analysed in a very efficient way compared to other methods. The ability to customise the results, and the usage of the built-in optimiser, enable the designer to easily obtain the desired behaviour of their designs in a routine manner. The PBA technique together with an expert database driven mesh generator allows the creation of useful and moderate meshes to speed up the performance.

Application examples of a patch and wire antenna given in this paper demonstrate the usefulness and design improvements achieved by applying PBG structures.

The presented results for the waveguide and microstrip filters are in excellent agreement with the data published in [2] and [3] respectively.

All simulations were performed on a 450MHz Pentium III, unless otherwise stated.

References:

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