A Novel Compact Suspended Stripline Resonator

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***Abstract*—Suspended stripline (SSL) provides a transmission line medium featuring many advantages, but due to the effective permittivity being close to unity, distributed elements are usually bulky. This letter introduces a novel SSL resonator, which is both compact and low loss. For that purpose, cuboid shaped bricks of metal are incorporated into the SSL channel in the vicinity of the open-circuited side of the resonator. Through this capacitive loading, the area occupied by the resonator can be reduced by a factor of about 5, yet maintaining a high quality factor. The feasibility of this new resonator type is demonstrated with an example bandpass filter at 670 MHz center frequency showing both compact size and low insertion loss.**

***Index Terms*—Bandpass filter (BPF), compact-sized, low-loss, suspended stripline (SSL) filter.**

I. Introduction

SUSPENDED stripline (SSL) has proven to be an excellent transmission line system to realize various types of filters ([1], [2]). A larger cross section as compared to other planar transmission lines results in lower current densities, therefore reducing metallization loss. Typically, thin substrates are used, helping to keep dielectric loss low as well, since the major part of the electric field is located in air, which also results in low dispersion of the line. Furthermore, no radiation occurs thanks to the fully shielded assembly of the SSL.

A major drawback of this technique is the channel itself, usually built as a split block, as it requires additional fabrication effort. Some work has been conducted to tackle this issue. In [3], the lower cap is replaced by a thick FR4-substrate which has a microwave substrate laminated on top of it. The lower cap is then formed by via rows and bottom side metallization. In [4], the whole SSL is integrated into a stack of silicon by means of micro-machining.

Due to its shape, the SSL channel is capable of supporting rectangular waveguide mode propagation, which often imposes an upper frequency bound on devices realized with this transmission line medium.

Another flaw of SSL, when compared to microstrip or coplanar line, is the usually large size of transmission line elements. This is due to a considerable amount of electromagnetic field being located in air, resulting in an effective dielectric constant close to unity. To cut dimensions down, quasi-lumped elements can be used ([2]). In [5], a special coupling structure is presented for reducing the lengths of the distributed resonators.

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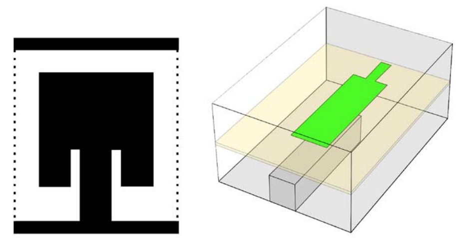

(a) (b)

Fig. 1. SSL resonator as used in [2] (a). Isometric view of the proposed novel SSL resonator (b). The metallization is located on the bottom side of the substrate. For dimensions see Fig. 2(c).

In this letter, a novel resonator structure is presented, which is compact compared to previous resonators, yet offering comparable quality factors. Section II introduces the novel resonator; its properties are checked against previous resonators. Section III presents a fifth order bandpass filter employing the new resonator. Simulated and measured responses are provided.

II. Novel Resonator

Fig. 1(a) shows the top view of a quasi-lumped SSL resonator used in [2], approximating a parallel LC-circuit. By means of edge-coupling, this resonator can be used for realizing bandpass filters.

In order to miniaturize the resonator, the following possibilities can be exploited:

- Increase the impact of the inductive part. This can be achieved by narrowing the strip width or increasing the length of the inductive strip. With regard to Fig. 1(a), one may also increase the inset of the inductive part. However, all of these methods tend to increase metallization loss. Since this is the dominant loss mechanism within the SSL, the unloaded quality factor of the resonator will be heavily degraded.
- Increase the impact of the capacitive part. This can be achieved by narrowing the SSL channel, making the gap between the open end of the resonator and the opposing wall as small as possible, though the gain in capacitance is moderate. Lowering the channel height increases the capacitance but at the same time weakens the inductance. Another method is to use a backside metallization connected to the ground potential, opposite to the location of the capacitive part. That way, within the area of overlapping, the electric field is mostly confined to the dielectric which, together with the reduced metal separation, increases the capacitance significantly. The drawback of this method is the increasing dielectric loss.

The novel idea in this letter is to achieve an enhancement in resonator capacitance, therefore miniaturizing its size without diminishing the quality factor.

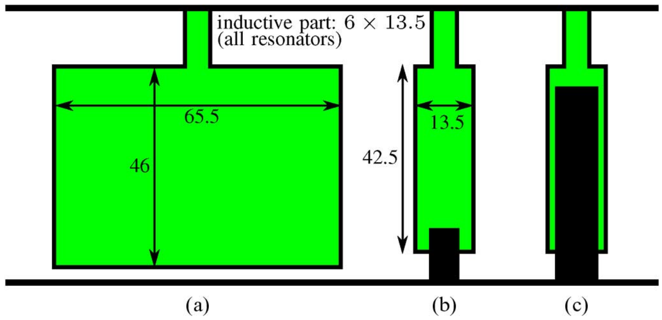

Fig. 2. Size comparison of different SSL resonators. Conventional resonator (a), backside-metallized resonator (b) and the novel resonator (c). Overlapping back-metallized (6.5 mm × 5.5 mm) (b) and brick (9.5 mm × 37.75 mm) (c) areas are shown in black. All units are in mm.

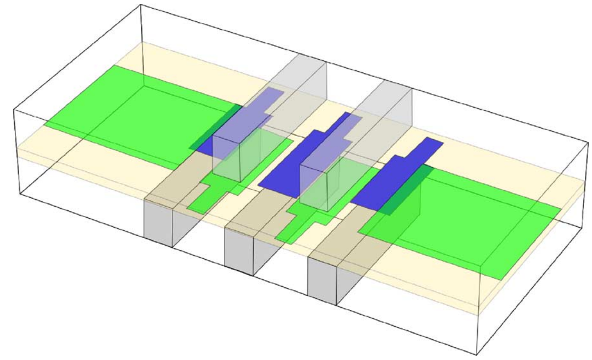

Fig. 3. Isometric view of the fifth order bandpass filter employing the novel resonator. Blue (dim) metallization is located on the bottom of the substrate whereas green (light) polygons are on top of it.

TABLE I
COMPARISON OF DIFFERENT SSL RESONATORS

	Dimensions		Unloaded quality factor
	mm	fractions of λ (476 mm)	
(a)	65.5×59.5	0.138×0.125	628
(b)	13.5×56	0.028×0.118	370
(c)	13.5×56	0.028×0.118	900

A single resonator of the proposed type is shown in Fig. 1(b). The metallization, whose shape is similar to the resonator shown in Fig. 1(a), is located on the bottom side of the substrate. A brick, consisting of the same metal as the SSL channel, is located close to the open end of the resonator, but is not interfering with the short circuited end.

In that way, a small air filled gap is left between the brick and the resonator. This geometrical arrangement provides a much higher capacitance than the same structure without the brick, therefore lowering the resonance frequency. Since the electric field is confined within air, there is no dielectric loss.

In order to show the feasibility of this setup, the novel resonator is compared to two other forms of SSL resonators. These are the resonator shown in Fig. 1(a) (termed conventional resonator, without an inset), as well as a backside-metallized variant of it.

All three resonator configurations are simulated with a full-wave simulator [6]; their sizes are tuned such that all of them exhibit the same resonance frequency of 630 MHz. The channel has a width of 70 mm and a height of 30 mm (excluding the substrate); as substrate 1 mm thick RO4003 is used. For the novel resonator, the height of the brick is chosen for a resulting gap of 1 mm.

Fig. 2 and Table I provide the results of the comparison, where all pictures in Fig. 2 are drawn with the same scale, giving a visual comparison of the resonator sizes. As can be observed from the numbers given in Table I, the space occupied by the novel and back-metallized resonator is a factor 5 smaller than that of the conventional resonator.

The unloaded quality factors of the resonators are calculated according to the method presented in [7, pp. 660–663]. For that purpose, fullwave simulations with [6] are conducted for each resonator, taking into account metallization and dielectric losses. The resonators are coupled very loosely to the ports in order to render external loading insignificant. From the resulting bell-shaped curve of $|S_{21}|$ the unloaded quality factor can be determined as

$$Q_{\text{ul}} = \frac{f_{\text{res}}}{\Delta f_{3\ \text{dB}}}$$

where f_{res} is the resonance frequency (maximum of the bell-shaped curve) and $\Delta f_{3\ \text{dB}}$ refers to the 3 dB bandwidth around the resonance frequency.

Due to the confinement of the electric field to the substrate, the backside-metallized resonator has a comparable low quality factor. The novel resonator is also ahead of the conventional one, since it features even lower electric field density within the substrate.

III. EXAMPLE FILTER

The benefit of the novel resonator shall be demonstrated by an example filter. For that purpose, a fifth order bandpass filter with a center frequency of 670 MHz and a bandwidth of 160 MHz has been designed, built, and measured. The minimum return loss within the passband is specified as 20 dB. Fig. 3 shows an isometric sketch of the filter. In order to realize the fractional bandwidth of 24%, a tight coupling of the resonators is necessary. This is achieved by alternately placing the resonators on the top and bottom side of the substrate and providing some overlapping between consecutive resonators.

The initial geometry is obtained by calculating the prototype coupling matrix from the specification according to Cameron [8] and afterwards applying the method of Hong and Lancaster [9] to establish a relation to the geometrical parameters. Unlike [2], where manual optimization is used, in this work a more effective hybrid optimization approach is taken using the coupling matrix approach [10], [11]. For that purpose, a coupling matrix extraction is performed on the simulated scattering parameters of the filter, yielding a surrogate model. The extracted coupling matrix is then compared to the prototype coupling matrix suggesting suitable alterations to the filter geometry. For the proposed filter, five iterations were necessary to obtain the results presented in Fig. 5.

There are different methods for the practical implementation of an SSL channel. In [2], [12] the substrate is suspended by a groove. This work also uses a split block assembly for realizing the channel. However, within the perimeter area of the substrate,

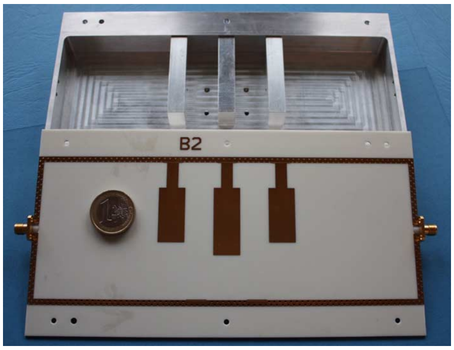

Fig. 4. Photography of the fabricated filter. Note the via-fence around the perimeter of the filter. One half of the SSL channel with the bricks screwed in place is shown in the background.

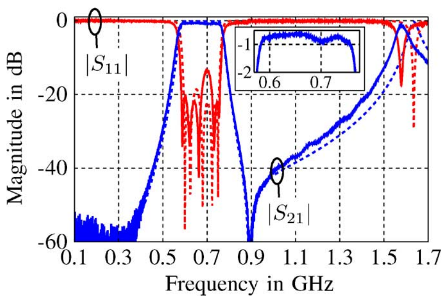

Fig. 5. Measured results of the fabricated filter geometry (solid) compared to the simulated results of optimized geometry (dotted).

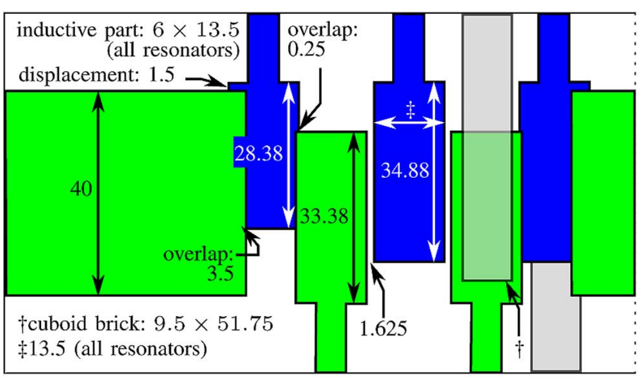

Fig. 6. Dimensions of the proposed filter. Due to symmetry, dimensions are only given on the left half, whereas the position of the bricks is indicated on the right. All units are in mm.

through-vias are placed in order to prevent redirecting the current around a groove.

Since the SSL channel is to be used for other filters as well, it is designed to be reconfigurable. For that purpose, the bricks are fabricated as separate units to be screwed to the channel at their respective positions. The configuration of half of the channel for the filter presented is shown in Fig. 4. The distance between substrate (1.2 mm thick RO4003) and bricks is 1 mm. Channel dimensions are the same as given in Section II. The planar size of the filter is 72 mm × 70 mm, accounting for 0.16 × 0.16 wavelengths at the center frequency. Other filter dimensions are given in Appendix A.

Measured results of the fabricated filter are shown in Fig. 5, where good agreement with the simulation can be observed. A slight increase in bandwidth can be explained by the fact that the used substrate is actually a compound of two layers of RO4003. As a result of fabrication, the prepreg joining these two layers exhibits some shrinkage, leading to a smaller substrate height than intended. This leads to a tighter inter-resonator coupling increasing the filter bandwidth.

As expected, the filter shows a very low insertion loss, as can be seen from the inset in Fig. 5. An insertion loss of about 0.7 dB can be read, which includes the two transitions from coaxial-to-SSL transmission line.

IV. Conclusion

A novel type of suspended stripline resonator has been presented in this letter. A cuboid shape brick is inserted in the SSL channel in order to increase the capacitive loading of the resonator. In that way, the area occupied by the resonator is reduced while maintaining a high unloaded quality factor. An example filter employing the novel resonator was designed and fabricated, exhibiting a very low insertion loss.

Appendix A
Dimensions of Example Filter

See Fig. 6.

References

[1] J. D. Rhodes, "Suspended substrates provide alternatives to coax," *Microw. Syst. News*, vol. 9, pp. 134–143, 1979.

[2] W. Menzel and A. Balalem, "Quasi-lumped suspended stripline filters and diplexers," *IEEE Trans. Microw. Theory Tech.*, vol. 53, no. 10, pp. 3230–3237, Oct. 2005.

[3] W. Menzel and J. Al-Attari, "Suspended stripline filters integrated with standard multilayer printed circuit boards," in *Proc. German Microw. Conf*, 2009, pp. 1–4.

[4] C.-Y. Chi and G. Rebeiz, "Planar microwave and millimeter-wave lumped elements and coupled-line filters using micro-machining techniques," *IEEE Trans. Microw. Theory Tech.*, vol. 43, no. 4, pp. 730–738, Apr. 1995.

[5] W. Menzel, L. Zhu, K. Wu, and F. Boegelsack, "Compact broadband planar filters," in *Proc. 31st Eur. Microw. Conf.*, Sep. 2001, pp. 1–4.

[6] Sonnet em. ver. 12.52, Sonnet Software Inc..

[7] G. Matthaei, L. Young, and E. Jones*, Microwave Filters, Impedance Matching Networks, Coupling Structures*. Norwell, MA: Artech House, 1980.

[8] R. J. Cameron, "General coupling matrix synthesis methods for chebyshev filtering functions," *IEEE Trans. Microw. Theory Tech.*, vol. 47, no. 4, pp. 433–442, Apr. 1999.

[9] J.-S. Hong and M. J. Lancaster, "Couplings of microstrip square open-loop resonators for cross-coupled planar microwave filters," *IEEE Trans. Microw. Theory Tech.*, vol. 44, no. 11, pp. 2099–2109, Nov. 1996.

[10] R. Ruf and W. Menzel, "A Toolset for Optimization and Tuning of Bandpass and Lowpass Filters," 2012.

[11] S. Bila, "Direct electromagnetic optimisation method for microwave filter design," *Electron. Lett.*, vol. 35, no. 5, pp. 400–401, 1999.

[12] A. Balalem, W. Menzel, J. Machac, and A. Omar, "A simple ultra-wideband suspended stripline bandpass filter with very wide stop-band," *IEEE Microw. Wireless Compon. Lett.*, vol. 18, no. 3, pp. 170–172, Mar. 2008.