EARTH'S FIELD NMR GRADIENT/FIELD COIL SYSTEM

GRADIENT COILS:

- HOMOGENIZE LOCAL EARTH'S MAGNETIC FIELD
- PERMIT MEASUREMENT OF SPIN-SPIN RELAXATION (T_2)
- DEMONSTRATE ONE-DIMENSIONAL NMR IMAGING (MRI)
- GENERATE OBSERVABLE (AND AUDIBLE) SPIN-ECHOES

HELMHOLTZ COILS:

- PERMIT ABSOLUTE MEASUREMENT OF NUCLEAR MAGNETIC MOMENTS
- PROVIDE FIELDS FOR EXPERIMENTS ON ^{31}P AND ^{2}H NUCLEI
- SHOW QUANTITATIVELY THAT MAGNETIC FIELDS ADD AS VECTORS

Instruments Designed For Teaching

TEACH SPIN

The Earth's Field Gradient/Field Coil System (EFGFC1-A) is a valuable addition to the Earth's Field Nuclear Magnetic Resonance (EFNMR1-A) apparatus. Although the EFNMR1-A offers a long list of experiments that can be performed in liquids that contain either hydrogen or fluorine, these Gradient/Field Coils, with their controller, make possible even more experiments, with more nuclei, in more locations. This apparatus was developed by Professor David Van Baak of Calvin College in collaboration with TeachSpin. Dr. Van Baak has written the detailed instruction manual for both the instructor and the students. We believe that the Earth's Field NMR, with this coil system, is without doubt the best instrument for students beginning their study of magnetic resonance. It has no equal!

THE INSTRUMENT

The unit has two types of field coils, **Gradient** and **Helmholtz**. The coil system is mounted in a frame allowing its z-axis to be aligned along the ambient field. This is accomplished with the aid of a permanent magnet dip needle placed inside the coils.

The primary function of the three gradient coils is to cancel the three relevant first-order gradients in the local magnetic field: $\partial B_z/\partial x$, $\partial B_z/\partial y$, $\partial B_z/\partial z$. It has often been difficult for instructors to locate a space within a teaching laboratory where the local Earth's magnetic field is sufficiently uniform over the sample. In such environments, the free-induction decay (FID) time is limited by the nonuniformity of the magnetic field rather than by intrinsic spin-spin interactions within the sample. Severe local field gradients may even cause the precession signal to decay to an imperceptible level in a time comparable to the 50 msec ring-down time after the polarization field has been turned off; thus making the FID impossible to observe.

Consider Figure 1 the free-induction decay signal from a distilled water sample taken at the "best" location at the TeachSpin development laboratory. Now examine Figure 2. Here the currents in the three gradient coils have been adjusted to maximize the decay time of the FID signal. The ambient magnetic field has been made more homogeneous by a factor of about 20!

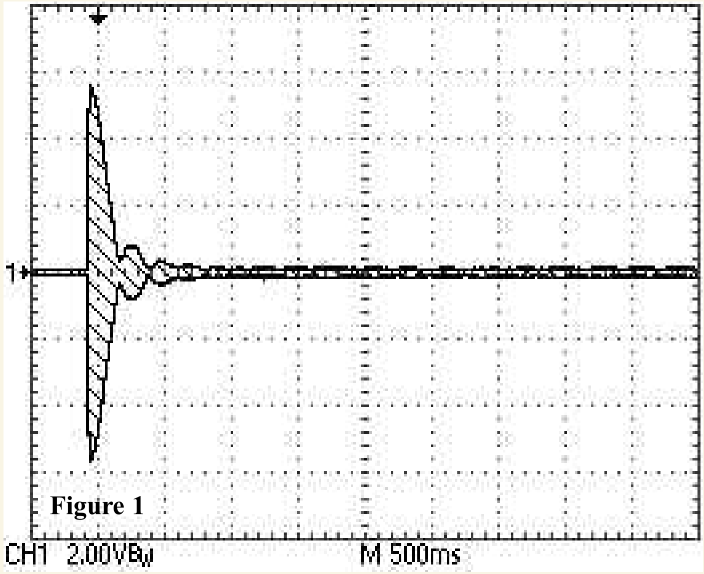


Figure 1

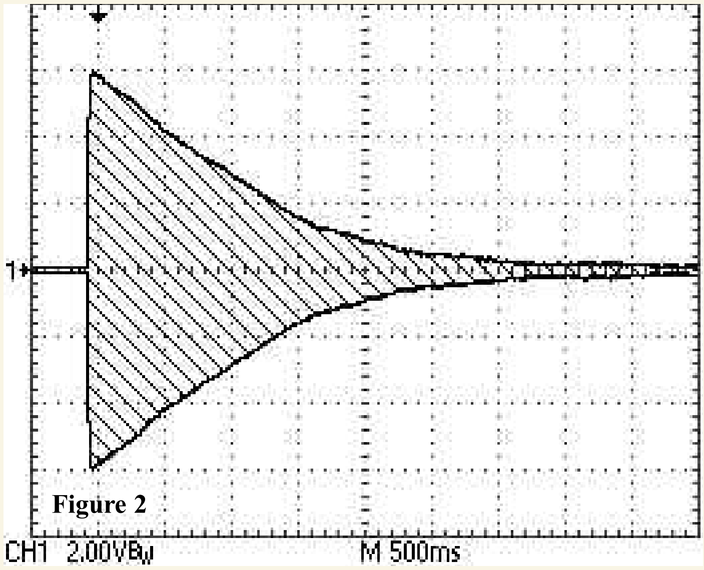
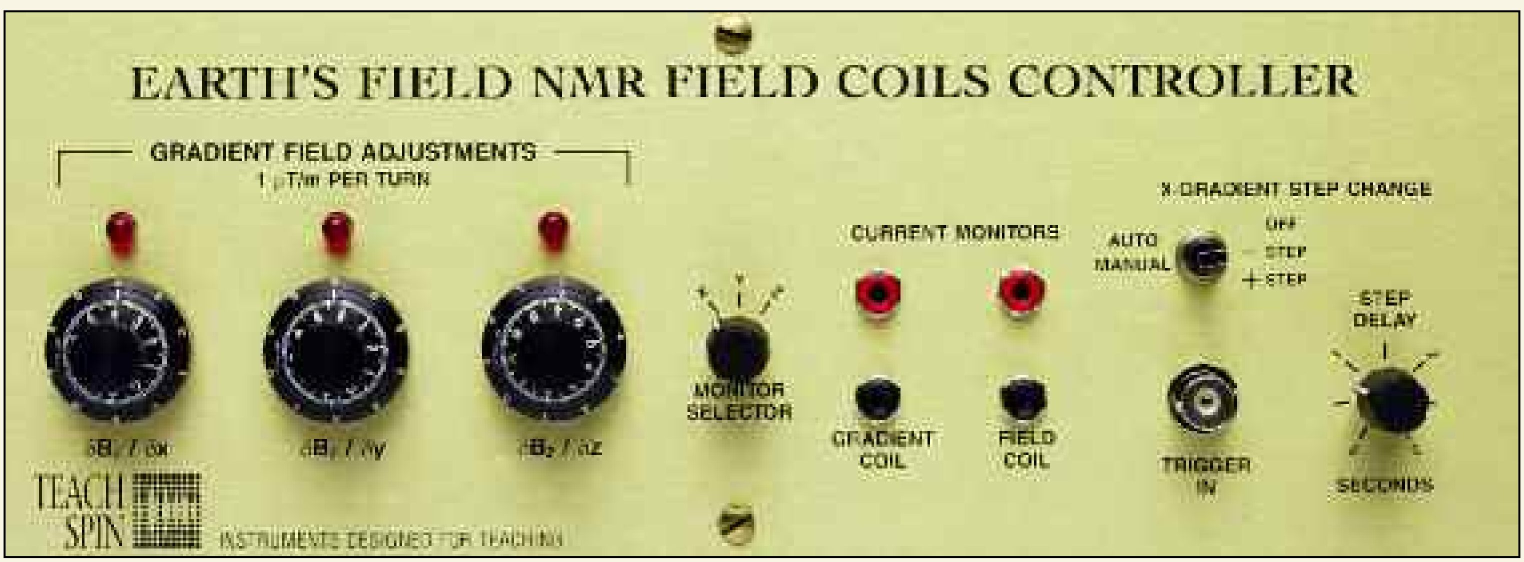


Figure 2



The Helmholtz coils can be used to create known changes in the magnitude of the ambient Earth's magnetic field across the sample, thus bringing more nuclei into the range of the apparatus.

STUDENT EXPERIMENTS

In addition to making the T_1 measurements done with the original EFNMR1-A more accessible, the gradient/field coil system allows students to perform many entirely new types of experiments.

Spin-Spin Relaxation Time, T_2

With the currents in the gradient coils adjusted to yield decay times on the order of 2 seconds in distilled water, it becomes possible to study the way doping the water with various impurities changes T_2. Students may be surprised that NaCl has no effect while $CuSO_4$, even in very low concentrations, shortens T_2 dramatically. Figure 3 shows our measurements of T_2 as a function of $CuSO_4$ concentration. These measurements may be compared to measurements of the spin-lattice relaxation time T_1 at the same concentrations.

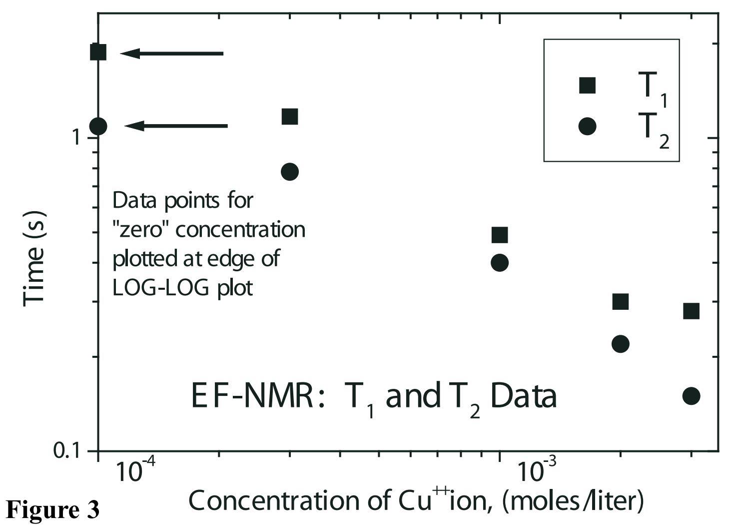


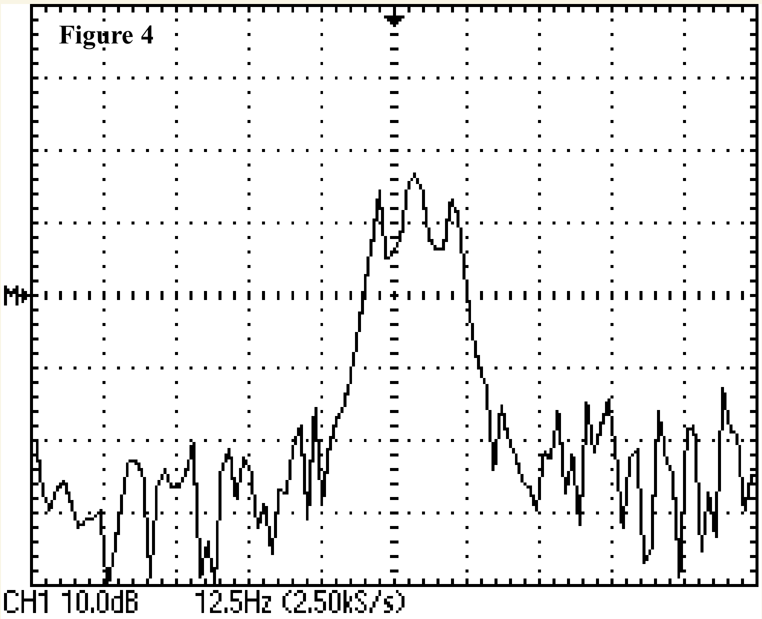
Figure 3

NMR Imaging

The gradient coils also allow students to study the basic physics of MRI, magnetic resonance imaging. The one-dimensional image, created with our special seven-section segmented sample, is a simple but excellent introduction to the fundamentals of this important medical diagnostic technique.

The basis of all MRI is the use of a deliberate, tailored, magnetic field gradient across the sample. This is accomplished by first creating a "gradient free" environment for the sample and finding the precession frequency. A deliberate $\partial B_z/\partial x$ gradient is then introduced along the cylindrical axis of the segmented sample. The physical implication of this magnetic configuration is that any proton's x-coordinate in position space has been mapped into the FID signal's frequency-space departure from the originally observed frequency.

Figure 4



The Fourier transform of this signal, shown in Figure 4, makes the various spectral components of the FID signal immediately obvious. This data was taken with only three of the seven sections filled with water. Note the three peaks in the central area. Knowing the magnitude and direction of the x-gradient, one can reconstruct the separation of the three water filled cells. Even more information about the sample can be obtained by doping individual sections with different concentrations of $CuSO_4$ and measuring the signal intensity as a function of polarization time. In MRI lingo, this is known as a T_1 image.

Spin-Echo

The celebrated phenomenon of the spin-echo can be observed using this gradient coil system. Spin-echoes are observed when the sample is in a magnetic field in which field gradients, rather than spin-spin interactions, limit the FID decay time.

To observe a spin-echo using only the gradient coils, the student first optimizes the gradient field for maximum FID decay time. Then, a deliberate x-gradient is applied using the step-change toggle switch. This gradient can be reversed manually, or, by using the step-delay control, after a preset time. Figure 5 shows the result of using a 1 sec step-delay. The FID decay goes to zero in about 200 msec, but, because there is still coherence in the spin system, we can reconstitute the signal as a spin-echo at 2 sec by reversing the gradient. In this TeachSpin apparatus, the term "echo" takes on new meaning since the students can actually hear the echo signal in real time from the speakers in the EFNMR1-A.

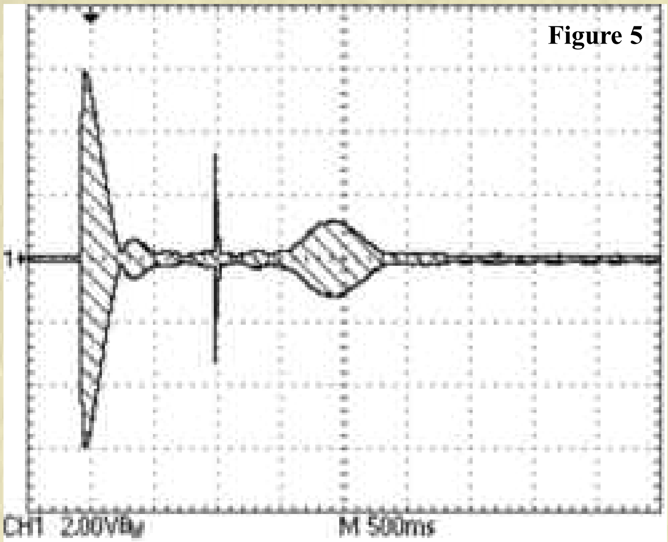


Figure 5

Absolute g-value

The ratio of the magnetic moment to the angular momentum of a nucleus is called the "gyromagnetic ratio" or g-value. It has a unique value for each nuclear species. Simultaneous measurements of the magnetic field and the precession frequency are needed to determine the g-value of any nuclei. Since the Helmholtz coils have a known geometry and number of turns, a calibrated current meter allows an absolute determination of the magnetic field. By measuring the precession frequency of the FID, the absolute g-value can be determined. The gyromagnetic ratio of the proton can be measured to better than 1% precision in absolute units.

"Other" Nuclei

To accommodate the variation in local Earth's magnetic fields, the EFNMR1-A can be tuned from 1600 to 2600 Hz. However, using the Helmholtz coils and an additional 3A current regulated power supply, at least four common nuclear moments can be made to precess within this tuning range. Students can experiment with heavy water, phosphoric acid, and other interesting chemicals, some of which have important biological applications. In addition to determining nuclear g-values, for ^{2}H, ^{19}F, and ^{31}P, students can study spin-spin as well as spin-lattice relaxation in these materials. Figure 6 shows the FFT signal (on a logarithmic scale) of the ^{31}P in phosphoric acid standing over 20 db above the noise.

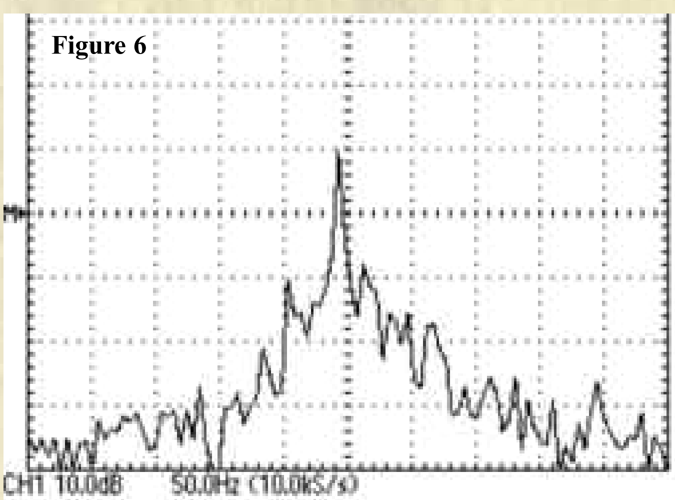


Figure 6

Vector Addition

A measurement of the precession frequency as a function of Helmholtz-coil current can be fitted to a quadratic model for the vector addition of the Earth's and Helmholtz fields to show, quantitatively, that magnetic fields are vectors (Figure 7). This analysis also measures any misalignment angle between the Earth's and Helmholtz coil fields.

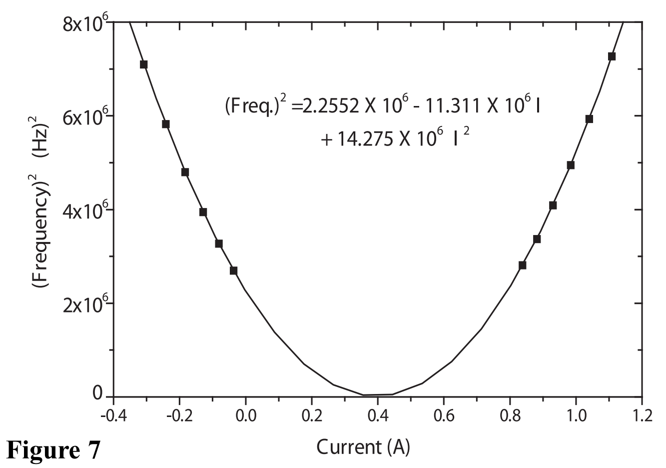


Figure 7

RECOMMENDED ACCESSORIES

Current Regulated Power Supply 3A, 36V
Segmented Sample Holder
Magnetic Dip Compass

SPECIFICATIONS

Helmholtz Coils
- 30 Turns/coil, #20 AWG Copper Wire
- Average Coil Radius: 30.23 cm
- Total Series Resistance: 3.8 Ω
- Maximum Continuous Current: 3A
- Coil Constant: 89 μT/A
- Uniformity: 0.01% over sample volume

Gradient Coils
- Range: 5 μT/m
- Calibration Constant: 250 μT/m per A

Controller
- Maximum gradient current: ±20 mA
- Step delay time: 0−2.5 s
- Maximum step current: ±10 mA

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