Radio-frequency cardiography using a balanced 300MHz loop resonator: ventricular volume changes influence resonator efficiency at 7T

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INTRODUCTION: In this contribution radio-frequency cardiography (rf-CG) is proposed as a method to derive physiological cardiac information non-invasively and without the need to attach an electric to the human skin. Information about the cardiac cycle is in particular desired during cardiac MRI in order to reduce artifacts related to cardiac wall motion. In the past, several approaches were suggested using high frequency radiation and induction coils in near proximity to the chest, but not fixed to the human upper body [1,2]. However, recordings of the pure cardiac cycle related signal was only possible during breath hold (apnoe). The sensitivity of rf coil loading to the human respiration cycle has been previously reported for MRI coils at 3T [3]. Ultra wide band (UWB) scanning (covering 10GHz bandwidth) was proposed by Thiel et al. as an alternative, yet expensive approach [4]. Herein we propose an inexpensive narrow-band approach that can be incorporated as part of an MRI detector. Balanced 300MHz loop resonators were developed and deployed in a way that the influence of the respiration on the measured signal was suppressed and the physiological cardiac signal was correlated with standard electrocardiographic (ECG) recordings in order to better understand the rf-CG signal with regard to the cardiac cycle. **METHODS:** Two radiofrequency loops (50mm diameter, 1mm thick silver wire) were tuned to 300MHz via two variable series trimmer capacitors (2 to 8pF, Temex, France) connected in parallel to the coil inductance, matching to the 50-Ohm coaxial cable impedance (RG58, Radionics, Ireland) was achieved via a further series trimmer capacitor. Balanced ground connection was ensured by a thorough fine tuning process. A third fixed value capacitor (4.6pF, Temex, France) was incorporated into the coil design to segment the conductor length and increase the overall necessary tuning capacitance to above self-capacitance values of the wire. A plastic enclosure was manufactured from white Acrylonitrile Butadiene Styrene (ABS) using a 3D printer (Replicator 1 dual, MakerBot Industries LLC, Brooklyn, NY). The enclosure enabled to fix the resonator on the volunteer's chest using an elastic strap and a commercially available strap buckle clip. The unloaded-to-loaded quality factor measured to be 8 (coil 1 - white cable) and 4.1 (coil 2-black cable). The difference may have been caused by the different application of hot glue to fix the conductor inside the plastic enclosure hence changing the inherent loading of each resonator – both resonators remained equally stable. The rf-CG resonators were connected to a vector network analyser (DG8SAQ USB-Controlled VNWA 3, SDR-Kits, Wilts, UK). After careful calibration the transmission attenuation (s_{21}) was acquired with a dwell-time of 4ms at 300MHz using software provided by SDR-Kits on a portable desktop computer (MacBook Air , Apple Inc., Cupertino, CA). The data was post-processed via a self-written MATLAB (Nattick, MA) routine.The ECG recordings were acquired on a separate personal computer using an Olimex ECG-shield and Arduino microcontroller and BrainBay (V1.8, the open EEGProject). Simple strap on wrist band electrodes attached to the right and left arm, as well as to the left ankle (reference) served for deriving the ECG from all volunteers. The data files were converted to an EDF file in EDFbrowser and later coregistered with rf-CG data in MATLAB. The data was synchronized during post-processing with the help of triggers set by lifting the left wrist electrode and touching the rf-CG resonator simultaneously several times during the recordings.One of the rf-CG resonators (coil 1) was used to record Magnetic Resonance Images (MRI) at 7T when placed on the chest bone of a fourth volunteer. The following sequence parameters were chosen for the un-triggered 2D gradient echo sequence recording: FOV 400mm x 400mm, 8mm slice thickness, TR/TE=700ms/1.32ms, 1average, 144 phase encoding steps, 651 Hz/pixel read-out bandwidth, 10° flip angle, 1.0417mm x 1.0417mm nominal pixel resolution. The axial slice across the chest bone and the heart is presented in Figure 1. The region covered by the rf-CG coil clearly penetrates the chest cage to cover most of the cardiac volume. **RESULTS AND DISCUSSION:** Three volunteers (age 36±34yrs) were examined with the described rf-CG and ECG method during apnoe and free breathing. A 30 second rf-CG and ECG recording for volunteer 1 is presented in Figure 2. The minimum rf-CG signal was measured during the QRS-complex of the ECG signal (sharp peak) with the maximum signal measured shortly after the peak. The variation of the rf-CG signal from the mean signal during 30s periods was measured during both phases and is tabulated as mean and standard deviation in Table 1. No significant difference was detected between breath hold and free breathing indicating that indeed the proposed sensor arrangement allows for cardiac cycle recordings without the influence of respiration – a challenge for previously suggested techniques [1-4]. The schematic comparison of ventricular volume changes [5] relative to rf-CG signal changes suggest that the rf-CG signal closely correlates with ventricular volume changes and most likely reflects left ventricular variations in blood volume changes as it is well known that such conductivity changes affect coil loading and hence the transmission attenuation between two resonators. The results show that cardio-physiological measurements can be derived using a standard MRI detector coil which may pave the path for providing lead-free triggering mechanisms via rf-CG recordings.

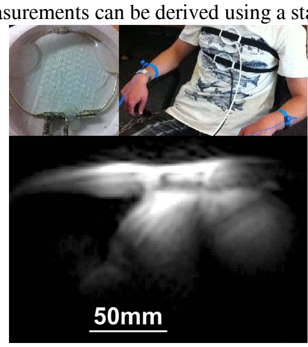

Figure 1: rf-CG and MRI 300MHz resonator (upper left) and arrangement of rf-CG sensors on the chest bone of a volunteer who was also connected to the blue ECG wrist bands (upper right). Below: the MRI result acquired with one rf-CG resonator positioned on a fourth volunteer's chest and no triggering.

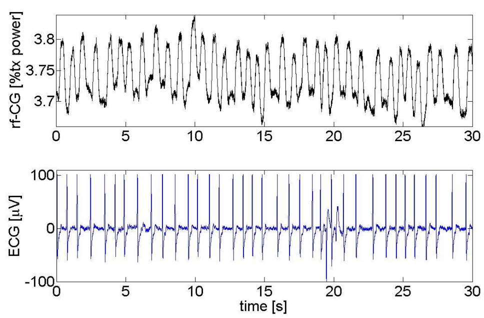

Table 1: analysis of rf-CG variations

	Δrf-CG breath hold [%mean]	Δrf-CG free breathing [%mean]
Vol.1	*1.33*	*2.06*
Vol.2	*0.77*	*1.97*
Vol. 3	*1.03*	*1.22*
mean±std	**1.04±0.28**	**1.75±0.46 (p = 0.09)**

Figure 2: synchronized rf-CG and ECG data recordings acquired for a freely breathing volunteer with an arrhythmic heartbeat (no p and t-wave, delays between heart beats).

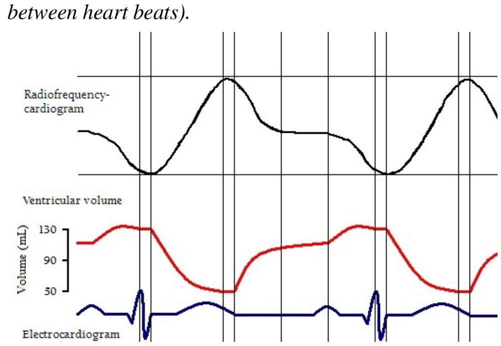

Figure 3: schematic comparison of the rf-CG and the catheterized ventricular volume measurements [5] in relation to the standard ECG recording,

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