

Earth's Field Nuclear Magnetic Resonance (NMR) Gradient/ Field Coil System FCS-3018



EPC / PRODUCTS / APPLICATION / SOFTWARE / ACCESSORIES / CONSUMABLES / SERVICES

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►► INTRODUCTION

Gradient Coils:

- Homogenize Local Earth's Magnetic Field
- Permit Measurement of Spin-Spin Relaxation (T₂)
- 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 ³¹P and ²H Nuclei
- Show Quantitatively that Magnetic Fields Add as Vectors



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. And, of course, the Gradient Coils can be used to make the local earth's magnetic field in the teaching laboratory significantly more homogenous over the sample. This, in turn, allows the nuclei in all parts of the sample to precess at the same rate, producing a free-induction decay signal by the intrinsic spin-spin interaction T₂, rather than by the magnetic field inhomogeneity. As a result, locations in which signals were once too small to use now become viable experimental locations.

The Gradient/Field Coil System was initially developed by Professor David Van Baak of Calvin College to be used with his TeachSpin EFNMR1-A. Once we saw it in action, we knew we had to make it universally available. Collaborating with Dr. Van Baak, we have created a robust apparatus that can be used on many levels. 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!

►► **INSTRUMENT**

The EFNMR Gradient/Field Coil System has two types of field coils, Gradient and Helmholtz. The coil system is mounted in a non-magnetic frame that allows the 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 during alignment. The magnitude and direction of the current passing through each of the three gradient coils is controlled by a 10 turn potentiometer on the front panel of the controller. These currents can be individually monitored by measuring the voltage across a built-in 0.1 ohm standard resistor in series with the coil selected on the front panel.

The primary function of the three gradient coils is to cancel the three relevant first-order gradients in the local magnetic field:

$$\frac{\partial B_z}{\partial x}, \quad \frac{\partial B_z}{\partial y}, \quad \frac{\partial B_z}{\partial z}$$

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 non-uniformity of the magnetic field rather than by intrinsic spin-spin interactions within the sample. Severe local field gradients may 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, making the FID impossible to observe.

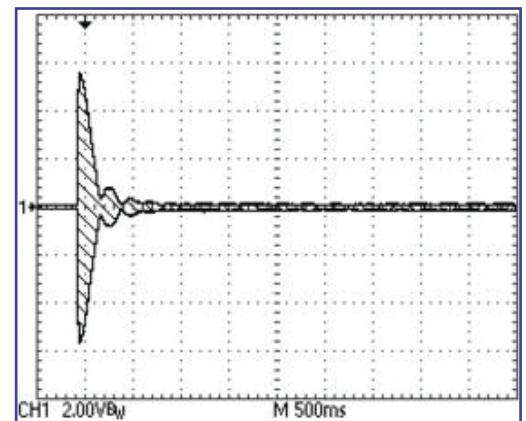


Fig. 1: FID in Ambient Earth's Field

Using the gradient coils at the TeachSpin development laboratory dramatically improved our signals. Consider the free-induction decay signal shown at the above right in Figure 1. This signal, from a distilled water sample, was taken in the ambient magnetic field of one of our "best" locations at the TeachSpin development laboratory. Now, examine the signal shown below, taken in the same location with the same sample. Here, the currents in the three gradient-coils were adjusted to maximize the decay time of the FID signal. The ambient magnetic field had been made more homogeneous by a factor of about twenty!

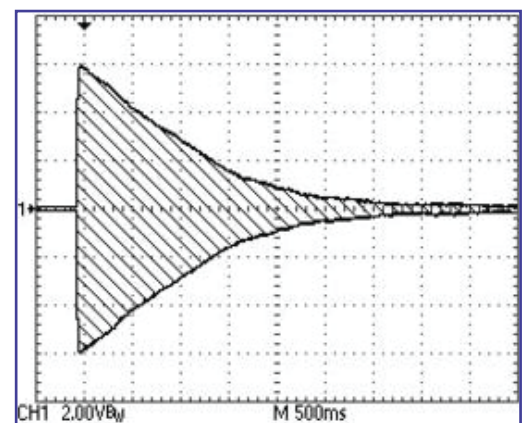


Fig. 2: FID Optimized by Gradient Coils

Control of the magnetic field gradients also allow the creation of deliberate one dimensional gradients of the magnetic field to be imposed along the sample. This, in turn, maps spatial locations in the sample to precession-signal location in frequency space. Using TeachSpin's "Segmented Sample Holder," and a user supplied Fourier transform analysis, students can perform experiments in one-dimensional magnetic resonance imaging.

The Helmholtz coils, which can be accurately modeled from their geometry, can produce a uniform magnetic field of up to 270 micro tesla which can be used to change the magnitude of the ambient Earth's magnetic field across the sample. This increased range of magnetiac fields allows more nuclei to be brought into the tuning range (1.6 - 2.5 KHz) of the apparatus. Now students can experiment with nuclei including 31P, and 2H.

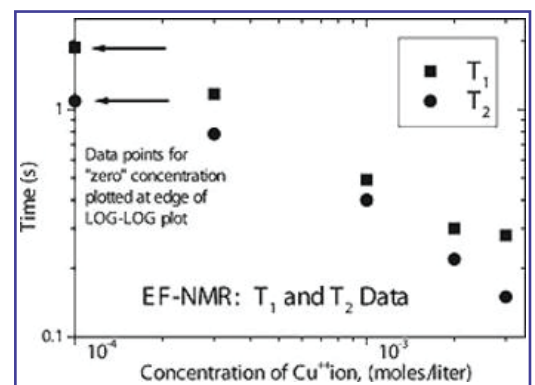
► Experiments

In addition to making the T1 measurements done with the original EFNMR1-A more accessible, the Gradient/Field Coil system allows many entirely new types of experiments.

Experiments with the Gradient Coils

Spin-Spin Relaxation Time T2

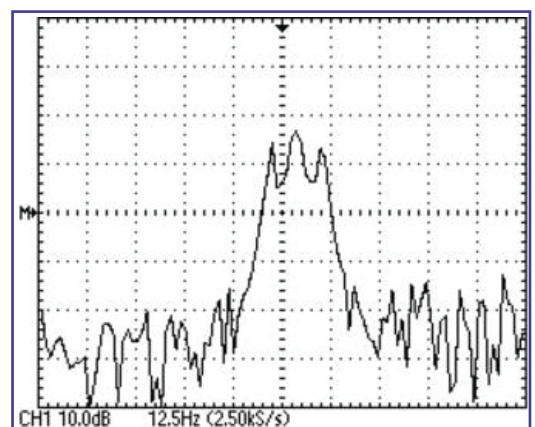
With the currents in the gradient coils adjusted to yield decay times on the order of 2 seconds in distilled water, it becomes possible to study the effects on T2 of doping the water with various impurities. Students may be surprised that NaCl has no effect while CuSO4, even in very low concentrations, shortens T2 dramatically. Figure 3 shows our measurements of T2 as a function of CuSO4 concentration. These measurements may be compared to measurements of the spin-lattice relaxation time, T1 at the same concentrations.



NMR Imaging

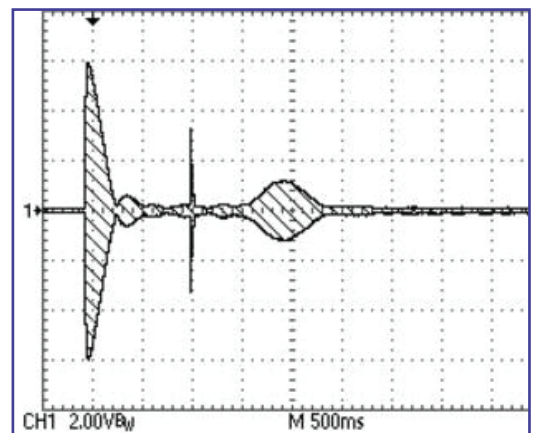
The gradient coils also allow students to study the basic physics of MRI, magnetic resonance imaging. The one-dimensional image, created with our special seven-section segmented sample is a simple but excellent introduction to the fundamentals of this important medical diagnostic technique.

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 $\frac{\partial B_z}{\partial x}$ 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.

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! 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 T1 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, 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.

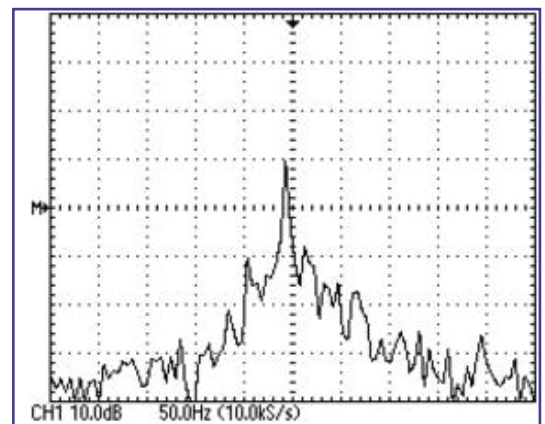
Experiments with the Helmholtz Coils

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.

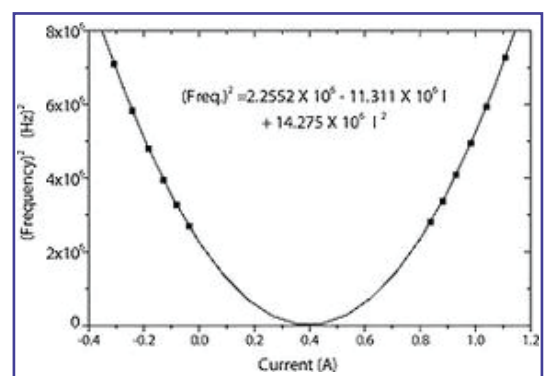
"Other" Nuclei

To accommodate the variation in local Earth's magnetic fields, The EFNMR1-A can be tuned from 1 600 to 2600 Hz. However, using the Helmholtz coils and an additional 3 A 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 ²H, ¹⁹F, and ³¹P, 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 ³¹P in phosphoric acid standing over 20 db above the noise.



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.



►► Specifications

Helmholtz Coils

- 30 Turns/coil, #20 AWG Copper Wire
- Average Coil Radius: 30.23 cm
- Total Series Resistance: 3.8W
- Maximum Continuous Current: 3A
- Coil Constant: 89 $\mu\text{T/A}$
- Uniformity: 0.01% over sample volume

Gradient Coils

- Range: $\pm 5 \mu\text{T/m}$
- Calibration Constant: 250 $\mu\text{T/m}$ per Amp

Controller

- Maximum gradient current: $\pm 20 \text{ mA}$
- Step delay time: 0-2.5 s
- Maximum step current: $\pm 10 \text{ mA}$

Recommended Accessories:

- New Spin Flip Coils (See Newsletter 2 for details)
- Current Regulated Power Supply 3A, 36V
- Segmented Sample Holder
- Magnetic Dip Compass

▶▶ **Regulatory compliances**



▶▶ **Corporate Social Responsibility**

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