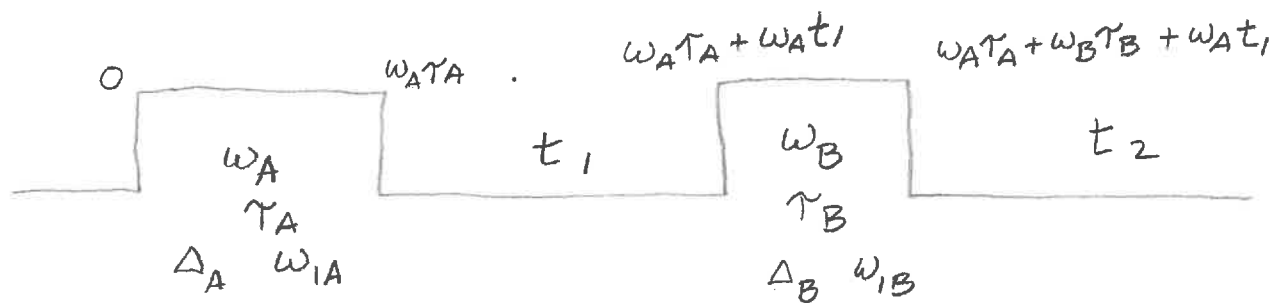


Frequency Shifted Pulse

Tom BARBARA



• phase continuous switching at the end of t_1

$$-(\Delta_a P_z + \omega_{1a} P_x) \tau_A$$

$$-\omega_a \tau_a P_z$$

$$-\omega_0 t_1 P_z$$

$$(\omega_a \tau_a + \omega_a t_1) P_z$$

$$-(\Delta_b P_z + \omega_{1b} P_x) \tau_B$$

$$-(\omega_a \tau_a + \omega_a t_1) P_z$$

$$-\omega_b \tau_b P_z$$

$$-\omega_0 t_2 P_z$$

$$-(\Delta_a P_z + \omega_{1a} P_x) \tau_A$$

$$-(\omega_0 - \omega) P_z t_1$$

$$-(\Delta_b P_z + \omega_{1b} P_x) \tau_B$$

$$-(\omega_0 t_2 + \phi) P_z$$

$$\phi = +\omega_a \tau_a + \omega_a t_1 + \omega_b \tau_b$$

Freq jump only in XMTR arm, so RCVR phase

$$\text{is } \omega_a \tau_a + \omega_a \tau_b + \omega_a t_1 = \phi_R$$

Shifted
pulse

$$e^{-(\omega_b - \omega_a) \tau_b P_z} e^{-(\Delta_b P_z + \omega_{1b} P_x) \tau_b}$$

$$\Delta_b = \omega_0 - \omega_b = \omega_0 - \omega_a + \omega_a - \omega_b$$

$$= \Delta_a - \delta\omega$$

$$\delta\omega = \omega_b - \omega_a$$

freq shift
has a
phase
shift

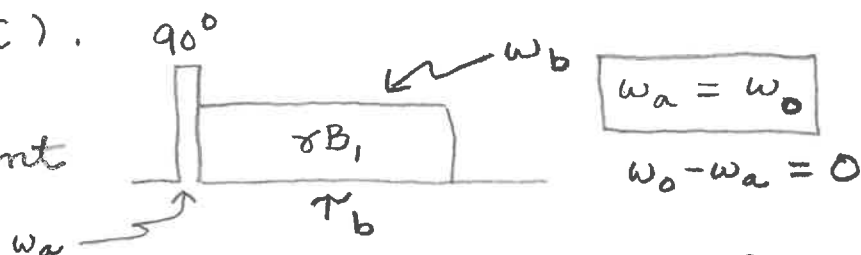
$$e^{-\delta\omega \tau_b P_z} e^{-((\Delta_a - \delta\omega) P_z + \omega_{1b} P_x) \tau_b}$$

(Not!) Bloch Siegert Shifts

TOM
BARBARA

- The effect of an off resonance pulse on transverse magnetization is often referred to as a "Bloch Siegert Shift", even though Bloch and Siegert were originally addressing the effects of the counter rotating component of a linear polarized Rf pulse. Phys Rev 57, 522 (1940)
- Normally, of course, an off resonance pulse is not counter rotating, it is just far from resonance compared to the Rabi frequency.
- The technique is often used to map the spacial variations in $|\gamma| B_1(z)$.

Consider the experiment



The 1st pulse is on resonance, and the second long pulse is shifted away from resonance such that $\omega_0 - \omega_b \gg |\gamma| B_1$

For the second pulse, frequency shifted to ω_b , we can take $\cos \theta \sim 1$, $\sin \theta \sim 0$ and $\Omega = \sqrt{\Delta_b^2 + \omega_1^2}$

- The effect of our long weak pulse is given by

$$e^{\Delta_b \tau_b P_z} e^{-\Omega \tau_b P_z} M_y \quad \Delta_b = \omega_0 - \omega_b$$

$$\Omega = \sqrt{\Delta_b^2 + \omega_1^2} \approx \Delta_b \left(1 + \frac{1}{2} \frac{\omega_1^2}{\Delta_b^2} \right)$$

- $\therefore$ If transverse magnetization is present during a weak off resonance pulse, a phase shift may be observed.