Gradient Coils Systems

$$G_x = \frac{\partial B_x}{\partial x} \qquad G_y = \frac{\partial B_y}{\partial y} \qquad G_z = \frac{\partial B_z}{\partial z}$$

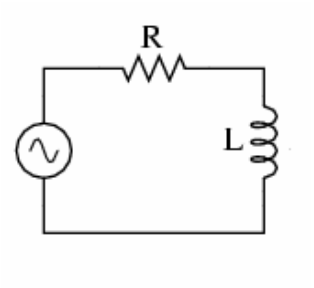
G_x, G_y: Transverse gradients
G_z: Longitudinal gradient

Improvement in Gradient Coils Design

- The use of distributed-winding coils
- The introduction of the stream for current density
- The use of the cylindrical harmonic expansion of the magnetic field variation
- Improved fabrication methods (printed circuits)
- High current gradient drivers

Effect of Coil's Inductance

- The inductance of a gradient coil is one of the major factors that measures the quality of the coil



Rise Time

- Rise time (τ): time it takes for the current to rise 63 % of its full value

$$\tau = L/R$$

- R must be kept minimum to limit power consumption -> the inductance is the major determinant of how fast a coil may be ramped with a given power supply -> the rise time has a well defined minimum

Why τ Important ?

- For fast enough rise time and large field strengths, the voltage induced in tissue by a rapidly changing field may stimulate the firing of peripheral nerves to a painful degree (the magnetic field threshold for nerve stimulation is on the order of 10 mT if the field is switched in 100 microns or less)

How to Reduce the Rise Time

- We can reduce the rise time by using more powerful gradient drivers
- -> reduce τ by q
- -> i(t) = $\frac{V}{R}\left[1-e^{-q(R/L)t}\right]$
- Substitute in $L\frac{di}{dt}+Ri=V$
- -> $V(t)=V\left[1+(q-1)e^{-q(R/L)t}\right]$

Current Amplifiers

- To achieve high current:
  - Connect linear audio amplifiers in series and/or in parallel to achieve the desired combination of voltage and current
  - > driven in a current controlled mode, in which a large voltage (preemphasis) is available to counteract the back-emf generated in the gradient coil during switching
  - Assuming negligible R: $\tau = L \frac{I_{\max}}{V_{\max}}$

Current Amplifiers (cont'd)

- Supply a large (350 A) well regulated DC current, and to control it by chopping it at high frequency (> 80 kHz), output is passed through a low pass filter to remove ripple
- Use of high power silicon switches which can handle current of several hundred amperes and voltages up to 1 kV

Figure of Merit

- The quality of a gradient coil is measured by
  - Coil efficiency (η), which is a measure of the filed gradient at the center of the coil produced by a unit current
  - L
  - Gradient homogeneity, the difference of the desired field and the field actually achieved over the volume of interest

Figure of Merit (cont'd)

$$\beta = \frac{\eta^2 / L}{\left\{ V^{-1} \int_V d^3 r \left[B(r,\phi,z) / B_D(r,\phi,z) - 1 \right]^2 \right\}^{1/2}}$$

Where, B_D – desired field

B – achieved field