TECHNICAL NOTE

Development of a Patch Antenna Array RF Coil for Ultra-high Field MRI

Manabu Nakajima1,2, Iwao Nakajima1,2, Shigeru Obayashi2, Yuji Nagai2, Takayuki Obata2, Yoshiyuki Hirano2, and Hiroo Ikehira2*

1Takashima Seisakusho Co., Ltd., Tokyo, Japan
2National Institute of Radiological Sciences (NIRS), Molecular Imaging Center
4–9–1, Anagawa, Inage-ku, Chiba 263–8555, Japan
(Received January 24, 2007; Accepted September 5, 2007)

In radiofrequency (RF) coil design for ultra-high-field magnetic resonance (MR) imaging, short RF wavelengths present various challenges to creating a big volume coil. When imaging a human body using an ultra-high magnetic field MR imaging system (magnetic flux density of 7 Tesla or more), short wavelength may induce artifacts from dielectric effect and other factors. To overcome these problems, we developed a patch antenna array coil (PAAC), which is a coil configured as a combination of patch antennas. We prototyped this type of coil for 7T proton MR imaging, imaged a monkey brain, and confirmed the coil’s utility as an RF coil for ultra-high-field MR imaging.

Keywords: MRI, patch antenna array, RF coil, ultra-high magnetic field

Introduction

Magnetic resonance (MR) imaging is used for many purposes as a high-performance, noninvasive system of measurement. In recent years, the increased magnetic flux of MR systems has enabled greater resolution and imaging speed. However, for high-magnetic-field MR imaging systems, the increase in Larmor frequency and shortening of wavelength have given rise to many problems from the radiofrequency (RF) coil used for generating B1 magnetic fields and detecting MR signals.1

A conventional volume RF coil, such as birdcage and saddle-type coils, is formed as a single LC resonator in its entirety, which largely restricts the coil’s dimension and thereby adjustment of its resonance frequency to the Larmor frequency. Thus, such RF coils cannot be tuned to higher frequencies without reducing their dimensions, and use of an ultra-high magnetic field MR imaging system may require division of the field of view (FOV) to be imaged and consequent increased scan time.2,3

To overcome this limitation of conventional RF coils, we developed a patch antenna array coil (PAAC) that comprises an array of patch antennas, each of which is a half-wavelength dipole antenna coupled with a ground plane. The PAAC operates as an RF coil by combining the multiple elements resonating each. Because each element is a resonator, the limitation of coil size based on the shortness of wavelength can be mitigated. PAAC elements are quite different from those of the birdcage coil, which is also a volume coil.

Impedance varies depending on position of the feeding point. At the end of the antenna element, impedance is maximized; nearer the center of the element, impedance is less.

We prototyped this type of coil for 7T proton MR imaging, imaged a monkey brain, and confirmed PAAC’s utility as an RF coil for the MR system.

Materials and Methods

The resonance frequency of the patch antenna is determined by the length of the element (Fig. 1) and its distance to the ground plane. In this case, element length is proportional to the wavelength of resonance frequency. In the prototyped PAAC, the end of the element is connected to a ground plane by a capacitor. Changing the capacity of this capacitor is electrically equivalent to changing the length of the element and so can be used to adjust the resonance frequency of the PAAC.

The impedance of the PAAC can be adjusted by the location of the feeding point, independently from the resonance frequency. However, it should be noted that the resonance frequency and the im-
Fig. 1. A single element of a patch antenna array coil (PAAC) with a feeder. The gray plate in the figure shows the antenna element, and the white plate shows the ground plane. The ground plane arcs to configure a volume coil.

Fig. 2. Panoramic image of a patch antenna array coil (PAAC). A cylindrical configuration of the PAAC comprising 8 patch antenna elements.

Fig. 3. Photograph of the patch antenna array coil (PAAC) prototype. The PAAC is configured from 8 elements in a cylindrical shape. Elements and ground planes, both made of copper, are fixed to the case, which is an acrylic cylinder.

Table 1. Characteristics of the PAAC element

<table>
<thead>
<tr>
<th>Element size</th>
<th>Length</th>
<th>200 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Width</td>
<td>20 mm</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>32 μm</td>
</tr>
<tr>
<td>Distance from ground plane</td>
<td></td>
<td>10 mm</td>
</tr>
<tr>
<td>Material</td>
<td>Copper</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Size of the PAAC

<table>
<thead>
<tr>
<th>Inner diameter</th>
<th>200 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil length</td>
<td>200 mm</td>
</tr>
</tbody>
</table>

Table 3. Measured electric value of the PAAC

<table>
<thead>
<tr>
<th>Resonance frequency</th>
<th>300.3 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance</td>
<td>69.2 Ω</td>
</tr>
<tr>
<td>Q-value</td>
<td>463</td>
</tr>
</tbody>
</table>

pedance are changed by setting an object inside. Moreover, because the PAAC has the characteristic that each element resonates, it can be configured as a volume coil by various arrangements in addition to that shown in Fig. 2 with 8 elements. In addition, although the length of each PAAC element is limited based on the wavelength, as mentioned, a volume coil with a large inner capacity may be devised using a different configuration, for example, arranging multiple elements in an axial direction.

Because excitation pulses can be transmitted by each element as a result of this characteristic, adjusting excitation power to each element may control equalization of the B1 magnetic field.

Results

We designed and developed a PAAC for 7T proton MR imaging to contain a sphere with a diameter of 150 mm in the imaging area (Fig. 3).

The details of each PAAC element are shown in Table 1. The sizes of this volume coil configured with 8 elements are shown in Table 2.

We created 2 feeding points, each designed with an angle of 90 degrees. These are connected with the system via a hybrid circuit.

Figure 4 shows the measurement results of the electric characteristic (impedance) of PAAC shown in Table 1.
in Fig. 3 in an unloaded condition. Major measured values are shown in Table 3.

With the feeding point positioned 50 mm from the end of the element, the measured impedance was over 50\(\Omega\), but generally, the impedance would be lower in a loaded condition. Although the value was measured in an unloaded condition, the Q-value exceeded 450. These measurements show that PAAC maintained the functions of an antenna using this configuration.

From these measurements, we judged that PAAC could be applied to the actual MR system. We tested our hypothesis by imaging a monkey brain using a 7T MR system of the National Institute of Radiological Sciences (Fig. 5) and found PAAC’s utility as an RF coil. However, the relation between coil size and imaging range must be further clarified to verify imaging performance.

Discussion and Conclusion

We designed and prototyped PAAC as an RF coil for a high-magnetic-field MR system and measured its electric characteristic. In addition, we confirmed the prototype’s utility by conducting test imaging with an actual MR system, but additional verification of imaging performance is necessary.

In the future, to maximize PAAC’s characteristics as an RF coil, we wish to further verify the characteristics of a single element and the method for configuring PAAC as a volume coil. As PAAC is utilized more, we also wish for clarify its application to ultra-high magnetic fields.

In an MR system utilizing ultra-high magnetic fields, specific absorption rate (SAR) will become a more serious problem. Because PAAC provides a high degree of freedom in the configuration of a volume coil, SAR may be reduced by applying a configuration according to the imaging condition. We wish to promote further studies and research regarding this aspect.

References