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Study and Design of Ultra-Wideband – Band-Pass Microstrip Filters for Wireless Communication Systems

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DEDICATION

I dedicate this project to "ALLAH" Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout the years of study and on His wings only have I soared.

I also dedicate this work to my parents whom have encouraged me all the way and whose encouragement has made sure that I give it all it takes to finish that which I have started.

To my brothers Yacine, Zaki & Youcef plus to my only support in this life, my second mother, my sister Asma and their children Aymen & Anes.

To my friends specially whom walked with me for five years or more, Sabrina, Imen, Hadjer & Asma. For everyone helped me to walk in my success road.

Thank you all. My love for you can never be quantified.
God bless you.

Ziadi Amina

DEDICATION

I dedicate the fruit of this modest work and all the efforts made in order to accomplish it

To our master and the greatest teacher our prophet Muhammad "peace be upon him".

To my dear parents, whom support me and guide me in all my study path "god bless them"

I hope that their dream is achieved.

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Tidjani Sayhia, Ziadi Amina

Abstract

The RF / microwave filters have been widely studied in recent years due to the increasingly stringent requirements of selectivity, small size, low cost and low insertion loss (IL). This work presents a study and design of an ultra-wide band bandpass microstrip filter (UWB BPF), which constitute one of the key elements in a communication system, blending with the new technique of the ground plane known by defected ground structure (DGS) in the aim to reduce the size, cost and optimize the characteristics of new filters.

Key words: UWB, BPF, insertion loss, rejection, DGS, design, simulation.

دراسة و تصميم مرشحات تمرير النطاق ذات النطاق الترددي العريض الفائق (ميكروستريب) باستخدام تقنية DGS، في أنظمة الاتصالات اللاسلكية

ملخص

لقد تمت دراسة مرشحات الترددات اللاسلكية أو الميكروويف على نطاق واسع في السنوات الأخيرة، بسبب المتطلبات الصارمة و المتزايدة للانتقائية، و الحجم الصغير ، و التكلفة المنخفضة مع ضمان أقل مستوى في ضياع الإدراج. و في هذا السياق يقدم عملنا دراسة لمرشح تمرير النطاق ذو النطاق الترددي العريض الفائق (ميكروستريب)، الذي يشكل واحدا من العناصر الرئيسية لأنظمة الاتصالات، مع إدخال التقنية الجديدة المعروفة بالحفر على السطح الأرضي للمرشح المعروفة ب DGS (الهيكل الأرضي المنشق) بهدف تقليص الحجم و تقليل التكلفة وتحسين خصائص المرشحات الجديدة.

الكلمات المفتاحية: النطاق الترددي العريض الفائق، مرشحات تمرير النطاق، ضياع الإدراج، الرفض، DGS، تصميم، محاكات.

Etude et conception de filtre passe bande ultra large bande microrubans avec DGS pour les systèmes de communication sans fil

Résumé

Les filtres RF / micro-ondes ont été largement étudiés ces dernières années en raison des exigences de plus en plus strictes en matière de sélectivité, petite taille, faible coût et de faible perte d'insertion (IL). Ce travail présente une étude d'un filtre ultra large bande passe-bande (ULB PB) micro-ruban qui constituent l'un des éléments clés dans un systèmes de communication, combiné avec la nouvelle technique du plan de masse connue sous le nom de structure de sol défectueuse (DGS) Pour réduire la taille, le coût et optimiser les caractéristiques des nouveaux filtres.

Mots clés: ULB, FPB, pertes d'insertion, rejection, DGS, conception, simulation.

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List of Abbreviations

- ✓ **ADC:** Analog-to-digital converter
- ✓ **ADS:** Advanced design system
- ✓ **BPF** :Band pass filter
- ✓ **BSF:** Band-Stop Filter
- ✓ **BRF:** Band Reject Filter
- ✓ **BW:** Bandwidth
- ✓ **CPW:** Coplanar waveguide
- ✓ **CE:** Consumer electronics
- ✓ **DGS** :Defected ground structure
- ✓ **DVD**: Digital video disc
- ✓ **EM** :Electromagnetic
- ✓ **FCC:** Federal Communications Commission
- ✓ **FBW:** Fractional bandwidth
- ✓ **GPS:** Global Positioning System
- ✓ **HPF:** High-Pass Filter
- ✓ **HP-DGS:** Horizontally periodic DGS
- ✓ **HTS:** High temperature superconductors
- ✓ **HDTV:** High definition television
- ✓ **IEEE:** Institute of electrical and electronics engineers
- ✓ **IE3D:** Integral Equation Three-Dimensional (electromagnetics)
- ✓ **IL:** Insertion loss
- ✓ **ISM:** dispositifs Industriels, Scientifiques and Médicaux.
- ✓ **Lc:** Coupling length
- ✓ **LPF:** Low pass filter
- ✓ **MMR:** Multiple-mode resonator
- ✓ **MIC:** Microwave integrated circuit

- ✓ **MAI:** Multiple-access interference
- ✓ **MOM:** Method of moment
- ✓ **P-DGS:** Periodic DGS
- ✓ **PPM:** Pulse position modulation
- ✓ **PVR:** Personal video recorder
- ✓ **RADAR:** Radio Detection And Ranging
- ✓ **RF:** Radio frequency
- ✓ **RFID:** Radio frequency identification
- ✓ **RFIC:** Radio Frequency Integrated Circuits
- ✓ **RL:** Return loss
- ✓ **SNR:** Signal to noise ratio
- ✓ **TEM:** Transversal Electromagnetic
- ✓ **VP-DGS:** Vertically periodic defected ground structure.
- ✓ **VSWR:** Voltage standing wave ratio
- ✓ **UWB:** Ultra-wide band
- ✓ **WLAN:** Wireless local area networks
- ✓ **WPAN:** Wireless Personal Access Network

List of Symbols

- ✓ **E :** Electric field
- ✓ **H :** Magnetic field
- ✓ **c :** Velocity of light in free space
- ✓ P_r**:** Received power (watt)
- ✓ P_t**:** Transmitted power (watt)
- ✓ G_t**:** Transmission gain
- ✓ G_r**:** Receiving gain
- ✓ **d** : Distance between transmission and receiving antennas (meters)
- ✓ **f :** The transmission frequency (Hz)
- ✓ **P :** Polarization
- ✓ **n :** Medium refractive index
- ✓ **ω :** Angular frequency
- ✓ **fo :** Central frequency
- ✓ **fc :** Cutoff frequency
- ✓ **B :** Channel Banwidth (HZ)
- ✓ **C :** Maximum channel capacity(bits/sec)
- ✓ **S :** Signal power(watts)
- ✓ **N :** Noise power(watts)
- ✓ **Lc:** Coupling length
- ✓ **L:** Inductance
- ✓ **C:** Capacitance
- ✓ **R :**Resistance
- ✓ **εr.:** Relative dielectric constant of the material
- ✓ **εe :** Effective dielectric constant
- ✓ **h :** Substrate height
- ✓ **Zo :** Characteristic impedance
- ✓ **λo :** Wave length in free space

- ✓ **λg :** Wavelength in the guided medium
- ✓ $\boldsymbol{a_n}$**:** Incident normalized power wave
- ✓ $\boldsymbol{b_n}$**:** Reflected normalized power wave
- ✓ $\boldsymbol{S_{11}}$**:** Forward Reflection Coefficient
- ✓ $\boldsymbol{S_{12}}$**:** Reverse Transmission Coefficient
- ✓ $\boldsymbol{S_{21}}$**:** Forward Transmission Coefficient
- ✓ $\boldsymbol{S_{22}}$**:** Reverse Reflection Coefficient
- ✓ **t:** Thickness
- ✓ $\boldsymbol{V_n}$**:** Voltage in the port n
- ✓ $\boldsymbol{I_n}$**:** Current in the port n
- ✓ **W:** Width

INTRODUCTION

Introduction

Ultra-wideband (UWB) transmission has recently received great attention in both academia and industry in wireless communication applications. An UWB system is defined as any radio system that has a -10 dB bandwidth larger than 20 % (500 MHz) of its center frequency. The recent approval of UWB technology by Federal Communications Commission (FCC) of the United States reserves the unlicensed frequency band between 3.1 and 10.6 GHz for indoor UWB wireless communication systems [1].

Due to the several advantages of UWB technology, many technical challenges are existing, such as antenna design, and filter design. Microwave filters are important components for channel selection and signal separation in modern communication systems, such as radars, satellites, and wireless communication systems. Furthermore, various microstrip filters have been reported for modern applications, so, it is important in RF/microwave applications to design a filter with a small size, light weight, low cost and high performances, such as low insertion loss and high selectivity in the pass-band [2].

At any communication system, a passive bandpass filter is required to insure the signal bandpass and avoid interference inter symbols, because the signal spreads over a very large bandwidth.

In recent years, there have been several new concepts applied to distributed microwave circuits. One such technique is defected ground structure (DGS), where the ground plane metal of a microstrip circuit is intentionally modified to enhance performances. The name for this technique means that a “defect” has been placed in the ground plane, which is typically considered to be an approximation of an infinite, perfectly conducting current sink. Indeed, a ground plane at microwave frequencies (300 MHz – 300 GHz) is far removed from the idealized behavior of perfect ground. The introduction of a (DGS) is essentially for reducing the size, and optimizing the transmission characteristics of filter structures [3].

In this work, we propose a bandpass filter based on Multi-mode Resonators (MMRs) provides (3.1 – 10.6 GHz) bandpass range, which have been widely used in RF/microwave filters due to their small size, planar structure and ultra-wide realizable bandwidth.

This thesis contains three chapters organized as follow:

Chapter I: Overview about UWB technology, its definition, advantages, disadvantages, and its applications in wireless communication systems.

Chapter II: UWB BPF definition, development, types, characteristics, applications, and some expressions used in filters. Then, the defected ground structure (DGS) concept.

Chapter III: simulation and discussion of the proposed UWB BPF.

Finally, conclusion of this work and some suggestions for future works will be presented.

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CHAPTER 01

Literature review

contents

This chapter provides a brief overview about ultra-wideband (UWB) technology, which is agreed in February 2002 by the Federal Communications Commission (FCC), for communication applications in the 3.1–10.6 GHz frequency band. A summary of scattering parameters will be presented. This is followed by the discussion about Planer technology, especially microstrip lines which are compact size, low cost and, easily integrated with other passive or active devices, in addition, they manage low power transmission.

1. Introduction

Digital systems have historically been based on impulse radio concepts. Impulse radio refers to the generation of series of very short duration pulses, of the order of hundreds of picoseconds, so, each pulse will have a very wide spectrum [1]. Consequently, the UWB technology emerged.

In order to study an UWB bandpass filter, we must be informed about the key parameters that define a filter and shows us the relationship between its input and its output. Then they allow us to know the bandwidth, the returned or the loss power and the transmitted power. All these parameters can be defined through "Scattering Parameters".

Microstrip lines are very important components in the design of any printed filter. For microwave device applications, microstrip filters generally offer the smallest sizes and the easiest fabrication. Microstrip lines can be designed for frequencies that are ranging from a few gigahertz, or even lower, up to at least many tens of gigahertz [2].

This chapter contains the following sections: firstly, we will define ultra-wideband (UWB) technology, its spectral requirements allocated by the U.S Federal Communications Commission (FCC), its advantages and limitations, and especially, its applications in wireless communication systems. Next, an overview about scattering parameters will be reported where we will emphasis on dispersion matrix of two port network. Finally, we will highlight outlines about microstrip line definition, applications and characteristics, in addition to some analysis and synthesis formulas.

2. UWB technology

2.1. Definition

On February 14, 2002 the approval of UWB technology made by the (FCC) of the United States, which reserved the unlicensed frequency band between 3.1 and 10.6 GHz (7.5 GHz) for UWB wireless communication systems. This allocation was strictly to define and restrict the radio frequency (RF) emissions of this technology and bandwidth to allow coexistence. The minimum bandwidth of UWB (fractional bandwidth) as defined by the FCC must follow one of the two constraints listed below [3]:

- ✓ The minimum bandwidth must be greater than 20% of the center frequency;
- ✓ The minimum bandwidth must exceed 500 MHz.

To allow coexistence, power regulations for this technology were also strictly defined. The max of power emitted must be under -41.3 dBm/MHz. This is equivalent to 7.41 mW/MHz of average continuous power transmission [3].

Fractional bandwidth is a factor used to classify signals as narrowband, wideband, or ultra-wideband and is defined by the ratio of bandwidth at -10 dB points to center frequency [4].

$$\boldsymbol{FBW = \frac{BW}{f_c} \times 100\%} \qquad \text{(I.1)}$$

Where:

$$BW = f_h - f_l \text{ and } f_c = \frac{f_h + f_l}{2}$$

With f_h and f_l as the highest and lowest cutoff frequencies (at the -10 dB point) of an UWB pulse spectrum, respectively.

Here is the classification of signals based on their fractional bandwidth:

FBW < 1%	**Narrowband**
1% < FBW< 20%	**Wideband**
FBW > 20%	**Ultra-wideband**

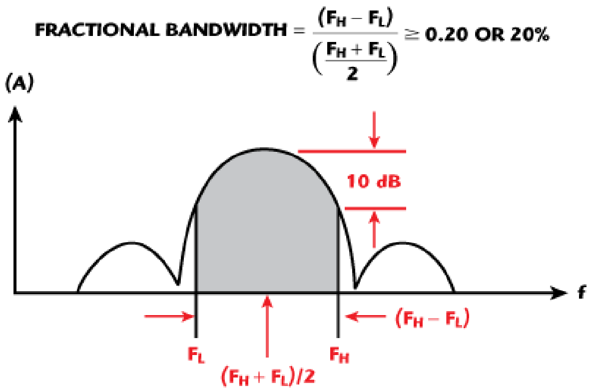

Figure.I.1. Fractional spectrum bandwidth.

2.2. UWB Advantages

Ultra-Wideband (UWB) is a short duration, pulsed RF technology that achieves the highest possible bandwidth at the lowest possible center frequency [5].

Shannon's channel capacity, equation (I.2), shows that, the capacity "C" increases linearly with the bandwidth, "B", while it increases only logarithmically with the signal to noise ratio "S/N". Thus, sending data faster in a communication system implies; increasing its capacity by increasing the bandwidth, without any losing in power resources [6].

$$C = B.log_2(1 + \frac{S}{N}) \qquad (I.2)$$

Where:

C = Maximum channel capacity (bits/sec);

B = Channel Bandwidth (Hz);

S = Signal power (watts);

N = Noise power (watts).

In addition, we know that the frequency have an inverse relationship with time duration; which is shown in the equation (I.3):

$$f = \frac{1}{T} \qquad (I.3)$$

Therefore, all UWB advantages are hardly related to these two principles. We can classify the main advantages according to UWB specifications in the following parts [5]:

a) **Key advantages of increased bandwidth:**

The first advantages category are due to UWB short pulses (large bandwidths 7.5 GHz):

- performed robustly against multipath ;
- The ability to choose accurately a frequency range for sending data effectively in the presence of multipath ;
- Communications with very low RF profiles (low power consumption) ;
- Achieve high data rates and high spatial resolution (to discriminate between targets in close proximity to each other in a radar system);
- The capability for expansion in the number of devices used simultaneously;
- Carrier less signal propagation.

Figure.I.2 presents the large operating capacity of an UWB system, in a deferent spectrum applications:

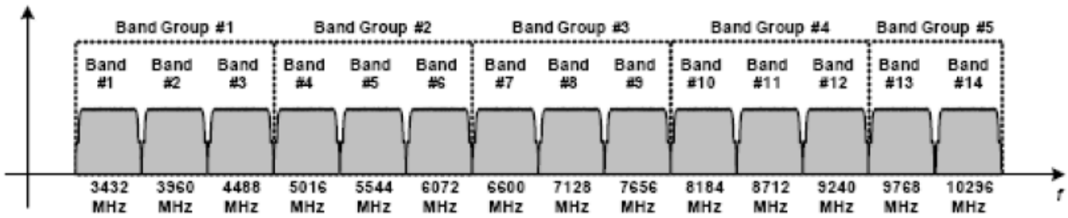

Figure.I.2. UWB standard spectrum allocation [6].

b) **Key advantages for power requirement:**

The FCC's power requirement of –41.3 dBm/MHz, equals to 74 nanowatts/MHz for UWB systems, puts them in the category of unintentional radiators, such as TVs and computer monitors. Such power restriction allows UWB systems to reside below the noise floor of a typical narrowband receiver, and enables UWB signals to [5]:

- Minimal or no interference with current radio services (coexistence);
- Ability to work with low SNRs;
- Low transmit power;
- Low cost ;

- Simple transceiver architecture ;
- Resistance to jamming ;
- Low Probability of intercept and detection ;
- High security;
- Simplicity in implementation, low cost of devices.

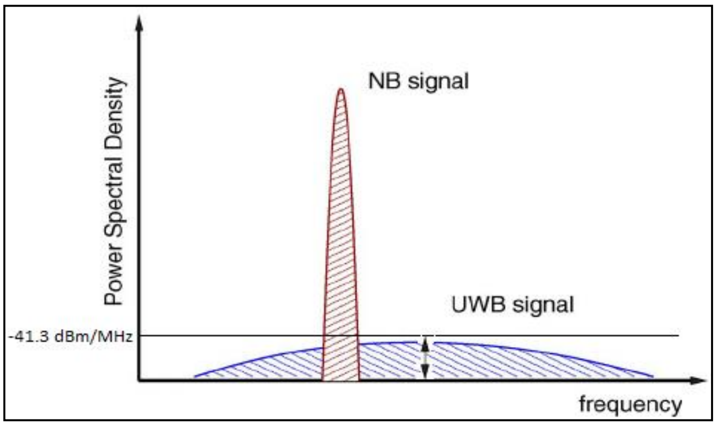

Figure.I.3. Maximum Power Spectral Density for UWB signal.

Figure.I.4 illustrates the general idea of UWB's coexistence with narrowband and wideband technologies.

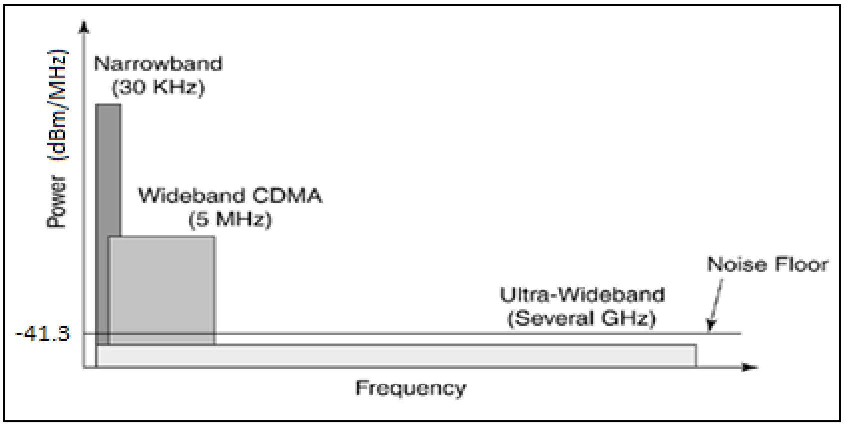

Figure.I.4. Coexistence of UWB signals with narrowband and wideband signals in the RF spectrum [7].

Table.I.1 shows the main advantages and benefits of UWB systems over narrowband wireless technologies.

Table.I.1. Advantages and benefits of UWB communications [7].

Advantage	Benefit
Coexistence with current narrowband and wideband radio services	Avoids expensive licensing fees.
Large channel capacity	High bandwidth can support real-time high-definition video streaming.
Ability to work with low SNRs	Offers high performance in noisy environments.
Low transmit power	Provides high degree of security with low probability of detection and intercept.
Resistance to jamming	Reliable in hostile environments.
High performance in multipath channels	Delivers higher signal strengths in adverse conditions.
Simple transceiver architecture	Enables ultra-low power, smaller form factor, and better mean time between failures, all at a reduced cost.

2.3. UWB Compared to Current Wireless Technology Standards

The demand for high speed, short range and low power, has not yet been provided in current wireless technologies (like Wi-Fi and Bluetooth), UWB has the potential to meet and surpass these demands.

Wi-Fi standards (802.11a/b/g), works well when used for transferring data, but was not designed for high definition streaming audio and video, unlike UWB technology. These standards are also known to consume power at approximately two orders of magnitude greater (around 100 mW) than UWB projections (around 0.5 mW). This high power consumption makes the Wi-Fi standards less ideal for smaller portable devices requiring large data rates [6].

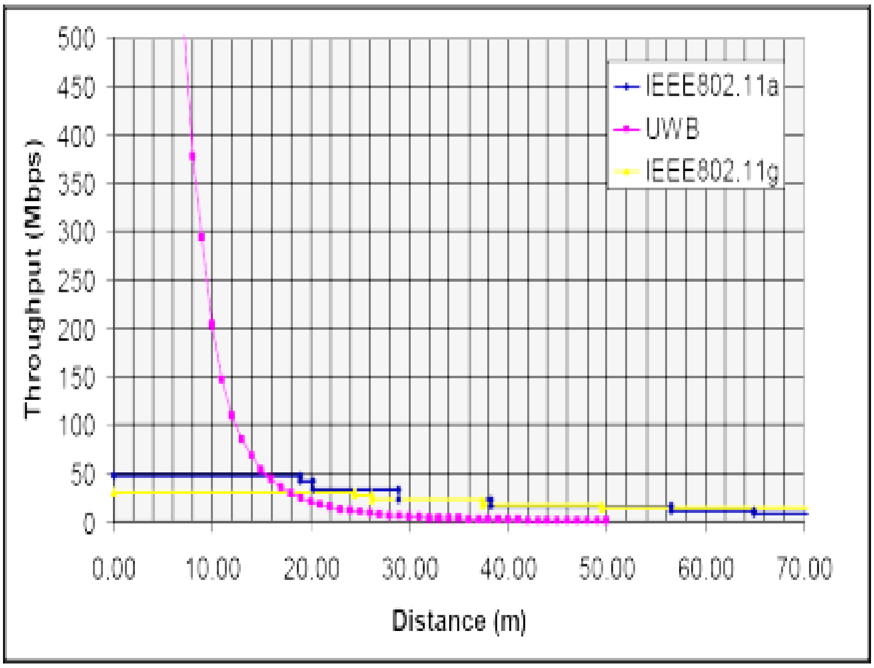

Figure.I.5. Data Rate of UWB Compared to Current Wi-Fi Standards [6].

Bluetooth has been great at providing wireless transmission for a majority of portable devices that do not require high data rate transmission. When compared to UWB, the fastest possible Bluetooth v2.0 is about 20 times slower than the slowest UWB transmission. On top of that, UWB uses less energy. Bluetooth also operates in the noisy unlicensed 2.4GHz ISM band which was chosen for world-wide capabilities, but this noisy channel often decreases the capabilities of Bluetooth transmission [6]. The following table illustrates the differences between UWB technology and other standards.

Table.I.2. Comparison of UWB technology with other WLANs [6].

Standard	Bluetooth	802.11a	802.11b/g	UWB (projected)
Coverage	10 m	50 m	100 m	10 m
Frequency Band	2.4 GHz	5 GHz U-NII Band	2.4 GHz ISM Band	3.1 – 10.6 GHz
Usable Frequency	83.5 kHz	200 MHz	80 MHz	7.5 GHz
Data Rate	1 Mbps	54 Mbps	11 Mbps	50 Mbps

2.4. UWB Disadvantages

Actually, with every advantages there are many disadvantages and challenges. UWB as a technology still has some hurdles to overcome, before it is fully realized for production. These limitations, could be the results of some properties of an UWB signal like: low output power, short duration, …etc, or it is caused by the transmission medium: according to the widely used Friis transmission formula [7]:

$$P_r = P_t G_t G_r \left(\frac{c}{4\pi d f}\right)^2 \tag{I.4}$$

Where:

$\boldsymbol{P_r}$**:** received power (watt), $\boldsymbol{P_t}$**:** transmitted power (watt), $\boldsymbol{G_t}$**:** transmission gain of emission antenna, $\boldsymbol{G_r}$**:** receiving gain of receiving antenna , $\boldsymbol{c}$: Velocity of light in free space , $\boldsymbol{d}$: distance between transmission and receiving antennas (meters), $\boldsymbol{f}$ **:** the transmission frequency (Hz).

The weak and low-powered UWB pulses, throughout the transmission channel, can be subject of many phenomena, like: pulse-shape distortion and multi-access interferences. Because, according to the equation (I.4), received power P_r drastically changes with the wide range of frequencies covered by the UWB spectrum. These phenomena makes channel estimation like a very complicated operation and a high frequency synchronization is needed.

Channel estimation, sampling and synchronizing nanosecond pulses, place major limitations on the design of UWB systems [7]:

→ To estimate channel parameters, such as attenuations and delays of the propagation path, it is important to use training sequences. These sequences undergo severe pulse distortion, which make difficult to predict the shape of the template signal that matches the received signal.

→ In order to sample these narrow pulses, very fast (on the order of gigahertz) analog-to-digital converters (ADCs) are needed. Moreover, the strict power limitations and short pulse duration make the performance of UWB systems highly sensitive to timing errors such as jitter and drift. This can become a major issue in the success of pulse-position modulation (PPM) receivers, which rely on detecting the exact position of the received signal.

Figure.I.6 represents an UWB multiple-access channel. The addition of multiple-access interference (MAI) to the unavoidable channel noise and narrowband interference can significantly degrade the low-powered UWB pulses and make the detection process very difficult [7].

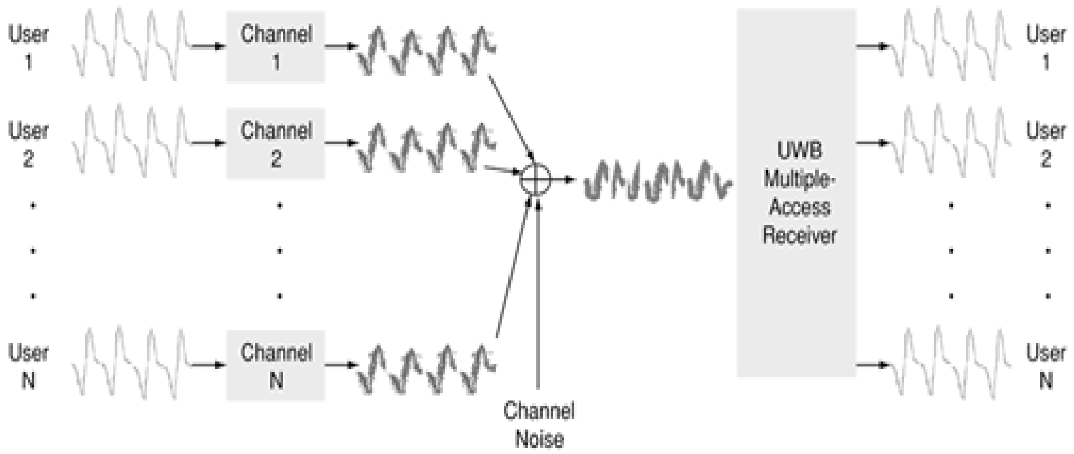

Figure.I.6. An UWB multiple-access channel [7].

Table.I.3 summarizes challenges and problems that narrow pulses can bring to UWB communication systems.

Table.I.3. Some challenges and problems associated with UWB systems [7].

Challenge	**Problem**
Pulse-shape distortion	Low performance using classical matched filter receivers (which correlate the received pulses with a predefined template).
Channel estimation	Difficulty predicting the template signals.
High-frequency synchronization	Very fast ADCs required.
Multiple-access interference	Detecting the desired user's information is more challenging than in narrowband communication.
Low transmission power	Short range area: Information can travel only short distances (10-20m) [8].

2.5. UWB Applications

There is a wide number of applications that UWB technology can offer over other narrowband technologies. They range from data and voice communications through to radar and tagging. Some of the current and future applications of UWB technology are [3]:

a) In Wireless Communication Systems:

1. High bandwidth wireless network for homes and offices;

2. Roadside information stations that can be deployed where the messages may contain weather reports, road conditions, construction information and emergency assistance communication;

3. Automotive in-car services like real time video for directions and passenger entertainment, or download driving directions from PDA for use by on board navigation system ;

4. Short range voice, data and video applications;

5. Military communications on board helicopters and aircrafts which would otherwise have too many interfering multipath components.

b) In Radars

1. Ground penetrating radar;
2. Vehicular Radars used for collision avoidance/detection and sensing road conditions;
3. Through wall imaging used for rescue, security and medical applications;
4. Identification tags;
5. Radar security fence.

c) In Precision Location Tracking

1. In container inventory systems: RFID (Radio frequency identification);
2. GPS;
3. Localization in search and rescue efforts.

3. Scattering parameters

S-parameters or dispersion coefficients, are power wave descriptors that allow us to define the input-output relations of a network in terms of incident and reflected power waves at desired point in the circuit as shown in Figure .I.7 [9].

We define an incident normalized power wave a_n and a reflected normalized power wave b_n as:

$$\begin{cases} a_n = \frac{1}{2\sqrt{Z_0}}(V_n + Z_0 I_n) \\ b_n = \frac{1}{2\sqrt{Z_0}}(V_n - Z_0 I_n) \end{cases} \quad (I.5)$$

Where the "n" index refers to port 1 or 2 and "Z_0" is the characteristic impedance of the connecting lines on the input and output sides of the network. We will assume for simplicity that both impedance have the same value.

With the above formulas we can obtain the following voltage, current and power expressions:

$$\begin{cases} V_n = \sqrt{Z_0}(a_n + b_n) \\ I_n = \frac{1}{\sqrt{Z_0}}(a_n - b_n) \end{cases} \quad (I.6)$$

$$P_n = \frac{1}{2}Re\{V_n I_n^*\} = \frac{1}{2}Re\{|a_n|^2 - |b_n|^2 + (b_n a_n^* - b_n^* a_n)\} = \frac{1}{2}(|a_n|^2 - |b_n|^2) \quad (I.7)$$

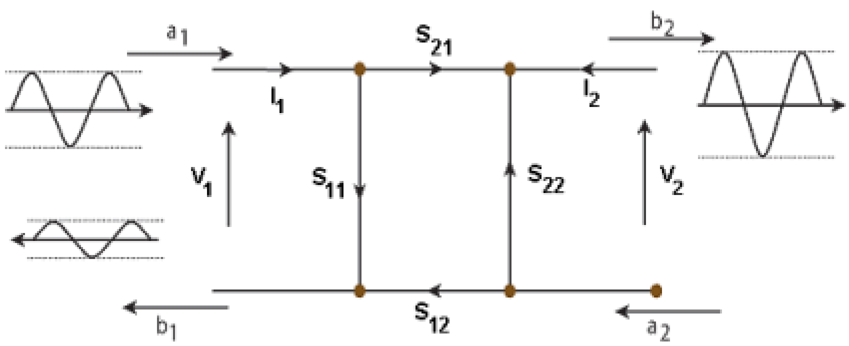

Figure.I.7. Convention used to define S-parameters for a two-port network [9].

Where $(b_n a_n^* - b_n^* a_n)$ is purely imaginary, and physically we can obtain that the average power delivered through port ''n'' is equal to the power in the incident wave minus the power in the reflected wave. So, the definition of a generalized scattering matrix (S-parameters matrix) would be:

$$\begin{Bmatrix} b_1 \\ b_2 \\ \vdots \\ b_M \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \dots S_{1M} \\ S_{21} & S_{22} & \dots S_{2M} \\ \vdots & \vdots & \ddots \; \vdots \\ S_{M1} & S_{M2} & \dots S_{MM} \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ \vdots \\ a_M \end{Bmatrix} \quad \text{(I.8)}$$

Where: $S_{ij} = \left.\frac{b_i}{a_j}\right|_{a_k=0} \quad ; k \neq j$

For two-ports network:

$$\begin{Bmatrix} b_1 \\ b_2 \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \end{Bmatrix} \quad \text{(I.9)}$$

This matrix is known as dispersion or S-parameters matrix where term definitions are:

- ✓ Forward Reflection Coefficient: $S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} = \frac{reflected\ power\ wave\ at\ port\ 1}{incident\ power\ wave\ at\ port\ 1}$
- ✓ Forward Transmission Coefficient: $S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} = \frac{reflected\ power\ wave\ at\ port\ 2}{incident\ power\ wave\ at\ port\ 1}$ (I.10)
- ✓ Reverse Reflection Coefficient : $S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0} = \frac{reflected\ power\ wave\ at\ port\ 2}{incident\ power\ wave\ at\ port\ 2}$
- ✓ Reverse Transmission Coefficient: $S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0} = \frac{reflected\ power\ wave\ at\ port\ 1}{incident\ power\ wave\ at\ port\ 2}$

The conditions $a_2 = 0$ and $a_1 = 0$ imply that no power waves are returned to the network at either port 2 or port 1. This can only be ensured when the connecting transmission lines are terminated into their characteristic impedance [9].

The wave's equations of the network is given below [3]:

$$b_1 = S_{11}a_1 + S_{12}a_2 \quad \text{(I.11)}$$

$$b_2 = S_{21}a_1 + S_{22}a_2 \quad \text{(I.12)}$$

As with the ABCD parameters, in case the network analyzed has some special characteristics, the parameters will meet certain properties:

- If the network is reciprocal, then S_{12}= S_{21} ;

- If the network is symmetrical then additionally S_{11}=S_{22} ;

- For a passive network with no losses, transmitted and reflected powers must equal incident power, meeting the following equations [9]:

$$\begin{cases} |S_{21}|^2 + |S_{11}|^2 = 1 \\ |S_{12}|^2 + |S_{22}|^2 = 1 \end{cases} \tag{I.13}$$

- If the network is reciprocal (S_{12}=S_{21}), and symmetrical (S_{11}=S_{22}); so we say that this network is with no losses.

The reflection coefficient at the input side is expressed in terms of "S_{11}"under matched output according to:

$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = \frac{b_1}{a_1}\bigg|_{a_2=0} = S_{11} \tag{I.14}$$

Where V_1^+ and $V_1^-$are respectively the incident and the reflected wave voltages at the input side.

Scattering parameters in RF and microwave field can represent various network features such as gain, return loss (RL), voltage standing wave ratio (VSWR), insertion loss (IL), stability and so on. The S-parameters are vector quantities but usually their magnitudes are useful in communication systems. From S-parameters, some RF/Microwave field features are given below.

- We can define the Voltage Standing Wave Ratio (VSWR) at port 1 in terms of S_{11} as [9]:

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \tag{I.15}$$

VSWR gives us a measure of how well the load is impedance-matched to the source [3].

4. Planer technology

The use of a planer technology is a solution to solve problems according to voluminous structures spectral occupation and heavyweight. The weakness of planer circuits is that, it presents very important insertion losses than voluminous topologies.
However, contrary to voluminous technologies, the realization of microstrip transmission lines simplify the interconnections. It is used as well in printed circuit technology than integrated circuit technology [10].

4.1. Microstrip transmission line

4.1.1. Definition

Microstrip transmission line is the most popular and used planar transmission line in Radio frequency RF applications, exploited for designing certain components like filters, couplers and transformers. The wave type propagating in this transmission line is a quasi-Transversal electromagnetic wave "quasi-TEM" (see appendix N°01). The microstrip transmission line consists of metallic strip of width **W** and the thickness **t**, metallic ground and between it dielectric substrate with constant $\boldsymbol{\varepsilon_r}$ of thickness **h** [3], as shown in the Figure.I.8. The characteristic impedance $\boldsymbol{Z_0}$ of the line is determined in terms of width W, thickness **t** and dielectrics substrate constant $\boldsymbol{\varepsilon_r}$.

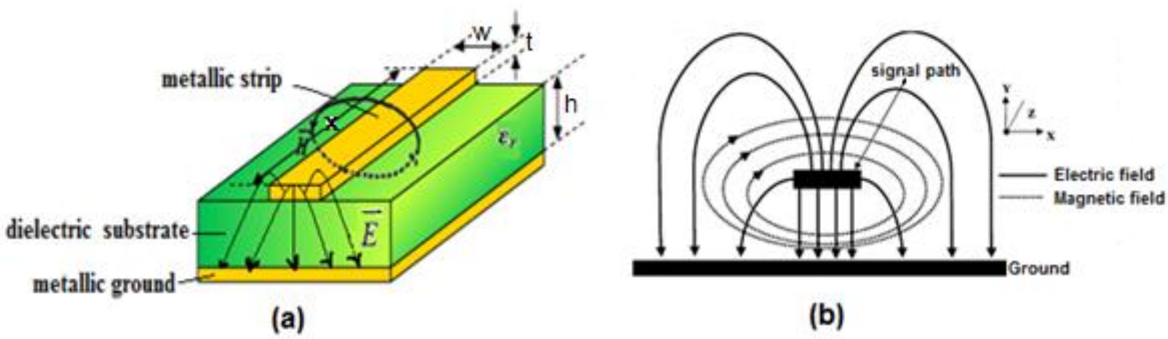

Figure.I.8. View of a microstrip line and its lines of electric and magnetic fields, **(a)** whole view, **(b)** zoom in [3, 10, 11].

- Both electric and magnetic fields are present in the transmission lines. These fields are perpendicular to each other and to the direction of wave propagation for TEM mode waves, which is the simplest mode, and assumed for most simulators (except for microstrip lines which assume ''quasi-TEM'', which is an approximated equivalent for transient response calculations).

- Electric field is established by a potential difference between two conductors: implies equivalent circuit model must contain capacitor.
- Magnetic field induced by current flowing on the line: implies equivalent circuit model must contain inductor [11].

4.1.2. Application and characteristics of Microstrip lines

Microstrip lines can be used in the manufacturing of some microwave components, therefore UWB filters can be made from them. Due to some suitable features, microstrip line is widely used (regardless of low power handling capacity) in the transmission of microwave frequency signals. The features may include [4]:

- ✓ Its simple geometry;
- ✓ Small size and low cost;
- ✓ Absence of difficulties in devices integration and mass production;
- ✓ Good repeatability and reproducibility.

4.1.3. Analysis and synthesis formulas

A. Analysis formulas

The analysis of the microstrip line is to determine from the physical parameters, the effective permittivity, and the equivalent width necessary to the determination of characteristic impedance of this line. The approximate expressions are analytical presented in the literature [10].

For the microstrip we have for the narrow lines w /h < 3.3:

$$Z_c = \frac{119.9\pi}{\sqrt{2(\varepsilon_r+1)}}\left[ln\left(4\frac{h}{w}+\sqrt{16\left(\frac{h}{w}\right)^2+2}\right)-\frac{1}{2}\left(\frac{\varepsilon_r-1}{\varepsilon_r+1}\right)\left(ln\frac{\pi}{2}+\frac{1}{\varepsilon_r}ln\frac{\pi}{4}\right)\right] \quad (I.16)$$

For wide lines, w /h > 3.3:

$$Z_c = \frac{119.9\pi}{\sqrt{2(\varepsilon_r)}}\left[\frac{w}{2h}+\frac{ln4}{\pi}+\frac{\ln(e\pi^2/16)}{2\pi}\left(\frac{\varepsilon_r-1}{\varepsilon_r{}^2}\right)+\left(\frac{\varepsilon_r+1}{2\pi\varepsilon_r}\right)\left(ln\frac{\pi e}{2}+ln\left(\frac{w}{2h}+0.94\right)\right)\right]^{-1} \quad (I.17)$$

B. Synthesis formulas

The synthesis is used to determine the dimensions and the nature of the used dielectric, for a given characteristic impedance.

$$\frac{w}{h} = \begin{cases} \frac{8}{\exp(A) - 2\exp(-A)} & w/h \geq 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left(ln\,(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right)\right] & w/h \leq 2 \end{cases} \qquad \text{(I.18)}$$

Where: $$A = \frac{Z_c}{\eta_0}\,\pi\sqrt{2(\varepsilon_r + 1)} + \left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

$$B = \frac{\pi}{2\sqrt{\varepsilon_r}}\frac{\eta_0}{Z_c}$$

Effective relative dielectric constant (ε_{eff}) can be calculated by the following formula:

$$\begin{cases} \varepsilon_{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\left(1 + \frac{12h}{w}\right)^{-1/2} & w/h > 1 \\ \varepsilon_{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\left[\left(1 + \frac{12h}{w}\right)^{-1/2} + 0.04\left(1 - \frac{w}{h}\right)^2\right] & w/h < 1 \end{cases} \qquad \text{(I.19)}$$

5. Conclusion

In this chapter, an overview about UWB technology have been discussed. Whereas, it has been stated that UWB promises, in contrast with spread spectrum radio technologies that achieve a few megabits per second in 100s of kilometers, to achieve high data rates at the lowest possible transmit power in a very short range, that will make more multimedia applications possible with high definition streaming and high speed, and providing high degree of security at a reduced cost.

Additionally, S-parameters have been discussed to study power rates or input/output rates, and calculate the Insertion Loss (IL) and the Return Loss (RL) concerning a filter. As well as, microstrip lines advantages listed previously made them very suitable for the design of an UWB bandpass filter. The second chapter will give, as an adequate background, details and explanations about the definition of UWB bandpass filter, and its advantages. Also, Defected Ground Structure "DGS" technical will be explained.

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CHAPTER 02

UWB Band-Pass Filters

contents

This chapter will present theoretical basics enabled to get more description about some important tools like development of UWB-BPF, its different types, characteristics and applications also all about filters such as definition, types, and filter parameters and some related expressions with filters. Some types of UWB-BPFs without and with DGS will be cited. Then we will pass to the Defected Ground Structure (DGS), its equivalent circuit types and some structures based on DGS.

1. Introduction

Ultra-wideband band pass filters (UWB BPF) play an important role in the development of UWB systems. So, with the enlarging in filter application in wireless communication systems, different techniques have been used to develop these UWB filters. Generally, lumped-element filter design is unpopular since the difficulty of its use at microwave frequencies along with the limitations of lumped-element values [1]. Designers needed a new procedure and structure to make low insertion loss and perfect convention between simulated and experimental results. Introducing Defected ground structure (DGS) technique is one of the key solutions to realize the superior performances [2].

In this chapter, an UWB-BPF history, an overview about DGS and UWB BPF structures based on DGS are presented.

2. Filter definition

The filter is a two-port network used to control the frequency response at certain point in a microwave system. It provides transmission at frequencies within the pass-band of the filter and attenuation in the rest of the band, the stop-band. Typical frequency responses include low-pass, high-pass, and band-pass and band-reject characteristics. The perfect filter would have infinite attenuation in the stop-band, and zero insertion loss with a linear phase response (to avoid signal distortion) in the pass-band [3].

2.1. Classification of filters

There are four primary categories of filters which are:

- **Low-Pass Filter (LPF):** A low-pass filter passes low frequency signals, and rejects signals at frequencies above the filter's cutoff frequency (*f*c);
- **High-Pass Filter (HPF):** The opposite of the low-pass is the high-pass filter, which rejects signals below its cutoff frequency (*f*c);
- **Band-Pass Filter (BPF):** A band pass filter allows signals with a range of frequencies (*f*c1, *f*c2). (pass band) to pass through and attenuates signals with frequencies outside this range;
- **Band-Stop Filter (BSF) or Band Reject Filter (BRF) :** A filter with effectively the opposite function of the band-pass is the band-reject or notch filter;

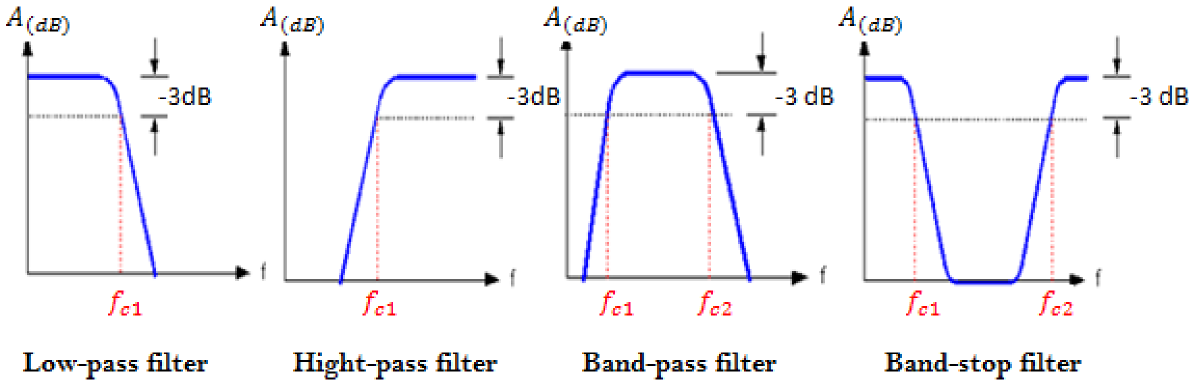


Figure.II.1. Frequency responses of the four types of filters.

3. Ultra wideband band-pass filter (UWB BPF)

3.1. Development of UWB Band pass Filters

After the release of UWB band pass filters with a pass band of the same frequency range (3.1 GHz - 10.6 GHz and a fractional bandwidth of 110%), challenges for conventional filter designs increased.

- ✓ Before mid-2003, the bandwidth of the pass band for a BPF was extended from 40% to 70%. These filters are named broad band pass filters. They were not covering the whole UWB frequency range yet. In [4], a band pass filter covering the whole UWB frequency range with a fractional bandwidth of 110% was realized by fabrication signal lines on a loss composite substrate. A successful transmission of the UWB pulse signal was demonstrated using the proposed band pass filter. This is one of the early reported filters that possess an ultra-wide pass band. However, it has a high insertion loss in the pass band due to the loss substrate. Not much research work was reported in 2003 and 2004.
- ✓ In 2004, a ring resonator with a stub was proposed which shows a bandwidth of 86.6% [5]. A band pass filter covering the whole UWB frequency band was a challenge for microwave filter designers and researchers in that period of time.
- ✓ In 2005, there are mainly four types of structures that are able to realize an ultra-wide pass band.
- ✓ In 2006, micro strip multiple-mode resonator (MMR) based on UWB band-pass filters are proposed with improvement in the rejection of the upper stop-band. It has been done by introducing interdigital micro strip coupled lines at the two sides of the MMR. A high-pass filter consisting of a transmission line with two embedded U-shaped slots is cascaded with a low-pass filter which is a dumbbell-shaped defected ground structure array in the ground

plane, to obtain a pass band from 3 GHz to 10.9 GHz. With novel high-pass and low-pass structures, the band-pass filter obtains a wider bandwidth than the filter taking a similar approach in 2005. With regards to the UWB band-pass filters design by cascading a high-pass and a low-pass filter, a systematic consistent and analytical method was proposed. There are a good number of new structures proposed that exhibit an ultra-wide pass band [3].

- ✓ In 2007, UWB band-pass filters with a notch stop-band from 5 GHz to 6 GHz for filtering the wireless local-area network (WLAN) is a new topic branched out in this area. Additional components are introduced providing the notch stop-band at the desired frequency. An embedded open-circuit stub was proposed providing a sharp notch stop-band. It is integrated into a UWB band-pass filter providing the stop-band from 5 GHz to 6 GHz. A stub is introduced in the broadside-coupled microstrip-CPW structure to generate a notch stop-band at WLAN frequency range [5].

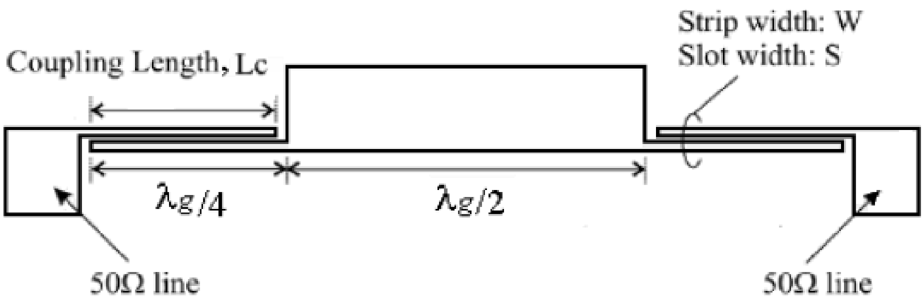


Figure.II.2. The schematic of a micro strip multi-mode resonator (MMR) with two parallel coupled lines at two ends [5].

3.2. Different types of UWB BPF

a) Microstrip multi-mode resonator with two parallel-coupled lines at two ends, it consists of a micro strip multi-mode resonator (MMR) and a parallel-coupled line at each end of the network.

- ✓ The MMR has two identical high-impedance sections with a length of quarter guided wavelength at two sides and a low-impedance section with a length of half guided wavelength in the middle.
- ✓ The MMR in the filter generates first and third resonant mode at the edges of the UWB pass band. The parallel-coupled lines are modified to obtain the ultra-wide pass band. This could be done by adjusting the coupling length *Lc* [5], [6].

b) The CPW MMR, this type of structure consists of a CPW MMR on one side and a microstrip input and output on the other side. The CPW MMR is responsible for generating the first and third resonant mode for the UWB pass band, which is similar to a micro strip MMR [5],[7], its geometry can be varied.

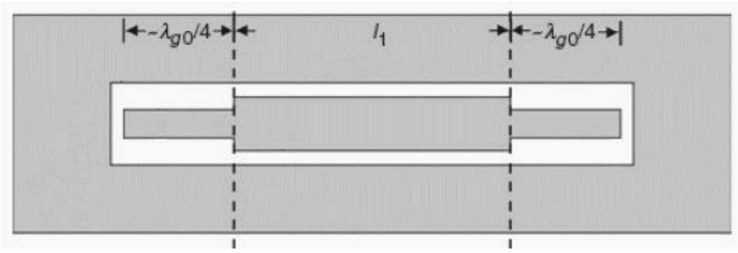
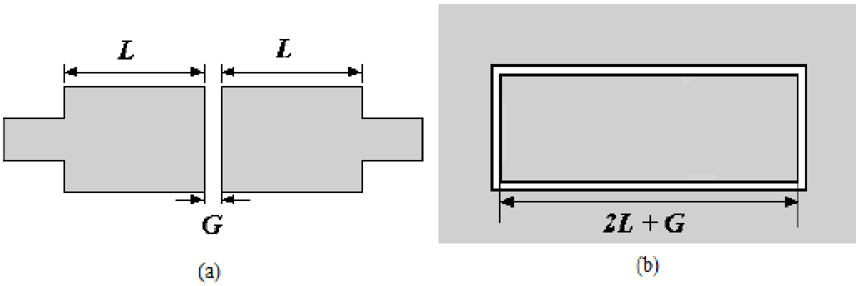


Figure.II.3. The schematic of a CPW MMR in [5]-[7].

c) Broadside coupled of microstrip-CPW, also capable to have a fractional bandwidth of 110%. There is a broadside coupled microstrip line on one side of the substrate and an open end CPW on the other side of the substrate. The length of the coupled line equals to $\lambda_g/2$ in order to obtain a 110% bandwidth [5], [8].



Figur.II.4. The schematic of the proposed broadside-coupled micro strip-CPW structure in [5], [8], (a) top view, (b) bottom view.

d) The fourth type of BPF that has a bandwidth as high as around 100% is **the combination of a high-pass filter and a low-pass filter**, a stepped-impedance low pass filter is embedded into a high-pass filter with quarter-wavelength short-circuited stubs, achieving a pass-band from 3 GHz to 10 GHz. Obviously, the latter uses an area much less than the former. Both BPFs consist of a high-*Z*, low-*Z* LPF and an HPF structure designed with shunt quarter wave short-circuited stubs separated with $\lambda_g/4$ sections, acting as impedance inverters. The variable λ_g is the guided wavelength at a proper frequency f_0 which will be addressed shortly [9].

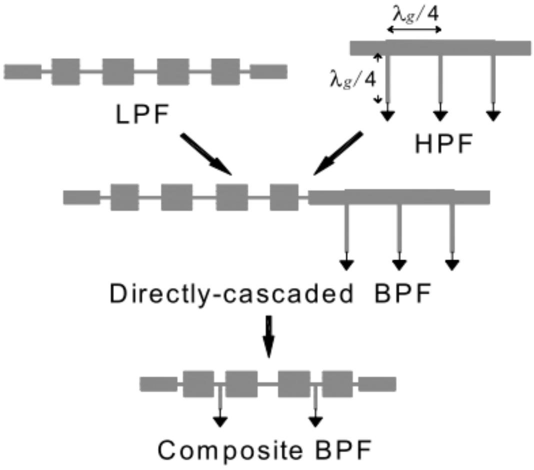


Figure.II.5. Evolution of the proposed composite BPF [9].

e) Short circuited quarter wave-length stubs, This filter was designed using a combination of low-pass filter (LPF) with typical quarter-wavelength short-circuited stubs high-pass filter (HPF), followed by an optimization for tuning in-band performance. The filter comes with a good performance, including an ultra-wideband bandpass (3.1-10.6 GHz), low insertion loss, sharp rejection, flat group delay, high selectivity, and excellent performance outside of the bandpass. There are many structures designed which based on this technology [10].

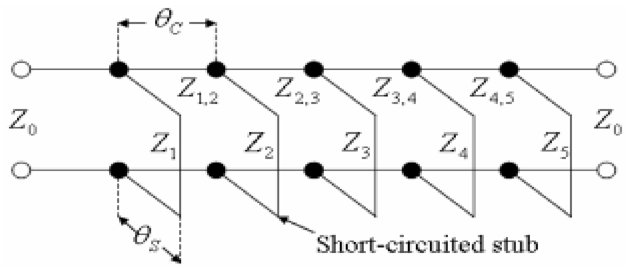


Figure.II.6. Conventional of five short-circuited stubs filter [11].

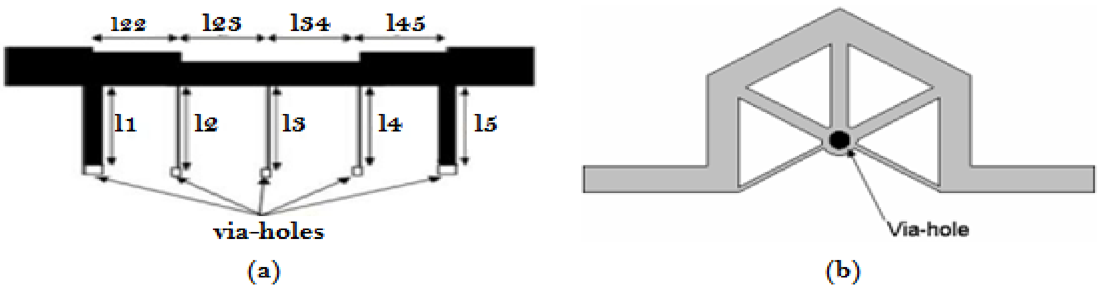


Figure.II.7. UWB BPFs based on quarter-wavelength short-circuited stubs, (a) layout of BPF short circuited to ground through via at each end (b) structure with five short-circuited stubs via the same hole [11], [12].

3.3. UWB BPF characteristics

Nowadays, the UWB have been developed and widely applied, so there are several advantages for UWB radio system such as:

- ✓ transmitting higher data rates;
- ✓ needing lower transmit power;
- ✓ simplifying the error control coding.

In such systems, an UWB filter is one of the key components, which should exhibit wide bandwidth with low insertion loss over the whole band. In order to meet the FCC limit, good selectivity at both lower and higher frequency ends and flat group-delay response over the whole band are required [5].

3.4. UWB BPF application

a) WPAN (Wireless Personal Access Network)

- ✓ Desktop and Laptop PCs;
- ✓ Printers, scanners, Storage devices, etc ;
- ✓ Connectivity to mobile and consumer electronics (CE) devices;
- ✓ MP3, games, video;
- ✓ Cameras, DVD, PVR, HDTV.

b) Personal connectivity

- ✓ Positioning, geo-location, localization, high multipath environments, obscured environments;
- ✓ Communications: high multipath environments, short range high data rate low probability of intercept/ interference;
- ✓ Radar/ Sensor: (motion detector, range-finder, etc.), Military and Commercial [13].

4. Expressions used in filters

4.1. Insertion loss

In the best possible way, an ideal filter would Introduce no loss of power in the bandwidth (zero insertion loss), actually there is a certain amount of power loss related to the filter. The insertion loss quantifies how much below the 0dB line the power amplitude response drops [14].

$$IL(dB) = -20log_{10}|S_{21}| \qquad \text{(II.1)}$$

4.2. Return loss

In technical terms, RL is the ratio of the power reflected back from a device under test, by a discontinuity in a transmission line or optical fiber, to the power launched into that device, usually expressed as a negative number in dB. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line.

$$RL(dB) = -20log_{10}|S_{11}| \tag{II.2}$$

4.3. Pass band

Pass band is the band of frequencies that is allowed to pass through a filter. Pass band is equal to the frequency range for which the filter insertion loss is less than a specified value.

4.4. Cut-off frequency

Cut-off frequency is the frequency at which the filter insertion loss is equal to 3 dB.

4.5. Stop band

Stop band is equal to the frequency range at which the filter insertion loss is greater than a specified value. It is the band out of the pass band.

4.6. Ripple

The flatness of the signal in the passband can be quantified by specifying the ripple or difference between maximum and minimum amplitude response in dB. Chebyshev filter response allows us to control the magnitude of the ripple [14].

4.7. Bandwidth

For a bandpass filter, it is the difference between upper and lower frequencies typically recorded at the 3dB attenuation points above the passband.

$$BW^{3dB} = f_u^{3dB} - f_L^{3dB} \tag{II.3}$$

4.8. Rejection

For an ideal filter we would obtain infinite attenuation level for the undesirable signal frequencies. However, in reality we expect an upper bound due to the deployment of a finite number of filter components. Practical designs often specify **60dB** as the rejection rate.

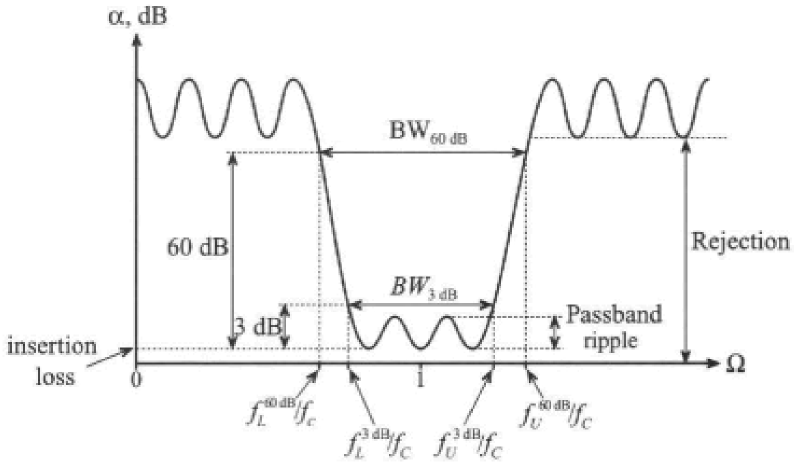


Figure.II.8. Generic attenuation profile for a bandpass filter [14].

Achieving the best power profile, and the lowest insertion loss, designers develop a new method and structure to overcome on the limitations of lumped-element. Introducing Defected ground structure (DGS) technique is one of the key solutions to achieve the best performances [3].

5. Defected Ground structures (DGS)

Over the past few years, there has been a different new concept applied in order to distribute microwave circuits. The one of these techniques is defected ground structure or DGS, where the ground plane metal of a micro strips circuit is intentionally modified to enhance performances. This technique's name is simply means that a "defect" has been placed in the ground plane, what is generally regarded as an approximation of 'an infinite, current collector perfectly-conducting. Indeed, a ground plane at microwave frequencies is far removed from the idealized behavior of perfect ground. Although the additional perturbations of DGS alter the uniformity of the ground plane, they do not render it defective [15].

5.1. DGS as Periodic Structures

Since last few years, almost 2001, many searchers have been tried to use periodic DGSs to improve the performance of amplifiers, power dividers, and oscillators. So they suggested to use a micro strip line with periodic DGS at the output for harmonic tuning of different components. A periodic uniform dumbbell shaped DGS shown in Figure II.6 is used in order to suppress the higher order modes of a power amplifier. Later on 2004, they commenced considering the non-uniform periodic DGS with relative amplitude distribution following a Chebyshev or binomial distribution or exponential function, as shown in Figure.9 (a).

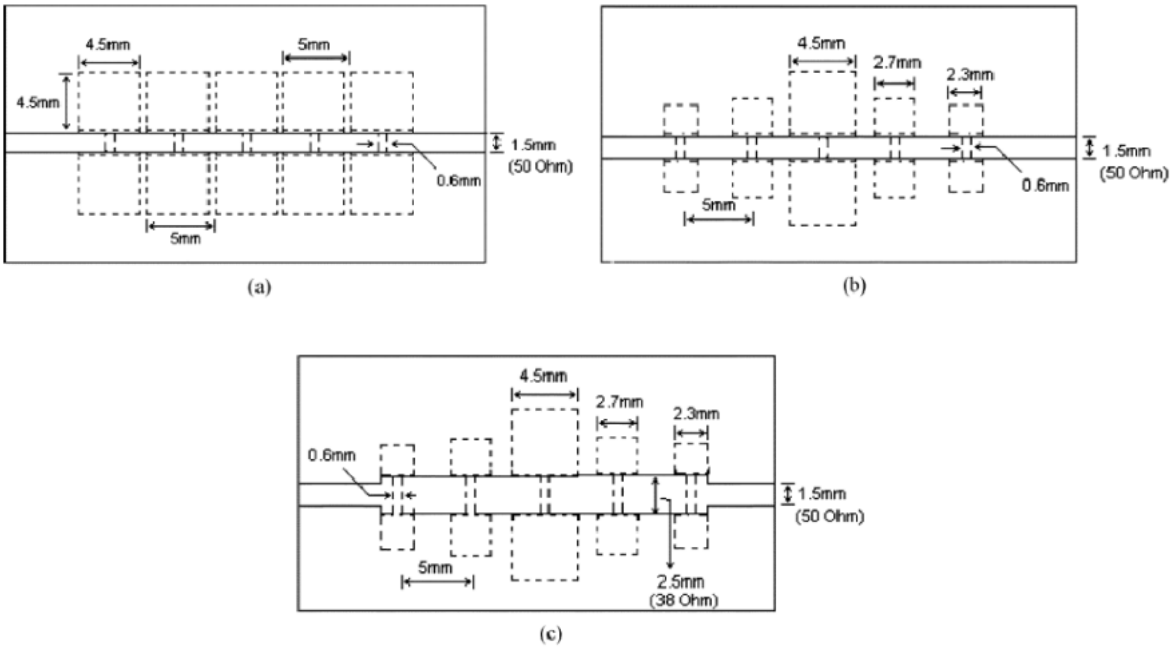


Figure.II.9. (a) A dumbbell shaped DGS etched in the ground plane of a microstrip line with periodic uniform distribution, **(b)** binomial distribution, **(c)** exponential distribution [16].

Other types of P-DGS are represented in Figure.II.10 and Figure.II.11.

Figure.II.10 shows horizontally periodic DGS (HP-DGS) that is used to widen the stop-band of frequency response curve and provides slow wave characteristics.

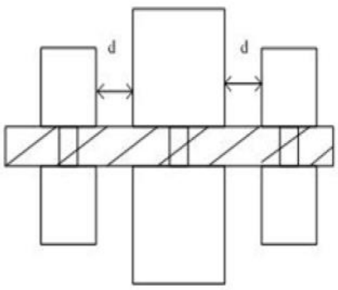


Figure.II.10: Periodic HP-DGS [3]

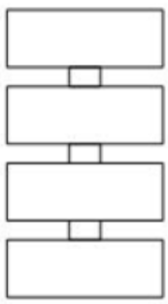


Figure.II.11. Periodic VP-DGS [3].

5.2. Different forms of DGS

Many various shape of DGS have been studied such as a concentric ring circle, spiral, dumbbells, elliptical and U- and V- slots. Each DGS form can be represented as a circuit consisting of inductance and capacitance, which can lead to a certain frequency band gap determined by the shape, dimension and position of the defect.

DGS furnish a supplementary degree of liberty in microwave circuit design and can be used for different types of utilization [3].

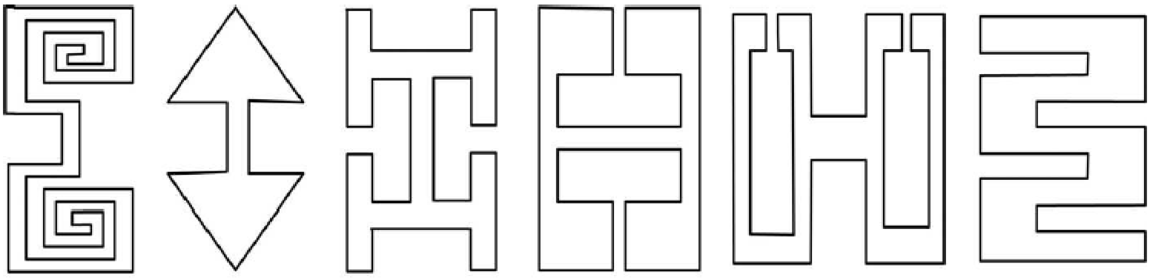


Figure.II.12. Different types of DGS: (a) spiral head (b) arrow-head slot (c) “H” shape slot (d) square open-loop with a slot in middle section (e) open loop dumbbell (f) inter-digital DGS [3].

5.3. Advantages of DGS

The most important characteristics of DGS are:

- ✓ Disturbs shielding fields on the ground plane;
- ✓ Increases effective permittivity;
- ✓ Capacitance and inductance of transmission line;
- ✓ One-pole LPF characteristics;

5.4. Disadvantages of DGS

The DGS have a principal disadvantages which is the radiations. Radiation within enclosed microwave circuits can be difficult to include in simulation. Limit conditions are usually set to be absorbing (no reflections), which make simpler calculations, but eliminate the structures around the circuit being tested.

In some cases, the size of the enclosure will make the problem too large to achieve a solution in a reasonable time, and the details of the physical structure may take a very long to determine and enter into the software [17].

Also, the EM simulation is assuredly accurate for the circuit itself, but with uncertainty of radiation effects, the construction and careful evaluation of a prototype is strongly recommended. An experienced designer may be able to create a simplified model of the enclosure for more accurate simulation, but measurement remains essential for verification. A lesser disadvantage is that DGS structures increase the area of the circuit. However, the additional area will usually be less than that of alternative solutions for achieving similarly improved performance [18].

5.5. Equivalent circuit of DGS

Today, a DGS can be designed by three types of equivalent circuits:

a) *LC* and *RLC* equivalent circuits;

b) π shaped equivalent circuit;

c) Quasi-static equivalent circuit.

a) *LC* and *RLC* equivalent circuits

The rectangular pieces of dumbbell DGS play a key role of the augmentation of the effective inductance and the slot part collect charge and increases the effective capacitor of the micro strip line. Two rectangular defected areas and one connecting slot correspond respectively to the equivalently added inductance (*L*) and capacitance (*C*). Accordingly, a resonance occurs at a certain frequency because of the parallel *L*-*C* circuit [19].

Figure.II.13 represents the equivalent circuit DGS and of and one-pole Butterworth prototype of the LPF.

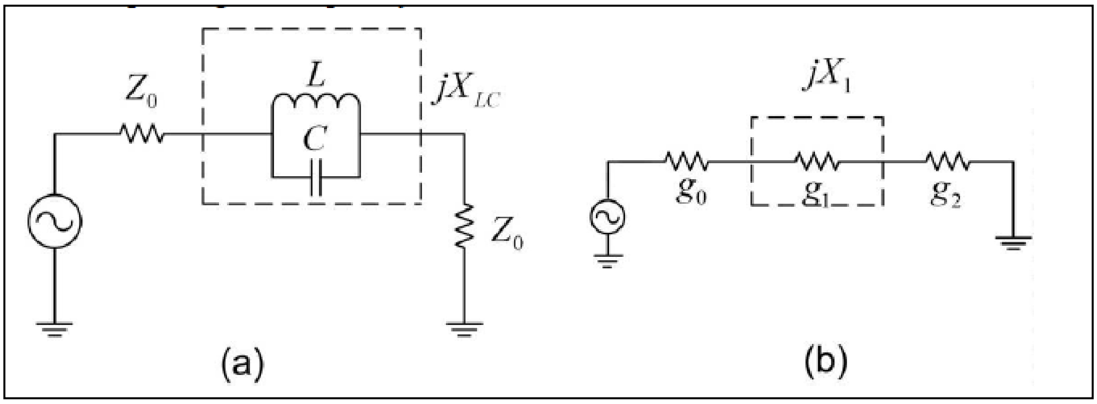


Figure.II.13. LC equivalent circuit: (a) equivalent circuit of the dumbbell DGS circuit, (b) Butterworth-type one-pole prototype LPF circuit [19].

For matching DGS to Butterworth LPF circuits, the reactance values of both circuits are similar at the cut off frequency. So L and C are derived as follows:

$$X_{LC} = \frac{1}{\omega_0 C}\left(\frac{\omega_0}{\omega} - \frac{\omega}{\omega_0}\right) \quad \text{(II.4)}$$

✓ Where ω is the resonance angular frequency of the parallel LC resonator.

$$C = \frac{\omega_c}{Z_0\, g_1} \cdot \frac{1}{\omega_0^2 - \omega_C^2} \quad \text{(II.5)}$$

$$L = \frac{1}{4\pi^2 f_0^2 . C} \quad \text{(II.6)}$$

- ✓ Where f_0 and f are resonance and cutoff frequency which can be acquired from the results of EM simulation;
- ✓ The advantages of most DGSs are comparable to the dumbbell DGS, thus they could be discussed by one-pole Butterworth LPF too. Moreover, radiation effects are more or less neglected;
- ✓ DGS unit can be modeled most efficiently by a parallel R, L, and C resonant circuit connected to transmission lines at its both sides as shown in Figure.II.14 [20].

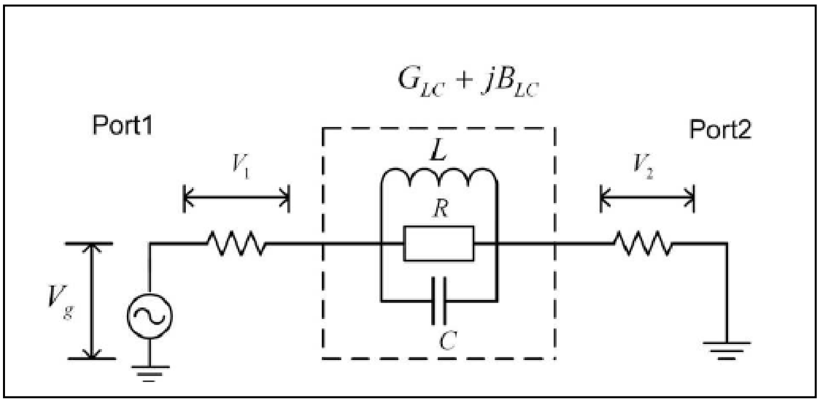


Figure.II.14. RLC equivalent circuit for DGS [20].

$$C = \frac{\omega_c}{2Z_0(\omega_0^2 - \omega_c^2)} \quad \text{(II.7)}$$

$$L = \frac{1}{4\pi^2 f_0^2 . C} \quad \text{(II.8)}$$

$$R(\omega) = 2Z_0 \Big/ \sqrt{\frac{1}{|S_{11}|^2} - \left(2Z_0\left(\omega_c - \frac{1}{\omega_L}\right)\right)^2 - 1} \quad \text{(II.9)}$$

b) π shaped equivalent circuits

There are circuits more precise than the model LC and RLC equivalent circuit model have been proposed in some literature such as a π shaped equivalent circuit as shown in Figure.II.15.

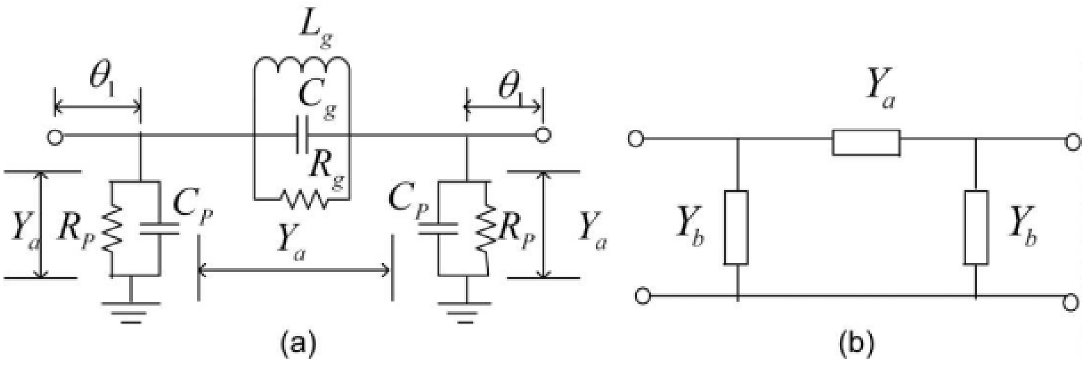
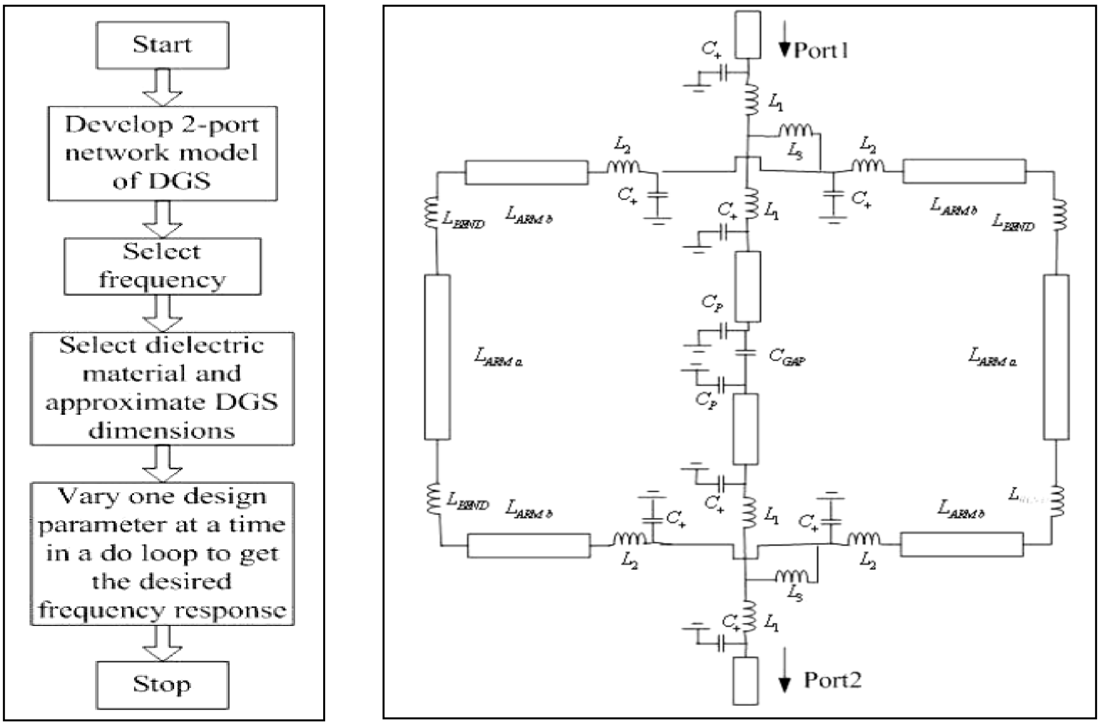


Figure.II.15. π shaped equivalent circuit for unit DGS: (a) equivalent circuit, (b) π shaped Circuit.

c) Quasi-static Equivalent Circuit

Quasi-static equivalent circuit model of a dumbbell DGS is progressed which is directly derived from the physical dimensions of dumbbell DGS as shown in Figure.II.16.



(a) (b)

Figure.II.16. New design and analysis method of DGS: (a) analysis method of DGS, (b) Equivalent-circuit model of unit cell DGS [19].

This method offer a global understanding of the physical principle of DGS, in addition to how the DGS creates band-stop and band-pass responses and which dimensions play the most necessary role to create the distinct performance. Presently, the equivalent circuits are especially concerned about influences of the addition of DGS such as radiation.

Consequently, the optimization founded on an equivalent circuit network is highly desirable to design and improve this kind of circuit configuration [3].

6. UWB BPF structures based on DGS

6.1. Micro strip Multi-mode Resonator (MMR) UWB-BPF (structure 1)

The schematic studied in [3] shown in Figure (II.17) of the proposed filter represents a BPF for ultra-wideband (UWB) applications based on multiple-mode resonator (MMR) using interdigital feed lines structure combined with defected ground rectangular structure (DGS), aiming to transmit the signal in the whole UWB pass band of (3.1 – 10.6 GHz). It is designed on a substrate with a relative dielectric constant of ε_r = 10.8 and a thickness of h=1.27 mm.

The use of parallel coupled feed lines is able to enhance the coupling degree between the feed lines. This coupling can be adjusted to control the bandwidth. Accordingly, the symmetrical parallel coupled feed lines can work together to keep he UWB-BPF in the desired range. The input and output ports are designed to $Z_0$of 50 Ω.

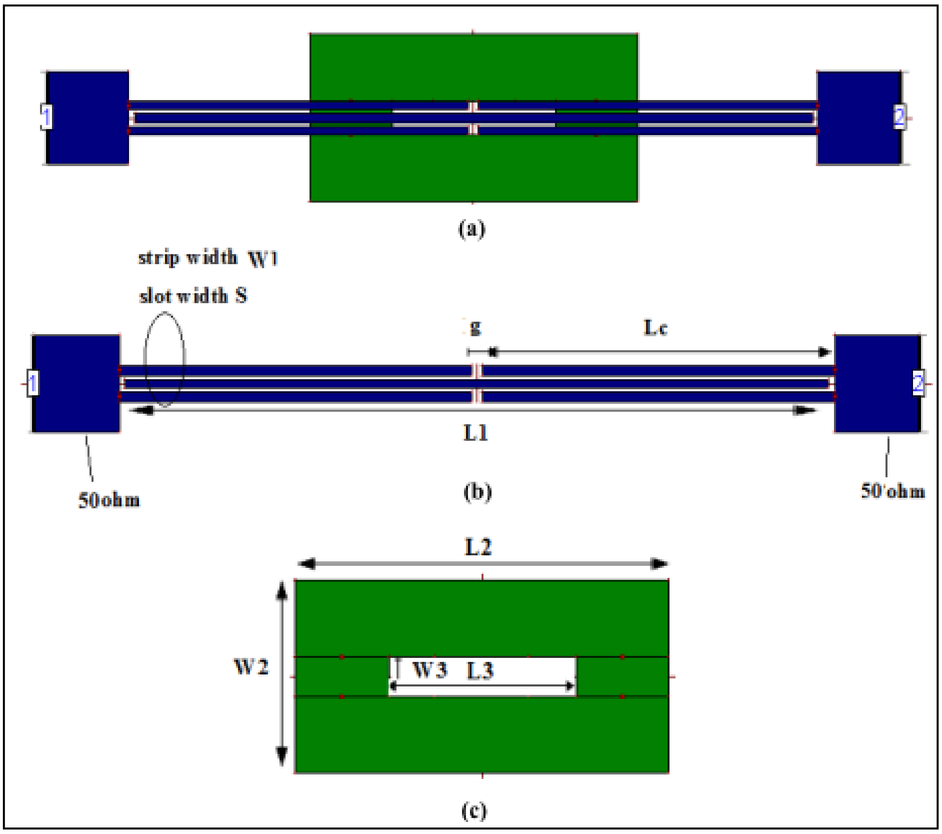


Figure.II.17. (a) the layout of the MMR with DGS (b) the schematic of the top view(c) the schematic of bottom view.

6.2. Via-less UWB filter using patched micro strip stubs (structure 2)

The proposed filter, studied in [21] and shown in Figure .II.18 is originally modeled from a 5 poles quarter-wavelength short-circuited stubs with vias. The substrate is set to have relative permittivity, ε_r of 2.2 and thickness of 0.508 mm. In this structure, all short-circuit elements (vias) have been replaced by microstrip patches thus creating “via-less” structure. Four different sizes of microstrip transmission line are implemented into the UWB filter and then simulated to obtain the optimum S-parameters and frequency responses.

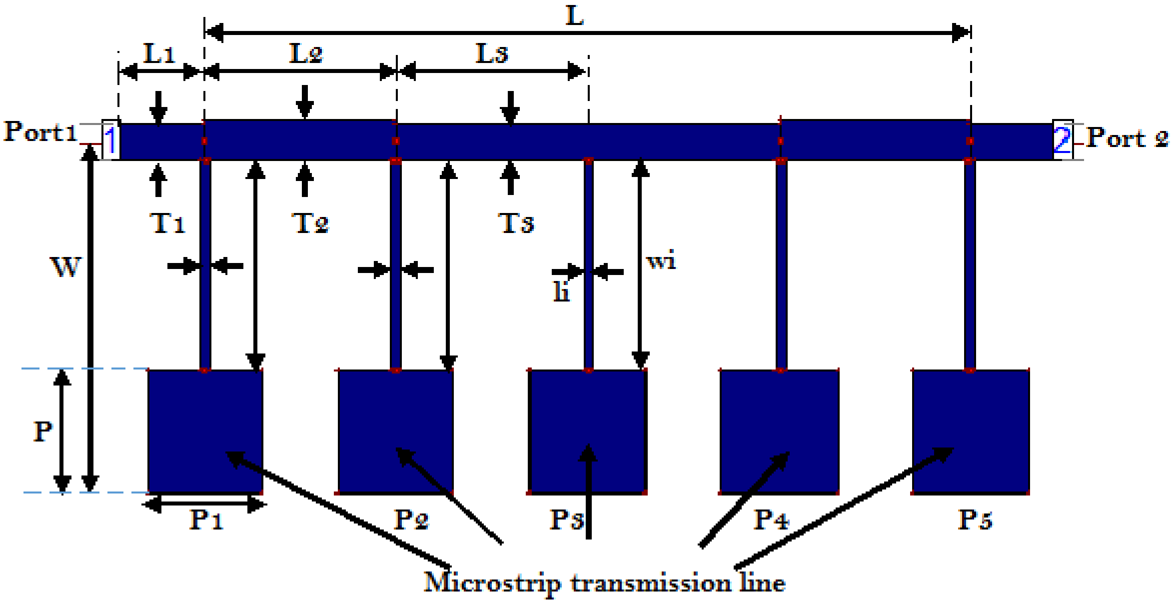
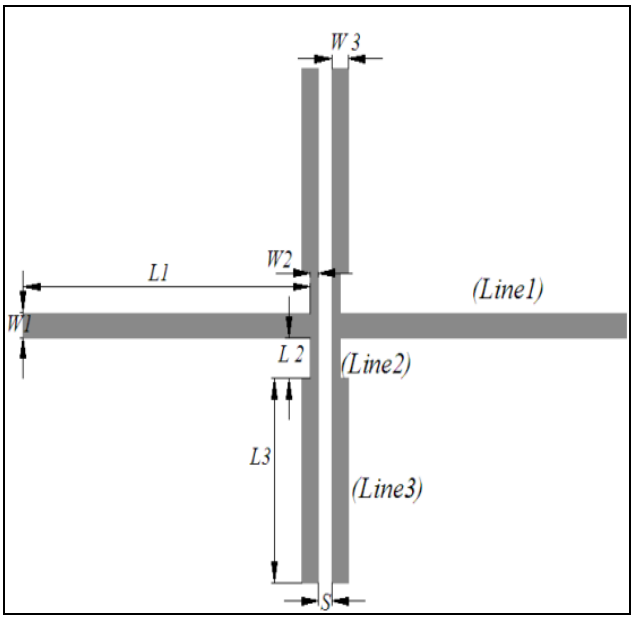


Figure.II.18. Five poles “via-less” quarter-wavelength UWB filter with micro strip patch as short circuit element.

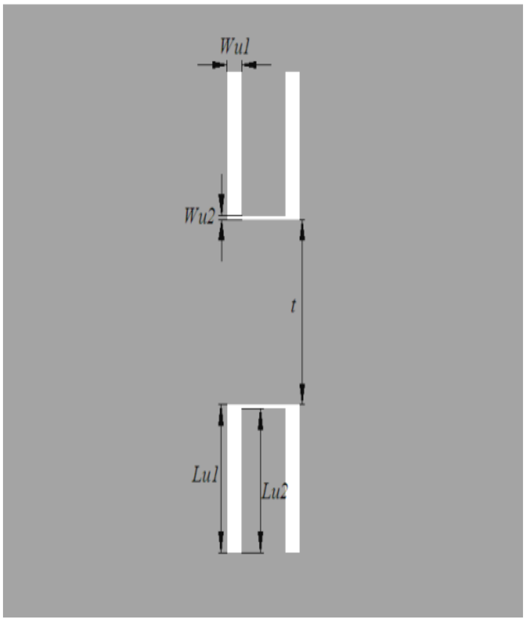
6.3. UWB Filter based on coupled micro strip lines with DGS (structure 3)

The proposed filter, studied in [22] and shown in Figure.II.19 is designed to be symmetrical, just as two rotated “T” with their head next to each other. From the input feed line to the coupled line, there are three lines in the “T” unit. Line1 is designed to be the 50 Ω input or output feed line. Line 3 mainly in fluencies the bandwidth character.

Line 2 is responsible to match impedance of Line 1 and Line 3. The gap distance S is a key part in the whole UWB band pass filter design. The substrate used has a relative dielectric constant of ε_r = 2.2 and a thickness of h=0.508 m.



(a)



(b)

Figure.II.19. Structure of the UWB Band pass Filter with DGS.
(a) Top view, (b) Bottom view.

7. Conclusion

In this chapter, the theoretical basics stated previously allows to obtain detailed description of the main concepts and important tools like development of UWB-BPF, filter parameters, and mean outlines about defected ground structure with its equivalent circuits. This concepts shall be applied in the design of a BPF used in UWB framework, which constitutes the purpose of the third chapter in which we will simulate, discuss and improve the first structure.

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CHAPTER 03

Results and Discussions

contents

1. Introduction
2. Design procedure
3. Simulation results
4. Equivalent circuits by ADS
5. Conclusion

This chapter presents the practical part of this work, filter design and results, using "IE3D" software, will be shown and discussed. An illustrative analysis will be helpful in the study of such filters. Firstly, the filter will be studied alone from its own characteristics, then after the application of the DGS. Secondly, a comparative study of the different parameters of the proposed UWB-BP filter will be presented. Different structures of the DGS plan will be applied. In addition, the equivalent circuit of the structure will be carried out by the Advanced Design System "ADS" software.

1. Introduction

In order to realize a functional UWB communications system, the design and fabrication of a small size but high-performance bandpass filter is critical. Many efforts in the design and development of bandpass filters (BPFs) for UWB applications have led to a variety of UWB filter types. In this chapter, an UWB-BPF structure using defected ground structure (DGS) is designed and simulated, and a comparative study after the analysis process will be reported [1].

The aim of this chapter is to get a filter with small size, light weight, low cost and high performances, such as low insertion loss and high selectivity in the pass-band and high return loss. Furthermore, to satisfy the UWB bandwidth from 3.1 to 10.6 GHz.

Zeland IE3D software has been employed to design and simulate the proposed structures, it is the first SCALABLE EM design and verification platform that delivers the modeling accuracy for the combined needs of high-frequency circuit design and signal integrity engineers across multiple design domains: filters, antennas, MICs, RFICs, etc. It is useful in the calculation and plot of the S_{21}, S_{11} parameters, VSWR, current distributions as well as the radiation patterns [2]. Equivalent circuit model (ECM) is done by ADS software is used especially to take the design into its equivalent circuit model (ECM).

2. Design procedure

The design of an UWB-BPF follows different steps, which are very important to the realization and the simulation of this last, also to get the right layout and the best results [2]:

a) **Filter selection:** The chosen filter must satisfy all requirements needed in this work (compact size, low insertion loss, high rejection…).

b) **Substrate preparation and calculation of ports dimensions:** The first step after new software file opening is to enter substrate parameters, and from "LineGauge" of the "IE3D" software, ports dimensions can be extracted to insure the 50Ω microstrip line for adaptation.

c) **Meshing:** After filter design, meshing is the operation of dividing filter layout into many parts, each part represents a matrix. This operation facilitates simulation calculations.

d) **Simulation:** Which necessitate the frequency selection (start and end frequencies), and the step frequency. To ensure accuracy in S-parameter results, we choose a small step frequency. Thus, a frequency range from 1 to 15 GHz is selected and 151 frequency points are taken.

e) Return Loss and insertion loss: They are extracted from simulated curves, where IL must be minimum, and RL must be maximum inside the pass band. Bandwidth can be measured from IL or (S_{21}) curve at -3dB.

f) The 3D current distribution: It gives the EM fields' distribution, and how is wave's propagation through the structure.

3. Simulation results

3.1. Structure 1 (MMR UWB-BPF)

The filter's layout which is presented in Figure.II.17 of Chapter II, was proposed in [2], the dimensions of this filter are given in Table.III.1, shown below:

Table.III.1. Dimensions (in mm) of the Structure 1.

parameters	Dimensions [mm]
Lc	4.143
L1	8
L2	4
L3	2
S	0.05
g	0.134
W1	0.1
W2	2
W3	0.4

In addition, port dimensions are calculated from "LineGauge" of the "IE3D" software, to get the 50 Ω microstrip line. So, we found the port length equal to 1.4063 mm, this value is optional, and the width equals 1.11483 mm ≈ 1.115 mm.

+

3.1.1. Simulation of the filter without DGS

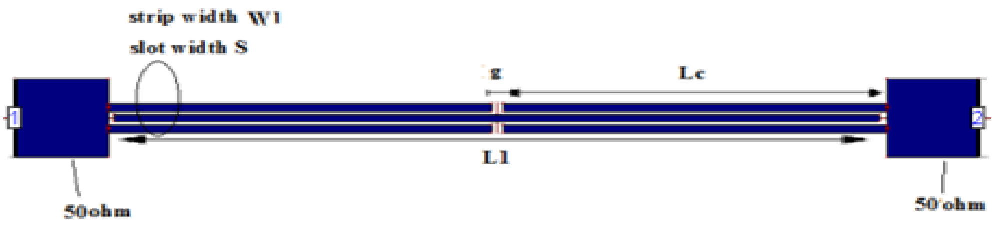

Figure.III.1. Filter layout of the MMR UWB-BPF (structure1).

The simulated S-parameters $S_{21}$and S_{11} of the UWB-BPF are shown in Figure.III.2. The filter has one transmission band ranges from 3.2 GHz to 10.62 GHz, an insertion loss of $|S_{21}| = 0.4$ dB and a return loss of $|S_{11}| = 11.1$ dB. This filter presents a fractional bandwidth of 107.38% and has a total size of 11.23x1.115 mm².

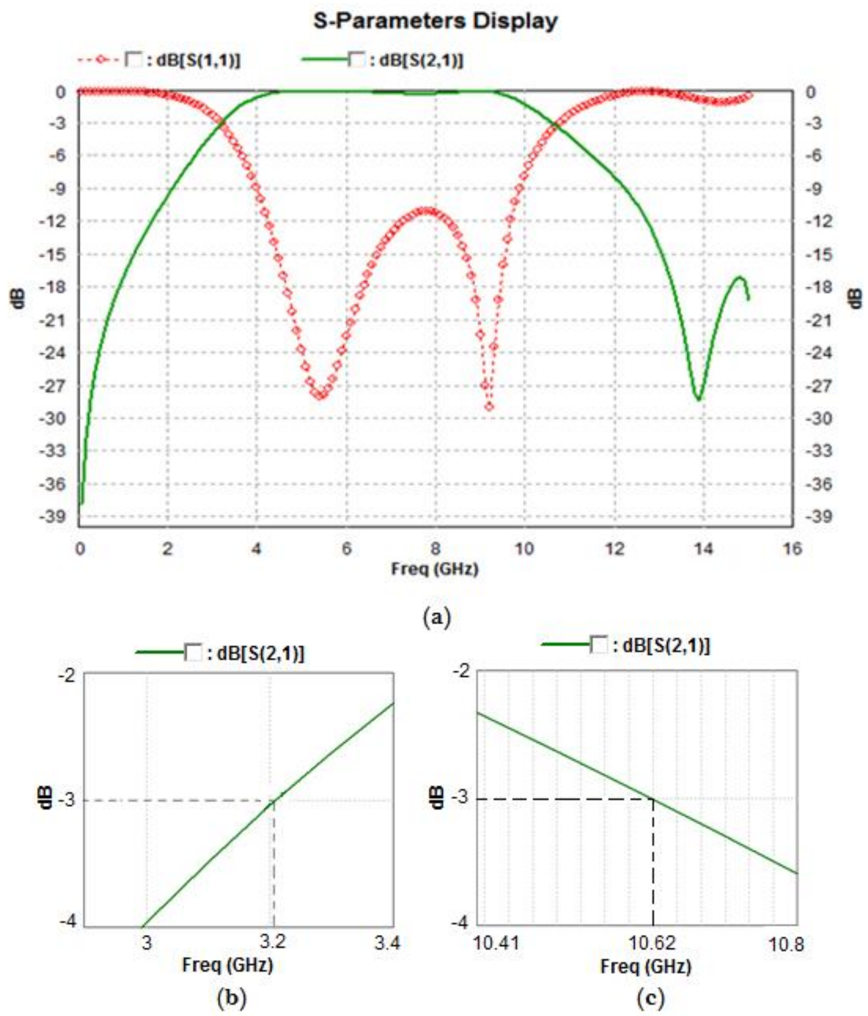

Figure.III.2. (a) Simulation results $S_{21}$and S_{11} of the proposed filter without DGS, zoom in of: (b) the lower frequency, (c) the uper frequency, at -3dB.

Analyzing these simulation results from Figure.III.2 appears that the filter occupies approximately a frequency band equals to 7.42 GHz (which is lower than conventional UWB BPF signal). However, this filter presents a low insertion loss, and a high return loss.

3.1.1.1. Effect of the filter dimensions on its performances

For studying the filter's parametric effects, some dimensions have been changed. Changing Lc, L1 or g, S and W1 respectively, while fixing other values given in Table.III.1, and simulate the filter parameters to extract the optional S_{21}, S_{11} results, this allows us to select the most appropriate filter which satisfy all UWB-PBF requirements.

A) Influence of the Length L1

The investigation of filter parameters effect on its performances, is realized through the introduction of some changes in its dimensions. Figure.III.3 shows the magnitude of the transfer function (S_{21}) when L1 varies to 4mm, 7.5mm, 8mm, and 8.25mm, while the other parameters of the structure are kept constant. The characteristics of the filter are summarized in Table.III.2.

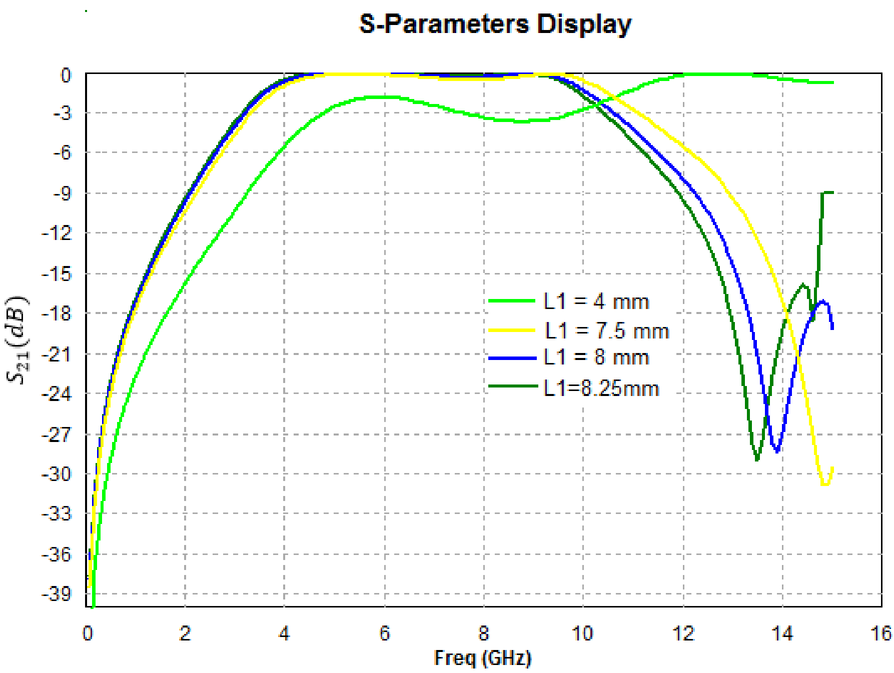

Figure .III. 3: Magnitude of S_{21} of the structure 1 for different lenghts L1.

Figure.III.3 shows that with each increase of the length L1, the bandwidth decreases and the attenuation zeros becomes closer which limits the bandwidth to 7.25 GHz when L1 = 8.25mm.

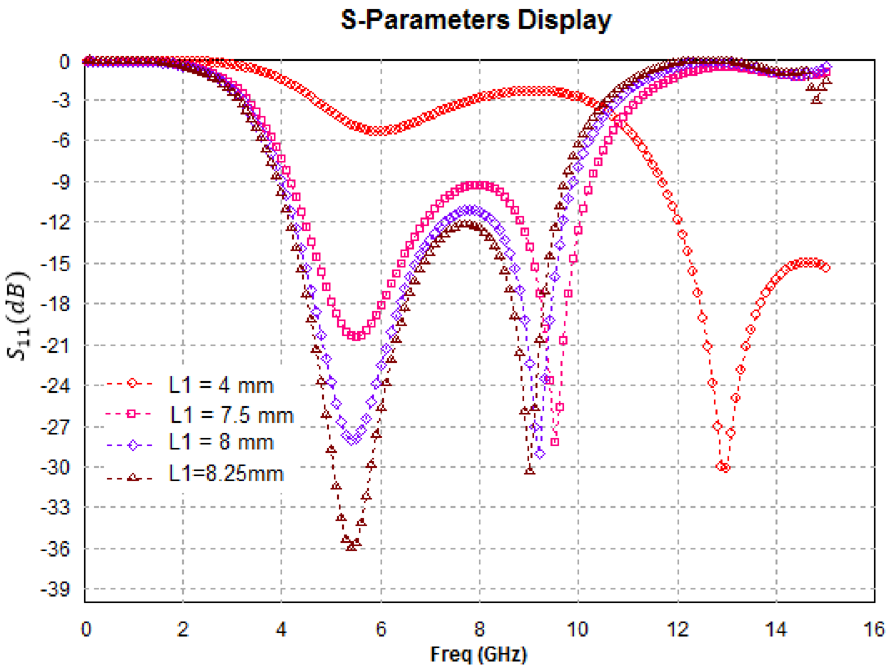

Figure.III.4. Magnitude of S_{11} of the structure 1 for different values of L1.

From Figure.III.3, and Figure.III.4 we can extract the following characteristics of this filter using different lengths of L1. Results are summarized in Table.III.2.

Table.III.2. Simulated results of the structure 1 for different values of L1.

L1 (mm)	|Insertion loss| (dB)	|Return loss| at f_c (dB)	Stop-band (GHz) at -15 (dB) Rejection	-3dB Bandwidth (GHz)
4	< 3.69	2.4	2.1- no rejection	> 4.72
7.5	< 0.59	9.2	1.2 – 13.8	[3.34 – 11.1]
8	< 0.39	11.1	1.2 – 13.1	[3.2 – 10.62]
8.25	< 0.32	12.2	1.2 – 12.8	[3.15 – 10.4]

The best pass band filter, must achieve a very small insertion loss (closer to zero), because IL is the transmission gain, which represents the ratio between input power in port 1 and output power in port 2, in another meaning, it gives the quantity of power received after traveling across filter elements. In addition to attain the highest return loss levels (more than 10 dB). Also, to reach the best frequency selectivity, a good BPF needs to obtain a sharp rejection.

From Table.III.2, the best filter which achieves the bandwidth, and the needed characteristics is that has L1 = 8mm.

B) Influence of the gap Length "g" and "Lc"

Changing the length of the gap "g" returns to change "Lc". So, in this part we will study the effect of the variation in the gap length "g" on filter characteristics. Curves will be presented in Figure.III.5, and results will be arranged in the Table.III.3.

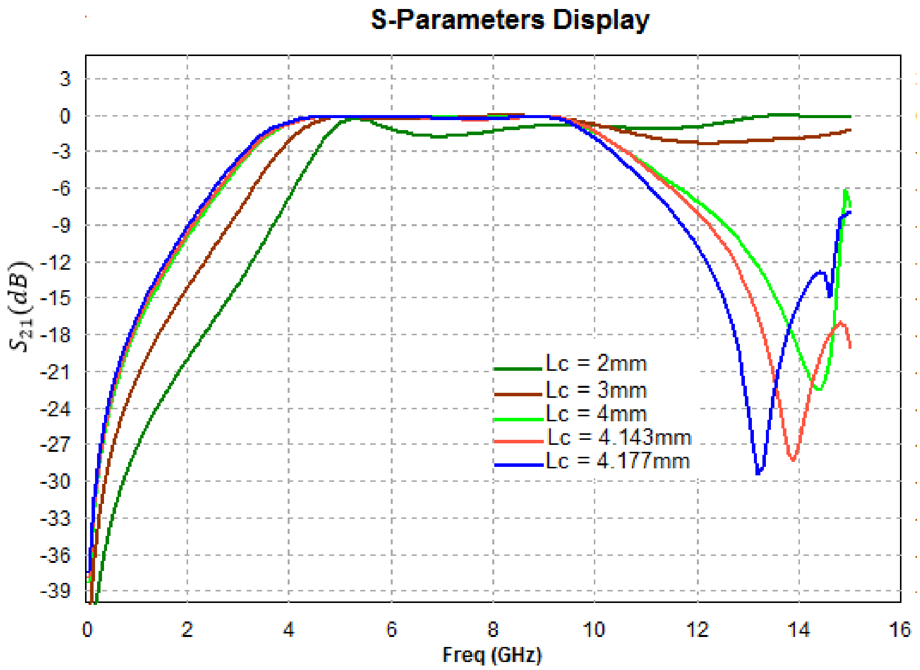

Figure.III.5. The frequency respons of the structure1 for different lengths of Lc.

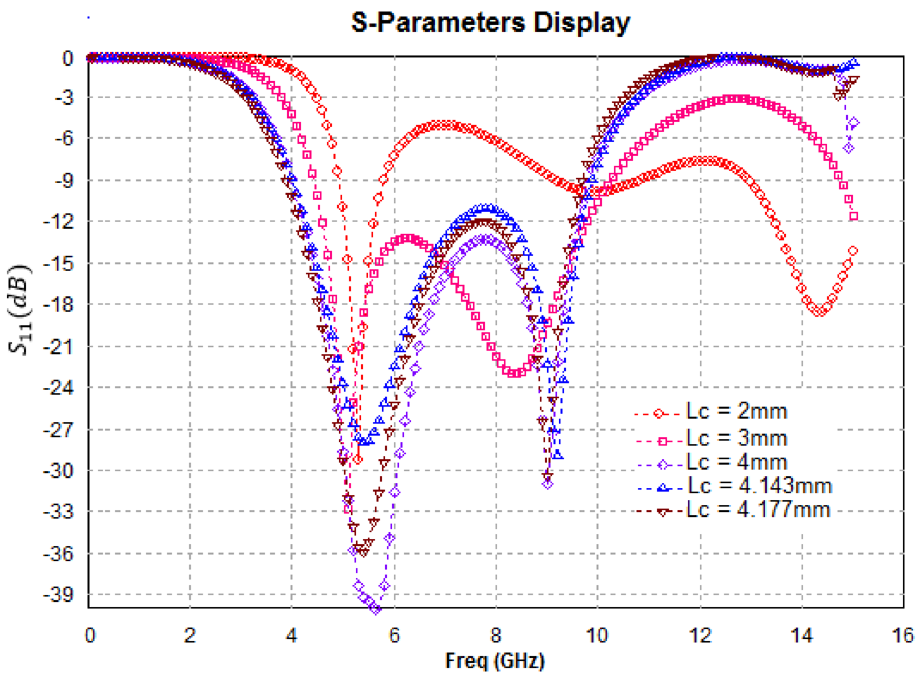

Figure.III.6. Return loss magnitude S_{11} of the structure1 for defferent lengths of Lc.

As a remark, varying the gap between the two sides microstrip coupled lines, also affects the bandwidth and the return loss of the filter as shown in Figure.III.5 and Figure.III.6. With every increase of Lc, bandwidth decreases, but return loss has not a proportional relationship with Lc.

Table.III.3. Simulated results of the structure 1 for different values of Lc.

Lc (mm)	|Insertion loss| (dB)	|Return loss| at f_c (dB)	Stop-band (GHz) at -15 (dB) Rejection	-3dB Bandwidth (GHz)
2	< 1.8	29.3	2.8 – no rejection	> 4.5
3	< 0.36	13.2	1.35 - ∞	> 3.8
4	< 0.25	13.3	1.3 – 13.6	[3.25 – 10.6]
4.143	< 0.39	11.1	1.25 – 13.05	[3.2 – 10.62]
4.177	< 0.33	12	1.2 – 12.5	[3.1 - 10.4]

When the gap is equal to 0.134 mm (Lc = 4.143mm), the filter shows a bandwidth of 7.42 GHz, but the IL and the RL are not in the best levels comparing with the other results but this problem can be solved later using DGS.

C) **The influence of the slot width S**

The slot width S is set consecutively to 0.01 mm, 0.04 mm, 0.05 mm, and 0.1 mm, while the other parameters are kept constant (W1=0.1 mm, Lc =4.143 mm, L1=8, g=0.134 mm). The simulated S-parameters are plotted in Figure.III.7 and Figure.III.8. Filter characteristics are collected in Table.III.4.

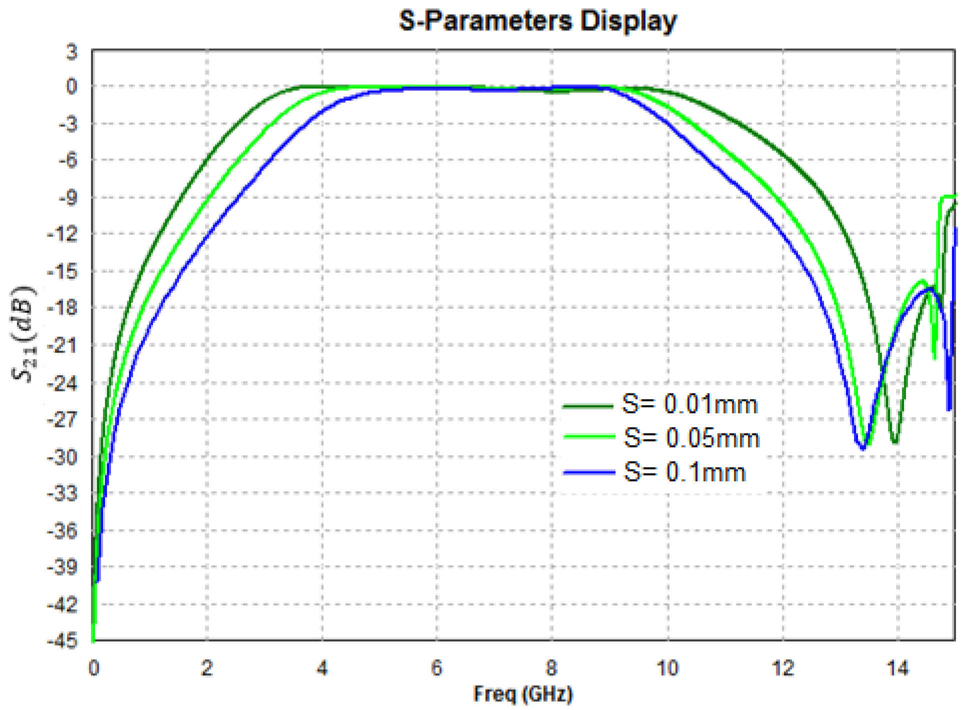

Figure.III.7. The frequency respons of the structure1 with defferent slot lengths S.

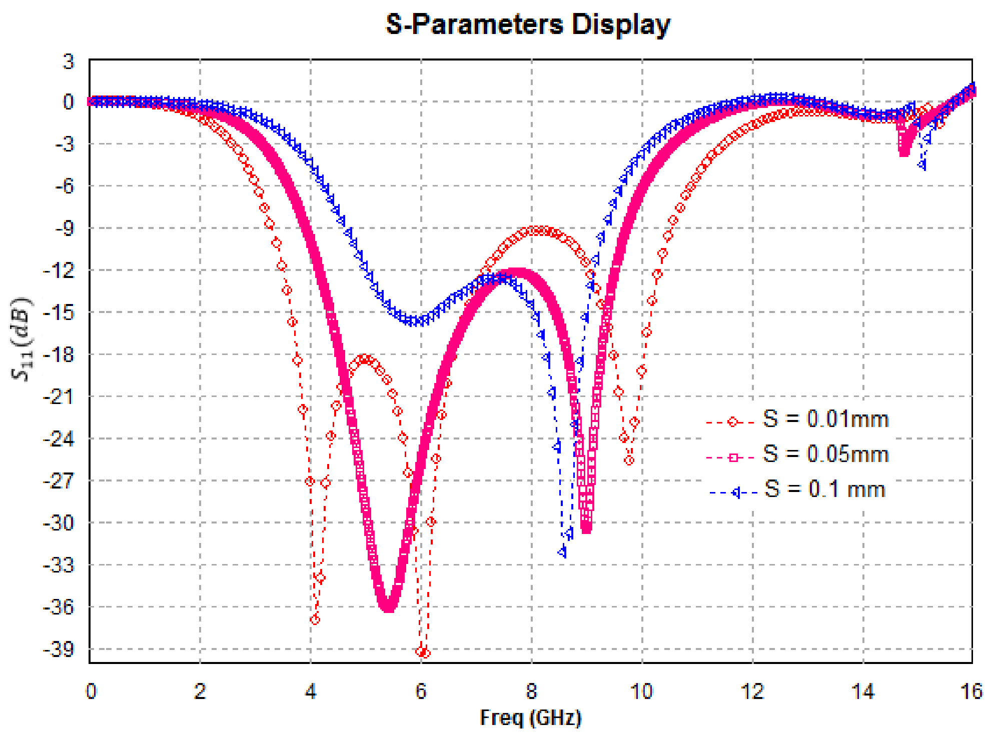

Figure.III.8. Return loss magnitude S_{11} of the structure1 with defferent slot lengths.

Table.III.4. Simulated results of the structure 1 for different values of S.

S (mm)	|Insertion loss| (dB)	|Return loss| at f_c (dB)	Stop-band (GHz) at -15 (dB) Rejection	-3dB Bandwidth (GHz)
0.01	< 0.18	9.8	0.9 – 13.7	[2.6 – 11.2]
0.04	< 0.4	10.8	1.1 – 3.2	[3.08 – 10.8]
0.05	< 0.39	11.1	1.2 – 12.7	[3.2 – 10.62]
0.1	< 0.35	12.6	1.6 – 12.4	[3.72 – 9.98]

It can be seen from Table.III.19 that by increasing the width S, the bandwidth of the filter decreases. When S is equal to 0.01 mm, the filter occupies an ultra-wide bandwidth from 2.6 to 11.2 GHz (which is wider than conventional UWB BPF), and an insertion loss less than 0.18 dB. But when S = 0.04 mm, and when S = 0.05 mm, the filter satisfy approximately the conventional UWB by a BW = 7.72GHz, and BW = 7.42GHz respectively, with an insertion loss less than 0.4 dB and 0.39 dB.

Therefore, this filter is very suitable and practical filter, where the bandwidth can be tuned and controlled by the slots between interdigital feed lines. Which makes filtering operation and frequency selectivity at any frequency band, inside the conventional range, depending on one simple parameter.

D) The influence of the strip width W1

In this part, the effect of the variation in the strip width will be studied. It has been taken as strip widths, miniaturized values to ensure the compact size of the filter.

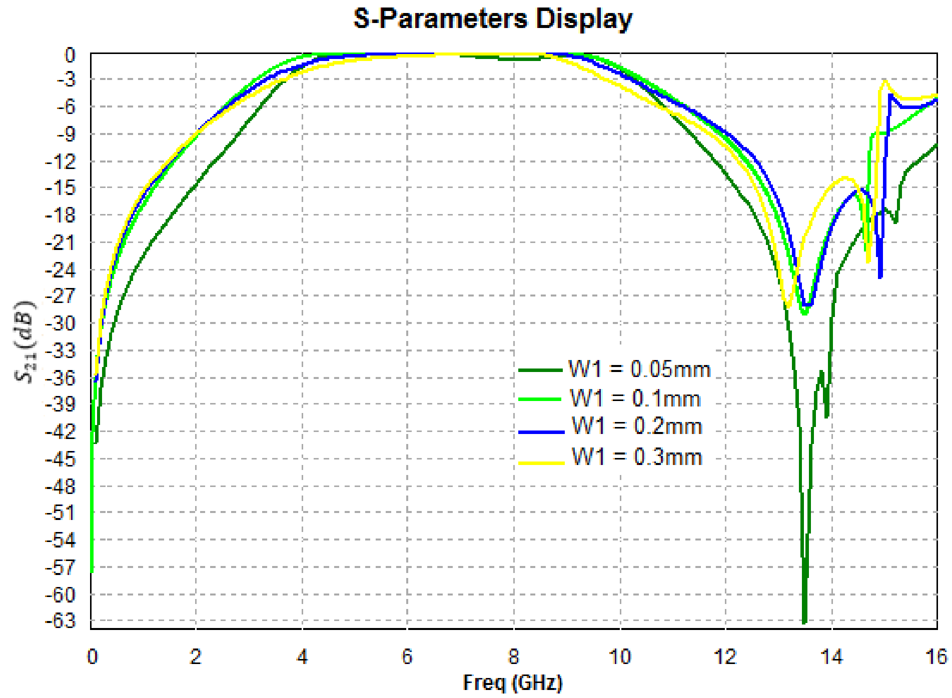

Figure.III.9. The frequency respons of the structure1 with different strip widths W1.

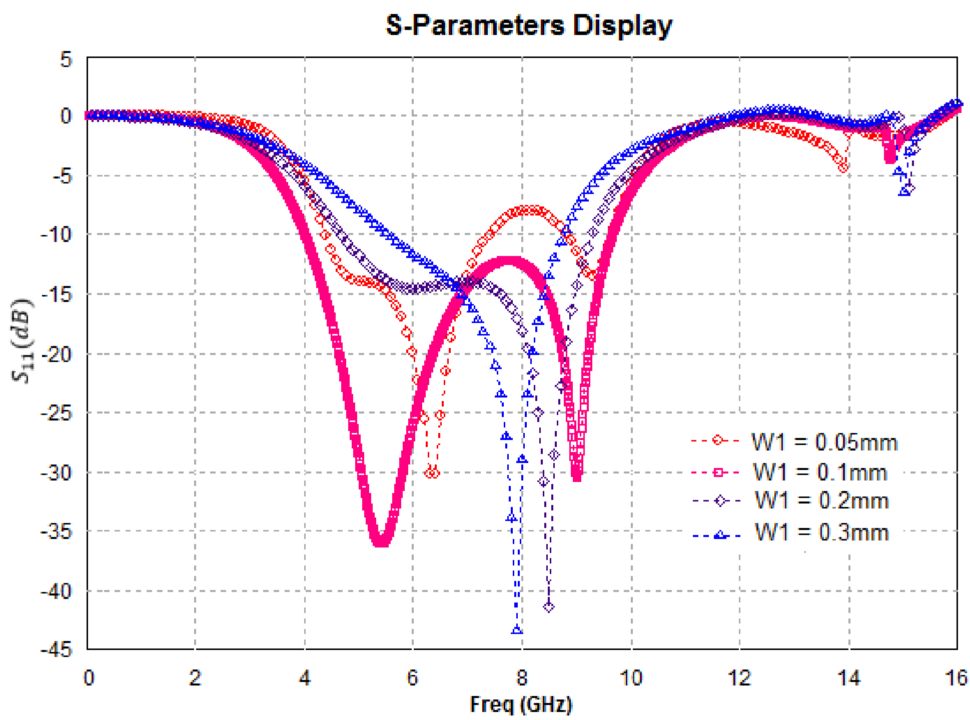

Figure.III.10. Return loss magnitude S_{11} of the structure1 with different strip widths W1.

Table.III.5. Simulated results of the structure 1 for different values of W1.

W1 (mm)	|Insertion loss| (dB)	|Return loss| at f_c (dB)	Stop-band (GHz) at -15 (dB) Rejection	-3dB Bandwidth (GHz)
0.05	< 0.8	8	1.97 – 12.2	[3.7 – 10.3]
0.1	< 0.39	11.1	1.3 – 13.05	[3.2 – 10.62]
0.2	< 0.31	13.96	1.1 -12.9	[3.35 – 10.2]
0.3	< 0.5	43.4(notched)	1.08 – 12.6	[3.65 – 9.75]

From Table.III.5, it is very clear that the favorite filter is that with strip width of W1 = 0.1 mm, which achieve the bandwidth and has a good rejection, a high return loss, and a lower insertion loss, in addition to the compact size.

3.1.1.2. Current distribution of the structure1

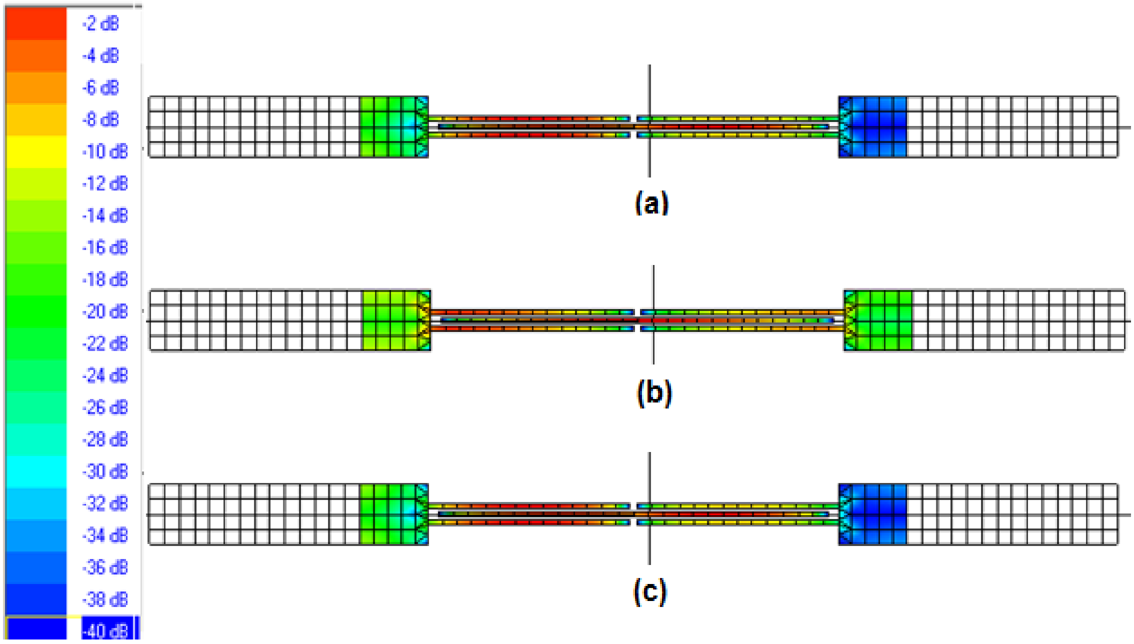

Figure.III.11. Current distribution of the structure1 without DGS: (a) freq = 0.8 GHz, (b) fc = 6.9GHz, (c) freq =13.1 GHz.

Current distribution gives a general idea about the filter selectivity, if it is really a BPF or not, and defines the effective parts of the filter.

Figure.III.11 shows that the maximum power is situated in the interdigital feed lines, where it can be modified to apply any optimization into the filter performances. The blue color in (a) and (c) in the stopbands of the filter response, mains that no power pass through the structure, and the green to the red color shows that signal passes in this frequency.

3.1.2. Simulation of the filter with DGS

Defected Ground Structure (DGS) implementation in microstrip can be used not only as tuning elements but also to reduce the size of classical passive circuits, and to decrease return loss power. In the case of this UWB BP filter design, it is composed of a rectangular shape DGS etched around a center mini-rectangle.

To investigate the effect of a DGS on the filter performances, different shapes will be studied and applied to the filter design and a comparison between simulated results will be discussed.

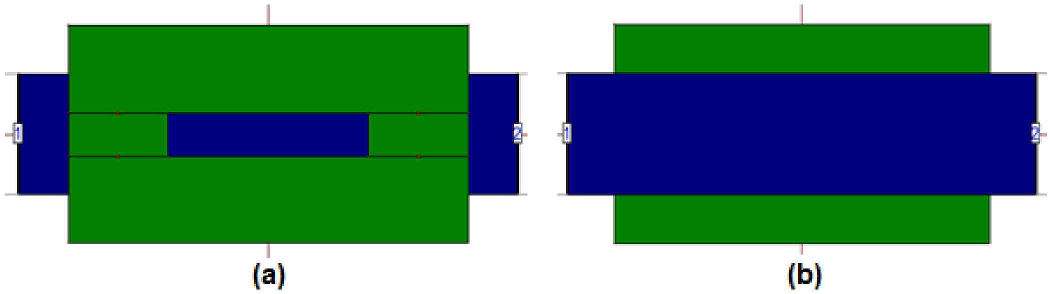

Figure.III.12. Defected Ground Structure (DGS): (a) top view, (b) bottom view with a 50Ω microstrip line for the simulation.

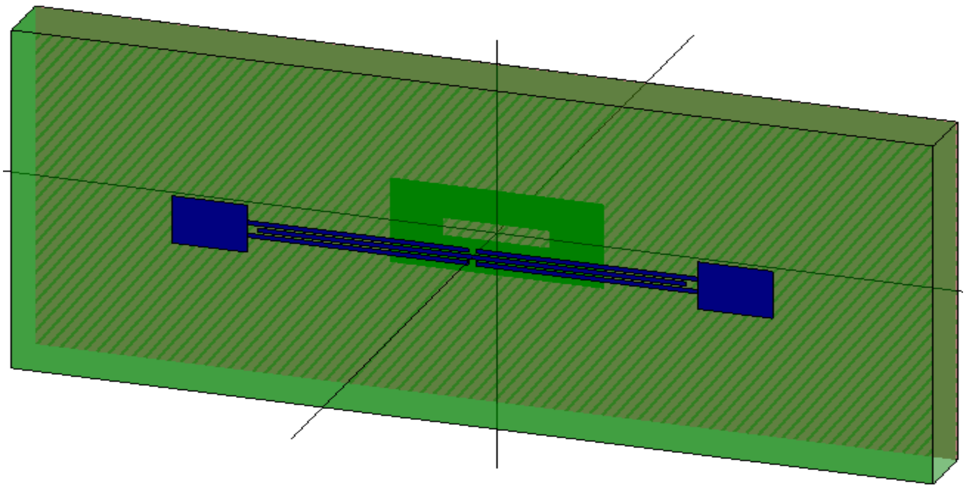

Figure.III.13. The design of the filter with DGS (structure1).

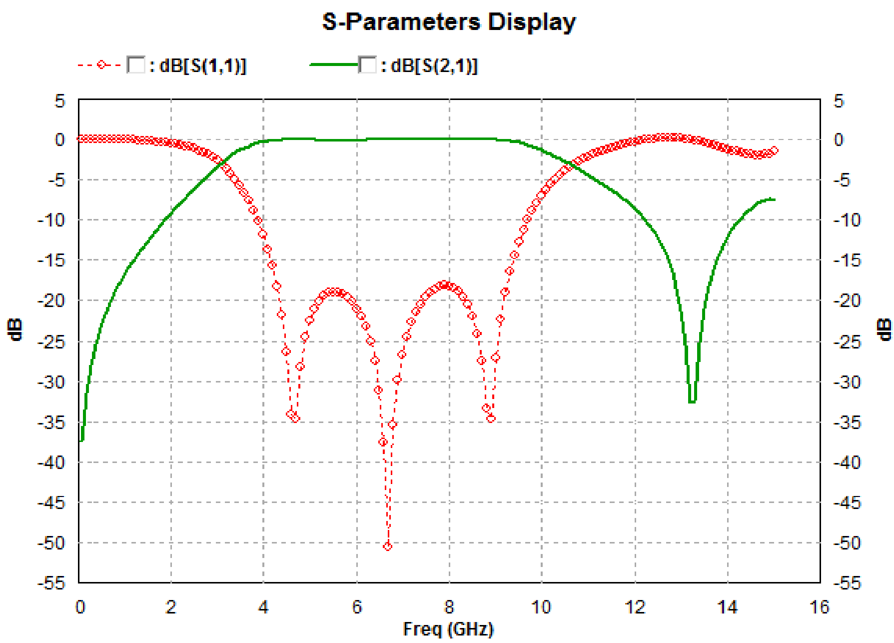

Figure.III.14. Simulation results $S_{21}$and S_{11} of the proposed filter with DGS.

The structure1 with DGS shown in Figure.III.15, is simulated using the dimensions noted previously in Table.III.1, where it get to 19 dB return loss, which is a very high rate with a very low insertion loss lower than 0.18 dB .

3.1.3. The Modified Structure 1 (modified DGS)

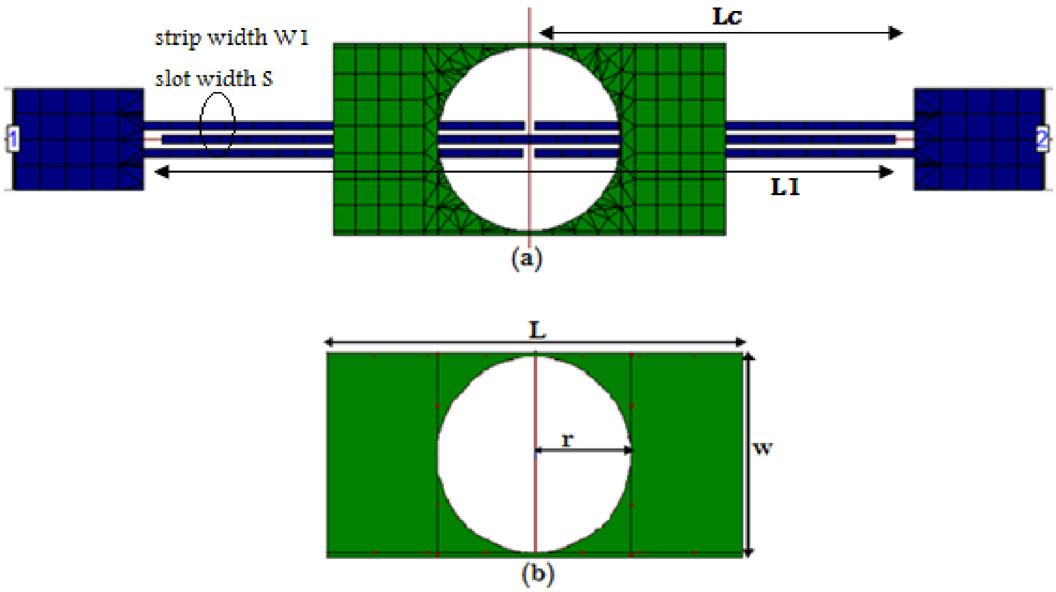

Figure.III.15. Layout of the modified structure1: (a) filter with proposed DGS, (b) the proposed DGS layout.

Table.III.6. Dimensions (in mm) of the modified Structure 1.

parameters	Dimensions [mm]
Lc	4.143
L1	8
L2	4
L3	2
S	0.05
g	0.134
L	4.277
w	2.1
r	1

3.1.3.1. Simulation of the proposed filter

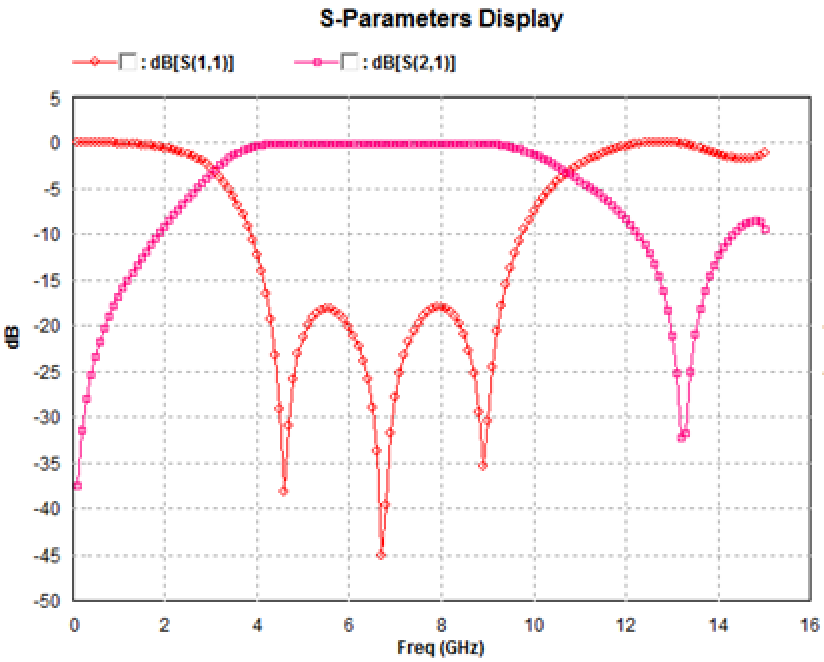

Figure.III.16. Simulation results $S_{21}$and S_{11} of the proposed filter with modified DGS for L = 4.277mm.

In order to investigate the frequency characteristics of the filter with new DGS section, we have simulated this filter and we have considered the effect of the parameters that affect to $|S_{21}|$. Table.III.7 presents the obtained results.

3.1.4. Comparison between structure1 and modified structure1

Table.III.7. Simulated results of the Mod-structure 1 for different values of L.

L (mm)	|Insertion loss| (dB)	|Return loss| at f_c (dB)	Stop-band (GHz) at -15 (dB) Rejection	-3dB Bandwidth (GHz)
4.277	< 0.24	18	1.2 – 12.7	[3.08 – 10.6]
6.3485	< 0.24	13.3	1.18 – 12.78	[3 - 11]
8.42	< 0.21	9	1.13 – 12.7	[2.96 – 10.89]

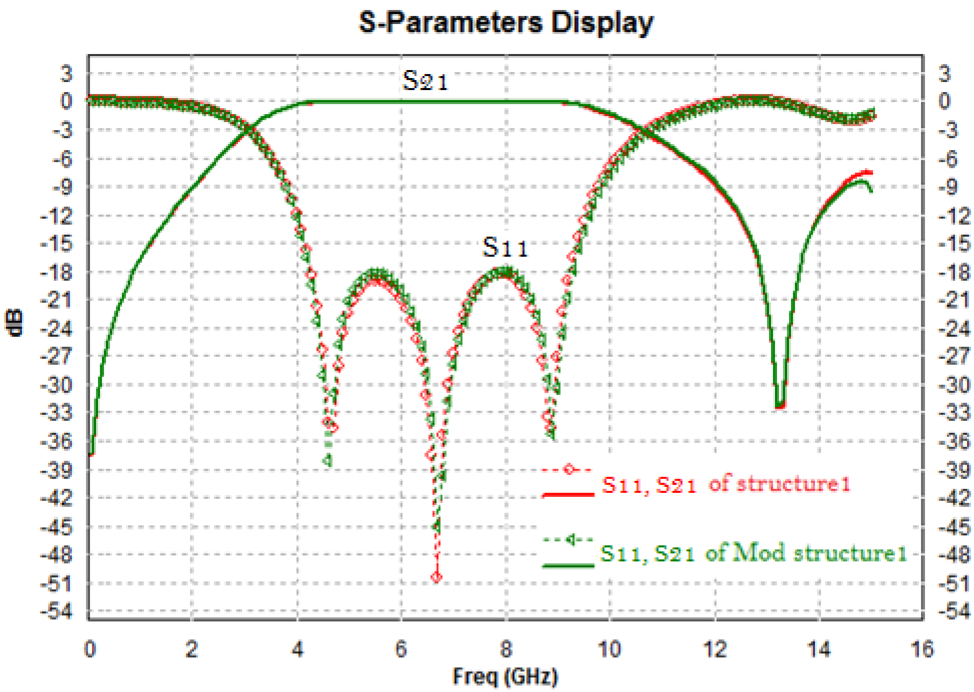

Figure.III.17. Comparison of S-parameters of structure1 and modified structure1.

We can extract from Figure.III.17 the following results presented in Table.III.8: where we can remark the small differences between these structures. Structure1 has a reduced insertion loss, an elevated return loss, and occupies the full and exact UWB bandwidth (7.51GHz), but a modest rejection. When the modified structure1, presents a low insertion loss higher than the fist one, a high return loss, and satisfy the whole UWB bandwidth with 7.52 GHz, and has a rejection higher than the first one.

Table.III.8. Comparison of simulation results of structure1 and the modified structure1.

Structure	|Insertion loss| (dB)	|Return loss| at f_c (dB)	Stop-band (GHz) at -15 (dB) Rejection	-3dB Bandwidth (GHz)
Structure1	< 0.18	19	1.2 – 12.7	[3.09 – 10.6] = 7.51
Modified Structure1	< 0.24	18	1.2 – 12.7	[3.08 – 10.6]= 7.52

3.1.5. Comparison of structure 1 without and with DGS

In order to investigate the main effect of using the (DGS), it is appropriate to do a comparison between the simulation results of the structure 1 without DGS and structure 1 with DGS, and to extract the differences between filters performances.

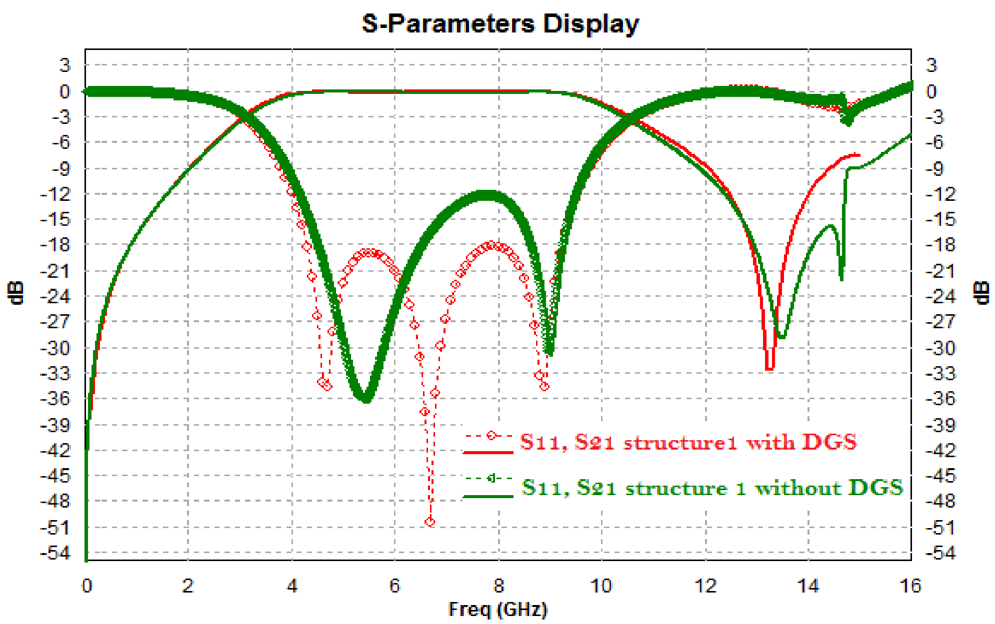

Figure.III.18. Comparison of S-parameters of the structure1 without and with DGS.

The use of DGS makes possible to realize filters with small sizes, in addition to provide high RL levels and low IL. Hence, DGS have been developed to improve characteristics of the UWB BPFs in the aim of reducing the size, increase the coupling, and optimize S-parameters.

3.1.6. Comparison of the structure 1 with other structures

Table.III.9. Comparison of the main parameters between structure1 and other structures.

Filter	Center frequency (GHz)	|Insertion Loss| (dB)	|Return loss| (dB)	Bandwidth (GHz)	Size (mm²)
This work	6.85	< 0.18	> 19	7.51	11.23 x 2
[3]	7.3	< 1	< 10	8.4	22 x 11
[4]	6.33	0.8	14.88	7.22	16.1 x 21
[5]	7.5	< 0.104	18	7.5	22.4×12

From Table.III.9, we note that our structure with DGS, achieves interesting results from its extremely reduced size, highest RL better than 19 dB, low IL lower than 0.18 dB, and satisfy the center frequency 6.85 GHz and the frequency range 7.5 GHz of an UWB signal which makes it very precise and very selective. Comparing with the filter in [5], which has good performances especially obtaining the lowest IL lower than 0.104 dB, and accomplishing 7.5 GHz bandwidth but switched from its center frequency, the proposed filter gives the best performances in the lowest center frequency.

4. Equivalent circuits by ADS

In electrical engineering and science, an equivalent circuit refers to a theoretical circuit that retains all of the electrical characteristics of a given circuit. Often, an equivalent circuit is sought that simplifies calculation, and more broadly, that is a simplest form of a more complex circuit in order to help in analysis. In its most common form, an equivalent circuit is made up of linear, passive elements [6].

The equivalent circuit of the structure 1 with DGS is presented in Figure.III.19 reached by ADS ECM method. the extracted equivalent circuit parameters for the defected ground structure unit section are obtained from the electromagnetic simulation using the resonance frequency from S_{11} curve (w_0) and -3 dB cutoff frequency (w_c) taken from the S_{21} curve. Thus, f_0= 11.5 GHz, f_c= 21GHz. Employing Equations (II.7), (II.8), and (II.9) from chapter II, we obtain [7]: **C = 2.67 pF** ; **L = 0.031 nH** ; **R = 183.15 ohm**.

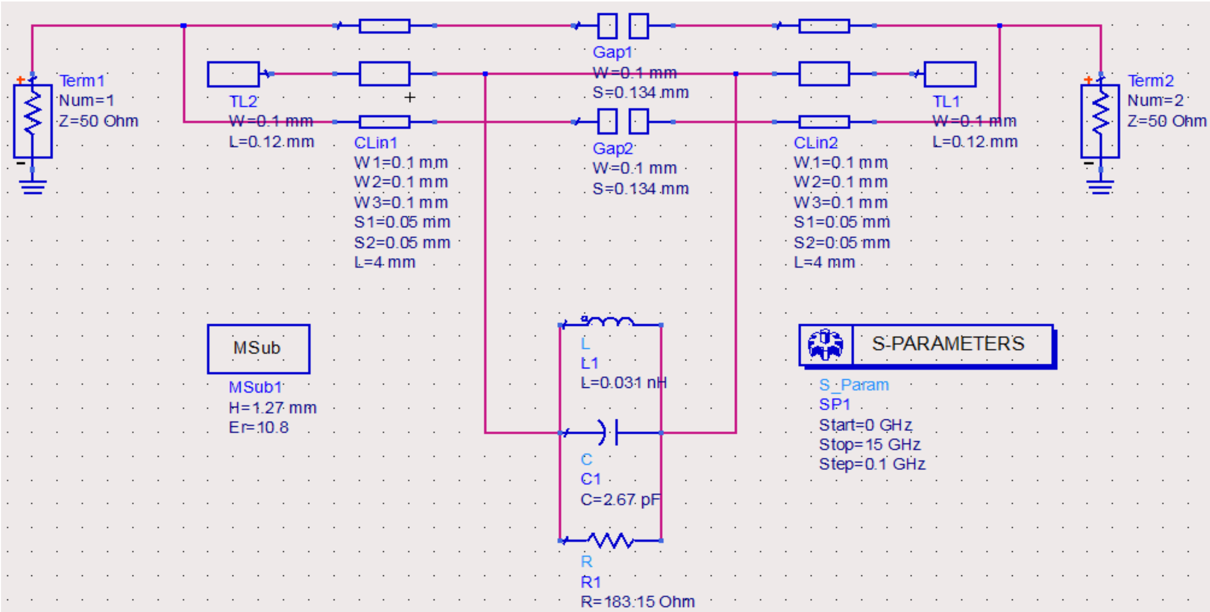

Figure.III.19. Equivalent circuit model (ECM) of structure 1 with DGS.

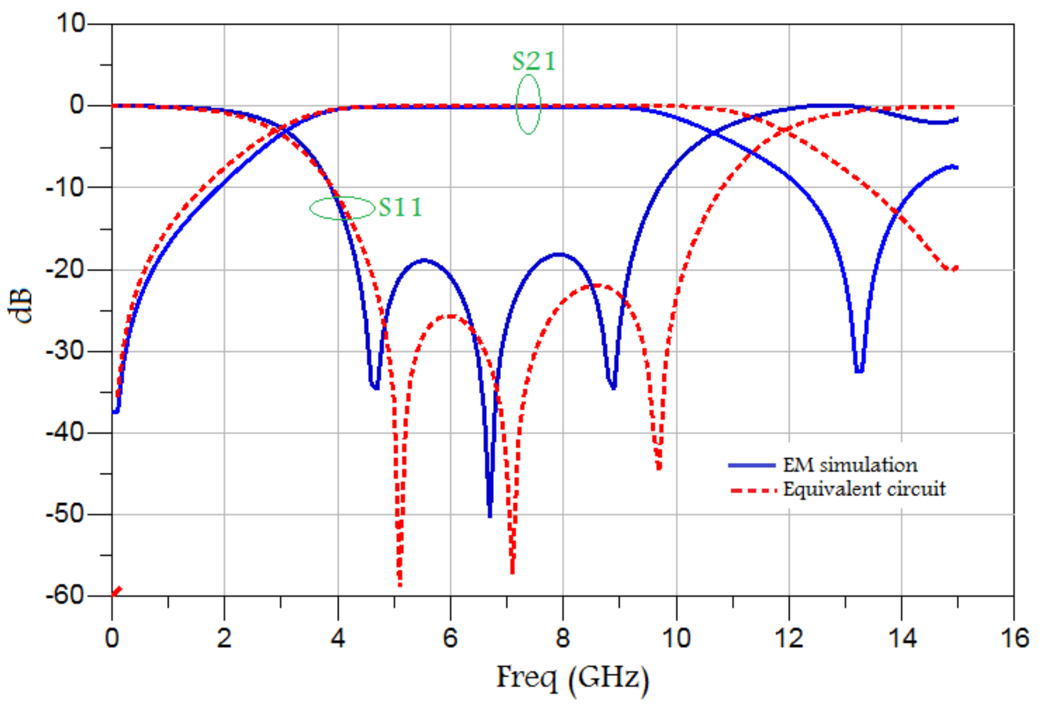

Figure.III.20. S-parameters of Equivalent circuit model and EM Simulations of the structure 1 with DGS.

Table.III.10. Comparison of the main parameters of the structure1 with DGS by IE3D and ECM ADS simulation.

Parameters	Simulated by IE3D	Simulated by ADS
Center frequency (GHz)	6.85 GHz	7.39 GHz
Bandwidth (GHz)	7.51 GHz	9.01 GHz
|Return Loss| = S_{11} (dB)	higher than 19 dB in the passband	higher than 22.2 dB in the passband
|Insertion Loss| = S_{21} (dB)	Lower than 0.18 dB in the passband	Lower than 0.03 dB in the passband
Stop-band (GHz) at -15 (dB) Rejection	1.4 GHz – 12.9GHz	1.1 GHz – 14.4 GHz

From Figure.III.21, it can be noticeable that the equivalent circuit has given favorite results than IE3D simulation looking to S-parameters, with a RL higher than 22.2 dB in the passband, and an IL lower than 0.03 dB. Comparing to the other parameters, IE3D simulated results are more selective with a rejection stop-band at -15 dB from 1.4 GHz to the upper cutoff frequency 12.9 GHz, and 7.51 GHz frequency ranging from 3.1 to 10.6 GHz similar to that of an UWB passband.

5. Conclusion

In this chapter, the design and simulation procedure is implemented, and a comparative study of an UWB BPF with and without DGS has been presented. We have successfully designed and developed an extremely compact UWB BPF with DGS, based on MMR microstrip lines elements with improved UWB passband response, using simulation and equivalent circuit model (ECM) methods. The filter design is suitable for UWB communication applications from 3.1 to 10.6 GHz, in which miniature filters are important for both infrastructure equipment and embedded transceiver devices.

This filter provides good performances which can be competitive, they are:

- ✓ Covers the large frequency band approximatively from 3.1 to 10.6 GHz;
- ✓ Low insertion loss of 0.18 dB;
- ✓ Very high return loss of 19 dB;
- ✓ A compact size with 11.23 × 2 mm²;
- ✓ Bandwidth control Insured by the symmetrical interdigital feed lines.

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CONCLUSION

Conclusion

UWB BP microstrip filters play pivotal roles in wireless or mobile communication systems. In this way, we have studied and designed an UWB BPF with a new concept providing efficiency and good performances which is Defected Ground structure.

This work includes three main sections organized as follow, the first chapter presents an overview about UWB technology, its definition, advantages, disadvantages, and applications in wireless communication systems. The second chapter illustrates the UWB BPF, its development, types, characteristics, and applications. In addition, it provides outlines about the defected ground structure (DGS) and its equivalent circuit. Three UWB BPFs are selected, two of them are based on DGS, which are Multiple-Mode Resonator (MMR), The third one without DGS, is a via-less five poles quarter-wavelength stubs structure. This structure will be attached with rectangular etched DGSs like a proposed DGS structure as a future work. The third chapter shows the design steps and discusses the simulation results of the proposed filter.

Our work shows a compact Bandpass Filter (BPF) using DGS for Ultra-Wideband (UWB) Systems. The proposed BPF consists of Interdigital coupling structure at the top and the rectangular-shaped DGS with a small rectangle etched on its middle at the bottom of the substrate. This filter provided insertion loss of 0.18 dB, return loss of 19 dB, rejection of 32.6 GHz. The filter exhibited an ultra-wide bandwidth from, 3.1 – 10.6 GHz, insured by the symmetrical interdigital feed lines. The designed filter was simulated using electromagnetic simulator "IE3D", using substrate with dielectric constant of 10.8, and thickness of 1.27 mm. The total size of the developed filter is $11.23 \times 2 \times 1.27\ mm^3$. The filter design is suitable for UWB communications applications from 3.1 to 10.6 GHz, in which miniature filters are important for both infrastructure equipment and embedded transceiver devices.

The modeling of our proposed microstrip filter was generated using "ADS", and the S-parameters results were compared with the EM simulation ones.

This contribution highlights the main role of a Defected Ground Structure in a filter design, which is the maintain of the return loss in a highest level, offers improved performances, and reduces the whole filter size.

In summary, we have designed a tuned UWB BPF structure which satisfied all requirements of lowest insertion loss, highest return loss, high rejection and compact size, also, the simulation results are in satisfactory agreement with the FCC regulations.

Future work

The structure 2 proposed in the second chapter will be modified and optimized as follow:

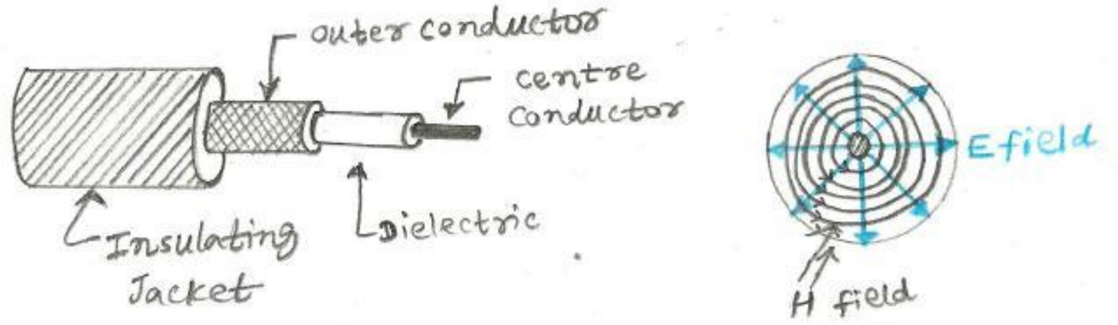
- ✓ The minimization of the total size of this filter;
- ✓ The creation of a new DGS design;
- ✓ Modeling this UWB BPF.

APPENDIX

Appendix N° 01:

- **Difference between TEM wave and quasi TEM wave**

TEM wave referred as Transverse electromagnetic wave. In this mode, electric field and magnetic field are perpendicular to each other and perpendicular to the direction of propagation. This mode exists in a structure having two excited conductors surrounded by dielectric material. One of the example is coaxial cable as shown in the figure below. In which E field is in radial direction, H field is around in the form of concentric circles and direction of propagation is in the length of the cable.



Quasi TEM wave mode exist in a microstrip line. The term quasi refers that this wave is resembling to TEM wave. As we know in microstrip top and bottom is conductor part and middle one is dielectric. Hence in microstrip, wave propagates through the air above the top pattern and through the dielectric substrate. Due to this two different mediums having different resistivities wave propagates with different speeds in both the regions. This is referred as quasi TEM mode.

Appendix N° 02:

- **Overview of IE3D Software**

IE3D is a full wave, method of moments (MOM) based electromagnetic simulator for analyzing and optimizing planar and 3D structures in a multi-layer dielectric environment. It solves Maxwell's equation in integral form and its solutions include the wave effects, discontinuity effects, coupling effects and radiation effects. The simulated result includes S,Y, and Z-parameters, VSWR, RLC equivalent circuits, current field distribution, near and far field estimation, radiation pattern etc.

IE3D is an extremely useful tool in the design of MMICs, RFICs, RF printed circuits, Microstrip and wired RF Antennas, multilayer PCBs and IC interconnections.

Key Features

- ✓ IE3D Fast EM Design Kit for real-time full-wave EM tuning, optimization and synthesis.
- ✓ Multi-fold speed improvement and multi-CPU support for much improved efficiency.
- ✓ Equation-based schematic-layout editor with Boolean operations for easy and flexible geometry editing and parameterization.
- ✓ Lumped element equivalent circuit automatic extraction and optimization for convenient circuit designs.
- ✓ Improved integration into Microwave Office from Applied Wave Research.

Applications of IE3D

- ✓ RF circuits, LTCC circuits and RF ICs.
- ✓ Microwave, RF and wireless antennas.
- ✓ RFID tag antennas.
- ✓ HTS filters.
- ✓ Electronic packaging and signal integrity.
- ✓ Microwave circuits and MMICs.
- ✓ Many other low to high frequency structures.

Appendix N° 03:

❖ Advanced Design System (ADS)

Advanced Design System (ADS) continues to lead the RF EDA industry with the most innovative and commercially successful technologies, including Harmonic Balance, Circuit Envelope, Transient Convolution, Key sight Ptolemy, X-parameters, Momentum and 3D EM simulators (including both FEM and FDTD solvers). With ADS's Wireless Libraries and circuit-system-EM co-simulation technology, ADS provides full, standards-based design and verification within a single, integrated platform.

Key Features

- ✓ Complete schematic capture and layout environment ;
- ✓ Innovative and industry leading circuit and system simulators ;
- ✓ Direct, native access to 3D planar and full 3D EM field solvers ;

- ✓ Largest number of process design kits (PDKs) developed and maintained by leading foundry and industry partners ;
- ✓ EDA and Design Flow Integration with companies such as Cadence, Mentor, and Zuken ;
- ✓ Optimization Cockpit for real-time feedback and control when using any of 12 powerful optimizers ;
- ✓ X-parameter model generation from circuit schematic and Key sight's NVNA for nonlinear high-frequency design ;
- ✓ Up-to-date Wireless Libraries enable design and verification of the latest emerging wireless standards.