B1 field uniformity improvement at 400 MHz using multi-channel excitation birdcage

V. Taracila[1], L. S. Petropoulos[1,2], T. P. Eagan[1], T. K. Kidane[1], T. N. Baig[1], R. W. Brown[1]

[1]Case Western Reserve University, Cleveland, Ohio, United States, [2]Hitachi Medical Systems, Twinsburg, Ohio, United States

Overview:

The move to higher field strengths in MRI systems is made to take advantage of an increase in signal-to-noise and image resolution. A challenge, however, is the associated decrease in dielectric wavelength. At 400 MHz the electromagnetic wavelength, which is λ_0=75 cm in the air, is reduced inside a head-like conducting dielectric body (ε=58, σ=0.4-1.5 S/m) to $\lambda = \lambda_0/\sqrt{\varepsilon} = 9.8$ cm which is smaller than the human torso or head. At frequencies of 120 MHz and above, experimentally (theoretically) bright spots have been observed (simulated) in tissue samples which have been ascribed to a "dielectric resonance" effect [1-3]. However it is understood, the source of the problem is the transverse magnetic field nonuniformity associated with the shortened dielectric wavelength, which can lead to a distorted image. In this paper, we strive to improve the B1 uniformity of the transverse RF field at 400 MHz by using a multi-channel birdcage-like structure, where for each channel, a different azimuthal current behavior is considered. Using the magnitude combination of these images, a more uniform image is obtained. As a result of such methodology, we are able to reduce the B_1 field variation inside a head sample from 50% down to less than 10%.

Theory

A 2D model of a shielded birdcage coil suitable for head imaging is considered. The radius of the birdcage is chosen to be 14.6 cm and radius of the shield is 17.6 cm. With the neglect of length corrections, a long dielectric cylinder with a radius of 9.25 cm, electric permittivity 58 and conductivity 0.7 S/m is located concentrically in the middle of a shielded birdcage structure. We work with an analytic expression of the transverse field of the shielded birdcage coil in cylindrical coordinates for different dielectric regions and propagation constants. To connect these regions, continuity of the transverse and normal components of the magnetic and electric fields is enforced at the dielectric-dielectric interface. The magnetic field is required to vanish outside the shield. It is useful to consider current distributions given by single azimuthal harmonics (cos*mφ*), for each of which the field pattern has the same cos*mφ* dependence. With channels denoted by their own index *m*, the general expansions of the vector potential inside the different sample regions have the form

$$\mathbf{A}_m(r,\varphi,t) = \hat{z} C_m J_m(kr)\cos m\varphi e^{i\omega t} \tag{1}$$

where C_m is a constant depending on boundary conditions, the position of the sources and the radius of the shield. $J_m(x)$ is a Bessel function, and $k^2 = i\mu_0\omega\sigma + \mu_0\varepsilon_0\varepsilon\omega^2$ is the dispersion relation in the sample. By driving the birdcage at different *m*'s, we acquire images with different profiles, as shown in Fig.1.

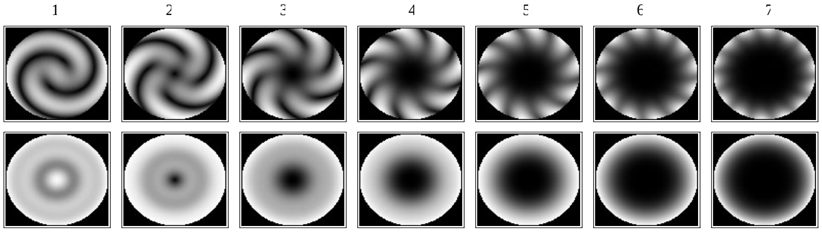

Fig.1 Field profiles for excitation channels with *m*=1,2,3,4,5,6,7 and cos *mφ* current distributions.

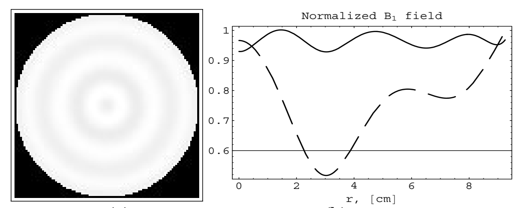

Fig.2. Combined images at 400 MHz from 7 channels

In the upper row of Fig. 1, real values of the transverse magnetic field are plotted and in the lower row absolute values of the transverse magnetic field are plotted. Only for *m*=1, the traditional birdcage coil index, is there a signal in the center of the sample. For the other excitations, the distributions are increasingly peripheral. This effect is due to both the proximity to the birdcage currents and the screening effect of the eddy currents induced inside the sample. In order to optimize a combination of signals from the different channels, the following functional is employed

$$F[\alpha_1,\alpha_2,\ldots,\alpha_N;r] = B_1(0) - \sum_{m=1}^{N}\alpha_m B_m(r) \tag{2}$$

where $B_m(r)$ is the amplitude of the magnetic field produced by the *m*'s channel at radius *r*, and α_m are unknown weighting factors to be determined, *N* is the number of channels. By minimizing $F[\alpha_1,\alpha_2,\ldots,\alpha_N;r]$ we can find the weighting factors for each channel. Each channel has a different profile for the standing wave generated in the sample. Because the minima and maxima of the transverse magnetic fields generated by these channels do not occur at the same locations, we can combine them so to compensate for any suppressed information (signal). As an example of this methodology, a birdcage structure with a limited number of channels (7) is considered and the weighting factors based on Eq. (2) are determined.

Results and Discussion

By superposing the images acquired with seven different channels and weighting them properly, a magnitude image representing the uniformity of the transverse field is generated. In Fig 2(b), a comparison between the resulted magnitude image (solid line) and the simple birdcage coil (dashed line) at 400Mhz is presented. It is characteristic that the resulting magnitude image for the weighting method has a transverse field with 2.2% non-uniformity from the mean or less than a 10% peak-to-peak variation, while the transverse B_1 field of the shielded birdcage with m=1 produces a 17% non-uniformity variation from the mean or a 50% peak-to-peak variation. The corresponding weighting factors needed to achieve a 2.2% variation from the mean value are:

m	1	2	3	4	5	6	7
α_m	0.96	–0.04	6.71	–30.33	110.79	–217.02	148.69

This technique can be extended to a 3D variant using analytical and numerical solutions for a lossy sphere in a multi-channel birdcage.

Conclusions

As the results indicate for a cylindrical phantom, it is possible in spite of the wavelength effects to use a multi-channel birdcage for the improvement of image uniformity at 400MHz, obtaining a reduction from 50% (peak-to-peak for a standard cos φ birdcage) down to less than 10% by superposing images taken with several $\cos m\varphi$ type channels. In this case, it is possible to obtain a uniform image at 400 MHz. Another way of extracting information out of the sample is to generate interference between standing waves created by different channels. In this case changing the phase delay between the channels the bright spot can be shifted in the selected slice of the sample in a controllable way (RF-interferometry) opening the possibility to replace some function of the gradients by the transmit RF-coil.

References

[1] J. Tropp, *Image brightening in samples of high dielectric constant*, Journal of Magnetic Resonance, 167 (2004) 12-24;

[2] D. K. Spence, S. M. Wright, *2-D Full Wave Solution for the Analysis and Design of Birdcage Coils*, Concepts in Mag. Res. Part B, Vol. 18B(1) 15-23 (2003). [2] D.

[3] T. S. Ibrahim, Abstract 1643, 12th ISMRM, Kyoto Japan, 2004.