# RF coils for high resolution imaging of the human visual cortex at ultra-high fields

## 6.1 Summary

In **Chapter 2**, we show the benefits of constructing a semi-cylindrical, shape optimised, 16ch phased array Rx / 4ch phased array Tx RF coil targeted at acquiring high resolution, in-vivo anatomical and functional MRI data of the human visual cortex at 7T. The close fitting coil former allows both transmit and receive coils to lie in close proximity to our region of interest – namely the primary and secondary visual areas and does not require tuning and matching for individual subjects, resulting in reduced scan preparation times. The RF coil's transmit field characteristics were simulated using EM simulation software and validated through acquired flip angle maps, while SAR analysis was also undertaken to determine safety limits for human use in accordance with IEC 60601-2-33 standards. The coil was also subjected to thorough bench tests, using a human torso shaped phantom filled with tissue-mimicking dielectric solution. The coil's performance was assessed through several MRI acquisitions, whereby its SNR, receiver noise correlation, tSNR, and g-factors were calculated and compared to that of a commercial 32ch Rx / 1 ch Tx coil. fMRI studies at standard and sub-millimeter resolutions was acquired across both coils on human subjects, using a standard visual stimulus. The constructed transmit and receive sections showed good interelement decoupling and low mean noise correlation values. The SNR for the 16 ch coil was about 1.5 times that of the standard coil in the human occipital lobe, and exhibited lower g-factors for accelerated imaging. The frontally-open design of the RF coil presented the human subjects with a viewing angle of almost 30° - 3 times that of the commercial coil. This was reflected in the fMRI data acquired, as the combination of a wide viewing angle and dense receiver coil layout in the region of interest results in the 16 channel Visual Arc coil showing activation deeper into the occipital lobe, both in the superior-inferior and anterior-posterior directions at 1.2 mm and 0.8 mm isotropic resolutions.

**Chapter 3** describes the contruction, testing and validation of a 16 channel receive coil for high resolution anatomical and quantitative imaging of large, ex-vivo brain samples using a wide-bore 9.4T scanner, with the coil's performance tested through bench tests and ex-vivo scanning of a human occipital lobe. The cylindrical, phased array layout of the receive channels, with an imaging volume of $80^3$mm$^3$, covers the entire sample, while ensuring that the small receive coils are in close proximity with the sample. The resulting noise correlation was an average of 22%, with each coil showing substantial $B_1^-$ penetration depth. Compared to a 31ch Rx/16 ch transmit head coil at 9.4T, the 16 ch Rx large sample post-mortem coil shows a five-fold increase in SNR in the periphery, and a two-fold increase in the center. The transmit profiles generated by a CP mode excitation using a dedicated 16 ch Tx coil for 9.4T show the expected high central fields dropping off towards the periphery, since the sample dimensions are close to the wavelength at 9.4T. Additionally, further $B_1^+$ inhomogeneity was detected in the anterior-porterior direction. Using a kT-points excitation method, a more homegeneous excitation profile was achieved. The differences between the $B_1$ corrected and uncorrected SNR maps show the importance of having additional control over $B_1$ through kT-points transmit methods. The high SNR inherent to the coil allowed us to acquire 100$\mu$m and 60$\mu$m isotropic $T_2^*$ weighted data, while a multi-echo 3D GRE sequence was used to acquire multi-contrast $T_2^*$ weighted data at 200$\mu$m for quantitative $T_2^*$ mapping of the entire human occipital lobe. The $qT_2^*$ mapping at 200$\mu$m isotropic shows a clear definition of cortical architecture details, specially in the Stria of Gennari, with the estimated $T_2^*$ values being comparable to with previously reported values in post-mortem samples.

**Chapter 4** expands upon the concepts outlined in Chapter 2 in order to build and characterise an RF coil with a conformal phased array receiver geometry and a multi-channel transmit section, with the aim of achieving high resolution anatomical and quantitative MR imaging of intact, post-mortem human brains at 9.4T. A 3D conformal sample container for post-mortem human brains was first designed in SolidWorks using anatomical MRI data, then surface-rendered and extruded in all directions and designed into a volumetric container in 2 halves. The receiver former was then modelled as a precise fit around the sample container and 24 receive coils were laid out in a phased array configuration on the former. The 8 transmit loops were laid out on two halves of a hollow, ellipsoidal shell, with 4 on each side. The coil's performance was evaluated through bench tests and ex-vivo scanning, and its SNR compared to that of a in-vivo, whole head coil at 7T. The measured SNR showed a five-fold increase in SNR at the periphery and a three-fold increase in the center for the whole brain coil over the whole head coil at 7T. The whole brain coil also showed a low, average noise correlation of 20%, while certain coil pairs exhibited a high noise correlation due to a combination of sub-optimal overlap - and thus reduced decoupling - and shared acquired resistance through the sample under investigation. The 24 receive loop design also allowed for accelerated imaging in a single phase encode direction up to a factor of 3, showing highly independent spatial selectivity of the loops and low g-factors. This, coupled with the high SNR capability of the coil can allow for significant trade-offs between SNR and acquisition times. The inhomogeneous $B_1^+$ profile generated by a CP mode transmit excitation was successfully rectified by using a kT-points parallel transmit method, resulting in a homogeneous excitation in the region of interest. High resolution anatomical and quantitative MR data was acquied at 100$\mu$m and 200$\mu$m respectively. The 100$\mu$m isotropic GRE datasets enabled clear definition and contrast of anatomical structures, especially in cortical gray matter, with the Stria of Gennari in the primary visual cortex clearly visualised. High quality $qT_2^*$ maps were generated through mono-exponential fitting of multi-echo, 200$\mu$m isotropic $T_2^*$-weighted data, with the resulting $qT_2^*$ volumes showing superior quantitative contrast, effectively helping delineation of cortical layering. These high resolution anatomical and quantitative data have the potential of being used towards the creation of 3D MRI-based anatomical atlases. This combination of superior resolution of the 100$\mu$m $T_2^*$ weighted data and the high SNR and homogeneous contrast from the 200$\mu$m $qT_2^*$ estimated data can enable us to label deep gray matter and help distinguish several subcortical structures on the basis of $T_2^*$ contrast.

In **Chapter 5** we describe the development and construction of a layered, 23 channel receive / 7 channel transmit planar coil for high resolution histological MR imaging of large, ex-vivo tissue slabs of thickness of up to 1 cm, at 9.4T. Electromagnetic simulations were undertaken to determine the ideal transmit coil geometry, capable of producing a homogeneous $B_1^+$ field in the FoV. On the receive side, 4 cm wide circular loops were segmented in three equal arcs and each placed in a different layer of a 4-layered PCB, providing a flat surface for sample placement and also increasing the coil filling factor. All transmit and receive coils were sufficiently decoupled from each other using a combination of mutual and preamplifier decoupling methods, with the receive channels exhibiting very low noise correlations due to the flat geometry. The SNR exhibited by the coil shows a mostly homogeneous $B_1^-$ distribution, which can be suitably improved by utilising more aggressive parallel transmit shimming methods. The anatomical data acquired using a coronal slice of a human occipital lobe at 250$\mu$m isotropic shows delineation between white matter and gray matter areas, and can be further improved upon by using sequence parameters optimised to the sample under investigation.

## 6.2 Discussion

The aim of this thesis was to investigate and develop RF coils for high resolution MR imaging, with an emphasis on anatomical and functional imaging of the human cortex, at ultra-high fields of 7T and 9.4T. The studies presented within this dissertation demonstrate the importance of developing sample and target region - specific RF coils towards achieving high resolution MR imaging of both in-vivo subjects and ex-vivo samples. With the introduction of higher field strength MRI scanners, particularly ultra-high fields of 7T and above, and the