Publication Year	2014
Acceptance in OA@INAF	2023-01-20T15:21:31Z
Title	Low cost elliptic filter for wireless application
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DOI	10.1109/TELFOR.2014.7034519
Handle	http://hdl.handle.net/20.500.12386/32957

Low Cost Elliptic Filter for Wireless Application

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***Abstract* — In this paper we present a low cost 7-pole elliptic microwave filter. The operating band of the filter is between 2 and 5 GHz. The proposed filter has been designed and optimized both on a FR-4 substrate and on a paper substrate, using a commercial electromagnetic software, and finally fabricated on the FR-4 substrate.**

***Keywords* — Elliptic low pass filter applications, FR-4, paper substrate, microstrip seven-pole elliptic filter.**

I. INTRODUCTION

MOST components in microwave circuits, such as couplers, filters, dividers, can be realized with microstrip, where the device is constituted only by metallization on the substrate: this makes the microstrip circuits less expensive, more compact, lighter than their counterparts in traditional metallic waveguide, and can provide an excellent ease of integration with other components on a single board.

The microwave band is overcrowded, so that elliptic filters [1], presenting a steep transition between the in-band and out-of band ranges, are becoming more and more popular. As a matter of fact, elliptic filters [2] achieve the narrowest transition band for the same filter order in comparison to other filter types. Further, because the rippling effect is distributed across both the pass-and stop-bands in the elliptic filter, it is an excellent candidate for a low pass filter where the amount of error needs to be minimized on both sides of the cutoff frequency. Under this considerations, elliptic filters (and quasi-elliptic filters) are used for wireless communications (and WiMAX) and personal communication networks, because they have answered to specific demands of miniaturization, portability, low-manufacturing cost and high performance in RF and millimeter-wave wireless systems [3].

For WiMAX systems, it is necessary a channel selection filter with variable bandwidth [4]; in [5], a switched capacitor ladder structure and making use of the design of a 5th order elliptic filter (in CMOS technology) is presented, which its bandwidth is adjustable for WiMAX standard. Again, in [6] is presented a design of a single band 1X2 WiMAX RF FEM on a liquid crystalline polymer (LCP) based organic substrate. In this case too, the front end module design is made up of an inductively coupled pseudo-elliptic band pass filter. In recent years, the design and implementation of these filters with high-temperature superconduction (HTS) and on unconventional substrate like paper (due to an increasing interest in addition to the interest for environmental friendly electronics [7]) has been presented. In HTS technology, this leads to an increased sensitivity and selectivity; planar HTS technology also allows to create filtering devices with compact size and could provide more performance not achievable with any other technology [8]. The HTS receiver front-end subsystems of the base station for wireless communications have been widely investigated over the past several years [9]. There are several papers reported on extremely narrowband highly selective HTS filter [10] for third-generation wireless communication applications and other applications like radio astronomy [11].

The use of unconventional substrate is due to the continued demand for adaptability, space, light weight and cost savings. Paper, in particular, is a low-cost substrate since it is organic, and thus, universally available; together with the radio frequency identification (RFID) and wireless sensors, paper represents one of the most important fields of interest [12]-[13].

In this paper we report the electromagnetic design of a 7-pole elliptic microwave filter using a paper substrate. In order to validate this approach, the proposed filter has been first designed and optimized using Sonnet software, and finally fabricated on the FR-4 substrate.

II. FILTER DESIGN

Fig. 1 illustrates two commonly used network structures for elliptic function low pass filters [14]. In Fig. 1(a), the series branches of parallel-resonant circuits are introduced for realizing the finite-frequency transmission. For the dual realization form in Fig. 1(b), the shunt branches of series-resonant circuits are used for implementing the finite-frequency transmission zeros. Either form may be used, because both give the same response [15].

The main specifications of the chosen prototype are:

Cutoff frequency @ 3 dB = 2.05 GHz
Insertion Loss L_{AS} @ 2.25 GHz < -30 (or -25) dB
Return Loss LR < 15 dB

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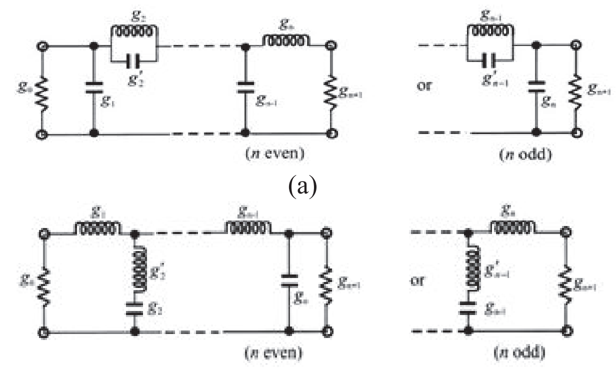


(a)

(b)

Fig. 1. Low pass prototype filters for elliptic function filters with (a) series parallel-resonant branches, (b) its dual with shunt series-resonant branches.

The degree for an elliptic function low pass prototype to meet a given specification may be found from design tables such as Table 3.3 [15]. For instance, considering Ω_s, which is the equal-ripple stop band starting frequency, and the pass band ripple factor L_{AR}, calculated considering the return loss value, we can determine immediately $n = 7$, which is the order of the elliptic filter. The element values g_i for elliptic function lowpass prototype filters may be obtained from the same table assumption $Z_{low} < Z_0 < Z_{high}$, all inductors are realized using high-impedance lines with characteristic impedance Z_{high}=122Ω, whereas all capacitors are realized using low-impedance lines with characteristic Z_{low}=26Ω. All relevant microstrip design parameters (listed in Table 1), are calculated considering the open-end effect for the capacitive lines and using the design equations presented in [15, Ch.4].

- For $\frac{W}{h} < 2$

$$\frac{W}{h} = \frac{8\exp(A)}{(\exp(2A) - 2)}$$

Where, $A = \frac{Z}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}(0.23 + \frac{0.11}{\varepsilon_r})$

- For $\frac{W}{h} > 2$ (1)

$$\frac{W}{h} = \frac{2}{\pi}[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\{\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\}]$$

Where, $B = \frac{60\pi^2}{Zc\sqrt{\varepsilon r}}$

The microstrip filter is designed to have a cutoff frequency f_c=2.05GHz and input/output terminal impedance Z_0=50Ω.

Therefore, the L-C element values, which are scaled to Z_0 and f_c, can be determined by

$$\mathrm{L}_i = \frac{1}{2\pi \mathrm{f}_c} z_0 g_{Li} \qquad \mathrm{C}_i = \frac{g_{Ci}}{2\pi \mathrm{f}_c z_0} \qquad (2)$$

while initial physical lengths of the high and low impedance lines for realization of the desired L-C elements can be obtained according to the design equations

$$\beta l = \frac{\omega cL}{Zhigh} \qquad \beta l = \omega cZlowC$$

(3)

Where the propagation constant depends on the effective dielectric constant of the considered substrate.

III. PROPOSED OPTIMIZATION TECHNIQUE

Initial dimensions of the circuit lines don't meet the design specifications because of the approximation involved, mainly (3). This section presents the our iterative method of gradual optimization to design two low pass filters on different substrates. Acting only on the width of the three capacitors, which affect very specific frequency bands within the range of our interest (from 0 to 5GHz), it is possible to obtain the desired cut-off frequency while maintaining a good slope and a shape to ensure an acceptable agreement with the design specifications.

After an initial parametric analysis on the three capacitors, to get their effect on the complete S-matrix, a cut-and try procedure has been performed to get the final design.

Acting on the only capacitive widths with small successive corrections, leads to the optimized dimensions for the two devices (Table 1, 2).

IV. SIMULATION AND MEASURED RESULTS

In this paper, two elliptic low pass filters on different substrates have been designed and simulated using the simulation software Sonnet, to validate the proposed concept.

A. Elliptic low pass filter on FR-4 substrate

The first device has been designed, simulated and fabricated using a FR-4 substrate with 1.6 mm height and dielectric constant ε_r=4.3. The thickness of copper is 0.035 mm and the loss tangent (tanδ) is 0.02. The design is verified by Sonnet EM Simulation, a full-wave analysis engine which takes into account all possible coupling mechanisms. The strip are connected to SMA connectors R125.414.000 by two tapered matching lines. In order to have a meaningful comparison between the simulated and measured results, the fabricated filter is evaluated by extracting its S_{11} and S_{21}. The simulated and measured data are overlapped in order to have better insight for comparison. The layout of the microstrip filter with n=7 is given in Fig. 2; the fabricated filter on FR-4 substrate is illustrated in Fig. 3 while Fig. 4 shows the simulated (using Sonnet EM Simulator) and measured (using ROHDE&SCHWARZ ZVA 67 Vector Network Analyzer and the ZV-Z218 calibration kit) frequency responses of this filter: it is evident that the measured results are in excellent agreement with the simulated values.

TABLE 1: INITIAL AND OPTIMIZED DIMENSIONS OF THE ELLIPTIC LOW PASS FILTER (FOR N=7) ON FR-4 SUBSTRATE.

Section ***l_i*** ***[mm]***	***Z_{high} or Z_{low}*** ***[Ω]***	***Initial Widths*** ***[mm]***	***Optimized Widths*** ***[mm]***
l_{L1} = 4.14	122	0.38	0.38
l_{C2} = 5.45	26	8.06	7.35
l_{L3} = 4.94	122	0.38	0.38
l_{C4} = 1.63	26	8.06	5.47
l_{L5} = 3.8	122	0.38	0.38
l_{C6} = 2.17	26	8.06	5.47
l_{L7} = 1.84	122	0.38	0.38
l_{L2} = 1.54	122	0.38	0.38
l_{L4} = 9.93	122	0.38	0.38
l_{L6} = 9.93	122	0.38	0.38
$l_{50Ω}$ = 10	50	3.1	3.1

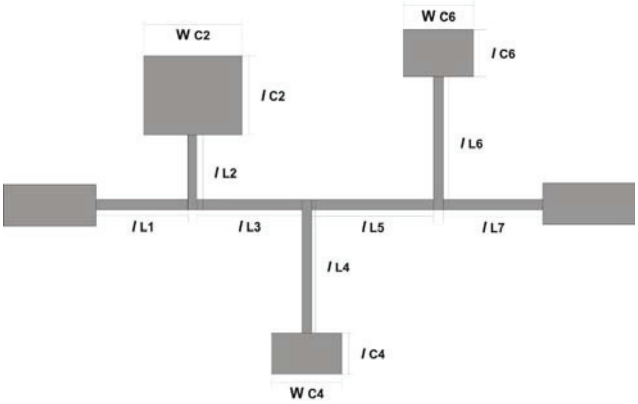


Fig. 2. Layout of the 7-pole Elliptic Low Pass Filter.

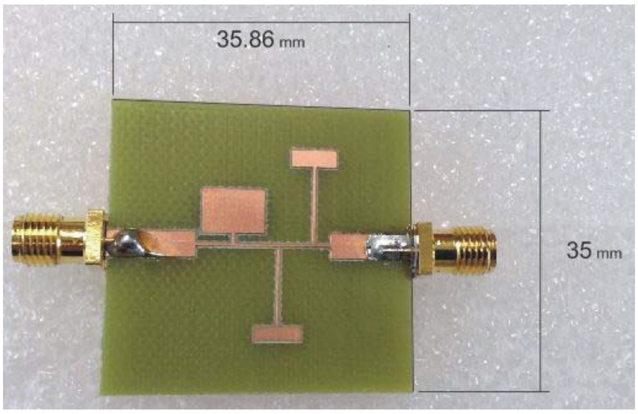
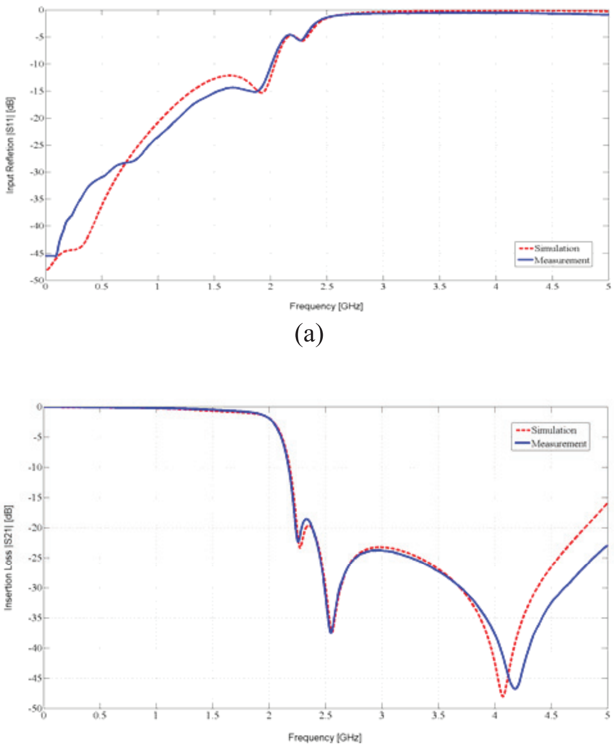


Fig. 3. Fabricated Elliptic Low Pass Filter on FR-4 substrate.



(a)

(b)

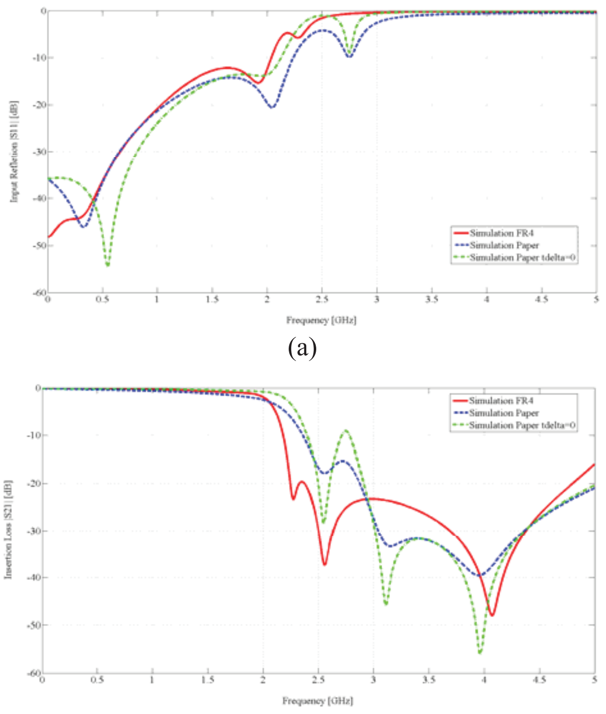
Fig. 4. Comparison of simulated (dashed lines) and measured (continuous lines) performance for the Elliptic Low Pass Filter n=7 on FR-4 substrate, (a) S_{11} parameters, (b) S_{21} parameters.

B. *Elliptic low pass filter on Paper substrate*

The second device has been designed and simulated using a paper substrate. We selected a 0.26 mm dielectric substrate thick, with a thickness of copper 0.035 mm, a dielectric constant $\square_r$=3.3 and a loss tangent of 0.08. Fig. 5 shows the comparison between S-parameters on FR-4 and paper substrate. Since the main problem of paper substrate [16] is the high dielectric losses, we shown also the responses with tanδ=0.

TABLE 1: INITIAL AND OPTIMIZED DIMENSIONS OF THE ELLIPTIC LOW PASS FILTER (FOR N=7) ON PAPER SUBSTRATE.

Section ***l_i*** ***[mm]***	***Z_{high} or Z_{low}*** ***[Ω]***	***Initial Widths*** ***[mm]***	***Optimized Widths*** ***[mm]***
l_{L1}=4.79	122	0.1	0.1
l_{C2}=7	26	1.53	1.08
l_{L3}=5.72	122	0.1	0.1
l_{C4}=2.56	26	1.53	0.4
l_{L5}=4.39	122	0.1	0.1
l_{C6}=3.2	26	1.53	0.76
l_{L7}=2.14	122	0.1	0.1
l_{L2}=1.79	122	0.1	0.1
l_{L4}=11.52	122	0.1	0.1
l_{L6}=11.52	122	0.1	0.1
$l_{50Ω}$=5	50	0.62	0.62



(a)

(b)

Fig. 5. Comparison between Scattering parameters S_{11} (a) and S_{21} (b): on FR-4 substrate (continuous lines); on Paper substrate with tanδ=0.08 (dotted lines) and with tanδ=0 (dashed lines).

V. RESULTS AND DISCUSSION

Fig. 4 presents the comparison of input reflection (S_{11}) and insertion loss (S_{21}), obtained by Sonnet EM simulation, and the measured results for the filter prototype designed on FR-4 substrate. It is clear that the result achieved show an excellent agreement with the specifications; the overlapped curves show the same cutoff frequency (2.05 GHz) and a very small difference of decibels at 2.25 GHz: the simulated insertion loss is -19.2 dB while the measured one is -21 dB. The resulting comparison between FR-4 and Paper substrate is showed in Fig. 5. It can be observed that the scattering parameters are similar but they show a different slope; in particular, filter designed on FR-4 substrate shows a better slope than the filter designed on Paper substrate. The discrepancy is due to a different dielectric loss tangent; a lower value of loss tangent (0.02 on FR-4) allows to have a more pronounced slope compared to a greater value (0.08 on Paper); therefore, it has been shown that FR-4 substrate allows to have a greater selectivity than Paper substrate. Considering in Fig. 5(b) a 0 loss tangent on the paper substrate, it can be observed that the two slopes are very similar.

VI. CONCLUSIONS

In this paper two microstrip elliptic low pass filters on different substrates were described. In particular, filter on the commercial FR-4 substrate was fabricated using a LPKF Printed Circuit Board ProtoMat C100 prototyping machine and its parameters were measured using Vector Network Analyzer. From the measured results it is evident that it corresponds well to the simulated model. The fabricated elliptic low pass filter could be used in wireless applications and for the IF section of the Sardinia Radio Telescope, with significant simplification and cost reduction.

ACKNOWLEDGMENT

Alessandro Fanti gratefully acknowledges Sardinia Regional Government for the financial support (P.O.R. Sardegna F.S.E. Operational Programme of the Autonomous Region of Sardinia, European Social Fund 2007-2013 - Axis IV Human Resources, Objective l.3, Line of Activity l.3.1 Avviso di chiamata per il finanziamento di Assegni di Ricerca).

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