A Novel Segmented Double-Tuned Quadrature High-field MR Coil With Exceptional Tuning Stability

F David Doty[1], Glenn N Doty[1], Scott Deese[1], JB Spitzmesser[1], Daniel Arcos[1], David L McCree[1], Laura L Holte[1], Paul D Ellis[1], Sylvie Clerjon[2], and Jean-Marie Bonny[2]

[1]DOTY Scientific Inc. 700 Clemson Rd. Columbia SC 29229 [2]INRA, QuaPA, AgroResonance, Saint-Genes-Champanelle, France

Introduction

There is urgent need for a more satisfactory high-field, large, double-tuned rf coil to better support hyperpolarized ^{13}C MR with its enormous SNR enhancement, and also ^{23}Na MR, with its longer history of significant contributions to the biochemistry of various disease states and their progression. The novel coil presented here promises to be a significant step toward addressing that need. We present a novel High Frequency-segmented DT coil design showing an unprecedented degree of minimization of E fields, even with long samples, with little compromise in B_1 efficiency at either frequency and with greater potential for scalability to whole-body DT T/R circular-polarization coils at high fields.

Background

Current double-tuned quadrature designs:

Design	pros/cons
trap-based[1]	often plagued by nearby parasitic modes and poor LF efficiency.
Alternating rungs	major penalties on the LF; often exhibits lower ^{1}H efficiency.
multi-ring structures[2]	demonstrated best performance on the LF channel, but HF channel produces high E fields in sample regions axially well beyond the target FOV.

All are fundamentally incompatible with HF segmentation in the central region.

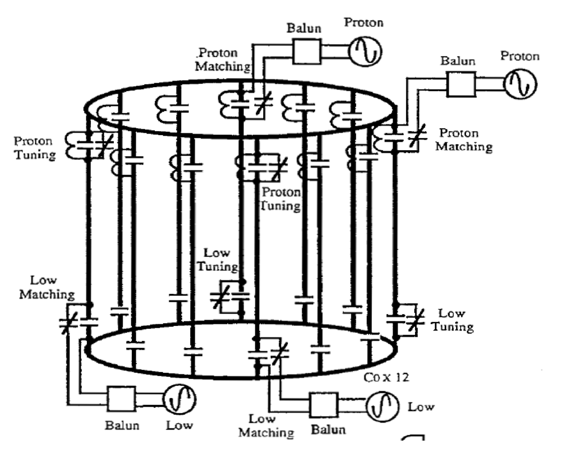


Fig. 1 Simplified schematic of Shen's unbalanced DT LP BC[1].

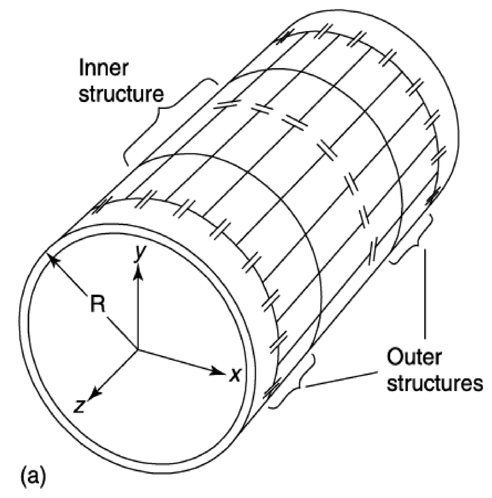


Fig. 2 The most common 4-ring DT BC structure[2].

Advanced DT Quadrature Coil for Highest fields

Novel segmented DT Volume Coil (VC):

- First-ever capacitively segmented DT volume coil – which is essential for efficient operation of large coils at very high fields.
- Compatible with multi-nuclear LF tuning, for ^{1}H/^{31}P through ^{1}H/^{13}C

Other features:

- multilayer dielectric shielding;
- optimal tapering of Crozier-like rung geometry;
- balanced-low-pass at both frequencies.
- a blend of some (Vaughan) TEM and (Edelstein) BC field characteristics;
- Includes novel matching circuitry.

All contribute to its remarkably low HF E/B throughout long samples and hence the negligible tuning shifts with changes in the sample.

Simulations and Bench Measurements

Simulations performed using Genesys, CST, and COMSOL models were in remarkable agreement with experiments.

For a full saline sample (16 cm diameter, 17 cm long) of 1 S/m, mean π/2 pulse length throughout the sample at 900 W CP is seen to be under 0.8 ms for ^{23}Na at 52.9 MHz and ~0.6 ms for ^{1}H at 200 MHz.

Detailed CST simulations showed compatibility with multi-nuclear H/X head coils up to 7 T.

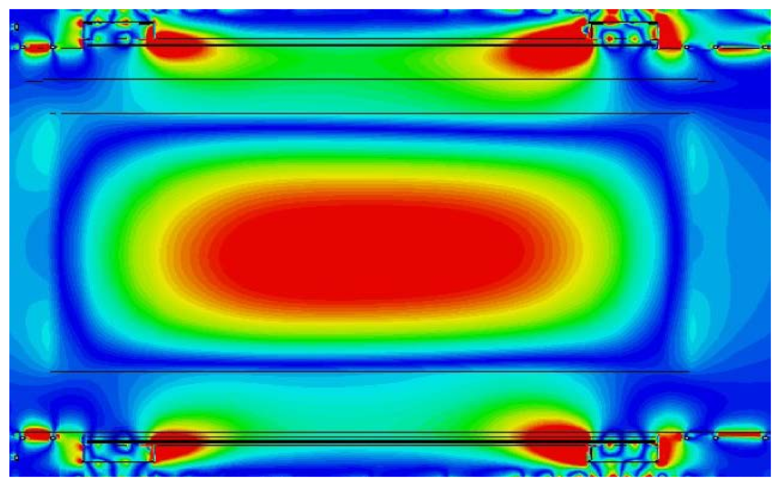


Fig. 3 The ^{1}H B_1+ field in the 200 MHz 20 cm DT coil with an extra long saline sample

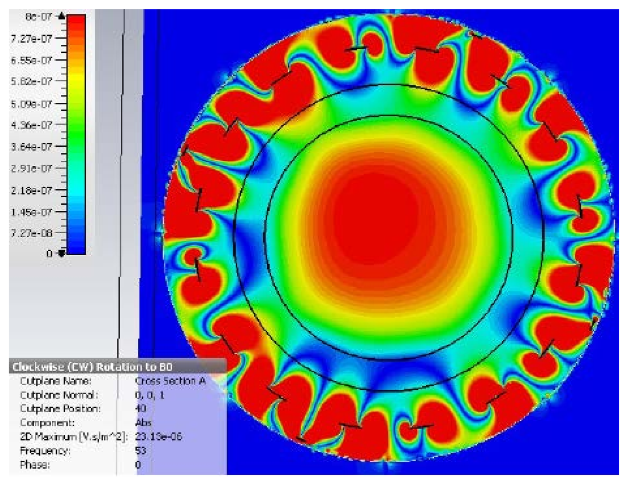
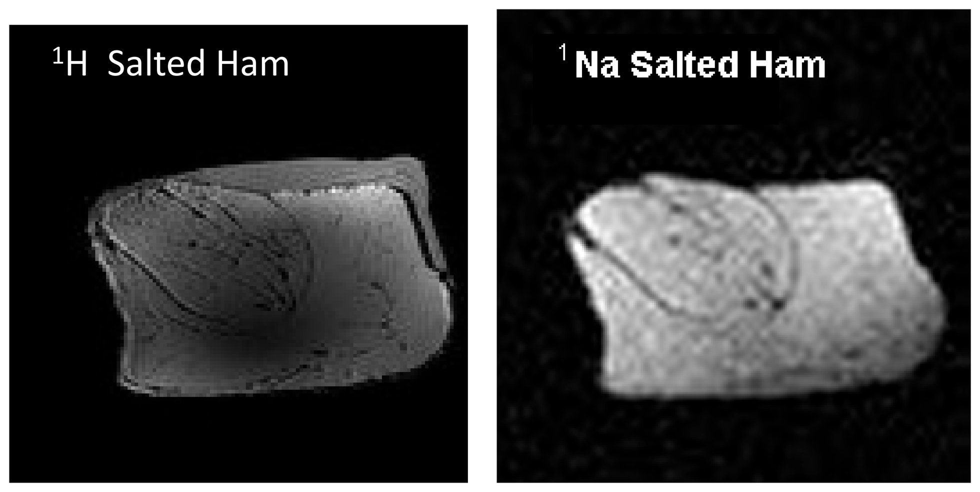


Fig. 4 The ^{23}Na B_1+ field in the 200 MHz 20 cm 8-section DT coil.

MR Data at 4.7 T from INRA, France, Dr. Sylvie Clerjon

Shown here are (first) ^{1}H and then ^{23}Na images of a transversal slice through a Norwegian traditional dry salted ham. This product is known to have a 9% average salt content in the finished product. As seen in the sodium image, salt distribution is nearly homogeneous, as it is near the end of the salt cure process.



There is no salt in the fat parts (mainly upper and right, as seen from the rapid ^{1}H image acquired on the same slice). Sodium imaging protocol: Chemical Spectroscopy Imaging (CSI), TE/TR=1.6ms/200ms. Resolution is 2*2*5 mm. Total acquisition time is 1 hr 49 min.

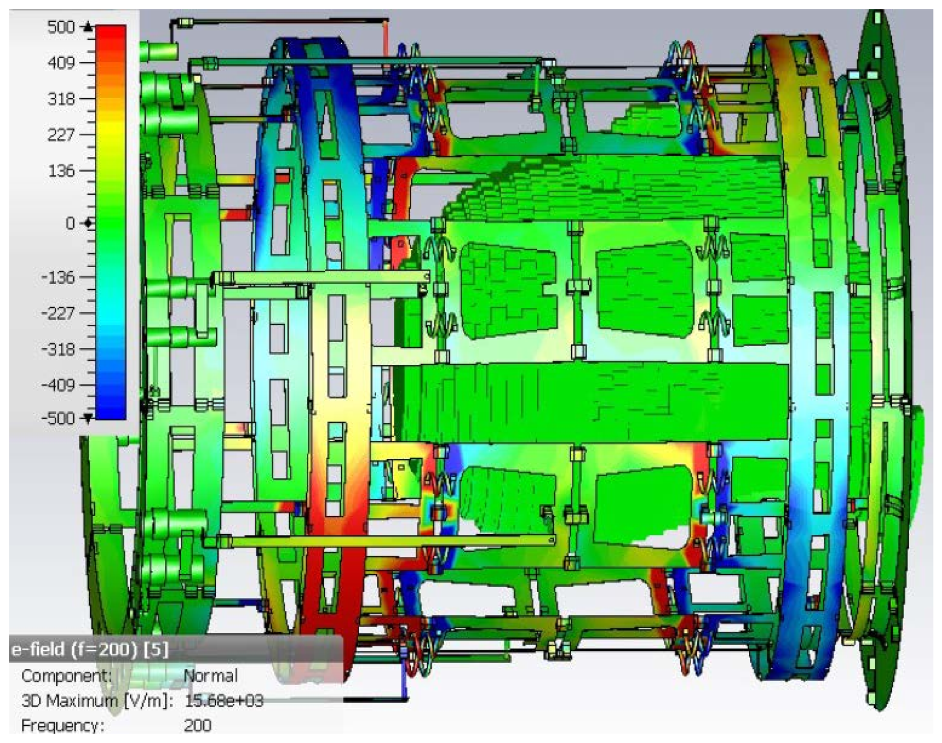


Fig. 5 E-normal on the surface of the coil structure at 4.7 T, from CST simulations.

20 cm ^{1}H/^{23}Na DT Quadrature coil, 4.7 T

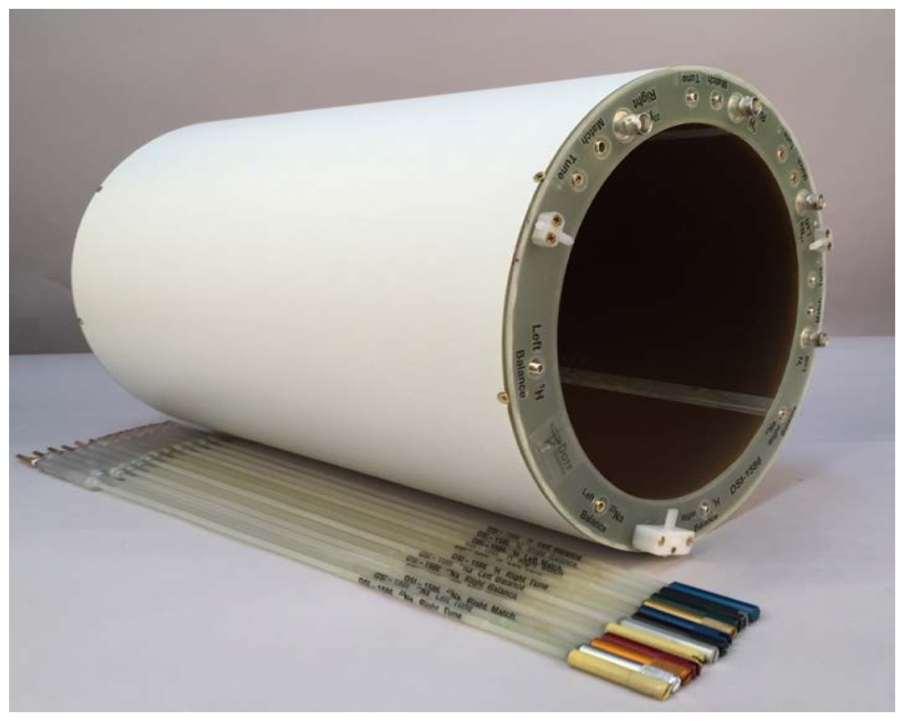


Fig. 6 4.7 T ^{1}H/^{23}Na volume coil. 20 cm ID x 20 cm RF rung length (25 cm OD).

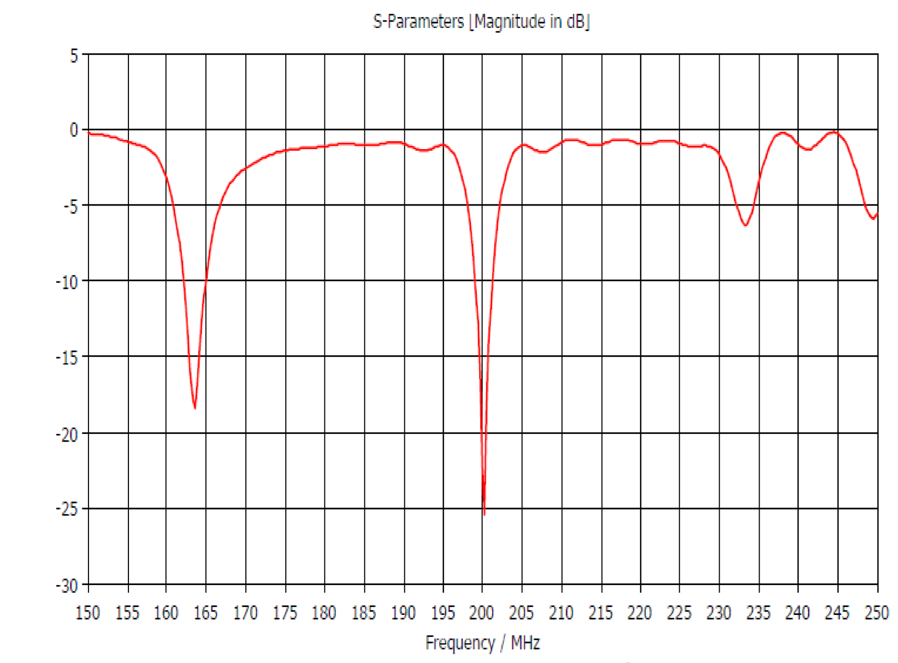


Fig. 7 The best simple check for completeness and validity of the 3D EM simulations is the agreement of S11 plots (HF shown above) with experiment. The nearest inhomogeneous modes are ~15% away.

References

1. Shen GX, Wu JF, Boada FE, Thulborn KR. *Magn. Reson. Med*. 1999. **41**:268-275

2. Murphy-Boesch J, Srinivasan R, Carvajal L, and Brown TR. *J. Magn. Reson*. Series *B*. 1994; **103**, 103-114.