A Wire-free, Radio-Frequency, Shielded Projection Window for MRI Suites

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Introduction

The investigation by fMRI of neural mechanisms associated with visual stimuli is now relatively common. Potentially, one of the most effective methods of presenting a subject with visual data is by projection onto a screen at the end of the magnet bore. The subject then views the screen via a suitably-placed mirror. However, this arrangement is more difficult to implement than might be supposed. The windows in MRI suites are usually at the *front* of the suite and the knees and feet of the subject can interfere with forward vision. Further, even if they did not interfere, the radio-frequency (RF) screening wires that are embedded in most windows introduce Moiré patterns in the image that degrade it and are distracting. This is particularly so with high-field systems where double-wire screening is often employed. Thus projection onto a screen at the rear of the magnet with the projector inside the suite is used in many institutions.

Video projectors use ferromagnetic materials, chiefly in their power transformers but also as radio-frequency chokes that help suppress interference emitted by the discharge light source. RF interference can also be generated from harmonics of the video electrical signals that produce the image. If projectors are placed in a sufficiently strong magnetic field, the ferromagnetic materials may approach saturation, with results ranging from poor operation to blown fuses, interference generation and in extreme cases, risk of fire. There may also be a "missile threat" if the projector is not securely anchored. In addition, the cables coming to the projector through the suite shield may carry interference, both into and out of the suite, unless high-order RF filtering of the video lines is employed. In short, video projectors have no place in an MRI suite yet, out of necessity, are often found there during fMRI experiments.

To place the projector safely *outside* the suite, a suitable projection window is needed and this can be a waveguide (well below its cut-off frequency) through which interfering (received or transmitted) RF signals are severely attenuated but light can propagate unhindered[1]. Unfortunately, however, the light beam from a projector rapidly diverges and this can render the size of an effective waveguide very large, depending on the relative positions of the projector, the screen and the shielding wall. At 128 MHz, a square waveguide must be of side << 1.65 m (0.707 λ)[1] to be well below cut-off and of length at least twice its side to produce 80 dB attenuation. Placement of a projector at the rear of our 3 T suite poses an additional challenge as the best place for the projector is at the rear door! Predictably, operation of our Siemens imaging system with the rear door open degrades image quality, generates substantial RF emissions in contravention of government regulations and interferes with other MRI systems. Clearly, a projection window at the rear of the suite or even in the door would be advantageous, but it would have to be an RF shield without embedded wires. We therefore describe here such a window.

A Salt Water Window

The use of an aqueous sodium chloride solution for electrostatic screening purposes is venerable. However, it may also be used as an RF screen provided it is of sufficient conductivity σ for the frequency in question. Propagation at frequency ω of electric and magnetic fields through a conductor is as $\exp(-ikz)$, where $i = \sqrt{-1}$, z is distance and the complex wavenumber k is given by $k^2 = \mu\mu_0\varepsilon\varepsilon_0\omega^2 - i\omega\mu\mu_0\sigma$. Here μ_0 is the permeability and ε_0 the permittivity of free space, and μ is the relative permeability and ε the relative permittivity (dielectric constant) of the solution. For a saturated salt solution[2], $\mu = 1$, $\varepsilon = 80$ and $\sigma = 22.6$ S/m. Hence, at 128 MHz $k^2 = 576 - 22841i$ which is overwhelmingly imaginary; thus propagation decays exponentially as $\exp(-z/\delta)$ where $\delta = 9.48$ mm. Hence a salt solution of thickness 10 cm should attenuate by over 90 dB which should suffice. Snell's Law gives no reason to think that projection through a salt solution enclosed in parallel glass walls of good optical quality should be less than satisfactory and indeed, excellent image quality is retained. Thus it remains to test the RF properties of the solution.

Methods

The 20 x 20 x 10 cm salt water cell of Fig. 1 was constructed from glass glued with silicone aquarium sealant (Dow Corning, Midland, MI, USA) and adhesive copper foil (available at stained-glass window shops). The copper passes to the cell exterior where it can be attached to the MRI suite RF screen. Copper is not corroded by oxygen-free saline but solder is. Further, saline appears to attack both non-cured sealant and the copper's adhesive, causing the solution to become cloudy and have a precipitate. Thus when constructing the cell, it is essential that edges and joints in the copper be covered with well-cured silicone. Filling the cell and then sealing the lid is problematic. Once full of saline there is no oxygen left in the cell to cure any exposed silicone. It follows that a compressible gasket must isolate the internal saline from external glue which, in its turn must seal extremely well to avoid leakage and subsequent corrosion. Attention must also be paid to expansion and contraction. Fortunately, leaving a small layer of air is not detrimental as the gap forms a waveguide well below its cut-off frequency. Note that placing the copper outside the glass and relying on capacitance for the electrical connection to the saline is ineffective.

The cell was tested with the aid of two 50 cm dipole antennæ, a shielded enclosure (1 m^3) with a 20 x 20 cm hole in a wall and a network analyser (10 dBm output). One dipole was placed inside the enclosure and the other 1 m outside the hole. The transfer function varied rather haphazardly with frequency in the range 10 to 300 MHz due to resonances in the enclosure, but was always from 45 to 65 dB above the noise floor. However, when the saline cell was placed in front of the hole with the copper flanges attached to the enclosure, emissions dropped to below the noise floor, indicating that the cell was shielding to at least the 65 dB level.

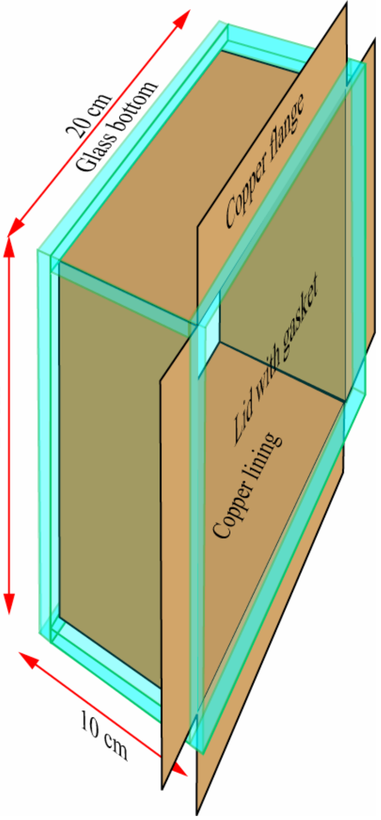

Figure 1. An experimental projection window – a copper-lined cell for holding a saturated salt solution.

Conclusion

We have demonstrated that it is possible to make a saline projection window for an MRI suite that offers excellent image transmission qualities while maintaining shielding efficacy. The marine window construction and sealing techniques used on larger ships should allow openings of any desired size to be constructed.

References

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2. R. C. Weast (ed.) Handbook of Chemistry and Physics, 58th edn., CRC Press, Cleveland OH, USA, 1977.