A new detection scheme for ultrafast 2D COSY

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Introduction

NMR plays a significant role in determining structures and dynamics of various physical, chemical, and biological systems at molecular level. The introduction of 2D techniques accelerates and extends the application of NMR spectroscopy. Unfortunately, numerous t_1 increments have to be collected for a 2D spectrum with good resolution, which leads the experiment fairly time-consuming. The spatial encoding ultrafast technique enables 2D NMR spectra to be acquired in a single scan [1]. In this abstract, a new ultrafast 2D COSY method based on continuous constant-time phase-modulated spatial encoding was proposed and experiments were performed to verify its feasibility and advantages over the previous method.

Methods

The pulse sequence is shown in Fig. 1a. A π-π chirped pulse scheme is used to encode evolution phases along the z-orientation. For the π chirped pulses, the RF sweeps from initial frequency offset O_i to final frequency offset O_f at a constant rate. A pair of bipolar z-orientation field gradients ($+G_e$, $-G_e$) over equal time during the course of encoding are used. Two $\pi/2$ hard pulses are respectively imposed before and after the π-π module. A z-orientation field gradient (G_p) is also necessary to localize the peaks in the direct dimension. The EPI detection block is used in the decoding period. In the EPI detection block, the evolution phases at different coordinates are decoded with the help of a pair of bipolar z-orientation field gradients (G_a and $-G_a$). The EPI detection block is repeated N_2 times.

Experiments were performed at 298 K on a Varian NMR System 500 MHz spectrometer using a 5 mm ^{1}H{^{15}N-^{31}P} indirect detection probe equipped with 3D gradient coils. A sample of n-butylbromide/$CDCl_3$ was used. The duration of the $\pi/2$ RF pulses was 10.8 μs. The effective sample length was L = 1.6 cm. The π chirped pulses were created from the Pbox subroutine libraries at a digitization rate of 1.0 μs with an adiabatic coefficient of 1.2 to fulfill the adiabatic passage requirements. The gradient switching time was δ = 5.0 μs, and G_a = 30 G/cm, T_a = 200 μs, and N_2 = 80. The other relevant parameters were as follows: G_e = 15 G/cm, t_1^{max} = 40 ms, t_{mix} = 10 ms, G_p = 10 G/cm, and t_p = 0.25 ms. For comparison, real-time phase-modulated encoding experiment was also carried out (Fig. 1b) [2]. The effective encoding time was 78.95 ms. The $\pi/2$ pulse was created at a digitization rate of 1.0 μs with a adiabatic coefficient of 0.068. The other relevant parameters were as follows: $G_e^{(\pi/2)}$ = 3.91 G/cm, $G_e^{(\pi)}$ = 37.2 G/cm, t_{mix} = 20 ms, G_p = 10 G/cm, and t_p = 0.05 ms.

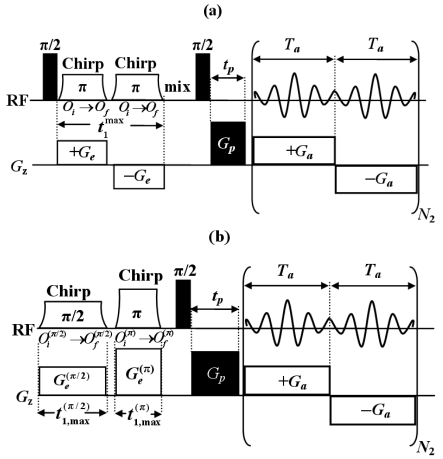

Fig. 1 (a) Constant-time phase-modulated encoding sequence; (b) real-time phase-modulated encoding sequence.

Results and Discussion

The resulting 2D ^{1}H-^{1}H COSY spectra of the n-butylbromide/$CDCl_3$ sample are illustrated in Fig. 2, together with the initial parts of the time-domain signals. Both spectra were processed with the same procedure and same post-processing parameters. The comparison between the two spectra (Fig. 2a and 2b) indicates that they have approximately identical resolution in the direct dimension, while the spectrum obtained with our new method has higher resolution in the indirect dimension. The higher resolution would benefit the application of ultrafast 2D COSY method on complex proton systems. The comparison between the time-domain signals in Fig. 2c and 2d indicates that the signal obtained with our new method has higher signal-to-noise ratio (SNR) than that obtained with the real-time phase-modulated encoding method. Four echoes can be clearly observed during each $+G_a$ or $-G_a$ sampling period in Fig. 2c, whereas the echoes in Fig. 2d are not so clear due to serious noises. The better result from our new method (higher resolution and SNR) may be mainly attributed to the less diffusion and transverse relaxation effects, the larger spatio-temporal encoding constant and the elimination of J splitting [3].

In practice, it is significant for an experiment to be performed rapidly and conveniently. In constant-time phase-modulated encoding 2D COSY experiment, instead of two different chirped pulses, two same π chirped pulses, together with a pair of reverse gradients ($+G_e$, $-G_e$) over equal time during the course of spin encoding are used. So the experiment is relatively easy to implement, without too much cumbersome parameter calibration work. By contrast, in the real-time phase-modulated encoding 2D COSY experiment, the conditions of $G_e^{(\pi/2)}t_{1,max}^{(\pi/2)} = 2G_e^{(\pi)}t_{1,max}^{(\pi)}$ and $G_e^{(\pi)} \approx G_e^{(\pi/2)}$ are chosen for the indirect-domain encoding, and the $\pi/2$ and π chirped pulses should be set according to the relevant parameters ($G_e^{(\pi/2)}$, $G_e^{(\pi)}$, $t_{1,max}^{(\pi/2)}$, and $t_{1,max}^{(\pi)}$). Therefore, a longer time is needed to calibrate these parameters and generate the $\pi/2$ and π chirped pulses for a 2D COSY spectrum. Moreover, the result of real-time phase-modulated encoding experiment is more sensitive to experimental parameter variations, such as pulse power or frequency offset [3].

In summary, compared to the previous real-time phase-modulated method, the present ultrafast COSY method not only gives much better spectral SNR and resolution, but also is much easier to implement.

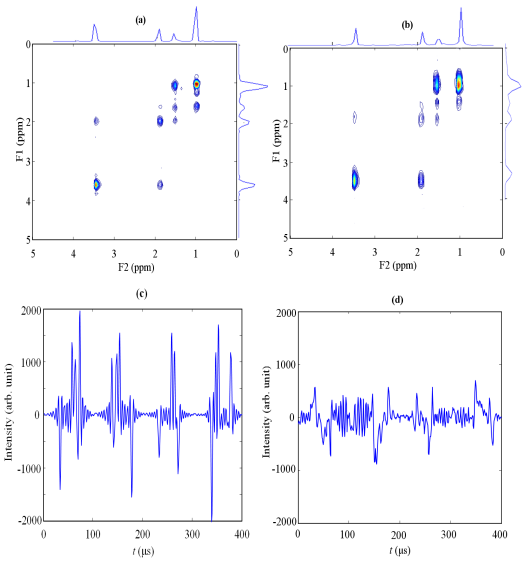

Fig. 2 2D ^{1}H-^{1}H COSY spectra of n-butylbromide/$CDCl_3$ sample. (a) Spectrum obtained using the pulse sequence shown in Fig. 1a; (b) spectrum obtained using the pulse sequence shown in Fig. 1b; (c) time-domain signal corresponding to (a) acquired in the first two decoding periods; (d) time-domain signal corresponding to (b) acquired in the first two decoding periods. Both (a) and (b) were recorded within about 20 s. Their accumulated projections along both direct and indirect dimensions are shown in an absolute value mode for comparison.

Acknowledgment

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