25 April 1941 Report No. R-1726

NAVY DEPARTMENT

FR-1726

Report

on

Test of Lucite Loops

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON D. C.

Number of Pages: Text - 7 Tables - 14 Plates - 13

Authorization: BuShip's Letr. S67/97(11-6-DR6) of 8 Nov. 1940 to Director NRL

Date of Test: From 3 February 1941 to 20 March 1941

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Distribution: BuShips 10
NAS Anacostia 1

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TABLE OF CONTENTS

Subject	Page
Authorization for Test	1
Object of Test	1
Abstract of Test	1
Conclusions	1a
Recommendations	1b
Description of Material Under Test	2
Method of Test	2
Data Recorded during Tests ;	3
Discussion of Probable Errors	3
Results of Test	3
Conclusions	8

Tables

Comparison of Loop Q	Table	1
Comparison of Loop Q	..	2
Loop Sensitivity Factor	..	3
Sensitivity of Model DW and Lucite Loops	..	4
Sensitivity of Model DW and Lucite Loops in Field	..	5
Effect of Various Temperatures	..	6
Effect of Changes in Humidity	..	7
Comparison of Loop Q	..	8
Deviation Caused by Airplane	..	9
Loop Distributed Capacity	..	10
Loop D.C. Resistance	..	11
Loop Inductance		12
Weights of Loops	..	13
Dimensions of Loops		14

Plates

Effect of Humidity on Sensitivity	Plate	1
Effect of Humidity on Sensitivity		2
Comparison of Loop Q		3
Comparison of Loop Q		4
Comparison of Loop Directional Sensitivity		5
Comparison of Loop Field Sensitivity		6
Comparison of Loop Effective Height		7
Loop Dimensions		8
Construction of Lucite Loop		9
Loop Construction		10
High Temperature Effect on Shield		11
Shielded and Unshielded Lucite Loops		12
Model DW and Lucite Shielded Loops		13

AUTHORIZATION FOR TEST

1. This problem was authorized by Bureau of Ship's letter, reference (a).

Reference: (a) BuShip's Ltr. S67/97(11-6-DR6) of 8 Nov. 1940 to Director, NRL.

OBJECT OF TEST

2. The object of these tests was to determine the suitability for Naval Aircraft Service of direction finder loops enclosed in a composition of Lucite and as to the possible adoption of this type construction in place of the present type aluminum shielded loop.

ABSTRACT OF TEST

3. The loop samples were operated in direct comparison with the Model DU direction finder equipment and observations made for sensitivity, antenna effect, accuracy of bearings, unilateral operation with changes in temperature and humidity and the thermal variation with rapid changes in temperature. The equipment was installed in a type SBC-4 airplane and its operation compared directly to that of a Model DU direction finder. Comparative operation performance between the loops and the Model DW loop was observed in the field.

CONCLUSIONS

(a) It is concluded that this type loop construction, with copper shielding, possessing several desirable operating features above that of the present type loop construction, be considered for use on future equipment of the DU-DV-DW and DU-1 series aircraft direction finder equipment.

(b) The loop winding is not affected by moisture or temperature changes and retains its electrical values during severe conditions of humidity-temperature variations and during rapid temperature changes.

(c) The reduced size of the loop permits of the use of a streamlined housing that would be practically prohibited with the Model DW loop; this would remove the loop from the air stream and allow of fairly simple remote control for rotation in addition to protecting the loop fitting and transmission line from water seepage.

RECOMMENDATIONS

The following recommendations are made in order to insure of maximum operating efficiency under service conditions:

(a) That the cementing process be developed to a stage wherein all traces of air pockets are removed when the loop sections are cemented together.

(b) Provide more substantial connector lugs wherein the loop leads are securely fastened mechanically to the connectors before making a soldered contact.

(c) That the loop surface, where the sections are cemented together, be rounded or smoothed off before the copper shield plating process is made.

DESCRIPTION OF MATERIAL UNDER TEST

4. Three Lucite composition type loops were submitted for test by The Scientific Coil Company of Cleveland, Ohio, consisting of two shielded and one unshielded loops. The loops are all identical in size, the loop winding consisting of 10 turns of #18 bare copper wire.

Dimensions of the loops are as follows:

Outside diameter	- 8"
Height	- 8 3/8"
Width	- 3/4"
Inside diameter	- 4 7/8"

5. The loop construction is not that of a completely moulded form as generally believed, the loop consisting of three pieces which are cemented together, apparently under pressure. The center piece contains the loop winding which is wound in threads so as to leave a flat surface on which outer pieces are cemented. This construction is shown on Plate 10. Depending upon the success of the cementing operation the loop winding would be impervious to moisture and possess sufficient mechanical strength to withstand service use. The shielded type loop is constructed the same as the plain unshielded loop and is then plated with copper to a depth of .003" which forms a complete electrostatic shield.

METHOD OF TEST

6. The loops having practically the same value of inductance as the Models DU and DW loops were compared for sensitivity with the Model DW by mounting the loops directly upon the Model DW Coupler Unit. Loop directional sensitivity was compared by use of the transmission line radiated field method which determines the field strength necessary to produce a receiver output of 10 milliwatts with a 4:1 signal plus noise to noise ratio. The receiver used with all loops was a Model RU-6.

7. The effect of varying temperature and humidity was determined by placing the loops within a temperature-humidity controlled cabinet. The loop was excited by a transmission line antenna whose radiated field strength was maintained constant. The loop was connected to a Model DW coupler unit located outside the cabinet; the coupler unit being connected to the input of a Model RU-6 receiver, the receiver gain was held constant and the output observed with changes of temperature and humidity at the loop location. The effect of humidity was observed by maintaining a temperature of 50°C and slowly increasing the relative humidity to 100% or saturation.

8. The effect of rapid temperature changes upon the coefficient of expansion and contraction of the Lucite was observed by submerging the loop in boiling water for one-half hour and then upon removal from the boiling water was immediately enclosed in dry ice for one-half hour; several cycles of this test were conducted.

9. The antenna effect or antenna pick-up of the unshielded loop and the deviation caused by nearby metal was observed by installing the unshielded loop within the rear cockpit of a metal hull airplane and bearings observed in comparison with a shielded Model DU direction finder.

DATA RECORDED DURING TESTS

10. The data recorded during the various tests consisted of the following:

(a) Expansion and contraction with rapid changes of temperature.

(b) Effect of temperature changes upon the loop sensitivity.

(c) Effect of high relative humidity upon the loop sensitivity.

(d) Comparison of sensitivity with Model DW loop.

(e) Comparison with Model DU loop in metal airplane.

(f) Loop distributed capacity.

(g) Values of loop "Q".

DISCUSSION OF PROBABLE ERRORS

11. The overall limits for the various measurements are estimated as follows:

Sensitivity	± 10%
Temperature	± 5%
Humidity	± 5%
Distributed capacity	± 1%
Value of Loop "Q"	± 1%

RESULTS OF TEST

12. Effect of Temperature - Humidity

(a) The results of the various tests show that this type of loop is impervious to temperature and humidity. The loop maintains its "Q" when subjected to a temperature of 60° C and a relative humidity of 100%.

(b) At a constant temperature of 60° C the loops were subjected to a relative humidity of 100%, the loss in sensitivity of the shielded loop was 3%, the unshielded loop showed a loss of 8%. Plate 1 and Table 1 give data taken on this test.

(c) After the above humidity test the loops were subjected to a constant temperature of 60° C with a relative humidity of 100% for a period of 8 hours. The shielded loop showed a loss in sensitivity of 3%. The unshielded loop, after 5 hours test, showed a loss of 60%. Upon examination it was found that a small air bubble had broken through the surface of the Lucite composition allowing moisture to penetrate to the loop winding. This puncture was repaired with polystryrene and the loop functioned normally again. The puncture was apparently caused by a large air bubble which broke through the surface when subjected to high temperatures. Plate 2 and Table 2 contain data on this test.

(d) It was noticed that there were many small air bubbles along the loop winding but these did not move or change shape during the temperature run. The bubble that broke through the outer surface was located at a sharp bend of the loop wire.

(e) It would appear from the above that care should be taken when cementing the loop together in that the loop windings fit tight in the slots to prevent large air pockets from remaining within the loop after sealing the form together.

(f) The loops were tested to observe the effect of rapid temperature changes upon the expansion of the Lucite form to determine if the Lucite was subject to fractures. The loop forms were immersed in hot water at a constant temperature of 60° C for a period of one-half hour after which they were immediately enclosed with dry ice, the temperatures of the loop form varying from -40 to -50° C. This cycle was repeated five times and there was no indication of fractures on any of the three loop forms.

(g) As the loop form is composed of three pieces, and is not a completely moulded form as was generally believed, a test was made to determine under what conditions these pieces would disseminate and render the loop inoperative.

(h) A copper plated shielded type and the unshielded loop were placed in a hot water bath of 60° C for 8 hours without any evidence of cracking or peeling of the shield.

(i) After this 8 hour submersion in a 60° C bath the loops were firmly held at the base and a pressure pull applied to the top of the loop form to determine the softness of the Lucite after having been subjected to a temperature of 60° C for 8 hours.

(j) The amount of pull applied at the top of the loop to bend the loop 1/8" off center was 6 lbs.

(k) The loops were immersed in dry ice for a period of 5 hours at an average temperature of -43° C after which they were dropped on a hard surface and repeatedly struck with a hard metal object. The pressure applied at the top of the loop required 8 lbs to bend the form 1/8". There were no indications of fractures in the Lucite during the above tests.

(l) A test was conducted to determine under what conditions the expansion of the loop form would break the cementing and thus crack the plated copper shield.

(m) A shielded loop was immersed in hot water maintained at boiling point (212° C), after 3 hours the outside portions of the loop form began to break away from the inner piece which contains the loop winding. The copper shield was broken at several points around the outside periphery of the loop form; after 5 hours the loop was completely ruined as can be seen from Plate 11.

(n) The results of these temperature-humidity tests indicate that under conditions of normal service, that is, at temperature from -30 to 60° C and with a relative humidity in excess of 95%, this type loop construction will offer improved operating service over that of the present type shielded loops used on the Model DU, DV, DW and DU-1 equipment.

Sensitivity

13. The sensitivity of the "Lucite" loops were compared with that of the Model DU and DW loops. As the inductance of the Lucite loops are practically the same as that of the DU and DW loops comparison was made by using the DW and DU coupling units.

14. The sensitivity of the DW equipment, using the Lucite loops is less than when using the DW loop as the effective height of the Lucite loop is less than that of the DW loop.

15. The Model DW loop is 10 1/2" mean diameter and has a loop winding of 6 turns while the Lucite loops are 6 1/2" mean diameter and have 10 turns of winding, thus the effective height of the DW loop is 55% greater than the Lucite loops. In order for a direct comparison the effective height of the two loops should be equal; this would require an additional 5 turns on the Lucite loop for a total of 15 turns.

16. The only reason that a comparison was made between the DW and Lucite loops is that both loops have practically equal inductance and would match the coupling transformer input impedance.

17. As mentioned above, the effective height of the Lucite loop is 55% less than the DW loop but the overall sensitivity when using the Lucite loop in place of the DW loop is much better than the ratio of effective heights would indicate. This is due to the higher Q value of the Lucite loops which becomes an important factor in the overall sensitivity. The sensitivity factor is the product of the loop effective height and the value of loop Q, (Q H eff).

18. Although the average value of Q for the shielded Lucite loop is 20% greater than that of the DW loop the result is an average overall sensitivity of the DW loop, whose effective height is 55% greater than the Lucite loop, of 24% greater than the Lucite loop. This means that if the effective height of the two loops were equal, then the Lucite loop would have a greater sensitivity than the DW loop due to the higher value of "Q". Calculations and measurements have shown that if the two loop effective heights are equal then the sensitivity will vary as the square root of the "Q" value ($\sqrt{Q}$).

19. It would seem logical, from the above, to increase the loop turns of the Lucite loop from 10 to 15 turns which would give the Lucite loop the same effective height as the DW loop, and then use to advantage the increased sensitivity due to the higher "Q" of the Lucite loop.

20. This is based on the fact that the "Q" is equal to $\frac{WL}{R}$ and it could be expected that the inductance will increase at a greater rate than the resistance provided the same size wire is used. This could result in a 6 1/2" diameter loop having a directional sensitivity approximately 20% greater than that of the standard 12" diameter loop used with the Model DW-DU-1 series equipment. This, however, increases the inductance 2.44 times which results in a loop impedance of approximately three times that of the DW loops.

21. This would mean a loop whose impedance would be practically equal to that of the old RDF series equipment and would revert back to the so-called high impedance loop. However, it would appear more practicable to retain the low impedance loop in view of previous experience with high impedance loops and this may be accomplished by proper loop coupling transformers designed to give a resulting directional sensitivity equal to that of the present Model DU-1 equipment. This does not appear to present a severe engineering problem.

The transmission line would also have a low impedance characteristic which would be less effected by moisture and water seepage than the higher impedance lines.

22. The shielded type Lucite loop performed satisfactorily as a unilateral direction finder, practically as good as the Model DU and DW, ratios of unilateral maximum to minimum greater than 10 to 1 were obtained over the frequency range of 500 to 1500 kcs using the same sense antenna as with the Models DU and DW.

23. From the results of the tests conducted on the Lucite loops, especially with regard to their operation with severe conditions of temperature and humidity, it is recommended that this type loop construction be considered for use on future equipment of the DU-DW and DU-1 type.

24. The use of smaller diameter loops will permit using a stream line housing to exclude the loop from the air stream. This housing would be fairly small for 6 1/2 diameter loops and could be of the moulded fabric type, this would also serve to protect the loop and transmission line from water seepage.

25. The shielded and unshielded loops were mounted on a Model DU Coupler Unit and compared with a Model DU loop in a Type SBC-4 metal airplane for deviation caused by surrounding metal. No excessive deviation was observed when using the Lucite loops. Data on these tests is contained in Table Number 9.

CONCLUSIONS

26. It is concluded that this type loop construction, with copper shielding, possessing several desirable operating features above that of the present type loop construction, be considered for use on future equipment of the DU-DV-DW and DU-1 series aircraft direction finder equipment.

27. The loop winding is not affected by moisture or temperature changes and retains its electrical values during severe conditions of humidity-temperature variations and during rapid temperature changes.

28. The reduced size of the loop permits of the use of a streamlined housing that would be practically prohibited with the Model DW loop; this would remove the loop from the air stream and allow of fairly simple remote control for rotation in addition to protecting the loop fitting and transmission line from water seepage.

TABLE 1.

COMPARISON OF LOOP Q

Capacity uuf	DW Loop Freq. Kcs.	Q	Lucite Shielded Freq. Kcs.	Q	Lucite Unshielded Freq. Kcs.	Q
0	5100	60	4640	97	4070	70
50	4340	73	3950	124	3575	97
100	3300	98	3000	163	2680	145
200	2410	120	2200	180	1980	190
300	2000	125	1800	183	1630	205
400	1730	132	1570	180	1430	205
700	1260	125	1150	152	1040	183
900	1130	131	1030	150	930	176
1200	1000	130	905	140	825	170
1400	930	132	840	137	770	168
2500	750	126	680	125	618	157
5000	470	110	420	95	385	126
7500	400	105	365	88	330	115
10000	380	103	345	85	315	113

TABLE 2

COMPARISON OF LOOP Q

One Side of Loop Grounded

Capacity uuf	DW LOOP Freq. Kcs.	Q	Lucite Shielded Freq. Kcs.	Q	Lucite Unshielded Freq. Kcs.	Q
0	4720	40	3940	55	3700	47
50	4070	55	3460	78	3120	60
100	3180	77	2770	118	2680	85
200	2380	102	2100	153	1940	114
400	1660	122	1535	170	1410	131
600	1350	123	1210	151	1170	140
800	1180	130	1070	151	965	142
1000	1100	135	980	153	870	142
1400	940	139	850	148	760	150
2500	680	133	610	126	560	139
5000	468	110	410	97	382	121

TABLE 3

COMPARISON OF LOOP SENSITIVITY FACTOR (K)

DW Loop				Lucite Shielded				
Freq. Kcs.	H eff uu	Q	K	Freq. Kcs.	H eff uu	Q	K	DW / Lucite
300	2.1	90	189	300	1.3	80	104	1.81
400	2.8	105	294	400	1.8	95	171	1.72
500	3.5	110	385	500	2.3	105	242	1.59
700	4.8	125	600	700	3.1	127	394	1.52
1000	7.0	128	895	1000	4.5	150	675	1.32
1200	8.4	125	1050	1200	5.4	165	890	1.18
1500	10.5	130	1365	1500	6.7	180	1200	1.14

TABLE 3 (Continued)

ASSUMING EQUAL H eff AND LUCITE Q

DW Loop		Lucite Shielded		
Freq. Kcs.	K	Freq. Kcs	K	DW / Lucite
300	189	300	168	1.12
400	294	400	266	1.10
500	385	500	367	1.05
700	600	700	610	.84
1000	895	1000	1050	.86
1200	1050	1200	1385	.76
1500	1365	1500	1890	.73

TABLE 4.

COMPARISON OF DW AND LUCITE LOOP
Directional Sensitivity using Model DW Coupler Unit and RU-6 Receiver. NCW Sensitivity.

Sensitivity, microvolts per meter.

Freq. Kcs	DW	Lucite Shielded	DW / Lucite
200	71	92	21%
400	58	75	29%
600	47	64	26%
800	39	54	28%
1000	32	44	27%
1200	27	36	25%
1500	26	34	23

Model DW loop has 50% greater effective height than Lucite loop.
Lucite loop less 20% greater "Q" than Model DW loop.
Sensitivity measured by transmission line method, 4:1 ratio signal plus noise to noise, standard output 10 milliwatts.

TABLE 5

COMPARISON OF LOOP SENSITIVITY

Relative Received Signal Strength
Model DW Coupler Unit and RU-6 Receiver used.

Freq. Kcs.	Model DW Output Volts	Lucite Shielded Output Volts	DW / Lucite %
232	10	6.9	31
600	10	6.9	31
630	10	7.0	30
950	10	7.5	25
1060	10	7.0	30
1170	10	7.7	23
1460	10	7.1	29

Model DW loop has % greater effective height than Lucite loop
Lucite loop has 20% greater "Q" than Model DW loop.

TABLE 6

Effect of Temperature - Humidity
Lucite Loops
Temperature 60° C

% Humidity	Shielded Loop Output Volts	Shielded Loop % Loss	Unshielded Loop Output Volts	Unshielded Loop % Loss
30	10	0	10	0
40	10	0	10	0
50	10	0	10	0
60	10	0	10	0
70	10	0	9.8	2
80	10	0	9.4	6
90	10	0	9.2	8
95	9.9	1	9.2	8
100	9.7	3	9.2	8

TABLE 7

Effect of Temperature - Humidity
Lucite Loops
Temperature 60° C

Humidity in excess of 95%

Time Hours	Shielded Loop Output Volts	% Loss	Unshielded Loop Output Volts	% Loss
1	10	0	10	0
2	10	0	10	0
3	10	0	10	0
4	10	0	9.8	2
5	10	0	4.0	*60
6	10	0	9.7	3
7	9.9	1	9.7	3
8	9.8	2	9.7	3

* Loop punctured, was repaired and test continued.

TABLE 8

Comparison of Loop "Q"

Freq. Kcs.	Model DW "Q"	Lucite Shielded "Q"	Lucite / Model DW
300	80	82	.97
500	115	108	.84
600	124	127	1.024
800	138	145	1.05
1000	138	153	1.11
1200	129	150	1.16
1400	122	162	1.33
1600	121	168	1.39
1800	119	165	1.39
2000	112	157	1.40

TABLE 9

Comparison of Loop Deviation in Airplane
Model DU Equipment used as standard.

Bearing, degrees azimuth

Freq. Kcs	Model DU	Lucite Shielded	Error	Lucite Unshielded	Error
232	330	330	0	332	+2
600	41	41	0	44	+3
710	37	38	+1	42	+5
950	12	13	+1	10	-2
1060	26	26	0	21	-5
1170	44	44	0	43	-1
1210	17	18	+1	20	+3
1460	352	351	-1	349	-3

Loops mounted in rear cockpit of scouting plane, metal fuselage.

TABLE 10

Loop Distributed Capacity

	Model DW	Lucite Shielded	Lucite Unshielded
Capacity, uuf	18.6	17.0	18.6

TABLE 11

Loop D.C. Resistance

	Model DW	Lucite Shielded	Lucite Unshielded
Resistance, ohms	.15	.18	.20

TABLE 12

Loop Inductance

	Model DW	Lucite Shielded	Lucite Unshielded
Inductance, uh	25.6	21	31

TABLE 13

Weights of Loops

Model DW	Lucite Shielded	Lucite Unshielded
2 lbs. 2 oz.	13 oz.	13 oz.

TABLE 14

Loop Dimensions

Model DW	Lucite
a - 8 3/4"	a - 5"
b - 12"	b - 8"
c - 12 3/4"	c - 8 1/2"

Dimensions referred to Plate No. 8.

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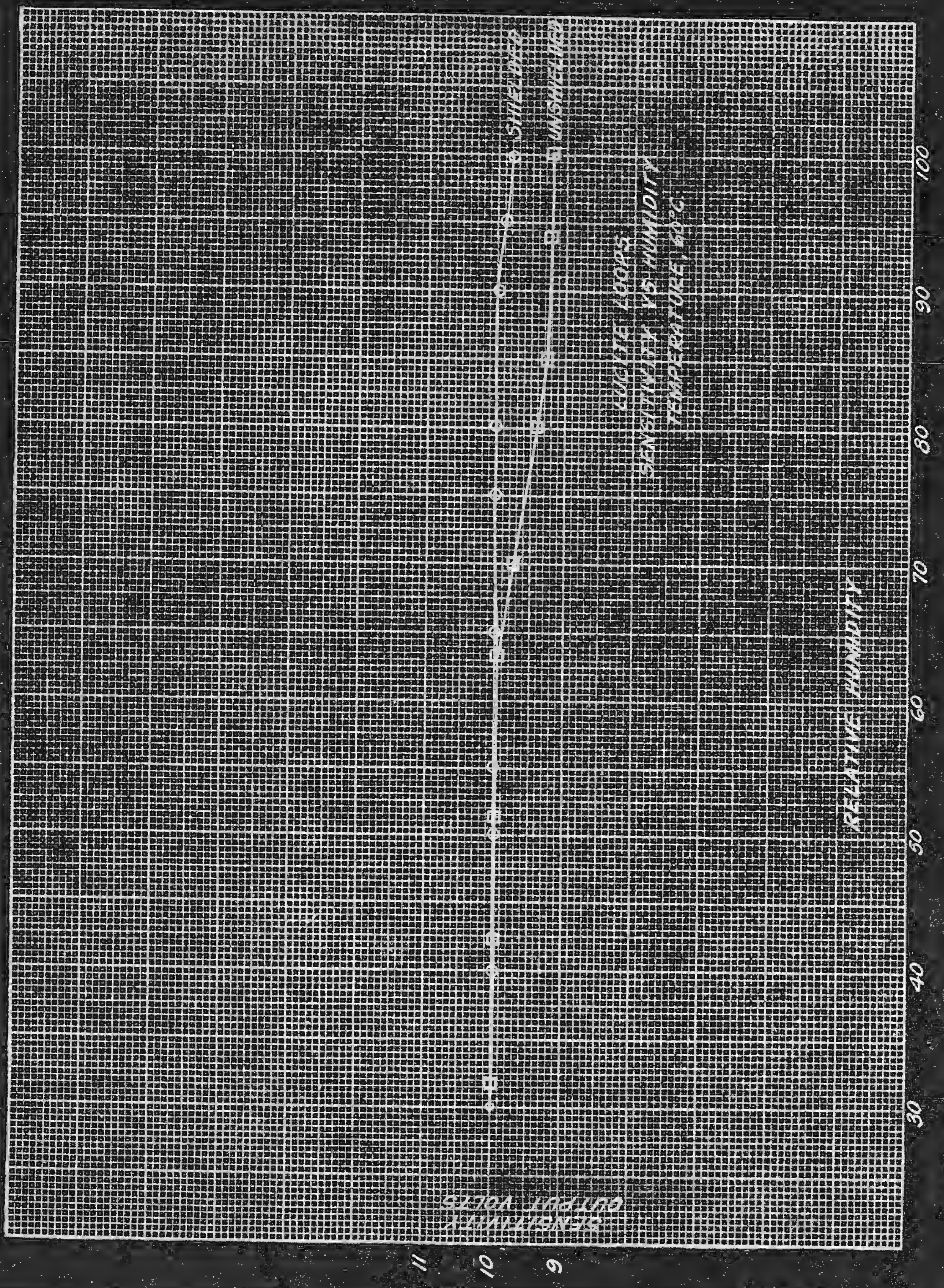

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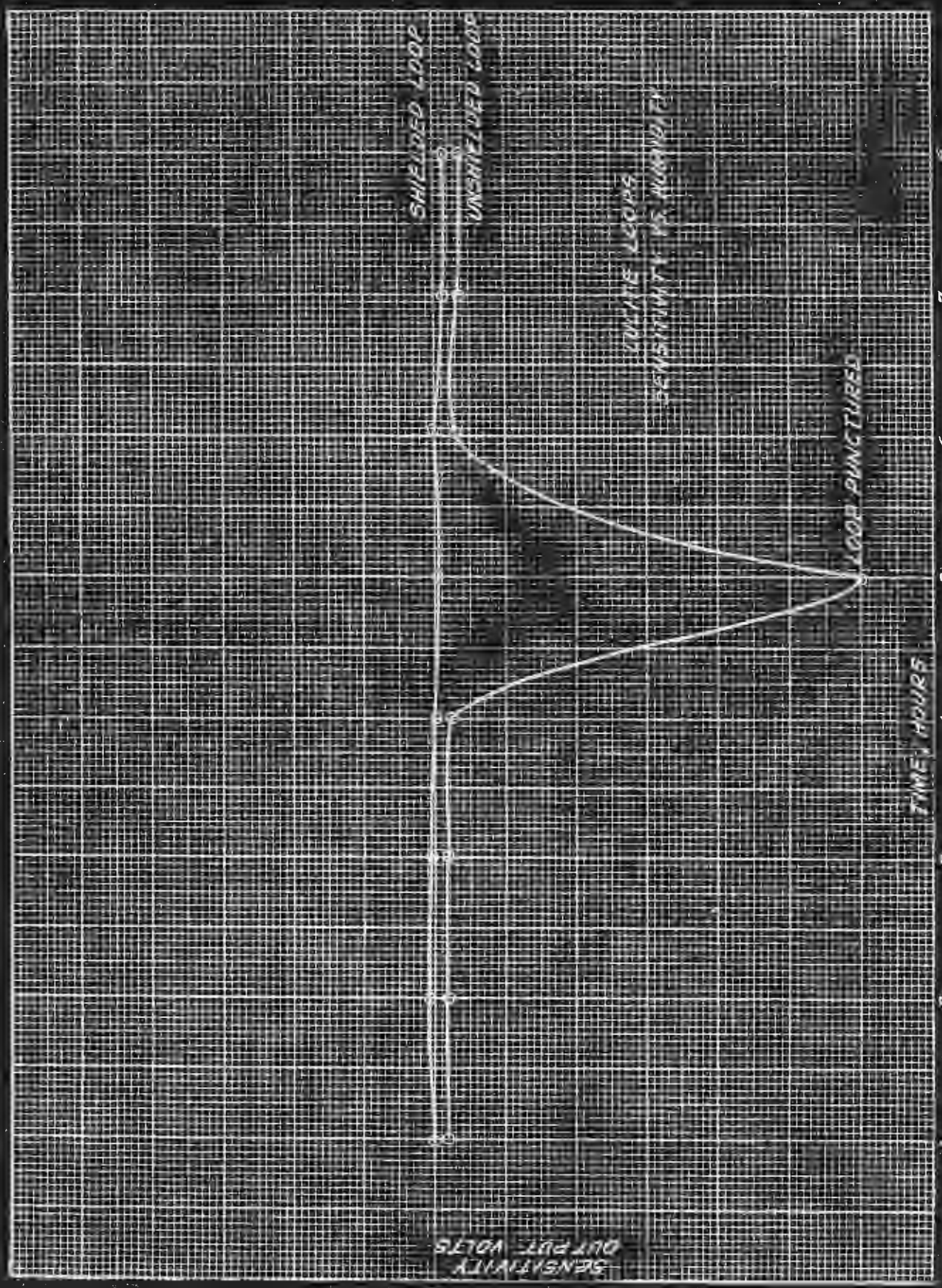

PLATE 2

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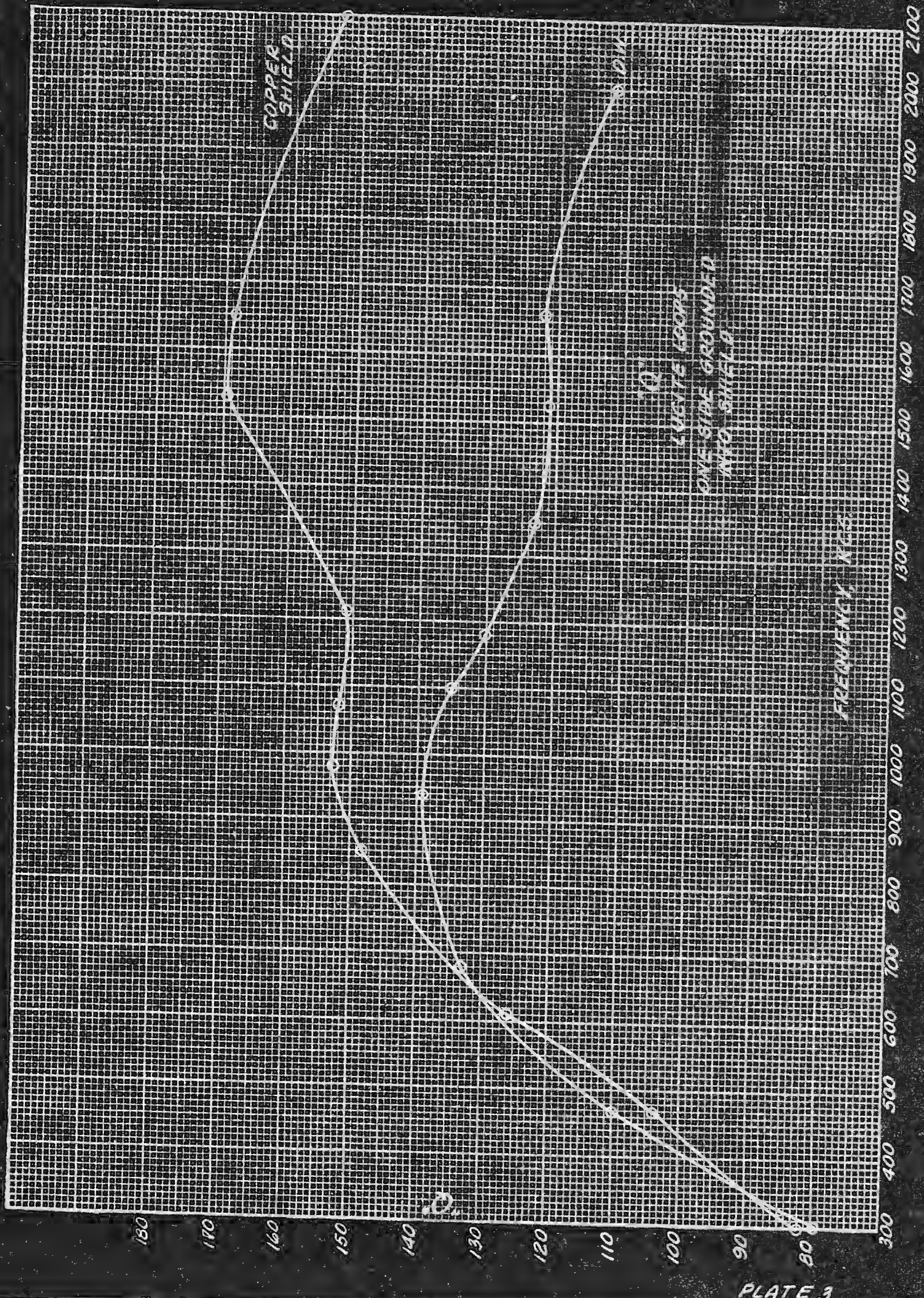

PLATE 3

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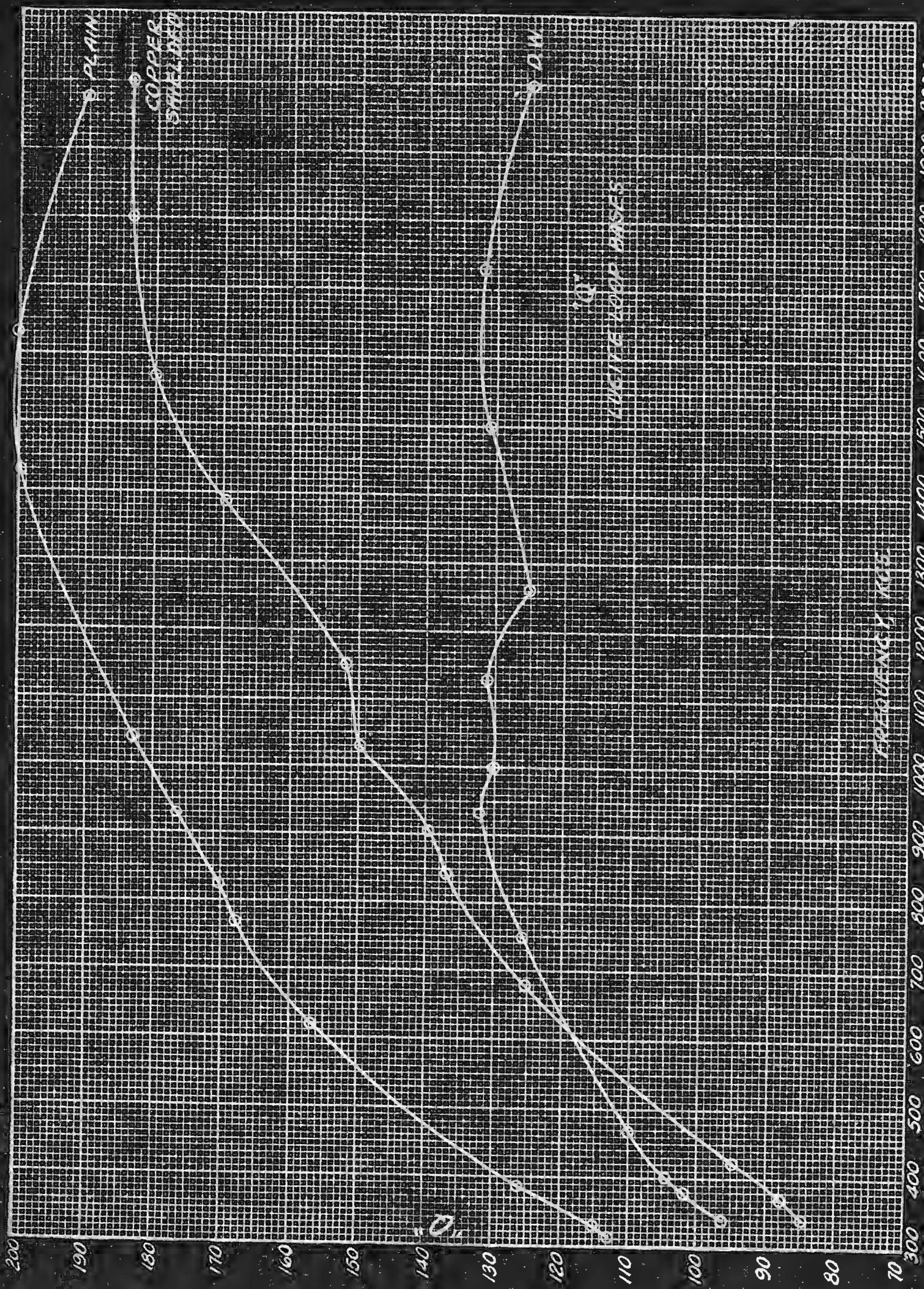

PLATE 4

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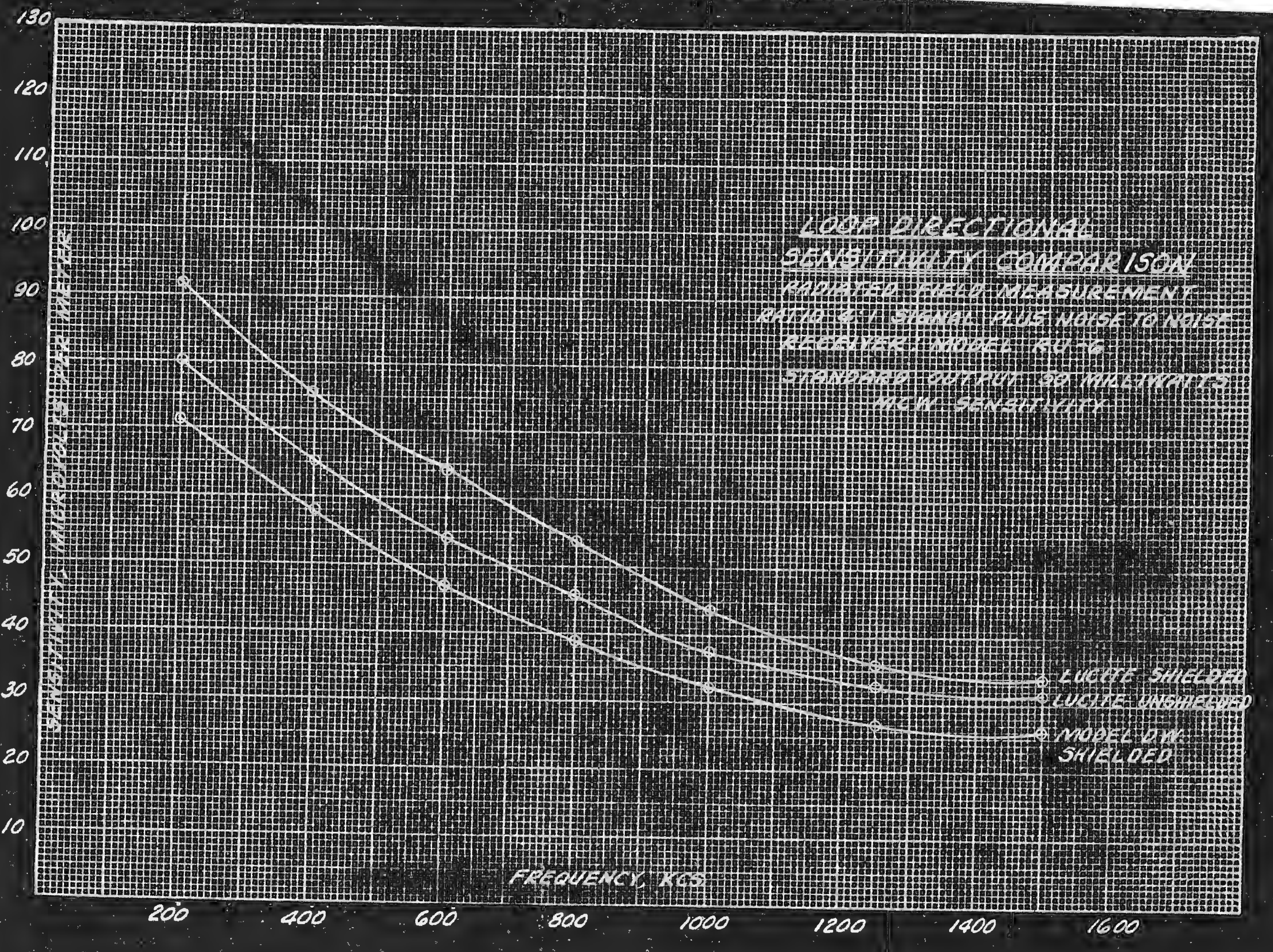


PLATE 5

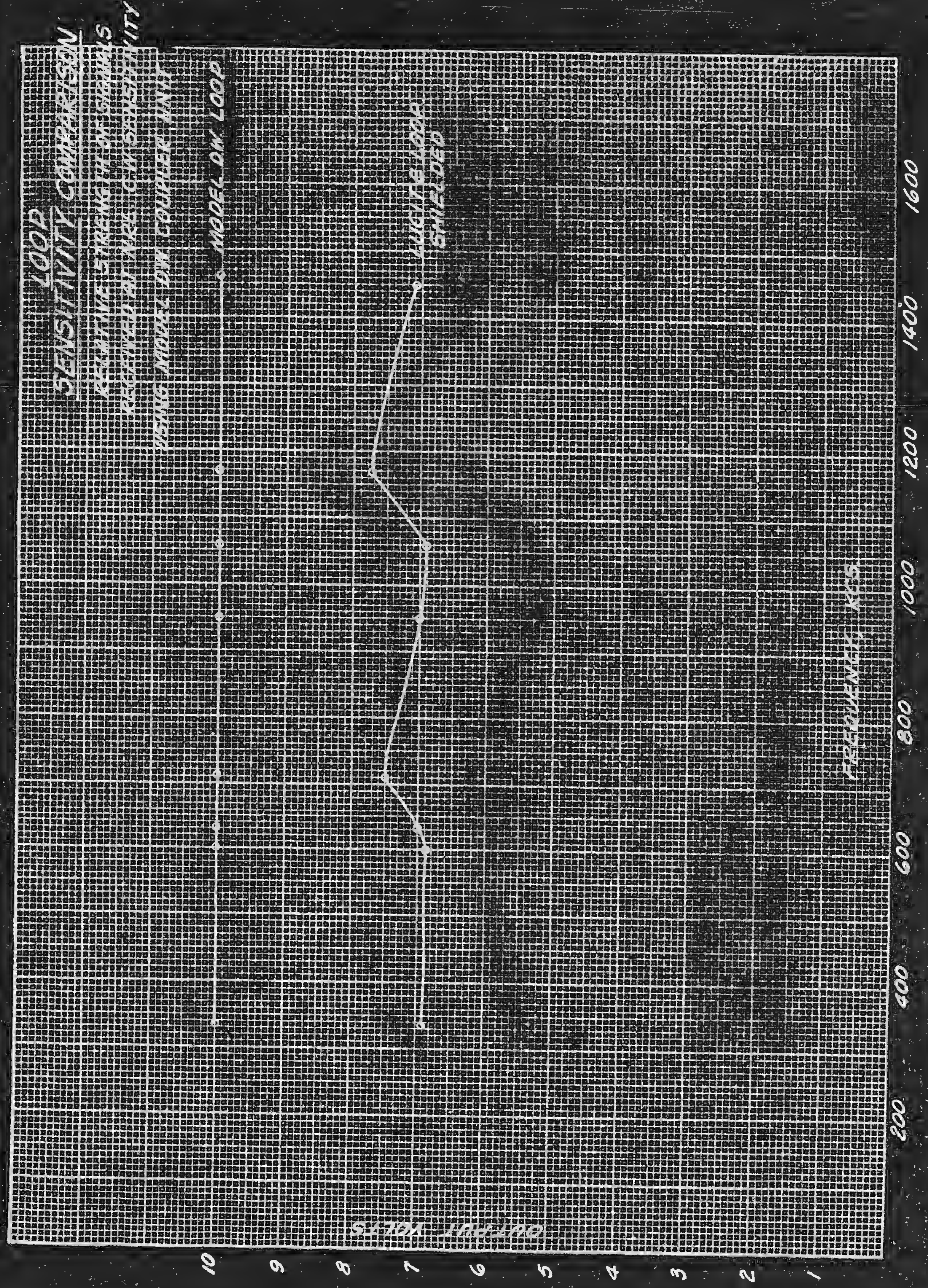
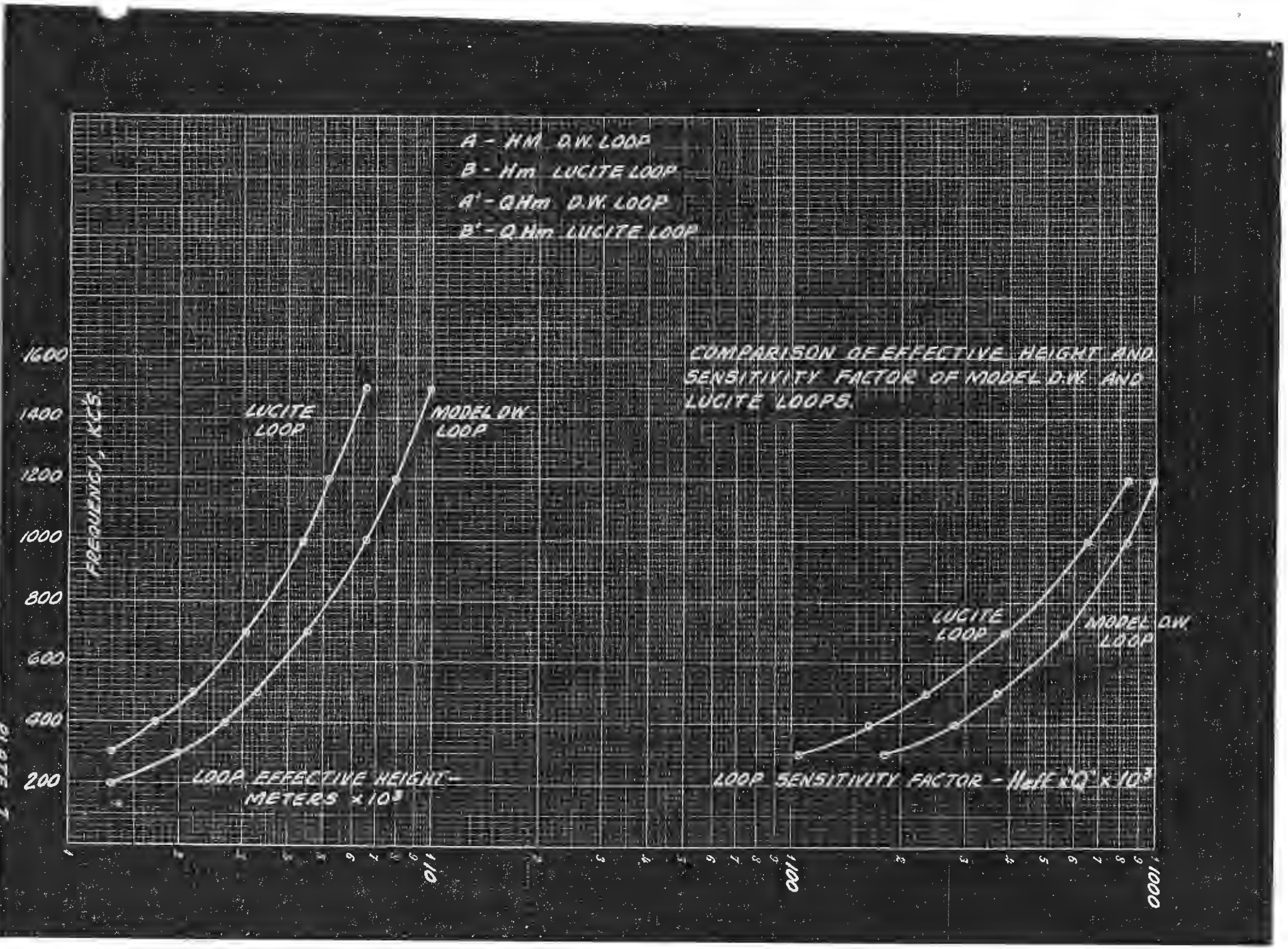
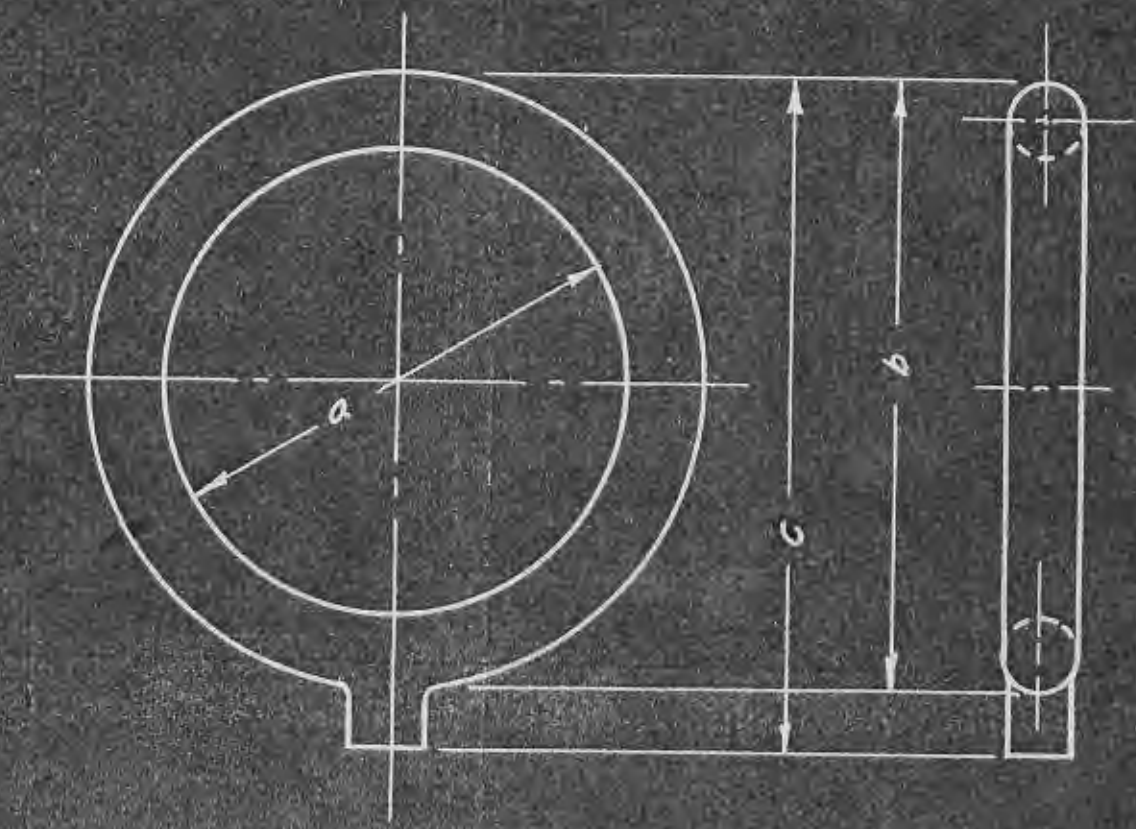

LOOP
SENSITIVITY COMPARISON
RELATIVE STRENGTH OF SIGNALS
USING MODEL DW COUPLER UNIT
MODEL DW LOOP
LUCITE LOOP
SHIELDED
FREQUENCY, KCS
OUTPUT VOLTS
200
400
600
800
1000
1200
1400
1600
10
9
8
7
6
5
4
3
2
1

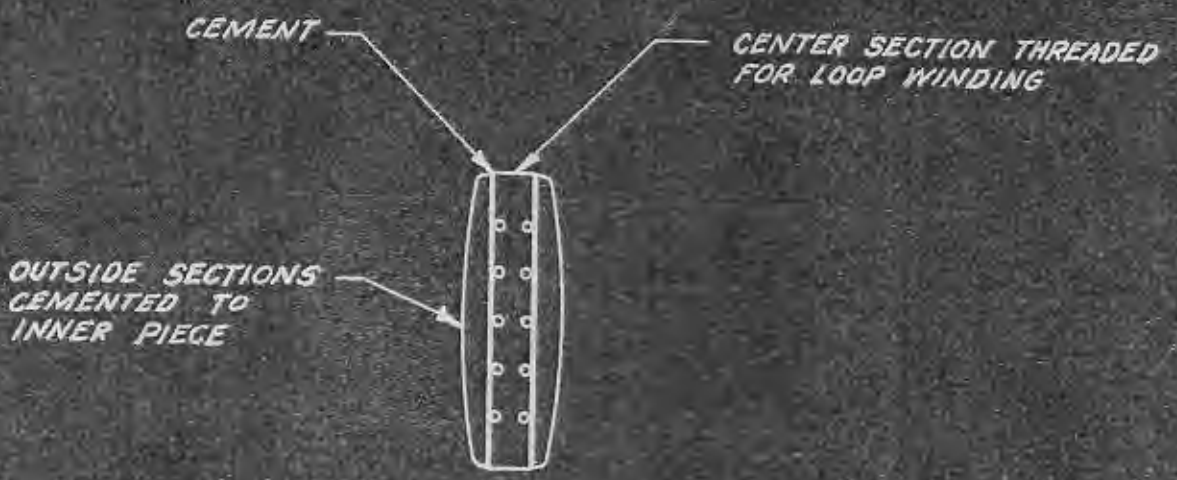
PLATE 6


A - Hm D.W. LOOP
B - Hm LUCITE LOOP
A' - Q Hm D.W. LOOP
B' - Q Hm LUCITE LOOP
COMPARISON OF EFFECTIVE HEIGHT AND SENSITIVITY FACTOR OF MODEL D.W. AND LUCITE LOOPS.
FREQUENCY, KC/S
1600
1400
1200
1000
800
600
400
200
LUCITE LOOP
MODEL D.W. LOOP
LOOP EFFECTIVE HEIGHT - METERS x 10³
LUCITE LOOP
MODEL D.W. LOOP
LOOP SENSITIVITY FACTOR - Heff "Q" x 10³
100
1000



LOOP DIMENSIONS

PLATE 8



CROSS SECTION OF LOOP CONSTRUCTION

PLATE 9