THE RADIOFREQUENCY BRIDGE METHOD OF DETECTING NUCLEAR RESONANCE SIGNALS

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This is to certify that the

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THE RADIOFREQUENCY BRIDGE METHOD OF DETECTING NUCLEAR RESONANCE SIGNALS

By

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Alfred Edward Villaire Jr.

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I The Nature of the Investigation

Pauli (i) first suggested the existence of a nuclear magnetic moment in 1924. It was later pointed out that a nucleus in a magnetic field would have an energy characteristic of the orientation of its magnetic moment. Güttinger (ii) and Majorana (iii) pointed out, in the early 1930's, that under the proper conditions the magnetic moment would reorient itself in the magnetic field. Since that time, physicists have been devising instruments to detect the energy absorbed by such a reorientation. It might be pointed out that the energy change involved in the reorientation of one nuclear magnetic moment (say that of hydrogen) is of the order of 10^{-19} erg. The first successful resonance absorption experiment was reported in 1946 by Purcell, Torrey and Pound (iv).

This thesis reports an investigation of such instruments undertaken in this laboratory. The circuits used, while not original or new, have just fairly recently been adapted for this type detection. Particular attention has been given to a study of the relative performance of two types of bridge circuits.

II Nuclear Resonance

Associated with a nucleus of non-zero spin is a magnetic moment

(1)
$$\bar{\mu} = g \frac{e}{2Mc} \bar{p} ,$$

where $\bar{p}$ is the angular momentum of the nucleus, e the proton charge, M the proton mass, c is the velocity of light, and g, called the gyromagnetic ratio, is a number characteristic of a given nuclear species in a given nuclear energy state.

If a nucleus of magnetic moment $\bar{\mu}$ is placed in a static magnetic field $\bar{H}_0$, the magnetic moment vector (or the angular momentum vector) will precess about $\bar{H}_0$ with the frequency

(2)
$$\bar{\omega}_0 = -g \frac{e}{2Mc} \bar{H}_0$$

regardless of the angle between $\bar{\mu}$ and $\bar{H}_0$. This is called the Larmor precession frequency.

The potential energy of a magnetic moment in a magnetic field $\bar{H}_0$ is, apart from an additive constant,

(3)
$$U = -\bar{\mu} \cdot \bar{H}_0 = -g \frac{e}{2Mc} \bar{p} \cdot H_0 .$$

For the proton, with which this paper will be entirely concerned, the magnitude of the projection of $\bar{p}$ along the field direction is $\frac{1}{2}\hbar$. The $\frac{1}{2}$ is the value of the spin, I, for protons. This factor gives rise to two (2I + 1) Zeeman energy levels. Thus,

(4)
$$U = \mp \frac{1}{2} g \frac{e\hbar}{2Mc} H_0 .$$

The factor $e\hbar/2Mc = \mu_0$ is called the nuclear magneton, and has the value $\mu_0 = 5.049 \times 10^{-24}$ erg/gauss (1). Finally, we may write

(4')
$$U = \mp \frac{1}{2} g \mu_0 H_0 .$$

The lower (negative) energy characterizes protons with $\bar{\mu}$ (and $\bar{p}$) parallel to the field $\bar{H}_0$ and the upper energy level represents protons "anti-parallel" to the field.

Assuming it is possible to cause the protons in the magnetic field to absorb energy, protons in the lower state would be raised to the upper state. The energy necessary per proton to accomplish this is

(5)
$$\Delta U = U(\text{upper}) - U(\text{lower}) = g \mu_0 H_0 .$$

For 8,000 gauss one obtains $\Delta U = 24 \times 10^{-20}$ erg.

The detection of the absorption of this small amount of energy would be indeed difficult. However, the use of a sample of finite size insures the presence of millions of protons or possible absorbers.

If one applies the Bohr frequency condition to this transition, he obtains

(6)
$$h\nu_0 = \Delta U = g \mu_0 H_0 .$$

Note that this is simply the Larmor equation (in scalar form) where $\nu_0 = \omega_0 / 2\pi$.

This means that in order to produce transitions one must apply energy of just the Larmor frequency. This act of the nuclei, absorbing energy at one frequency only, is called nuclear resonance.

For protons in a field of 8,000 gauss, $\nu_o = \Delta U/h = 37$mc. This is in the short wave radio range of the electromagnetic spectrum.

III Methods of Detecting Nuclear Resonance

There are several methods of detecting the resonance. One of these is the molecular beam magnetic resonance method of Rabi (2,3). Others involving strictly electronic equipment are the bridge method of Purcell and the "bridgeless" (oscillator-receiver) methods of Roberts (4) and Williams (5).

A. The Super-regenerative Receiver

By means of this instrument resonances are observed by noting the variation in the output of a super-regenerative oscillator when condition (6) is realized. A super-regenerative oscillator consists of a vacuum-tube circuit which would execute normal oscillations at a radiofrequency were it not for an audiofrequency "quench voltage" which is applied to one of the tube elements in such a manner as to prevent the radiofrequency oscillations from attaining their normal amplitude. The sample is placed in the tank coil of the oscillator and acts on this coil at resonance.

The output of the super-regenerative oscillator is fed into an audio amplifier or an a.m. receiver and thence to a cathode ray oscilloscope. The resonance absorption peaks are displayed directly on the oscilloscope.

We investigated the super-regenerative method for about a year and a half. In that time many different circuits were tried; the

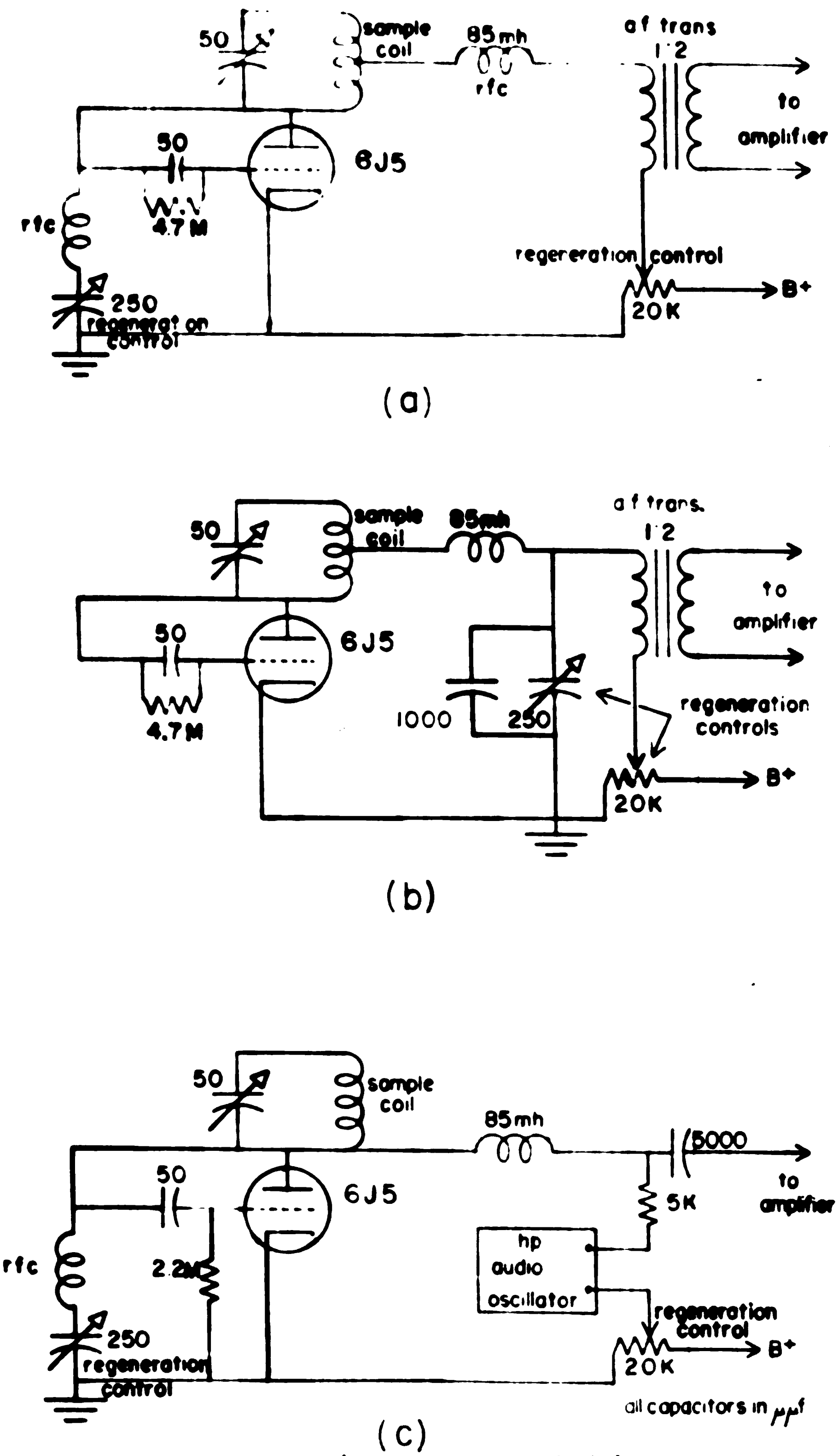


Figure 1 Super-regenerative oscillators (a) & (b) self-quenched, (c) externally quenched.

three shown in Figure 1 worked well. Two are "self-quenched" the third externally quenched (6). One advantage of the super-regenerative receiver over the bridge method is that the frequency of operation may be varied over a rather large range by merely tuning the tank circuit. This greatly simplifies the search for resonances. Such a search involves sweeping either the magnetic field or the frequency; in general, a smooth variation in the magnetic field over a large range is difficult to effect.

The spectrum of a super-regenerative oscillator consists of a central frequency ν_0 plus a large group of side-bands of frequency $\nu_0 \pm n\nu_q$ where n is an integer and ν_q is the quench frequency. The relative intensities of the various spectral components depend upon the conditions at which the oscillator is operated. Any of the frequencies

$$\nu = \nu_0 \pm n\nu_q \qquad (n = 0, 1, 2, \cdots) \tag{7}$$

is capable of producing a resonance absorption provided condition (6) is fulfilled. This fact can be used to advantage in search for resonances, as it is usually easier to recognize a series of absorption peaks corresponding to the frequencies in equation (7) than to recognize a single peak which might be lost in the random noise signals. A disadvantage of the side-bands is that it is often quite difficult to pick out one of the frequencies (7) which is causing a resonance. This is especially true if Ho is modulated by a varying field of appreciable amplitude. (A periodic modulation is necessary for oscilloscope presentation.)

The great disadvantage encountered was that whenever the receiver was adjusted so as to be very sensitive, it saturated the sample (7).

It might be well to point out that certain circuits employing external quench gave signals which showed no saturation effects; however, this type circuit was abandoned because it seemed rather insensitive compared to the internally quenched type.

The saturation effect may be explained as follows:
Only protons in the lower (parallel) energy state may absorb energy to be detected as a resonance. The Boltzmann distribution function shows an excess of protons in the lower energy state and there are several relaxation mechanisms operating within the sample which return the nuclei from the upper state to the lower. If, however, we send in a radiofrequency signal of too high an intensity, the natural relaxation mechanisms will be unable to compete and the lower level rapidly becomes depopulated. This, of course, changes the shape of the absorption line, destroying its symmetry. The effect may even annihilate the resonance in samples which have no paramagnetic constituents. Since it was the line shape itself which was to be investigated, another method of detection was sought.

B. The Radiofrequency Bridge

The radiofrequency bridge method of detection employs essentially three separate components: the oscillator, the bridge (containing the sample coil), and the detector-amplifier (radio receiver). Since the oscillator and the detecting mechanism (bridge) are separate, one may place an attenuator between them, thereby reducing or removing the saturation effect without appreciably affecting the sensitivity.

~~side bands~~. Also a dispersion signal as well as an absorption may be obtained from the bridge. The bridge is the essence of simplicity, as it is just a passive quadrupole network. A detailed description is given in the following section.

IV Radiofrequency Bridge Circuits

A. General Theory

The circuits used are of the "parallel" bridge type (8). A parallel bridge consists of two circuits which receive the same input signal and whose outputs are connected. Theoretically, the output signal of one "arm" of the bridge may be made equal in amplitude to and 180° out of phase with the output signal of the other "arm". In this manner a null balance is acheived.

The sample to be investigated is placed in one arm of the bridge; at nuclear resonance the balance is disturbed and a signal is passed from the oscillator to the receiver through the bridge. This radiofrequency signal is modulated by the resonance absorption or dispersion signal. This amplitude modulation is detected by an a.m. receiver and then presented on an oscilloscope or a strip chart recorder.

In general, the parallel bridge may be represented schematically as follows:

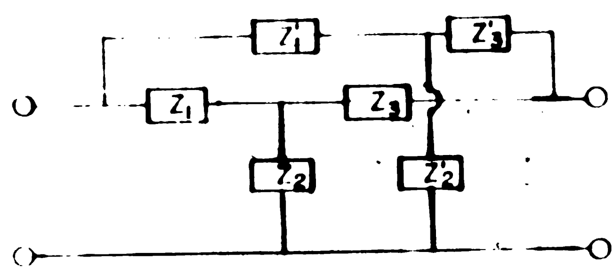


Figure 2.

In order to investigate the balance (null) conditions each arm may be taken separately and represented thus

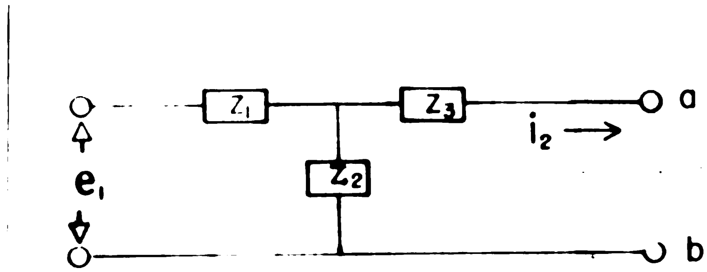


Figure 3.

e_1 being the applied voltage and i_2 the output current. The general circuit equations for such a network are

(8)

$$e_1 = z_{11} i_1 + z_{12} i_2$$

$$e_2 = z_{21} i_1 + z_{22} i_2 \,.$$

By shorting points a and b one obtains the representation

(9)

$$e_1 = z_{11} i_1 + z_{12} i_2$$

$$0 = z_{21} i_1 + z_{22} i_2 \,.$$

These may be solved for the ratio $\frac{e_1}{i_2}$ yeilding

(10)

$$\frac{e_1}{i_2} = -\frac{z_{11} z_{22}}{z_{21}} + z_{12} \,.$$

This ratio is called the transfer impedance, Z_T. By the reciprocity theorem $Z_{12} = Z_{21}$; hence,

(11)

$$Z_T = -\frac{z_{11} z_{22}}{z_{12}} + z_{12} \,.$$

The input impedance Z_{11} is that presented to an observer "looking" into the circuit from the left. This is seen to be $Z_1 + Z_2$. The output impedance Z_{22} is that seen looking into the circuit from the right. This is $Z_3 + Z_2$. The impedance common to both input and output is $Z_{12} = Z_2$. Substituting these into (11) one obtains

(12)
$$Z_T = \frac{e_1}{i_2} = -\left(Z_1 + Z_3 + \frac{Z_1 Z_3}{Z_2}\right) .$$

In a similar manner, one obtains for the other arm of the bridge

(13)
$$Z_T' = \frac{e_1}{i_2'} = -\left(Z_1' + Z_3' + \frac{Z_1' Z_3'}{Z_2'}\right) .$$

In the bridge circuit, Figure 2, it is seen that the output terminals of the two arms are connected. This means i_2 and i_2' flow in the same circuit and, since we want a null, their sum must be zero:

(14)
$$\dot{i}_2 + \dot{i}_2' = 0 .$$

Employing (12) and (13), one obtains

(15)
$$\frac{e_1}{Z_T} + \frac{e_1}{Z_T'} = 0 \quad \text{or}$$

$$Z_T + Z_T' = 0 .$$

Finally, this becomes

(16)
$$Z_1 + Z_3 + \frac{Z_1 Z_3}{Z_2} + Z_1' + Z_3' + \frac{Z_1' Z_3'}{Z_2'} = 0 .$$

This is the general equation of balance for any parallel type bridge. In later sections it will be applied specifically to the two bridges used.

Relation of the Bridge Signal to the Nuclear Susceptibilities

Consider the tuned circuit containing the sample coil,

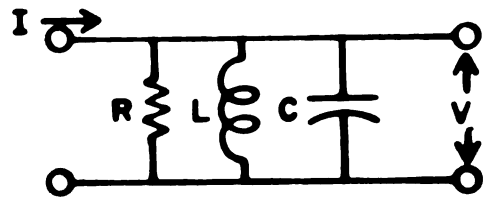


Figure 4.

where R is the equivalent shunt resistance of the coil. The inductance of the coil may be represented by

(17)
$$L = L_o[1 + 4\pi q(\chi_e + \chi_n)].$$

L_0 is the inductance of the coil without the sample in place and q is a filling factor. If the radiofrequency field in the coil were homogeneous, q would be the fraction of the coil volume filled by the sample. χ_e represents the various electronic susceptibilities and χ_n is the nuclear susceptibility. The inductance may be rewritten as

(18)
$$L = L_o(\mu_e + 4\pi q\chi_n)$$

where $\mu_e = 1 = 4\pi q\chi_e$ would be the permeability of the sample if it had no nuclear moment. The electronic susceptibilities have no resonance properties near the nuclear resonance, so μ_e may be considered a constant for this calculation. The nuclear susceptibility has the value χ_o for any magnetic field which does not satisfy the resonance condition (6). χ_n changes markedly on passing through the resonance:

$$\chi_o \cong 10^{-7}, \ \chi_{n\,res.} \cong 10^{-5}.$$

When the bridge is balanced, the L-C combination is very close to a resonance

(19)
$$\omega C = \frac{1}{\omega L_o \mu_e}$$

where ω is the frequency of the signal generator and where the value of $4\pi q \chi_o$ has been neglected. This condition does not change appreciably at nuclear resonance. The input admittance at or near nuclear resonance is

(20)
$$Y = \frac{1}{R} + j\left[\omega C - \frac{1}{\omega L_o(\mu_e + 4\pi q \chi_n)}\right] .$$

Making use of (19) and the fact that $|4\pi q \chi_n| << 1$, this becomes

(21)
$$Y \cong \frac{1}{R} + j\,\frac{4\pi q\,\chi_n}{\omega L_o \mu_e} .$$

Writing Q for $R/\omega\mu_e L_o$ and $\chi' - j\chi''$ for χ_n this becomes

(22)
$$Y = \frac{1}{R}\left[\,1 + 4\pi q Q \chi'' + j\,4\pi q Q \chi'\,\right] .$$

Notice that χ'', the imaginary part of the susceptibility, leads to a real or dissapative term in Y. This means that the absorption is proportional to χ''.

When the circuit is supplied by a constant current source I, the potential drop across it is

(23)
$$V = I/Y = IR\left[\,1 + j\,4\pi q Q \chi_n\right]^{-1} .$$

Writing V_o for IR and assuming that $|4\pi q Q \chi_n| << 1$, (23) may be written

(24)
$$V \cong V_o(1 - 4\pi q Q \chi_n).$$

This voltage V is joined with an out of phase signal of approximately equal amplitude from the other arm of the bridge. Let this second voltage be denoted by $-V_1$ and replace χ_n by $\chi' - j\chi''$; then the signal fed to the receiver is proportional to

(25)
$$v = V - V_1 = V_o - V_1 - 4\pi q Q V_o(\chi'' + j\chi').$$

One may think of this output voltage as being the sum of two vectors, $(V_o - V_1)$ and

(26)
$$v_x = -4\pi q Q V_o(\chi'' + j\chi').$$

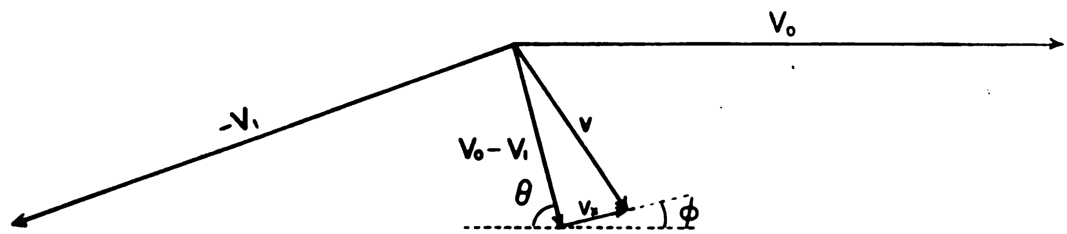


Figure 5. Voltages present at the bridge output terminals.

From the cosine law;

(27)
$$|v|^2 = |V_o - V_1|^2 + |v_x|^2 + 2|V_o - V_1||v_x| \cos(\theta + \phi).$$

The phase angle of v_x with respect to V_o is ϕ. This angle is specified by

(28)
$$\tan\phi = \frac{\chi'}{\chi''}.$$

From this can be obtained the relations

(29)

$$\cos\phi = \frac{1}{\sqrt{1+\tan^2\phi}} = \frac{\chi''}{\chi} \quad \text{and}$$

$$\sin\phi = \frac{\chi'}{\chi}.$$

Making use of these and the expansion of cos $(\theta+\phi)$ and neglecting the very small $|V_\chi|^2$, one obtains, finally,

(30)

$$|V|^2 \cong |V_0 - V_1|^2 + 2|V_0||V_0 - V_1|\, 4\pi q Q(\chi''\cos\theta - \chi'\sin\theta).$$

The first term is purely radiofrequency; the second term is the modulation. The output of the a.m. receiver, assuming it is a square law detector, is then proportional to

(31)

$$8\pi q Q\,|V_0||V_0 - V_1|(\chi''\cos\theta - \chi'\sin\theta);$$

this is plotted by the oscilloscope. Two distinct cases are readily distinguishable.

Case I: $\theta = 0$ or π - The oscilloscope plots the absorption curve χ'' under this condition of pure amplitude unbalance. (See Figure 5)

Case II: $\theta = \pi/2$ or $3\pi/2$ - The oscilloscope plots the dispersion curve χ' under this condition of pure phase unbalance.

For other values of θ, mixtures of χ' and χ'' appear. They are easily recognized by their lack of symmetry.

Various theoretical considerations (9,10) lead to the curves of Figure 6 for the expected shapes of χ' and χ''.

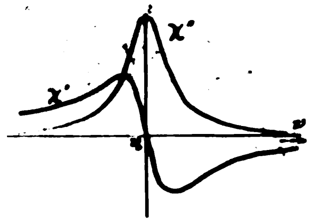


Figure 6. The behavior of the real and imaginary parts of the magnetic susceptibility near resonance. ν_0 is the oscillator frequency. The frequency of Larmor precession, ν, is changed by varying the magnetic field H_0(see eq.(2)) through the resonance value.

B. Twin "T" Bridge

Using the notation of section IV A and Figure 7, the various impedances for the twin "T" bridge are

(32) $$Z_1 = -j/\omega C_1, \quad \frac{1}{Z_2} = \frac{1}{R} + j\left(\omega C - \frac{1}{\omega L}\right), \quad Z_3 = -j/\omega C_2$$

$$Z_1' = -j/\omega C_1', \quad \frac{1}{Z_2'} = j\omega C', \quad Z_3 = R'.$$

where R is the equivalent shunt resistance of the coil. Substituting these values into equation (16) and separating the resulting equation into real and imaginary parts, one obtains that at balance

(33) $$\frac{1}{\omega^2 L} = C + C_1 + C_2\left(1 + \frac{C_1}{C_1'}\right) \qquad \text{phase balance}$$

$$\frac{1}{R} = \omega^2 C_1 C_2 \left(1 + \frac{C'}{C_1'}\right) R' \qquad \text{amplitude balance.}$$

Notice that phase and amplitude are adjusted independently by means of the tuning condensers C and C' respectively. (See section V for a numerical calculation.)

C. Purcell Bridge

Using the notation of section IV A and also that of Figure 8, the impedances for the Purcell bridge are

(34) $$Z_1 = -j/\omega C_1, \quad \frac{1}{Z_2} = \frac{1}{R} + j\left(\omega C - \frac{1}{\omega L}\right), \quad Z_3 = -j/\omega C_2$$

$$Z_1' = -j/\omega C_1', \quad \frac{1}{Z_2'} = \frac{1}{R'} + j\left(\omega C' - \frac{1}{\omega L'}\right), \quad Z_3' = -j/\omega C_2' .$$

Equation (16) must be transformed to accomodate the half wave length line which appears in Figure 8. This line acts as a transformer of ratio -1:1. This action necessitates replacing by its negative the transfer impedance of the arm of the bridge in which the line appears. Thus, equation (16) reads

(35) $$Z_1 + Z_3 + \frac{Z_1 Z_3}{Z_2} - Z_1' - Z_3' - \frac{Z_1' Z_3'}{Z_2'} = 0 .$$

Substituting the values of (34) into (35), the balance conditions are

(36) $$\frac{1}{C_1 C_2}\left(C_1 + C_2 + C - \frac{1}{\omega^2 L}\right) = \frac{1}{C_1' C_2'}\left(C_1' + C_2' + C' - \frac{1}{\omega^2 L'}\right)$$ phase balance

$$R C_1 C_2 = R' C_1' C_2'$$ amplitude balance.

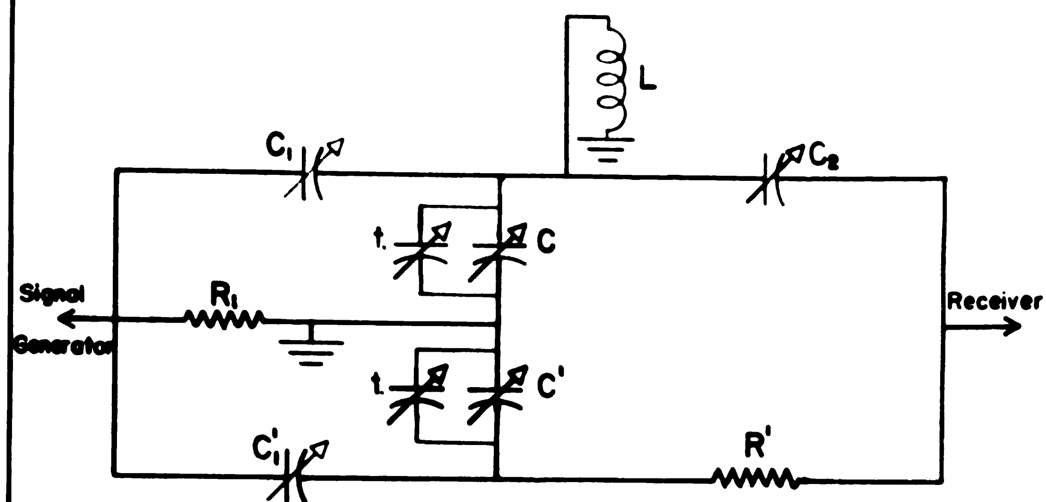
Notice that there is no convenient separate adjustment for amplitude balance, as ordinarily only C and C' are accessable for tuning.

A numerical calculation is given in section V.

V Construction and Operation

A. Twin "T" Bridge

The twin "T" bridge (11) is, except for the sample coil, entirely encased in an aluminum box. The top is readily removable for adjustment of the series condensers. These, however, are set only



R_1	$50\,\Omega$	C_2	$3\,\mu\mu f$
R'	$100\,\Omega$	C_1'	$8\,\mu\mu f$
C_1	$1\,\mu\mu f$	C,C'	$65\,\mu\mu f$ with
L	See text	t,t	$5\,\mu\mu$ trimmers.

Figure 7. Radio frequency "Twin-T" bridge (after Anderson)

once for approximate null balance and then remain fixed. All ordinary balance adjustments are made by means of the parallel tuning condensers and their trimmers which can be manipulated from the outside by means of the four knobs (see Figure 14.) The sample coil is connected to the circuit by means of about ten inches of half-inch brass tubing. This tube is grounded to the box and axially through it runs the lead to the tuning condenser C. The sample coil itself consists of about seven turns of number 14 plated copper wire.

The three series condensers C_1, C_2 and C_1' are ceramic disc type trimmer condensers which are adjustable from 5 - 50 $\mu\mu f$. If smaller values are necessary, they are made up by placing several of these trimmers in series. The values shown in Figure 7 are the approximate settings for C_1, C_2 and C_1' at balance. Due to their small size, accurate measurment is difficult.

The tuning condensers C and C' are of the midget variable type. Their range is about 10 - 65 $\mu\mu f$. The trimmers on these are of a special type. That on C is made up of two brass discs; one is on a micrometer screw and may be advanced toward the other giving a very fine adjustment. (This is necessary due to the extreme sharpness of the null.) The trimmer on C' is a two plate variable condenser and obtains its slow action by means of a worm gear drive.

When the bridge is set for a null at 33.5 mc., C is about 65$\mu\mu f$ (including about 12$\mu\mu f$ of distributed capacitance in connections to the coil) and C' is about 39 $\mu\mu f$.

If one inserts into equation (33) these values of C and C' and the values shown in Figure 7 for the other components he obtains

$$L \cong .32\ \mu h$$

$$R \cong 13\ K\Omega$$

$$Q = \frac{R}{\omega L} \cong 190.$$

Computation of these values employed $\omega^2 = (2\pi \nu)^2 = 4.43 \times 10^{16}$ /sec ^{2} which corresponds to the frequency ν = 33.5 mc. at which the bridge was balanced.

The resistor R is used to present an impedance match to the 50Ω co-ax line which connects the bridge to the oscillator.

B. Purcell Bridge

This bridge is similar to one used by Bloembergen, Purcell and Pound at Harvard (12). Its physical construction, aside from the circuit differences, is very similar to that of the twin "T" bridge. Except for the sample coil, the entire circuit is enclosed in a copper box. Ceramic trimmers are used for the series coupling condensers; the values indicated in Figure 8 for C_1, C_2, C_1' and C_2' are for a null near 34 mc.

The sample coil and connecting apparatus is the same as that used for the other bridge. The "dummy" coil L', in the other arm of the bridge is similar to the sample coil but is contained inside the case. This coil is loaded with a paraffin block to reduce its Q to a value comparable to that of the sample coil.

The tuning condensers C and C' are of the 65$\mu\mu$f midget variable type. The trimmers paralleled across them are three plate variables and constitue the fine tuning arrangement.

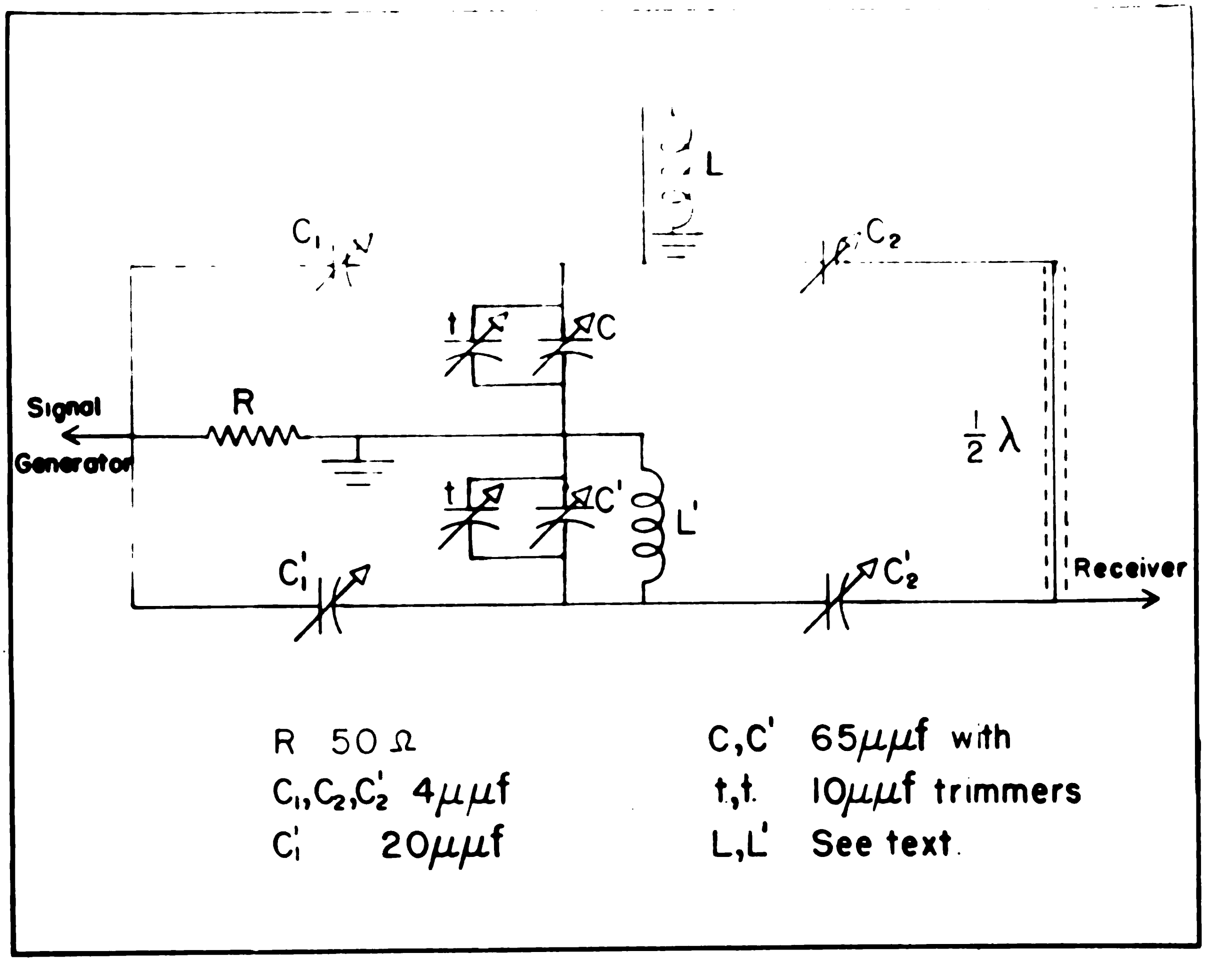


Figure 8. Radio frequency bridge (after Bloembergen, Purcell, and Pound.)

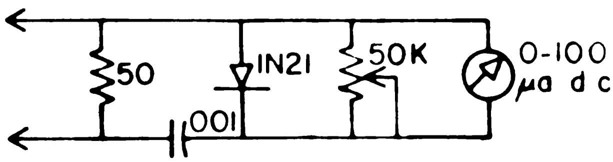


Figure 9. The detector used to balance the bridge

For a null at 33.5 mc., C is set at 68μμf (including about 10μμf in connections to the sample coil) and C' is set at 44μμf. Using the values indicated in Figure 8 for C_1, C_2 and C_2' and changing the value of C_1' to 7μμf, equation (36) yeilds

$$L' \cong .66\,\mu h$$
$$R' \cong 7.4\,k\Omega$$
$$Q' = \frac{R'}{\omega L'} \cong 53\,.$$

Computation of these values employed the results obtained for the sample coil (R,L) in the twin "T" balance conditions.

It was necessary to calculate the length of cable needed to form a half wave length line. The relation between the wave length in vacuum and in a cable with dielectric constant κ is

$$\lambda' = \frac{\lambda_{vac}}{\sqrt{\kappa}} \tag{37}$$

if one neglects the magnetic susceptibility. The coaxial cable employed had a polyethylene dielectric. This substance has a dielectric constant of 2.26 (13). For a frequency of 30 mc., $\lambda_{vac} \cong 10.0$ meters and

$$\frac{\lambda'}{2} = \frac{1}{2}\,\frac{10.0}{\sqrt{2.26}}\,m = 3.33\ m.$$

The cable actually employed was 3.41 meters long. The bridge balanced over the range 30 - 34 mc., showing that the length is not too critical.

The experimental set-up is shown in Figure 10. The output of the signal generator was taken through a variable attenuator and was then fed into the bridge. Here the radiofrequency signal could act

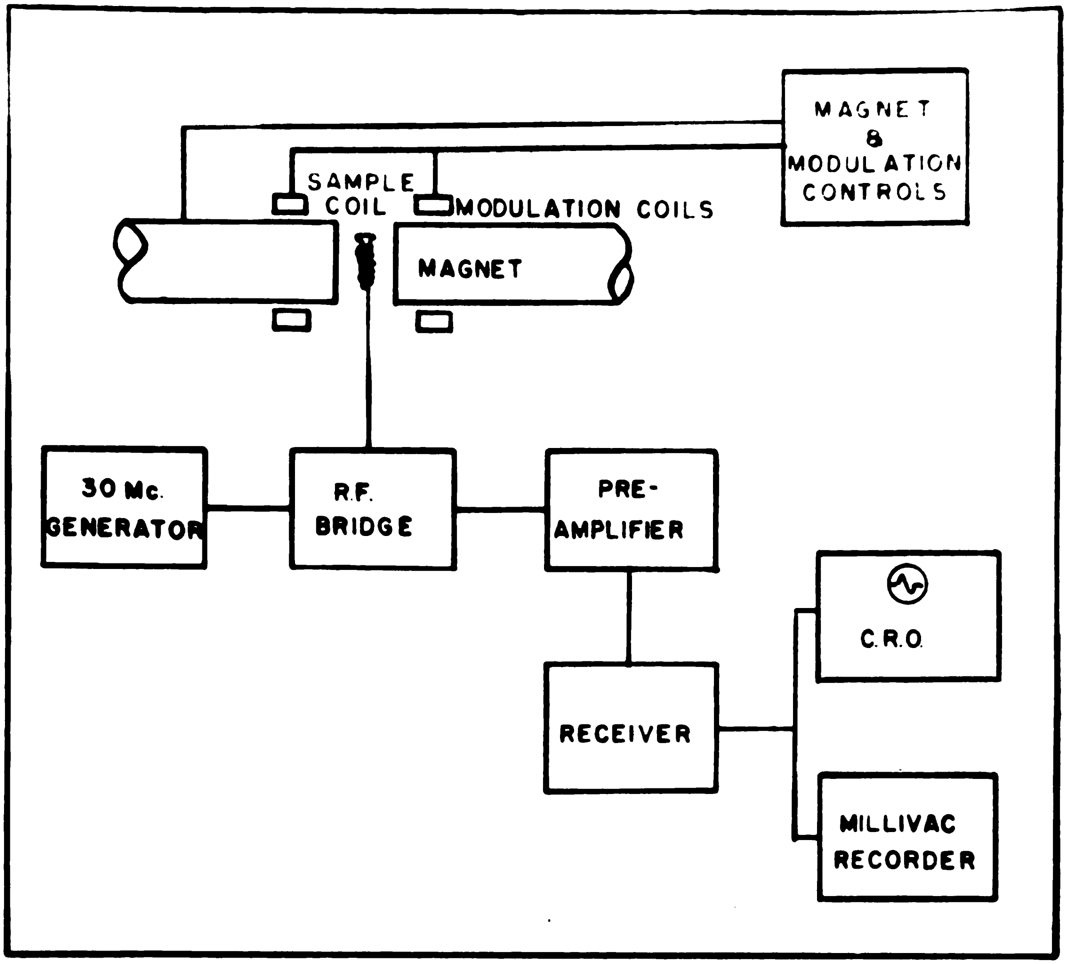


Figure10. Block diagram of the experimental arrangement.

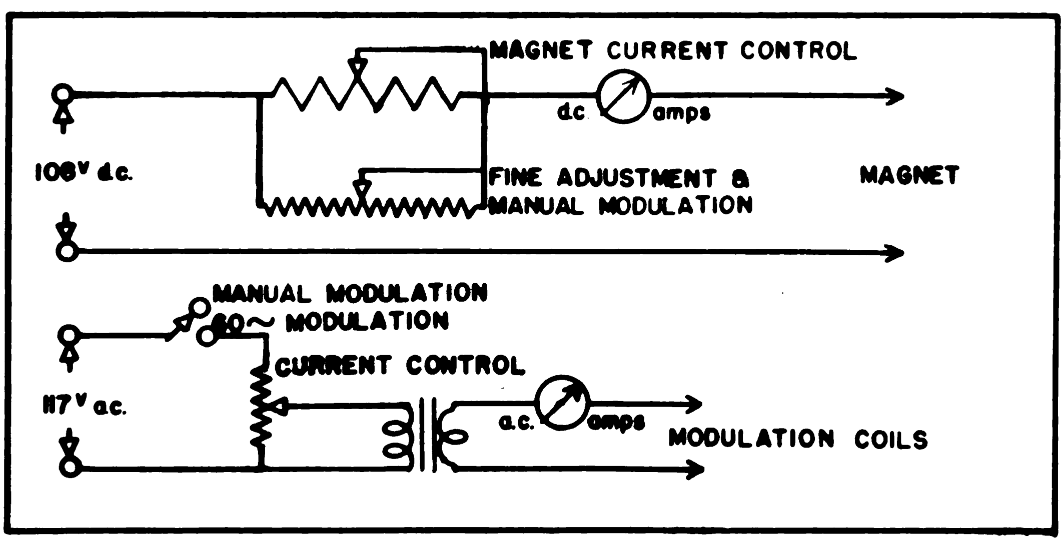


Figure11. Magnet and modulation controls.

on the sample, producing the resonance.

The sample coil was placed between the poles of a large electromagnet (14). The field produced by this magnet is variable and ordinarily was set at about 8,000 gauss. A current of 12 amperes was necessary to produce this field in a gap of 2 inches. On the pole pieces and immediately adjacent to the gap were two Helmholtz coils (the modulation coils.) A 60 cycle alternating voltage was imposed on these coils. If the static field H_0 was set near resonance value, the coils would cause the field at the position of the sample to be swept through the resonance value 120 times a second. In this manner, the resonance occurred periodically and could be viewed on an oscilloscope. The output of the bridge was fed to the receiver, a Hallicrafters SX-62. Sometimes a preamplifier was inserted between bridge and receiver to boost the signal strength and the signal to noise ratio. From the receiver, the signal was applied to an oscilloscope with sweep synchronized with the field modulation. The oscilloscope had a Poloroid Land Camera attachment with which the photographs in the following section were taken. Occasionally the receiver output was placed on a Millivac-Sanborn strip chart recorder. For this type record the field was modulated by manually operating the rheostat (see Figure 11) in the magnetic field circuit. This caused the field to pass slowly through the resonance value.

The critical problem of balancing the bridge was solved in two ways. The output of the Purcell bridge could be fed into the detector shown in Figure 9. The tuning condensers on the bridge were then adjusted first for a maximum reading on the microammeter as one of the circuits was tuned to resonance and then for a minimum on the

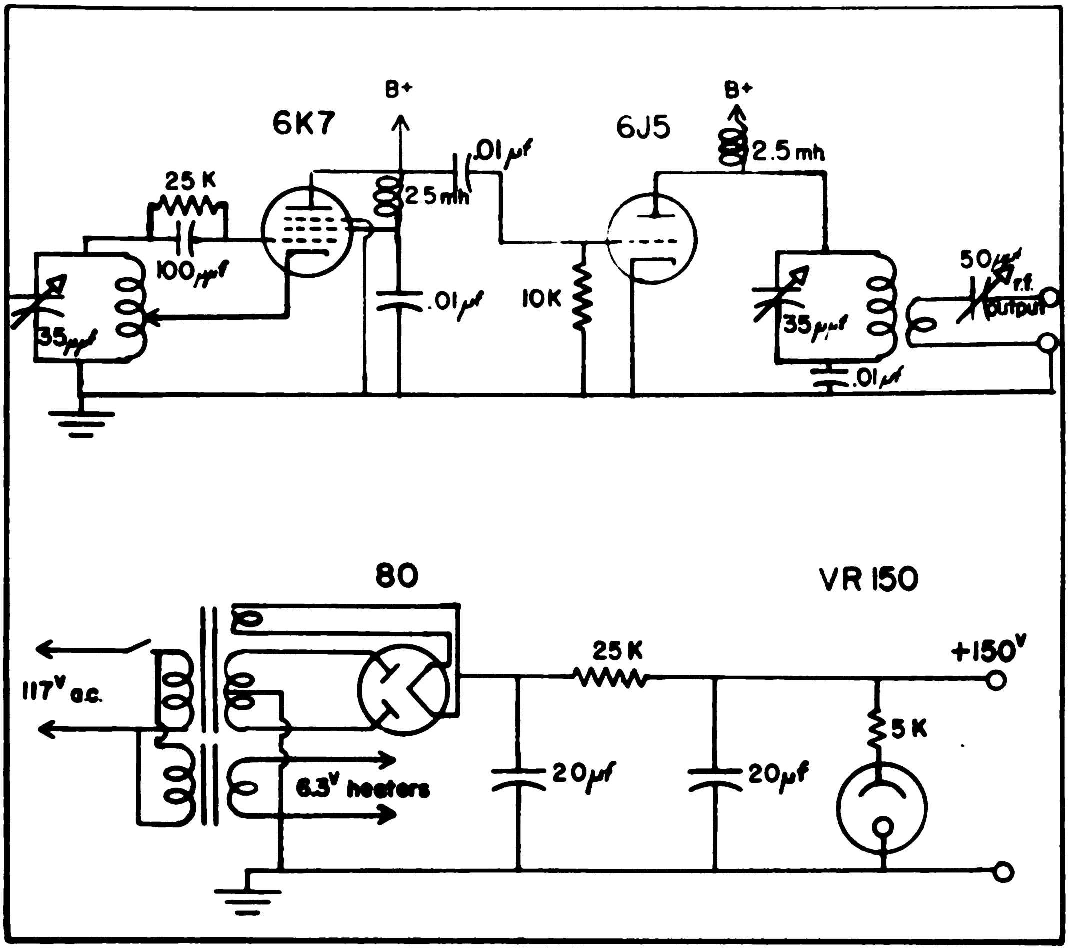


Figure 12. The 30 megacycle signal generator and power supply.

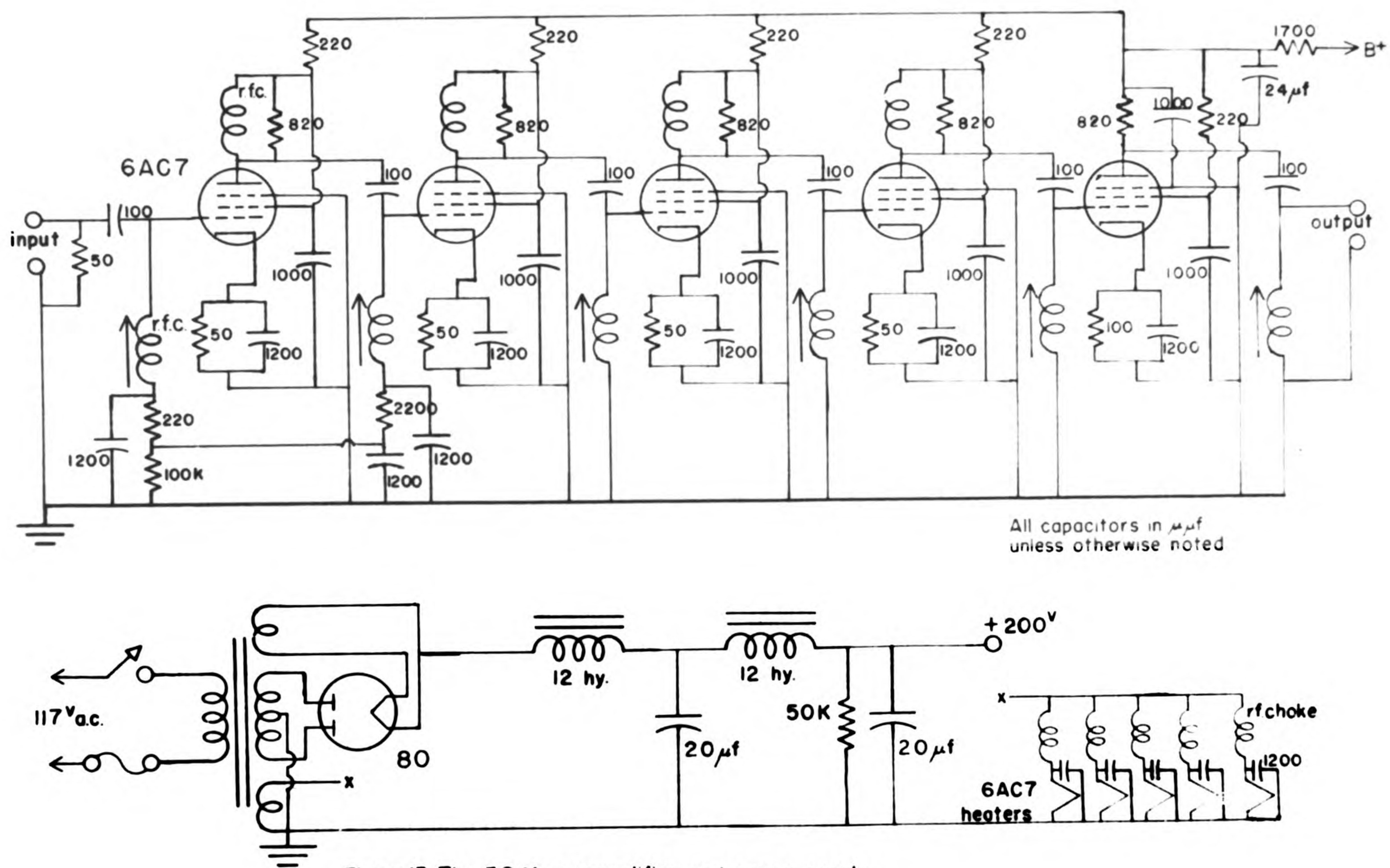


Figure 13. The 30 Mc preamplifier and power supply.

meter as the other circuit was tuned to resonance thus balancing out the output of the first circuit.

Theoretically, this method could be employed with the twin "T" bridge; however, because of the very small series coupling capacitors the output of this bridge was small and a somewhat more sensitive detector would have been necessary.

The other method employed for balancing either bridge was to observe the pattern on the oscilloscope. The trace was rather smooth unless the bridge was balanced; at balance, the characteristic random noise appeared on the screen. The resonance could usually then be observed by adjusting the field to the proper value.

VI Results and Apparatus Photographs

The following set of photographs indicates the type of results obtained with the two bridges.

It should be noticed that the signals are reasonably like the shapes indicated in Figure 6. The performances of the two bridges are comparable as regards sensitivity and signal to noise ratio.

All the photographs are for protons except Figure 19 which shows the resonance in Fluorine. This is included to show that the instruments will detect other than proton resonances.

Also included are several photographs of the apparatus used. These photographs indicate construction details and the overall set-up.

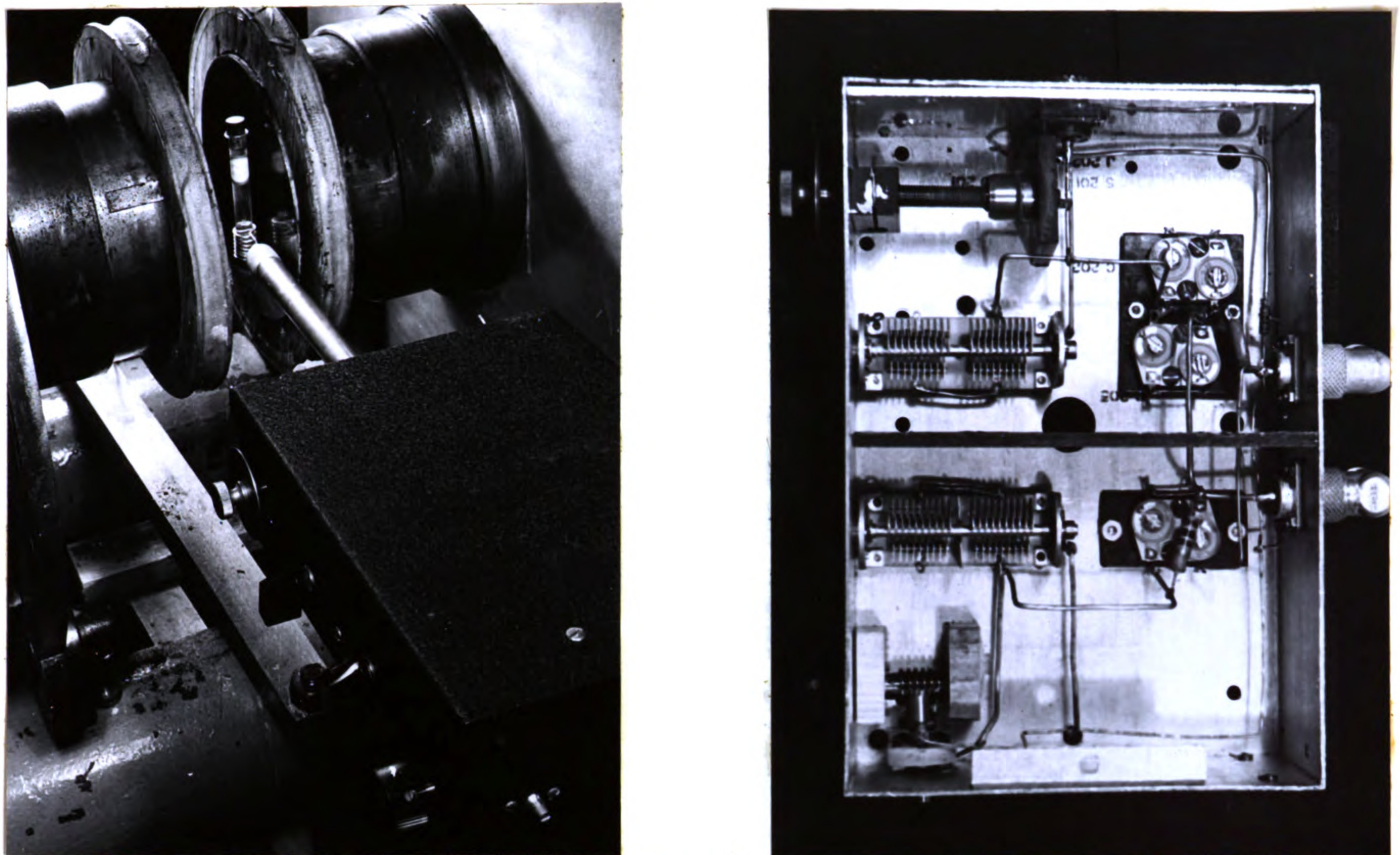


Figure 14.

The twin "T" bridge. Left: in place before the magnet. Right: interior view.

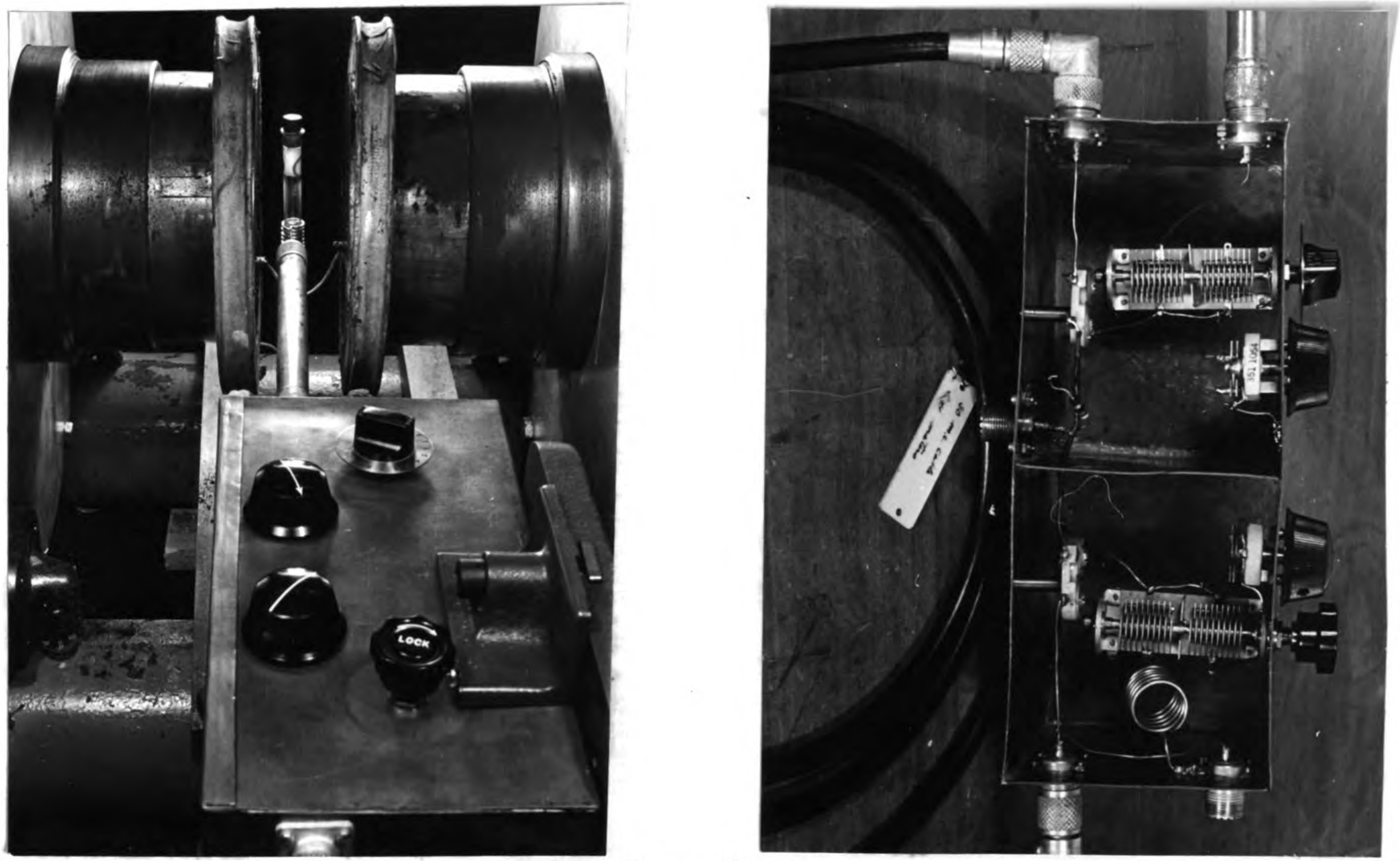


Figure 15.

The Purcell bridge. Left: in place before the magnet. Right: interior view.

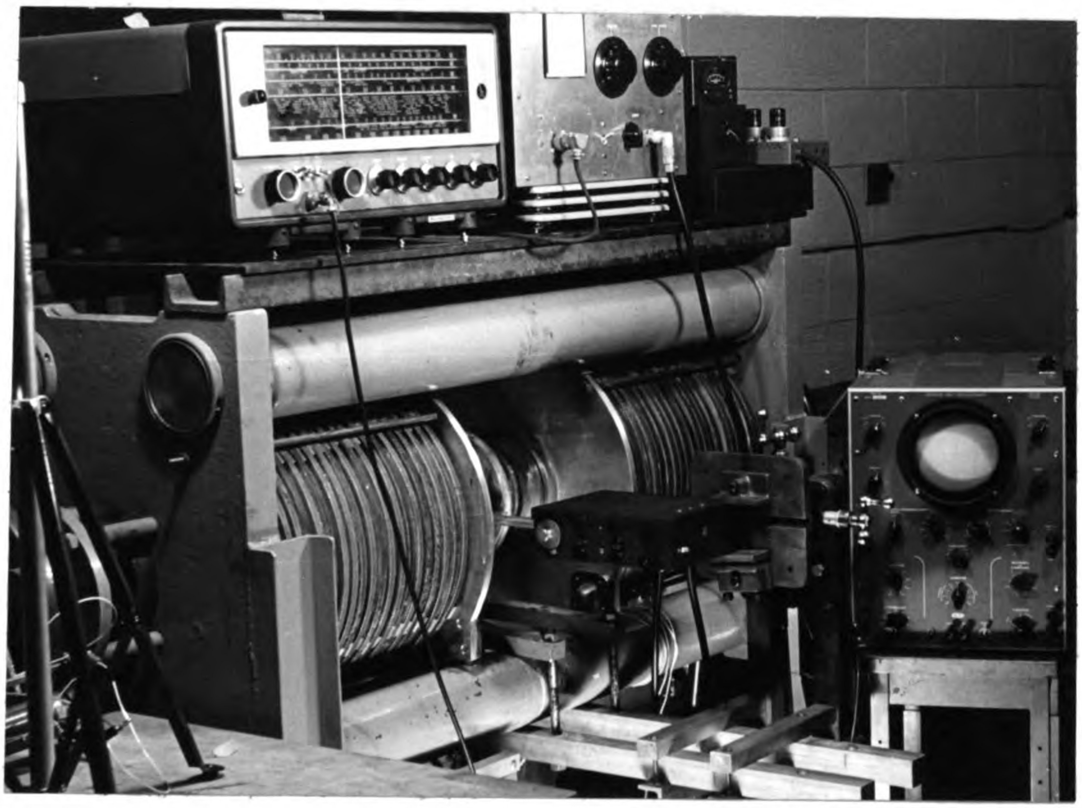


Figure 16. General view of apparatus.

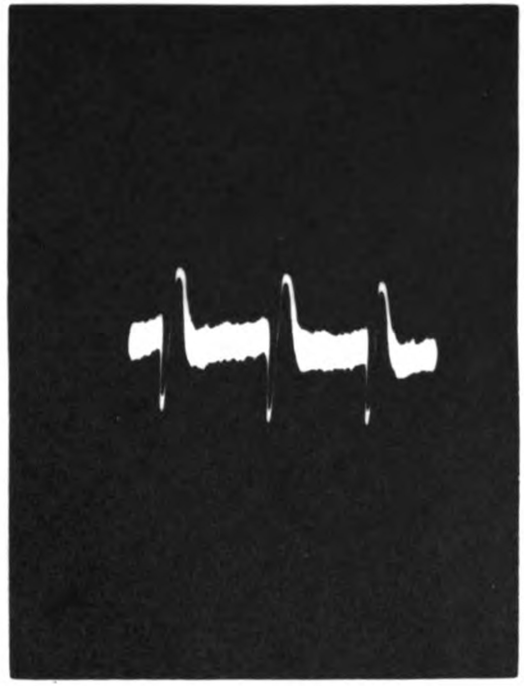


Figure 17.

Various dispersion signals obtained with the twin "T" bridge. The signals are from protons in water. The sample has been adjusted with ferric chloride to accelerate thermal relaxation effects. The oscilloscope sweep is from right to left.

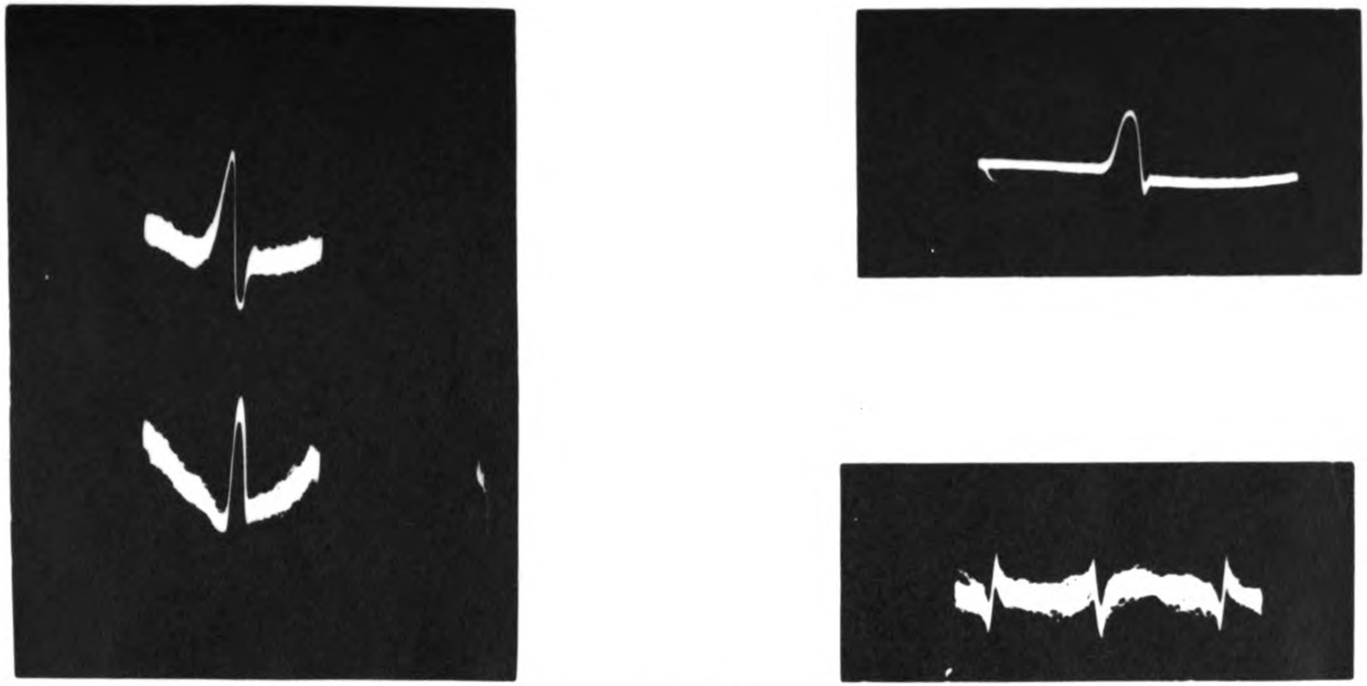


Figure 18.

Signals from the Purcell bridge.

Left: Absorption and dispersion signals from protons in water. Right: Upper— Absorption signal from protons in water. The bump on the trailing edge is slight evidence of the "wiggles" phenomenon (15).

Lower— Proton dispersion signal. Notice that two adjacent signals are reversed in form. The modulation field sweeps through the resonance in two directions— field increasing and field decreasing. This effect is explainable with the aid of Figure 6.

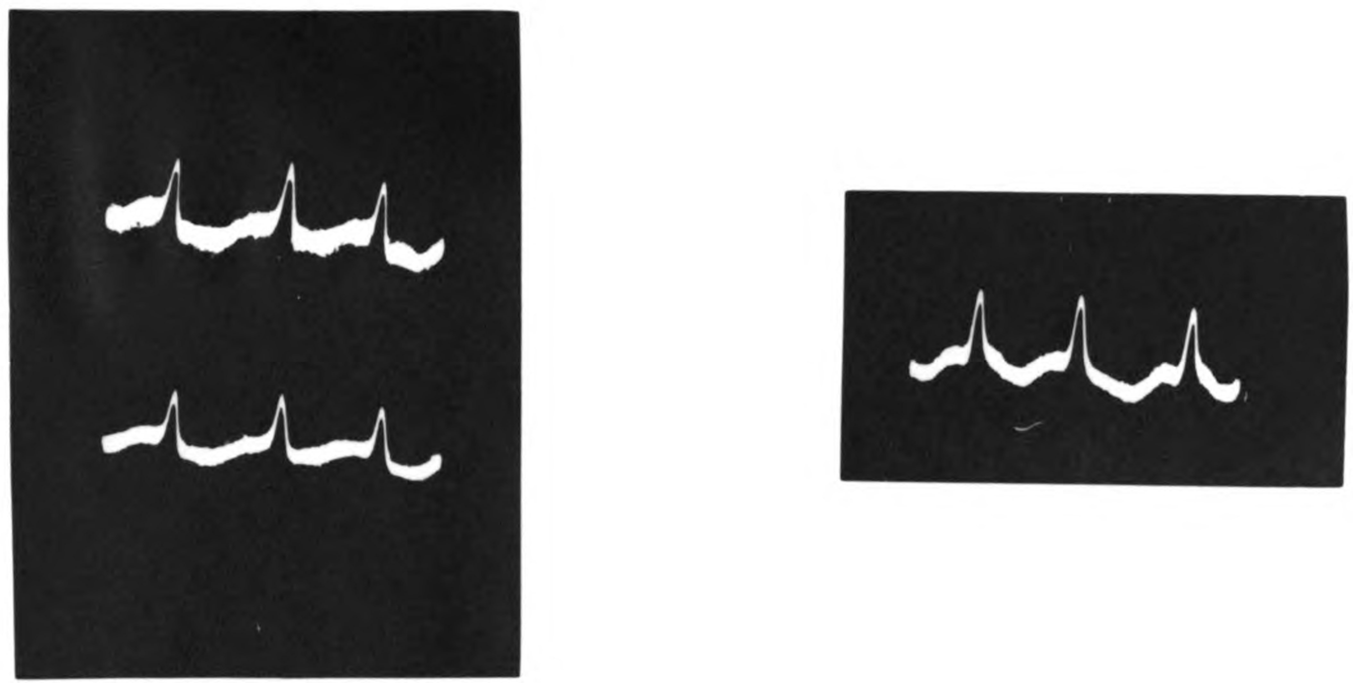


Figure 19.

Absorption signals from Fluorine. Left from the Purcell bridge, right from the twin "T" bridge.

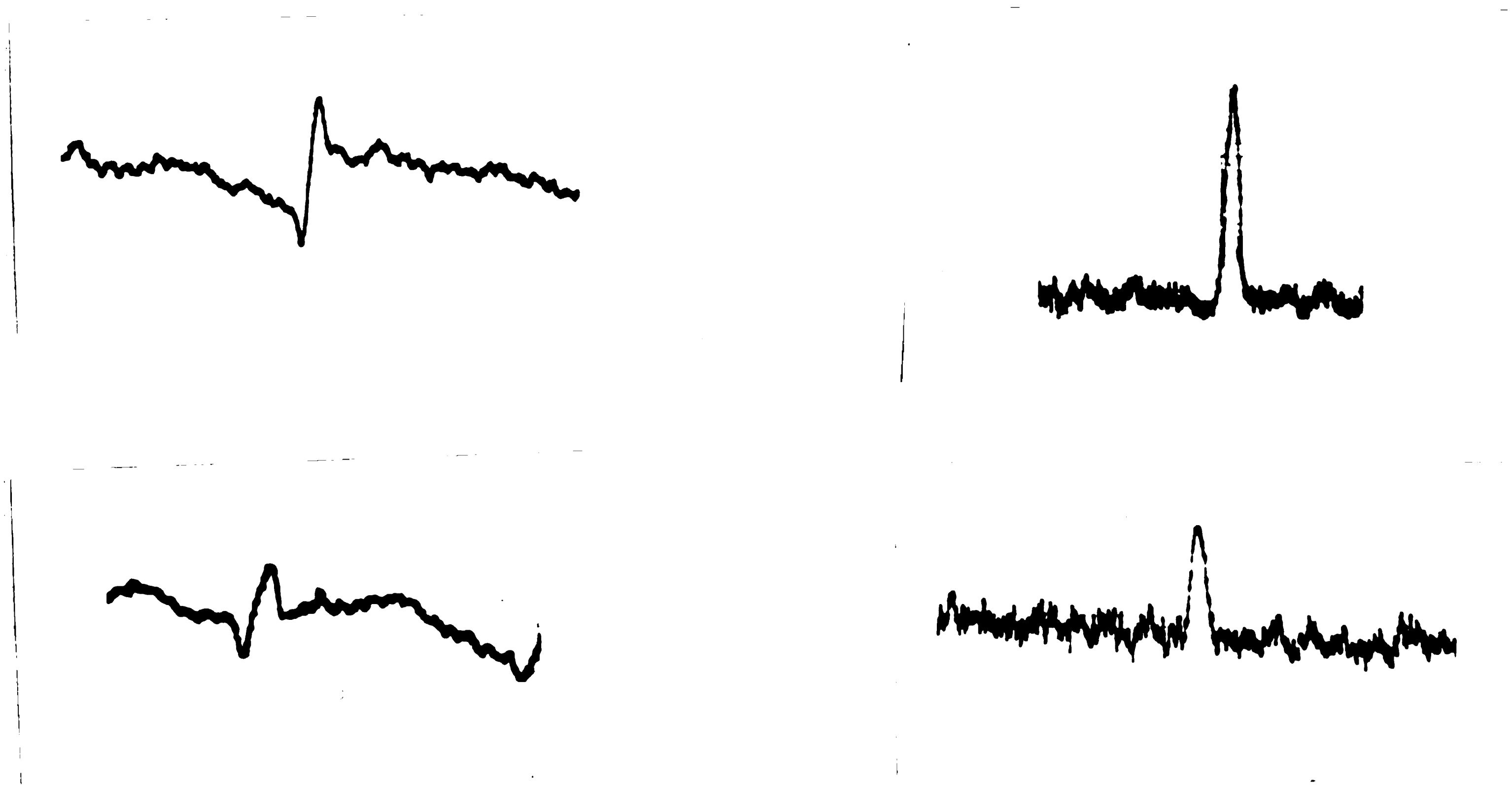


Figure 20.

Signals obtained from the twin "T" bridge on the Millivac-Sanborn recorder. Left: dispersion signals. Right: absorption signals. These traces are for a recorder sensitivity of about 250 $\mu v/cm$. The sample was water.

VII Summary

The difficulties encountered in the course of obtaining the foregoing pictorial data bring to mind certain obvious suggestions for improvement.

With regard to the associated equipment, the main criticism is noise and instability. Improvement could be effected in the signal to noise ratio by using a tuneable preamplifier of good quality. Reduction in the noise level could be brought about by using a non-microphonic, crystal controlled oscillator and by using battery power for all of the electronic equipment.

With regard to the bridges themselves, it is not certain that optimal balance conditions have yet been acheived. Obtaining the best balance involves the tedious process of trial and error adjustment of the series condensers.

If one looks at the dispersion curves of Figure 17 (right), he will notice that there is not the reversing effect explained in Figure 18. This may be evidence of saturation in the twin "T" bridge. There is no resistive path to ground in the non-sample arm of the twin "T" bridge. It is possible that this circuit is not dissapating much energy and, as a consequence, the radiofrequency power level is too high in the sample arm. This strange effect demands further investigation if the patterns of this bridge are to be counted as reliable.

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