Progress In Electromagnetics Research, Vol. 115, 79–94, 2011

COAXIAL NARROWBAND FILTERS USING A VERSATILE SUSPENDED RESONATOR

A. Jaimes-Vera and I. Llamas-Garro †

Centre Tecnologic de Telecomunicacions de Catalunya (CTTC)
Barcelona 08860, Spain

A. Corona-Chavez

National Institute for Astrophysics, Optics and Electronics
Puebla 72840, México

Abstract—In this paper, two four-pole filters at X-band are presented, both designs use a coaxial quarter wavelength resonator suspended in air by short circuits between the coaxial center and outer conductor. Different couplings between suspended resonators have been used to obtain a Chebyshev and a quasi-elliptic response. The Chebyshev filter was designed to have a 9.2 GHz centre frequency with a 4% fractional bandwidth. The second design is a quasi-elliptic filter composed of two vertically stacked rectangular coaxial lines, where one pair of resonators is placed on the lower coaxial line and another pair is located on the upper line. Coupling between coaxial lines is achieved through an iris in the common coaxial ground plane. The quasi-elliptic filter has been designed to have a centre frequency of 9.1 GHz with a 4% fractional bandwidth. Two transmission zeros located at the sides of the passband have been successfully achieved with the proposed filter topology. Experimental results for both designs are presented, where a good agreement with simulations has been obtained.

1. INTRODUCTION

Combline and interdigital filters have been widely used in many applications, such as cellular communications base-stations. Present filter generations for mobile communications require high performance

Received 4 February 2011, Accepted 17 March 2011, Scheduled 22 March 2011
Corresponding author: Ignacio Llamas-Garro (llamasi@ieee.org).
† A. Jaimes-Vera is also with Signal Theory and Communications Department, Technical University of Catalonia, 08034 Barcelona, Spain.

filters, with high selectivity and good out of band rejection, including device miniaturization. The performance of conventional filters can be improved by introducing transmission zeros at the sides of the bandpass response to achieve sharp selectivity with good out of band rejection [1–5].

Commonly coaxial-combline cavity filters with transmission zeros have been designed by means of coupling probes embedded in the filter fixture [6], also the use of extra cavities or small metal plates among the resonators [7, 8] have been used. The designs presented in this paper use a suspended resonator into a multilayer structure; allowing different coupling arrangements to produce electric, magnetic and mixed couplings, enabling quasi-elliptic function approximation or flat group delay responses, without using extra coupling probes, extra cavities or folded structures. The multilayer structure can provide a wide range of couplings, an easy introduction of cross couplings and size reduction [9–12]. The proposed resonator is a quarter wavelength long suspended by stubs, suitable for the design of narrowband filters using coaxial lines. A wideband coaxial filter can be found in [13]. This paper provides the design and implementation of a Chebyshev filter, a description of the feed line used to interconnect the devices with the measurement equipment, and a detailed design and characterization of a quasi-elliptic filter.

This paper presents the design and development of Chebyshev and quasi-elliptic filters at around 9 GHz, where only few works can be found [10, 14–16], since most of combline and interdigital filters are designed between 1 and 2 GHz for mobile communications. Table 1 shows a list of coaxial/combline/interdigital filters operating between 1 and 9 GHz including their most outstanding features. A comparison among combline or interdigital filters and the work presented in this paper has been done. The unloaded quality factor [17] for each design has been calculated from measured results using Eq. (1). Where the $g's$ are the lowpass element values, BW is the filter 3 dB bandwidth and IL is the mid passband insertion loss.

$$Q_0 = \frac{4.34 \sum_{i=1}^{n} g_i}{BW\ IL} \tag{1}$$

It is apparent from Table 1 that the devices presented in this paper have a quality factor between the high Q obtained through optimized conventional coaxial-combline designs and interdigital or microstrip-combline filters. The filters presented in this paper are made from planar metal layers; this implementation allows scaling the designs to millimeter wave frequencies, using micromachined structures [18].

The structures here presented were implemented into air-filled coaxial lines using stacked planar layers, avoiding radiation and

Table 1. Performance summary of coaxial, combline and interdigital filters operating in a frequency range from 1 to 9 GHz.

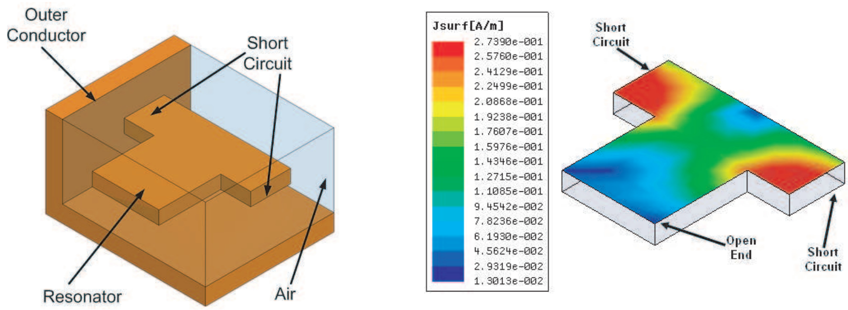
Primary Author	Chuma [19]	Zheyu [20]	Yi-Ming [21]	Yani [9]	Shih-Cheng [22]	Ying [8]	Huan [23]	Hoi-Kai [24]	Ting [25]	Tao [26]	Chi-Yang [27]	This paper	This paper
Year	2000	2008	2006	2005	2007	2009	2009	2004	2004	2007	2001		
Technology	Cx	Cb	Cb	In	Cb	Cx	Cx	In	In	Cb	In	Cx	Cx
Filter Function	E	C	E	E	E	E	E	B	B	C	C	C	E
Number of resonators	4	5	4	4	2	6	3	3	3	5	3	4	4
Central Frequency (GHz)	1.747	2.0175	2.4	2.25	1.43	1.54	1.73	0.7	0.9	9.6	9.5	9.2	9.1
Fractional Bandwidth (%)	4.3	0.75	4.2	31	11.5	3.2	4.5	12	15	8	10	5.7	2.88
Insertion Loss (dB)	0.46	1.49	1.2	1.0	2.78	-	0.77	1.3	1.5	1.93	2.5	1.07	1.7
Q_o from Eq.(1)	897	2602	352	57			343	139	96	188	56	355	166
Midband Return Loss (dB)	>15	>20	>25	>15	>18	>20	>17	>10	>9	>20	>12	>17	>20
Area (cm^2)			2.36	1.3	5.32			19.25	21	-	0.16		
Volume (cm^3)	57.5	30.34				284.47	90			-		23.14	29.03

Cx-Coaxial Filter Cb-Cbline Filter In-Interdigital Filter
E-Elliptic Function C- Chebyshev Function B-Butterworth Function

dielectric losses and crosstalk between adjacent lines. The use of a multilayer structure allowed size reduction and a wide range of possible couplings between versatile resonators. The introduction of cross couplings has been achieved without the use of additional cavities or coupling probes. These filters show a competitive response and a good balance among losses, size and quality factor; furthermore filter implementation using stacked planar layers allows scaling the devices to the millimeter wave region using micromachining techniques.

2. SUSPENDED COAXIAL RESONATOR AND FEED LINE

The quarter wavelength resonator suspended by short circuits inside an air filled rectangular coaxial cable used to design the filers presented in this paper is shown in Fig. 1(a). The resonator has the maximum magnetic field density next to the short circuited stubs, and the maximum electric field at the opposite side, as shown in Fig. 1(b)



(a) (b)

Figure 1. Suspended quarter wavelength resonator (a) Schematic of the quarter wavelength resonator (side and top walls removed for clarity). (b) Surface current distribution at a resonant frequency of 9.1 GHz.

where surface current distribution at the resonant frequency of 9.1 GHz is plotted. Therefore electric, magnetic and mixed couplings can be obtained by choosing adequate resonator configurations [28]. The different inter-resonator arrangements and coupling types that can be achieved with the proposed resonator are shown in Fig. 2. By placing the two short circuited sides of the resonator facing each other, as shown in Fig. 2(a), a magnetic coupling can be obtained. Electric coupling can be attained by placing side by side the open end of the resonators as shown in Fig. 2(b). It is apparent from Fig. 2 that the response of the electric and magnetic coupling arrangements are out of phase; these couplings have been used to produce the quasi-elliptic filter discussed in Section 4. Mixed couplings have been obtained by placing resonators on different coaxial layers, coupled by an iris on the common coaxial ground plane between them as shown in Fig. 2(c).

A suspended transmission line is used to interface the rectangular coaxial filters for measurements. Fig. 3(a) shows a photograph of the 50 Ω suspended feed line used to input/output energy to the filter in a *back-to-back* configuration. This transmission line has been optimized by simulations to minimize reflection losses at the transitions with round connectors. A slot on both sides of the feed line is used to mount SMA connectors (see Fig. 3(b)). This transmission line is formed by the union of five copper layers, the overall dimensions of the transmission line are $26 \times 29.8 \times 12\,\text{mm}^3$, and the technical drawing of layer 3 is presented in Fig. 3(b). The final feed line is a piece of coaxial transmission line all surrounded by air, and suspended by quarter wavelength transmission line stubs at the center frequency of

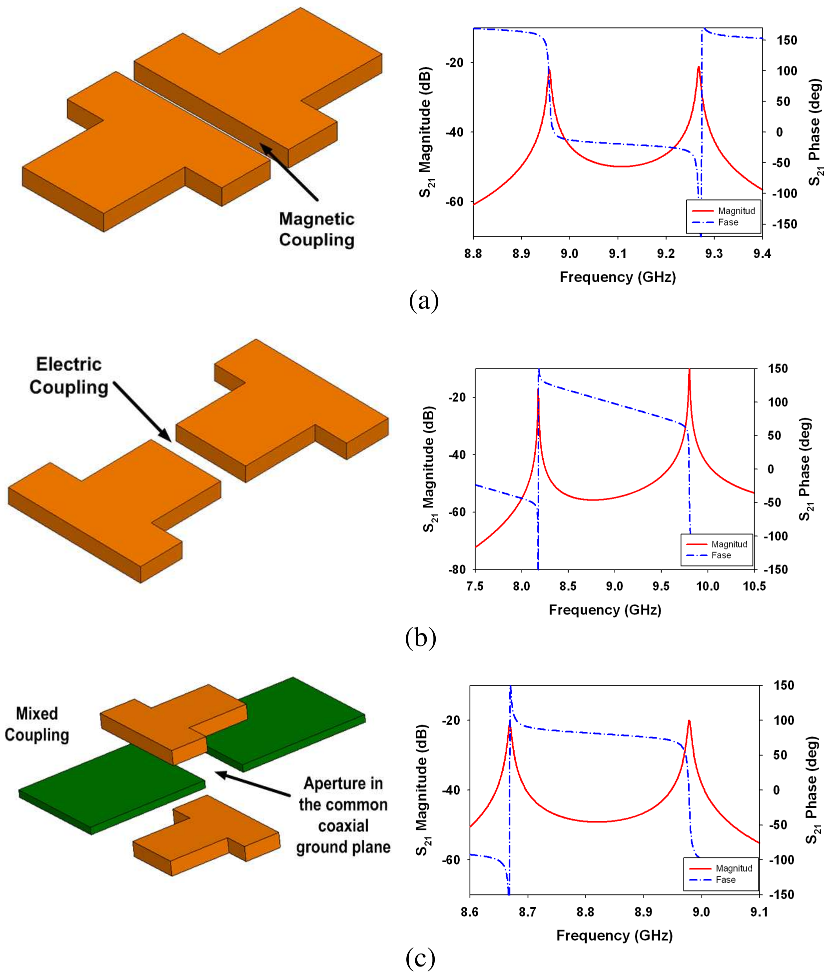
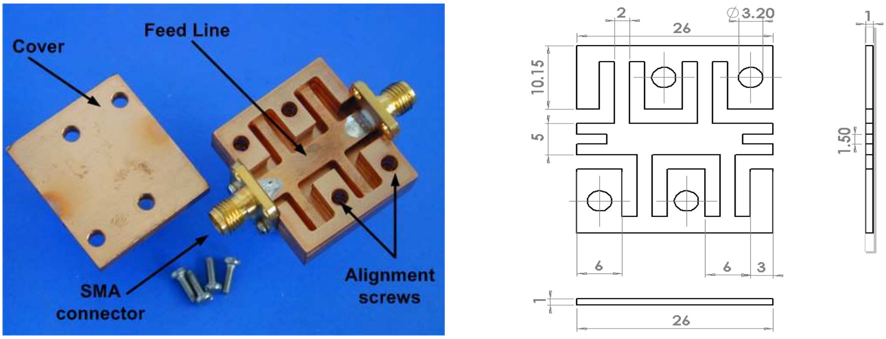


Figure 2. Inter-resonator couplings, (a) Magnetic coupling. (b) Electric coupling. (c) Mixed coupling.

the filters; resulting in an open circuit were the stub makes contact with the coaxial center conductor.

Simulated and measured results of the suspended transmission line in a *back-to-back* configuration are presented in Fig. 4. All simulations were done using HFSS considering a copper conductivity value of 5.8×10^7 S/m. The differences between the simulated and measured response is caused by fabrication tolerances related to the designs presented in this paper, which are discussed in detail in Section 5.



(a) (b)

Figure 3. Coaxial feed line in a *back-to-back* configuration (a) Photograph of the coaxial feed line. (b) Technical drawing of the coaxial feed line, layer 3 (dimensions in millimeters).

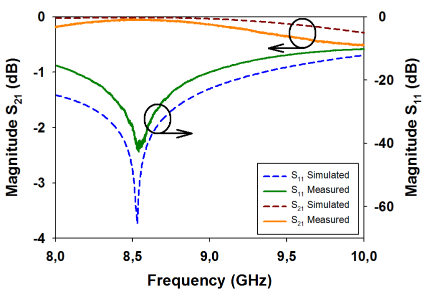


Figure 4. Simulated and measured response of the coaxial feed line in a *back-to-back* configuration.

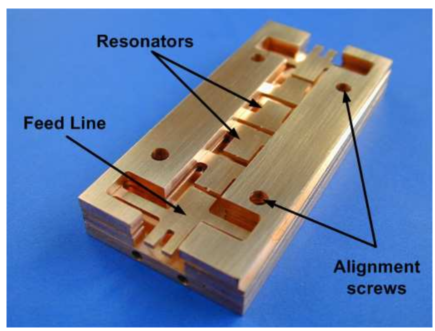


Figure 5. Photograph of the coaxial Chebyshev filter.

3. NARROWBAND CHEBYSHEV COAXIAL FILTER

In this section, a narrowband coaxial filter with a Chebyshev response is presented. The filter was designed using rectangular coaxial transmission lines, where the resonators are suspended along with the feed lines that provide the input/output to the device, as shown in Fig. 5. The entire topology is formed by five conductive layers stacked and compressed together to obtain the coaxial filter.

The design procedure for this filter follows the methodology provided in [17], which consists in calculating the coupling coefficients between resonators (K_{ij}) and the external quality factor (Q_e), achieved by full wave simulations using HFSS. The equations to obtain the theoretical couplings between resonators and the external quality factor can also be found in [17]. The design data and parameters used for this filter are summarized in Table 2, which contains the lowpass element g values, the required K_{ij} and Q_e for the design. The external quality factor (Q_e) obtained by electromagnetic simulations is shown in Fig. 6, similarly inter-resonator couplings (K_{ij}) are shown in Fig. 7. The filter was designed at 9.2 GHz with a 0.01 dB passband ripple and a 4% fractional bandwidth. A lumped element equivalent circuit for the Chebyshev filter is presented in Fig. 8.

The filter is formed by five layers, which are stacked and compressed together. Layer 3 is the main layer, which contains the four resonators and the feed lines, layers 2 and 4 create a coaxial cavity, and finally layers 1 and 5 shield the complete structure. The overall

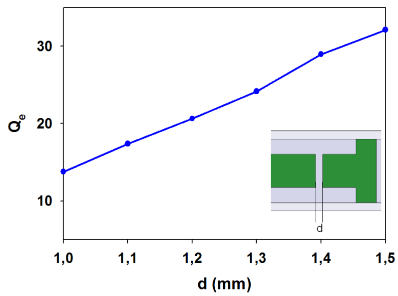


Figure 6. External quality factor (Q_e) for the coaxial filters.

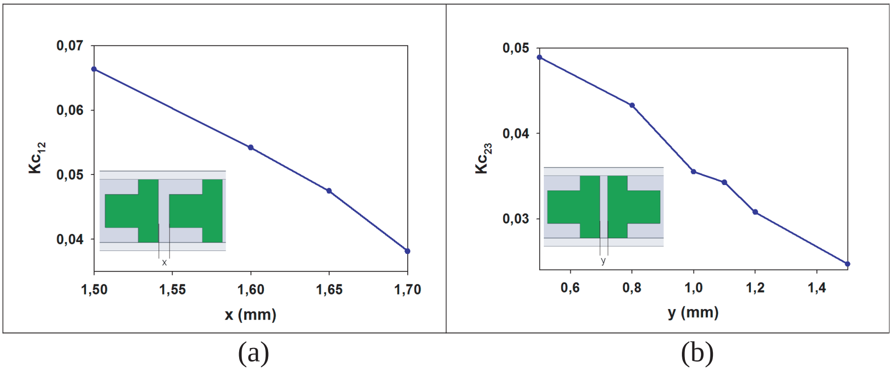


Figure 7. Coupling coefficients for the Chebyshev filter. (a) Coupling coefficient between resonators 1 and 2. (b) Coupling coefficient between resonators 2 and 3.

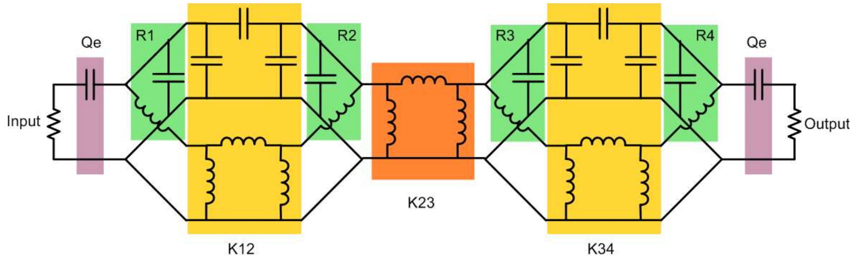


Figure 8. Equivalent circuit for the Chebyshev filter.

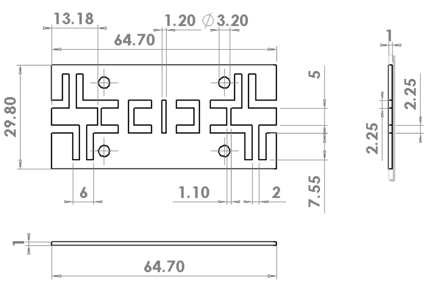


Figure 9. Technical drawing for layer 3 of the coaxial Chebyshev filter (dimensions in millimeters).

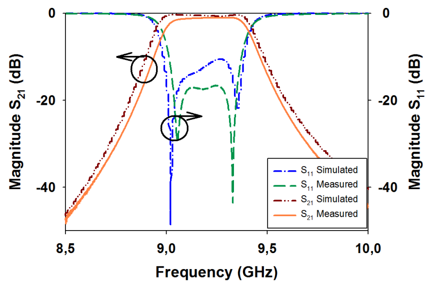


Figure 10. Chebyshev filter simulated and measured results.

Table 2. Chebyshev filter design parameters.

Number of resonators 4					
Filter lowpass element g values					
$g_0 = 1$	$g_1 = 0.7129$	$g_2 = 1.2004$	$g_3 = 1.3213$	$g_4 = 0.6476$	$g_5 = 1.1008$
Q_e and K_{ij}					
	$Q_{e1} = 17.82$	$Q_{e2} = 17.82$	$K_{12} = 0.043$	$K_{23} = 0.031$	

dimensions of the filter are $29.8 \times 64.7 \times 12\,\text{mm}^3$. Layers 1 and 5 are 3.25 mm thick, layers 2 and 4 are 2.25 mm thick, and layer 3 is 1 mm thick. Fig. 9 presents the technical drawing of layer 3. In Fig. 10, simulated and measured results of the filter are presented. A good agreement between theory and experiment has been obtained. A slight bandwidth reduction and insertion loss increase can been observed in measurements, caused by fabrication tolerances, layer misalignment and the effect of using nine brass tuning screws to obtain the measured response. The use of tuning screws allowed adjusting couplings (Q_e and K_{ij}) during measurements, which resulted in an improved S_{11} response with respect to simulations.

4. NARROWBAND QUASI-ELLIPTIC COAXIAL FILTER USING VERTICALLY STACKED COAXIAL LINES

A quasi-elliptic function filter is designed using two vertically stacked coaxial cables. Two resonators are placed on the upper coaxial line, and two others on the lower line along with the feed lines that provide the input/output to the device. The entire topology is formed by nine conductive layers stacked and compressed together to obtain the two coaxial transmission lines. An iris in the common coaxial ground plane allows the cross coupling arrangement between resonators. In Fig. 11, a schematic view of the layers that form the topology is presented (layers 1 and 9 have been omitted for clarity). The center conductors of the coaxial lines (layers 3 and 7) are shielded by layers 1, 2, 4 and 6, 8, 9 respectively. Layer 5 is the common coaxial ground containing two irises to couple between the adjacent coaxial lines.

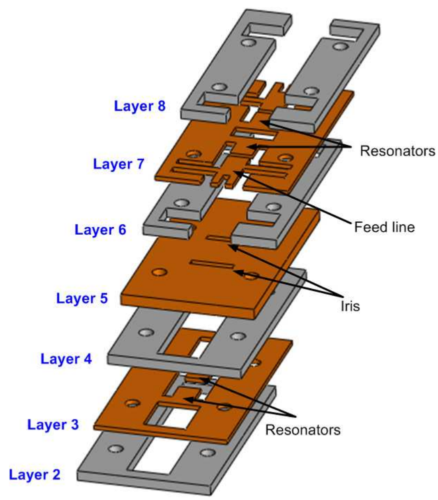
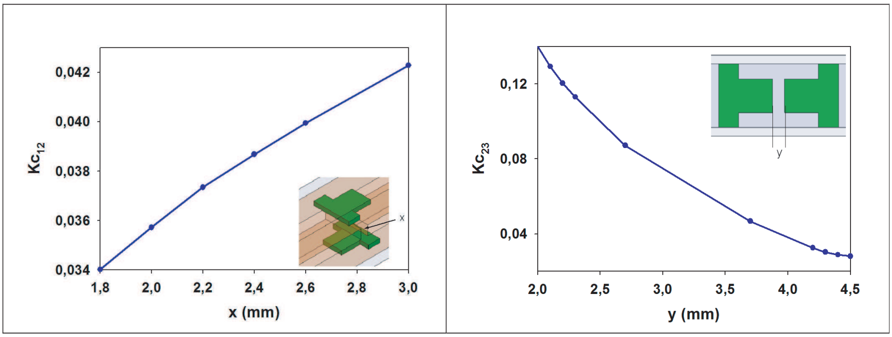


Figure 11. Exploded view of the quasi-elliptic filter (layers 1 and 9 omitted for clarity).

The design procedure for this filter follows the same methodology described in previous section. The design data and parameters used for this filter are summarized in Table 3, which contains the lowpass quasi-elliptic element g values, the required K_{ij} and Q_e for the design, where Ω_d relates to the position of the transmission zeros in a quasi-elliptic topology. K_{14} has a negative sign since this coupling is out of phase with respect to K_{23}. The external quality factor obtained by simulations for this design is shown in Fig. 6. In Figs. 12(a) and (b),

Table 3. Quasi-elliptic filter design parameters.

Number of resonators 4					
Lowpass filter element g values for $\Omega_d = 2.00$					
$g_0 = 1$	$g_1 = 0.95449$	$g_2 = 1.38235$	$g_3 \approx 1$	$J_1 = -0.16271$	$J_2 = 1.06062$
Q_e and K_{ij}					
	$Q_e = 23.862$	$K_{12} = K_{34} = 0.0348$	$K_{23} = 0.0307$	$K_{14} = -6.8 \times 10^{-3}$	



(a) (b)

Figure 12. Coupling coefficients for the quasi-elliptic filter (a) Coupling coefficient between resonators 1 and 2. (b) Coupling coefficient between resonators 2 and 3.

inter-resonator couplings between resonators 1–2 and 2–3 are shown, respectively. The coupling between resonator 1 and 4 is shown in Fig. 7(b). The filter was designed at 9.1 GHz with a 0.01 dB passband ripple and a 4% fractional bandwidth.

After obtaining the optimum spacing between resonators and feed lines, the filter can be realized. Fig. 13 shows a lumped element equivalent circuit for the quasi-elliptic filter. Fig. 14(a) shows two photographs of this filter, referring to Fig. 11, showing an open view of the two coaxial lines that compose this filter. Fig. 14(b) contains the technical drawings of the two center conductors for the coaxial lines (layers 3 and 7) and their corresponding dimensions. Overall dimensions of the filter are $29.8 \times 48.7 \times 20\,\text{mm}^3$. Layers 1 and 9 are 3.25 mm thick, layers 2, 4, 6 and 8 are 2.25 mm thick, layers 3 and 7 are 1 mm thick, and layer 5 is 2.5 mm thick.

Simulation and measurements of the filter are shown in Fig. 15, 8 simulations were done displacing the layers that compose the filter randomly, using values ranging between 100 and 300 µm (this misalignment range was extracted from the fabricated filter using an optical microscope). One of these simulations was arbitrarily

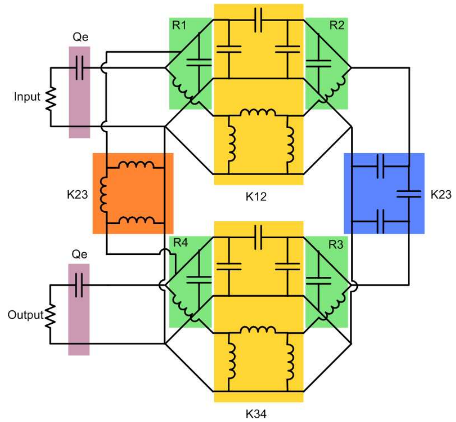


Figure 13. Equivalent circuit for the quasi-elliptic filter.

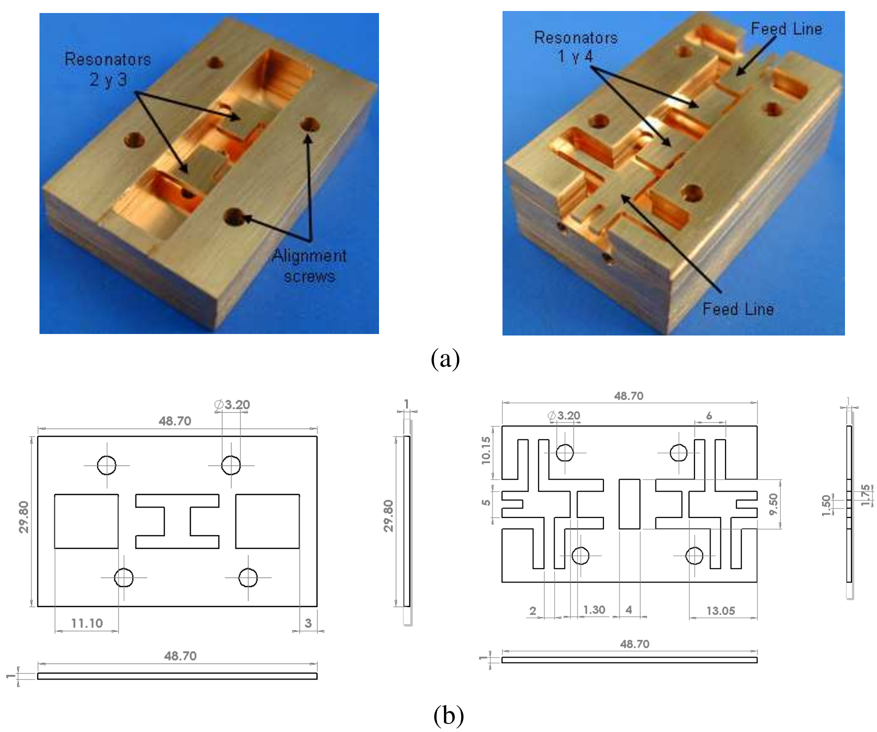


Figure 14. Quasi elliptic filter. (a) Open view photographs of the quasi-elliptic filter. (b) Technical drawings of layers 3 and 7 of the quasi-elliptic filter (dimensions in millimeters).

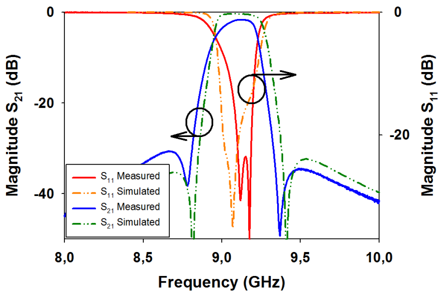


Figure 15. Simulated and measured results for the quasi-elliptic filter implemented on stacked coaxial lines.

selected to be included in Fig. 15. The effect of fabrication tolerances is discussed in detail in Section 5. A good agreement between simulated and measured results was obtained. The increase in losses is attributed to the use of eight brass tuning screws and a reduction in bandwidth which is associated with higher insertion losses in general filter implementation. The measured bandwidth decreased from 4% considered for the design to 2.88% experimentally, the simulation with misaligned layers showed a bandwidth of 3.44%. The transmission zero on each side of the passband was successfully achieved using the proposed vertically integrated coaxial filter topology.

5. TOLERANCE STUDY

This section presents an analysis of the fabrication tolerances associated with the devices presented in this paper. Fabrication tolerances include: layer misalignment, rounded corners and fabrication inaccuracies. Rounded corners arise from using a 2 millimeter diameter tool to manufacture main parts of the devices, layer misalignment is related to unwanted displacements between the layers that form the devices, and finally fabrication inaccuracies relate to deviations in the dimensions of each fabricated layer with respect to device blueprints.

A fabrication tolerance study has been carried out on the quasi-elliptic filter, to understand the inherent fabrication inaccuracies related with the devices presented in this paper. These tolerances have been characterized and studied. Firstly each piece of the device has been measured using an optical microscope and compared with the blueprints provided for their fabrication. A fabrication deviation inaccuracy between 40 and 100 μm has been observed on the pieces.

Using the optical microscope, the misalignment tolerances between layers have been extracted, and found to be in between 100 and 300 μm among layers. Misalignment tolerances have been simulated using HFSS to understand the diverse effects that these produce on the frequency response of the device (note that piece inaccuracy contributes to this overall misalignment among layers). Layer misalignment produces overlaps between layers that result in a reduction of coupling coefficients, producing bandwidth reductions between 7 and 23.8%. These overlaps also slightly change resonator dimensions, which causes slight frequency shifts on the filter response.

The effect of rounded corners present on the manufactured device has been studied. Through simulations, rounded corners on the resonators produce a 13.5% reduction in bandwidth with respect to a device presenting perfectly straight edges. Rounded corners on other parts of the device present negligible effects.

The combination of the diverse fabrication tolerances on implemented devices produces deviations in the filter measured responses with respect to simulations. In this section, the effect of each type of tolerance has been considered separately. Considering a simulation with all tolerances together has been avoided due to the complexity of the optical measurements and simulations, nevertheless good understanding of the deviations present in the responses due to fabrication tolerances has been addressed. Micromachining techniques can provide more precisely constructed layered devices operating at higher frequencies.

6. CONCLUSION

Two coaxial filters have been successfully designed and characterized at X-band using the proposed versatile suspended coaxial resonator, which allows the design of cross coupled filters. A new type of narrowband quasi-elliptic filter using vertically stacked coaxial lines has been presented. The filter uses cross-couplings to produce a quasi-elliptic response with a pair of transmission zeros. The filter implementation using planar machined metal layers allows scaling the designs to millimeter wave frequencies using micromachining techniques.

ACKNOWLEDGMENT

This work has been financed by research Project PIB2010BZ-00585 from the Spanish ministry of science and innovation.

Jaimes V. Aline wishes to thank CONACYT for scholarship No. 198264°.

All authors wish to thank Nahu Pérez Pérez at the Aspheric Surfaces Laboratory, Large Millimeter Telescope at the National Institute for Astrophysics, Optics and Electronics, Mexico for machining the prototype filter.

All authors wish to thank Joaquim Giner at the Signal Theory and Communications Department, Technical University of Catalonia, Barcelona, Spain, for polishing and assembling the device.

REFERENCES

1. Zhu, Y. Z., Y. J. Xie, and H. Feng, "Novel microstrip bandpass filters with transmission zeros," *Progress In Electromagnetics Research*, Vol. 77, 29–41, 2007.
2. Zhu, Y. Z., H. S. Song, and K. Guan, "Design of optimized selective quasi-elliptic filters," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 10, 1357–1366, 2009.
3. Wang, Y. X., "Microstrip cross-coupled tri-section stepped-impedance bandpass filter with wide stop-band performance," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 2–3, 289–296, 2009.
4. Shen, W., W.-Y. Yin, and X.-W. Sun, "Compact substrate integrated waveguide transversal filter with microstrip dualmode resonator," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 14–15, 1887–1896, 2010.
5. Wang, C., Z. Zhang, L. Shi, L. Shen, H. Liu, and D. Ahn, "Miniaturized hairpin filter using asymmetrical spurlines with multiple transmission zeros," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 2–3, 341–349, 2010.
6. Wang, C. and K. A. Zaki, "Full-wave modeling of electric coupling probes in comb-line resonators and filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 48, No. 12, 2459–2464, Dec. 2000.
7. Cogollos, S., R. J. Cameron, R. R. Mansour, M. Yu, and V. E. Boria, "Synthesis and design procedure for high performance waveguide filters based on nonresonanting nodes," *IEEE MTT-S International Microwave Symposium Digest*, 1297–1300, Honololu, Jun. 2007.
8. Wang, Y. and M. Yu, "True inline cross-coupled coaxial cavity filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, No. 12, 2958–2965, Dec. 2009.

9. Mu, Y., Z. Ma, and D. Xu, "A novel compact interdigital bandpass filter using multilayer cross-coupled folded quarter-wavelength resonators," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 12, 847–849, Dec. 2005.
10. Adam, H., A. Ismail, M. A. Mahdi, M. S. Razalli, A. Alhawari, and B. K. Esfeh, "X-band miniaturized wideband bandpass filter utilizing multilayer microstrip hairpin resonator," *Progress In Electromagnetics Research*, Vol. 93, 177–188, 2009.
11. Rebenaque, D. C., J. Pascual-Garcia, F. Q. Pereira, J. L. Gomez-Tornero, and A. A. Melcon, "Novel implementation of transversal filters in multilayered microstrip technology," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 8–9, 1241–1253, 2010.
12. Adam, H., A. Ismail, M. A. Mahdi, and A. R. H. Alhawari, "Compact wideband bandpass filter using hybrid hairpin and half wave parallel coupled resonator in multilayer microstrip configuration for X-band application," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 14–15, 1855–1865, 2009.
13. Zhang, Q. and Y. Lu, "Dimensional synthesis for wide-band band-pass filters with quarter-wavelength resonators," *Progress In Electromagnetics Research B*, Vol. 17, 213–231, 2009.
14. Ismail, A., M. S. Razalli, M. A. Mahdi, R. S. A. R. Abdullah, N. K. Noordin, and M. F. A. Rasid, "X-band trisection substrate-integrated waveguide quasi-elliptic filter," *Progress In Electromagnetics Research*, Vol. 85, 133–145, 2008.
15. Gu, J., Y. Fan, and Y. Zhang, "A X-band 3-D SICC filter with low-loss and narrow band using LTCC technology," *Journal of Electromagnetic Waves and Applications*, Vol. 23, No. 8–9, 1093–1100, 2009.
16. Wang, Z., Y. Jin, R. Xu, B. Yan, and W. Lin, "Substrate integrated folded waveguide (SIFW) partial H-plane filter with quarter wavelength resonators," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 5–6, 607–617, 2010.
17. Hong, J.-S. and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, John Wiley and Sons Inc., 2001.
18. Lancaster, M. J., J. Zhou, M. Ke, Y. Wang, and K. Jiang, "Design and high performance of a micromachined K-band rectangular coaxial cable," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No. 7, 1548–1553, Jul. 2007.
19. Chuma, J. M. and D. Mirshekar-Syahkal, "Compact dielectric loaded combline filter with low insertion-loss," *30th European Microwave Conference*, 1–4, Oct. 2000.

20. Wang, Z., Q. Wang, and Y. Zhai, "Design of an economical compact combline filter," *ICMMT 2008 International Conference on Microwave and Millimeter Wave Technology*, Vol. 1, 308–310, Apr. 2008.
21. Chen, Y.-M., S.-F. Chang, C.-C. Chang, T.-J. Hong, and W.-C. Lo, "A compact step-impedance combline filter with symmetric insertion-loss response and wide stopband range," *IEEE MTT-S International Microwave Symposium Digest*, 1209–1212, Jun. 2006.
22. Lin, S.-C., C.-H. Wang, Y.-W. Chen, and C. H. Chen, "Improved combline bandpass filter with multiple transmission zeros," *Asia-Pacific Microwave Conference*, 1–4, Dec. 2007.
23. Wang, H. and Q.-X. Chu, "An inline coaxial quasi-elliptic filter with controllable mixed electric and magnetic coupling," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, No. 3, 667–673, Mar. 2009.
24. Pang, H.-K., K.-M. Ho, K.-W. Tam, and R. P. Martins, "A compact microstrip $\lambda/4$-SIR interdigital bandpass filter with extended stopband," *2004 IEEE MTT-S International Microwave Symposium Digest*, Vol. 3, 1621–1624, Jun. 2004.
25. Ting, S. W., K. W. Tam, and R. P. Martins, "Novel interdigital microstrip bandpass filter with improved spurious response," *Proceedings of the 2004 International Symposium on Circuits and Systems*, Vol. 1, 984-7, May 2004.
26. Yang, T., R., Xu, and L. Xiao, "Compact combline bandpass filter using LTCC technology," *International Conference on Microwave and Millimeter Wave Technology*, 1–4, Apr. 2007.
27. Chang, C.-Y., "A novel CPW interdigital filter," *2001 Asia-Pacific Microwave Conference, 2001*, Vol. 2, 621–624, Dec. 2001.
28. Llamas-Garro, I. and A. Corona-Chavez, "Quarter wavelength self supported coaxial resonators for use in low-loss narrowband wireless communication filter design," *IEEE ICEEE 2006 3rd IEEE International Conference on Electrical and Electronics Engineering*, 347–350, Sep. 2006.