ISMRM 2015 Educational Session title: MR Physics for Physicists

B_1^+ Shimming & Parallel Transmission

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Highlights:

- A whirlwind tour of the first decade of parallel transmission in MRI.
- An overview of some of the most prevalent methods.
- A brief perspective on the challenges ahead.

Target Audience: MR physicists interested in developing or using parallel transmit methods.

Outcome/Objectives: Provide a brief historical overview highlighting some of the most prevalent methods and concepts in parallel transmission with the goal of providing a starting point for researchers new to this subfield of MRI.

Abstract: At the time of writing parallel transmission just entered its second decade in MRI. About 13 years ago, at this same conference (1,2), two independent scientists each presented their incarnation of the same revolutionary idea; "parallel transmission" (3,4). This new technique effectively translated concepts form parallel imaging on the receive side, an idea established years earlier (5 - 7), to the transmit side. In this lecture: we will review some of the key milestones leading up to the introduction of parallel transmission, explain what sets it apart from radiofrequency (RF) excitation field (B_1^+) shimming, explore some of the prevailing methods and applications, and consider several possible directions of future research.

Background: Contrary to the way it is sometimes perceived, parallel transmission is more than just a technique for mitigating RF non-uniformities in ultra high field MRI. In the years leading up to the introduction of parallel transmission, radiofrequency (RF) coils with an array of transmit elements had already been introduced to reduce B_1^+ non-uniformities (8, 9). In these so-called transmit-array coils each element was driven with a different phase and amplitude to shim out strong spatial variations in the B_1^+ field. At the time, other researchers explored an alternative solution, which aim to directly steer the spin flip-angle induced by tailored combination of RF and gradient waveforms (10 - 12). In the small tip-angle approximation, this concert of gradients and RF waveforms trace out a trajectory through transmit k-space (10). Redistributing the RF energy in this space not only provides a mechanism to mitigate B_1^+ non-uniformities, it also allows any arbitrary excitation pattern to be implemented. Thus, for example, select areas in the field of view can be isolated to reduce flow artifacts or to "zoom in" on an area. However, physical and physiological limitations of the gradients and RF power resulted in relatively long RF pulses. Even an optimized pulse can easily exceed 8ms (13), which is much longer than the desired repetition time in many clinical MRI sequences.

Parallel transmission: The key insight leading to parallel transmission is the analogy between k-space in receive and transmission. In the late nineties, parallel imaging was introduced as a framework to accelerate the MR acquisition process by undersampling k-space on the receive side (1). It was shown that, using an array of receive coils, the missing parts could be deduced from the neighboring data points (11,12). In particular, it was shown that the spatial harmonics induced by phase encoding gradients could be synthesized using a suitable combination of receive coil sensitivities (11). Similarly, parallel transmission leverages the independent B_1^+ sensitivities provided by an array of transmit coils to undersample trajectories in transmit k-space. Hence, parallel transmission is sometimes called transmit-SENSE (1), underlining once more the similarities with the SENSE technique in parallel reception (13).

Prevalent Methods: Since the introduction of parallel transmission, a variety of transmit k-space trajectories have been proposed. Generally speaking each design targets a specific application. Among the most popular are: “Fast k_z” or “Spokes” for slice selective sequences [12], k_T–points [14] and Spins [15] for nonselective sequences, and spherical trajectories for reduced field of view imaging [16]. To design the subject specific RF waveforms accompanying these trajectories, the spatial domain method [17] combined with the variable exchange method [18] is often used. The successful implementation of these methods is contingent on high quality B_1^+ maps [19]. One other very important aspect of parallel transmission is RF safety. To this end, Virtual Observation Points (VOP’s) are often incorporated in the pulse design to constrain the localized energy deposition [20]. Over the years, a large number of methods have been proposed each focusing on a different aspect of parallel transmission. The aforementioned techniques merely summarize some of the most prevalent with the goal to provide a starting point for those interested in the field.

Challenges: Many challenges still remain before the full potential of parallel transmission can be unleashed. In particular, its focus on B_1^+ control can result in an un-tractable workflow. Most MRI sequences contain at least two or three different pulses for each slice, slab, or volume that need to be optimized independently for every new subject. RF pulse design techniques thus need to be both fast and robust to minimize the downtime between acquisitions. In particular the design of large flip-angle pulses remains challenging due to the breakdown of the small-tip-angle approximation.

One long-standing question in parallel transmission is how to deal with RF safety. Although VOP’s have made localized specific absorption rate (SAR) monitoring more tractable, it still relays on pre-simulated RF field distributions, which generally don’t capture the specific anatomical and dielectric properties of the subject under investigation. Not only will there be minute anatomical differences between the subject and simulation model, their position and posture in the coil can be different as well. All of these factors can lead to deviations from the true local SAR, which must by constrained reliably in order to satisfy the RF safety limits (21).

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