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Araştırma Makalesi / Research Article

Ultra-Wideband Microstrip Filter Design with Super-Shaped Defected Ground Structures

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Abstract
Ultra-wideband (UWB) microstrip filter design has been proposed by applying defected ground conductor structures designed with the superformula approach. Simultaneously, the effects of the materials used in the designs on the filter properties have been examined. Once the filter characteristics have been determined, the filter design has carried out in the AWR program. The filter structure has been designed based on an 8 GHz center frequency fifth-order Chebyshev response ultra-wide bandpass filter. The filter model designed in AWR has transferred to the HFSS program, and the effect of FR4 and RO3035 materials on filter characteristics have been investigated. The various number of defects, each shaped with superformula, is opened to the base conductor, and their effects are observed. The parameters in the superformula proposed by Johan Gielis have been calculated in the MATLAB program. PCB productions of the designed filters have been made, and experimental measurements have been taken with the Anritsu spectrum analyzer. When the results obtained from electromagnetic simulation programs have compared with the experimental measurement results of the filters produced, it has been seen that the results are consistent with each other.

Keywords: Superformula, ultra-wideband filter, super-shaped microstrip filter, defected ground structure.

Süper-Şekilli Kusurlu Taban Yapıları ile Ultra Geniş Bant Mikroşerit Filtre Tasarımı

Öz
Süperformül yaklaşımıyla tasarlanan taban iletkeni kusurlu yapılar uygulanarak ultra geniş bantlı (UWB) mikroşerit filtre tasarımları gerçekleştirilmiştir. Filtre yapısı, 8 GHz merkez frekanslı 5. dereceden Chebyshev tepkili ultra geniş band geçiren filtre karakteristiklerine uygun olarak AWR programında tasarlanmıştır. Hedeflenen özelliklere uygun olan model HFSS programına aktarılıp FR4 ve RO3035 gibi farklı laminantların kullanımının filtre özelliklerine etkisi hesaplanmıştır. Filtrenin taban iletkenine farklı sayılarda süperformül yaklaşımıyla oluşturulan yapılar açılarak etkileri incelenmiştir. Burada, Johan Gielis tarafından önerilen süperformüldeki denklem parametreleri MATLAB programı kullanılarak açılan kusurların yapıları oluşturulmuştur. Tasarlanan filtrelerin PCB üretimi yapılmış olup Anritsu spektrum analizör cihazı ile deneysel ölçümleri alınmıştır. Elektromanyetik simülasyon programlarından elde edilen sonuçlar ile üretilen filtrelerin deneysel ölçüm sonuçları kıyaslandığında, sonuçların birbirleri ile uyumlu olduğu görülmektedir.

Anahtar kelimeler: Süperformül, çok geniş bant geçiren filtre, süper şekilli mikroşerit filtre, kusurlu taban yapılı filtre.

1. Introduction

Communication tools have become an indispensable part of our life; therefore, advanced technologies' designs carry vital importance in many aspects. Mobile technologies should offer their users a faster and more qualified experience every year. The devices must be designed with broader bandwidth at higher

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frequencies to provide these expectations. During the production of these technologies, filters have held a mandatory role in RF and microwave applications.

With permission to use Ultra-Wideband (UWB), namely the frequency range of 3.1 GHz and 10.6 GHz for academia and industrial research, unlicensed use, the work has started in this field continued to gain speed. Levy's studies for UWB applications in 1970 and 1974 could be shown based on these studies [1,2]. Studies with UWB filters started to increase in 2005 [3]. One of these was Shaman and Hong's filter study obtained with short or open circuit lines. Here, they used five short-circuit lines and brought a ninth-order microstrip bandstop filter design. However, its dimensions were much more extensive than other designs, and in subsequent studies, the aim has been to decrease in size [4]. In another study conducted in 2007, the UWB structure was obtained with lateral lines, using the sidelines by three open-circuit. The microstrip has provided great flexibility in the UWB-BPF structure piecewise-frequency approximation method. As a result, there has been dimensional shrinkage, high selectivity, low insertion loss in the filters. Due to their characteristics, radar systems have been made according to the UWB region [5].

In 2016, innovative studies on the UWB filter model started. An important example of this is a model consisting of large surface double microstrip parallel rings [6]. Using a ring-type parallel plate here was easier to change the characteristic impedance and bandwidth. It was observed that the bandwidth of the analyzed ultra-wideband BPF was extended from 3.05 to 10.3 GHz in the 5.3 GHz center frequency with -15dB attenuation. Besides, the filter's operation, the insertion loss of almost 2 dB in most of the UWB range, and the large-coated UWB filter design provided a soft group delay in the passband range for indoor communication systems. Xi and Hun designed a bandpass filter with a third-order Chebyshev response with a 9 GHz center frequency and 500 MHz bandwidth. Its volume has been somewhat reduced compared to conventional filters [7].

The frequency character changes have been observed due to the imperfections in the filters' base conductors. The Defected Ground Structures (DGS) provide the filter in a more uniform, small size, and reduced cost. The DGS has been implemented in the form of a barbell in the bandpass filter model. It has been used in subsequent studies in directional couplers, low pass filter design, and circuit dimension reduction. Other studies based on structures with DGS are power dividers, microstrip antennas, and microwave filters. Circuit size has been reduced by opening faults to the base conductor in power dividers. Small size, sharp bandstop capability, and wide stopband have been used to obtain multi-band characteristics. Also, the DGS provides harmonic control in microstrip antennas and improves the radiative properties of patch antennas.

Nature-inspired studies on RF technologies have applied the superformula to microstrip structures. In 2010, Simeoni et al. used the superformula approach in the antenna study for UWB. In 2013, Bia et al. examined the antenna's electromagnetic character designed with superformula for high-frequency applications [9]. Shaimaa and Dib designed a new UWB microstrip-fed patch antenna with a superformula structure [10]. In 2016, a patch antenna was designed with UWB by Omar et al. This antenna has been operated between 3.1 GHz-10.6 GHz as a saw-toothed circular form under the Super-Formula [11]. In 2018, Seyfollah et al. Designed the frequency selective surface formed by unit cells consisting of square metallic rings surrounding new curves created from a super formula for miniaturization and incident angle stability [12]. In 2019, the Characteristic Mode analysis of a super-shaped patch antenna in a drop-shaped was analyzed for electric current and magnetic current values [13].

Despite several studies on super-shaped antennas, there is not enough investigation for filter applications of superformula. In this study, ultra-wide bandpass microstrip filters have designed with a pass band gap of approximately 10 dB from the 3.1 GHz to 12 GHz band range. The defected ground structures have been formed by using the superformula. Several base materials have been used for comparison. The experimental and theoretical results of the filters have been compared.

2. Material and Method

2.1. Band-Pass Filter Design and Simulation

The AWR program is preferred to create filter prototypes. The program can calculate whether the desired filter response can be obtained with the filter simulations by entering necessary information such as the desired filter type, approach method, filter degree, cutoff frequency, and bandwidth. In this study, the bandpass filter type is chosen. The Chebyshev prototype is used for sharp descents from the passband to the stopband as the typical feature expected from the filter. The fluctuation level is set to 0.5 dB. Input and output impedance values are 50 Ω. The bandpass microstrip filter's physical dimensions created with the 5th order Chebyshev model with 8 GHz center frequency are shown in Table 1.

Table 1. Physical dimensions of the fifth-order Chebyshev model bandpass filter with 8 GHz center frequency

Width	Size (mm)	Length	Size (mm)
W1	1.7060	**L1**	2.8243
W2	0.9639	**L2**	5.2907
W3	3.5926	**L3**	5.4764
W4	0.8708	**L4**	5.3571
W5	4.3554	**L5**	5.4337
W6	0.7790	**L6**	5.5092

The dielectric materials for the comparison are selected as R03035 (ε_r = 3.5) and FR4 (ε_r = 4.4). Dielectric material height is 0.76 mm, and conductor copper thickness is 0.035 mm. The circuit dimensions of the designed microstrip filter are 2.2 cm×2.9 cm. The physical view of the microstrip filter created in the AWR program is given in Figure 1.

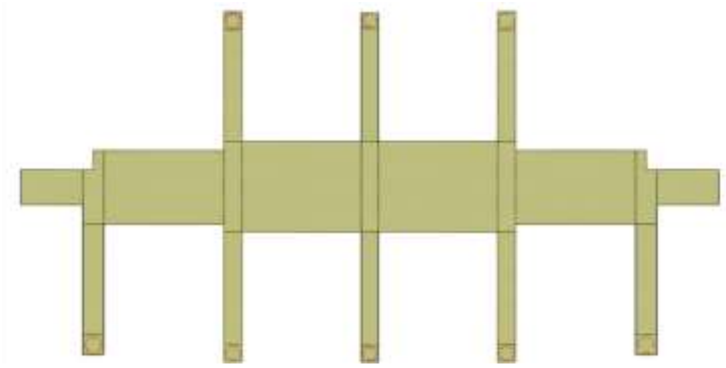

Figure 1. The Design of Microstrip Structure of Bandpass Filter with the fifth-order Chebyshev model at 8 GHz center frequency in AWR Program

Responses are given in Figure 2 for the bandpass broadband filters created using RO3035 and FR4 dielectric materials. The dielectric materials' change has affected the bandpass frequency limits by approximately 8%, as seen in Figure 2. For RO3035, the responses illustrate green line-S21 (dB), and blue line-S11 (dB); for FR4, red line-S21 (dB), black line-S11 (dB). As ε_r increases in the material, bandpass limits shift towards lower frequencies. From Figure 2, it can be seen that the filter with RO3035 laminate has broader bandwidth and bandgap than the filter with FR4 laminate.

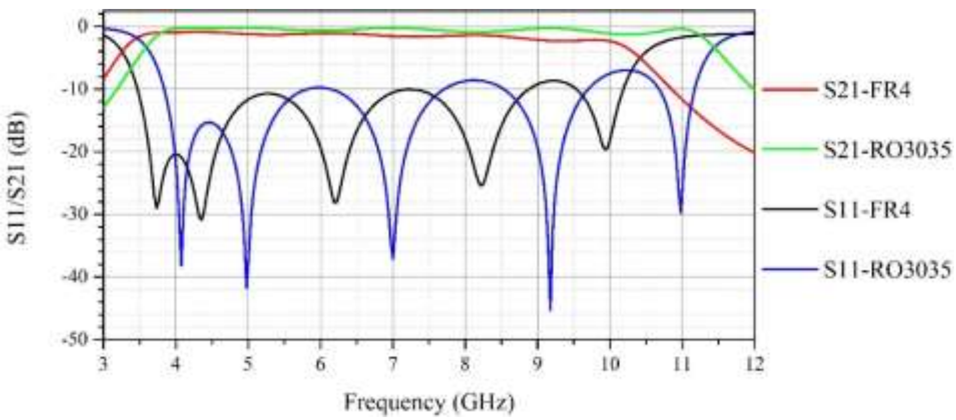

Figure 2. Return Loss and Insertion Loss comparations for defectless bandpass filters with RO3035 and FR4 laminates in the HFSS program

2.2. Filter Design by Super-Formula Based Defected Ground Structure

In this study, the superformula approach proposed by Johan Gielis in 2000 has been used for structures with ground conductor defects to increase bandwidth. The formula shown in Equation 1 is the generalized form of the super-ellipse [8].

$$f(\theta) = \left(\left| \frac{\cos\left(\frac{m}{4}\theta\right)}{a} \right|^{n_2} + \left| \frac{\sin\left(\frac{m}{4}\theta\right)}{b} \right|^{n_3} \right)^{-1/n_1} \qquad (1)$$

Here, six parameters describe the super-shapes which are inspired by nature. The parameters of a and b illustrate the ratio of the outer boundary lengths of the shape. In our study, we choose them equally, but it does not have to be. When the n parameters (n1, n2, and n3) are selected as greater than one, the patch will be circular. It is not necessary to choose the parameters as integer numbers. The parameter m identifies the number of the corners of the sections of the shape. The genetic algorithm provides the optimal selection of the parameters.

15 and 25 defects in the Ipomoea (Laughter) flower shape are opened on the designed microstrip filter's base conductor using Super-Formula. Its effect on the bandwidth is investigated. The design takes place in three-stages. Firstly, as shown in Figure 3, a base conductor defect is created using the MATLAB program. The value of 6 parameters in the super-formula to create the desired flower structure are a=1, b=1, m=5, n1=n2=n3= 1. In the second stage, 15 defects are opened in the base conductor, as seen in Figure 4. In the third stage, 25 defects have been drawn out to see the effects of the number of defects.

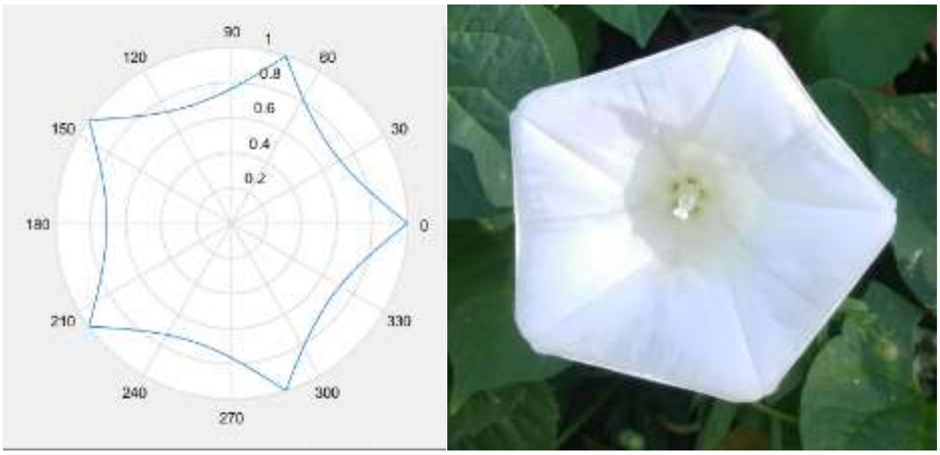

Figure 3. (a) Gielis's Super-Formula in MATLAB, (**b)** Ipomoea Flower

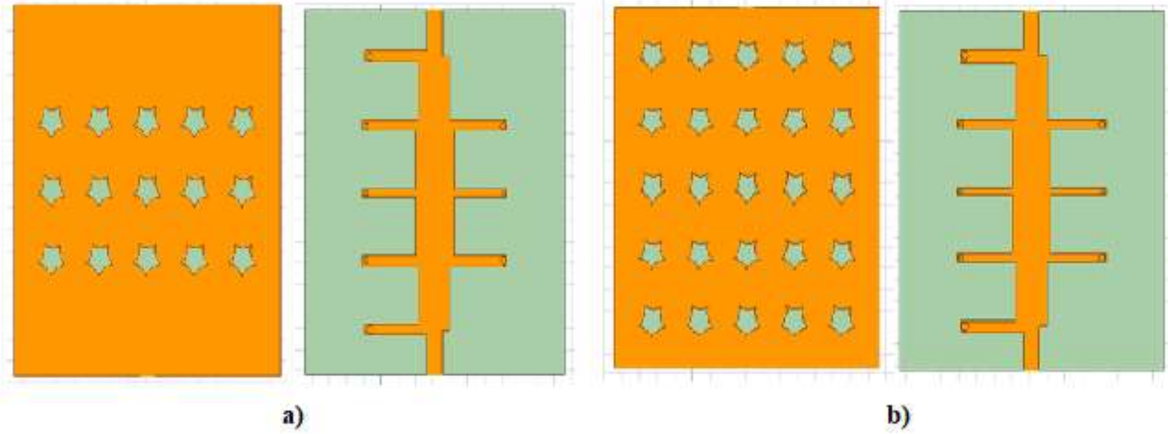

Figure 4. Back and front views of the designed UWB filter models with DGS **(a)** 15 defects, (**b)** 25 defects

3. Results and Discussion

The filter models with the defectless ground conductor and defected structures have been compared in Figure 5. It shows the theoretical results of the proposed filters, which RO3035 has used as laminates. The results present that the bandwidth increases with the number of defects opened to the filters' base conductor. For the modeled filters, the comparison table of bandwidths is shown in Table 2. The filters, which are modeled with RO3035 laminates, have broader bandwidths than FR4. This result is valid for all proposed filters as the defectless model, and the models with 15 defects and 25 defects. It has been observed that the laminates affect the filter efficiency at approximately 8% in the bandwidth.

While modeling the filter, the main target is to create the most compatible model with the filter characteristics. There are various approaches here. However, to obtain the theoretical design results in practical application, the losses should be the lowest. The critical thing in practical application is that it should be suitable for production. In the model designed within the study's scope, an extensive bandpass filter design between 3.3 GHz and 10.3 GHz, which is the target bandwidth, was successfully created with both Rogers 3035 and FR4 base material properties.

Table 2. The comparison table of the bandwidths of the models according to the effect of dielectric materials

The Properties of Filters	Defectless	15 Defects	25 Defects
Bandwidth (GHz) for RO3035	7,68	8,06	8,40
Bandwidth (GHz) for FR4	7,10	7,47	7,72

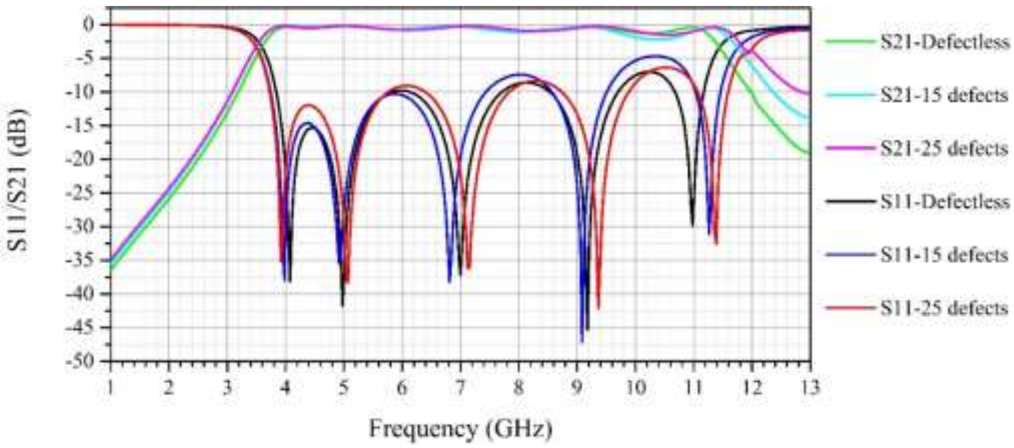

Figure 5. Return Loss and Insertion Loss comparisons of UWB filters with the defectless, 15 and 25 defects on the ground in the HFSS program.

After completing the filter's theoretical analysis, we have fabricated the filters for experimental study and found them compatible. Figure 6 shows the back and front sides of one of the fabricated filters as an example, which has ipomoea-shaped 15 defects on the ground structures. The filters are connected to SMA sockets for the measurements. In this case, the base conductor's defect opening indicates that the microstrip filter can be reduced to small sizes for the same frequency range, or the bandwidth can be increased in the exact dimensions.

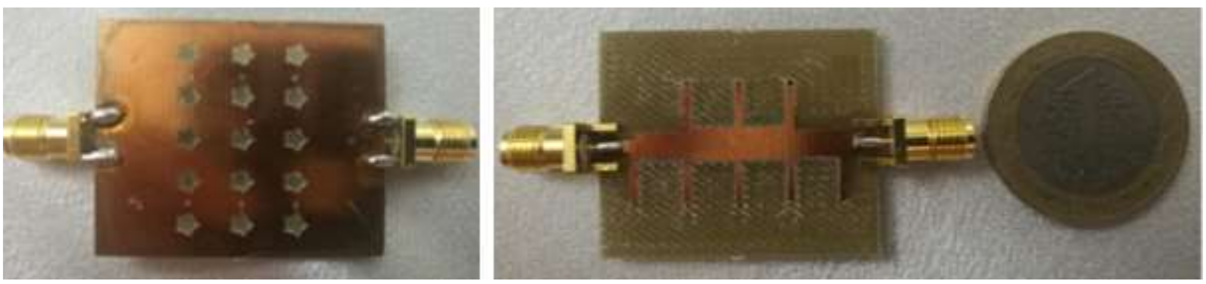

Figure 6. The back and front sides of the filter which has 15 defects on the ground structure

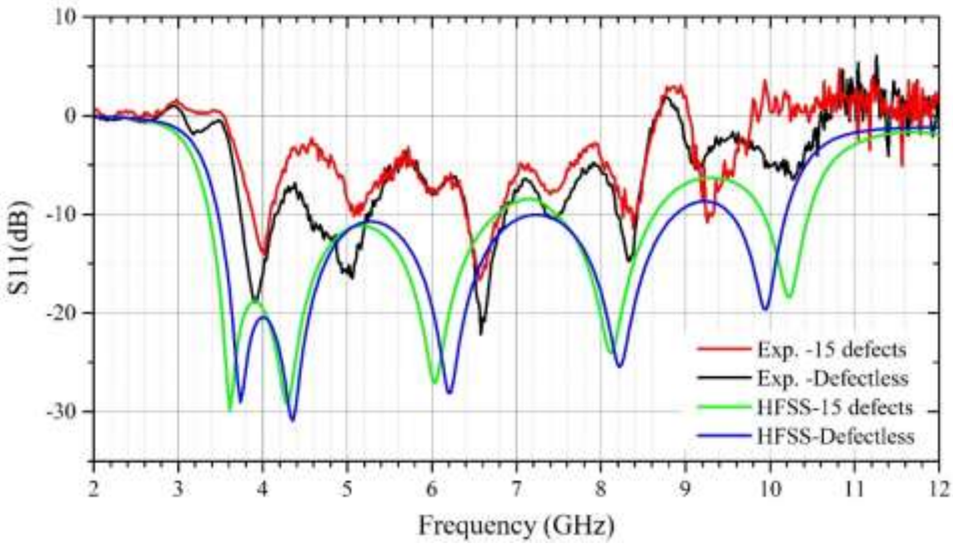

Figure 7. Comparison of the theoretical and measurement results of reflection losses from bandpass filters for the defectless and 15 defects on the ground conductor

Figure 7 shows a comparison of the theoretical and measurement results of reflection losses from filters, which are defectless and 15 defects on the ground conductor. The filter design with the FR4 structure is produced as desired. The fact that the inside of the via hole structures formed during the production phase does not provide enough transmission between the base and the microstrip structure. The issues at the production have reduced bandwidth. It caused distortions in the low and high-frequency regions of the specified band range.

4. Conclusion

In this study, ultra-wide-band bandpass filter models were carried out using defected ground structures shaped by the superformula. It has been shown that broadband filters can be established by increasing the bandwidth using microstrip structures with defective base conductors. PCB production of the designed filters was made, and the experimental measurements were taken. The results obtained from electromagnetic simulations and the filters' experimental measurements were compatible with each other. Structures formed by the superformula approach in different numbers of defects on the filter's base conductor indicate that smaller size filters could be designed for the same operation bandwidth. The effect of using different laminates such as FR4 and RO3035 on filter properties was also investigated, and the results showed that the filter with RO3035 laminate has broader bandwidth and bandgap than the filter with FR4 laminate. As dielectric permittivity was increased in the laminate, bandpass limits shifted towards lower frequencies. The production issues reduced the bandwidth and caused distortions in the low and high-frequency regions of the specified band range.

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Authors' Contributions

C.B. and I.D. intellectualized the original idea. C.B. supervised the project. I.D. carried out simulations and performed the experiments. Both authors contributed to the writing and editing of the manuscript.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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