Compact Base-Station Filters Using TM-Mode Dielectric Resonators

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Abstract – A compact base-station filter using TM-mode dielectric resonators is presented. The TM-mode operation is chosen because of its capability of realizing compact resonator cavities at convenient quality factors. Fundamental properties of those dielectric resonators are discussed. Furthermore, results of a realized filter panel are shown. To improve the insertion loss performance of the TX-RX-duplexer, the lowpass filter is included in the phasing section.

I. INTRODUCTION

In Fig. 1 the basic setup of a cylindrical TM-mode dielectric resonator is shown. A dielectric rod with diameter $d_c$ and height $H$ is placed coaxially in a cylindrical, metallic cavity with diameter $d_o$ and the same height as the dielectric rod. A hole with diameter $d_i$ might be included into the ceramic to allow the intrusion of a tuning screw for the adjustment of the resonance frequency.

Bandpass filters with TM$_{010}$-mode dielectric resonators have first been reported 1978 by Kobayashi and Yoshida [1]. In comparison to other dielectric resonators, they show relatively wide spurious-free stopband performance. The drawback is the requirement of having a proper electric contact between the ceramic material and the top and bottom of the metallic cavity. Due to different coefficients of thermal expansion, mechanical stress might be harmful to this contact. On the other hand, an air-gap at the bottom or top would lead to an undesired frequency shift.

Different solutions to overcome this problem were presented. In [1] the mechanical stress was avoided by letting the ceramic rod expand into holes at the top and bottom of the housing to reduce the frequency shifting due to thermal changes of the air-gap. However, the essential problem of the frequency stability was not solved. In [2] the problem was solved by using a dielectric shielding cavity of the same material as the inner dielectric rod. This technique was improved in [3] by fabricating a dielectric shielding cavity and the inner rod out of a single block. Furthermore, dual mode operation was achieved by integrating two perpendicular inner rods into the ceramic block, although multi-mode operation of TM-mode resonators for a channel dropping filter using triple mode resonance was already reported in [4] before.

In [5] different coupling and tuning mechanisms were discussed. Moreover, cross-coupling was introduced to realize elliptic bandpass filters. In [6, 7] a similar cross coupling technique was applied to realize a bandpass filter at 1.9 GHz for a micro-cell base-station. In [8] further miniaturization technologies of dielectric resonator filters for mobile communications are reviewed.

Our solution to overcome the mechanical stress between the dielectric rod and the enclosing cavity is the application of a flexible cover as published in [9]. Furthermore, the top and bottom of the cavity are silver-plated to avoid any air-gaps and resulting frequency shifts.

Our design was realized at 2 GHz, since our objective is the application in base-stations for third generation mobile communication systems [10].
II. Basic Analysis

Field simulations have been performed to characterize the basic behavior of a single TM-mode resonator (as depicted in Fig. 1) with respect to its fundamental and first spurious mode frequency as well as the expected unloaded quality factor. The dielectric material consists mainly of the compounds ZrO$_2$ and TiO$_2$. It has a relative dielectric constant of approx. $\epsilon_r \approx 42$ and an unloaded quality factor of 20,000 at 2 GHz. The housing is silver-plated ($\sigma = 60 \cdot 10^6$ S/m).

The TM$_{ij0}$-modes are independent of the height $H$ of the resonator, which is $H = 27$ mm for the realized filter panel. The dependency of the fundamental and first spurious mode of a single resonator on its outer cavity diameter $d_o$ is shown in Fig. 2. The inner diameter $d_i$ is fixed to $d_i = 3$ mm. The ceramic radius $r_c = d_c/2$ is varied to keep the fundamental mode at a constant frequency of $f_1 = 1.95$ GHz. How the ceramic radius $r_c$ depends on outer diameter $d_o$ is presented in Fig. 3. Also, the simulated quality factor is shown in Fig. 3. Note, that the real quality factor is lower due to (1) non-ideal contacts between the ceramic and the cover and (2) to lower conductivity of the housing because of its surface roughness. Moreover, the outer diameter should be chosen slightly smaller for reasons of tunability of the resonator, since the tuning screw can only lower the frequency. This and the losses due to the tuning screw itself will further lower the quality factor measured.

The first spurious mode and the quality factor both increase with growing outer cavity diameter $d_o$. However, the space in the realized filter panel and correspondingly the size of the diameters were limited. To save costs, the ceramics for the receive channel (RX) bandpass filter with center frequency of $f_c = 1.95$ GHz and the transmit channel (TX) bandpass filter with $f_c = 2.14$ GHz were chosen to have the same diameter of $d_c = 12$ mm, while the outer diameter of the cavities were chosen differently to achieve the desired center frequencies. The resulting outer diameter of the RX-resonators was set to $d_o = 21.6$ mm, while the outer diameter of the TX-resonators was set to $d_c = 18.7$ mm. Consequently, the first spurious modes were expected to be at $f_2 = 3.1$ GHz and $f_2 = 3.2$ GHz, respectively, whereas the simulated quality factors were $Q = 5200$ and $Q = 4800$, respectively. The measured values were approx. 30% lower than the simulated ones.

III. Realized Filter Panel

In Fig. 4 a block diagram of the designed filter panel is shown. The filter panel consists of a TX-RX-duplexer and a single receive unit. Isolators are included to achieve a matching which is virtually independent of units connected. Besides the bandpass filters, lowpass filters are added to suppress spurious response up to 12.75 GHz. Since the requirements for the transmitting path, a three section stepped-impedance lowpass filter instead of a seven section one was included for the single RX path.

In Fig. 5 a photograph of the realized filter panel is depicted, which has a size of $169 \times 76 \times 39$ mm$^3$. In Fig. 6 the corresponding concept drawing of the setup is sketched. The bandpass filters are to support the 20 MHz center band of the UMTS-spectrum. Due to this, simple three and four pole Chebychev bandpass filters are sufficient, which facilitates the compact design of the overall unit. The RX resonator cavities have a rectangular base shape of approx. $20 \times 20$ mm$^2$ instead of a circular shape to achieve a more
Fig. 4: Block diagram of the designed base station filter.

Fig. 5: Photograph of the compact base station filter with TM-mode dielectric resonator.

Fig. 6: Concept drawing of the filter.

compact layout. Note, that the coupling apertures have to be considered for the exact determination of the cavity size, since the resonance frequency strongly depends on the outer dimensions of the cavity as can be inferred from Fig. 3.

A brief summary of the measured performance of the filter panel is given in Table 1. Exemplary, in Fig. 7 the insertion loss $S_{21}$ of the single RX filter is shown within a frequency range of 1.6 GHz to 3.8 GHz. The bars indicate the blocking specification required. The first spurious response lies in the range of 2.8 GHz to 3.0 GHz. In Fig. 8 the measured temperature performance of the return loss of an RX filter is shown for a temperature range of $-10^\circ$C to $70^\circ$C. In Fig. 9 the measured temperature performance of the insertion loss is depicted. The frequency shift of the -20 dB blocking value at the lower stopband side amounts to 0.43 MHz, i.e., 5 kHz/K, while the corresponding blocking value at the upper stopband has a shift of 1.04 MHz, i.e., 13 kHz/K. By adjusting proportions of the compounds of the ceramic material, the temperature compensation can further be improved. Note, that the the expansion of the metallic body also needs to be considered for the compensation.

IV. IMPROVEMENT

In Fig. 10 the concept drawing of an improved design of the filter panel is depicted. The insertion loss performance of the realized TX-RX-duplexer is reduced by including the lowpass filter into the phasing section. In doing so, the lowpass filter for the RX path could be realized as a three section stepped-impedance lowpass filter. This lowpass filter is placed at the output of the RX path, since the phasing section for the RX path was quite short. Furthermore, in the first version there was a minor interference between the closely placed isolators, which slightly deteriorated the insertion loss performance. As a result, the insertion loss has become lower than 0.65 dB for all paths: the bandpass filters are contributing $\approx 0.35$ dB, the isolator $\approx 0.2$ dB and the lowpass filter and coaxial lines for connection and phasing section $\approx 0.1$ dB. I.e., the bandpass contributes only roughly half of the losses.

V. CONCLUSIONS

A compact base-station filter using TM-mode dielectric resonators was presented. Fundamental properties of the dielectric resonators were discussed. To improve the insertion loss performance of the realized TX-RX-duplexer, the lowpass filter is included into the phasing section. As a result, the bandpass only contributes roughly half of the insertion losses of the filter panel.
References


