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Experimental Verification of Composite Inversion Pulses Obtained by Series Expansion of the Offset Angle*

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Over the years, the limitations of the simple 180° inversion pulse have been realized (*1, 2*) and several improvements have been suggested (*3–7*). However, the longer and more elaborate the composite pulse, the less likely it will be used by practicing spectroscopists. This fact is best exemplified by the common use of a simple phase-alternating inversion pulse (*1*) although other more complicated composite pulses with better inversion characteristics have been published (*7, 8*). In a preceding paper we derived a series of composite inversion pulses that theoretically achieve "good" inversion over a wider range of offset with fewer pulses than any previously proposed pulses (*9*). In this Note we present the experimental verification of the theoretical results.

Figure 1 compares the theoretically determined offset dependence of three members of this composite-pulse family with the experimentally determined offset dependence. The agreement between theory and experiment is excellent, confirming the superior inversion characteristics of this family of composite pulses. Furthermore, the sequences are robust. For example, each element of the four pulse sequence can be set 1° off from the predicted value with no discernible change in the offset dependence.

Table 1 compares the total rotation and inversion with other equivalent composite pulses. The three pulse sequence compares favorably with the commonly used 90°_x 180°_y 90°_x composite pulse (*1*). In particular, the inversion of the three-pulse sequence proposed in (*9*) has an inversion over the 1.1 kHz bandwidth more uniform than that of the former pulse. The four-component composite pulse achieves a 1.3 kHz

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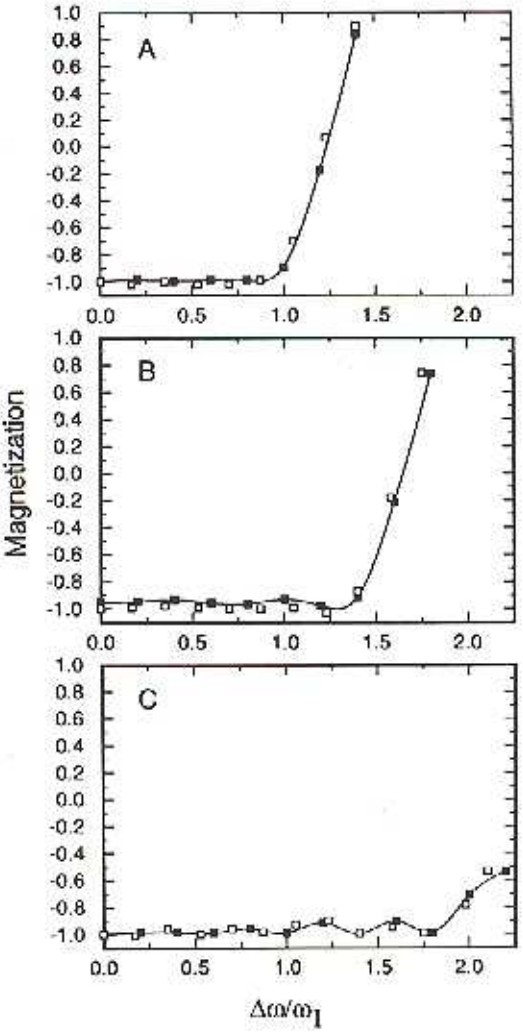

FIG. 1. A comparison of the experimentally determined (_) and theoretically calculated (■) spin inversion profile of three composite pulses: (A) 86.8, 205.5, 304.5; (B) 38.2, 110.7, 159.3, $\overline{249.5}$; (C) 140.0, $\overline{149.3}$, 315.3, $\overline{115.2}$, 70.3, 83.5. The bar indicates a 180° phase shift. All experimental data points were acquired on a 2% H_2O in D_2O sample lightly doped with $Cr(acac)_3$. All data were collected at 500.1 MHz on a Varian VXR 500S NMR spectrometer at a radiofrequency field strength of 1.14 kHz for the inversion pulse.

inversion bandwidth over a relatively small rotation angle and the six-pulse sequence achieves a 1.8 kHz bandwidth at the expense of some small oscillations of inversion efficiency.

In conclusion, we have experimentally verified three new composite inversion pulses. The four-component inversion pulse, in particular, is a significant improvement over any previously published equivalent pulse.

TABLE 1

Composite pulse	$\Delta\omega/\omega_1$	Total rotation (degrees)	Reference
90°_x, 180°_y, 90°_x	±1.0	360	*1*
86.8, $\overline{205.5}$, 304.5	±1.1	597	This paper
$\overline{34.2}$, 123.0, $\overline{197.6}$, 288.8	±1.0	643.6	*7*
38.2, $\overline{110.7}$, 159.3, $\overline{249.5}$,	±1.3	558	This paper
158.0, $\overline{171.2}$, 342.8, $\overline{145.5}$, 81.2, $\overline{85.3}$	±1.5	984	*7*
140.0, 149.3, 315.3, $\overline{115.2}$, 70.3, $\overline{83.5}$	±1.8	874	This paper

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