Filters at Microwaves Frequencies with Double Confocal Elliptical Ring Resonator

Filtros a Frecuencias de Microondas con Doble Resonador en Anillo Elípticos Confocales

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Abstract

This work describes the results of computational simulations and measurement of a multiband filter using double elliptical ring resonator excited by coplanar slot line waveguide for the design of microwave filters in RF communications systems. By means of the equation of optics, the dimensions of materials that fill the dielectric resonators can be found. Two novels multiple filters with low insertion loss are proposed and fabricated. These filters are composed of a cell of double elliptical ring resonator and a section of coupled lines. There is good agreement between the simulated and experimental results. A value computational calculus of scattering S11 and S21 of elliptical coupled resonators is made and measured, and the possible uses in microwave filters are discussed.

Keywords

Elliptical resonator; microstrip filters; microwaves filters; printed circuits; resonators filters; scattering parameters.

Resumen

Este trabajo describe los resultados de las simulaciones computacionales y medidas de filtros multibanda utilizando doble resonador elíptico excitado por guía de onda ranurada coplanar para diseñar filtros a la frecuencia de microondas en sistemas de comunicaciones de RF. Por medio de las ecuaciones de Maxwell se deduce la ecuación de las frecuencias de resonancia en función de sus dimensiones y de los materiales de las elipses. Se proponen y construyen dos nuevos filtros compuestos por una celda de doble resonador en anillo elíptico y una sección de línea coplanar acoplada. Se hace un cálculo computacional y se miden los parámetros de dispersión S11 y S21 de los resonadores elípticos acoplados, obteniendo una concordancia entre ellos, y se discuten las posibles aplicaciones como filtros en microondas.

Palabras clave

Resonador elíptico; filtros en microondas; circuitos impresos; filtros resonadores; parámetros de dispersión.

1. INTRODUCTION

Waveguide filters based in resonators are frequently found in satellite and mobile communication systems, due to their advantages in terms of mass and volume reduction, low losses, and thermal stability (Mansour, 2004). The cost of individual filters and the issue of mass production are important, whereas volume and weight are critical in satellite communications (Kudsia et al., 1992). The rapid expansion of wireless communication industry has increased the demands for microwave filters and diplexers for both handsets and base station applications. Coaxial cavity filters are commonly used due to their low cost and their spurious-free performance, but these kinds of filters have limited quality factor values, and thus a different technology must be employed to match the new filtering requirements.

The high-Q dielectric resonator filters have emerged as the baseline design for wireless base stations. In an airplane, when the onboard wireless communication services are provided, many other systems may be used simultaneously. Compact equipment that supports multimode/multiband wireless systems is very attractive. As a result, a multimode/multiband system is becoming a focus issue for miniaturization and simplicity. Highly integrated multiband components such as antennas and filters are becoming important under this kind of trend. As a key component in the communication system mentioned above, multiple band filters play an important role in weakening the interference among communication systems, due to coexisting narrowband applications.

Various topologies have been proposed and developed to realize filters with multiple stop band responses (Shaman & Hong, 2007; Tu & Chang, 2005; Tu & Chang, 2006; Chin et al., 2007; Levy et al., 2006; Yang et al, 2004; Hsieh & Wang, 2005). Shaman and Hong describe a general configuration for cross-coupled wideband bandstop filters, based on an n-stub optimum band stop filter with cross-coupling between the I/O feed lines (Shaman & Hong, 2007). Microstrip BSFs using shunt open stubs and spurlines have been described (Nguyen & Chang, 1985). The concept of integrating band stop filters into a conventional band stop or band pass filter has been proposed (Wolff, 1972). Chin et al. (2007) implemented two parallel-connected different-length open stubs for resonating at dual anti-resonance frequencies to realize a dual-band band stop filter. Jeng et al. (2006) proposed a distributed perturbation scheme of the ring resonator with no need of extra stubs or notches.

This work describes the analysis and the results of applying the model of the standing waves in elliptical mirrors in the propagation of microwave in materials used to construct resonators devices that have an elliptical topology and high frequency filters, and preliminary simulations (using 3D electromagnetic simulators) indicate that these can become an advantage in restricting, selecting and controlling the excitation modes of the resonators. Initially, it is established that the resonant behavior occurs in elliptical resonant structures. After, a discussing about the elliptical resonators excited by slot line transmission lines is done. This leads to the concept that can be extended to representative circuits of the resonators, using the symmetry of the elliptical mirrors. Later, models for the elliptical resonant sections drawn are described, and finally, practical applications, supported by the results of the computational simulations are proposed. The concept of the proposed filters is validated both by simulations and experiments.

2. METHODOLOGY

2.1 Resonance Modes of Elliptical Resonators

In elliptical coordinate, ξ is the radial coordinate and takes the values $\xi \in [0,\infty)$, and the coordinate η is an angular coordinate taking the range $\eta \in [0,2\pi)$, as is show in Fig. 1 and Fig. 2. k is the wave number of elliptical resonator (ER) and k_z is the wave number of the ER in z direction. f_o is the semi-focal distance of ellipse. The scalar Helmholtz equation is as (1), (Tadjalli, A. & Sebak, A. 2004):

$$\frac{2}{{f_0}^2(cosh2\xi - cos2\eta)}\left(\frac{\partial^2}{\partial\xi^2}+\frac{\partial^2}{\partial\eta^2}\right)\begin{Bmatrix}E_z\\H_z\end{Bmatrix}+(k^2-k_z^2)\begin{Bmatrix}E_z\\H_z\end{Bmatrix}=0 \qquad (1)$$

Assuming that E_z and H_z can be written in the form of (2)

$$R(\xi, g).S(\eta, g).\begin{bmatrix}\sin(k_z z)\\ \cos(k_z z)\end{bmatrix} \tag{2}$$

Equation (1) can be rewritten as (3)

$$\frac{1}{R}\frac{\partial^2 R}{\partial \xi^2} + \frac{k^2 - {k_z}^2}{2}{f_0}^2 cosh2\xi = \frac{1}{S}\frac{\partial^2 S}{\partial \eta^2} - \frac{k^2 - {k_z}^2}{2}{f_0}^2 cos2\eta \tag{3}$$

where R and S are, respectively, the radial and angular Mathieu function (Tadjalli, A. & Sebak, A. 2004). $k_c=(k^2-k_z^2)^{1/2}$ is the elliptical cross-section wave number. The height of the ER is denoted by h. Defining $q=k_c^2 f_0^2/4$, and ξ_0 as the lateral surface of ER, the boundary condition gives the resonant frequencies can be written in the form as (4)

$$k_{z_p} = \frac{(2p+1)\pi}{2h}; p = 0,1,2,..\ f_{e_{nmp_o}}\binom{TE}{TM} = \frac{c}{2\pi\varepsilon_r}\sqrt{k_{ce_{nm_o}}\binom{TE}{TM}^2 + k_{zp}^2} \tag{4}$$

where c is velocity of light and ε_r is the permittivity of dielectric. The elliptic boundary of the ER is given by $\xi=\xi_0$=constant, and the eccentricity e of the ellipse is defined as (5)

$$e = \frac{f_o}{a} = \frac{1}{cosh\xi_0} \tag{5}$$

On the elliptic boundary *($\xi=\xi_0$)*:

$$\begin{aligned} &TE: R_{e_{n_o}}(\xi_0) = 0\\ &TM: \frac{\partial R_{e_{n_o}}}{\partial \xi}|_{\xi=\xi_0}\end{aligned} \tag{6}$$

For a harmonic n has an infinite set of possible values of q that satisfy (6). Let $q^{TE}{}_{nm}$ the m-th zero of R of n-order and $q^{TM}{}_{nm}$ the m-th zero of derivetive of R of the n-th-order. For each $q^{TE}{}_{nm}$ or each

$q^{TM}{}_{nm}$ there exists a corresponding frequency $f^{TE}{}_{nm}$ or $f^{TM}{}_{nm}$. Solving q for resonant frequencies leads to (7)

$$f_{e_{nmp}}{}_{o}^{\binom{TE}{TM}} = \frac{c}{2\pi\varepsilon_r}\sqrt{\frac{4q_{nm}^{\binom{TE}{TM}}}{f_0} + k_{zp}^2} \quad (7)$$

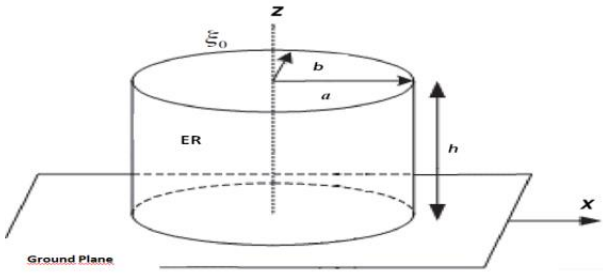


Fig. 1. Dimensions of an elliptical resonator. Source: (Tadjalli, A. & Sebak, A. 2004)

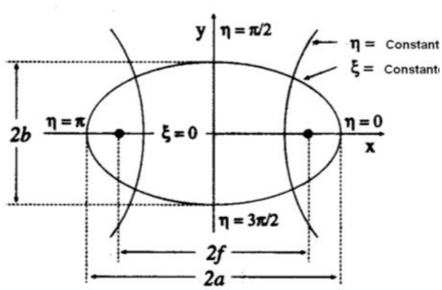


Fig. 2. Geometry parameters in elliptical coordinates of an elliptical resonator. Source: (Tadjalli, A. & Sebak, A. 2004)

Except for the first harmonic n=0, all modes can be even or odd. The confocal elliptic structure is a very versatile configuration and offers a reasonable controllability over the positions of its resonant modes. Also, it can be possible obtaining resonant frequencies by controlling the ratio a/b.

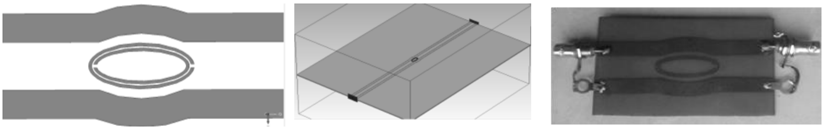
2.2 Resonator Elliptical Double Confocal Rings

Generally, the bandwidth of a wireless access communication system ranges from 2.4 to 2.5 GHz or 5.0 to 5.8 GHz. In order to suppress interference with the aircraft navigation system, multiple stop bands should be available at special frequencies. More resonance cells could be employed, but the size of the circuit would inevitably increase. We performed a simulation of a planar double-resonator configuration with two ports and thickness of 1.0 mm (ADS, 2010; CST, 2010), and with dimensions 80X80mm, strip-width of the microstrip line w_m =2.0 mm, distance from the input port 1of the left side of the slot 8.91mm, distance from port 1 to the left-end of the double ellipse is 6.28mm, the width of the slots w_s=2.4mm, length of slot l_s=7.69mm, minor axis of the ellipse 2b=21.39 mm, distance from end to end double-resonator 66.72mm, the microstrip length of the focus on output port 2 is l_{m2}=10.21mm, the slot length of focus at the output is 2.4mm, width of the slot resultant of the right side is 0.2mm. The vertical distance in the center of the double resonator is 16.2mm.

3. RESULTS AND ANALYSIS

3.1 Double-Planar Resonator Confocal Rings Parallel

The Fig. 3a), 3b) and 3c) shows the structure of the parallel double-planar resonator confocal rings. The Fig. 4 shows the magnitude of the parameters scattering S_{11} and S_{21} simulated with CST-MICROWAVES SUITES and ADS (ADS, 2010; CST, 2010). The Fig. 5 shows the magnitude of the parameters scattering S_{11} and S_{21} measured, in dB. Can be observed resonances frequencies at 300, 650 and 750MHz, (both coupled) that are approximate at those of the simulation of Fig. 4: 330, 650(~2 X 330) and 950 MHz(~3 X 330MHz).



a) b) c)

Fig. 3. a) Double-planar resonator confocal rings parallel configuration, b) Side view, c) Top view with details of the configuration constructed. Source: Author

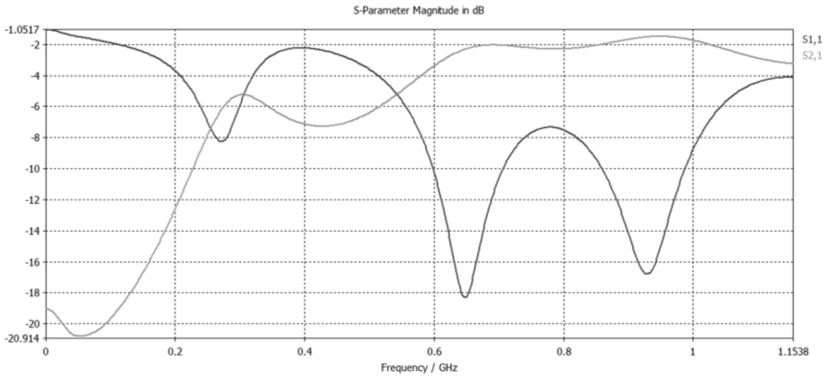
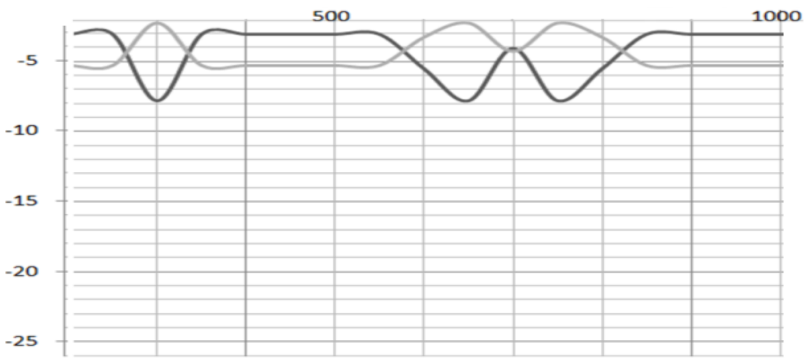


Fig. 4. $|S_{11}|$ (black curve) and $|S_{21}|$ (grey curve) simulated for the structure of the Fig. 3(b). Source: Author

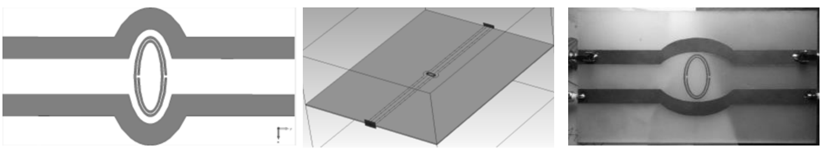


Frequency (MHz)

Fig. 5. $|S_{11}|$ (black curve) and $|S_{21}|$ (grey curve) measured in dB for the structure of the Fig. 3(c). Source: Author

3.2 Double-Planar Normal Resonator Confocal Rings

The Fig. 6(a), (b) and (c) shows the structure of the normal double-planar resonator confocal rings. The Fig. 7 shows the magnitude of the parameters scattering S_{11} and S_{21} simulated with CST-MICROWAVES SUITES and ADS (ADS, 2010; CST, 2010). The Fig. 8 shows the magnitude of the parameters scattering S_{11} and S_{21} measured, in dB. Can be observed resonances frequencies at 600 MHz, 750 MHz (both coupled) and 950 MHz that are approximate at those of the simulation of Fig. 7: 650MHz and 850 MHz, both coupled. A 2.5 times higher structure was built and measured for frequencies below to 200MHz, and has been obtained the curves of the Fig. 9, where are observed the resonances frequencies in 10, 40 and 55MHz (both coupled), 90 and 115MHz, (also both coupled).



a) b) c)

Fig. 6. (a) Double-planar resonator confocal rings normal configuration. (b) Side view with details of the slots in normal double-planar resonator confocal rings configuration. (c).Construction of the normal double-planar resonator configuration. Bottom view of the slot line. Source: Author

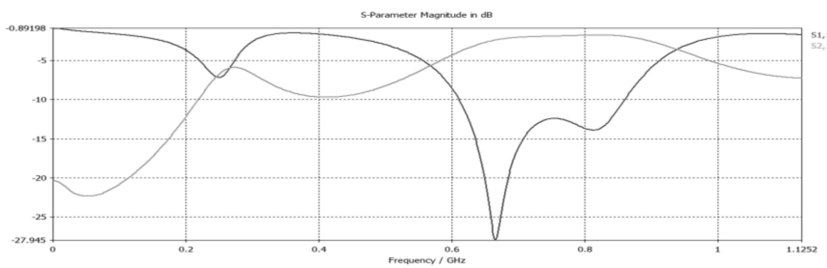
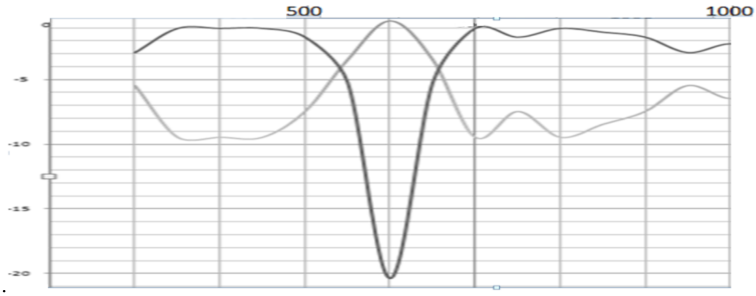
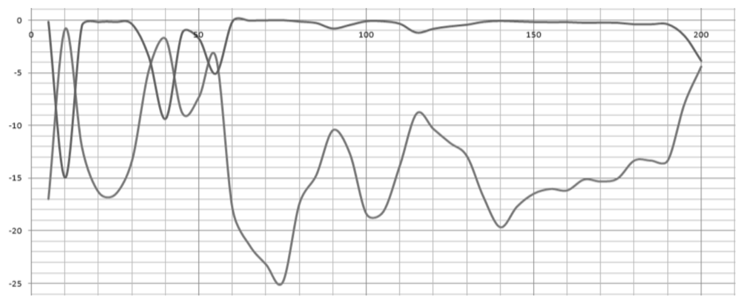


Fig. 7. $|S_{11}|$ (black curve) and $|S_{21}|$ (grey curve) simulated for the structure of the Fig. 6. Source: Author



Frequency (MHz)
Fig. 8. $|S_{11}|$ (black curve) and $|S_{21}|$ (grey curve) measured in dB, for the structure of the Fig. 6(c). Font: Author



Frequency (MHz**)**
Fig. 9. $|S_{11}|$ (upper curve) and $|S_{21}|$ (bottom curve) measured in dB, to frequencies below 200MHz, for the structure of the Fig. 6(c). Font: Author

4. CONCLUSIONS

It has been doing the computational simulations and measurement of two multiband filters using double elliptical ring resonator excited by coplanar slot line waveguide, for the design of microwave filters in RF communications systems.

There is good agreement between the simulated and experimental results when are compared the resonant frequencies of Fig. 4 and 5, can be identifies two coupled frequencies in 650 and 750MHz, and other in 300MHz for the ring parallels. For the filter with normal rings, has been found coupled frequencies in 600 MHz, 750 MHz, and other in 950MHz, when are compared the Fig 7 with the Fig. 8. For frequencies below to 200MHz, has been obtained the curves of the Fig. 9 for the same filter with normal rings, where are observed the resonances frequencies in 10, 40 and 55MHz (both coupled), 90 and 115MHz, (also both coupled). These coupled frequencies are the basis for designing filters in cascade with elliptical rings of size different. Both configuration of rings basically have resonant frequencies around 600, 750 and 900MHz, corresponding to high region of VHF and are appropriates for applications in mobile communications, indicate that can become an advantage in restricting, selecting and controlling the excitation modes of the resonators.

Another advantage of using elliptical rings as fitters is that these have more resonant frequencies that the circulars rings, between the same width band, permitting select more number the central frequencies and the type of filter desired, as band-pass, low-pass, high-pass or reject-band. The normal rings permitting design filter in more low frequencies that those of parallel rings. Can be optimized and moved down their frequencies painting over the rings with films elliptical of dielectric material of high value of dielectric permittivity. The original idea presented in this work to use resonators elliptical thin ring resonator with electric fields inside only tangential to the surface can to be used for designing a wide variety of filters used, by example, in an airplane, when the onboard wireless communication services are provided. These resonators with elliptical double confocal rings can be used also for constructing arrays with performance as metamaterials.

5. ACKNOWLEDGMENTS

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