# Multiline Transmission Line Modelling and Experimental Testing of 3 T TEM Resonators

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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 and spectral resolution [1]. However, high field MR requires the design and use of specialised volume or surface RF coils (resonators). The TEM resonator design has been proposed [2-3] for its better RF characteristics (self-resonance, radiation losses, quality factor, B1 sensitivity, RF homogeneity) with respect to the standard birdcage coil. In a recent study [4] it has been shown that the TEM design has a higher sensitivity to RF perturbation, i.e. a higher RF inhomogeneity. Novel and effective methods to map the RF field of TEM resonators have recently been reported [5]. The first step in the design of an N-element TEM resonator is the calculation of the frequency response of its (N/2)+1 modes. To achieve this several methods have been proposed [2-3,6-8]. The theory of Multiconductor Transmission Lines (MTL) [8] has been used to model the frequency response of TEM resonators made of N coupled coaxial [10] or microstrip [11] elements. In the present work we have modified the MTL model, for simulation of the TEM resonator response, by including the following features: 1) accounting for the short coaxial element approximation; 2) including within the model losses in the coaxial elements; 3) allowing for asymmetrical (front-back) adjustment of the tuning rods. We present theoretical data and a comparison with experimental results obtained with a 3 T head-sized TEM prototype composing 24 elements.

## MTL MODEL AND EXPERIMENTAL RESULTS

We follow the geometrical parameters and notation of the TEM resonator as reported by Baertlein et al [10], with the general model modified as described above. Considering an array of N transmission line elements (TLE's) as in the TEM resonator, the voltages $Vn(z)$ and currents $In(z)$ of the nth TLE can be written as column vectors $\boldsymbol{V}$ and $\boldsymbol{I}$, which satisfy the vector transmission line equations: $d\boldsymbol{V}/dz=-\boldsymbol{ZI}$, and $d\boldsymbol{I}/dz=-\boldsymbol{YV}$, where $\boldsymbol{Z}$ and $\boldsymbol{Y}$ are the mutual impedance and admittance matrices of the lines, respectively. The modal voltages $\boldsymbol{V}^m$ are expressed as forward and backward propagating waves, and are given by: $\boldsymbol{V}^m=exp(-gz)*\boldsymbol{V}^{m+} + exp(+gz)*\boldsymbol{V}^{m-}$ , were $g$ is the propagation constant. The voltage wave amplitudes $\boldsymbol{V}^{m+/-}$ can be calculated from the admittance of the coaxial element line $\boldsymbol{Y}_0^m$, and the impedance of the termination load line $\boldsymbol{Zc}^{m+/-}$. It can be shown that the frequency response of the TEM resonator can be calculated as A= -log(P). The function P is the product of N terms, the nth is given by $[1-G^{n+}G^{n-}exp(-2g_nL_t)]$, where $L_t$ is the length of the TEM resonator and $G^{n+/-}$ are the reflection coefficient at the resonator ends. The short coaxial element approximation and the losses in the coaxial elements, were considered in the modified MTL model by calculating the load impedance of each line as $1/(l(G+j\omega C))$, where $l$ is the tuning length, $G$ and C are the conductance and the capacitance per-unit-length, respectively. The asymmetrical adjustment of the tuning rods was obtained by setting different values of the capacitance at the ends of each line. An example of the calculated frequency response of a TEM resonator made of 24 elements is reported in Fig. 1. In the simulation the length of the tuning rods was set to 7.9 cm. The other geometrical dimensions are the same as the TEM prototype shown in Fig. 2. The TEM prototype (dia 37cm, length 19cm) with 24 coaxial elements (pitched circle dia of elements 28.3cm) and a segmented RF shield. Each TLE was made of: two copper rods each forming half the inner conductive element (dia 0.64cm); a copper tube (ext dia 1.6cm, wall 0.24cm, length 18cm); and a PTFE tube (ext dia 1.12cm, int dia 0.64cm, length 18cm). The end rods were connected to the front and back of the RF shield by brass connectors. The modes were measured with a network analyzer (HP8712C). In Table 1 are reported the calculated response for TEM resonators composing 8, 16, and 24 coaxial elements. For comparison Table 1 also reports the measured frequencies of the N=24 TEM prototype. We found a good agreement between calculated and measured frequencies. We found a better agreement for the lower modes (M<4) and the maximum difference was 5%.

## CONCLUSIONS

We have presented a MTL model for the calculation of the frequency response of TEM resonators made by coaxial transmission line elements. A comparison of theoretical and experimental data, obtained with a 3 T head size TEM prototype shows a good agreement. These results should be useful when designing TEM resonators and predicting their resonant frequencies in the range 100 to 400 MHz.

| MODE | THEORY, N=8, f (MHz) | THEORY N=16, f (MHz) | THEORY N=24, f (MHz) | EXPERIMENT N=24, f (MHz) |
|---|---|---|---|---|
| 0 | 159,9 | 131,3 | 111,5 | 106,2 |
| 1 | 173,9 | 148,2 | 127,4 | 128,0 |
| 2 | 184,9 | 164,7 | 143,7 | 139,4 |
| 3 | 191,9 | 180,4 | 160,2 | 157,4 |
| 4 | 194,4 | 194,4 | 176,6 | 175,8 |
| 5 | | 206,1 | 192,5 | 194,1 |
| 6 | | 215,0 | 207,4 | 210,7 |
| 7 | | 220,5 | 221,0 | 225,5 |
| 8 | | 222,4 | 232,8 | 238,1 |
| 9 | | | 242,4 | 248,6 |
| 10 | | | 249,6 | 256,7 |
| 11 | | | 254,0 | 263,0 |
| 12 | | | 255,5 | 266,6 |

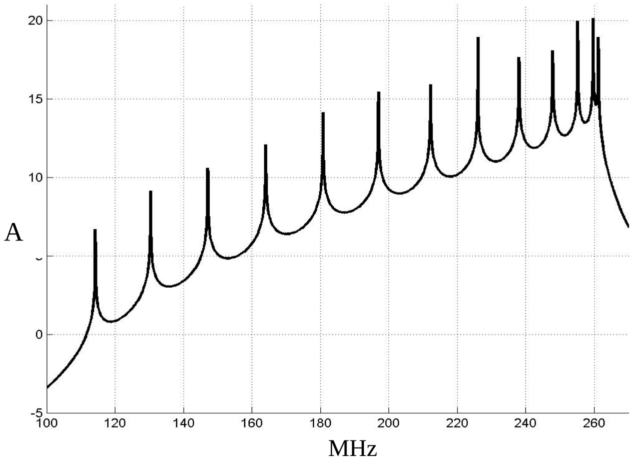

Fig. 1 The calculated MTL response *A* of the 3 T TEM resonator.

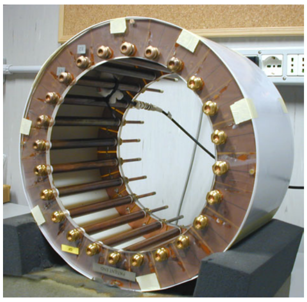

Fig. 2 The 3 Tesla TEM prototype made of 24 coaxial elements.

REFERENCES

[1] Vaughan JT, et al, MRM 46, 24 (2001). [2] Roeschman P, USP 4,746,866 (1988). [3] Vaughan JT, et al, MRM 32, 206 (1994). [4] Tropp J, Proc ISMRM pg 1129 (2001). [5] Avdievich NI, et al, MRM 50, 13 (2003). [6] Chingas GC, et al, Proc ISMRM pg 1426 (1996). [7] Tropp J, et al, Proc ISMRM, pg 421 (1999). [8] Alecci M, et al, Proc ISMRM pg 566 (2000). [9] Paul CR, Analysis of MTL, Wiley, 1994. [10] Baertlein BA, et al, IEEE TBE 47, 535 (2000). [11] Bogdanov G, et al, MRM 47, 579 (2002).