

“Simple modelling of DGS to design 1D-PBG low-pass filters”

Ieltxu Garde, Miguel Javier Yábar and Carlos del Río

Antena Group

Dpto. Ingeniería Eléctrica y Electrónica

Universidad Pública de Navarra

Campus Arrosadía s/n, 31006 Pamplona, Spain

Phone: +34 948 169326 Fax: +34 948 169720

E_mail: carlos@unavarra.es

Abstract.- The use of defected ground structures (DGS) is being intensively explored by the microwave filter designer community. The DGSs are one possible implementation of a 1D Photonic Band Gap (1D-PBG) where some defect structures are patterned on the ground plane of a microstrip circuit.

In this paper, the relation between the behaviour of the DGS structures and the classical microwave filter design theory is established. In particular, a simple model procedure based on the classical microwave filter design theory by using DGS structures is presented. In order to illustrate the method, two low-pass filters are designed, fabricated and measured.

Keywords: microstrip filters, low-pass filters, defected ground structures (DGS), photonic band gap structures (PBG)

I. INTRODUCTION

Recently, many papers proposing different and new methods to design microstrip filters using concepts of periodic structures, the so-called 1D-PBG filters, have been published and presented in different journals and conferences around the world by many groups.

The original idea and the generic way to refer to these structures, Photonic Band Gap, comes from the optics field, nevertheless there are people that propose to change the meaning of the 'P', recalling these structures as Periodic Band Gap structures, at least for the microwave applications. The bases of this idea are quite well founded since the filtering properties of the periodic structures are well established by the microwave classical theory [1] and the Photonic Band Gap structures are always periodic structures.

In this paper a new point of view of the 1D-PBG filters is given. In general, when some portion of conductor is removed beneath the microstrip, some kind of resonator is obtained, since two impedance discontinuities at certain distance have been defined. Thus, for each DGS unit cell which is characterized by the reflection coefficients and the electrical distance between the discontinuities, a particular resonant frequency and a specific quality factor could be obtained. Very often, these kind of resonances generate very deep transmission drops through the whole structure being defined exclusively by the physical dimensions of the unit cells.

Furthermore, it is also well known that placing several DGS cells equally spaced along a microstrip transmission line, an additional filtering effect is possible since a periodic structure is defined. In this case, the resonant frequencies are defined mainly by the periodic structure instead of the unit cell, taking each unit cell as a reflection coefficient variable with frequency. This filtering effect is properly the one expected

from a PBG structure and it usually exhibits a broader and smoother effect on the transmission response.

These two different filtering effects are very often simultaneously present at the 1D-PBG filters, and even they could be properly tuned to add the two effects at the same band, increasing the rejection and also the bandwidth of the gap.

As it was justified above, almost every unit cell proposed in the literature has some kind of resonant behaviour at a certain frequency. The fundamental idea of this paper is to model these cells at the frequencies below its resonant frequency as a series inductance. It will be proved that the inductance value can be tuned basically with the outer perimeter of the defect. Thus, once we have assumed this simple model for the defects, directly applying the classical microwave theory a low-pass filter with a specific frequency response can be obtained.

Two different filters have been designed, fabricated and measured, with very good agreement between simulations and measurements.

II. CHARACTERIZATION OF THE DGS UNIT CELL

Many different Defected Ground Structures (DGS) unit cells have been proposed in the literature to design filters, [2]-[4]. In order to obtain a specific frequency response, techniques like “tapering”, “windowing”, “chirping” and so on, are usually applied.

The idea itself comes from the optics field and also the design techniques have been imported from that field. Sometimes, these techniques are not necessarily the best choice at microwave and millimetre wave frequencies, because the resulting filters are larger than the classical ones.

The real problem of this kind of filters based on PBG structures is the lack of a clear relation of the physical dimensions and shape of the unit cell with the equivalent lumped component circuit. If the defect on the ground plane is considered as a pure resonator at certain frequency, and assuming a natural low-pass behaviour for these kind of structures, each defect at lower frequencies could be modelled as a series inductor since the impedance increases with the frequency.

A very simple test was performed in order to see how accurate was the assumption of considering a series inductance to model, for instance, a simple circle hole beneath the microstrip. Using an optimiser and comparing the frequency response of only one defect, a value for the equivalent series inductance of 0.633nH was found. Calculating the response of cascading several holes and connecting several inductances in series with some length of transmission line in between, the same kind of frequency response could be obtained. As it can be seen in Figure 1, the equivalence is good enough, and a maximum difference of 1 dB can be found between the different curves.

In this case, the resonant frequencies for the cells are at higher frequencies which are not represented in the plot. The frequency response is quite common for periodic structures, with a relatively broad bandwidth and very smooth shape.

Thus, once the equivalence is demonstrated, the next step is to solve the way back, and relate the inductance value with the physical dimensions of the defect.

Working with the equivalent circuit of inductances, and increasing the value of the equivalent series inductance a deeper rejection is reached. Furthermore, by changing the distance between the inductances the central frequency of the gap is moved up when the distance decreases, and down when the distance increases. This movement in frequency fits quite well with the theory of periodic structures, i.e., the shorter the period, the higher the central frequency and vice versa.

Therefore, if it would be possible to define higher values of inductance keeping the physical distance between defects, the response of the periodic structure would be improved by increasing the rejection.

In the previous example, if instead of creating holes on the ground plane, annular slots with the same radius are used, the response is practically the same. This shows that the outer perimeter is the parameter which controls the equivalent inductance value. This can be understood looking at the current distributions created on the ground plane, where the only significant values are concentrated along the edge of the hole. Thus, increasing the length of the outer perimeter, higher inductance values could be designed.

This leads to propose an alternative unit cell [4] which is represented together with its obtained equivalent series inductance values in figure 2.

The main advantage of this new cell is that the inductive effect is localised in one specific point of the transmission line; therefore, it can be assumed that the inductance value is punctual.

As the main parameter to define the inductance value is the outer perimeter, many other shapes could be used, and the behaviour will be almost the same. The only possibility of discrepancy between different shapes could be found in the radiation features that could increase when larger slots are used. Note that in all the cells presented and studied in this paper, the radiation is negligible.

The frequency response of this kind of unit cell is a parallel LC series resonator. For our work, the resonant frequency of the unit cell is placed above of the cut-off frequency of the low-pass filter, assuming the inductive behaviour for the structure at lower frequencies.

Since the equivalence between the outer perimeter and the inductance value is established, one should be able to design filters just applying the classical theory.

III. FILTER DESIGN AND MEASUREMENTS

The design procedure is based on transforming the circuit with the Kuroda identities, in order to obtain an equivalent circuit with only series inductances and transmission lines with different impedances. The unit cell chosen is the one of figure 2, and the series inductance of the discrete elements will be tuned by changing the outer perimeter of the corresponding defect.

Let's design a low pass filter with a cut-off frequency of 4GHz and ripple of 0.5dB in the pass band. Figure 3 shows the transformation of the normalised low-pass filter into its equivalent circuit.

All the distances are fixed by the cut-off frequency of the filter, 4GHz. Because of the initial symmetry of the coefficients, the final design is also symmetric, and only two different values of inductance are needed to fully implement the filter. Extracting from the figure 2 the appropriate value of x to fit the inductances, the final layout of the DGS filter is shown in figure 4.

The total length of the filter is $\lambda/4$ at the cut-off frequency. On the upper part, the layer of the microstrip lines, the different impedances are implemented with different transmission line widths. On the other side, the ground plane layer, the conductor is removed creating the two quasi-ellipsoidal slots connected with another thin slot as it is shown in figure 4.

The final appearance of the DGS filter seems that it has been obtained starting with a pure periodic structure and applying a "windowing" effect. The clear difference is that with the proposed method the matching is automatically adjusted by means of the obtained values of the inductances, and no additional techniques to improve the frequency response are needed.

Figure 5 presents the simulated response of the DGS filter together with the results of a conventional low-pass filter implemented with transmission lines obtained by the Richard's transformation with the same specifications.

The predicted behaviour is rather good: the ripple is 0.8 dB (versus 0.5dB), and at 4GHz the attenuation is 0.44dB (expected value 0.5dB). As it can be seen in figure 5, the resonant frequencies of the different unit cell used in the design are distributed over the refused frequency band or the band-gap of the structure.

Figure 6 shows the measured results for the fabricated DGS low-pass filter combined with the simulated data. An impressive agreement between the two curves can be observed. Because of the measurements were performed with a spectrum analyser a small ripple is detected probably due to the effects of the real SMA connectors not included in the simulation and the directional coupler used to obtain the reflection response.

In figure 7 the photographs of the fabricated low pass filter with the DGS section can be seen.

Finally, in order to show that really the proposed technique works in all the cases, another Chebyshev low-pass filter (7th order) with a cut-off frequency of 4 GHz and 0.1 dB ripple level is implemented. Figure 8 shows the measured and simulated results for the fabricated DGS low-pass filter. The measured ripple is 0.64dB, and the cut-off frequency is a little bit smaller than 4GHz. The photographs of the filter are shown in Figure 9. The total length of the filter is six times $\lambda/8$, less than one wavelength.

IV. CONCLUSIONS

In this paper, a really simple method to implement low-pass filters by modifying both sides of the microstrip guiding structure has been presented. The method is based on the modelling of the DGS used as series inductances at lower frequencies by changing basically the outer perimeter of each particular defect.

The obtained filters are really competitive with other filters, shortening the length keeping the electromagnetic features in the pass and rejected bands.

Two low pass filter have been designed, fabricated and measured with a really good performance.

REFERENCES

- [1] David M. Pozar, "Microwave Engineering", Wiley, 2^d edition, chapter 8, 1998.
- [2] D. Ahn, C. S. Kim, J. S. Park, J. Kim, Y. Qian, and T. Itoh, "A design of the Low-Pass Filter using the novel microstrip Defected Ground Structure", IEE Transactions on Microwave Theory and Techniques, Vol. 49, No. 1, pp. 86-92, Jan. 2001.
- [3] D. Ahn, C. S. Kim, J. S. Park, and J. B. Lim, "A novel 1-D periodic defected ground structure for planar circuits", IEEE Microwave and Guided Wave Lett., Vol. 10, No. 41, pp. 131-133, April 2000.
- [4] "Diseño de filtros de banda rechazada usando defectos en el plano de masa 1-D no periódicos", Ieltxu Garde, Degree's Final Project, Department of Electrical and Electronical Engineering, Public University of Navarre, July 2002.

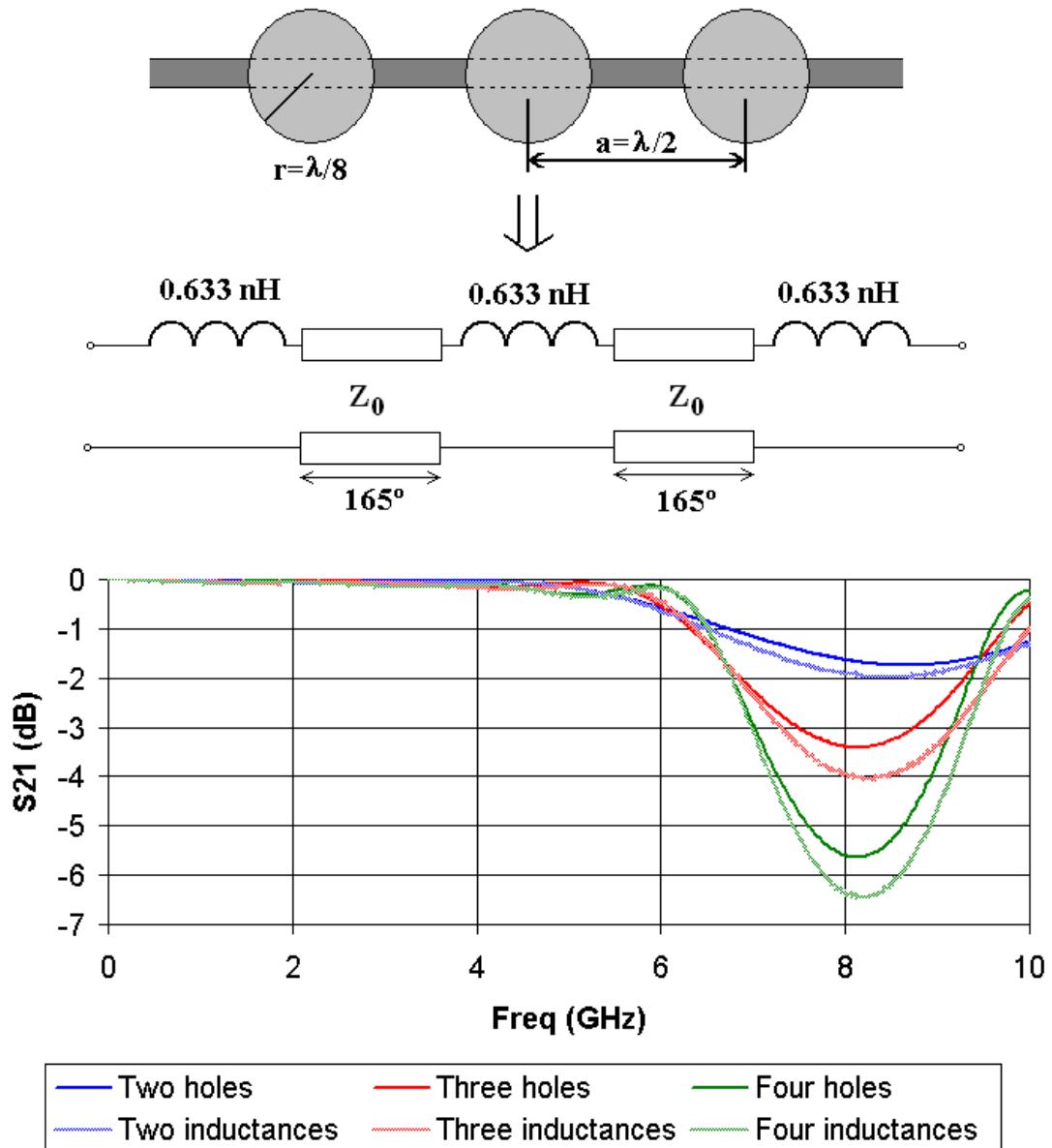


Figure 1: Equivalence between circular holes drilled on the ground plane beneath the microstrip line and a combination of series inductances with transmission lines between them. At the bottom, the transmission coefficient S_{21} versus the frequency is represented for both cases. (λ is defined at 8 GHz)

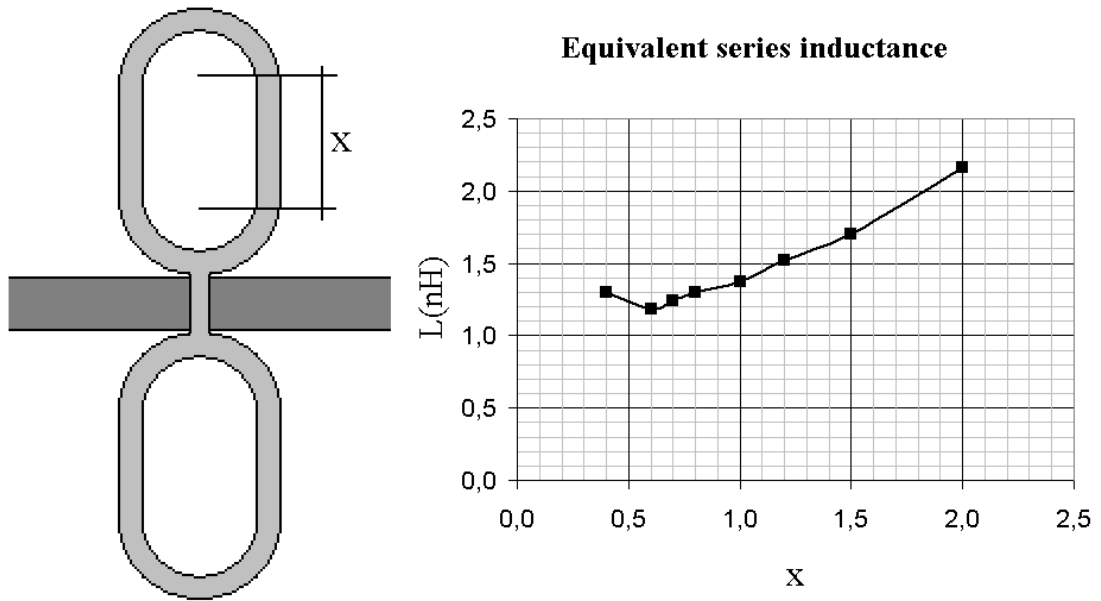


Figure 2: Configuration of the new DGS proposed, and the optimised equivalent series inductance from different values of x . The optimisation is valid up to 4GHz.

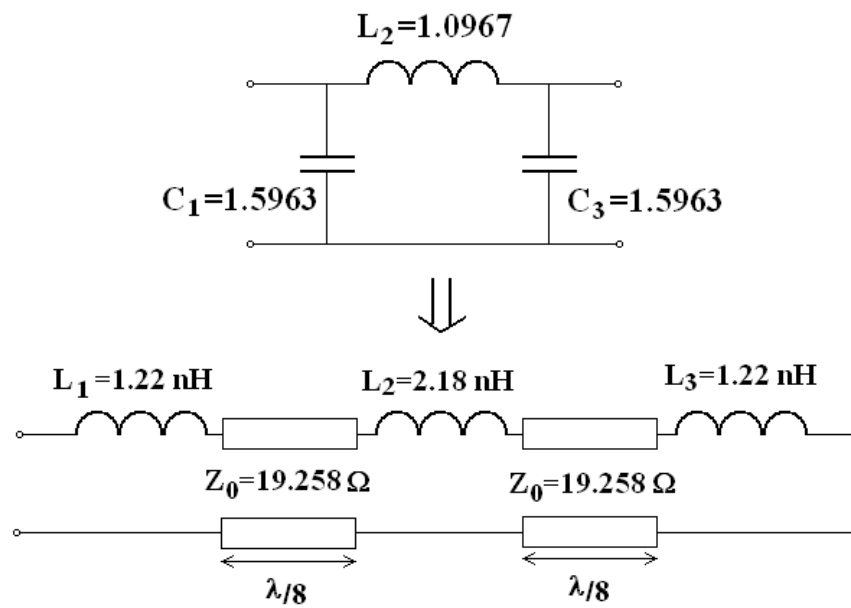


Figure 3: Normalised equivalent low-pass filter with ripple of 0.5 dB in the pass-band (upper) and its equivalent circuit with series inductances and transmission lines, with $Z_0 = 50 \Omega$ (lower).

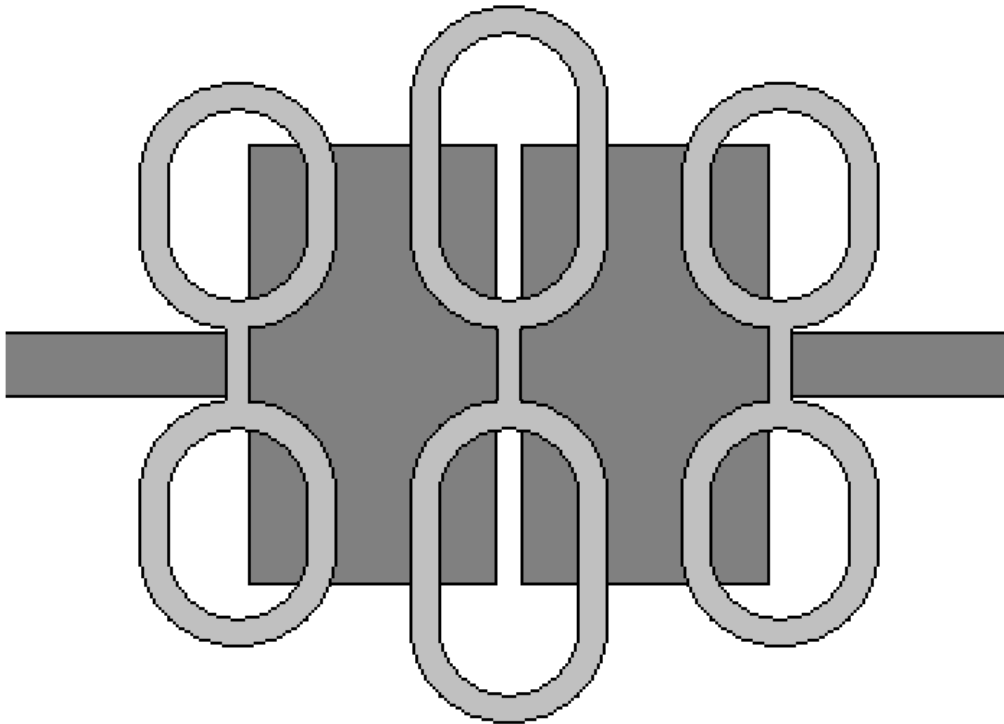


Figure 4: Layout of the 0.5 dB ripple DGS low-pass filter prototype. In dark colour the upper layer with the transmission line, and in light colour the slot on the ground plane layer.

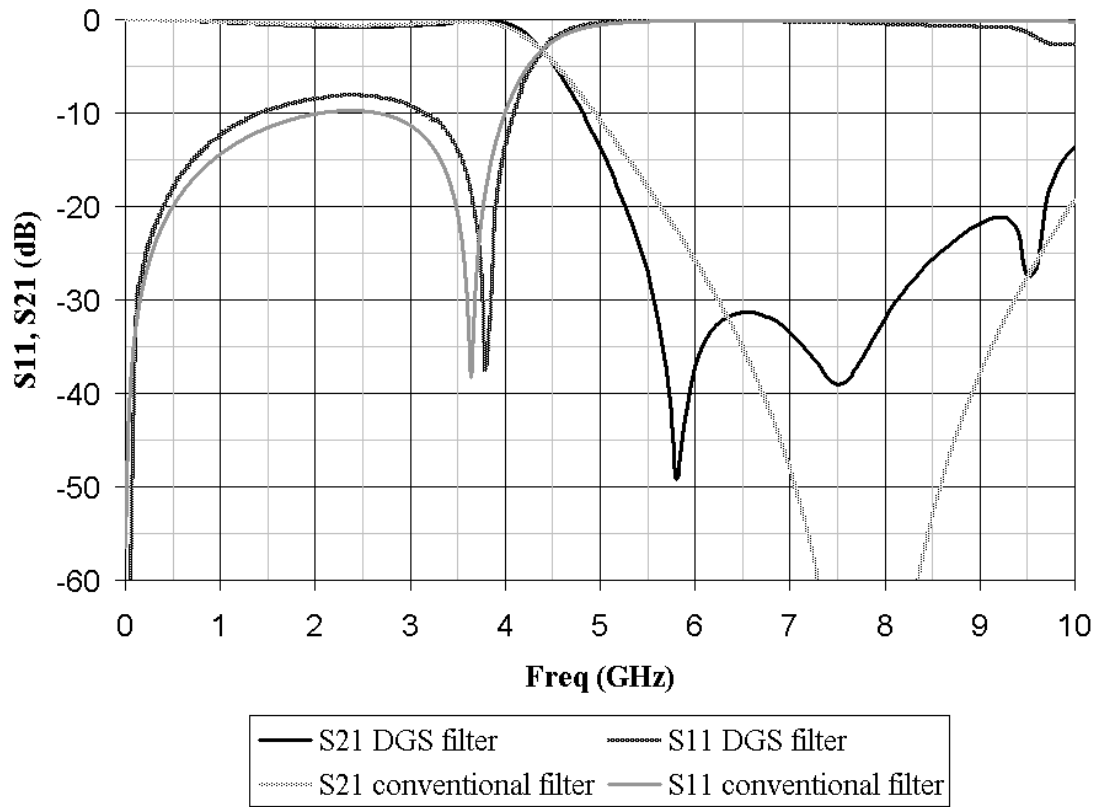


Figure 5: Simulated frequency response of the DGS filter and the conventional low-pass filter.

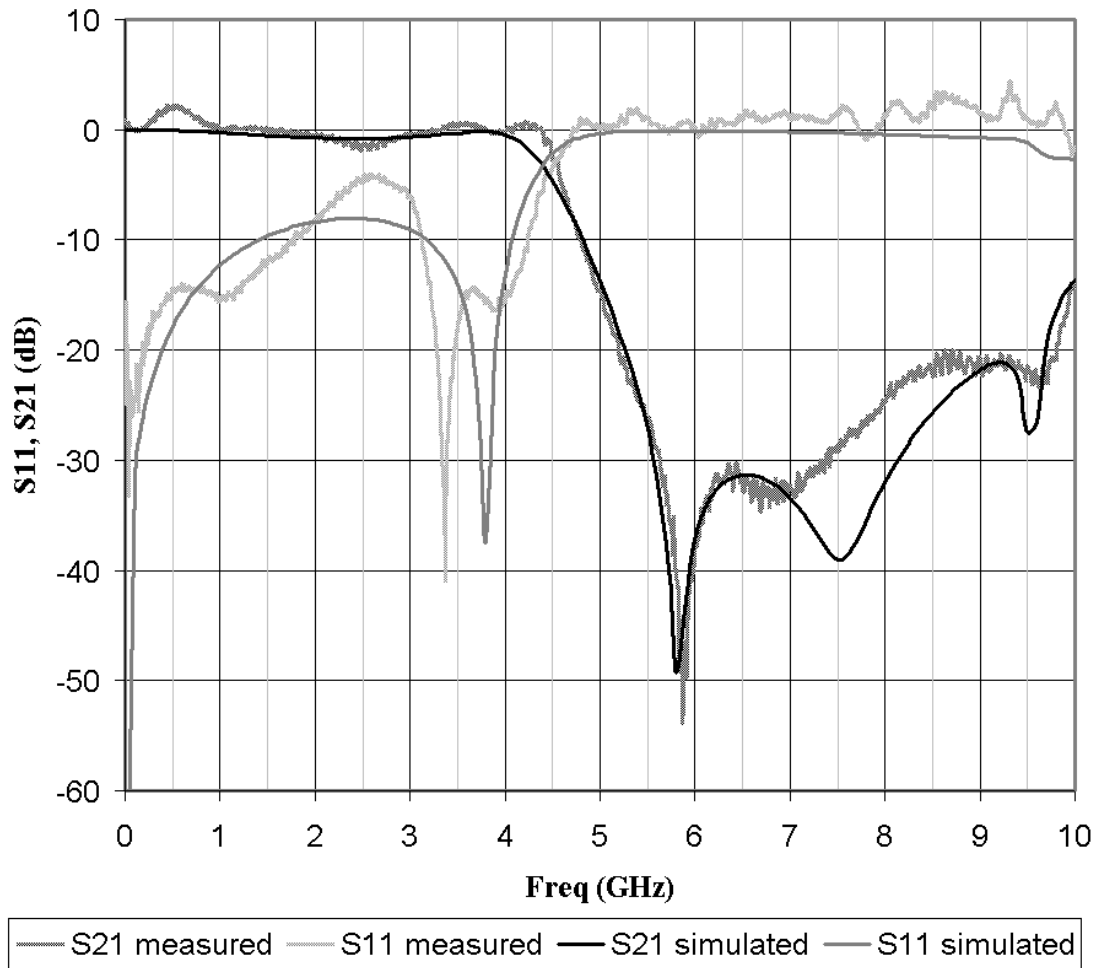


Figure 6: Comparison of the measured and simulated results for the fabricated DGS low-pass filter.

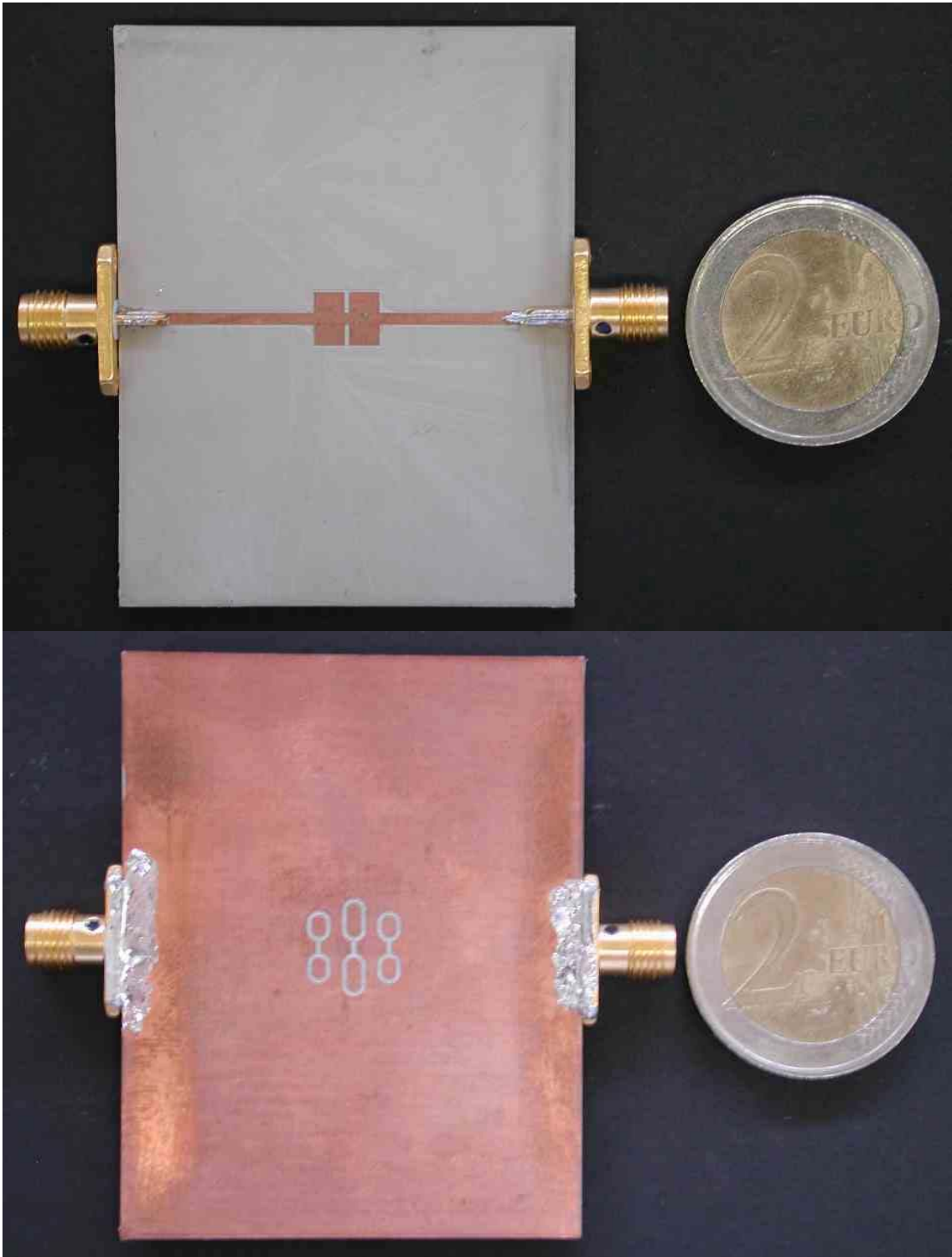


Figure 7: Fabricated DGS low-pass filter of 0.5dB ripple.

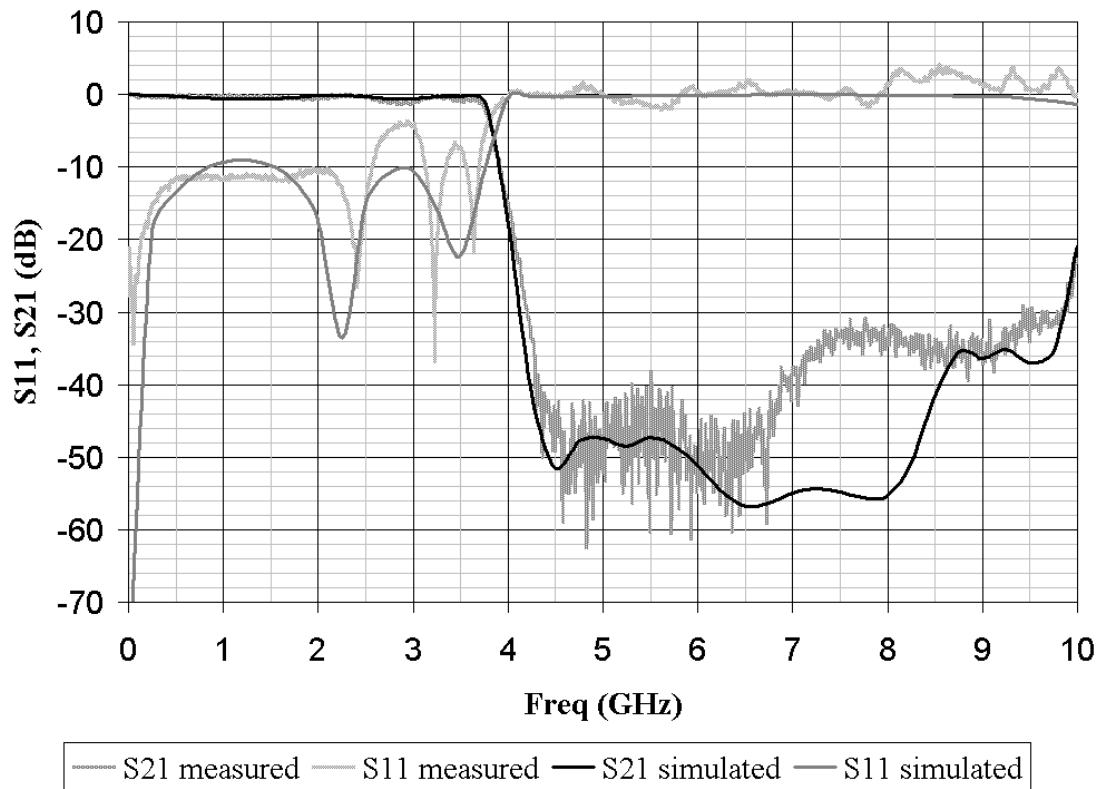


Figure 8: Comparison of the measured results for the fabricated DGS Chebyshev low-pass filter 7th order and 0.1 dB of ripple with the simulated data of a low-pass filter.

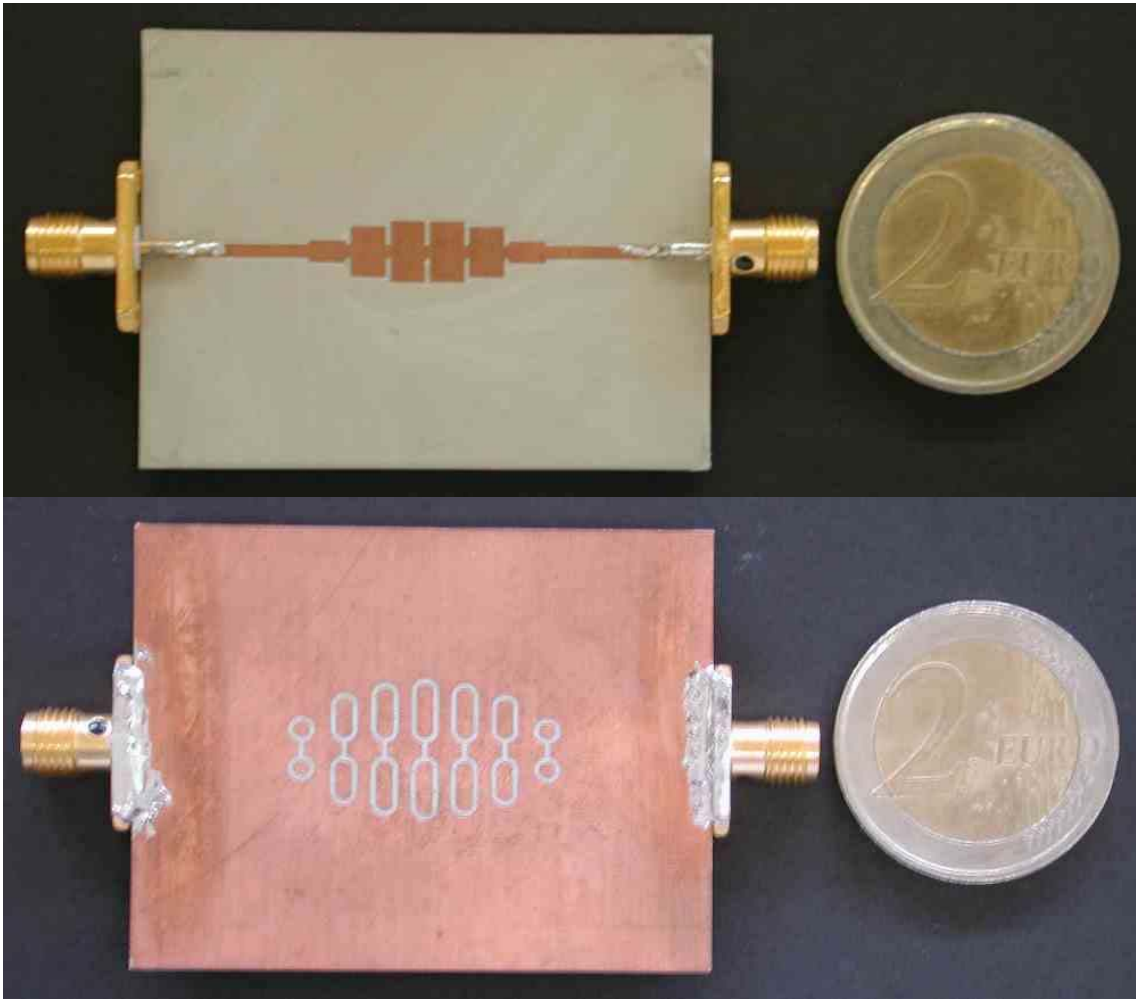


Figure 9: Fabricated DGS Chebyshev low-pass filter 7th order and 0.1 dB of ripple.