A New strategy for Fast Radiofrequency CW EPR Imaging: Direct Detection with Rapid Scan and Rotating Gradients

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Abstract

Rapid field scan on the order of T/sec. using high frequency sinusoidal or triangular sweep fields superimposed on the main Zeeman field was used for direct detection of signals without low-frequency field modulation. Simultaneous application of space-encoding rotating field gradients to perform fast CW EPR imaging using direct detection that could, in principle, approach the speed of pulsed FT EPR imaging. The method takes advantage of the well-known rapid-scan strategy in CW NMR and EPR that allows arbitrarily fast field sweep and the simultaneous application of spinning gradients that allows fast spatial encoding. This leads to fast functional EPR imaging and, depending on the spin concentration, spectrometer sensitivity and detection band width, can provide improved temporal resolution that is important to interrogate dynamics of spin perfusion, pharmacokinetics, spectral spatial imaging, dynamic oxymetry, etc.

Introduction

The very short transverse relaxation times (T_2) of common stable free radicals such as nitroxides do not easily permit them to be studied using time-domain spectroscopy and are conveniently detected and imaged by CW EPR. The relatively slow scan rates of the field necessitated by the conventional low frequency field modulation and phase sensitive detection method makes the imaging time long, especially if one is performing spectral spatial imaging. Ohno et al. (1) and, later, Deng et al. (2) suggested scanning the Zeeman field in small incremental steps and at each step rotating the gradient field vector through 360° in a plane. The resulting pseudo projection can be rearranged into conventional static-gradient-field-scan projections before performing spectral or spectral spatial imaging. Even in this method, the use of field modulation and phase sensitive detection limits the scan speed. EPR spectroscopy and imaging can also be performed using rapid scan (on the order of T/s) with direct detection (3, 4). Very fast scans will lead to FID-like wiggles which can be removed by Fourier deconvolution technique commonly used in rapid scan correlation NMR. The present work describes athird alternative to perform rapid CW EPR imaging *via. the* ***combination of rapid scan of the magnetic field and the simultaneous rotation of the gradients with direct detection,*** rapid scan rotating gradient CW EPR imaging, RSRG-CW-EPRI at 300 MHz.

Experimental and results

The strategy of rapid scan and rotating gradient EPRI can be easily discerned by looking at the matrix of projections and angles (**Bθ**) given in Fig.1. In the present strategy the measurement is done parallel to diagonal or anti-diagonal that corresponds to simultaneous gradient rotation and field sweep. The fast field sweep of direct detection is accomplished by superposing a sinusoidal or triangular AC sweep of appropriate amplitude and using pairs of tuned orthogonal gradient coils low frequency rotation of the gradient in a give plane can b e easily accomplished. In fact field sweep rates on the order of T/s, at a few kHz frequency and gradient rotations at about three times the frequency of sinusoidal field sweep, allows rapid collection of 'pseudo-projections' at times on the order of 100 μs per projection. Signal averaging can also be done to improve SNR. Successive pseudo-projections are obtained by synchronously phase shifting the gradients through 360° in equal steps (or by incremental acquisition delay) to gather al the elements of the **Bθ** matrix**.** The schematics of simultaneous rapid sinusoidal sweep and the gradient rotations are given in Fig.2. There is no field modulation, and the signals out of the microwave bridge are mixed down to base band, and are amplified by a low noise amplifier with a band width about 1-2 MHz and are digitized using an Aquiris DAQ. The resulting pseudo projections are re-organized to get the conventional projections and then a filtered back-projection is performed to generate the image. Preliminary 2D imaging by this method is also shown in Fig.2.

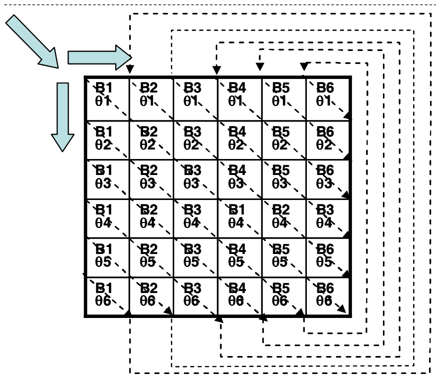

Fig.1 Elements of the Bθ matrix. The large horizontal arrow represents the conventional way of collection projections row-wise. The big vertical arrow represents the stepped-gradient-rotating-gradient approach of Ohno et al. and Deng. et al**.** The dotted slanted arrows represent the present method that corresponds to the simultaneous application of the field sweep field and rotating gradients with step-wise phase-shift.

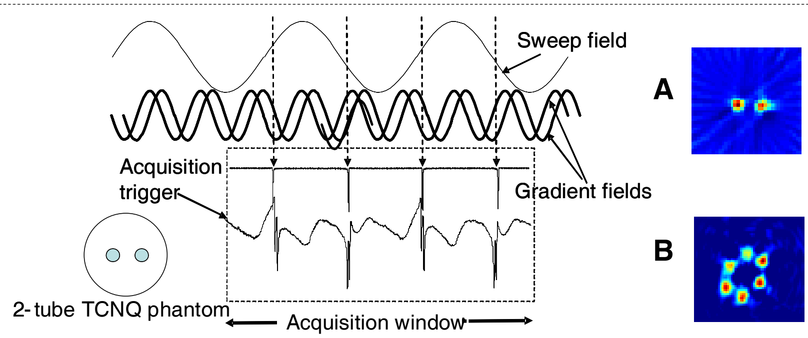

Fig.2 Direct detected rapid scan absorption EPR signals of a phantom sample consisting of two capillary tubes containing a mg each of particulate TCNQ (N-methylpyridinium tetrcyanoquinodimethane, a stable charge-transfer complex that give an exchange-narrowed single line EPR spectrum) sample. The top sinusoid represents the rapid scan sweep, and the two higher frequency sinusoids represent the x and z gradients, which together provide the rotating gradient in the xz plane. The left side of the dotted box represents the start of the trigger. The field scan frequency was 333.33 Hz and the gradient rotation frequency was 1 kHz. The sampling frequency was 4 Ms/s and 25000 points were collected, giving rise to two downfield scans (first and the third spectrum) and two up field scans (second and the fourth spectrum). The zero-gradient spectra (upper) and the spectra under rotating gradient (lower) at an arbitrary starting phase are shown. (A) 2D image of the 2-tube phantom (B) image of a 6-tube phantom

The results presented here preliminary, 'proof-of-principal" data. We are in the process of further optimizing the speed of rapid scan rotating gradient CW imaging in two and three dimensions, as well as performing spectral-spatial imaging and oxymetry.

References

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