

A novel Re-entrant Cap Tuning Technique For TM-Mode Dielectric Resonators and Filters

Abdulrahman Widaa¹, Michael Höft²
Chair of Microwave Engineering
Kiel University
Kiel, Germany
{¹aw, ²mh}@tf.uni-kiel.de

Abstract—This paper reports a new tuning technique for TM mode dielectric resonators and filters. The proposed concept is based on the use of a hollow envelope (cap) to tune the resonant frequency instead of/in addition to the conventional intruding screw/rod-based method. The presented technique provides highly desirable advantages of tunable components including the wider tuning capabilities, simple configuration, and the improved Q factor. For proof of concept purposes, a tunable resonator is designed, fabricated, and measured. Also, a comparison with the conventional tuning technique is presented. The measured results demonstrate a wide tunability > 90% with a high Q-factor up to 3119 promoting the application of the proposed mechanism in high-performance tunable components.

Keywords—cap, dielectric resonator, high-performance, re-entrant, tunable.

I. INTRODUCTION

High-performance reconfigurable resonators and filters represent an indispensable component of the various evolving frequency-agile RF systems and applications. In space communication for instance, the future flexible satellite payloads have stringent specifications of widely tunable, high-Q, compact, and high-power compatible filters. Unfortunately, most of the available reconfigurable filter designs in the open literature cannot meet these challenging requirements. On one hand, despite the advantages of compactness and good tuning capabilities that planar/hybrid configurations can offer, they suffer from the low Q factor and the limited power performance. On the other hand, while air-filled waveguide cavity filters can demonstrate high Q and can handle high power levels, they are still burdened by the large bulky structures and the small frequency tuning ranges [1].

Considering the drawbacks of the aforementioned structures, dielectric resonator filters were introduced in different emerging applications due to their highly desirable advantages including the miniaturized size and high Q factor. Accordingly, a couple of reconfigurable DR filters were also presented using different tuning means and DRs at different operation modes. For example, in [2], a magnetized ferrite was utilized to change the H-field of the DR and therefore tuning the resonant frequency. Also, for the purpose of providing fast tuning speed, tunable DR filters were designed using electrical switching/tuning components (RF MEMS, varactors) as in [3] and [4]. However, filters based on magnetic and electrical tuning techniques experience major drawbacks limiting their employment in high-performance applications, including the

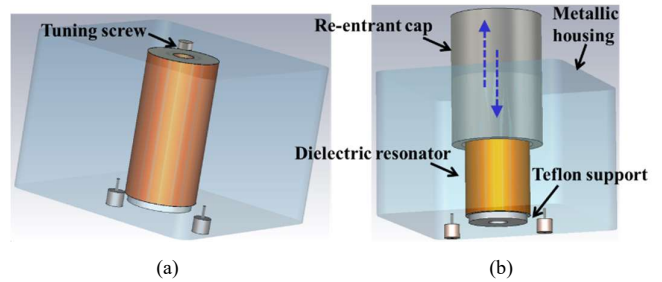


Fig. 1. 3D views of a reconfigurable TM mode dielectric resonator: (a) With the conventional tuning screw and (b) With the proposed re-entrant cap.

inability to handle high-power signals, low-Q, and the increasing loss and overhead complexity due to the integration of the tuning circuitries with the dielectric filter cavities. Therefore, mechanical tuning is still the most favorable straightforward technique to design high-Q and high-power compatible reconfigurable filters. A couple of tunable dielectric filters were introduced using different mechanically movable elements (cavity sidewall, disks, screws, etc....) [5]–[7]. A piezoelectric transducer was used in [5] to control the movement of a flexible top sidewall to change the resonant frequency of the DR cavity. However, the measured results have shown lower Qs < 550 and a small tuning range from 4.94 GHz to 5.15 GHz in addition to the increased integration complexity. Another group of tunable DR filters was presented with various dielectric resonator configurations (HEM₁₁, TE₀₁) [6], [7]. Frequency control is achieved by the movement of a tuning disc/plate at the vicinity above the DR either manually or through utilizing electrically-induced MEMS/piezoelectric actuators. Despite those filters had shown higher Qs, they still share all other drawbacks of the earlier sidewall-based configuration, plus the appearance of unwanted spurious resonances caused by tuning components. Furthermore, as an additional air vicinity is required above the resonators for tuning, DR filters based on both tuning techniques are bulkier and occupy larger space. Therefore, due to all of the above limitations, there still an essential demand for more compact dielectric filter structures with more efficient and flexible tuning mechanisms.

In recent years, transverse magnetic (TM_{01δ}) mode dielectric resonators and filters have gained an increasing attention over other DR structures and employed successfully in various high-performance applications (e.g. satellite [8], cellular base stations [9]) due to their desirable advantages of

more miniaturized size, decent high-Q, better stability, and improved spurious-free responses. These attractive features strongly promote the introduction of reconfigurable TM mode DR structures. The fundamental TM_{018} operation mode is induced by attaching the DR directly or with small gaps to the metallic cavity [10], [11]. Unfortunately, this configuration makes the tuning more challenging and just excluded in intruding means inside the DR body. Tuning screws/plugs were introduced in dielectric filters to mainly compensate for the tolerances and adjust the fixed filter responses [12]. More further, they can also be used as a convenient means to design tunable DR filters because of their simple straightforward configuration [13]. In general view, the screw-based tuning suffers from few downsides including the increasing losses and the limited tuning capabilities, in addition to the appearance of unwanted effects at high power levels (e.g. multipactor, corona). Accordingly, the introduction of more efficient alternative tuning mechanisms for TM mode resonators and filters is highly appreciated.

In the paper, a new so-called “re-entrant cap” tuning technique is introduced for the applications of TM mode dielectric resonators and filters. The proposed concept provides different advantages in comparison with the conventional screw-based tuning including the wider tuning ranges and the better Q factors. Furthermore, both tuning concepts can be used exhibiting flexibly extended tuning windows (dual tuning). The proposed tuning mechanism is presented and validated in the following sections and also compared with the screw/rod-based method.

II. CAP-TUNING CONCEPT AND DESIGN

Initially, the use of intruding tuning screws/rods inside the resonator’s body seems like a convenient frequency tuning option in TM mode DR structures (Fig. 1(a)). It’s even more efficient with the fundamental TM_{018} mode where the E-field is more concentrated at the center of the DR, and therefore, the screws can cut more field lines and wider tuning ranges can be achieved. Unfortunately, this interruption of high field densities also leads to an increasing loss and may cause a significant deterioration in the Q factor. As a result, the achievable tuning capabilities will be also compromised.

The configuration of the proposed tuning technique for TM mode dielectric resonators is depicted in Fig. 1(b). The operation concept is simply based on the introduction of a movable hollow cylindrical envelope (cap) to tune the resonant frequency of the TM mode DRs. The frequency is tuned by two means simultaneously through the same single cap-tuner providing the advantage of a wider tuning window. Firstly, the penetration of the cap inside the resonator cavity interrupts the fields to change the resonant frequency. Secondly, the frequency is also controlled by the change in the space between the DR and cap cover which functions as a movable cavity sidewall. Additionally, the tuning range can be increased furthermore by introducing an optional tuning screw/rod at the opposite side (dual tuning). Also, another desirable advantage of the proposed TM mode cap-tuning concept is the higher Q-factors in comparison with the conventional screw-based method. This is mainly due to the lower tuner-field interaction losses and also to the wider gap between the DR and the movable part of the sidewall (cap).

To proof the above-mentioned claims of our proposed cap-tuning concept over the conventional screw-based technique, a reconfigurable TM mode dielectric resonator is introduced

in Fig. 1 using both tuning means. Both structures were analyzed using an Eigen-mode solver in CST software environment. The resonator is a TM mode dielectric resonator operating at the fundamental TM_{018} [11] ($DK=44$, $Q_u=12500$ @ 3.5 GHz, outer diameter = 10 mm, inner diameter = 3 mm). A small 1 mm space between the resonator and the bottom/top metallic walls is chosen for the sake of easier assembly and obtaining high Q. The used tuning cap has 14 mm diameter and 1.5 mm of wall thickness, while the tuning screw has a diameter of 2 mm. The simulated results of screw-based and re-entrant cap tuning methods are shown in Fig. 2 and Fig. 3, respectively. Also, the results are summarized in Table 1. It can be clearly seen that the proposed re-entrant cap tuning technique has a wider tuning range and better Q factor at the same time. The resonant frequency is tuned from 3.13 GHz to 1.07 GHz while the unloaded-Q is changing from 4780 – 1481 in the case of using brass as a material for all metallic parts including screws and caps. Additionally, the frequency can be tuned further to 0.88 GHz when the dual tuning feature is utilized. On the other side, the frequency tuning range in the screw-based case is 2.89 GHz – 1.46 GHz with Q_u of 4479 – 1426.

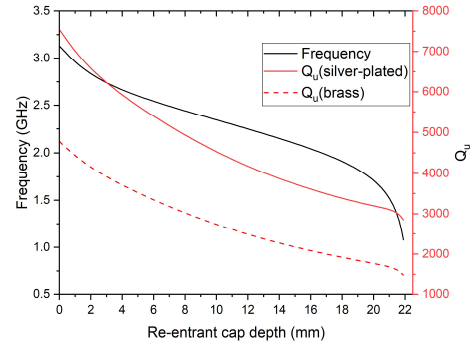


Fig. 2. Simulated frequency and unloaded Q-factor (Q_u) as a function of the re-entrant cap depth inside the TM mode dielectric resonator cavity.

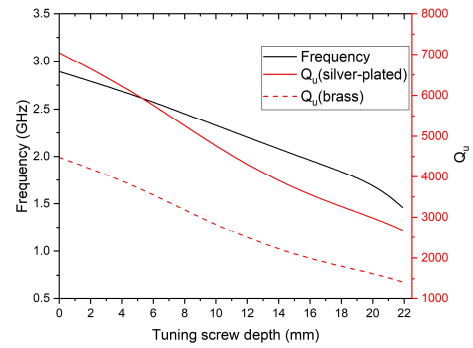


Fig. 3. Simulated frequency and unloaded Q-factor (Q_u) as a function of the tuning screw depth inside the TM mode dielectric resonator body.

TABLE 1 Comparison between the conventional screw-based tuning method and the proposed re-entrant cap tuning technique

Technique/Material	Tunability	Average Q_u
Screw/Brass	65.7%	2952
Cap/Brass	98%	3130
Screw/Silver-plated	65.7%	4860
Cap /Silver-plated	98%	5196

III. EXPERIMENTAL VALIDATION

Prototypes were manufactured and measured to experimentally validate the proposed re-entrant cap tuning technique for TM mode dielectric resonators. The used TM mode resonator is an SV440 from Kyocera [14] (DK= 44, $Q_u = 44000$) with the same dimensions as the simulated ones in the previous section. The metallic parts, including the tuning cap, were all manufactured out of brass metal ($\sigma = 1.59 \times 10^7$ S/m). The tuning screw here is a silver-plated M2 screw. The resonators are weakly coupled using SMA connectors in order to extract the effective Q. The assembled prototype and the measured results of the screw-tuned DR are depicted in Fig. 4. The frequency is tuned from 2.89 GHz to 1.65 GHz with 54.6% tunability. Also, the measured Q factor is 2710 – 561 (average $Q = 1713$). Fig. 5 shows the manufactured cap-tuned DR and its measured results. A wide tunability of 91.9% was obtained from 3.38 GHz to 1.24 GHz with a Q factor of 3119 – 307 (average $Q = 1635.5$). Unwanted spurious resonances are noticed at the higher tuning states. This can be improved by proper optimization of the tuning cap and the resonator cavity. The measurements generally agree with the simulations demonstrating that the cap tuning concept can offer > 60% wider tuning than the traditional screw-based method with a decent Q factor.

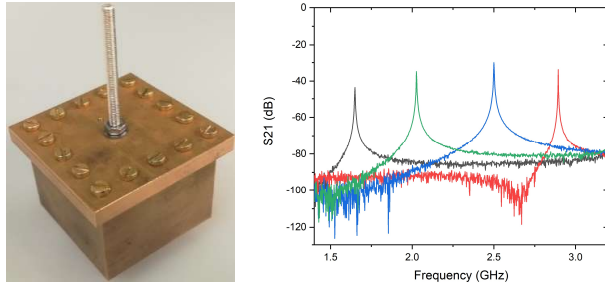


Fig. 4. Photograph and measured results of the screw-tuned TM mode dielectric resonator.

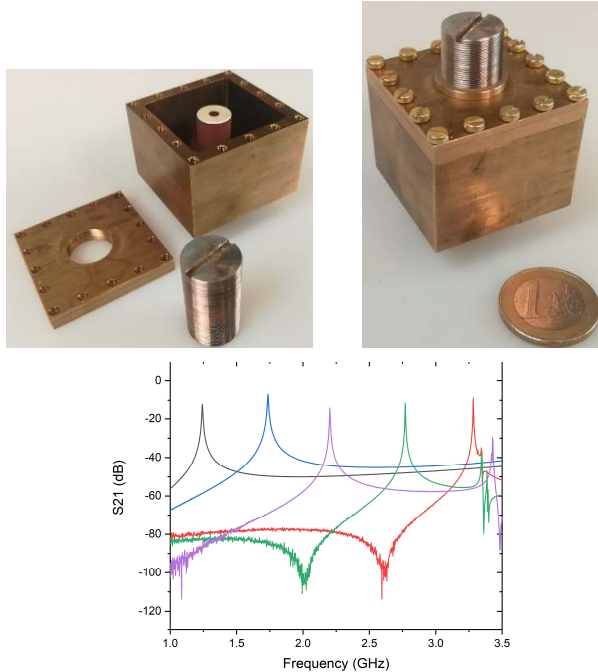


Fig. 5. Photographs and measured results of the cap-tuned TM mode dielectric resonator.

IV. CONCLUSION

A new cap-based tuning concept was introduced for the applications of TM mode dielectric resonators and components. A comparison between the proposed technique and the traditional screw-based tuning method was also presented. The results show various desirable features for the applications of high-performance tunable filters including the wider tuning capabilities and the better Q factor.

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