A rigid analysis and experiments for the complementary modes in the multi-port reception of a volume strip array

R. F. Lee[1], and R. Xue[1]
[1]Radiology, New York University Medical Center, New York, New York, United States

INTRODUCTION Impedance mismatch at the receive ports not only can reduce the coupling in a phased array (1), but also can generate inversed magnetic fields in the complementary modes (CM) of a volume strip array (VSA) (2). Usually an *n*-element coupled cyclic symmetric structure with a shield has *n*/2+1 modes, in which only the homogeneous mode is useful since all others have signal null at iso-center. The inverse magnetic fields of *n*/2+1 CM of a coupled VSA, are exactly opposite: the complementary homogeneous mode has a signal null at the center, while all other CM are not, which open up the opportunities to (a) utilize other modes for controllably compensating the dielectric resonance effect in higher fields, and (b) analytically optimize sensitivity of each element for parallel imaging. Here a rigid analysis and some experiments are presented to illustrate such CM.

METHOD Any *n*-element VSA can be described by a $n\times n$ impedance matrix **Z**. If the VSA is a cyclic symmetrical structure, **Z** is an *nxn* circulant matrix which can be diagonalized to **Ψ** by the discrete Fourier transform (DFT) matrix **F**. For any port *q* on a VSA, if its reflection is defined as $\Gamma(q)=Ze/Z_{qq}$, here *Ze* is the preamplifier input impedance observed at port, Z_{qq} is the q^{th} diagonal element of **Z**, then the current-mode-distribution of a VSA can be analytically derived from the Kirchov's equations as in Eq. [1]

$$\mathbf{I_m}(k)\propto\begin{pmatrix}(\psi_0+Ze)^{-1}\\(\psi_1+Ze)^{-1}\\\vdots\\(\psi_{n-1}+Ze)^{-1}\end{pmatrix}=\begin{pmatrix}(\psi_0+\Gamma(0)Z_{00})^{-1}\\(\psi_1+\Gamma(1)Z_{11})^{-1}\\\vdots\\(\psi_{n-1}+\Gamma(n-1)Z_{(n-1)(n-1)})^{-1}\end{pmatrix}. \quad [1]$$

Here ($\psi_0, \ldots, \psi_{n-1}$) is the Fourier transform of the first row of **Z**. If the VSA is tuned to its homogeneous mode as suggested in Ref. (2), such distribution becomes Eq. [2]

$$\mathbf{I_m}(k)\propto\begin{pmatrix}1/Ze\\\frac{n}{2}Z_{00}+1/Ze\\1/Ze\\\vdots\\1/Ze\\\frac{n}{2}Z_{00}+1/Ze\end{pmatrix}=\frac{1}{Ze}\begin{pmatrix}1\\1/\left(1+(n/2)/\Gamma\right)\\1\\\vdots\\1\\1/\left(1+(n/2)/\Gamma\right)\end{pmatrix}. \quad [2]$$

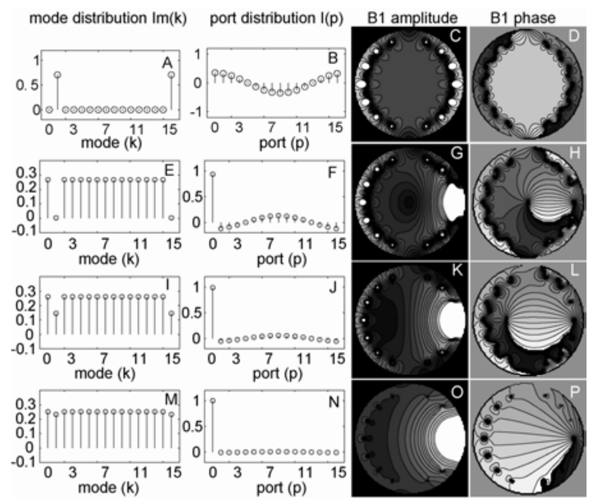

Fig.1

Equation [2] suggests that when $\Gamma<<n/2$, a homogeneous mode illustrated in Fig. 1 (A-D) becomes its CM shown in Fig. 1 (E-H). The complementary effect in both mode distribution and field are obvious. When $\Gamma\sim n/2$, VSA is in a state between the CM and decoupled mode, see Fig. (I-L). While if $\Gamma>>n/2$, VSA becomes a decoupled array, see Fig. 1 (M-P). All other CM can be analyzed in the same principal.

RESULTS A 16-ch VSA and a 16-ch transmit/receive RF interface were constructed for 1.5T Siemens Magnetom Avanto system, see Fig. 2. One of our experiments was to tune all 16 channels of the VSA to its homogeneous mode. Its complete impedance spectrum (containing 16/2+1=9 peaks) is shown in Fig. 3 (A-B) and its tuning and matching performance of each channel when all 16 elements coupled together is shown in Fig. 3 (C-D). The impedance matrix at resonance frequency which can fully characterize the VSA was measured by S-parameter while loaded with human head, and then converted to impedance, see Fig. 4. Each sub-figure of Fig. 4 represents one row in Z (* is real, o is imaginary).

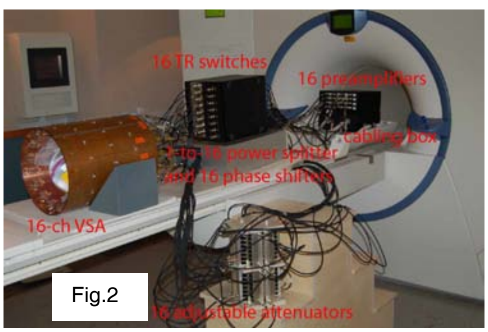

Fig.2

Some typical imaging results of the complementary modes are shown in Fig. 5 where Γ = (Ze/Zqq=150/50=3) < (*n*/2=8), which is a quasi CM but no pure CM since Γ is only less than but not greatly less than *n*/2. On the other hand, Fig. 6 shows the results where Γ=(600/50=12) > 8, which is a quasi decoupled mode but not perfect decoupled mode since G is only larger than but no greatly larger than 8. Γ can be adjusted by varying input impedance of preamplifiers, the length of the cables between ports and preamplifiers, and structure of TR switches.

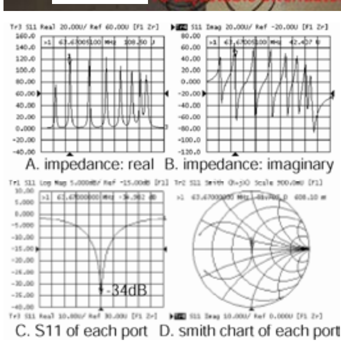

Fig. 3 The test results of the VSA.

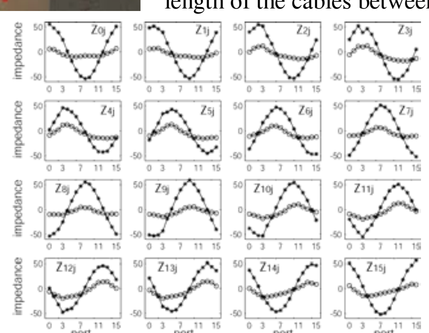

Fig. 4 The Impedance matrix of the VSA.

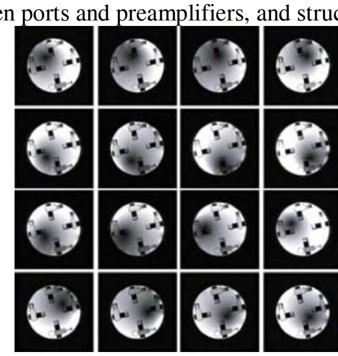
Fig. 5 The 16-ch quasi-CM images.

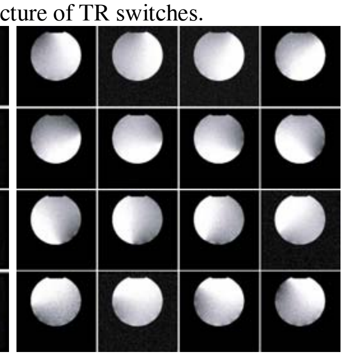
Fig. 6 The 16-ch quasi-decoupled

CONCLUSIONS CM imaging provides some opportunities to use many modes that are not traditionally being used, which could be applied in compensating dielectric resonance in higher field. It also presents an analytic mean to optimized sensitivity profiles for parallel imaging.

REFERENCES: (1) Roemer, P., et al, MRM 16:192, 1990. (2) Lee, RF, et al, Proc. 13th ISMRM, p. 676, 2005, Miami, FL