Switchable Short Quadrature Body Coil with Two Axial Uniformity Modes

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Introduction

For compact high field MRI systems such as at 3T, it is desirable to have a short quadrature body coil (QBC). A short QBC has the advantages of less required peak power, less exposed RF power for a patient and less SAR than a longer QBC. Typically a QBC is a shielded birdcage coil. Shortening the QBC has some impact on the axial uniformity and, in a few applications, a more uniform transmit field can be beneficial. Here we describe a switchable QBC which can switch between a short and long uniformity mode as needed. As an example, the Finite Difference Time Domain (FDTD) method is used to calculate B_1-field for a switchable 3T QBC.

Methods

There are mainly two types of QBCs: birdcage [1] and TEM [2]. The difference between a birdcage coil and a TEM coil is the scheme for RF current return paths for the axial conductors. For a birdcage coil, the axial conductors or rungs combine with the end rings, typically on a common radius, to form a cage structure. A RF screen is always used for a birdcage QBC to isolate itself from electrically lossy structures outside the QBC, such as gradient coils and shim coils. The RF screen is not otherwise a necessary part of the birdcage QBC structure. For a TEM coil, an external RF "screen" is required to provide RF current return paths for the RF coil. The axial elements of the TEM coil connect to the RF "screen" with lumped capacitive elements. There is no need for the end ring structures. In Figure 1, we show the generic schematics for two types of QBCs, where only 4 elements are shown but the full coil typically consists of 8 or more identical elements repeated around a circular form and the N^{th} element is connected to the 1^{st} element completing the coil. In the TEM coil diagram the RF screen is marked as a ground. Both types of QBCs can generate similar homogeneous B_1-field inside the coils. For the same coil sizes, a birdcage QBC has the advantages of higher coil efficiency and lower SAR in a patient than those of a TEM QBC. However, for the TEM QBC, B_1-field uniformity along the coil axial direction is better than that of the birdcage QBC.

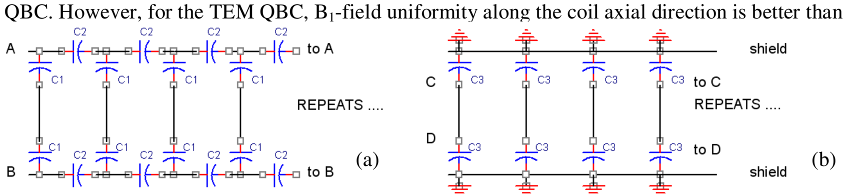

Figure 1. (a) 4 elements of N conductors of a bandpass birdcage coil; (b) 4 elements of N conductors of a TEM coil.

Recognizing the similarity of the two designs, switches could be arranged to connect and disconnect the components of the coil to achieve either a bandpass birdcage as shown in Figure 1(a) or a TEM coil as shown in Figure 1(b). In the special case where C1 of the birdcage design as an equal value to C3 of the TEM design the switching can be simplified as shown in Figure 2(a) and (b). Note that for simplicity only 2 elements of a multi-element circuit are shown. When the switches are open, the QBC resonates as a birdcage coil. The switches when closed short out C2 removing it from the circuit and the QBC resonates as a TEM coil. PIN diodes are special electronic components that can be wired to perform the switching function. Figure 2(c) shows an example of a PIN diode connected with a reverse bias voltage which prevents current flow in the diode and also prevents signal flow. This is electrically equivalent to an 'open' or 'off' switch. Figure 2(d) shows a PIN diode connected with forward bias current which causes current flow in the diode and allows signal flow. This is electrically equivalent to a 'closed' or 'on' switch. The RFC components are RF chokes which prevent the flow of the RF signal into the biasing circuitry.

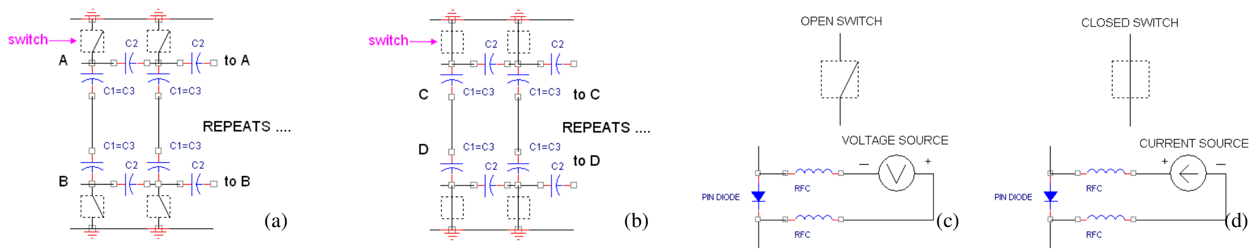

Figure 2. (a) coil resonates as a bandpass birdcage coil when switches open; (b) coil resonates as a TEM coil when switches closed; (c) pin diode wired to control the switch "open"; (d) pin diode wired to control the switch "closed".

Results

To demonstrate two axial uniformity modes of a switchable QBC, we model a 16-element QBC at 128MHz (3T) using the XFDTD software package (Remcom, Inc., State College, PA). As an example, we choose the diameter of the coil to be 60cm and length of 40cm. The RF shield has the diameter of 68cm and length of 100cm. Rung capacitors in the axial conductor are shared by both birdcage and TEM coils. The switches are simulated by two values of resistors R1 and R2. R1 is placed in two end rings, while R2 is placed in the conductors that connect the axial elements to the RF shield at both ends. To simulate the closed switch case in Figure 2(b), where the QBC resonates as a TEM coil, R1 is set to 10kΩ and R2 is set to 0.2Ω, which allows the rung current flow easily to the RF shield rather than to the end rings. To simulate the open switch case in Figure 2(a), where the QBC resonates as a birdcage coil, R1 is set to 0.2Ω and R2 is set to 10kΩ. The QBC model is first tuned to the TEM resonant mode. Then the value of the end ring capacitors is adjusted to tune the QBC to the birdcage resonant mode. In Figure 3, we calculate [3] and plot the normalized B_1-field [$|B_1^+|/|B_1^+|(0)$] along the x-axis and z-axis of an unloaded QBC that resonates as a TEM coil and a birdcage coil, respectively. $|B_1^+|(0)$ is the $|B_1^+|$-field at isocenter. In the transverse plane, the two QBCs have comparable $|B_1^+|$-field uniformity. Along the z-axis for the case when $|B_1^+|$ falls off from 1 to 50%, the uniformity region is 38cm-long for the birdcage mode and 63cm-long for the TEM mode. With the switch of resonant mode from birdcage to TEM, we have the possibility to utilize two independent uniformity modes for transmit or even for transmit and receive – both while keeping the QBC physically short.

Discussion

It is desirable to have a short QBC for high field MRI systems such as 3T, where SAR can be higher than at 1.5T. A short birdcage QBC provides the benefits of less peak power and less SAR in patients. Some sagittal and coronal imaging applications can benefit from a QBC with a larger region of axial uniformity. A switchable QBC design has been described that is physically short and has two modes of uniformity, in which each mode is associated with different SAR characteristics.

References

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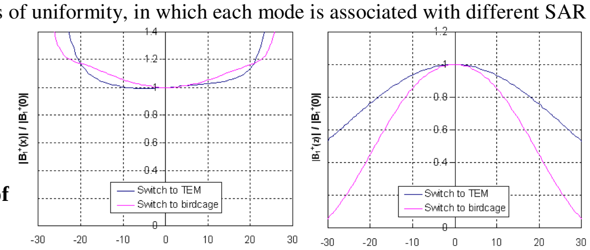

Figure 3. Normalized $|B_1^+|$-field along the x-axis and z-axis of a switchable QBC.