Parallel-Plate Waveguide for Subject-Insensitive RF Transmission

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Introduction: Conventional RF coils are resonant structures tuned to one or two fixed Larmor frequencies. They are high-Q structures sensitive to different loading conditions. This can be especially problematic for high-field applications where the coil/subject coupling is expected to be much stronger. In order to avoid frequency tuning, a broadband RF coil that utilizes the transverse electromagnetic (TEM) mode of a parallel-plate waveguide was developed. Due to the lack of resonance, it is more stable with respect to different loadings. Furthermore, the same coil can be utilized at distinct frequencies due of the frequency-independent nature of the TEM mode.

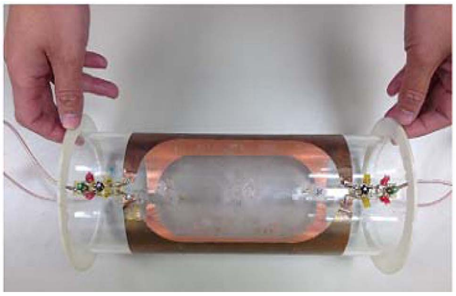
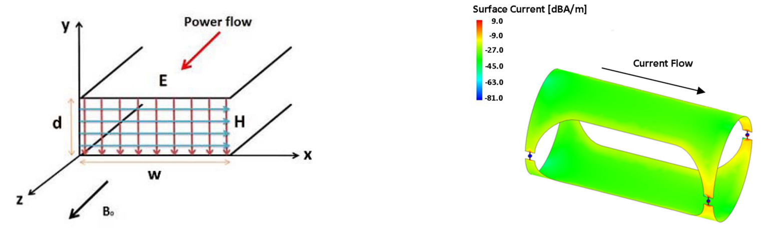
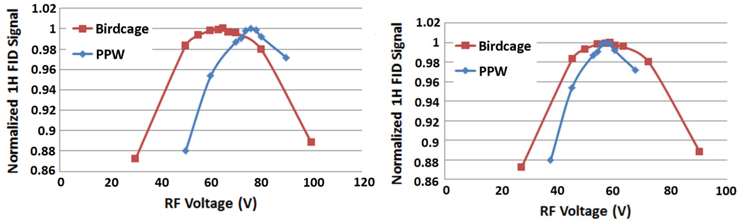


Figure 1. The parallel-plate waveguide for MRI.



(a) (b)

Figure 2. (a) EM field distribution and (b) the current distribution of the TEM mode.



(a) (b)

Figure 3. The measured transmit efficiency (a) before and (b) after calibrations with front-end loss.

(a) (b)

Figure 4. Spin-echo images acquired on a 7 Tesla scanner on (a) transverse and (b) sagittal plane.

Methods: The coil consists of two parallel conductors of width *w* and separated by a distance *d* (Fig.1). According to microwave engineering theories, the electromagnetic field between the two conductors is the combination of TEM, transverse electric (TE) and transverse magnetic (TM) modes[1]. None of the modes are resonant (at discrete frequencies), but both TE and the TM modes have a cutoff frequency below which the electromagnetic fields become evanescent. In contrast, the TEM mode does not have a cutoff frequency. Its wave impedance is frequency independent and its magnetic field distribution is uniform in the plane transverse to the main axis of the waveguide (Fig. 2a). These features make the TEM mode suitable for MRI imaging.

Both ends of the parallel conductors are split into two halves to provide an entrance to imaging subject (Fig. 1). At each gap, a broadband Chebyshev matching network was applied to match the 50-Ohm cable impedance to the 200-Ohm TEM wave impedance. A single RF power input was used to feed two ports at one end of the coil by using a broadband Wilkinson power divider. At the other end of the coil, a second broadband Wilkinson power combiner was applied to combine the existing power into one output. This combined power output was then fed in-phase with the power input (from the system) by using a third Wilkinson power combiner. This forms a re-entrant scheme that recycles the RF power that would otherwise be dumped into a terminating load[2].

Results and Discussion: Figure 2(b) shows the current distribution on the conductor surface simulated by FEKO®. Due to the lack of reactive components for tuning, a uniform current distribution is observed. When loaded with an 8-cm cylindrical saline phantom, the reflection coefficient was -15.9 dB at 297 MHz. When loaded with the human forearm that is much thinner than the saline phantom, the reflection coefficient was -16.6 dB. Figure 3 compares the transmit efficiency of the proposed coil with an eight-run birdcage coil of the same size at 7 Tesla. It was performed by measuring the signal density with different voltage levels of a free-induction-decay (FID) sequence on a Siemens Magnetom scanner. With the re-entrant scheme, the transmit efficiency of the proposed coil is similar to birdcage coil. Finally, Figure 4 shows the spin-echo images acquired by using the proposed coil as a transceiver at 7 Tesla. The uniformity and coverage of the proposed coil are similar to birdcage coil.

Conclusions: A broadband parallel-plate waveguide was developed for MRI. Due to the frequency-independent nature and the lack of reactive tuning components, it is insensitive to loading conditions with exhibit imaging qualities comparable to resonant birdcage coil.

References: 1) Pozar DM. Microwave engineering, New York: John Wiley & Sons; 1998. 2) Carter PS, Feedback systems for traveling wave antennas. US Patent 2,290,314. July 21, 1942.