Artifacts in Magnetic Resonance Imaging from Metals

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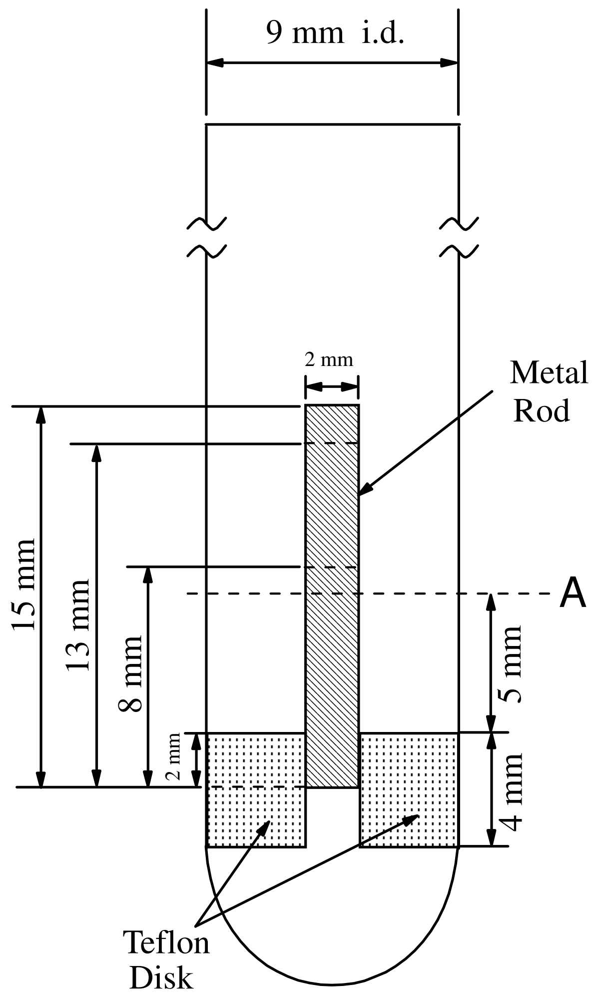
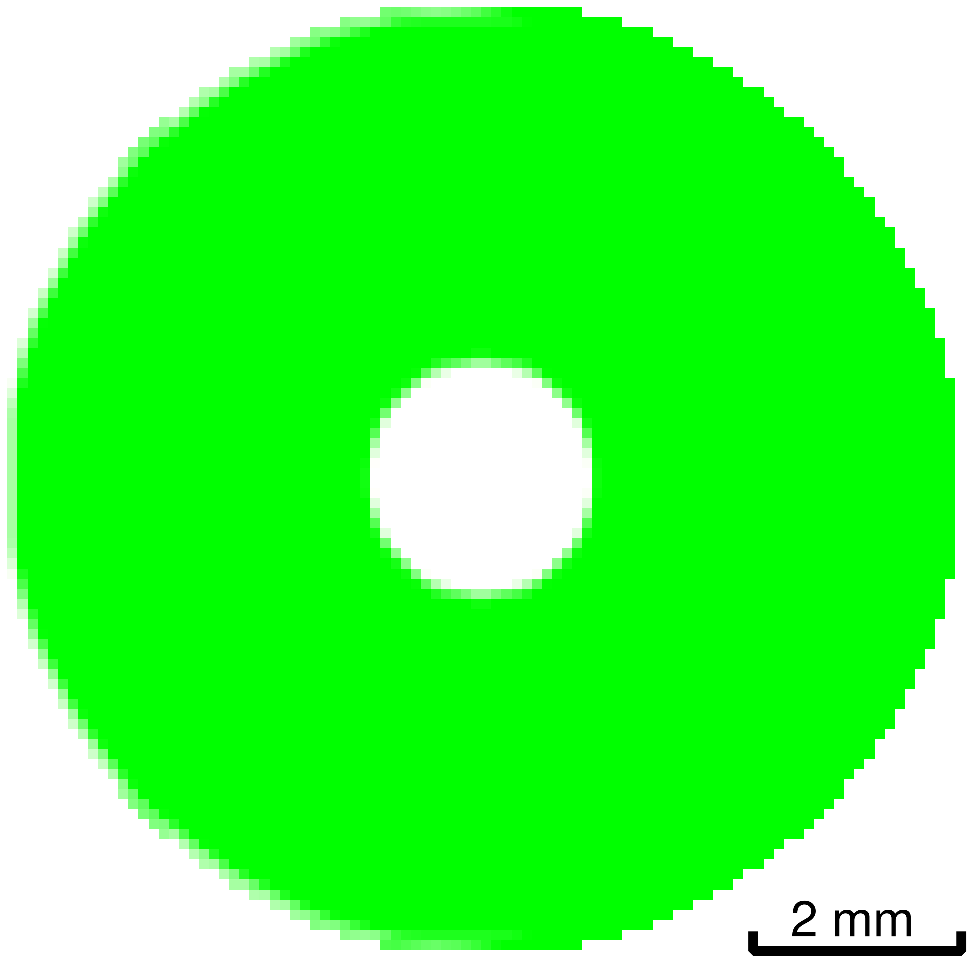
ABSTRACT

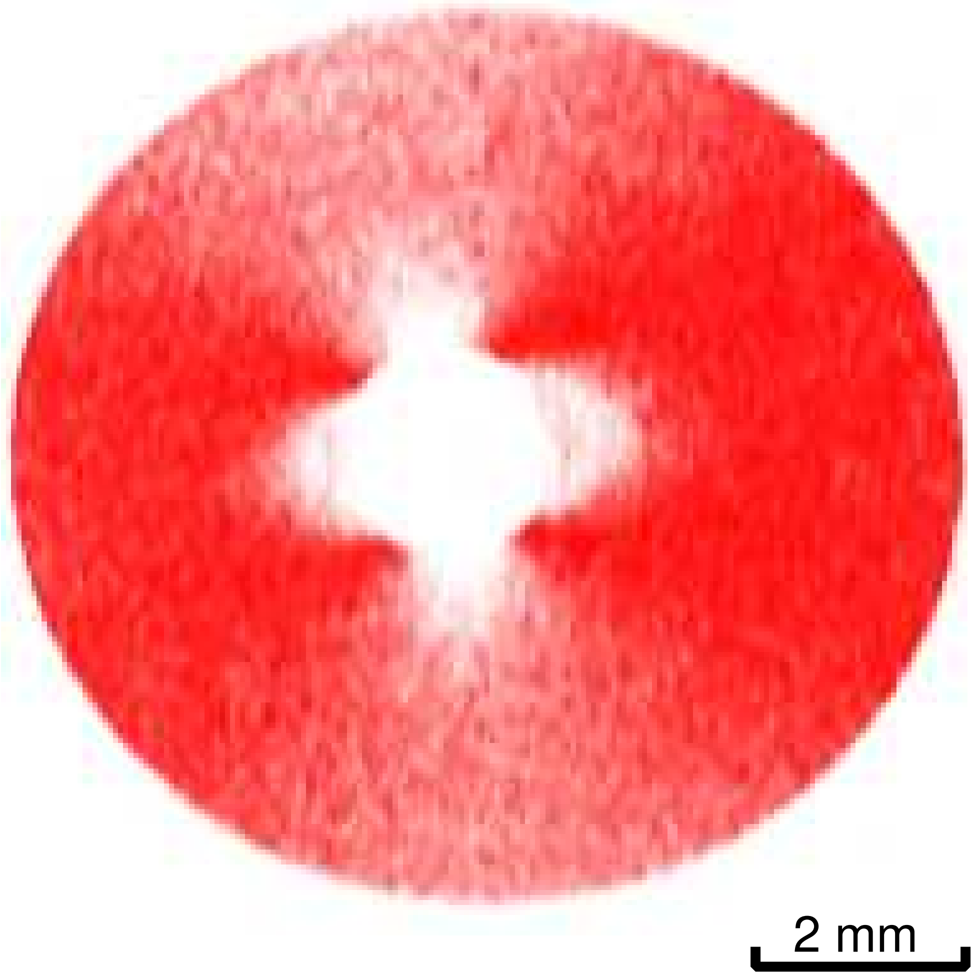
Metallic biomedical implants, such as aneurysm clips, endoprostheses, and internal orthopedic devices give rise to artifacts in the magnetic resonance image (MRI) of patients. Such artifacts impair the information contained in the image in precisely the region of most interest, namely near the metallic device. Ferromagnetic materials are contraindicated because of the hazards associated with their movement during the MRI procedure. In less-magnetic metals, it has been suggested that the extent of the artifact is related to the magnetic susceptibility of the the metal, but no systematic data appear to be available. When the susceptibility is sufficiently small, an additional artifact due to electrical conductivity is observed. We present an initial systematic study of MRI artifacts produced by two low susceptibility metals, titanium (relative permeability $\mu_r \approx 1.0002$) and copper ($\mu_r \approx 0.99998$), including experimental, theoretical, and computer simulation results.



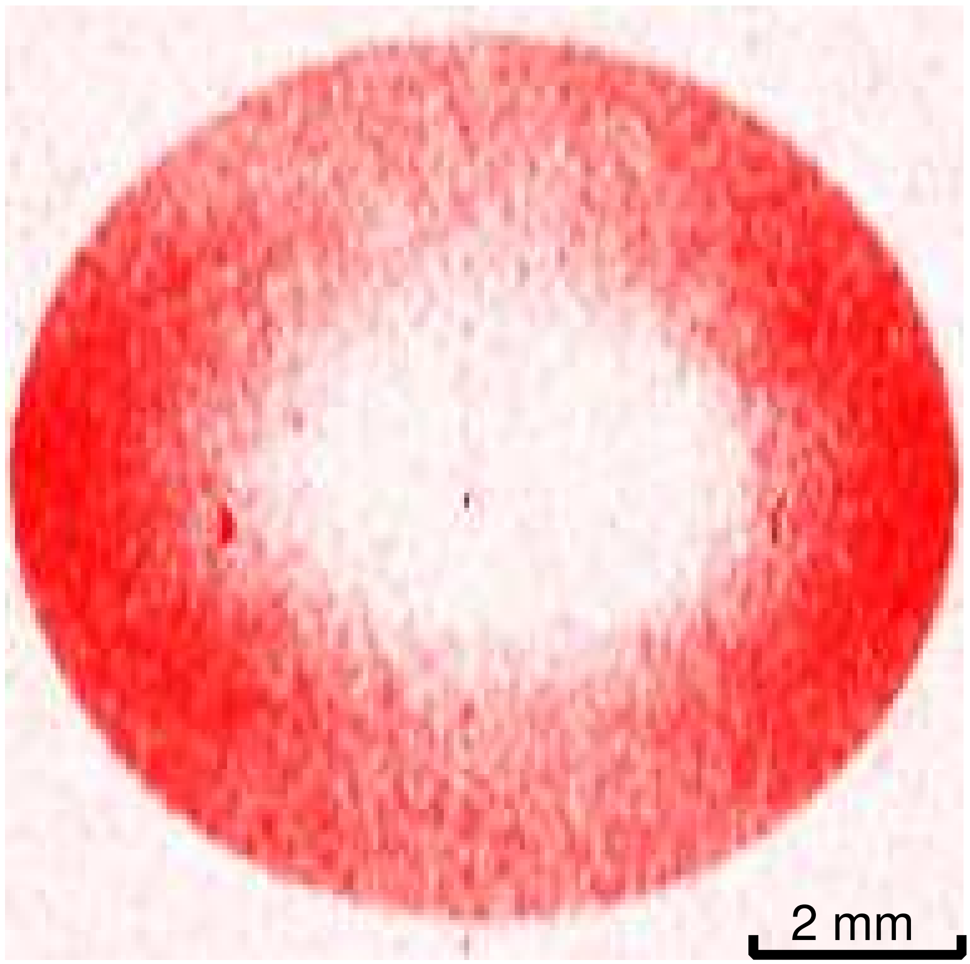
Schematic of MRI/NMR experiments. All MR images measured and calculated for cross-section A.



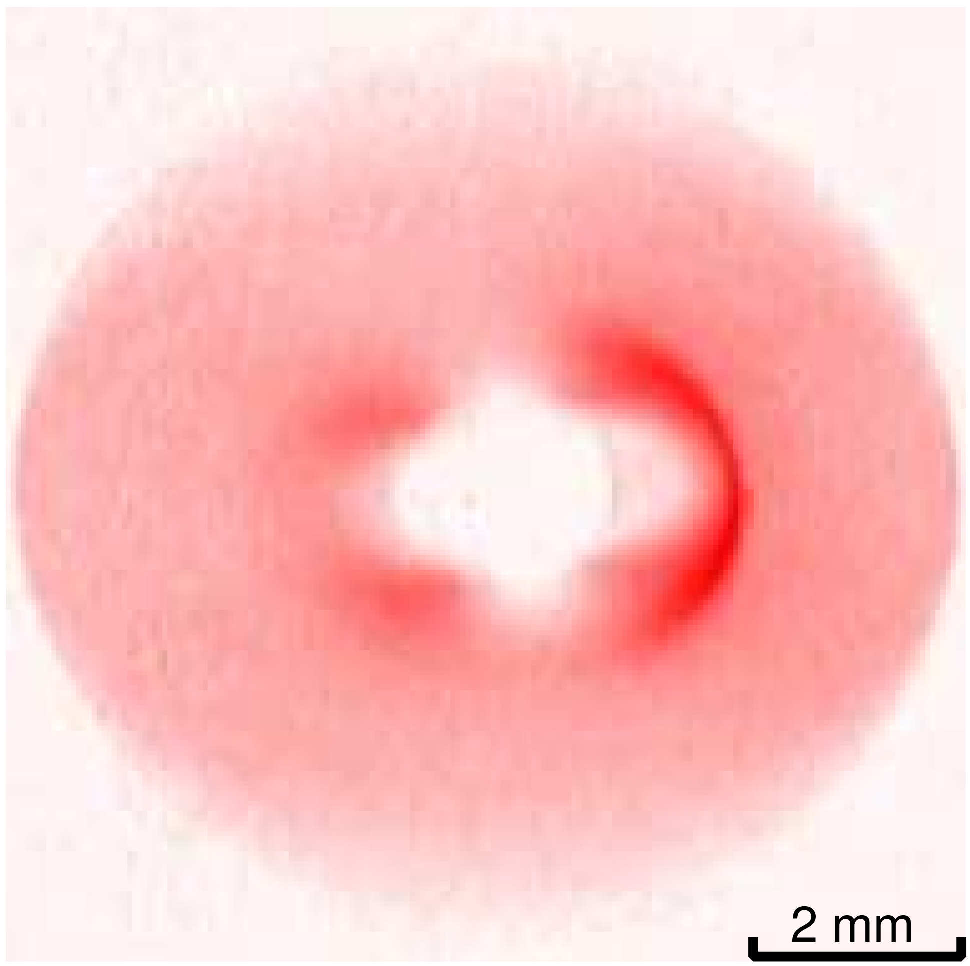
Ideal (artifact-free) cross-sectional MR image of a 2 mm diameter rod.



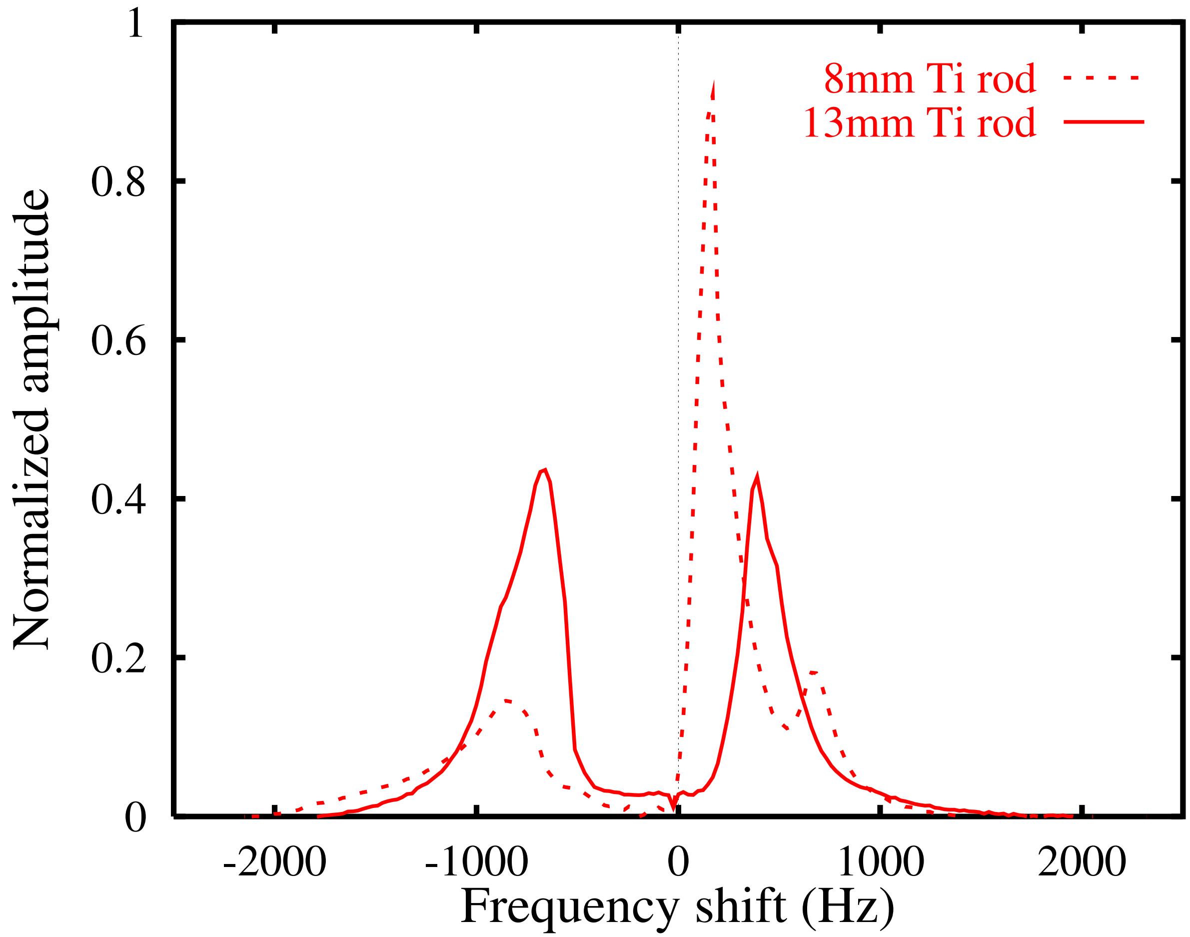
Experimental MR image of a 15 mm long by 2 mm diameter Cu rod. The slice was taken perpendicular to the rod 7 mm from one end. The image did not vary much with rod length or slice position.



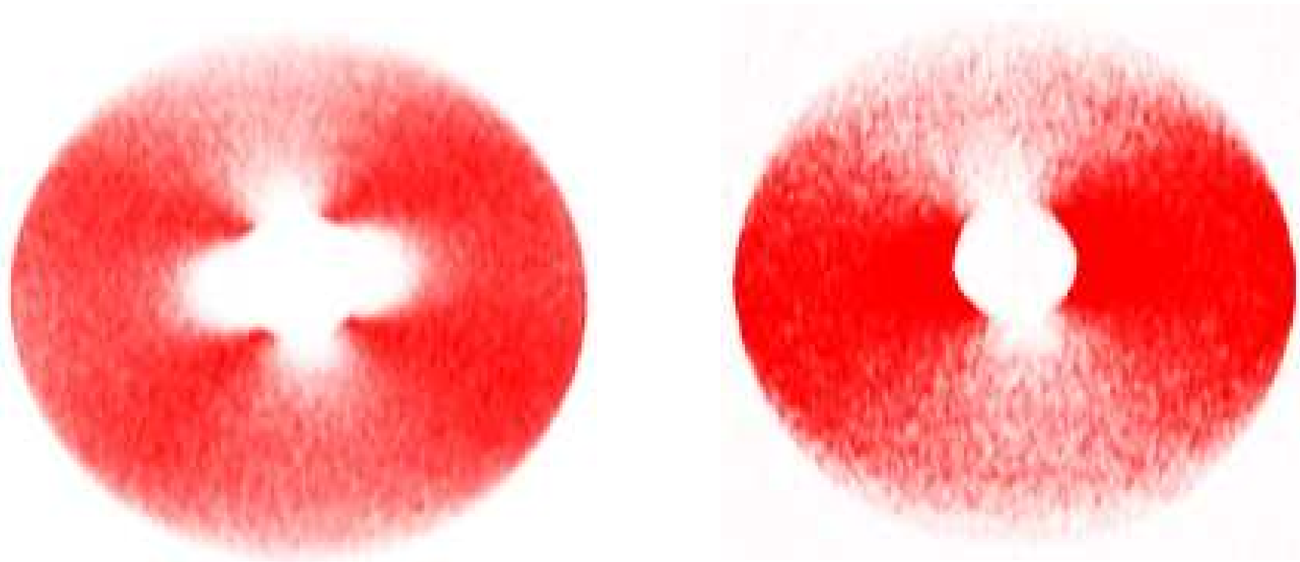
Experimental MR image of an 8 mm long by 2 mm diameter Ti rod. The slice was taken perpendicular to the rod 1 mm from one end.



Experimental MR image of a 13 mm long by 2 mm diameter Ti rod. The slice was taken perpendicular to the rod 6 mm from one end.



Experimental: Fourier transform of free induction decays for 2 mm diameter Ti rods of lengths 8 mm and 13 mm.



(a) (b)

Experimental MR image of a 13 mm long by 2 mm diameter Cu rod, obtained with (a) a $(\pi/2)$-τ-π-τ-echo pulse sequence, and (b) a reduced amplitude pulse sequence.

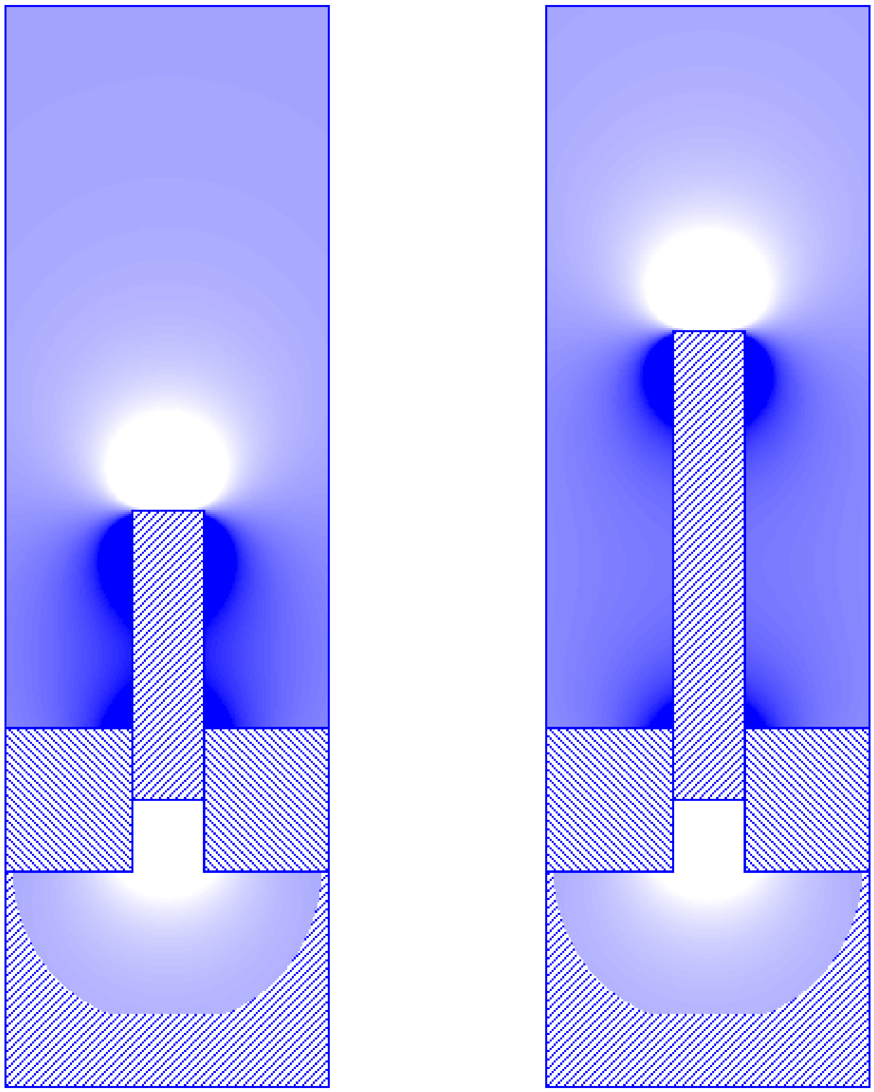
Susceptibility induced distortion to static field:

$$B_z^{\text{static}} \approx B_0 + \frac{B_0 \chi_v R^2}{4} \left\{ \frac{z - z_t}{\left[x^2 + y^2 + (z - z_t)^2\right]^{3/2}} - \frac{z - z_b}{\left[x^2 + y^2 + (z - z_b)^2\right]^{3/2}} \right\}$$

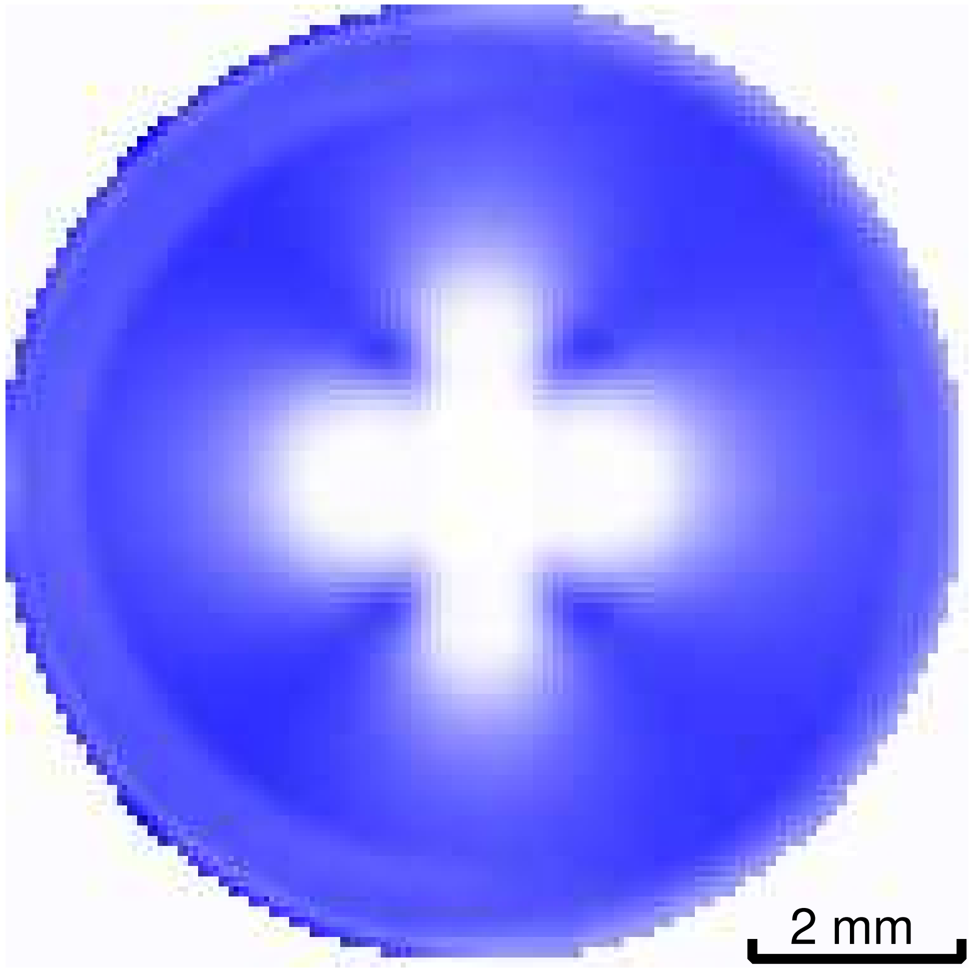
Eddy current induced distortion to RF field:

$$\begin{aligned} B_x^{\text{RF}} &\approx -2xyB_{\text{applied}}^{\text{RF}} R^2 \left(x^2 + y^2\right)^{-2} \\ B_y^{\text{RF}} &\approx B_{\text{applied}}^{\text{RF}} \left[1 + R^2 (x^2 - y^2) \left(x^2 + y^2\right)^{-2}\right] \end{aligned}$$

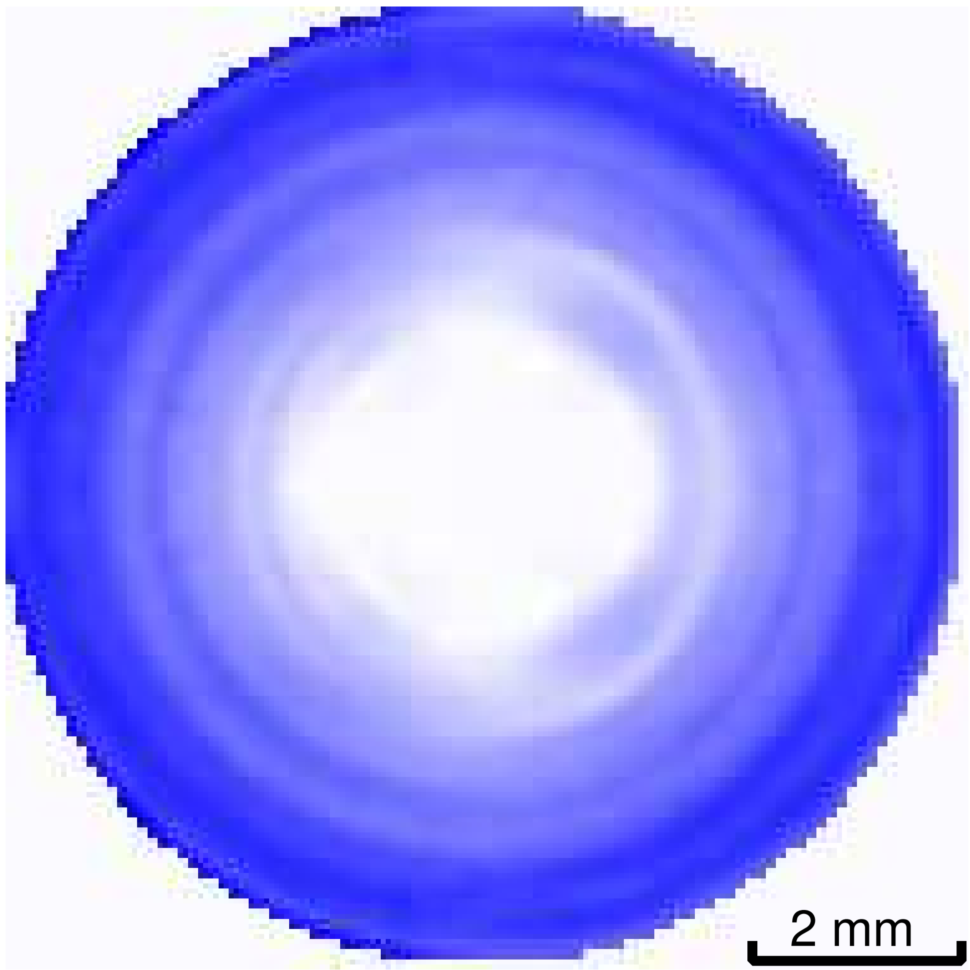
Where R is bar radius, z_t and z_b are the top and bottom of the bar, and χ_v is the material susceptibility.



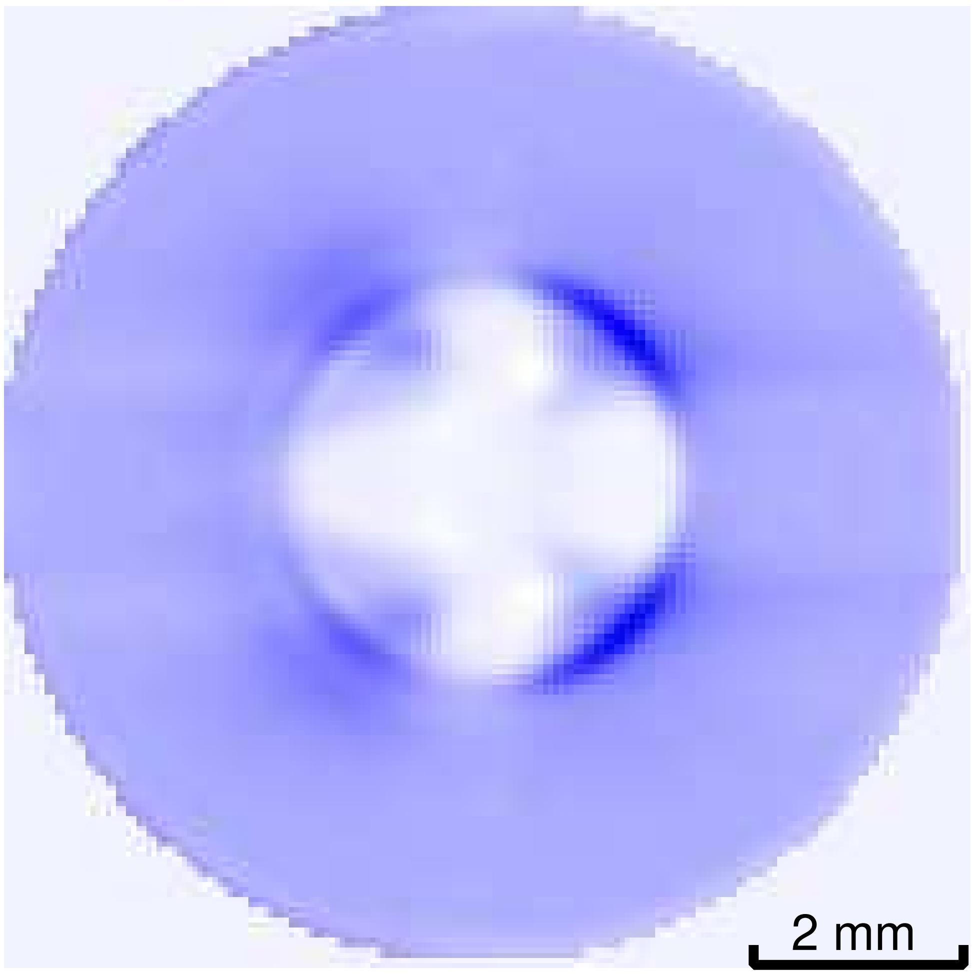
Simulated field strengths for 2 mm diameter Ti rods of lengths 8 mm (left) and 13 mm (right). The NMR tube inner diameter is 9 mm.



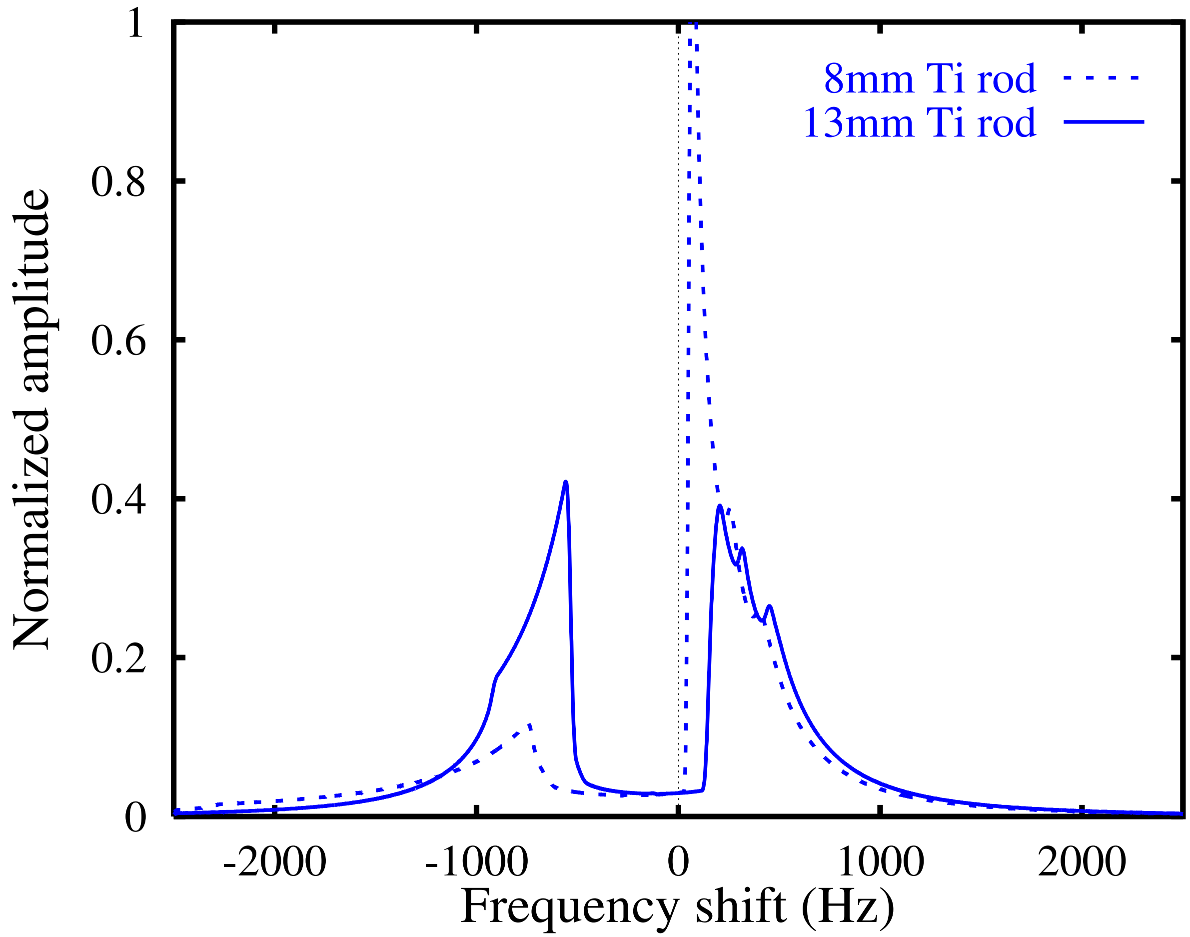
Simulated MR image of a 15 mm long by 2 mm diameter Cu rod. The slice was taken perpendicular to the rod 7 mm from one end.



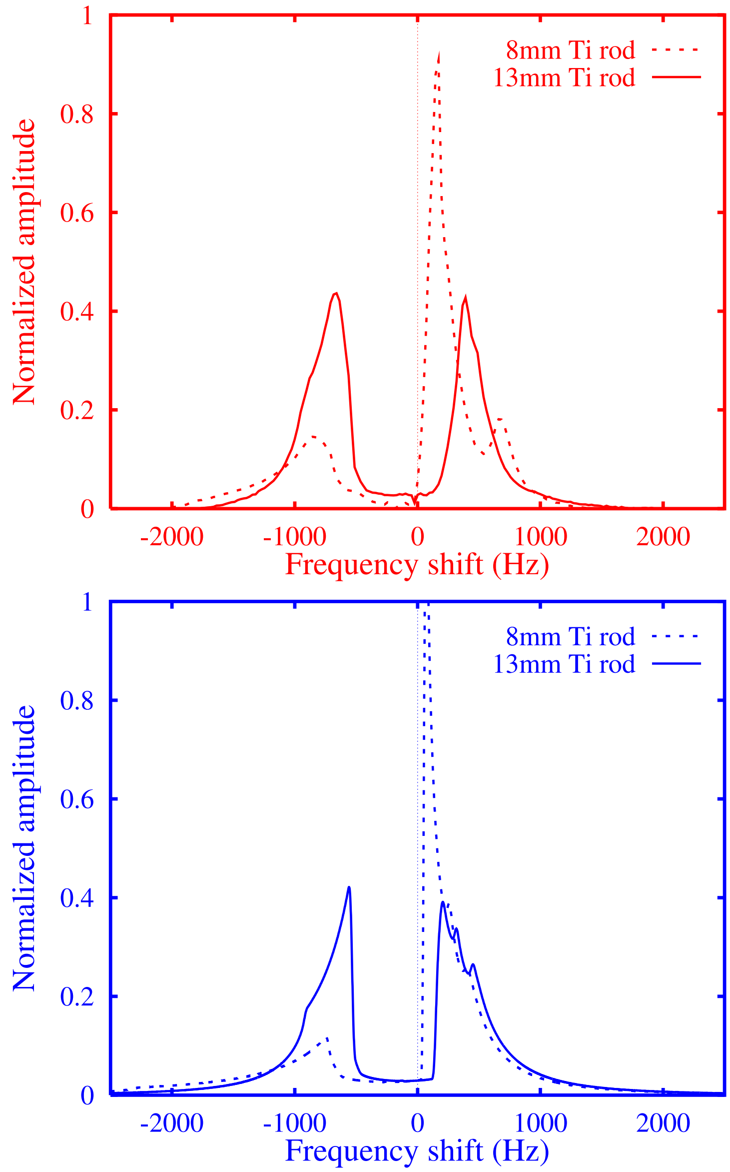
Simulated MR image of an 8 mm long by 2 mm diameter Ti rod. The slice was taken perpendicular to the rod 1 mm from one end.



Simulated MR image of a 13 mm long by 2 mm diameter Ti rod. The slice was taken perpendicular to the rod 6 mm from one end.



Simulation: Fourier transform of free induction decays for 2 mm diameter Ti rods of lengths 8 mm and 13 mm.



Fourier transform of experimental (red) and simulated (blue) free induction decays for 2 mm diameter Ti rods of lengths 8 mm and 13 mm.

SUMMARY

- MRI artifacts from metals in the body come from two distinct sources: susceptibility **and** electrical conductivity.
- Artifacts from susceptibility can be controlled by reducing the object's susceptibility.
- Susceptibility artifact is sensitive to geometry.
- Conductivity of the metal has little effect on the eddy current artifact.
- It may be possible to control the eddy current artifact by modifying the pulse sequence and MRI reconstruction.