Low Pass Filter with Wide Rejection Band in Microstrip Technology

Israel Arnedo*, Ivan Arregui, Francisco J. Falcone, Miguel A. G. Laso, and Txema Lopetegi
Department of Electronic Engineering, Public University of Navarre, Campus de Arrosadia E-31006 Pamplona, Spain
israel.arnedo@unavarra.es

***Abstract*—In this paper, a new technique to design low pass filters in microstrip technology is proposed. The technique is based on the use of the transverse microstrip resonant mode and it is an excellent tool for the design of filters with stringent requirements like sharp cutoff frequency response and wide rejection bandwidth. Due to the fact that these features are not easily achieved with conventional methods, it is a very promising technique. As an example, a design with a cutoff frequency of 2 GHz and a rejection band up to 15 GHz is shown. As it will be seen, the steep slope achieved in the example is equivalent to that obtained with a classical 29th-order Chebyshev low pass filter.**

***Index Terms* —** Periodic Structures, Microstrip Filters, Low-Pass Filters.

I. INTRODUCTION

In the last decades, the research and development of periodic structures has reached an important relevance in microwave technology. At the end of the 90s several structures in planar technology with periodic perforations in the dielectric of the substrate were proposed [1]. Afterwards, these devices were modified with patterns etched in the metallic ground plane as in [2,3] to simplify the manufacture process and widen both the rejection band and the pass-band. In order to improve the frequency response, a sinusoidal profile was printed in the ground plane and the level of the spurious bands was reduced [4] because, generally, these kind of structures, which are usually known as PBG/EBG (Photonic Band-Gap / Electromagnetic Band-Gap) structures, introduce a rejected band at the tuning frequency and also at its harmonic frequencies, being this last issue a serious drawback in some applications. Moreover, periodic devices have been designed in microstrip line so that the tuning frequency is the only one rejected [5], removing the harmonic bands completely. These structures and their design techniques are usually limited by relatively small variations in the profile in order to avoid the excitation of the transverse resonant mode. However, in this paper, the transverse resonant mode is going to be the key point to design low pass filters using quasi-periodic structures.

This paper has been divided into two parts. In the first one, the new technique proposed to design low pass filters is explained. We will start giving a rough expression for the cutoff frequency of the filter, which we will correct empirically taking into account the profile of the unit cell. Afterwards, the necessary instructions will be given so as to achieve the suitable matching and rejection levels depending on the period that is chosen, the tapering used and the slot required in the ground plane.

In the second part, a filter with stringent requirements will be designed to validate the proposed technique. This filter will have a steep slope, a wide reject band and a small layout area. Finally, in order to compare our design with a filter resulting from a classical procedure, we will use the stepped-impedance method [6,7]. This method, which is based on alternating low and high impedance sections, is widely used and generally provides good results. However, several difficulties come up when stringent specifications like steep slope and wide rejection band are required because the former increases the number of sections and the latter is uncontrollable since at high frequencies the short sections assumption does not hold. All these difficulties are sorted out in the design that we propose.

All the simulations have been carried out in microstrip technology over RO3010 substrate (ε_r = 10.2, dielectric thickness h = 1.27 mm) with 50 Ω input and output ports.

II. THEORETICAL BACKGROUND OF THE PROPOSED METHOD

Using the method proposed in this paper, it is possible to design devices like the one sketched in Fig. 1. The following physical parameters are used in the design process: maximum and minimum widths of the corrugated conducting strips (W_{max}, W_{min}), period of the perturbation (Λ), and maximum width of the slot etched in the ground plane (W_{slot}). In the following paragraphs, we are going to explain how to design a low pass filter, giving suitable values to these parameters, and we will detail the relationship between them and the frequency specifications.

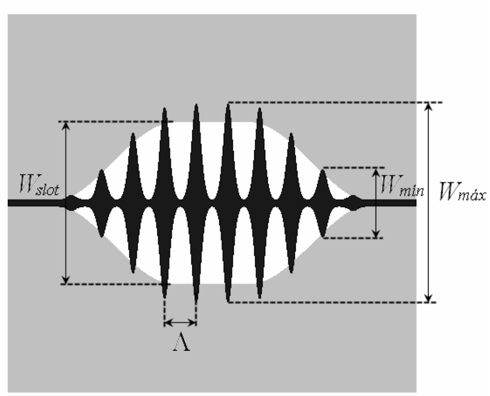


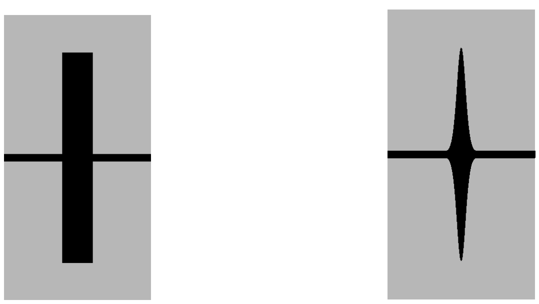
Fig. 1. Physical parameters of the device. The upper plane conductor strip is represented in black, and the ground plane is represented in grey.

This method is based on the excitation of the transverse microstrip resonant mode. If the width of the conductor strip is large enough to allow for the excitation of the transverse resonant mode, a large power transfer will take place at the cutoff frequency of that mode. The effective length of this resonator is $W + 2 \cdot d$ [8], where W is the width of the strip and $d = 0.2 \cdot h$ is the factor used to model the fringing capacitances [9], which appear in the strip edges due to the cumulative field.

This phenomenon, which is always avoided in classical periodic structures, produces strong coupling to the backward quasi-TEM microstrip mode resulting in high rejection at the cutoff frequency of this transverse resonant mode (f_{CT}) [8]:

$$f_{CT} = \frac{c}{\sqrt{\varepsilon_r} \cdot (2 \cdot W + 0.8 \cdot h)} \tag{1}$$

In eqn. (1), c is the speed of light in vacuum.



a) b)

Fig. 2. Microstrip line: a) uniform width b) sinusoidal variation of the coupling coefficient.

This empirical expression in eqn. (1) is proposed for a microstrip line with uniform width like the one shown in Fig. 2a. However, we are going to use as fundamental period of our periodic structure one that yields to a sinusoidal coupling coefficient between the forward and backward quasi-TEM mode like the one sketched in Fig. 2b, which will provide better return losses. The mathematical expression for this profile can be found in [5]. Moreover, due to the fact that fringing capacitances depend on the profile chosen, eqn. (1) is going to be just a rough approximation. More accurate values for the f_{CT} have been obtained simulating several periods with different widths. The commercial electromagnetic package chosen has been Agilent™ Momentum and the results provided have been plotted in Fig 3, where it can be seen the difference between the transverse resonant frequency calculated from eqn. (1) and the one obtained in the simulations.

According to these simulation results and to eqn. (1), it is possible to design a low pass filter consisting of several periods with different widths in order to reject different frequencies. It is worth noting that the widest periods (W_{max}) reject the lowest frequencies, while the narrowest periods (W_{min}) reject the highest frequencies. The former ones are responsible for a steep slope, so that increasing the number of the widest periods it is possible to achieve a steeper slope. The tapered narrowest periods, which are needed to achieve the wide rejected band, are also necessary to have good return losses at the upper-end frequencies of the pass-band. Meanwhile, the period, Λ, has influence on both the pass- and the rejection bands. Specifically, a long period provides better return losses (due to the fact that the profile variation is smoother) and a shorter one provides a more uniform rejection level (because it allows us to make a more distributed rejection).

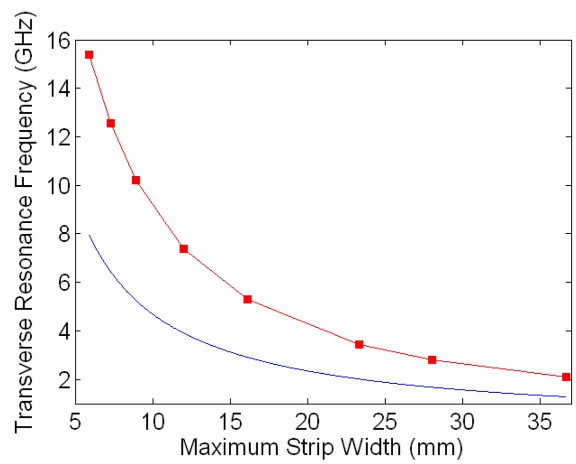


Fig. 3. Transverse resonant frequency depending on the width of the strip: frequency obtained from eqn. (1) (blue line) and frequency obtained in simulations (red squares).

The Bloch wave theory has been used to improve the return losses at the lower-end frequencies of the pass-band [9]. Due to the fact that large widths are essential to excite the transverse resonant mode, the Bloch impedance of the structure will be low when compared to the impedance of the ports. Therefore, it is necessary to include a tapered slot in the ground plane [10] to increase the Bloch impedance of the structure and to make it similar to the impedance of the ports (50 Ω) at the pass band. The maximum width of the slot used in this kind of devices (W_{slot}) will depend on the maximum width of the strip, and the window used to taper the slot will be the same that was used to taper the periods of the strip. Therefore, due to the fact that the transverse resonant mode will have part of its electric field in the dielectric and another part in the air, the relative permittivity used in eqn. (1) could be replaced by an effective permeability, ε_{eff}, which will depend on the width of the slot. Nevertheless, it has been checked that this phenomenon is not very significant and the energy is mostly kept inside the dielectric.

III. SIMULATION RESULTS

In order to validate the proposed method, we are going to design a low pass filter with a cutoff frequency of 2 GHz, steep transition slope and a wide rejection band up to 15 GHz.

In the first place we will do it with the proposed method and secondly with the classical one.

A. *Proposed method*

Following the procedure explained in the previous section, it has been designed the device shown in Fig. 4. If we want to reject starting at 2 GHz we need to fix W_{max} to 36.7 mm, and in order to reject up to 15 GHz the strip width has to be reduced to W_{min} = 5.9 mm. To fulfill the requirements we have used 23 periods (Λ = 2.618 mm), giving a total device length of L = 60.214 mm, which means approximately one wavelength at the cutoff frequency. Five of these periods feature the maximum width, W_{max}, and are placed at the center of the structure, and nine additional periods, tapered with a Hanning window, have been added on both sides. Finally, we have made a slot in the ground plane (W_{slot} = 30 mm) also tapered with the Hanning window [7].

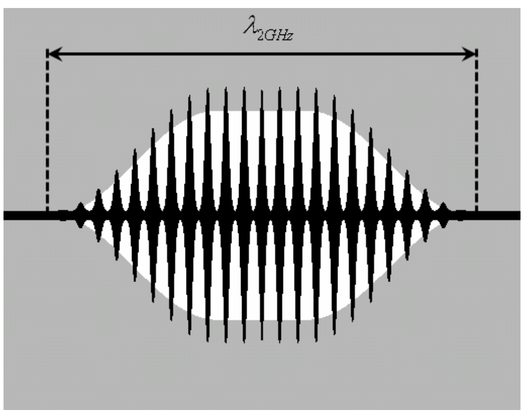


Fig. 4. Proposed low pass filter.

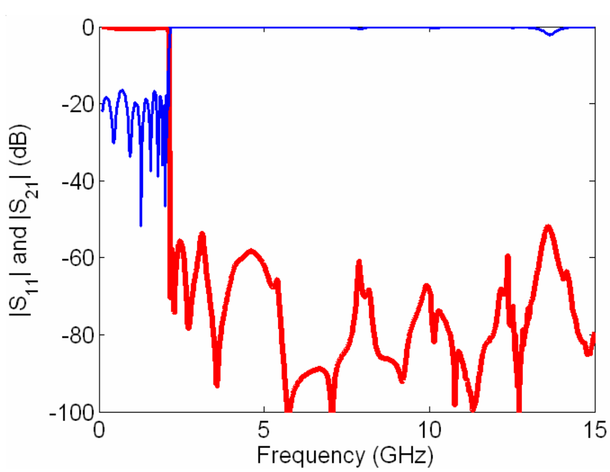


Fig. 5. Frequency response of the proposed low pas filter: $|S_{11}|$ (dB) in blue thin line and $|S_{21}|$ (dB) in red thick line.

The whole structure has been simulated using CST Microwave Studio®, and its frequency response is shown in Fig. 5. Return losses are better than 15 dB in the pass-band, and the rejection band has an attenuation better than 50 dB in almost the entire band.

B. *Classical method: stepped-impedance.*

For comparison purposes, we designed a low pass filter in microstrip technology with a similar frequency response, applying the classical and extensively used stepped-impedance method. To carry out this design a tool included in Agilent™ ADS has been used. This tool, named Filter DesignGuide, allows us to design stepped-impedance filters from particular specifications.

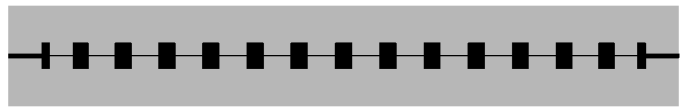


Fig. 6. Stepped-impedance low pass filter.

In order to achieve the same slope and similar pass- and rejection bandwidths it has been necessary to synthesize a Chebyshev filter with the following specifications: attenuation in the pass-band A_p = 0.05 dB, attenuation in the rejection band A_s = 50 dB, maximum frequency of the pass-band F_p = 2.075 GHz and minimum frequency of the rejection band F_s = 2.160 GHz.

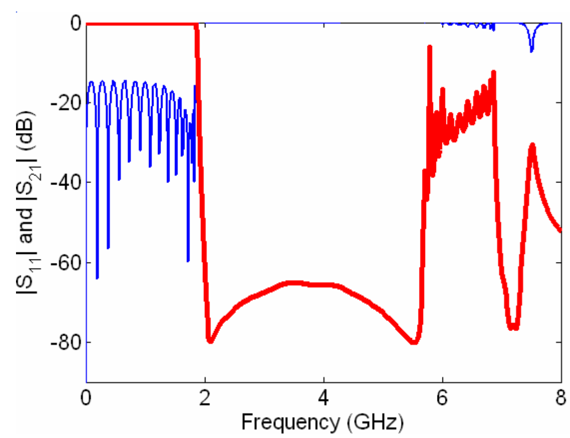


Fig. 7. Frequency response of the stepped-impedance low pas filter: $|S_{11}|$ (dB) in blue thin line and $|S_{21}|$ (dB) in red thick line.

Due to the steep slope required, it has been necessary to use a 29th-order Chebyshev low pass filter, which is a really high order for this kind of designs. Taking into account that the number of high and low impedance sections is equal to the order of the filter, and provided that a maximum impedance of Z_{0max} = 94 Ω (W = 204 µm) and a minimum impedance of Z_{0min} = 15 Ω, (W = 7.669 mm) are used, the resulting device, depicted in Fig. 6, has a total length of 180.5 mm. The frequency response is shown in Fig. 7. In this figure it can be seen a slight frequency shift and also that the pass-band is not as good as in the specifications due to the fringing capacitances of the low impedance sections. Moreover, it is important to point out that a spurious pass-band appears at 5.5 GHz. This spurious band has made impossible to achieve a wider rejection band with enough attenuation to fulfil the required performance. This is due to a limitation of this classical design method based on *short* alternating sections, *short* being understood as much smaller than $\lambda / 4$, since this will not be true at high frequencies.

IV. CONCLUSIONS

In this paper, we have proposed a novel method that allows us to design compact low pass filters in microstrip technology with stringent frequency requirements. The method is based on the use of the transverse microstrip resonant mode, and on the theory of tapered quasi-periodic structures. The design proposed is a very interesting option to minimize the noise in wireless systems which are within an Ultra-Wide Band (UWB) [11] personal area network, because of the wide rejected bandwidth that completely includes the UWB mask (from 3.1 GHz to 10.6 GHz in the FCC specifications).

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