# SELF-QUENCHED SUPER-REGENERATIVE DETECTOR FOR NUCLEAR MAGNETIC RESONANCE

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## Summary

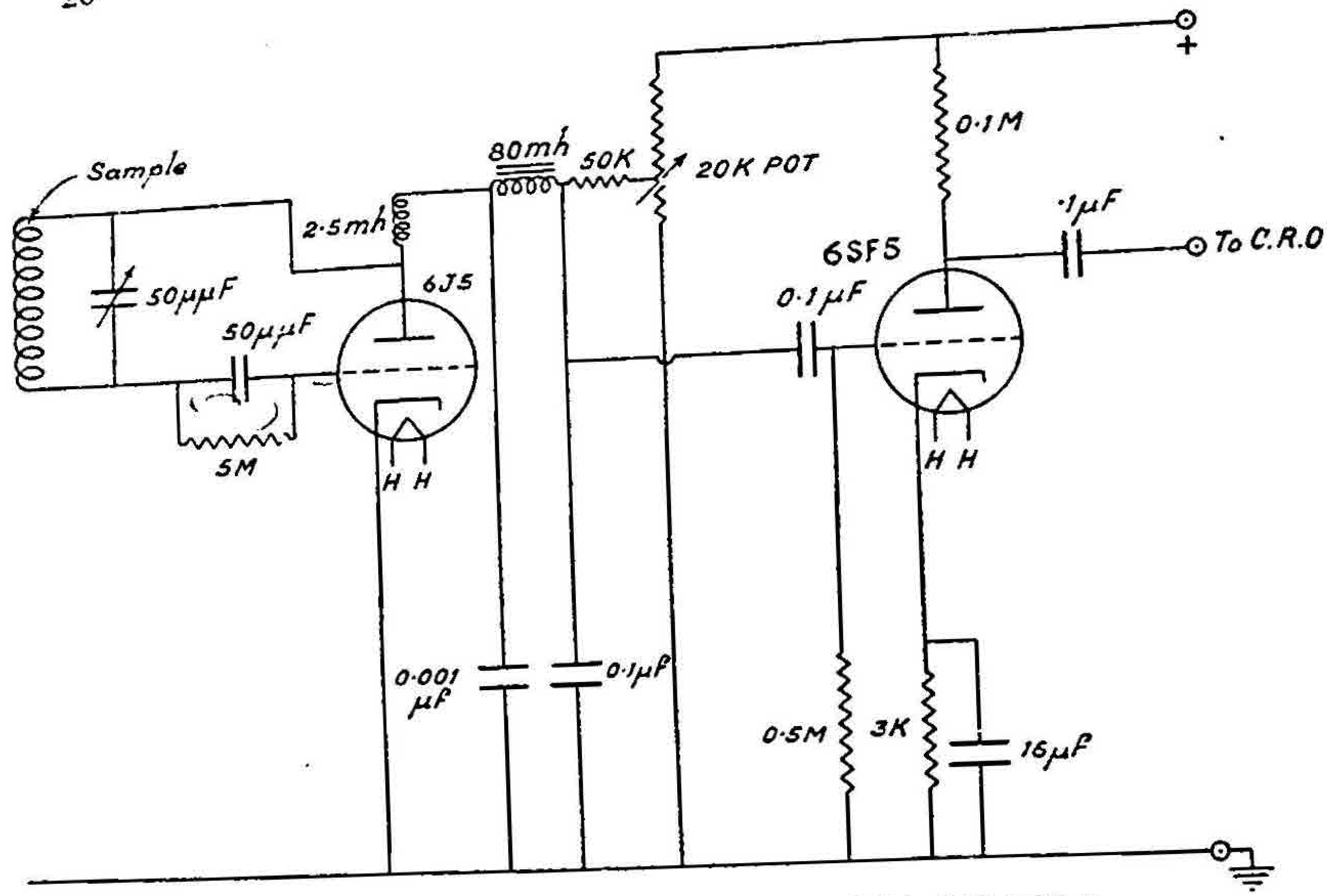
The self-quenched super-regenerator has been used to obtain nuclear magnetic resonance signals and has been found to be simple and sensitive. Experiments with the use of a r.f. coil capable of being rotated with respect to the magnetic field have indicated that the apparatus could be made to respond to induction or absorption. The sensitivity of the apparatus has been determined and is about ten times less than ultimate possible with the bridge method.

## 1. Introduction

There are several methods of observing the phenomenon of nuclear magnetic resonance. They are (*a*) the absorption bridge method (Bloembergen, Pound, Purcell, 1948), (*b*) the nuclear induction method (Bloch, 1946), (*c*) the super-regenerative method (Roberts, 1947), (*d*) the regenerative oscillator method (Roberts, 1947) and (*e*) the pulse method (Torrey, 1949). The first two offer the ultimate signal to noise ratio and sensitivity. The next two are by far the simplest. The super-regenerative oscillator has a simpler version, namely, the self-quenching type. This, however, is not a mere variation of the super-regenerator, for it has many advantages of its own. Apart from the simplicity, the particular quench wave form generated by self-quenching is best suited for high sensitivity. These considerations made an investigation of the use of the self-quenched super-regenerator for observing nuclear magnetic resonance desirable and in what follows the results of the investigation are set forth.

## 2. The Apparatus

A familiar self-quenching circuit has been chosen. Here the self-quenching is performed by the large grid leak resistance. The circuit is shown in Fig. 1. The circuit functions at all radio frequencies and has been used at frequencies above 1 Mc/s. The quench frequency is 20 Kc/s. The oscillator coil is wound on glass forms and is capable of being placed along with its shield within the $\frac{3}{4}''$ gap of the electromagnet. The magnet pole-pieces are of the truncated pyramid type and have a pole face area $3'' \times 3''$.




SELF QUENCHING SUPER-REGENERATOR

FIG. 1

The main exciting coils are of thin wire and at a current of 1·5 amperes through them, a field of 6000 oersteds can be obtained in the ¾" air gap. An extra pair of coils are provided on the magnet limbs through which a 60 cycle alternating current of magnitude 1 to 3 amperes can be sent by means of a transformer. The magnetic field can be stabilized to a very high degree of stability by a simple method described by the author elsewhere (Suryan, 1952). The audio output of the super-regenerator is fed to a Cossor cathode-ray oscillograph whose linear sweep is synchronized with the mains frequency.

The sample under investigation is placed inside the r.f. coil. With the alternating current suitable to give 10 oersteds sweep, it is easy to locate the resonance as the magnetic field is varied by means of a rheostat because one sees a train of waves pass the screen of the oscillograph on passing through resonance.

## 3. OPERATION

It is estimated that the noise-muting sensitivity of the super-regenerator is of the order of 10 μV. This is particularly of importance when the apparatus is used to respond to very small signals under nuclear induction conditions. Under all conditions of operation the oscillator functions coherently. Otherwise, the analysis of the oscillations into a fundamental and a number of side band frequencies is of no meaning. The oscillator is most sensitive when it is just coherently oscillating. The super-regenerator can respond to both nuclear induction and absorption. Roberts who was the first to suggest the use of a super-regenerator for observing nuclear magnetic resonance mentions that his apparatus respond to nuclear induction effect a voltage being induced in the r.f. coil by the precessing nuclei. On the other hand, Williams and Zimmerman mention that their super-regenerator responded to absorption of radio frequency energy. In the present investigation experiments have been performed to know the particular mode of operation.

It will be recalled that the nuclear induction and absorption effects behave differently with respect to r.f. power level. Absorption effects are pronounced only at small power levels and saturation of the sample sets in at higher power levels. Induction, on the other hand, approaches a maximum as the power level is increased. Therefore it was decided to vary the power level of operation, or to be more precise the effective r.f. magnetic field was varied to find whether the signal varied accordingly. It is inconvenient to vary the power level of the oscillator by adjusting the plate supply voltage because that by itself changes the mode of operation and sensitivity. Therefore the following arrangement was adopted. The r.f. coil was wound on a small glass tube and the substance was placed inside it in a thin-walled glass bulb. The coil had its end faces vertical and the coil could be rotated about a vertical axis so as to set the axis of the coil at any desired angle with respect to the direction of the magnetic field. It will be noted that only one rotating component of the plane polarized r.f. field is effective in stimulating absorption or emission by precessing nuclei in a magnetic field. The amplitude of the effective circularly polarized component is given by half the transverse component of the plane polarized r.f. magnetic field in the coil, the component along the magnetic field is ineffective. Thus on rotating the coil from the transverse to the longitudinal position the effective r.f. magnetic field varies as cos $\theta$, $\theta$ being the angle of inclination of the coil axis to the transverse direction and it varies from zero to a maximum determined by the operating conditions. The signal which is dependent on the effective r.f. magnetic field varies as the coil is rotated.

The curve in 2 (*a*) shows the variation when the plate voltage was low and the quenching was just insufficient to stop the oscillations, where nuclear resonance absorption was prominent. It is seen that the curve shows a maximum and then falls off, the maximum occurring where the effective power level is optimum. On the other hand, the curve 2 (*b*) obtained with

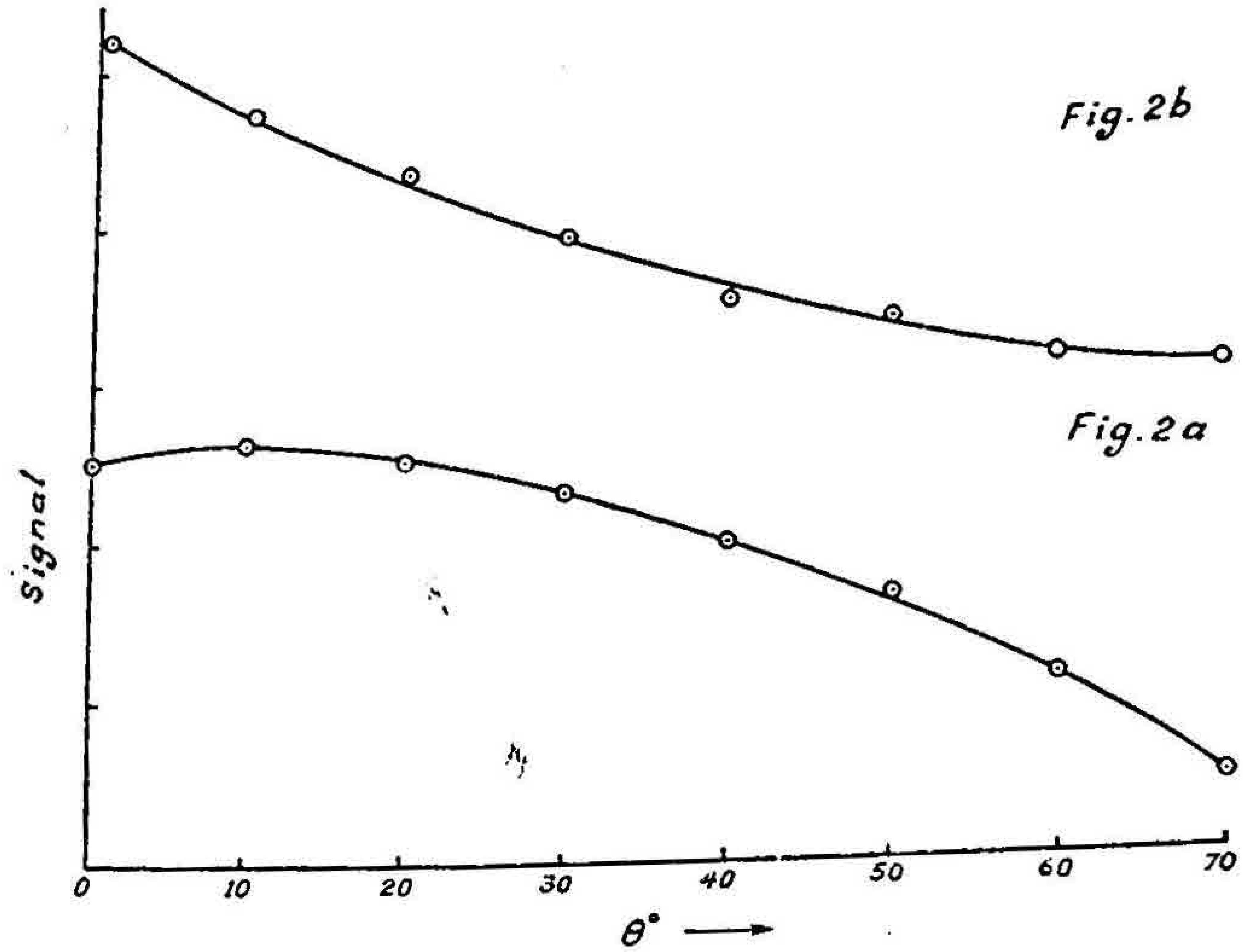



FIG. 2

higher plate voltage and quenching more pronounced, is different and shows a steady decrease with fall in r.f. field. Also it must be remembered that while the absorption effect depends on the effective power level, induction involves cos $\theta$ as the induced voltage in the coil due to precession will be proportionately smaller because of the inclination of the coil. Thus the type of a nuclear resonance signal obtained in the super-regenerator can be found. Also this experiment shows that only the magnetic field component of the R.F. is responsible for stimulating nuclear magnetic resonance.

In order to convey an idea of the overall sensitivity, one set of data of signal *vs.* quantity of substance has been presented in Fig. 3. It is found that the response is not linear and the smallest quantity of water in which proton signals have been observed with an overall signal noise ratio equal to 4, at 1500 oersteds is 1/20 c.c. For comparison the ultimate signal noise ratio for 1/20 c.c. of water can be calculated for the band widths employed by means of Pound, Purcell, and Bloembergen's (1948) formula. It comes to be 25. That is, the present arrangement has perhaps an overall signal

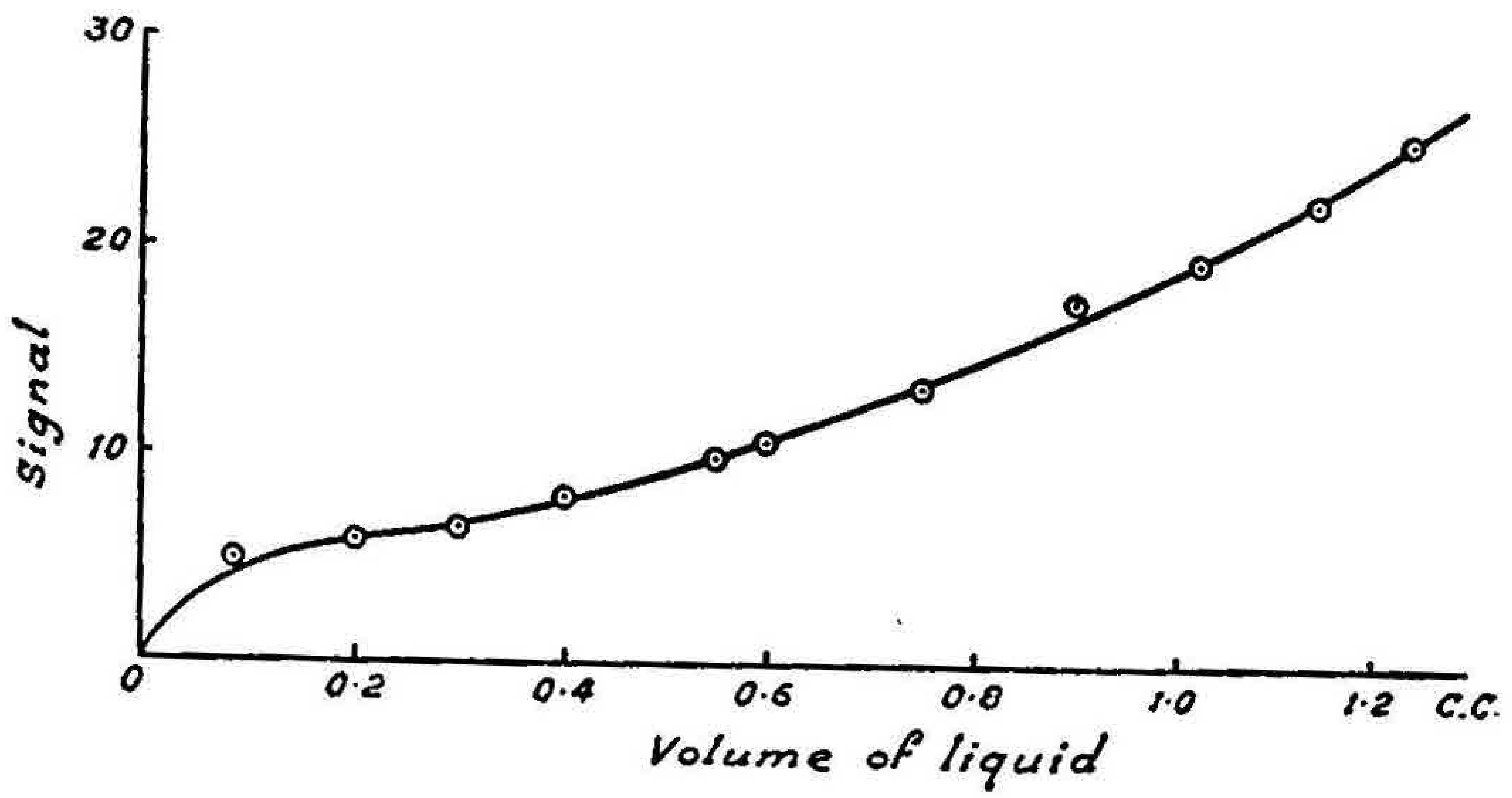



FIG. 3

to noise ratio not less than one-tenth of the ultimate possible with the bridge method. On the other hand, the r.f. gain is very high and the effect of hum and microphonics are less. The large noise limits the value of the smallest observable signal. It has been found possible to operate the circuit to obtain well-defined nuclear resonances at 200 oersteds field strength. It should be possible to extend the technique to 50 oersteds.

As already mentioned, the super-regenerator spectrum consists of a number of side bands and resonances due to all of them could be obtained if the A.C. modulation is large enough. It is found that for proton resonances in solutions of paramagnetic substances, the signal increases in magnitude as the A.C. modulation is increased and then decreases with further increase of A.C. modulation.

Application of the phenomenon of nuclear magnetic resonance to other fields of study requires a simple and sensitive apparatus and the self-quenched super-regenerator has been found to meet the requirements. It is of particular use where accurate measurement and monitoring of magnetic fields are concerned. The apparatus described in this paper has been working satisfactorily over a period of many years in this laboratory and has been used for a variety of experiments (Suryan, 1951).

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