Practical methods for improved B1+-homogeneity in 3T breast imaging

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Purpose: 3T MRI is increasingly used because of its intrinsic SNR benefits compared to 1.5T MRI. However, there are increased transmit RF field (B_1^+-) inhomogeneities at 3T, which can lead to SNR loss, image shading, errors in quantitative parameters, and other drawbacks. In breast MRI in particular, the phenomenon of left-right B_1^+-asymmetry in the breast has been observed [1-3]. (Fig. 1) This abstract presents simulations of several different methods for compensating left-right B_1^+-asymmetries in the breast region by means of 1) 2-channel RF shimming (*I*/*Q*-phase/amplitude adjustments); 2) dielectric-absorptive shimming; or 3) a combination of 1) and 2). Both approaches are adaptable to a wide range of MR systems, and are especially relevant to scanners that do not have full parallel transmit capabilities. The methods can be combined in different ways to yield a simple, practical, and inexpensive procedure without SAR penalty for ensuring uniform contrast and quantitative parameter estimates, and ultimately, more accurate detection and therapeutic monitoring of breast cancer.

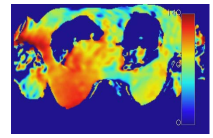


Fig. 1: B_1^+ map of reference scan.

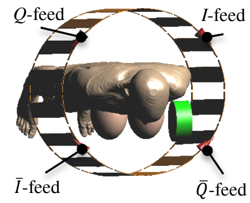


Fig. 2: Human model in RF coil and port configuration.

Methods: Experimental B_1^+ mapping was performed on a 3T GE Discovery MR750 scanner using the built-in transmit-only body RF coil. Coil and human body were modeled in a commercial simulation package, and various proposed shimming methods were evaluated.

Modeling: A commercial FDTD solver (SEMCAD X, SPEAG, Zürich) was used for modeling and simulation purposes. The receive coil was modeled as a 16-leg highpass birdcage type with primary coil diameter of 62 cm, tuned to 128 MHz. Four independent excitation ports located at 45 (*I*), 135 (*Q*), -45 ($\bar{Q}$), and -135 ($\bar{I}$) degrees with respect to the central coronal plane, respectively, were implemented with pairwise independently adjustable amplitudes and phases, giving rise to the flexibility of analyzing both two- and four-port transmit configurations, both of which are commonly used in practice. Modeling of the human body was performed using a member of the Virtual Family (Ella, female, 26 years, IT'IS Foundation, Zürich). To allow clearer visualization of B_1^+ over a larger breast region, additional mammary tissue was added to the Ella model, with the electric properties of fat (ε_r = 5.64, σ = 0.03 at 128 MHz) and skin (ε_r = 65.44, σ = 0.52 at 128 MHz). (Fig. 2)

RF shimming: Improving B_1^+-homogeneity by means of independent adjustment of the *I*- and *Q*-phases alone was attempted in a first step, followed by full RF shimming (both amplitude and phase of *I* and *Q*). For this purpose, B_1^+ field characteristics from each port were calculated and superimposed according to their relative phases/amplitudes, allowing for a fine-tuning of the imhomogeneities arising from patient loading.

Dielectric-absorptive shimming: Disks of dielectric-absorptive material were inserted in proximity to the breast with the higher B_1^+ amplitude (Fig. 2) in order to divert the field lines for generating a more uniform field distribution across the cross section of the breast. Materials of different electrical properties and dimensions, located at several distances to the breast, were studied.

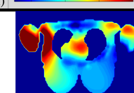
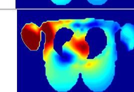
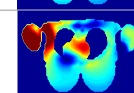
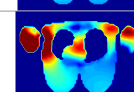
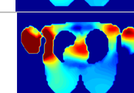
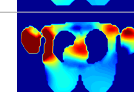
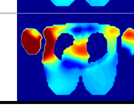
	RF shimming			Dielectric-absorptive shimming			B_1^+ Nominal change over average (%)	LR ratio
	I (W)	*Q* (W)	Δφ (deg)	σ (S/m)	*h* (mm)	*d* (mm)	80 100 120 140	
a)	CP			n/a				1.46
b)	1	1	130	n/a				1.25
c)	1.2	0.8	120	n/a				1.19
d)	CP			5	60	30		1.25
e)	CP			2	60	10		1.22
f)	CP			5	60	10		1.15
g)	1.1	0.9	110	5	60	10		1.09

Fig 3: B_1^+ maps for different shimming scenarios (*h*, *d* = disk height and distance)

Results: Experimental B_1^+ maps of 30 breast patients were used to identify an average B_1^+ amplitude ratio between left and right breast of 1.32. Simulations of coil characteristics yielded at a *Q*-factor of 216.3 and 37.5 for the unloaded and loaded cases, respectively. Left-right asymmetry was identified as a consequence of a shift in coil resonance after patient loading. With no alterations in "standard" circularly polarized (CP: *I*/*Q* phase difference = 90 deg) coil drive, the simulated 2-port B_1^+ map is shown in Fig. 3a. Phase-only RF shimming yielded an optimized result for a phase delay of 130 degrees between *I*- and *Q*-feeds (Fig. 3b). Full RF shimming with modest additional amplitude shimming is shown in Fig. 3c; this produced moderate additional improvement in B_1^+ symmetry. Dielectric-absorptive shimming results (Fig. 3d-f) are shown for a disk of 60 mm height, at distances of 10 mm and 30 mm from the breast surface, and conductivities of σ = 2 S/m and 5 S/m, respectively. Additional experiments have shown that the most influential parameters are disk distance and conductivity, with only a minor dependence on disk geometry. Fig. 3g depicts the combination of both *IQ* phase- and dielectric-absorptive shimming yielding the most uniform B_1^+ field distribution throughout the breast cross-section. It can be seen that the simulations reproduce the experimentally measured L/R B1+ ratio reasonably accurately, and that both RF and dielectric-absorptive shimming are effective at decreasing this asymmetry, with the combination of both methods leading to the most effective flattening of this asymmetry.

Discussion: *IQ* phase adjustment is readily implementable on many modern systems today and hence a straightforward and effective method, given the negligible additional improvement afforded by full shimming. Dielectric-absorptive shimming is easily accomplished by mounting an appropriate material on the breast coil. Compared to similar approaches using high-dielectric materials with low conductivity, the requirements on disk geometry and position are simpler, accounting for an easily implementable and cost-effective method if some increase in signal loss can be tolerated. Compared to more complex and cost-intensive parallel transmit methods, the presented approach does not lead to concerns about increased SAR in the patient. Results shown are by simulation only, and consider a single anatomical model, and therefore may not accurately predict optimal parameters for real experiments across a wide range of body sizes/shapes. Glandular tissue has not been modeled but is assumed to add localized heterogeneity to the B_1^+ map (Fig. 1) due to its higher losses.

Conclusion: Inhomogeneities in B_1^+ in breast MR at 3T have been studied and improved using RF- and dielectric-absorptive shimming, offering a cost-effective solution to this field distortion problem using easily implementable methods.

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