DESIGN OF A COMBLINE MICROWAVE CAVITY FILTER FOR THE E1 GALILEO BAND

E. Boni(1), G. Giannetti(1), S. Maddio(1)

(1) Department of Information Engineering, University of Florence
Piazza San Marco 4, I-50121 Firenze, Italy.
giacomo.giannetti@unifi.it

Abstract

A combline microwave cavity filter for the E1 Galileo band (1559-1591 MHz, fractional bandwidth (FBW) equal to 2%) is designed and simulated. The standard approach low pass prototype-bandpass-inverter coupled resonator is followed and for the realization the combline cavity filter type is chosen. The filter presents post-production tuning capabilities mitigating manufacturing tolerances. For the lumped prototype a 5^{th}*-order Chebyshev filter with 0.5 dB ripple is considered. A good agreement between the Chebyshev prototype and simulations is achieved in passband.*

Index Terms *– Combline microwave cavity filter, E1 Galileo band, filter design.*

I. INTRODUCTION

Microwave filters are commonly used in satellite communications thanks to their high selectivity that allows to filter out signals that are close in the frequency spectrum [1], [2]. We are interested in a L-band microwave filter that receives the E1 Galileo signal ($1559 - 1591$ MHz) [3] and that filters out the Iridium signal ($1616 - 1626.5$ MHz) [4]. Particularly, we need this filter to equip *LaBarchettaMagica* [5], [6], a demonstrator of an autonomous ship.
In Section II. the specifications for the filter are provided, the combline microwave cavity filter is designed following the standard approach low pass prototype-bandpass-inverter coupled resonator and the filter dimensions are calculated considering the combline cavity filter type for the implementation. Then in Section III. the results for the bandpass prototype and those from simulations are compared. Finally, conclusions are drawn in Section IV..

II. FILTER DESIGN

The specifications for the designed filter are determined by the frequency bands of the desired and undesired signals. Then, the lower and upper passband frequencies match those of the E1 Galileo band, that is, 1559 MHz

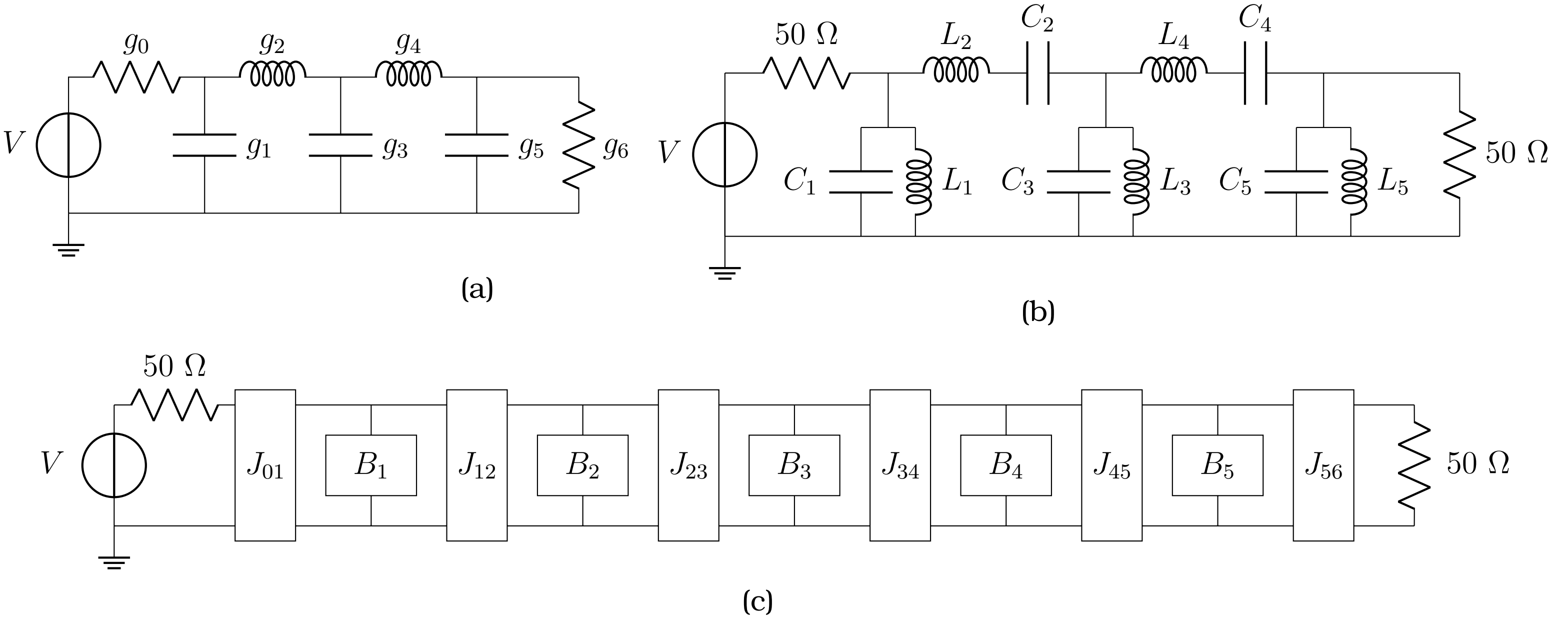

Figure 1: Standard approach to filter design: **a**, low pass prototype; **b**, bandpass prototype; **c**, admittance inverter coupled resonators.

and 1591 MHz, respectively. The upper stop band frequency is the lower frequency of the Iridium signal, that is, 1616 MHz. For the sake of symmetry, the lower stop band frequency is taken equal to 1534 MHz. The attenuation at the lower and upper stop band frequencies must be at least 20 dB. The center frequency is $f_0 = 1575$ MHz, the bandwidth $\mathrm{BW} = 32$ MHz and the fractional bandwidth $\mathrm{FBW} = \mathrm{BW}/f_0 = 2\%$.

The standard approach to filter design using a) low pass prototype, b) bandpass, and c) inverter coupled resonators is depicted in Fig. 1. For the filter prototype we opted for a 5th-order Chebyshev prototype with 0.5 dB ripple. The immittance values for the low pass prototype are $g_0 = g_6 = 1$, $g_1 = g_5 = 1.7058$, $g_2 = g_4 = 1.2296$, $g_3 = 2.5409$ [7]. In Fig. 1a the immitances with even indexes are impedances while those with odd indexes are admittances; g_0 and g_6 represent the source and load resistances, respectively.

The bandpass filter is obtained from the low pass prototype denormalizing with respect to a) resistance and b) frequency. The formulae for the denormalization with respect to the resistance are: $L' = R_0 g_{2,4}$, $C' = g_{1,3,5}/R_0$, $R_s = R_0 g_0$, $R_l = R_0 g_6$, where $R_0 = 50\,\Omega$, and L', C', R_s, and R_l are the denormalized inductances, capacitances, source and load resistors, respectively. The frequency transformation is: $j\omega = Q\left(j\omega/\omega_0 + \omega_0/j\omega\right)$, where j is the imaginary unit, ω' is the angular frequency for the low pass prototype, ω the angular frequency for the bandpass prototype, $\omega_0 = 2\pi f_0$, and $Q = 1/\mathrm{FBW}$ the quality factor of the filter. The frequency transformation transforms the shunt

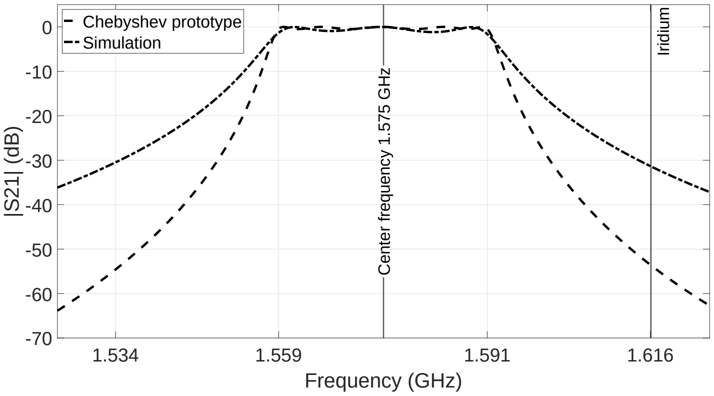

Figure 2: Filter responses for the Chebyshev prototype and simulation.

capacitances of the low pass prototype filter into shunt resonators and the series inductances into series resonators [7]. The unloaded resonance frequencies for all resonators is the center frequency, $f_0 = (2\pi\sqrt{L_i C_i})^{-1}$.

For realization it is advisable to have only shunt or series resonators. The combline cavity filter implementation that we chose requires shunt resonators. Then the series resonators are transformed into shunt resonators by means of admittance inverters, as shown in Fig. 1c, where the B_i is the susceptance of the i^{th} shunt resonators and $J_{i,i+1}$ the admittance inverter between the i^{th} and $(i+1)^{\text{th}}$ shunt resonators [7].

The technical drawing of the filter and its main dimensions are depicted in Fig. 3. This is composed by shunt resonators realized by means of shorted transmission lines whose physical length is $L = \lambda_0/8 = 23.8$ mm, being λ_0 the wavelength at f_0 in vacuum. The resonator line admittance Y_{ai} is chosen equal to $1/70$ S to give good resonator unloaded Q's [7]. The impedance Z_{IN} at the free end of a short circuited line with characteristic impedance $Z_{ai} = 1/Y_{ai}$ is given by $Z_{IN} = jZ_{ai}\tan(\theta_0)$, being $\theta_0 = \pi/4$ the electrical length at f_0. Then, the short circuited line behaves as an inductance of value $L_i^s|_{i=1 \text{ to } n} = Z_{ai}/\omega_0$. The values of the distributed capacitances are $C_i^s|_{i=1 \text{ to } n} = 1.4$ pF and are found applying the condition $L_i^s C_i^s = \omega_0^{-2}$ to the shunt resonators. The gap $G = 4$ mm between the free ends and the ceil of the cavity contributes to the distributed capacitance. The rest of the distributed capacitance is achieved by means of tuning screws penetrating into holes drilled inside the resonators. The screw diameter is $D = 3$ mm, the diameter of the resonator holes is $D_i = 5.5$ mm. The addition of post-manufacturing tuning elements allow to mitigate the manufacturing tolerances. To enhance the possibility of post manufacturing tuning, four coupling screws with diameter D are placed in the middle between adjacent resonators. The outer resonators are fed by means of coaxial cables entering the cavity at an height of $H = 20$ mm. The cavity width is chosen to be $b = 16$ mm while the distances

$S_{i,i+1}$, $i = 1, 2, 3, 4$ between resonators and their diameter are evaluated from the curves expressing the capacitance toward ground and the coupling capacitance between adjacent resonators for a coupled stripline with rectangular conductors [7], [8]. The rectangular striplines are then converted to circular ones equating the perimeters. For easiness the diameter D_0 of each resonator is set equal to the average diameter. The spacing between resonators is decreased by 5% while the diameter is increased by 5% to reduce 'cut and try' effort [8]. Eventually, the distance between end resonators and cavity walls is fixed to $E_g = 8$ mm. Table I lists the physical dimensions.

Table I: Physical dimensions of the technical drawing in Fig. 3.

Parameters	b	$S_{12} = S_{45}$	$S_{23} = S_{34}$	E_g	L	G	H	D	Di	Do
Value (mm)	16	15.7	17.0	4	23.8	4	20	3	5.5	7.7

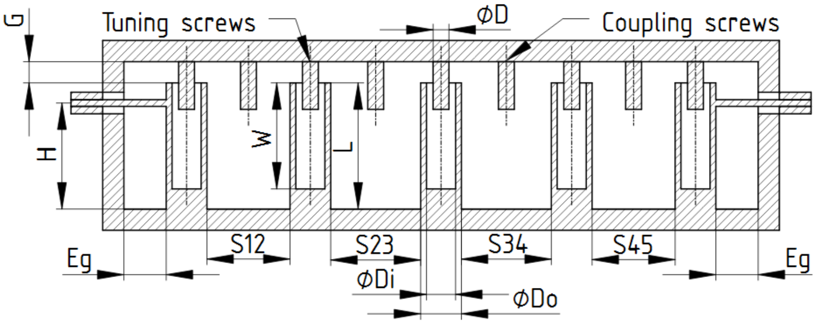

Figure 3: Technical drawing of the filter. The width of the cavity is b.

III. RESULTS

The designed filter is modelled and simulated in HFSS [9]. Here the penetration of both tuning and coupling screws is varied to tune the filter. Figure 2 compares the results for the bandpass Chebyshev prototype and the simulation, showing a good agreement in passband and the fulfillment of the specifications. The discrepancy between the two responses outside the passband is due to the fact that the distributed shunt resonators well approximate the lumped resonators only around the center frequency.

IV. CONCLUSION

A combline microwave cavity filter for the E1 Galileo band is designed following the standard approach low pass prototype-bandpass-inverter coupled resonators. A 5^{th}-order Chebyshev prototype with 0.5 dB ripple is selected to fulfill the requirements. For the realization the combline cavity filter type is chosen and the resonators are realized by means of shorted transmission lines loaded with distributed capacitances. The results for the Chebyshev prototype and those from the simulations are compared and a good agreement is found in the passband. The future developments are to realize and characterize the filter, and to exploit it for the satellite link of *LaBarchettaMagica* [5], [6].

REFERENCES

[1] E. Judith Sen, N. Shanil Mohamed, K. S. Smitha, S. Joy, T. J. Apren, and K. K. Mukundan, "Design of L band cavity filter for GPS receiver," in *2016 International Conference on Communication Systems and Networks, ComNet 2016*, 2017. DOI: `10.1109/CSN.2016.7824022`.

[2] J. Zhang, C. J. You, Z. Jiao, J. Zhu, Q. Xiao, and J. Cai, "A tunable LTCC fourth-order bandpass filter with high selectivity for L-band satellite applications," *Microwave and Optical Technology Letters*, vol. 63, no. 4, 2021, ISSN: 10982760. DOI: `10.1002/mop.32709`.

[3] C. J. Hegarty, "GNSS signals - An overview," in *2012 IEEE International Frequency Control Symposium, IFCS 2012, Proceedings*, 2012. DOI: `10.1109/FCS.2012.6243707`.

[4] S. R. Pratt, R. A. Raines, C. E. Fossa, and M. A. Temple, "An operational and performance overview of the IRIDIUM low earth orbit satellite system," *IEEE Communications Surveys & Tutorials*, vol. 2, no. 2, 2009, ISSN: 1553-877X. DOI: `10.1109/comst.1999.5340513`.

[5] E. Boni, M. Montagni, and L. Pugi, "Project VELA, Upgrades and Simulation Models of the UNIFI Autonomous Sail Drone," in *Lecture Notes in Electrical Engineering*, vol. 627, 2020. DOI: `10.1007/978-3-030-37277-4{\_}45`.

[6] M. Montagni. "Labarchettamagica." (2016), [Online]. Available: `http://www.labarchettamagica.it/` (visited on 05/27/2022).

[7] G. Matthaei, "Microwave filters, impedance-matching networks and coupling structures," *Artech House Book*, pp. 775–809, 1980.

[8] D. Natarajan, "A practical design of lumped, semi-lumped and microwave cavity filters," *Lecture Notes in Electrical Engineering*, vol. 183, 2013, ISSN: 18761100. DOI: `10.1007/978-3-642-32861-9{\_}1`.

[9] "Ansys — engineering simulation software." (2022), [Online]. Available: `https://www.ansys.com/` (visited on 05/28/2022).