# Numerical study of the waveguide magnetic field via the principal mode for MRI at 3 T

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## Introduction.

Waveguides have been successfully used to generate magnetic resonance images at 7 Tesla for whole-body systems [1]. We have previously shown that the waveguide approach can also be used with magnetic field intensities lower than 7T and whole-body systems [2]. A parallel-plate waveguide was used in this previous work since it is probably the simplest waveguide available. The fundamental mode ($TM_0$) describes uniform magnetic fields tangent to the copper plates. The $TM_0$ mode can propagate at any frequency and there are no variations of the fields inside the waveguide. Numerical simulations of the magnetic field generated by a parallel plate waveguide were computed at 3T via the propagation of the principal mode.

## Material and Methods.

The parallel plate waveguide is the simplest structure consisting of two parallel electrically conducting (PEC) plates. This waveguide is used for propagating uniform circularly cylindrical waves having their axes normal to the plane. The computation of the transverse electromagnetic (TEM) modes can be done using:



Figure 1. Illustration of copper parallel-plate waveguide showing boundary conditions and $TM_0$ mode propagation.

$$\frac{\partial^2 H_y}{\partial x^2} + \frac{\partial^2 H_z}{\partial x^2} = -\omega^2 \mu \varepsilon H_y \quad (1),$$

where $\mu = 4\pi \times 10^{-7}$ H/m, $\varepsilon = \varepsilon_0 \varepsilon_r, \varepsilon_0 = 1 \times 10^{-9}/36\pi$ F/m, and $\omega$ is the frequency, $\varepsilon_r = 80$ for copper. The finite element method (FEM) was used to numerically compute $TM_0$ with propagation along the $z$-direction together with eq. (1) and a commercial software tool. All numerical simulations were performed using COMSOL MULTIPHYSICS (V. 3.2, Comsol, Burlington, MA, USA) at 128 MHz (proton resonant frequency at 3T). The simulation arrangement is shown in Fig. 2: the waveguide was assumed to be 20x20x20 cm and made out of copper sheets. These computations included a simulated human phantom, built using the COMSOL graphical interface. It was assumed that the relative permittivities for the bone and muscle were 15 and 65 respectively. The two circular coils were used for reception and were located at either end of the waveguide as shown in Fig. 2.



Figure 2. Top. Phantom and mesh. Middle and Bottom. Simulation of magnetic fields in different orientatios for $TM_0$ mode of a phantom leg.

## Results and Discussion.

The numerical computations of the magnetic fields of a parallel plate waveguide using the fundamental mode along the $z$-direction were computed using FEM. This method is particularly good for solving complex geometries. Fig. 2 shows the mesh and phantom and the simulations of the magnetic field of a simulated human leg for the principal mode in different orientations. Fig. 3 displays a comparison between the human leg image acquired with a 3T clinical imager (Philips Medical Systems, Best, NL), and a numerical simulation of the magnetic field in the same orientation. From Figs. 2 and 3, an increment in the field intensity at the very centre of the waveguide for all simulations can be observed. Hyperintensities were observed in the volunteer's entire leg image (Fig. 3.a) at the same location as in the magnetic field simulations of both Fig. 2 and Fig. 3.b). Generally, waveguide-generated images showed a relatively good quality images. However, this numerical approach can be of some assistance to understand the mechanisms involved in the formation of the magnetic fields generating the MR images. We have demonstrated that the simulation of magnetic fields via the calculation of the fundamental mode of a waveguide can be useful to predict image quality. In this study, circular coils were employed for the reception of the field. This also paves the way for the study of other possible waveguide configurations for other magnetic field intensities and different magnet bores.



Figure 3. a) Entire leg image acquired with waveguide approach [2]. b) Simulated magnetic field with $TM_0$ mode for a phantom leg.

**References**. 1. Brunner DO, et. al. Nature 457;994:2009. 2. Vazquez F, et. al., ISMRM-ESMRMB, 3792, 2010. Cheng DK, Fundamentals of Engineering Electr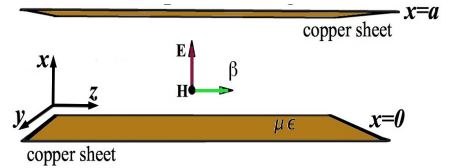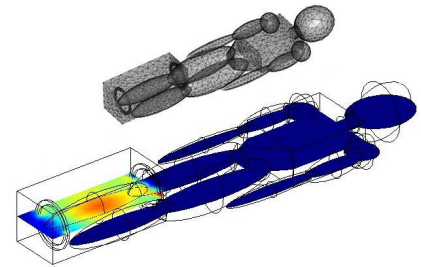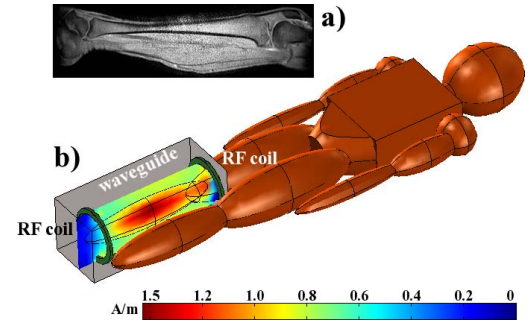omagnetics. Prentice Hall, NJ, 1992.