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NAVY DEPARTMENT

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[redacted]

Report

of

Test of Model LD-4 Frequency Measuring Equipment

(Redesigned Preliminary Model)

Submitted by

Bendix Radio Corporation.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

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

R. W. Armstrong, Junior Physicist.

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

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

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AUTHORIZATION

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

Reference: (a) BuEng.ltr. NOs-53017 (8-13-W8) of 16 August 1937.
(b) Specifications RE 13A 401E.
(c) Preliminary Report on original model LD-4, NRL ltr. S67/74 of 10 December 1937.
(d) Supplement to Preliminary Report, NRL ltr. S67/74 of 6 January 1938.
(e) Technical Information, Model LD-4 Equipment.

OBJECT OF TEST

2. The object of the test was to determine whether the redesigned preliminary 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 21 March and tests were begun 23 March. 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 were 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) This equipment complies with the governing specifications with the exception of heterodyne oscillator frequency drift during tube warm-up, and in several minor particulars mentioned under recommendations.

(b) When the small changes suggested in recommendations (a) to (g) of this report shall have been made, it is considered that this equipment will be suitable for Naval use.

Recommendations

Recommendations for minor changes are made below. The subparagraph numbers under "Results of Test" in which comment is made relative to these recommendations are appended in parentheses.

(a) The crystal frequency adjusting control should be removed from the front panel, and made accessible through a hole in the panel provided with a cover. If a screw driver is required to actuate the control, no damage must result when a metallic screw driver makes contact with the edge of the hole in making an adjustment. An alternative provision would be a locking means on the present style of control to prevent accidental change in the crystal frequency. (See comment on subparagraph 4-20 herein.) No objection is offered to making the locked oscillator control similar in design to that of the crystal frequency adjusting control.

(b) The window through which hundreds of tuning dial divisions are read should be extended vertically so that two adjacent numbers are visible at all settings. (2-26).

(c) An additional telephone jack should be provided in parallel with the present output jack to permit simultaneous observation of the audio output in both the receiver and transmitter rooms. (4-6).

(d) The terminals of all leads in both power cables should be permanently and plainly marked as to potential, polarity, "a.c. only" or "a.c. or d.c." as applicable. (3-3).

(e) The tuning condenser knob should be clamped to its shaft by two set screws instead of one. (This knob became loose twice during test.)

(f) Fuses in the heater circuit and in the plus side of the tube plate supply should be of sufficient capacity to prevent burnout under slightly greater than normal current. (3-26).

(g) In place of the 1-inch diameter ventilating holes in the sides of the power unit, the substitution of louvres is suggested; a sample metal plate stamped with satisfactory louvres has been submitted by the contractor.

(h) In addition to the above recommendations for minor changes by the contractor, it is recommended that the omission of a door in the front panel for access to the tubes, the use of a single cabinet of two compartments instead of two cabinets, and the use of the locked oscillator in place of a multivibrator be accepted as entailing no obvious disadvantage to the Naval service. (See comment on subparagraphs 1-3, 3-19, and 4-22.)

MATERIAL UNDER TEST

4. The material under test consisted of the redesigned 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 5000 kilocycles. The calibration of the heterodyne oscillator may be checked through 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 of 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.

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 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.

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, $\pm$ 0.0002 per cent.
Frequency change of the crystal and heterodyne oscillators with tilting, $\pm$ 1 cycle at 800 kilocycles.
Audio output power, $\pm$ 5 per cent.
Ambient temperature in the extreme temperature tests, $\pm$ $2^{o}C$.

RESULTS OF TEST

8. A representative of the contractor was present as an observer during the performance of many of the tests and the results of all tests were made known to him at his request in order to enable him to make minor adjustments or modifications to overcome any defects in or objection to the equipment as they appeared. This procedure resulted in the improvement of the equipment in a number of respects, such as a reduction of the frequency drift of the heterodyne oscillator during the warming up period and reduction in the frequency change of the heterodyne oscillator with tilting of the equipment up to 45^{o}. The contractor undertook to remedy any defect as well as to incorporate any change suggested to improve the equipment for Naval use, even though not specifically required. While the completion of the tests was delayed by this procedure, the ability of the contractor to supply an improved product was demonstrated and the date of delivery of production equipments has probably not been appreciably delayed.

9. The following comments cover the results of the tests. When a test had to be repeated after a modification by the contractor, the results of the last test are given. The subparagraph numbers below refer to the similarly numbered paragraphs in specifications, reference (b).

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 1. 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 $+1^{o}C.$ and $+44^{o}C.$ 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. The use of smaller holes or louvres in the sides of the power unit is considered preferable to 1-inch holes as shown in Plate 1, and the contractor has indicated his intention to use louvres of a type which is considered satisfactory by this Laboratory.

2-11. The equipment was operated for a short time at a temperature of approximately 65^{o} 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.

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

2-15. The equipment was mounted on a platform and inclined at an angle up to 45° from the vertical without any damage and with a very slight change in the frequency of the heterodyne oscillator (see Table 2). The crystal frequency was not affected by this tilting.

2-16 and 2-17. The equipment was subjected to very intense vibration for a period of time in excess of one hour at frequencies of vibration up to approximately 25 impulses per second. 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 covers on the two heater system relays which are mounted quite close together vibrated enough to touch each other and cause a rattling noise at certain amplitudes and frequencies of vibration. The contractor's representative stated that these covers will be fastened in place by set screws to prevent this condition recurring.

(b) Both relays vibrated open intermittently under excessive vibration of a high frequency. It was noted that the heater circuits were wired to require current through the relay coils in order to open the heater circuits, thus leaving only the spring action to hold the relay contacts closed. The contractor agreed to modify the wiring so that current through the relay coils holds the contacts closed (instead of open) and prevents the opening of the heater circuits during intense vibration. When the relays are open, the width of the gap is sufficient to prevent the contacts from vibrating shut. This change of the relay wiring has been made in the model after which satisfactory operation under excessive vibration was experienced. This change of relay wiring has another advantage, since a failure of one of the vacuum tubes (on the plate current of which the relays function) would now cut off the heat instead of allowing it to become excessive and melt the thermal fuse.

(c) The nut used to secure the bleeder resistor in the power pack fell off, leaving the resistor unsupported. It was noted that the teeth on the periphery of the external type lock washer used under this nut extended out beyond the nut so that the locking action was imperfect. The contractor has expressed the intention to use the internal type of lock washer (with teeth next to the screw) throughout the equipment. The r.f. leads are soldered as required.

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 not provided on this preliminary model.

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

2-25. The equipment has operated continuously for a number of days without any damage or loss of accuracy.

2-26. The dials are satisfactory except that on the hundreds dial of the heterodyne oscillator, only one number can be seen through the window at a time at certain settings of the tuning condenser. This can be eliminated by extending slightly the length of this window.

2-27. No comment.

2-28. Insulating material of grade G is used where required except that the heterodyne oscillator inductance coil switch plate is of Micalex, 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. Since it is important that the tube supply leads never be connected to the d.c. line, and since the proper polarity of the d.c. connection is essential to d.c. heater operation, it is necessary that the terminals of the two sets of leads be permanently and plainly marked. For example, the tube supply leads should be labeled "A.C. Only" and the heater leads "A.C. or D.C." with the d.c. polarity indicated.

3-5. With this equipment it is possible:

(a) To measure the frequency of a transmitter in the same room at any frequency from 100 kilocycles to 25 megacycles. With the LD-4 heterodyne oscillator set at 4500 kilocycles, a Model TBK-5 transmitter was adjusted to 18 megacycles by listening on the LD-4 telephone receivers.

(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 LD-4 heterodyne oscillator set at 5 megacycles.)

(c) To check or recalibrate the 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.

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 142 pounds which is 43 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 is held at 50 ± .2°C. for ambient temperature between +1 and +44°C. The temperature of the heterodyne compartment is controlled at 45°C.; this increases to 45.6°C. at an ambient temperature of 44°C. and at the extremely low temperature of + 1°C. the heterodyne temperature drops to approximately 41.5°C. with the tubes inoperative. The equipment operates satisfactorily at extreme ambient temperatures. When the tubes are turned on at normal ambient temperature the heterodyne oscillator compartment temperature increases during the first 15 minutes approximately 1°C. Thermal fuses with a melting point of approximately 65°C. are used in series with both heaters as a protective device against excessive overheating in case of the failure of the heater circuits to open 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 heaters, 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 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 four machine screws. The complete operation of replacing a tube in the measuring unit required approximately four minutes. It is not believed that the omission of the door in the front panel is a disadvantage since the greater panel space available has permitted the arrangement of parts so as to give increased ease of access over previous models of the LD equipments.

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. A thermal fuse is mounted in the crystal box and one in the heterodyne oscillator compartment. It was noted that one of the three ampere fuses in the heater supply leads opened during the test, and since the normal current drawn in this circuit is three amperes, it is believed that this fuse should have somewhat greater current carrying capacity. Furthermore, the fuse at the input of the tube filter system opened immediately on the application of a potential of 340 volts specified by the contractor for emergency operation. This is apparently due to the charging current to the filter condensers overloading the fuse at the instant of applying the potential. A fuse of suitable rating should be used in this position.

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

3-28. A maximum power input for operating the equipment including all tubes and both heaters was measured to be 440 watts distributed approximately as follows:

Inner or crystal oven - 39 watts.
Outer or heterodyne oscillator oven - 255 watts.
Heater control tubes and circuits - 53 watts.
Measuring unit tubes and circuits - 93 watts.

3-29. The calibration of the heterodyne oscillator supplied with the preliminary model consisted of a tabulation of frequencies and corresponding condenser settings for the several coils. All of the harmonic points required in the specifications are included in this list. No interpolation chart was furnished with the equipment. It is believed that calibration consisting of a tabulation of the frequency, corresponding condenser setting, kilocycles per division, and divisions per kilocycle (four columns in all) with suitable instructions for interpolation to obtain any frequency or setting not found in the list would be preferable to an interpolation chart from the point of view of the accuracy obtainable.

3-30. The change of crystal frequency due to change in crystal oscillator tubes was approximately .0002 per cent. The change of heterodyne oscillator frequency due to change of tube is quite small (approximately .02 per cent) 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 38180.
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 large overlap between the ranges. The band changing switch is considered to be satisfactory in design.

4-2. A voltage regulator is included in the power unit which maintains the tube potential constant for any input voltages from approximately 90 to 130 volts. The heterodyne oscillator circuit is of the negative transconductance oscillator type as shown on the wiring diagram of reference (e). This circuit has the advantage of requiring no feed-back coil.

4-3. The heterodyne oscillator frequency drift during the warming up period of the vacuum tubes is indicated in Table 1 and Plate 5. It will be noted that the frequency drift is in excess of the specified limit in certain instances. During this warming up period, the temperature of the heterodyne oscillator compartment rises approximately 1°C. in the first twelve to fifteen minutes as indicated by the thermometer mounted in the compartment. In order to compensate for the effect of this temperature change on the frequency of the heterodyne oscillator, a thermal compensating condenser has been mounted near the heterodyne oscillator tube and connected in parallel with the tuning condenser. This thermal compensating condenser consists of two small condenser plates, one of which is mounted on a bi-metallic strip which is adjusted to change the spacing between the two plates and therefore the capacity of the condenser in response to the temperature change, so as to compensate for the frequency change of the heterodyne oscillator circuit elements resulting from the temperature change, due to the operation of the oscillator tube. It is possible that the design of this condenser might be improved to cause it to respond more quickly and thus reduce the number of minutes during which the frequency drift is rapid. The small recurring frequency variations shown on Plate 5 and repeating about every three minutes correspond to the heating cycle of the heterodyne oscillator heater. The equipment meets the overall frequency measuring accuracy as discussed below under paragraph 4-13.

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

4-5. See comment above on paragraphs 3-23 to 3-25.

4-6. Requirements of this specification regarding the operation of this equipment in the presence of a transmitter are complied with except that it appears that paragraph 4-6(2) specifies a telephone outlet for extending the telephone circuit to the transmitter room while the equipment is mounted in the receiver room of a ship or station. See recommendation (f) of this report.

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 994 cycles and that of the 500 cycle oscillator was measured to be 500 cycles.

4-8. The r.f. output of the heterodyne oscillator is a number of times greater than the 100 microvolts required at 20 megacycles. 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. It was noted, however, that the audio output was somewhat affected by tuning the crystal frequency adjusting condenser so as to change the crystal frequency about three cycles. Therefore, the power output of the production units should be checked after the final adjustment of the crystal frequency.

4-9. The calibration curve of the frequency meter is essentially linear over the used portion of all bands. The kilocycles per division along the condenser scale vary somewhat, as shown on Plate 6 for coils 9 and 16. However, the calibration points given are sufficiently close together so that the frequency error due to interpolation is quite small.

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 $\pm$ 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 while the equipment was clamped to the vibration table and the table tilted up to 45° in all directions. No change in frequency was noted when the tilt was to the front or back, but a change of approximately .0005 per cent was produced by a tilt of 25° to the right or left (of the operator facing the equipment) and of approximately .0007 per cent at an angle of 45°. This frequency stability with tilting is considered to be quite good. See Table 2. No change in the crystal frequency was observed with tilting up to 45°.

4-13. Frequency measurements can be made with this equipment to an accuracy of ± .005 per cent by checking the heterodyne oscillator against the available crystal controlled harmonics and interpolating between the checking points for any intermediate frequency or condenser setting. A large number of frequencies was carefully measured by means of this equipment, most of them involving an interpolation over the largest number of divisions necessary in the use of the equipment, and the average error in the measurements was .0028 per cent. The maximum error was .0056 per cent. These measurements were made after the tubes had been operating for more than one-half hour so that no frequency drift due to warming up of the heterodyne oscillator is included in the above values. The reset accuracy is quite high: The average frequency error in eight resets of the condenser dial at different positions of the tuning range was .0002 per cent, and the maximum error was .0004 per cent. The back-lash was not more than 0.3 division which is quite low in a condenser scale of 5000 divisions.

4-14. See comment 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 crystal are available throughout the range of the heterodyne oscillator. The crystal oscillator circuit is of the tuned plate type with two condensers in series, one of which is a variable air condenser by means of which the crystal frequency may be changed a total of approximately 2.5 cycles. Since the setting of this condenser should never be changed after the final adjustment at the contractor's plant (unless the equipment is being standardized by the use of a frequency standard of much greater accuracy than that of this equipment), it is recommended that the control knob for this condenser be removed from the front panel and a slotted shaft be provided for screw driver adjustment through a hole in the front panel. A switch is provided by means of which the calibrator may be turned off while the heterodyne frequency meter is left operating.

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 90° of the range of the adjusting condenser.

4-23. The crystal frequency was measured to be 100,003 cycles per second with the crystal adjusting condenser set as received. The crystal frequency could be brought within the tolerance of $\pm$ .001 per cent by means of the crystal frequency adjusting condenser. However, when so adjusted, the crystal r.f. output was somewhat reduced. No change in crystal frequency was observed due to the time of operation of the crystal controlled oscillator.

4-24 to 4-27. The temperature coefficient of frequency of the crystal oscillator was measured to be approximately 26 parts per million per degree Centigrade. The crystal was not removed from the holder for examination. The holder is a Navy standard transmitting type ceramic case holder with adjustable air-gap. No change in crystal frequency with tilting of the equipment at any angle up to 45° in any direction was observed (a frequency change of .0001 per cent could have been detected).

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 440 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. See comment on paragraph 3-9.

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.

CONCLUSIONS

10. This equipment complies with the governing specifications with the exception of heterodyne oscillator frequency drift during tube warm-up, and in several minor particulars mentioned under recommendations.

11. When the small changes suggested in recommendations (a) to (g) of this report shall have been made, it is considered that this equipment will be suitable for Naval use.

Table 1

Frequency Drift of LD-4 Heterodyne Oscillator
During Tube Warm-Up Period.

Minutes After Tubes "On"	Frequency Drift - Cycles			Frequency Drift in Per Cent		
	As Received	After Modified*	Spec. Limit	As Received	After Modified*	Spec. Limit
			120 kc Test			
5-10	-5	-17	2.2	0.0042	0.0140	0.0018
10-15	-4	2	1.8	0.0033	0.0017	0.0015
15-20	+1	-3	1.6	0.0008	0.0025	0.0013
20-25	+1.5	+3	1.0	0.0012	0.0025	0.0008
25-30	+1	+3	-	0.0008	0.0025	-
			800 kc Test			
5-10	-44	-49	14.4	0.0055	0.0061	0.0018
10-15	-12	+15	8.8	0.0015	0.0019	0.0011
15-20	- 6	+17	4.0	0.0007	0.0021	0.0005
20-25	- 6	7	4.0	0.0007	0.0009	0.0005
25-30	+ 7	4	-	0.0009	0.0005	-
			4500 kc Test			
5-10	-182	-179	81	0.0036	0.0040	0.0018
10-15	- 53	37	50	0.0012	0.0008	0.0011
15-20	+ 26	31	23	0.0006	0.0007	0.0005
20-25	+ 40	18	23	0.0009	0.0004	0.0005

* "After Modified" refers to following changes by contractor:

(1) Mounting bracket of tuning condenser changed to reduce tilting effect on frequency.

(2) Thermostat relocated in heterodyne compartment.

(3) New design of thermal compensating condenser installed.

NOTE: Plus and minus signs in columns 2 and 3 indicate direction of frequency drift if continuous in direction during 5-minute period.

Table 2

Effect of Tilting LD-4 Heterodyne Oscillator
(800 kilocycles)

Direction of Tilt	Degree of Tilt	Frequency Change in Per Cent
Right	25	0.005
Right	45	0.0078
Left	25	0.0038
Left	45	0.006
Front	25	0.000
Front	45	0.000
Back	25	0.000
Back	45	0.000

Table 3

Audio Output Power of LD-4 Equipment

Heterodyne Frequency Oscillator (kcs)	Output in Milliwatts	
	350 Cycles	1100 Cycles
5000	55	37*
4500	55	35*
4200	65	43
3000	200	88
3000**	150	70
2980**	110	63
2960**	128	71
2000**	190	83
2000	210	90
1980**	150	70
600**	230	90
600	235	93
580**	210	92
120**	212	70
100**	210	88
100	235	95

* Specification minimum is 40 milliwatts.
At 5000 kc, 40 milliwatts output was obtained at a beat frequency of 1012 cycles.
At 4500 kc, 40 milliwatts output was obtained at a beat frequency of 945 cycles.

** Locked oscillator on.

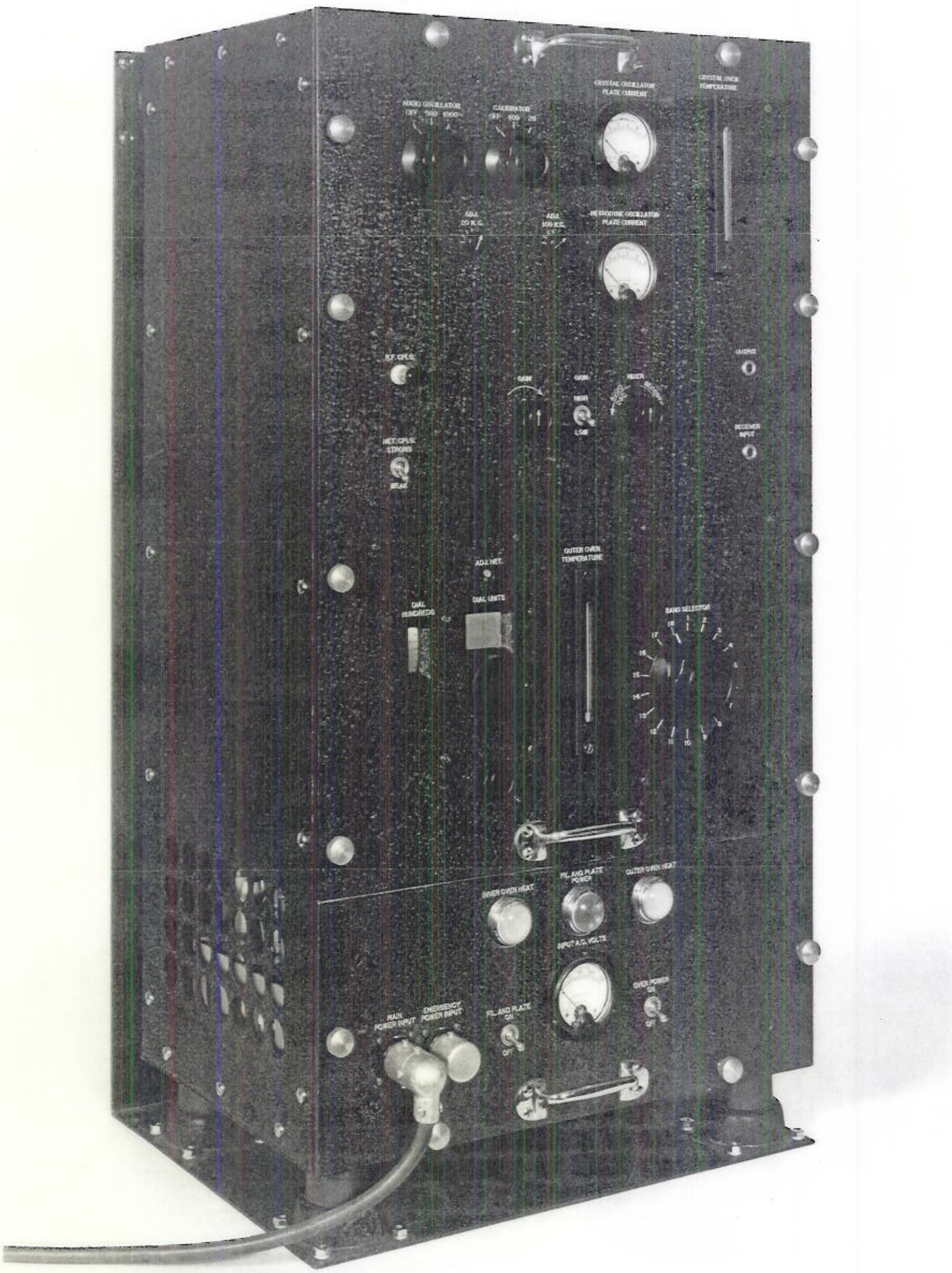
CRYSTAL OSCILLATOR PLATE CURRENT
CRYSTAL OVEN TEMPERATURE
AUDIO OSCILLATOR
CALIBRATOR
HETERODYNE OSCILLATOR PLATE CURRENT
R.F. CPLG.
GAIN
HIGH
LOW
MIXER
RECEIVER INPUT
HET. CPLG.
STRONG
WEAK
ADJ. HET.
DIAL HUNDREDS
DIAL UNITS
OUTER OVEN TEMPERATURE
BAND SELECTOR
INNER OVEN HEAT
FIL. AND PLATE POWER
OUTER OVEN HEAT
INPUT A.C. VOLTS
OVEN POWER
MAIN POWER INPUT
EMERGENCY POWER INPUT
FIL. AND PLATE

Plate 1

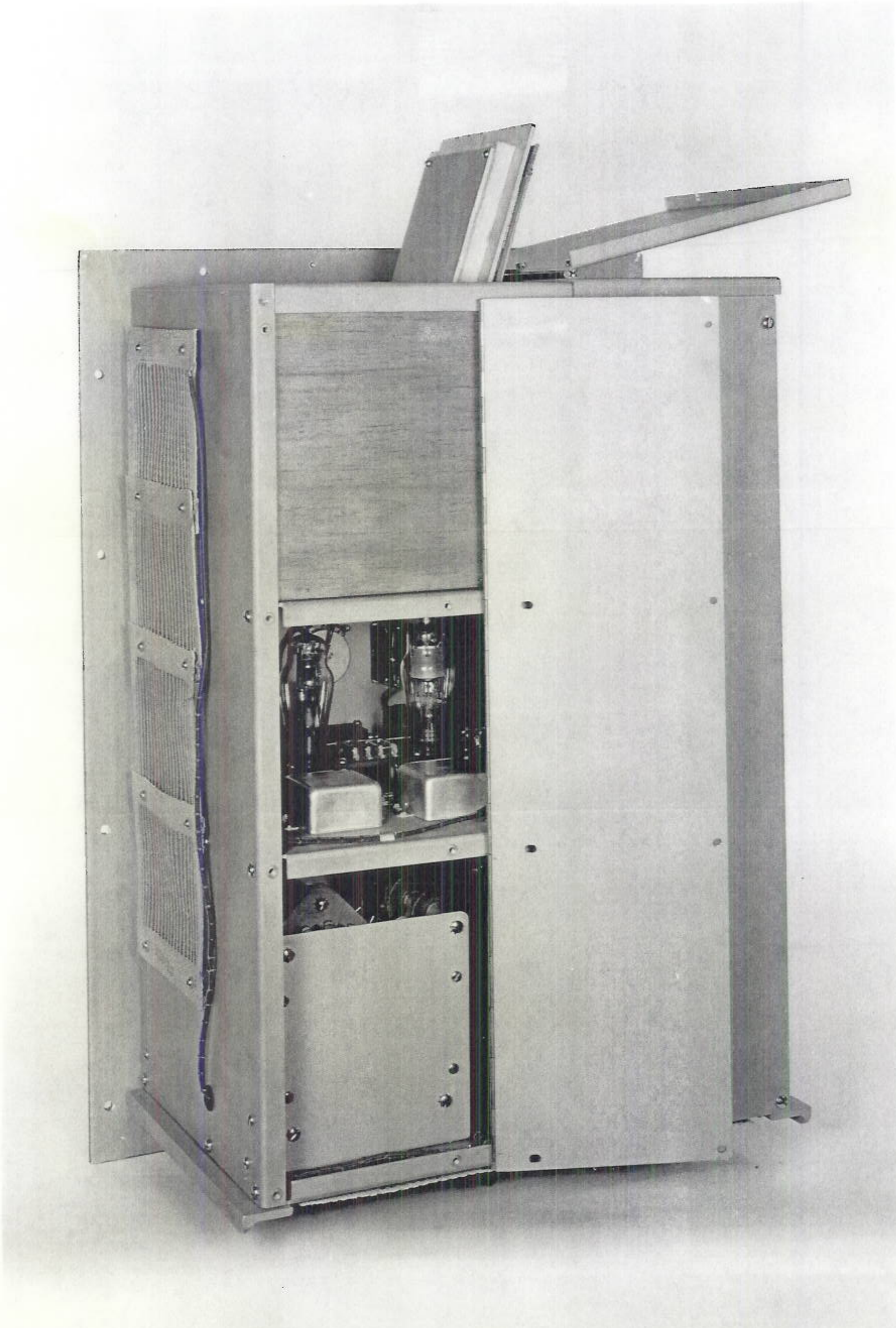

Plate 3

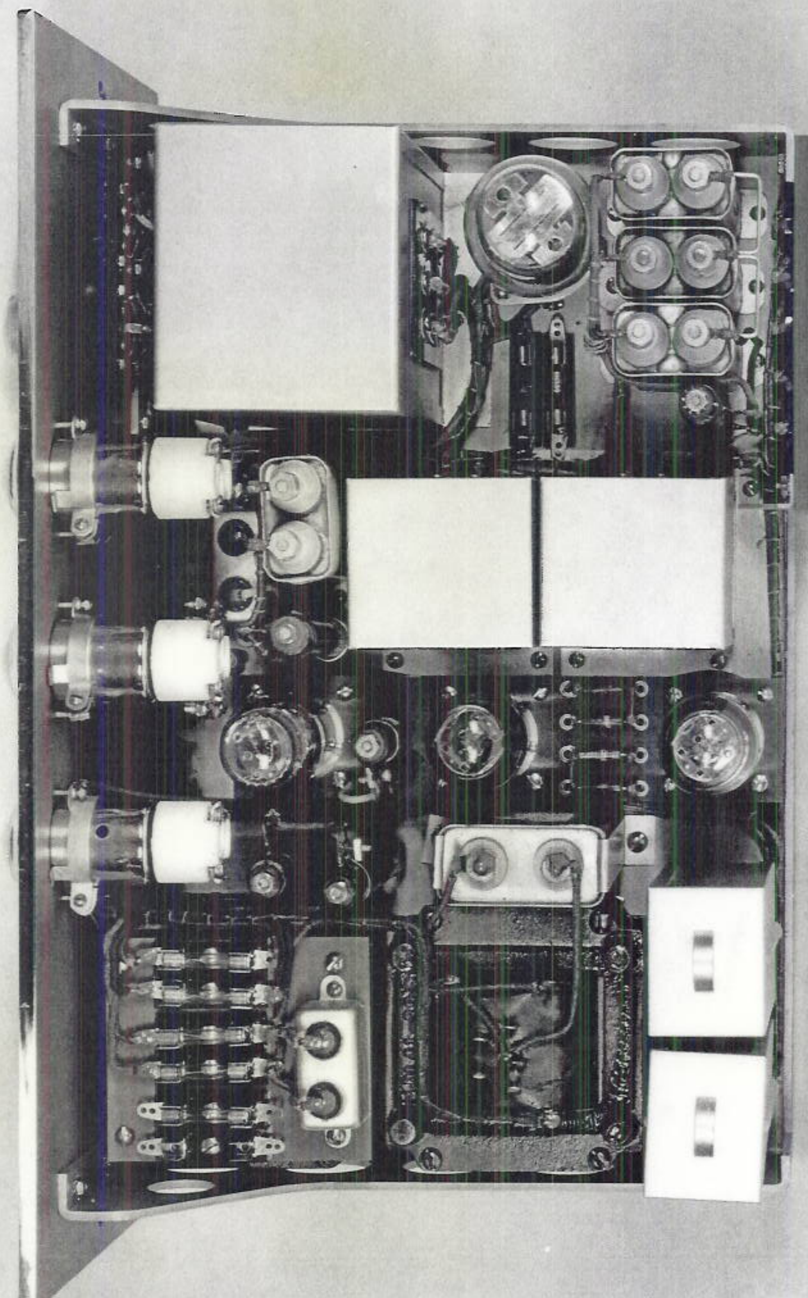

Plate 4

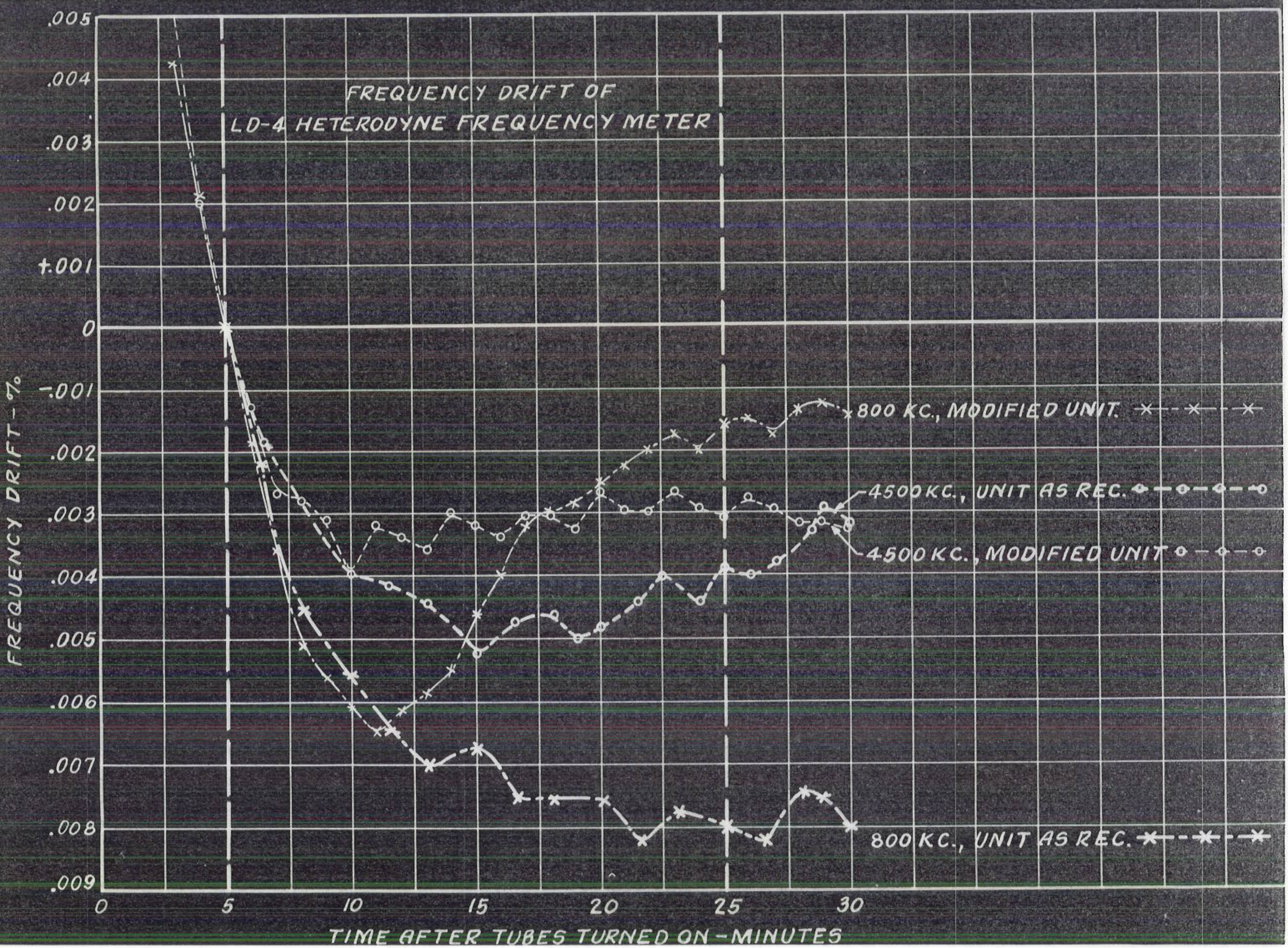
FREQUENCY DRIFT OF
LD-4 HETERODYNE FREQUENCY METER
FREQUENCY DRIFT - %
.005
.004
.003
.002
+.001
0
-.001
.002
.003
.004
.005
.006
.007
.008
.009
0
5
10
15
20
25
30
TIME AFTER TUBES TURNED ON - MINUTES
800 KC., MODIFIED UNIT.
4500 KC., UNIT AS REC.
4500 KC., MODIFIED UNIT
800 KC., UNIT AS REC.

PLATE 5

LD-4 HET. FREQ. METER (SECOND MODEL)
KC/DIV. CURVE FOR COILS 9 & 16

COIL 9 = 560 TO 720 KC.

COIL 16 = 2600 TO 3320 KC.