Determining the Tuning and Matching Requirements of RF coils using Electromagnetic Simulation and Electric Circuit Analysis

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Introduction: Tuning and matching the RF coil to the desired Larmor frequency and characteristic impedance of the MR scanner's RF system is necessary for optimal performance. Determining these requirements using analytical methods soon becomes difficult for arbitrary RF coils with complex geometries, Faraday shields and lossy dielectric loads. Fortunately, this sort of problem lends itself to Computational Electromagnetic Modelling (CEM) methods. Therefore, in this work the Transmission-Line Modelling (TLM) method [1], which is a full-wave CEM method, is used in conjunction with electric circuit analysis to determine the tuning and impedance matching requirements of arbitrary RF coils.

Methods: TLM models of a single tune capacitance (STC) Alderman-Grant coil (Fig. 1a), a simple distributed tune capacitance (SDTC) Alderman-Grant coil (Fig. 1b), and complex distributed tune capacitance (CDTC) low- and high-pass birdcage coils (Figs. 1c-d) in the unloaded and Krebs (ε_r = 74, σ =1.5 S/m) loaded conditions were created using Micro-Stripes™ propriety TLM software package (Flomerics Ltd., Surrey, UK). Equivalent lumped-element circuit components were extracted from the TLM simulations, and equivalent circuit representations were derived for both balanced capacitive (Fig. 2a) and series-tuned inductive matching (Fig. 2b) schemes using methods described elsewhere [2,3]. Then electric circuit analysis [4-6] was applied to the equivalent circuit representations to determine the tuning and matching requirements for both matching schemes for a Larmor frequency of 300 MHz and a 50 Ω characteristic impedance respectively. Tuning and matching interactions for both matching schemes, including the occurrence of mode splitting due to co-tuning inductively coupled coils were also considered in this work. Experimental comparisons were performed using corresponding actual RF coils constructed with calibrated variable tuning and matching capacitors, and S_{11} measurements on a network analyser (HP8712ET, Agilent Technologies, Palo Alto, CA, USA).

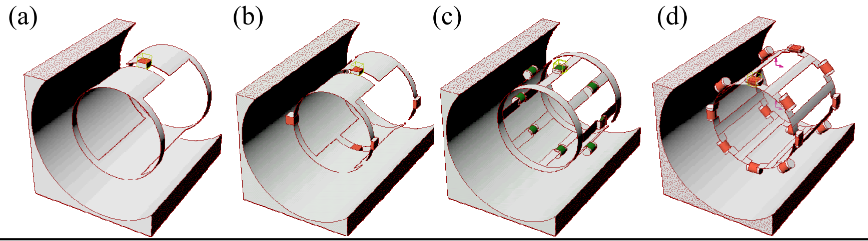

Fig. 1. TLM models of (a) STC Alderman-Grant coil, (b) SDTC Alderman-Grant coil, (c) CDTC low-pass birdcage coil and (d) CDTC high-pass birdcage coil.

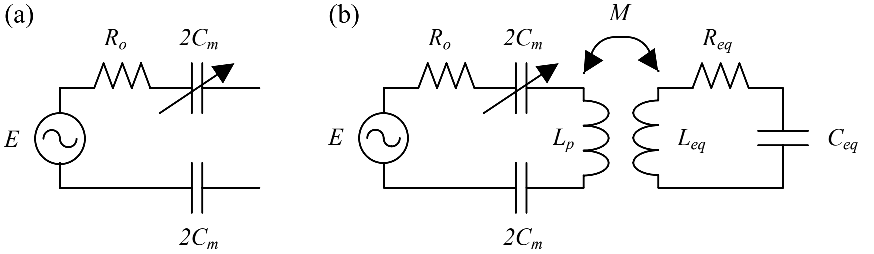

Fig. 2. Equivalent circuit representations of (a) Balanced capacitive matching scheme, (b) Balanced series-tuned inductive matching scheme.

Results & Discussion: Tables 1 and 2 show excellent agreement between the TLM predicted and experimentally determined (EXP) values for the variable tuning and matching capacitances *Ct* and *Cm*, for both the capacitive and inductive matching schemes (< 3pF). These results demonstrate the utility of combining a CEM modelling method with electric circuit analysis, with the distinct advantage to the RF coil designer of a reduced dependence on bench measurements and proto-typing methods. However, the failure to predict the tuning and matching range for the CDTC low-pass birdcage coil requires further work. Finally, the methods presented here are applicable to all RF coils, impedance matching schemes and CEM methods where equivalent lumped-element circuit representations can be derived.

Table 1. Capacitive Tuning & Matching

RF Coil	Load	*Ct* (pF)		*Cm* (pF)	
		TLM	EXP	TLM	EXP
STC Alderman-Grant	Unloaded Krebs	5.2 5.0	3.9 3.9	0.4 0.8	0.6 0.8
SDTC Alderman-Grant	Unloaded Krebs	23 21	26 23	1.8 3.4	1.8 3.9
CDTC LP bird	Unloaded Krebs	5.6 5.2	* *	0.9 1.7	* *
CDTC HP bird	Unloaded Krebs	18 16	18 16	2.3 4.9	2.8 6.1

Table 2. Capacitive Tuning & Inductive Matching

RF Coil	Load	*Ct* (pF)		*Cm* (pF)	
		TLM	EXP	TLM	EXP
CDTC LP bird	Unloaded Krebs	6.2 5.8	* *	1.7 4.6	* *
CDTC HP bird	Unloaded Krebs	19 15	16 15	1.2 3.5	3.4 3.9

* Denotes failure to tune and match at 300 MHz and 50 Ω.

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References

1. Johns PB and Beurle RF, *Proc. IEE*, 118, No.9, 1203-8 (1971).
2. Cassidy PJ *et al., MAGMA* 14, 1:20-29 (2002).
3. Cassidy PJ *et al., Proc. Int. Soc. Mag. Reson. Med.* 11; 2378 (2003).
4. Chen CN and Hoult DI, Biomedical Magnetic Resonance Technology, Bristol & New York: IOP Publishing (1989).
5. Krauss HL *et al.,* Solid State Radio Engineering, New York: John Wiley & Sons (1980).
6. Terman FE, Radio Engineers' Handbook. New York and London: McGraw-Hill Book Company, Inc. (1943).