Introduction: The complex permittivity ($\varepsilon'$) of biological tissues depends on their biochemical composition and the applied frequency. Best known is the effect of cell membranes (Maxwell-Wagner effect) leading to a frequency dependent tissue conductivity ($\beta$-dispersion band at about 1MHz) [1]. Various techniques have been developed to measure tissue conductivity in Hz-MHz range. In MR current density imaging (MR-CDI) [2,3] and MR electrical impedance mapping (MR-EIT) [4], an external current is injected into the tissue inducing local changes in the B$_0$ (Bz) field. This allows for the determination of current density and conductivity using MR phase mapping. In contrast, electrical properties tomography (RF-EPT) [5,6] determines tissue conductivity by measuring local B1+ distortions without external current source. This method, however, is fixed to the Larmor frequency, which is far above the $\beta$-dispersion band. In this study we investigate a related method that measures the tissue conductivity in the biologically interesting low frequency (LF,=Hz-kHz) range [8]. A first implementation of this method – LF-EPT– is based on similar reconstruction principles as MR-CDI, but it employs the imaging gradient instead of electrodes to induce (eddy) currents.

Theory: The reconstruction is based on Ampere’s circuit law which relates the curl of the magnetic field to the total current density. In the kHz frequency range, the contribution related to the displacement current (Maxwell’s correction) can be omitted for biological tissue. Thus, only the free current density related to the tissue conductivity remains (Fig 1). The frequency band of the induced current depends on ramping process (signal shape) of the gradient. By varying this shape several low frequency ranges can be probed.

Material and Methods: The measurement method is essentially equal to the measurement procedure for RF-EPT. Two different phase images are acquired with a spin echo sequence (TR = 1200ms, TE = 5.3 ms, resolution 1×1×3 mm$^3$) using two opposing read out directions [6]. Measurements were done on a 3T MR system (Achieva, Philips Healthcare, Best, the Netherlands). Two phantoms were investigated, one with 3 different cylindrical saline compartments (each 200 cm$^3$, conductivities 0.0/2.0/0.8 S/m), the other with 2 compartments of saline and uncooked apple sauce (each 200 cm$^3$, conductivities 0.8/0.2 S/m at 128MHz) In the RF-EPT, the contribution of eddy currents was eliminated by adding the two phase images. In LF-EPT, the contribution of the RF magnetic field was eliminated by subtracting the phase images, resulting in twice the eddy current induced phase. This phase was converted to B$_z$ by including the echo time and gyromagnetic ratio. To obtain the induced current distribution from the B$_z$ field, we employed a reconstruction method based on [2]. This method requires 2 orientations of the phantom to compute one component of the curl of B1 (Eq 1) resulting in the current density component $J_z = \partial J_x - \partial J_y$ (Fig 2).

Results and Discussion: In Figure 3, the results are shown for the two phantoms. The RF conductivity using RF-EPT shows clearly the expected conductivity contrast (Fig 3b). The $J_z$ current density from LF-EPT shows a contrast consistent with the differences in saline concentrations. These findings correspond with the shapes of the central phase profiles, i.e. the parabolic curvature for the RF case and the linear slope of the LF case (Fig 3a). Also, comparing saline and apple sauce (Fig 3c), the RF phase profiles exhibit the expected parabolic curvatures. Their LF phase profiles are, however, almost identical suggesting that the induced current densities are equal at LF. This could suggest different frequency dependences of the conductivity for water and apple sauce. However, as the current density is a mixed quantity consisting of conductivity and electric field, that cannot be confirmed yet. Future research is needed to reconstruct LF conductivity from current density maps, and also avoiding the need for measurements of two orientations [8].

Conclusions: We investigated a method to derive information about LF induced current, which is related to the conductivity of biological material, using induced eddy currents generated by the imaging gradients. First experiments show that this method is feasible in phantoms. Information about LF conductivity is interesting as it is directly related to cellular structures.