2nd Prototype of an Automatic Tune and Match RF Transceive coil: Design and Evaluation

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Target audience

RF engineers and MR scientists with a basic knowledge of MR hardware.

Purpose

To maximize efficiency of RF field (B1) generation and MR signal reception, RF coils and interface circuits must be tuned at the Larmor frequency and matched to the 50 ohm input impednace.[1-4] The research trends in MR systems have been moving towards ultra-high magnetic fields and multi-channel RF coils. It, however, requires manual frequency tuning and impedance matching before every MR experiment because the loading-induced variation of RF performances becomes serious at ultra-high fields.[2-6] To overcome the time-consuming and impractical manual adjustments, this study proposes an electrically driven automation system to rapidly and accurately tune and match RF coils. The 2nd prototype automatic RF coil has been built with some major upgrades after we presented the feasibility of applying automatic tuning and matching in a multi-channel transceive RF coil at 7T.[2-3] The scientific and clinical utility of multi-channel systems that enable parallel MR imaging will not be fully realized without the proposed automatic frequency tuning and impedance matching technology at ultra-high fields.

Methods

Figure 1 shows the 2nd prototype of 8-channel RF transceive TEM head coil with the automatic tuning and matching system. The stand-alone automatic RF coil needs only an RF-unblank signal, three DC power lines, and eight RF pulse inputs and is fully compatible with existing MR scanners. Each channel is scalable and composed of a TEM resonator, a capacitor array based on PIN diode switching, an on-coil RF power detector, and an electrical main control unit. Some major upgrades in the 2nd prototype are: (1) a highly accurate RF power detector with a home-built high directivity coupler, (2) an extended uniform B1 field by adjusting impedance of the resonator's conductor line, (3) a robust algorithm to find the best tuned and matched condition, and (4) two modes of simultaneous or sequential tune/match operation in multi-channel structures. A controller distributes an external RF-unblank signal (to enable tuning) to every channel simultaneously or sequentially. Based on this RF-unblank signal, each channel is independently tuned and matched in about half of a second, and thus the 8-channel coil requires less than 5 seconds to automatically compensate loading effects in sequential tune/match mode. An RF power detector with a high directivity coupler (Directivity > 40 dB) provides an accurate RF power measurement of reflection for the main control unit. The algorithm in the main controller searches and computes an optimal configuration of the capacitor arrays to minimize the reflected RF power. The targeted condition is less than 4% of RF power reflection (VSWR = 1.5) at every channel. Before evaluating the RF coil inside the magnet, the performance of system functions was validated on the test bench as shown in Figure 2. S-parameters, S_{11}, at every channel are on the Smith chart (inside dotted circles) with selected four different loading and setup cases, and the results of automatic functions satisfy the requirement of the targeted condition at 297.2 MHz for 7T. To check the high power capability and gradient coil interferences, the RF input power was incrementally increased up to approximately 1kW inside the 7T magnet (Siemens Magnetom, Erlangen, DE).

Results

The capacitor arrays with fine capacitor values produce high accuracy during automation but cannot cover wide loading conditions. Adversely, coarse values cover wide range but are inaccurate. After finding optimal values, the automatic tuning and matching functions have accomplished high accuracy over 95%, and it can cover most adult head sizes with the 8-channel RF coil. Figure 3 shows the impact of human head loading on MR images (RF input power = 100 watt). The left image is the result after human head loading before tuning and matching, and the right image having higher flip angle is the result of the automatic tuning and matching. Figure 4 presents the comparison among detuned/mismatched, manually tuned/matched, and automatically tuned/matched conditions with a cylindrical phantom. It is clear not only that the tuned/matched condition has higher B1 fields, but also that the result generated by the automatically tuned/matched condition is similar to the result generated by the manually tuned/matched condition. Uncorrected human head gradient echo images (resolution=1x1 mm, TR/TE=300/4 ms, 5 mm slice thickness) are successfully obtained as shown in Figure 5. Although there is an unavoidable noise generated by MR-incompatible prototyping electronics, these images do not have significant defects or distortions. Developing MR-compatible electronics will help to reduce the unwanted noise level in the near future.

Conclusion

This study presents the realization of the automatically tuned and matched multi-channel RF tranceive coil with electrically driven devices. The 2nd prototype of the automatic RF coil offers improved accuracy, durability, and B1 field distribution. Finally, the RF coil makes it possible to successfully collect human head images without significant artifacts or distortions. This automatic technology is not limited to ultra-high field applications and also has clinical relevance: correcting patient's motions, improving throughput time, and patient setup time because the automatic functions can be done in or out of the magnet; before or during experiments.

Acknowledgements

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References

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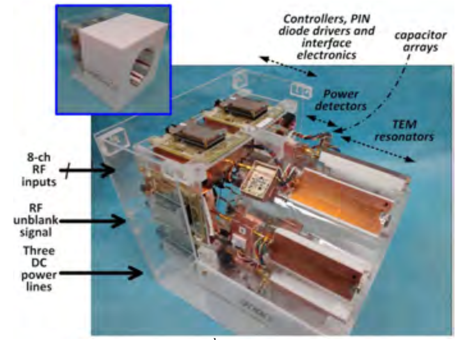

Figure 1. Photo of the 2nd prototype of an automatic RF signal tune and match RF transceivercoil.

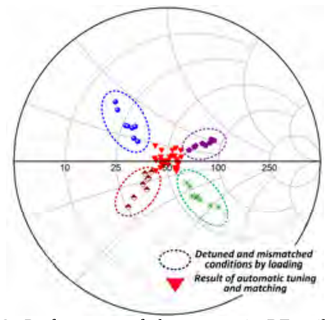

Figure 2. Performance of the automatic RF coil on the Smith Chart (S_{11} at 297.2 MHz) with four different loading and setup conditions.

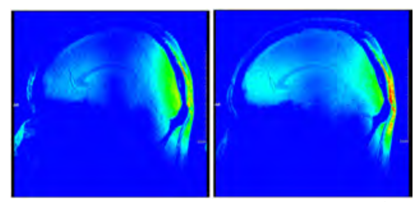

Figure 3. Detuned and mismatched MR image (left) and tuned and matched MR image (right).

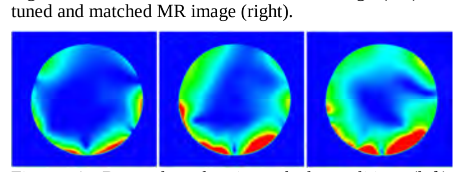

Figure 4. Detuned and mismatched condition (left), manually tuned and matched condition (center), and automatically tuned and matched condition (right)

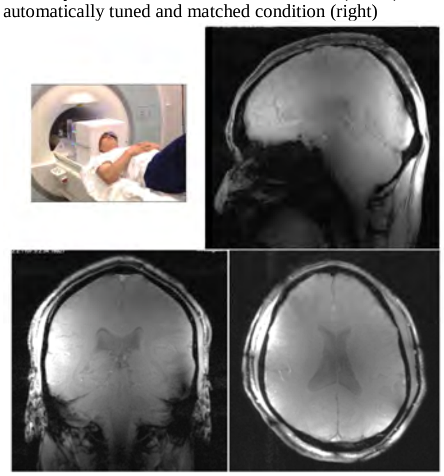

Figure 5. Human head images at 7T with the automatic RF signal tune and match RF transceive coil.