CAD Modeling of a Microwave Rectangular Coaxial Filtering Device

Aline Jaimes-Vera[1], Ignacio Llamas-Garro[2], Alonso Corona-Chavez[2], Ignacio Zaldivar-Huerta[1]

[1] Electronics Department, [2] Large Millimeter Telescope, National Institute for Astrophysics, Optics and Electronics.
Luis Enrique Erro #1, Tonanzintla Puebla, Mexico. CP 72840
ajaimes@inaoep.mx

Abstract

In this paper we discuss the adequate filter parameter selection to obtain a low loss coaxial cable, out of which a narrowband filtering device is designed. The design parameters under interest are the attenuation constant (α) obtained, which will depend on the size of the rectangular coaxial cross section used. And the decision beyond which frequency higher order modes should start to propagate through the cable resulting in a dispersive coaxial cable. The tradeoff between these two parameters is discussed in detail. After the coaxial design parameters are chosen to meet a design specification, (in this paper a 4 pole, 4% fractional bandwidth filter, centered at 9 GHz), the design of an air filled coaxial feed line is discussed, followed by the design of the microwave filter, and finally the integration of the complete device is presented. The coaxial cable discussed in this paper uses air as the propagation medium, thus resulting in a conductor loss limited structure, where no dielectric or radiation losses are present. All calculations were done using Ansoft HFSS a commercial full wave 3D EM simulator.

1. Introduction

Coaxial waveguide structures are commonly used in microwave and millimeter-wave integrated circuit devices [1, 2], because they are compact in size, and presented low loss and low dispersion, making them a suitable structure for the design of millimeter-wave filters [3]. Coaxial devices are frequently operated in such a way that only the fundamental TEM mode is excited. The coaxial line can also support TE and TM waveguide modes in addition to a TEM mode [4, 5]. When used in microwave devices, these modes are usually evanescent, and so have only a reactive effect near discontinuities or sources where they are excited. However it is important to be aware of the cutoff frequency of the lowest order waveguide-type mode, to avoid having a dispersive coaxial cable, resulting in the superposition of two or more propagation modes with different propagation constants (β).

The modes depend strongly on the structure cross-sectional shape and size [6, 7]. Thus it is crucial to obtain an adequate rectangular coaxial cross section to assure a coaxial cable operating in the TEM mode only and having a minimum attenuation through the coaxial microwave circuit [8]. As a result we will have a compromise and trade off between the size of the rectangular coaxial cross section used, the attenuation through the cable, and the frequency beyond which higher-order modes begin to propagate.

This paper is divided in five parts. Section 2 contains the procedure to obtain an adequate selection of a rectangular coaxial cross section to be considered for the microwave filtering device. In section 3, the design of a self supported feed line, used to interface the filtering device to external circuits, e.g. measurement equipment or other components on a system or subsystem is discussed. In section 4 the design of a microwave filter at X band is presented, having 4 poles and a 4% fractional bandwidth at 9 GHz, the filter topology consists of suspended, compact rectangular coaxial resonators, suspended using short circuits between the coaxial center and outer conductors. In section 5, the complete microwave filtering device is presented. Finally section 6 contains conclusions and further work.

2. Rectangular coaxial cable design

The design of a microwave coaxial cable will depend on choosing an adequate rectangular coaxial cross section. A tradeoff between the loss of the cable and the maximum usable frequency under a TEM mode appears. In filter design it is attractive to obtain the lowest loss through the cable to obtain high Q resonators. This section discusses how the rectangular coaxial cross section is chosen, which will be used to form the microwave filtering device shown in the next sections of this paper.

17th International Conference on Electronics, Communications and Computers (CONIELECOMP'07)
0-7695-2799-X/07 $20.00 © 2007 IEEE

Fig. 1 shows the cross section of a coaxial cable. To illustrate the effect of having different coaxial cross sections, we compare 3 different sizes, chosen to have a 50 Ω characteristic impedance, which are given in table 1 and refer to fig 1. From table 1 we can conclude that the choice of the rectangular coaxial cross section will result in different attenuations constants, a big size results in low loss compared to having small coaxial cross sections. The choice of an adequate rectangular coaxial cross section should take into account the maximum usable frequency under a TEM mode; this is also illustrated in table 1, where the frequency beyond which higher order modes propagate is given. All simulations in this paper assume copper with a conductivity of 5.8×10^7 siemens/m.

Before using the coaxial cable to produce microwave circuits, e.g the microwave filter presented in the next sections of this paper. The first step is to choose an adequate rectangular coaxial cross section. The objective is to have a TEM propagation, avoiding the propagation of higher order modes, and having good loss performance.

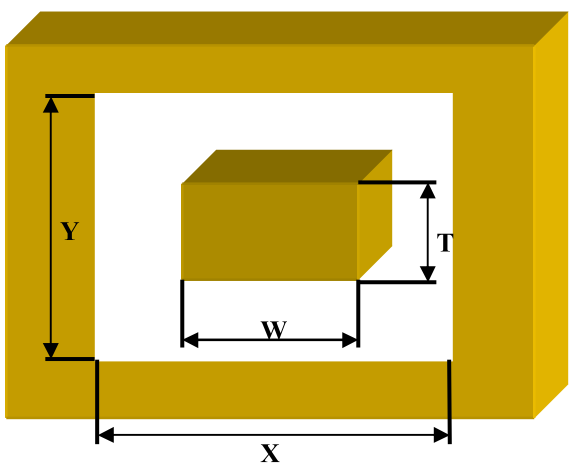

Fig 1. Cross section of a coaxial line

The different cross sections under study are simulated and their attenuation constant compared in fig 2. From table 1, and fig 2, cross section A is chosen to be the adequate rectangular coaxial cross section to be used. This decision is taken based on the frequency response of the filtering device. The filtering device has a center frequency of 9 GHz, and occupies a 4% fractional bandwidth. For this cross section, the lowest higher order mode, the TE_{10}, begins to propagate at 15 GHz as given in table 1, which lies outside the band of interest, according to the filtering device frequency specifications, and results in adequate loss selection for the filtering device compared to cross sections B and C. Fig. 3 contains the simulation result of the attenuation constant for cross section A, where it can be clearly appreciated that beyond 15 GHz, the TE_{10} mode propagates. Similarly fig. 4 contains the simulation of the propagation constant for cross section A, which once again confirms the propagation of the TE_{10} mode beyond 15 GHz.

Table 1
Rectangular coaxial cross section comparison

	Cross Section A X: 9.5 Y: 5.5 W: 5.0 T: 1.0	Cross Section B X: 7.5 Y: 4.35 W: 3.6 T: 1.0	Cross Section C X: 5.5 Y: 3.18 W: 2.2 T: 1.0
α (9GHz)	0.038	0.049	0.070
Higher order modes (GHz)	15.0	18.5	23.2

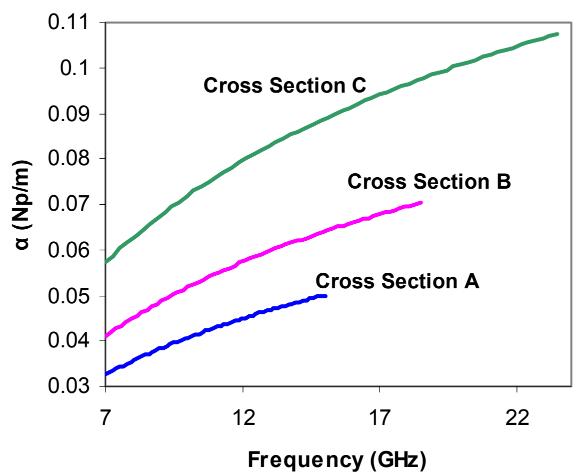

Fig 2. Attenuation constant for different cross-section areas

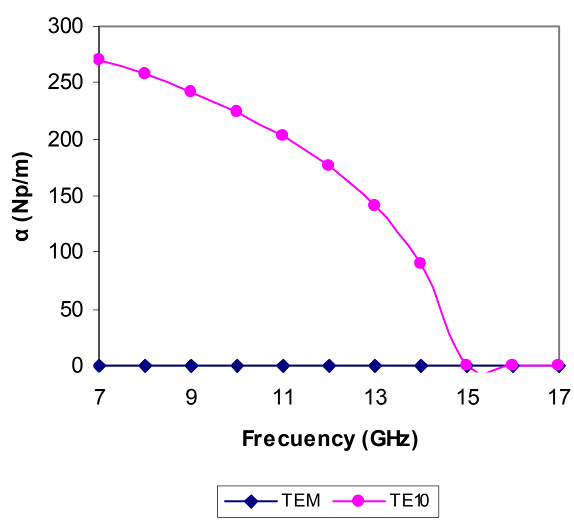

Fig 3. Attenuation constant for cross section A

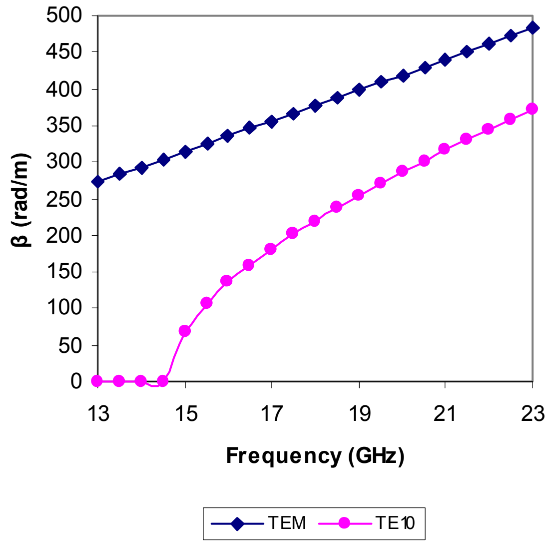

Fig 4. Propagation constant for cross section A

The size of the rectangular coaxial cross section is decided using the criteria exposed in this section, and will now be used in the design of the proposed microwave filtering device, which is discussed in the following sections of this paper.

3. Feed Lines

Fig 5 shows the proposed feed line, which is coupled to the input and output of the device. The feeds are a piece of suspended coaxial transmission line all surrounded by air. The coaxial line supports itself by the use of quarter wavelength transmission lines, as shown in fig 5. These transmission lines serve as a mechanical support to hold the coaxial center conductor in air. The supporting stubs are a quarter wavelength long at 9GHz, and are in short circuit with the outer conductor, resulting in an open circuit were the stub makes contact with the coaxial center conductor at 9 GHz. The response of the feed lines, shown in fig 6, have a wideband response, were the fractional bandwidth was found to be at around 118% at 9 GHz.

4. Filter

The filter was designed at 9 GHz for X band operation, using a rectangular coaxial structure. This structure is capable of high power handling. The design procedure of this filter follows a traditional filter design method [9], which begins with a low pass prototype filter, and then a band pass transformation is applied and the coupling coefficients between resonators (K_{ij}), and the external quality factor (Q_e) can be obtained through full wave simulations [9].

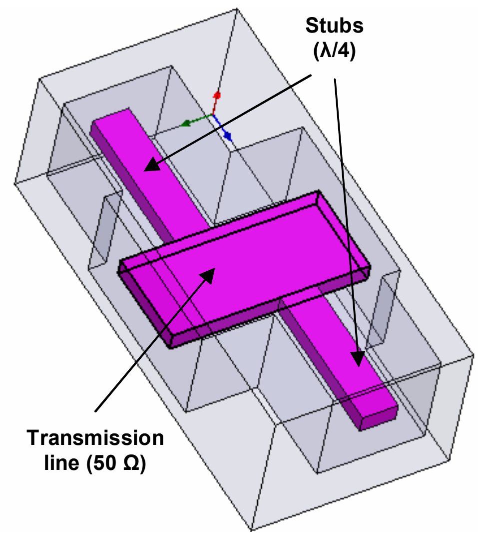

Fig 5. Transmission line supported in air

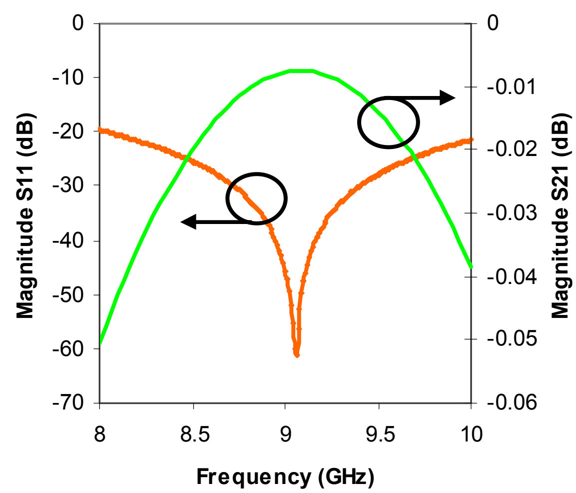

Fig 6. Feed line response using Ansoft HFSS

The design equations to obtain the theoretical couplings between resonators and the external quality factor related to the input and output coupling to the filter can be found in [9]. The resulting coupling between resonators obtained for this particular filter topology shown in fig 7 (where the resonators are numbered 1 through 4), are shown in fig 8a and b respectively . Since the filter is symmetrical, only half of the values are given. Fig 8a shows the coupling obtained between resonators 1 and 2, and fig 8b shows the coupling obtained between resonators 2 and 3. Similarly the external quality factor obtained for this filter topology is shown in fig 9 related to the input and output coupling to the filter.

The filter was designed to have a 0.01 dB pass band ripple and a 4% fractional bandwidth at 9GHz, with a Chebyshev response. This filter topology determines the final response of the filtering device discussed in the next section of this paper.

The response of the filter is shown in fig 10. The filter response shows a good agreement with the design parameters, in terms of bandwidth and filter response. A maximum pass band return loss over the designed bandwidth of -10dB has been obtained.

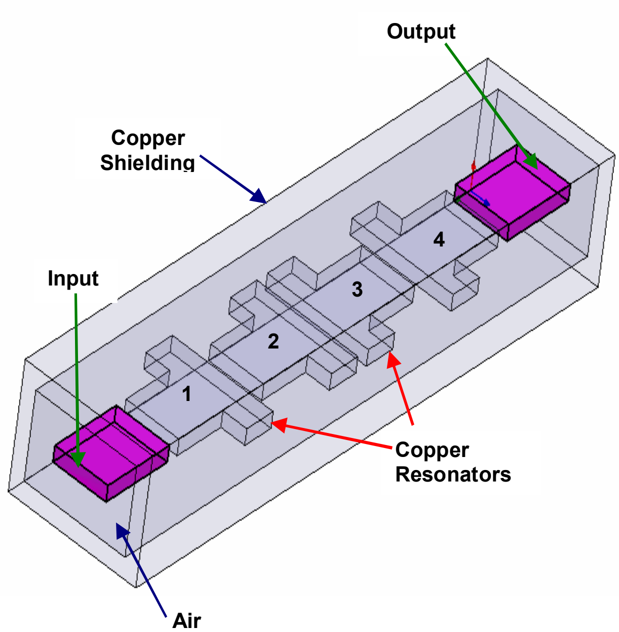

Fig 7. Microwave filter topology inside a rectangular coaxial cable

5. Microwave Narrowband Filtering Device

After obtaining the optimum spacing between resonators and feed lines, the structures are placed together to form the final microwave narrowband filtering device shown in fig 11. The total structure consists of four quarter wavelength resonators and two feed lines supported by quarter wavelength stubs. The four resonators are the main body of the device, which determines the 4% fractional bandwidth response at 9 GHz of the complete filtering device. To the sides of this main body suspended feed lines are placed each suspended by two quarter wavelength stubs, these feed lines have a 118% fractional bandwidth at 9GHz, resulting in a low loss suspended rectangular coaxial transmission line.

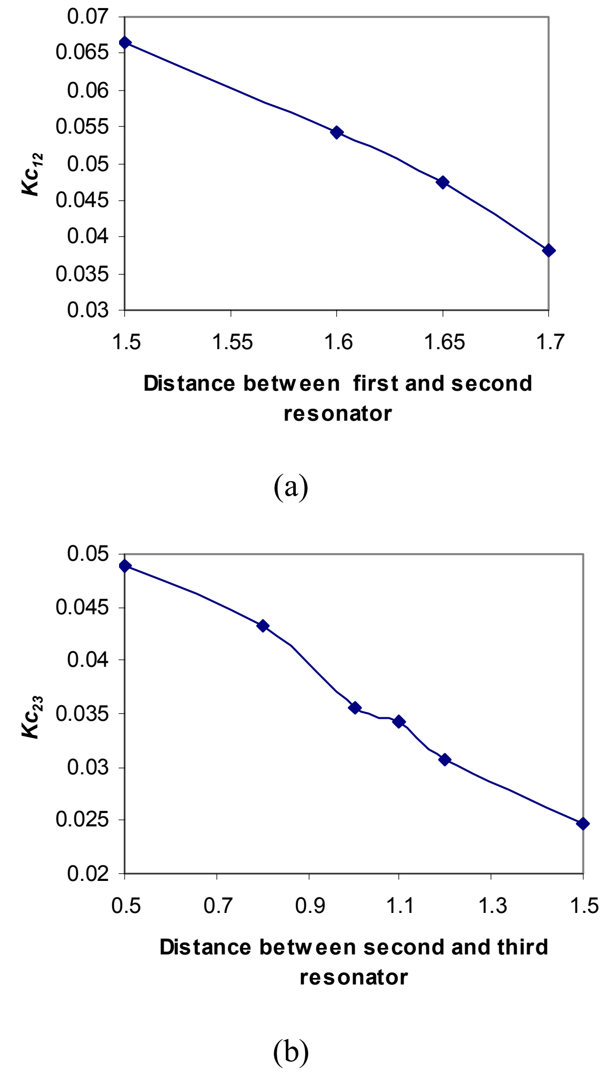

Fig 8. Calculated (a) Kc12, (b) Kc23

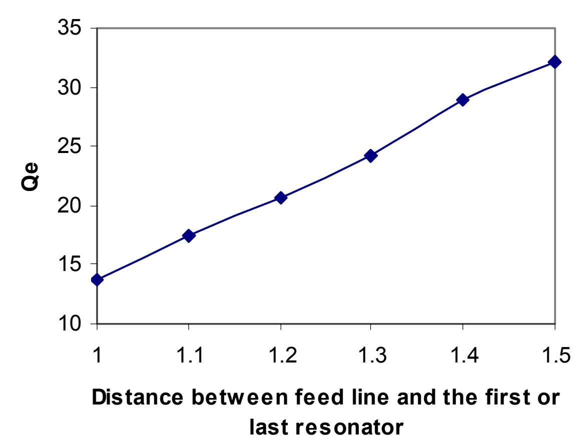

Fig 9. Calculated Qe

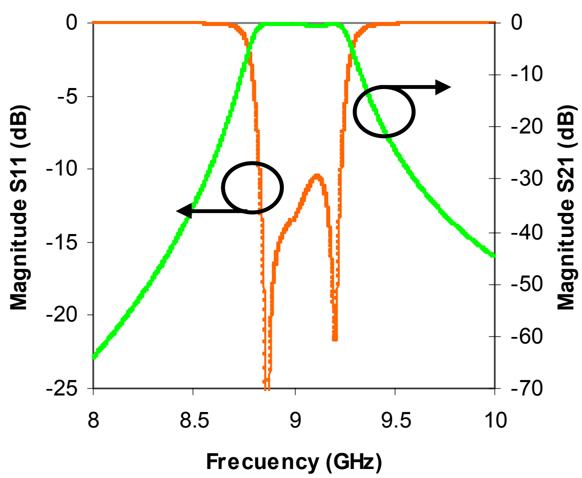

Fig 10. Filter response using Ansoft HFSS

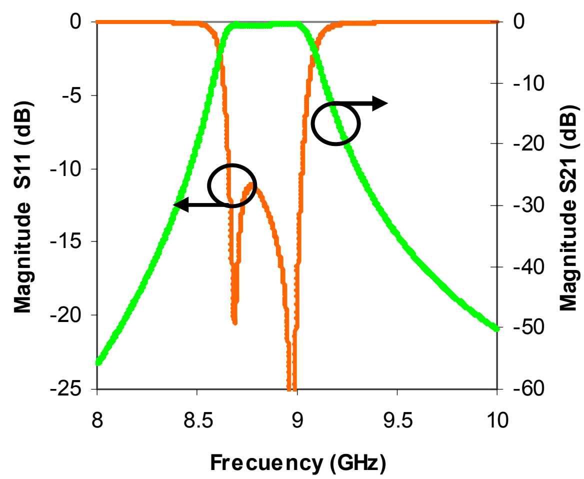

Fig 12. Microwave device frequency response using Ansoft HFSS

Fig 12 shows the simulated response of the complete device, using HFSS. The maximum return loss obtained after simulations was at around -11dB. The simulation results agree well with theoretical calculations.

6. Conclusions

A new type of rectangular coaxial microwave filtering device has been presented, the procedure of choosing an adequate rectangular coaxial cross section was discussed in detail, where a tradeoff between the loss and the maximum usable frequency was described.

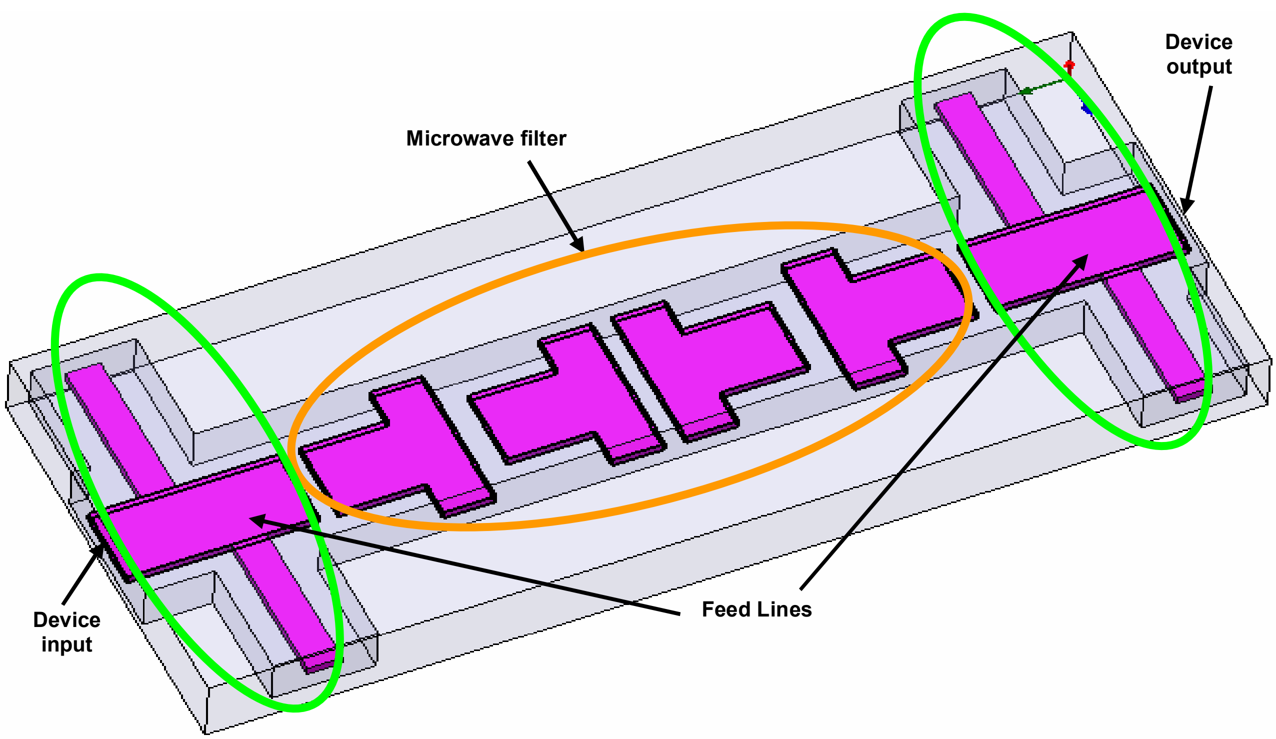

Fig 11. Microwave rectangular coaxial filtering device

A narrowband microwave filtering device was modeled using CAD, consisting in a narrowband filter design fed by suspended coaxial transmission lines. The complete model was presented in this paper and future work involves fabrication and experiment with rectangular coaxial transmission lines made using copper sheets.

7. Acknowledgements

One of the authors Jaimes-Vera Aline wishes to thank CONACYT for scholarship No. 198264.

8. References

[1] Jennifer A Bishop, Majid M. Hashemi, Kursad Kiziloglu, Lawrence Larson, Nadir Dagli, Umesh Mishra, "Monolithic coaxial transmission lines for mm-wave ICs", *High speed semiconductor devices and circuits, Proceedings IEEE/Cornell conference on advanced concepts,* 5-7 August 1991, pp 252-260

[2] Ignacio Llamas-Garro, Yongsung Kim, Chang-Wook Baek, Yong-Kweon Kim, "A Monolithic Surface Micromachined Half-Coaxial Transmission Line Filter". *IEEE trans. on microwave theory and techniques, to appear (December 2006 issue)*

[3] I. Llamas–Garro, M.J. Lancaster, and P.S. Hall, "Air filled square coaxial transmission line and its use in microwave filters", *IEE proc. pt. H.,* Vol 152, No.3, June 2005, pp 155-159

[4] Pozar David M., *Microwave and RF wireless systems*, John Wiley & Sons, 2001

[5] Collin Robert E., *Fundations for microwave engineering*, McGraw-Hill, Second edition, 1992

[6] L. Gruner, "Higher order modes in square coaxial lines", *IEEE trans. on microwave theory and techniques*, Vol. 31, No 9, September 1983, pp 770-772.

[7] L. Gruner, Higher order modes in rectangular coaxial waveguides, *IEEE trans. on microwave theory tech.*, Vol. MTT-15, Aug. (1967), pp 483-485

[8] K.H. Lau, "Loss calculations for rectangular coaxial lines", *IEE proc. pt. H*, Vol. 135, No. 3, June 1988, pp. 207-209.

[9] Jia-Sheng Hong and M. J. Lancaster, *Microstrip filters for RF/Microwave applications*, John Wiley and Sons Inc, 2001

0-7695-2799-X/07 $20.00 © 2007 IEEE