BROADCAST ENGINEERING MEASUREMENTS

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1950

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Date thesis is presented May 10, 1950

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BROADCAST ENGINEERING MEASUREMENTS

INTRODUCTION

The Federal Communications Commission has issued Rules and Regulations governing the construction and operation of standard broadcast stations. They have also published a set of Standards of Good Engineering Practices which contains interpretations and expansion of the Rules and Regulations of the Commission. These standards expand the Rules and Regulations with respect to technical aspects and set up engineering principles for use as a guide in the solution of allocation problems in broadcasting. These standards depict the policies of the Engineering Department of the Federal Communications Commission concerning technical procedure and the minimum requirements in engineering.

Since August 1, 1949, the Federal Communications Commission has required annual proof of compliance with these standards by all licensees to insure conformance with minimum operating performances. In addition, it is necessary to have performance measurements made within four months immediately preceding the date of application for renewal of the station's license.

The purpose of this paper has been to collect and compile necessary information covering the method to be followed in conducting the required performance measurements. A simple, direct, and methodical arrangement of obtaining these data has been presented.

The material has been assembled in three parts:

1. Audio Frequency Standards and Measurements.
2. Radio Frequency Standards and Measurements.
3. Propagation Standards and Measurements.

Each section has been treated individually and the methods of securing and presenting the data are outlined. The methods herein described are not the only ones applicable, but they are methods that are simple, accurate, and dependable.

AUDIO FREQUENCY STANDARDS AND MEASUREMENTS

This section describes the overall audio frequency response requirements as set forth by the Engineering Division of the Federal Communications Commission.

The material has been arranged in the following order:

1. Extracts from the Standards of Good Engineering Practice pertaining to audio frequency measurement.
2. Speech input equipment for broadcast use.
3. Recommended equipment and procedure for conducting tests on broadcast station audio frequency equipment.
4. Data and curves obtained from typical field measurements.

The Federal Communications Commission requires compliance with the following specifications pertaining to the performance and method of testing of the audio frequency equipment which is used in a standard broadcast station:

"The specifications deemed necessary to meet the requirements of the Standards of Good Engineering Practice with respect to design, construction, and operation of standard broadcast stations are set forth below:

A. Design

1. The total audio frequency distortion from microphone terminals, including microphone amplifier, to antenna output does not exceed 5 percent harmonics (voltage measurements of arithmetical sum or r.s.s.) when modulation from 0 to 84 percent, and not over 7.5 percent harmonics (voltage measurements of arithmetical sum or r.s.s.) when modulating 85 percent to 95 percent (distortion shall be measured with modulating frequencies of 50, 100, 400, 1000, 5000, and 7500 cycles up to tenth harmonic or 16,000 cycles, or any intermediate frequency that readings on these frequencies indicate is desirable.

2. The audio frequency transmitting characteristics of the equipment from the microphone terminals (including microphone amplifier unless microphone frequency correction is included in which event proper allowance shall be made accordingly) to the antenna output does not

depart more than 2 decibels from that at 1000 cycles between 100 and 5000 cycles.

3. Adequate margin is provided in all component parts to avoid overheating at the maximum rates power output.

B. Installation--The installation shall be made in suitable quarters.

C. Spare tubes--A spare tube of every type employed in the transmitter and frequency and modulation monitors shall be kept on hand. When more than one tube of any type are employed, the following table determines the number of spares of that type required:

Number of each type employed	Spares required
1 or 2	1
3 to 5	2
6 to 8	3
9 or more	4

D. Operation--In addition to the specific requirements of the rules governing standard broadcast stations, the following operating requirements shall be observed:

1. The maximum percentage of modulation shall be maintained at as high level as practi-

cable without causing undue audio frequency harmonics, which shall not be in excess of 10 percent when operating with 85 percent modulation.

2. Spurious emissions, including radio frequency harmonics, and audio frequency harmonics, shall be maintained at as low a level as practicable at all times in accordance with good engineering practice.

E. Studio equipment--The studio equipment shall be subject to all the above requirements where applicable except as follows:

1. If it is properly covered by an underwriter's certificate, it will be considered as satisfying the safety requirements.

2. Section 8191 of article 810 of the National Electrical Code shall apply for voltages only when in excess of 500 volts.

No specific requirements are made relative to the design and acoustical treatment. However, the studios and particularly the main studio should be in accordance with the standard practice for the class of station concerned, keeping the noise level as low as possible."

To comply with the foregoing requirements, it is necessary to have measurements made by a competent engineer whose qualifications are acceptable to the Federal Communications Commission. The measurements are required to be made before the station can be initially licensed and must be conducted at least once each year thereafter. It is also necessary to have performance measurements made within a period of four months immediately preceding the date of application for renewal of the station's license.

Because of standization within the industry, speech input amplifiers have an input impedance of 30, 50, 125, 250, 500, or 600 ohms. The input circuit may be connected for either balanced or unbalanced operation with respect to ground. Test equipment is available with various values of output impedance and with either balanced or unbalanced termination. However, most test equipment available has been designed with a 600 ohm or higher value of impedance and an unbalanced to ground output circuit. In such cases a matching network must be used to properly connect the test equipment to the required microphone amplifier input terminals.

A simple, practical, and economical matching network must fulfill the following requirements:

1. The signal output of the signal generator or oscillator shall not be distorted by the method of coupling to the equipment under test.
2. An attenuation of approximately 50 decibels shall be provided over the operation range of 50 cycles to 16,000 cycles, and this attenuation shall be equal over the range of 30 to 15,000 cycles for any selected value.
3. Proper match of the input impedance of the input amplifier to the output of the audio signal generator or oscillator shall be accomplished.
4. Noise or hum shall not exceed -70 decibels.

Figure 1-A illustrates a network designed to comply with these requirements. It is designed to properly match an audio oscillator which is unbalanced to ground into a balanced speech amplifier input with a minimum of noise, hum, and distortion. It has been designed for a 600 ohm unbalanced input and a 50 ohm balanced output. The attenuation of the network is approximately 45 decibels. The noise level alone, due to the matching network, is approximately -68 decibels.

The Audio Frequency Oscillator is terminated with the 600 ohm resistor while the speech input equipment is terminated with the 50 ohm resistor. The two terminating resistors are coupled together with the 20,000 ohm resistor. Hence, any noise voltages generated within the Audio Oscillator will flow through the low 600 ohm resistor rather than the large 20,000 ohm resistor. Therefore, the 20,000 ohm resistor is in effect an isolating resistor. Proper choice of the isolating resistor, combined with two terminating resistors, form a π network with the approximate desired attenuation.

Figure 1-B has been included to illustrate the method of connecting this network in the circuit. For optimum performance all leads must be kept as short as possible. A network of this type has shown an equal transmission over the range of frequencies from 30 cycles to 20,000 cycles. Above 20,000 cycles the capacitance of the leads has resulted in a slightly higher attenuation with increasing frequency.

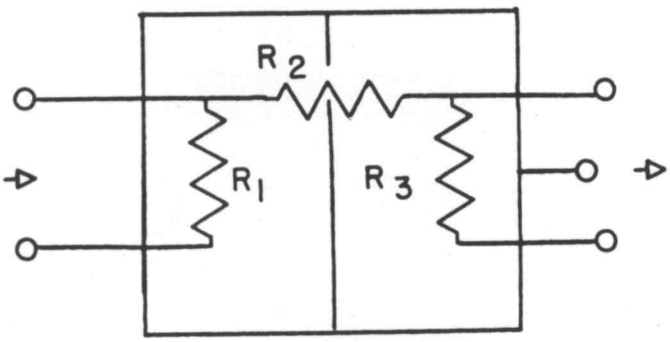


Figure 1-A

R_1 = 600 ohms (Z_o for input signal)

R_2 = 20,000 ohms (isolation)

R_3 = 50 ohms (Z_o of microphone channel)

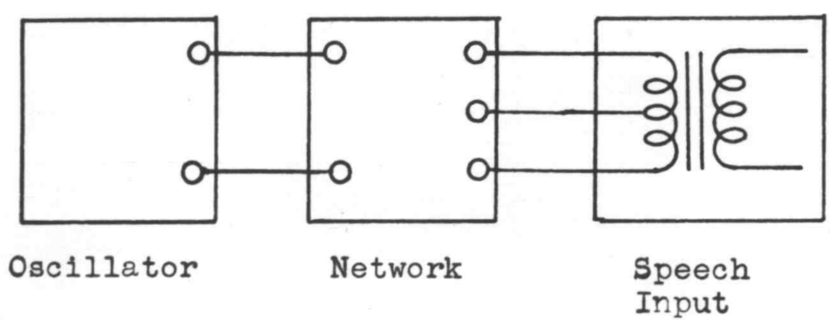


Figure 1-B

Part 1--Recommended Procedure for Obtaining Audio Frequency Response Data:

The required performance specifications have been quoted from the Standards of Good Engineering Practices of the Federal Communications Commission:

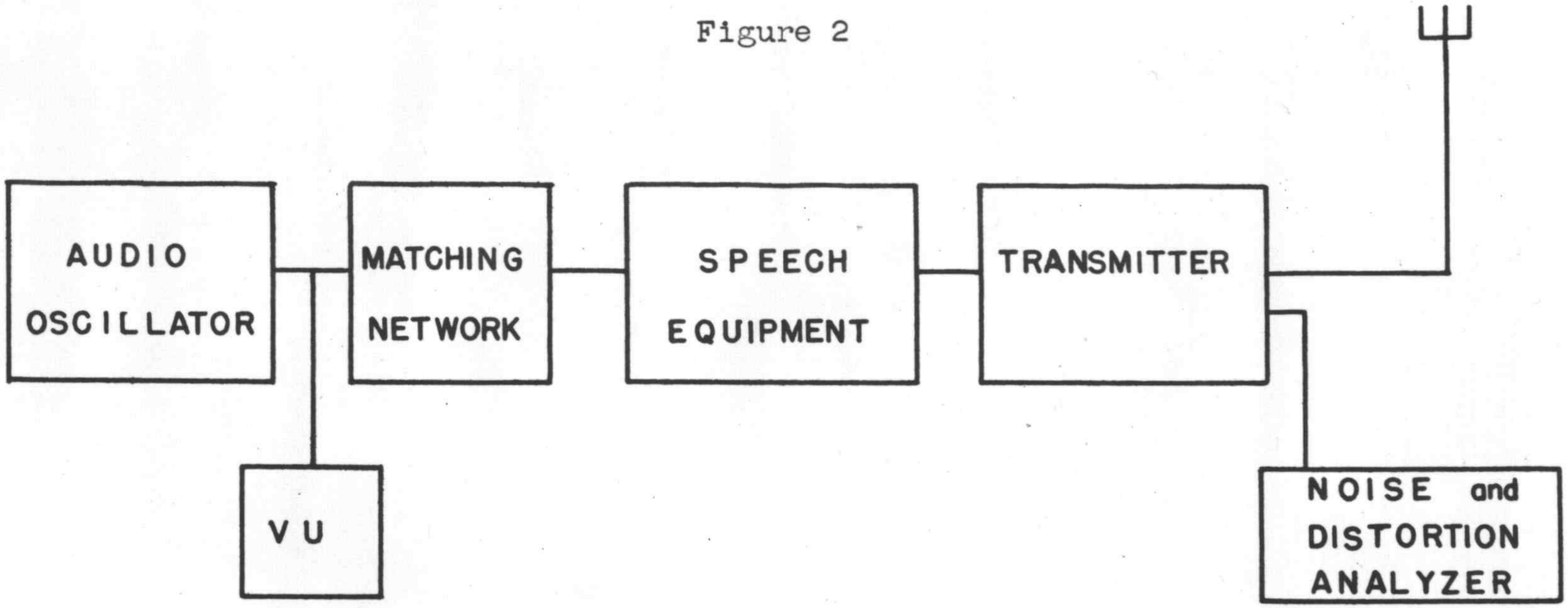
> "The audio frequency transmitting characteristics of the equipment from the microphone terminals (including microphone amplifier unless microphone frequency correction is included in which event proper allowance shall be made accordingly) to the antenna output does not depart more than 2 decibels from that at 1000 cycles between 100 and 5000 cycles."

Equipment required for testing:

1. Audio Signal Generator or Audio Oscillator.
2. Matching network and signal attenuator.
3. Noise and Distortion Analyzer.
4. Station Modulation Monitor.
5. Vacuum Tube Voltmeter or Volume Level Indicating Meter.

Figure 2 illustrates the arrangement of equipment for performance measurements.

Figure 2



ARRANGEMENT OF EQUIPMENT FOR
PERFORMANCE MEASUREMENTS

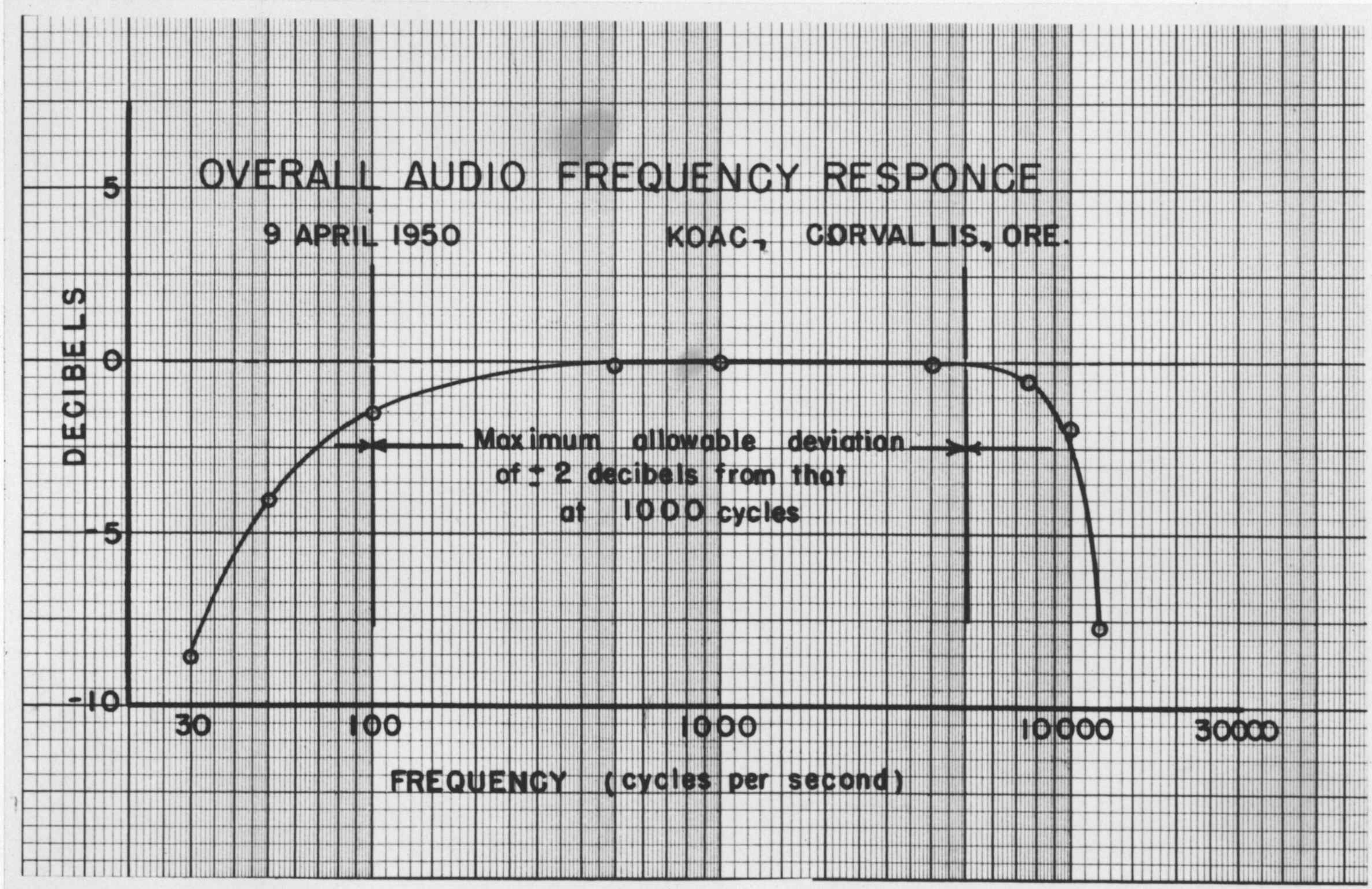
Recommended Test Procedure:

1. All station equipment must be adjusted for normal operating conditions. The transmitter must be operating into the regular antenna or the equivalent artificial antenna. All limiting amplifiers in the system must be by-passed so that they do not limit the signal applied to the transmitter.
2. The Audio Oscillator is connected through the matching network to the microphone input terminals of the microphone pre-amplifier.
3. The Audio Oscillator is set for 1000 cycles per second and the antenuator adjusted until the modulation monitor meter reaches the desired value of 84 percent modulation of the transmitter carrier. The Vacuum Tube Voltmeter is connected across the output terminals of the Audio Oscillator and when the desired value of modulation has been obtained, the Vacuum Tube Voltmeter or Volume Level Indicating Meter readings are to be recorded. This value must be maintained constant throughout the tests.

4. The Noise and Distortion Analyzer is connected across the input of the modulation monitor and adjusted to zero decibels at 1000 cycles. Then, for the various frequencies applied to the speech equipment, the change in decibels may be read directly from the distortion meter.
5. These data may be recorded in a manner shown in Table 1.
6. The results of the data obtained are plotted with the 1000 cycle response as datum. Curve 1 illustrates a method of presenting this information in graphical form.
7. An alternate method of obtaining these data may be used. The Audio Oscillator is set for 1000 cycles per second and the attenuator adjusted for the desired value of modulation. The Vacuum Tube Voltmeter or Volume Level Indicating Meter is used to measure the input level to the circuit at 1000 cycles per second. For each other frequency used, the attenuator of the Audio Oscillator is adjusted until the modulation monitor meter reads the desired value. The new readings of the Vacuum Tube Voltmeter are recorded as shown in Table 1.

OVERALL AUDIO FREQUENCY RESPONSE 9 April 1950									KOAC, Corvallis, Oregon
APPLIED FREQUENCY (cycles per second)	30	50	100	500	1000	4000	7500	10,000	12,000
DEVIATION (decibels)	-8.6	-4.0	-1.4	-0.2	0	-0.1	-0.5	-1.9	-7.8

Table 1



OVERALL AUDIO FREQUENCY RESPONCE
9 APRIL 1950
KOAC, CORVALLIS, ORE.
DECIBELS
5
0
-5
-10
Maximum allowable deviation
of ± 2 decibels from that
at 1000 cycles
30
100
1000
10000
30000
FREQUENCY (cycles per second)

Curve 1

Part 2--Recommended Procedure for Obtaining Total Audio Frequency Distortion:

The required performance specifications have been quoted from the Standards of Good Engineering Practices of the Federal Communications Commission:

> "The total audio frequency distortion from microphone terminals, including microphone amplifier, to antenna output does not exceed 5 percent harmonics (voltage measurements of arithmetical sum or r.s.s.) when modulated from 0 to 84 percent, and not over 7.5 percent harmonics (voltage measurements of arithmetical sum or r.s.s.) when modulating 85 percent to 95 percent (distortion shall be measured with modulation frequencies of 50, 100, 400, 1000, 5000, and 7500 cycles up to tenth harmonic or 16,000 cycles, or any intermediate frequency that readings on these frequencies indicate is desirable)."

Equipment required of conducting tests:

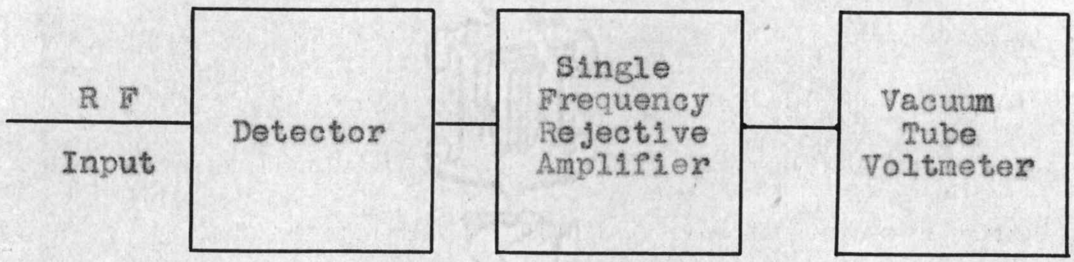
1. Audio Frequency Signal Generator or Audio Oscillator.
2. Matching audio frequency network.
3. Noise and Distortion Analyzer.
4. Station Modulation Monitor.
5. Vacuum Tube Voltmeter.

Figure 2 illustrates the arrangement of equipment for performance measurements.

Recommended Test Procedure:

1. All station equipment must be adjusted for normal operating conditions. The transmitter must be operated into the regular antenna or the equivalent artificial antenna. All limiting amplifiers in the system must be by-passed so that they do not limit the signal being applied for test purposes.
2. The Audio Oscillator is connected through the matching network to the microphone pre-amplifier input terminals. The Vacuum Tube Voltmeter is connected across the output terminals of the Audio Oscillator. The Audio Oscillator is set for 1000 cycles per second and the attenuator adjusted until the modulation monitor meter reads between 0 and 84 percent. 80 percent modulation is recommended as the standard value to be used.
3. The Noise and Distortion Analyzer is connected to the transmitter output either by capacitive or inductive coupling. It is practical to connect the Analyzer in parallel with the input terminals of the modulation monitor.

4. Operation of Noise and Distortion Analyzer:



BLOCK DIAGRAM OF

NOISE AND DISTORTION ANALYZER

Figure 3

The Noise and Distortion Analyzer utilizes the "Total Distortion Measurement" method of obtaining data. A stable signal frequency voltage is impressed upon the input terminals of the microphone pre-amplifier. The transmitter is then operated in the normal manner. The Noise and Distortion Analyzer is coupled to the transmitter either inductively or capacitively.

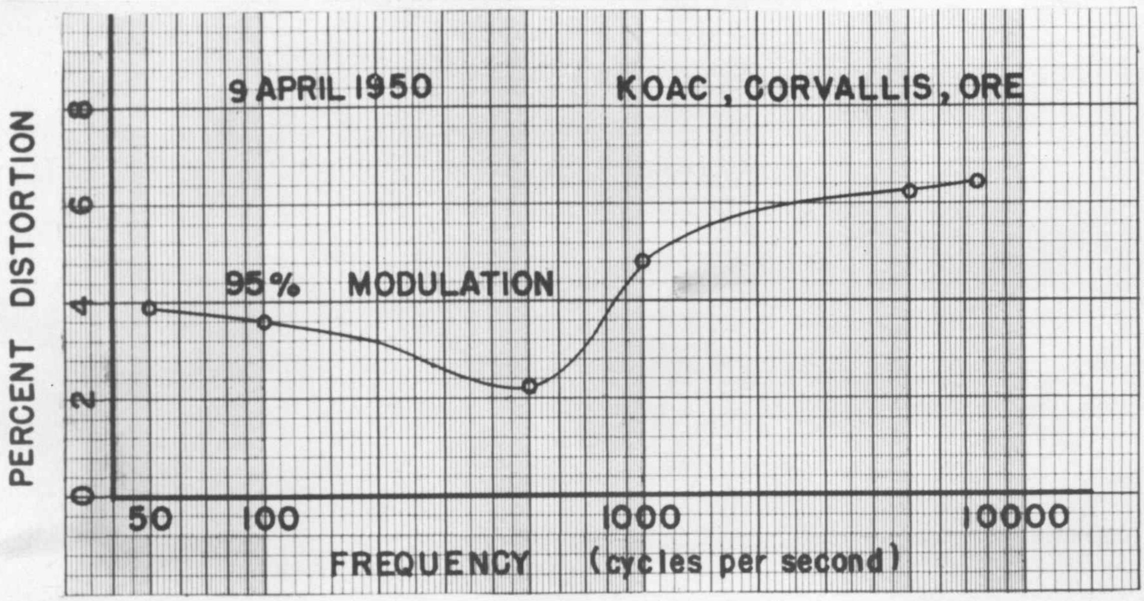
The fundamental signal frequency is then eliminated, or "balanced out" within the instrument, from the total audio output signal. The residual of the output signal represents the amount of distortion present. The percentage is indicated directly by the instrument meter.

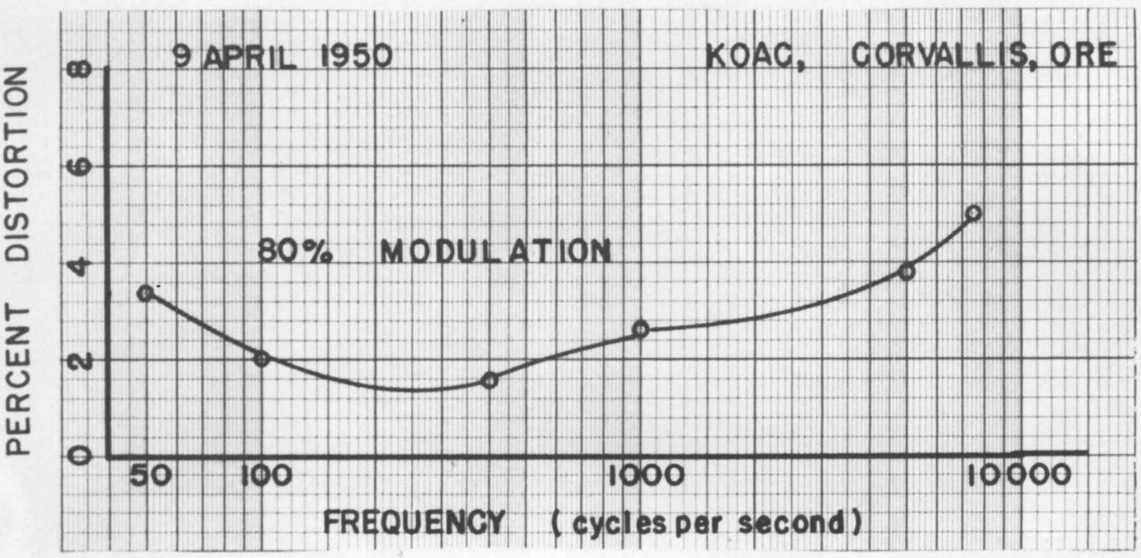
5. The same procedure outlined in parts 2, 3, and 4 is to be followed in adjusting the Audio Oscillator and the Analyzer for the different required frequencies of 50, 100, 400, 1000, 5000, and 7500 cycles per second at the desired 80 percent modulation.
6. All readings shall be recorded in the form indicated by Table 2. The tabulated data are then transferred to a graph illustrated by Curve 2.
7. Steps 2, 3, 4, 5, and 6, immediately preceding, shall be repeated for a modulation value between 85 and 100 percent modulation. It is recommended that the value of 95 percent modulation be accepted as the standard test value.

9 April 1950 TOTAL AUDIO HARMONIC DISTORTION KOAC, Corvallis, Oregon

APPLIED FREQUENCY (cycles per second)	50	100	400	1000	5000	7500
PERCENT DISTORTION 95% Modulation	3.9	3.5	2.2	4.8	6.2	6.3
PERCENT DISTORTION 80% Modulation	3.4	2.0	1.5	2.6	3.8	5.0

Table 2





Curve 2

TOTAL AUDIO

HARMONIC DISTORTION

RADIO FREQUENCY STANDARDS AND MEASUREMENTS

This section describes the radio frequency requirements as set forth by the Engineering Division of the Federal Communications Commission.

The material has been presented in the following order:

1. Extracts from the Standards of Good Engineering Practices pertaining to radio frequency measurements.
2. Precautions to be observed in radio frequency shielding.
3. Individual measurements for compliance including
   a. Carrier Shift
   b. Hum and Extraneous Noise
4. Data and curves obtained from typical measurements.

The following specifications pertaining to radio frequency equipment have been set forth by the Federal Communications Commission for compliance as to the method of testing and the performance of equipment used in the standard broadcast stations:

"The specifications deemed necessary to meet the requirements of the Rules and Regulations and good engineering practice with respect to design, construction, and operation of standard broadcast stations are set forth below. These specifications will be changed from time to time as the state of the art and the need arises for modified or additional specifications.

A. Design--the general design of standard broadcast transmitting equipment (main studio microphone--including telephone lines, if used, as to performance only--to antenna output) shall be in accordance with the following specifications. For the points not specifically covered below, the principles set out shall be followed:

The equipment shall be so designed that:

1. The maximum rated carrier power (determined by section 3.42) is in accordance with the requirements of section 3.41.
2. The equipment is capable of satisfactory operation at the authorized operating power with modulation of at least 85 to 95 percent with no more distortion than 7.5 percent.
3. The carrier shift (current) at any percentage of modulation does not exceed 5 percent.

4. The carrier hum and extraneous noise (exclusive of microphone and studio noises) level (unweighted r.s.s.) is at least 50 decibels below 100 percent modulation for the frequency band of 150 to 5000 cycles and at least 40 decibels down outside this range.
5. The transmitter shall be equipped with suitable indicating instruments in accordance with the requirements of section 3.58 and any other instruments necessary for the proper adjustment and operation of the equipment.
6. Adequate provision is made for varying the transmitter power output between sufficient limits to compensate for excessive variations in line voltage, or other factors which may affect the power output.
7. The transmitter is equipped with automatic frequency control equipment capable of maintaining the operating frequency within the limit specified by section 3.59.
   a. The maximum temperature variation at the crystal from the normal operating temperature shall not be greater than:

(1) Plus or minus 0.1 C. when an X or Y cut crystal is employed, or

(2) Plus or minus 1.0 C. when low temperature coefficient crystal is employed.

b. Unless otherwise authorized, a thermometer shall be installed in such manner that the temperature at the crystal can be accurately measured within 0.05 C. for X or Y cut crystal or 0.5 for low temperature coefficient crystal.

c. It is preferable that the tank circuit of the oscillator tube be installed in the temperature controlled chamber.

8. Means are provided for connection and continuous operation of approved modulation monitor and approved frequency monitor.

9. Adequate margin is provided in all component parts to avoid overheating at the maximum rated power output.

B. Construction--In general, the transmitter shall be constructed either on racks and panels or in totally enclosed frames protected as required by article 810 of the

National Electrical Code and as set forth below:

1. Means shall be provided for making all tuning adjustments, requiring voltages in excess of 350 volts to be applied to the circuit, from the front of the panels with all access doors closed.
2. Proper bleeder resistors or other automatic means shall be installed across all the condenser banks to remove any charge which may remain after the high voltage circuit is opened (in certain instances the plate circuit of the tubes may provide such protection; however, individual approval of such shall be obtained by the manufacturer in case of standard equipment, and the license in case of composite equipment).
3. All plate supply and other high voltage equipment, including transformers, filters, rectifiers and motor generators, shall be protected so as to prevent injury to operating personnel.
   a. It is not necessary to protect the equipment in the antenna tuning house

and the base of the antenna with screens and interlocks, provided the doors to the tuning house and antenna base are fenced and locked at all times, with the keys in the possession of the operator on duty at the transmitter. Ungrounded fencing or wires should be effectively grounded, either directly or through proper static leaks. Lightning protection for the antenna system is not specifically required but should be installed.

b. The antenna, antenna lead-in, counterpoise (if used), etc., shall be installed so as not to present a hazard. The antenna may be located close by or at a distance from the transmitter building. A properly designed and terminated transmission line should be used between the transmitter and the antenna when located at a distance.

4. Metering equipment.

a. All instruments having more than 1,000 volts potential to ground on the movement shall be protected by a cage or cover in addition to the regular case. (Some instruments are designed by the manufacturer to operate safely with voltages in excess of 1,000 volts on the movement. If it can be shown by the manufacturer's rating that the instrument will operate safely at the applied potential, additional protection is not necessary.)

b. In case the plate voltmeter is located on the low potential side of the multiplier resistor with one terminal of the instrument at or less than 1,000 volts above ground, no protection case is required. However, it is good practice to protect voltmeters subject to more than 5,000 volts with suitable over-voltage protective devices across the instrument terminals in case the winding opens.

c. The antenna ammeters (both regular and remote and any other radio frequency instrument which it is necessary for the operator to read) shall be so installed as to be easily and accurately read without the operator having to risk contact with circuits carrying high potential radio frequency energy.

C. Wiring and Shielding.

1. The transmitter panels or units shall be wired in accordance with standard switchboard practice, either with insulated leads properly cabled and supported or with rigid bus bar properly insulated and protected.
2. Wiring between units of the transmitter, with the exception of circuits carrying radio frequency energy, shall be installed in conduits or approved fiber or metal raceways to protect it from mechanical injury.
3. Circuits carrying low level radio frequency energy between units shall be either concentric tube, two wire balanced lines, or properly shielded to prevent the pickup of modulated radio frequency energy from the output circuits.
4. Each stage (including the oscillator) preceding the modulated stage shall be properly shielded and filtered to prevent un-

intentional feedback from any circuit following the modulated stage (an exception to this requirement may be made in the case of high level modulated transmitters of approved manufacture which have been properly engineered to prevent reaction).

5. The crystal chamber, together with the conductor or conductors to the oscillator circuit shall be totally shielded.
6. The monitors and the radio frequency lines to the transmitter shall be thoroughly shielded.

D. Installation.

1. The installation shall be made in suitable quarters.

E. Spare tubes--A spare tube of every type employed in the transmitter and frequency and modulation monitors shall be kept on hand. When more than one tube of any type are employed, the following table determines the number of spares of that type required:

Number of each type employed	Spares required
1 or 2	1
3 to 5	2
6 to 8	3
9 or more	4

F. Operation--In addition to the specific requirements of the rules governing standard broadcast stations, the following operating requirements shall be observed:

1. The maximum percentage of modulation shall be maintained at as high level as practicable without causing undue audio frequency harmonics, which shall not be in excess of 10 percent when operating with 85 percent modulation.
2. Spurious emissions, including radio frequency harmonics, and audio frequency harmonics, shall be maintained at as low a level as practicable at all times in accordance with good engineering practice.
3. In the event interference is caused to other stations by modulating frequencies in excess of 7500 cycles or spurious emissions, including radio frequency harmonics

and audio frequency harmonics outside the band plus or minus 7500 cycles of the authorized carrier frequency, the licensee shall install equipment or make adjustments which limit the emissions to within this band or to such an extent above 7500 cycles as to reduce the interference to where it is no longer objectionable.

4. The operating power shall be maintained within the limits of 5 percent above and 10 percent below the authorized operating power and shall be maintained as near as practicable to the authorized operating power.

5. In case of excessive shift in operating frequency during warm-up periods, the crystal oscillator shall be operated continuously. The automatic temperature control circuits should be operated continuously under all circumstances."

Radio Frequency Shielding:

The following precautions will be of help in reducing the effects of radio frequency pick-up in the measuring equipment:

1. Orient the A-C line plug for lowest residual readings.
2. Chasis of the Noise and Distortion Analyzer should be well grounded to the station ground bus.
3. Short A-C power cords should be used and by-passed with condensers where necessary.
4. Radio frequency chokes should be placed in the voltmeter terminal leads.
5. The voltmeter terminals should be shielded.
6. Matching-network box should be well grounded.
7. Signal Generator or Audio Oscillator case should be grounded.
8. In extreme cases the meter leads should be by-passed and the meter front should be shielded.

Part 3--Recommended Procedure for Obtaining Carrier Shift Data:

The required performance specifications have been quoted from the Standards of Good Engineering Practices of the Federal Communications Commission:

> "The carrier shift (current) at any percentage of modulation does not exceed five percent."

Carrier Shift may be referred to as Asymmetrical Modulation. In amplitude modulation systems the information is transmitted by varying the amplitude of the radiated wave, commonly referred to as the carrier wave, in accordance with the intelligence to be transmitted.

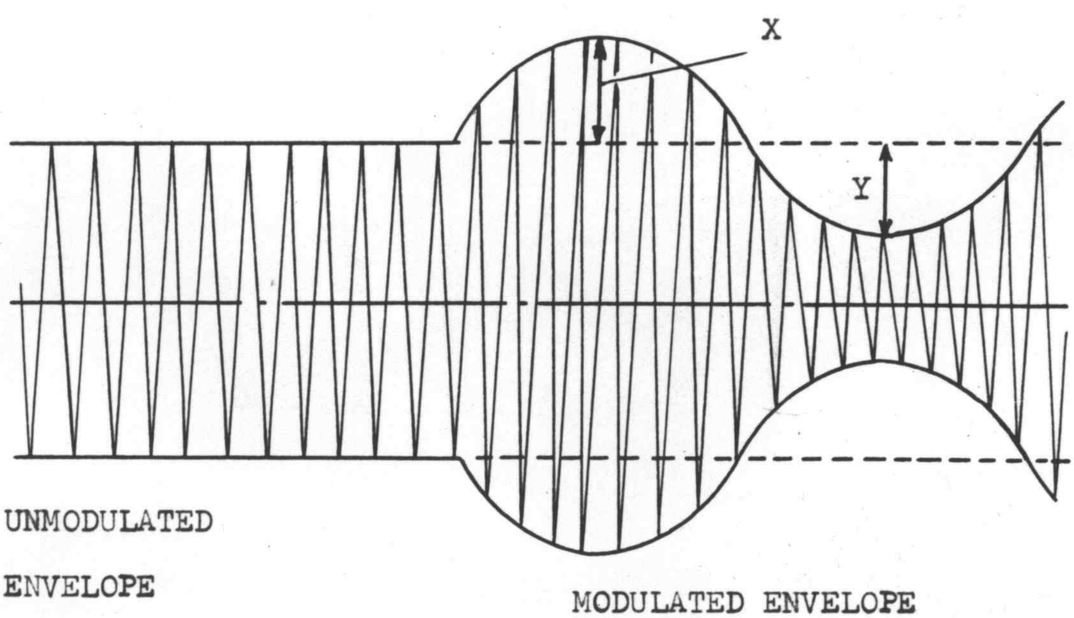
Carrier shift occurs when the amplitude (or depths) of the modulation peaks are not of equal magnitude in both the positive and negative directions. Figure 4 illustrates the carrier envelope both before and after modulation. When distance "X" is not equal to distance "Y", then carrier shift is said to have occurred.

For a complex signal wave, positive carrier shift occurs if the time average of the positive half cycles exceeds that of the negative half cycles; negative carrier shift occurs when the reverse is true.

CARRIER SHIFT

WITH

AMPLITUDE MODULATION



Negative Carrier Shift occurs if "Y" is greater than "X".

Positive Carrier Shift occurs if "X" is greater than "Y".

Figure 4

The expression, "carrier shift", does not mean that the frequency of the carrier has been changed in any way during modulation.

Data showing carrier shift at 25, 50, 85, and 100 percent modulation with a 400 cycle tone is recommended as sufficient to satisfy the test requirements. A 400 cycle signal has been chosen because it is representative of the average frequence of complex speech or music waves.

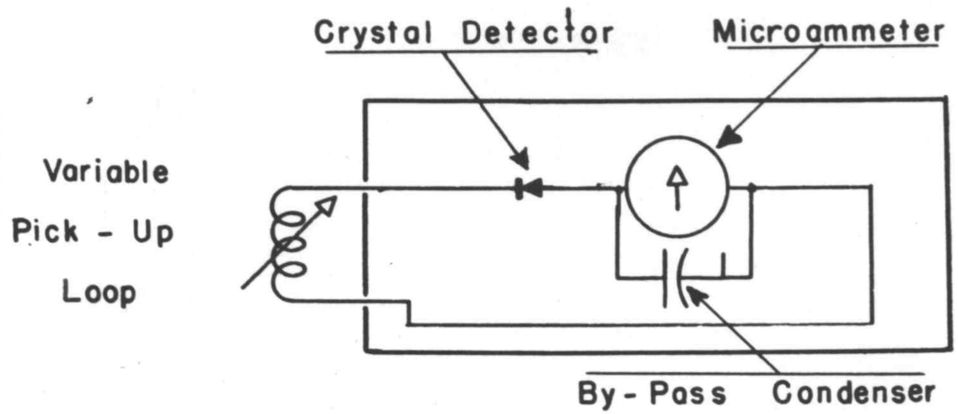
Equipment required for testing:

A. Method 1

1. Audio Signal Generator or Audio Oscillator.
2. Audio Frequency Matching Network.
3. Linear Radio Frequency Detector or Station Carrier Shift Indicating Meter (Figure 5).

B. Method 2

1. Audio Signal Generator or Audio Oscillator.
2. Audio Frequency Matching Network.
3. Noise and Distortion Analyzer or suitable detector.
4. Station Modulation Monitor.
5. Vacuum Tube Voltmeter or Volume Level Indicating Meter.



R· F· DETECTOR

Figure 5

Recommended Test Procedure:

1. All station equipment must be adjusted for normal operating conditions. The transmitter must be operating into the station antenna or equivalent artificial antenna. All limiting amplifiers in the system must be by-passed so that they do not limit the input signal being applied to the transmitter for test purposes.
2. The Audio Oscillator is connected into the microphone input terminals of the microphone pre-amplifier through matching network. Connect the Vacuum Tube Voltmeter across the output terminals of the Audio Oscillator.

   A. Method 1

   3. The station's Carrier Shift Meter is used. With carrier on and <u>no</u> modulation applied, adjust the Carrier Shift Meter for a reading of 100. Record as in Table 3.
   4. Apply the various percentages of modulation and record the meter reading in Table 3.
   5. The variations will give the carrier shift directly in percentage. The

tabulated data are then transferred to a graph illustrated by Curve 3.

B. Method 2

3. Connect monitoring output provided in final tuned-circuit of transmitter to radio frequency terminals of Distortion Analyzer or other linear detector. (Figure 5).
4. Maximum radio frequency voltage should not exceed 15 decibels.
5. Connect a high impedance (several megohms) input D-C voltmeter from ground to the output terminal of the detector circuit.
6. Tune the radio frequency control on the detector for maximum voltmeter reading without modulation. Record this value on a suitable form such as Table 4.
7. Increase the attenuator setting on the Audio Oscillator until station modulation monitor indicates 25 percent modulation. Record the new D-C voltmeter reading.

8. Repeat step 6 for 50, 85, and the highest percentage of modulation (not to exceed 100 percent) obtainable.

9. Carrier Shift may now be calculated:

$$\text{Percent Carrier Shift} = \frac{(E_o - E')}{E_o} \times 100 \text{ Percent}$$

E_o = Voltmeter reading without modulation.

E' = Voltmeter reading with modulation.

Record these calculated values.

Of the two methods described, method 1 is preferable from the stand-point of simplicity. These methods may be used to check the accuracy of the station modulation monitor.

PERCENT CARRIER SHIFT				
PERCENT MODULATION	25	50	85	100
READING WITH MODULATION	100	100	98	96
READING WITHOUT MODULATION	100	100	100	100
PERCENT OF CARRIER SHIFT	0	0	-2	-4

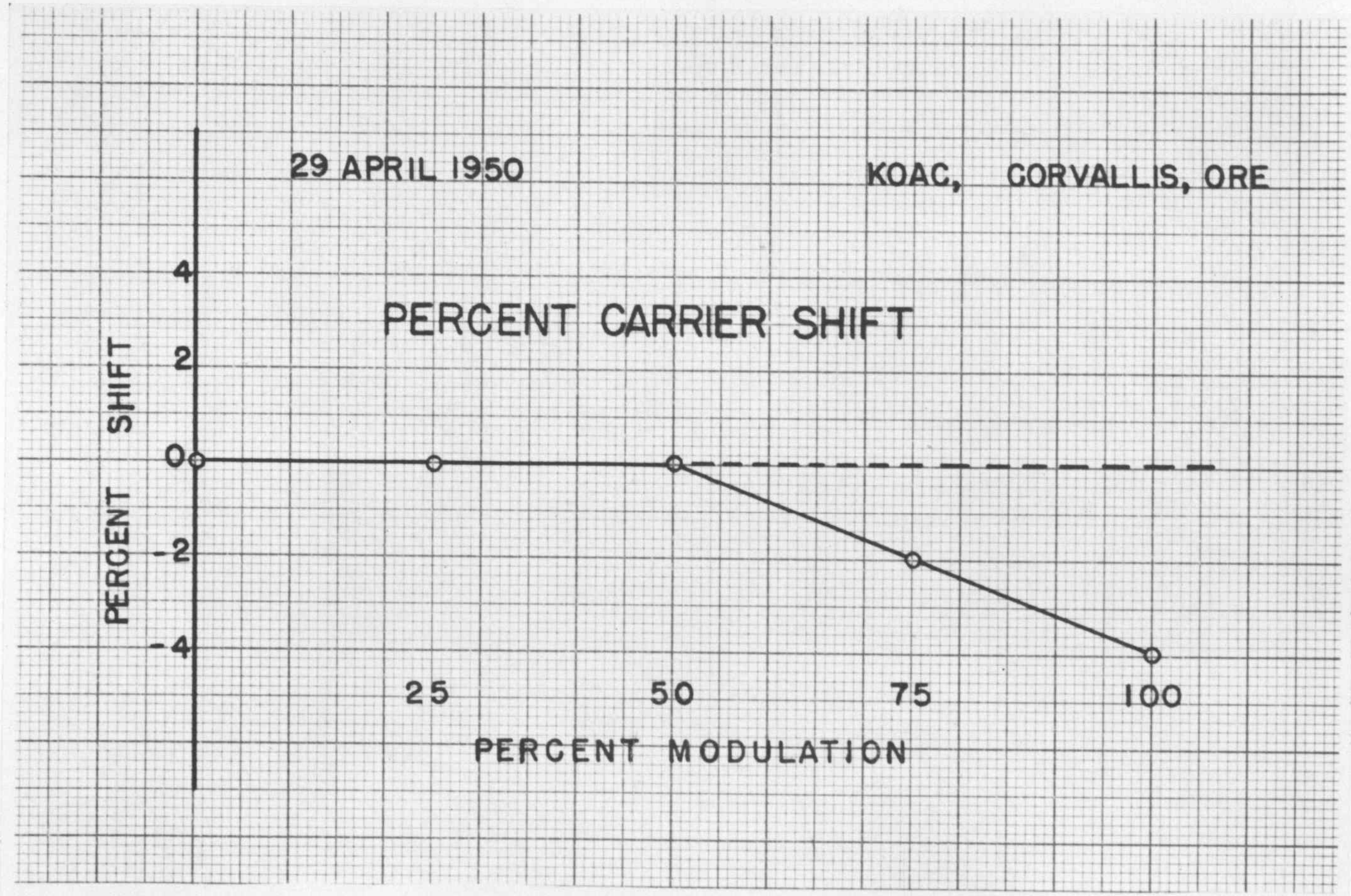
Method 1

Table 3

PERCENT CARRIER SHIFT				
PERCENT MODULATION	25	50	85	100
VOLTMETER READING WITH MODULATION	4.0	4.0	3.92	3.84
VOLTMETER READING WITHOUT MODULATION	4.0	4.0	4.0	4.0
CALCULATED CARRIER SHIFT	0	0	-2	-4

Method 2

Table 4


29 APRIL 1950
KOAC, CORVALLIS, ORE
PERCENT CARRIER SHIFT
PERCENT SHIFT
4
2
0
-2
-4
25
50
75
100
PERCENT MODULATION

Curve 3

Part 4--Recommended Procedure for Obtaining Noise Data:

The required performance specifications have been quoted from the Standards of Good Engineering Practices of the Federal Communications Commission:

> "The carrier hum and extraneous noise (exclusive of microphone and studio noise) (unweighted r.s.s.) is at least 50 decibels below 100 percent modulation for the frequency band of 150 to 5000 cycles and at least 40 decibels down outside this range."

The ear is a nonlinear system that responds logarithmically. The frequency range of the average normal ear is from 20 to 20,000 cycles. The reproduction of speech with perfect fidelity requires a frequency range from 100 to 8000 cycles, that for orchestral music from 40 to 14,000 cycles. However, the frequency range from 150 to 5000 cycles is the most general response range of the ear. In view of these and other pertinate facts, the Engineering Division of the Federal Communications Commission has issued the specifications that require the noise level to be at least 50 decibels down from the 100 percent modulation level throughout the frequency band from

150 to 5000 cycles, and at least 40 decibels down at all other frequencies.

A method of weighting noise utilizing the Noise and Distortion Analyzer is simple, accurate, and fast. If the noise level over the total audio frequency range at the transmitter output terminals is not 50 decibels down, it is desirable to determine the nature and cause of this undesirable noise level.

1. Power supply noise.

   Determine if the high noise level is due to fundamental or harmonic frequencies of the power supply. This may be accomplished in the same manner in which the distortion measurements were made. By excluding these frequencies one by one (60, 120, 180, 360, etc.), the undesirable frequency may be determined. In general, the large part of the interference due to power supplies, may be corrected by proper filtering.

2. Circuit Noise.

   If the undesirable noise is not due to the power supply and the noise components are fairly evenly distributed throughout the entire audio frequency band, the cause may be found in the audio circuits. Audio circuit noise may be divided into three general classifications:

a. Thermal-Agitation Noise

All electrical conductors contain free electrons that are in continuous random motion. At any instant, it can be expected that by pure chance more electrons will be moving in one direction than in another, with the result that a voltage will be developed across the terminals of the conductor if it is open-circuited, or a current will be delivered to any connected circuit. This voltage (or current) varies in a random manner and so represents noise energy distributed throughout the frequency spectrum from the very lowest frequencies to frequencies well above the highest used in radio work. This effect is commonly referred to as "thermal-agitation noise", since the motion of the electrons results from thermal action.

b. Noise in Resistors

Noise in resistors is due to the random motion of electrons within them. The noise energy is proportional to the resistance, the absolute temperature, and the frequency band width over which the noise is observed and is independent of the material of which the resistor is made. The noise energy increases with absolute temperature because the molecular agitation is proportional to this. The noise is probably made up of extremely short and sharp pulses resulting from the impact of the electrons with the molecules. These pulses are probably so short and sharp that they are made up of a continuous distribution of frequency components of equal amplitude up to the highest frequencies in use today. As a result, the noise energy is uniformly distributed over the useful r-f spectrum.

c. Tube Noise

Random noise similar in character to that produced in a resistance is generated in tubes as a result of irregularities in electron flow. Tube noise can be divided into the following classes:

(1) Shot effect, representing random variations in the rate of emission of electrons from the cathode;

(2) Partition noise, arising from chance variations in the division of current between two or more positive electrodes;

(3) Induced grid noise, produced as a result of variations in the electron stream passing adjacent to a grid;

(4) Gas noise, generated by random variations in the rate of production of ions by collision;

(5) Secondary emission noise, arising from random variations in the rate of production of secondary electrons;

(6) Flicker effect, a low-frequency variation in emission that occurs with oxide-coated cathodes;

(7) Faulty tube construction.

Shot effect in the presence of space charge, partition noise, and induced grid noise, are the principal sources of tube noise that must be considered in ordinary radio work. Circuit noise may be eliminated by changing circuit components and tubes until the noise level is reduced to an acceptable level. The first audio amplifier generally contributes the greatest proportion of the undesirable noise, and it is recommended that this unit be the first to be examined when inspecting for undesirable circuit noise.

3. Regenerative Noise.

   If the overall audio response curve indicates regeneration effects (sharp audio peaks) at either the low or high end of the frequency band, then the circuit noise may be regenerated to undesirable levels. The best solution of this problem is the proper adjustment of the feed-back loop circuit to eliminate the existing positive feed-back condition.

Equipment required for testing:

1. Audio Signal Generator or Audio Oscillator.
2. Matching audio network.
3. Noise and Distortion Analyzer.
4. Station Modulation Monitor.
5. Vacuum Tube Voltmeter.

Figure 2 illustrates the arrangement of the equipment for performance measurements.

Recommended Test Procedure:

1. All station equipment must be adjusted for normal operating conditions. The transmitter must be operating into the regular station antenna or the equivalent artificial antenna. All limiting amplifiers in the system must be by-passed so that they do not limit the signal applied to the transmitter for test purposes.
2. The Audio Oscillator is connected through the matching network to the microphone input terminals of the microphone pre-amplifier. The Vacuum Tube Voltmeter is connected in parallel across the oscillator output terminals.
3. The radio frequency terminals of the Noise and Distortion Analyzer are connected into the monitoring output provided in the final tuned circuit of the transmitter. An alternate method of connection is the use of the feed-back loop to the station's modulation monitor. The Noise and Distortion Analyzer compares directly the noise level when no signal was applied to the level occurring at 100 percent modulation. The instrument is adjusted for 0 decibels indication at 100 percent modulation.

The signal generator is then removed from the input terminals of the microphone preamplifier and replaced with a wirewound resistor of the proper terminating value.
The instruments meter will now indicate the noise level below 100 percent modulation directly.

PROPAGATION STANDARDS AND MEASUREMENTS

The history of propagation studies has been covered briefly including the factors which affect the propagation of the broadcast frequencies. The features which distinguish the broadcast band from the other types of service and the types of broadcast service are briefly outlined.

The material has been presented in the following order:

1. History of radio wave propagation.
2. Factors affecting propagation.
3. Broadcast band requirements and types of broadcast service.
4. Extracts from the Standards of Good Engineering Practices including the explanation of the various types of channel allotment.
5. Comparison of one channel each in the three general types of channels.
6. Field Intensity measurement methods.
7. Antenna Impedance measurement methods.

Radio Wave Propagation:

The history of radio wave propagation began with the equations derived by the British mathematical physicist, James Maxwell, in 1865 and 1873. In these equations Maxwell worked out the fundamental laws governing the propagation of electro-magnetic waves through space or through any medium. He determined that electro-magnetic phenomena were essentially wave phenomena and showed that light itself was an electro-magnetic wave. In 1888 Heinrich Hertz demonstrated the existance of waves which were undeniably magnetic. Hertz verified the theories of Maxwell and established the close relationship between the waves he generated and the light waves. He proved the laws of wave propagation. As a result of these experiments, Hertz arrived at the conclusion that there must be a special medium other than air in which these waves travel and that this medium transmitted waves of light. Thus, originated the theory of the existance of an all permeating medium which scientists called the "hypothetical ether" and which eventually led to the identification of radio waves as "ether waves". As propagation theory developed, the reference to ether waves gradually changed to electro-mangetic waves since scientists now question the existance of ether as an all permeating medium. Other scientists carried on the experimental work and in 1895 Marconi produced an apparatus that was capable of communication over a distance by means of radio waves. Radio-telephony was made possible in 1920 by the creation of the three element vacuum tube by Dr. Lee DeForest. Radio communication takes place by means of electrical energy in electro-magnetic form which is radiated from the transmitting antenna and propagated through free space with the velocity of light.

The following factors affect propagation of all Radio Frequency waves:

1. Conductivity of earth along propagation path.
2. Dielectric constant of earth along propagation path.
3. Conducting layers called the ionosphere in the upper atmosphere.
4. Earth's magnetic field.
5. Refractive index of the atmosphere.
6. Absorption of the atmosphere.
7. Diffraction.
8. Reflection.

Not all factors are independent; reflection at the earth's surface involves earth conductivity and dielectric constant for the region of reflection.

The effect of the above enumerated factors depends mostly upon the frequency. Some factors vary on a daily, seasonal, and year-by-year cycle. The effectiveness and the height of the various layers of the ionosphere have been directly related to the sunspot cycle.

Frequencies in the range from 550 kilocycles to 1600 kilocycles are used primarily for broadcast purposes, where the objective is to deliver to the receiver a signal which is strong enough to override all ordinary interference and which is as free as possible from fading, distortion, and other factors detrimental to propagation. This is in contrast with most other circumstances, where the primary objective is usually to deliver an understandable but not necessarily interference-free and distortionless signal to the receiver.

Daytime broadcasting depends entirely upon ground-wave propagation, since sky waves at broadcast frequencies are completely absorbed during the daytime. The strength of broadcast signals in the daytime, accordingly, depending upon the earth's conductivity and the carrier frequency. In general, the signal strength dies out more rapidly the lower the earth's conductivity and the higher the frequency of the signal.

The region about a broadcast transmitting station in which the signal strength in the daytime is adequate to override ordinary interference is termed the daytime primary service area. The field strength required depends upon the noise level and will be high in built-up areas and quite low in rural areas.

The actual area that receives primary coverage in the daytime depends not only upon the required field strength, but also upon the transmitter power, the directivity of the transmitting antenna system, the earth's conductivity, and the carrier frequency. It is apparent that even at high power, with the highest earth conductivities commonly encountered, and at the lowest frequencies available for broadcast use, primary coverage typically does not exceed 50 to 100 miles. At the higher broadcast frequencies, or with low earth conductivity, the distance over which primary coverage is maintained is much less.

The region outside of that receiving primary coverage, where the field strength is sufficient to give a useful signal but is still not sufficient to override interference fully, is said to receive secondary coverage. The region of daytime secondary coverage is determined by the same factors as the primary coverage, but with high powers, high earth conductivity, and the lower broadcast frequencies it may extend to a distance of several hundred miles.

At night, a sky wave of considerable intensity is returned to earth by the ionosphere. The resulting situation that exists at night consists of three distinctive zones. Near the transmitter, the sky wave is relatively weak compared with the ground wave and the latter predominates. As the distance from the transmitter is increased, the ground wave becomes attenuated, whereas the sky wave becomes stronger, thus making the ground and sky waves of approximately equal strength. At still greater distances, the sky wave tends to become still stronger and to maintain a relatively high and constant signal strength for considerable distances.

The reason for this behavior of the sky wave lies in the fact that, as the distance from the transmitter is increased, the sky wave that reaches the receiver represents energy radiated from increasingly lower vertical angles, and the characteristics of broadcast antennas are such that the radiated energy is greater, the lower the angle above the horizon. Furthermore, in view of the fact that the sky wave commonly reaches a height of about 60 miles at broadcast frequencies, the sky wave must travel nearly as far to reach receivers near the transmitter as receivers a few hundred miles away.

The sky-wave attenuation and path at broadcast frequencies are to a first approximation independent of frequency, so that the distant nighttime reception, which depends upon the sky wave, is about equally satisfactory for all frequencies. This is in contrast with the daytime (or ground-wave coverage) for which the low frequencies are the most effective.

In recognition of the foregoing information the Federal Communications Commission has set up comprehensive regulations governing the use of the various channels by the licensees. The following are extracts from the Standards of Good Engineering Practices as set forth by the Federal Communications Commission:

"A. Operation--In addition to the specific requirements of the rules governing standard broadcast stations, the following operating requirements shall be observed:

1. In the event interference is caused to other stations by modulating frequencies in excess of 7500 cycles or spurious emissions, including radio frequency harmonics and audio frequency harmonics outside the band plus or minus 7500 cycles of the authorized carrier frequency, the licensee shall install equipment or make adjustments which limit the emissions to within this band or to such an extent above 7500 cycles as to reduce the interference to where it is no longer objectionable.
2. The operating power shall be maintained within the limits of 5 percent above and 10 percent below the authorized operating power and shall be maintained as near as practicable to the authorized operating power.
3. Licensees of broadcast stations employing directional antenna systems shall maintain

the ratio of the currents in the elements of the array within 5 percent of that specified by the terms of the license or other instrument of authorization."

"Objectional interference from a station on an adjacent channel shall be considered to exist to a station when, at the normal protected contour of a desired station, the field intensity of the groundwave of an undesired station operating on an adjacent channel exceeds a value specified in Table V.

"Objectional interference from a station on the same channel shall be considered to exist to a station when, at the field intensity contour specified in Table IV with respect to the class to which the station belongs, the field intensity of an interfering station operating on the same channel exceeds for 10 percent or more of the time the value of the permissible interferring signal set forth opposite such class in Table IV."

Table IV
Permissible Interference Signal
For Broadcast Stations

Class of Station	Class of Channel	Permissible interfering signal on the same channel	
		Day	Night
Ia	Clear	5 uv/m	Not duplicated
Ib	Clear	5 uv/m	25 uv/m
II	Clear	25 uv/m	125 uv/m
III-A	Regional	25 uv/m	125 uv/m
III-B	Regional	25 uv/m	200 uv/m
IV	Local	25 uv/m	200 uv/m

Table V
Interference Ratios

Frequency separation of desired to undesired signals	Desired groundwave to		Desired 50% sky wave to undesired 10% sky wave
	undesired groundwave	undesired 10% sky wave	
0 kc	20:1	20:1	20:1
10 kc	1:1	1:5	---
20 kc	1:30	---	---

INTERFERENCE TABLES

From The

STANDARDS OF GOOD ENGINEERING PRACTICES

The Rules and Regulations of Good Engineering Practices as set forth by the Federal Communications Commission establishes three classes of channel priority--the Clear channel, Regional channel, and the Local channel.

<u>The Clear Channel</u>:

Class 1 stations operate with powers of not less than 10 or more than 50 kilowatts. These stations are designed to render primary and secondary service over an extended area and at relatively long distance. Their primary service areas are kept free from objectional interference from other stations on the same and adjacent channels. Their secondary service areas are kept free from objectional interference from stations on the same channel. Class 1 stations are protected to 100 microvolts per meter groundwave contour on the same channel and to 500 microvolts per meter groundwave contour from adjacent channel stations for both day and night time operations.

Class 2 stations are secondary stations on clear channels with powers of not less than 0.25 kilowatts or more than 50 kilowatts. These stations are required to use a directional antenna or other means to avoid causing interference within the normally protected service area of other Class 1 or Class 2 stations. These stations normally render primary service only--the area of which depends upon the geographical location, power, and frequency. There is mutual protection to 2500 microvolts per meter groundwave contours for stations of this class.

<u>The Regional Channel</u>:

Class 3 stations operate on regional channels and normally render primary service to the metropolitan district and rural area contained there-in and continguous there-to. These are divided into two classes--Class 3-A stations and Class 3-B stations.

Class 3-A stations operate with powers of not less than 1 kilowatt or more than 5 kilowatts. These are protected to 2500 microvolts per meter groundwave contour, nighttime, and to 500 microvolts per meter groundwave contour, daytime.

Class 3-B stations operate with powers not less than 0.5 kilowatt or more than 1 kilowatt, nighttime, and 5 kilowatts, daytime. They are protected to 4000 microvolts per meter groundwave contour, nighttime, and to 500 microvolts per meter groundwave contour, daytime.

The Local Channel:

Class 4 stations operate on local channels normally rendering primary service only to a city or town and the suburban and rural areas continguous there to with powers not less than 0.1 kilowatt or more than 0.25 kilowatt. These are protected to 500 microvolts per meter groundwave contour, daytime, and the recommended protection of 4000 microvolts per meter groundwave contour, nighttime.

The Class of any station is determined by the channel assignment, the power, and the field intensity contour to which it renders service free from interference from other stations as determined by the Standards of Good Engineering Practices.

Channel Service Comparison:

The following information has been obtained from a comparison of the population covered by the various types of channel service.

In the Standard Broadcast band from 540 kilocycles to 1600 kilocycles, inclusive, there are 107 ten kilocycles channels established. These are divided between the three classes previously described as follows:

1. Clear Channels:

United States stations	46 channels
Foreign American stations	14 channels
Total Clear Channels	60 channels

2. Regional Channels:

United States stations	41 channels

3. Local Channels:

United States stations	6 channels

As of 6 April 1950, there were 2118 standard A M stations operating "on the air".

On one typical channel in each class the following was true as of 1 January 1950:

1. Clear Channel, 700 kilocycles -- 1 station operating
2. Regional Channel, 590 kilocycles--15 stations operating
3. Local Channel, 1230 kilocycles -- 148 stations operating

For daytime operation only a comparison of the population coverage of each of these channels to the total population of the United States gives the following results:

A. Population of the United States as given by the 1940 census was 131,669,275.

B. Population covered by each class of channel based upon the 1940 census figures:

1.	Clear channel	28,679,000
2.	Regional channel	25,684,000
3.	Local channel	8,031,900

C. Ratio of coverage

1.	Clear channel	21.8 percent
2.	Regional channel	19.5 percent
3.	Local channel	6.2 percent

Part 5--Field Intensity Measurements

The required performance specifications have been quoted from the Standards of Good Engineering Practices of the Federal Communications Commission:

> "Beginning as near to the antenna as possible without including the induction field and to provide for the fact that a broadcast antenna not being a point source of radiation (not less than 1 wave length or 5 times the vertical height in the case of a single element, i.e., non directional antenna or 10 times the spacing between the elements of a directional antenna), measurements shall be made on 8 or more radials, at intervals of approximately 1/10 mile up to 2 miles from the antennas, at intervals of approximately 1/2 mile from 2 miles to 6 miles from the antenna, at intervals of 2 miles from 6 miles to 15 or 20 miles from the antenna, and a few additional measurements if needed at greater distances from the antenna."

For directional antennas the following is required in addition to the foregoing:

> "However, when more complicated patterns are involved, that is, patterns having several

sharp lobes or nulls, measurements shall be taken along as many additional radials as necessary to establish the pattern definitely."

Also, it is further required for all types of antenna systems that the harmonic content shall be not greater than 5 percent of the total.

Equipment required:

1. Transmitter and antenna systems operating.
2. An approved field intensity meter.

Precautions to observe:

1. Output power of station must be maintained at the licensed power as determined by the direct method--

   Antenna Resistance X $(\text{Antenna Current})^2$

2. Shadows and reflections due to terrain or large structures.
3. Interference from other stations--measurements should be taken during the periods of least interference.
4. Proximity of meter to overhead lines and to vehicles, etc. should be avoided as much as possible.

5. Make measurements as prescribed in the individual instruction book for the field intensity meter used.

Recommended Test Procedure:

1. Determine where to go, how far to go, and how to get there. Normally, in addition to the 8 radials required for non directional arrays, radials are also required in the direction of all nulls of directional arrays. Try to arrange the measurements so that you can travel out on one radial and return on another one. At least 20 readings should be taken on each main radial.
2. Adjust the output power to correspond to the licensed power and make arrangements to see that it is maintained constant.
3. Proceed to the first point selected; mark and number said point on your map. Make your field intensity measurement and record the data in a form such as Table 5. Also, record description of the point selected, point number, time of measurement, and any other information deemed important.

4. Proceed to the next point and repeat the process again, recording all pertinent data.
5. When taking data in nulls, the following procedure is recommended:
   a. Measure field intensity in the direction from the array.
   b. Swing the receiving loop around in a 360 degree circle and observe the field intensity meter.
   c. Record the maximum field intensity meter reading and the azimuth it is received from (if different from that of the array proper). Refer to Table 6, Curve 4, and Figure 6.
6. Having secured all of the field readings, these data should be plotted for each radial.

   Method A:

   Using log-log coordinate paper, plot the field intensity as ordinate and the distance as absicissa.

   Method B:

   Using semi-log coordinate paper, plot the field intensity <u>times</u> the distance as ordinate on the log scale and the distance as absicissa on the linear scale.

Regardless of the method used, the proper curve to be drawn through the points plotted shall be determined by comparison with the theoretical curves given in the "Standards of Good Engineering Practices Concerning Standard Broadcast Stations".

After comparing theoretical curves until the one which matches most closely is found, draw it on the curve sheet as well as the inverse distance curve corresponding to that curve. The field intensity at one mile for the particular radial must be the ordinate on the inverse distance curve at one mile. Refer to Curve 5.

After all radials have been plotted in this manner, a curve shall be plotted on polar coordinate paper from the field intensities obtained which will give the inverse distance field pattern at one mile. Refer to Curve 6. The radius of a circle with an area equal to the area of this pattern is the effective field of the array.

Station KOAC. Date Nov. 7, 1947.

FIELD INTENSITY DATA

(Meter Serial No. RCA 547)

Frequency 550.0 kc. By GSF.

POINT No.	DIST. (miles)	DESCRIPTION	FREQ. MEAS.	TIME	F I (mv/m)	ATTEN. CONST.	REMARKS
1	0.9	Radial at Azimuth angle of 295 degrees from Array.	550.0	2:05 p	340	100	
2	1.5			2:15 p	220	100	
3	1.7			2:30 p	170	100	
4	1.9			2:45 p	165	100	
5	2.2			3:00 p	115	100	
6	3.0			3:20 p	75	10	
7	4.6			3:40 p	47	10	
8	10.4			4:15 p	13	10	
9	10.5			4:20 p	10.5	10	
10	12.8			4:50 p	9.5	1	
11	15.4			5:15 p	7.3	1	

Table 5

Station KERG. Date Nov. 4, 1949.

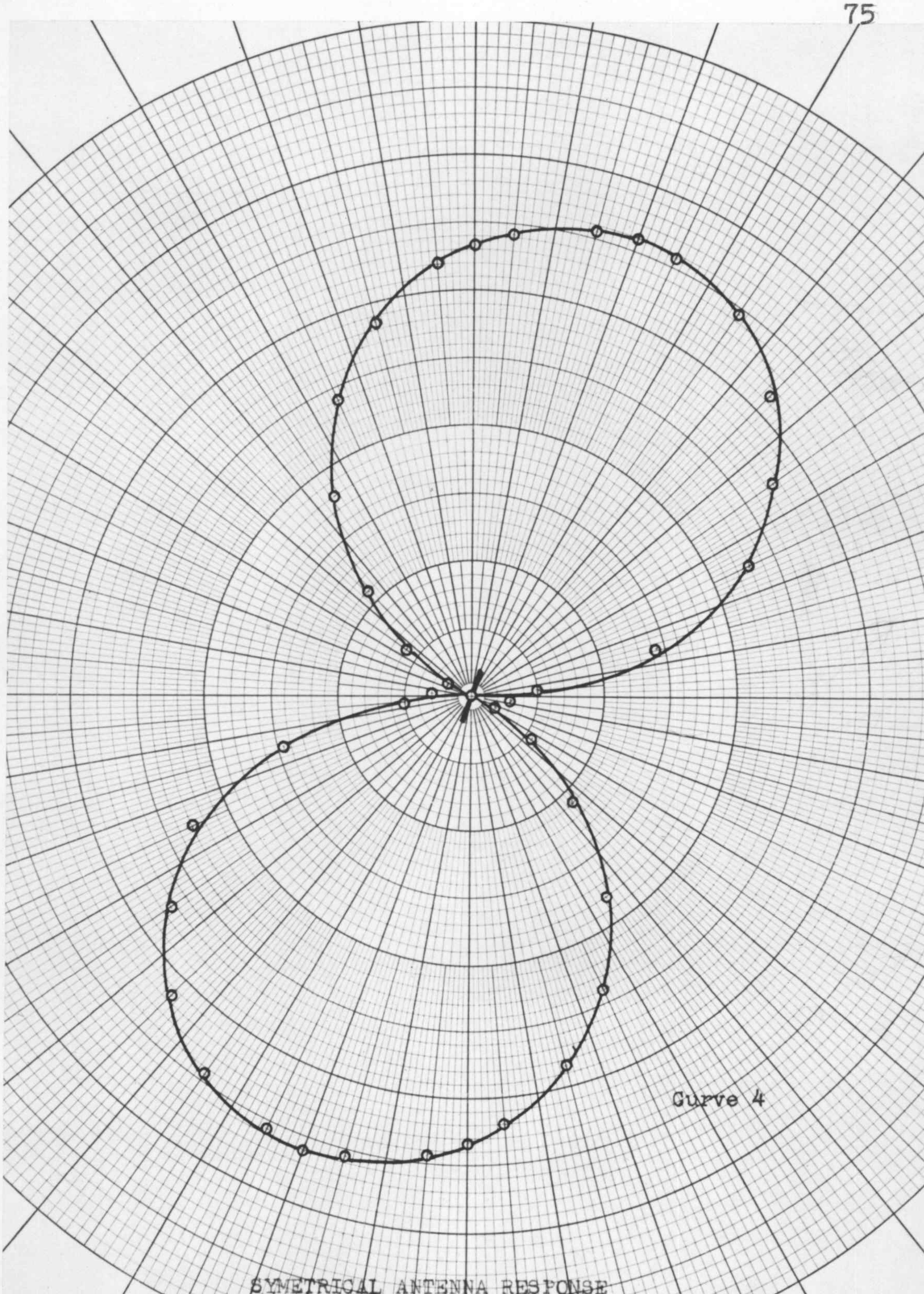
FIELD INTENSITY DATA

(Meter Serial No. RCA 648)

Carrier Frequency 1280 kc. By CA, ALH.

POINT No.	DIST. (miles)	DESCRIPTION	FREQ. MEAS.	TIME	F I (mv/m)	ATTEN. CONST.	REMARKS
							Azimuth angle of FI meter loop.
2 a	1.0	Monitoring point at one mile in the tight null on the 35 degree azimuth.	1280	7:15 p	6.65	10	195
b					6.85	10	200
c					7.1	10	210
d					7.2	10	215
e					7.16	10	220
f					6.9	10	230
g					6.3	10	240
h					6.4	10	190
i					5.7	10	180

Table 6



SYMETRICAL ANTENNA RESPONSE

Proof of no antenna effect on the FI Meter Loop

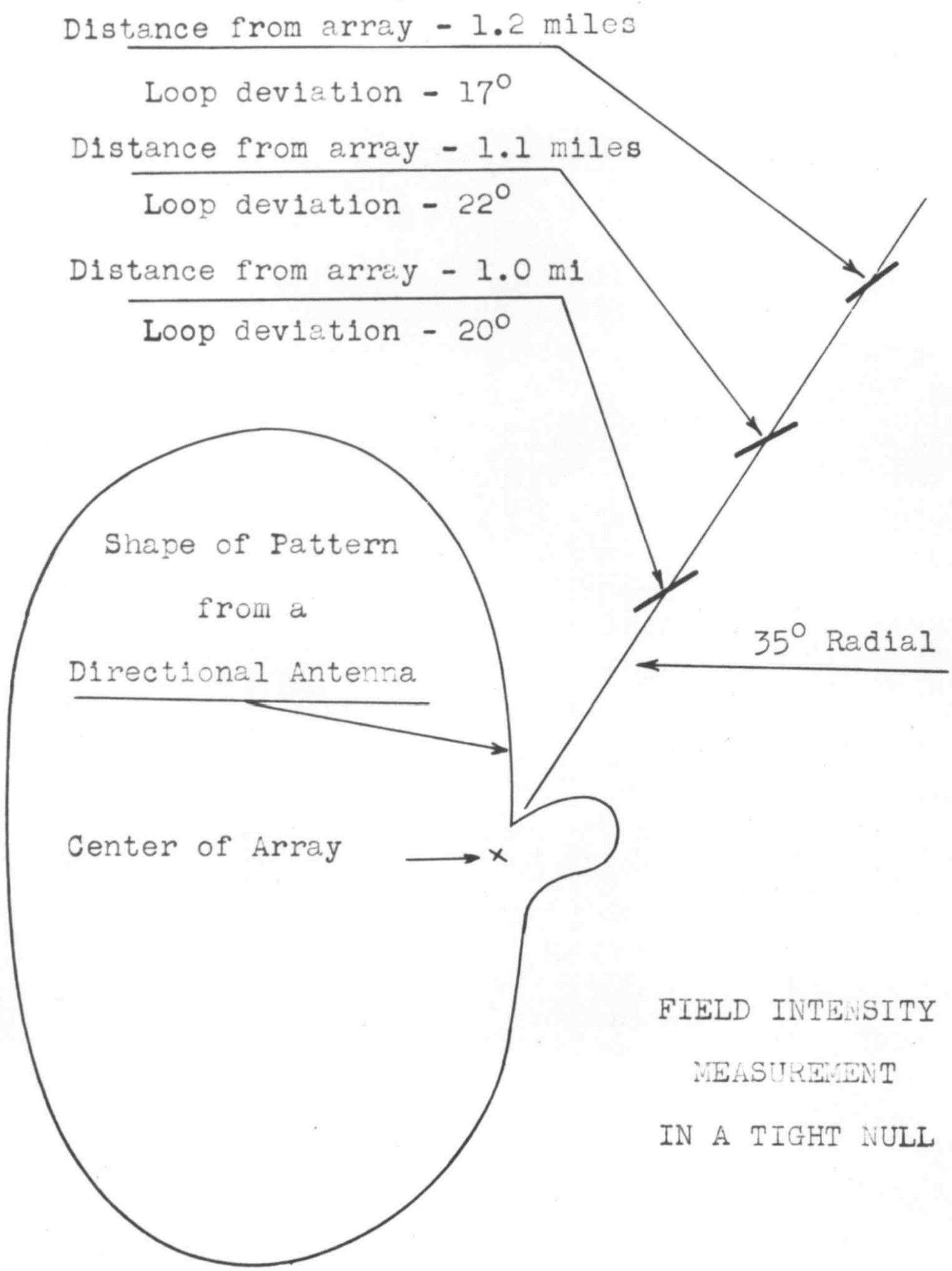
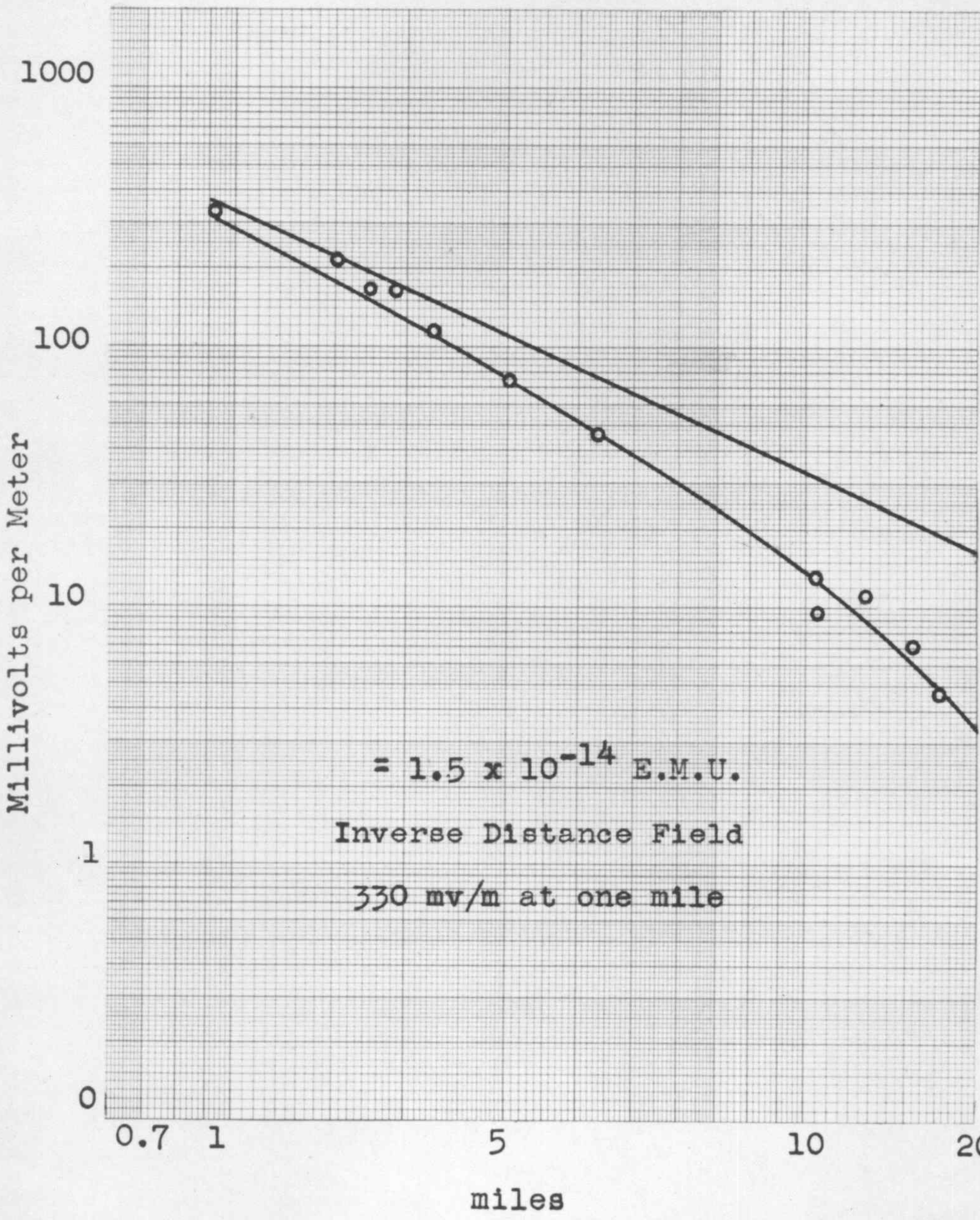

Distance from array - 1.2 miles
Loop deviation - 17°
Distance from array - 1.1 miles
Loop deviation - 22°
Distance from array - 1.0 mi
Loop deviation - 20°
Shape of Pattern
from a
Directional Antenna
35° Radial
Center of Array
FIELD INTENSITY
MEASUREMENT
IN A TIGHT NULL

Figure 6

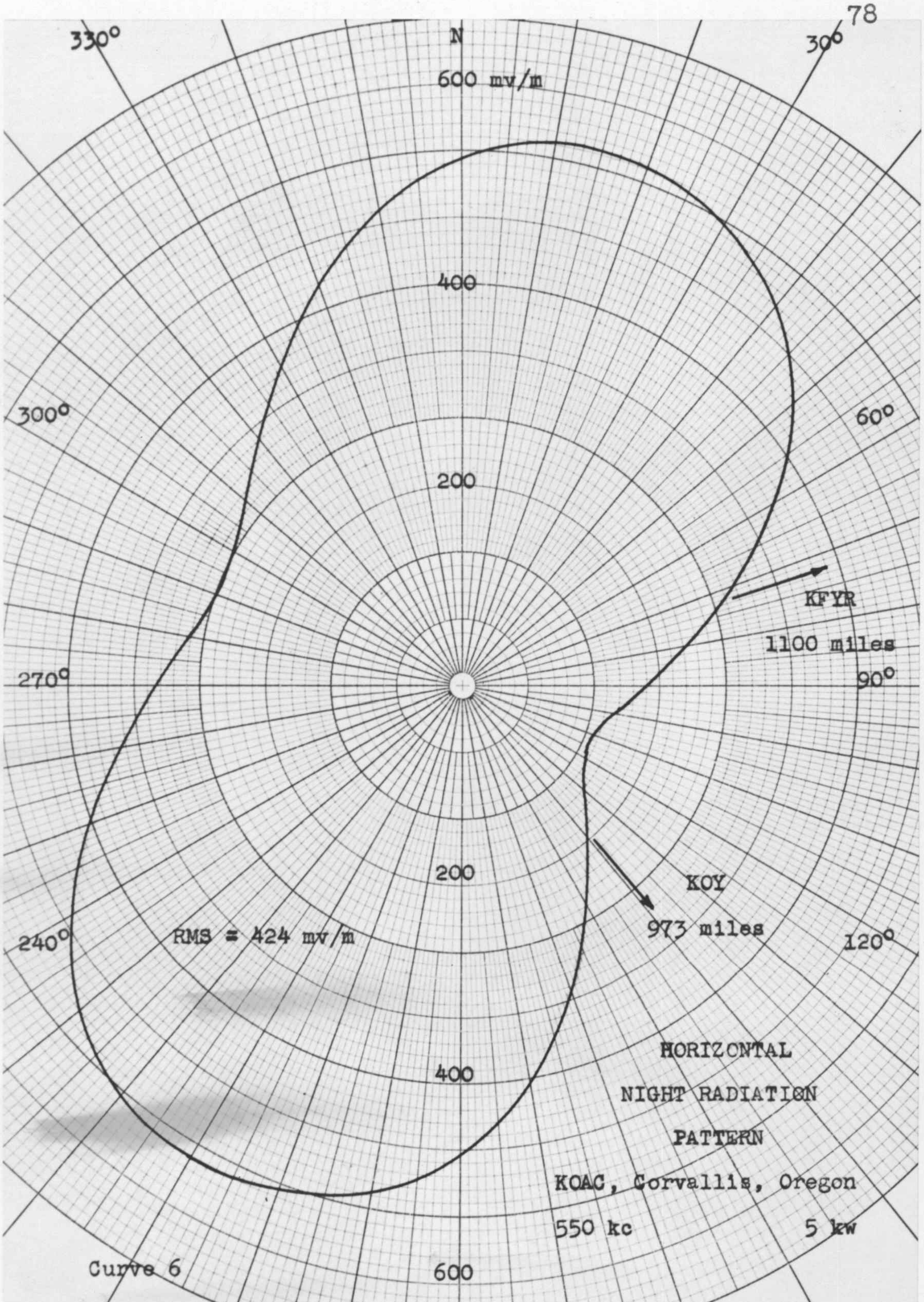
FIELD INTENSITY - DISTANCE CURVE

Radial - 295°

KOAC, Corvallis, Oregon



Curve 5


N
330°
30°
600 mv/m
400
200
300°
60°
KFYR
1100 miles
270°
90°
200
KOY
973 miles
240°
RMS = 424 mv/m
120°
HORIZONTAL
NIGHT RADIATION
PATTERN
400
KOAC, Corvallis, Oregon
550 kc
5 kw
Curve 6
600
210°
180°
150°

Part 6--Antenna Impedance Measurements

The required performance specifications have been quoted from the Standards of Good Engineering Practices of the Federal Communications Commission:

"Antenna Resistance Measurements:

a. Antenna resistance at operating frequency.

b. Description of method employed.

c. Tabulation of complete data.

d. Curve showing antenna resistance versus frequency."

Antenna Resistance measurements are necessary to determine the proper matching (or tuning) of single elements and multi-element arrays. They are also necessary for the direct power measurement method of determining transmitted power. These measurements also determine the transmitter efficiency.

Precautions to be observed before attempting to make antenna impedance measurements include:

1. All shunting capacitance and lighting circuit shunts to the antenna must be removed. Tower must be completely isolated from all circuits.
2. Adequate grounding practices of test equipment must be observed.

3. Lightning arrestors (if any) should be mounted horizontally and must have the proper settings.

Equipment required:

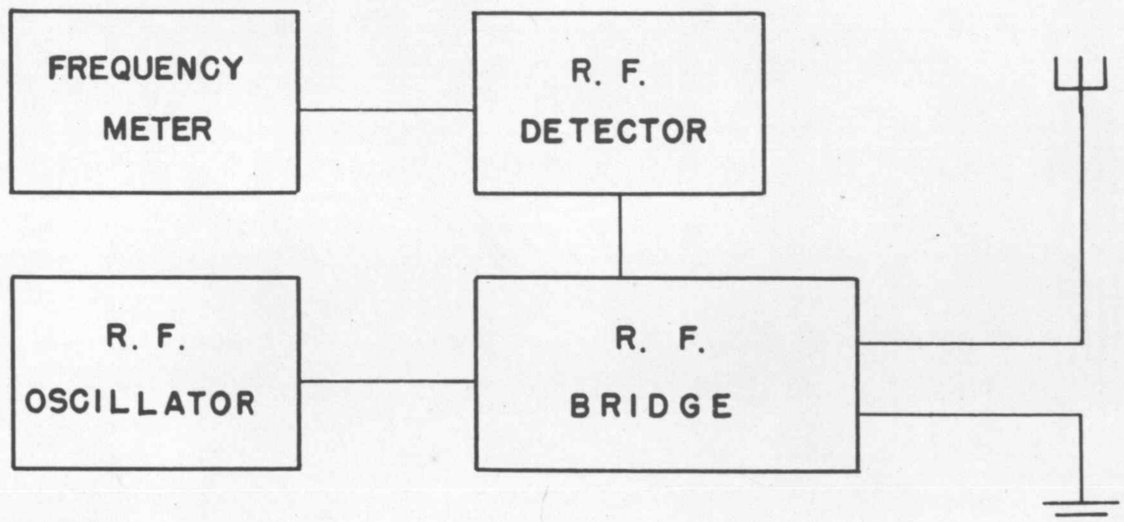
1. Radio frequency bridge.
2. Radio frequency signal generator.
3. Frequency measuring device (Navy Model LM or Army BC-221 Frequency Meters are applicable)
4. Bridge detector (radio receiver).

Figure 7 illustrates the arrangement of equipment to measure Antenna Resistance.

Recommended Test Procedure:

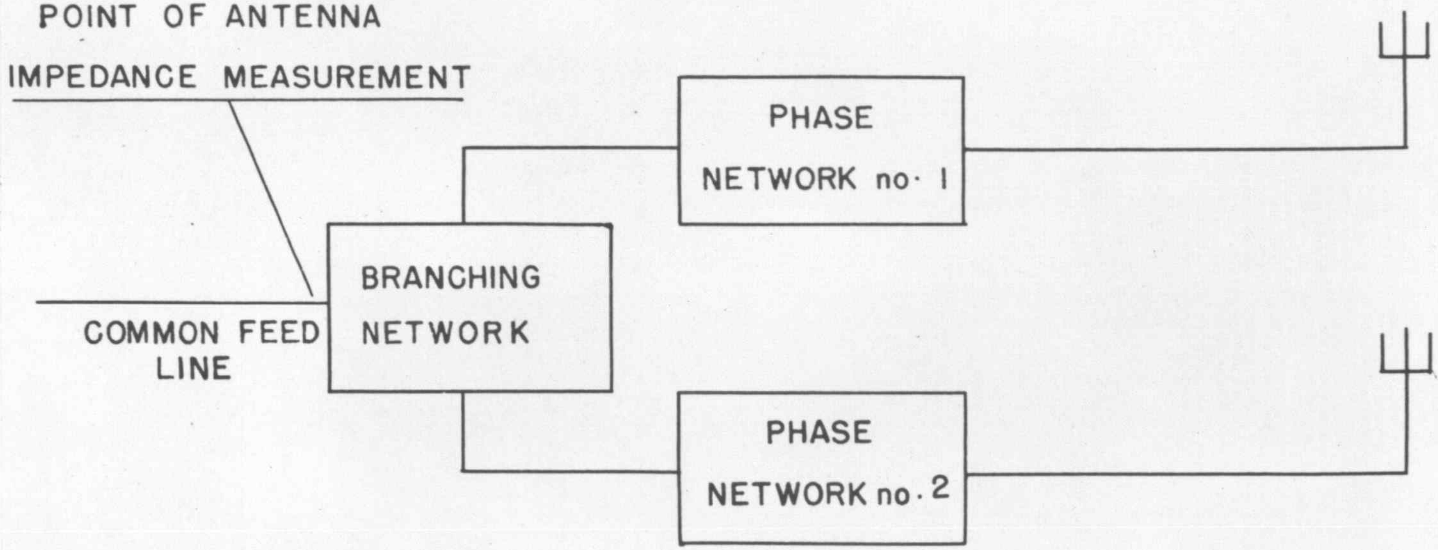
1. Equipment is to be arranged as illustrated in Figure 7.
2. Measurements are taken at the isolated tower with all other circuits, shunts, etc. removed. In multi-element arrays the reactance will be influenced by the presence of the other towers, but the resistive component will not be affected. Figure 8 illustrates the point of measurement for directional antennas.

Figure 7



METHOD OF ANTENNA RESISTANCE MEASUREMENT

Figure 8



IMPEDENCE MEASURING POINT FOR
A DIRECTIONAL ANTENNA

3. The radio frequency bridge is arranged to measure the resistive and reactive components of the antenna measurements with direct readings of resistance. Values of resistance are read directly from the bridge dial when a sharp balance of resistance and reactance components of the antenna is obtained at each frequency. Reactance values are read directly from the bridge and are corrected by dividing by the frequency (in megacycles) at which the measurement is made.
4. All measurements should be made when the near by channels are essentially free from interfering signals. Frequency calibration may be obtained from the station oscillator.
5. Measurements should be made from 30 kilocycles above and to 30 kilocycles below the operating frequency. These measurements are made by the use of the frequency measuring device for frequency calibration. The signal generator is adjusted to a sub-audible beat with the frequency meter after the frequency meter dial has been set to the desired frequency.

6. The data should be recorded on a form such as illustrated in Table 7 and plotted as in Curve 7.
7. For multi-element arrays the data are taken at the point of common radio frequency input. The data should be recorded and plotted in the same manner as (6) above.
8. A list of the following should be compiled and made a part of the measurement:
   a. Manufacturer's name and the type of instrument.
   b. Serial Number of the instruments.
   c. Manufacturer of the instruments.
   d. Manufacturer's rated accuracy of the instruments.
   e. The date, accuracy, and by whom each instrument was last calibrated.

TABLE OF ANTENNA IMPEDANCE DATA

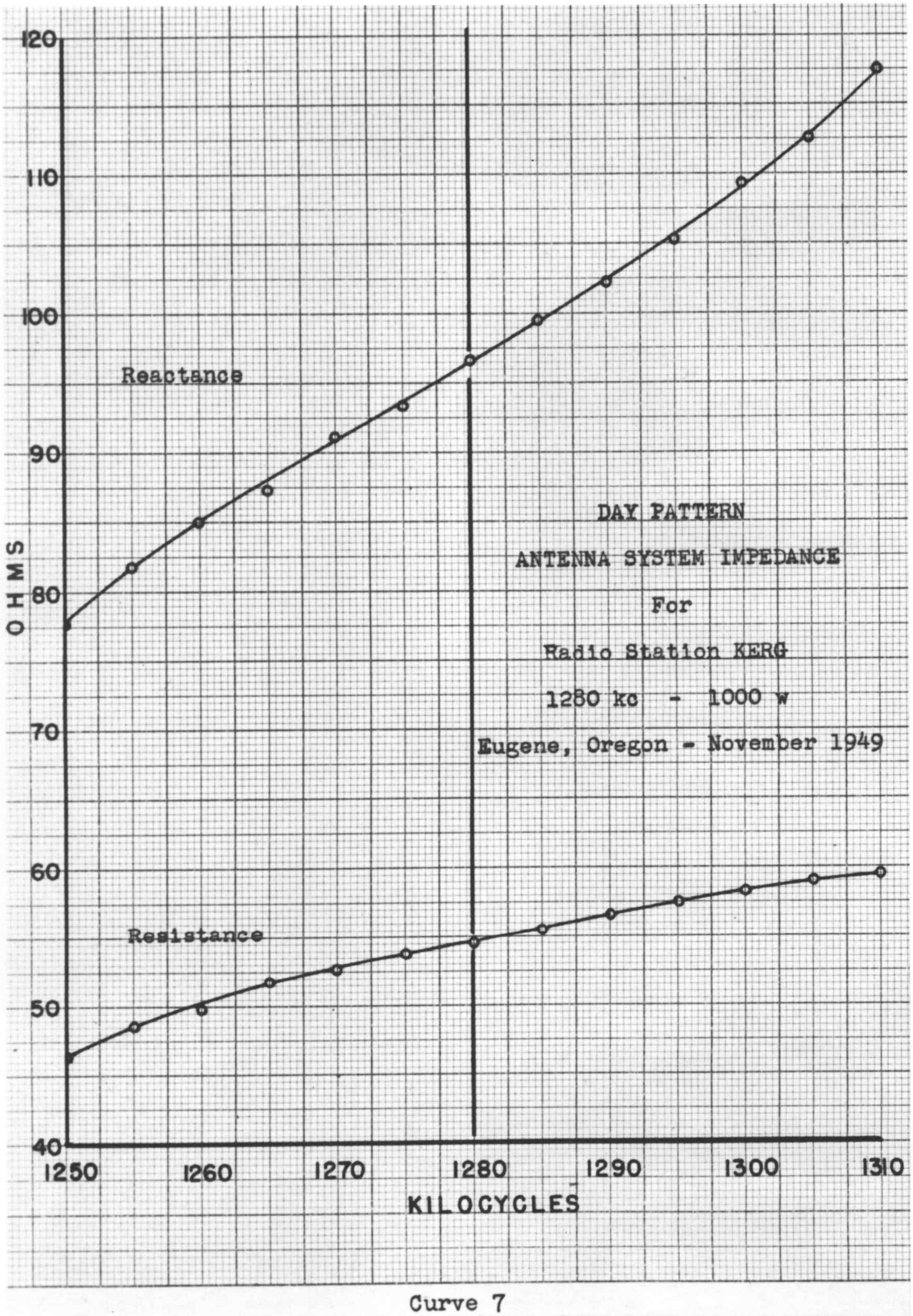
DAY PATTERN

Station KERG. Date Nov. 1949.

Frequency 1280 kc. By EM, ALH.

FREQUENCY (kc)	RESISTANCE (ohm)	REACTANCE CORRECTED (ohm)
1250	46.5	77.7
1255	48.7	81.7
1260	49.9	85.1
1265	51.9	87.2
1270	52.7	91.4
1275	53.6	93.3
1280	54.5	96.8
1285	55.6	99.5
1290	56.4	102.2
1295	57.3	105.5
1300	58.2	109.3
1305	58.9	112.6
1310	59.6	117.5

Table 7


120
110
100
90
80
70
60
50
40
OHMS
Reactance
Resistance
DAY PATTERN
ANTENNA SYSTEM IMPEDANCE
For
Radio Station KERG
1280 kc - 1000 w
Eugene, Oregon - November 1949
1250
1260
1270
1280
1290
1300
1310
KILOCYCLES

Curve 7

CONCLUSIONS:

This paper has presented the collected and compiled information covering the various performance measurements as required by the Federal Communications Commission.

A recommended method of testing has been set forth for each of the performance measurements required.

For each of the recommended measurements the following items have been considered:

1. Simplicity.
2. Accuracy.
3. Methodical arrangement.
4. Dependability.
5. Practicability.

It is felt that these recommendations will alleviate the confusion that results because of the several possible test methods.

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