JSC-11159

ACOUSTIC SENSOR
ENGINEERING EVALUATION TEST REPORT

Job Order 39-429

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For

CONTROL SYSTEMS DEVELOPMENT DIVISION

National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
Houston, Texas

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PROJECT SPACE SHUTTLE

ACOUSTIC SENSOR ENGINEERING EVALUATION TEST REPORT

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FOREWORD

This report documents the results of engineering evaluation tests performed on two types of acoustic sound pressure level sensors at Johnson Space Center, Houston, Texas. These sensors are candidates for use on the Shuttle Orbiter vehicle to monitor ambient noise in the crew compartment during crew rest periods. Prior to the test activity, the piezoelectric device was favored because it is less expensive and directly compatible with the on-board Wideband Signal Conditioner (WSC). The more precise capacitive type sensor is generally regarded as "the standard of the industry" and requires a special power supply and a preamplifier to interface the sensor with the Shuttle instrumentation system electronics.

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SECTION PAGE

1.0 SUMMARY

Eight one-inch diameter acoustic sensors were subjected to the evaluation tests. There were four each capacitive ("condenser") microphones, Bruel and Kjaer (B&K) Model 4161, and four each piezoelectric microphones, B&K Model 4117. Three sensors of each type were subjected to environmental exposures of temperature, humidity and vibration. The fourth sensor of each type was not exposed to these environments and served as a reference unit for each group.

Except for the humidity exposures, which were passive, each Model 4161 capacitive sensor was individually tested in sequence with the essential polarization voltage power supply, B&K Model 2807, and preamplifier, B&K Model 2619. One unit exhibited anomalous characteristics after the humidity exposure. The unit subsequently returned to normal after being dried out in an oven at 115°F for two hours.

Except for the passive humidity exposures, each B&K Model 4117 piezoelectric sensor was also individually tested, sequentially, with a laboratory type charge amplifier, Endevco Model 2730. Two apparent failures occurred during these tests. The diaphragm on one sensor was found to be ruptured after the fourth cycle of the passive humidity exposure. A second sensor showed an anomaly after random vibration tests, at which time the sensor sensitivity was consistent at about one-half of its former value, -6.3 dB error. The diaphragm appeared normal in the second unit.

The test methods and procedures used were essentially as described in LEC-6884, Acoustic Sensor Evaluation Test Procedures, no date.

2.0 SENSORS TESTED

The four each B&K Model 4161 and 4117 test articles were new units procured by Lockheed Electronics Company, Inc. for these tests. The serial numbers were as follows:

Model	Serial Numbers
4161	541898, 541937, 541938, and 541939
4117	535219, 535221, 535228, and 535234

The B&K Model 4161 microphone is a free-field sound measurement sensor, which simply means the sensor has a minimal effect on the sound field in which it is placed. The microphone is one inch in diameter and utilizes the capacitive or condenser principle of transduction. The sensor requires 200 volt direct current (Vdc) for polarization and a preamplifier to condition the high impedance output signal. High stability, flat linear response, and relatively high sensitivity make the capacitive microphone system the most suitable system available for precisely measuring sound pressures for many applications.

The B&K Model 4117 sensor is also a one-inch diameter free-field microphone. However, the electrical output signal is self-generated by the piezoelectric transduction principle. The favorable characteristics of this device include low cost, very high signal source capacitance, and the fact that polarization voltage is not required. In addition, the effects of water condensation on the back of the diaphragm are not as severe as in the capacitive type microphone. According to the manufacturer, however, this type of microphone does not adequately fulfill the requirements for precision sound pressure measurements.

3.0 TEST EQUIPMENT AND SETUPS

The test equipment and environmental test apparatus used are listed in Tables I and II, respectively.

Figures 3-1A and 3-1B show the test setup configuration for the Model 4161 capacitive microphone and the Model 4117 piezoelectric microphone, respectively, used during the baseline calibration, temperature, confidence checking and post-environmental tests. The same figures are applicable to the vibration tests except the sound level calibrator was not utilized.

The Amplitude Linearity and Frequency Response tests utilized the same equipment, except an oscillator and the Dees calibrator were substituted for the B&K Calibrator. The setups for these tests are shown in Figures 3-2A and 3-2B for the Model 4161 and 4117 respectively.

The humidity tests were passive exposures and therefore no test setup is shown.

TABLE I. — TEST EQUIPMENT — ACOUSTIC SENSOR EVALUATION TEST

Item No.	Description	Manufacturer	Model No.	Serial No./ ID No.	Error Tolerance	Test Function
1	Acoustic Calibrator	Dees Electronics/ Photocon Systems	9005	2087	±1 dB (-10.9%, +12.2%)	Input stimulus (pressure-frequency response)
2	Adapter for Bruel & Kjaer Type 4161 Microphone	Dees Electronics/ Photocon Systems		4074		Mount test microphone in calibrator
3	Oscillator	Hewlett-Packard	3310B	1201A00951		Frequency source
4	Power Supply	Bruel & Kjaer	2807	524367		Excite system
5	Counter, electronic	Hewlett-Packard	5233L	512-01560		Set frequency of oscillator
6	Digital voltmeter	Fluke	8120A	61988	0.01%	Read output

TABLE I. — TEST EQUIPMENT — ACOUSTIC SENSOR EVALUATION TEST (CONCLUDED)

Item No.	Description	Manufacturer	Model No.	Serial No./ ID No.	Error Tolerance	Test Function
7	Oscilloscope	Tektronix	502A	51088		Observe waveshape
8	Preamplifier	Bruel & Kjaer	2619	539802 539992		Impedance conversion
9	Sound Level Calibrator	Bruel & Kjaer	4230	542701	±0.25 dB (±3%)	Calibration at 93.6 dB SPL, 1,000 Hz
10	Adapter	Bruel & Kjaer	DB0375	--		Connect 1-inch microphone to 1/2-inch preamplifier
11	Adapter	Bruel & Kjaer	UA0310	4207		Interface between test microphone sensor and DB0375 Adapter after humidity (ONLY AS NECESSARY)
12	Analog Voltmeter, true rms	Ballantine Laboratories, Inc.	32307	020-2205	2% Actual	Monitor output during random vibration
13	Charge Amplifier	Endevco	2730	AD40 and AD42	±0.1 dB	Condition output signal of B&K Model 4117 microphone

TABLE II. – ENVIRONMENTAL EQUIPMENT

Item No.	Description	Manufacturer	Model No.	Error Tolerance	Test Function
1	Temperature Chamber	Delta Design		±2.8°C (±5°F)	Temperature exposure and thermal shock exposure
2	Humidity Chamber	Blue M	FR366 PBX		Humidity exposure
3	General vibration lab excitation system	MB	C-126		Vibration test
4	Quartz thermometer	Hewlett-Packard	2801A	±0.1°C (±0.2°F)	Measure air temperature in chamber

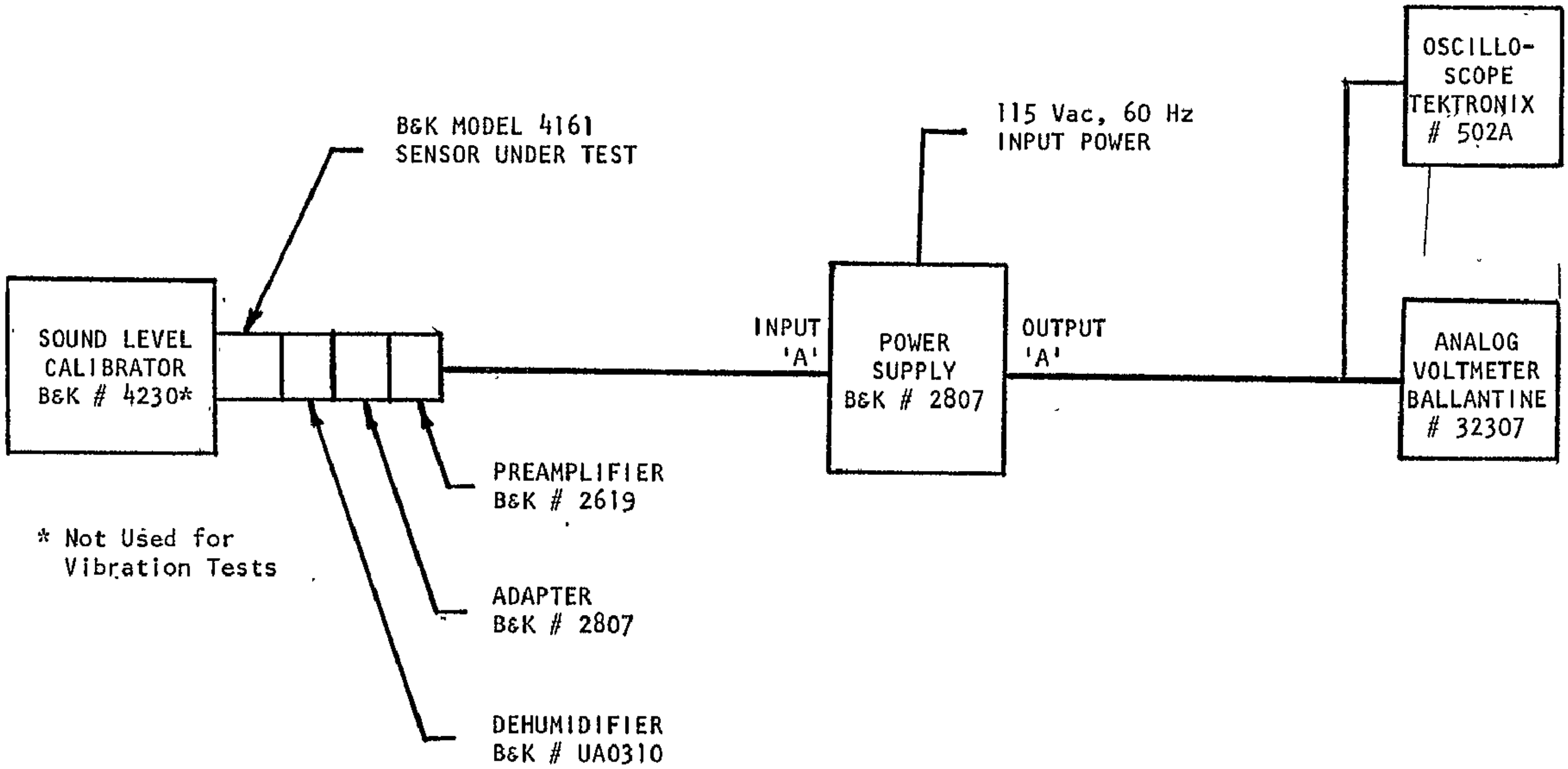

FIGURE 3-1A. - B&K Model 4161 test setup (except frequency response, amplitude, linearity and humidity).

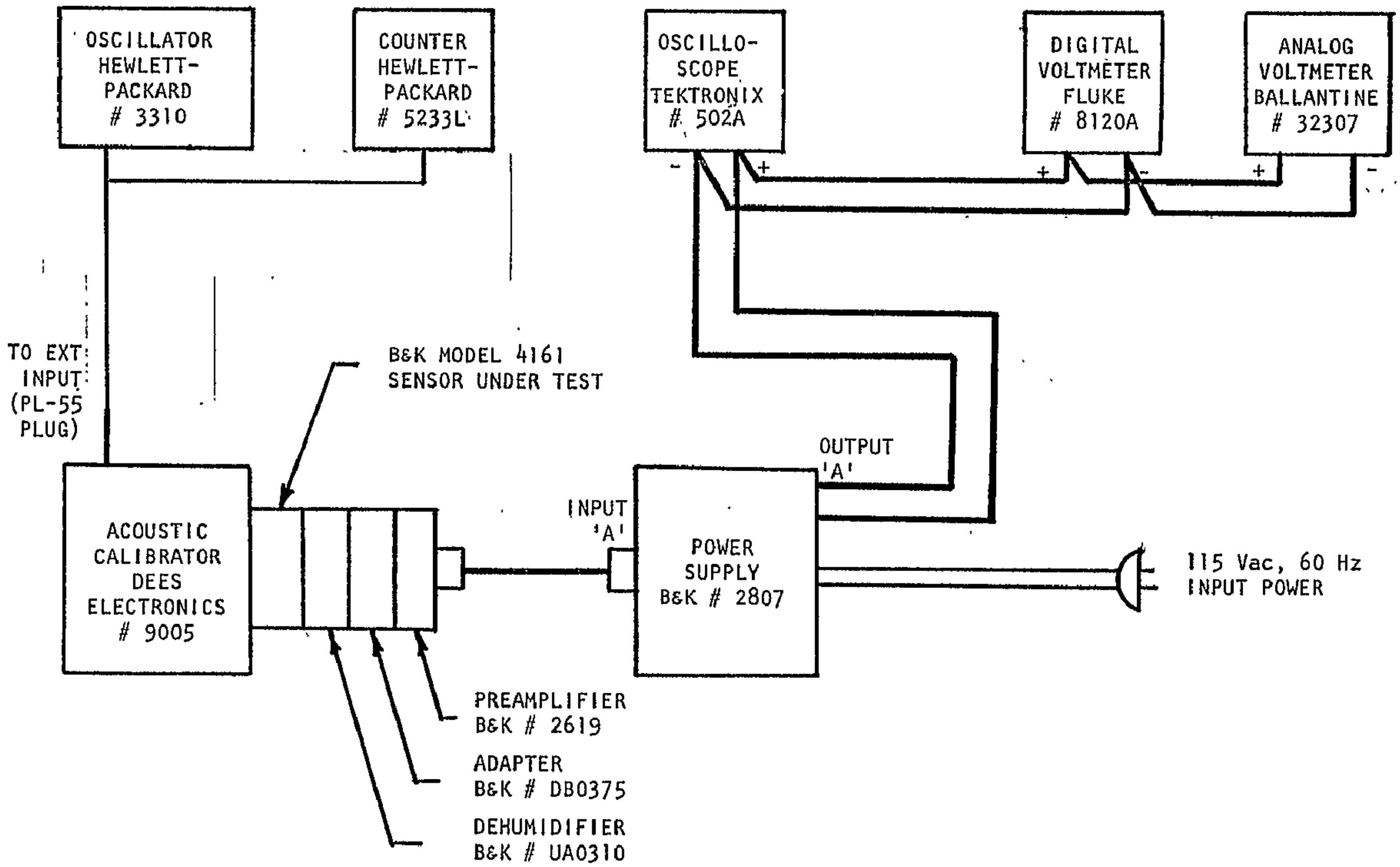

FIGURE 3-1B. - B&K Model 4161 frequency response and amplitude linearity test setup.

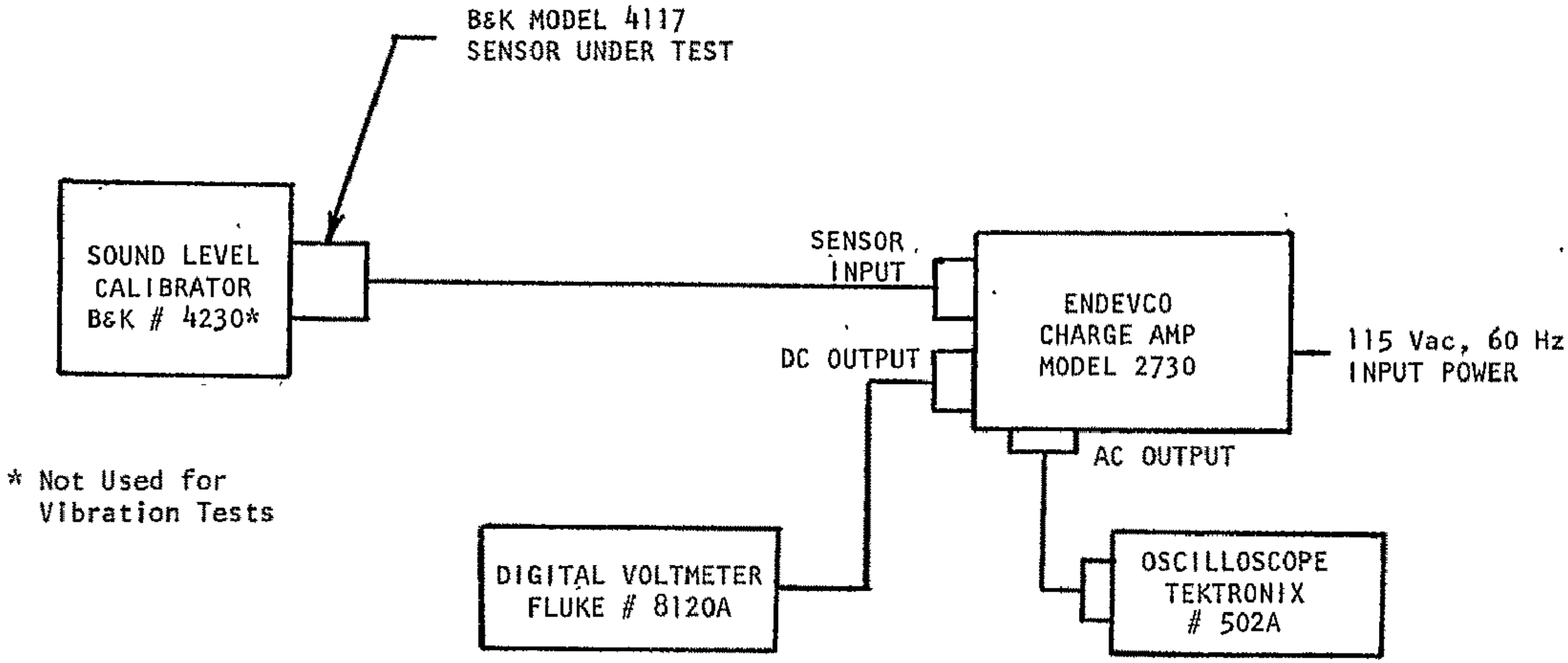

FIGURE 3-2A. - B&K Model 4117 test setup (except frequency response, amplitude, linearity and humidity).

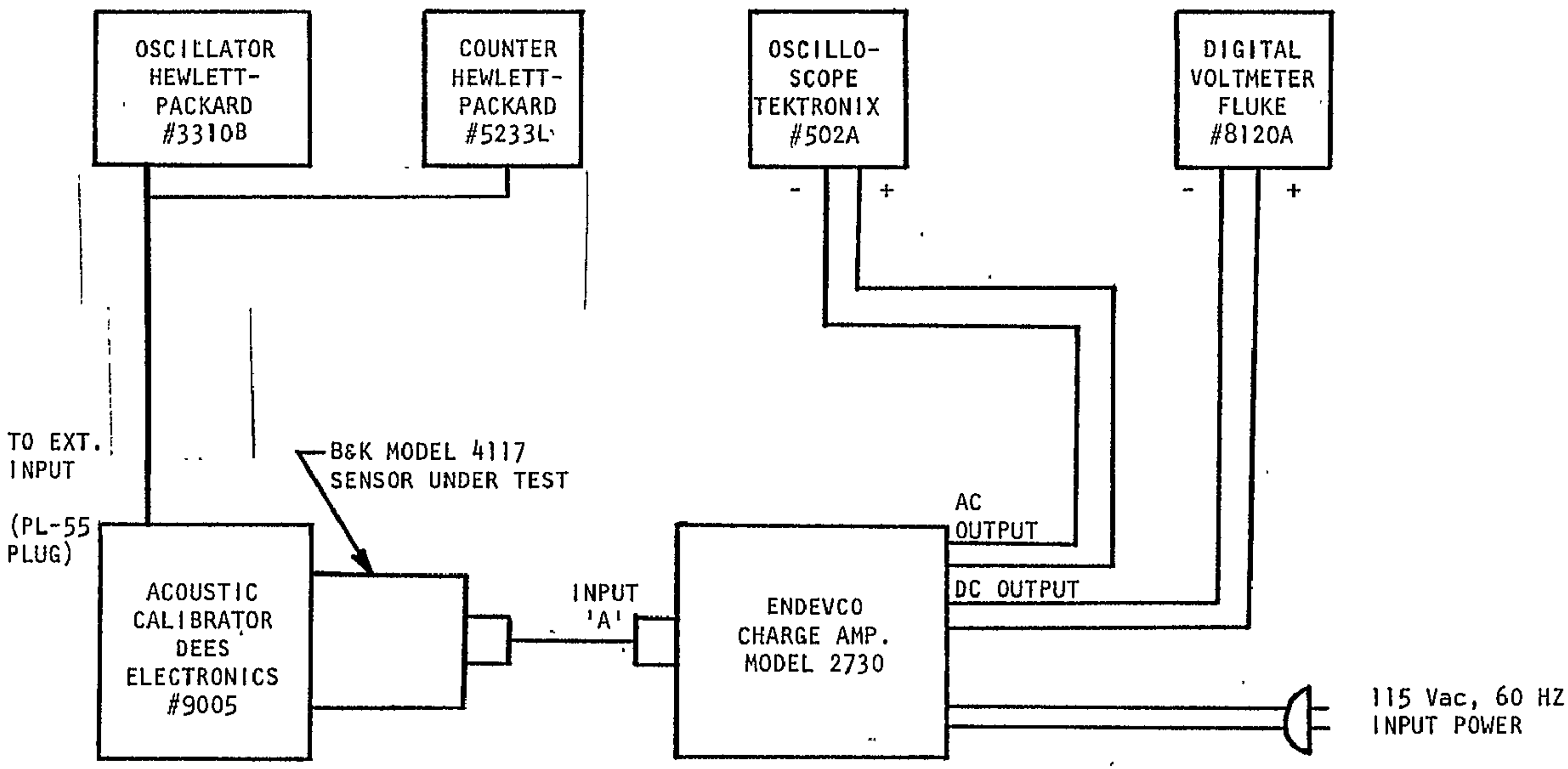

FIGURE 3-2B. - B&K Model 4117 frequency response and amplitude linearity test setup.

4.0 TEST DESCRIPTION

The test methods and procedures used were essentially as described in LEC-6884, Acoustic Sensor Evaluation Test Procedures, no date. A brief description of the tests, in the order in which they were performed, is included in this section.

4.1 Pre-environmental Tests

4.1.1 Visual Inspection - A thorough visual examination was made of each of the eight test articles, including the electrical connection. The primary purpose of the inspection was to detect and note any evidence of poor workmanship or possible physical damage.

4.1.2 Calibration - Baseline calibration data consisting of three independent measurements on each of the eight sensors was obtained. The test setup shown in Figure 3-1A was used for the four Model 4161 sensors, and the setup shown in Figure 3-2A was used for the four Model 4117 sensors. A warmup time of 30 minutes was allowed prior to making the measurements.

The B&K Sound Level Calibrator, Model 4230, produced 94 ± 0.25 decibel (dB) sound pressure level (SPL) at 1000 Hertz (Hz).

Notes: (1) According to the manufacturer, the Model 4161 sensor is actually stimulated at 93.6 dB SPL "Free-Field."

(2) $\text{dB SPL} = 20 \log \frac{P}{P_o}$

where $P_o = 2 \times 10^{-5}$ Newtons per square meter, root-mean-square

4.1.3 Frequency Response and Amplitude Linearity Tests - The frequency response and amplitude linearity tests were conducted with each Model 4161 and each 4117 sensor installed in the test setups shown in Figures 3-1A and 3-2A, respectively. All eight test articles were tested with a 30 minute warmup time allowed on each sensor prior to reading and recording the measurements.

4.1.3.1 Frequency Response at Indicated 100 dB SPL - The Dees Calibrator, Model 9005, was set for 100 dB SPL indicated pressure field at each of the 15 "preferred frequencies" between 250 and 8000 Hz as given in ISO Recommendation R.266, International Organization for Standardization, Geneva, Switzerland. The output was measured and recorded at each frequency and three runs were performed on each of the eight sensors.

4.1.3.2 Amplitude Linearity at 1000 Hertz - The Hewlett-Packard (HP) Model 3310B oscillator was set for 1000 Hertz and the Dees Calibrator was adjusted in steps of 10 dB from indicated 100 dB SPL to indicated 140 dB SPL. The output was measured and recorded for each indicated SPL on each of the eight sensors.

4.2 Environmental Tests - The environmental tests were performed on three each of the Model 4161 and 4117 acoustic sensors. The fourth unit of each sensor model was not exposed to the environmental tests and served as a reference for the respective sensor type. These "reference" units were recalibrated concurrent with the other units following each environmental test to obtain comparative data.

Model 4161 serial numbers 541898, 541937 and 541938, and Model 4117 serial numbers 535219, 535221 and 535228 were exposed to the environmental tests. Model 4161 serial number 541939 and Model 4117 serial number 535234 were utilized as reference units.

4.2.1 Temperature Tests - The environmental test articles were all exposed to the temperature test conditions in accordance with the profile shown in Figure 4-1.

The B&K type 4230 Sound Level Calibrator was mounted on the test microphone, which was placed in the temperature chamber and positioned in the vertical direction with the diaphragm facing upward. The Sound Level Calibrator was energized by means of an external switch wired to the calibrator in the temperature chamber.

Initially, a 30 minute warmup period was allowed before the sensor output was measured and recorded at +75°F. Thereafter, each temperature transition was made in a time interval of 15 to 20 minutes. Data was recorded after a 30 minute stabilization time at each test temperature: +55°F, +35°F, +55°F, +75°F, +95°F, +120°F, +95°F, and +75°F.

A total of six sensors, three of each type, was exposed to the temperature excursion, and three data runs were performed on each sensor.

4.2.2 Humidity Test - The environmental test articles were passive during the humidity exposures. The test was conducted in a manner similar to MIL-STD-810B (USAF), method 507, procedure 1. All six sensors were exposed to a total of seven 24-hour cycles. Each 24-hour cycle consisted of 6 hours at 95 percent (%) relative humidity (R.H.) at a temperature of +71 degrees, Centigrade (°C), and 16 hours at 85% R.H. with temperature decreasing gradually from +71°C to +28°C as depicted in Figure 4-2. The three sensors of the same type were exposed to the humidity conditions simultaneously.

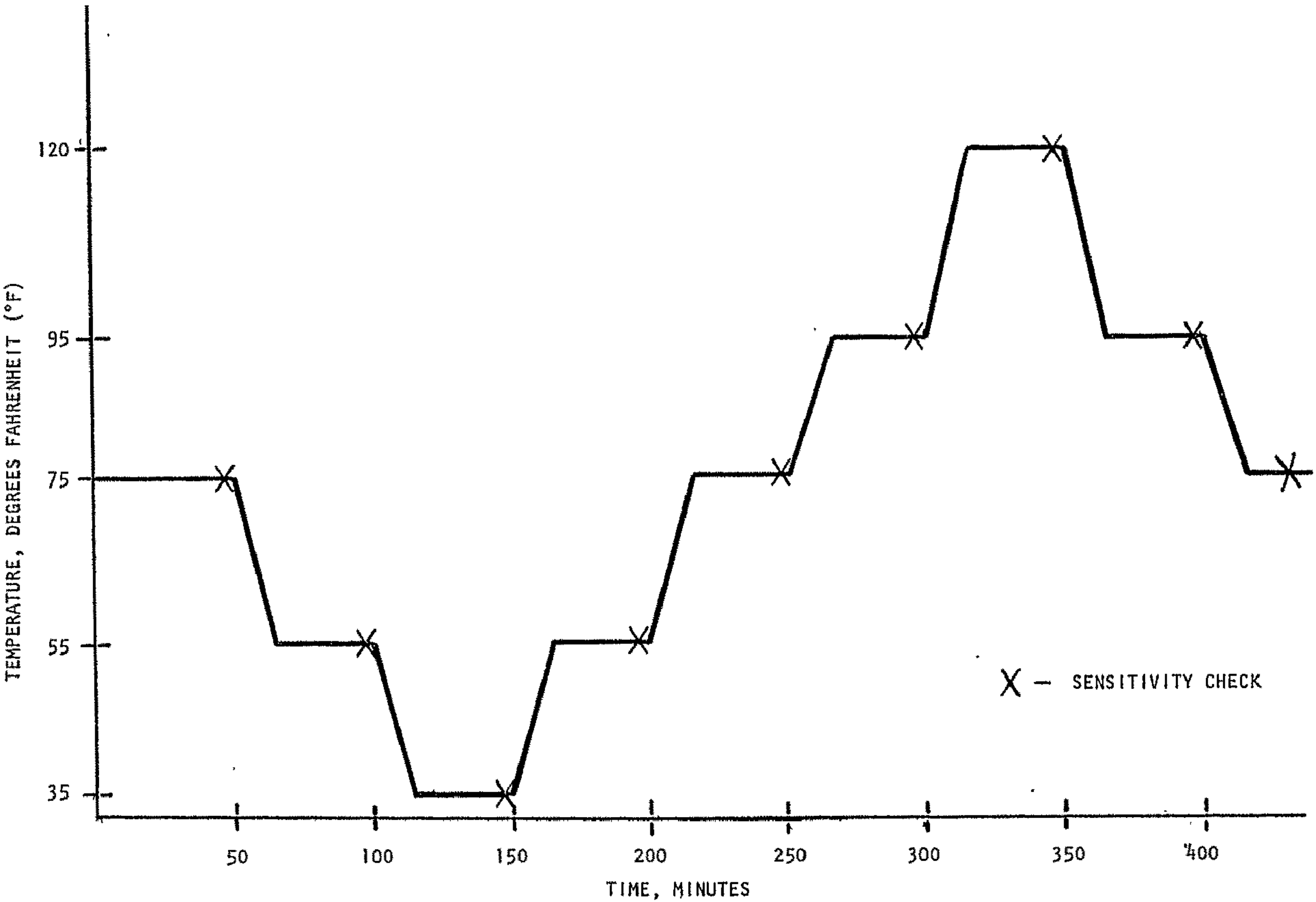

FIGURE 4-1. - Temperature profile.

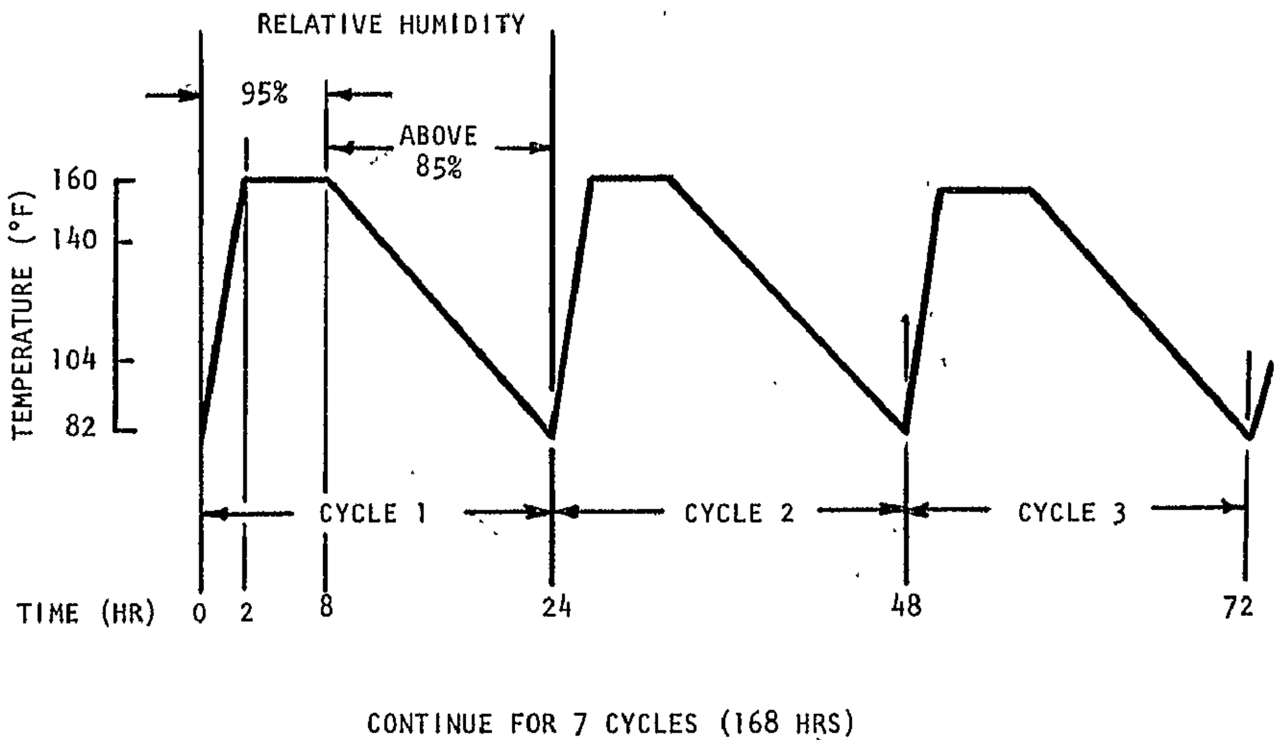

FIGURE 4-2. - Humidity exposure.

A confidence check was performed on each sensor after the humidity exposure using the B&K type 4230 Sound Level Calibrator. The elapsed time required to achieve proper operation was noted and recorded, and sensor output was measured and recorded after the standard 30 minute warmup time period.

4.2.3 Vibration Tests - The test configuration was the same as in Figures 3-1A and 3-2A for the B&K Model 4161 and 4117 sensors respectively, except the Sound Level Calibrator was not utilized. Three sensors of each type were exposed individually.

The vibration fixture for the Model 4161 firmly clamped the entire assembly, consisting of the sensor, Model 2619 preamplifier, and Model DB0375 adapter.

A second vibration fixture was used for the Model 4117 which provided for direct mounting of the sensor by means of its external threaded 22 millimeter fitting.

4.2.3.1 Sinusoidal Sweep - A sinusoidal sweep was performed on each of the functional environmental test articles in each of the three orthogonal axes. The sweep was from 20 Hz to 2000 Hz to 20 Hz, at a rate of one half octave per minute (oct/min) and the level was 1.0 gravity (g.) peak.

4.2.3.2 Sinusoidal Dwell at 1000 Hertz - Each functional environmental test article was vibrated in the sinusoidal mode at 1000 Hz, in the direction of the sensing axis, at a level of 5.0 g rms, equivalent to 7.07 g peak. The alternating current (ac) waveshape was monitored and the microphone output was measured on the appropriate voltmeter and recorded. The raw data obtained represented the combined response of the sensor to the ambient SPL and the mechanical vibration acceleration.

4.2.3.3 Random Vibration - Each functional environmental test article was vibrated in the random mode in each of the three orthogonal axes at an overall level of 10.2 g rms with the following spectral density:

20 Hz to 150 Hz @ +6 dB/octave

150 Hz to 900 Hz @ 0.09 g^2/Hz

900 Hz to 2000 Hz @ -9 dB/octave

Sensor output was measured on the appropriate voltmeter and recorded. The raw data obtained represented the combined response of the sensor to the ambient SPL and the mechanical vibration acceleration.

4.3 Post-environmental Tests - All functional sensors were subjected to exactly the same tests as the pre-environmental tests, but in reverse order, such that the calibration and visual inspection were the final test considerations.

5.0 TEST RESULTS

5.1 Visual Inspection - The appearance of each sensor was proper prior to and upon completion of tests, except for Model 4117, serial no. 535219, which suffered a ruptured diaphragm. The ruptured diaphragm was discovered when the sensor exhibited anomalous characteristics after exposure to the humidity tests described in Paragraph 4.2.2.of this report.

5.2 Calibration, Frequency Response and Amplitude Linearity - All eight test articles were deemed acceptable for use in these evaluation tests based upon the pre-environmental calibration, frequency response and amplitude linearity tests. The data are displayed graphically and included with the post-environmental data in Attachment A to this report to facilitate comparison.

5.3 Environmental Tests

5.3.1 Temperature Tests - All six exposed sensors survived the temperature tests. The temperature dependency of the Model 4161 and 4117 test articles is shown graphically in Figures 5-1 through 5-3 and Figures 5-4 through 5-6, respectively. Note that the B&K Model 4161 capacitive device appears more favorable than the B&K Model 4117 piezoelectric sensor.

5.3.2 Humidity Test - The three Model 4161 test articles survived the passive humidity exposures. One unit, S/N 541938, did not function properly immediately following the humidity test. Inspection disclosed the apparent accumulation of moisture inside the unit. The unit was placed in an oven for two hours at +115°F and dried out. Subsequently the measured performance characteristics returned to normal.

Three B&K Model 4117 piezoelectric microphones were passively and simultaneously exposed to the humidity environment. After four cycles of exposure, serial no. 535219 was inoperative. Examination revealed that the foil diaphragm was ruptured. This type of catastrophic failure is usually indicative of improper handling. However, it is possible that the combined environments of moisture and temperature were too stringent for the sensor. The temperature approached the upper limit specified by the manufacturer, and an epoxy cement is used to attach the fragile force summing diaphragm to the piezoelectric element. The other two sensors were not affected by exposure to seven humidity cycles.

5.3.3 Vibration Tests - During vibration exposure, it was ascertained that the electrodynamic shaker was generating a high SPL, 90 to 95 dB SPL. Calculations were made to resolve the portion of the microphone output that was attributable to the mechanical vibration. The data processing showed that the B&K Model 4117

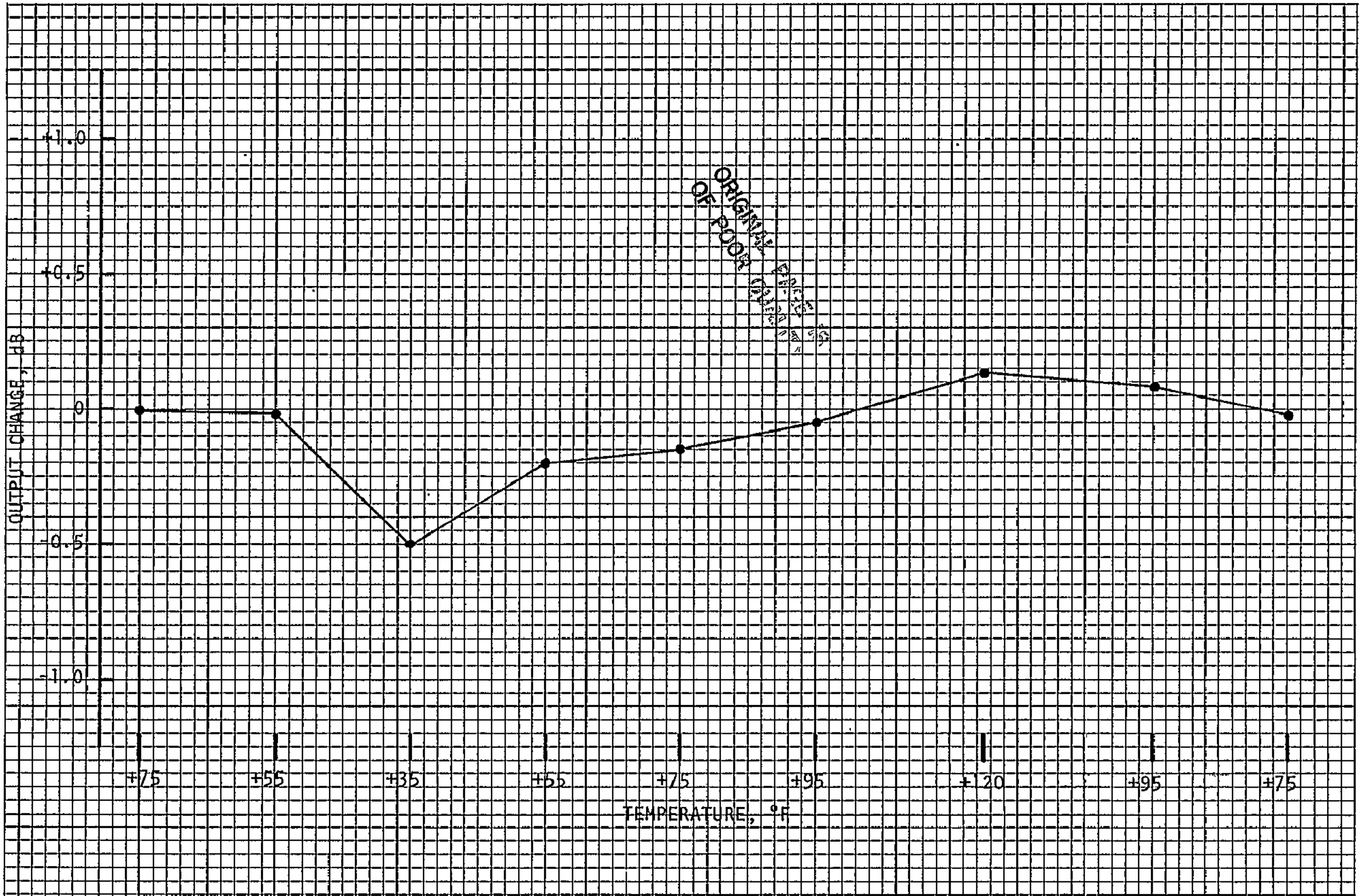

FIGURE 5-1. - Sensitivity change versus temperature, B&K Model 4161, Serial Number 541898.

FPI MI-10 X 10 TO 1 INCH
10TH LINE HEAVY

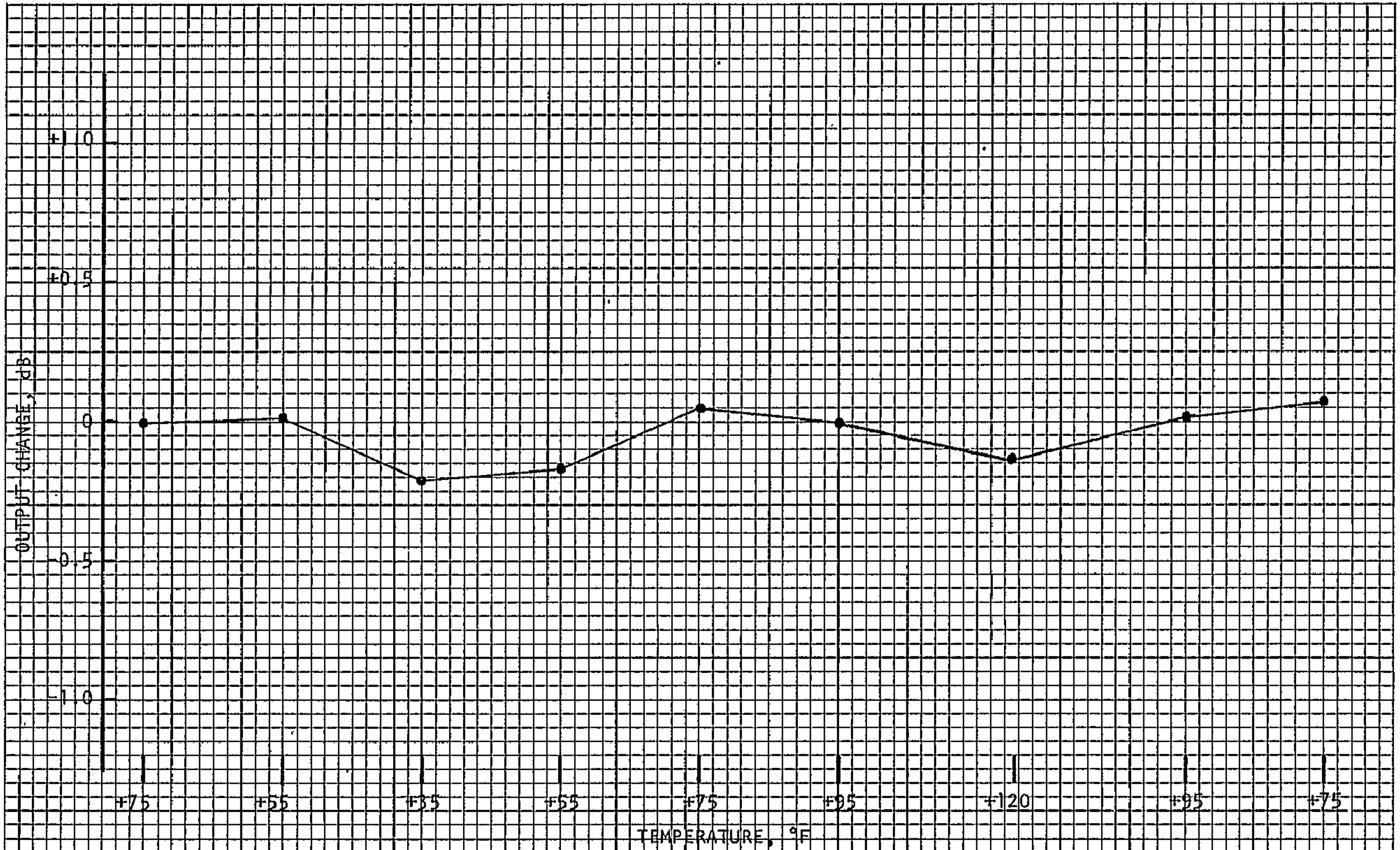

FIGURE 5-2. - Sensitivity change versus temperature, B&K Model 4161, Serial Number 541937.

FPI M1—10 X 10 TO 1 INCH
10TH LINE HEAVY

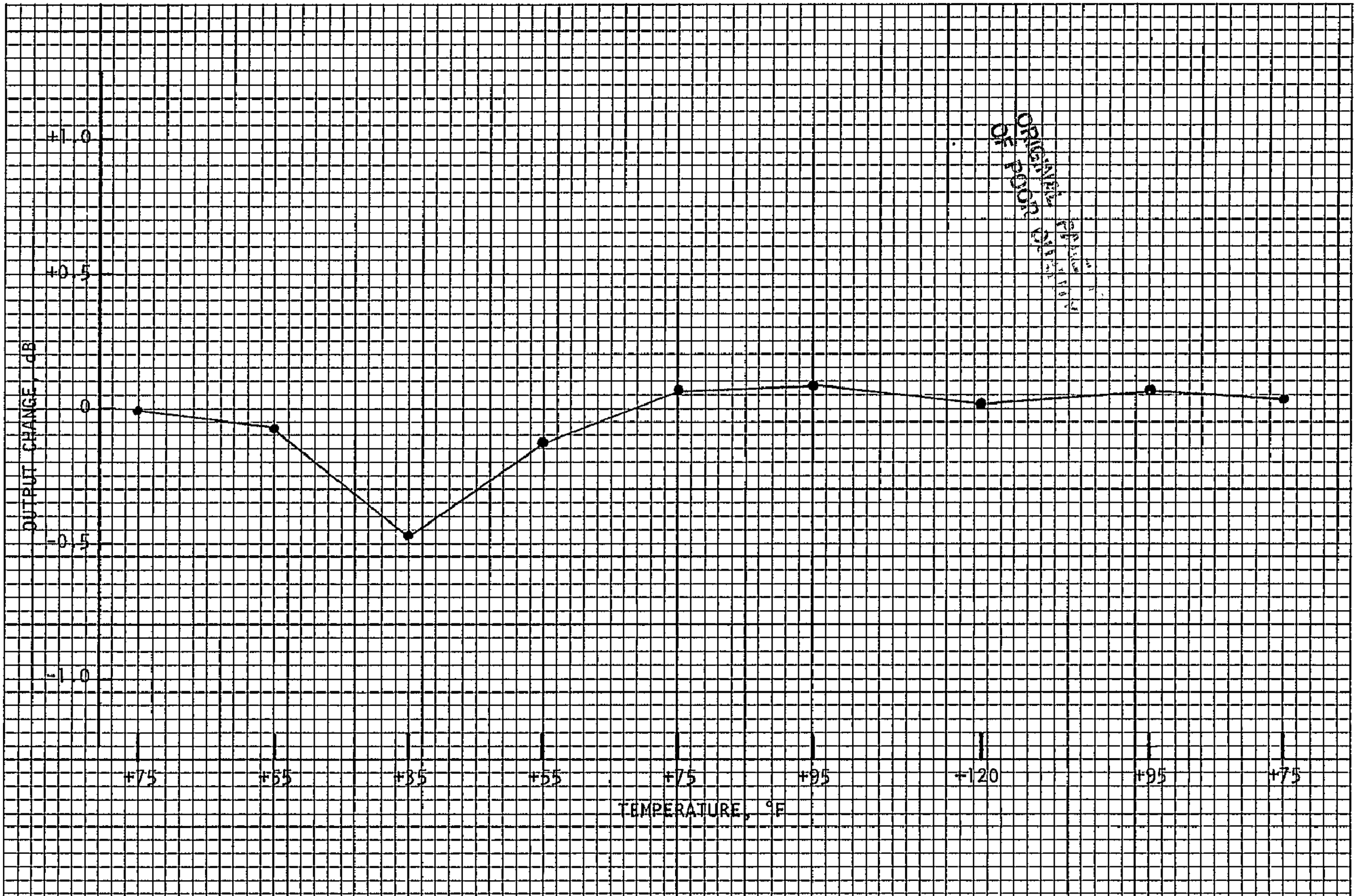

FIGURE 5-3. - Sensitivity change versus temperature, B&K Model 4161, Serial Number 541938.

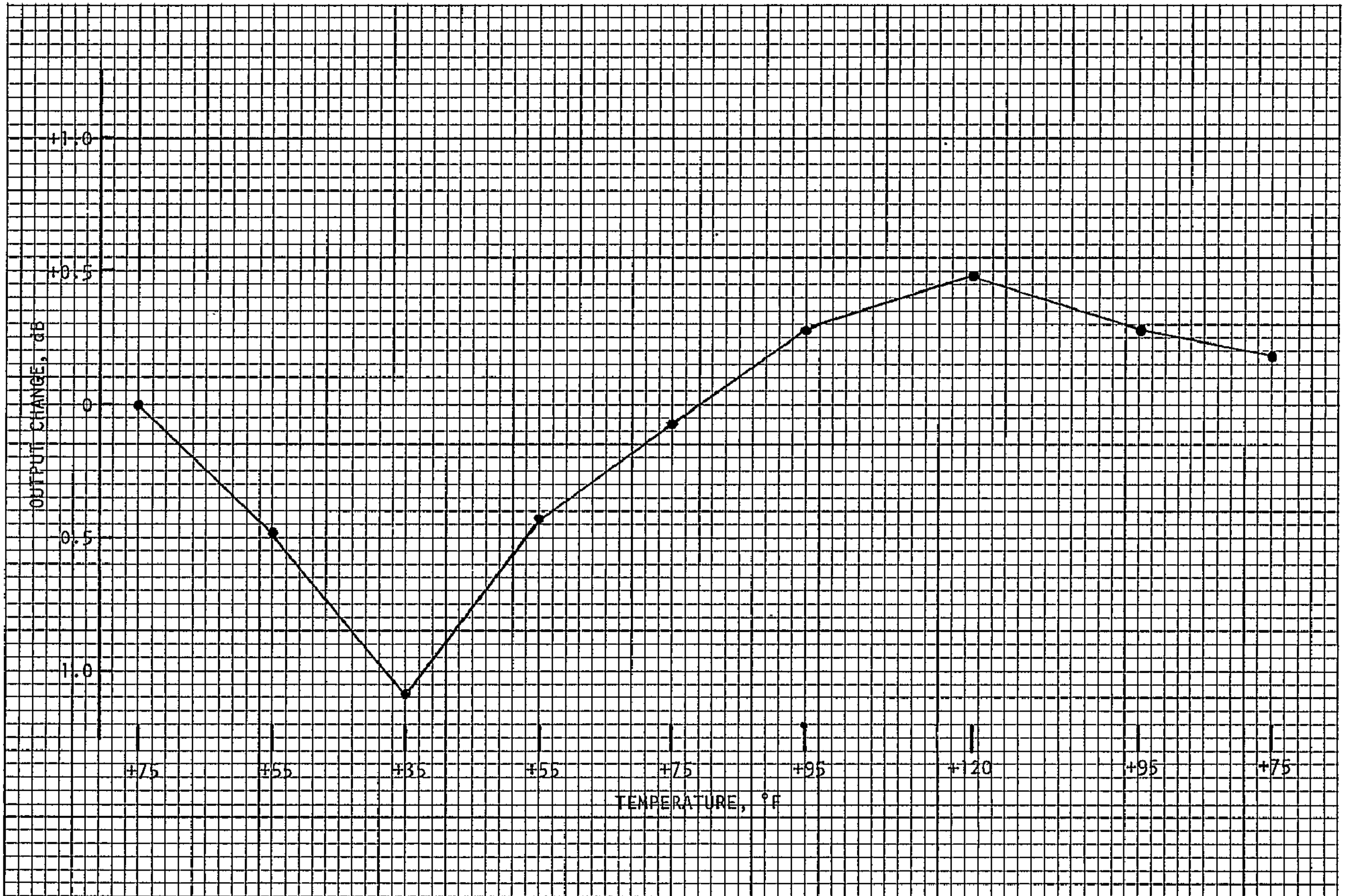

FIGURE 5-4. - Sensitivity change versus temperature, B&K Model 4117, Serial Number 535219.

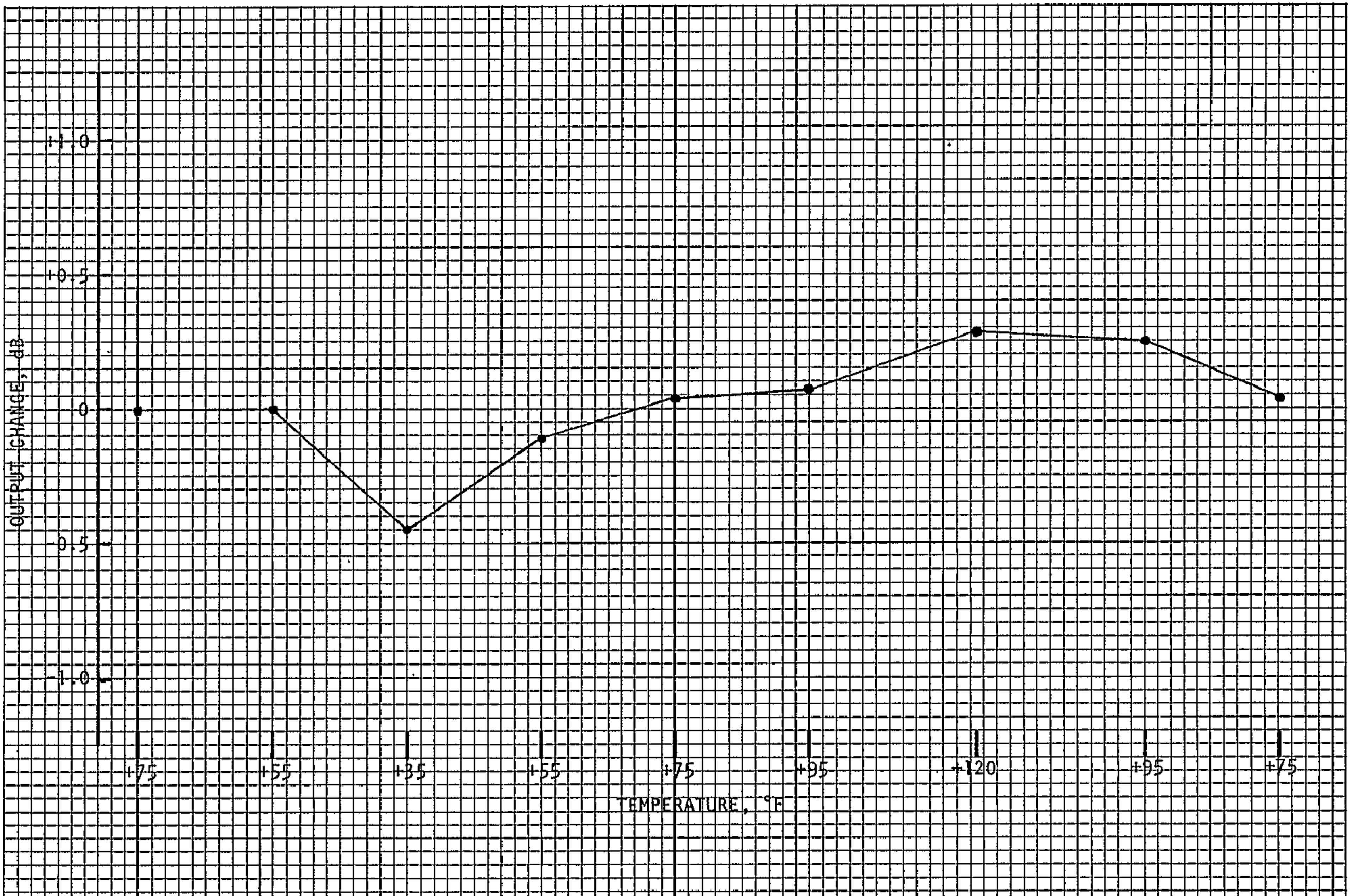

FIGURE 5-5. - Sensitivity change versus temperature, B&K Model 4117, Serial Number 535221.

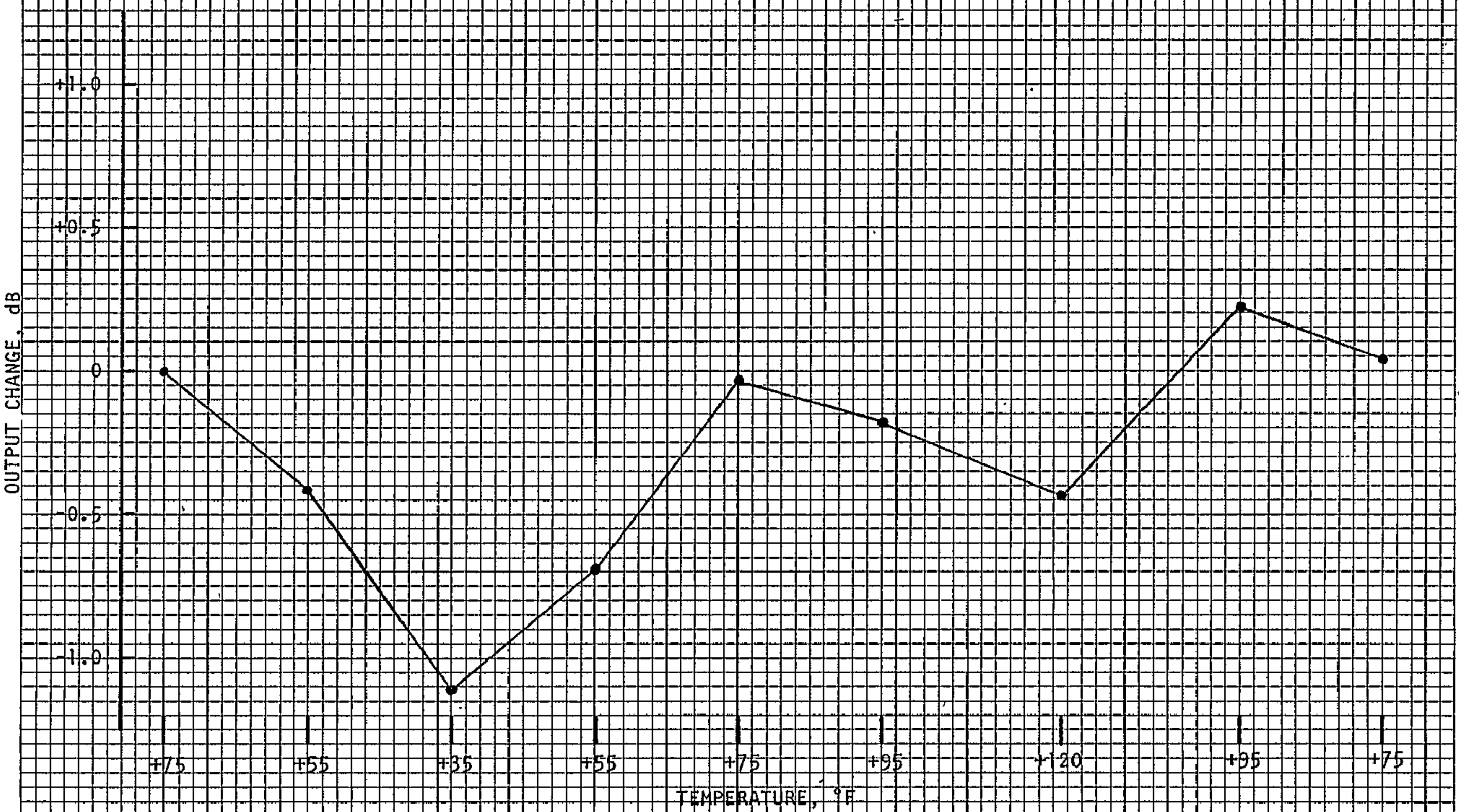

FIGURE 5-6. - Sensitivity change versus temperature, B&K Model 4117, Serial Number 535228.

piezoelectric microphone response to vibration was about four times, or 12 dB, greater than the response of the B&K Model 4161 capacitive microphone.

The three B&K Model 4161 capacitive microphones survived the vibration exposure without failure or degradation of performance.

The first of two B&K Model 4117 piezoelectric microphones tested showed an anomaly after random mode vibration. Sensor serial no. 535228 had an output about one-half of its pre-random vibration value when it was checked following random vibration exposure. The diaphragm appeared to be normal by visual examination but subsequent calibration checks produced results consistent with the new lower sensitivity or -6.3 dB error in SPL measurement (see Figure A-37). At post-environmental test, the Amplitude-linearity relationship looked good although the output sensitivity was lower (reference Figure A-28). However, the frequency response characteristic exhibited decreasing output amplitudes as a function of increasing frequency (see Figure A-13). Consequently, sensor serial number 535228 is deemed to have failed as a result of random vibration exposure.

The second model 4117 test article survived the vibration tests with no significant change in characteristics.

5.3.4 Post-environmental Calibration, Frequency Response and Amplitude Linearity - All functional test articles were subjected to a post-environmental test calibration frequency response and amplitude linearity tests which were congruent to the pre-environmental tests. The data is displayed graphically and included with the pre-environmental data in Attachment A to this report to facilitate comparison. Post-environmental test data for the Model 4117, serial number 535219, is not included due to the failure noted after the humidity test.

6.0 CONCLUSIONS

Both the B&K Model 4161 and Model 4117 capacitive microphones are deemed suitable for use on the Shuttle Orbiter vehicle based upon the results of the tests described herein. The Model 4117 is apparently less precise and much more fragile. One Model 4117 test article, serial number 535219, failed following the humidity test. Another unit, serial number 535228, had a substantially degraded output following random vibration exposure. Otherwise the sensitivity repeatability of all the test articles was within 1 dB of the respective initial value throughout the test program. The repeatability of each of the eight test articles is shown in Figures A-31 through A-38 in the attachment to this report.

The B&K Model 4161 capacitive microphone is the more precise and durable of the two types tested. However, it requires a polarization voltage power supply and a preamplifier, both expensive specialized electronics, in order to interface the sensors with the Shuttle Orbiter instrumentation system.

The B&K Model 4117 piezoelectric sensor is relatively inexpensive, directly compatible with the Shuttle Orbiter wideband signal conditioner charge amplifier, and probably has the greatest sensitivity of any microphone on the market. However, the Model 4117 is fragile and special precautions will be necessary to avoid inadvertent damage to the sensor if this type is used. A special vented plastic protective cap is required on the Model 4117 sensor. The non-vented silica gel dessicant type provided with the Model 4161 sensors will fit the Model 4117 but could cause the thin foil diaphragm to rupture due to overpressure.

An aircraft type installation mounting fixture would be needed for either of the two types of sensors. The Model 4117 piezoelectric sensor is not electrically isolated from the case; therefore, the external mounting provisions would have to include electrical isolation.

ATTACHMENT A

Pre- and Post-environmental Calibration, Frequency Response and Amplitude Linearity Test, and Sensor Sensitivity Repeatability Data

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TABLE A-I

Acoustic Sensor Pre- and
Post-environment Test Calibration Data

TABLE A-I. - ACOUSTIC SENSOR CALIBRATION TEST DATA

Sensor Identification	Calibration Data: Pre-Environmental	Calibration Data: Post-Environmental
Model 4161	Output, millivolts (mV), with preamplifier	
S/N 541898	1. 53.8 mV	1. 49.8 mV
	2. 53.8 mV	2. 49.4 mV
	3. 54.3 mV	3. 49.6 mV
S/N 541937	1. 52.5 mV	1. 47.2 mV
	2. 52.0 mV	2. 49.6 mV
	3. 51.4 mV	3. 48.5 mV
S/N 541938	1. 48.5 mV	1. 43.5 mV
	2. 48.4 mV	2. 45.9 mV
	3. 48.3 mV	3. 44.6 mV
S/N 541939	1. 48.2 mV	1. 46.5 mV
	2. 48.7 mV	2. 48.5 mV
	3. 48.6 mV	3. 46.0 mV
Model 4117	Output, pico Coulombs peak (pC pk)	
S/N 535219	1. 23.24 pC pk	Failure noted after Humidity Test
	2. 23.58 pC pk	
	3. 23.57 pC pk	
S/N 535221	1. 22.52 pC pk	1. 21.92 pC pk
	2. 22.69 pC pk	2. 21.97 pC pk
	3. 22.63 pC pk	3. 21.96 pC pk
S/N 535288	1. 22.14 pC pk	1. 11.54 pC pk
	2. 22.27 pC pk	2. 11.54 pC pk
	3. 22.06 pC pk	3. 11.59 pC pk
S/N 535234	1. 20.30 pC pk	1. 20.49 pC pk
	2. 20.46 pC pk	2. 20.46 pC pk
	3. 20.78 pC pk	3. 20.50 pC pk

FIGURES A-1 THROUGH A-8

B&K Model 4161 Pre- and Post-environmental Frequency Response Data

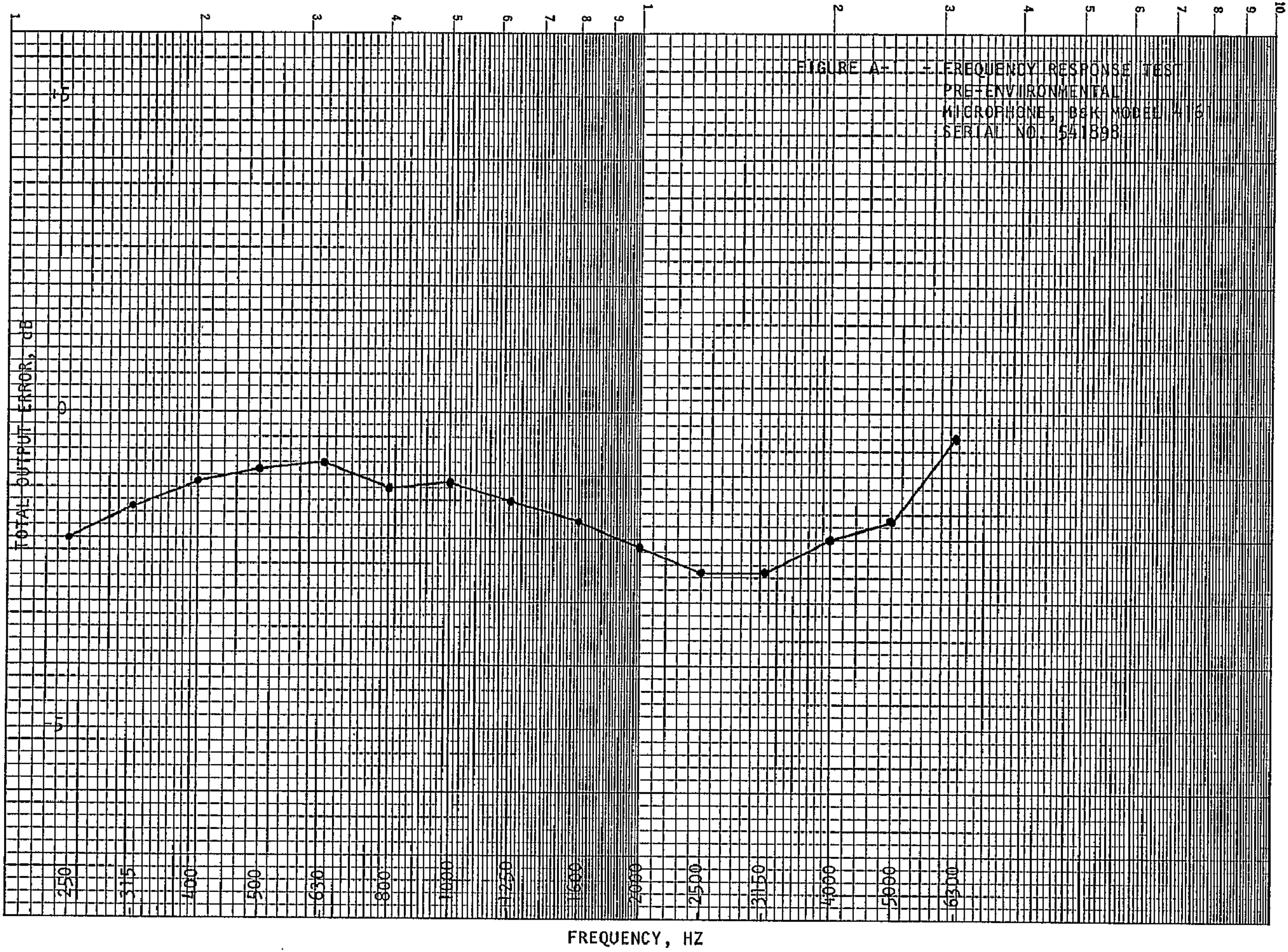


FIGURE A- - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4136
SERIAL NO. 541898

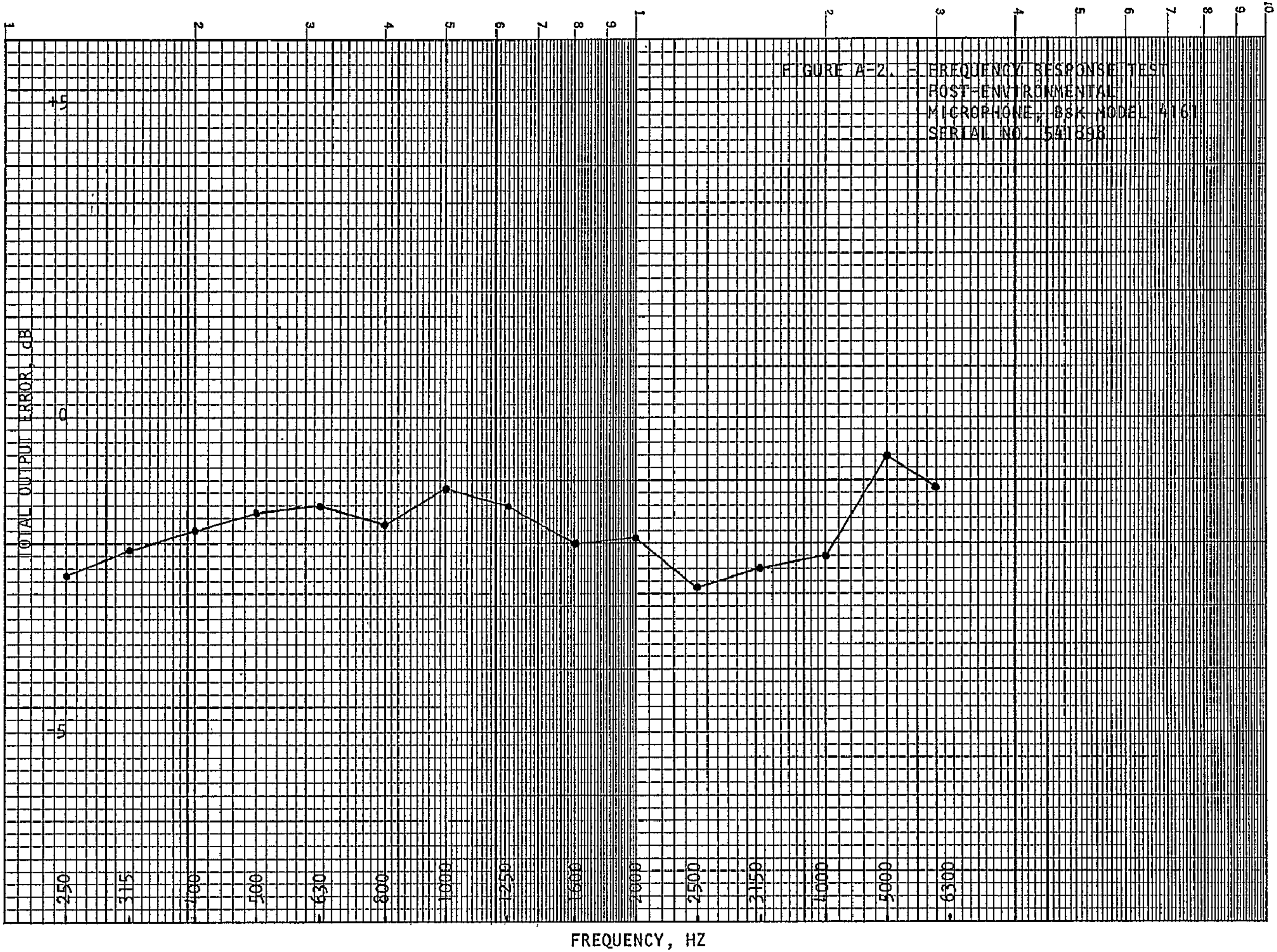


FIGURE A-2. - FREQUENCY RESPONSE TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541898

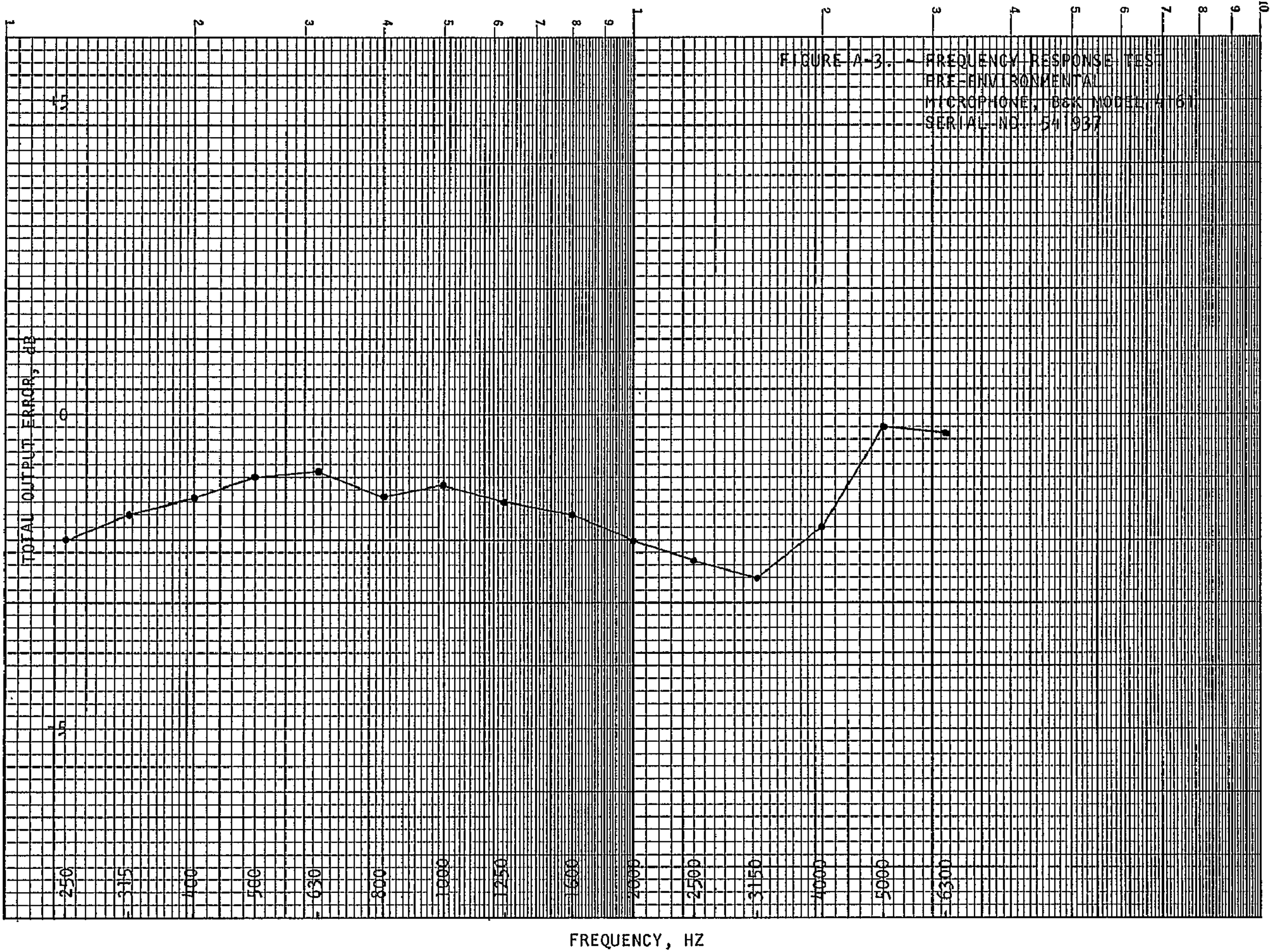


FIGURE A-3. - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541937

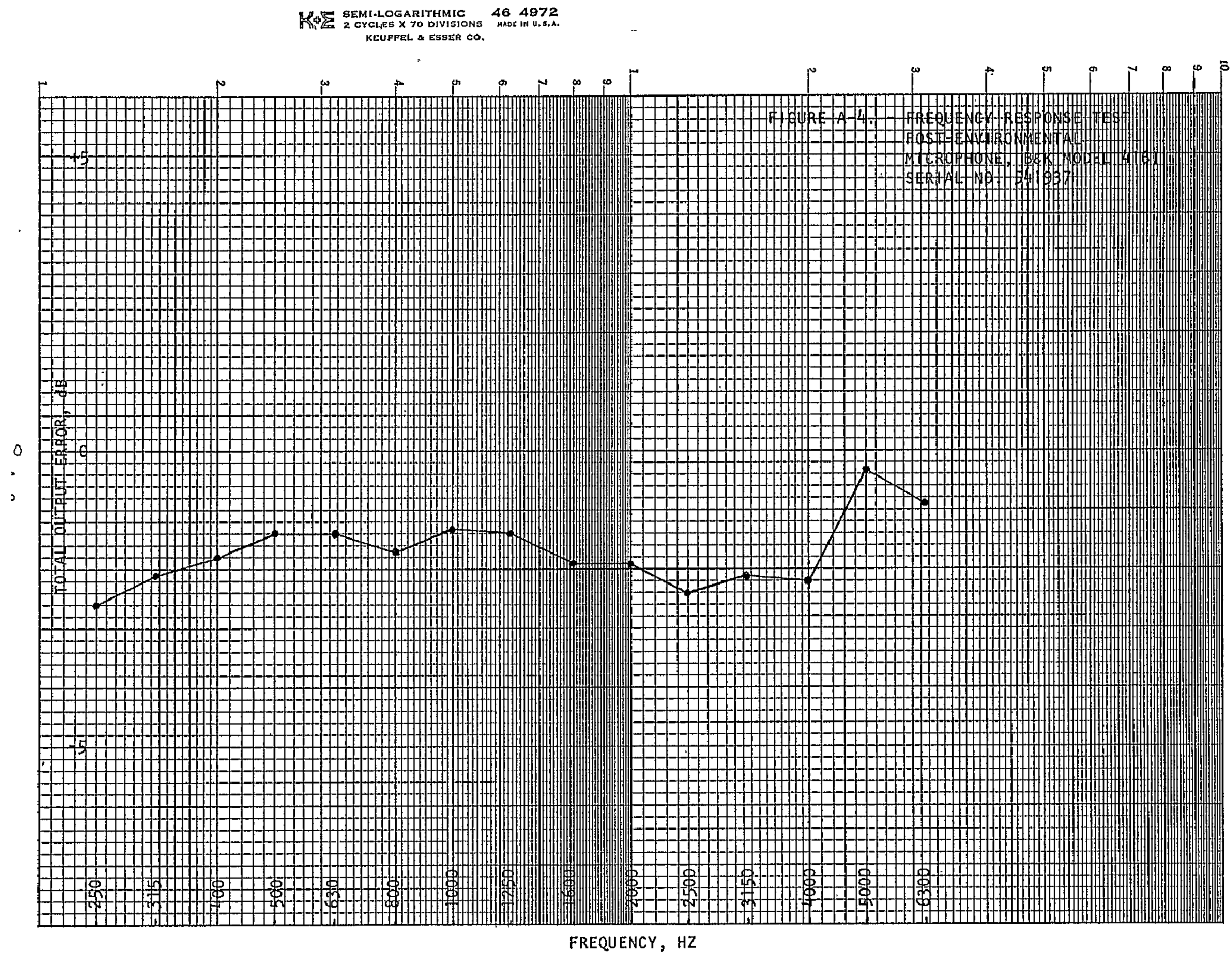


FIGURE A-4. FREQUENCY RESPONSE TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 341937

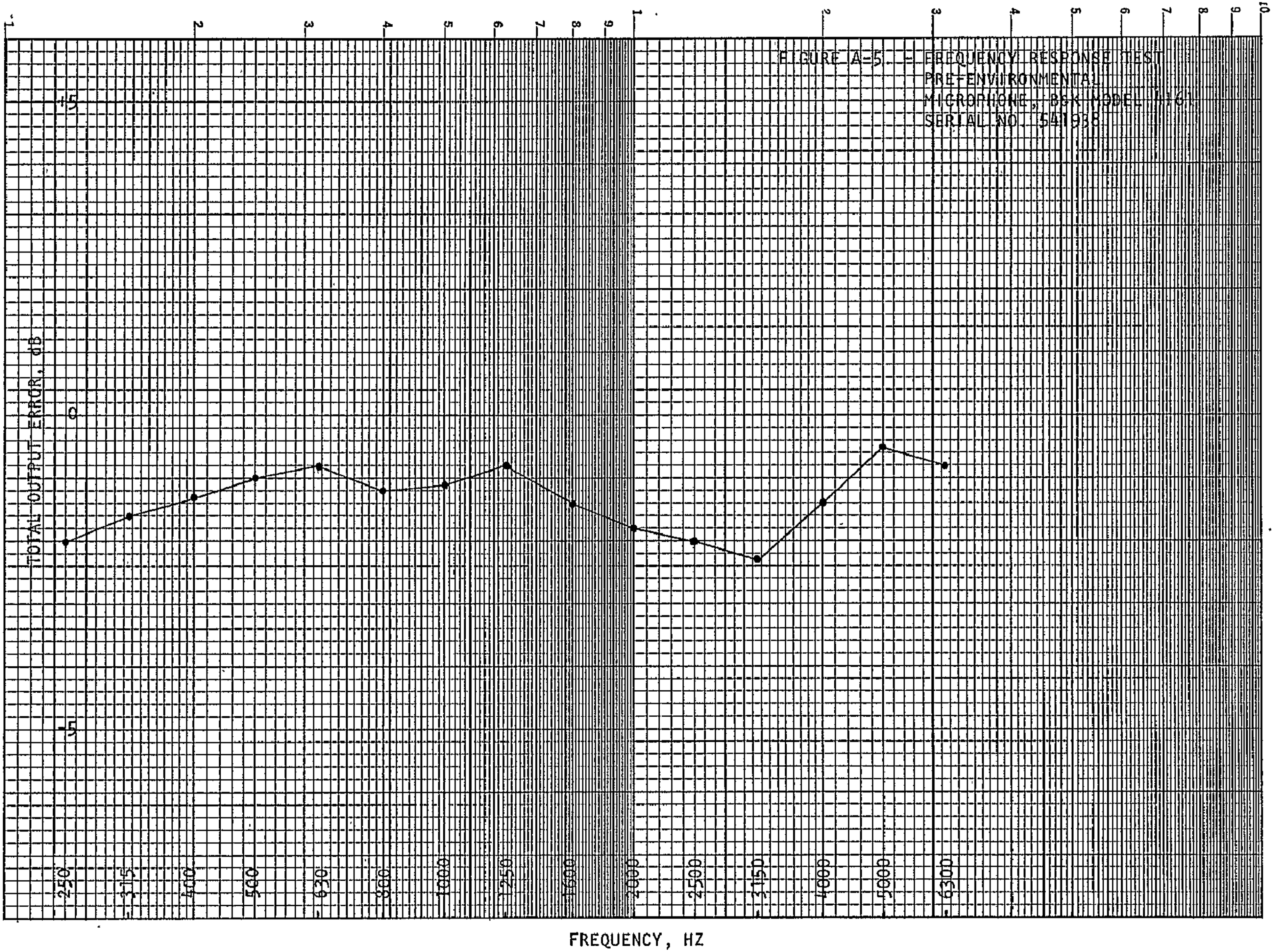


FIGURE A-5. - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541938

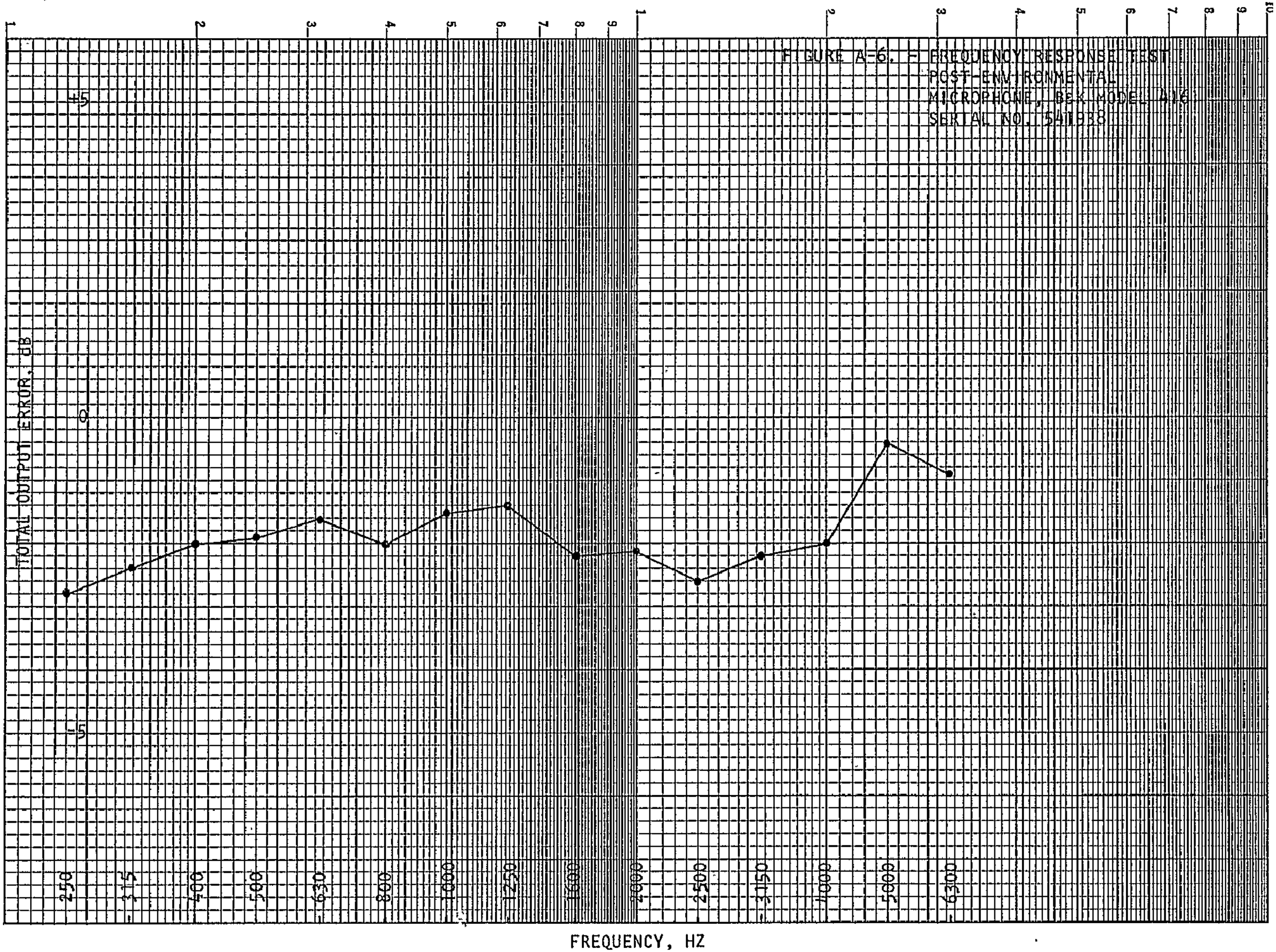


FIGURE A-6. - FREQUENCY RESPONSE TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 416
SERIAL NO. 541938

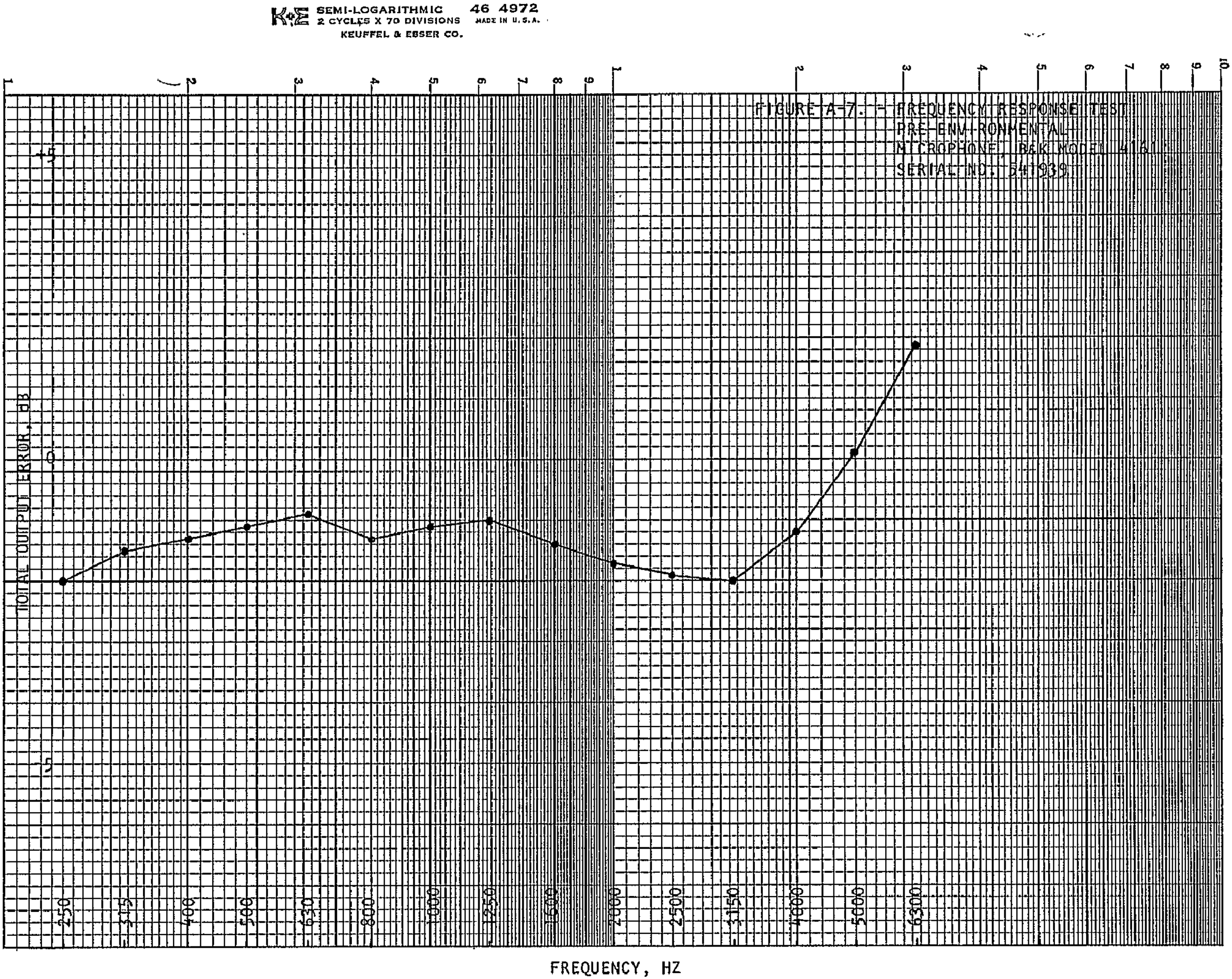


FIGURE A-7. - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541939
TOTAL OUTPUT ERROR, dB
+5
0
-5
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
FREQUENCY, HZ
K&E SEMI-LOGARITHMIC 46 4972
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

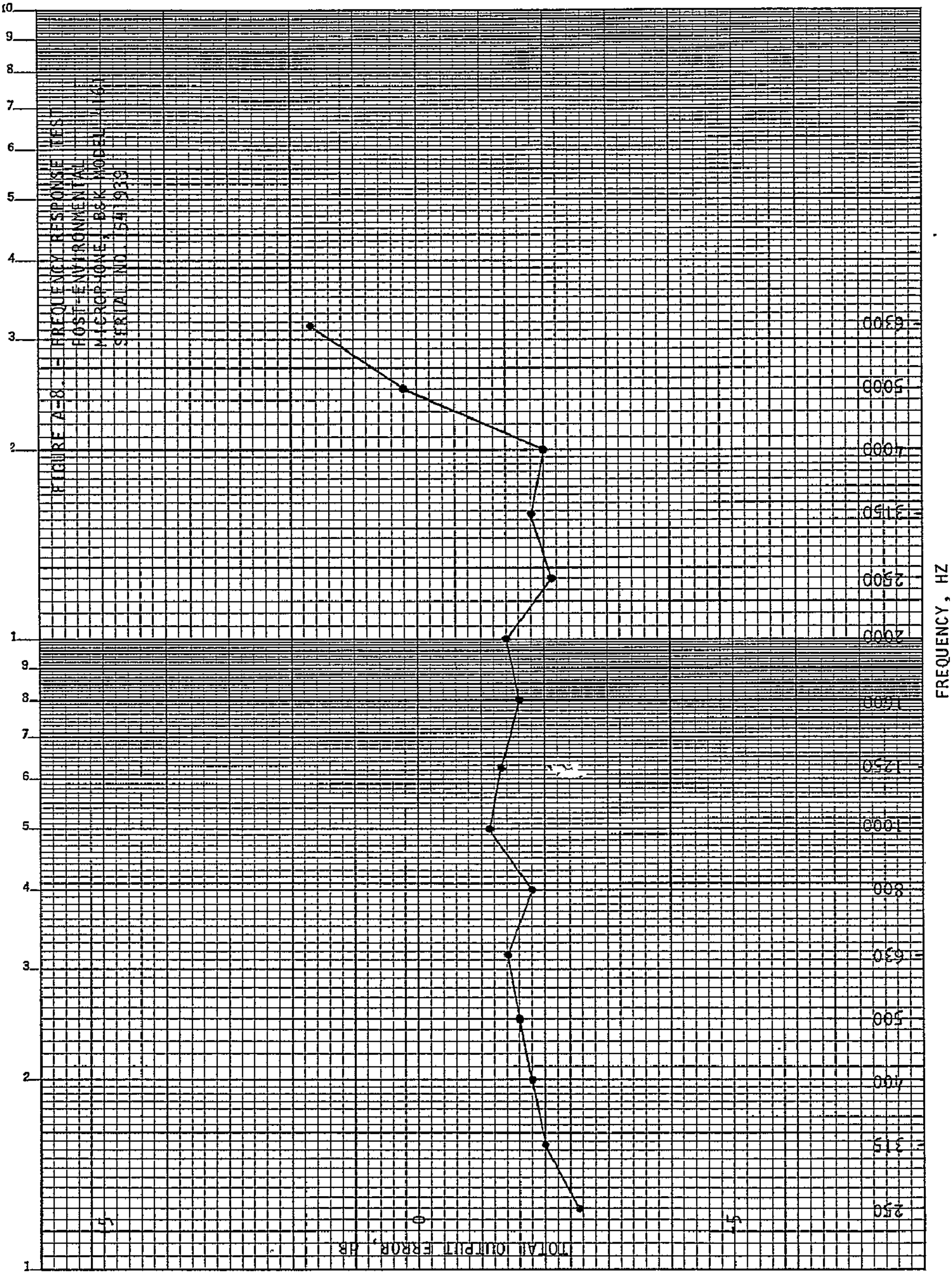


FIGURE A-8. - FREQUENCY RESPONSE TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541939
6300
5000
4000
3150
2500
2000
1600
1250
1000
800
630
500
400
315
250
-5
0
5
TOTAL OUTPUT ERROR, dB
FREQUENCY, HZ

FIGURES A-9 THROUGH A-15

B&K Model 4117 Pre- and Post-environmental Frequency Response Data

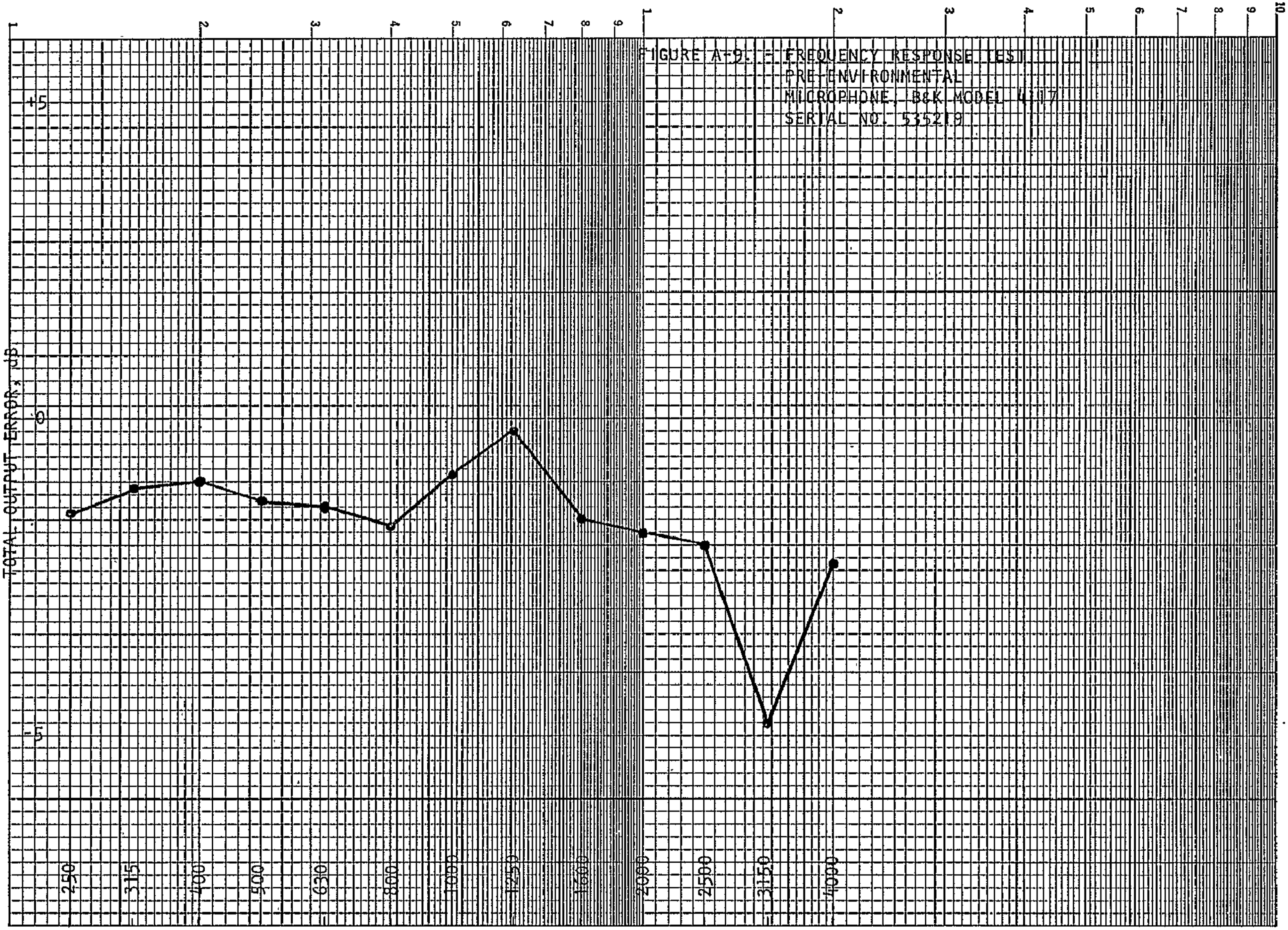


FIGURE A-9. - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535219

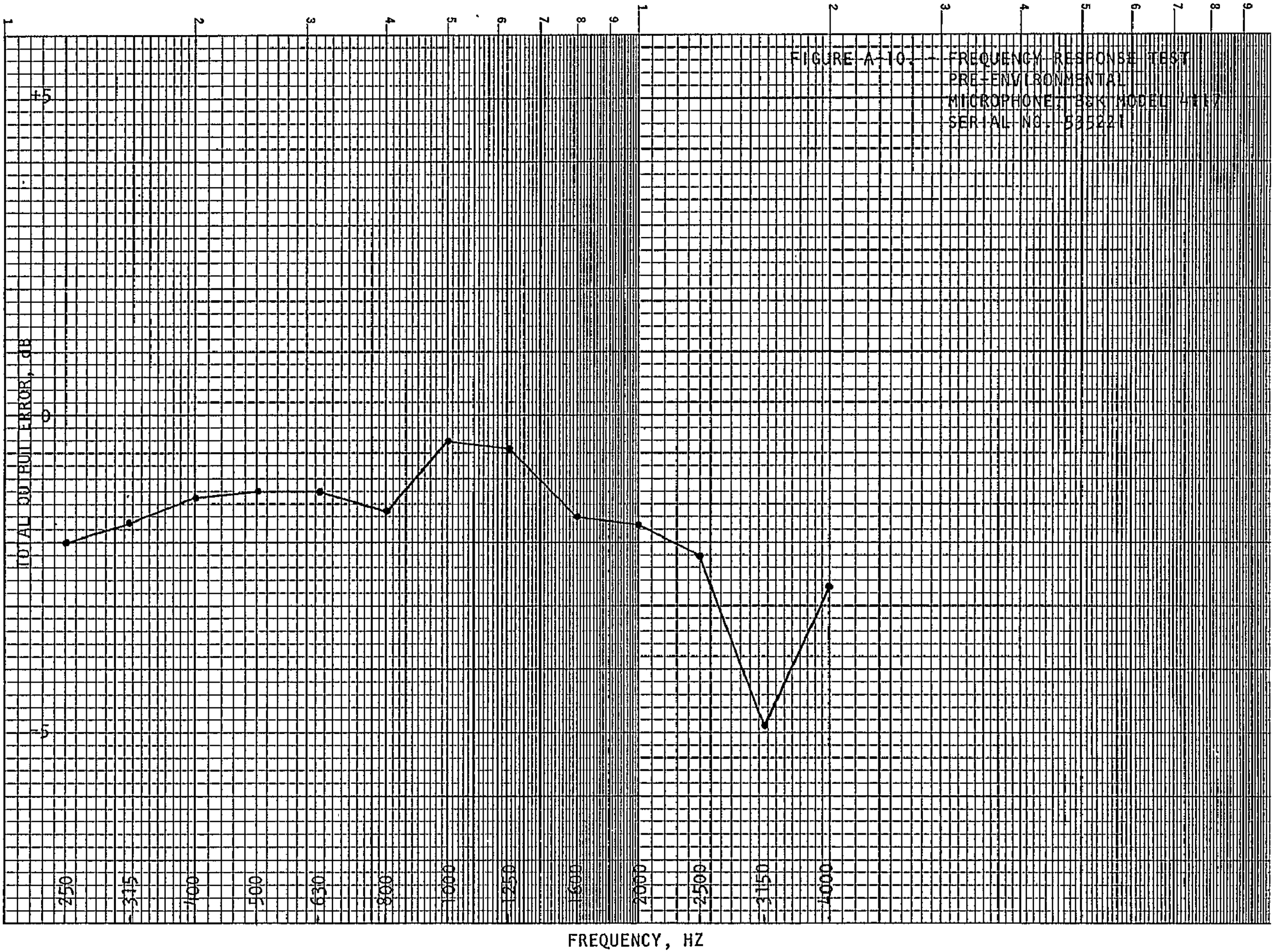


FIGURE A-10. - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535221

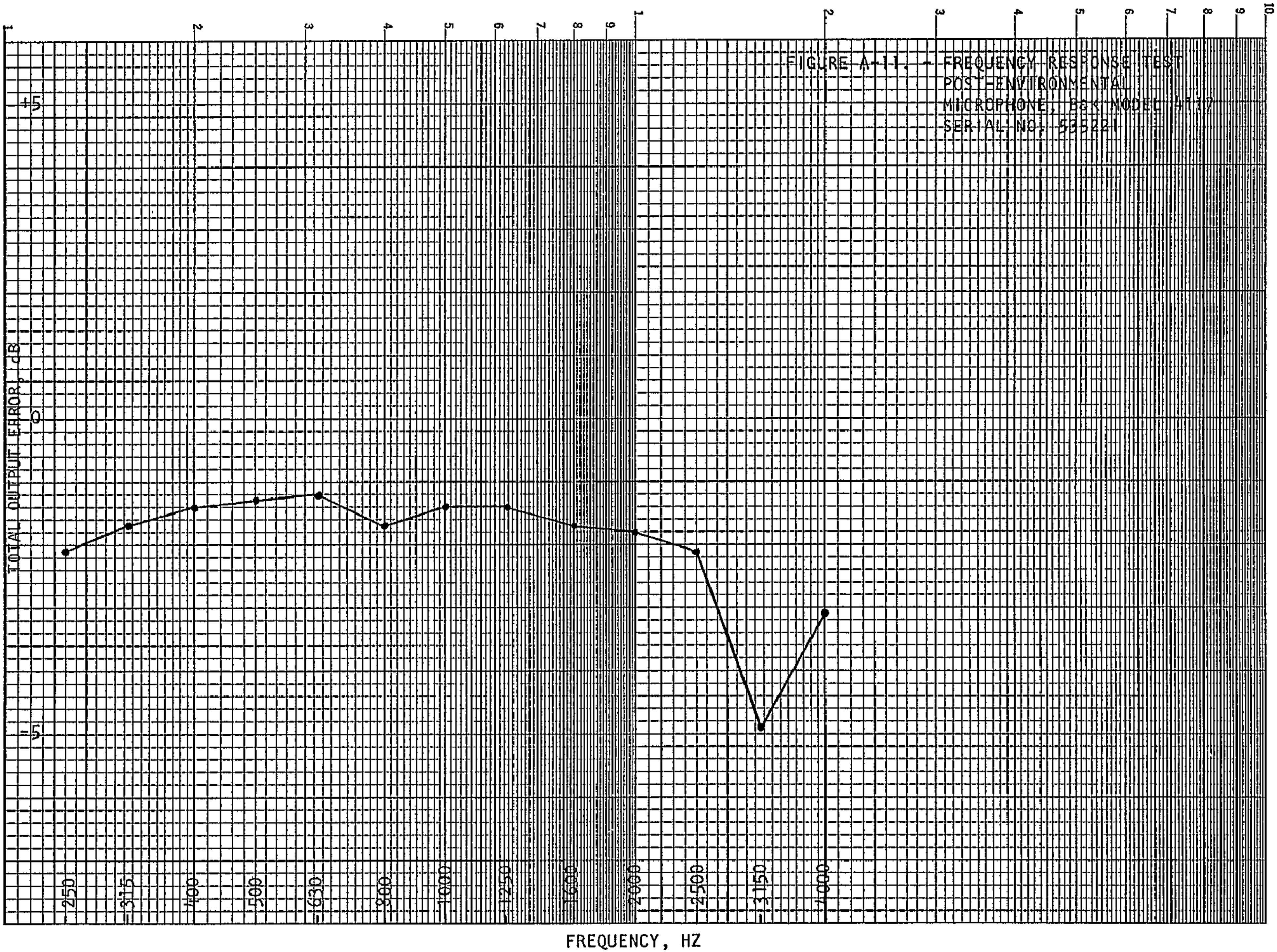


FIGURE A-11. - FREQUENCY RESPONSE TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535221

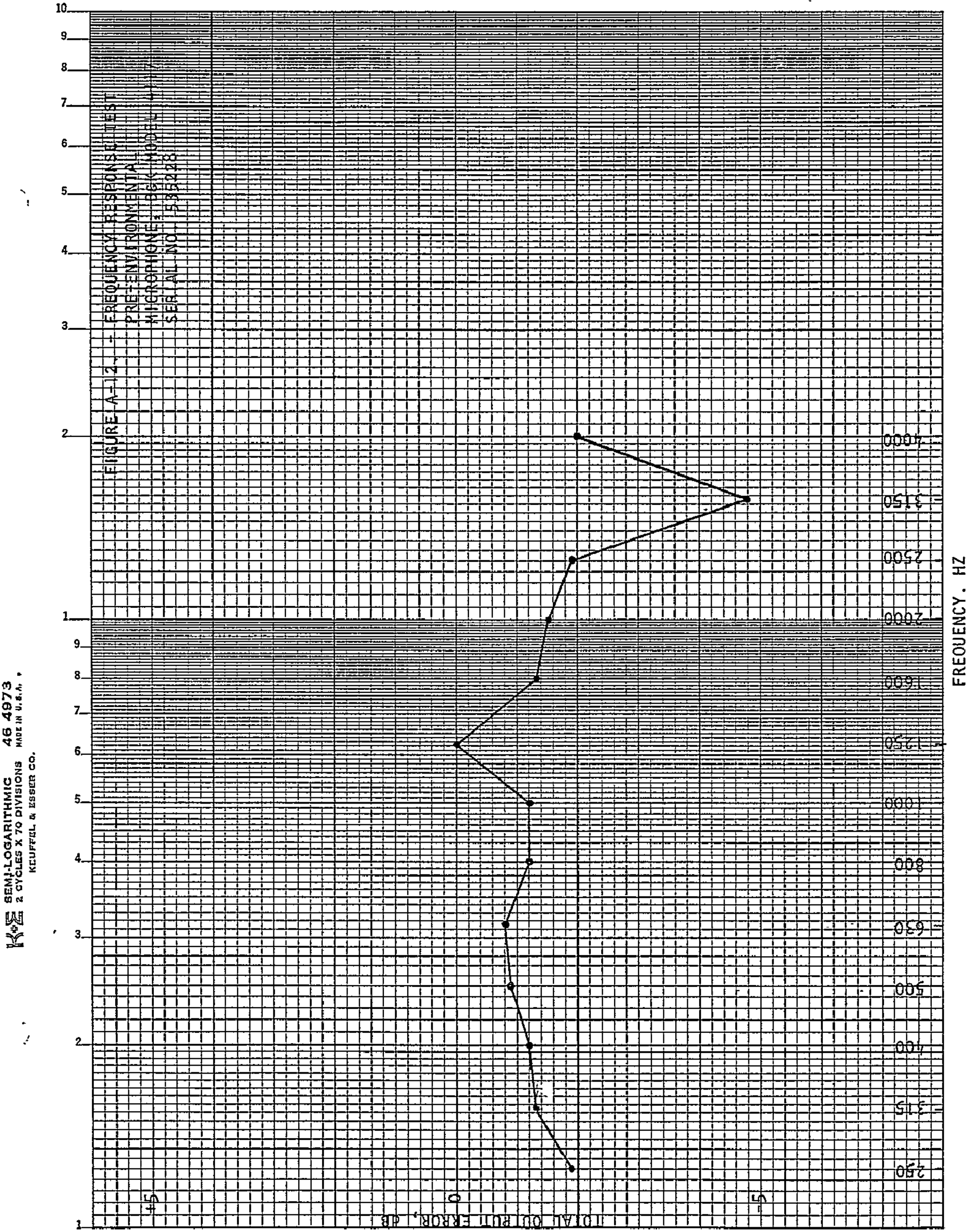


FIGURE A-12 - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE: B&K MODEL 4117
SERIAL NO. 533228

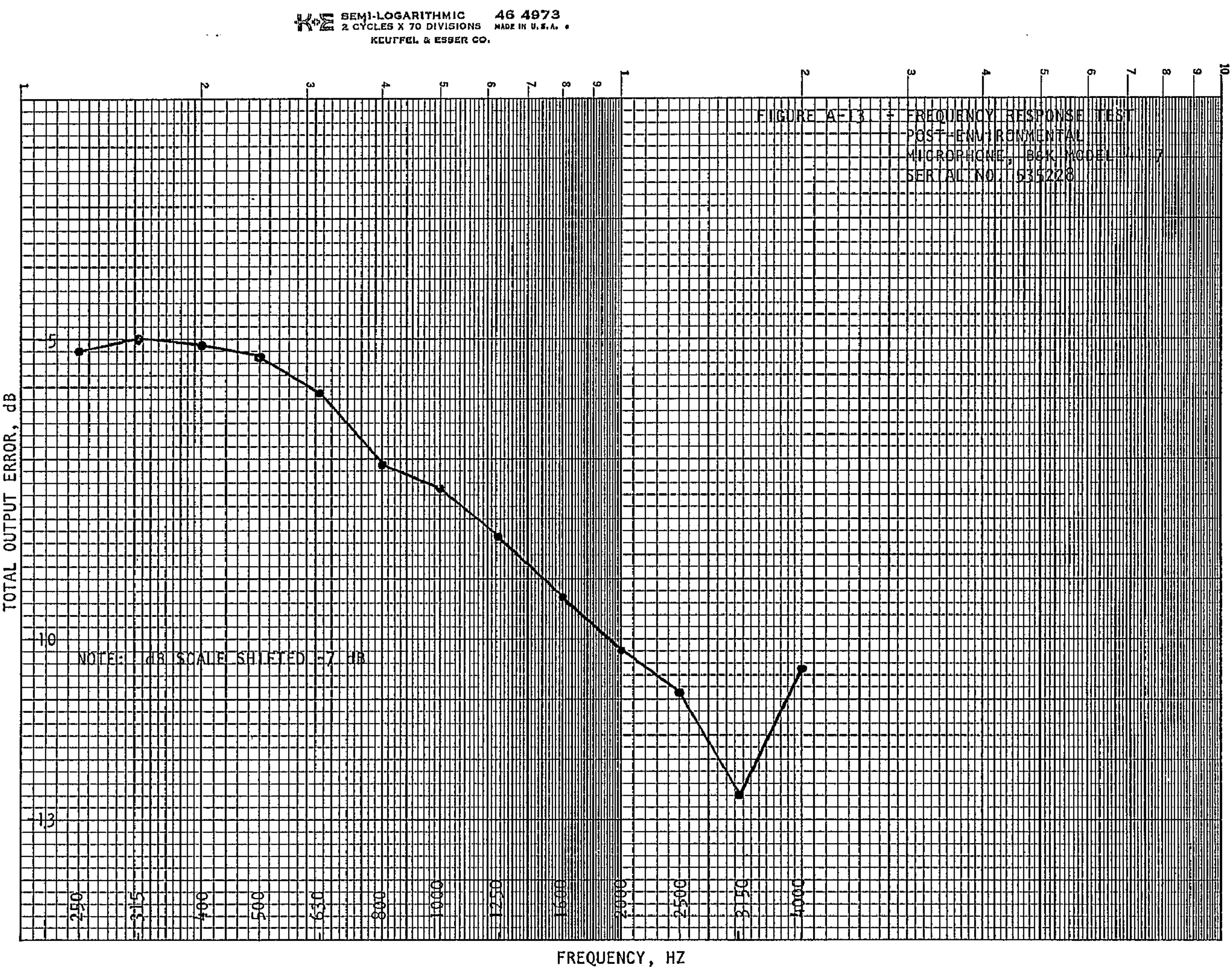


FIGURE A-13 - FREQUENCY RESPONSE TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL
SERIAL NO. 535228

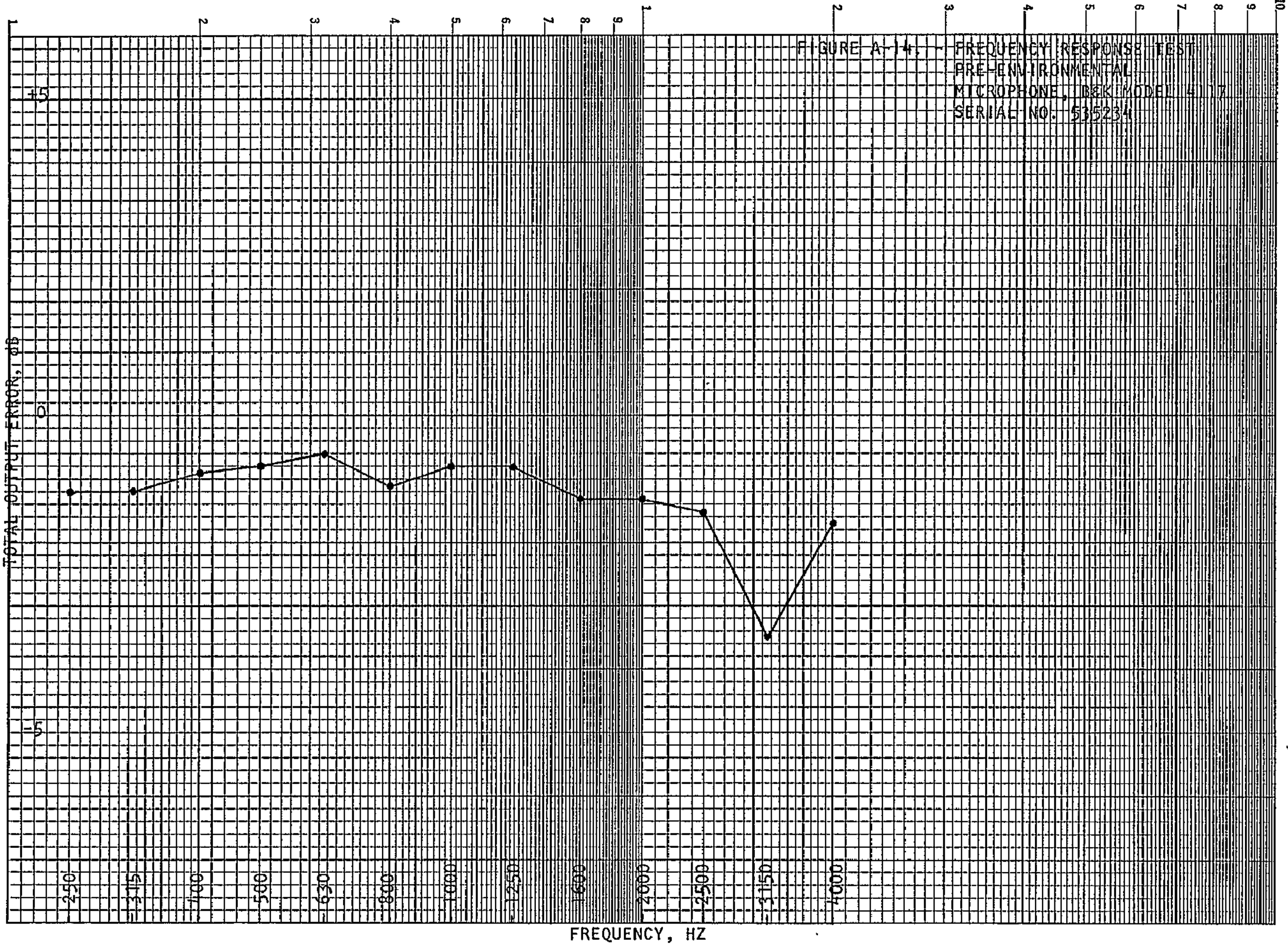


FIGURE A-14. - FREQUENCY RESPONSE TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535234

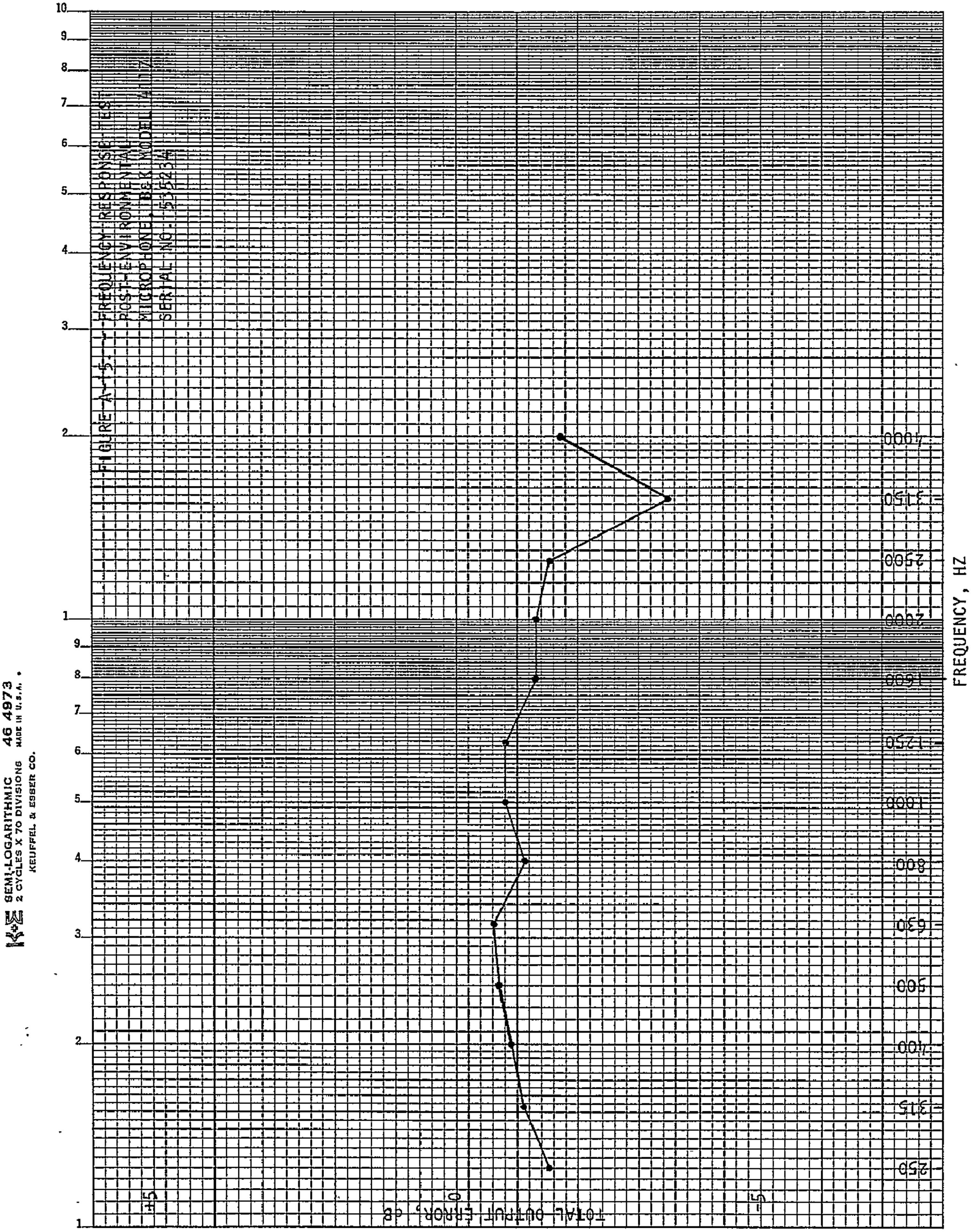


FIGURE A-5. - FREQUENCY RESPONSE TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535234
FREQUENCY, HZ
4000
3150
2500
2000
1600
1250
1000
800
630
500
400
315
250
+5
0
-5
TOTAL OUTPUT ERROR, dB
SEMI-LOGARITHMIC 46 4973
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

FIGURES A-16 THROUGH A-23

B&K Model 4161 Pre- and Post-environmental
Amplitude Linearity Test Data

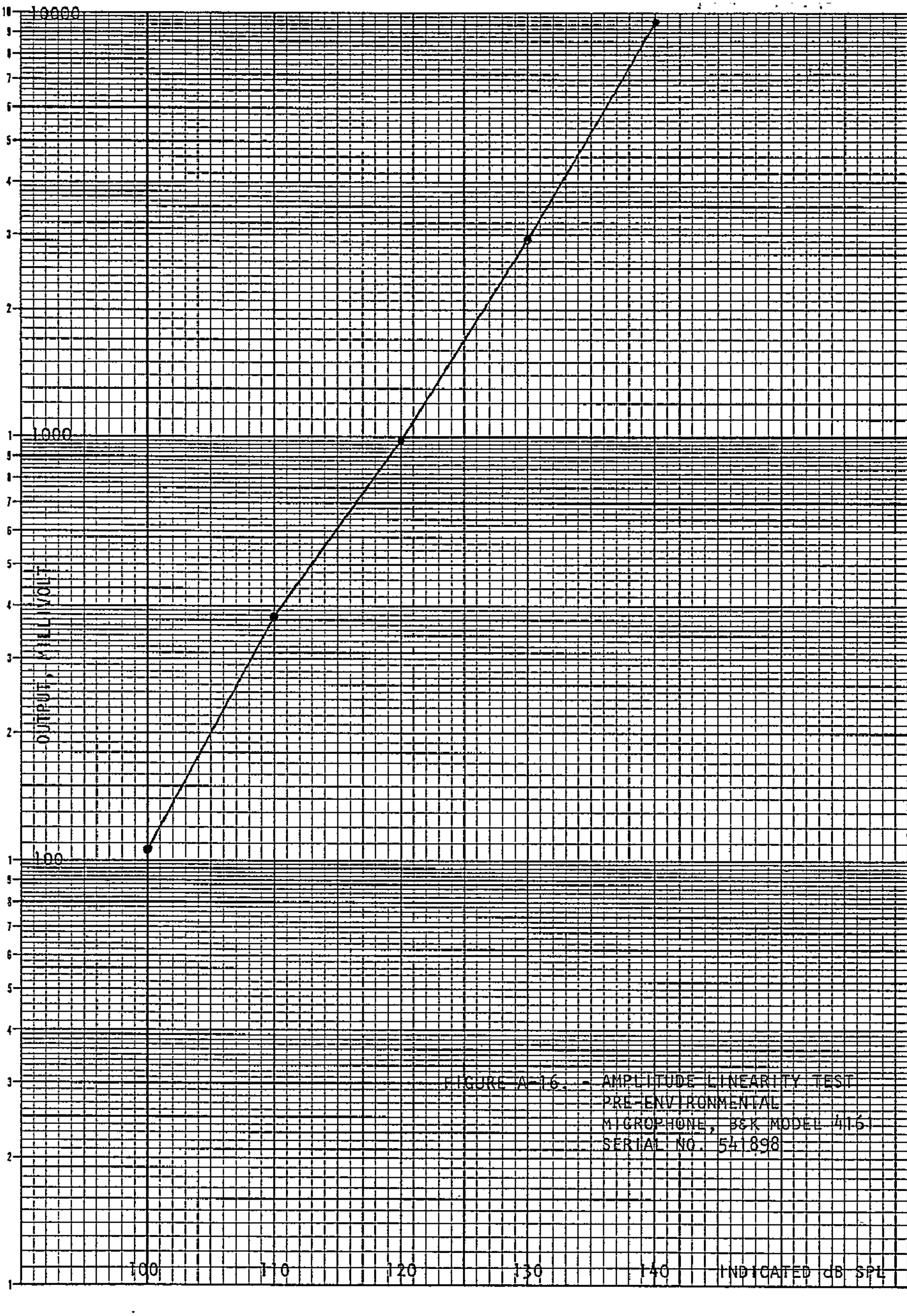


FIGURE A-16. - AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541898

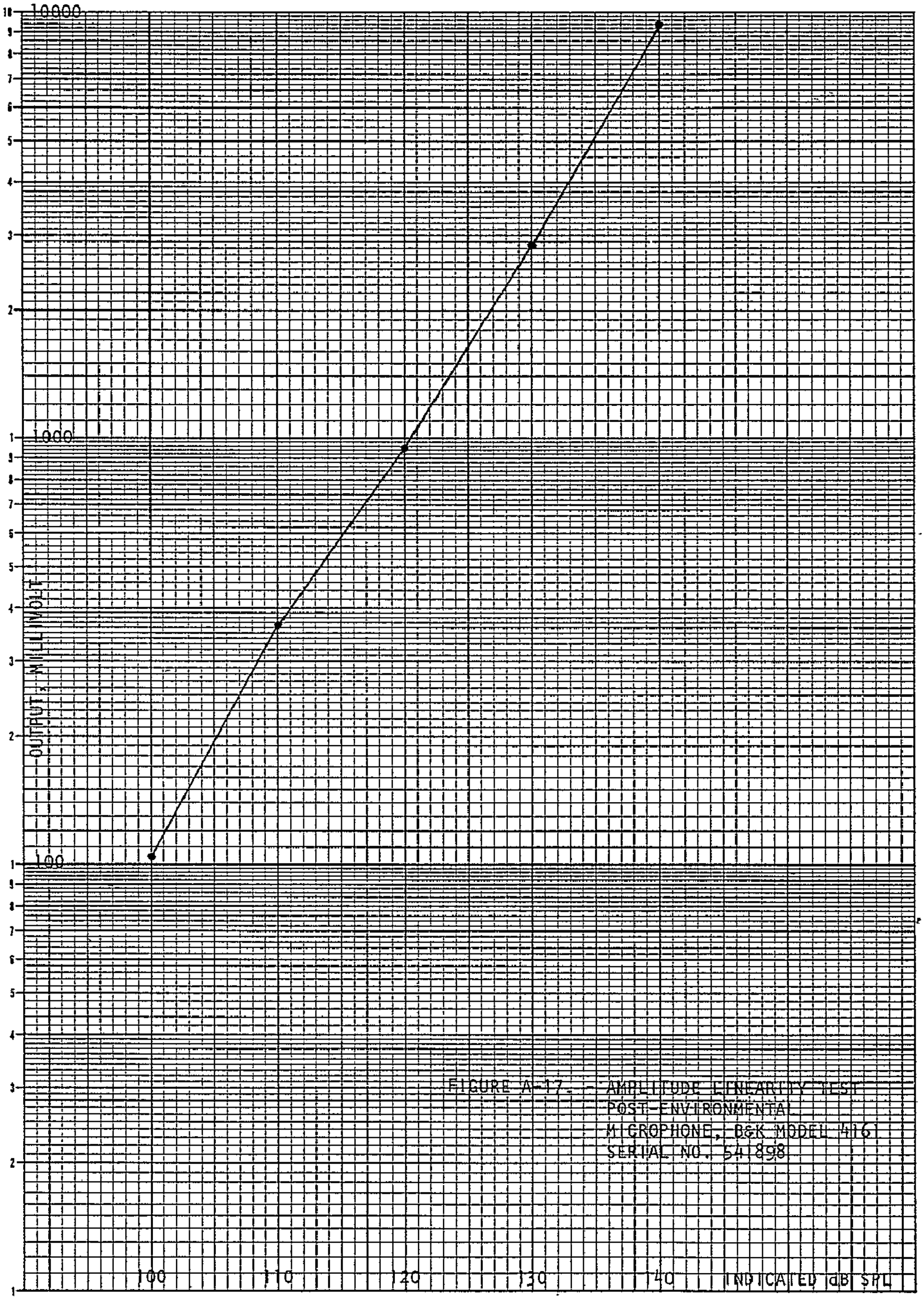


FIGURE A-17. - AMPLITUDE LINEARITY TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541898

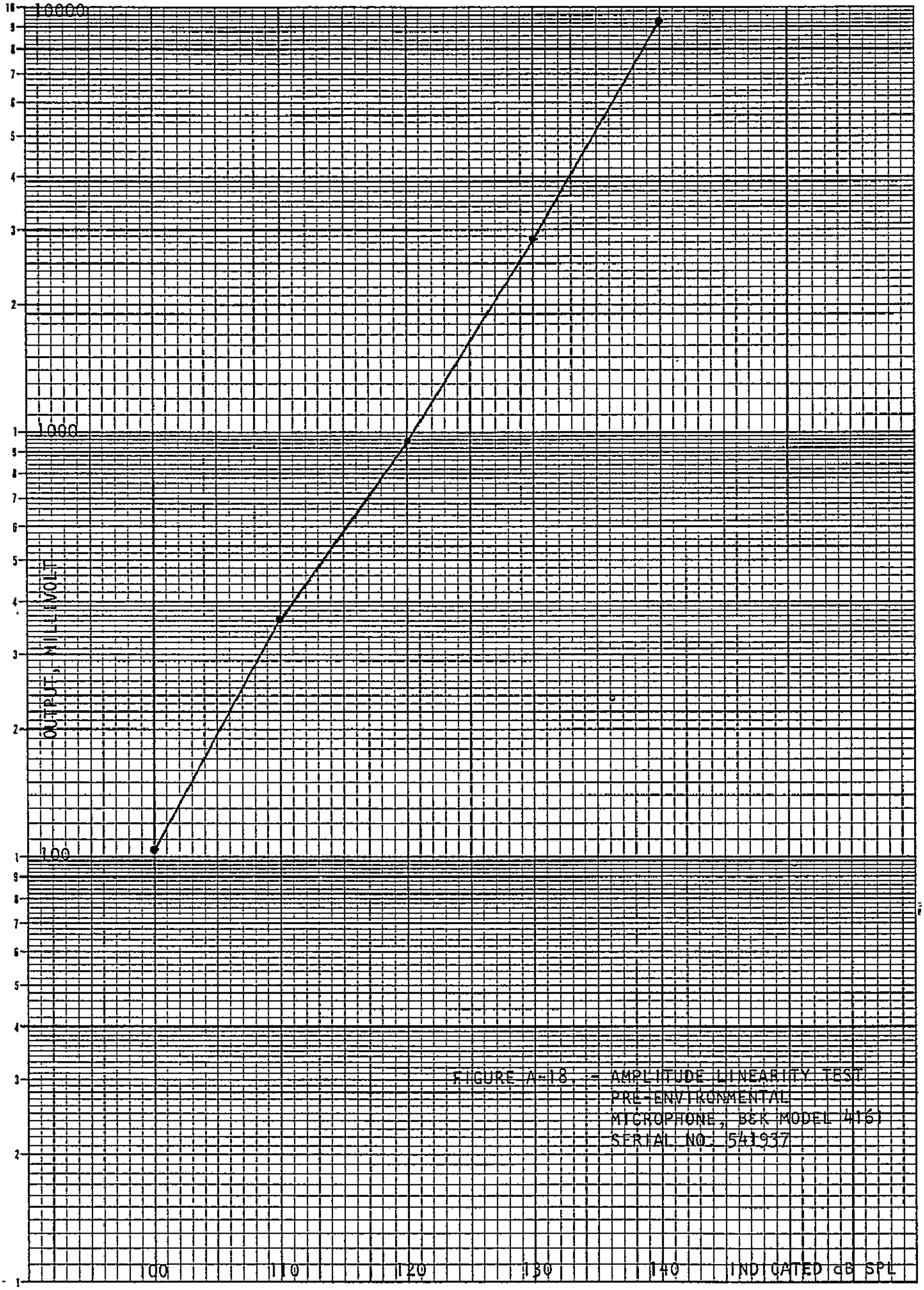
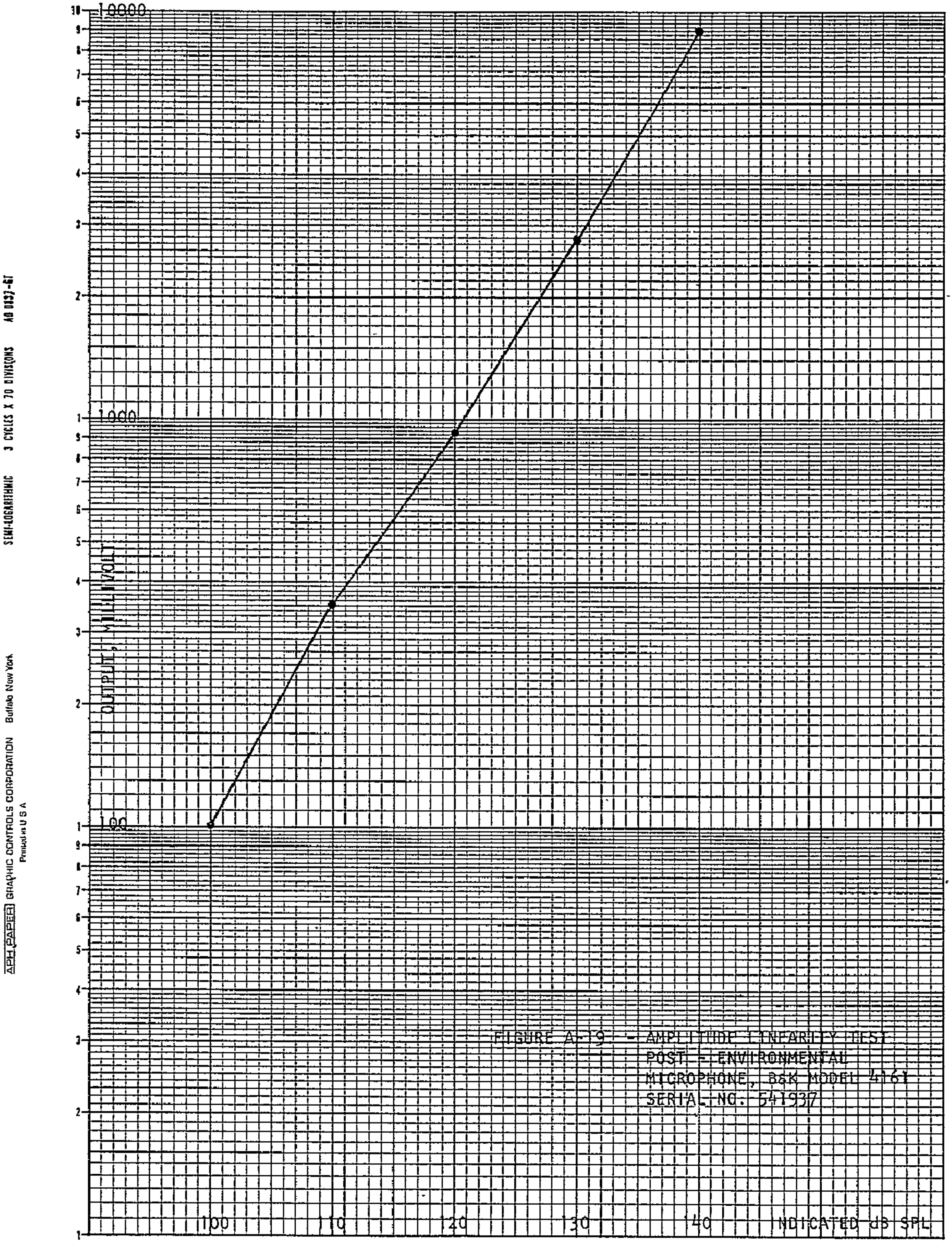


FIGURE A-18. - AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541937

SEMI LOGARITHMIC 3 CYCLES X 70 DIVISIONS

GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo, New York Printed in U.S.A.



10000
1000
100
OUTPUT, MILLIVOLT
100
110
120
130
140
INDICATED dB SPL
FIGURE A-19 - AMPLITUDE LINEARITY TEST
POST - ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541937
SEMI-LOGARITHMIC 3 CYCLES X 70 DIVISIONS AO 0832-6T
APH PAPER GRAPHIC CONTROLS CORPORATION Buffalo New York
Printed in U S A

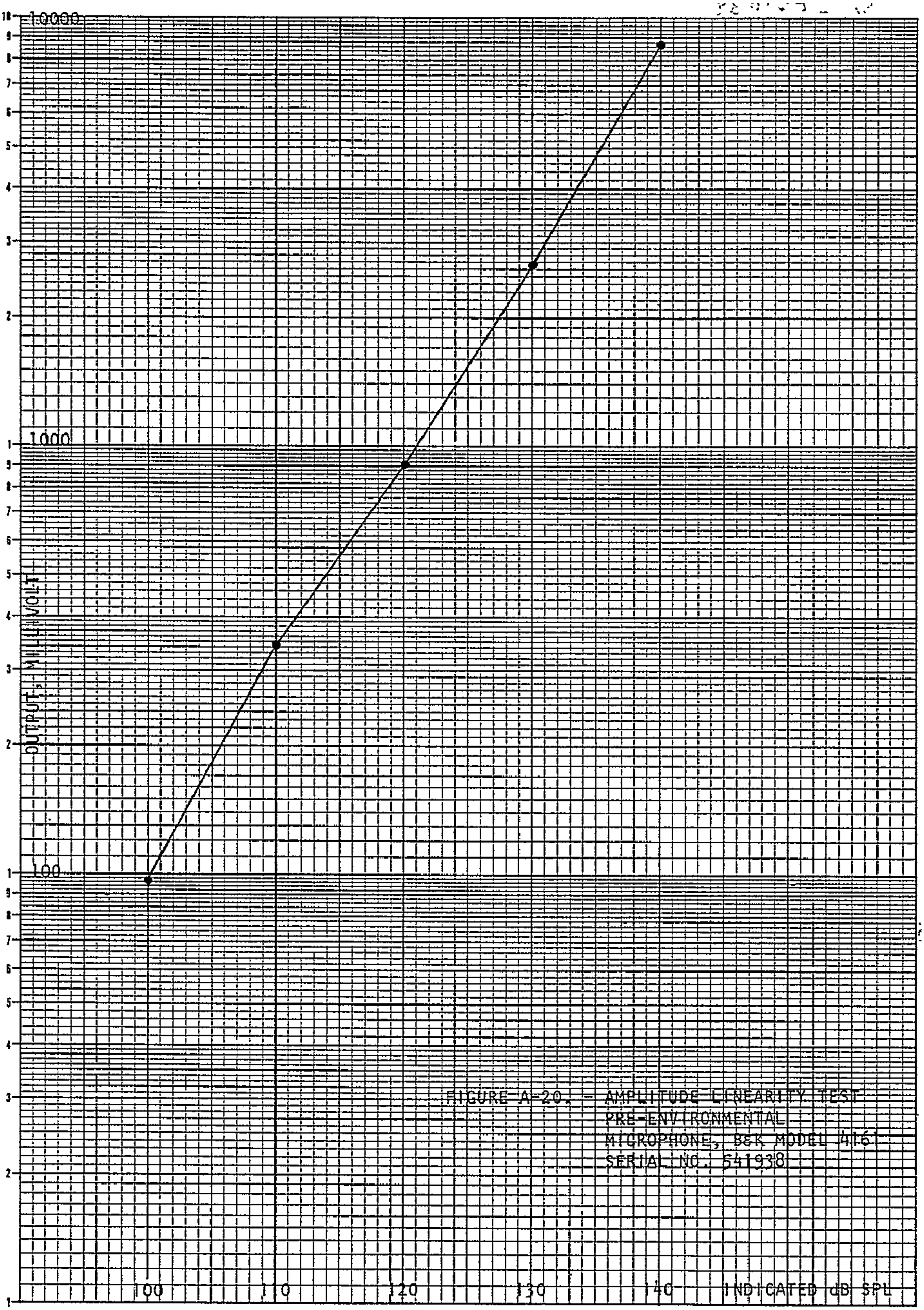
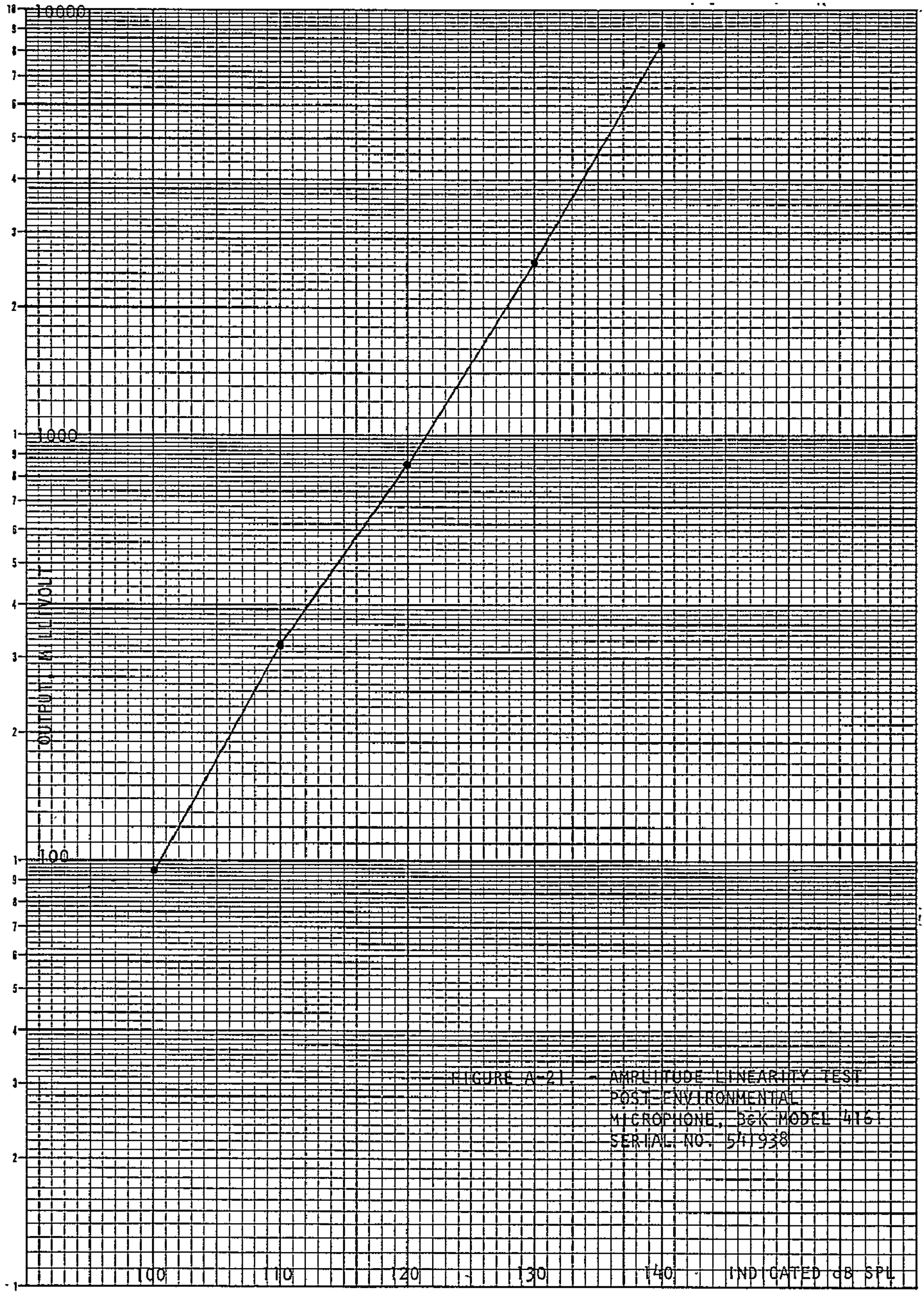


FIGURE A-20. - AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541938


10000
1000
100
OUTPUT, MILLIVOLT
100
110
120
130
140
INDICATED dB SPL
FIGURE A-21. - AMPLITUDE LINEARITY TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541938

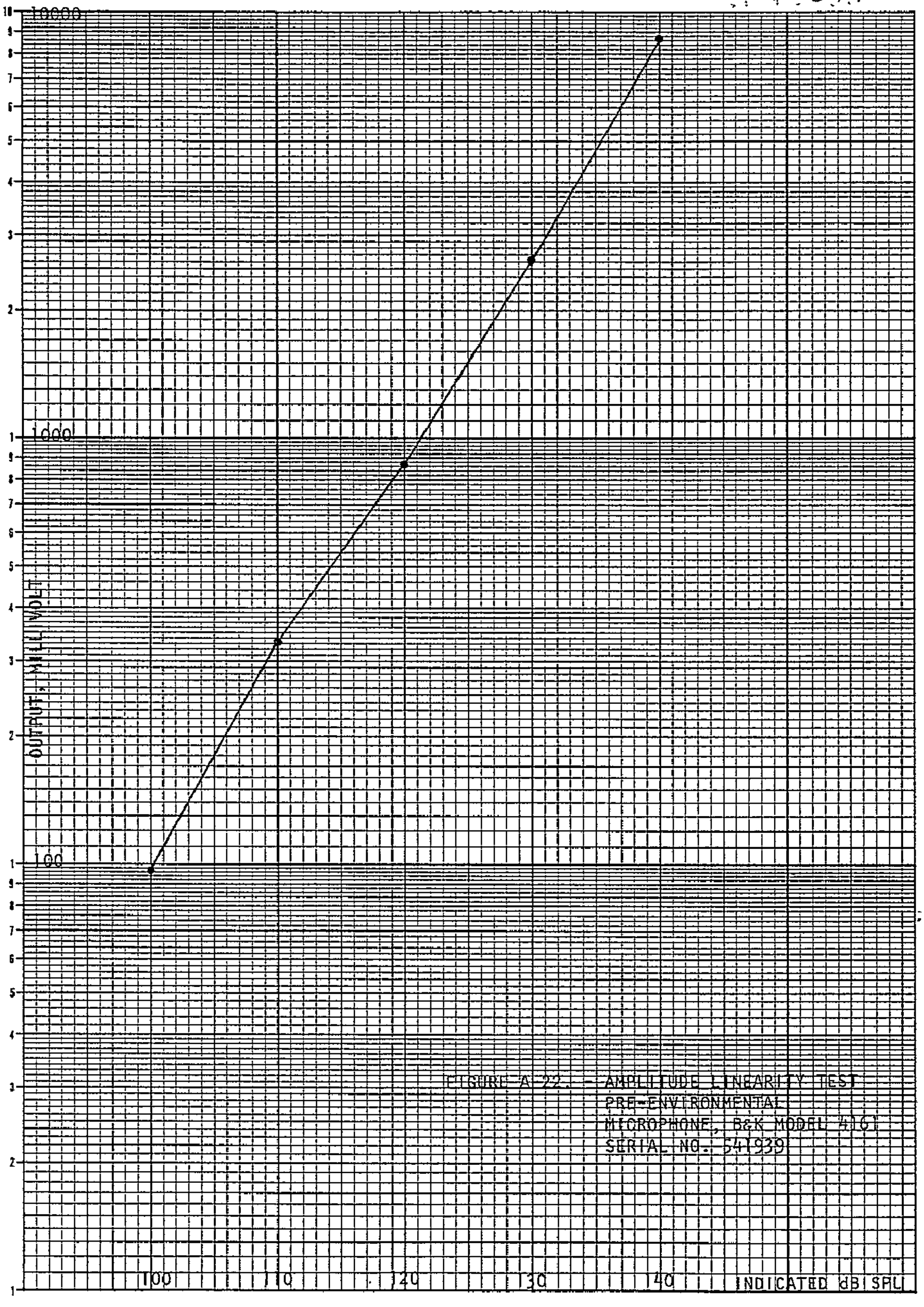


FIGURE A-22. - AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541939

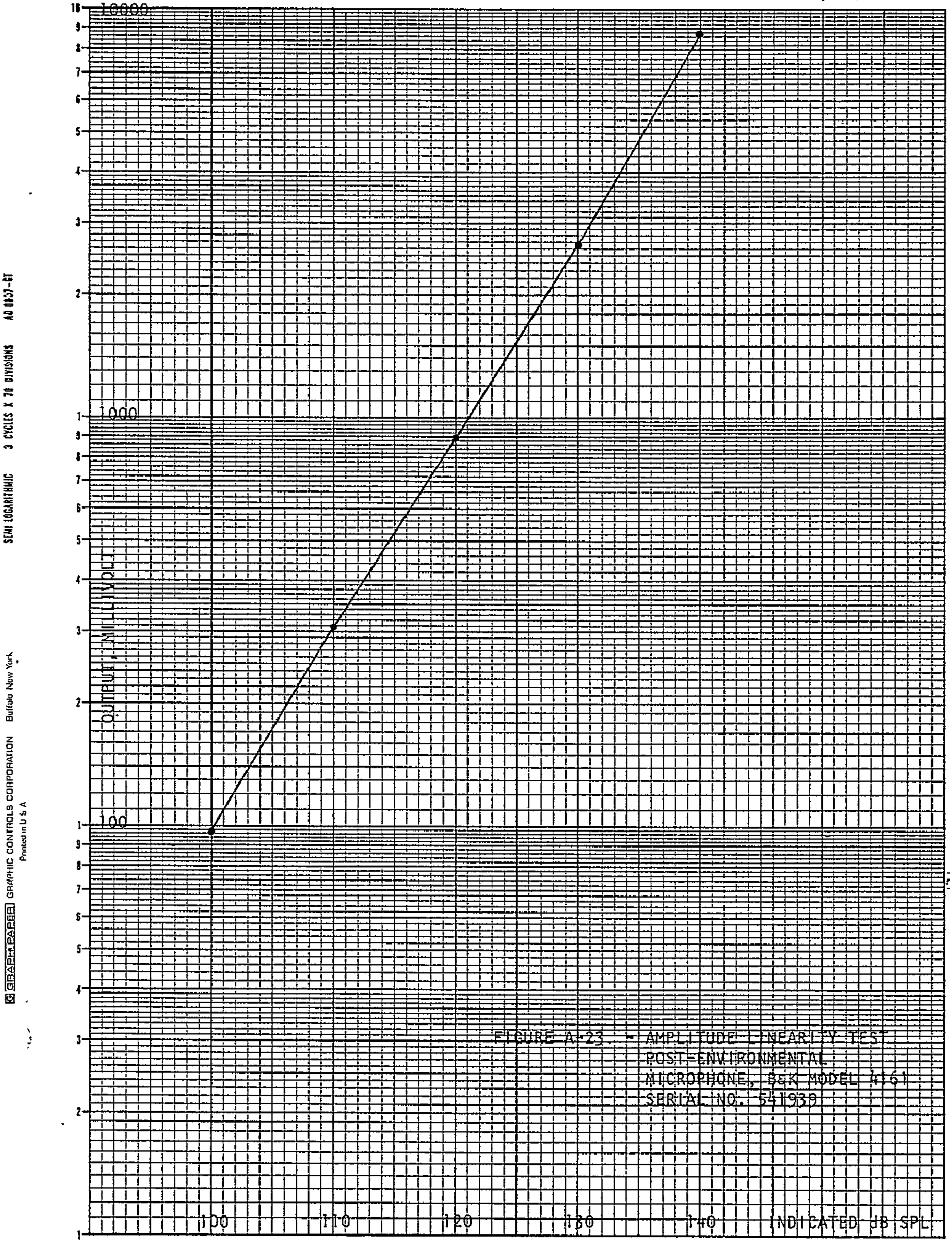


FIGURE A-23 - AMPLITUDE LINEARITY TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541939

FIGURES A-24 THROUGH A-30

B&K Model 4117 Pre- and Post Environmental
Amplitude Linearity Test Data

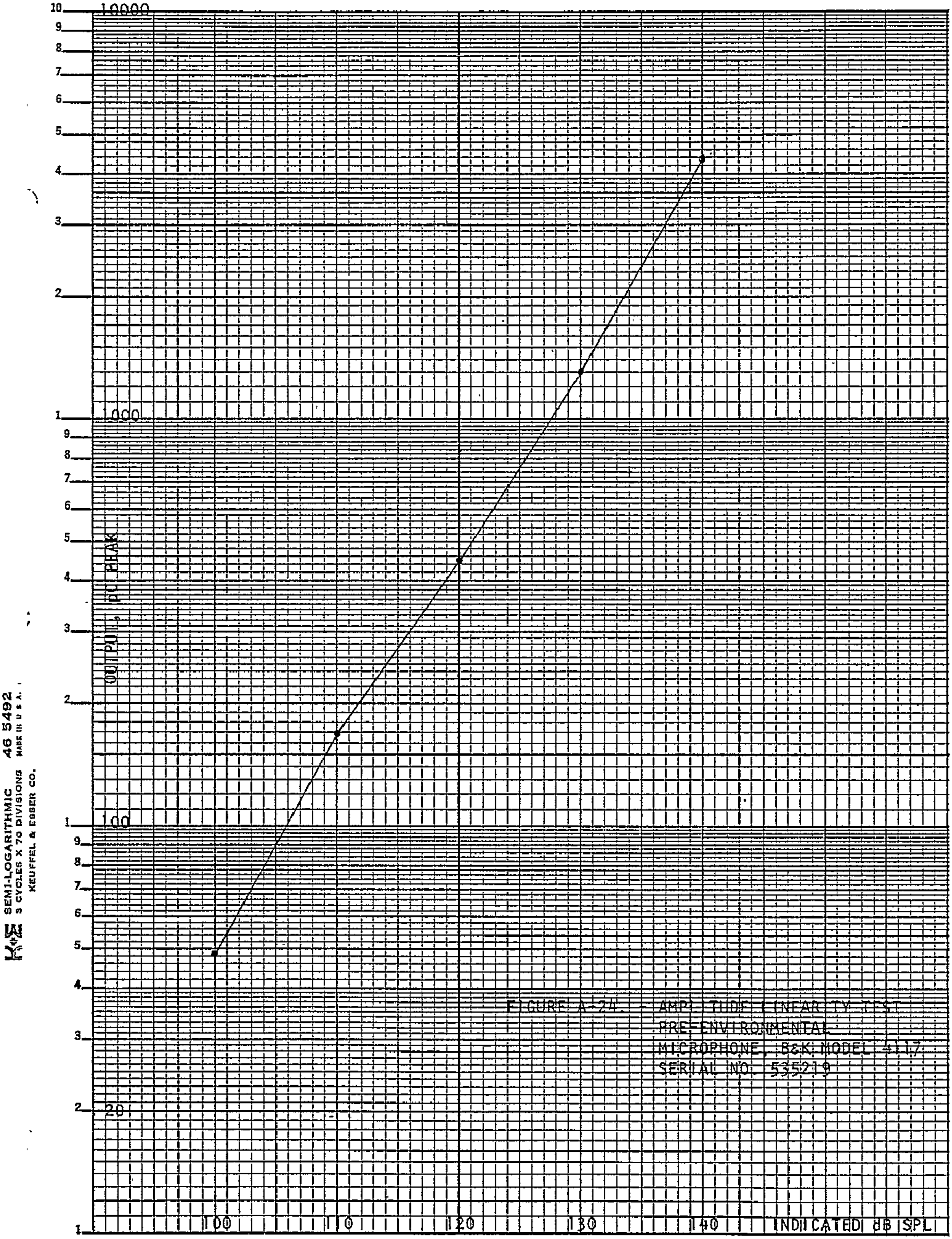


FIGURE A-24. - AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535219

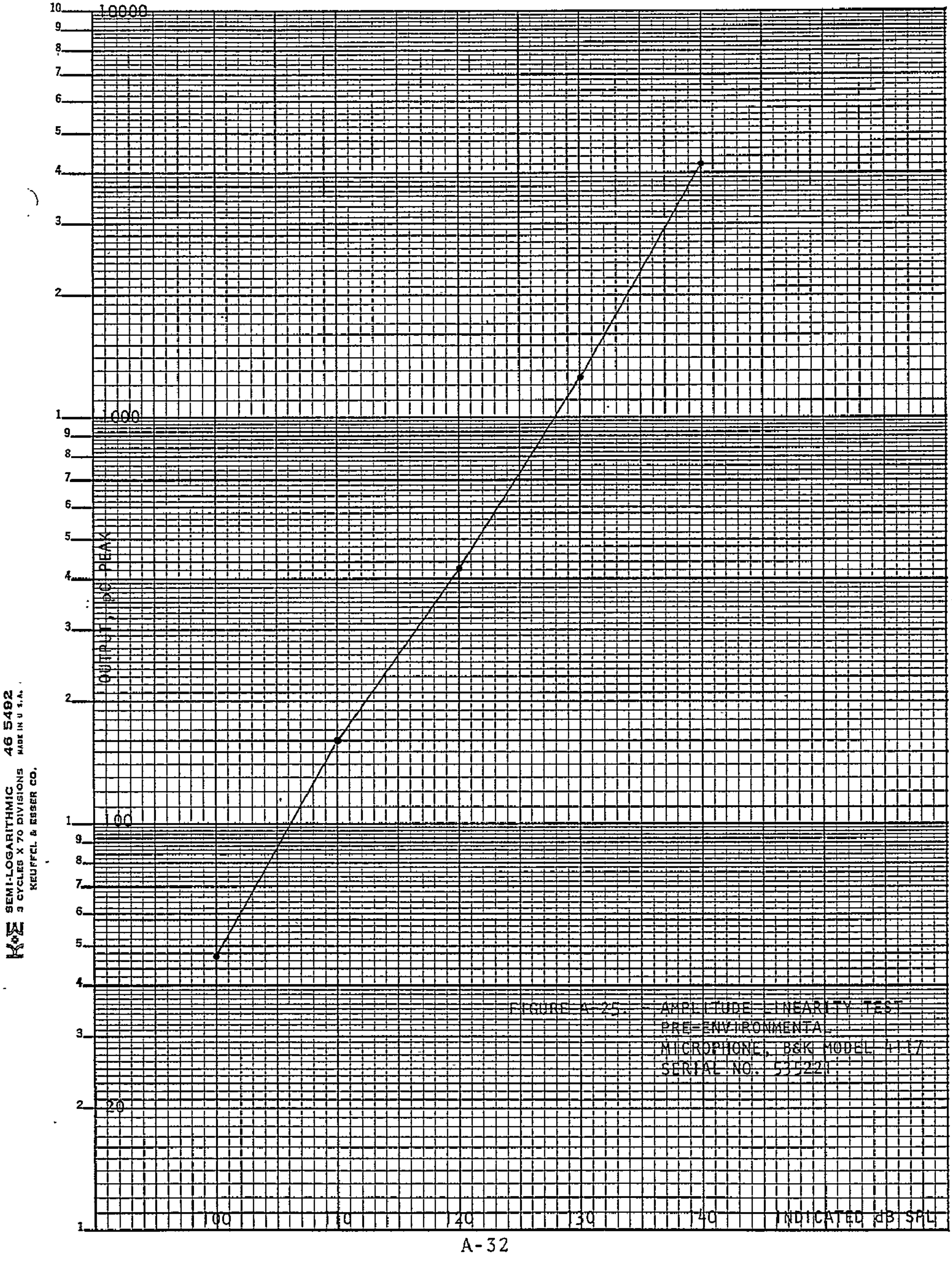
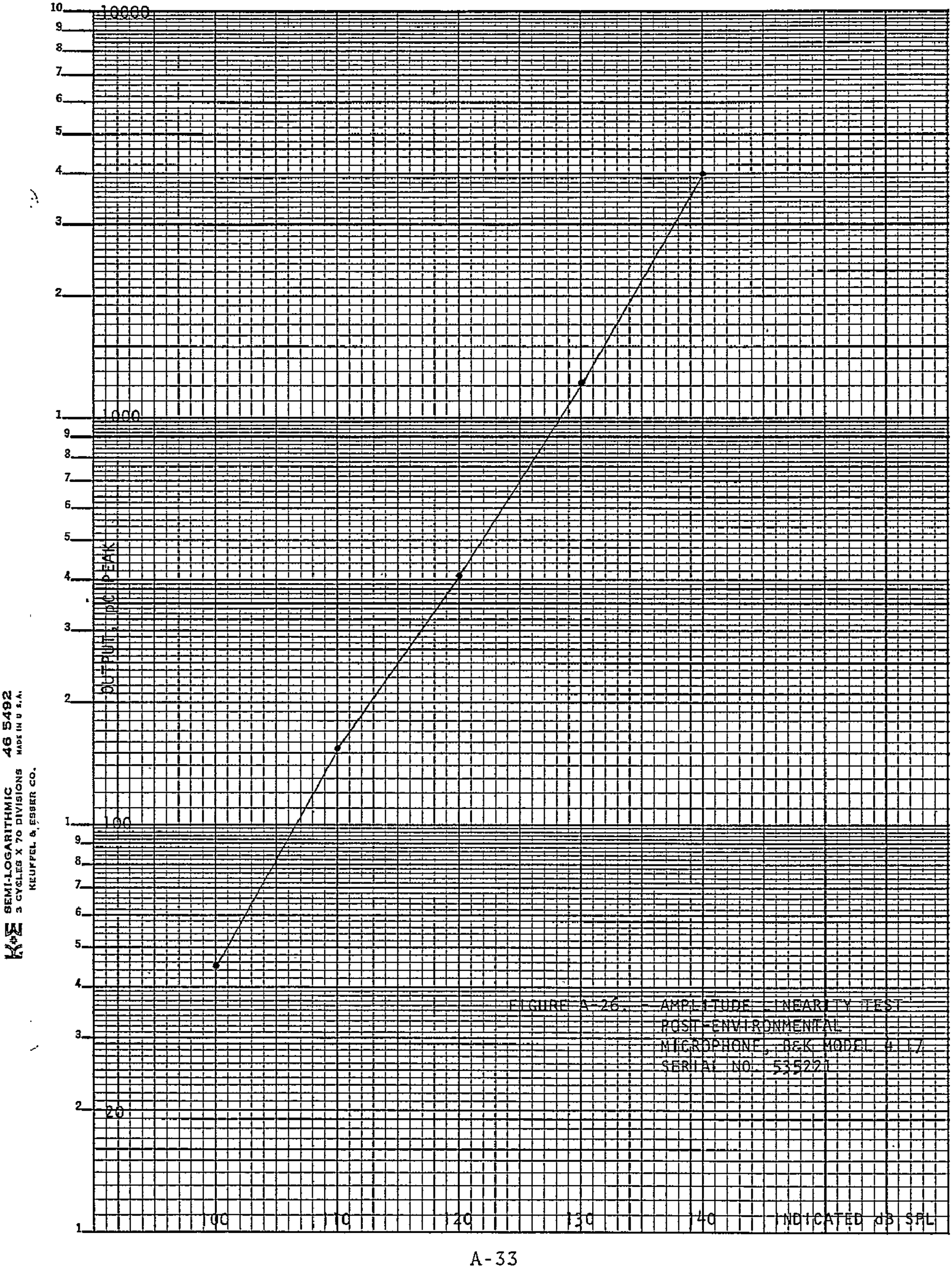


FIGURE A-25. AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535221



10000
1000
100
20
OUTPUT, DC PEAK
100
110
120
130
140
INDICATED dB SPL
FIGURE A-26. AMPLITUDE LINEARITY TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535227
KE SEMI-LOGARITHMIC 46 5492
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

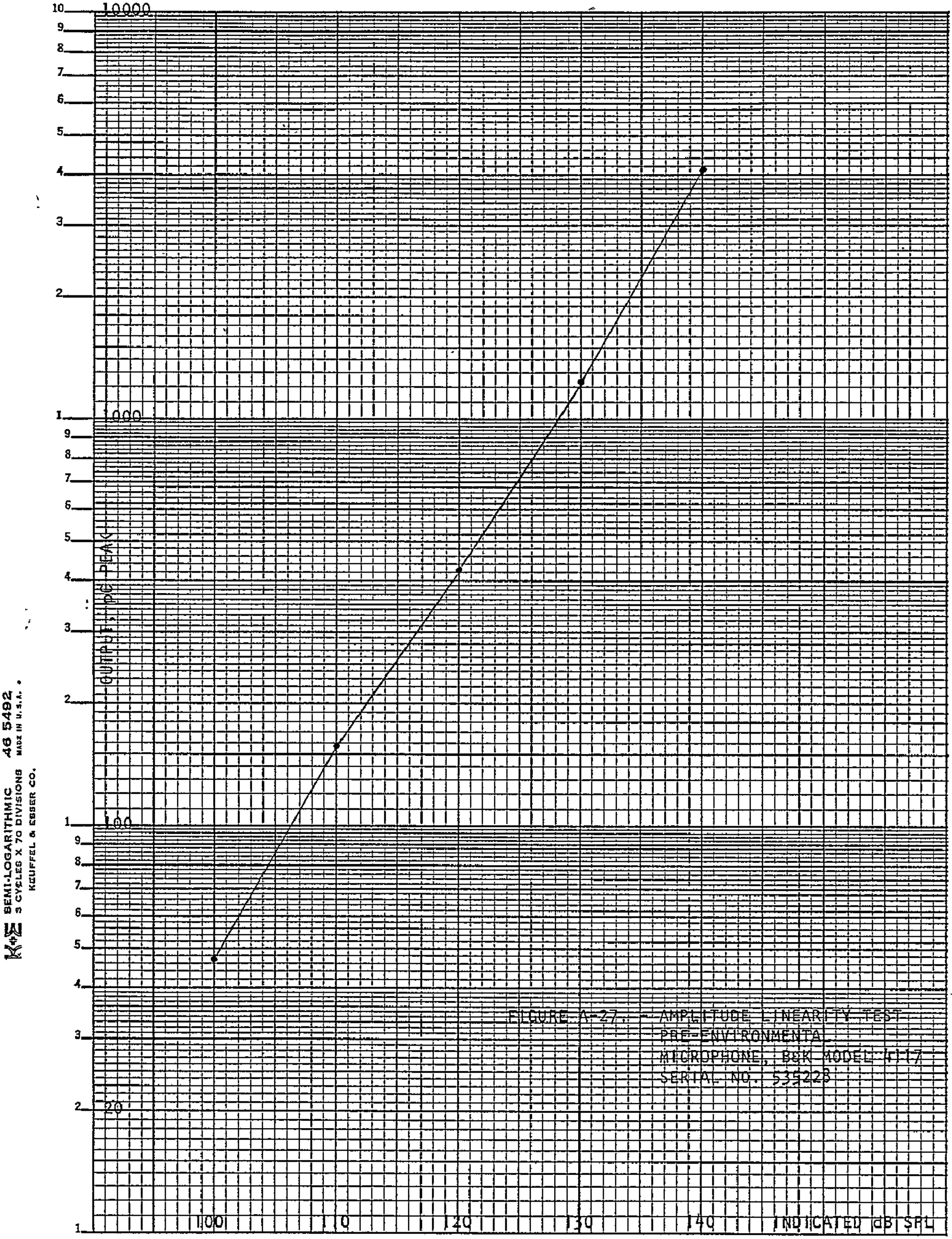


FIGURE A-27. - AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535223

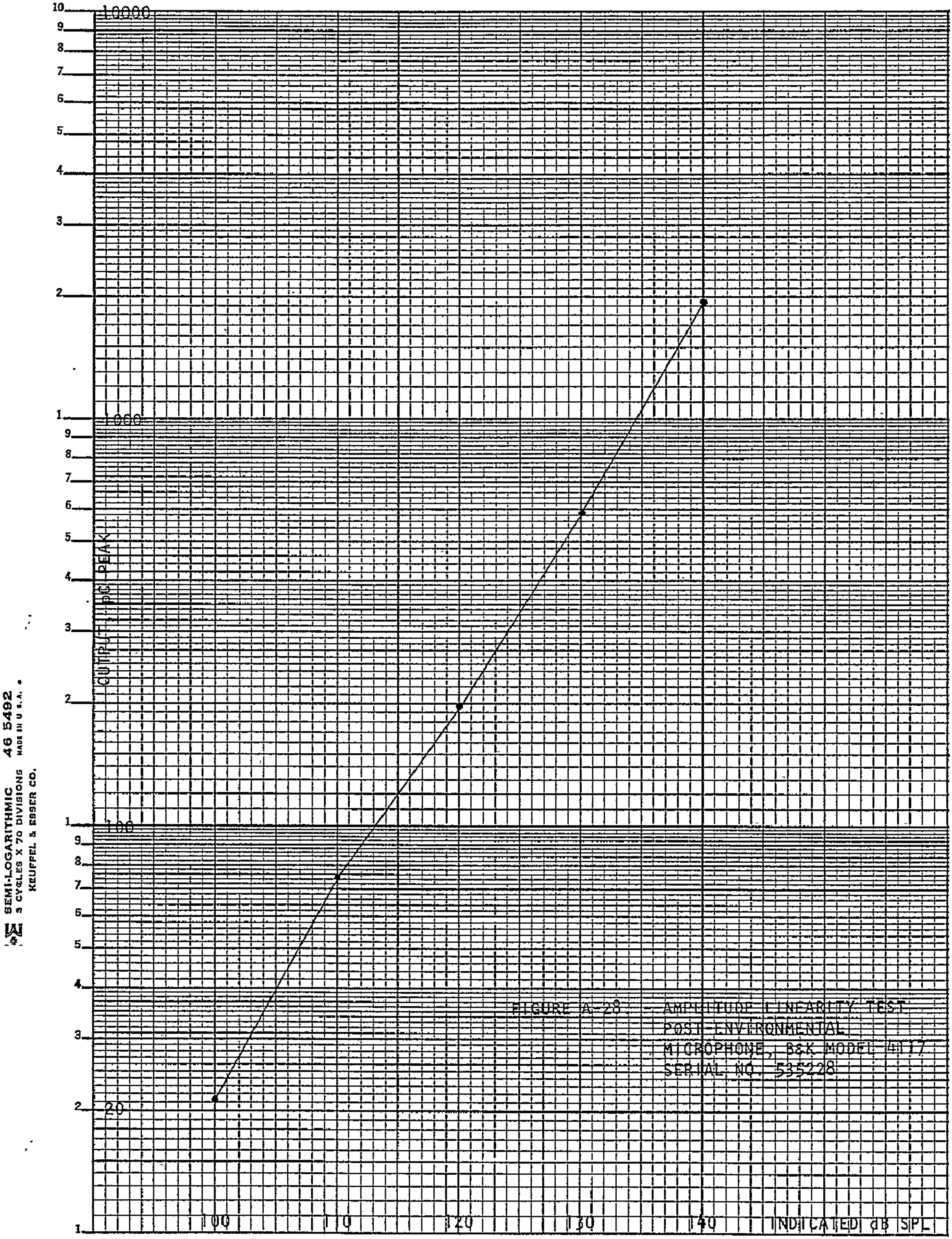


FIGURE A-28 - AMPLITUDE LINEARITY TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535228

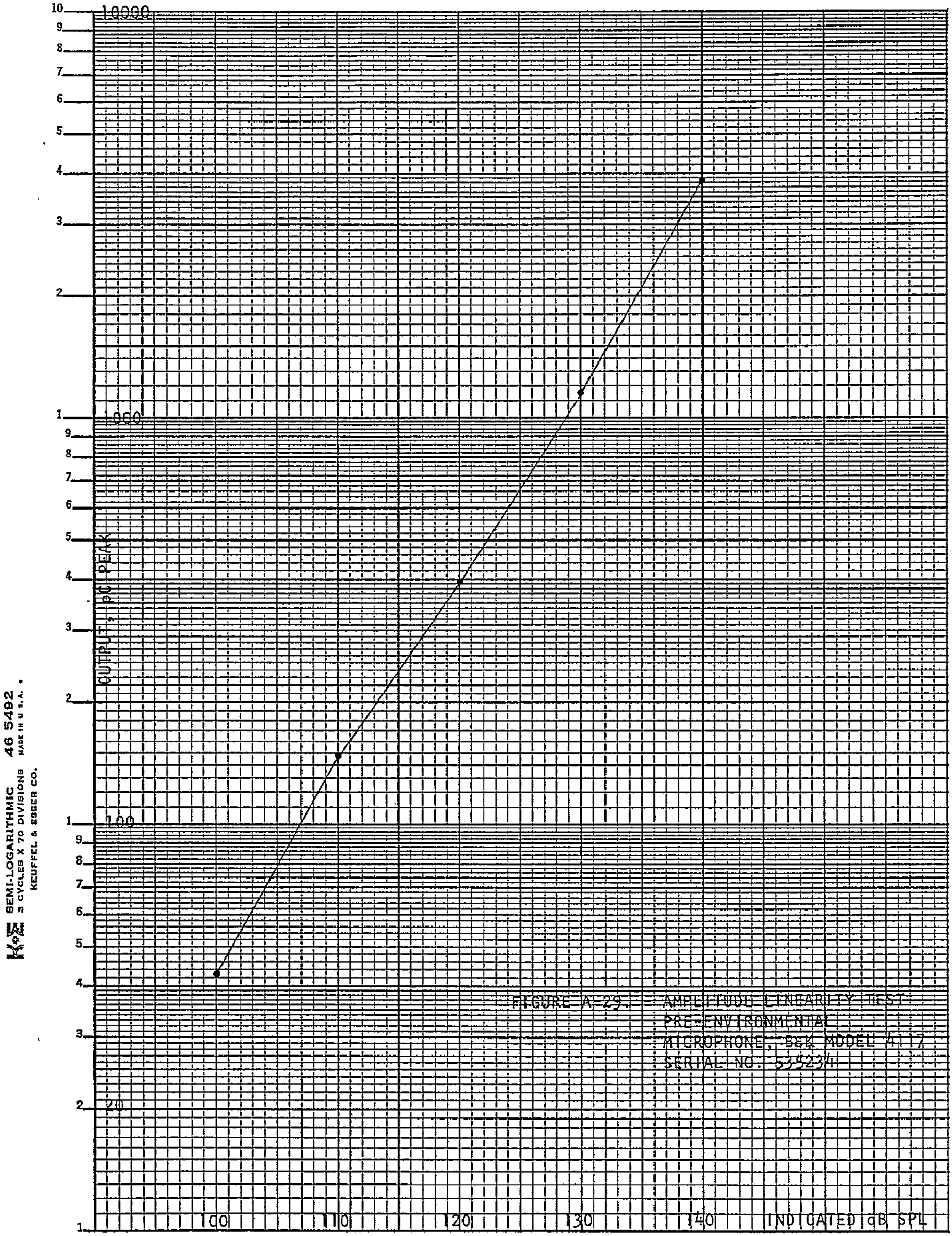


FIGURE A-29. AMPLITUDE LINEARITY TEST
PRE-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535234

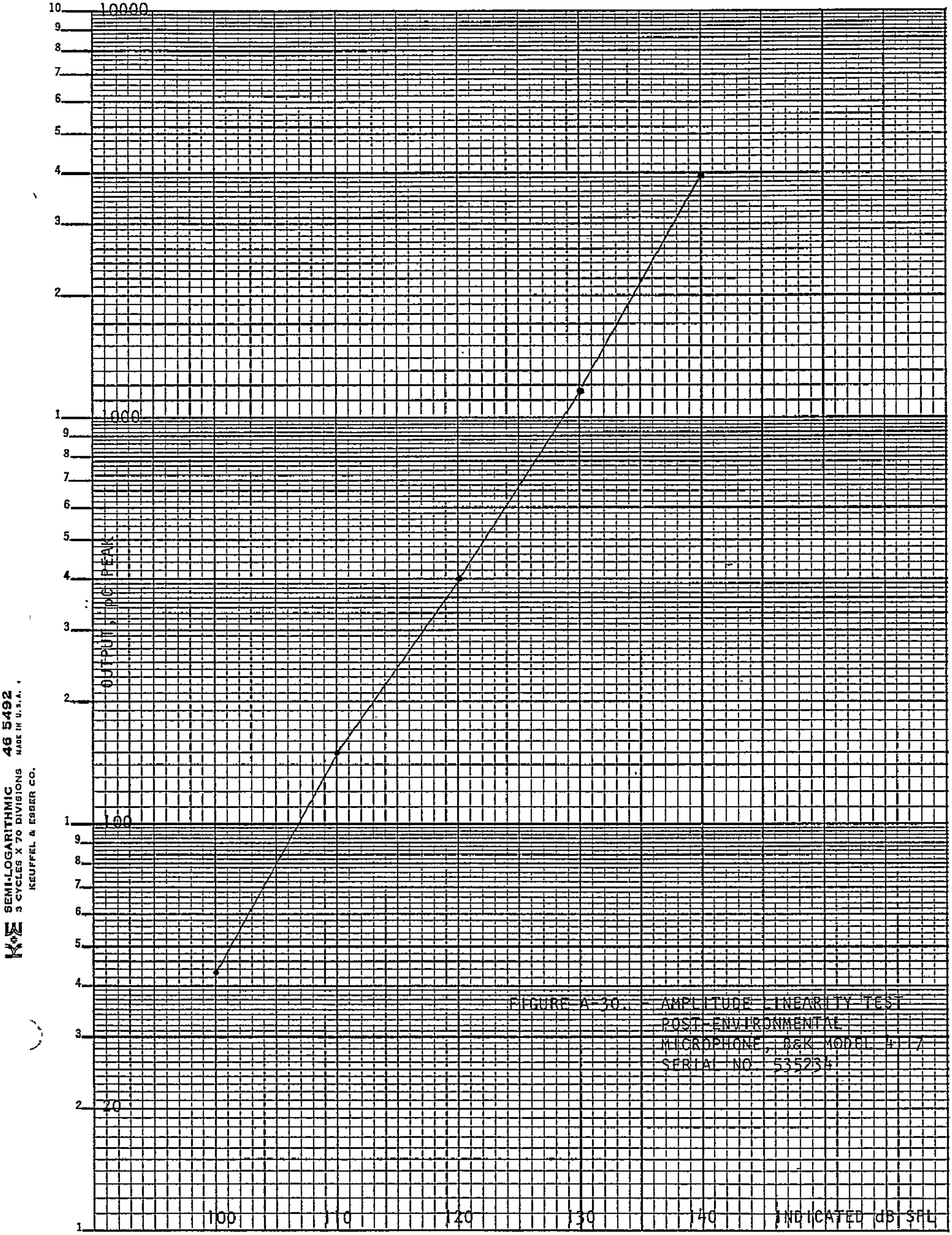


FIGURE A-30. - AMPLITUDE LINEARITY TEST
POST-ENVIRONMENTAL
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535234

FIGURES A-31 THROUGH A-34

B&K Model 4161 Sensitivity
Repeatability Data

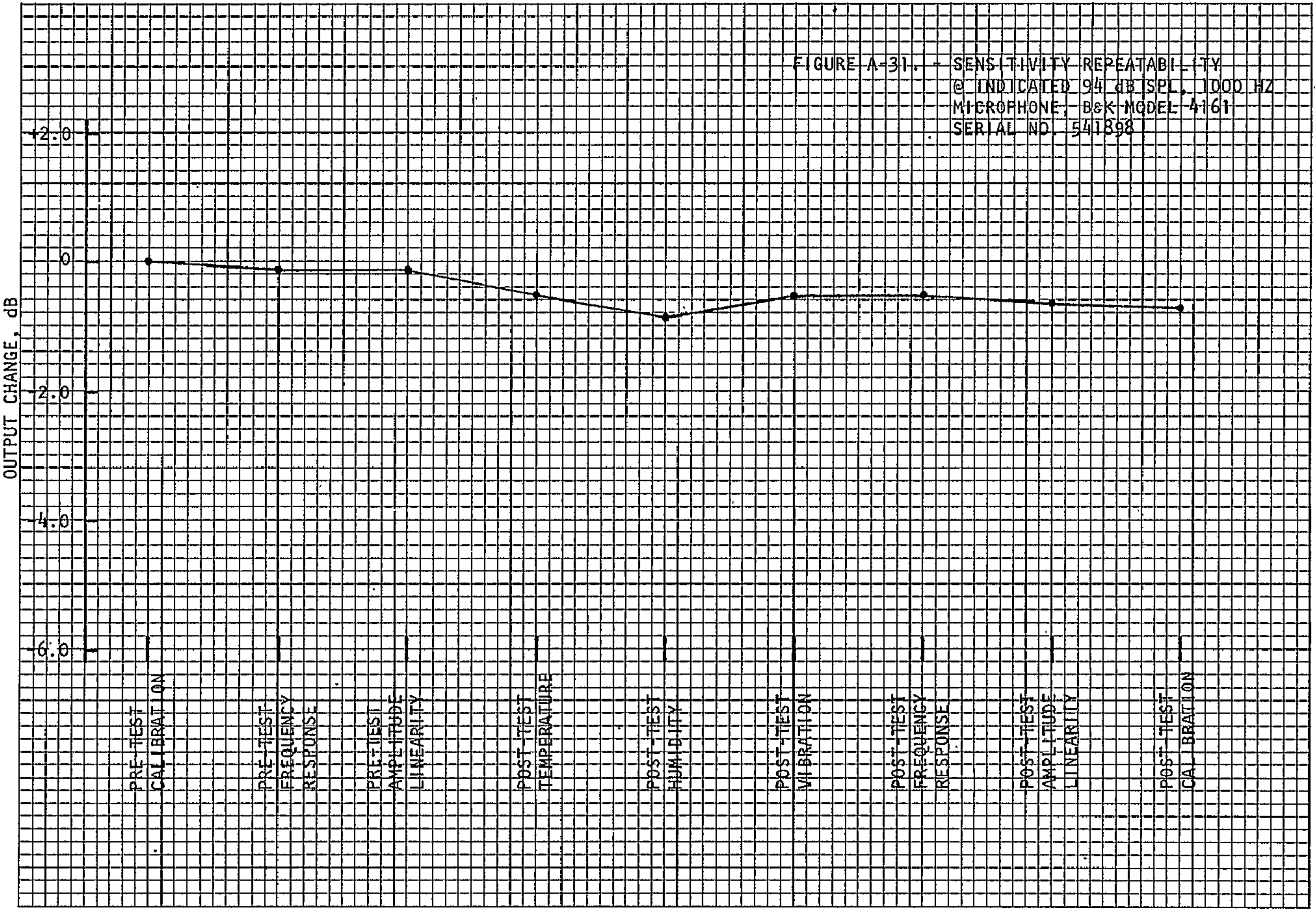


FIGURE A-31. - SENSITIVITY REPEATABILITY
@ INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541898

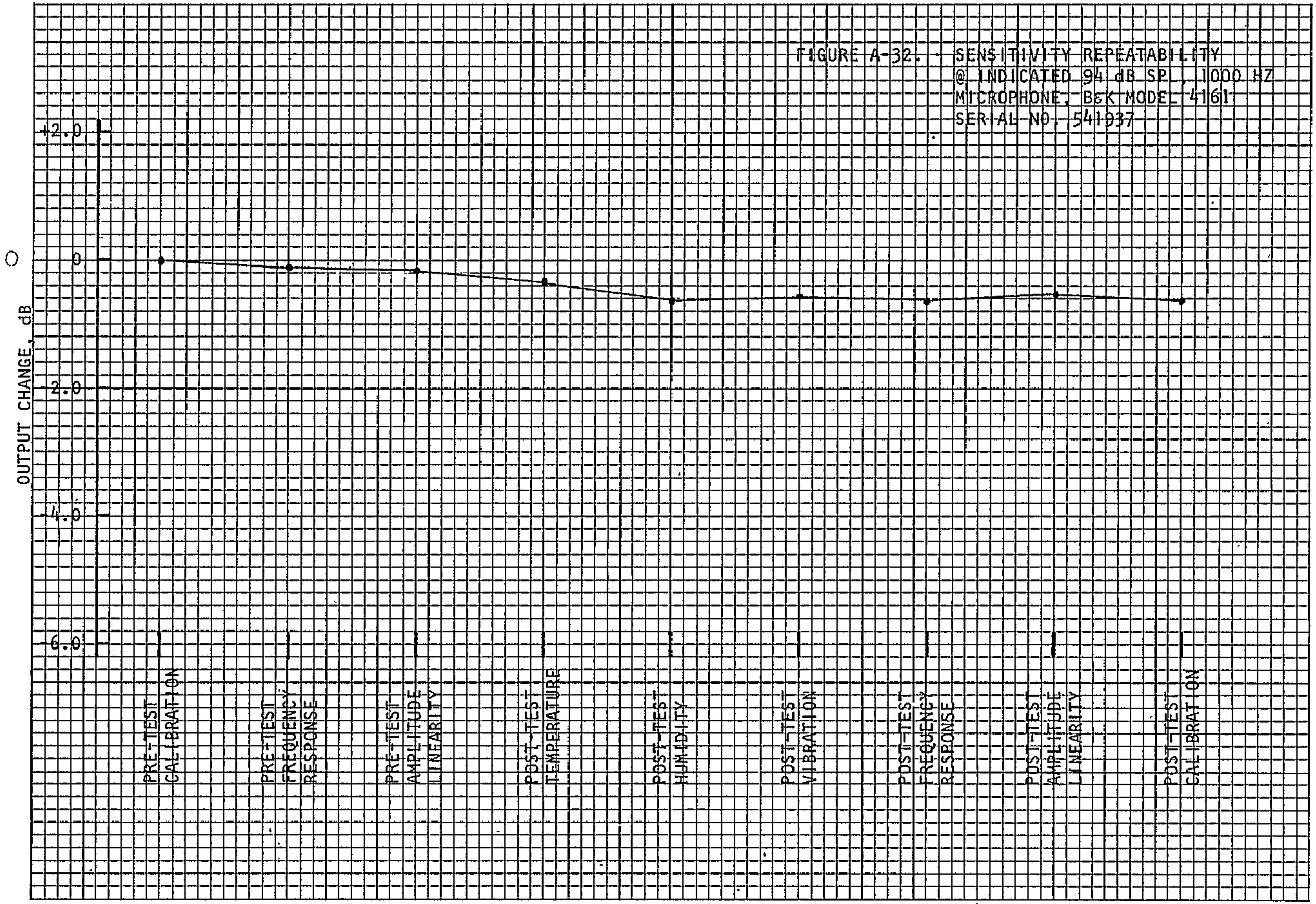


FIGURE A-32. SENSITIVITY REPEATABILITY
@ INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541937

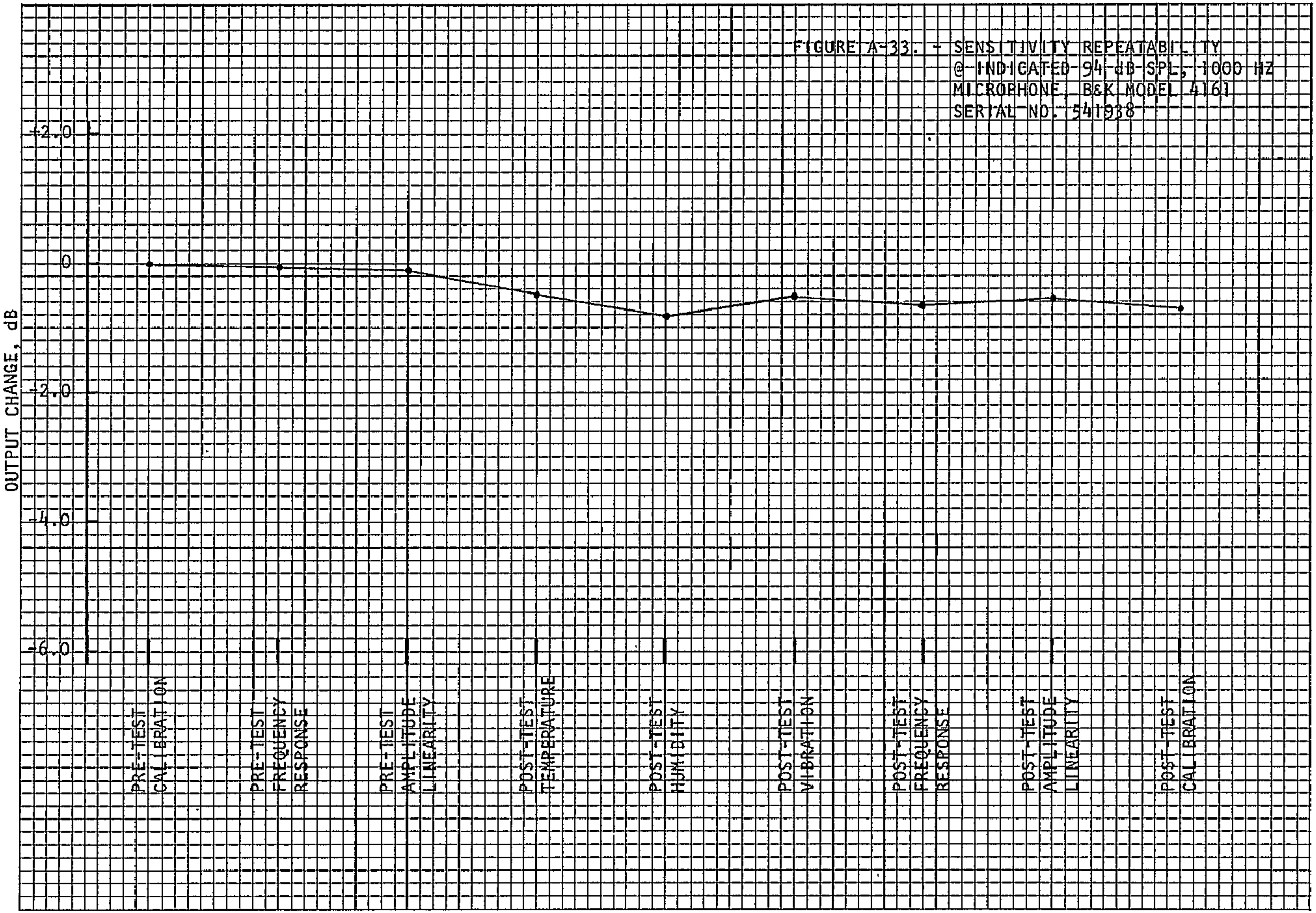


FIGURE A-33. - SENSITIVITY REPEATABILITY
@ INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541938

10TH LINE HEAVY

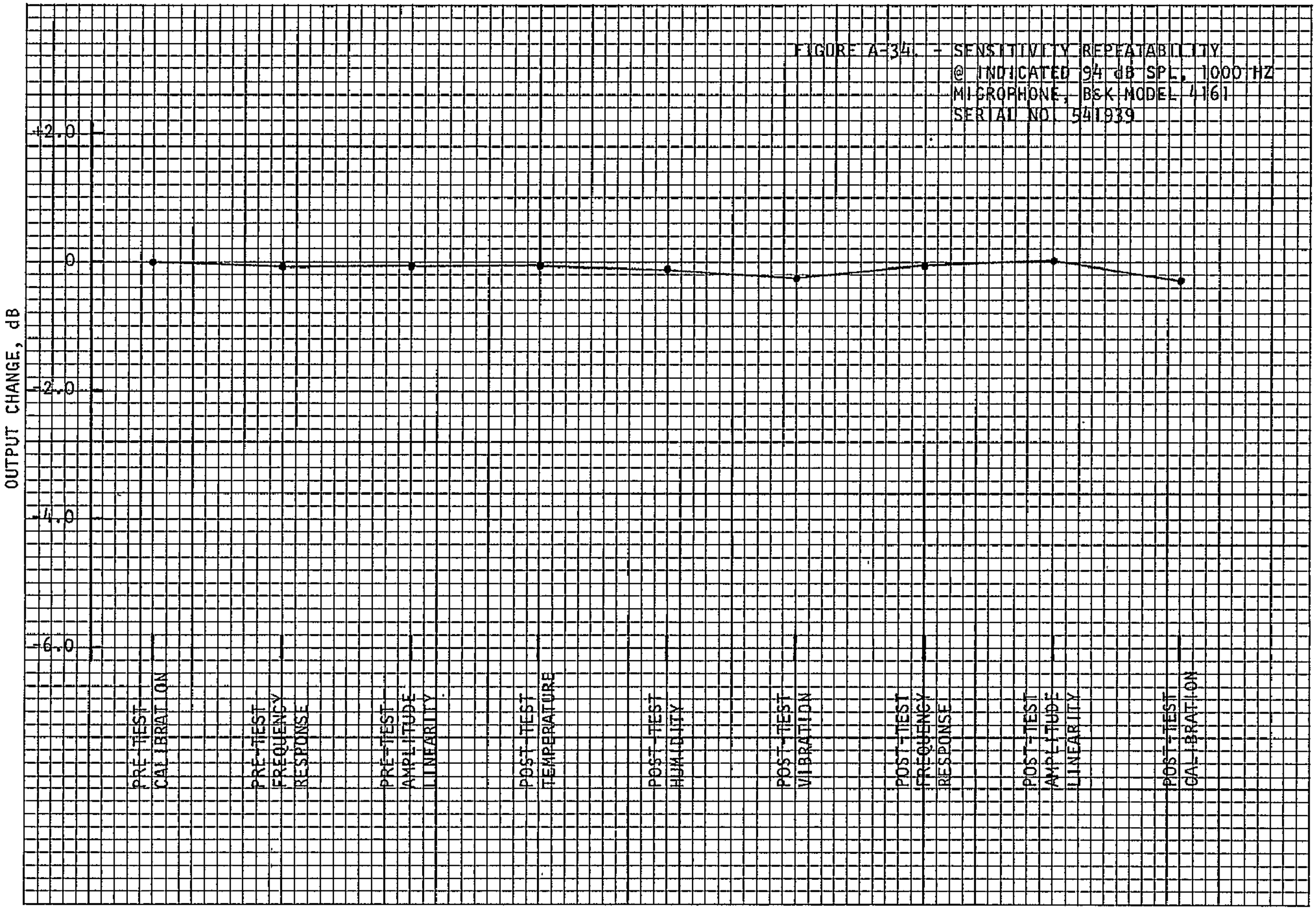


FIGURE A-34. - SENSITIVITY REPEATABILITY
@ INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4161
SERIAL NO. 541939

FIGURES A-35 THROUGH A-38

B&K Model 4117 Sensitivity
Repeatability Data

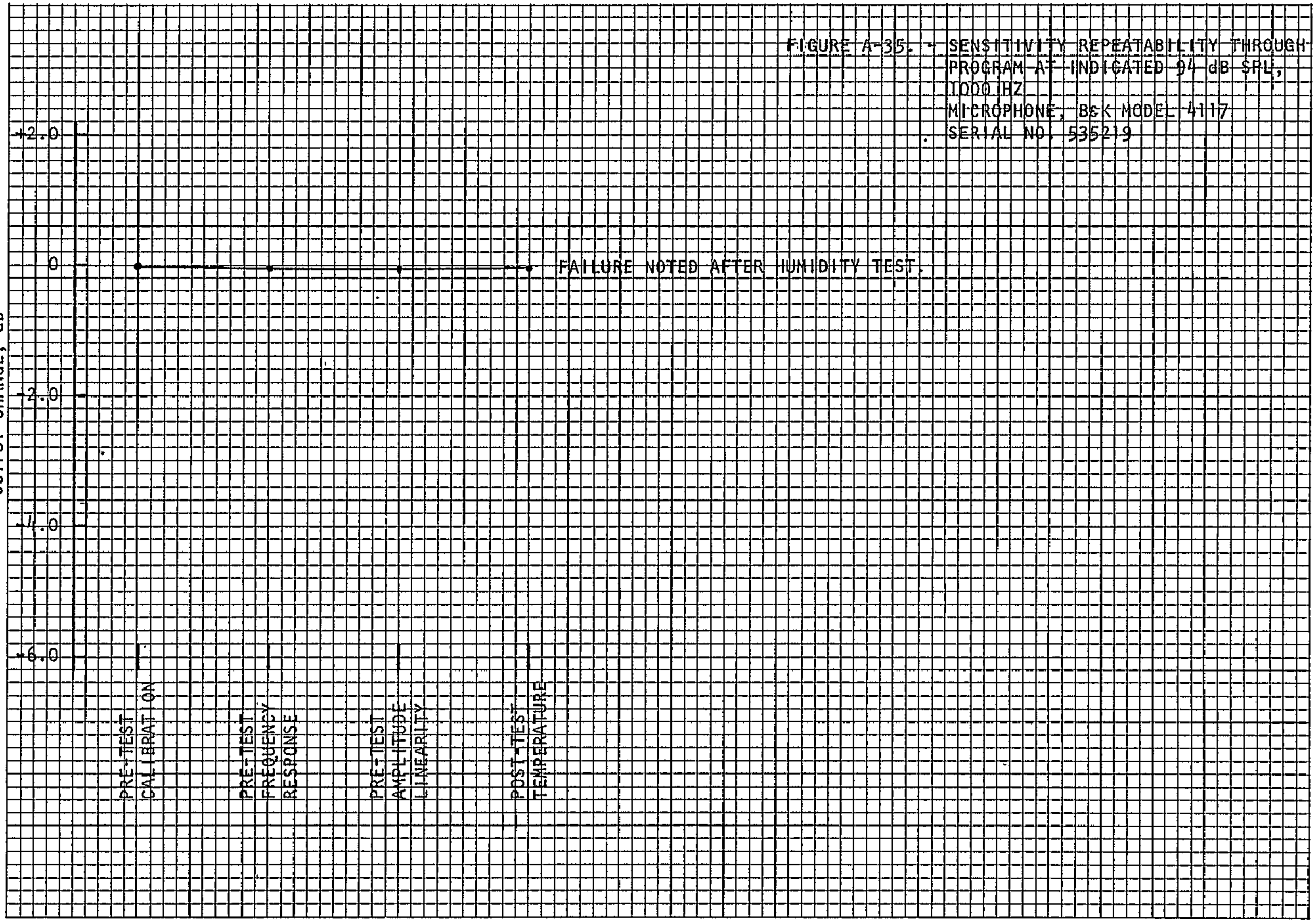


FIGURE A-35. - SENSITIVITY REPEATABILITY THROUGH PROGRAM AT INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535219

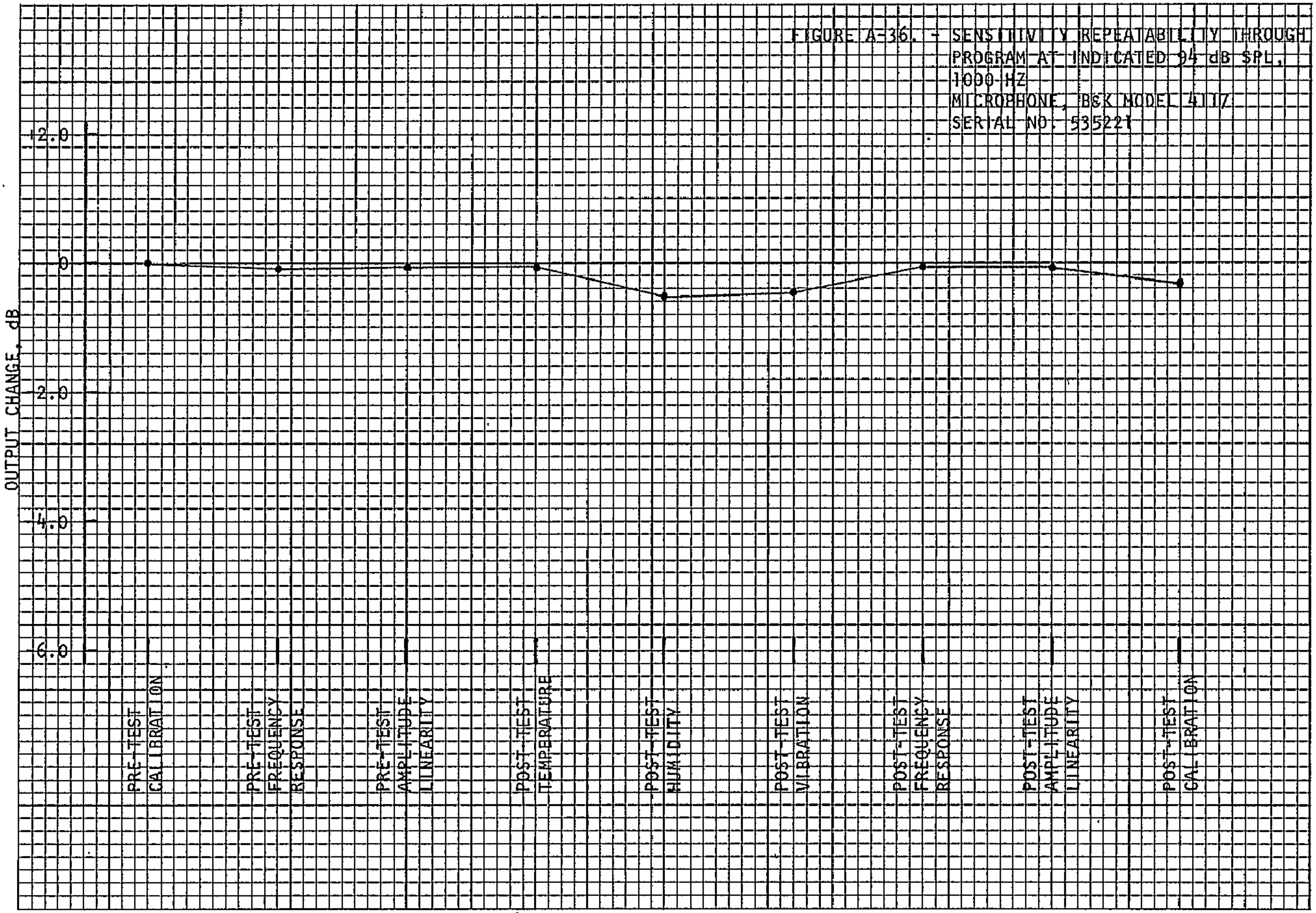


FIGURE A-36. - SENSITIVITY REPEATABILITY THROUGH PROGRAM AT INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535221

FIGURE A-37. - SENSITIVITY REPEATABILITY THROUGH PROGRAM AT INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535228

10TH LINE HEAVY

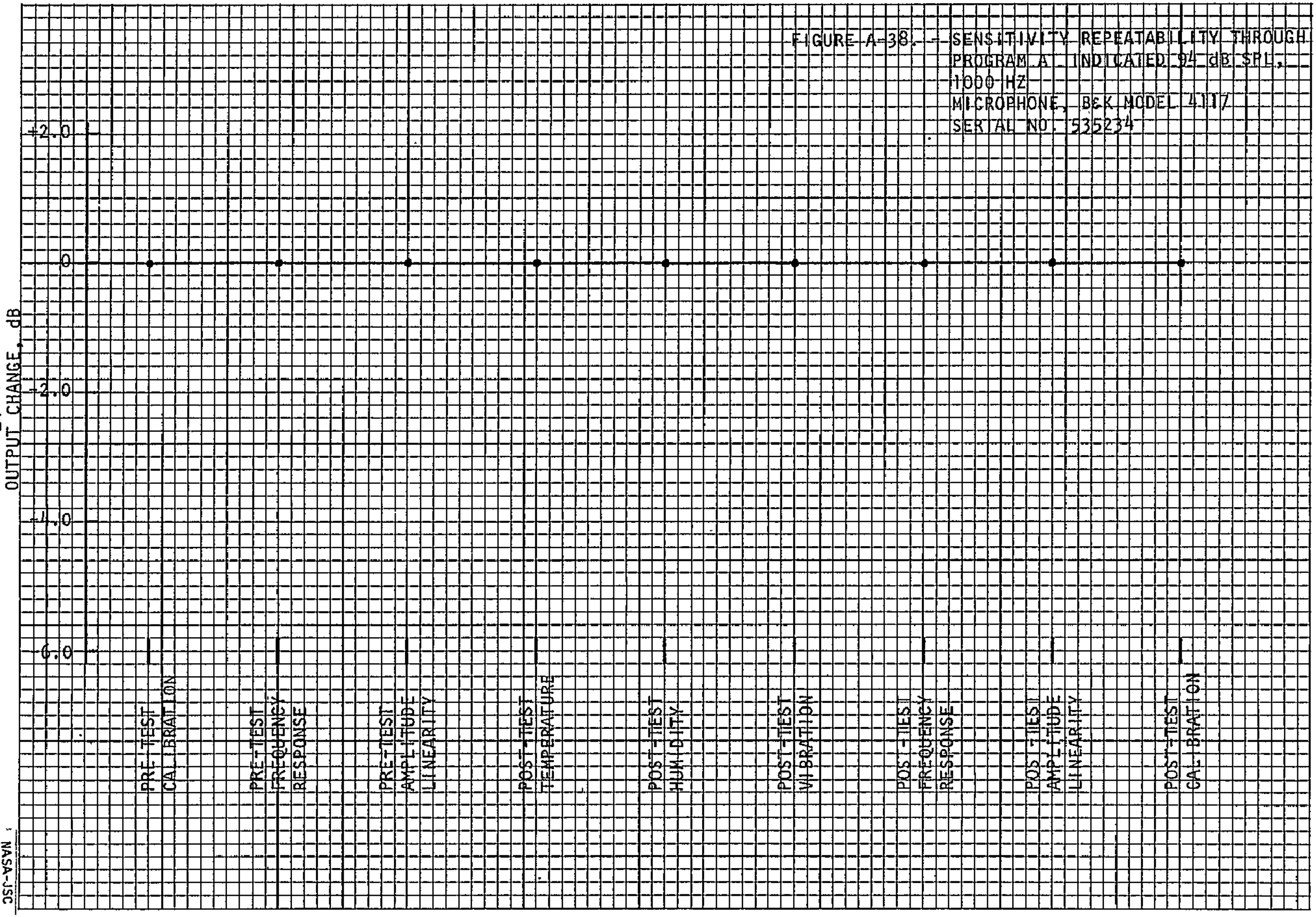


FIGURE A-38. - SENSITIVITY REPEATABILITY THROUGH PROGRAM A, INDICATED 94 dB SPL, 1000 HZ
MICROPHONE, B&K MODEL 4117
SERIAL NO. 535234

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