Quarter Wave Multi Layer Cable Balun

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Introduction

MRI Systems consist of three main parts: Main magnet, Gradient System and Body RF coil. Usually beside the system itself, surface coils are used to enhance SNR. One of the critical problems coil designer confront is the parasitic current induced on the coil cables during transmit phase of the MRI sequence. Also, during receive phase, cables must not couple to the multiple coil elements, otherwise the unwanted effects like shading, oscillations and heating could occur. Typical method of reducing the current on cables is by utilizing cable baluns. In MRI for systems lower then 7T field strength the baluns are made as resonance structures comprised of an inductor surrounding the cable in resonance with well chosen capacitor. In this work we try to accommodate the well-known quarter wave balun to the low frequencies without adding length to the signal transmission line and without adding any lumped circuit components.

Theory

Mathematical description of quarter wave balun is given in [1], where it is defined more generally as a "short-circuited $\lambda/4$ line". When the transmission line has an electric length of $90°$ and one is shortened (or has very low impedance), then from the other end the line has very high impedance. Ultimate observed impedance depends on the losses of the transmission line and the effective resistance of the short. The impedance of the short-circuited $\lambda/4$ line is given by the general formula [1]

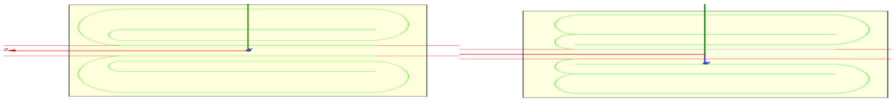

Figure 1. Sketch of the quarter wave folded balun (LEFT - Spiral Folding, RIGHT- Incremental Folding): "red" - cable, "green" - balun's conducting surfaces, "yellow" - dielectric material. surface.

$$Z_{in} = \left(\frac{1}{R} + 2j\Delta\omega C\right)^{-1}, \quad \text{with } R = \frac{Z_0}{\alpha l} \quad \text{and } C = \frac{\pi}{4\omega_0 Z_0} \tag{1}$$

where Z_0 is characteristic impedance of the line, ω_0 is the system frequency and α the loss factor of the line. Characteristic impedance of the line is given by the particular topology of the cross-section of the cable. For example, in the case of cylindrical cables characteristic impedance is given by $Z_0 = \sqrt{\mu_0\mu/(\varepsilon_0\varepsilon)}\ln(b/a)/(2\pi)$, with $b > a$ been radii of the coaxial cylinders. For microstrip and stripline topologies characteristic impedance formulae can be found in [1].

In our work we propose folding the transmission line longitudinally in several layers. The radii of each layer is calculated so that characteristic impedance is preserved. For example, in cylindrical cable case, respective radii are calculated using the formula for characteristic impedance of the coaxial cable

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu_0\mu}{\varepsilon_0\varepsilon}}\ln\frac{r_{i+1}}{r_i} \tag{2}$$

so that the layers radii respect the relationship

$$\frac{r_1}{r_0} = \frac{r_2}{r_1} = \frac{r_3}{r_2} = \ldots \tag{3}$$

The consecutive layer could be folded incrementally or spirally as represented in Figure 1.

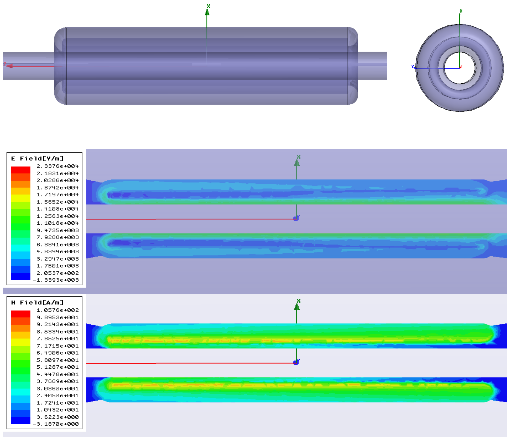

Figure 2. Top: Folded Quarter Wave Balun: 10 cm total length, 2.74 cm total diameter; Middle and Bottom: A cross-sectional view of the magnetic and electric field distribution of the balun at the frequency of interest. This balun has spiral folding therefore its shortened end is located on the second layer. Entrance into the quarter wave balun is on the right side of the figure. It can be observed that electric field drops gradually from the entrance till the balun's end.

Results and Discussion

Based on the chosen values of the dielectric constant and system frequency, one needs to calculate the number of layers and their corresponding radii. As an example of simulation we chose dielectric permittivity of $\varepsilon = 16$ and loss tangent of $\tan\delta = 0.02$. Quarter wave at 64 MHz will be in this case equal to 29.3 cm. We chouse the total balun length to be 10 cm, so in this case we will need to fold the quarter wave on three coaxial cylindrical surfaces. Their respective radii are calculated using the formula (3) so that if starting with cable radius of 5 mm the resulting layer radii and characteristic impedance will be $r_0 = 5\text{mm}, r_1 = 7\text{mm}, r_2 = 9.8\text{mm}, r_3 = 13.72\text{mm}, Z_0 = 5\Omega$. The mechanical model is represented in Figure 2, where the spiral folding topology was considered. Electric and magnetic fields inside the balun are plotted in the same figure, showing maximum magnetic field at the entrance of the balun and maximum electric field at the end of the balun. The balun can be also build in rectangular topology, provided that the characteristic impedance is kept continuous without significant discontinuities between layers.

Conclusion

Quarter wave cable balun is serious alternative to the tuned bazooka balloon for high field systems. For fields above 1.5T, the quarter wavelength in dielectrics with high dielectric permittivity (typically >10) the multilayer quarter wave balun could be a viable alternative. Its controlled geometry makes needs no tuning and eliminates soldering of multiple capacitors. Also, it was found experimentally that this type of balun has much lower temperature during MRI scans. When linear quarter wave balun is too long for specific frequency, it can be folded as described above.

Acknowledgments

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References

1. Pozar, Microwave Engineering, page 275,