Radiofrequency Coil Design and Decoupling for Magnetic Resonance Imaging

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Abstract
In an effort to decrease patient imaging time and reduce the cost of clinical Magnetic Resonance Imaging (MRI) studies, current research trends are to employ multiple radiofrequency (RF) coils. However, as a result of Faraday’s law of mutual induction, these coils will experience magnetic coupling which may cause reduced signal-to-noise ratios. To address this, we have compared several decoupling methods including overlapping coils, shared inductive decoupling, and the recent method proposed by R. Aal-Braij1 et al., for nearest neighbor coils. Although these methods work well for nearest neighbor coils decoupling, there has not yet been a method proposed to decouple both nearest and next nearest neighbor coils.

What are Radiofrequency Coils?
In magnetic resonance imaging, protons in a sample align with a powerful external main magnet (typically 1.0-7.0 Tesla fields) due to the protons’ intrinsic spin. Figure 1 below shows the net magnetisation vector (the sum of the protons’ spins), M, aligned with the external magnetic field along the z-direction.

A radiofrequency (RF) coil is a magnetic coil that is then used to transmit a “pulse” which tips the magnetisation vector away from the direction of the external magnetic field.

If a second RF coil is brought near an RF coil which is receiving a signal, then the magnetic flux from the first coil will pass through the second coil (as pictured above). However, according to Faraday’s Law (mentioned earlier), the changing magnetic flux from the first coil through the second coil will induce an emf in the second coil. But, if the second coil experiences an induced emf, then by Faraday’s Law it will also create a changing magnetic flux which will induce an emf in the first coil. This inductance of coil two by coil one, and coil one by coil two, is the same, and is referred to as the Mutual inductance of the coils.

Because of the mutual inductance between the two coils, the signal from one coil is not independent of the other and the coils are said to be coupled. Coupling between coils adds noise and reduces the signal-to-noise ratio that is crucial to imaging applications, such as detecting a small tumor, and also causes a split in the resonance frequency of the coils.

The figure on the left, above, shows a single coil resonating at 300 MHz [axis not shown]. The figure on the right shows that same coil next to an identical coil. The original resonance frequency is split by the mutual inductance between the coils. Controlling the frequency of the coils is also important for imaging applications, and so the coils must be decoupled if multiple coils are to be used in MRI studies.

Multi-Coils
One of the biggest barriers to further widespread use of Magnetic Resonance Imaging is cost. Although the equipment itself is quite expensive, one of the easiest ways to reduce the cost of an MRI scan and make it available to more people sooner, is to reduce the scanning time of patients (this allows doctors to use their time to treat more patients, thereby reducing the cost of each individual scan).

Current trends in MRI hardware research are to employ multiple RF coils, which allow for larger sample areas to be imaged at the same time. However, the use of multiple coils presents new research challenges. Consider the following:

Capacitive Decoupling
Another method for decoupling is to use a capacitor in shared-leg coils.

Overlapping Coils
One way to decouple RF coils is by having them overlap. This allows magnetic flux to proceed through another coil in the opposite direction of the non-overlapping area, and by simple experimentation, the area of overlap can be adjusted such that the mutual inductance between the coils is cancelled by the flux through the overlapping area.

However, one key disadvantage of this method of decoupling is the loss of effective area for each coil because of overlap, requiring more coils that are close together. Also, while this method decouples neighboring coils, if a third coil is present, even if it is overlapped with the middle coil, there will still be coupling between the outside, or next nearest neighboring coils.

Conclusions
As greater numbers of radiofrequency coils are used in magnetic resonance imaging to reduce scanning time and cost, magnetic decoupling remains an important issue. Although decoupling of nearest neighbor coils has previously been accomplished only through the use of preamplifier electronics, the present research indicates that there may be promising alternative methods for decoupling both nearest and next nearest neighbor coils.

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