Balanced Feed Lines with Bridged Shield Gaps for RF Coil Arrays

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Target Audience: RF engineers, physicists interested in MRI hardware

Purpose. Contributions on coil-feed designs as the main subject are generally rare in the MRI literature. Most coil simulations end at feed ports of the elements, inherently assuming that the interaction with transmission lines and common mode-traps are negligible. Recently, a 2×4 dual-row transmit array for 7T head imaging has been introduced that employs a novel feed-line concept. In particular, all adjustment elements are included in a match box, and balanced lines with an electrical length of either λ/2 or λ provide connections to the loops in both rows. At the match-box end, all line shields are connected. For common-mode current rejection, the shields have one or multiple gaps, which are bridged by resistors or capacitors (Fig. 1). Goal of the current project is a comprehensive investigation of the performance of this feed-line concept

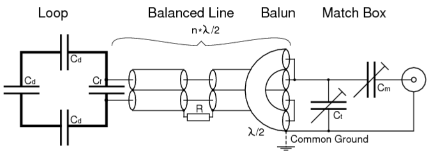

Fig. 1: Feed concept for a single channel.

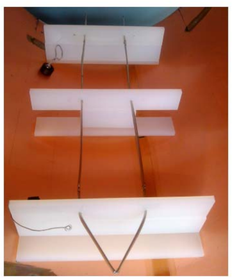

Fig. 2: Experimental setup. Cable shields of the both pick-up loops are grounded at the copper tube.

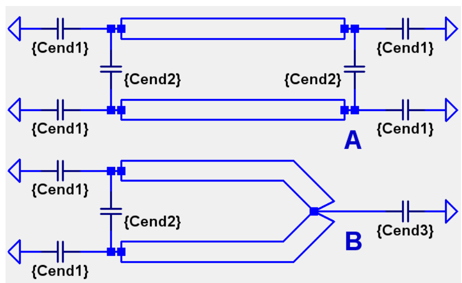

Fig. 3: Equivalent circuit diagrams for parallel lines **(A)** and lines with V-shaped end segment **(B)**.

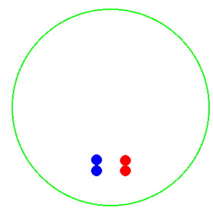

Fig. 4: Cross section of outer line system (not to scale).

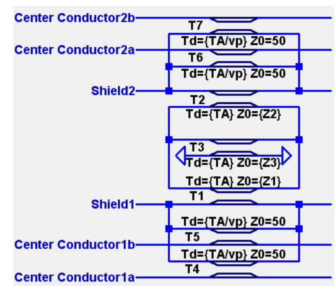

Fig. 5: Basic SPICE circuit. Several segments may be chained.

Methods. For bench-top studies with a the vector network analyzer ZVT 8 *(Rhode&Schwarz, Munich, Germany)*, a simplified system consisting of two balanced lines was built (Figs. 2, 3) that also permits straightforward simulation. The setup is inspired by Boskamp [2], however, with small loops instead of dipoles for excitation. Each line consisted of a 70cm-long pair of hand-bendable coax cable *(.141SRF-C-P-50, JYEBAO, Taipei Shien, Taiwan)*. The cable shields were soldered together every few centimeters. These lines were arranged symmetrically and axially parallel (distance 100 mm) in a copper tube (860mm long, 608mm inner diameter), 182mm off-center. At one end, the line shields were connected to form a V-shaped segment of 100mm length. Two shield gaps (2mm long) per line were located at 140 mm from each end. We note that the copper tube and the line shields form a twin-axial transmission line (Fig. 4). Hence, the entire system can be considered as a multi-conductor line.

An approach for SPICE modeling was adapted from Marx and Eastin [3]. Fig. 5 represents the basic circuit. The outer system (Z1, Z2, Z3) was calculated by atlc [4], a special 2D simulator for computing the properties of arbitrarily shaped transmission lines. Input is simply the cross section as bitmap file (Fig. 4); the mesh is defined by the pixel size. The continuously changing characteristic impedances of the V-shaped segment were approximated by five discrete steps (90-10mm spacing). Additionally, the fringe fields at the ends of the lines have to be taken into account. Their impact can be modeled by virtual capacitances on the cable shield ends. In preliminary experiments without shield gaps with two parallel straight lines (Fig. 3A), Cend1 and Cend2 were obtained and, subsequently, Cend3 modeling the fringe field of the V-shaped segment, was determined (Fig. 3B). As long as no shield gaps are included, wiring of the inner conductors is irrelevant. However, upon inserting the gaps, conditions must match those shown in Fig. 1. As a λ/2-delay-line balun has very low impedance near its operating frequency when driven in common mode, the inner conductors were shorted to the line shield on the match box and left open on the loop side.

Results and Discussion. Transmission-line parameters computed by atlc were Z1=Z2=204.5 (199.6, 186.9, 168.6, 139.3, 74.0) Ω and Z3=44.4 (49.8, 63.2, 82.0, 111.5, 174.2) Ω for 100 (90, 70, 50, 30, 10) mm spacing. Remarkably, Z1+Z3≈249.7±1.0 Ω was consistently obtained independent of line spacing. End capacitances of Cend1=0.25 pF, Cend2=0.26 pF and Cend3=1.3 pF yielded the best fit to experimental data. The stray capacitance of an open gap was estimated as 0.3 pF. The model was tested for various conditions between 50 and 450 MHz. Table 1 compares predicted and measured S21 peaks for open shield gaps demonstrating excellent agreement. As already shown experimentally [1], resistively bridged shield gaps can reduce unwanted coupling by damping parasitic resonances. By simulation, a lowest Q of 8.7 was achieved with a resistance of ≈ 55 Ω, which is an uncritical value. Unwanted effects, such as peak splitting, are effectively avoided. However, we cannot completely exclude that some power may be dissipated by coupling with adjacent loops. When bridging the gaps with 8.2 pF capacitors, a notch was produced just below 300 MHz in simulation as well as in experiment (Fig. 6). Fig. 6A further shows effects of additional capacitive loading (0 to 0.25 pF) parallel to Cend2 (see Fig. 3B): *(i)* The green curves (no gaps) indicate a peak shift towards operating frequency, leading to conditions of unwanted susceptiblity to so-called hand effects. *(ii)* The red curves (gaps bridged by resistor) do not show a significant influence. *(iii)* The blue curves (gap bridged by capacitor) have a common central notch that remains unaffected, even for unrealistically high loads. Consistent behavior was observed experimentally. As yet, there was no evidence of unwanted interaction between two balanced lines. Future work will include optimization of the number and locations of gaps for both resistive and capacitive bridging as well as full 3D EM simulations.

99.7	184.2	253.3	257.2	299.6	341.9	386.6	406.2
100	185	254	258	304	342	385	401

Table 1: Validation of SPICE simulations (open shield gaps) showing the frequency (in MHz) of peaks in S21 response as predicted **(top row)** vs. experimental result **(bottom row)**.

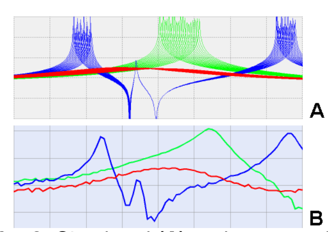

Fig. 6: Simulated **(A)** and measured **(B)** frequency response from 260 to 340 MHz (green: no gaps, red: 82 Ω, blue: 8.2 pF connected parallel to the gaps).

Conclusion. Treating the proposed balanced feed system as multi-conductor transmission-line circuit achieved excellent agreement with experimental data indicating that the concept prevents sheath waves without the need of conventional traps. It appears promising, particularly for multi-element arrays. The notch frequency in case of gaps bridged by capacitors is almost independent of different loading conditions.

References. [1] R. Müller et al. *Proc. ISMRM* 22: 1317 (2014). [2] E.B. Boskamp et al. *Proc. ISMRM* 20: 2691 (2012). [3] K.D. Marx & R.I. Eastin. *IEEE Trans. Microwave Theory Tech.* 38:1123 (1990). [4] D. Kirkby. *http://atlc.sourceforge.net/transmission_line.html*