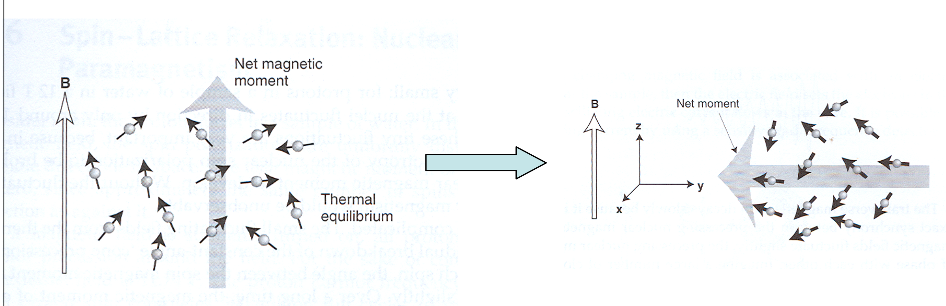
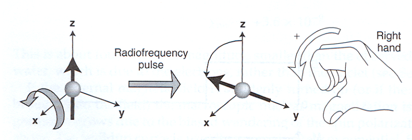
Bioengineering 280A
Principles of Biomedical Imaging

Fall Quarter 2005
MRI Lecture 4

RF Excitation





From Levitt, Spin Dynamics, 2001

RF Excitation

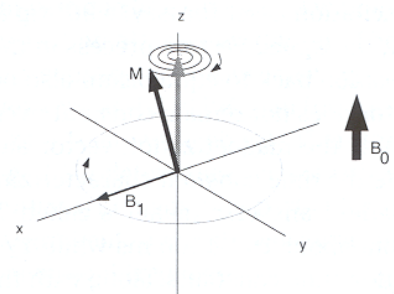
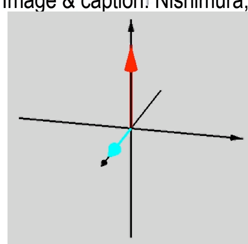


Image & caption: Nishimura, Fig. 3.2



At equilibrium, net magnetizaion is parallel to the main magnetic field. How do we tip the magnetization away from equilibrium?

B_1 radiofrequency field tuned to Larmor frequency and applied in transverse (*xy*) plane induces nutation (at Larmor frequency) of magnetization vector as it tips away from the *z*-axis.

- lab frame of reference

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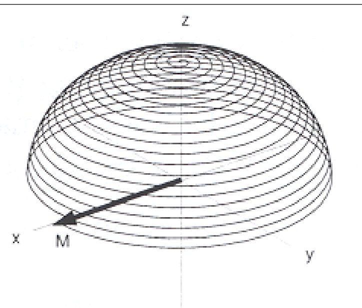
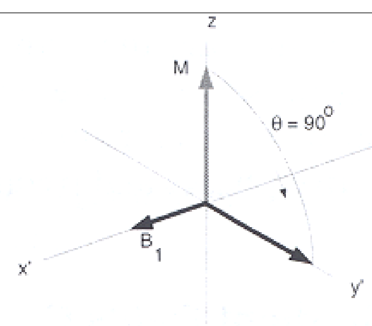
http://www.eecs.umich.edu/%7Ednoll/BME516/

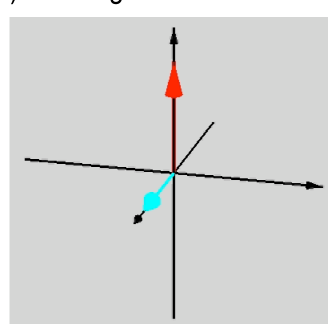


a) Laboratory frame behavior of **M**

Images & caption: Nishimura, Fig. 3.3



b) Rotating frame behavior of **M**



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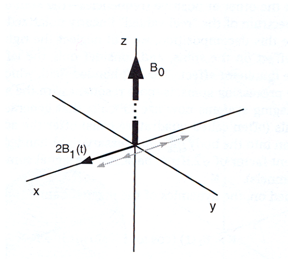

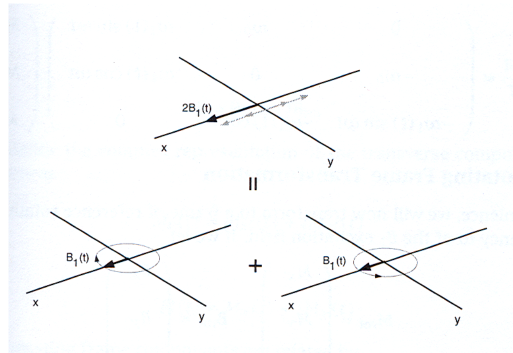

$$\mathbf{B_1}(t) = 2B_1(t)\cos(\omega t)\mathbf{i}$$
$$= B_1(t)\big(\cos(\omega t)\mathbf{i} - \sin(\omega t)\mathbf{j}\big) + B_1(t)\big(\cos(\omega t)\mathbf{i} + \sin(\omega t)\mathbf{j}\big)$$

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Nishimura 1996

Rotating Frame Bloch Equation

$$\frac{\mathrm{d}\mathbf{M}_{rot}}{dt} = \mathbf{M}_{rot} \times \gamma \mathbf{B}_{eff}$$

$$\mathbf{B}_{eff} = \mathbf{B}_{rot} + \frac{\omega_{rot}}{\gamma}; \quad \omega_{rot} = \begin{bmatrix} 0 \\ 0 \\ -\omega \end{bmatrix}$$

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$$Let\ \mathbf{B}_{rot} = B_1(t)\mathbf{i} + B_0\mathbf{k}$$

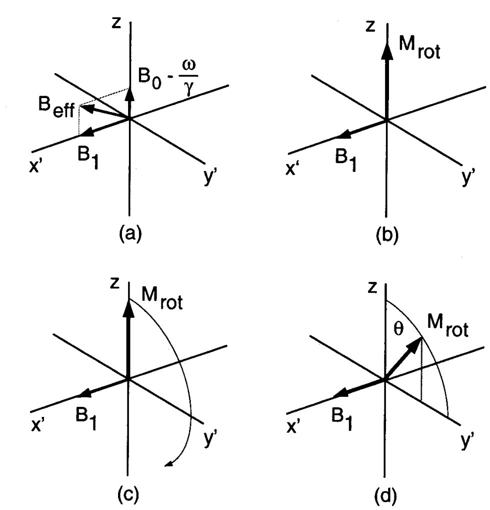
$$\mathbf{B}_{eff} = \mathbf{B}_{rot} + \frac{\omega_{rot}}{\gamma}$$

$$= B_1(t)\mathbf{i} + \left(B_0 - \frac{\omega}{\gamma}\right)\mathbf{k}$$

If $\omega = \omega_0$

$$= \gamma B_0$$

Then $\mathbf{B}_{eff} = B_1(t)\mathbf{i}$



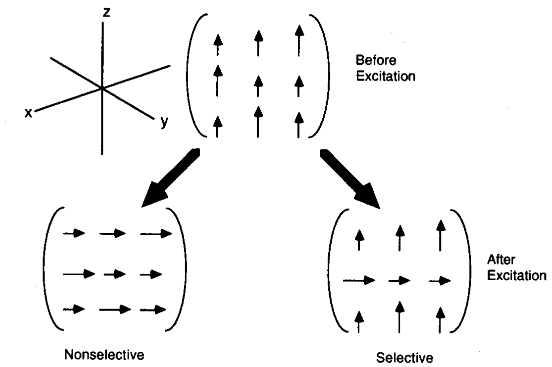
Flip angle

$$\theta = \int_0^{\tau} \omega_1(s)ds$$

where

$$\omega_1(t) = \gamma B_1(t)$$

Nishimura 1996



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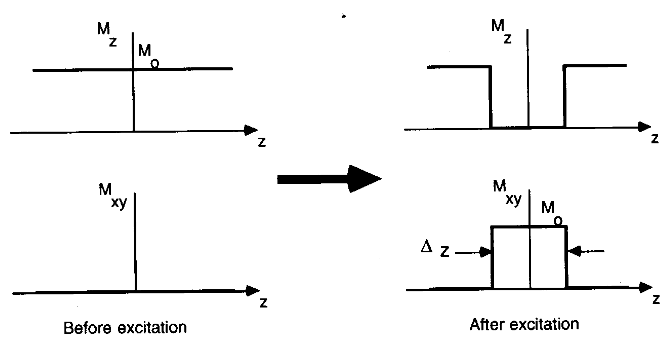

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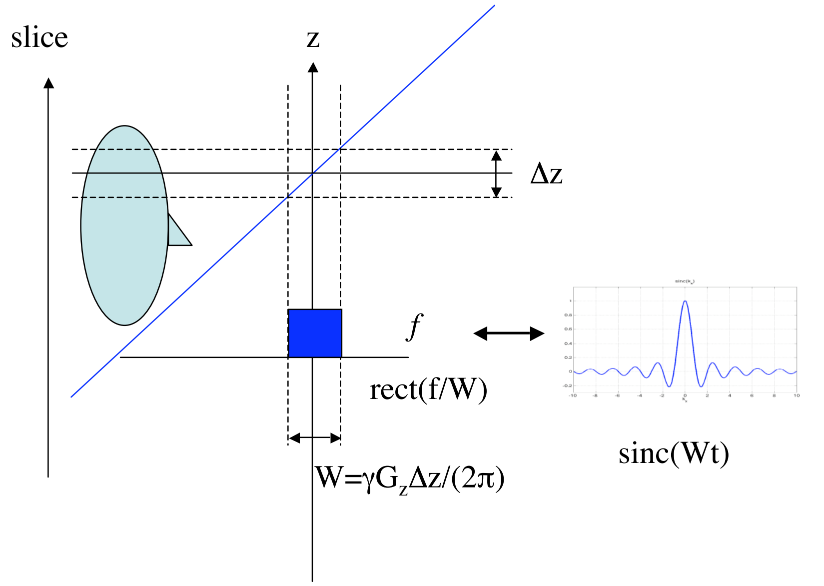
Slice Selection



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$$\text{Let } \mathbf{B}_{rot} = B_1(t)\mathbf{i} + \left(B_0 + \gamma G_z z\right)\mathbf{k}$$

$$\mathbf{B}_{eff} = \mathbf{B}_{rot} + \frac{\omega_{rot}}{\gamma}$$

$$= B_1(t)\mathbf{i} + \left(B_0 + \gamma G_z z - \frac{\omega}{\gamma}\right)\mathbf{k}$$

If $\omega = \omega_0$

$$\mathbf{B}_{eff} = B_1(t)\mathbf{i} + \left(\gamma G_z z\right)\mathbf{k}$$

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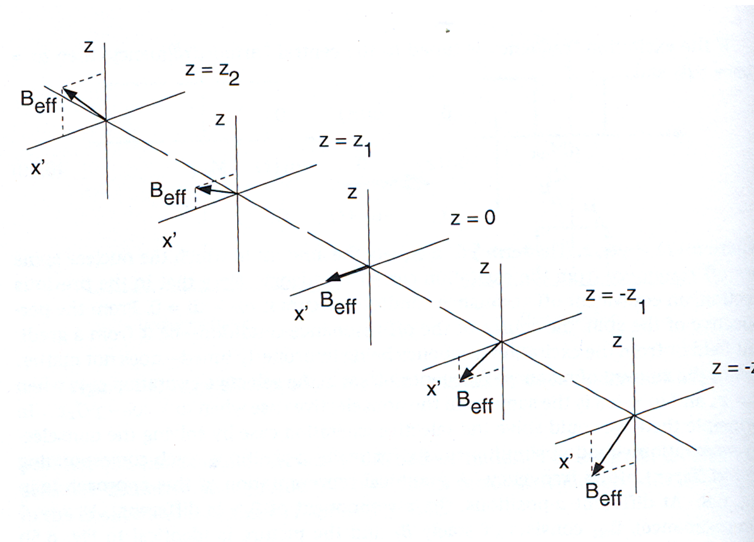

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Small Tip Angle Approximation

$$M_r(t,z) = jM_0 \exp(-j\omega(z)t)\int_0^t \exp(j\omega(z)s)\omega_1(s)ds$$

For symmetric pulse of length τ

$$M_r(\tau,z) = jM_0 \exp(-j\omega(z)\tau/2)\int_{-\tau/2}^{\tau/2} \exp(j2\pi f(z)s)\omega_1(s+\tau/2)ds$$
$$= jM_0 \exp(-j\omega(z)\tau/2)F\left\{\omega_1(t+\tau/2)\right\}\Big|_{f=-f(z)=-\frac{\gamma}{2\pi}G_z z}$$

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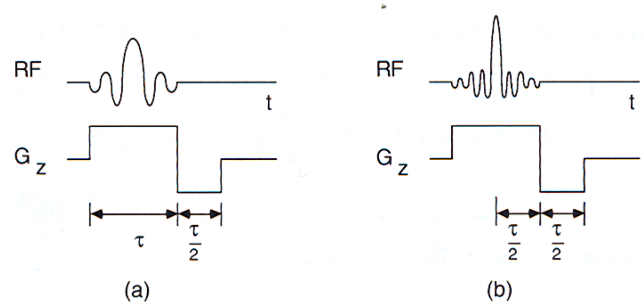

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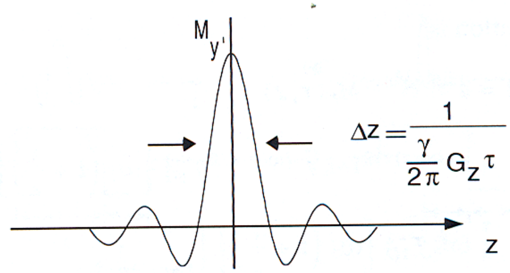

$$\Delta z = \frac{1}{\frac{\gamma}{2\pi} G_z \tau}$$

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Nishimura 1996