

SAR reduction through Dark modes excitation

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Introduction: SAR reduction has become an important topic in RF pulse design particularly at high-field strength and in the context of parallel transmission. Various RF pulse design algorithms [1-5] have been proposed for SAR minimization. Here, we propose a strategy which employs the “dark modes” of excitation coil array to cancel local E fields that produce local SAR hotspots. The method is based on the observation that some modes of an array coil (e.g. birdcage with the wrong circular polarization or modes with B_1 fields along z) produce E fields but not useful excitation of MR magnetization (i.e. no B_1^+). We can therefore energize these “dark modes” exclusively with the goal of cancelling local SAR hot-spots.

Theory: B and E field distributions: It is widely, but erroneously, believed that the E field and B field distributions are similar thanks to their inter-relationship in Maxwell's equations. Figure 1 shows the differences in E and B distributions in a uniform birdcage mode. It is clear that the skin depth effect in the conductive body primarily attenuates the E-field and leaves the B field relatively unaffected. Secondly, the E field is highly modulated by the local conductivity pattern within the body while the magnetic properties of the body are uniform and relatively weak (measured in ppm) resulting in a smooth spatial distribution of B fields. Based on these observations, significant local E field amplitudes can exist in a region with very little excitation B_1^+ field.

Local SAR Mitigation via Dark Modes: We exploit the differences in E and B distributions and the helicity of gyroscopic precession (requiring a particular circular polarization of B_1 for spin excitation) and focus here on the birdcage modes of a cylindrical array formed by the Butler matrix as shown by a simulated example at 3T in Fig. 2. In applying our dark mode SAR reduction strategy, we first utilize the standard “bright” B_1^+ modes of the coil array (top row) to create the desired RF excitation pattern. The resulting local E-field distribution is then calculated. We then use the dark B_1^+ modes (bottom row) to form an E-field distribution that cancels the E field at specific local SAR hotspots of the bright modes excitation. The bright and dark modes are driven simultaneously as to create the desired excitation and with local SAR cancellation. While this strategy will not lower global SAR (since more power will be used), our goal is local SAR reduction at a few hot spots where local SAR is the limiting factor. This design philosophy provides a division between the excitation and SAR minimization design; thereby reducing computation burden. Specifically, the local SAR minimization calculation can be performed rapidly since it only involves calculating drive coefficients for the dark modes that would optimally mitigate the E fields at a few spatial SAR hot spots, without concern for the spatial fidelity of the excitation (to the degree that the dark modes are dark)

Methods: We simulated the E and B field of an eight channel loop coil array at 3T on

the Swiss virtual family head model “Ella” using REMCOM FDTD software. A simple uniform RF shimming excitation was created via the excitation of the four bright modes. The four dark modes were then used to reduce the E-field at the four brightest 10g local SAR hotspots generated by the bright mode RF pulses. The hotspots were required to be >3 cm apart to avoid selecting multiple hotspots from the same region.

Results and Discussion: The right column of Fig. 2 shows the excitation profile from conventional RF shimming (top), and RF shimming with dark mode SAR reduction (bottom). Negligible differences in the efficiency or spatial uniformity of the excitation is observed as the dark modes B_1^+ field is relatively low and only small voltages were actually required for the E-field cancellation. The top row of Fig. 3 shows the local SAR maps containing the 4 brightest hot-spots in the bright-mode RF shim excitation. Note that the 3rd hottest spot is located at the front of the head and not at the right ear due to our requirement that the hot spots be >3 cm apart. The bottom row of Fig. 3 shows the SAR for the RF shim + Dark mode local E field cancellation. A 27% reduction in the peak SAR_{local} was observed (from 12 to 8.8 W/kg) with only minor (~5%) increase in SAR_{global} from power applied to the dark modes. We note that the local SAR at some other areas in the head do increase from the dark mode excitation (not shown) but the hottest spot of the combined excitation is at the location of the second hottest spot of the bright mode only excitation.

Conclusion: In this work, we suggest that coil geometries previously discarded as inefficient because they produce the wrong circular polarization of B_1 fields in the z directions are actually useful for excitations where SAR_{local} is the limiting factor. For RF shimming with a birdcage-like array, the method significantly reduces SAR_{local} with only minor increase in SAR_{global} or degradation of spatial excitation uniformity. The dark mode SAR reduction method can be used in conjunction with other SAR minimization algorithms which can be applied during the bright mode pulse design. It is also applicable to pTx pulses other than RF shimming. In such case, the dark modes will need to be dynamically driven to track the time varying local E field hot spots. Furthermore, the dark mode concept extends particularly well to selective excitations, e.g., spoke design where the encoding limits the excitation to within a thin slice. Areas outside of the selected slice contain E and B fields, but the B fields do not cause excitation. Thus any subset of coils without significant B_1^+ fields in the excited slice can be thought of as dark modes and can be used to cancel E field hot-spots.

Support: NIBIB K99EB012107, NIBIB R01EB006847 and NCRR P41RR14075 **References:** 1. Zhu Y, MRM 2004;51:775 2. Zhu Y, ISMRM06 p599 3. Liu Y et al, ISMRM08 p1314 4. Graesslin et al ISMRM08 p621 5. Lee J et al, ISMRM10 p105

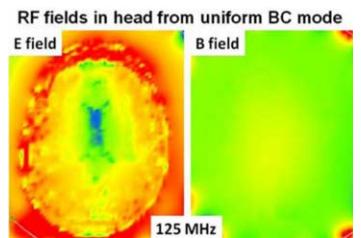


Fig. 1 E & B fields in brain for 125 MHz excitation of uniform birdcage

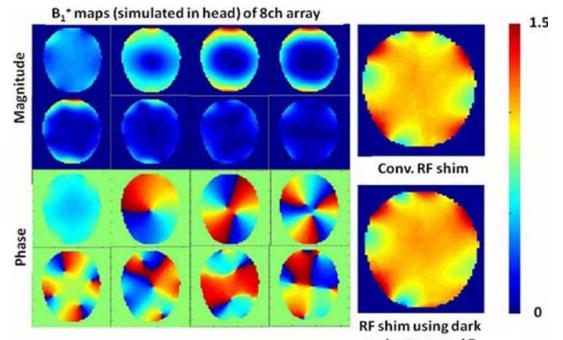


Fig. 2 Left: B_1^+ magnitude and phase of the bright and dark modes of the coil array. Right: Excitation results for RF shimming, and RF shimming with dark mode SAR

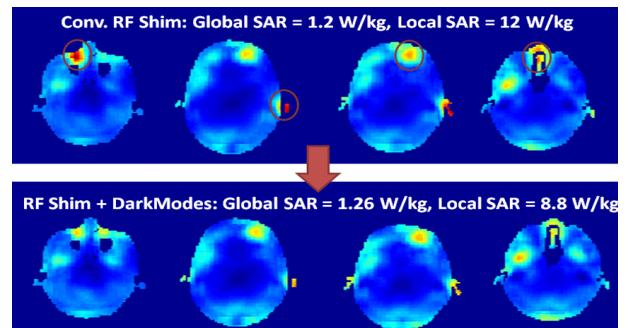


Fig. 3 Local SAR hotspots for conventional shimming (top) and shimming with dark mode SAR reduction