22 December 1938

NRL Report No. R-1503
BuEng.Prob. F3-12

NAVY DEPARTMENT
BUREAU OF ENGINEERING

FR-1503

Report of Test

of

Model LD-4 Frequency Measuring Equipment
(Third Model)

submitted by the

Bendix Radio Corporation.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

Number of Pages: Text - 24 Tables - 7 Plates - 13

Authorization: BuEng.let. NOs-53017(8-13-W8) of 16 August 1937.

Date of Test: 30 August to 5 October 1938; 8 November to 15 December 1938.

Prepared by: R.B. Owens
R.B. Owens, Associate Radio Engineer
Chief of Section.

Reviewed by: A. Hoyt Taylor
A.Hoyt Taylor, Principal Physicist,
Superintendent, Radio Division.

Approved by:
H.M. Cooley, Captain, USN,
Director.

Distribution:
BuEng (5)

vhw

TABLE OF CONTENTS

APPENDICES

AUTHORIZATION

1. This problem was authorized by Bureau of Engineering letter, reference (a). Other pertinent correspondence is listed as references (b) to (i).

Reference: (a) BuEng.let. NOs-53017(8-13-W8) of 16 Aug. 1937.
(b) Specifications RE 13A 401E.
(c) NRL let. S67/74 of 10 Dec. 1937. (Preliminary report on first model.)
(d) NRL let. S67/74 of 6 Jan. 1938. (Supplement to reference (c).)
(e) NRL Report No. R-1449. (Report on second model.)
(f) NRL let. S67/74 of 7 July 1938. (Supplement to reference (e).)
(g) BuEng.let. NOs-53017(1-6-W7) of 1 July 1938 to Resident Inspector of Naval Material, Baltimore.
(h) BuEng.let. NOs-53017(1-6-W7) of 1 July 1938 to Bu.S&A.
(i) Preliminary Instructions for Testing Model LD-4 Frequency Meters. (Bendix Radio Corp.)

OBJECT OF TEST

2. The object of the test was to determine whether the third submitted model of the Model LD-4 frequency measuring equipment complies with the governing specifications, reference (b), and is suitable for Naval use.

ABSTRACT OF TEST

3. The equipment was received on 29 August 1938 and tests were begun the following day. It was inspected for mechanical construction, wiring, accessibility of parts, types of material employed and general workmanship. The operation of the crystal controlled oscillator and of the heterodyne oscillator was studied with respect to frequency stability with tilting of the equipment, time of operation, change of tubes and variation of line voltage. The operation of the 20 kilocycle locked oscillator which is controlled by the crystal oscillator output was noted as well as that of the audio frequency oscillator. The temperature control systems were tested for control of the temperature of the heterodyne oscillator and of the crystal, both at normal room temperature and also at extremely low and high ambient temperatures. The audio frequency output power delivered, due to beats between the heterodyne oscillator and harmonics of the crystal or locked oscillator, was measured at a number of frequencies. The measuring unit was operated within a few feet of a radio transmitter to determine if any undesired effects would occur, due to installation of the equipment close to a transmitter. The suitability of the heterodyne oscillator for adjusting the frequency of receivers, both in the fundamental range of the LD-4 as well as up to 30 megacycles, was determined by the use of standard Navy receivers. The overall accuracy of the heterodyne oscillator was carefully noted. The effect of severe vibration was observed, both with respect to its mechanical and electrical effects. In addition to the normal operation of the equipment from an alternating current source, the operation of the heating system on direct current and of the measuring unit on batteries for emergency use was observed.

Conclusions

(a) The equipment as delivered to this Laboratory on 29 August complied with the governing specifications except as follows:

(1) The crystal became sluggish in starting oscillation after 2 weeks of observation and the crystal frequency change with tilt to the left was 2-1/2 times the allowed value; a second crystal drifted in frequency .003% in a week.
(2) Frequency change of the heterodyne oscillator with tilt to the right and left was 5 times the allowed value when the angle of tilt was as great as 25°.
(3) No door was provided in the panel for tube replacement.

(b) When this equipment was tested after final modification following redelivery to this Laboratory on 23 November, it complied with all requirements of the specifications except that no tube door was provided.

(c) An equipment identical with the improved model mentioned in (b) above but containing a satisfactory tube door in the front panel complies with the specifications in all respects except that the crystal oscillator frequency changed 0.0018% as a result of intense vibration for a period of 2-3/4 hours.

(d) The model after final modification and the model similar to it with the tube door are considered suitable for Naval use provided each individual crystal is mounted with particular care to minimize the effect of intense vibration on the crystal oscillator frequency.

Recommendations

It is recommended:

(a) That the model as submitted on 29 August be considered unsuitable for Naval use for the reasons stated under Conclusion (a).

(b) That this model after final modification as well as the similar equipment with the tube door be considered suitable for Naval use provided particular care is taken in mounting the crystals in their holders so as to minimize the effect of intense vibration on the crystal oscillator frequency (as in the case of the model mentioned in Conclusion (b)).

(c) That the tube door in the front panel be required in production units.

(d) That the provision for continuous heating of the heterodyne oscillator tube which is incorporated in these models be accepted, if frequency stability during the first five minutes of tube operation is important.

(e) That the use of one cabinet of two compartments for the measuring and power units, instead of two separate cabinets clamped together, be accepted as satisfactory and as involving no disadvantage to the Service.

(f) That the heterodyne oscillator coil selector switch knob be locked to its shaft so as to prevent the possibility of rotation, which would lead to uncertainty as to the coil in the heterodyne oscillator circuit, since the knob carries the coil selector pointer. (One knob became loose during test even though three set screws are now used.)

(g) That the Bureau consider if lock washers of the external shake-proof type which extend beyond the screw heads are desired, as in this model, under screws on the front panel.

MATERIAL UNDER TEST

4. The material under test is the third submitted preliminary model of the Model LD-4 combined heterodyne frequency meter and crystal controlled calibrator manufactured by the Bendix Radio Corporation. The fundamental range of the heterodyne oscillator is from 100 to 5,000 kilocycles. The calibration of the heterodyne oscillator may be checked throughout its range by means of harmonics of a 100 kilocycle crystal controlled oscillator and a 20 kilocycle locked oscillator rigidly controlled by the crystal output at exactly one-fifth the crystal frequency. An audio frequency oscillator having fundamentals of 500 and 1000 cycles per second is incorporated in the unit as well as a detector and a two stage audio frequency amplifier for making audible the beats between the heterodyne oscillator and harmonics of the crystal or locked oscillator. The temperature of the crystal is controlled at 50° C and that of the heterodyne compartment at approximately 45° C. The equipment operates through its power unit directly from a 110 to 115 volt, 60 cycle source. The frequency measuring unit and the power unit are mounted in two compartments of a metal cabinet which is provided with a shock-proof mounting frame. This equipment is the same as that covered by reference (e) except for a number of changes which were incorporated to overcome the objections to the second model as stated in references (e) and (g). These changes are listed in detail under RESULTS OF TEST.

METHOD OF TEST

5. The crystal calibrator frequency was determined by comparison with the Navy primary frequency standard. The frequency drift of the heterodyne oscillator with time of operation was measured by observing the drift in the beat frequency between the heterodyne oscillator and the primary frequency standard or the LD-4 crystal by means of an interpolation oscillator, the drift in the latter being eliminated by frequent comparison with a precise 1000 cycle source. The effect of line voltage change and of tilting the equipment on the frequency of the heterodyne oscillator and of the crystal was determined in a similar manner by comparison with the primary frequency standard. The audio frequency output power available as a result of beats between the heterodyne frequency meter and harmonics of the crystal or locked oscillator was measured by means of an output power meter. The equipment was operated in a temperature controlled compartment at ambient temperatures between +1° and +44° C in order to observe the effect of these extreme temperatures on the operation of the temperature control systems of the equipment. The unit was set up within a few feet of a radio transmitter to note if damage or blocking occurred, as well as to determine the suitability of the equipment for measuring the frequency of transmitters both in the fundamental range of the LD-4 equipment as well as up to approximately 25 megacycles, by use of harmonics of the heterodyne oscillator. It was coupled to the input of Navy standard radio receivers tuned to frequencies up to 30 megacycles for the purpose of determining whether the radio frequency output of the heterodyne oscillator was sufficient to permit an adjustment of receivers up to this frequency. A number of frequency measurements were made with the equipment to determine the accuracy obtainable with it at various parts of the frequency range. The equipment was mounted on a vibration test stand and its operation was observed while it was being subjected to extreme vibration for a period of 7 hours.

DATA RECORDED DURING TEST

6. The data recorded during the test are given under RESULTS OF TEST and in the appended tables.

DISCUSSION OF PROBABLE ERRORS

7. The errors in the several measurements are not greater than the following:

Crystal frequency, ± 0.0002 per cent.

Frequency change of the crystal and heterodyne oscillator with tilting, ± 1 cycle at 800 kilocycles.

Audio output power, ± 10 per cent.

Ambient temperature in the extreme temperature tests, ± 2° C.

RESULTS OF TEST

8. The changes in this model from the second model which was reported in reference (e) will first be given, followed by a detailed statement of the results of the tests performed on this model as compared with the requirements of the governing specifications. This equipment differs from the model covered by reference (e) in the following respects:

(a) The heterodyne oscillator circuit has been changed from the negative transconductance oscillator to a modified Colpitts circuit.

(b) The heterodyne oscillator tube has been removed from the heterodyne compartment and mounted immediately above in the next shielded compartment to avoid adding heat to the heterodyne compartment by the operation of the tube; the bi-metallic thermal compensating condenser has been omitted as unnecessary.

(c) A transformer has been added to heat the heterodyne oscillator tube heater whenever the oven power switch is closed. This is to minimize heterodyne oscillator frequency drift during the first few minutes after closing the filament-plate switch for applying power to the other tubes.

(d) The tuning condenser knob is secured to the shaft with three set screws instead of one.

(e) The control knob for the crystal vernier frequency adjustment and also that for adjustment of the locked oscillator circuit have been removed from the front panel and are now accessible by means of a screw driver inserted through a hole in the front panel. The hole in the panel for screw driver adjustment of the heterodyne oscillator compensating condenser and the two holes mentioned just above are provided with thin metal dust covers which are attached to the panel and may be rotated for access to the slotted shaft beneath the surface of the panel.

(f) Two additional shock absorbing units have been added between the back of the cabinet and the mounting frame to provide greater support for the equipment should it be installed by clamping to a bulkhead without any support beneath it.

(g) An additional telephone jack has been provided to permit both local and remote observations of the audio output.

(h) The relay covers have been screwed on to prevent rattling or loosening from intense vibration.

(i) Name plates have been added as shown in Plate 5.

(j) The rectifier tube is a Type 38183.

(k) The window in the panel through which the hundreds of tuning condenser divisions are read has been extended so that two adjacent numbers are visible at all settings of the condenser dial.

(l) The fuses are of sufficient capacity so as not to open circuit when the specified d.c. emergency potential is applied.

(m) An interpolation chart has been furnished with this equipment.

(n) A coil range chart is attached to the front panel, showing the maximum and minimum frequency for each band of the heterodyne oscillator.

(o) The leads of both the main and the auxiliary power cables are labeled as to potential, and polarity where applicable.

9. The following comments cover the results of the tests. The subparagraph numbers below refer to the similarly numbered paragraphs in the specifications, reference (b). Since this equipment is in many respects unchanged from the one covered by reference (e), much of that report applies to this model; however, to avoid repeated references to that report, this report will be made complete, although certain paragraphs will be identical to the corresponding paragraphs of reference (e).

1-1 and 1-2. The equipment complies with the fundamental requirements as a frequency measuring device for use ashore and afloat.

1-3. The equipment is contained in one rugged metal cabinet which is mounted in a shock-proof frame. The cabinet contains two compartments, one housing the measuring unit and the other the power unit as shown in Plate 5. The use of a single cabinet instead of two cabinets clamped together is considered quite satisfactory since the location of the controls is such that no advantage would be gained by mounting the power unit above the measuring unit which would be possible if two separate cabinets were provided.

1-4. All power required to operate the equipment is obtained from a 110 to 115 volt, 60 cycle source.

1-5 to 2-2. No comment.

2-3 and 2-4. The equipment is very ruggedly constructed throughout and the workmanship appears to be of the best quality. The heterodyne oscillator coil switch is of the self-positioning type.

2-5. The equipment operated satisfactorily at ambient temperature between 0° C and +45° C. The coils are impregnated with a wax which is understood to be a type tested and approved by this Laboratory. No humidity test was given this equipment.

2-6. No comment on plating of metal surfaces is offered.

2-7 and 2-8. Use of iron and wood has been kept to a minimum as required.

2-9. All elements operate without any evidence of overloading.

2-10. The power unit is suitably ventilated by means of holes in the bottom and three sides of the cabinet, as shown in Plates 5 and 8.

2-11. The equipment was operated for a short time at a temperature of approximately 65° without any compound flowing out of any container.

2-12. Vacuum tubes are not subjected to excessive potential.

2-13. The equipment was operated within five feet of a Model TBN-2 and a Model TBK-5 transmitter without any damage or blocking of the tubes. No coupling lead on the LD-4 was necessary to obtain sufficient radio frequency pick-up for a strong audio frequency beat note. No damage will occur from failure of vacuum tubes or grounding of the coupling binding post or telephone receivers. The audio output power obtained from the equipment under different conditions of radio frequency coupling to nearby transmitters is shown in Table 6.

2-14. The equipment is designed for safe and satisfactory operation.

2-15. The equipment was tilted up to 45° from the normal position without any damage. See paragraph 4-12 and 4-27 below for effect on heterodyne oscillator and crystal frequency resulting from tilting the equipment.

2-16 and 2-17. The equipment was subjected to very intense vibration for a period of time in excess of seven hours at frequencies of vibration up to approximately 25 impulses per second and at an amplitude in excess of 1/8". The frequency of the heterodyne oscillator was quite stable, although under the most intense vibration the beat note was somewhat rough at the upper portion of the frequency range. However, the unit could be set approximately to zero beat when the equipment was being excited into such intense vibration that the condenser dial setting could not be read. The equipment withstood the vibration test unusually well. The following mechanical troubles were a result of the vibration test:

(a) The Type 38183 rectifier tube was dislodged from its socket after 30 minutes of vibration; the socket spring contacts were squeezed together slightly and the tube was not again unseated during 6-1/2 hours of test.
(b) The porcelain base of one of the pilot lamps became loose after the first hour. It was screwed tight and did not again become loose during the remainder of the test.
(c) At the end of two hours the lead connecting resistor number 107 to the tap on resistor number 105 in the power unit broke off. (See reference (i), Fig. II, for the location of these resistors in the oven control circuit.) This was caused by the movement of the upper end of resistor number 107 which is mounted vertical with respect to the sub-panel to which it is clamped by a threaded stud through the hole in its winding tube with a disk of phenolic insulation over the upper end of the resistor tube against which the securing nut on the stud bears. This disk appears to have been slightly deformed or compressed by the pressure applied and as a result the upper end of the resistor was slightly free to vibrate. The manufacturer's representative has replaced this disk with a heavy metal plate machined to fit in place which should prevent a recurrence of this trouble.
(d) After 3-1/2 hours of vibration the crystal oven relay vibrated open intermittently. A slight adjustment of the relay remedied this defect.
(e) After 7 hours the crystal would not start into oscillation readily but had to be given a sharp jolt and its frequency was 0.009% higher than before the test. The manufacturer's representatives found on removing the crystal from its holder that a minute spot on the lower surface of the crystal had been worn shiny against the bottom plate of the holder; when the crystal was turned over in its holder its activity was restored and the frequency was now only 0.002% high.
(f) One of the two small set screw wrenches which were furnished for convenience in tightening the knob set screws was dislodged from under the spring retainers provided in the power unit; improved provision should be made for securing these wrenches.

2-18. It is believed that the design and the control of the circuits of the equipment are as simple as consistent with the requirements of the specifications.

2-19. All necessary indicating instruments and controls are located on the front panel and their functions indicated by suitable lettering.

2-20. The equipment is suitably shielded and no body capacity effects occur.

2-21. The electrical indicating instruments are of the 2-1/2 inch type as required. The replacement of parts is considered to be as convenient as possible in an equipment of this style.

2-22. Name plates are provided as required. See Plate 5.

2-23 and 2-24. No comment on these requirements for production equipments is submitted.

2-25. The equipment was operated continuously for a number of days without any damage or loss of accuracy, except for change in frequency of crystal #2 discussed in paragraphs 4-24 to 4-28 below.

2-26. The dials, scales, and band selector switch comply with the requirements of this paragraph. The hundreds window of the heterodyne oscillator tuning dial has been extended so that two adjacent numbers are visible at all settings.

2-27. This paragraph of the specifications is merely explanatory.

2-28. Insulating material of Grade G is used where required except that the heterodyne oscillator inductance coil switch plate is of Mycalex, which is a Grade F material. This is considered satisfactory due to the necessity of accurately spacing the large number of holes, which is quite difficult in a non-machinable material.

2-29. The wiring is color coded as required.

2-30 to 2-32. The insulation of the wire used appears to be satisfactory but no tests were made on the component parts of the equipment.

2-33. Condensers such as the heterodyne compensating condenser are of the air dielectric type.

2-34. No electrolytic condensers were used.

2-35 to 2-43. No tests were made on condensers, resistors, etc. used in this equipment.

2-44 to 2-46. The finish of the surface of the cabinet and of metal parts complies with the requirements of these specifications as far as can be determined by inspection.

2-47. The thermometers conform to Specifications RE 13A 486C (Style 2), and the thermostats to Drawing No. RE 40A 120A as to dimensions.

3-1. The equipment consists of the required units and component parts except that a locked oscillator is provided in place of the multivibrator as a source of harmonics, spaced 20 kilocycles apart. (See comment under paragraph 4-20.)

3-2 and 3-4. See comment under paragraph 1-3. The power unit and the measuring unit are connected together when they are placed in their compartments.

3-3. A suitable cable is provided for coupling the power unit to an outlet of an alternating current supply line. This cable contains a pair of leads for the tube supply and another pair for the heater supply in order that the source of power for operation of the heater systems may be either an a.c. or d.c. 110 volt supply. A grounding lead is also included in this main power cable. The terminals of the leads are marked by means of stamped thin metal plates wired on to the insulated leads to indicate the source of power (a.c. or d.c.) and the polarity in the case of the heater leads if d.c. is to be used.

3-5. With this equipment it is possible:

(a) To measure the frequency of a transmitter in the same room at any frequency between 100 kilocycles and 25 megacycles by using the audio output of this equipment when its fundamental or a harmonic is beating with the transmitter signal. At frequencies above 5 megacycles, the Model LD-4 heterodyne oscillator frequency is set at a sub-multiple of the transmitter frequency; for example, to measure or adjust a transmitter to a frequency of 18 megacycles the Model LD-4 heterodyne oscillator is set at 1/4 this frequency. See Table 6 for specific data.
(b) To adjust a CW receiver to any frequency from 100 kilocycles to 25 megacycles. A Model RAB receiver was adjusted to 30 megacycles with the Model LD-4 heterodyne oscillator set at 5 megacycles, and the audio output of the receiver was many times the value essential for satisfactory measurement.
(c) To check or recalibrate the Model LD-4 heterodyne frequency meter every 20 kilocycles throughout its entire range and at many other frequencies directly from crystal controlled harmonics.

3-6. See comment above under paragraph 2-44.

3-7. See comment under paragraph 2-19.

3-8. See comment above on paragraph 1-3.

3-9 and 3-10. The measuring unit and the power unit may be removed from their compartments after the removal of the knurled thumb nuts, and all necessary electrical connections are made between the two units by means of plug and jack terminal strips on inserting the units into their respective compartments. The terminal strip carrying the plugs for the power unit is mounted in the box but the corresponding strip for the measuring unit is mounted on the back of the measuring unit. See Plates 6 and 8. If the latter plugs were also mounted in the box, with the jacks on the measuring unit, the possibility of bending the plugs out of alignment in servicing the equipment would be greatly reduced. (See paragraph 12(j).)

3-11. The overall dimensions of the equipment including the shock-proof mounting frame are as follows:

Height - 35 inches.
Width - 18 inches.
Depth - 14-3/4 inches.

The depth is measured flush with the front panel. The power cable block extends 2-3/8 inches beyond the front panel. Of the above dimensions for height and depth, 2-3/8 inches represent the space occupied by the shock-proofing mounting frame. The weight of the equipment is 147 pounds which is 38 pounds below the maximum weight allowed.

3-12. The shielding of the equipment is satisfactory. The output transformer is designed for use with 600 ohm head telephones.

3-13. The temperature of the crystal compartment was maintained between 49.9 and 50.1° C when the equipment was in ambient temperatures between 0 and 45° C. The heterodyne oscillator compartment which is normally controlled at 45° C decreased to 42.5° C in an ambient temperature of 0° C with the tubes off and to 43.5° C with the tubes on. In an ambient temperature of 45° C the heterodyne compartment temperature was approximately 48° C. The equipment operates satisfactorily at extreme ambient temperatures and the controlled temperatures of the heterodyne and crystal compartments comply with the requirements. Thermal fuses with a melting point of approximately 70° are used in series with both heaters to guard against excessive overheating of the equipment in case of the failure of the heater circuits to operate at the proper temperatures.

3-14. Suitable thermostats, heaters and other elements of the temperature control circuits are used. The thermostats do not carry the current which actuates the relays but each thermostat operates in the grid circuit of a vacuum tube to change the bias, and the resulting change of plate current causes the relays to function. This arrangement should result in long thermostat life. For alternating current operation of the temperature control systems, a rectifier tube provides direct potential for the two tubes associated with the operation of the relays.

3-15. The heating systems may be operated on direct current by simply connecting the heater plug to a 110 volt, direct current source, provided the polarity is properly chosen to apply a positive potential to the plates of the two tubes for supplying current to the relays. Emergency direct current operation of the tubes is achieved by removing the jumper plug on the power unit marked "Emergency Power Input" and inserting the emergency power cable plug. A 6-volt filament battery and a plate potential of 340 volts are recommended by the contractor as the direct current tube supply. Satisfactory operation may be obtained with somewhat reduced radio and audio output power by the use of a plate potential of about 200 volts in place of 340. The 220 volt d.c. line cannot be used as emergency plate potential if a ground exists at any other than its -220 volt terminal, since the cabinet of the LD-4 equipment is connected to the negative terminal of the emergency plate supply and also grounded through the ground lead in the main power cable. If, however, the main power cable should be removed from its socket before connection is made to the emergency tube supply no short would occur on using the 220 volt d-c line, but the potential existing between the negative side of the line and ground would be applied between the cabinet of the LD-4 equipment and any grounded metal surface. It is suggested that the final Instruction Book include suitable precautions in case the d-c line should be used in place of batteries for emergency plate supply.

3-16. The metal case may be grounded upon installation without any objectionable effect. A ground lead is provided in the main power cable as previously stated. No grounds will be applied to the a-c supply line by connection to this equipment.

3-17 and 3-18. The inductance changing switch appears to be well designed and contact can be made on only one coil at a time.

3-19. No door is provided in the front panel for the replacement of tubes. Access to the tubes in the power unit is gained by removing the securing thumb nuts and withdrawing the unit from its compartment. In the case of the measuring unit, a hinged inner shield must, in addition, be opened by the removal of seven machine screws. The complete operation of replacing a tube in the measuring unit required approximately four minutes. A tube door would obviously be an advantage in the case of vessels such as submarines where practically no space may be available to rest the unit outside its compartment.

3-20 and 3-21. The functions of all controls are indicated by suitable words engraved on the front panel.

3-22. All indicating instruments essential to the proper operation of the equipment are mounted on the front panel.

3-23 to 3-25. The tuning dial of the heterodyne oscillator conforms to the requirements of these paragraphs, except that the tuning condenser scale is divided into 50 main divisions instead of 25, thus giving twice the number of vernier divisions that are required. This doubling of the number of tuning condenser divisions is considered an advantage since the frequency change per division is reduced to one-half.

3-26. Fuses are provided in both sides of the tube supply leads to the primary of the power transformer, and also in both sides of the heater supply leads. The positive side of the d-c plate supply line is also fused. One thermal fuse is mounted in the crystal box and one in the heterodyne oscillator compartment. No fuses failed during the test with either a-c or d-c supply on the tubes.

3-27. The accessibility of the parts of this equipment for replacement or repair is considered to be quite good.

3-28. The maximum power input for operating the equipment including all tubes and both heaters was measured to be 455 watts, distributed approximately as follows:

Inner or crystal oven - 39 watts.

Outer or heterodyne oven - 270 watts.

Heater control tubes and circuits
including heterodyne oscillator heater - 56 watts.

Measuring unit tubes and circuits
exclusive of heterodyne oscillator heater - 90 watts.

The power consumed is below the maximum limit of 500 watts.

3-29. The calibration of the heterodyne oscillator consists of a tabulation of frequencies and corresponding condenser settings for the several coils. An interpolation chart is provided in a satisfactory form. This consists of a sheet of cross section paper mounted in a thin sheet aluminum frame 18-1/4 by 21-3/4 inches and covered with celluloid. This paper is marked with frequency intervals of 3.33, 5, and 6.67 kilocycles as well as 10 and 20 kilocycles. A heavy thread is secured at the lower left corner of the sheet of cross section paper. When this thread is drawn taut to cover the intersection of the lines representing kilocycles and the condenser divisions contained within the interpolation interval, the number of divisions or kilocycles for any part of the interpolation interval may be read off the chart at the intersection of the thread with the desired frequency or divisions difference as the case may be.

3-30. The average change of crystal frequency due to change in crystal oscillator tubes was 0.00006%, but with added regeneration it was 0.0013%. The change of heterodyne oscillator frequency due to change of tubes is quite small and the calibration can be readily corrected by means of the compensating condenser.

3-31. The radio frequency leads are such as to retain their position and avoid change in the calibration. Insulating bushings are not used in this model where the crystal leads pass through the walls of the balsa wood box to the crystal.

3-32. The following types of vacuum tubes are employed in the equipment:

Crystal oscillator, type 38076.
Buffer and locked oscillator (one tube), type 38077.
Mixer tube, type 38077.
Heterodyne oscillator, type 38646.
Audio oscillator, type 38076.
First audio amplifier, type 38077.
Second audio amplifier, type 38076.
Rectifier for measuring unit, type 38183.
Rectifier for temperature control tubes, type 38184.
Temperature control tubes (two), type 38041.

HETERODYNE FREQUENCY METER

4-1. The frequency range of the heterodyne oscillator is from 100 to 5000 kilocycles, as specified, and is covered by the use of 18 inductance coils with sufficient overlap between the ranges. The band changing switch is considered to be satisfactory in design.

4-2. A Raytheon automatic voltage regulator is included in the power unit which maintains the tube potential constant for any input voltage between approximately 90 and 130 volts. An increase of 10% in the applied voltage from 110 volts changes the heterodyne oscillator frequency only 0.0002%, and a decrease of 10% changes the frequency only 0.0001%. The total frequency change for a line voltage change from 90 to 130 volts was only 0.001%. These figures are based on a test made at 4500 kilocycles. A repeat at 800 kilocycles indicated a frequency change of only .0005% for a voltage change from 90 to 130 volts. This high degree of frequency stability with a large change in line voltage is a very desirable characteristic of this equipment. The heterodyne oscillator employs a Colpitts type of circuit.

4-3. The heterodyne oscillator frequency drift during the warming up period of the vacuum tubes is indicated in Table 1 and Plates 2, 3 and 4. Drift runs were made at 120, 800 and 4500 kilocycles as specified and repeat runs were made at the two higher frequencies. In Table 1 the drift is given in per cent and the specified limit is included for comparison. It will be noted on the first run the frequency drift was in all cases less than the maximum allowed and that the average of the two runs is also below the limit except in the case of the last two periods on the 800 kilocycle test where it is slightly larger. These runs were all made with the heterodyne oscillator heater kept continuously heated by means of a special transformer provided as previously stated. From the curves of Plates 2 and 3 entitled "Before Final Modification", it will be observed that the rate of frequency drift is not appreciably greater during the first five minutes than thereafter.

4-4. The frequency range of the heterodyne oscillator is covered by the use of 18 frequency bands.

4-5. The requirements of this paragraph of the specifications are met. See comment herein on paragraph 3-23 to 3-25.

4-6. The equipment may be used in the same room with standard types of radio transmitters without loss of accuracy or blocking (provided excessive signal voltage is not fed into the equipment by the use of too long a coupling lead to the coupling binding post). See comment on paragraph 2-13. An additional telephone jack has been added for connecting the audio output of the equipment to telephones in a separate room while still observing the output at the equipment in another pair of head telephones.

4-7. A mixer circuit is incorporated in this equipment for use in setting receivers that cannot be adjusted to zero beat reception so that the output of the receiver may be tuned to the 1000 cycle note produced by the audio oscillator in this equipment when the heterodyne oscillator is tuned to the desired receiver frequency and coupled to the input of the receiver. The frequency of the 1000 cycle oscillator was measured to be 1005 cycles and that of the 500 cycle oscillator was measured to be 504 cycles.

4-8. The r-f output of this equipment is much greater than in the case of previous similar equipments. Its r.f. output at 30 megacycles is approximately 260 microvolts with the LD-4 heterodyne oscillator set at 5 megacycles. This produces an audio output signal from a Model RAB receiver in excess of 80 milliwatts at 1000 cycles when the receiver is set at approximately maximum sensitivity, whereas a telephone signal power of less than 1 milliwatt is sufficient for r-f measurements.

The audio frequency output power available at the telephones of the LD-4 equipment resulting from beats between the heterodyne oscillator fundamental and crystal, or locked, oscillator harmonics is very large, as shown in Table 3. The 40 milliwatt output requirement at 5 megacycles is greatly exceeded as well as the 5 milliwatt output on 20 kilocycle harmonics up to 3 megacycles.

4-9. The calibration curve of the heterodyne frequency meter is essentially linear over the used portion of the frequency bands. The change in frequency per division change in setting along the condenser scale is quite uniform between 400 and 4800 divisions as shown by the kilocycles per division curves for coils 10 and 16 on Plate 1. The improvement from the previous model in this respect may be noted by comparing Plate 6 of reference (e) with Plate 1 herein. This improved condenser characteristic resulting from a redesign of the tuning condenser plates minimizes the error in interpolation along the condenser scale. See comment on paragraph 4-13 below.

4-10 and 4-11. A compensating condenser is provided in parallel with the tuning condenser for correcting the frequency of the heterodyne oscillator to maintain the accuracy of the calibration due to changes resulting from the change of tubes, aging, etc. This condenser has a range corresponding to approximately ± 200 divisions of the main tuning condenser when the compensating condenser is set at its mid-scale position.

4-12. The effect of tilting the equipment on the frequency of the heterodyne oscillator was determined by manually tilting the cabinet up to 45° forward, backward, to the right, and to the left. The equipment could not be tilted while mounted by means of its rack since the tilting table was disassembled due to its being moved to a new location. From previous tests it was noted that the tilt effect was less when the mounting surface was tilted instead of merely the cabinet. The results of this test are given in Table 2 from which it will be observed that the front and back tilt produce very slight frequency changes, while the right and left tilt cause frequency changes several times greater than the 0.0005% specified, when the angle is greater than 25°.

4-13. Frequency measurements can be made with this equipment to a high degree of accuracy by checking the heterodyne oscillator against the available crystal controlled harmonics and interpolating between the checking points for any intermediate frequency or condenser setting. The average error in measuring a large number of frequencies was 0.0012%, whereas the specifications state that the error shall not be greater than 0.005%. These measurements do not involve any frequency drift since the time consumed in any one measurement was less than 1 minute. The uniformity of the kilocycles per division is a great aid in making interpolations along the condenser scale with a minimum error. The reset accuracy is of a very high order. The average frequency error in 8 resets of the condenser dial was 0.0002%. The back lash is very slight; of 16 determinations at different parts of the tuning condenser range the average back lash was only 0.1 division with a maximum of 0.2 division which is unusually low in a condenser scale of 5,000 divisions.

4-14. See comment above on paragraph 3-12.

4-15. A coupling binding post on the front panel provides a means of exciting a receiver from the r-f output of the heterodyne oscillator.

4-16. The detector and audio frequency amplifier are satisfactory, and the audio output power is very large as shown in Table 3.

4-17. Undesired beat notes generated in the equipment may be sufficiently reduced in audibility by means of the adjustment of the coupling and gain control.

4-18 and 4-19. Both the zero beat and the matched tone method may be used in frequency measurements. An auxiliary dial is provided which may be used to determine directly the mid-point setting when using the matched tone method.

CALIBRATOR

4-20 and 4-21. A 100 kilocycle crystal controlled calibrator is provided as the frequency standard of the equipment. Harmonics of this frequency are available throughout the range of the heterodyne oscillator. The crystal oscillator circuit is shown on Plate V of reference (i). A crystal frequency adjusting condenser is provided which produces a total frequency change of approximately .9 cycle on the crystal fundamental. Access to this condenser is effected through a covered hole on the panel and adjustment is made by means of a screw driver. A switch is provided by means of which the calibrator may be turned off while the heterodyne frequency meter is left in an operating condition.

4-22. The function of the multivibrator (the generation of harmonics every 20 kilocycles from a source controlled by the crystal output) is served by a locked oscillator consisting of a single tube circuit instead of two tubes as in the case of the multivibrator. If this circuit is not rigidly controlled at one-fifth the crystal frequency by the crystal oscillator output, a continuous audio note is heard in the telephone receivers. A condenser is provided for varying the frequency of this circuit to produce locked synchronism at only one sub-multiple of the crystal frequency, that is, at 20 kilocycles. In this model locked synchronism is effected over approximately 70° of the range of the adjusting condenser.

4-23. The frequency of the crystal received in this equipment was 100,000 ± 0.5 cycle which is within the specified value.

4-24 to 4-27. The crystal holder is a Navy standard transmitting type ceramic case holder with adjustable air gap. The temperature coefficient of the crystal received in this equipment was approximately 28 parts per million per degree Centigrade, which is within the specified limit. The effect of tilting on the crystal frequency was satisfactorily low for all directions of tilt except to the left (of the operator facing the equipment). At an angle of 25° the frequency change with left tilt was 0.00023% and at 45° it was 0.0005, whereas 0.0002% is allowed. (See Table 4 under crystal number 1.) This crystal became sluggish in starting into oscillation after approximately 2 weeks (about 14 September); the manufacturer removed the equipment to his plant on 16 September with the consent of the Bureau for making minor changes. The equipment was returned to this Laboratory on 19 September with the crystal circuit changed by the introduction of regeneration. This was found to be unsatisfactory since the crystal excitation caused an increase in the crystal temperature due to its vigorous oscillation and a consequent decrease in the frequency of approximately 0.0014% in 30 minutes of crystal operation. In addition, the change in frequency with shift of tubes was quite large, being in some cases 0.002%. A second and thicker crystal was furnished and the added regeneration removed on 26 September at which time a smaller crystal plate circuit coil was used. This crystal was much more active than the previous one before regeneration was added to it, but it was observed to change frequency by 0.003% (low) in a week. This crystal was in the equipment during the vibration test and as previously stated it became sluggish after 7 hours of excessive vibration. (See paragraph 9, sub-paragraph 2-16(e).) For tilt effect on this crystal, see Table 4 under crystal number 2. The operation of these two crystals in the circuit provided was obviously unsatisfactory, either in regard to frequency instability or development of sluggishness in vibration

4-28. See paragraph 4-21 above.

4-29 and 4-30. "Weak" and "strong" coupling between the calibrator and the heterodyne frequency meter may be selected by means of a switch. The calibrator supplies sufficient r-f output on all harmonics within the range of the heterodyne frequency meter.

POWER UNIT

5-1 to 5-3. The power unit contains all parts and circuits necessary to operate the equipment from a 110 volt, 60 cycle source. The total power required is 455 watts. See comment on paragraph 3-28.

5-4. In place of a manually operated line voltage regulator, there is built into the power unit a Raytheon 60 watt voltage regulator which maintains the tube supply voltage constant with any line potential between approximately 90 and 130 volts. This is a very desirable feature. The heater supply voltage is not controlled by this regulator but satisfactory heater operation is not dependent upon a constant potential.

5-5. See comment on paragraphs 3-9 and 3-10 above.

5-6. An emergency power cable is provided for d.c. operation of the measuring unit. This cable is plugged into the jack labeled "Emergency Power Input" on the power unit panel. See comment on paragraph 3-15.

5-7. Direct current may be used for heater supply merely by removing the heat supply plug from the a.c. line and inserting it into a 110 volt, d.c. outlet with attention to the polarity. See comment above on paragraph 3-3.

5-8. The power unit may be removed from its cabinet without disconnecting any wires. (See comment on paragraph 3-9 above.)

5-9 to 5-13. The heater power and the tube power for the measuring unit are controlled by separate switches on the power unit panel. Indicating lamps show when the heater power is applied to each of the heaters (crystal or heterodyne oscillator). A voltmeter and pilot lamp indicate when the power is applied to the transformer for a.c. supply to the measuring unit tubes. Fuses are provided as previously stated and the heater systems have operated continually for many days without any failure or damage. See also comment on paragraph 3-16.

SUMMARY OF RESULTS OF TESTS

10. The equipment complies with the requirements except in regard to the following:

(a) Crystal frequency stability and activity as determined by tests of crystals 1 and 2 as described above.

(b) Heterodyne oscillator frequency change with extreme tilting to the right and left.

(c) The power unit and the measuring unit are housed in separate compartments of a single cabinet instead of in separate cabinets clamped together.

(d) No door is provided in the front panel for tube replacement in the model as submitted on 29 August.

11. The equipment is characterized by the following desirable features:

(a) Automatic voltage regulation for the tube supply.

(b) Unusually large audio frequency (telephone) output power.

(c) Unusually large r-f voltage at the coupling binding post.

(d) Unusually high r-f sensitivity to signal voltages fed into the equipment at the coupling binding post.

(e) The combination of negligible back lash and reset error, highly uniform frequency change per division change of tuning condenser dial, and the use of a 5,000 division condenser scale instead of 2500 result in an equipment with which a high degree of frequency accuracy can be obtained.

Test of Model with Tube Replacement Door in Front Panel.

12. The equipment covered by the above report was removed by the contractor on 20 October with the consent of the Bureau and an extension of 2 weeks to overcome the deficiencies mentioned in paragraph 10 above. On 8 November the contractor delivered to the Laboratory not the same model which was removed, but a different unit fundamentally the same but containing a number of changes which are listed below:

(a) A tube door in the front panel of the measuring unit for replacement of tubes was provided, as required in paragraph 3-19 of the governing specifications. Slight rearrangement of the controls on the front panel and of some circuit elements inside of the equipment was made.

(b) The surface of the crystal and of the crystal holder plate on which the crystal rests are ground to a high polish to reduce damping.

(c) A slight change in crystal dimensions was made for increasing crystal activity.

(d) The crystal oven thermostat was relocated to reduce the time necessary for the crystal to reach its operating temperature.

(e) The heterodyne oscillator oven thermostat was moved from the inner edge of the shield of the heterodyne compartment to a position near the center of the heterodyne compartment and close to the thermometer. The mounting arrangement of the thermostat was changed leaving the bulb in free air instead of inside a metal block, and a 6 watt lamp has been placed near the thermostat and across the heater power supply line to shorten the thermostat cycle of operation.

(f) The heterodyne oscillator tuning condenser has been enclosed in a metal shield to reduce the frequency change due to tilting.

(g) The heterodyne oscillator tube grid lead has been made rigid through most of its length by being placed inside a stiff insulating tube, to reduce the possible movement of this lead when changing tubes, and the consequent effect upon the frequency calibration.

(h) The heating effect in the heterodyne compartment of the tubes on the shelf above this compartment has been simulated by the addition of 3 small resistors which dissipate heat when the filament-plate switch is in the off position in order to minimize the frequency drift of the heterodyne oscillator due to temperature change after the tubes are turned on. (The heterodyne oscillator tube heater is heated as in the third model without the door whenever the oven power switch is closed even when the filament plate switch is open.)

(i) The r-f leads to the coupling binding post have been spaced from the panel by suitable small stand-off insulators.

(j) The plug and jack mounting strips provided for connecting the measuring unit to the power supply have been interchanged so that the jacks are now mounted on the rear of the measuring unit in place of the plugs, since there was some possibility that the exposed plugs might be bent out of alignment in handling the measuring unit outside its cabinet. See Plates 6 and 10.

(k) External shake-proof lock washers are used on all cabinet screws including those on the front panel.

13. Tests were performed on this model to determine the following:

(a) Crystal temperature coefficient of frequency.
(b) Crystal frequency at the rated temperature.
(c) Effect of tilting on the crystal frequency.
(d) Effect of changing tubes on the crystal frequency.
(e) Effect on the crystal frequency of varying the crystal adjusting condenser through its range.
(f) Frequency drift of the heterodyne frequency meter during the first 30 minutes after closing the filament-plate switch.
(g) The effect of tilting on the heterodyne frequency meter frequency.
(h) Audio output power for telephone use.
(i) Effect of low ambient temperature on the controlled temperature of the heterodyne oscillator and the crystal.
(j) Effect of high ambient temperature on the temperature of the heterodyne oscillator and crystal.
(k) Effect of vibration.
(l) R-F output available at the coupling binding post.

14. The results of the tests of this model with the tube door are given below with the applicable paragraph of the specifications appended in parentheses.

<u>Crystal Temperature Coefficient of Frequency</u>

The crystal temperature coefficient of frequency is approximately 18 parts per million per degree Centigrade which is considerably less than that of the crystals previously used in these models. (Paragraph 4-25.)

<u>Crystal Frequency</u>

The crystal frequency was 100,000 $\pm$ 0.1 cycles, whereas a tolerance of $\pm$ 1 cycle is allowed. (Paragraph 4-23.)

<u>Tilt Effect on Crystal Frequency</u>

The effect of tilting up to 45° from the normal on the crystal frequency is shown in Table 4. It is in all cases less than the allowed value of .0002%. (Paragraph 4-27.)

Effect on Crystal Frequency of Changing Crystal Oscillator Tubes

The change of crystal frequency resulting from the change of crystal oscillator tubes was too small to measure in two instances and in the third case it was less than .0002%. (Paragraph 4-23.)

Effect on the Crystal Frequency of Varying the Crystal Frequency Adjusting Condenser

The total range of variation of the crystal oscillator frequency by means of the crystal frequency adjusting condenser was .0013% or from a frequency of 99,999.1 to 100,000.4 cycles in the case of this equipment. (Paragraph 4-28.)

Frequency Drift of the Heterodyne Oscillator

The frequency drift of the heterodyne oscillator for each 5 minute interval from 5 minutes after the filament-plate switch is closed until 20 minutes later is given in Table 1 for radio frequencies of 120, 800, and 4500 kilocycles. The data taken at 800 and 4500 kilocycles are plotted on Plates 2 and 4. It will be noted that the frequency drift is decidedly less than the specification limits which are included in Table 1. These runs were made with the heterodyne oscillator tube kept continuously hot by means of a special transformer provided. Graphs of the frequency drift taken with the tube cold previous to the beginning of the run are also shown on Plates 4 and 4A which indicate that the drift is quite rapid during the first 5 minutes of heating. A comparison of the curves with the tube hot and cold indicates the advantage of the provision for keeping the heterodyne oscillator tube heated when the filament-plate switch is off. (Paragraph 4-3.)

Effect of Tilt on the Frequency of the Heterodyne Oscillator

The effect of tilting the equipment on the frequency of the heterodyne oscillator is extremely slight as shown in Table 2 in the column headed "Model with Tube Door." (Paragraph 4-12.)

Audio Output Power

The audio output power available at the telephone jack caused by beats between crystal and locked oscillator harmonics on the one hand and the fundamental of the heterodyne frequency meter on the other is many times larger than required and is of the same order of magnitude as that in the third model described previously in this report. See data in Table 3. (Paragraph 4-8.)

Low Ambient Temperature Operation

When this Model LD-4 equipment is operated in an ambient temperature of -1° C, the thermometer in the heterodyne oscillator compartment does not drop more than 1°C from the normal value of 45° C while a 5° change is allowed; the indicated change in the crystal temperature was 0.20° C while 0.25° C change is permitted. The above observations were taken with the tubes off. With the tube switch on for a period of 2 hours, the heterodyne temperature was only 0.5° C below its normal value and that of the crystal was the same as with the tubes off. (Paragraph 3-13.)

High Ambient Temperature Operation

When the equipment was operated in an ambient temperature of 42°C, the temperature of the heterodyne oscillator compartment rose from 45 to 46.6° C and the crystal temperature rose from 49.90 to 50.10° C. At the extremely high ambient temperature of 48° C, the heterodyne thermometer indicated a temperature of 50.30° C and the crystal temperature was 50.45° C after all tubes had been in operation for 3 hours. Under these conditions the temperature rise in the crystal compartment was 0.55° C, whereas the specification limit is 0.25° C. This temperature change is a natural result of the dissipation of the tube power in the equipment, combined with the effect of thermal insulation required. The operation of this unit at excessively high ambient temperatures is considered satisfactory. (Paragraph 3-13.)

Operation of the Heater System with the 6 Watt Lamp in the Heterodyne Compartment Removed

The addition of a 6 watt 110 volt lamp to the heterodyne oscillator heater circuit (placed within a few inches of the thermostat) has changed the length of the heater cycle from about 6 minutes to about 15 seconds so as to eliminate the slight recurring temperature change with heater operation, and consequent frequency variation of the heterodyne oscillator. Since failure of this lamp might occur, a test of the heterodyne oscillator operation with the lamp removed was made at normal room temperature with the following results:

(a) The heater cycle changed from about 15 seconds to about 6.5 minutes and the heterodyne oscillator compartment thermometer indicated a temperature change during the heat cycle from 44.8 to 45.0° C with the tubes off or on.

(b) The frequency of the heterodyne oscillator executed a slight periodic variation corresponding to the heating cycle as shown in one of the curves on Plate 4. The magnitude of this frequency cycle was approximately ±0.0005%. The failure of this 6 watt lamp in the heater circuit is indicated by the large change in the length of the heat cycle as mentioned just above and also by the absence of the visible illumination caused by the lamp which may be observed through the window provided for reading the tuning condenser dial. Therefore the use of this lamp as part of the heterodyne oscillator heater system is not considered objectionable. (Paragraphs 3-13 and 4-3.)

Vibration Test

The equipment withstood the most intense vibration which could be applied to it by the use of the transmitter vibration table, at all frequencies within the range of the testing table for 2-3/4 hours. The heterodyne oscillator frequency was extremely stable durihg vibration; the beat note was quite pure in quality and the zero beat setting was sharply defined, even at 5 megacycles without any "mush" as noted to some extent in the previous models of the LD-4 equipment. The only damage done was as follows:

(a) The filaments of the 3 pilot lamps were broken after 1-1/4 hours of test. Replacement lamps were not damaged during the remainder of the test.

(b) The relays "chattered" open and closed at a critical frequency of vibration when the amplitude of vibration was intense. This was found to be due to the effect of vibration on the thermostats and not to the adjustment of the relays, since the relays did not "chatter" except when the thermostats were heated to their operating temperature. This rapid operation of the relays does not affect temperature control; it appears to be due to "splashing" of the mercury in the capillary of the thermostats which can occur only when a minutely small movement of the mercury can make or break contact inside the thermostat.

(c) The crystal frequency was 0.0018% higher after the vibration test than before. The contractor's representative states that an increase in the clamping pressure on this crystal in its mounting can probably eliminate this effect. (Paragraph 4-12.)

Radio Frequency Output

The radio frequency output voltage available at the coupling binding post of this model is quite large; the output in micro-volts at a number of frequencies is given in Table 7, including values on harmonics of 4500 kilocycles up to the sixth.

15. In summarizing, the results of the tests of the model with the tube door indicate that this equipment complied fully with the operational requirements of the specifications except for the frequency change of the crystal after vibration.

Retest of the Model without Tube Door after Final Modification

16. The equipment without the tube door which, as stated above, was removed by the contractor on 20 October, was returned on 23 November with all eleven modifications incorporated in it which are detailed in paragraph 12 , in describing the model with the tube door, with the exception of item (a), that is, the door was not added to this finished model. This equipment is referred to hereafter as "Model After Final Modification." This unit was retested in certain particulars to determine if the undesirable characteristics mentioned in Conclusion (a) had been eliminated. The results of the retest of this model are given below with the relevant specification paragraphs appended in parentheses.

Crystal Temperature Coefficient of Frequency

This is the same as that of the crystal in the model with the tube door, approximately 18 parts per million per degree Centigrade. (Paragraph 4-25.)

Crystal Frequency

The crystal frequency was measured to be 100,000 $\pm$ 0.1 cycles. (Paragraph 4-23.)

Tilt Effect on Crystal Frequency

The effect on the crystal frequency of tilting the equipment is given in Table 4 from which it will be observed that the frequency is extremely independent of tilt in all directions up to 45°. (Paragraph 4-27.)

Frequency Drift of the Heterodyne Oscillator

The frequency drift of the heterodyne oscillator after final modification is given in Table 1 (column 4) and in Plates 2 and 3. These data were taken with the heterodyne oscillator tube heated previous to the beginning of the drift runs as provided in the wiring of the equipment; under this condition the frequency drift is very slight. (Paragraph 4-3.)

Audio Output Power

The audio output power was checked at several frequencies and found to be in general somewhat less than that of the same equipment before the final modification, but still much more than required. (See Table 3 in column headed "After Final Modification." (Paragraph 4-8.)

Vibration Test

As a result of intense vibration for a period of 2-3/4 hours, no failure or damage occurred except that some chattering of the relays was noted after the thermostats had reached their operating temperatures as mentioned in paragraph 14 above. The heterodyne oscillator frequency was extremely stable during vibration even at 5 megacycles. No change in crystal frequency occurred due to the vibration test.

17. In summarizing, the results of the retest of this model indicate that it complies fully with the requirements of the governing specifications with the exception that the tube door has been omitted. No difference has been observed between the operation of this model after modification and the similar model which includes the tube door, except that the frequency of the crystal in the latter equipment was slightly affected by the vibration test. (Paragraph 4-12.)

CONCLUSIONS

18. The equipment as delivered to this Laboratory on 29 August complied with the governing specifications except as follows:

(a) The crystal became sluggish in starting oscillation after 2 weeks of observation and the crystal frequency change with tilt to the left was 2-1/2 times the allowed value; a second crystal drifted in frequency .003% in a week.

(b) Frequency change of the heterodyne oscillator with tilt to the right and left was 5 times the allowed value when the angle of tilt was as great as 25°.

(c) No door was provided in the panel for tube replacement.

19. When this equipment was tested after final modification following redelivery to this Laboratory on 23 November, it complied with all requirements of the specifications except that no tube door was provided.

20. An equipment identical with the improved model mentioned in paragraph 19 above but containing a satisfactory tube door in the front panel complies with the specifications in all respects except that the crystal oscillator frequency changed 0.0018% as a result of intense vibration for a period of 2-3/4 hours.

21. The model after final modification and the model similar to it with the tube door are considered suitable for Naval use provided each individual crystal is mounted with particular care to minimize the effect of intense vibration on the crystal oscillator frequency.

TABLE No. 1

Frequency Drift of Model LD-4 Heterodyne Oscillator

Minutes After Closing Tube Switch	FREQUENCY DRIFT IN PERCENT					
	First Run	Second Run	After Final Modification	Model with Tube Door: Tube hot	Model with Tube Door: Tube cold#	Spec. Limits
			120 KILOCYCLES			
5-10	0.0008	---	0.0033	0.0008	0.0025	0.0018
10-15	0.0004	---	0.0008	0.0004	0.0008	0.0015
15-20	0.0008	---	0.0008	0.0004	0.0000	0.0013
20-25	0.0004	---	0.0008	0.0000	0.0000	0.0008
			800 KILOCYCLES			
5-10	0.0011	0.0014	0.0008	0.0001	0.0020	0.0018
10-15	0.0008	0.0009	0.0003	0.0003	0.0006	0.0011
15-20	0.0004	0.0011	0.0003	0.0006	0.0005	0.0005
20-25	0.0004	0.0008	0.0004	0.0001	0.0002	0.0005
			4500 KILOCYCLES			
5-10	0.0012	0.0017	0.0005	0.0005*	0.0015	0.0018
10-15	0.0006	0.0008	0.0002	0.0005*	0.0003	0.0011
15-20	0.0004	0.0004	0.0002	0.0004*	0.0006	0.0005
20-25	0.0002	0.0008	0.0005	0.0004*	0.0007	0.0005

See Plates 2, 3, 4 and 4A for graphs of 800 and 4500 kilocycle drift runs.

* Mean of two test runs.

\# Data in columns 2-5 taken with heterodyne oscillator tube pre-heated. Data in column 6 taken with tube cold at start of test.

TABLE No. 2

Effect of Tilting Model LD-4 Heterodyne Oscillator

Direction of Tilt	Degree of Tilt	FREQUENCY CHANGE IN PERCENT Before Modification	After Modification	Model with Tube Door
Right	25	0.0026	0.0000	0.0003
"	45	0.0047	0.0001	0.0004
Left	25	0.0025	0.0001	0.0000
"	45	0.0037	0.0002	0.0000
Front	25	0.0005	0.0001	0.0000
"	45	0.0009	0.0002	0.0000
Back	25	0.0001	0.0001	0.0004
"	45	0.0002	0.0002	0.0006

Specification Limit - 0.0005%

NOTE: Heterodyne Oscillator set at 800 Kilocycles.

TABLE No. 3

Audio Output Power of LD-4 Equipment

Heterodyne Frequency Oscillator (Kcs)	AUDIO OUTPUT POWER - MILLIWATTS					
	Before Final Modification		After Final Modification		Model With Tube Door	
	350 cycles	1100 cycles	350 cycles	1100 cycles	350 cycles	1100 cycles
5000	68	45	53.8	52.4	- -	- -
5000*	64	38	26.2	30.8	- -	- -
4980	- -	- -	28.2	31.4	- -	- -
4500	131	79	66.8	62.9	131	72
4500*	92	50	57.6	59	65.4	30.1
4480	- -	- -	- -	- -	31.4	18.4
3000	272	109	314	131	314	124.5
3000*	262	107	229	124.5	301	120.5
2980*	265	105	128.4	236	295	115.3
2000	278	111				
2000*	269	110				
1980*	272	110				
1000	308	98				
1000*	317	105				
980*	318	107				
600	249	65				
600*	301	79				
580*	314	84				
120*	197	48				
100	272	50				
100*	187	37				

NOTE: * Locked Oscillator On.

TABLE No. 4

Tilt Effect on LD-4 Crystal Frequency

		FREQUENCY CHANGE (CYCLES IN 100,000)				
Direction of Tilt	Degree of Tilt	Crystal #1	Crystal #1 with Regeneration	Crystal #2	Crystal #3	Crystal in Unit with Tube Door
Right	25	0.02	0.20	0.21	0.07	--
"	45	0.20	0.20	0.43	0.13	0.11
Left	25	0.23	0.13	0.33	0.07	--
"	45	0.50	0.18	0.66	0.07	0.00
Front	25	0.13	0.06	0.20	0.03	--
"	45	0.13	0.06	0.33	0.10	0.00
Back	25	0.00	0.20	0.27	0.03	--
"	45	0.17	0.20	0.80	0.10	0.11

Specification Limit = 0.0002% or 0.20 cycles.

Crystal #1 was delivered in the equipment 29 August.
Crystal #2 is a thicker crystal put in equipment on 26 September after Crystal #1 had become sluggish in starting oscillation.
Crystal #3 was delivered in the equipment 23 November. Regeneration which was added to crystal on 17 September was not satisfactory and was removed by manufacturer.
Equipment with tube door received 8 November.

TABLE 5

R.F. Sensitivity of Model LD-4 Equipment with Tube Door

(Input Microvolts for 1 Milliwatt Output at 1000 Cycles)

Frequency (Kcs)	(μv)
100	1700
300	1800
400	1900
450	1650
500	1500
600	1550
700	1600
1500	2200
2500	3200
3500	4600
4500	5900

TABLE 6

LD-4 Operation Close to Transmitters

(Third Model Before Final Modification)

Transmitter Frequency Kcs.	LD-4 Frequency	Distance LD-4 to Antenna	LD-4 Coupling Lead Length	LD-4 Audio Output in Milliwatts
500	500	6 ft.	None	26.0
500	500	12 ft.	None	0.8
500	500	12 ft.	6 ft.	75.0
500	1000	12 ft.	6 ft.	150.0
500	1000	12 ft.	None	Not heard
1500	1500	12 ft.	6 ft.	175.0
1500	1500	12 ft.	None	1.5
1500	3000	12 ft.	6 ft.	200.0
1500	3000	12 ft.	None	Not heard
4500	4500	3 ft.	None	22.0
4500	2250	3 ft.	None	22.0
4500	1500	3 ft.	None	22.0
4500	4500	10 ft.	None	0.2
4500	4500	10 ft.	6 ft.	110.0
9000	4500	10 ft.	6 ft.	130.0
9000	4500	10 ft.	None	0.4
18000	4500	10 ft.	6 ft.	85.0*
18000	4500	10 ft.	None	0.5

NOTES: Transmitter used on 500 and 1500 Kcs. was TBN-2; on other frequencies XTBK-5. Approximate power - 400 watts.

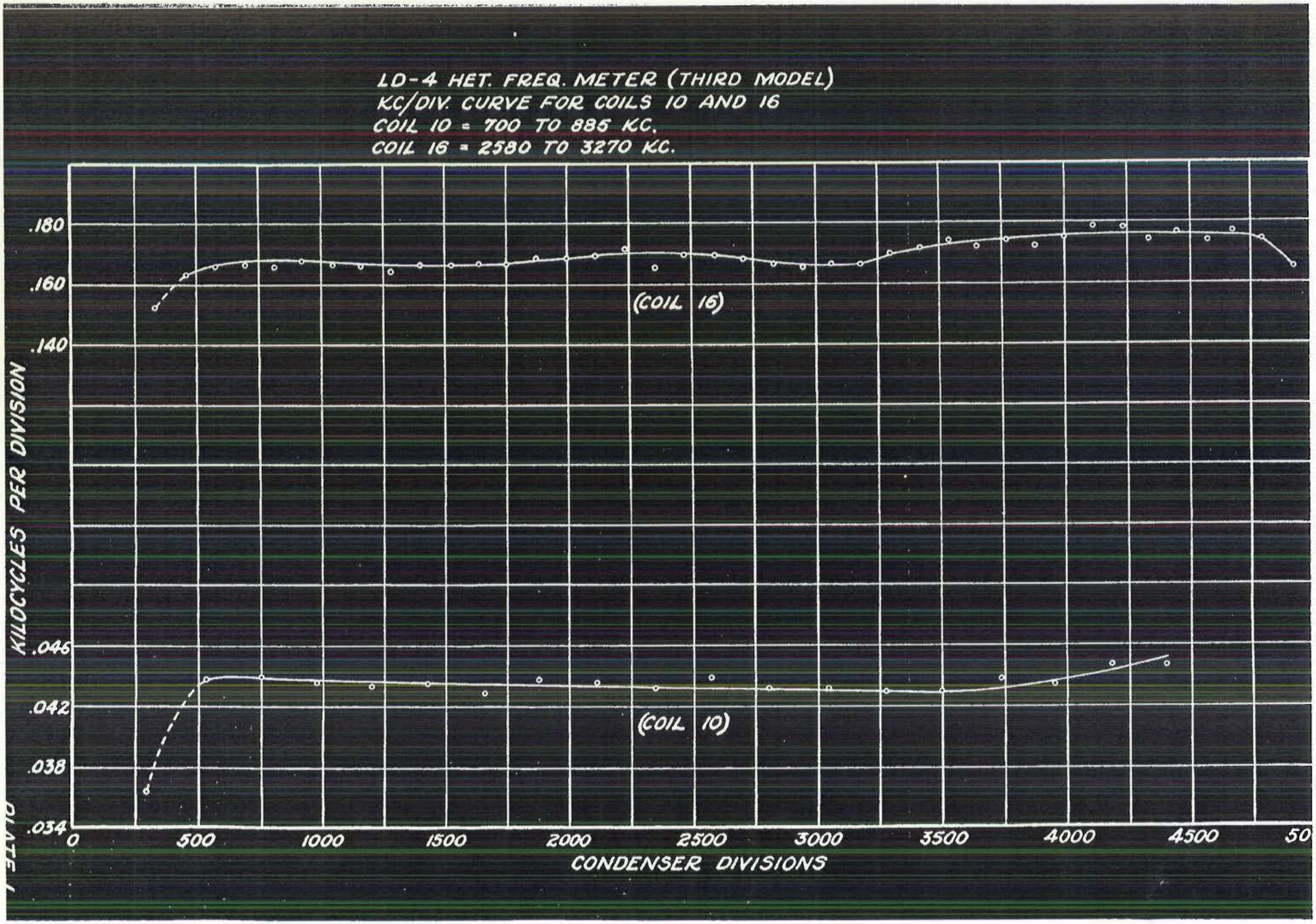
Transmitter antenna consisted of 500 W lamp and a 12 ft. lead on high potential terminal.

* Detector blocks at 1000 cycles with switch on "strong" coupling but not on "weak". All outputs are for "strong" coupling, and maximum gain at beat note frequency of about 500 cycles.

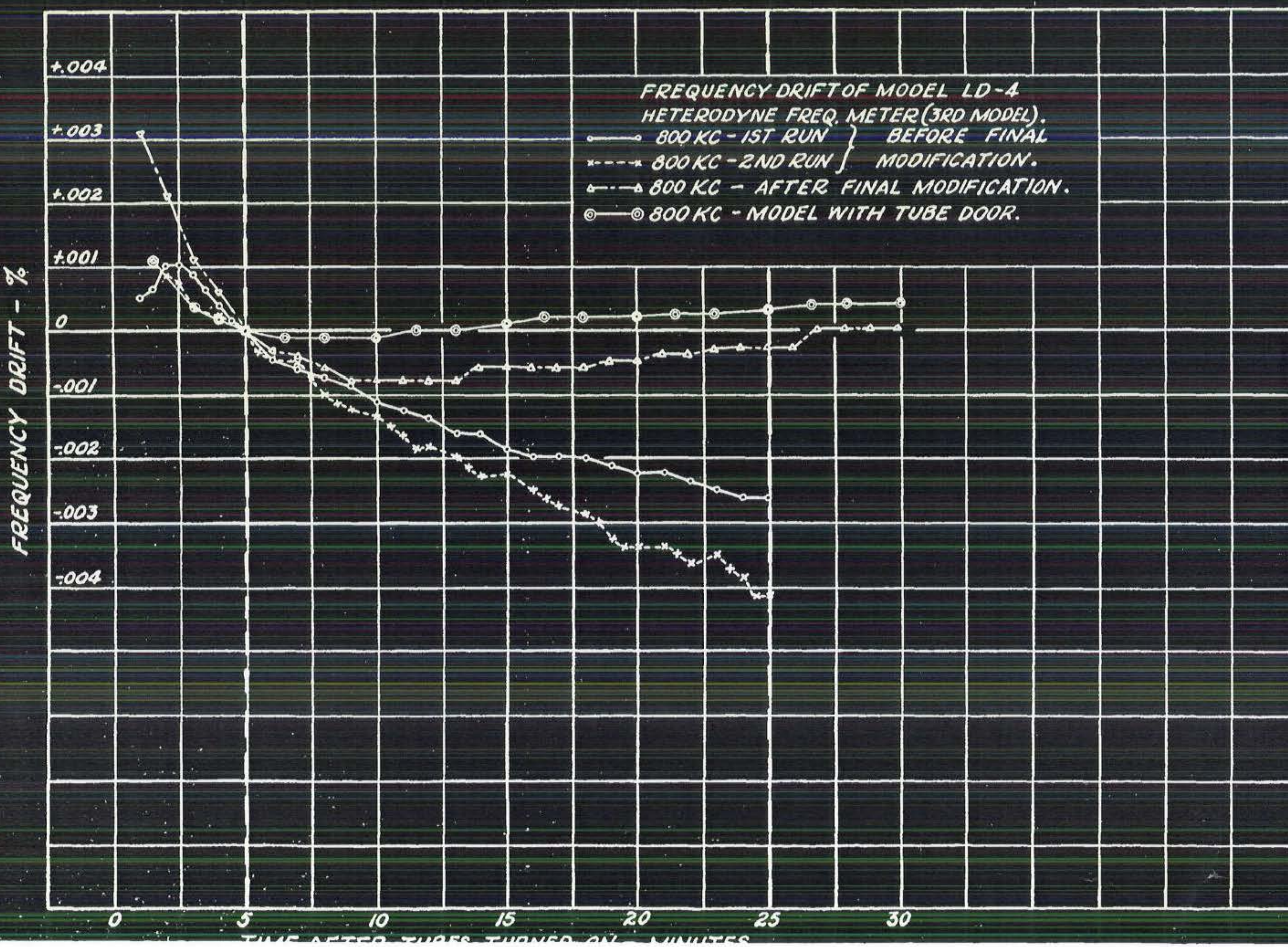
TABLE 7

R.F. Output of Model LD-4 Equipment - Unit with Tube Door

LD-4 Freq. (Kcs.)	Recvr. Freq. (Kcs.)	LD-4 R.F. Output (microvolts)
100	100	9400
400	400	64000
1000	1000	100000+
2500	2500	12000
4500	4500	15000
4500	9000	16000
4500	13500	360
4500	18000	565
4500	22500	1800
4500	27000	350



LD-4 HET. FREQ. METER (THIRD MODEL)
KC/DIV. CURVE FOR COILS 10 AND 16
COIL 10 = 700 TO 885 KC.
COIL 16 = 2580 TO 3270 KC.
KILOCYCLES PER DIVISION
.180
.160
.140
.046
.042
.038
.034
(COIL 16)
(COIL 10)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
50
CONDENSER DIVISIONS



FREQUENCY DRIFT OF MODEL LD-4
HETERODYNE FREQ. METER (3RD MODEL).
800 KC - 1ST RUN
800 KC - 2ND RUN
BEFORE FINAL MODIFICATION.
800 KC - AFTER FINAL MODIFICATION.
800 KC - MODEL WITH TUBE DOOR.
FREQUENCY DRIFT - %
+.004
+.003
+.002
+.001
0
-.001
-.002
-.003
-.004
0
5
10
15
20
25
30

PLATE 2

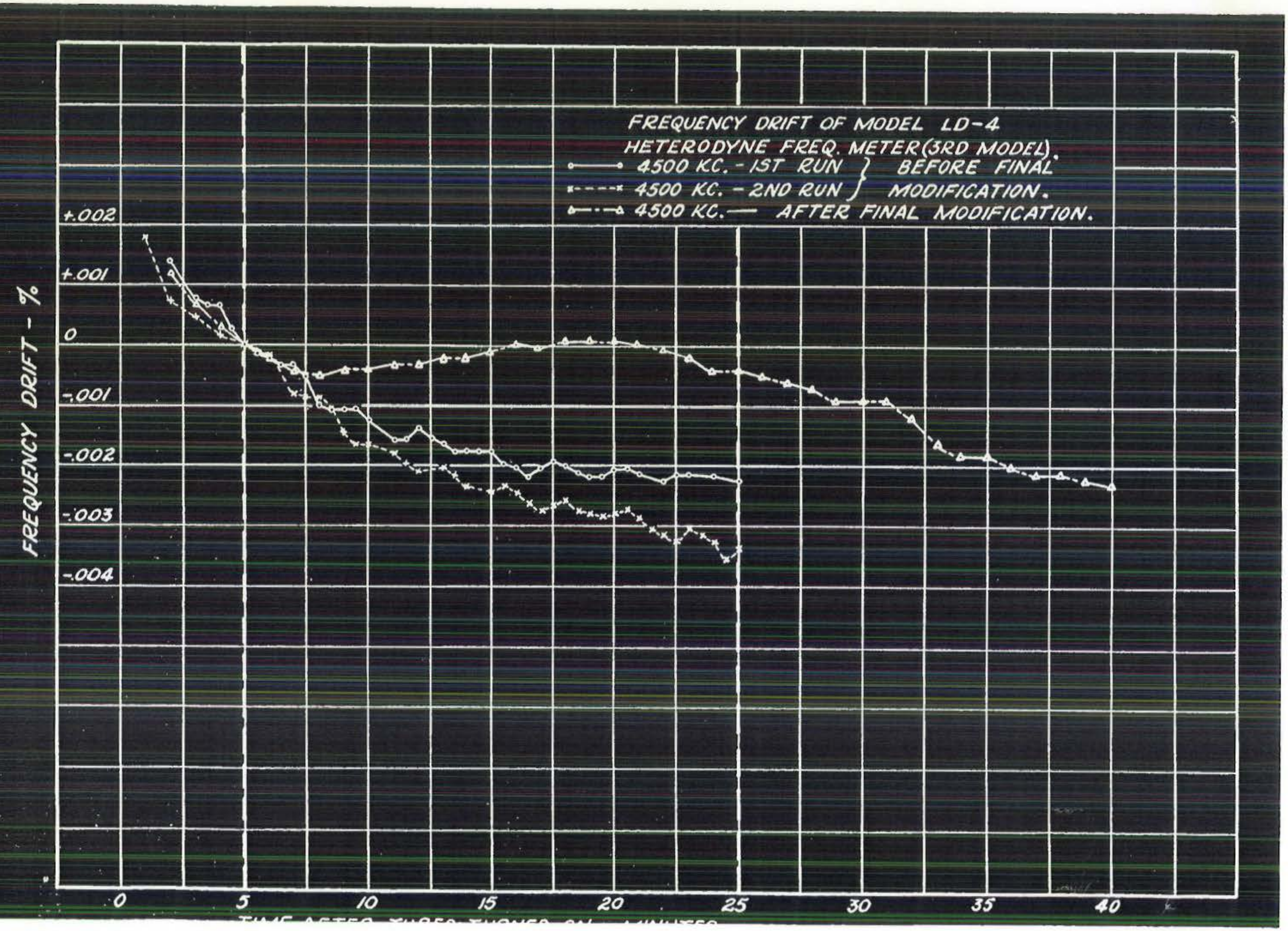

FREQUENCY DRIFT OF MODEL LD-4
HETERODYNE FREQ. METER (3RD MODEL).
4500 KC. - 1ST RUN
4500 KC. - 2ND RUN
BEFORE FINAL MODIFICATION.
4500 KC. — AFTER FINAL MODIFICATION.
FREQUENCY DRIFT - %
+.002
+.001
0
-.001
-.002
-.003
-.004
0
5
10
15
20
25
30
35
40

PLATE 3

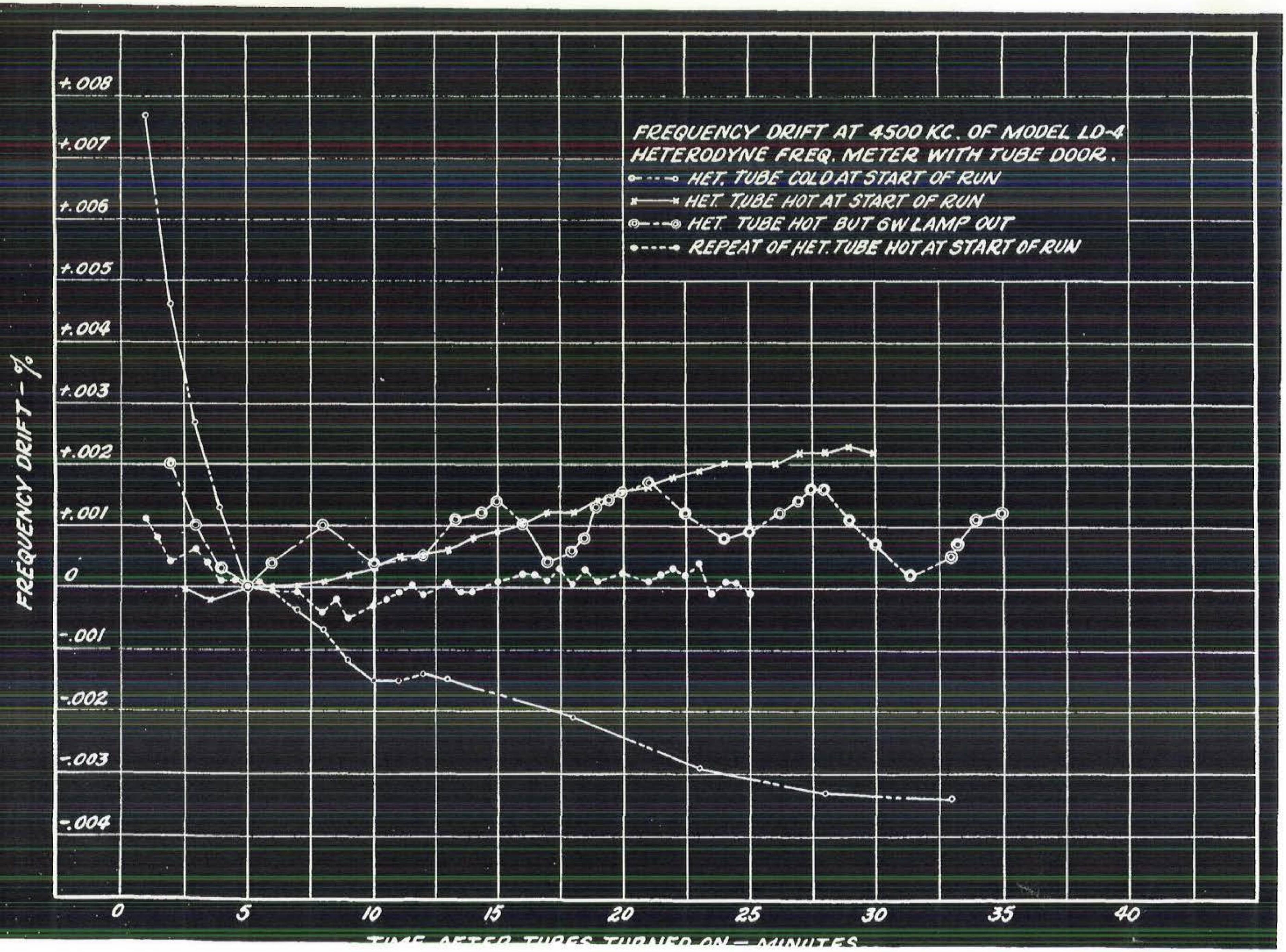

FREQUENCY DRIFT AT 4500 KC. OF MODEL LD-4
HETERODYNE FREQ. METER WITH TUBE DOOR.
HET. TUBE COLD AT START OF RUN
HET. TUBE HOT AT START OF RUN
HET. TUBE HOT BUT 6W LAMP OUT
REPEAT OF HET. TUBE HOT AT START OF RUN
FREQUENCY DRIFT - %
+.008
+.007
+.006
+.005
+.004
+.003
+.002
+.001
0
-.001
-.002
-.003
-.004
0
5
10
15
20
25
30
35
40

PLATE 4

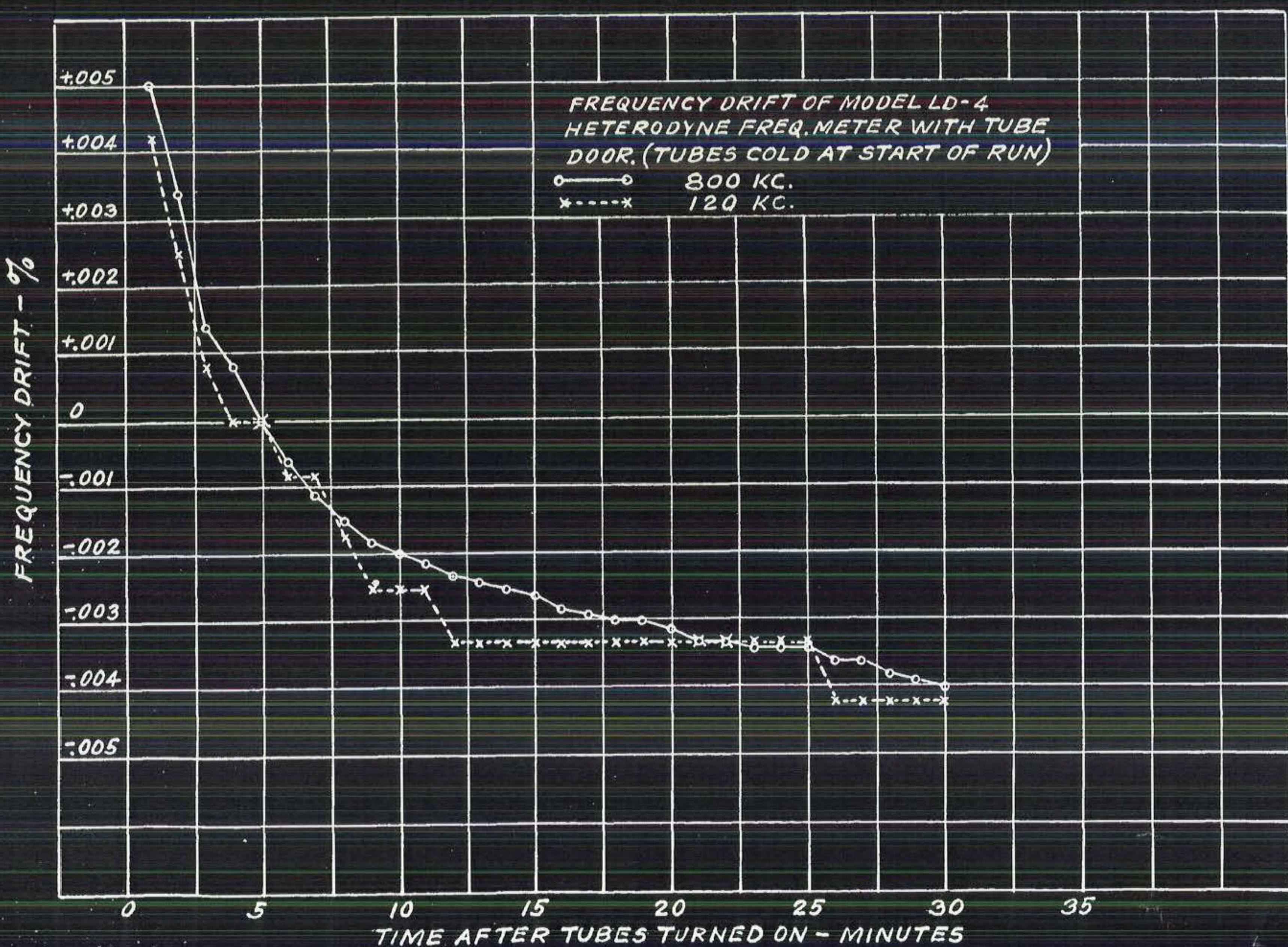
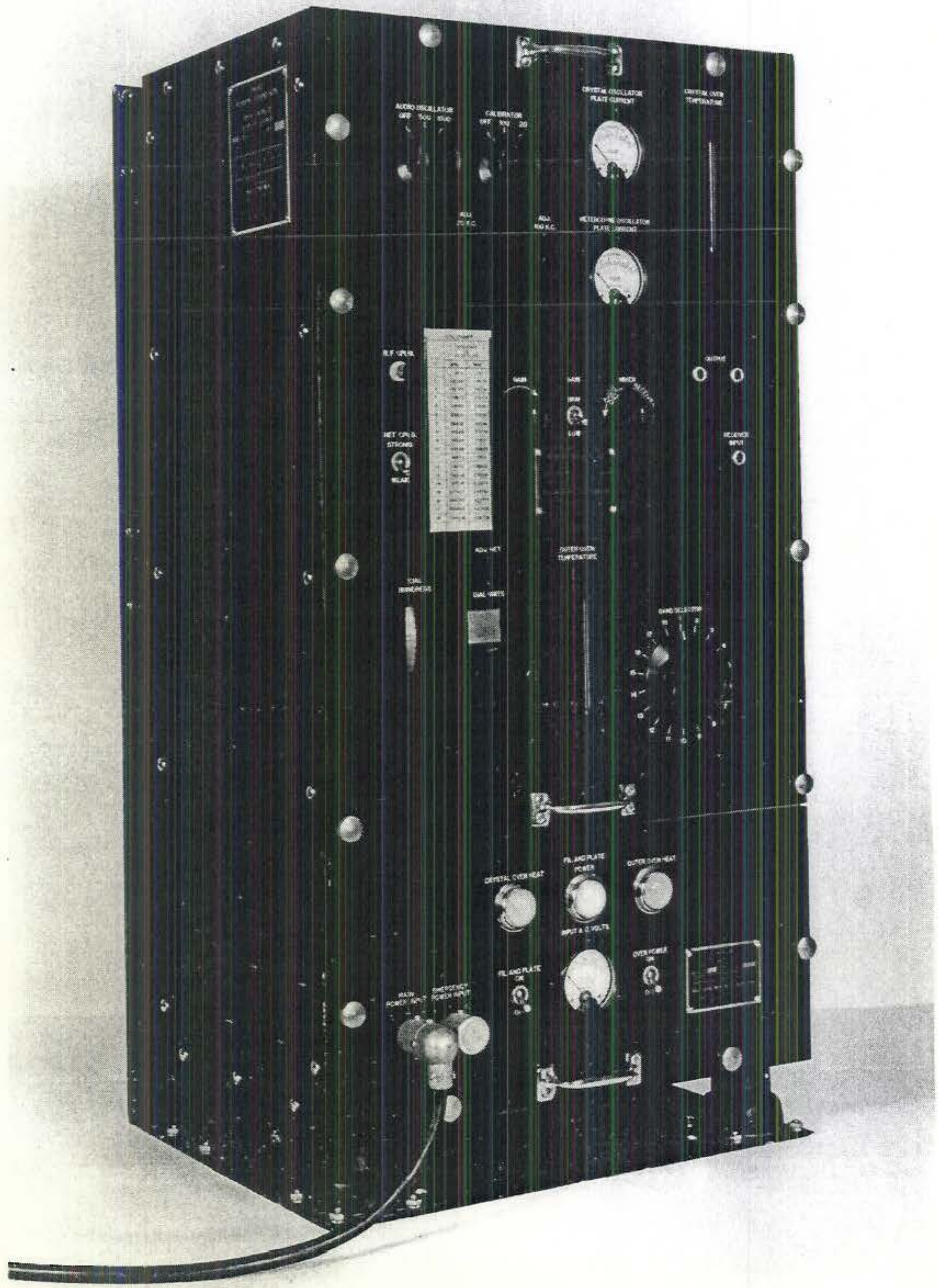

FREQUENCY DRIFT OF MODEL LD-4
HETERODYNE FREQ. METER WITH TUBE
DOOR. (TUBES COLD AT START OF RUN)
800 KC.
120 KC.
+.005
+.004
+.003
+.002
+.001
0
-.001
-.002
-.003
-.004
-.005
FREQUENCY DRIFT - %
0
5
10
15
20
25
30
35
TIME AFTER TUBES TURNED ON - MINUTES

PLATE 4A


AUDIO OSCILLATOR
OFF 500 1000
CALIBRATOR
OFF 100 20
CRYSTAL OSCILLATOR PLATE CURRENT
CRYSTAL OVEN HEAT
FIL AND PLATE POWER
OUTER OVEN HEAT
MAIN POWER INPUT
EMERGENCY POWER INPUT