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Optimization of Microstrip Ring UWB filter using ANN-PSO

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Abstract- Ultra-Wide Band (UWB) is promising technology for many wireless applications due to its large bandwidth, good ratio of transmission data and low power cost. The main goal of this work is to design an UWB filter suitable for that purpose in the frequency band 3.1-10.6 GHz. In order to achieve that goal, one UWB filter configuration is investigated, designed and characterized. Theoretical analysis is done to compute the filter parameters, such as the return loss, insertion loss and attenuation characteristic over the full frequency band. The size of this filter is also studied because of its important aspect on the frequency behavior.

Index Terms- UWB, filter, frequency response, insertion loss, return loss.

I. Introduction

UWB technology is promising and attractive for local area networks, position location, tracking and radar systems. The technology has the characteristics of low cost, high data transmission rate and very low power consumption. Many UWB devices and circuits are proposed and investigated widely [1-5].

It is important to reduce their size and weight in order to integrate them with other components as a compact system. Compact and broadband bandpass filter (BPF) is a key passive component and highly demanded in a UWB system. A planar BPF based on a microstrip structure can provide the advantages of easy design, low cost, compact size.

A microstrip BPF widely used in a variety of RF/microwave and millimeterwave systems and compact UWB microstrip BPF can be used in a UWB communication system. UWB filters should have a fractional bandwidth of more than 70.0% and it is very difficult to achieve such a wide passband with a traditional parallel-coupled transmission line structures. A practical requirement exists for UWB BPF with a strong coupling structure that can be easily realized and fabricated.

A ring shaped microstrip resonator circuit with quarter wavelength short circuited stub is analyzed using EM theory and resulting dimensions are utilized to design a single section of an UWB filter in the desired frequency range. Consequently five such circular ring resonators are designed and successive stages are coupled using interconnected lines. Here proper tuning stub is used to implement a strong coupling between the input/output port and the resonator. Thus an UWB microstrip BPF with low loss is designed and further optimized for best achievable frequency response.

After the release of UWB bandpass filters with a passband of the same frequency range (3.1 GHz -10.6 GHz, a fractional bandwidth of 110%) were challenges for conventional filter designs. Before mid 2003 the bandwidth of the passband for a bandpass filters was extended from 40% to 70% [2]. These filters are named as broad bandpass filters.

They were not covering the whole UWB frequency range. In [3] a bandpass filter covering the whole UWB frequency range with a fractional bandwidth of 110% was realized by fabrication signal lines on a lossy composite substrate. A successful transmission of the UWB pulse signal was demonstrated using the proposed bandpass filter. This is one of the early reported filters that possess an ultra-wide passband. However, it has a high insertion loss in the passband due to the lossy 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% [4]. A bandpass filter covering the whole UWB frequency band was a challenge for microwave filter designers and researchers in that period of time. There are mainly four types of structures that are able to realize an ultra-wide passband.

II. UWB Filter configuration

UWB was originally developed for military communications and radar. In the field of UWB technology different methods and structures [2- 6] has pushed development of new UWB filters.

Lumped-element filter design is generally unpopular due to the difficulty of its use at microwave frequencies along with the limitations of lumped element values. Hence conventional microstrip filters are often used. The new proposed filter design is based on ring resonators having quarter wavelength short-circuited stub and realized in microstrip configuration.

The paper focuses on systematic design and realization of an UWB in printed circuit configuration. The filter design is done with ring shaped resonator and realized in microstrip configuration. The diameter of the ring is designed according to the frequency requirements and stub matching is used to tune the filter to the desired band of operation. Stub width and ring diameter, inter ring separation is taken as design parameter to optimize its frequency response performance. It is designed as per FCC recommended band from 3.1-10.6 GHz.

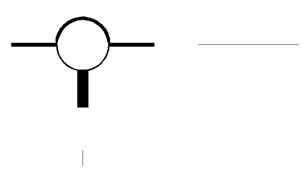

Figure 1. Ring resonator configuration as filter

III. UWB Filter design process

The UWB is designed using ANN model of ring resonator and PSO optimization techniques. Here Artificial Neural Network (ANN) and Particle Swarm Optimization (PSO) algorithm is used for the synthesis of the UWB filter using ring resonator. The PSO algorithm is used to optimize the filter geometry in order to obtain a wideband performance of the microstrip filter. The configuration of the ring structure acting as resonator is shown in Figure 1. whose resonance frequency is controlled by a tuning stub. The stub dimensions are fed as input to a trained ANN to model the reflectance and transmittance of the single ring resonator. In this work micro strip substrate is used in order to realize the filter using ring structure (substrate thickness 10 mil, dielectric constant 9.8). Analysis using method of

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moment and further simulation using commercial software tools is performed to investigate and verify the performance of the ring filter. The EM simulation results are in good agreement with those obtained using the ANN algorithm. The objective of this work is to use the ANN model coupled with the particle swarm optimization (PSO) algorithm to synthesize the UWB filter using multiple rings and optimize its performance as UWB filter. In this design, successive stages of coupled circular ring structure with proper tuning stub is used to implement strong coupling between the input/output port and the resonator.

Figure 2. Measured results of reflectance and transmittance of a single ring microstrip filter

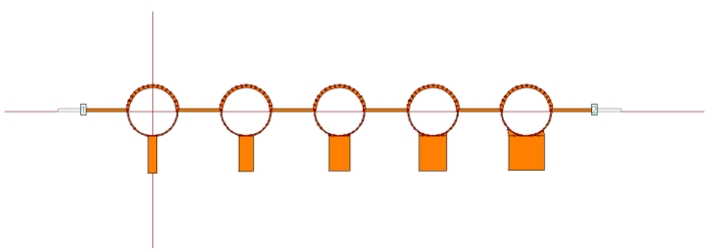


Figure 3. UWB filter configuration using ring structure

The EM simulation tools are used to optimize the frequency response performance of this UWB filter. Simulated results predict performance of the filter as per FCC Standard. It is observed that the design dimensions are critical in deciding the filter responses. The ring dimension and stub width are required to be precise for the microstrip filter under concern as per optimized results to meet the specification.Final pcb design is generated based on the optimized design for the multiple ring resonator structure with connecting lines. The filter hardware based on the optimized design is fabricated and measured to verify the UWB performance over the FCC band. The filter under concern is designed to provide an Insertion Loss $\leq$ 1 dB and average roll off 30 dB/decade. The measurement results are quite encouraging.

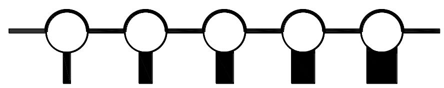


Figure 4. Layout of the UWB ring

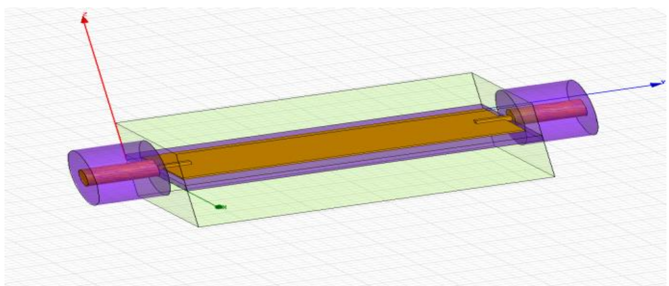


Figure 5. 3D model of UWB filter for simulation

The new proposed design of ring filter is associated with a quarter wavelength short-circuited stub for frequency tuning. Five sections are combined and optimized using PSO for its best achievable filter performance in the UWB frequency range from 3.1-10.6 GHz. A systematic design and realization of an UWB filter in microstrip configuration is done using stub tuned ring shaped resonator having single input and single output. The diameter of the ring is designed according to the resonating frequency requirements and stub matching is used to tune the filter to the desired band of operation. Stub width, ring diameter, inter ring separation is taken as design parameter for ANN model of each section of the ring. Five such sections are modeled using ANN to cover the whole UWB range and combined to form the integrated ring filter whose S parameters are computed using theory and verified by MOM simulation tools (IE3D). The reflectance and transmittance of the whole filter is optimized using PSO for FCC recommended band from 3.1-10.6 GHz.

III. THEORY OF RING RESONATOR

The theoretical investigation and analysis is done to relate the geometry parameters of the ring with its S parameters. Method of moments analysis in the spectral domain in conjunction with the Mixed-Potential Integral Equation (MPIE) approach is used by transforming the expansion and weighting functions [7-8]. Using the decomposition of Green's functions, the method of moment matrix entries can be reduced to a sum of two integrals. The first one is expressed in the spatial field and corresponds to the quasi-static contribution. It is analytically evaluated with the exponential terms in the function to be integrated. The integrals expressed in the spectral field and corresponding to the dynamic part have the advantage of being calculated on a finite range and this is independent of the choice of the basis and test functions. The integrals expressed in the spectral field are performed by using numerical integration [9-12]. The formulation begins with the development of an integral expression which defines the electric field resulting from an arbitrary current distribution. This integral expression employes a Green's function which relates the electric field at an arbitrary observation point to the current at an arbitrary source point. The MOM applies orthogonal expansions to translate the integral equation into a system of circuit-like simultaneous linear equations. Appropriate basis functions are used to expand the current distribution. Testing functions are used to invoke the electric field boundary conditions. Matrix methods are then used to solve for the expansion coefficients associated with the basis functions. The current distribution solution is then constructed from the expansion coefficients.

The MOM simulation tools (IE3D) are used to verify the performance of this filter in terms of S_{11} and S_{12} of this optimized wideband ring filter. It is observed that the design dimensions are critical in deciding the filter responses. The ring dimension and stub width are optimized to meet the specification and accordingly final PCB design is generated. The UWB filter is designed to provide an insertion loss $\leq$ 1 dB and average roll off of 30 dB / decade. Simulated results predict performances of the filter as per FCC Standards are shown in Figure 2. The filter based on the optimized design is fabricated and tested. The measurement results are quite encouraging.

IV. Design of ring filter

An exact analysis of the structure is very tedious. Hence a synthesis procedure is followed which involves a number of simplifying approximations that permit straightforward, easy to-use design calculations [13-16]. However these approximate design equations are found to be sufficiently accurate for most practical applications. The filter design is based on ring structure with quarter wavelength short-circuited stubs [17-22]. Here five short circuited stubs are designed for a distributed microstrip ring band pass filter whose connecting lines are non-redundant. In order to reduce the filter size the length of the connecting line are optimized. The characteristic impedances of these short-circuited stubs and the characteristic impedances of the connecting lines are chosen at 3.1 GHz. The dimension of the individual ring and its stub line impedance is computed using MOM considering fundamental resonance [23-30].

V. ANN model of ring filter

A training set of 670 randomly distributed points of the parameters in the range given in table I. The back-propagation training algorithm along with the sigmoid function as the activation function is used for the feed-forward network of the ANN in order to train it. Five sections of the ring resonators with controlling stubs are used to develop the full UWB ring filter. A three layer ANN with a hidden layer having 16 neurons is used to successfully model the geometry parameters of the ring such as diameter of the ring, characteristic impedance of the ring structure, inter ring separation and stub dimensions of individual ring to decide different resonance frequencies covering the UWB band. The training and testing data set is generated from the results of the analysis of the ring structure using method of moments. The accuracy of the trained network with this architecture is given in table II in terms of average error and standard deviation. Therefore, for a given set of input parameters, the geometry parameters of the ring can be accurately computed in the frequency range of interest in negligible time using the developed ANN.

VI. Development of UWB filter

The individual ring structure with microstrip line stub having extended ground plane is designed and simulated using IE3D for verification of the frequency response. The single ring filter structure is fabricated and impedance bandwidth is measured as shown in Figure 2(considering fundamental and harmonic frequencies). The measured result shows a frequency bandwidth of 1.3 GHz (8.0 GHz - 9.3GHz) with an insertion loss of 2.7 dB (average). Five such sections covering the whole UWB band is designed and integrated to form the UWB filter as shown in Figure 3 and 4 . It is observed that the integrated five section ring filter can be used for FCC regulated UWB operations where bandwidth enhancement of 150.0% or more is possible. Simulation model of the ring filter is shown in figure 5 and the frequency response of the five section ring filter is verified using MOM simulator for UWB operation as shown in figure 6.

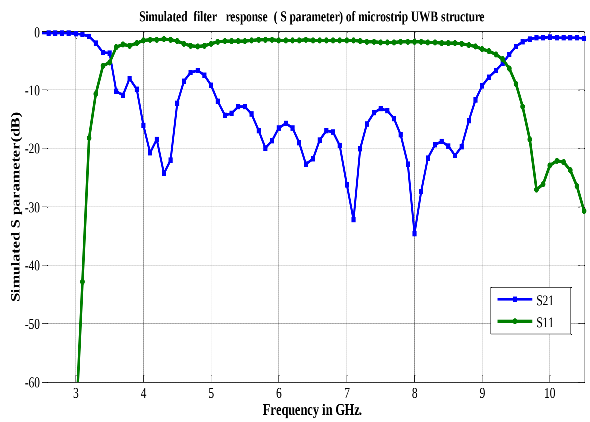


Figure 6. Simulated reflection & transmission characteristics of the UWB filter having five integrated ring in microstrip configuration.

VII. PSO fitness function

The reflectance and transmittance of the whole filter is optimized using PSO for FCC recommended UWB band from 3.1-10.6 GHz. The reflectance and transmittance of the integrated ring filter having five sections with different stub width and length are fed to PSO for bandwidth optimization of the same. A suitable fitness function for PSO is used considering maximum bandwidth and minimum return loss of the micro strip ring filter and is shown below.

Fitness $= \sum_{i=1}^{N} T_i - \sum_{i=1}^{N} R_i$

T_i=max (S_{21_i}, S_{21_D})

Si=min (S_{11_i}, S_{11_D})

$$T_i = \in S_{21_D} \qquad \forall S_{21_i} \le S_{21_D} \ \& \ \forall S_{21_i} \ge S_{21_D}$$

$$\in \min(S_{21_i}, S_{21_D}) \quad \text{otherwise}$$

$$R_i = \in S_{11_D} \qquad \forall S_{11_i} \le S_{11_D}$$

$$\in - S_i - \left| - S_{11_D} + S_i \right|^{Ki} \quad \text{otherwise}$$

Where the subscript i indicates different n frequency points. N indicates the total number of simulated frequency points. S_{11_D} (in dB), S_{21_D} (in dB) are the design requirements for S_{11} and S_{21} respectively. The sign $\forall$ indicates that this operation is taken as soon as this condition is satisfied at all frequencies. K_i is set to 1 for all test cases in order to reach an equally weighted sum of reflection coefficient and transmission coefficient. The possible maximum sum of all R_i is $-S_{11_D}$*N. It can be achieved if all S_{11} i are smaller than S_{11_D}. The PSO algorithm is converged within 50 iterations with sufficient accuracy (Figure 7.). The optimized dimensions of the stubs controlling the resonance frequency of individual rings are used to fabricate the UWB filter and the frequency response of the same is also verified from MOM simulator. The optimized dimensions of geometrical parameters of the five section ring filter are tabulated in table III. The fabricated ring filter is shown in Figure 8.

The MOM simulation tools (IE3D) are used to verify the performance of this filter in terms of S_{11} and S_{21} of this optimized wideband ring filter. It is observed that the design dimensions are critical in deciding the filter responses. The ring dimension and stub width are optimized to meet the specification and accordingly final PCB design is generated.

VIII. Measurement

The final filter layout is generated and fabricated using CER-10 using optimized dimension of the geometry parameters with best possible fabrication precession available. The final circuit after integration and packaging undergone for testing. The fabricated filter is measured for transmission and reflection performance with the help of Network Analyzer (E8363B). The measured attenuation and VSWR plot of the filter is shown in Figure (9.a-b). Measurement results shows good filter characteristic over the whole UWB band. The measured insertion loss over the band is 3.0 dB (average) and a 7.3 GHz filter passband from 4.41-10.29 GHz. with -10 dB return loss, and VSWR band width of 6.5 GHz is obtained. Measured results are compared with that of the simulated performance as shown in table IV. These results have indicated a very good agreement between simulation and measurements. This insertion loss can be further reduced using low loss substrate and SMA connectors. The fabrication process is required to be precise to improve this loss figure and to realize the full bandwidth for UWB operations. The mounting of the filters is required be rigid and full flatness of the substrate should be ensured to avoid surface wave loss. The other performance is seen to be satisfactory.

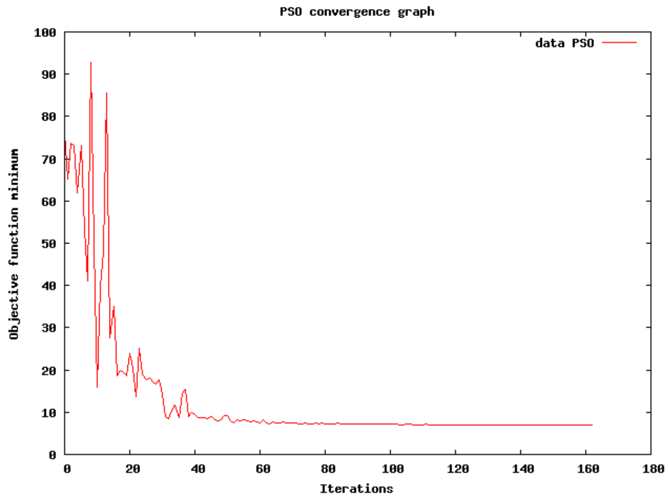


Figure 7. PSO convergence plot

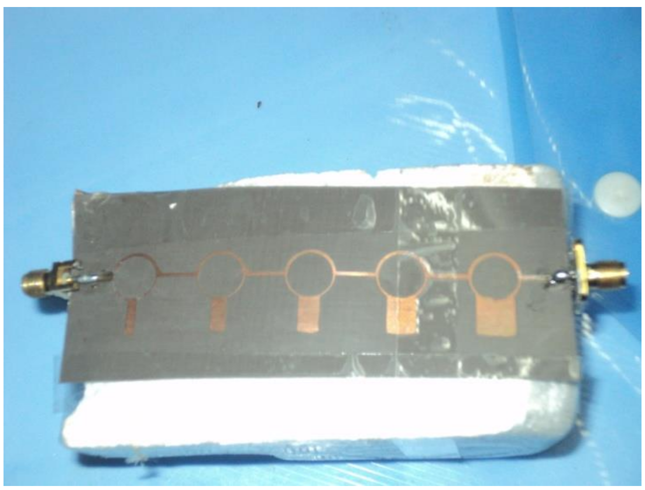
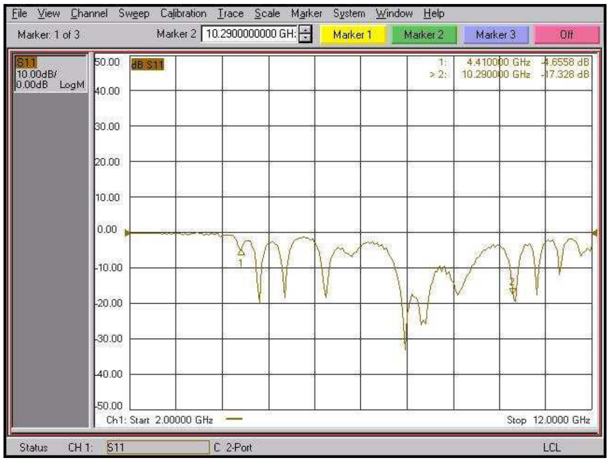


Figure 8. Fabricated ring filter in microstrip configuration.

(a) Reflection measurement



(b) Transmission measurement

Figure 9. Measured results of reflection and transmission characteristics of the UWB ring filter (a) Reflection measurement (b) Transmission measurement.

Table I Selection of Range of Input Parameters of Ring filter for ANN model

Ring diameter mm.	Characteristic impedance of ring ohm	Inter ring separation) mm.	stub length mm.	stub width mm.
0-7.0	5-150	0-14.0	8.0-25.0	0.5-4.0

Table II The accuracy of developed ANN model

ANN Input/output parameters	Ring dia (mm)	Characteristic impedance of ring (mm.)	Inter ring separation (mm)	Stub length (mm)	Stub width (mm)
Training	0.01	0.5	0.1	0.05	0.003
Average	0.05	0.5	0.3	0.5	0.03

error					
Testing Average error	0.02 0.04	0.7 0.6	0.2 0.4	0.06 0.4	0.004 0.04

Table III Optimized dimensions of the ring filter (ANN-PSO model)

Ring diameter) mm.	Characteristic impedance of ring in ohm	Inter ring separation in mm.	stub length mm.	stub width mm.
5.6	50.0	10.0	S1 8.5 S2 8.1 S3 8.0 S4 7.95 S5 7.8	S1 2.0 S2 3.03 S3 5.73 S4 6.23 S5 8.2

Table IV Comparison table of the simulated and measured performance of the UWB ring filter

Filter Parameter	Simulated	Measured
VSWR Bandwidth	5..8 GHz	5.88 GHz
Insertion loss	4 dB	3.0 dB(avg.)

CONCLUSIONS

In this chapter an UWB microstrip BPF with low insertion loss is designed and optimized for its frequency response performance using PSO. Each individual ring resonator is associated with a quarter wavelength short-circuited stub for frequency tuning. A systematic design and realization of an UWB filter in printed circuit configuration is done using stub tuned ring shaped microstrip structure having single input and single output. The diameter of the ring is chosen according to the resonating frequency requirements and stub matching is used to tune the filter to the desired band of operation. Stub width, ring diameter, inter ring separation is taken as input design parameter for the ANN model. Five different ring resonators are integrated to form UWB filter where the geometrical parameters of the individual ring resonators are obtained from output of respective ANN model. Five sections are combined and optimized using PSO where reflectance and transmittance of the integrated microstrip ring filter is optimized for UWB frequency range from 3.1-10.6 GHz. In this process of optimization the physical dimensions of individual rings are altered and the filter as a whole becomes capable of efficient transmission for UWB band. Finally the final filter layout is generated and fabricated using optimized dimensions of the ring structure with best possible fabrication precession available. The S parameters of the fabricated filter is measured to verify the transmission and reflection performance of the same with the help of VNA and compared with that of the simulated performance as shown in table IV. These results have indicated a very good agreement between simulation and measurements.

So it can be concluded that ANN-PSO technique is efficiently utilized for design and development of one UWB filter having optimum frequency response. The insertion loss and measured bandwidth are near to that of the desired value and can be improved further with some precautions.

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