# MEASUREMENT OF Q-FACTORS INCLUDING RADIATION LOADING OF STRIP-TYPE COILS FOR 7-TESLA MRI

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## Introduction:

Coils are used in MRI to generate (or sense) the $B_1$-field at RF-frequency. In order to create as high as possible $B_1$-field for a given input power, coils generally are designed as high-Q resonance structures and can be modeled in a G-L-C-resonator equivalent circuit. Just how high the Q-factor can become depends critically on the internal loss of the coil which creates the conductance G in our equivalent circuit and which can be minimized using capacitors with low loss tangent and conductors of good conductivity and large cross section. On the other hand, when the coil comes close to a patient inside the MRT, the coil is resistively loaded (in addition to some reactive loading) and the Q-factor falls to a much lower level compared to the Q-factor in free space; in this situation, the effective resistive (or dissipative) component in the resonator admittance, the conductance G, can be understood as the sum of the internal loss conductance and some additional “external” conductance. Therefore, a well accepted measure for the power deposition efficiency of an RF coil has been the ratio of the Q-factors “in free space”or “unloaded” and “loaded by the sample”. This, however, no longer is valid if we investigate coil designs for 7 Tesla: With strip conductor-type coils we have created conductor structures of 25 to 30 cm length that represent an “electrical” length of a quarter of a free-space wavelength and therefore act as efficient far-field radiators – measurements of radiation properties of dipole- and loop-type coil designs have demonstrated radiation gain figures on the order of 0 to 2 $dB_i$ , see companion abstract /1/. The far-field radiation is found a new and strong additional contributor to the loss of the coil in free space, lowering the “unloaded” Q-factor considerably. The present contribution presents measurements of the Q-factors of our dipole-type coil under various conditions in order understand better the properties of the coil and to separate internal losses.

## Methods and Construction:

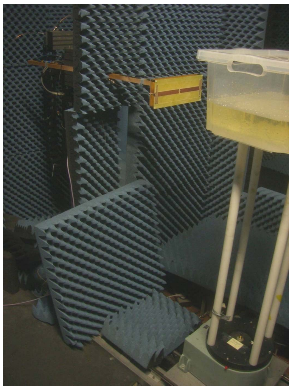

Fig.1

Our coil is used in our 8-element circular array and has been reported earlier /2/. It is a true half-wavelength dipole with 60% of the length of each arm folded in a meander with fine tuning caps at the ends to reduce the total length to 25 cm. The dipole is fed symmetrically at the centre and is elevated above a reflector plane by 20 mm. The currents in the reflector plate are basically excited by (parasitic) electromagnetic coupling leading to phase shifted current which has a reduced magnitude compared to the dipole current (behavior of a short “director” element in a Yagi-Uda dipole array).

Measurements of Q-factor have been performed using a Vector Network Analyzer (VNA). With the reference plane suitably shifted to represent the coil impedance as a G-L-C shunt resonator and presenting the reflection coefficient on a Smith Chart, the resonance bandwidth was measured as the difference of the corner frequencies below, $f^-$ , and above, $f^+$ , resonance frequency $f_0$ where we have the real part of the impedance equal to the absolute value of the imaginary part. This measurement can be applied without the need for perfect impedance match to the generator, but note that if the coil is matched, it leads to twice the Q-factor measured by the usually applied bandwidth between the -3dB-points of the reflection coefficient (which in fact leads to $Q_L$ , the Q-factor of the resonator loaded by the generator). In this presentation, we distinguish the measured Q-factors due to the various forms of loading: The Q-factor of our coil measured in our anechoic chamber (with appropriate spacing to the absorbers) is considered as “radiation-loaded”, when a sample comes near we consider the coil to be “radiation plus sample-loaded” and only when we enclose the coil by a conducting cavity which exclude radiation loss, we assume it “unloaded”.

The measurement set-up for the “radiation plus sample-loaded” Q-factor is to be seen in Fig.1 where the coil is placed in our anechoic chamber and a small phantom (plastic container filled with liquid) is placed in front of the coil on a moveable plastic table which allows to investigate mutual coupling effects in the coil impedance and Q-factor as a function of distance.

Fig.2 shows our “Wheeler cap”/2/, a barrel of 56 cm diameter and 85 cm height with an opening to allow the insertion of the coil. When the opening is closed, the coil is completely covered by a conducting surface which suppresses radiation and the measured “unloaded” Q-factor is increased over the “radiation-loaded” Q-factor as measured in the anechoic chamber.

Fig.2

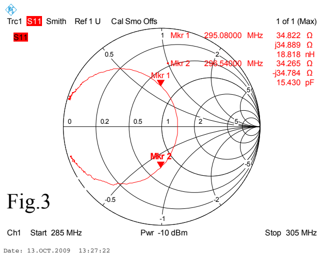

Fig.3

## Results:

As an example for the measurement of the resonator bandwidth, Fig.3 shows the reflection coefficient of our coil as a function of frequency with the two corner frequencies indicated by the markers. The Q-factor is calculated as $Q = f_0 /(f^+ - f^-)$=202; this means that the coil radiation efficiency is about 50% which is in good agreement with the measured far field gain of about 0 $dB_i$. Fig.4 presents the variation of the coil Q-factor as a function of the distance to the phantom. As the phantom comes closer, the Q-factor even increases around 100mm distance before it rolls off for ever closer spacing. Note that the Q-factors measured for far-away phantom and close phantom are quite similar which normally would be explained by too high internal losses of the coil. However, due to radiation losses, we cannot realize the unloaded condition in this experiment. Rather, we have to employ the Q-factor from the “Wheeler cap” measurement which now leads to a 2:1 ratio of unloaded-to-loaded Q-factor (at 100 mm distance to the phantom) and even higher for shorter distance. Never-the-less, from the “radiation plus sample-loaded” Q-factor, we cannot separate the contributions of radiation (which may change with distance) and sample excitation.

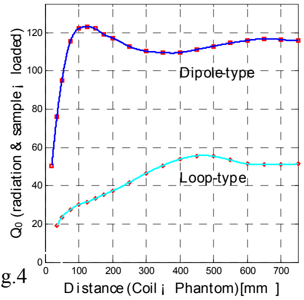

Fig.4

## Discussion:

Our strip conductor-type coil for 7-Tesla MRI exhibits strong radiation loading due to its length of a quarter-wave. The loading by a phantom is seen to be superimposed by mutual coupling effects in a similar way as known from antennas. When using the conventional figure of merit based on the “unloaded” to “loaded” Q-factors we have to perform the “unloaded” measurement with the coil under a ”Wheeler cap” in order to exclude the radiation loading. These results have been found to apply also for our loop-type coils.

## References

[1] K. Solbach et al., “Near- and far-field measurements of strip-conductor coils …”, abstract submitted, ISMRM2010.
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[3] H.A. Wheeler, “The radiansphere around a small antenna”, Proc. IRE, August 1959, 1325 - 1331.