In NMR, a radiofrequency field (RF) is used along the x-axis to apply a pulse. It is convenient to represent this RF as two counter-rotating fields with magnitude  $B_1$ .

#### 1. Represent these two rotating fields on a scheme.

#### 2. Represent the variation of the field along x (detection) vs. Time.

In the rotating frame, if the RF is chosen properly, the apparent Larmor frequency of the spin is zero. We now introduce the difference frequency, called offset, that is given as:

$$\Omega = \varpi_0 - \varpi_{rot}$$

#### **3.** Give the expression of the reduced field $\Delta B$ in function of the offset frequency.

In the rotating frame, the reduced field (along the z-axis) and B1 field add vectorially to give an effective field  $B_{eff}$ .

#### 4. What is the size of this effective field?

The tilt angle is the angle,  $\theta$ , between  $B_{eff}$  and the reduced field.

#### 5. Write the sin, cos and tan of $\theta$ . What happen when $\theta$ is $\pi/2, \pi$ ?

### 6. Do the same geometrical construction for the offset frequency and the effective frequency.

When the offset is zero, we talk about an "on-resonance pulse".

#### 7. What is the tilt angle is this case?

8. After the RF is applied, the magnetization is moved away from it original position. Represent on a scheme with the magnetization the different steps before a pulse, during the pulse and after the pulse.

In NMR, most experiments start with a hard pulse. As we usually have several resonances in the spectrum, each of which having a different Larmor frequency, it is not possible to be on-resonance

for all the lines in the spectrum. However, it is possible to make the RF field strength sufficiently large that for a large range of resonances the effective field stays very close to the z axis. Then, the magnetization behaves as if the pulse is on-resonance.

We want to acquire a proton spectrum covering a range of 10 ppm. The transmitter frequency is placed in the middle of the spectrum and we work on a 500 MHz apparatus.

# 9. What is the Lamor frequency?10. What is the maximum offset?

In the documentation of the apparatus, it is written that the pulse duration is 12  $\mu$ s for this experiment.

- 11. Calculate the frequency  $\omega_1$  (or field strength of RF)
- 12. Calculate the associated tilt angle.
- 13. How would you measure the most efficient pulse length?

## 14. Do the same calculation than in 11. and 12. for a proton spectrum recorded on a 300 MHz instrument with a spectrum covering 200 ppm.

The gyromagnetic ratio of  ${}^{31}$ P is  $1.08 \times 10^8$  rads ${}^{-1}$  T ${}^{-1}$ . This nucleus shows a wide range of shifts, covering some 700 ppm.

15. Estimate the minimum 90° pulse length you would need to excite resonances over this complete range to within 90 % of their theoretical maximum for a spectrometer with a  $B_0$  field strength of 9.4 T (the offset frequency must be 1.6 time larger than the RF field strength).