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January 16, 1959

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ABSTRACT

A system is described which allows the magnetic field of the "C" magnet of an atomic-beam magnetic-resonance apparatus to be locked to a resonance in the beam. The construction of the system is discussed and representative performance data are presented.

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INTRODUCTION

One of the greatest difficulties associated with the use of an atomic-beam apparatus for the measurement of atomic properties of radioactive nuclides is the drift of the magnetic fields with time. This is especially true if the beam detection is done by radioactive counting of collected samples. In the work referred to here the machine is to be used to measure a series of hyperfine-structure anomalies of cesium and rubidium isotopes. Since the measurements must be made to a high accuracy, it is necessary for the machine to be stable for long intervals of time. In order to achieve this, it was decided to develop a system by which the magnets could be locked to a resonance in the carrier beam. This has the added advantage that the locking and experimental beams see the same magnetic field, and thus the region of the field that is being locked is that in which the experiment is being performed. The magnetic field calibration is also done in this region. The system has proved very satisfactory and has been a great aid in working with narrow lines.

THEORY OF SYSTEM

The general shape of the peak of an atomic-beam resonance[1] is shown in Fig. 1.[*] In order to lock the magnet system to this resonance, it is necessary to develop an error signal that is capable of deciding which side of the resonance the machine is observing at a given time. To do this the rf that is being used to examine the resonance is frequency-modulated by an amount that is small compared with the resonance width. As can be seen from Fig. 1, the output signal then contains an ac component at the modulation

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[1] For a discussion of general atomic-beam technique see N. F. Ramsey, Molecular Beams (Oxford University Press, New York, 1955).

[*] Permission to use this figure through the courtesy of the National Company.

frequency, the phase of which, compared to the modulating signal, depends upon which side of the resonance is being examined. At the exact resonance frequency, this component has a null. This ac signal is detected with a phase detector whose reference is supplied by the modulation signal. The dc output of the phase detector then depends upon which portion of the resonance is being examined. This dc signal is used to regulate the current through the "C" magnet.

It can also be seen from Fig. 1 that, at exact resonance, there is an ac component produced at twice the modulation frequency. It is convenient to monitor this component so that one can tell at a glance if the machine is properly locked.

GENERAL DISCUSSION

A block diagram of the system is shown in Fig. 2. The primary frequency source is a Gertsch model AM-1 frequency generator,[2] which has been modified in order to allow the low-frequency oscillator to be frequency-modulated. The output of the low-frequency oscillator is either fed to a frequency multiplier, which supplies signals from 1 to 20 Mc and 100 Mc, or is used to lock the high-frequency oscillator, which supplies signals from 20 to 40 Mc plus harmonics. For frequencies below 200 Mc, the signals are fed to a pair of distributed amplifiers and then to the transition hairpins.

In this system no provision is made to generate signals in the range between 40 and 500 Mc, except at 100 Mc. Frequencies from 500 to 1000 Mc are generated with the Gertsch model FM-4, which is locked to the output of the AM-1. The output of the FM-4 goes to a 1-watt traveling-wave amplifier that drives the hairpin. In this manner an FM signal is provided in the range 1 to 40, at 100, and in the range 500 to 1000 Mc.

The beam is detected by means of a hot-wire surface-ionization detector.[3] The output of the detector goes directly to a preamplifier which, in turn, feeds the lock-in amplifier. This consists of two twin-tee amplifiers, one of which feeds a monitoring oscilloscope, while the other feeds a phase detector. The output of the phase detector goes directly to the magnet-current regulator that supplies current to the "C" magnet. The loop is completed through the beam to the rf system.

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[2] Gertsch Products, Inc., 11846 Mississippi Ave., Los Angeles 25, Calif.

[3] N. F. Ramsey, Op. Cit., p. 379.

RADIO-FREQUENCY SYSTEM

The Gertsch model AM-1 is a VHF interpolater that is capable of generating fundamental frequencies between 1 and 2 Mc and 20 to 40 Mc, plus harmonics up to 1000 Mc. It consists of two oscillators that can be phase-locked together. The low-frequency oscillator is used as a free-running oscillator and tunes from 1 to 2 Mc. For use in this application, it has been modified as shown in Fig. 3. The low-frequency oscillator is frequency-modulated by means of a crystal diode which is capacitance-coupled to the oscillator tank circuit. The diode is driven from the modulation oscillator (which is described later). The frequency deviation can be adjusted either by the amplitude of the modulation signal or by the variable coupling capacitor. The amount of frequency deviation available also depends upon the frequency to which the oscillator is tuned. The circuit probably could be improved by substitution of a voltage-tunable capacitor, such as the International Rectifier Corp. type 6.8SC20 for the crystal diode.

The high-frequency oscillator in the AM-1 can be phase-locked to a harmonic of the low-frequency oscillator. In this manner, the frequency modulation is transferred to the HF oscillator, which is used to provide fundamental frequencies from 20 to 40 Mc and to generate harmonics of these frequencies.

The output of the LF oscillator is fed to a standard frequency multiplier which supplies frequencies from 2 to 20 Mc and 100 Mc. The output of the multiplier goes to a Hewlett-Packard model 460A distributed amplifier and then to an Instruments for Industry model 500 distributed power amplifier which drives the hairpin. The output of the HF oscillator can also be fed to the distributed amplifiers and thence to the hairpin. This system is capable of supplying up to 3 watts of power from 1 to 40 and at 100 Mc.

The Gertsch model FM-4 is used to generate frequencies from 500 to 1000 Mc. It consist of an oscillator which tunes from 500 to 1000 Mc and which can be phase-locked to a harmonic of the AM-1. A frequency-modulated signal is thus produced which is fed to a 1-watt 500- to 1000-Mc traveling-wave amplifier,[4] which feeds the hairpin.

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[4] The traveling-wave amplifier used here is no longer available commercially. There are, however, several other traveling-wave amplifiers available that are suitable for this purpose.

This rf system has proved very satisfactory for this purpose. The center frequency of the Gertsch oscillator has a short-term stability of about 1 part in 10^7, and the generated frequencies are quite adequate for most atomic-beam experiments. The system suffers from somewhat small frequency deviation in the region of 1 Mc, but this probably could be improved with the above-mentioned substitution for the crystal diode.

MODULATION OSCILLATOR

The modulation oscillator is shown in Fig. 4. It is an rc oscillator using a 5814A tube, and it runs at a frequency of 100 cps. The output of the oscillator is coupled to a second 5814A which serves as a phase shifter and cathode follower. The output of the phase shifter is used to provide the reference signal for the phase detector. The output of the cathode follower drives one section of another 5814A cathode follower, which is used to drive the crystal modulator. It also supplies the dc bias for the crystal and allows the amplitude of the modulation signal to be controlled. Horizontal sweep for the monitoring oscilloscope is taken from the grid of this tube.

BEAM DETECTOR AND PREAMPLIFIER

The beam is detected on a surface ionization detector which consists of a 0.002 x 0.010-inch potassium-free tungsten ribbon.[5] The collector of the detector goes directly to the grid of the preamplifier. The preamp, which is shown in Fig 5, is mounted very near the detector and is completely enclosed in an aluminum box to provide shielding against 60-cycle pickup. The amplifier is battery-powered; the batteries are also contained inside the shield. For the beam intensities that are usually run in radioactive work, it was not necessary to use an electron multiplier, and this detector proved very satisfactory. The exit beam in the machine is about 0.060 in. wide and the detector, which is mounted vertically in the center of the beam, does not block very much of it.

[5] This ribbon was obtained from A. D. Mackay, Inc., 198 Broadway, New York 38, New York.

LOCK-IN AMPLIFIER

The lock-in amplifier is shown in Fig. 6. The first half of the 6AW8A is used as an input amplifier which drives two twin-tee amplifiers. One of these, which uses the second half of the 6AW8A, is tuned to 100 cps and provides the signal for the phase detector. The second twin-tee amplifier is a 6AU6 tube, and is tuned to 200 cps. When the system is properly locked on the peak of the carrier resonance, there is a 200-cycle component present in the signal and it is monitored through this amplifier.

The output of the first twin-tee amplifier drives the phase detector, which is similar to that used in the National Company Atomichron. It has the advantage that both the input and output signals are single-ended, while the reference signal is introduced in push-pull. The output of the phase detector, after being filtered, is fed to the magnet-current regulator, which is shown in Fig. 7.

MAGNET-CURRENT REGULATOR

The magnet-current regulator is a current-regulated power supply which uses power transistors as the series element. The regulator consists of a chopper amplifier followed by a synchronous detector, the output of which drives the transistors. Since the output of the phase detector is at zero volts, it is necessary to use a bucking battery in order to match it to the input of the regulator. The regulator supplies 0 to 5 amp to the "C" magnet.

When it is necessary to run the "C" magnet at more than 5 amp, the current is obtained from submarine storage batteries, as shown in Fig. 8. The variable resistor allows the current to be varied in 5-amp steps, and the regulator provides the fine control. In this manner, the magnet can be locked at any field desired.

PERFORMANCE

The locking system has been used in many runs on stable potassium and rubidium and in several runs on radioactive rubidium-86. The actual degree of field stablization is dependent upon the line width of the carrier resonance and on its field dependence. Representative performance of the system is indicated by observing the peak frequency of the calibrating resonance at various times during a run. Table I gives data from Rb^{86} investigations at three different values of the magnetic field. The system is operated with maximum loop gain, with the frequency

Table I

Representative performance of the lock-in system: Frequencies as a function of time Rb^{87} resonance (Mc)

Run Number 6: System locked on $\Delta F = 0$ resonance of Rb^{85} at 100.0 Mc

	Time					
	1315	1410	1505	1600	1700	1825
First reading	136.960	136.986	136.972	136.986	136.984	136.948
Second reading	136.981	136.986	136.982	136.981	136.985	136.953
Third reading	136.968	136.964	137.011	136.998	--	136.974
Average	136.970	136.979	136.988	136.988	136.985	136.958

Run Number 10: System locked on $\Delta F = 0$ resonance of Rb^{85} at 503.5 Mc

	Time					
	1505	1555	1645	1730	1815	1915
First reading	537.408	537.417	537.360	537.348	537.351	537.324
Second reading	537.336	537.408	537.411	537.357	537.354	537.324
Third reading	537.414	537.444	537.420	537.321	537.357	537.342
Average	537.386	537.423	537.397	537.342	537.354	537.330

Run Number 15: System locked on $\Delta F = 0$ resonance of Rb^{85} at 1.9 Mc

	Time						
	1510	1610	1705	1745	1805	1830	1907
First reading	2.848	2.846	2.845	2.844	2.846	2.847	2.844
Second reading	2.849	2.836	2.845	2.845	2.842	2.844	2.845
Third reading	2.849	2.834	2.846	2.848	2.845	2.847	2.843
Average	2.849	2.839	2.845	2.846	2.844	2.846	2.844

deviation adjusted to give best operation. Both Rb^{85} and Rb^{87} are present as carrier isotopes and either may be used to lock the field. For isolation of the oscillators, separate closely spaced hairpins were used, one for locking the field and the other for calibration and search.

In run Number 6, the field was locked to the (3, -3 ⟷ 3, -2) line of Rb^{85} at a frequency of 100 Mc. The frequency-modulated signal was obtained from the LF oscillator of the AM-1, having been multiplied by a factor of 60. The calibrating frequency was obtained from a Hewlett-Packard 608A signal generator, its frequency being monitored by a Hewlett-Packard 525 Frequency Counter. The calibrating line was the (2, -2 ⟷ 2, -1) line of Rb^{87}, having a line width in this instance of about 150 kc.

In run Number 10, the system was locked to the same Rb^{85} line at a frequency of 503.5 Mc, with the AM-1, FM-4 combination. The line in this instance was 400 kc wide (due to field inhomogeneities), and since the frequency deviation of the signal was limited so as not to pull the FM-4 off its phase-locked condition, the oscillator could not be swept very far down the sides of the resonance lines, therefore some decrease in performance is expected owing to the reduced strength of the error signal; however, the Rb^{86} resonance obtained in this run was quite satisfactory. The calibrating frequency was obtained from another AM-1, FM-4 combination with its frequency monitored by a Hewlett-Packard 540A transfer oscillator.

In run Number 15, the system was locked to the same Rb^{85} line at 1.9 Mc [illegible] with the LF oscillator of the AM-1, the line width being about 150 kc. The Rb^{87} calibrating frequency was obtained from a Tektronix Type 190A signal generator.

ACKNOWLEDGMENTS

The authors wish to thank Mr. George Schrader of the Lawrence Radiation Laboratory for designing and constructing the magnet-current regulator. This work was supported in part by the National Science Foundation, the U. S. Office of Naval Research, and the U. S. Atomic Energy Commission.

FIGURE LEGENDS

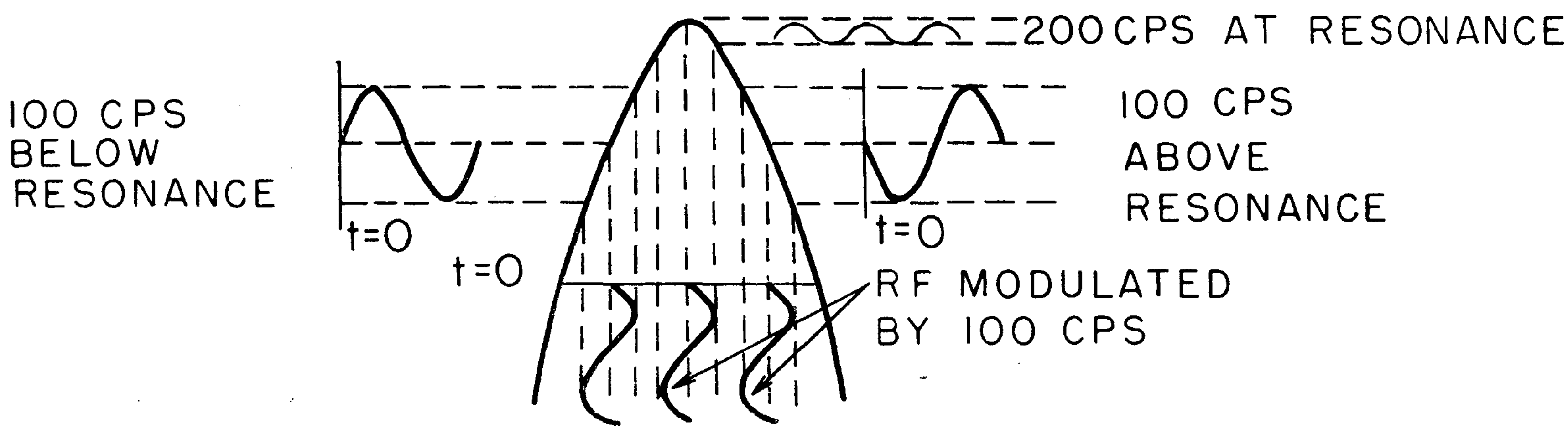
200 CPS AT RESONANCE
100 CPS BELOW RESONANCE
100 CPS ABOVE RESONANCE
t=0
t=0
t=0
RF MODULATED BY 100 CPS

Fig 1
55,112-1

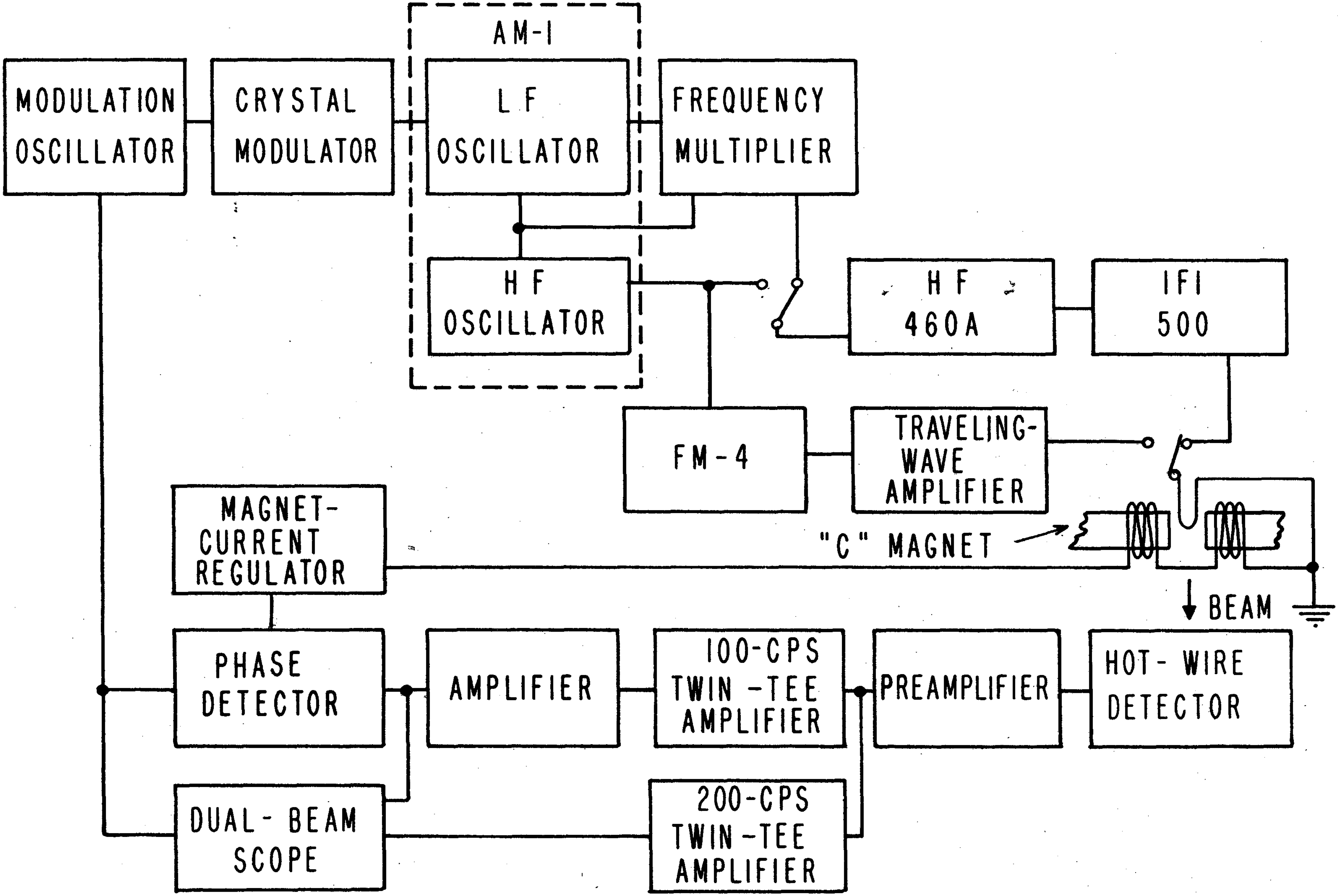
MODULATION OSCILLATOR
CRYSTAL MODULATOR
AM-1
L F OSCILLATOR
H F OSCILLATOR
FREQUENCY MULTIPLIER
H F 460A
IFI 500
FM-4
TRAVELING-WAVE AMPLIFIER
MAGNET-CURRENT REGULATOR
"C" MAGNET
BEAM
PHASE DETECTOR
AMPLIFIER
100-CPS TWIN-TEE AMPLIFIER
PREAMPLIFIER
HOT-WIRE DETECTOR
DUAL-BEAM SCOPE
200-CPS TWIN-TEE AMPLIFIER

Fig 2
55,114-1

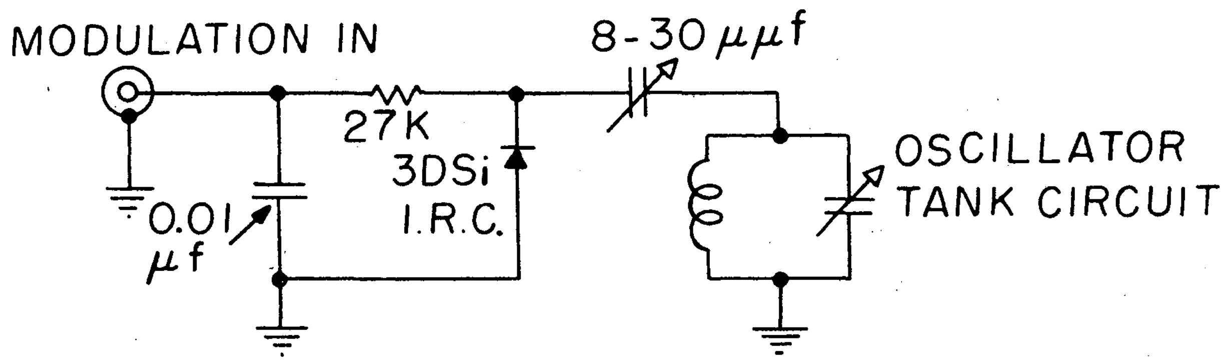
MODULATION IN
8-30 μμf
27K
3DSi
I.R.C.
0.01 μf
OSCILLATOR
TANK CIRCUIT

Fig 3

55,110-1

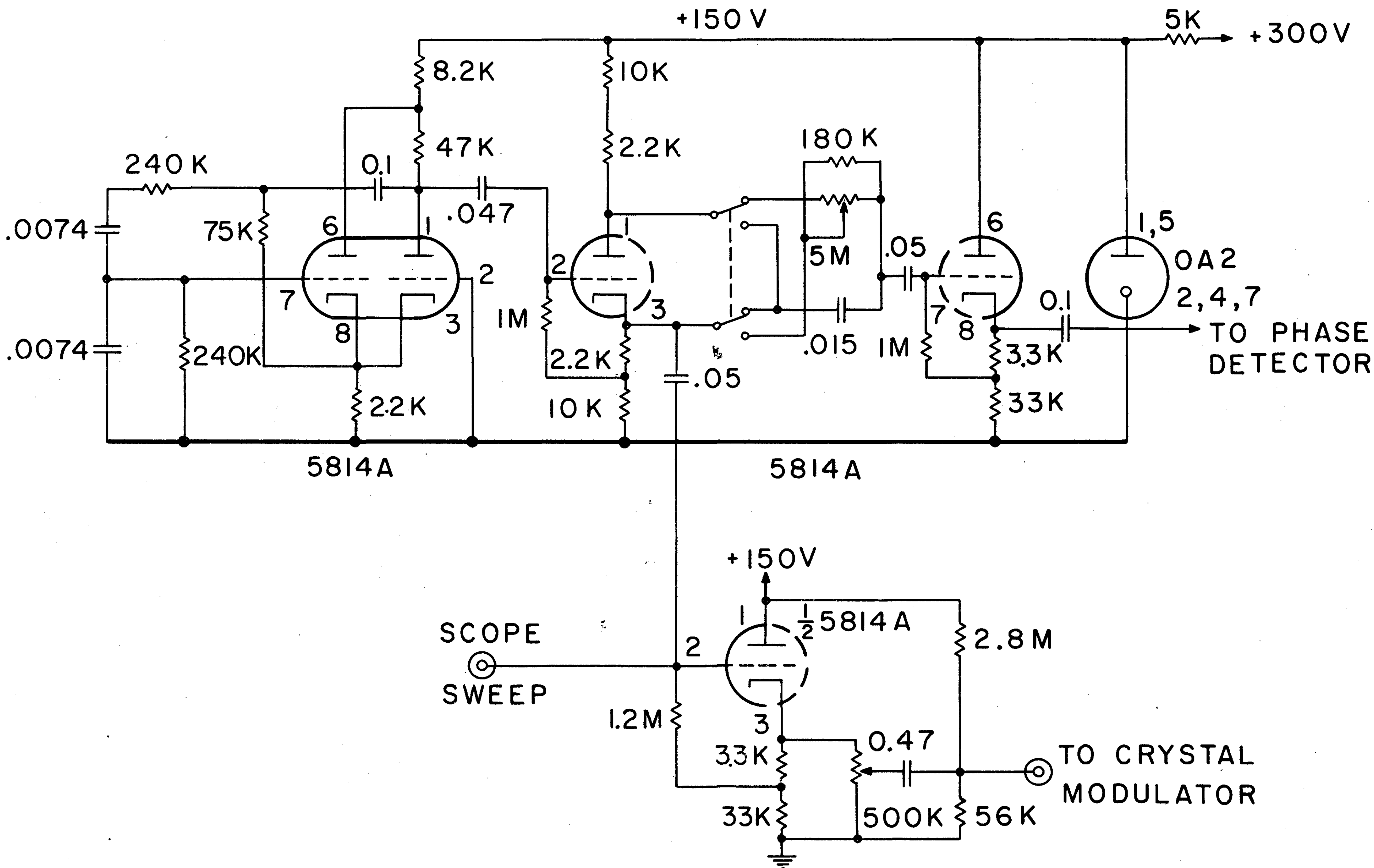
+150 V
5K
+300V
8.2K
10K
47K
2.2K
180K
240K
0.1
.047
.0074
75K
6
1
2
7
3
8
5M
.05
6
1,5
OA2
2,4,7
1M
.015
1M
0.1
TO PHASE
DETECTOR
.0074
240K
2.2K
.05
3.3K
2.2K
10K
33K
5814A
5814A
+150V
1
½ 5814A
SCOPE
SWEEP
2
2.8M
1.2M
3
3.3K
0.47
TO CRYSTAL
MODULATOR
33K
500K
56K

FIG 4

55,115-2

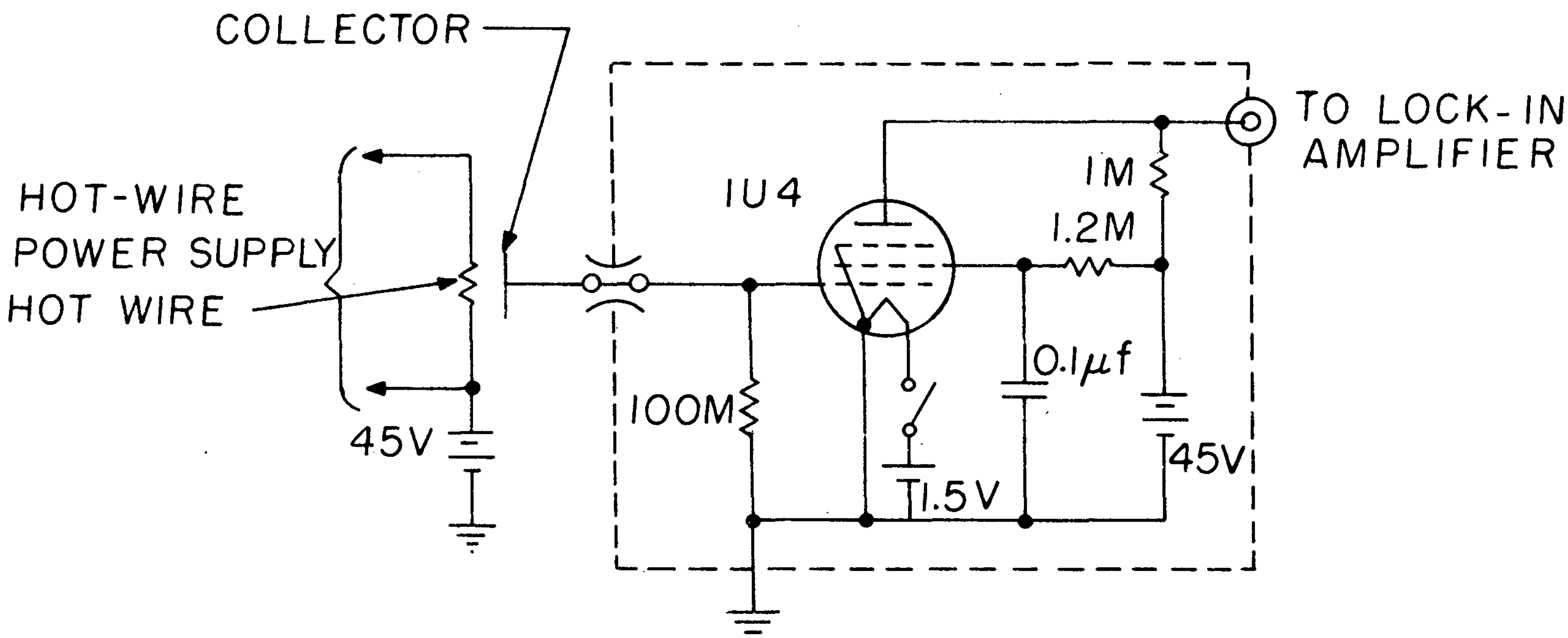
COLLECTOR
TO LOCK-IN AMPLIFIER
HOT-WIRE POWER SUPPLY
HOT WIRE
45V
1U4
1M
1.2M
100M
0.1μf
1.5V
45V

FIG 5

55,111-1

eRecordsUsa

eRecordsUsa

eRecordsUsa

eRecordsUsa

eRecordsUsa

eRecordsUsa

~~Box 26~~

~~1 Drg.~~

~~UCRL - 550~~

BOX 55

8605

2 Drawing

TO FIG. 7.

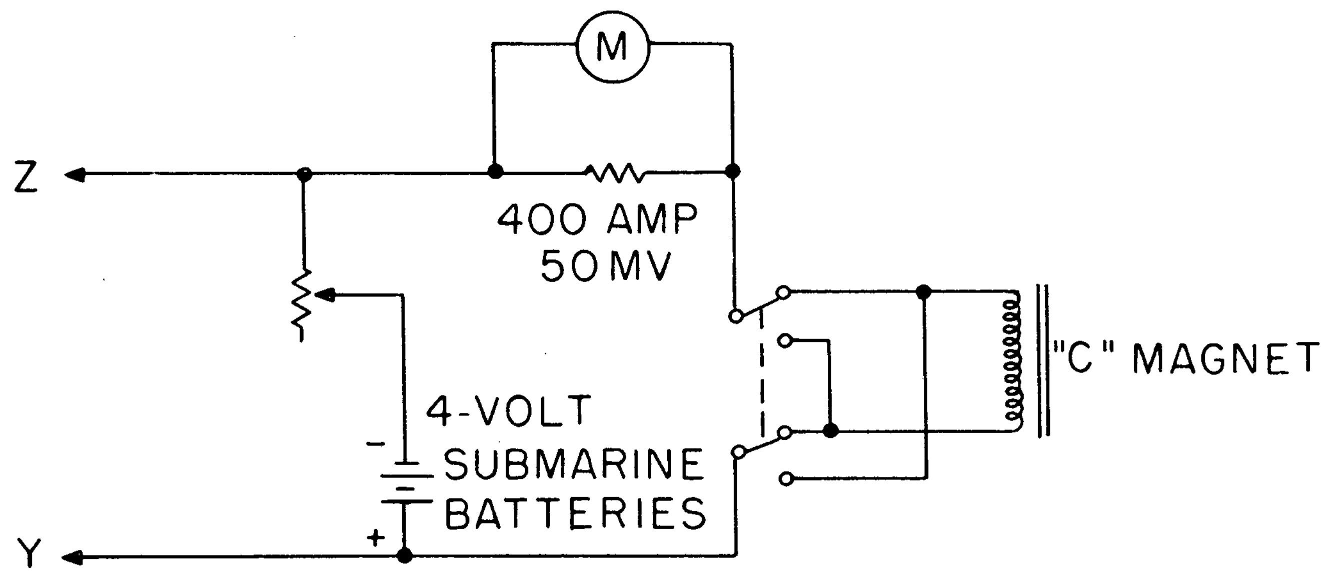

FIG 8
55,113-1