Analysis and Design of Re-Configurable Combline Filters Using Dielectric Tuners

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Abstract— **This article describes different tunable structures for typical waveguide combline filters. In this context, several configurations using dielectric tuners have been studied for resonators, inter-resonator couplings, and input/output couplings. All configurations are analyzed in a wide frequency range showing advantages and drawbacks. Using the best structures in terms of performance, a fully re-configurable filter has been designed. The filter provides a wide tuning range in terms of center frequency while maintaining a high Q factor, and a constant bandwidth and return losses. A first filter prototype has been designed at L-band. The structure demonstrates a tunability in terms of frequency range of about 400 %, thereby clearly demonstrating that the approach we propose is indeed a very promising candidate for implementing tunable combline filters based on dielectric tuners.**

Keywords— **Band-Pass Filter, Combline filters, Dielectric tuners, Reconfigurability**

I. Introduction

The frequency spectrum is currently flooded by mobile telephony, satellite communications, global positioning systems, and the Internet of Things (IoT). Undoubtedly, the available frequency spectrum is now a valuable commodity and many organizations are competing to obtain additional bandwidth for their applications. As a consequence, the efficient use of the frequency spectrum is currently the most challenging task for system and component designers. Therefore, the ability to reconfigure or tune any microwave passive component is the key feature for an efficient use of the spectrum allocated to any communication application [1].

The compressible bellow or plunger-based resonators are among the first solutions proposed to vary the cavity size and achieve filter tunability [2]. Furthermore, the contact-less plungers have also been recently proposed to provide a reactive, short circuit condition [3]. Alternatively, MEMS structures have also been integrated with resonant posts in order to tune the filter at C-band [4].

It is important to recall that combline filters are widely used in satellite applications mainly because of their compact size and wide spurious-free response. In addition, tuning and coupling screws can very easily be implemented in this type of filter [5]. As a matter of fact, most commercial combline filters are tuned with metallic screws [6]. However, there are a number of issues associated with the use of metallic screws. A first issue related to the use of metallic screws is the degradation of Q-factor, as shown in [5]. Another important issue is that metallic screws must be securely fastened to the body of the filter so that they cannot be used as the basis for remotely controlled tuning.

The objective of this paper is to discuss the use of dielectric tuners in combline filters. The use of dielectric tuners has, indeed, already been demonstrated for several waveguide filters [7], [8], showing first results with potential practical interest. The novel combline filter structure that we have developed has the following key features:

- The filter maintains a constant absolute bandwidth throughout the tuning range.
- It has a better quality factor as compared to other established topologies using metallic tuners.
- The relation between the variation of the penetration of tuning elements and the filter center frequency variation is approximately linear. As a consequence, the prediction of the filter center frequency is greatly simplified.
- The use of dielectric tuners eliminates the need for electrical contact with the body of the filter, thereby eliminating a common source of passive intermodulation (PIM).
- Opens the possibility of using low-accuracy, computer-controlled actuators to implement remotely controlled tuning.

II. Design Methodology

To develop a fully tunable combline bandpass filter, we have first carried out several studies in order to identify the best configurations with respect to the following features:

1) The tuning of all the resonators.
2) The input/output topologies suitable to maintain adequate Q_{ext} throughout the tuning range.
3) The inter-resonator coupling methods in order to obtain the maximum possible coupling strength variation.

A. Resonator Design

Typically, combline resonators can be tuned by varying the capacitance between the open end of the post and the opposite wall of the cavity. This is normally accomplished by inserting a metallic screw on the wall of the cavity, near the open end of the resonator [9], as shown in Fig. 1 (left).

However, there are some issues with this structure. The first is that the metallic screw must be securely fastened to the body of the filter. Remote tuning is therefore not possible. The second is that, even if a remote tuning mechanism could be developed, the structure would be extremely sensitive to the

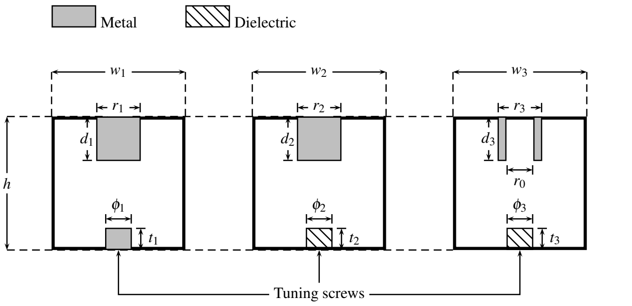

Fig. 1. Side view of the three compared structures. Cavity resonator with metal post and screw (left). Cavity resonator with metal post and dielectric screw (center). Cavity resonator with a hollow post and a dielectric screw (right).

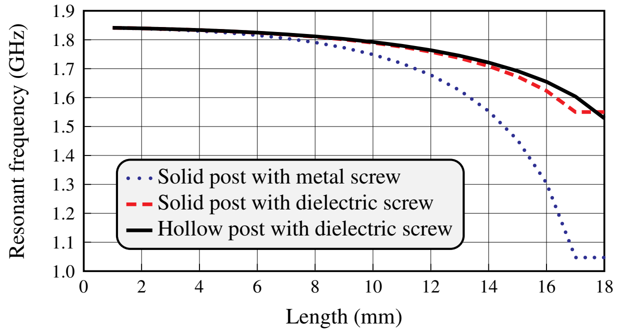

Fig. 2. Resonant frequency in terms of the penetration of the tuning screws for the three resonators shown in Fig. 1.

position of the metallic tuning screw, so that a practical (low cost) solution for an actuator-controlled remote tuning would not be possible. A dielectric screw could be used to decrease the sensitivity as shown in Fig. 1 (center). It has been observed during the experimentation that the weight of the cavity plays a crucial role when the filter is a part of a satellite payload. Therefore, the hollow metallic post is proposed in the present design as shown in Fig. 1 (right). This hollow post in the cavity provides a higher degree of freedom for the tuning element and a weight reduction of the whole structure as well.

The first feature understudy has been the variation of the resonant frequency of the fundamental mode of the cavity with the variation of the penetration of the tuning element for the three configurations in Fig. 1. The study of the resonator has been executed using an eigen-mode solver (CST Studio) using as fixed parameters of the cavities $w_1 = w_2 = w_3 = 50\,\mathrm{mm}$, $h = 50\,\mathrm{mm}$ and the length of the cavities in the perpendicular direction of the drawing is set to $40\,\mathrm{mm}$. The chosen dielectric is alumina ($\varepsilon_r = 9.9$). The resonator posts are set to $d_1 = d_2 = 32.0713\,\mathrm{mm}$ and $d_3 = 32.2905\,\mathrm{mm}$ in order to achieve the same resonant frequency. All diameters for the posts are set to $r_1 = r_2 = r_3 = 16\,\mathrm{mm}$. All tuning screw diameters are set to $11.8\,\mathrm{mm}$ and the inner diameter for the hollow case is $r_0 = 12\,\mathrm{mm}$.

The results are shown in Fig. 2 where we can obtain almost the same tuning range with the dielectric structures. However, the cavity in the Fig. 1 (right) has a reduced weight due to the hollow post. Furthermore, this configuration also allows more penetration of the dielectric post thus increasing the tuning range. A higher Q-factor has also been recorded. The main drawback is the lack of the nonlinear pattern penetration-frequency shift of these structures. As expected, the metal screw provides the maximal perturbation at the price of a high drop in the Q-factor.

In order to address the problem of the nonlinear behavior of the frequency shift versus the penetration, a new configuration is proposed. This configuration is shown in Fig. 3, where a dielectric tuner is inserted in the hollow post.

The values of the parameters used have been the same

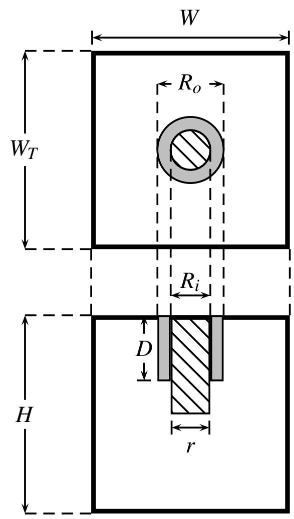

Fig. 3. Cavity configuration where the dielectric tuner is inserted in the hollow post (top view and side view).

as the ones used in Fig. 1 (right): $W = H = 50\,\mathrm{mm}$ for the housing with a length in the transversal direction of $W_T = 40\,\mathrm{mm}$. The outer and inner diameters of the hollow post are $R_o = 16\,\mathrm{mm}$ and $R_i = 12\,\mathrm{mm}$, respectively. The diameter of the dielectric rod is $r = 11.8\,\mathrm{mm}$. The height of the hollow post is $D = 32.2905\,\mathrm{mm}$. The only difference is that the dielectric screw in the bottom wall has been replaced with a dielectric rod located within the hollow post attached to the top wall.

The center frequency variation, as a function of the dielectric post length, is shown in Fig. 4 and compared with the previous results for dielectric shown in Fig. 2. As we can see in Fig. 4, an almost linear frequency change with respect to the penetration of the dielectric tuner has been achieved.

B. Input-Output Coupling Structure

While dealing with tunable filters, it is very crucial to maintain a constant input/output coupling (Q_{ext}) throughout the frequency tuning range in order to maintain a constant

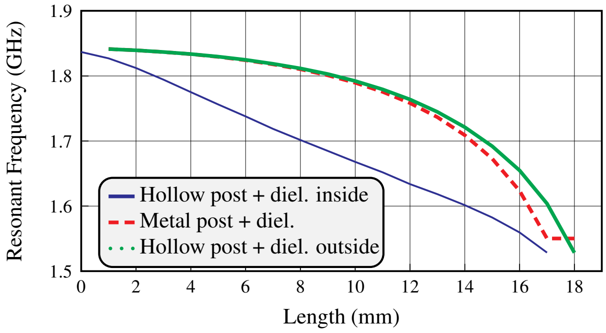

Fig. 4. Tuning range provided by the structure in Fig. 3 in terms of the length of the dielectric rod exceeding D compared with the results for dielectric tuners in Fig. 2.

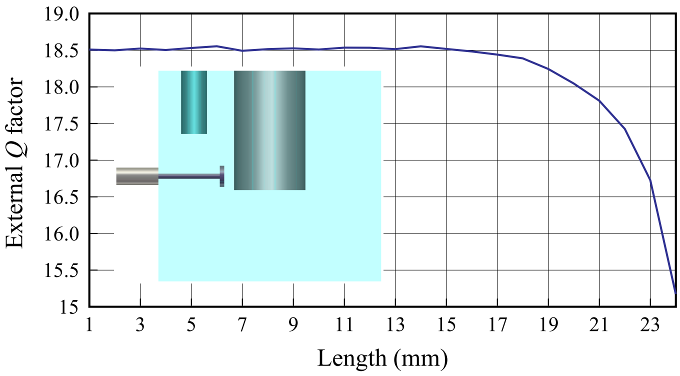

Fig. 5. Q_{ext} of the disc-type input topology with dielectric tuner proposed in [10].

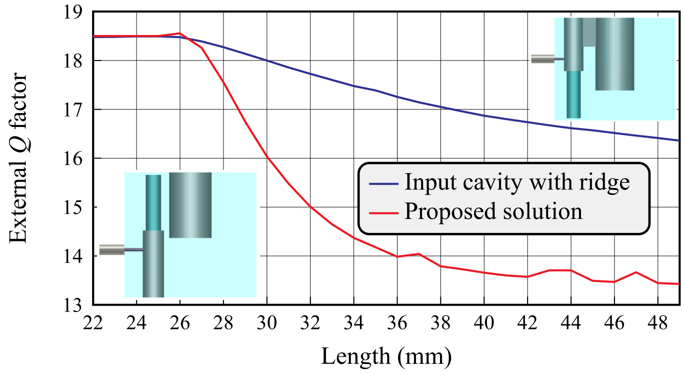

Fig. 6. Q_{ext} variation for two possible topologies: a ridge connecting the post (upper right corner) and the proposed solution inserting the dielectric from the opposite wall (lower left corner).

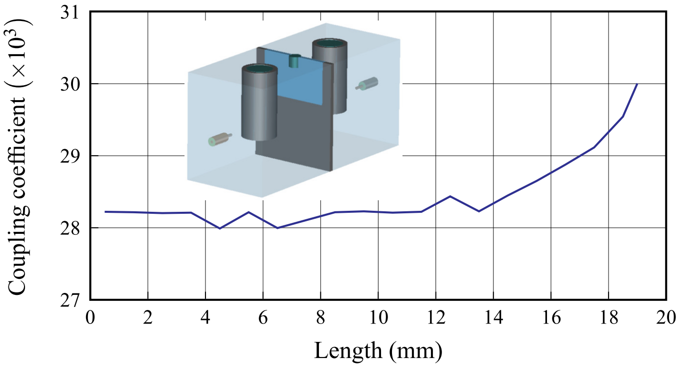

Fig. 7. Inter-resonator coupling using an inductive iris with a coupling screw.

bandwidth and return loss level. The Q_{ext} can be computed as follows:

$$Q_{\text{ext}} = \frac{f_0}{M_{S1}^2 BW} \tag{1}$$

According to the above expression, it is clear that lower Q_{ext} is required to implement the same input coupling strength at lower frequencies. The problem of achieving a tunable Q_{ext} has indeed been studied by several researchers. In [10], for instance, the use of a coaxial input probe with a metal disc at the end is proposed in order to vary the input capacitance (see inset of Fig. 5). The variation of Q_{ext} obtained is shown in Fig. 5. It clearly shows almost no variation until the dielectric post is sufficiently inserted, and then, the variation is steep and highly nonlinear.

Incorporating the input post in combline cavities significantly loads the first resonator. This leads to the reduction in the height of the resonator post that subsequently gives a range in the frequency tuning of the resonator post. Fig. 6 shows the experimentation carried out on two possible topologies: one with a ridge to increase the coupling, and one without the ridge but with the post in the opposite direction. The latter one will be the chosen topology, since it has recorded the most significant sweep in Q_{ext} values compared with the established solutions.

C. Inter-Resonator coupling

Generally, most of the combline filters use coupling windows in order to implement the desired inter-resonator coupling [5]. Metallic tuning screws are then located inside the coupling windows to tune the value of the coupling to the desired value (see inset of Fig. 7). However, as for the resonators, we have concluded that using metallic tuning screws is not adequate for the application under investigation.

The solution that we propose in this paper consists of using a short hollow metallic post, with a dielectric tuner inside, located on the wall opposite to the resonator post (see inset of Fig. 8). The results in Fig. 8 show the coupling range obtained by simulation. The extraction of the coupling values has been carried out with two resonators weakly coupled to the input/output ports and strongly coupled to each other, as described in [5]. The key point here is that without the coupling window, the dielectric post can be inserted deeper in the filter cavity thus implementing a stronger coupling between the cavities.

III. Full-Wave Model of Filter Prototype

With all the knowledge extracted from the previous studies, we can now design a four-pole combline Chebyshev filter in waveguide technology. The filter specifications are as follows:

- Center frequency must be tunable from $f_{0,\min} = 1.5424\,\text{GHz}$ up to $f_{0,\max} = 1.84212\,\text{GHz}$.

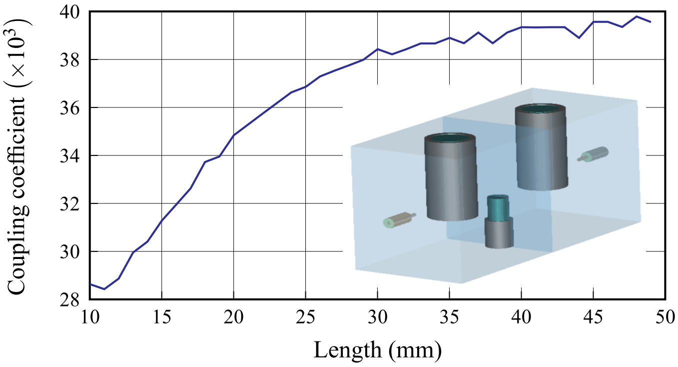

Fig. 8. Inter-resonator coupling using a dielectric post without a coupling window.

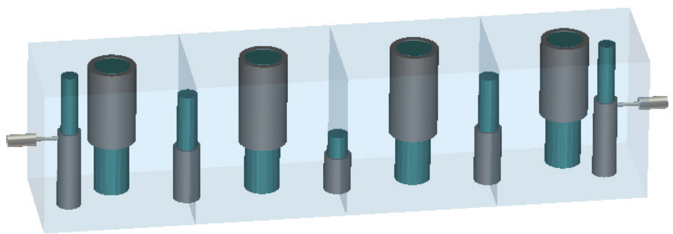

Fig. 9. EM model of the proposed combline filter.

- Bandwidth $BW = 75\,\mathrm{MHz}$ constant throughout the whole range of frequencies.
- Return losses: $RL > 25\,\mathrm{dB}$.

This means that the filter tuning range (as defined in [11]) is

$$\frac{f_{0,\max} - f_{0,\min}}{BW} \times 100 = 400\% \qquad (2)$$

without compromising the bandwidth and return loss performance.

Fig. 9 depicts the 3D structure of the proposed filter. The final prototype consists of a single housing of dimensions $40 \times 200 \times 50\,\mathrm{mm}$. The lack of irises or coupling windows produces a more convenient layout for the manufacturing process. The filter performance is shown in Fig. 10 where the two extreme cases for the tuning are shown. The simulations have been carried out with two different full-wave 3D simulators (Ansoft HFSS and CST Studio) in order to test the accuracy of the simulations. As we can see, the structure that we propose can maintain the same filter characteristics for a tuning range of 300 MHz.

IV. Conclusions

In this paper, we have discussed a novel configuration for tunable combline filters that are based on the use of dielectric tuners. The use of dielectric tuners greatly reduces the sensitivity of the filter center frequency with respect to the tuner position. As a result, the use of a low-cost computer-controlled linear actuator becomes now an attractive possibility for the implementation of remotely tuned combline filters. Moreover, further work is currently ongoing to explore the possibility of changing the filter bandwidth in addition to the center frequency. In conclusion, with the results presented in this paper, we have firmly established the proof of concept on a novel family of combline filters, that can become one of the key elements for future reconfigurable payloads for both ground and space applications.

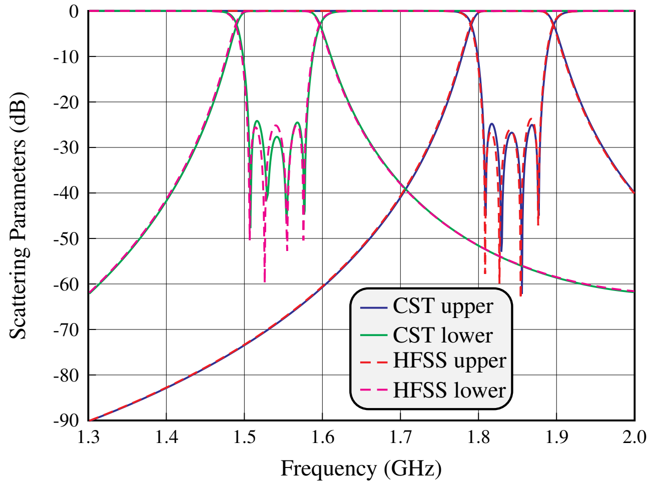

Fig. 10. Electrical response of the filter for two extreme cases of the tuning range (the upper frequency case requires the lowest penetrations of the tuners and the lower frequency case requires the deepest penetrations). Solid lines: simulation with CST. Dashed lines: simulation with HFSS.

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