Theory of Double Tuned TEM Resonators and Workbench Validation in a Frequency Range of 100-350 MHz

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INTRODUCTION

Imaging and spectroscopy at high static field (>3T) is proving to be very successful since it yields increased SNR, allowing improved spatial resolution, and also provides better spectral resolution. The single tuned TEM resonator design has been proposed [1-2] for its improved RF characteristics with respect to the standard birdcage coil. The theory of Multiconductor Transmission Lines (MTL) [3] has been used to calculate the N/2+1 modes of the single tuned TEM resonator, made of N *identical* coupled coaxial [4-6] or microstrip [7] elements. However, despite the important applications of high field multinuclei MRI, only one paper [2] reported the measured frequency response of a *double* tuned TEM resonator. In this study we present the MTL modelling of double tuned TEM resonators and workbench validation in a frequency range of 100-350 MHz.

MTL MODELLING

The MTL model of a single tuned TEM resonator made by N identical coaxial elements was previously described [4-6]. It was shown that the frequency response of the TEM resonator can be calculated as S=-log(P). The function P is the determinant of the matrix $\boldsymbol{[1^N -G^{m+}G^{m-}exp(-2g_mL_t)]}$, where L_t is the length of the TEM resonator and $\boldsymbol{G^{m+/-}=TG^{+/-}T^{-1}}$ are the matrices of the modal reflection coefficients at the two resonator ends $\boldsymbol{G}^{+/-}$. To calculate $\boldsymbol{G}^{m+/-}$ it is necessary to know the modal admittance of the coaxial transmission line element $\boldsymbol{Y_0^m=TY_0T^{-1}}$, where $\boldsymbol{Y_0}$ is a circulant matrix. This matrix is diagonalised by T, where $T_{mn}=(1/\sqrt{N})\exp[-j2\pi(m-1)(n-1)/N]$. For determination of $\boldsymbol{G}^{m+/-}$ it is also important to know the modal decomposition of the impedance of the termination load line $\boldsymbol{Zc^{m+/-}=TZcT^{-1}}$ [3], where $\boldsymbol{Z_c}$ is the matrix of the load impedances. Following the MTL model previously reported [5-6], the load impedance $\boldsymbol{Z_c}$ is a diagonal matrix with elements given by $Z_{cii}=j\omega L_{pii}+1/[j\omega(C\, l_{ii}^{+/-}+C_p)+G\, l_{ii}^{+/-})]$, where $l_{ii}^{+/-}$ is the rod tuning length of the short coax termination at the two ends, *G* and *C* are the conductance and capacitance per-unit-length, C_p and L_p are parasitic capacitance and inductance [5], respectively. For a single tuned TEM resonator composed by N identical elements, $l_{ii}^{+/-}$ has a constant value, and as a consequence $\boldsymbol{Z_c^{m+/-}}=Z_c\boldsymbol{1^N}$ is a diagonal matrix, which greatly simplifies the model. We have modified the MTL model to allow the setting of arbitrary values of Z_{cii} for each of the N coaxial elements composing the TEM resonator. In general, this gives a matrix $\boldsymbol{Z_c^{m+/-}}$ that is not diagonal. To obtain a double tuned TEM resonator, we have chosen two alternate sets of coaxial elements each made by N_L and N_H elements ($N=N_L+N_H$). In the simplest case, the double tuning is realized by setting the length of the termination rods equal to l_L for the N_L elements and l_H for the others N_H elements.

RESULTS AND DISCUSSION

To test the double tuned TEM theory, we have used a TEM prototype (dia 37cm, length 19cm) made of N=24 coaxial elements (pitched circle dia of elements 28.3cm) [8]. Each coaxial element was made of a copper outer tube, with a PTFE tube and two copper rods each forming half the inner conductive element. The end rods were connected to the front and back of the RF shield by brass connectors. The resonant modes were measured with a network analyzer (HP8712C). Capacitive matching allowed measurement of all the modes of the TEM prototype, except the M=0 mode. In a first practical implementation the double tuned TEM resonator was realised by setting the length of the rods at the patient side equal to $l_L^+=l_H^+$=78 mm for all the elements, while at the service end the length was set to l_L^-=78 mm (N_L=12) and l_H^-=24 mm (N_H=12), see Fig. 1. The simulated and measured frequency responses of the double tuned TEM resonator are reported in Fig. 2. Two groups of resonant modes (M_L=0,…,6 and M_H=0,…,6) are present, with the useful MRI modes labelled as M_{1L} (141.52 MHz) and M_{1H} (270.44 MHz). As shown in Table 1, a good agreement between theory and experiment is obtained, with the maximum deviation (8 %) corresponding to the higher modes. In a second implementation we choose to set l_L^-=78 mm (N_L=16) and l_H^-=24 mm (N_H=8). The corresponding simulated and measured frequency responses are also reported in Table 1. In this case two groups of resonant modes (M_L=0,…,9 and M_H=0,…, 5) are present, with the useful MRI modes labelled as M_{1L} (135.24 MHz) and M_{1H} (279.80 MHz).

In conclusion, we have reported the MTL modelling of double tuned TEM resonators. Workbench validation in a frequency range of 100-350 MHz shows a good agreement between theory and experiments. This work should be useful for future high field (3 to 9 T) multinuclei MRI applications.

REFERENCES
[1] Roeschman P, USP 4,746,866 (1988).[2] Vaughan JT, et al, MRM 32, 206 (1994).
[3] Paul CR, Analysis of MTL, Wiley, (1994).
[4] Baertlein BA, et al, IEEE TBE 47, 535 (2000).
[5] Vitacolonna, et al, Proc. ISMRM 1535 (2004).
[6] Vitacolonna, et al, Magma, Vol. 16, Suppl 1, s229-s230, (2004)
[7] Bogdanov G, et al, MRM 47, 579 (2002). [8] Alecci M, et al, MRM 48, 404 (2002).

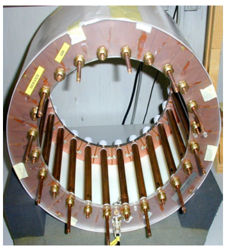

Fig. 1. Double tuned TEM prototype with l_L^-=78 mm (N_L=12) and l_H^-=24 mm (N_H=12).

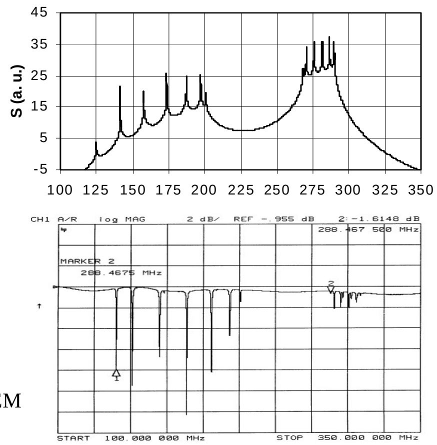

Fig. 2. Simulated (top) and measured (bottom) frequency response of the double tuned TEM resonator of Fig. 1.

TABLE1	l_L^-=78 mm (N_L=12) l_H^-=24 mm (N_H=12)			l_L^-=78 mm (N_L=16) l_H^-=24 mm (N_H=8)		
MODE	Theory (MHz)	Exp. (MHz)	Diff (%)	Theory (MHz)	Exp. (MHz)	Diff. (%)
M0L	125.04	NM	NM	119.40	NM	NM
M1L	141.52	140.31	-1	135.24	135.13	-0.1
M2L	157.92	151.24	-4	150.96	146.25	-3
M3L	173.52	170.04	-2	165.24	165.42	0.1
M4L	187.20	188.74	1	172.84	181.90	5
M5L	197.16	205.94	4	197.32	193.58	-2
M6L	201.00	218.44	8	203.48	216.27	6
M7L	NE	NE	NE	213.28	223.46	5
M8L	NE	NE	NE	220.76	235.30	6
M9L	NE	NE	NE	223.60	244.34	9
M0H	268.24	NM	NM	278.36	NM	NM
M1H	270.44	290.21	7	279.80	299.84	7
M2H	275.72	295.90	7	282.16	302.65	7
M3H	281.60	301.76	7	284.12	303.89	7
M4H	286.44	306.56	7	284.84	305.20	7
M5H	289.44	309.89	7	NE	NE	NE
M6H	290.04	310.60	7	NE	NE	NE