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Report on

A Uni-Control System for Sound Listening and Echo Ranging

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by

W. W. Wiseman

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NAVAL RESEARCH LABORATORY

BELLEVUE, D.C.

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23 December 1938 NRL Report No. S-1504

NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on

A Uni-Control System for Sound Listening and Echo Ranging

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

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Prepared by: W. W. Wiseman, Assistant Radio Engineer

Reviewed by: H. C. Hayes, Prin. Phys., Supt., Sound Division

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

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[redacted]

ABSTRACT

This report covers the development, principally by Mr. W. W. Wiseman, of a uni-control system for echo ranging and listening for use with any type of projector.

The essential and the unique features of the equipment are described in detail, and performance test data are included. The performance approximates or exceeds the present Bureau of Engineering specifications for this type of equipment insofar as they apply to this system.

The principal features are:

(a) Unit control - Single tuning control for transmitter and receiver, keeping them electrically interlocked on the same frequency.

(b) Unlimited continuously variable frequency range.

(c) Frequency stability inherently high.

(d) Controllable transmitter frequency displacement (swing) with no moving parts.

(e) Continuously variable power range of more than 20 decibels.

(f) Sharp tuned radio frequency and/or extremely sharp crystal filter receiver selectivity.

(g) Maximum usable receiver gain.

(h) Construction entirely of commercially available parts.

(i) Unit type of construction with major units detached or assembled as desired.

[redacted]

1. General Description

The complete system consists of a transmitter, a receiver-amplifier, a projector, a visual indicating and timing device, and necessary power supplies, all functionally integrated. The essential feature of the uni-control system is a single variable oscillator with two output channels. Through one channel the output of the variable oscillator is mixed with the output of a fixed oscillator to produce a difference frequency in the desired supersonic range for transmitting purposes. Through the receiving channel, the output of the variable oscillator is mixed with the incoming signal to give a difference frequency which is the intermediate frequency of the superheterodyne type receiver-amplifier. The intermediate frequency of the receiver is also the fundamental frequency of the fixed oscillator in the transmitter channel. Thus the transmitting and receiving frequencies are always electrically interlocked, so that the transmitter and receiver are necessarily tuned to the same frequency. By the proper selection of the oscillator frequencies, a relatively small percentage change in the single variable oscillator will tune both transmitter and receiver over the entire supersonic frequency band. This system is shown in block diagram in Plate I.

The visual indicator is actuated through an independent channel from the intermediate frequency of the amplifier. This is accomplished by mixing the output from an independent oscillator with the intermediate frequency to produce a sum frequency which is amplified and rectified as necessary to operate the visual indicator.

The whole equipment is well adapted to the unit type of construction to be assembled or stacked as desired.

2. Transmitter Characteristics

The preferred transmitter design should have the following characteristics:

(a) A power output of 1000 watts continuous duty.
(b) A power range of 20 decibels.
(c) A frequency range from 5 to 40 kilocycles.
(d) A frequency stability of ±.1% of the supersonic frequency for variations of line voltage, temperature or power output normally encountered in the Naval service.
(e) A total output distortion of less than 10% for any power or frequency within the specified range.
(f) A common frequency control for both receiver and transmitter.
(g) A means of electrically displacing the output frequency at an approximately uniform rate from a specified number of cycles below the set frequency to an equal number of cycles above the set frequency during a predetermined time interval, and means of manually selecting any desired range and/or time interval.
(h) A keying system providing for hand and/or automatic keying.

[redacted]

3. Transmitter Design

The wiring diagram for the transmitter under discussion is shown in Plate 2.

The variable oscillator is of the conventional electron coupled type. All the tuning for the driver and receiver is by means of the variable condenser C, having a capacity range of approximately 10 to 50 micromicrofarads.

Filter No. 1 is a cut-off filter designed to attenuate all frequencies above 230 kilocycles.

Two channels diverge from this point to the receiver and to the transmitter respectively. The transmitter channel goes directly to the injector grid of the mixer tube.

The fixed oscillator circuit is the same as the variable oscillator circuit, hence any changes due to line voltage, temperature, etc., will affect both oscillators and produce only a differential effect.

Filter No. 2 is a combination filter and attenuator to eliminate harmonics and to secure the proper voltage on the buffer grid.

The buffer serves to isolate the fixed oscillator and to provide for a manual gain control and automatic power stabilizer independent of frequency within the prescribed range. The output power level is selected by the manual control over a range of 20 decibels. The stabilization is accomplished by means of a 6H6 diode excited from the output circuit of the final stage. The D.C. component of the diode, which varies directly with the output power, controls the amplification of the buffer by changing the bias on the signal grid in such a way as to maintain a constant output power.

The output of the buffer is coupled through a tuned transformer to the signal grid of the mixer. The pentagrid mixer tube, type 6L7 was selected as particularly designed for this type of service. The variable oscillator frequency is introduced through the injector grid and the fixed oscillator frequency is introduced through the signal grid. The variable oscillator circuit design is such that it always supplies sufficient voltage to the injector grid fully to modulate the plate current of the detector section thus maintaining high efficiency and fidelity with frequency change. The voltage output at the difference frequency is then proportional to the voltage applied to the signal grid.

The plate circuit of the mixer tube is resistance-capacity coupled to Filter No. 3. This filter provides the proper low impedance at oscillator frequencies for the plate circuit and attenuates all frequencies above 50 kilocycles. From this point on the power is within the supersonic frequency range of 5 to 50 kilocycles and may be amplified as desired.

[redacted]

4. Frequency Displacement.

When echo ranging against a moving target there is a frequency displacement of the echo compared to the outgoing signal called the Doeppler effect. The displacement may be up or down depending on the relative motions of the ship and target. For a large Doeppler effect, the echo, therefore, might fall outside the band width of a very sharply tuned receiver which was tuned to the same frequency as the transmitter. If, however, the transmitted frequency is displaced during the keying interval by an amount as great as the Doeppler effect, some portion of the echo must fall exactly on the frequency to which the receiver is tuned. When used with a broader intermediate frequency band receiver, such frequency displacement gives the target echo a particular frequency characteristic which enables the operator better to distinguish it from other echoes or through interference. Also when used with a very sharply tuned projector to which the transmitter is approximately tuned, it assures that the driver frequency will coincide exactly with resonance frequency of the projector at some time during the keying interval.

The frequency of an oscillating circuit is determined by the L, C and R values of the circuit and by the tube constants. The tube constants, however, are affected by the potentials applied to the elements, thus affecting the frequency. By causing the potential on the suppressor grid of the fixed oscillator continuously to change in the same direction during the keying interval, the tube constants are correspondingly changed so as to cause a frequency displacement in the desired direction and amount without materially affecting the other properties of the oscillator. The performance of this circuit may be seen with reference to Plate 3. With the key open the battery V charges the condenser C to a small positive voltage above ground. When the key is closed, the effect of this voltage is to lower the normal frequency of the oscillator by an amount proportional to the applied voltage within certain limits. As the charge on the condenser is neutralized by the suppressor grid current, the frequency rises, becomes normal when the potential is zero, and continues to rise as the condenser is charged negatively until equilibrium is established. The magnitude of the initial frequency displacement is determined primarily by the battery voltage. The rate of the displacement is determined primarily by the CR constants of the suppressor grid circuit. Neither the magnitude nor the rate of the frequency displacement is dependent on the supersonic frequency. Obviously, both the magnitude and the rate of displacement are subject to certain limitation, but it has been demonstrated experimentally that it is practical to obtain a displacement sufficient to cover the Doeppler effects occurring in service.

5. Power Amplification

As stated in paragraph 3, amplification beyond the mixer tube may follow conventional design for any desired power output. This Laboratory has constructed an experimental model whose features are shown in Plate 2. It consists of a 6F6 amplifier transformer coupled to a pair of

6L6 tubes, push-pull, class AB_1, as a driver stage which is in turn transformer coupled to a pair of 849 tubes or to Eimac 250 TH tubes push-pull, Class B, as a power amplifier stage. The output transformer has taps to match various impedances from 10 to 1000 ohms. The maximum output power rating is 1 kilowatt continuous duty.

6. Experimental Tests

In order to determine whether the equipment conformed to the Transmitter Characteristics outlined in paragraph 2, it was subjected to the following tests:

Test I - A 10 ohm precision resistor was used as a load and the current through it was measured with a 0-10 ampere radio frequency meter good to 2% of the full scale reading.

The frequency stability was determined by measuring the beats between a 1000 cycle electrically driven tuning fork and the 1000 cycle heterodyne note from a supersonic receiver-amplifier.

As a matter of convenience for this test, power changes were made by varying the plate voltage on the power amplifier tubes keeping the excitation constant. This produced some distortion at low powers. Results are shown in Table 1.

Input Freq.	Output Amp.	Output Watts	Change in Beat Note	Line Volts
10 kilocycles	3	90	0 cycles	107
	5	250	+1	
	7	490	+2	
	10	1000	+3	
20 "	3	90	0	107
	5	250	+1	
	7	490	+3	
	10	1000	+1	
30 "	3	90	+2	107
	5	250	+1	
	7	490	0	
	10	1000	+5	
40 "	3	90	+1	106
	5	250	0	
	7	490	+3	
	10	1000	+3	

Conclusion: The frequency variation at any frequency between 10 and 40 kilocycles for a 10 to 1 variation in load is within 0.01% of the supersonic frequency. The variation of the beat note with time is ± 5 cycles in 5 minutes.

Test II

Variation in power output with frequency. After adjusting to 9.65 amperes with automatic power stabilization at 20 kilocycles, no other manual adjustments were made except to vary the frequency.

The results are shown in Table 2.

Frequency	Output Amperes	Output Power	% Change
5 kilocycles	9.8	960	+3
10	9.75	950	+2
20	9.65	931	0
30	9.65	931	0
40	9.6	922	-1
50	9.7	941	+1

Conclusion: For a 10 to 1 variation in frequency the output power is constant within ±4% or 0.2 decibel. No distortion was visible on the cathode ray oscillograph.

Frequency stability with variations in line voltage.

Test III

The set-up of apparatus was the same as in Test No. I except that a Variac was used to change the input line voltage.

Frequency	Line Volts	Beats per Second
20 kilocycles	115	+1
	120	+3
	125	+1
	100	-5
	110	-2
	115	0
	120	+3
	125	+2

Conclusion: The voltage regulation is adequate to maintain the frequency constant within ±0.02% of 20 kilocycles for line variations from 100 to 125 volts.

Frequency Displacement.

Test IV

The oscillator was operated with the conditions as shown in the data. Actual frequencies were measured by means of a crystal calibrator at the beginning and end of the displacement. The set frequency was 175 kilocycles.

[redacted]

Frequency Displacement	Sup. Grid Constants		
	E	R	C
-259	+4	0	.05
-211	+3	0	.05
-140	+2	0	.05
- 70	+1	0	.05
- 28	+0.5	0	.05
- 14	0.25	0	.05
0	0	0	0
+ 73	+4	1.5	.05
+122	+4	3.5	.05
+183	+4	6.5	.05
+209	+4	9.5	.05

Conclusion: These data show that in the upper half of the table, the lowering of the frequency is nearly proportional to the voltage E, applied to the suppressor grid and the lower half shows that the rise in frequency is nearly proportional to the resistance R. The magnitude and direction of the displacement are thus under control.

7. Receiver Characteristics

The preferred receiver design should have the following characteristics:

(a) Integrated with transmitter and projector for unit control.
(b) Frequency Range, 5 to 30 kilocycles.
(c) Selectivity (1) Broad - by tuned intermediate frequency circuits.
(2) Sharp - by crystal filter.
(d) Sensitivity, maximum practical, one microvolt or less for standard conditions.
(e) Frequency stability ±.01% of supersonic frequency.
(f) Output circuits for phones, loud speaker, lamp and output meter, independently or in any combination.
(g) One or more means of keeping the final audio signal to tolerable levels.
(h) Input circuit to couple to ED, MS and RS projectors with equal efficiency.
(i) Minimum number of controls to give the desired flexibility.
(j) General conformance to Bureau of Engineering specifications for sound equipment as far as they apply to this type of equipment.
(k) Frequency dial calibrated in kilocycles.

8. Receiver-Amplifier Design

The wiring diagram for the receiver-amplifier is shown in Plate 4. This description and the test data apply to the original experimental model which has undergone progressive modification during development. In a new model numerous details will be changed to improve the engineering design.

The projector may be coupled across a resistive or inductive input to the first tube. Any one of the three types of projectors may be coupled with equal facility by proper impedance matching. Untuned, balanced transformer coupling gives an optimum signal/noise ratio. It is now used with inductive types of projectors and a simple modification of the rochelle salt projector is proposed so that it also can be used with this type of input.

The first tube is a coupling and pre-amplifier tube. A triode is used to keep first circuit noises to a minimum. It is resistively coupled to the first mixer and supplies an amplified signal voltage above the circuit noise level of the mixer. It is recognized that a tuned input circuit would improve the signal/noise ratio, but tuning is impracticable over the frequency range from 5 to 30 kilocycles without destroying the simplicity and flexibility of the unit control tuning system. For a particular installation with a sharply resonant projector an input circuit with fixed tuning may be employed if desired. As will be shown later, this is not essential.

The second tube is the first mixer where the incoming signal is mixed with that of the variable oscillator. The pentagrid type mixer 6L7 is selected as most suitable. The incoming signal is applied to the signal grid and the variable oscillator signal is applied to the injector grid. As explained in the transmitter channel, the voltage output at the difference frequency is then accurately proportional to the voltage applied to the signal grid over a wide range of intensities The difference frequency is the intermediate amplifier frequency.

An intermediate frequency of 175 kilocycles was selected because standardized, commercial, component parts are available at this frequency. Shielding and by-passing problems are simplified at this frequency and a small percentage change in the variable oscillator frequency covers the whole supersonic range. As will be shown later, the desired selectivity has been obtained at this frequency. Intermediate frequency amplification and selectivity are obtained by the use of four tuned-grid, tuned-plate, loosely coupled transformers and type 6K7 tubes.

A quartz crystal filter was placed between the first mixer and the first intermediate frequency to obtain the "sharp" selectivity condition for echo ranging. A total band pass width of 125 cycles at -3 decibels, 350 cycles at -10 decibels and 1000 cycles at -20 decibels was obtained using a single quartz plate with damping applied to the electrodes. The filter may be switched in or out as desired from the front panel. A somewhat narrower band pass filter could be used with this equipment, because of its frequency stability and interlocked transmitter-receiver tuning, with a consequent gain in sensitivity. (Note statement in paragraph 4 for Doeppler effect.)

Two channels diverge from the last intermediate frequency stage to the audio and lamp channels respectively. The lamp channel will be described separately.

[redacted]

The audio channel consists of a pentagrid mixer, a heterodyne oscillator, an audio amplifier, the necessary filters and output indicators.

The intermediate frequency is introduced on the signal grid of the mixer and the beat oscillator on the injector grid. Although not especially adapted to this purpose a 6L7 tube was also used for the second mixer. It is coupled to the first audio amplifier tube by an audio transformer which offers high impedance to the audio frequency but low impedance to the oscillator frequencies.

A low pass filter was also inserted between the mixer plate and the audio transformer. Ahead of the filter a vacuum tube voltmeter was inserted to be used to adjust the fixed oscillator in the transmitter channel to the crystal filter frequency and to serve as an output indicator. The audio frequency beat oscillator is preferably turned off during alignment adjustments. The audio frequency beat oscillator has a frequency below the intermediate frequency, to give the proper Doeppler effect, and provision for small manual variation to give the desired pitch to the beat note.

The phone channel is tapped off the secondary of the transformer between the mixer and the first audio tube.

The first audio amplifier tube is resistance coupled to the loud speaker power tube. Between these two tubes an auxiliary tube is inserted to reduce the speaker output during the keying time. It effectively shunts the output of the first audio tube during keying but has no effect during reception because of its high resistance.

For convenience in this experimental model, the manual volume control was obtained by applying a positive bias to the cathodes of the intermediate frequency stages. The range is in excess of 50 decibels. In the new model a delayed automatic volume control will be incorporated in the intermediate frequency and a volume control provided in the audio frequency.

9. <u>Lamp Channel</u>

The purpose of this channel is to supply a d.c. voltage for flashing the visual indicator lamp. The present type lamp requires approximately 25 watts at 1,000 volts. In this system the echo is a displaced image of the outgoing signal.

The 175 kilocycle intermediate frequency voltage is applied to the signal grid of a 6L7 mixer and mixed with a voltage from an independent 290 kilocycle oscillator applied to the injector grid to give a sum frequency of 465 kilocycles to the grid of an intermediate frequency amplifier through a tuned-plate, tuned-grid transformer. The intermediate frequency amplifier is transformer coupled to a diode. The I. R. drop across the load resistance of the diode provides the necessary d.c. potential for actuating the triggering tube which in turn actuates the final power tube. The 465 kilocycle is a standard intermediate frequency and is a convenient means for isolation and control of the lamp channel.

The final power tube has an independent power supply.

10. <u>Keying System</u>

The essential feature of the keying system is the removal of the blocking bias voltage from the fixed oscillator and the reduction of the blocking bias on the subsequent amplifiers to normal operating values during transmission. In addition, the key operates, through a vacuum tube, a relay which transfers the projector from the "receive" to the "send" position during the keying time. The transfer takes place before the oscillations in the driver begin and after they are stopped, thus eliminating any arcing at the contacts.

It is also practical to eliminate the relay and use a system where the receiver is always connected to the projector, with some sacrifice of receiver performance when used over a 5 to 30 kilocycle frequency band.

11. <u>Test Data on Receiver</u>

Plates 5 to 17 show the results of recent tests made by the Receiver Section of the Radio Division on the model essentially as completed in October 1937.

Sensitivity curves are shown for both resistance input and transformer input.

Plate 5 shows the sensitivities in the broad and sharp conditions for a 100,000 ohm resistance input to be 1.5 microvolts in the sharp condition and 2.4 microvolts in the broad condition from 10 kilocycles to 35 kilocycles. From 10 kilocycles down to 5 kilocycles the sensitivity decreases .4 decibel in the sharp condition and 14 decibels in the broad condition. The flat response can be extended to lower frequencies by proper design of the preamplifier circuit.

Plate 6 shows the sensitivity for an untuned transformer input to be 0.4 microvolt or better down to 6 kilocycles in the broad condition.

Plates 7 to 11 show selectivities in the broad and sharp conditions for 5, 10, 15, 20 and 30 kilocycles. The selectivity is independent of the input frequency over this range.

Plates 12 and 13 show the selectivities of the first mixer and first intermediate frequency respectively.

Plate 14 shows the overall fidelity and Plate 15 shows the audio fidelity. The overall fidelity curve is peaked at 400 cycles and is down 6 decibels at 800 cycles. The 400 cycle peak is probably too low, but it can easily be shifted to higher frequency. The total width, however, is limited by the intermediate frequency selectivity. High selectivity for echo ranging is obtained at some sacrifice of fidelity.

Plate 16 shows the overall voltage gain for increasing voltage inputs in the broad and sharp conditions. The gain is approximately linear to 50 microvolts, and above 200 microvolts the gain is constant.

Plate 17 shows overall fidelity of the Ferranti #2732 input transformer.

12. The above description and test data cover the development of a unit-control system for echo ranging and listening for use with any type projector. The performance approximates the Bureau specifications for this type of equipment.

Additional advantages are:

(a) Unit control.
(b) Simplified operation.
(c) Unlimited, continuously variable, frequency range.
(d) Inherent frequency stability.
(e) Controllable frequency displacement for transmission.
(f) Continuously variable power range of more than 20 decibels.
(g) Construction entirely of commercially available parts.

13. It is believed that the system has novel features that should be covered by a patent assigned to the Government.

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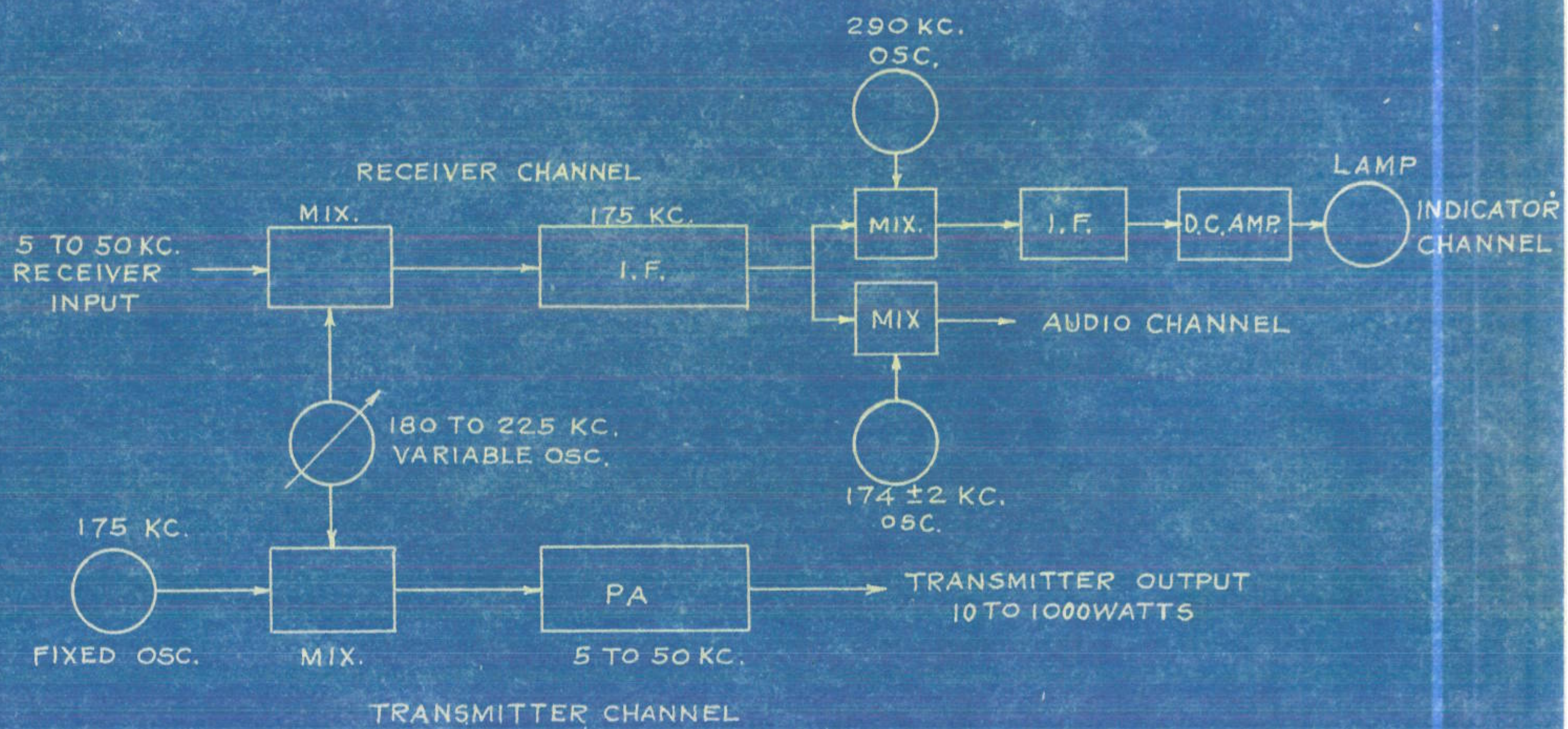


BLOCK DIAGRAM OF SYSTEM

PLATE I

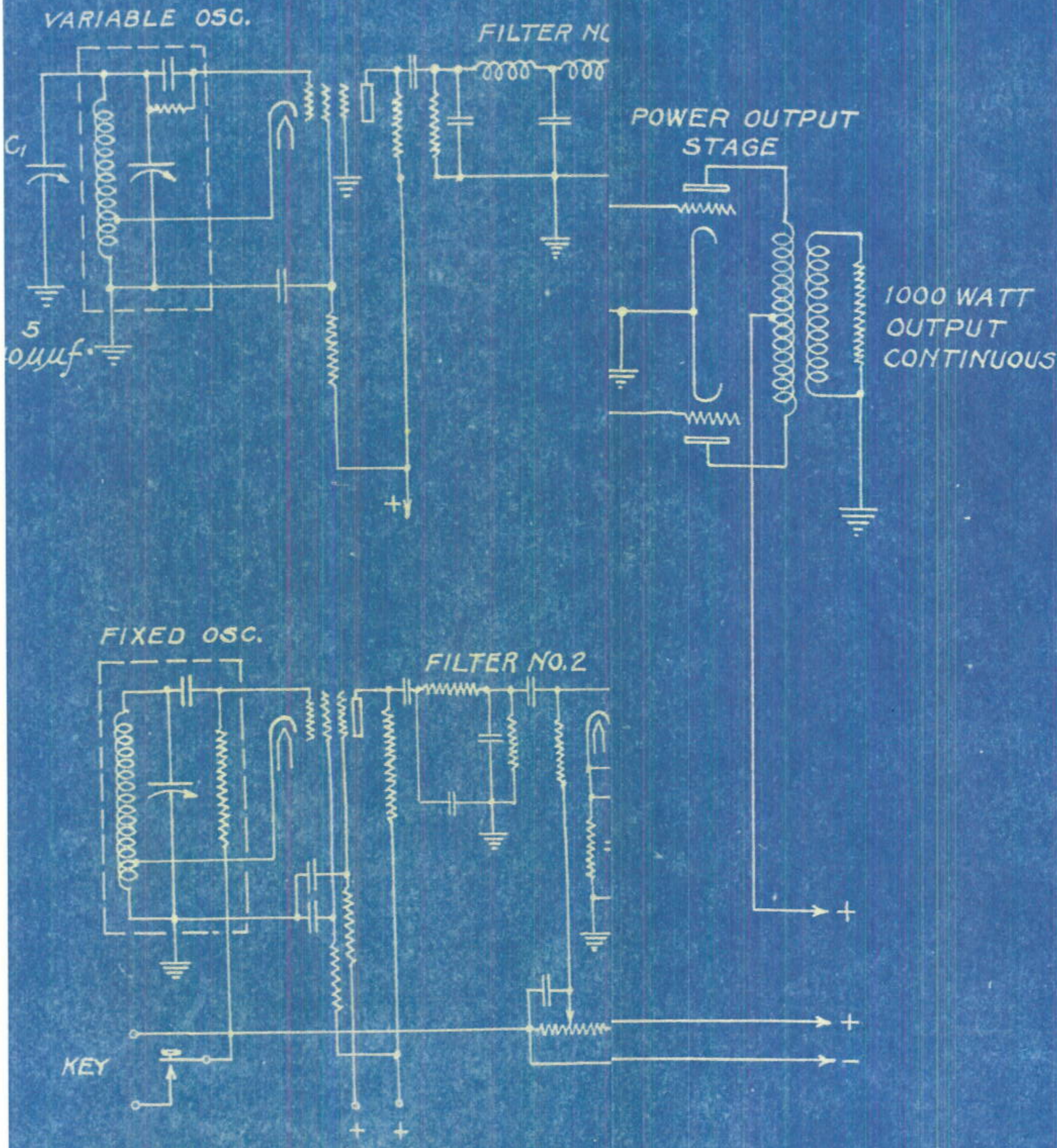

VARIABLE OSC.
POWER OUTPUT STAGE
1000 WATT OUTPUT CONTINUOUS
FIXED OSC.
FILTER NO.2
KEY

PLATE 2

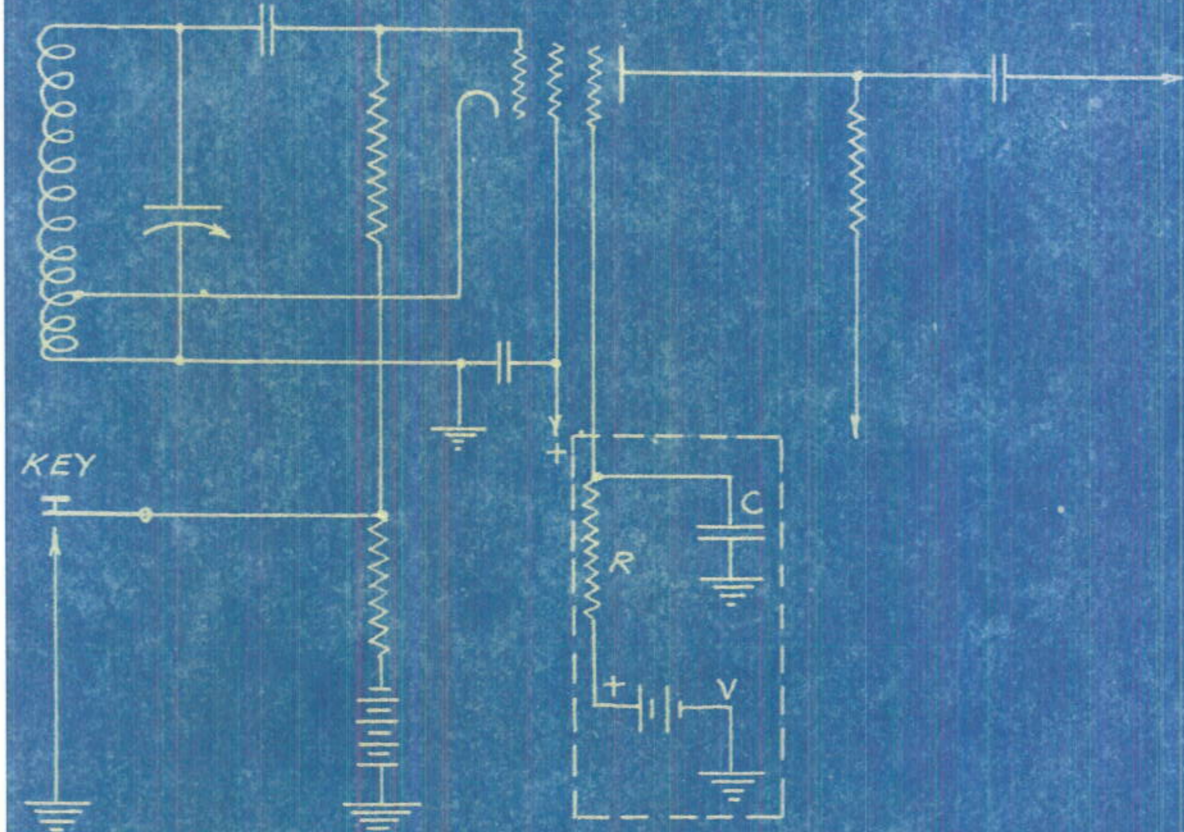
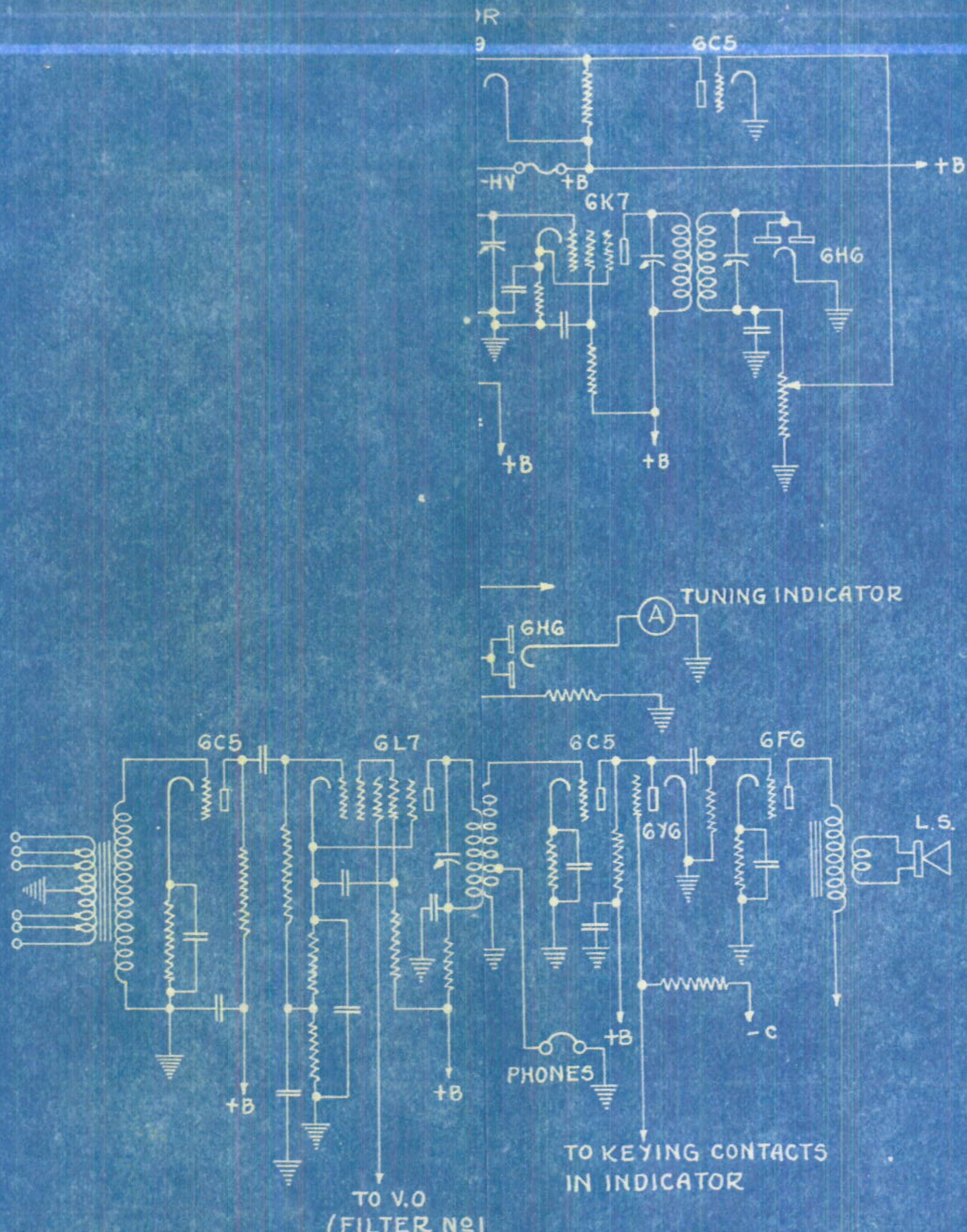
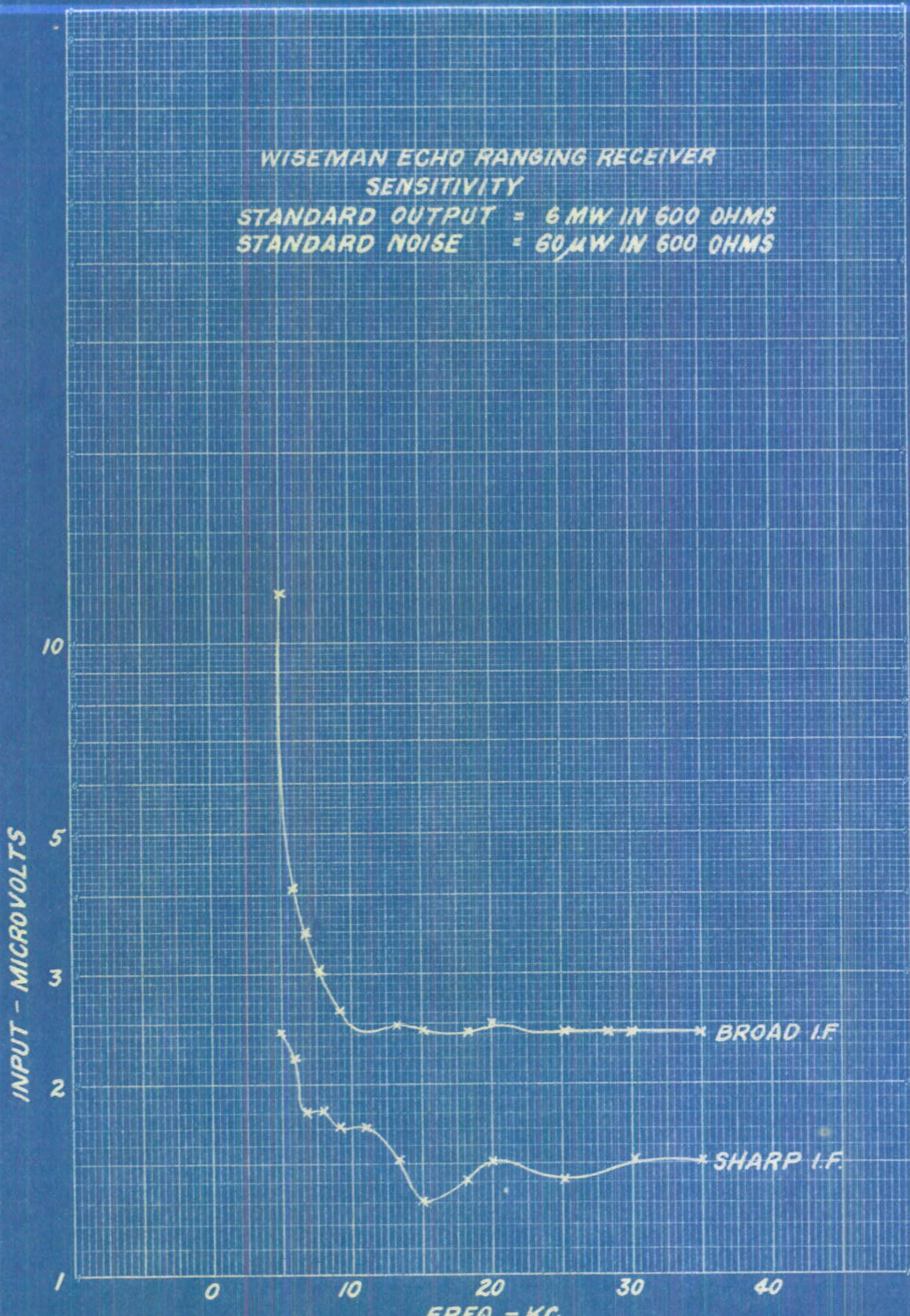


PLATE 3



OR
9
6C5
-HV
+B
+B
6K7
6H6
+B
+B
TUNING INDICATOR
A
6H6
6C5
6L7
6C5
6F6
6Y6
L.S.
-C
+B
PHONES
+B
+B
TO KEYING CONTACTS
IN INDICATOR
TO V.O
(FILTER No1

PLATE 4



WISEMAN ECHO RANGING RECEIVER
SENSITIVITY
STANDARD OUTPUT = 6 MW IN 600 OHMS
STANDARD NOISE = 60 µW IN 600 OHMS
INPUT - MICROVOLTS
1
2
3
5
10
0
10
20
30
40
FREQ. - KC.
BROAD I.F.
SHARP I.F.

PLATE 5

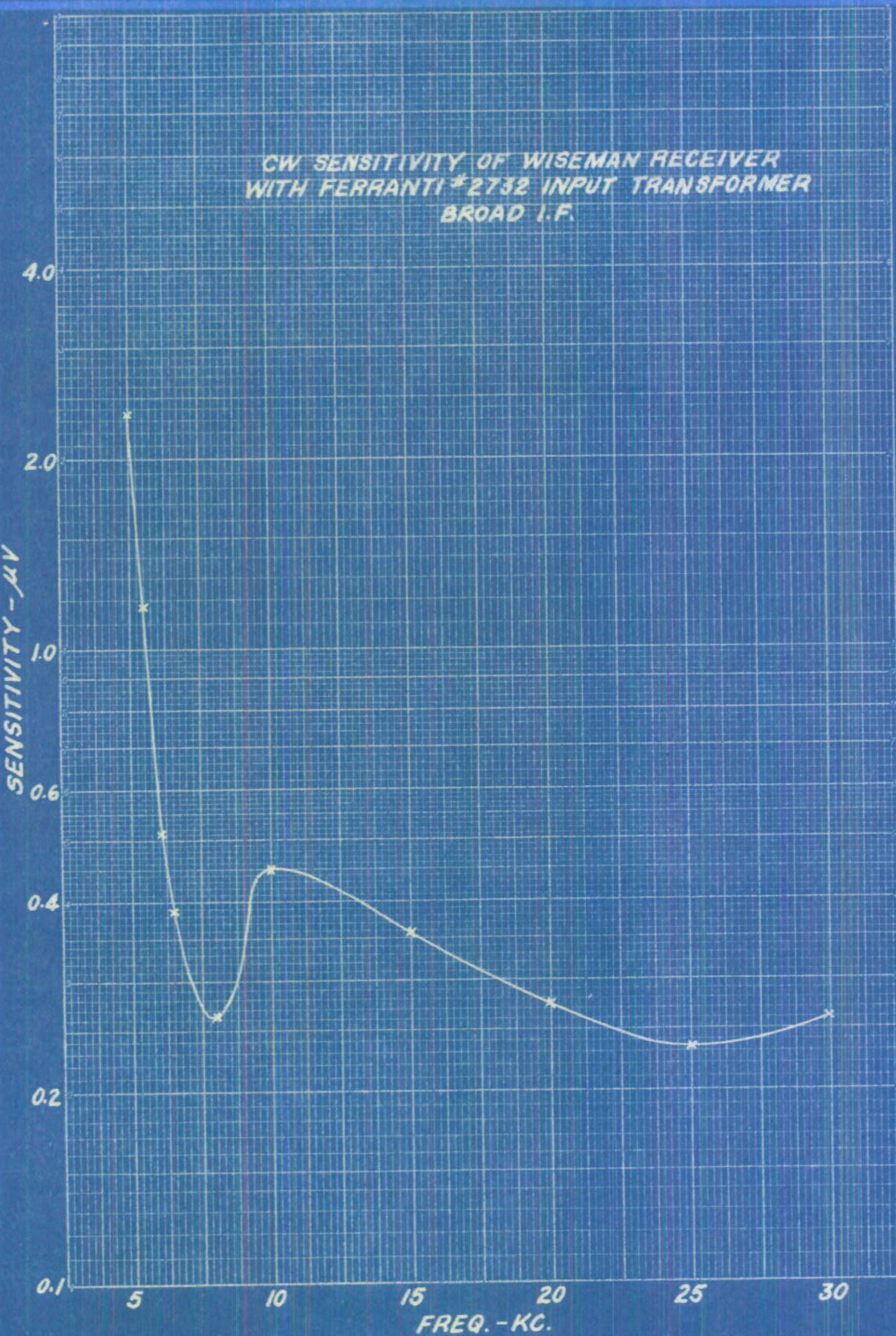

CW SENSITIVITY OF WISEMAN RECEIVER
WITH FERRANTI #2732 INPUT TRANSFORMER
BROAD I.F.
SENSITIVITY - μV
4.0
2.0
1.0
0.6
0.4
0.2
0.1
5
10
15
20
25
30
FREQ. - KC.

PLATE 6

BELLEVUE, D. C. DATE

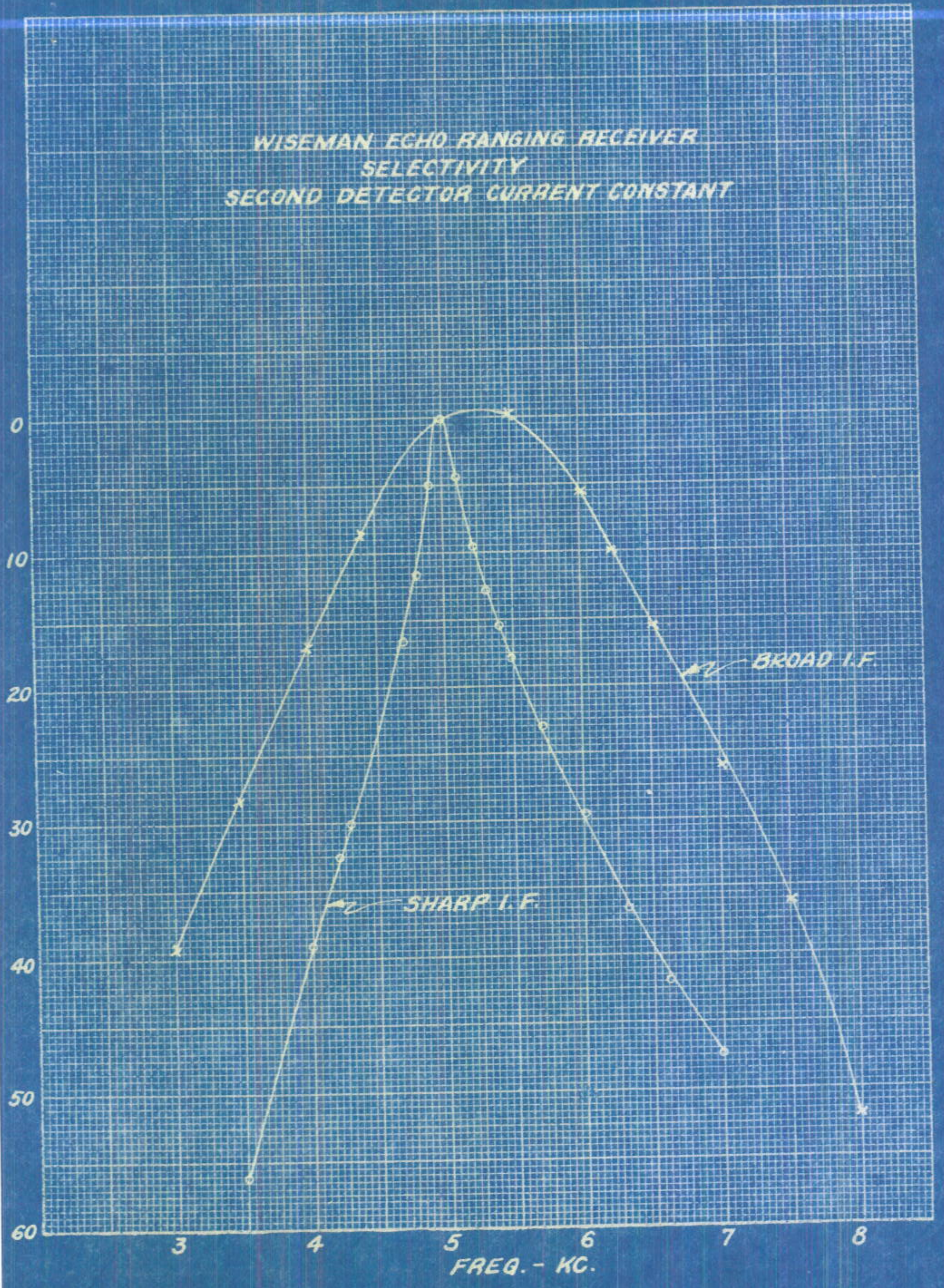


PLATE 7

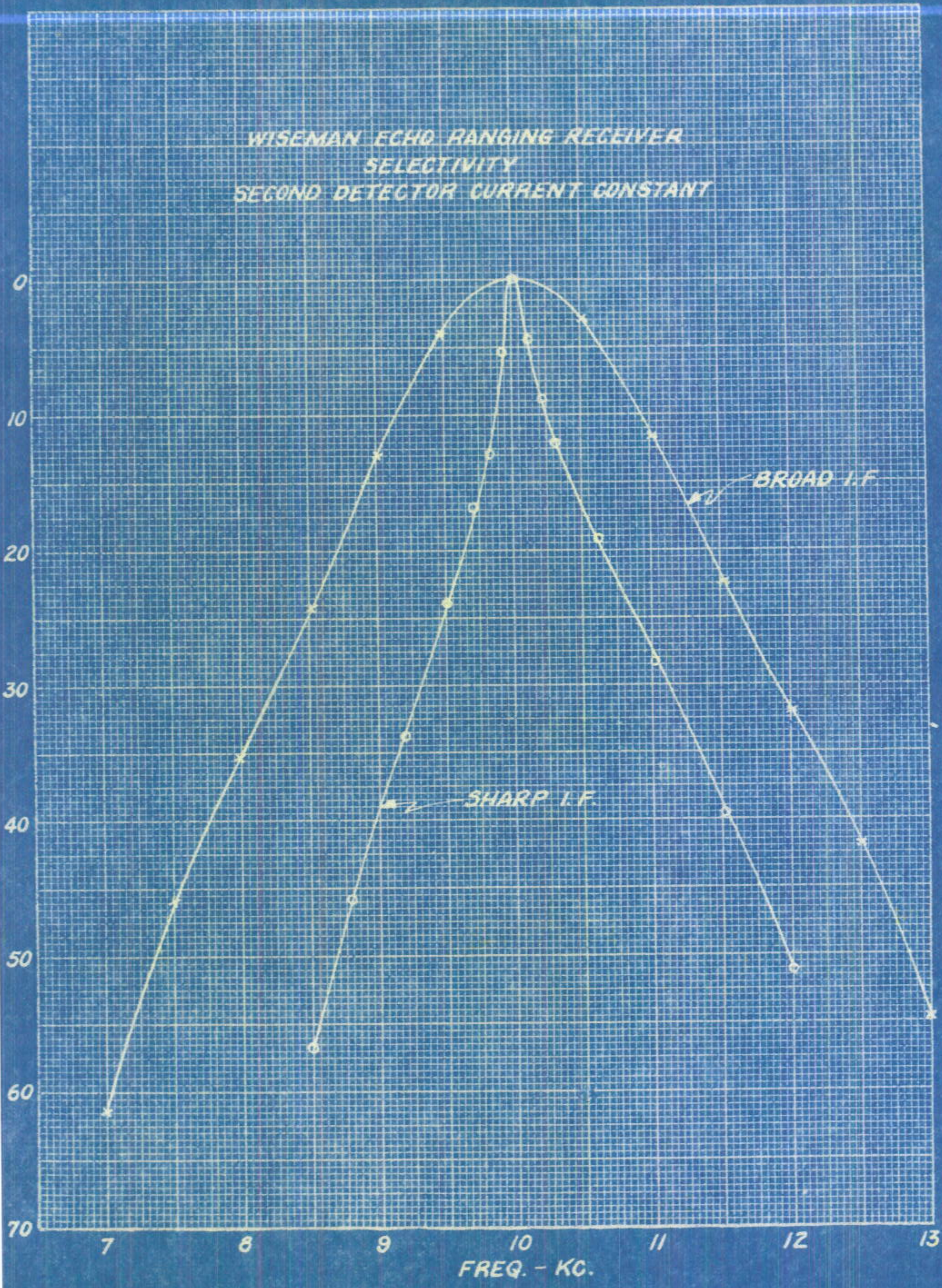

WISEMAN ECHO RANGING RECEIVER
SELECTIVITY
SECOND DETECTOR CURRENT CONSTANT
BROAD I.F.
SHARP I.F.
0
10
20
30
40
50
60
70
7
8
9
10
11
12
13
FREQ. - KC.

PLATE 8

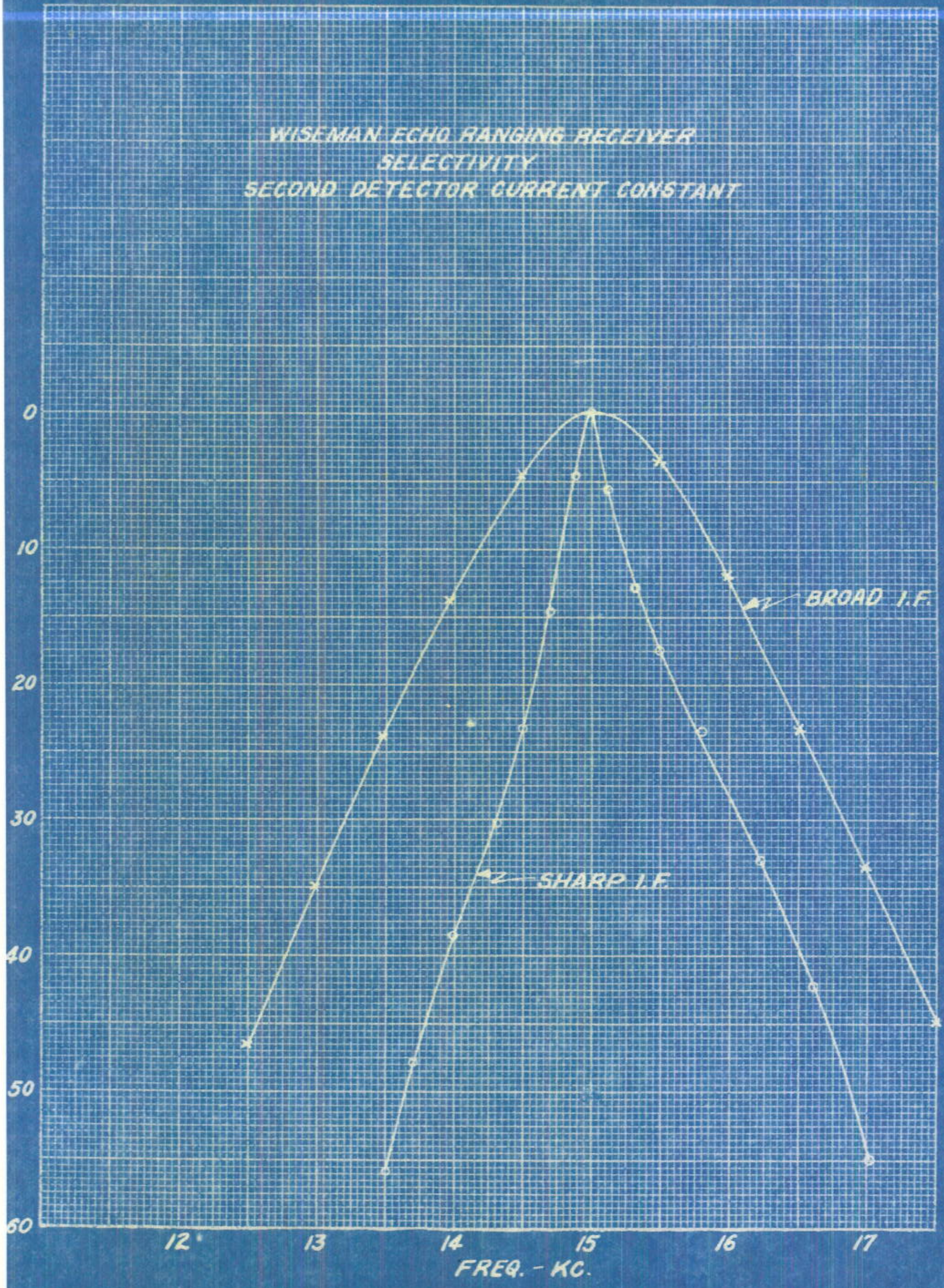

WISEMAN ECHO RANGING RECEIVER
SELECTIVITY
SECOND DETECTOR CURRENT CONSTANT
BROAD I.F.
SHARP I.F.
0
10
20
30
40
50
60
12
13
14
15
16
17
FREQ. - KC.

PLATE 9

DATE

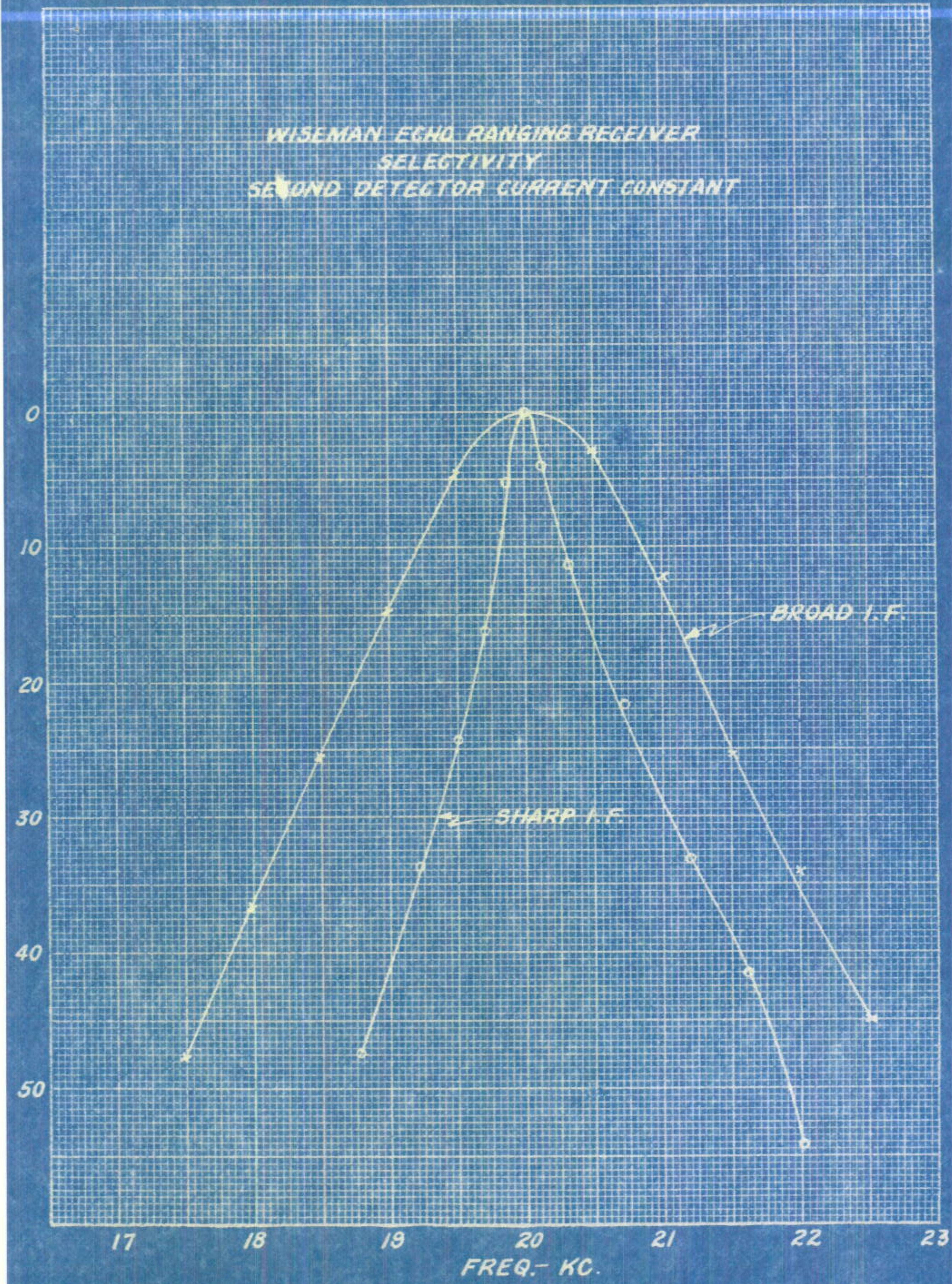


PLATE 10

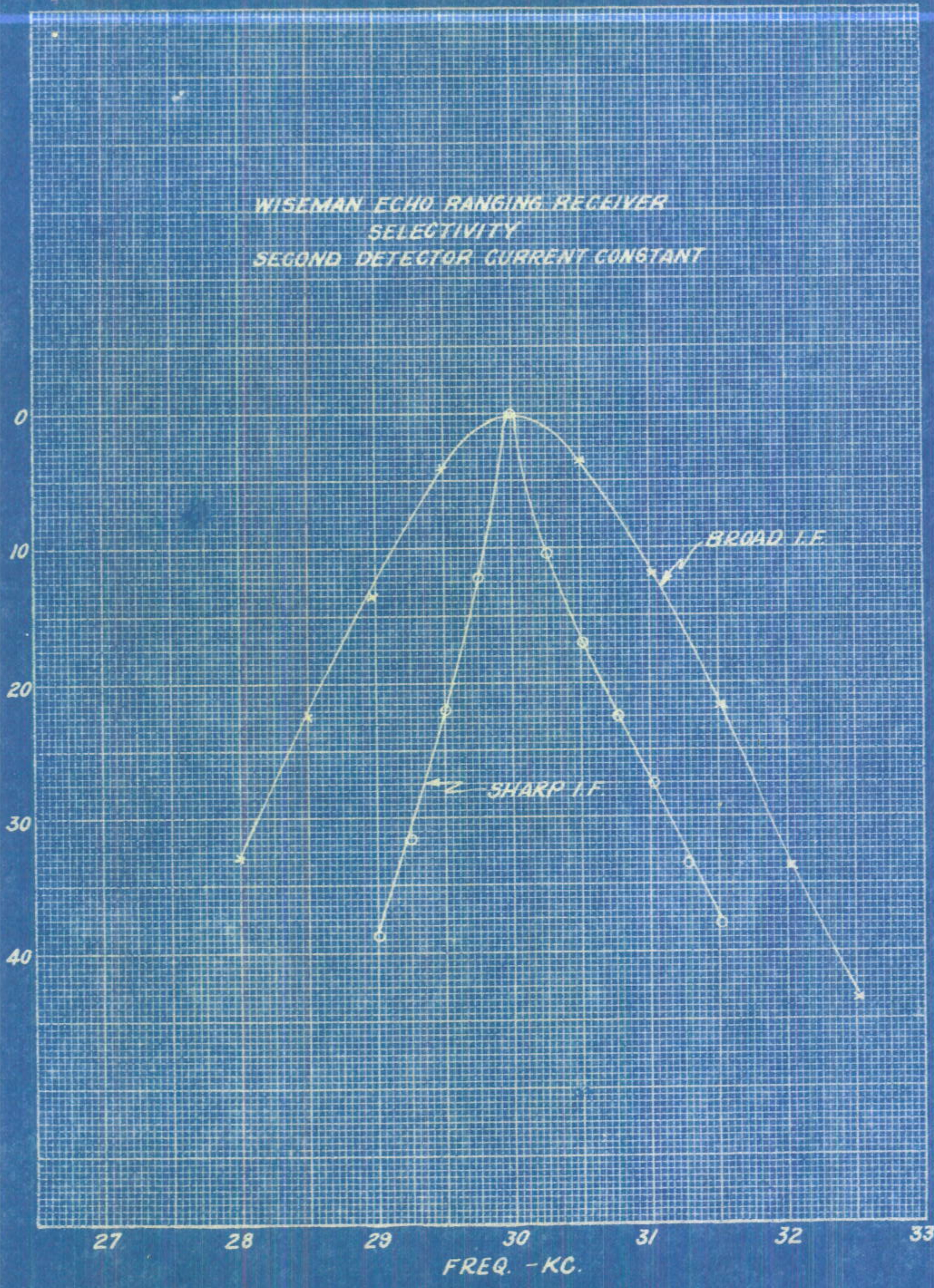

WISEMAN ECHO RANGING RECEIVER
SELECTIVITY
SECOND DETECTOR CURRENT CONSTANT
BROAD I.F.
SHARP I.F.
0
10
20
30
40
27
28
29
30
31
32
33
FREQ. - KC.

PLATE 11

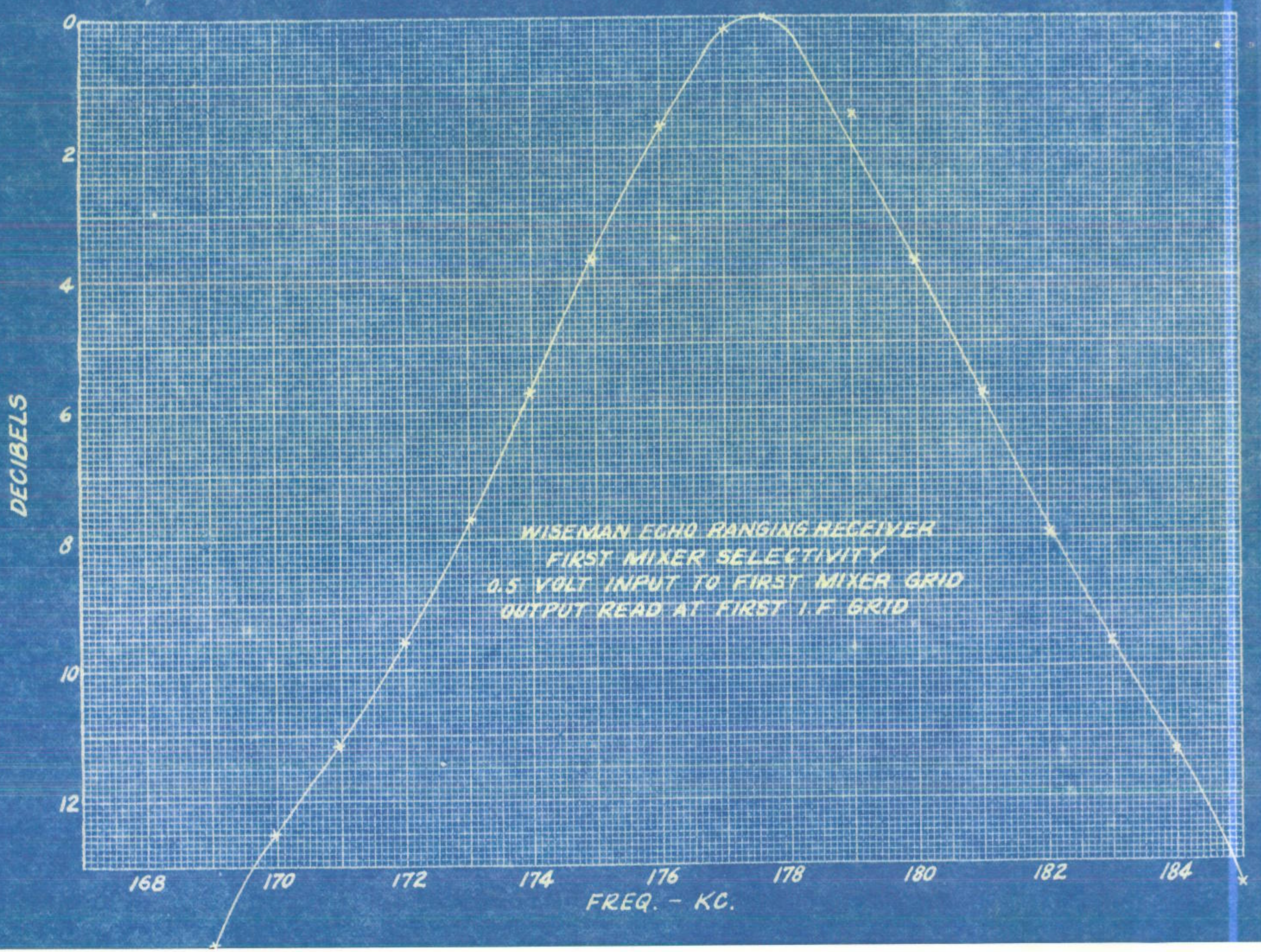


PLATE 12

BELLEVUE, D.C.

DATE

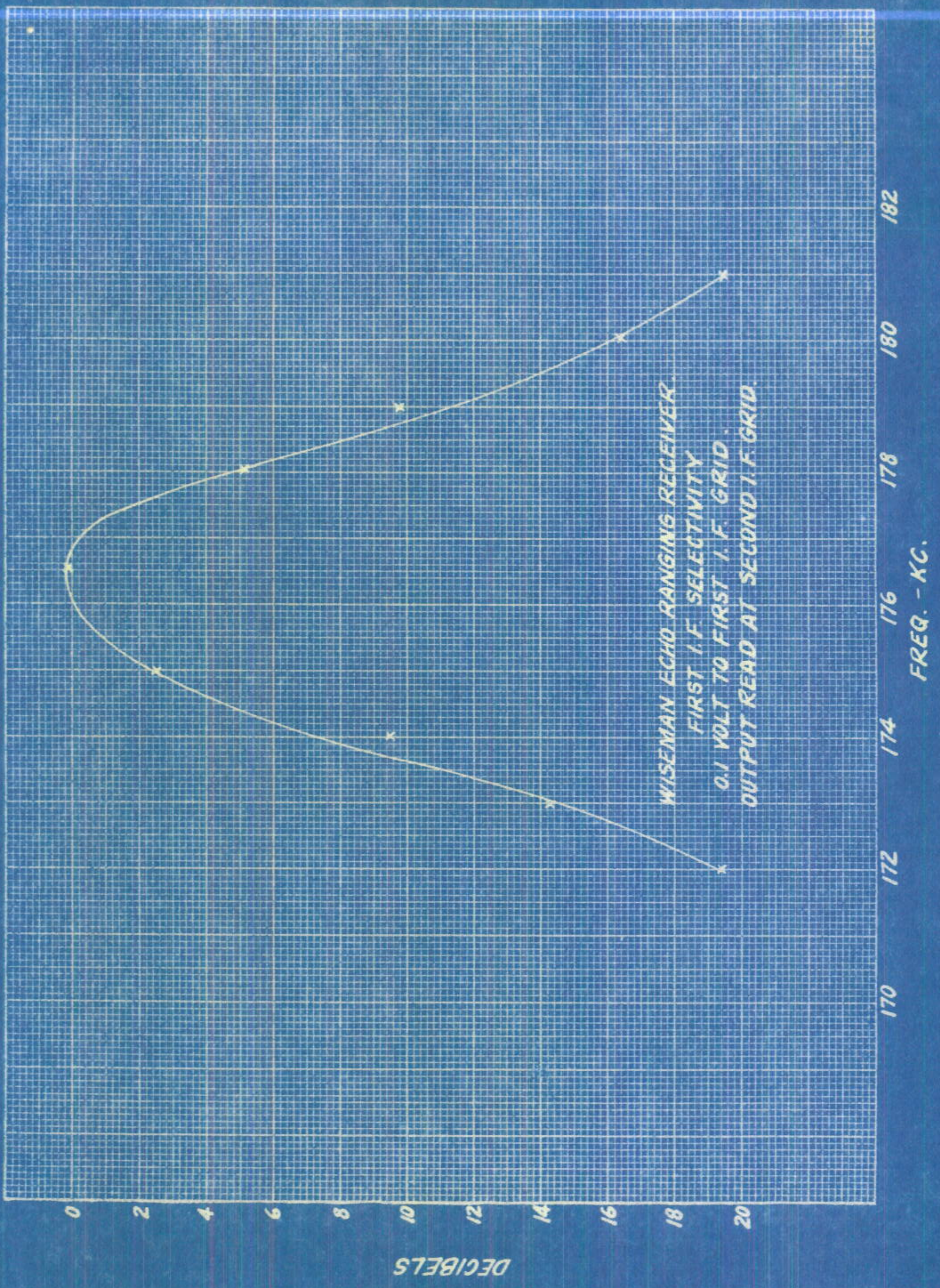

WISEMAN ECHO RANGING RECEIVER.
FIRST I.F. SELECTIVITY
0.1 VOLT TO FIRST I.F. GRID.
OUTPUT READ AT SECOND I.F. GRID.
FREQ. - KC.
170
172
174
176
178
180
182
DECIBELS
0
2
4
6
8
10
12
14
16
18
20

PLATE 13

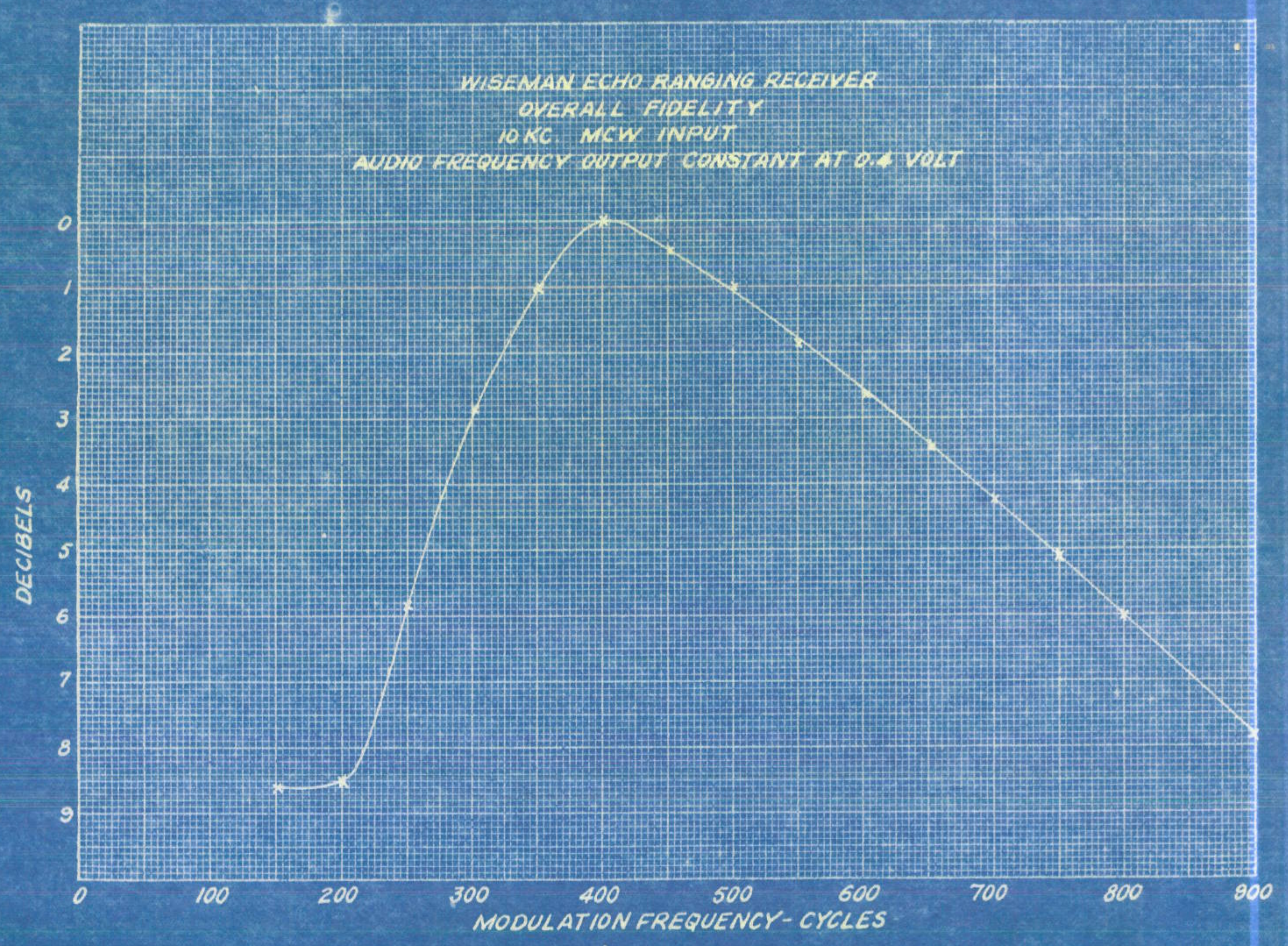

WISEMAN ECHO RANGING RECEIVER
OVERALL FIDELITY
10 KC. MCW INPUT
AUDIO FREQUENCY OUTPUT CONSTANT AT 0.4 VOLT
DECIBELS
0
1
2
3
4
5
6
7
8
9
0
100
200
300
400
500
600
700
800
900
MODULATION FREQUENCY - CYCLES

PLATE 14

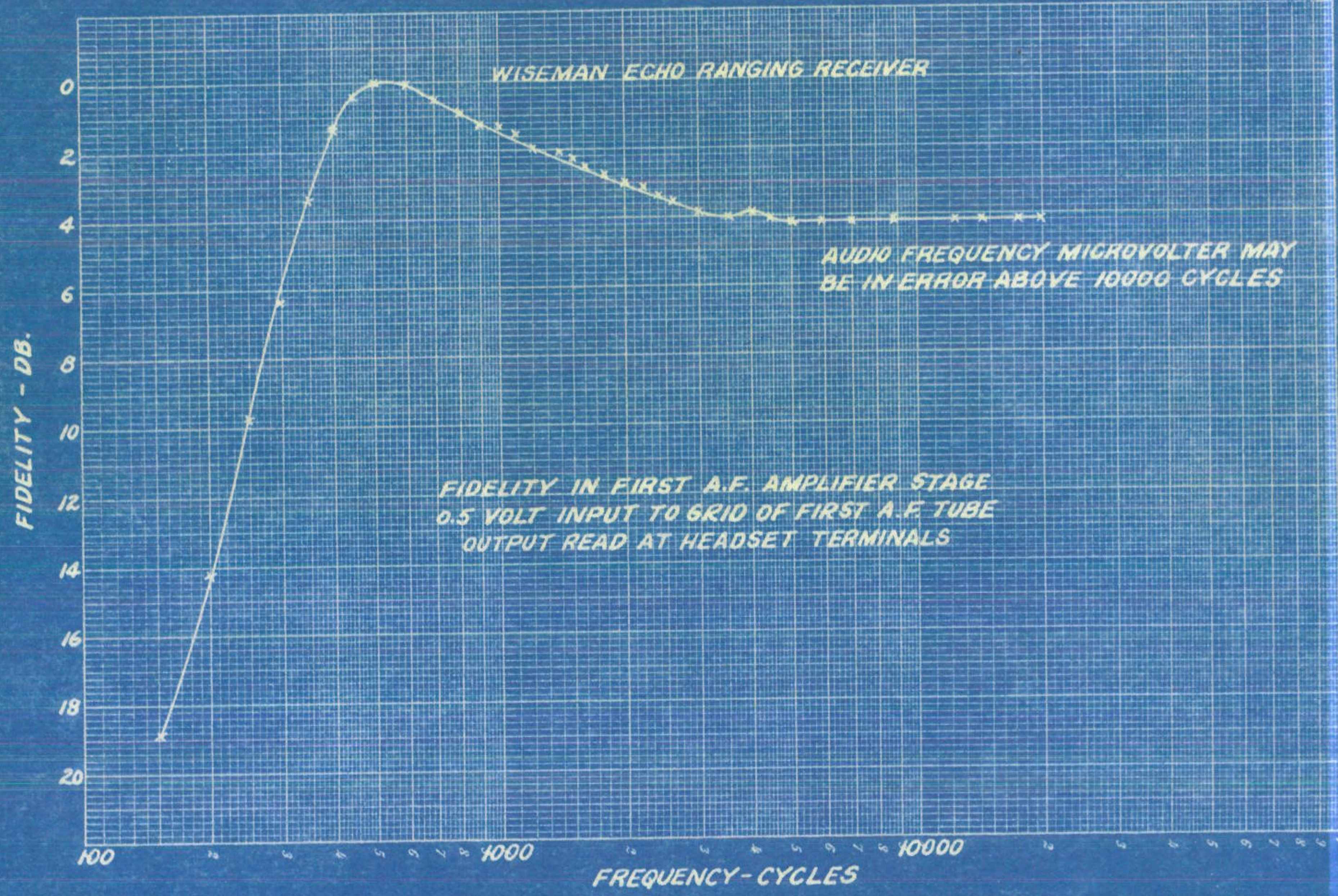
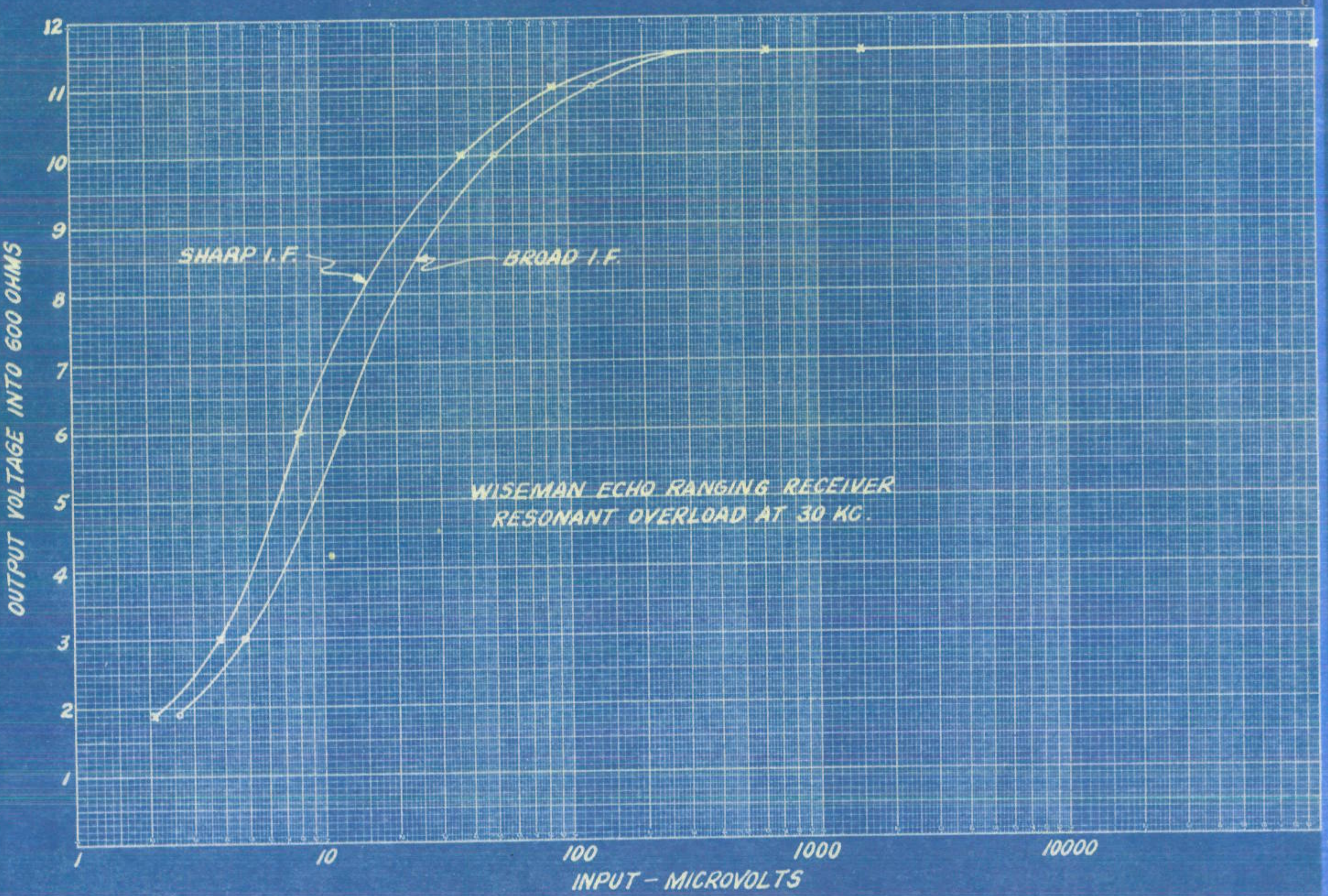

WISEMAN ECHO RANGING RECEIVER
AUDIO FREQUENCY MICROVOLTER MAY
BE IN ERROR ABOVE 10000 CYCLES
FIDELITY IN FIRST A.F. AMPLIFIER STAGE
0.5 VOLT INPUT TO GRID OF FIRST A.F. TUBE
OUTPUT READ AT HEADSET TERMINALS
FIDELITY - DB.
FREQUENCY - CYCLES
0
2
4
6
8
10
12
14
16
18
20
100
1000
10000

PLATE 15



WISEMAN ECHO RANGING RECEIVER
RESONANT OVERLOAD AT 30 KC.
SHARP I.F.
BROAD I.F.
OUTPUT VOLTAGE INTO 600 OHMS
12
11
10
9
8
7
6
5
4
3
2
1
INPUT - MICROVOLTS
1
10
100
1000
10000

PLATE 16

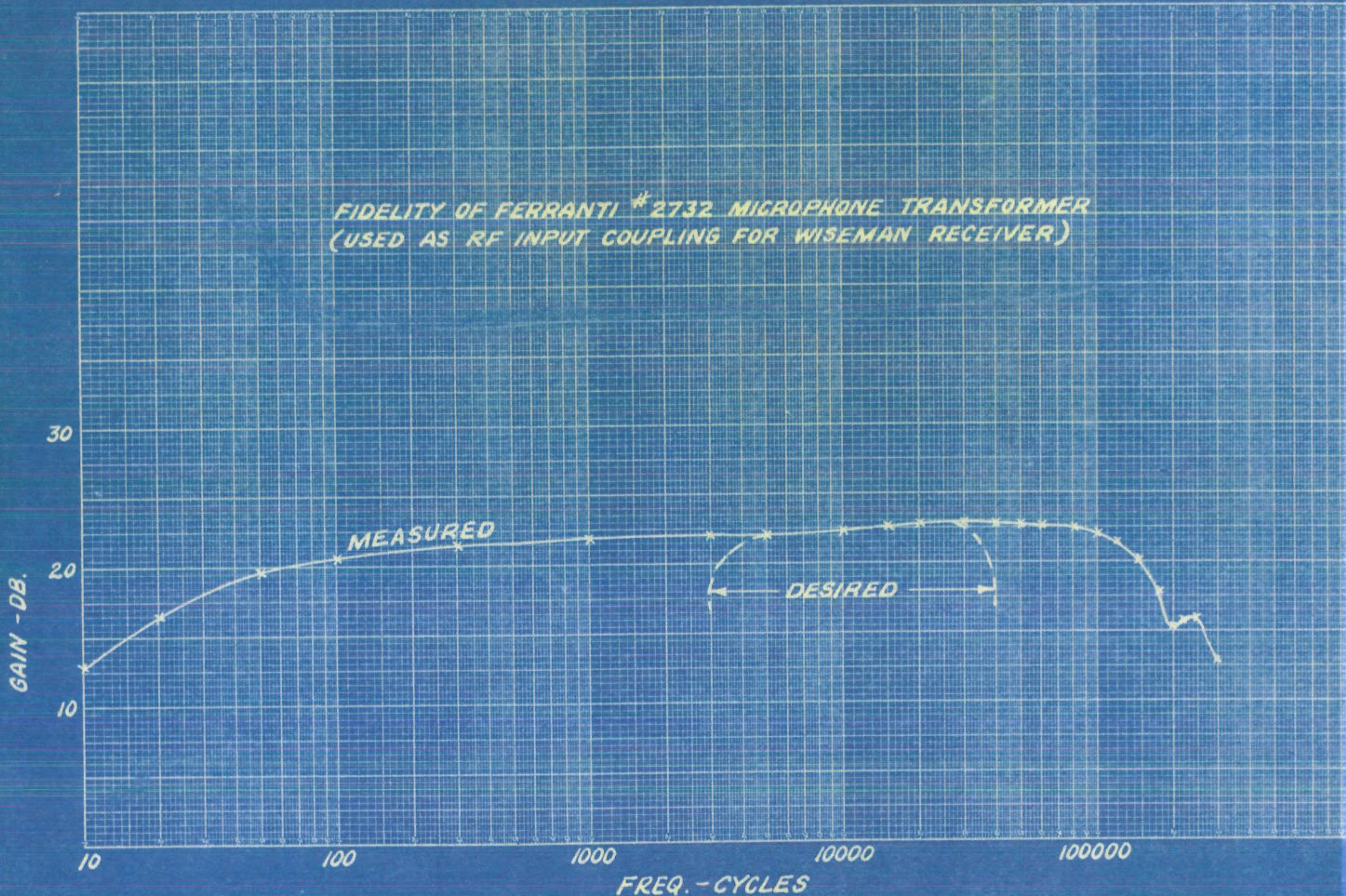

FIDELITY OF FERRANTI #2732 MICROPHONE TRANSFORMER
(USED AS RF INPUT COUPLING FOR WISEMAN RECEIVER)
MEASURED
DESIRED
30
20
10
GAIN - DB.
10
100
1000
10000
100000
FREQ. - CYCLES

PLATE 17