Decoupling Phased Array Transmitter Coils using Cartesian Feedback

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Introduction

The use of phased-array coils for signal reception in certain specialised areas of magnetic resonance imaging (e.g. spinal imaging) is well-established and as field strengths continue to increase, their use will become more prevalent. They hold the promise of yielding, at least for signal reception, a more homogenous spatial response function, particularly over elongated volumes of interest, and help to counteract propagation effects that are seen at high field strengths, e.g. field-focussing in head images at 8 T. Their success in so doing is, in part, because the mathematical manipulation of the image is a magnitude calculation. It has been hoped that similar benefits would accrue during transmission, but there are two main obstacles, the first being that the B_1 transmission field is the *vector and phasor* sum of fields from individual coils and this sum must obey Maxwell's equations. At high field strengths, a volume-homogeneous B_1 field is not a solution of Maxwell's equations (1), though homogeneous fields can be obtained over certain surfaces. Notwithstanding, the promise of a homogeneous field in even just a transverse slice is appealing, as is the flexibility inherent in the phased-array philosophy. The second obstacle is, however, electronic, and has held up the use of transmit arrays for over a decade. We propose here a solution.

Transmission Difficulties

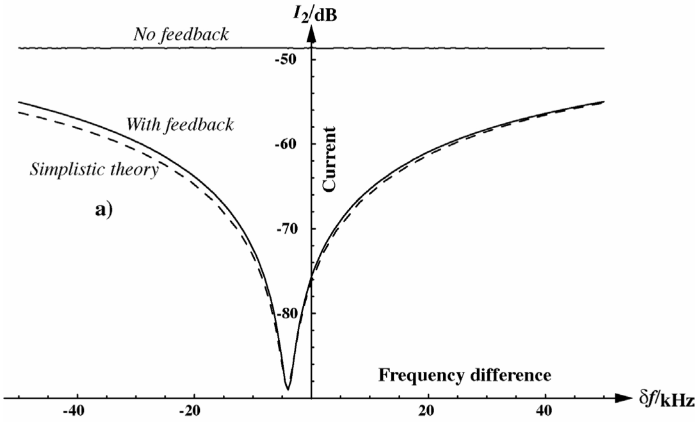
As an example, consider two adjacent coils powered by separate transmitters, the first of which has RF power applied. The second coil has zero applied power and is supposed therefore to have no current flowing. Interactions between coils pose a major problem. They arise from direct mutual induction and indirect coupling via the sample. Conduction and displacement currents in a sample induced by the B_1 field of the first coil create alternating fields that induce an EMF in the second coil. As that coil is tuned, substantial currents flow, spoiling the B_1 field distribution of the first coil and also inducing therein a back EMF that changes the first current. The current in the second coil can have arbitrary phase, depending on the relative sizes of the interaction mechanisms. Thus, to cancel the interaction, two phasor degrees of freedom are needed, an aspect of coil design that has been known since the earliest days of NMR when crossed-coil probes were used (2). Various solutions exist, but cancellation of the *resistive* component of any interaction involves losses that decrease signal-to-noise ratio and increase correlation between the two coils' noise voltages. Further, such solutions need constant adjustment with change of sample, temperature etc..

The well-known and effective solution for interactions during signal reception is to minimise the lossless *reactive* coupling with an appropriate bridge or paddle (2), and then to utilise pre-amplifiers that are noise-matched but grossly power mis-matched (3,4) such that each effectively presents a high impedance in series with its relevant coil. The same approach can be attempted during transmission by over-coupling the transmitters (3), but only modest success is obtained before they become inefficient and therefore costly. Thus array coils tend to be used only during reception, transmission being accomplished with a separate volume coil.

A Cartesian Feedback Solution

The Cartesian feedback method of spectrometer design and operation, described elsewhere in this conference, offers a solution to this problem for not only transmission, but also reception. Briefly, during transmission, the current flowing in a coil is monitored and compared with that required. (In coil 2 in the above example, zero.) Any error is noted and corrected, via that coil's transmitter, by negative feedback adapted for use at radio frequencies. Negative feedback effectively alters the output impedance of an amplifier. Here, it is used to boost, by the order of the open loop gain (e.g. 100), the output impedance that the transmitter effectively presents in series with coil 2 and current flow is thereby blocked. Note that the second coil's transmitter efficiency is maintained when coil 2 has power applied, as it is the *dynamic* impedance that is transformed.

To test this idea, two 10 cm square surface coils (126.6 MHz, Q = 406) were placed adjacent to one another (1.5 cm side separation) on the surface of a large saline phantom. Loaded Q-factors were 15 and 16. Reactive coupling was cancelled with a paddle (2) but –13.8 dB resistive coupling remained. Coil 1 was driven from a network analyser and the current in coil 2 monitored by the analyser with the aid of a capacitive tap across one of the tuning capacitors. During this experiment, coil 2 was connected to the spectrometer transmitter, but the latter was inactive. (Network analysers are expensive devices!) The spectrometer was now placed in feedback mode (open loop gain ~100, bandwidth 2 kHz), the current in coil 2 being monitored by the spectrometer receiver with a second tap. The current in coil 2 was immediately seen to diminish stably by a factor of ~100 on resonance, the efficacy of current cancellation reducing as one moved off resonance until at ± 100 kHz off resonance there was negligible reduction.



The reduction in induced current (in dBs) in the second surface coil with the application of Cartesian feedback as a function of frequency off resonance. Coupling is from a driven first coil via the intermediary of a conducting phantom. (The frequency offset is due to a discrepancy between the spectrometer's and the network analyser's frequency sources.)

It is clear from this preliminary experiment that Cartesian feedback may hold the key to using array coils during transmission. Our ongoing research focuses on the use of negative group delay techniques to increase the bandwidth over which current blocking is effective (c.f. the bandwidth of a selective pulse) and the extension of the method to multiple coils.

References

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