Pulse Sequence for Elimination of RF Receiver Coil Ring Down

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Introduction

Excitation RF pulses used in NMR produce a transient response in the receiver coil causing a ring down response. This usually requires a short time delay after excitation to prevent receiver overload. Current solutions to this problem are to use one or more techniques such as Q switching, receiver blanking and delayed data acquisition. A second problem with a finite transient response is the distortion of the B_1 lineshape. At typical MRI Larmor frequencies, this is not a significant problem because the transient response is fast compared to the RF modulation waveform.

Both of these effects are more pronounced at low frequencies. To appreciate this, consider the RF receiver coil time constant, τ, given by

$$\tau = L/R = Q/\omega. \qquad [1]$$

For a given Q, it is clear that τ increases with decreasing frequency. This effect is related to the skin effect where for a given coil geometry:

$$\tau \propto \delta \propto \omega^{-1/2}, \qquad [2]$$

where δ is the skin depth. With the advent of laser-polarized gases, MRI at extremely low fields is now possible. It is this application where these issues are clearly relevant.

Methods

To reduce the transient response, we propose the addition of a compensating pulse (or pulses). Such a pulse was proposed to provide eddy current compensation for gradient switching [1], and is analogous to other pre-emphasis schemes for gradient switching [2,3]. Consider the pulse sequence in Figure 1, which shows a standard square RF pulse with

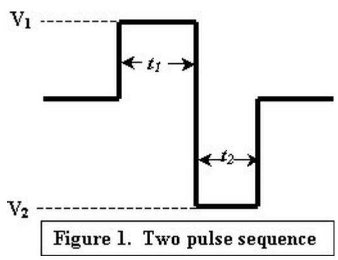

Figure 1. Two Pulse Sequence

height V_1 followed immediately by a compensation pulse with amplitude V_2. In order to eliminate ring down, we require that the RF current equal zero at time $t_1 + t_2$. Given a fixed V_1 and V_2, the solution for t_2 is given by:

$$t_2 = \tau \ln\left(1 - \frac{V_1}{V_2}(1 - e^{-t_1/\tau})\right). \qquad [3]$$

Note that V_2 is opposite in polarity (180° phase shifted) to V_1 so that as $|V_2|$ increases, t_2 decreases.

One can also include another compensation pulse that precedes V_1 to insure a flat current during t_1. Such a sequence is shown in Figure 2. The condition for a flat current response during t_1 is then given by $I(t_1) = I_1 = V_1/R$, where R is the resistance of the coil. In addition, we have the original criteria stated above that $I(t_o+t_1+t_2) = 0$. Assuming a known V_o, V_1 and V_2, the solutions are given by:

$$t_0 = -\tau \ln(1 - \frac{V_1}{V_0}) \qquad [4a]$$

$$t_2 = \tau \ln\left(1 - \frac{V_1}{V_2}\right). \qquad [4b]$$

Most likely, it is desirable to apply the shortest transition times. In this case, V_o and V_2 will be set to ±Vmax, the maximum output voltage of the output amplifier. Figure 3 illustrates t_o/τ and t_2/τ as a function of V_1/V_{max}. Note that under these conditions, the leading edge will always require a longer transition time.

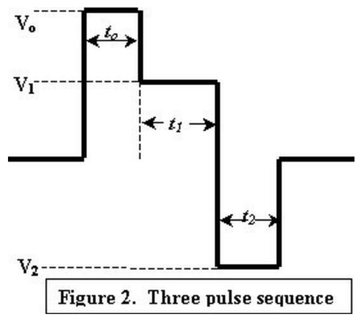

Figure 2. Three pulse sequence.

Results and Conclusions

As an example consider the following. Assume Q=100 and the Larmor frequency = 100kHz. The time constant of the RF coil is then 1/(2π)ms = 159µs. In practice, one may have to delay data acquisition for on the order of 10 time constants in order for the current to decay to an acceptable level for the receiver preamp. For this example, this means a delay of 1.59ms. Using the two pulse sequence and assuming $V_1 = -V_2$ and $t_1 = \tau$, $t_2 = \tau \ln(2 - \exp(-t_1/\tau)) = 0.49\ \tau = 78\mu s$. This is a reduction in the ring down time by a factor of 20. For the case shown in Figure 3, we note that the amplitude of the current in the RF coil during time t_1 is constant. Thus, the flip angle dependence on t_1 is linear. We conclude that pre- and post-compensation RF pulses not only reduce the ring down time in the receiver coil, but also make the adjustment of the flip angle through t_1 straightforward.

References

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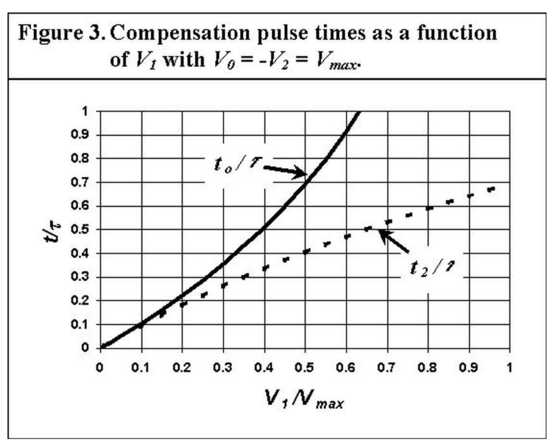

Figure 3.