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Clinical utility of an endorectal MRI-guided prostate probe: preliminary examinations

Abstract: Prostate cancer (PCa) is one of the most common cancer diseases in men in the western countries [1]. Besides the palpation, and the amount of prostate-specific-antigen's (PSA) inside the blood, the current diagnostic imaging technologies are not appropriate. Early diagnosis defining the exact tumor location, spread and margins could make efficient targeted biopsies and image-guided surgery. A multimodal imaging technique containing a transmit-receive surface coil for anatomical MR imaging, a (S)PET detector module, consisting of silicon photomultipliers (SiPM), for functional imaging and an ultrasound (US) probe are placed as close as possible to the prostate designed as an endorectal tube to increase sensitivity and spatial resolution. All materials that are used are non-magnetic. Advantages of the SiPM are diversified, like non-sensitive to magnetic fields, higher gain (10^5–10^6) than standard avalanche photodiodes (APD), good timing properties and compactness. The PET detector should reach approximately 1mm^3 spatial resolution together with 60ps FWHM Time-of-Flight resolution and a high efficiency to reduce scanning time and injected dose. A home-made transmit-receive coil surrounding the PET module improves signal-to-noise-ratio (SNR) with respect to standard coils will be present. The system will be used as a MRI-insert and be able to visualize anatomic and metabolic information together. The US-probe is guiding examination for correct overlapping of the multimodal images. This procedure will save time, costs and the need of co-registration. By combining all advantages of each system, it will necessarily update the non-invasive treatment of PCa. The system is adapted and tested to a 3 Tesla MR scanner called Trio A Tim system and Allegra system from the company Siemens healthcare with a larmor frequency of 123.2 MHz and an input of 50 Ω free from artifacts. First results on homogeneity of the transmit-receive coil will be presented. Preliminary measurements showing the proposed device is challenging but feasible.

Keywords: MRI, prostate cancer, SNR, transmit-receive coil, multimodal image.

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1 Introduction

Prostate cancer (PCa) is a malignant tumor of the prostate gland. In Germany, it is the most common tumor disease in males and the continuous increase of this number is problematic [2]. To stop the growth medical examination, diagnosis and treatments have to be upgraded.

The diagnostic imaging technology is an important field in the diagnostic of PCa, besides palpation and the amount of prostate-specific-antigen's (PSA) inside the blood. Most recent developments in MRI and PET will lead to significant improvements in both lesion detection and staging so the image fusion with integrated anatomic and metabolic information will offer a potential advantage in comparison to the available diagnostic tools. Transrectal Ultrasound (TRUS) still remains the most widely applied tool to guide prostate biopsies [3]. However, its utility in local staging is limited because extracapsular extension (ECE) and seminal vesicle invasion (SVI) are challenging to visualize unless there is gross extension of tumor.

The advantages of MR imaging with endorectal coils such as small distance to the region of interest, good sensitivity and a good SNR can be used to advance the early stage diagnosis [4]. The best diagnosis can be reached with a combination of different imaging technologies. The combination of the advantages of each system can advance the early stage diagnosis of PCa and has to be the next step.

The aim of this work was to build a transmit-receive coil that can be included, with other image technologies like a PET crystal or an US head, in a probe. Since this probe

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has to be inserted into the rectum of a patient the outer parameters of the coil are limited and have to be as small as possible. Therefore the best approach to build this coil is by integrating the best solutions for each limitation.

2 Materials and methods

A basic receive-only coil contains of a capacitance and inductivity. The outcome of the parallel connection of inductivity and capacitance is a resonant circuit. The electric field of the plates between the capacitor stores the energy of an electric impulse. The discharge of the capacitance brings up a loading of the inductivity's magnetic field. The ideal case of a resonant circuit would be no loss of the frequency f_0 when both reactance's are equal [5]. So the perfect resonance frequency is defined by:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

The home-made transmit-receive coil takes advantage of this method. In reality, this circuit loss energy due to the components and connecting wires. By changing the values of the capacitance and the inductivity the specific resonant frequency can be tuned. Only the values of the capacitance can be changed because the inductivity is part of the shape and size of the coil itself.

The transmit-receive coil is a surface coil consists of a loop of conducting non-magnetic materials, which are placed directly inside the men's body. This lead to an increase of sensitivity and a better spatial resolution. It is space saving, which solve a big problem of the MRI-guided prostate probe. The coil sends a high-frequent pulse to the hydrogen protons in the prostate. They are moving from their ground parallel to the antiparallel state. The coil receive the signal by flipping the protons back to their ground state[6].

Figure 1 shows the design of the transmit-receive coil, which is the newest layout with all the requirements.

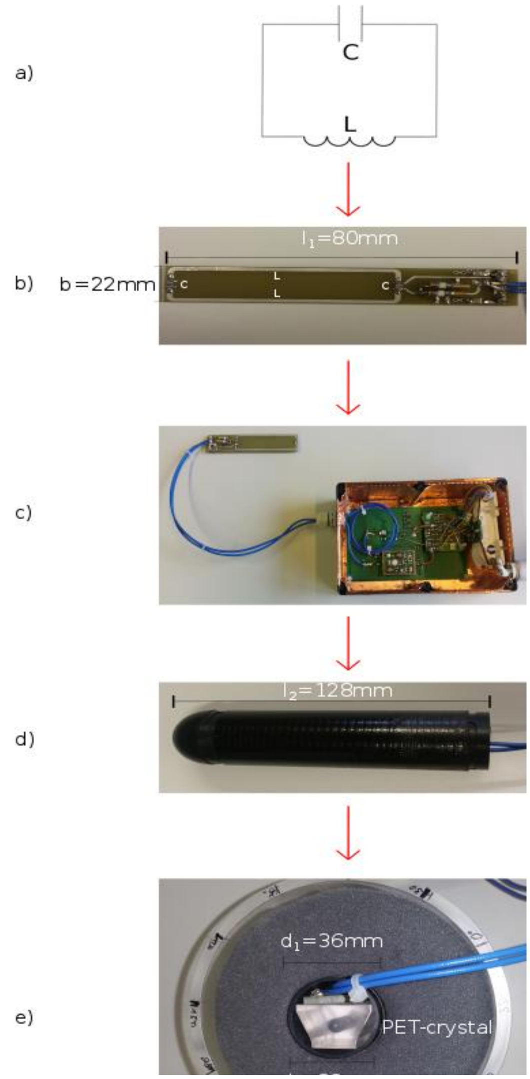

Figure 1: Layout and dimensions of the transmit-receive surface coil and its probe. The theoretically resonant circuit is shown in a), which is used to build the coil in b). It contains two inductors and two capacitors and is adapted to an amplifier c) for connection to the MRI system. d) and e) depict the dimensions and shape of the double-walled prostate probe due to its cooling system for the PET-crystal. The probe in e) contains the PET-crystal and the surface coil. The phantom is filled with foam material.

3 Measurements and results

Very important parameters for coils with a good adjustment are the scatter parameters, quality factor, signal-to-noise-ratio (SNR) and homogeneity.

A two port Rohde-Schwarz FSH4 spectrum- network analyzer accomplish the measurement of reflection or transmission sent by one port and received to the same or the other port (see **figure 2**). It is a good tuning and matching opportunity to adapt the circuit impedance to the analyzers impedance of 50 Ω. The scatter parameter is more than -30 dB.

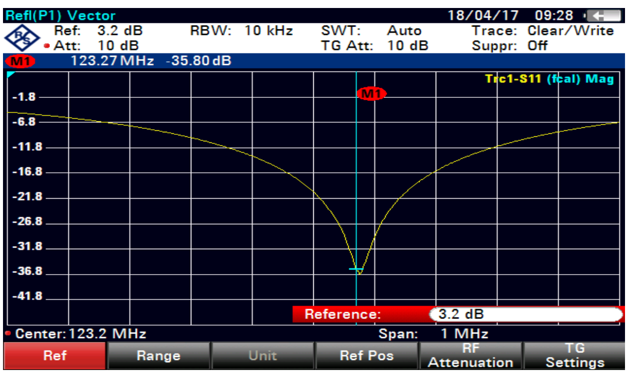

Figure 2: The scatter parameter S_{11} for the 3 T coil. The blue line marks the 123.2 MHz. Result is presented in dB.

The quality factor is defined by

$$Q_{ratio} = \frac{f_{max}}{f_O - f_U} \quad (2)$$

and is a measurement of losses due to the absorption of oscillations like it is shown in **figure 3**. The result of the quality factor is in a good range.

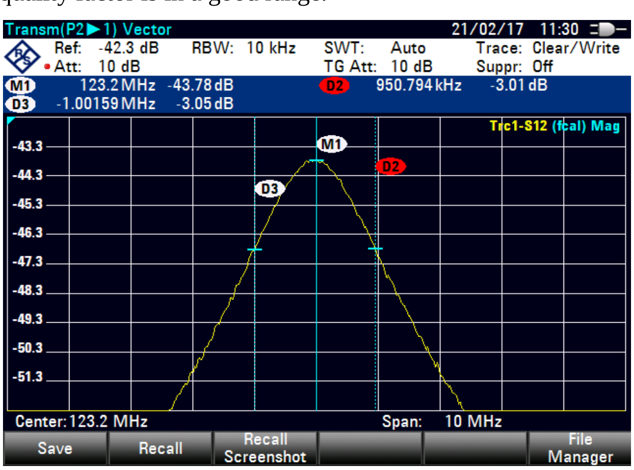

Figure 3: Determination of the quality factor. M1 marks f_{max}, D2 marks f_O and D3 marks f_U. Result of the factor measured in water is 64.3.

A good SNR (see **Eq. 3**) is reflected in the quality of the produced image by the coil. It is influenced by the strength of signals and background noise. The aim is to get the best contrast in the shortest time[7]. The equation can be described by the amplitude of the signal divided by the standard deviation of the noise. An alternative equation consists of the power of signal divided by the power of the noise in logarithmic measure unit stated in decibel.

$$SNR = \frac{A_{signal}}{\sigma_{noise}} = 10\,\lg\left(\frac{P_{singal}}{P_{noise}}\right) dB \quad (3)$$

Homogeneity profiles can be achieved by combining further S_{11} values at different positions in X and Y directions. **Figure 1e)** shows the phantom that has been used for measuring the values along the Y-axis in 1 cm steps and the X-axis in 30 degree steps. The homogeneity profile represents a good homogeneity along the X- and Y-axis.

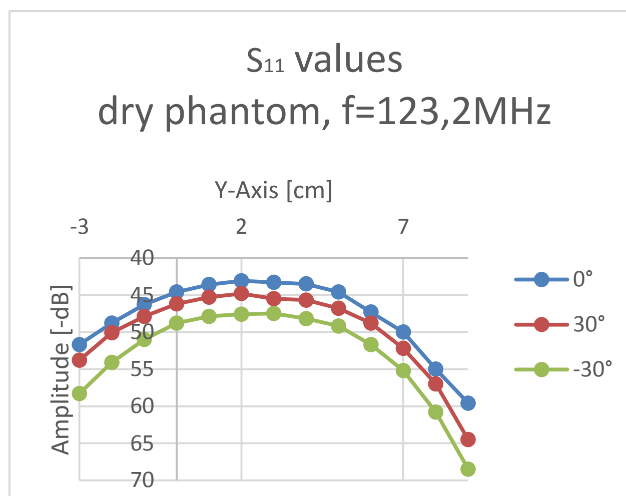

Figure 4: Diagram of the homogeneity profile of the transmit-receive surface coil by different X and Y steps. Zero degree at X-axis and from two to three cm at Y-axis is the middle point of the coil.

The PET-crystal was performed and tested by the Santa Lucia clinic and the Instituto Nazionale Di Fisica Nucleare in Rome. At present it is challenging to combine the US-head in front of the prostate probe.

First measurements of transmit-receive coil was created by the 3T Magnetom Trio A Tim System at Forschungszenrum Jülich (FZJ). The coil was placed in the middle of the phantom, which was filled with minced meat for a good analogy to the human body as good as possible. The phantom was also placed in the middle of the table. **Figure 5** lead to the conclusion that the SNR efficiency and the penetration depth have to be increased.

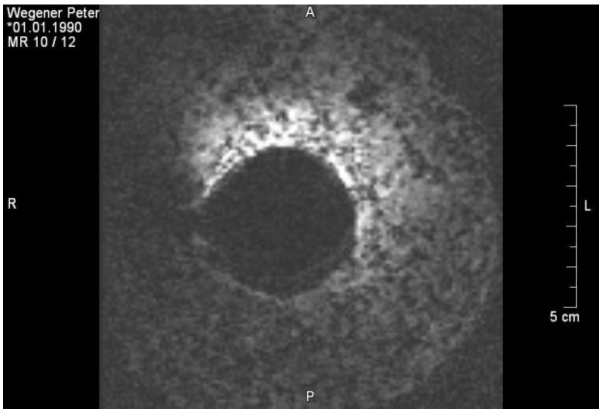

Figure 5: The transmit-receive coil at 3 T MRI-scanner at FZJ with f=123.2 MHz. Transversal slice of the phantom filled with meat.

4 Outlook and summary

All measurements have to be done with the new coil from **figure 1**. A first experiment with the new coil suggests a better SNR for a better image quality. This is an important factor because older coils shown the same good quality of the image like the normal body coil used to take an image of the prostate. The probe including devices for multimodal imaging will be used to advance the early stage diagnosis of PCa.

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