Abstract — In this paper, possibilities for increasing the quality factor of combline resonators are presented. Emphasis is placed on low fabrication costs. Circular and square shaped resonators are compared. The analysis is performed with a finite element simulator. To overcome numerical uncertainties of the Q-factor calculation, parametric sweeps and polynomial curve fitting are applied. As a result, the Q-factor can be increased by 5% by introduction of a base rounding.

I. INTRODUCTION

Combline microwave filters are widely applied in mobile and satellite communication systems because of their wide and easy tunability, relatively wide spurious free stop band, and low cost. Due to the inner conductor only medium Q-factors can be achieved. In [1] the Q-factor is increased by 14% via a periodic 6-disk inner conductor. Due to the slow wave property of periodic structures the height of the resonator is virtually enlarged, i.e. the inductance of the equivalent circuit is increased. The drawback of the structure is its higher manufacturing cost. The same holds for the introduction of dielectric materials [2], [3].

Another possibility to increase the Q-factor is the minimization of ohmic losses. In this work, the focus is set on modifications of the geometrical shape which are simple to realize. The analysis is performed at 2 GHz, since our objective is the application in base-stations for third generation mobile communication systems [4].

II. BASIC ANALYSIS

The basic setup of a cylindrical combline resonator with a circular base area is sketched in Fig. 1. The influence of the tuning rod and inter-resonator coupling is neglected in our analysis. The Q-factor can be estimated via the well known first order TEM-line model by calculation of power losses due to the corresponding surface currents [5]. The current distribution on the outer surface has already been depicted in Fig. 1.

As a result the maximum Q-factor will be obtained, if the ratio of the outer and inner diameter ratio is \( D/d = 3.59 \). In that case the damping of the equivalent coaxial waveguide is minimal [5]. As will be shown in the next section the ratio \( D/d \) should be slightly smaller. Note, that in our application a capacitor defines the gap \( h \) is sufficient. In principle, it could be increased by enlarging the tuning rod into a hole in inner conductor or a larger termination dish [5], [6]. The latter has to be preferred in case of high power applications.

For comparison of different resonator setups, calculations have been performed which are based on the results of Ansoft HFSS simulations. With the aid of the eigenmode solver the resonant frequency \( f_r \) and Q-factor can easily be determined. In those calculations the resulting frequency \( f_r \) of the adaptive finite element mesh refinement shows a good convergence behavior while the Q-factor bears numerical uncertainties. To avoid excessive mesh refinement we applied the following method. It is based upon the fact that we want to study the behavior in dependence of geometrical variations. Since the results would not change at small variations, polynomial curve fitting is applied to average numerical errors.

As an example the resulting resonant frequency and Q-factor in dependence of \( h \) and \( d \) are depicted in Figs. 2 and 3. The outer dimensions were set to \( H = 24 \text{ mm} \), \( D = 32 \text{ mm} \) and \( \sigma = 6.1 \times 10^7 \text{ (}\Omega \text{m})^{-1} \text{ (silver)} \) was assumed. Note, that the conductivity as well as resulting Q-factor will be lower than these values, since the manufactured housing will suffer from surface roughness and non-ideal contact of the top cover.

It is obvious that the gap \( h \) has to be tuned to keep the frequency \( f_r \) constant if \( d \) is varied. The optimum inner diameter for maximum Q-factor will be obtained if both arrays of curves hold the same slope as visualized in Fig. 4. As a result, the ratio \( D/d \) is approx. 4% larger than the optimum for coaxial waveguides.

In the same manner simulations have been performed with different outer diameters \( D \). Fig. 5 shows the resulting Q-factor, where the gap \( h \) is tuned for \( f_r = 2 \text{ GHz} \). Again, the ratio \( D/d \) is slightly larger than 3.59, – especially when the diameter \( D \) is larger than the height \( H = 24 \text{ mm} \).
III. COMPARISON: SQUARE AND COAXIAL WAVEGUIDES

Generally, square shaped combline resonators are preferred for filter realization. Their basic shape is sketched in Fig. 6. The radius $R_c$ of the corners is required due to the milling process (in our case: $R_c = 3$ mm). The results of Q-factor calculations which are in correspondence to those of the circular combline resonator are shown in Fig. 7. In this case, the optimal ratio of $D/d$ is slightly larger than 3.59.

To compare the performance of circular and square combline resonators the required base area should be considered. For the square resonators the base area amounts to $D^2$. To build compact filters with circular resonators hexagonal packaging is needed. Therefore, the base area calculates to $\sqrt{3}/2 D^2$, which is 1.1 times larger than the circular area. The resulting comparison of the Q-factor is shown in Fig. 8. It arises that the circular resonator shows an almost 1% better Q-factor if the results are related to those base areas. It is interesting to note that the Q-factor is almost equal if the comparison is related to the inner diameter $d$.

For the design of entire filter panels the available space has to be considered for the choice of the proper resonator type. If the complete base area is square, square resonators have to be preferred, since hexagonal packaging of round resonators will waste some space at the corners. But if the complete base area is rectangular and square resonators would not fill the space, circular resonators might be the better choice.

In the latter case, rectangular shaped resonators may also be considered. In our application the available base area for a single resonator is $3.2 \times 4.0$ cm$^2$. The calculated Q-factor at 2 GHz results to $Q = 5230$. Corresponding square and circular combline resonators with the same base area show $Q = 5340$ and $Q = 5370$, respectively. Square resonators do not fit into the overall base area, while circular ones do.

IV. BASE ROUNDING

The maximum current $I_{\text{max}}$ is flowing at the bottom of the resonator, as already depicted in Fig. 1. Since this current contributes a large part of the ohmic losses, we analyzed a modified setup where a base rounding $R_b$ is introduced, as sketched in Fig. 9. Such a base rounding can easily be manufactured by choice of a corresponding milling cutter. Due to this rounding the power loss contribution of the bottom is minimized. In contrast, the inductance is decreased. In Figs. 10 and 11 the results for a circular combline resonator...
with $H = 24$ mm and $D = 32$ mm are depicted. Obviously, the power loss minimization outweighs the inductance decrease, which results in an increase of 5% for Q-factor. As shown in Fig. 11, the inner diameter $d$ has to be built slightly smaller.

The introduction of a same rounding at the top corners of the resonator would lead to an additional improvement of the Q-factor, but it would be difficult to manufacture. Note, that the small rounding $R_t$ of the inner conductor is mainly applied to improve high power handling.

V. CONCLUSIONS

Possibilities for increasing the quality factor of combline resonators have been presented. The analysis has been performed with a finite element simulator. To overcome numerical uncertainties of the Q-factor calculation, parametric sweeps and polynomial curve fitting have been applied. Note, that this method can easily be applied for other numerical studies.

The comparison of circular and square shaped resonators show that for the filter design mainly those type should be chosen which will result in a maximum base area of the individual resonators. Furthermore, the Q-factor can be increased by 5% by introduction of a base rounding with almost no additional manufacturing costs. Measurements confirm the predicted improvements.
REFERENCES


