

7 March 1935

NRL Report No. R-1132

NAVY DEPARTMENT  
BUREAU OF ENGINEERING

Report on  
Tests of Model LK Frequency Drift Indicator  
(Preliminary Model)

NAVAL RESEARCH LABORATORY  
ANACOSTIA STATION  
WASHINGTON, D.C.

Number of Pages: Text - 17 Tables - 5  
Authorization: BuEng. ltr. NOs-35378 (8-30-W8) of 4 September 1934.  
Date of Tests: 31 January 1935 to 28 February 1935.

Prepared by:

J. C. Link,  
Jr. Physicist

R. B. Meyer,  
Assoc. Radio Engr.,  
(Chief of Section).

Reviewed by:

A. Hoyt Taylor, Physicist,  
Superintendent of Division.

Approved by:

H.R. Greenlee, Captain, U.S.N.,  
Director.

Distribution:

BuEng. (4)

ejj

APPROVED FOR PUBLIC  
RELEASE - DISTRIBUTION  
UNLIMITED

TABLE OF CONTENTS

<u>Subject</u>	<u>Page</u>
1. Authorization for Test.....	1
2. Object of Tests.....	1
3. Abstract of Tests.....	1
Conclusions.....	1-a
Recommendations.....	1-b
4. Description of Material under Test.....	2
5. Method of Test.....	2
6. Data Recorded.....	3
7. Discussion of Probable Errors.....	3
8. Results of Tests.....	3
9. Conclusions.....	16

APPENDICES

Frequency of Six Transmitter Crystals Provided with LK Equipment.....	Table 1
Test of 500 Cycle Scale of LK Equipment (One Crystal used in LH Equipment).....	Table 2
Test of 1000 Cycle Scale of LK Equipment (Two Crystals used in LH Equipment).....	Table 3
Test of 5000 Cycle Scale of LK Equipment (Four Crystals used in LH Equipment).....	Table 4
Power Input of LK Drift Indicator.....	Table 5

APPROVED FOR PUBLIC  
RELEASE - DATE 11/19/2011  
UNLIMITED

## AUTHORIZATION FOR TEST

1. The tests herein reported were authorized by reference (a). Other pertinent data are listed as references (b) to (h), inclusive.

- Reference: (a) Bueng. ltr. NOs-35378 (8-30-W8) of 4 September 1934 to Director, NRL.  
(b) Specifications RE 13A 493A.  
(c) Bueng. ltr. NOs-35378 (8-30-W8) of 21 November 1934 to BuS&A.  
(d) BuS&A ltr. NOs-35378 (SPM-x-4) of 24 November 1934 to Radio Research Co., Inc.  
(e) NRL ltr. S67/74 of 25 September 1934 to Bueng.  
(f) Contract NOs-35378 of 29 March 1934.  
(g) Radio Research Co. descriptive specifications.  
(h) BuS&A ltr. NOs-35378 (SPM-x-11) of 1 February 1934 to Radio Research Co., Inc.

## OBJECT OF TESTS

2. The object of the tests was to determine compliance of the preliminary Model LK equipment with the governing specifications and the suitability of the equipment for the purpose intended, and to determine whether changes should be recommended for incorporation in the final equipments in order to meet the paramount requirements of the specifications.

## ABSTRACT OF TESTS

3. The tests herein reported were conducted to determine the degree of compliance of the Model LK Frequency Drift Indicator (preliminary model) with the mechanical and electrical requirements set forth in references (b) and (f).

4. Determinations of frequency accuracy were made on the 500, 1000 and 5000 cycle scales of the visual indicator and the chart recorder.

5. The frequencies of the transmitter crystals supplied with the equipment were checked.

6. The power required from the supply lines was determined.

7. The effect of line voltage variations was investigated.

8. The frequency constancy over long periods of time was determined.

9. The operation of the temperature control circuits was investigated.

10. An investigation of the complete radio frequency range of the equipment between the limits of 100 kcs. and 26,000 kcs. was made in order to determine frequency coverage, overlap and adequacy of the input coupling circuits.

## Conclusions

(a) The general appearance of the LK equipment is pleasing and good materials and workmanship have been employed in its construction. The principle of double shielding employed throughout the equipment interferes to some extent with accessibility and introduces added weight; however, all parts are accessible and special provisions to improve accessibility have been made by equipping some of the shielded compartments with sliding covers provided with spring contacts. The efficient operation obtained and the freedom from interference assured by this complete shielding far outweighs the disadvantages accruing from its use.

(b) The performance of the present LK equipment is far superior to that obtained with the original model submitted for tests. This improvement has been wrought by the inclusion of new and improved circuits, more rugged indicating means for both the visual and recording elements and the providing of means whereby any one or any combination of the three indicating methods, visual, aural or recorder, may be selected at will. Line voltage variations as large as 10% do not affect the accuracy of the equipment and no injury results to the indicating meters if they are subjected to off scale frequencies.

(c) The instrument is capable of extremely flexible operation. Transmitters ranging in frequency from 100 kcs. to 26,000 kcs. with power outputs varying from 5 watts to 10,000 watts, may be checked with the LK equipment, and difference frequencies from zero to 5000 cycles may be measured. The accuracy of the equipment during test was excellent and all necessary adjustments may readily be made with ease.

(d) The most serious difficulty encountered during these tests was due to the intermittent failure of the temperature control circuits. The exact cause of these failures could not be determined but assurance was given by the contractor's representative that this difficulty would be eradicated. The heater circuits also require some modifications in order to provide for similar operation whether employing 110 volt or 220 volt input, and in order to limit the input power to less than 750 watts.

(e) Certain other small changes are indicated, such as the substitution of flexible leads where solid leads are now used, the addition of a few legends on the front panel and on the transmitter crystal containers. The original input coupling circuit failed to function properly at high frequencies, but this defect was eliminated by the substitution of a variable capacitor in place of the resistance potentiometer employed. The contractor provided gear trains by means of which a chart speed of either 3" or 6" per hour could be obtained and it is believed the 6" speed will give the better results.

## Recommendations

It is recommended:

(a) That stranded flexible leads be provided in place of solid wire leads for connecting to the grid terminals of all vacuum tubes. (See paragraph 43 of this report.)

(b) That additional legends be provided for identifying the following: (See paragraph 46.)

Tuning coils  
Calibration chart  
Crystal temperature

(c) That the contractor be required to improve the operation of the thermostat circuits and give assurance that these circuits will produce satisfactory results in the production models. (See paragraph 61.)

(d) That the contractor be required to modify the heater circuits so that approximately the same power is drawn on 110-volt operation as when employing 220-volt supply, and that the heat dissipated be adequate for the purpose required over the temperature range of minus 1 degree to 51.5 degrees Centigrade. (See paragraph 62.)

(e) That the name plates upon the transmitter crystals supplied with the equipment be engraved with the serial number of the particular LK equipment to which they belong. (See paragraph 75.)

(f) That the input coupling system be designed to utilize a variable capacitor of the proper value in place of the 50,000 ohm resistance potentiometer. (See paragraph 78.)

(g) That the Bureau of Engineering approve a chart speed of six inches per hour and require the contractor to supply the necessary gear train to produce this chart speed. (See paragraph 79.)

(h) That the preliminary model LK equipment be considered satisfactory for Naval use after the recommendations listed above have been complied with in a manner meeting the approval of the Bureau of Engineering.

## DESCRIPTION OF MATERIAL UNDER TEST

11. The material under test consisted of one complete Model LK Frequency Drift Indicator, Serial No. 1. The radio frequency range of this equipment is 100 kcs. to 26,000 kcs., while the audio frequency range is divided into three steps:

0 to 500 cycles

0 to 1000 cycles

0 to 5000 cycles

Measurements are effected by noting the difference frequency between a signal produced by the LK equipment and the signal produced by the transmitter under test. This difference frequency may be determined by means of a visual indicating meter or by means of a chart or tape recorder. In addition, a loud speaker is provided by means of which the difference frequency may be observed by aural means. The equipment was manufactured by the Radio Research Co., Inc., Washington, D.C. The Model LK equipment was first received at the Naval Research Laboratory on 29 August 1934, and after preliminary tests had been conducted which were reported in reference (e), the equipment was returned to the contractor for modification on 26 September 1934. The modified equipment was re-submitted to the Naval Research Laboratory on 31 January 1935.

## METHOD OF TEST

12. The equipment, when received, was examined to determine whether any breakage had occurred during transportation.

13. The equipment was then wired up and placed into commission. The preliminary instructions furnished were adequate for this purpose and a representative of the manufacturer witnessed most of the tests conducted.

14. A Model XF crystal controlled transmitter and a Model TAQ-4 transmitter were employed for test purposes to cover the radio frequency range involved, and the Model LK equipment was checked directly against a Model LH Visual Frequency Indicator. In addition, audio frequency checks were made by means of a thousand cycle frequency obtained from the Primary Standard at the Naval Research Laboratory and by means of an interpolation oscillator.

15. Power input determinations were made by means of a precision type wattmeter.

16. The operation of the equipment was studied when operating from a 110 volt and a 220 volt, single phase, 60 cycle source.

17. Compliance of the various component parts of the equipment with the mechanical and electrical requirements of the governing specifications was determined by careful inspection and measurements.

## DATA RECORDED

18. Complete data was recorded on all tests conducted and this information is contained in Tables 1 to 5, inclusive.

## DISCUSSION OF PROBABLE ERRORS

19. The Model LH Visual Frequency Indicator is, at the present time, the most accurate instrument available at the Naval Research Laboratory for measuring frequency shifts or changes over a limited range. In the case where it is possible to make the necessary measurements by means of one crystal in the LH equipment, the error of measurement is not greater than 2 cycles at most. However, in order to extend the audio frequency range of the LH equipment, it is necessary to employ two or more crystals of the proper frequency. During the first few minutes of oscillation a crystal has the tendency to change frequency slightly. Thus, as the crystals are changed in the oscillator circuit, certain errors are encountered. In the case of the LH equipment, it is estimated that this error is approximately 8 cycles at 4500 kcs. when four crystals are used. The LK equipment, as submitted, covers the range of radio frequencies in 50 kc. steps from 100 kcs. to 1000 kcs. and in 500 kc. steps from 1000 kcs. to 26,000 kcs., and is capable of measuring difference frequencies of 5000 cycles on either side of zero beat. Measurements over this wide range of frequencies are accomplished with such a degree of accuracy that it compares favorably with the best results which may be obtained with the LH equipment and hence it is difficult to determine definitely whether the small differences in frequency encountered during the measurements should be ascribed to the LH or to the LK equipment. In view of these limiting factors it has been necessary to assign a factor of tolerance to the measurements made. These factors are of necessity somewhat arbitrary, but since they are based upon the results of a large number of observations it is believed that they may be accepted as suitable for interpreting the results obtained during the tests of the Model LK equipment.

20. In view of the above tolerances, it is considered reasonable to assume that the Model LH measurements are accurate to within plus or minus 2 cycles when checking the 500 cycle scale of the LK equipment, 4 cycles, plus or minus, when checking the 1000 cycle range and 8 cycles, plus or minus, when checking the 5000 cycle scale.

## RESULTS OF TESTS

21. The Model LK equipment was received in good condition, no breakage having been incurred during shipment. It may be noted that the equipment was not packed in a shipping case, but was delivered to the Naval Research Laboratory by truck.

22. In the following paragraphs of this report reference is made to the governing specifications RE 13A 493A under which this equipment was constructed. Where no specific reference is made to any particular paragraph it is to be understood that the equipment under test complies with this paragraph and that no further explanatory remarks are considered necessary.

23. Paragraph 1-1. The Model LK Frequency Drift Indicator is satisfactory for use in the Laboratory and on the test floor for determining the drift in frequency of radio transmitters.

24. Paragraph 1-2. The Model LK equipment operates over a range extending from 100 kcs. to 26,000 kcs. by means of a series of nine plug-in coil systems. No variable frequency source of voltage was available which covered this entire range, but a great number of points were obtained throughout the range which showed beyond a reasonable doubt that coverage was complete and overlap was ample in all cases.

25. Paragraph 1-3. The equipment operates on the principle of measuring the difference frequency between a frequency generated in the LK equipment and the frequency of the transmitter under test or observation. For this purpose a visual indicator in the form of a meter is provided which operates over three ranges: 0 to 500 cycles, 0 to 1000 cycles, and 0 to 5000 cycles. A chart recorder, upon which a permanent record is drawn with ink, is also provided. The recorder is equipped with the three ranges incorporated in the visual recording element. In addition, a loud-speaker attachment furnishes an aural indication of the difference frequency.

26. Paragraph 1-4. The equipment, as furnished, requires nothing further for the type of operation specified. Six transmitter type crystals are provided adjusted to approximately the following frequencies: 2000 kcs., 2500 kcs., 3000 kcs., 3500 kcs., 4000 kcs., and 4500 kcs. (See Table No. 1.)

27. Paragraph 1-5. The equipment operates from either a 110-115 volt or 220-230 volt, single phase, 60 cycle supply.

28. Paragraph 1-6. The governing contract does not require spare parts to be submitted with the preliminary model and hence the provisions of this paragraph could not be checked.

29. Paragraph 2-2. The component parts of the equipment comply with the reference specifications listed under this paragraph. The following tubes are not contained in specifications RE 13A 346T, but the use of these tubes was approved in references (c) and (d).

5-2-3	Rectifier
75	Duplex Diode Triode
79	Class B Twin Amplifier
89	Triple Grid Power Amplifier
1-V	Rectifier

30. Paragraph 2-3. The equipment is ruggedly constructed and good materials have been used throughout. The frame of the equipment has been fabricated from hard aluminum angles, 1-1/4" x 1-1/4" x 3/16", strengthened by a sufficient number of cross members to insure rigidity and maintenance of alignment.

31. Paragraph 2-4. The workmanship used in the construction of this equipment is of good quality. A few items require minor modifications

and these points will be discussed under appropriate headings in the succeeding paragraphs of this report.

32. Paragraph 2-5. No definite tests could be undertaken to determine whether the equipment will operate satisfactorily in any temperature between the limits of minus 1 degree Centigrade and 51.5 degrees Centigrade. The temperature control facilities being provided at the Naval Research Laboratory have not been completed to date and the temperature control facilities at the National Bureau of Standards could not be utilized due to the fact that it would have been exceedingly difficult to move the several transmitters and power equipment necessary for their operation, and which were used in these tests, to the Bureau of Standards. In the opinion of the Naval Research Laboratory, however, the equipment as supplied should be capable of complying with this requirement. This opinion is based on the action of the LK equipment when subjected to such changes in ambient temperature as could be obtained during the test and by an examination and comparison of the temperature control circuit supplied with other equipment which has proved to be satisfactory. The equipment operates satisfactorily, except as to accuracy, for short periods of time when the control cabinet assumes a temperature as high as 65 degrees Centigrade. This was demonstrated by causing the cabinet temperature to rise to this value. No damage resulted from this test.

33. Paragraph 2-6. The items entering into the construction of this equipment have either been fabricated from non-corrosive materials or have been suitably protected against corrosion by the application of paint, lacquer or metallic coatings.

34. Paragraph 2-7. The use of iron and steel has been reduced to a practicable minimum.

35. Paragraph 2-8. Wood has not been used in the construction of this equipment. The temperature control compartment is insulated by means of two layers of celotex.

36. Paragraph 2-9. The design of the electrical circuits and controls is liberal. Fuses have been provided to protect the equipment against overloads.

37. Paragraph 2-10. The LK equipment is provided with ventilating louvres in the shielding near the bottom and top of the equipment and the bottom plate is perforated to permit free access of air. No signs of overheating were detected during the course of the tests.

38. Paragraph 2-11. The capacitors used in the construction of this equipment are such that they comply with the requirements of this paragraph.

39. Paragraph 2-12. No damage to the equipment would result from the failure of vacuum tubes, other than the resulting non-operation. The input circuits of the equipment, as originally submitted, suffered

damage when subjected to excessive coupling. A detailed explanation of this failure and the methods employed to overcome this defect will be found under paragraph 78 of this report.

40. Paragraph 2-13. The equipment is so designed that the vacuum tubes employed operate within the limits of the tube specifications. The following tubes are used in the Model LK equipment:

<u>Number</u>	<u>Type</u>
3	77
1	78
5	37
1	80
1	45
1	75
3	1-V
2	79
1	38
1	89
2	5-Z-3
4	874

41. Paragraph 2-14. The equipment is so designed, that safe and satisfactory performance will be assured when the modifications herein outlined have been made. The modified input circuit gives satisfactory performance (see paragraph 78). The thermostat circuit at present is unsatisfactory as outlined under paragraphs 61 and 62 of this report, and this condition must be corrected before the equipment can be considered as acceptable.

42. Paragraph 2-15. No damage to the equipment resulted from the handling it received during shipment or from the vibration and shocks incident to its use on the test floor. The LK equipment was moved about frequently and its operation was in no way affected. Accuracy and operation of the equipment remained unchanged.

43. Paragraph 2-16. Suitable lock washers have been provided to insure good contacts. Soldering of connections appears to have been accomplished in a workmanlike manner, each soldered contact being protected by means of the application of what appears to be red Duco. However, while inspecting the equipment with a view of determining the accessibility and ease of replacement of vacuum tubes, it was noted that the removable grid leads were fashioned from solid wire. After these leads had been manipulated several times, that is, after the grid connections had been made and removed, this solid wire broke. A representative of the contractor replaced all such solid leads with flexible stranded conductors which eliminated the trouble and in no way interfered with the operation of the equipment. Inspection of the production models should insure that flexible stranded leads are used in these locations.

44. Paragraph 2-17. The tubes in the LK equipment are provided with rigid mountings. The shocks and vibrations encountered during normal test procedure have not shown the necessity for flexible mountings and the present method is considered satisfactory.

45. Paragraph 2-18. Considering the extreme flexibility and range of the LK equipment, it is believed that the circuits are as simple as it is possible to make them commensurate with efficient operation. While the circuits themselves present several new ideas and applications, the controls by means of which the equipment is adjusted are simple and straightforward. Comparatively inexperienced personnel should be able to handle the equipment readily after receiving proper instruction.

46. Paragraph 2-19. All controls and indicating devices are located on the front panel, suitably marked for identification and operation. However, it is believed that certain additional legends should be added. The small door in the front panel by means of which access is given to the tuning coils should be provided with the legend "Tuning Coils." The calibration chart should be given the designation of "Calibration Chart," and the thermometer should be marked "Crystal Temperature." In addition to the controls and indicating instruments mounted on the front panel, a calibration chart is provided. This chart is mounted on rollers beneath a protective glass cover and is controlled by a knob on the front panel. This chart contains calibration curves for the various radio frequency coil systems so that any particular harmonic of either crystal may be selected, and also contains calibration curves of the three audio frequency ranges for both visual and recorder meters. On the 500 cycle scale the correction factor is so small that it can be neglected, and, unless absolute values of frequency are desired, the results read directly from the scales of the visual indicator or the recorder may be used for most measurements without consulting the chart.

47. Paragraph 2-20. All controls are so designed that body capacity effects do not interfere with operation of the equipment and the operator is not subjected to radio frequency burns.

48. Paragraph 2-21. All meters with the exception of the recording and visual meters are of the 3-1/2" flush type, suitably mounted and replaceable by meters having the maximum dimensions permitted by the specifications. The visual frequency indicating meter is a Weston Model 272, while the recorder is a graphic instrument manufactured by the Esterline-Angus Co. of Indianapolis, Indiana. The recorder is mounted in the top left-hand corner of the equipment and consumes a panel space of 12-1/4" x 16-1/4". The recorder is fitted with a hinged door by means of which access is provided for servicing operations. The door is fitted with a glass protected vision opening 6-1/2" wide by 10-3/4" high through which the tape and the calibration scale and pointer are visible. The pen of the recorder can be refilled by simply removing the pen, filling the ink reservoir and drawing the ink to the pen point with a suction device provided for this purpose. Need for refilling is indicated by the pointer leaving the chart and inclining upward. When ink is drawn to the pen point with the suction device the point returns to the proper position and makes contact with the chart. In addition an adjustment is provided by means of which the proper pen balance can be obtained.

49. Paragraph 2-22. The equipment is provided with a name plate of adequate size, affixed to the front panel. This name plate carries the following information:

RADIO EQUIPMENT  
FREQUENCY DRIFT INDICATOR  
MODEL LK SERIAL 1  
Frequency range 100 to 26,000 kcs.  
Supply 110-220 volts, 60 cycles  
Weight 525 lbs.

NAVY DEPARTMENT  
Bureau of Engineering  
Radio Research Co., Inc.

Bu.Reqn. 113 Contract NOs-35378 dated 3-29-34

50. Paragraph 2-23. The various units in the equipment are marked as to operating voltage, current, frequency, etc., but not with Navy type numbers.

51. Paragraph 2-24. No spare parts are furnished with the preliminary model in accordance with the terms of the governing contract.

52. Paragraph 2-25. The equipment is capable of continuous operation without damage, with the exception that trouble was experienced with the heater control circuits as outlined under paragraphs 61 and 62 of this report. A discussion of the accuracy of the equipment will be found in the following paragraphs of this report. It is possible to ground either side of the supply line to the LK equipment without interfering with operation. When this test was conducted no overload occurred and the frequency was not affected.

53. Paragraph 2-26. The scales and dials are so arranged that an increase in the values of settings increase the final controlled effect.

54. Paragraph 3-1. The Model LK complies with the requirements of this paragraph. The overall dimensions of the equipment are as follows:

	<u>Specification</u>	<u>Actual</u>
	<u>Requirements</u>	<u>Measurements</u>
Height	- 63"	62-1/2"
Width	- 29"	29"
Depth	- 25"	25"

The equipment weighs 525 pounds, which is the limit permitted by the specifications. In this connection it is desired to point out that the entire equipment employs the principle of double shielding. Each individual circuit, or groups of circuits, are enclosed in aluminum containers and in most instances these shielded containers are insulated from the main framework by means of isolantite insulators. This type of construction provides maximum protection against stray fields, feed back and

undesired pick-up effects. Naturally, this type of construction increases the weight of the equipment to a marked degree, but it is believed that the advantages accruing from its use in terms of consistent and efficient operation outweigh the disadvantage of increased weight.

55. Paragraph 3-2. The LK equipment is completely self-contained and is mounted upon suitable rubber tired castors. The equipment operates from either 110 volt or 220 volt, 60 cycle supply.

56. Paragraph 3-3. The equipment is mounted within a rigid frame, properly braced and strengthened. The sides and rear shields are removable and are secured by means of acorn nuts. The front panel provides the mounting for all meters, indicating devices and controls. Coupling is provided by means of an adjustable control which projects through the left-hand shield and which may be completely housed within the equipment when not in use. A ground terminal is provided at the rear of the equipment near the base. The same plug and cable arrangement by means of which the equipment is connected to the power supply affords the grounding connection.

57. Paragraph 3-4. The rubber tired castors are so mounted with respect to the center of gravity that no difficulty was encountered in moving the equipment about on the test floor.

58. Paragraph 3-5. The visual frequency meter is of the front-of-board type, while the recording device is mounted within the equipment proper and extends only slightly beyond the front panel. The loudspeaker is mounted behind the panel and is provided with a screened opening through the panel. A volume control is provided in connection with the speaker which reduces the output to any desired volume or removes the note entirely.

59. Paragraph 3-6. A ground lead connection is provided as described in paragraph 56 above.

60. Paragraph 3-7. Provision has been made for the use of either 110 volts or 220 volts by merely throwing a switch to the indicated voltage. The panel to which the supply line is brought is located at the left rear of the set and the supply lines may be brought to two terminals by means of any ordinary leads or to a plug through a shielded cable, the shield of this cable being grounded to the equipment. A special 25-foot length of cable is provided with the equipment.

61. Paragraph 3-8. Refillable fuses, mounted on the power panel and connected in the main line supply, are provided. The heater compartment is protected through the medium of a thermal fuse of the mercury woods-metal type. This fuse functioned satisfactorily on several occasions when the thermostat circuit failed to function properly. This failure of the temperature control circuit to function properly constitutes the most serious drawback of the equipment. The first failure was attributed to a faulty thermostat. The second failure appeared to be due to the replacement thermostat failing to make proper contact with the clips provided for connecting the thermostat in the circuit. This was remedied by connecting the thermostat into the circuit by means of flexible leads. However, even after this modification the heater control circuit failed to function a

number of times. The failures are of such a haphazard nature that it has been impossible to determine the exact cause of failure. However, it is believed that the second thermostat is also faulty, since the circuit operates satisfactorily for periods of a day or so and then becomes inoperative. When placed into commission again it will operate satisfactorily for a period of some hours before failing again. The actual current in the thermostat circuit was measured and found to be 0.2 milliampere. The manufacturer should be required to give assurance that these difficulties will be corrected and inspection of the production models should insure that the heater control circuits are satisfactory by means of long time tests.

62. Another feature of the temperature control system requires modification. Table No. 5 lists the data collected in connection with power input measurements. These measurements revealed the fact that the maximum power input at 110 volt operation is 500 watts, but at 220 volt operation this figure increases to 820 watts. Examination of the circuit shows that the heater resistance is unchanged when the voltage is shifted from 110 volts to 220 volts, thus causing the heater circuits to consume four times the power on 220 volts. It is recommended that this condition be corrected by inserting a resistor in series with the heater circuit when operating at 220 volts and that the voltage selector switch be provided with an additional pole by means of which this series resistor may be short circuited when 110 volt operation is being used. Care should be exercised to insure that sufficient heating capacity is provided in all cases to permit the equipment to operate over the required range of ambient temperatures.

63. Paragraph 3-9. This requirement of the specifications is complied with. (See paragraphs 56 and 60 above.)

64. Paragraph 3-10. The equipment employs two crystals for measurement purposes. One crystal is adjusted to 50 kcs. and the other to 500 kcs. These crystals are mounted in isolantite containers with adjustable air gaps. The original specifications state that the two cabinets, one inside the other, shall be provided. The contractor's descriptive specifications proposed an alternative wherein the single cabinet would be provided, which would meet the requirements of the specifications, and this alternative is supplied in the preliminary model. The crystal compartment is insulated by means of two layers of celotex and the compartment is equipped with circulating fan, thermostat, thermal fuse and suitable heater elements for maintaining the temperature constant.

65. Paragraph 3-11. Over the range of ambient temperatures encountered during these tests no variation of temperature of the crystal compartment could be noted on the thermometer indicating this temperature. In order to determine whether the heat cycle of the crystal compartment influenced the frequency of the equipment, a two-hour run was made where every effort was made to keep the frequency of the transmitter constant. The recorder was operated during this test and the resulting trace was a substantially straight line in which no effect which might be attributed to heat cycles could be detected.

66. Paragraph 3-12-1. The requirements of the specifications are met in regard to the input line voltmeter, main power switch, heater

switch and temperature indicator being mounted on the front panel. The heater and power indicator lamps are visible through the front panel, but are actually mounted on a sub-panel behind the front panel. Compensation for line voltage variation is automatic so no control is required; likewise, no heating control is required for the temperature controlled compartment.

67. Paragraph 3-12-2. Output control and indicator are mounted on the front panel.

68. Paragraph 3-12-3. The crystal selector switch is mounted on the front panel by means of which either the 50 kc. or the 500 kc. crystal may be selected. This switch is also provided with an "off" position. Directly beneath the selector switch are two flush type adjusting screws by means of which the frequency of either crystal may be varied between small limits to compensate for aging effects or any other effects which might tend to influence the frequency of the crystals. The radio frequency range of the equipment is covered by means of nine plug-in coil systems contained in shielded containers. These coil systems are inserted into the circuit through an access door in the front panel. The coils are stored in the upper section of the equipment in the rear.

69. Paragraph 3-12-4. The visual frequency meter, which is a 5 M.A. full scale instrument, is mounted on the upper right-hand corner of the front panel.

70. Paragraph 3-12-5. The recording meter and "on-off" switch are mounted in the upper left-hand corner of the front panel. The "on-off" switch is just to the right of the recorder.

71. Paragraph 3-12-6. The loud speaker is mounted just behind the top center of the front shield.

72. Paragraph 3-12-7. Four meters, in addition to the frequency meters, are provided, all of which are Weston meters of the 3-1/2" flush mounting type. The purpose and range of these meters are as follows:

Crystal oscillator plate current: 0 - 2 M.A. d.c.

Audio Amplifier Input Voltmeter: 0 - 25 volts a.c., rectifier type. This meter is provided with a red mark at 15 volts and the zero to 10 and 20 to 25 volt portions of the scale have been blanked out in order to indicate that the useful voltage range lies between 10 and 20 volts, with 15 volts indicated as the optimum voltage.

Harmonic Indicator: 0 - 1 M.A. d.c.

Input Line Voltmeter: 0 - 250 volts a.c.

73. Paragraph 3-12-8. Suitable controls and circuits are provided so that the visual frequency meter, the recording meter and the loudspeaker may be used at the same time, singly or in any combination desired. The circuits are so compensated that any one of the three indicating means may be switched in or out of the circuit without affecting the accuracy of the devices which remain in the circuit.

74. Paragraph 3-13. The contractor has provided chart paper in 96-foot rolls. The question of chart paper and chart speeds is discussed in detail in paragraph 79 of this report.

75. Paragraph 3-14. A set of six quartz crystals is provided. These crystals are contained in insulative air gap holders which are interchangeable with the Navy type SE-40000 holder. Table No. 1 shows the frequency value of the crystals when oscillating in a circuit employing a WL-680 tube. This was the only circuit readily available during the tests. The measurements using the LK equipment assume the LK 500 kc. crystal is exactly on frequency. The other column of measurements were secured from laboratory standards. No adjustments of the air gaps were made since in the test circuit used a far greater variation than 50 cycles could be secured by tank circuit tuning, and it would be difficult to differentiate between tank circuit changes and air gap changes. The failure of the crystals to produce beat notes of between 250 and 300 cycles cannot be attributed solely to the crystals since they were used in a circuit which did not employ a 38110 tube. It is believed that no difficulty will be encountered in utilizing the crystals provided in any of the test or transmitter circuits which may be encountered and obtain a difference frequency with the LK equipment which will fall on the 500 cycle scale. A suitable compartment is provided in the LK equipment for storing these six crystals. It is recommended that the serial number of the equipment appear on the crystal holders provided with each LK. Thus, if more than one equipment is being used at any given location, the danger of confusing the crystals would be eliminated.

76. Paragraph 4-1. The LK equipment may be used to indicate the output frequency and the frequency variation of radio transmitters over periods of time.

77. Paragraph 4-2. The Model LK equipment was checked against the Model LH equipment for a period of two days. During this time, numerous measurements were made and the greatest variation between the two equipments noted was 0.00038% and the average was less than this figure. Conditions did not permit continuous tests of 200 hours or more duration to be made, but no reasons are apparent why the equipment should not meet the requirement of 0.002% accuracy for long time operation. Reference (h) modified paragraph 4-2 of the specifications as follows: "Errors in indication, as measured at 5000 kcs., due to line voltage variation within the limits here given shall be less than the following:

- (1) Two cycles in the 0 - 500 cycle range.
- (2) Four cycles in the 0 - 1000 cycle range.
- (3) Twenty cycles in the 0 - 5000 cycle range."

The LK equipment was subjected to line voltage variations, both gradual and sudden, of plus and minus 10% without causing any noticeable frequency shifts. In addition a careful, detailed check was made of the three scales of the LK equipment, using the Model LH equipment as the checking means. Table No. 2 shows the results of the check of the 500 cycle scale made at 3000 kcs. It will be noted that the LH equipment indicated that the frequency shift was 500 cycles and that both the visual and recording meters of the LK equipment showed exactly the same frequency change, namely 500 cycles. The largest deviation between the LH and the LK visual meter anywhere on the scale was 5 cycles; the largest deviation between the LH and the LK recording meter was 4 cycles and the greatest difference between the LK visual meter and the LK recording meter was 5 cycles. Taking into account the tolerance factor as described in paragraphs 19 and 20 of this report as applying to the LH equipment and the tolerance permitted by reference (h) as stated above, it will be seen that the results obtained are accurate and in very close agreement. Table No. 3 shows the results of a check of the 1000 cycle scale of the LK equipment made at 3000 kcs. Table No. 4 shows the results of a check of the 5000 cycle scale of the LK equipment made at 4500 kcs. It will be noted that the results obtained indicate an accuracy which complies with the requirements of the governing specifications. The readings taken on the 5000 cycle scales of the LK equipment were corrected by means of the calibration chart furnished with the equipment. In Table No. 2 and No. 3, such corrections were not made since the deviation of the scale readings from the calibration charts is so small as to be negligible.

78. Paragraph 4-3. With the LK equipment it is possible to determine the frequency drift of a transmitter adjusted to any frequency in multiples of 50 kcs. from 100 kcs. to 1000 kcs. and in multiples of 500 kcs. from 1000 kcs. to 26,000 kcs. The LK equipment was tested at numerous points in the frequency range from 200 kcs. to 24,000 kcs. These two points represented the extreme values available in the transmitters used for testing the equipment which would give a beat frequency with the LK equipment. The 200 kcs. point worked very well and the harmonic indicator showed that the LK would reach the lower value of 100 kcs. required by the specifications. At the higher frequencies the input control of the LK, consisting of a 50,000 ohm wire wound clarostat failed to function properly. It not only did it fail to control the voltage, but with tight coupling it soon burned out. After an investigation of this trouble, a variable capacitor was substituted for the resistance potentiometer and with a little care in adjusting the external coupling, the input could be properly controlled over the entire frequency range. These changes were made by a representative of the contractor who gave assurance that this modified form of input circuit will be incorporated in the production models.

79. Paragraph 4-4. The audio beat frequency between the transmitter and the LK equipment can be indicated visually, aurally and may be recorded on a chart. Any one of three operations or any combination of the three operations can be accomplished at the same time. The chart provided with the recorder is 96 feet long and moves six inches per hour, thus giving a record for 192 hours. The requirements of paragraph 4-9 stated the chart speed should be approximately three inches per hour. The contractor

furnished a set of gears with the recorder for a six inch per hour speed and another for a three inch per hour movement. In the opinion of the Laboratory the six inch per hour speed is to be desired over the three inch per hour. At the lower speed there is a tendency for the recording pen to make a slight depression in the chart thus causing a slight lag in the recorded frequency; this is not so evident at a speed of six inches per hour. The faster speed also permits a better record to be obtained of frequency changes of short duration. Since the longer charts make it possible to obtain approximately 200 hours of operation at the six inch per hour speed it is recommended that the Bureau of Engineering request the contractor to supply gears which will permit a chart movement of six inches per hour.

80. Paragraph 4-5. Reference (h) modified this paragraph of the specifications as follows: "The scales shall be of suitable size and provide calibration markings, distributed approximately in a uniform manner, for indicating 5, 10 and 50 cycles per division, respectively, in the above ranges." The LK equipment, as submitted, has a visual indicator provided with an eight inch (8") scale which is divided into 100 equal divisions. A range switch is provided which permits the selection of any one of three ranges, i.e., 0 - 500 cycles, 0 - 1000 cycles, and 0 - 5000 cycles. Thus it will be seen that each division of the scale is equal to 5, 10 and 50 cycles respectively. Tests show that the various scales are in close agreement. For example, if a beat note of 300 cycles is impressed upon the instrument when employing the 500 cycle scale, this 300 cycle frequency may be read accurately on the 1000 cycle and 5000 cycle scales through the medium of the range selector switch. Further, tests showed that as the frequency drifted off of the 500 cycle scale, it is possible to insert the 1000 cycle scale and pick up the frequency at the exact reading where the 500 cycle scale ends. Then, as the frequency drifts off the 1000 cycle scale, the 5000 cycle scale may be thrown into use and the frequency picked up at the 1000 cycle point of the 5000 cycle scale. The ability of the LK equipment to operate in this manner constitutes one of the major improvements made in the equipment since the time it was submitted for test on 29 August 1934. Actual tests also show that no danger results to the visual meter or the chart recorder if the audio frequency impressed upon the 500 cycle range is actually 5000 cycles at normal input voltage. The indicating pointers merely go off scale on the high end of the range without affecting the zero adjustment or damaging the meters. The approved method of operation is to always start with the equipment set on the 5000 cycle scale, listen to the beat note by means of the loudspeaker and then select the proper scale for operation. However, if the observer should insert the wrong scale no damage will result.

81. Paragraph 4-6. The recording meter may be placed in or out of the circuit without affecting the calibration or other operating characteristics. The visual meter may also be placed in or out of the circuit without affecting the accuracy of the recording meter. The useful width of the recorder chart is 4-1/2", uniformly divided into 50 divisions. The recorder operates from the same range switch as the visual indicator (see paragraph 80 above). The accuracy of the recorder is greater than that required by the specifications as will be noted by referring to Tables No. 2, 3 and 4.

The specifications require an accuracy of plus or minus 5% of the true audio beat frequency. Reference to the above tables shows that the maximum deviation actually encountered is approximately 2.5%, while the average deviation is considerably less than this figure.

82. Paragraph 4-7. This paragraph of the specifications has been amended by references (c) and (d) to read as follows: "The visual indicator shall be readable to approximately one cycle in the 0 - 500 cycle range and to proportionate accuracies in the higher ranges. The recorder chart shall be readable to one per cent of the particular full scale range employed. The recorder calibration shall be uniform and not require reference to special calibration to attain the accuracy here required." The 0 - 500 cycle scale of the visual meter is readable to a single cycle and proportionate accuracies are obtainable on the higher ranges. It is also possible to read the recorder scale on the 500 cycle range to within one cycle with proportionate accuracies on the higher ranges without reference to the calibration chart.

83. Paragraph 4-8. A five watt transmitter, when operating into an actual antenna system, readily provides sufficient power to operate the LK equipment and the coupling system, as modified to provide for capacity adjustment of coupling as described in paragraph 78 above, is sufficiently flexible so that when operated in the vicinity of a 10 KW transmitter blocking will not result, nor will the accuracy of the equipment be impaired. Of course, sufficient pains must be taken to select a reasonable coupling adjustment.

84. Paragraph 4-9. The recording attachment is driven by a 110 volt, 60 cycle synchronous clock motor, with associated gears to produce the desired chart speed. As pointed out in paragraph 79 above, the contractor provided gears which gave a chart speed of 3 inches per hour and another set which gave 6 inches per hour. In the opinion of the Laboratory, for the reasons stated above, a chart speed of 6 inches per hour should be approved.

85. Section VI. The instructions submitted by the contractor were sufficiently complete to place the equipment into commission. In addition, a representative of the contractor was present during the tests herein outlined. No actual draft of an instruction book was submitted, hence the requirements of this section of the specifications could not be checked.

86. Section VII. The foregoing portions of this report indicate in detail the tests conducted. These tests were comprehensive and included tests of the nature outlined in this section of the specifications.

87. A summary of the defects noted, or such items as do not comply with the requirements of the governing contract, together with suggested changes or modifications, are listed below. (Note: The numerals enclosed in parentheses refer to the paragraphs of this report under which these items are discussed in detail.)

- (a) (43) Stranded flexible leads should be substituted for the solid wire leads connecting to the grid caps of the various vacuum tubes.

- (b) (46) Legends should be provided for the Tuning Coil compartment, the Calibration Chart and the indicating thermometer.
- (c) (61) The thermostat circuit failed to operate satisfactorily.
- (d) (62) An improved method should be provided for adapting the heater circuits to 110 and 220 volt operation.
- (e) (75) The serial number of the equipment should appear on the name plate of the transmitter crystals for identification.
- (f) (78) The original input coupling system was not satisfactory at high frequencies.
- (g) (79) A chart speed of 6 inches per hour should be specified in lieu of a speed of 3 inches per hour.

#### CONCLUSIONS

88. The general appearance of the LK equipment is pleasing and good materials and workmanship have been employed in its construction. The principle of double shielding employed throughout the equipment interferes to some extent with accessibility and introduces added weight; however, all parts are accessible and special provisions to improve accessibility have been made by equipping some of the shielded compartments with sliding covers provided with spring contacts. The efficient operation obtained and the freedom from interference assured by this complete shielding far outweighs the disadvantages accruing from its use.

89. The performance of the present LK equipment is far superior to that obtained with the original model submitted for tests. This improvement has been wrought by the inclusion of new and improved circuits, more rugged indicating means for both the visual and recording elements and the providing of means whereby any one or any combination of the three indicating methods, visual, aural or recorder, may be selected at will. Line voltage variations as large as 10% do not affect the accuracy of the equipment and no injury results to the indicating meters if they are subjected to off scale frequencies.

90. The instrument is capable of extremely flexible operation. Transmitters ranging in frequency from 100 kcs. to 26,000 kcs. with power outputs varying from 5 watts to 10,000 watts, may be checked with the LK equipment, and difference frequencies from zero to 5000 cycles may be measured. The accuracy of the equipment during test was excellent and all necessary adjustments may readily be made with ease.

91. The most serious difficulty encountered during these tests was due to the intermittent failure of the temperature control circuits. The exact cause of these failures could not be determined but assurance was given by the contractor's representative that this difficulty would be eradicated. The heater circuits also require some modifications in order

to provide for similar operation whether employing 110 volt or 220 volt input, and in order to limit the input power to less than 750 watts.

92. Certain other small changes are indicated, such as the substitution of flexible leads where solid leads are now used, the addition of a few legends on the front panel and on the transmitter crystal containers. The original input coupling circuit failed to function properly at high frequencies, but this defect was eliminated by the substitution of a variable capacitor in place of the resistance potentiometer employed. The contractor provided gear trains by means of which a chart speed of either 3" or 6" per hour could be obtained and it is believed the 6" speed will give the better results.

TABLE 1

Frequency of Six Transmitter Crystals  
Provided with LK Equipment

<u>Assigned Frequency</u>	<u>Laboratory Measurements</u>	<u>LK</u>
2000.250	2000.263	2000.248
2500.250	2500.263	2500.250
3000.250	3000.248	3000.260
3500.250	3500.090	3500.070
4000.250	4000.023	4000.000
4500.250	4500.230	4500.193

TABLE 2

Test of 500 Cycle Scale of LK Equipment  
(One Crystal used in LH Equipment)

<u>Absolute Frequency (LH Measure- ment)</u>	<u>LK Recorder</u>	<u>LK Visual Meter</u>	<u>Difference between Visual Meter &amp; LH</u>	<u>Difference between Recorder &amp; LH</u>	<u>Difference between Visual Meter &amp; Recorder</u>
3000.000	3000.000	3000.000	0	0	0
030	030	030	0	0	0
049	050	050	1	1	0
080	078	078	2	2	0
100	099	100	0	1	1
120	122	125	5	2	3
145	147.5	150	5	2.5	2.5
171	172.5	175	4	1.5	2.5
198	198.5	200	2	0.5	1.5
224	220	225	1	4.0	5
249	248.5	250	1	0.5	1.5
272	271	275	3	1	4
296	295	300	4	1	5
323	320	325	2	3	5
348	345	350	2	3	5
376	373	375	1	3	2
400	398.5	400	0	1.5	1.5
425	424.5	425	0	0.5	0.5
-	449	450	-	-	1
475	475	475	0	0	0
500	500	500	0	0	0

TABLE 3

Test of 1000 Cycle Scale of LK Equipment  
(Two Crystals used in LH Equipment)

<u>Absolute Frequency (LH Measure- ment)</u>	<u>LK Recorder</u>	<u>LK Visual Meter</u>	<u>Difference between Visual Meter &amp; LH</u>	<u>Difference between Recorder &amp; LH</u>	<u>Difference between Visual Meter &amp; Recorder</u>
3000.000	3000.000	3000.000	0	0	0
046	040	040	6	6	0
092	088	090	2	4	2
141	138	140	1	3	2
192	188	190	2	4	2
243	238	240	3	5	2
291	287	290	1	4	3
339	337	340	1	2	3
392	382	390	2	10	8
441	432	440	1	9	8
487	480	490	3	7	10
538	530	540	2	8	10
586	580	590	4	6	10
643	632	640	3	11	8
690	686	690	0	4	4
741	738	740	1	3	2
792	790	790	2	2	0
842	840	840	2	2	0
894	892	889	5	2	3
944	942	940	4	2	2
3001.001	994	990	11	7	4

TABLE 4

Test of 5000 Cycle Scale of LK Equipment  
(Four Crystals used in LH Equipment)

Absolute Frequency (LH Measurement)	LK Recorder	LK Recorder Corrected	LK Visual Meter	LK Visual Meter Corrected	Difference between Corrected Recorder & Absolute	Difference between Corrected Visual & Absolute	Difference between Corrected Visual & Recorded
4500.000	4500.000	4500.000	4500.000	4500.000	0	0	0
248	245	245	245	245	3	3	0
533	510	510	525	525	8	23	15
740	740	742	740	740	0	2	2
4501.015	4501.020	4501.020	4501.020	4501.012	3	5	8
280	285	285	280	271	9	5	14
455	465	465	465	452	3	10	13
717	720	719	740	725	8	2	6
924	975	975	950	930	6	51	45
4502.183	4502.200	4502.198	4502.215	4502.190	7	15	8
448	450	450	470	442	6	2	8
726	740	740	755	730	4	14	10
914	925	927	945	922	8	13	5
4503.231	4503.250	4503.250	4503.265	4503.245	14	19	5
463	475	475	495	477	14	12	2
674	690	692	700	685	11	18	7
963	990	990	995	985	22	27	5
4504.245	4504.275	4504.280	4504.270	4504.260	15	35	20
403	425	432	415	413	10	29	19
746	775	787	750	745	1	41	42
997	4505.025	4505.030	4505.000	4505.000	3	33	30

TABLE 5

Power Input of LK Drift Indicator

	<u>Watts</u>	
	<u>110 Volts</u>	<u>220 Volts</u>
Voltage regulator and heater control circuits	168	160
Heater Circuits	112	440
Power for R.F. and A.F. circuits	205	205
Recorder	<u>15</u>	<u>15</u>
Total	500	820