# "$M_Y$ way" – a new construction technique for broadband slice-selective refocusing pulses

**J. B. Murdoch**[1]
[1]Toshiba Medical Research Institute USA, Mayfield Village, OH, United States

Broadband spin-echo refocusing pulses are of interest not only for their highly nonlinear spin physics but also for their usefulness in PRESS spectroscopy, especially at higher field strengths where chemical shift misregistration can be a problem. A variety of techniques have been used to design these pulses, notably iterative minimization of a cost function [1-3], the Shinnar-Le Roux (SLR) algorithm [4], and SLR combined with subsequent flipping of **A** polynomial roots across the unit circle in a quest for a reduced $B_{1max}$ [5]. The last approach has been used to create an entire series of phase-modulated (PM) pulses, but the process is slowed by the need to search for an optimal combination of "flippers" amidst a tangle of roots.

Yet another method is to first generate a slice-selective self-refocused 90° excitation pulse, namely one that needs no subsequent gradient rephasing. Combining this pulse with a time-reversed version of itself creates a 180° refocusing pulse [6]. However, the resulting state of out-of-slice magnetization halfway through – $M_Z \cong 1$, $M_X \cong 0$, $M_Y \cong 0$ – is overly restrictive. For symmetric, purely amplitude-modulated (AM) refocusing pulses developed with other methods, we have found that the key magnetization characteristic halfway through the pulse is that $M_Y \cong 1$ inside the slice and $M_Y \cong 0$ outside. As such, rather than combining "traditional" self-refocused 90° pulses, one can specify merely the desired $M_Y$ response … and let $M_X$ and $M_Z$ run free.

The same approach can be used for higher-bandwidth phase-modulated pulses as well: start with either a slice-selective self-refocused PM 90° pulse or *(more generally)* a self-refocused PM 90° pulse with the desired $M_Y$ properties. When combining these pulses with their time-reversed counterparts, however, the imaginary component of the second piece must be inverted [6]. This creates an amplitude-symmetric, phase-antisymmetric refocusing pulse with a simple relationship between the refocusing profile $\boldsymbol{E}(\Delta\nu)$ and the $M_Z$ response profile: $\boldsymbol{E} = (1\text{-}M_Z)/2$ (i.e., consistent pancake flipping about one axis in the x-y plane) [2,5]. (Note, however, that this symmetry property is useful but not essential for pulse design. Refocusing pulses with different symmetries – asymmetric AM or fully symmetric PM, for example – **<u>can</u>** be generated by iterative techniques if the refocusing profile itself is used as the in-slice target function [2].) Finally the freshly forged combination typically benefits from some additional fine-tuning and optimization as an actual refocusing pulse.

A variety of both AM and PM refocusing pulses have been created with the "$M_Y$ way" technique, and some have found use in PRESS spectroscopy sequences at 3T.

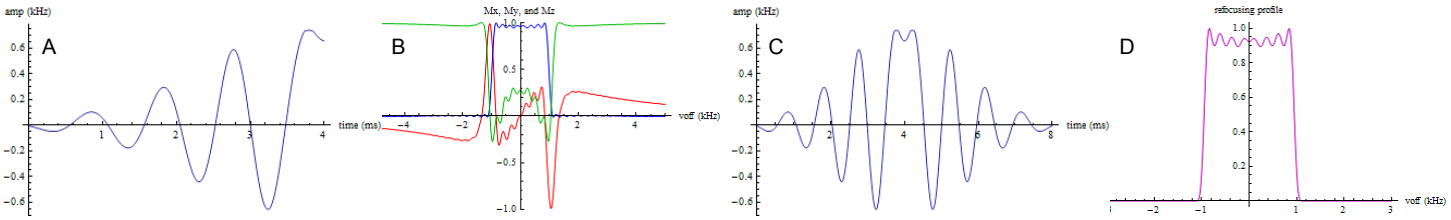



Figure 1. (A) A self-refocused "$M_Y$-design" pulse; (B) its $M_X$, $M_Y$, and $M_Z$ profiles in red, blue, and green; (C) a symmetric pulse constructed from (A); (D) the refocusing profile of pulse (C).

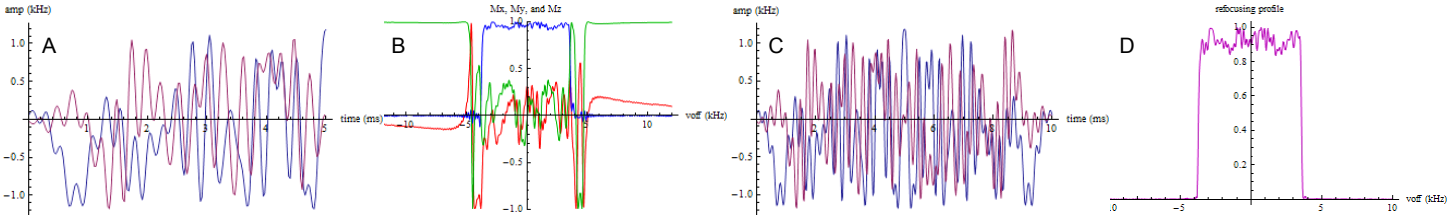
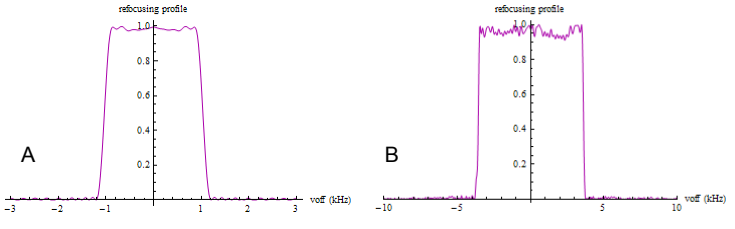



Figure 2. (A) A phase-modulated self-refocused "$M_Y$-design" pulse *(real and imaginary components displayed)*; (B) its $M_X$, $M_Y$, and $M_Z$ profiles in red, blue, and green; (C) an antisymmetric pulse constructed from (A); (D) the high-bandwidth refocusing profile of pulse (C).

Figure 3. Refocusing profiles for "refined" versions of the pulses displayed in Figs. 1 and 2. (Additional optimization was performed on the fused pulse halves to polish up the refocusing performance.) (A) The AM pulse from Fig.1; (B) the PM pulse from Fig.2.




## References

1. Conolly et al, IEEE Trans Med Imaging 1986; 2:106–115.
2. Murdoch et al, J. Magn Reson 1987; 74:226–263.
3. Matson et al, J. Magn Reson 2009; 199:30-40.
4. Pauly et al, IEEE Trans Med Imaging 1991; 10:53–65.
5. Schulte et al, J. Magn Reson 2008; 190:271–279.
6. Roberts et al, J Magn Reson 1993; B101:78-82.