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Design of a Sensitive ac Magnetic Susceptibility Measurement System

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A mutual-inductance bridge type ac magnetic susceptibility measurement system was built in our laboratory. With addition of a phase-sensitive prestage, it was simple to implement and provided a high signal-to-noise (S/N) ratio.

I. Introduction

Ac magnetic susceptibility measurements can provide valuable informaition on the magnetic structures especially when they have frequency dependences as in ferromagnets [1-6]. Besides, ac susceptibility measurement systems are generally much easier to build in laboratories than dc systems.

While mutual-inductanĉe method can give the maximum sensitivity when a pair of pickup coils are made to be identical, it is difficult in practice to match them for identical induced signal amplitudes and phases on reaching the lock-in amplifier inputs. This results in additional noise background, which makes weak para/diamagnetic signals hard to detect. Thus, in this work we have home-built a simple and sensitive ac magnetic susceptibility measurement system by using basic laboratory equipment and designing a low noise differential amplifier prestage to

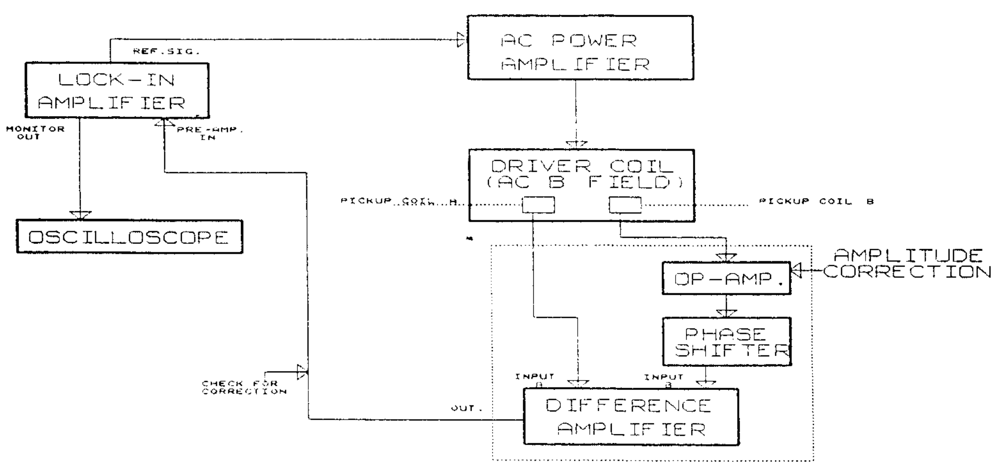

Figure 1. Block diagram for the ac magnetic susceptibility system.

take care of the pickup coil mismatch problem.

II. System design

Figure 1 shows the block diagram for the ac magnetic susceptibility measurement system built in our laboratory. It includes a lock-in amplifier, an oscilloscope, a liquid-helium dewar, a temperature controller, and a vacuum pump. The pickup coils are located inside the dewar tail for temperature dependence measurements, and the driving solenoid coil for generating ac magnetic fields is wound around the dewar tail as shown in Fig. 2. Sinusoidal reference output from the lock-in amplifier is amplified by a power amplifier, whose output current is supplied to the driving coil for ac magnetic fields up to few gauss. One of the pickup coils provides the reference voltage in the absence of a sample, and the sample is inserted into the other so that the difference of the voltages from the two coils corresponds to the susceptibility of the sample.

While a ferromagnetic iron sample gave reasonable signal to noise ratio before inserting a prestage between the pickup coils and the lock-in amplifier, the signals were too weak to detect when paramagnetic Gd_2O_3 or high-T_c superconductor samples were used at room temperature. Thus, in order to reduce the background noise arising from the pickup coil mismatch and to improve the S/N ratio, a prestage was designed to match the amplitudes and phases of the empty

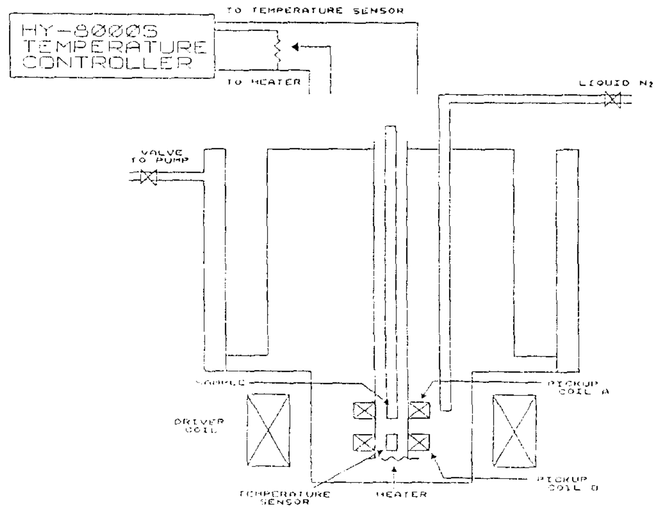

Figure 2. Schematic for the probe and temperature control unit.

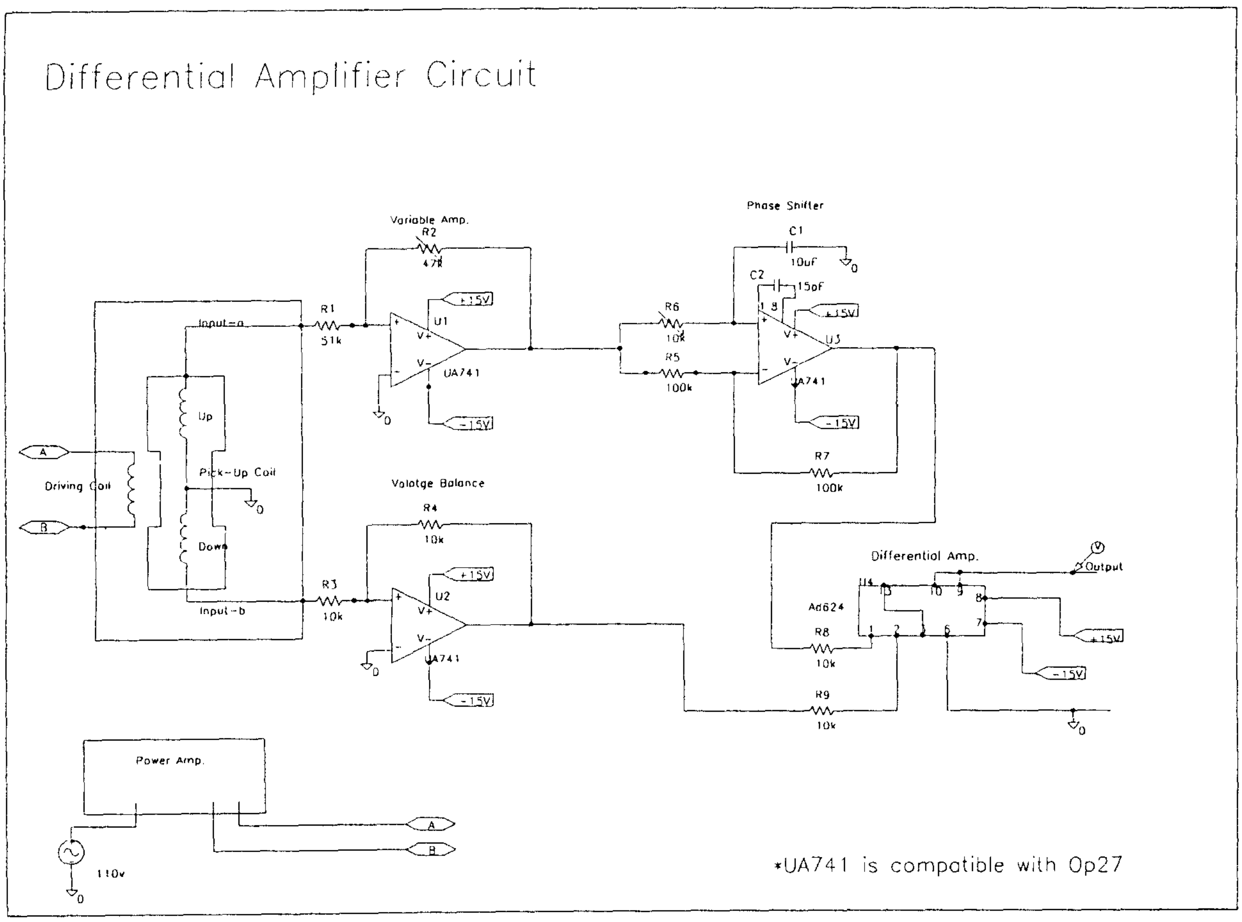

Figure 3. Circuit diagram for the prestage for minimizing the amplitude/phase mismatch from the pickup coils.

cell signals. Figure 3 shows the circuit diagram for adjusting the relative amplitude/phase of the empty cell input voltages. The op-amps with 100-ohm input impedances were chosen for high CMRR (common-mode rejection ratio) and for easy handling. As shown in the circuit digram for the prestage, the empty cell input voltages are first adjusted for equal amplitude and then phase-corrected before being fed into a differential amplifier for null output. After this "tuning" procedure, the sample is inserted into one of the pickup coils for susceptibility measurements, and the output from the prestage is fed into a lock-in amplifier input for the final output voltage.

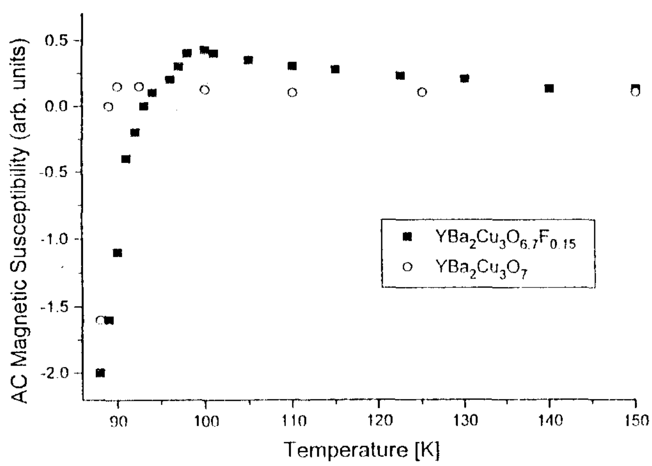

Figure 4. Ac magnetic susceptibility measurements on high T_c superconductor samples.

III. Results and discussion

After insertion of the prestage shown on Fig. 3, previously undetected paramagnetic signals from high-T_c samples yielded quite satisfactory S/N ratios. Actual measurements were made on an iron sample in a frequency range from few Hz up to few kHz to assess the improvement of the S/N ratio due to the prestage, which showed an improvement of well above two orders of magnitude in comparison to that before the insertion of the prestage. This indicates that our system is capable of variable ac magnetic susceptibility measurements of practically any magnetic material in wide frequency and temeperature ranges without excessive cost. Figure 4 shows ac susceptibility measurements performed on samples of high T_c superconductors employing the current setup. It is seen that the setup is capable of detecting the weak paramagnetic signals in the normal phase, and of practical research applications.

Summarizing this work, an ac magnetic susceptibility measurement system was built utilizing basic laboratory equipment and a prestage op-amp circuit. While relatively simple and inexpensive to implement, it turned out to be quite satisfactory for practical research purposes for any magnetic systems including high-T_c systems in the paramagnetic state.

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