Reverse-Decoupled Mode of Volume Strip Array for Parallel Imaging

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SYNOPSIS A reverse-decoupled mode in a volume strip array was identified in theory, and verified by bench testing and MR imaging. Its high SNR and low g-factor in the central region present a special edge for high acceleration parallel imaging. Its large noise correlation is cancelled in parallel reconstruction. A reduction factor 16 (4x4) on a 16-element VSA was achieved in MRI.

INTRODUCTION A volume strip array (VSA) [1] can be tuned to either the homogeneous mode (HM) [2,3] or the decoupled mode (DM) like a phased array [4]. Here we identified a new mode distribution for a VSA, reverse-decoupled mode (RDM), which has a mode distribution of DM subtracting HM. The sensitivity profile of RDM is also as if a subtraction of sensitivities in HM and DM, which has a dark region next to the strip, but a high SNR and distinguished phase in the central region for each element so that it can avoid the high g-factor in the center which often plagues high acceleration parallel imaging using a DM array. Also the noise correlations in RDM are cancelled during parallel reconstruction [5] so that they do not degrade performance. An advantage of RDM in high acceleration parallel imaging has shown experimentally in MRI.

THEORY An *n*-element VSA described in Ref. [1] can be characterized in terms of either ports or modes. In port-space, if $\mathbf{V}(p)$ is the port-voltage vector, $\mathbf{I}(p)$ is the port-current vector, $\mathbf{Z}$ is the impedance matrix of VSA, $\mathbf{Z^p}$ is the input impedance matrix of preamplifiers transformed to the ports of VSA, then $\mathbf{V}(p)=(\mathbf{Z}+\mathbf{Z^p})\mathbf{I}(p)$. In mode-space, the last equation becomes $\mathbf{V^m}(k)=(\mathbf{\Psi}+\mathbf{Z^p})\mathbf{I^m}(k)$, where $\mathbf{Z}=\mathbf{F^H\Psi F}$, $\mathbf{V^m}(k)=\mathbf{V}(p)$, $\mathbf{I^m}(k)=\mathbf{I}(p)$, $\mathbf{F}$ is DFT matrix since $\mathbf{Z}$ is a circulant matrix. When VSA is tuned to its homogeneous mode, the 1st row of $\mathbf{Z}$ is $\mathbf{Z_r}(p)=\pm(Z_{00}, \ldots, Z_{00}\cos(2\pi p/n), \ldots, Z_{00}\cos(2\pi(n-1)/n))$. The diagonal terms of $\mathbf{\Psi}$, $\mathrm{diag}\{\mathbf{\Psi}\}=\mathbf{FZr}(p)=(0, \pm(n/2)Z_{00}, 0, \ldots, 0, \pm(n/2)Z_{00})$, which is defined as Intrinsic Mode Distribution (IMD). In this mode, a mismatch ratio in port-space is $\gamma=Z_{00}/Z^p$, and then a mismatch ratio in mode-space is defined as

$$\Gamma = (\pm(n/2)Z_{00} + Z^p)\big/Z^p = 1 \pm n\gamma/2\,. \qquad (1)$$

When the "+" sign is selected, the extended IMD, $\mathrm{diag}\{\mathbf{\Psi}+\mathbf{Z^p}\}$, is shown in Fig. 1b which is the FFT of the 1st row of $\mathbf{Z}+\mathbf{Z^p}$ in Fig. 1a, its **B1** field almost resembles the decoupled mode due to the same principle as the preamplifier decoupling. However, if the "-" sign is selected in Eq. (1), the extended IMD becomes Fig. 1e, and its field map becomes Fig. 1f, in which, instead of a bright region next to the strip, it has a dark region next to the strip, as if???????? the subtraction of the homogeneous mode and the decoupled mode, we define it as reverse-decoupled mode.

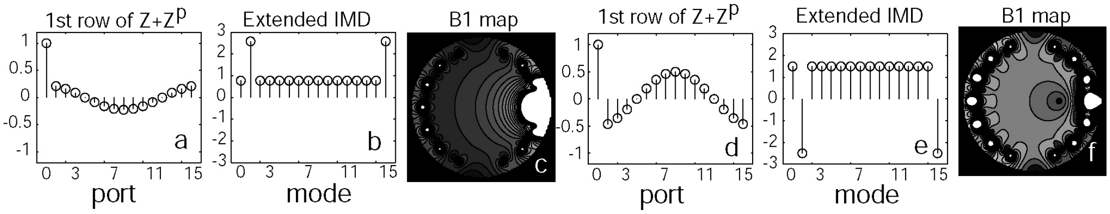

Fig. 1

EXPERIMENTS A 16ch VSA was constructed as in Ref. 1. The homogeneous mode of each strip was tuned to 70.25MHz and matched to 600Ω when other ports are open. When all ports are enabled simultaneously, the homogeneous mode of every strip was exactly on 63.67MHz; its unloaded impedance is 152Ω and loaded impedance is 51Ω, as shown in Fig. 2. The coupling impedance between one port to all other ports were calculated from the S11, S21, S12, and S22 measurements of all port pairs. Both test ports on network analyzer were matched to 1kΩ to simulate the high transformed impedance $\mathbf{Z^p}$ from 2Ω input impedance of preamplifier. The real and imaginary parts of measured $\mathbf{Z_r}(p)+\mathbf{Zp}$ are shown in Fig. 3. (a) and (b). The real and imaginary parts of its extended IMD $\mathrm{diag}\{\mathbf{\Psi}+\mathbf{Z^p}\}$ are in Fig. 3 (c,d), which strongly proved that RDM exists and its extended IMD is the same as predicted by theory.

A 2ch Tx/16ch Rx RF front-end was setup in a 32ch MRI scanner. The RDM predicted by the theory was proved with MRI, as shown in Fig. 4, the dark hole in front of each element is clear evidence. In this experiment, sixteen λ/4 coaxial cables with balun convert the input impedance of the preamplifier 2Ω into about 1kΩ at VSA ports. The combination of the negative IMD and high impedance at the ports yields a reverse-decoupled mode. Fig. 5a is a fully phase encoded image, and Fig. 5b is an image with a reduction factor 16 (4x4) using parallel MRI.

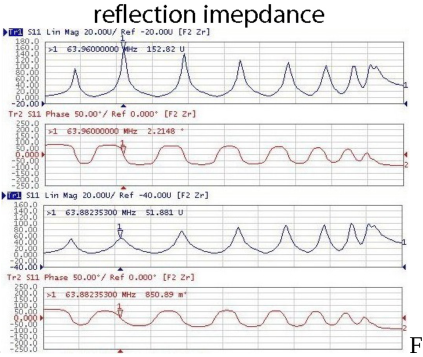

Fig.2

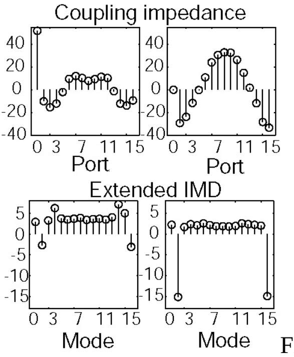

Fig.3

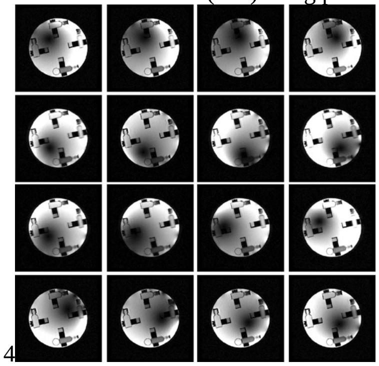

Fig. 4

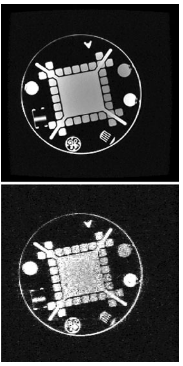

Fig.5

CONCLUSIONS We demonstrate the existence of RDM from theory, bench testing, and MR imaging. A VSA in reverse-decoupled mode has certain advantages over the decoupled mode for high acceleration parallel imaging: It has a high SNR and a low g-factor in the central region; and its high noise correlation iscancelled in parallel reconstruction

REFERENCES: [1] Lee RF et al, Proc 11th ISMRM, p467, Canada 2003. [2] Hayes CE et al, JMR, 63: 622, 1985. [3] Vaughan JT et al, MRM 32:206, 1994. [4] Leussler C et al, Proc 5th ISMRM, Canada 1997. [5] Ohliger M et al, MRM 52:628, 2004