UCRL-1843
UNCLASSIFIED

UNIVERSITY OF CALIFORNIA - BERKELEY

RADIATION LABORATORY

DISCLAIMER

UCRL-1843
Unclassified-Instrumentation Distribution

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

Contract No. W-7405-eng-48

A STABLE MICROWAVE REFERENCE SYSTEM

R. G. Smits and A. J. Schwemin

June 11, 1952

Berkeley, California

A STABLE MICROWAVE REFERENCE SYSTEM

R. G. Smits and A. J. Schwemin

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

June 11, 1952

ABSTRACT

A signal generator system continuously variable from 200 to 400 mc which is stable to one part in 10^8 is described. The principal component is a new harmonic crystal oscillator with this stability. This oscillator plus commercial equipment compose the system.

At the present time, the only way to measure changes of frequency of a few cycles per second in the megacycle frequency range is by comparison with a standard whose stability is known. Commercial oscillators are normally designed for high stability only where precision and accuracy are required such as in a secondary standard. Furthermore, such standards are not available above 100 mc. Frequently, however, precise knowledge of variations of frequency is of more interest than that of the absolute values. As the result of such a situation, the system described in this report was developed to provide a source of highly stable frequencies in the range of 200 to 400 mc. Although the system could probably have been calibrated to read absolute frequencies to at least $\pm$ 0.01 percent, no attempt to do so was made. Instead, effort was concentrated on stability.

A STABLE MICROWAVE REFERENCE SYSTEM

R. G. Smits and A. J. Schwemin

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

June 11, 1952

A block diagram of the system is shown in Fig. 1. The core of the system is the harmonic crystal oscillator which permits a choice of frequencies separated by about fifteen megacycles over the total range. Inbetween frequencies are obtained by mixing the chosen crystal oscillator frequency with the output of an oscillator variable between 0.1 and 10 mc. The stability requirement of this oscillator is an order of magnitude less than that of the system, since the stability requirement of the system is really a matter of cycles/sec drift. Of the commercial oscillators on hand, the General Radio Standard Signal Generator Model 1001A was satisfactory (Fig. 2) as long as its use was confined to this range of frequencies (Fig. 3) it was protected from acoustic and mechanical shocks, and was operated at constant temperature*. When combined with the special features of the crystal oscillator, commercial voltage regulators proved to have adequate control of voltage variations.

The crystal oscillator, see Fig. 2, consists of a basic oscillator stage plus several frequency multiplying stages. The stability of the unit depends of course on the oscillator stage. This stage uses any one of seven crystals, selected by a rotary switch from the front panel. The crystals are "AT" cut

---

* Metastatic Mercury Thermostatic Regulator of Braun, Knechl, Heimann, San Francisco, California.

crystals, which are operated at the temperature of their zero temperature coefficient, by being enclosed in a temperature-regulated oven, shown in Fig. 3. In the center of the oven there is a 1/4 in. thick copper box which contains the crystals and crystal selector switch. In addition to the bulb of a mercury thermostat*, the space around this box contains the entire oscillator circuit including the bottom of the oscillator tube socket and the plate tank circuit. This space is enclosed by a 0.060 in. copper box which provides rf shielding and insures uniform heating. The box is wrapped with fiberglass tape, the heating element and another layer of fiberglass tape. One-half inch of fiberglass insulation and a Dural case completes the oven. A well in the outer case allows the oscillator tube to be free from drafts, but outside the oven where its heat does not affect the circuit elements. (See Figs. 4, 5, and 6).

The use of an oscillator circuit in which the plate load is not part of the oscillatory system together with the 6AG7, which produces copious harmonics, permits tuning the plate circuit to the eighth harmonic. After two frequency doubling stages, the signal is fed to the final stage which either triples or quadruples.

The tank circuit used here had to be tunable from 200 - 400 mc and considerable difficulty was encountered with conventional L-C circuits and with tuned lines. It was found that the butterfly tank in the TN-18 tuning unit of surplus APR-4 receivers covered this range admirably. As these butterflies were not available commercially, copies were made.

Notice in Figures 4 and 5 that both ends of the output coupling loop are available at coax connectors. This arrangement allows the application

---

* Metastatic Mercury Thermostatic Regulator, Brown, Knechl, Heimann, San Francisco, California.

of a simple mixing technique in order to mix the stable variable oscillator frequency with the crystal-multiplier frequency. The General Radio oscillator is fed into one coax connector and output is taken from the other connector as the instantaneous sum of both signals. By using either a series or shunt crystal rectifier in the output lead, the sum and difference frequencies are produced. A type 1N56 crystal in a low capacity series holder has been found ideal for this purpose. The output of the crystal oscillator at the coax varies from 0.1 to 0.3 watt into a 50 ohm load when the plate supply voltage is 225 volts.

The plate supply for the crystal oscillator multiplier unit is a "Lambda" regulated d.c. supply, shown in Fig. 6. A "Sorensen" regulator supplies a.c. power to this plate supply, to the filament supply, the oven heaters and to the variable frequency oscillator. In order to reduce the possibility of hum-modulation the filaments of all rf tubes and the oven heater are operated on d.c. The filament supply consists of a step-down transformer, selenium bridge rectifier and a π section filter, using a 0.07 hy choke and two 4000 μf capacitors to supply 6 volts at 5 amperes with only 3 percent ripple. The heater supply uses a 110 v to 110 v isolation transformer, selenium bridge rectifier and a π section filter using a choke and two 80 μf capacitors. The 110 v d.c. output of the oven supply contains about 0.9 percent ripple and is switched on and off by a relay which is controlled by the thermostat. The stability requirements of this unit were given above as 10 cps over any 10 second interval or about two parts in 10^9 per second. The crystals used have temperature coefficients of less than 10^{-6} per degree centigrade. The crystal oven, therefore, has to hold temperature to within 5×10^{-3} °C per second. The thermostat control range is about 0.1 °C so the heating time constant of the crystals has to exceed 20 seconds. The heating time could have been adjusted by reducing the heater-supply voltage, but this was found unnecessary. The cooling time is increased by putting a bleed resistor R-2 (Fig. 2) across the thermostat contacts. The 1/4 in. thick copper box surrounding the crystals acts as a heat storage capacitor and reduces the temperature variations at the crystals.

The actual measurement of frequency stability of such a device is hindered by the lack of a reference at these frequencies. An experimental model of the crystal multiplier unit was re-activated to use as a reference. Both units were set to produce 345 mc outputs. By adding the outputs of both units and detecting the beat with an AN/APR-4 receiver it was possible to get an indication of the stability. A block diagram of the set up is shown in Fig. 8. Variation in the two crystal oscillator circuits produced a beat frequency of about 35 kc in the receiver output. In order to be able to record this with good accuracy, this frequency was beat against a stable audio frequency oscillator* to produce a recordable frequency below 200 cps. A portion of the drift plot is shown in Fig. 9a. The audio frequency oscillator was later beat against a 100 kc low frequency standard** to determine its stability (Fig. 9b). The 10 second drift is always less than 5 cycles for the entire test setup.

In checking the entire system, the short was removed and the variable frequency oscillator was fed in at point "Y", (Fig. 8). The series crystal mixer was inserted at point "X" to mix the General Radio oscillator with the test crystal oscillator. The audio oscillator and audio mixer were removed from the circuit and a pair of crystals selected to produce an rf difference of about 13 mc. (246 mc and 259 mc.) The General Radio oscillator was tuned to about 13 mc to produce a beat of about 150 cycles at the frequency meter.

---

* Hewlett-Packard 650 A.

** Hewlett-Packard Low Frequency Standard 100 D.

Two drift runs were made, one at high chart speed to study the short time stability of the system and one at slow speed to determine the long time drift. The short time run is shown in Fig. 10a, while Fig. 10b shows a portion of the long time run. It will be noted that the entire system runs, including the stable variable rf oscillator, appears better than the run using only the crystal oscillators and an audio oscillator. This led to the belief that the audio oscillator was the unstable part of the test system. The test of the audio oscillator (Fig. 9b) shows this is not so, and we are forced to the realization that the variations in Fig. 10b should be only 3/4 as great as those in Fig. 9a since in the former case the output stages were tripling while in the latter they are quadrupling. The General Radio oscillator therefore must contribute a negligible amount to the instability of the system.

It was desired to determine whether the power supply voltage regulation was satisfactory. A variac was inserted between the Sorensen regulator and the Lambda regulated d.c. plate supply. See Fig. 7, point "X". The a.c. voltage to the plate supply was set at 120 v and the system allowed to come to equilibrium. The Variac was quickly turned down to 112 volts output. Fig. 11 shows that there was no appreciable effect, and therefore the system is independent of voltage variation at the input of the plate supply.

A similar test was made with the Variac on the input of the Sorensen regulator. See Fig. 7, point "Y". At the designated time, the line voltage was jumped from 104 volts to 122 volts. The results shown in Fig. 12 indicate that the system is independent of power line variations.

In actual use, a frequency to be examined (in the 200-400 mc range) is fed to a receiver, along with a nearly matching signal from this reference standard. The beat frequency produced is measured with a frequency meter*.

---

* EPUT (Events per unit time) Berkeley Scientific Corp., Richmond, California.

Any changes in the applied frequency can then be read directly on the low frequency meter with at least the accuracy of 10 cps/ten second interval.

ACKNOWLEDGMENTS

The authors wish to express their thanks to C. S. Presenz and E. Wong for their whole hearted cooperation and fine engineering of these pilot models, including the oven.

Information Division
6/12/52 bw

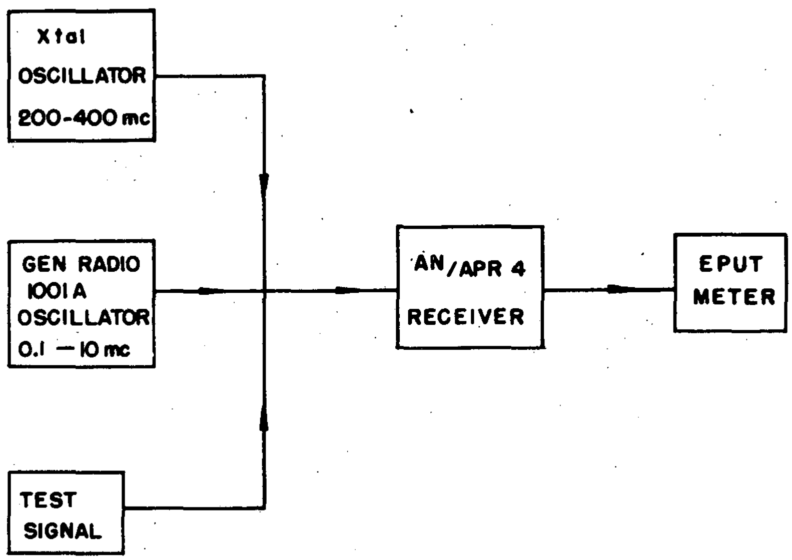


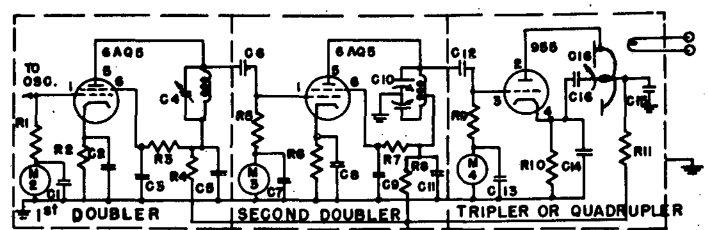
FIG. 1

BLOCK DIAGRAM OF REFERENCE SYSTEM

MU 3821

FIG. 2

FREQUENCY STANDARD 200 → 400 mc.

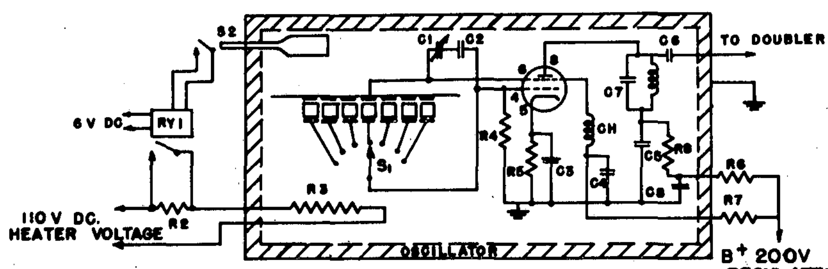


PARTS LIST

R 1-5-9 100K ½W
R 2-6 100Ω ½W
R 3-7 200K 1W
R4-8 1K 1W
R 10 5K 1W
R 11 2.5K 1W

C 1-2-3-5-7-8-9-11 1000μμf 400V CERAMIC
C 6-12 25μμf CERAMIC OR BUTTON
C 4 50μμf VARIABLE CARDWELL 2 BEARING
C 13-14-15-16 200μμf CERAMIC OR BUTTON
C 10 50-50μμf VARIABLE CARDWELL 2 BEARING
C 16 BUTTERFLY

M2 0-1 M.A. DC.
M3 0-1 M.A. DC.
M4 0-500μA DC



PARTS LIST

R2 100Ω ~20W
R3 HEATER RES
R4 50K ½W
R 5-6-8 100Ω 2W
R 7 500Ω 2W

C1 10μμf LINEAR
C2 25μμf CERAMIC
C3-4-5-8 1000μμf DISC.
C6 50μμf CERAMIC
C7 100μμf VAR. CARDWELL 2 BEARING

CH 1MH
RY1 SENSITIVE RELAY
S1 7POSITION ROTARY CERAMIC WAFER
S2 MERCURY THERMOSTAT

NOTE 1 OVEN UNIT SHOCK MOUNTED ON LORD MOUNTS.

NOTE 2 ALL LEADS INTO OVEN UNIT (EXCEPT RF DRIVE & DRIFT COND) THROUGH 1000μμf CERAMIC FEEDTHROUGH INSULATORS.

NOTE 3 ¼" COPPER WALL MASS AROUND CRYSTALS.

MU3822

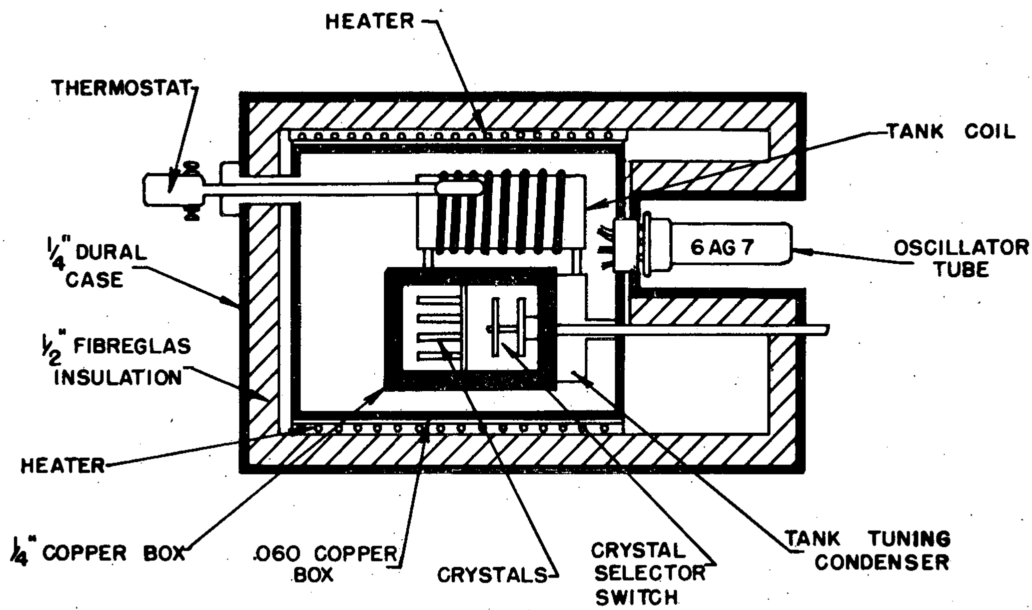


FIG. 3

CRYSTAL OVEN

MU 3823

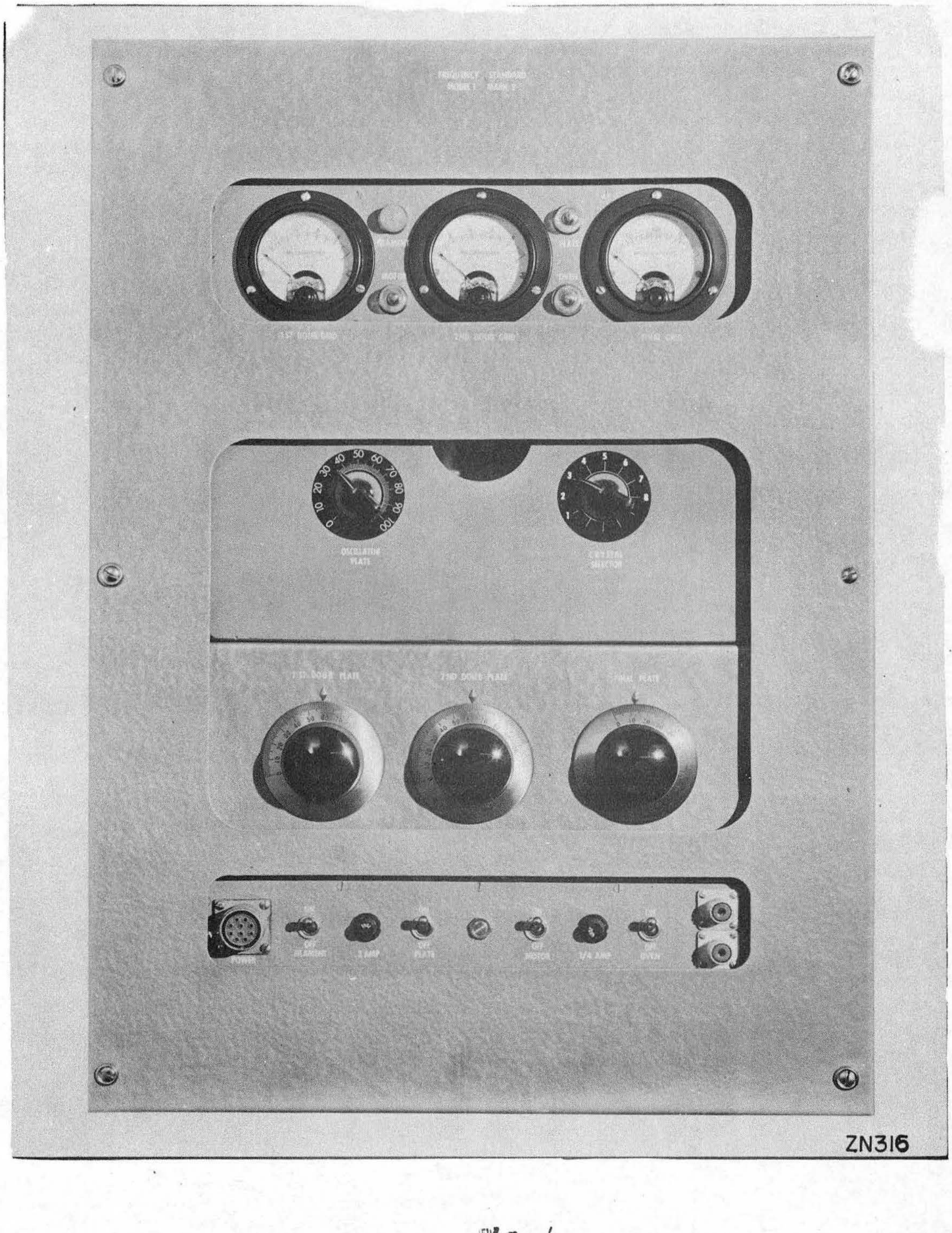


Fig. 4

Front view of oscillator

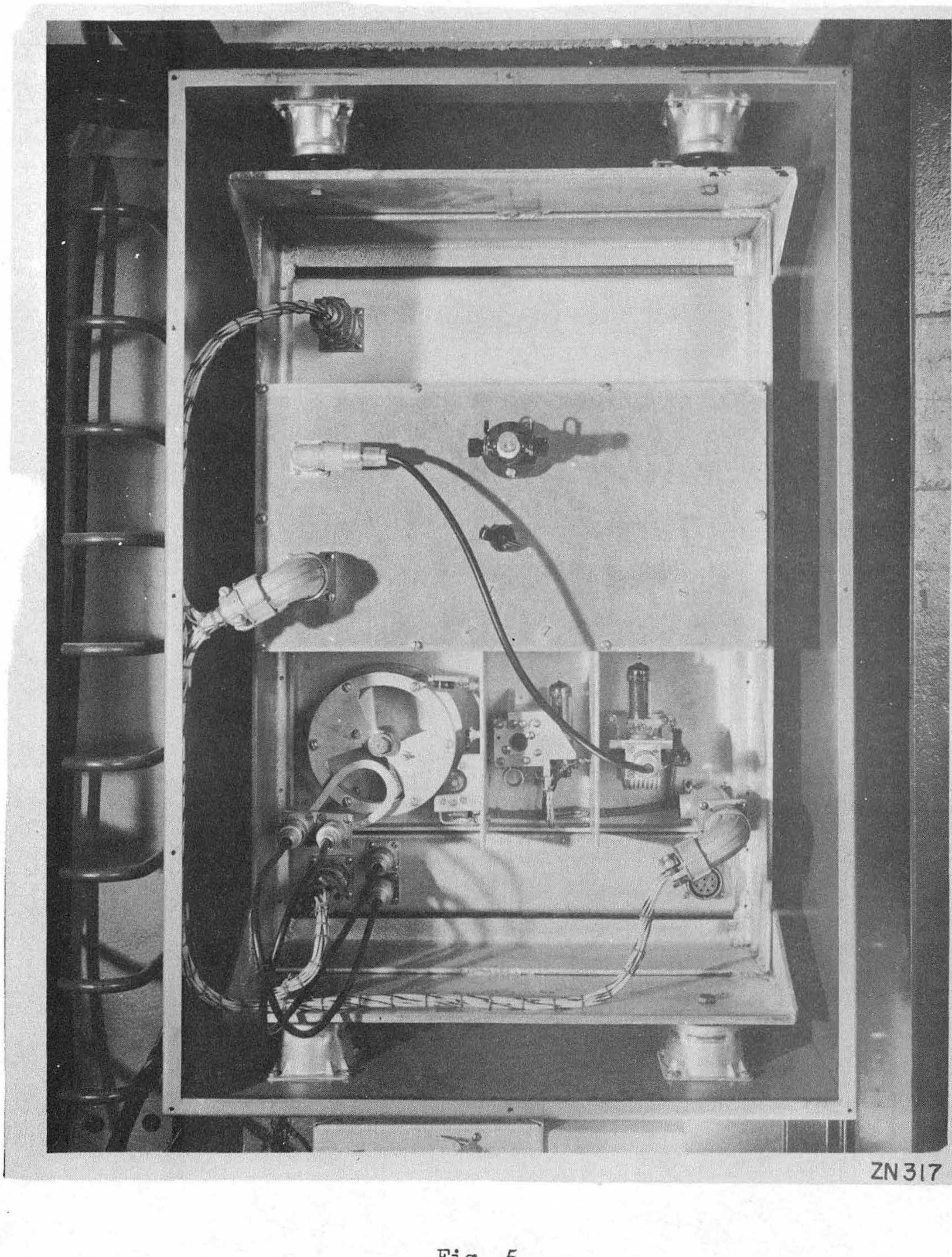


Fig. 5

Rear view of oscillator

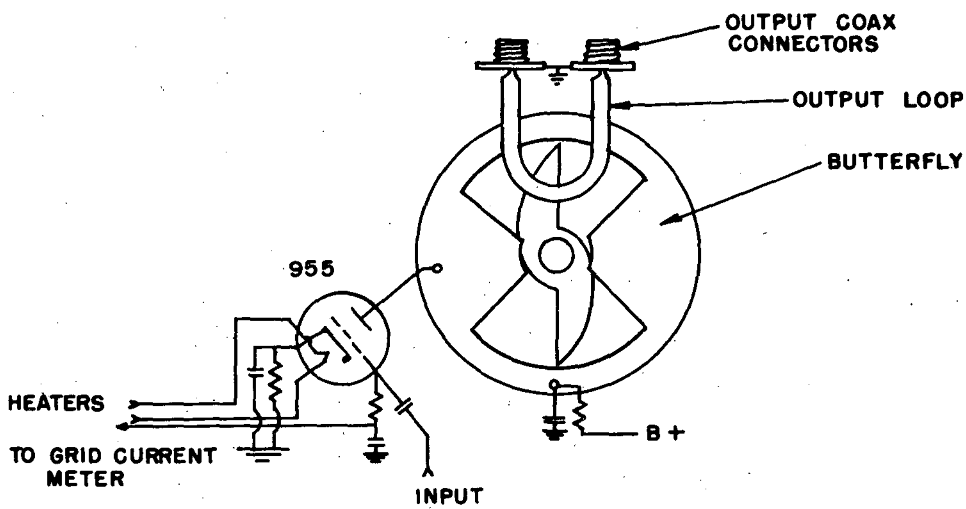


FIG. 6

OUTPUT TRIPLER OR QUADRUPLER

MU 3824

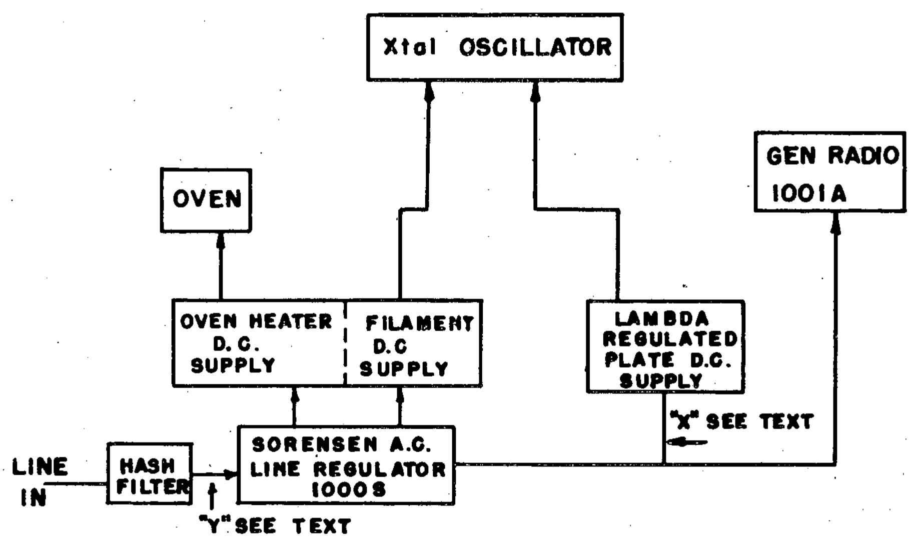


FIG. 7

POWER SUPPLY BLOCK DIA.

MU 3825

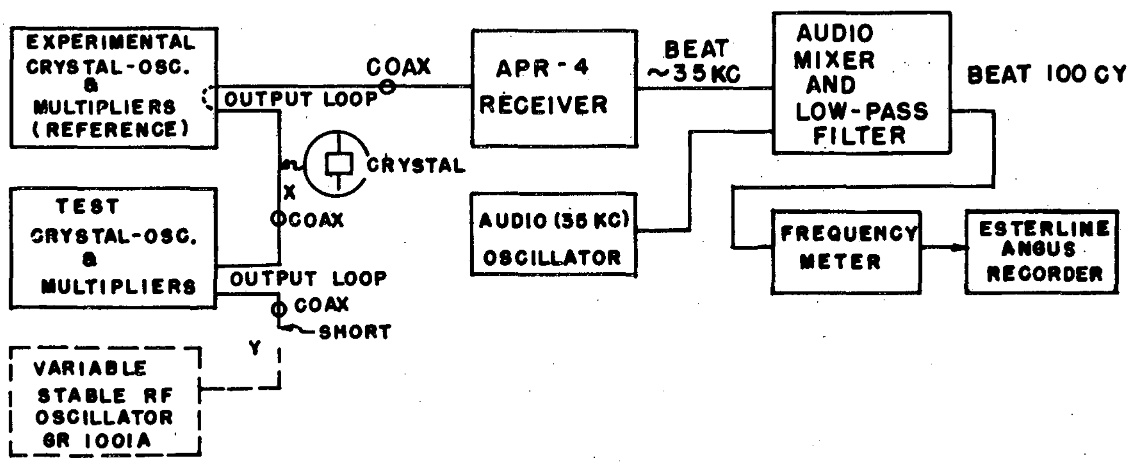

EXPERIMENTAL CRYSTAL-OSC. & MULTIPLIERS (REFERENCE)
OUTPUT LOOP
COAX
APR-4 RECEIVER
BEAT ~35 KC
AUDIO MIXER AND LOW-PASS FILTER
BEAT 100 CY
CRYSTAL
X
COAX
TEST CRYSTAL-OSC. & MULTIPLIERS
OUTPUT LOOP
COAX
SHORT
Y
VARIABLE STABLE RF OSCILLATOR GR 1001A
AUDIO (35 KC) OSCILLATOR
FREQUENCY METER
ESTERLINE ANGUS RECORDER

FIG. 8

MU 3826

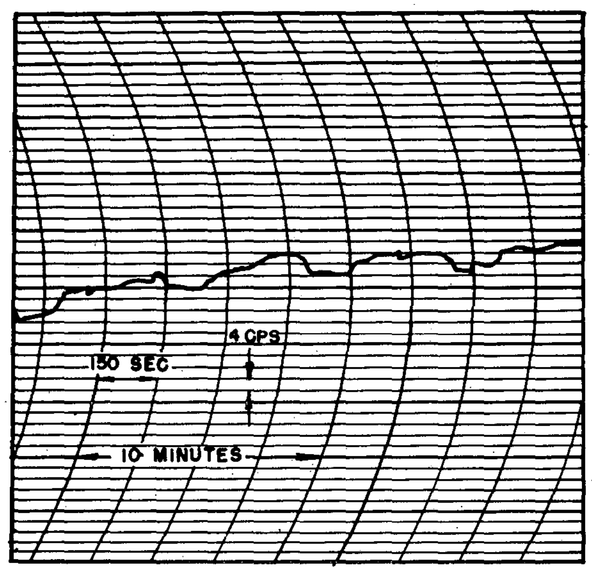


FIG 9a

MOD I #1 (EXPERIMENTAL)
X'tal #4
MOD I #2 (PRODUCTION)
X'tal #4
200 CY FULL SCALE
PREQUENCY ~345 mc.
DIFF. FREQUENCY ~35 KC REDUCED
TO <200 CY BY BEATING WITH
H.P. 650A 3-10-52 R.S.

SEE ACCOMPANYING GRAPH FOR
STABILITY OF H.P. 650A

MU 3827

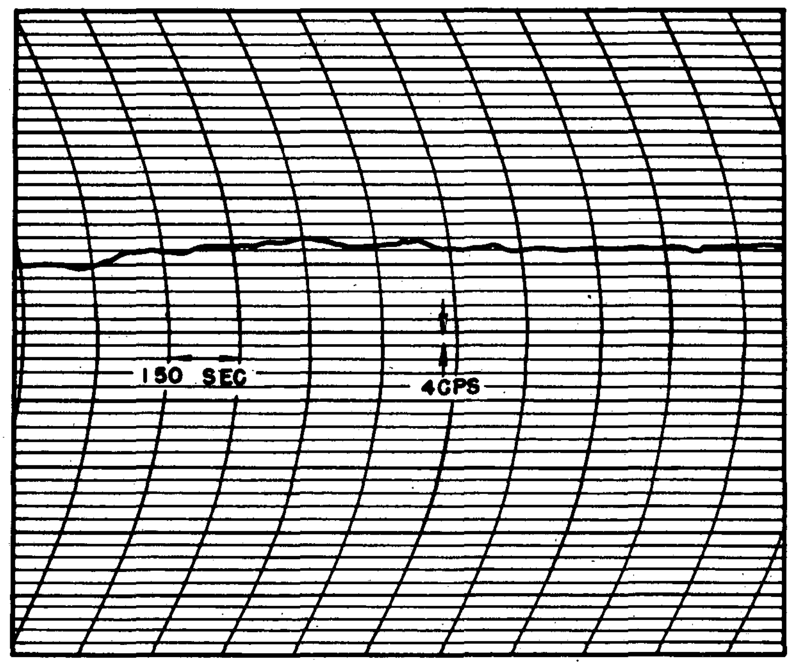


FIG. 9b

200CY FULL SCALE
H.P. 650A AT ~100 KC vs.
H.P. 100D STANDARD
3-9-52 R.S.

MU 3828

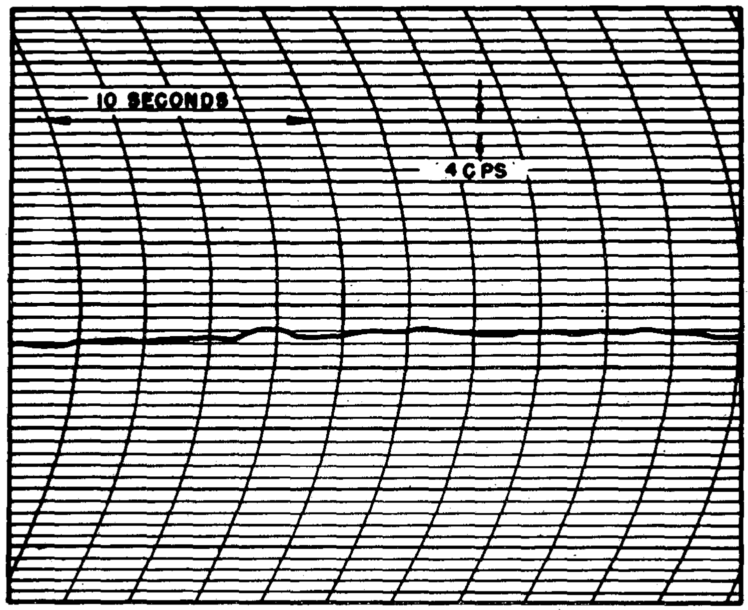


FIG. 10a

ENTIRE SYSTEM
200~ FULL SCALE
MOD 1#1 (EXPERIMENTAL) X'tal 3 246mc
MOD 1#2 (PRODUCTION) X'tal 4 259mc
STABLE VARIABLE-GENERAL RADIO ~13 mc
2-15-52 R.S.

MU 3829

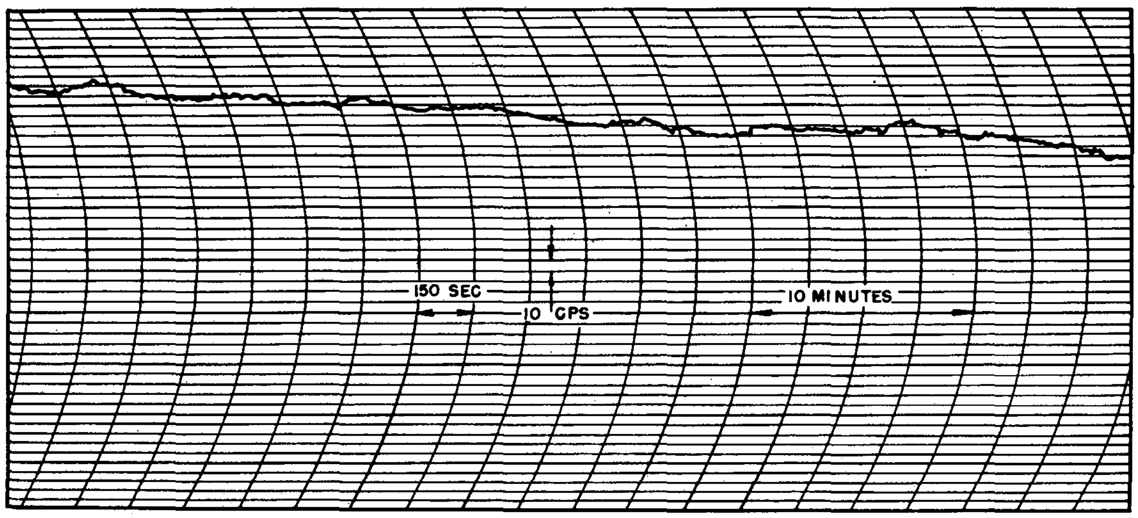


FIG. 10b

ENTIRE SYSTEM
500 ~ FULL SCALE (10~/DIV)
LONG TIME RUN
MOD 1 #1 (EXPERIMENTAL) X'tal 3 246 mc
MOD 1 #2 (PRODUCTION) X'tal 4 259 mc
STABLE VARIABLE OSC. G.R. #1001A
2-15-52 R.S.

MU3830

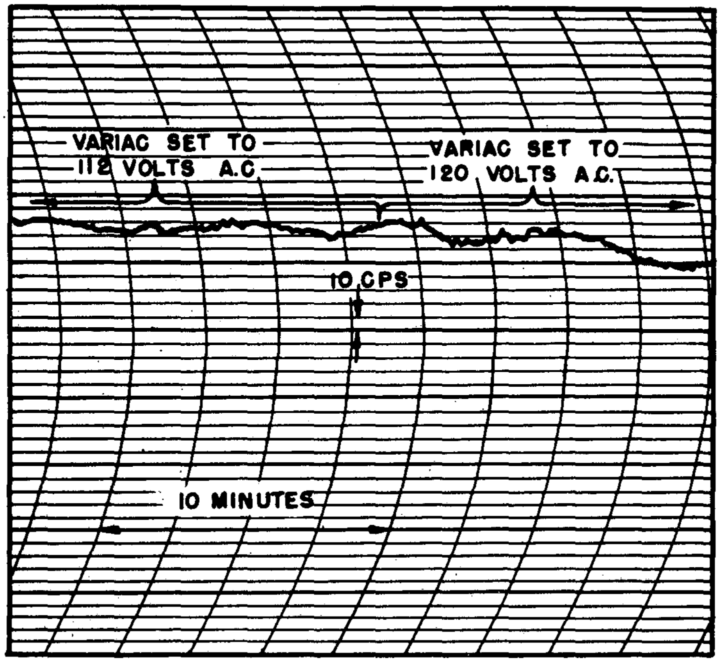


FIG. 11
500 CY FULL SCALE
VARIAC BETWEEN SORENSEN
AND LAMBDA PLATE SUPPLY
4-16-52 R. S.

MU 3831

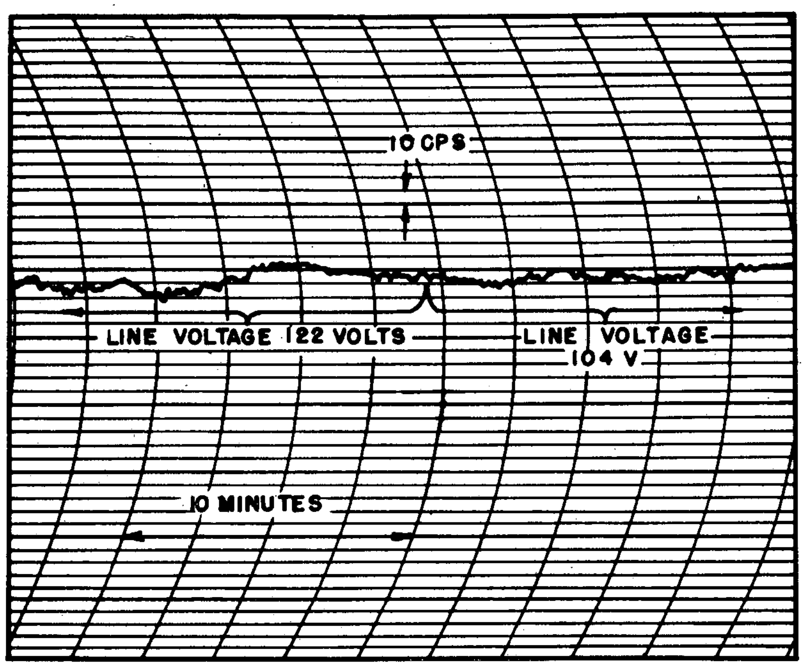


FIG. 12
500~ FULL SCALE
VARIAC ON INPUT TO SORENSEN
ENTIRE SYSTEM
2-16-52 R.S.

MU 3832