# Pulsed Field Gradients: Theory and Application

Barker, P. and Freeman, R. (1984) Pulse Field Gradients in NMR. An Alternative to Phase Cycling. *J. Magn. Reson.* **64**, 334-338.

Thus far we have considered two very distinct types of magnetic fields: The static (Zeeman) field that produces the bulk polarization and a time-dependent field, i.e., RF pulses. We now consider a magnetic field that is both temporally and spacially dependent.

We can also generate a magnetic field that may be gated, i.e., rapidly turned on and off, and which varies in strength across the sample chamber

The object of the PFG is to install a magnetic field gradient across the sample which adds/subtracts to the main (static) field, $\mathbf{B}_0$ in a coordinate-dependent fashion. During the gradient pulse spins in different locations experience different net magnetic field vectors.

The apparatus used to generate the field--gradient pulse may be diagrammed as shown below (from Barker and Freeman (1985)):

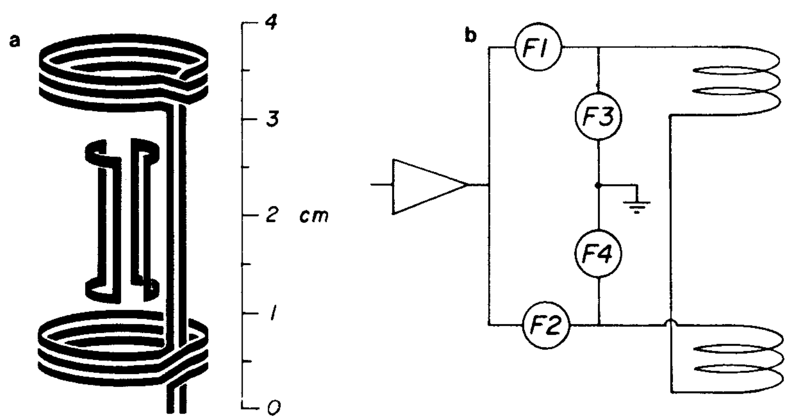
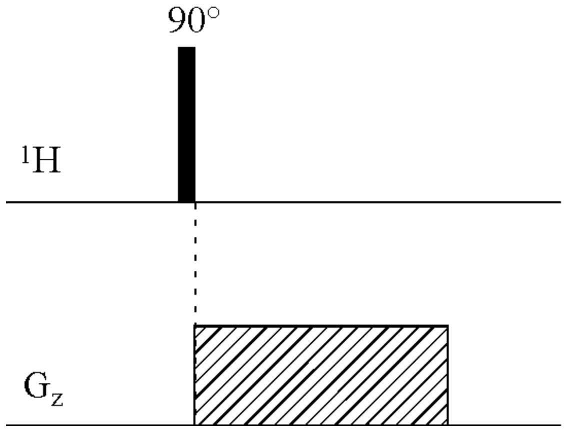



FIG. 1. (a) The geometrical arrangement of the field gradient coils with respect to the radiofrequency NMR coil (shown for simplicity without input leads). (b) Switching circuitry for reversing the polarity of the gradient coils and for damping the ringing after the pulses. During the gradient pulse either the field effect transistors F1 and F4, or F2 and F3, are conducting; after the pulse F3 and F4 are conducting.

**Figure 1 from Barker and Freeman (1984).**

The effects of the PFG may be demonstrated using the simple pulse sequence shown below:




Field gradient pulses are characterized by intensity (flux density), duration, and shape (i.e., rectangular, sine-bell,Gaussian, etc.).

From Barker and Freeman (1985):

> `...The principal attribute of the field--gradient technique is the ability to speed up experiments where the inherent sensitivity is so high that time averaging is unnecessary. However [sic], many phase-cycling schemes have now become so complicated (through the nesting of many independent cycles) that programming errors can easily arise, with dramatic losses in signal intensity. Gradient pulses seem easier to implement...'.

A dramatic statement given that the PFG apparatus in this case was 'home-built'.

The net effect of the PFG is to make the Larmor precession frequencies position dependent. Consider:

Free-Precession

$$\omega = \gamma B_0$$

Chemical Shift

$$\omega = \gamma\left(1-\sigma\right)B_0$$

PFG

$$\omega = \gamma\left(1-\sigma\right)B_0 + \gamma\left(1-\sigma\right)\Delta B_0 r_z$$

Since $|\sigma| \ll 1$ and $\Delta B_0 r_z \approx (30 \text{ G cm}^{-1})(1.5 \text{ cm}) \ll B_0 \approx 10^4 \text{ G}$, we may accept the approximation that $\sigma \Delta B \to 0$ and therefore that

$$\omega \cong \gamma (1 - \sigma) B_0 + \gamma \Delta B r_z$$

The effects may be diagrammed as shown below: