Design and construction of a heteronuclear 1H and 31P double tuned coil for breast imaging and spectroscopy

S. Obruchkov[1], K. Bradshaw[2], and M. D. Noseworthy[3]
[1]Medical Physics and Applied Radiation Sciences, McMaster University, Hamilton, ON, Canada, [2]Sentinelle Medical, Toronto, ON, Canada, [3]Electrical and Computer Engineering, McMaster University, Hamilton, ON, Canada

Introduction:

Current MRI literature of ^{31}P spectroscopy presents evidence of increased concentrations of phosphomonoesters (PME), and phosphodiester (PDE) as well as inorganic phosphate concentrations in breast tumor tissue. Human breast cancer studies have demonstrated the correlation between the disease progression and the PME, PDE peaks. Higher concentrations of phosphocholene were found to be present in higher grade tumors then low grade tumors [1,2]. Significant changes were also observed in metabolite concentrations as a response to chemotherapy and radiation therapy, thus ^{31}P spectroscopy could be used for breast cancer detection, tumor grading and monitoring therapy. A double tuned coil, compatible with Sentinelle Vanguard GE table, was designed and built to efficiently operate at resonant frequencies of ^{31}P and ^{1}H. This allows performance of experiments that simultaneous require RF transmition at both frequencies, as well as better quantification of ^{31}P metabolites, by applying B_1 corrections acquired using ^{1}H channel.

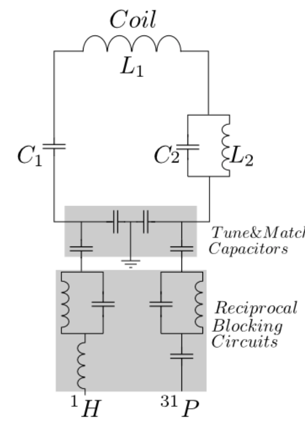

Figure 1: Circuit used to build a multitune coil.

Materials and Methods:

Theory: A surface coil can be approximated by a series RLC circuit, which will resonate at frequency $\omega_0^2=1/L_1C_1$, it is possible to split that resonance peak into two by using appropriate reacting components L_2C_2, see Figure 1 [3]. Setting L_1 and L_2 values and solving for the C_1 and C_2 components when reactance is zero, new resonance values ω_0 can be calculated by solving the second equation bellow:

$$Z = R_1 + i\left(\omega L_1\left(1-\frac{1}{\omega^2 L_1 C_1}\right) + \omega\frac{L_2}{1-\omega^2 C_2 L_2}\right) \qquad C_2 = \frac{w^2 L_1 C_1 - 1 + w^2 L_2 C_1}{w^2 L_2 (w^2 L_1 C_1 - 1)}$$

The values for the circuit were calculated using an in house program written in MATLAB (The Mathworks, Natick, MA, USA) and simulated using QUCS software (http://qucs.sourceforge.net/)


Figure 2: Vanguard Breast Biopsy table with a dual tuned coil.

Construction: The component values for C_1, L_2 and C_2 were calculated such that the coil would resonate at 51.73 MHz for ^{31}P and 127.8 MHz for ^{1}H. The components were distributed along the circumference of the coil to reduce the L_2 value, thus making it more feasible for construction. The coil was put into housing designed to fit into a commercial breast biopsy table, Vanguard (Sentinelle Medical, Toronto, ON Canada), Figure 2. Thus it is possible to swap the dual tuned coil during a clinical breast scan and replace it with the multichannel coil or perform a biopsy.

Decoupling: A breast phantom constructed in house from polyvinyl alcohol and a solution of methylphosphonic acid (Sigma-Aldrich, St. Lois, MO, USA) were scanned using a ^{31}P FIDCSI sequence with a TR=10s, and using a WALTZ-4 sequence on the ^{1}H channel for decoupling. This was performed using a stand alone proton decoupling system (GE Healthcare, Milwaukee, WI).

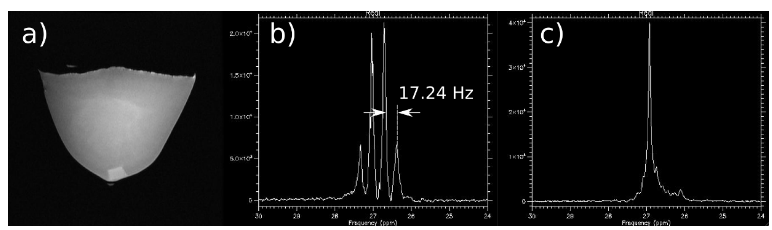

Figure 3: a) A T1 weighted ^{1}H image of a Polyvinyl alcohol breast phantom b) A solution of methylphosphonic acid scanned using FID CSI TR=10s no decoupling c) Repeated with WALTZ-4 decouplling.

Results:

While L_1 is fixed by the coil geometry it was found that choosing $L_2 = L_1/2$ gave best results during circuit simulations and hardware prototyping for best performances on both channels. Each channel was tuned and matched to 50Ω, although applying different loads affected the two channels similarly no rigorous studies were done to understand the relationship between different loads and circuit behavior.

Methylphosphonic acid ($CH_3P(O)(OH)_2$) has 4 peaks split by 17.24 Hz. After turning on the WALTZ-4 the peaks collapse into one increasing the SNR 4 times, due to the chemical structure of methylphosphonic acid no NOE enhancement was observed, Figure 3. No significant SNR penalty, due to noise injection was seen while running WALTZ-4 on the proton channel.

Discussion:

A dual tuned coil for breast imaging and spectroscopy was successfully designed and built to integrate with Sentinelle Vanguard breast biopsy system. This coil allows multinuclear data acquisition of ^{31}P while simultaneously performing decoupling experiments on ^{1}H channel. It is also possible to use this system for further calibration and quantification or ^{31}P metabolites.

References:

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