3 JUNE 1970

FINAL REPORT

EVALUATION OF THE KNOWLES CERAMIC TYPE MICROPHONE

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1.0 INTRODUCTION

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1.1 Scope

This Final Report covers the work accomplished in the evaluation of a relatively new ceramic microphone series developed by Knowles Electronics. The work was authorized according to the terms of Contract 5089, Task 7 and Work Order 11.

1.2 Purpose of the Evaluation

The purpose of the evaluation was to determine what benefits would be attained with the use of the ceramic microphone in place of a standard magnetic unit of comparable size. The acoustical characteristics of the sample microphones were measured using normal anechoic chamber techniques and instrumentation. The two basic types of units were then connected to operational devices and qualitative comparisons were made on the basis of informal listening tests.

1.3 Description of the Ceramic Microphone

The Knowles sub-miniature ceramic microphone, which is available in several models, contains a built-in FET pre-amplification stage. This feature provides a unit that has an effective output in the range of -60 dB(ref. 1V/μbar) which is approximately 10 to 15 dB higher than is attained from similar sized units in current use. The output impedance is nominally 12 kΩ.

A notable characteristic of the ceramic type microphone is the very smooth frequency response which is useable from below 100 Hz to 10 kHz. Figure 1-1 shows a comparison of the response characteristics of a ceramic microphone and a magnetic type which is common in the field today.

A possible drawback of the ceramic units under consideration is the bias requirement for the internal FET: 1.3 vDC at a maximum current of 50 μA; altho, as reported in the ESG Report, a single cell could provide the necessary bias for approximately two (2) years.

1.4 Basic Test Plan

A. Pre-Environmental Tests

1. Frequency Response Characteristics
2. Output at 1 kHz
3. Output Impedance vs Frequency
4. Signal-to-Noise Ratio

B. Environmental Tests

1. A 10-day humidity and temperature cycling of four (4) test microphones per Mil-Std. 810-B.

C. Post-Environmental Tests

1. Frequency Response Characteristics
2. Output at 1 kHz
3. Output Impedance vs Frequency
4. Signal-to-Noise Ratio

D. Additional Tests

1. Effect of Loads (DC and AC) on Microphone Parameters
2. Effect of DC Supply Voltage on Microphone Parameters
3. Susceptibility to Magnetic Fields
4. Listening Test Utilizing Typical Operational Equipment
5. Determine conditions under which ceramic microphone will become unstable.

1.5 Microphones to be Tested

1 ea BJ-1590	- Magnetic type, sound entrance on front face.
2 ea BJ-1591	- Magnetic type, sound entrance at one end.
1 ea BL-1670	- Ceramic type, sound entrance on front face.
2 ea BL-1671	- Ceramic type, sound entrance at one end.
1 ea BL-1680*	- Ceramic type, sound entrance on front face.

* A very thin version of the BL-1670 ceramic microphone.

2.0 TEST DESCRIPTION AND DATA

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2.1 General

This section describes the tests accomplished in the evaluation of the Knowles ceramic microphone with the built-in FET pre-amplification stage. The results of each test are given after the presentation of the procedure.

2.2 Identification of Microphone Connections

The ceramic microphone is provided with three (3) solder terminals; one for the positive side of the DC power supply, one for the audio output and a negative terminal for the power supply. The connection for the common audio lead is determined by which terminal of the power supply is common. Figure 2-1 shows the relative location of the ceramic microphone terminals.

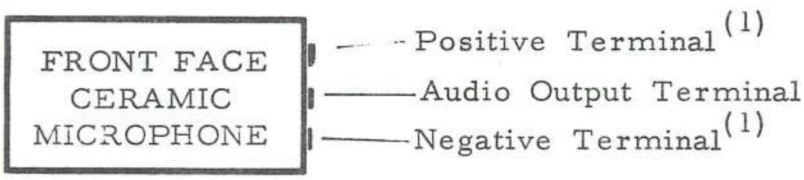

Figure 2-1. Relative Location of Terminals

[1] May be the common terminal for audio signal, depending on circuit.

2.3 Test Equipment

A. Small Anechoic Chamber and associated instrumentation.

B. SRT-60 Transmitter.

C. Communications Receiver, CEI, Model 702-A.

D. Dual Loop AGC Module[1]

2.4 Test Samples

#21	-	BJ-1590	Magnetic
#22	-	BJ-1591	Magnetic
#23	-	BJ-1591	Magnetic
#24	-	BL-1670	Ceramic
#25	-	BL-1671	Ceramic
#26	-	BL-1671	Ceramic
#27	-	BL-1670	Ceramic (exhibited above average current)
#28	-	BL-1680	Ceramic (very thin version of BL-1670)

2.5 Test Conditions

A. All frequency response measurements were accomplished with a Sound Pressure Level (SPL) = 74 dB (ref 0.0002 dynes/cm^2).

B. Microphone output for frequency response measurements is given in terms of dB(ref 1.0V/μbar): 1 μbar = 74 dB SPL.

C. The Bandwidth (BW) for the Equivalent Input Noise measurements was 200 Hz to 5.0 kHz.

D. The ceramic microphone was biased by an external 1.35 vDC battery unless otherwise stated.

(1) Developed under Contract 5089, Task 7 and Work Order 4.

2.6 Measurements

The measurements were accomplished with five BL-1600 series ceramic microphones and three BJ-1500 series magnetic units, as listed in Section 1.5 of this report. The BJ-1500 series magnetic microphones were included to provide a basis for comparison and control.

A. Frequency Response

General Results - The response characteristics of the microphones tested, compared closely with the data supplied by the manufacturer. A comparison of the response characteristics obtained during these tests and those supplied is given for the BL-1670 and BL-1671 microphones

The response characteristics of the BL-1680 unit, which is a very thin version of the BL-1670, is shown in Figure 2-4. A manufacturer's curve was not available for this microphone. This particular model has a notable frequency response characteristic for a sub-miniature transducer.

A comparison of the response characteristics of the BL-1670, BL-1680 and the BJ-1590 is shown in Figure 2-5. All three units have the sound entrance in the front face. The response characteristics for the three types of ceramic microphones considered in this evaluation are shown in Figure 2-6. It is evident from this set of curves that the ceramic microphone with the built-in FET pre-amplifier, has a useful response range from 100 Hz to 10 kHz that is free of peaks or dips.

Effect of Environmental Test -- There was no change in the response characteristics due to the environmental tests. The characteristics of the units before and after the environmental tests are shown in Figure 2-7, 2-8, 2-9 and 2-10.

Effect of DC Bias Voltage - There was no change in the response characteristics due to a change in DC bias voltage as shown in Figures 2-11, 2-12, 2-13 and 2-14.

Measurements - Frequency Response (cont)

Effect of Resistive Loads - Resistive loads with values between 600 ohms and an open circuit condition were attached to the output of the ceramic unit. There were no changes in the response characteristics as is shown in Figure 2-15 for the values of resistance listed on the graph. The same resistive loads were attached to the output of the magnetic microphone and the changes in characteristics are shown in Figure 2-16. The frequency at which the first resonant peak occurred, shifted from 1.7 to 2.4 kHz as the load condition changed from an open circuit condition to a 600-ohm load.

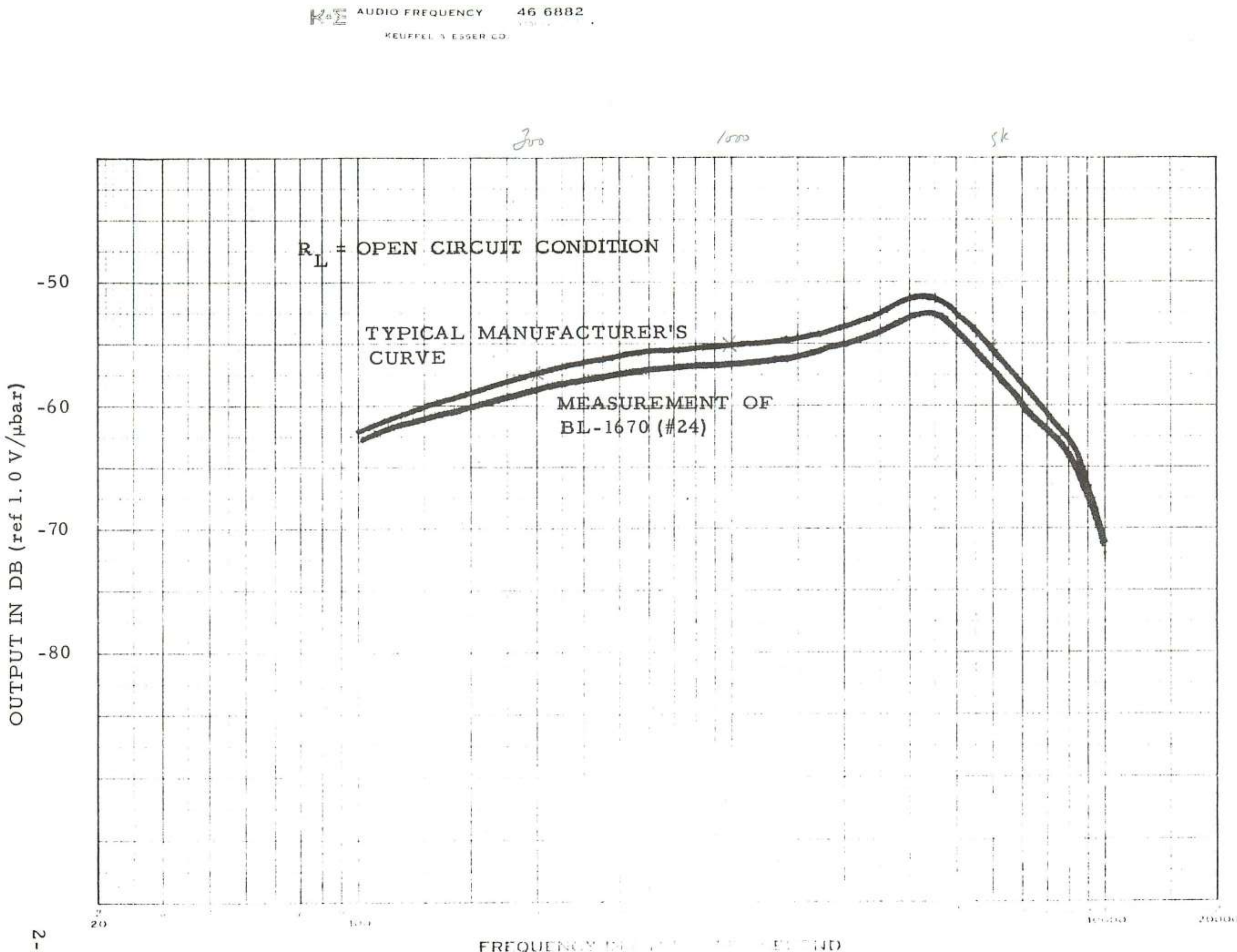

Figure 2-2. Comparison of Manufacturer's Curve with Measured Characteristics of Ceramic Microphone BL-1670 (#24)

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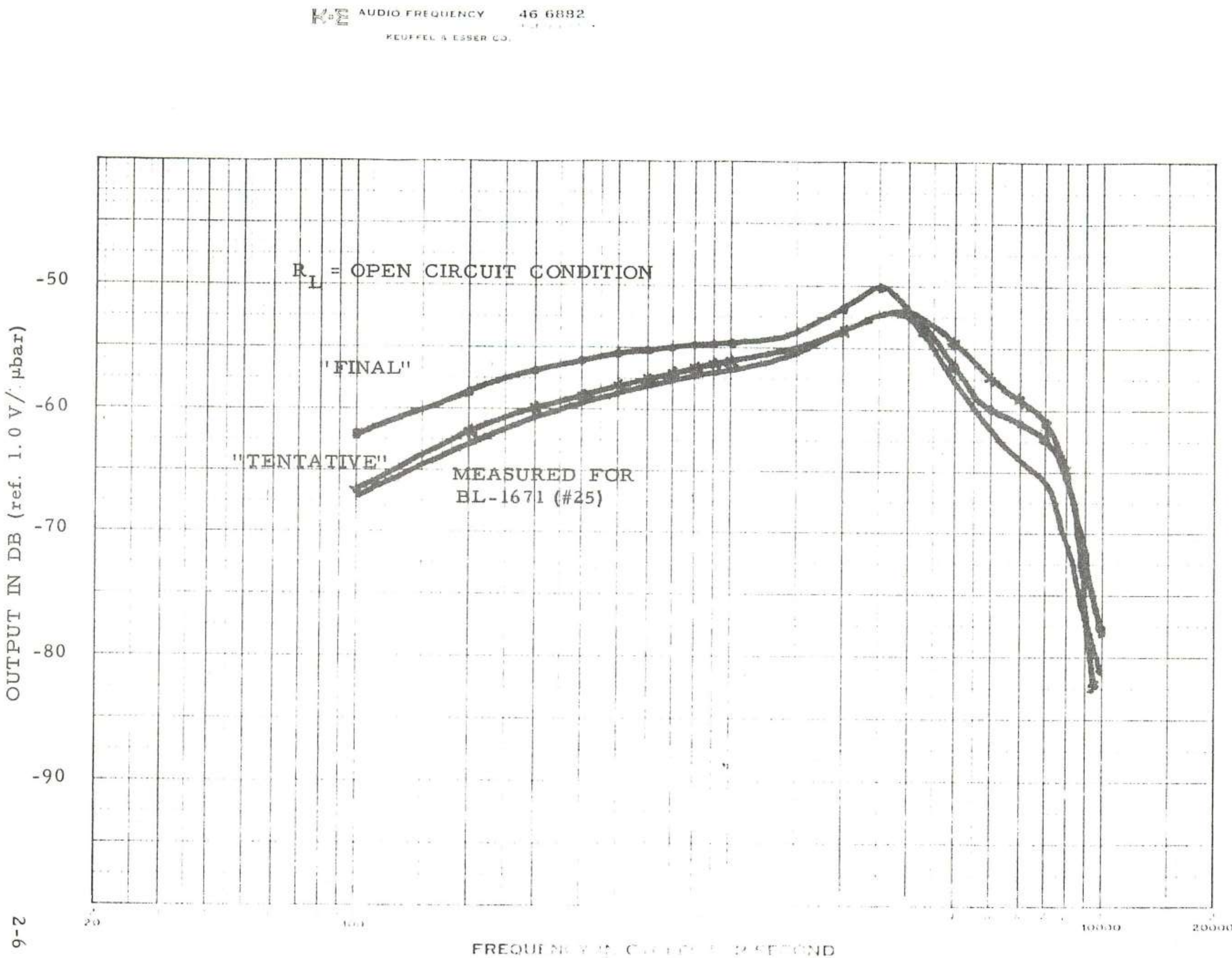

Figure 2-3. Comparison of Manufacturer's Curves with Measured Characteristics of Ceramic Microphone BL-1671 (#25)

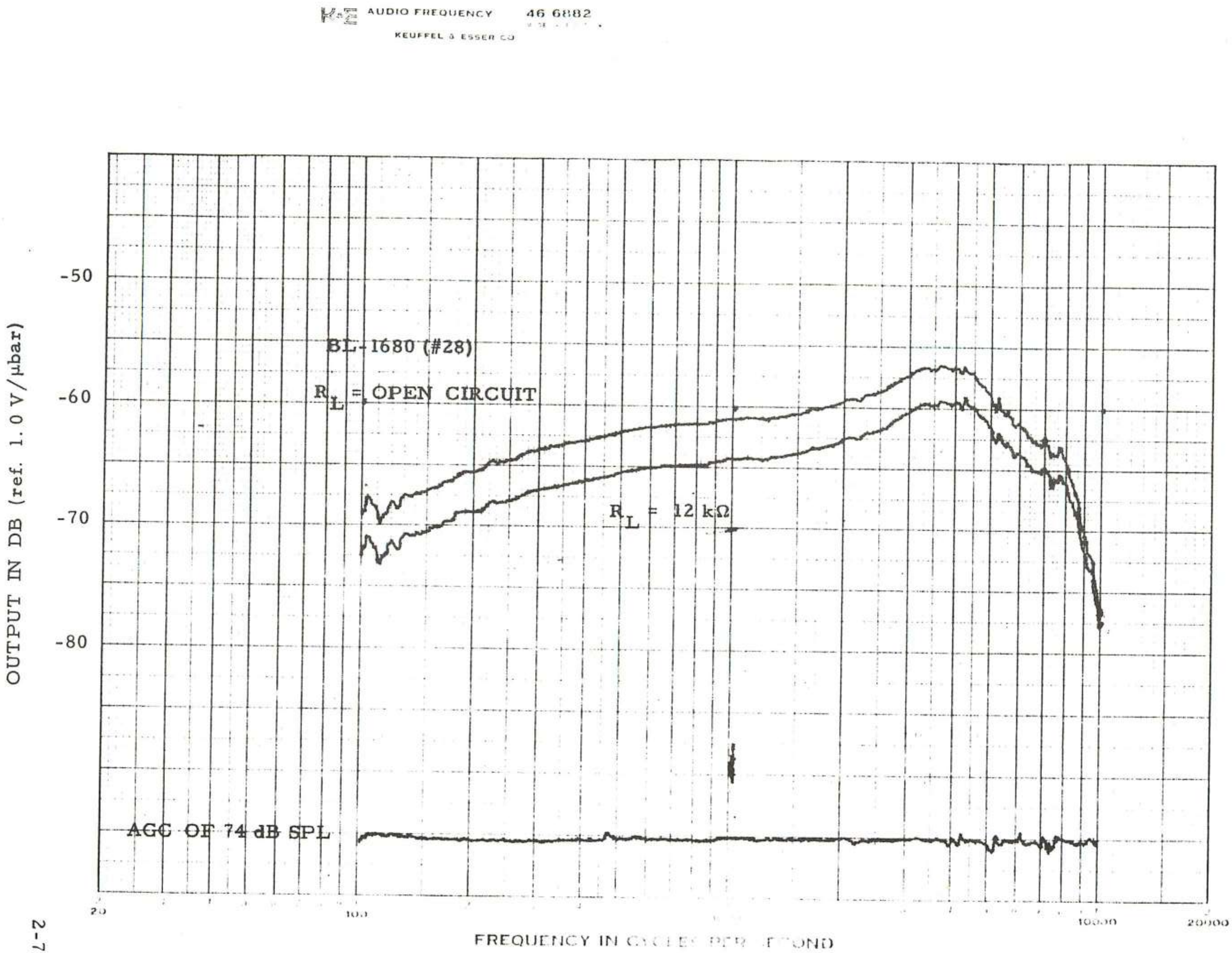

Figure 2-4. Response Characteristics of Ceramic Microphone BL-1680 (#28): $R_L = \infty$ and 12 kΩ

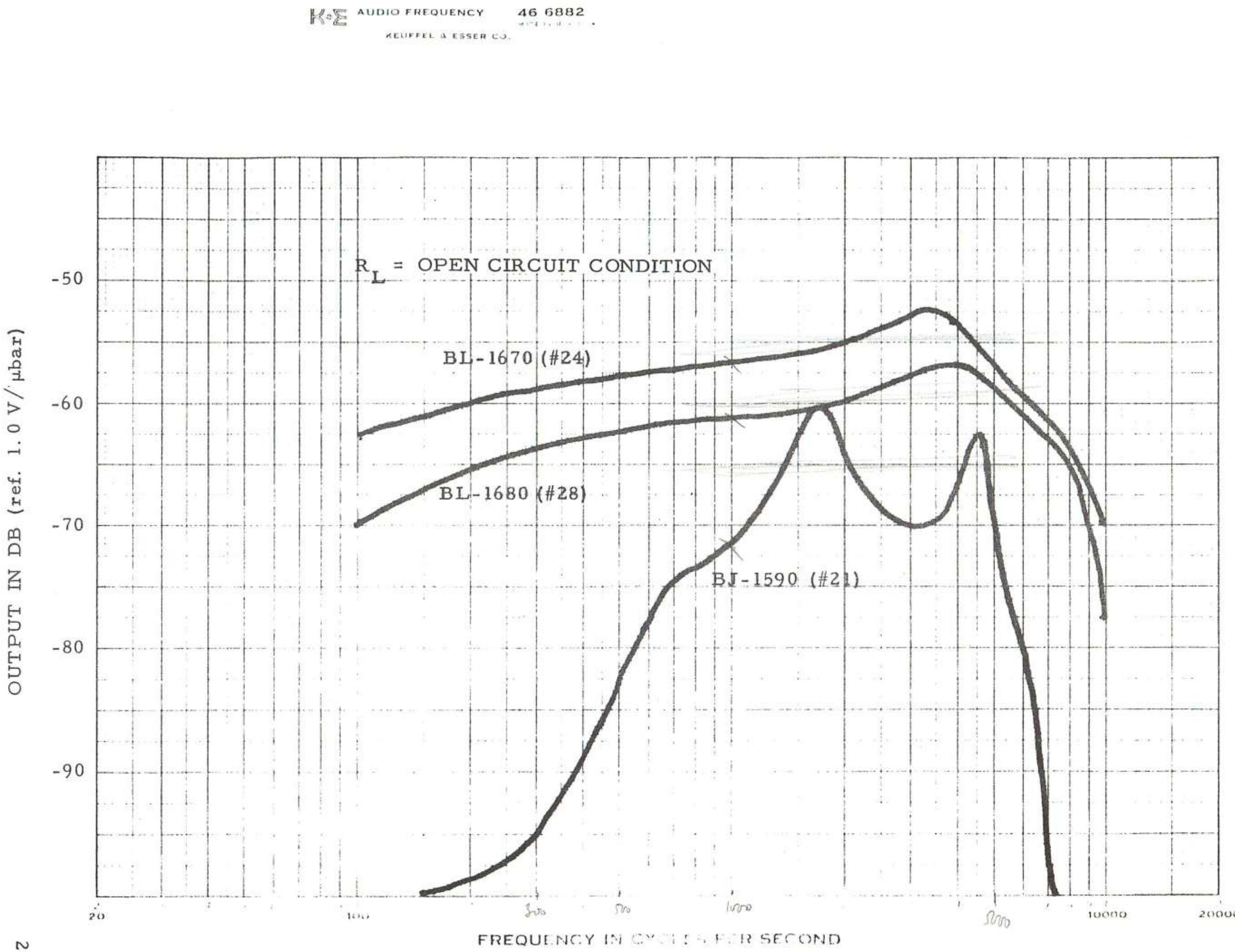

Figure 2-5. Comparison of Response Characteristics of the Ceramic BL-1600 Series and the Magnetic 1500 Series

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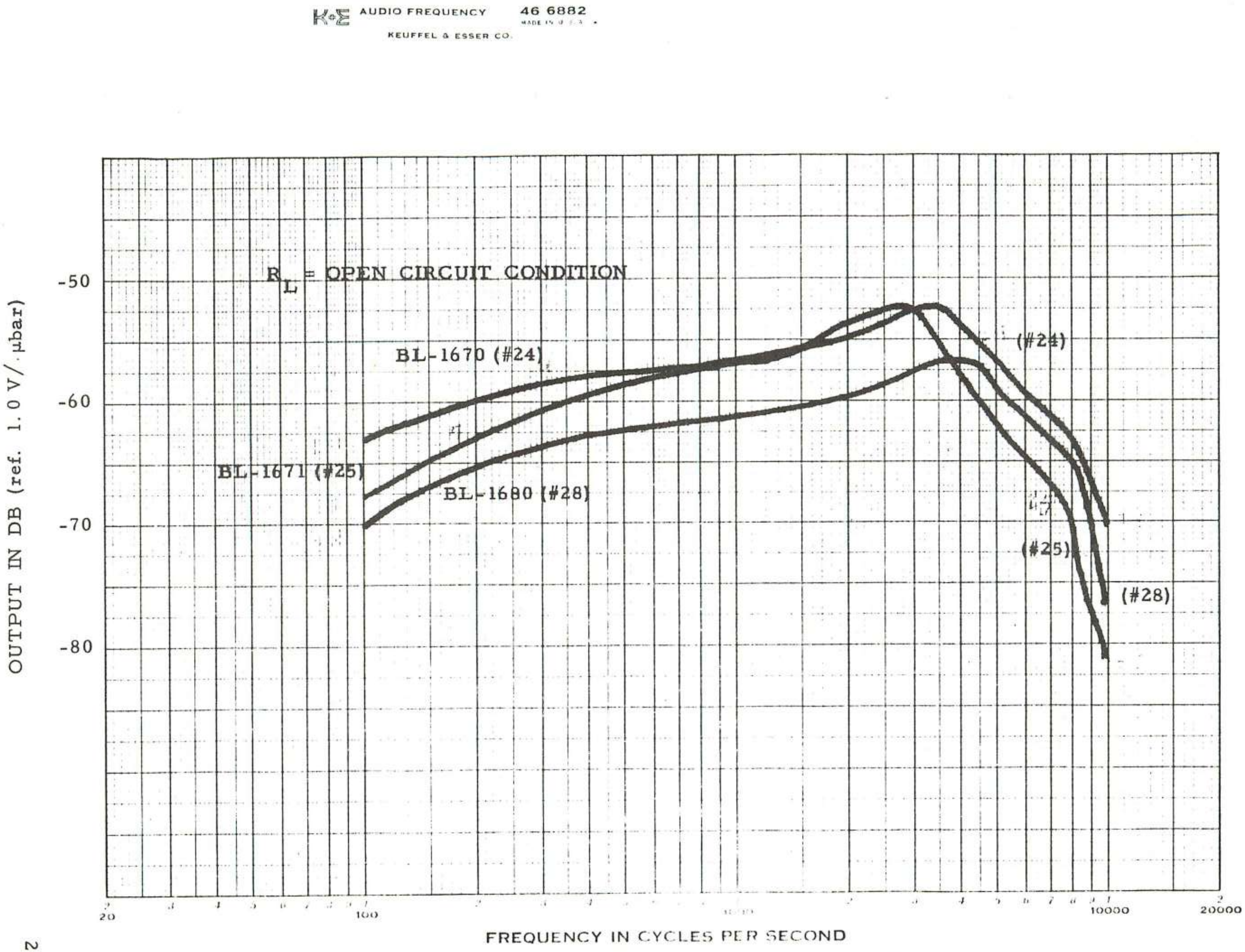

Figure 2-6. Comparison of Response Characteristics of the BL-1600 Series Ceramic Microphones

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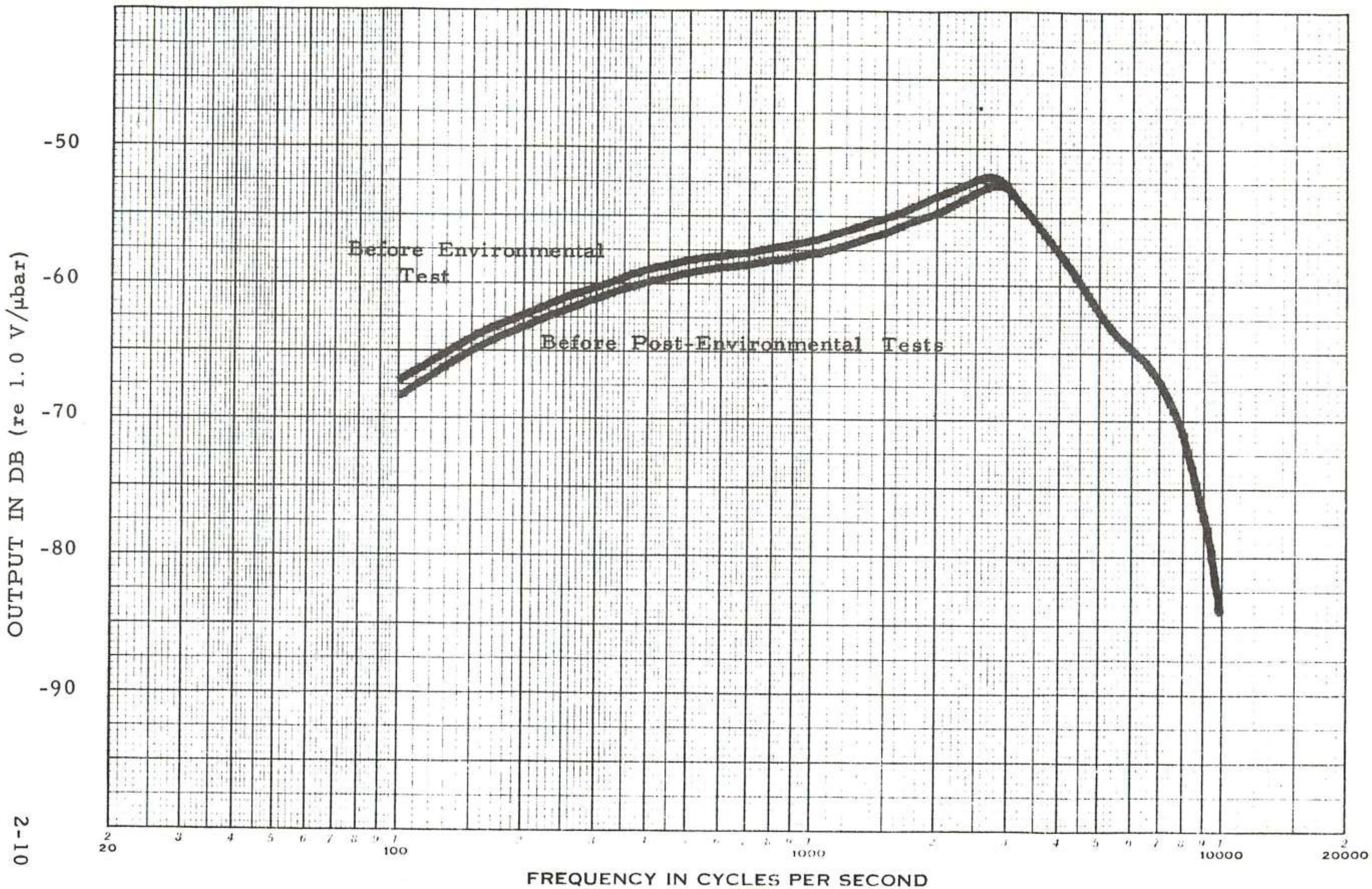

Figure 2-7. Calibration of Anechoic Chamber Using Ceramic Type Microphone (BL-1671 #27) Not Subjected To Environmental Test

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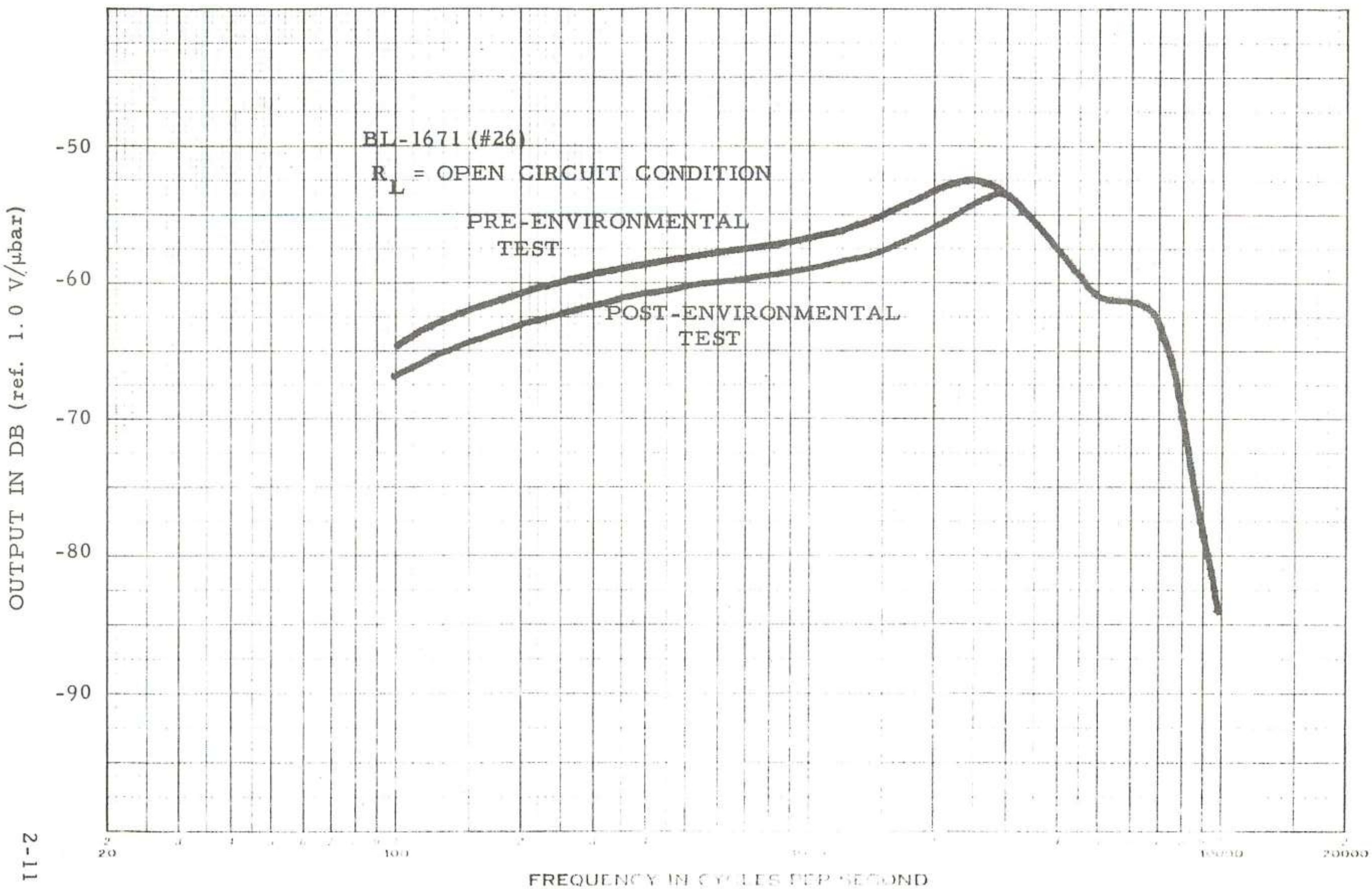

Figure 2-8. Comparison of Pre and Post Environmental Test Response Characteristics for BL-1671 (#26)

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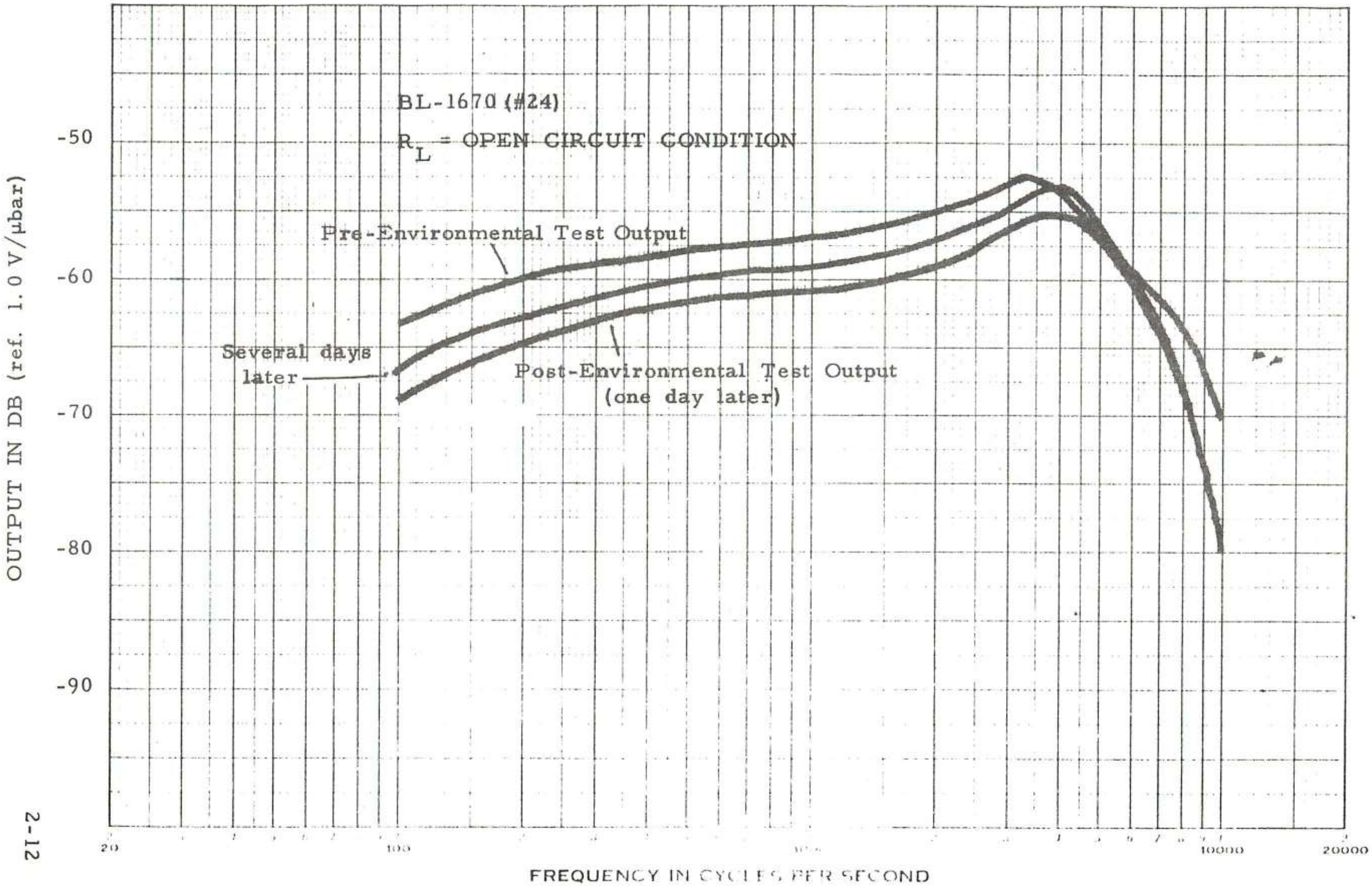

Figure 2-9. Comparison of Pre and Post Environmental Test Response Characteristics for BL-1670 (#24)

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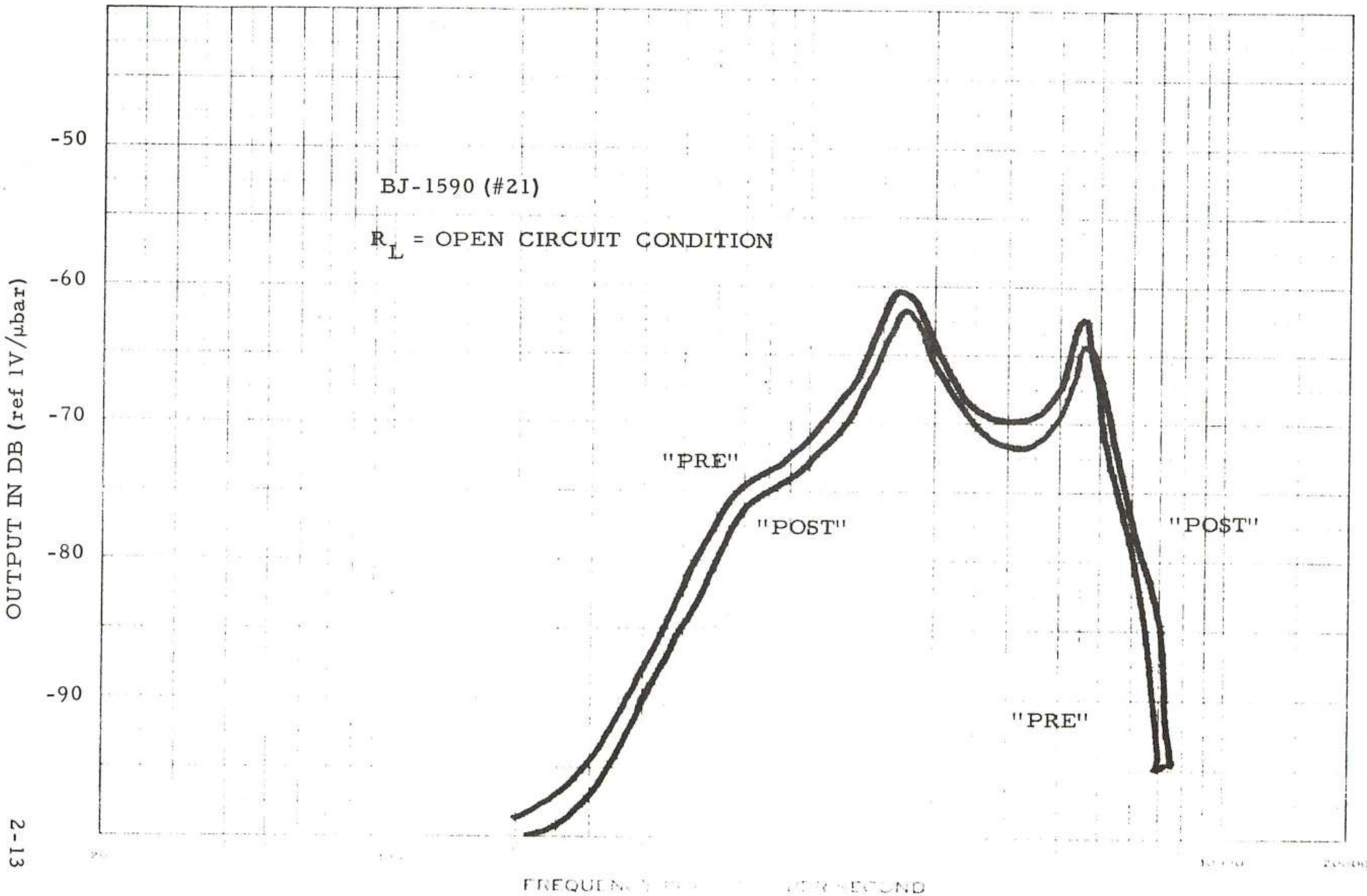

Figure 2-10. Comparison of Pre and Post Environmental Test Response Characteristics for BJ-1590 (#21)

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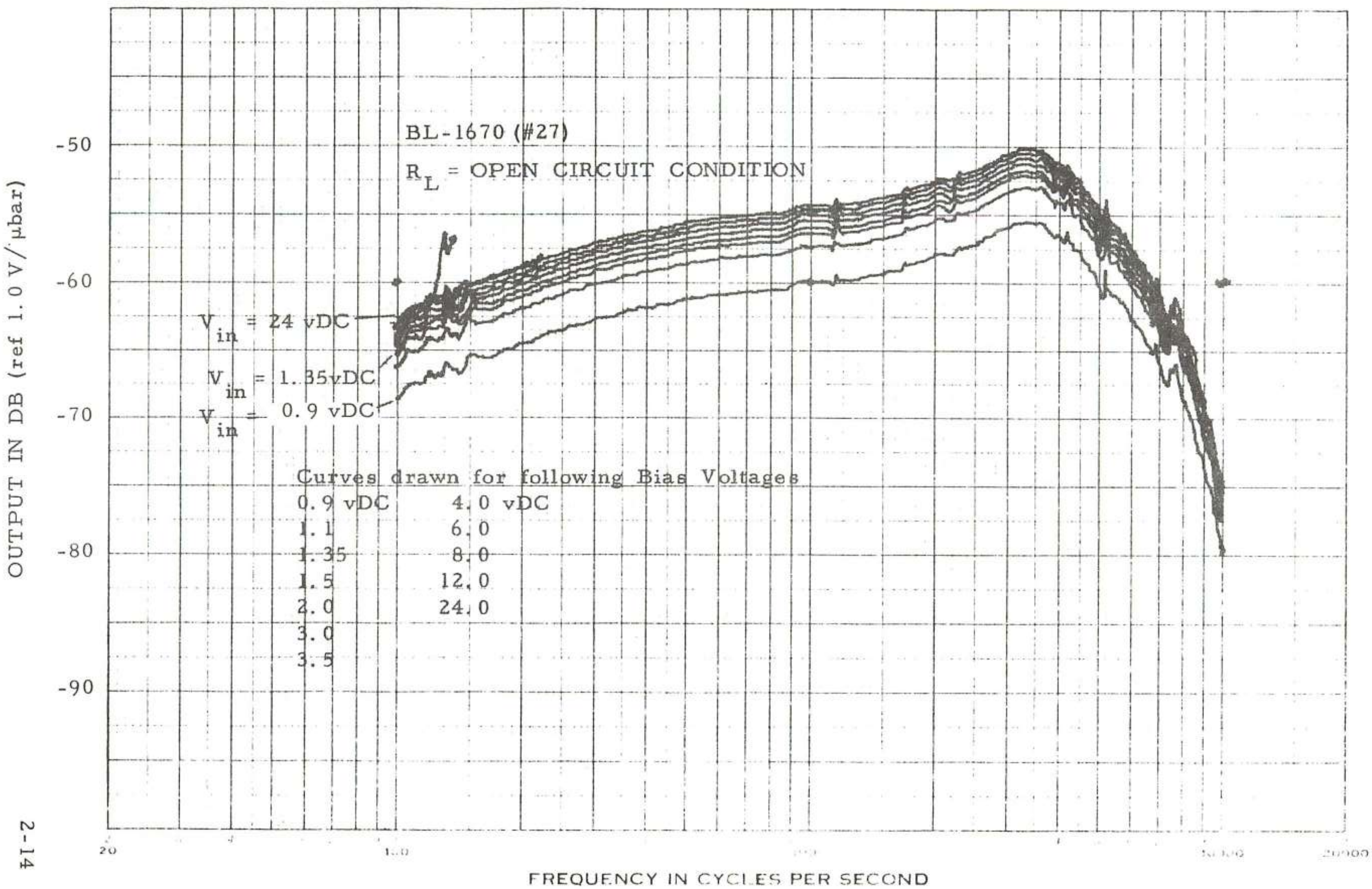

Figure 2-11. Effect of DC Bias Voltage on the Response Characteristics of BL-1670 (#27)

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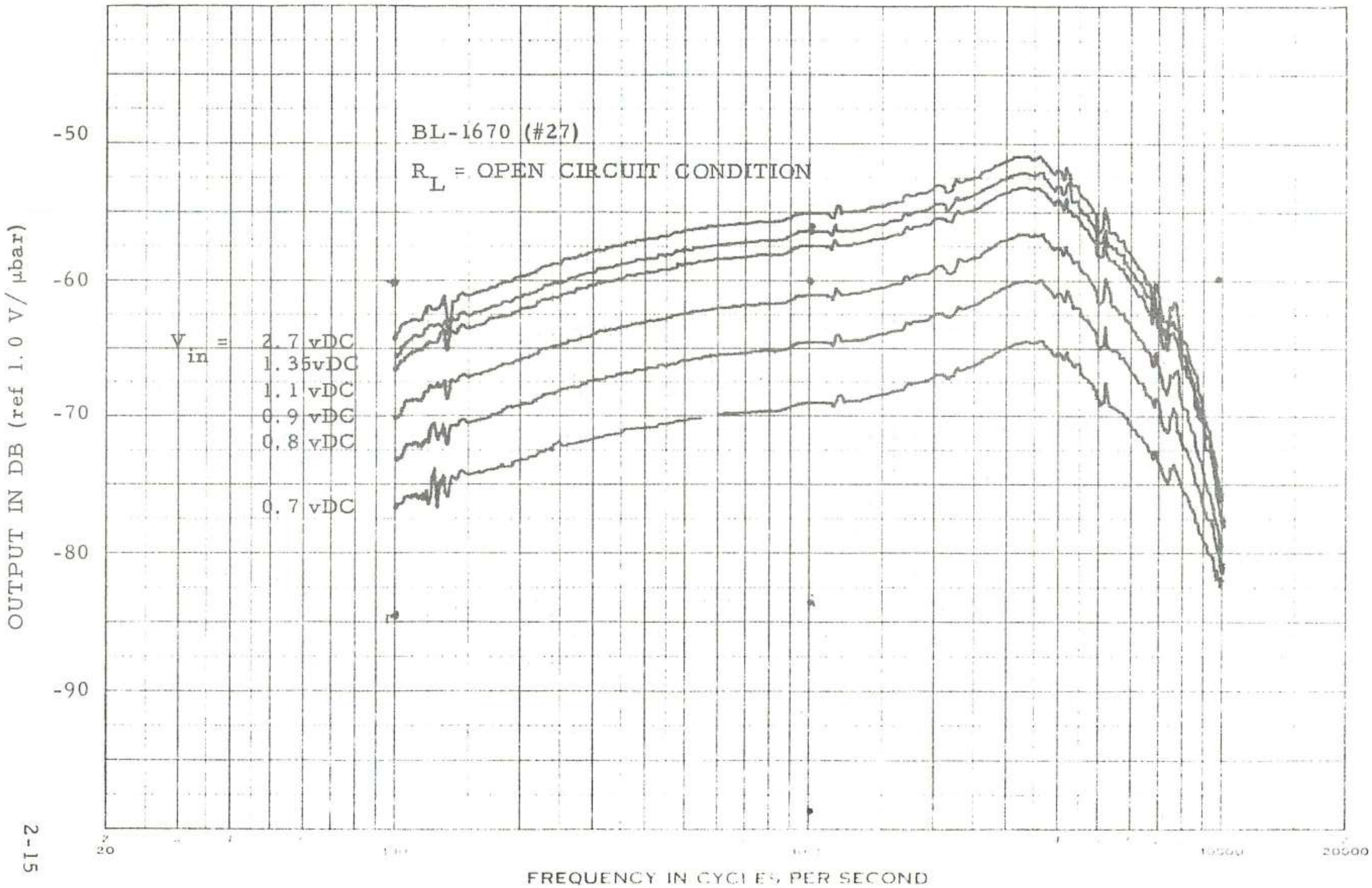

Figure 2-12. Effect of DC Bias Voltage on Response Characteristics For the BL-1670 (#27)

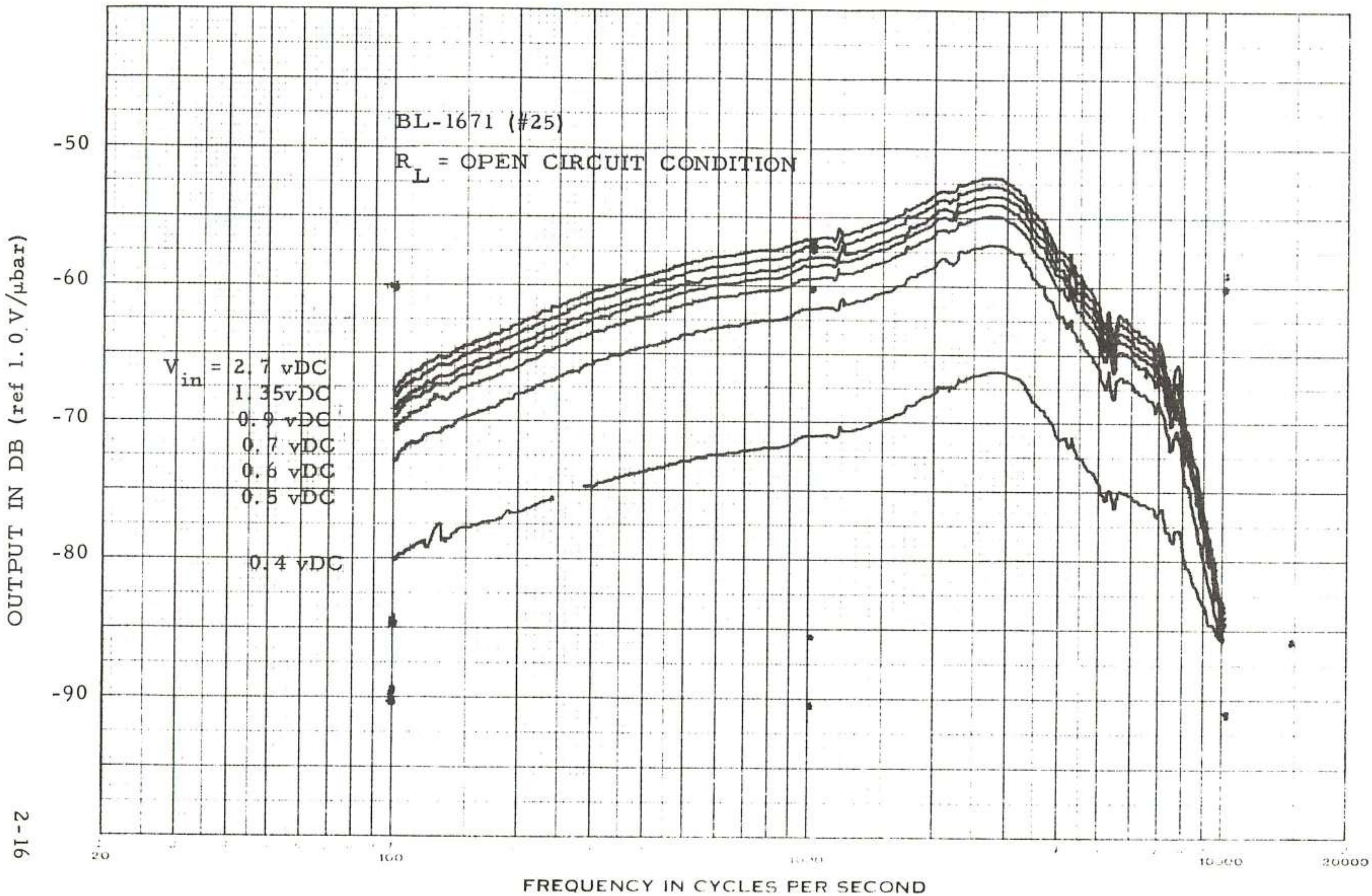

Figure 2-13. Effect of DC Bias Voltage on Response Characteristics For the BL-1671 (#25)

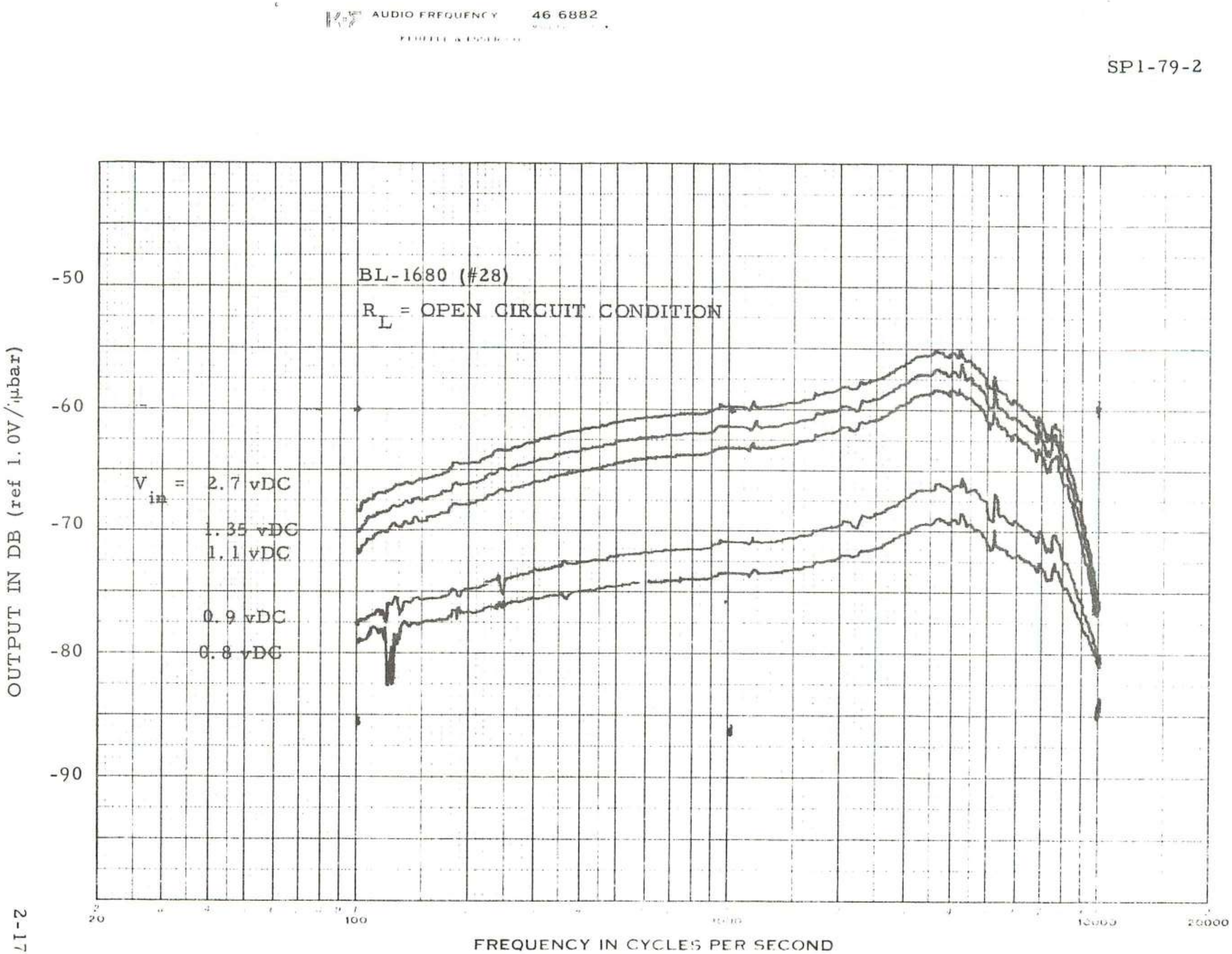

Figure 2-14. Effect of DC Bias Voltage on Response Characteristics For the BL-1680 (#28)

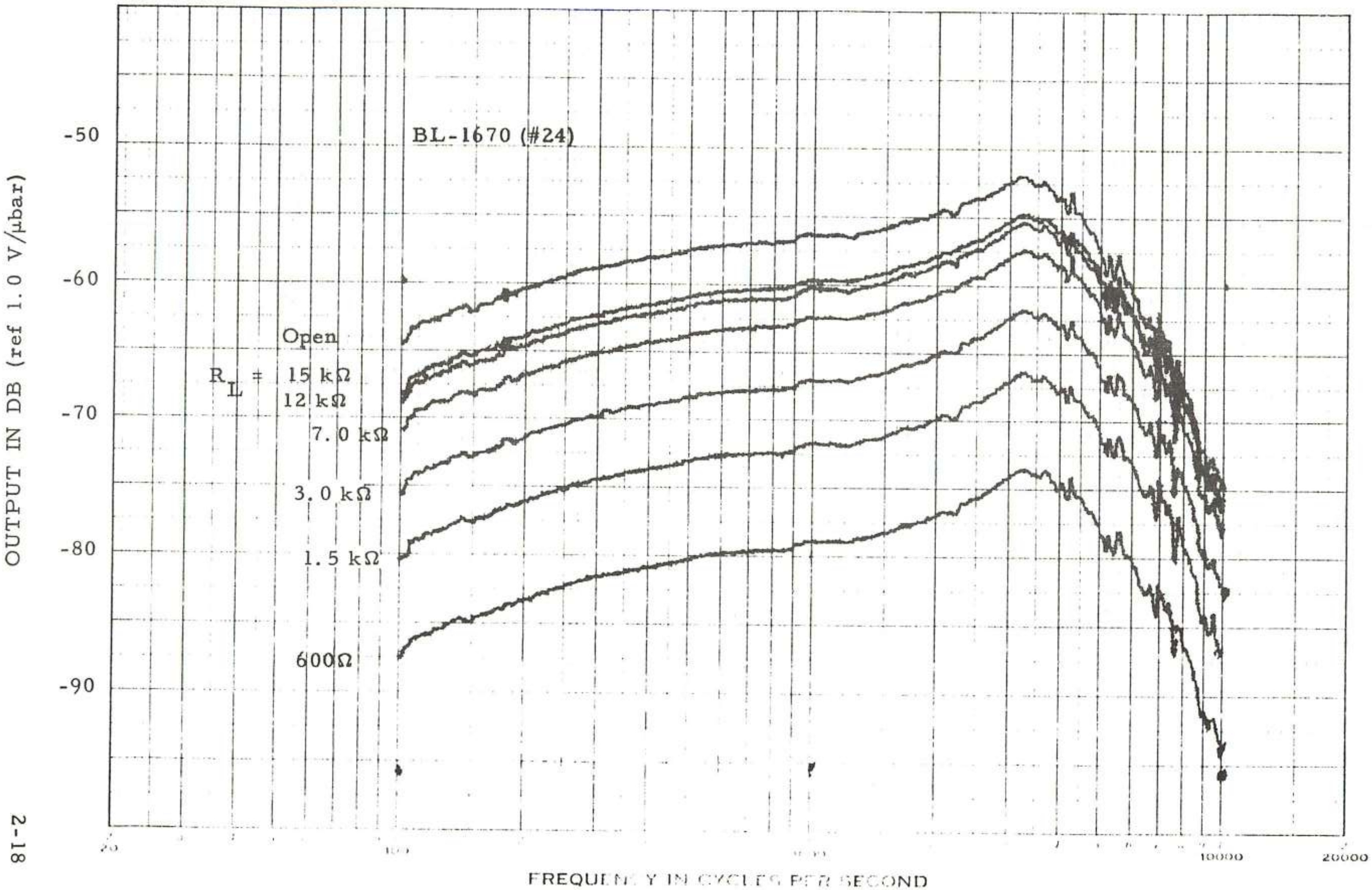

Figure 2-15. Effect of Load Impedance on Response Characteristics For the Ceramic Microphone BL-1670 (#24)

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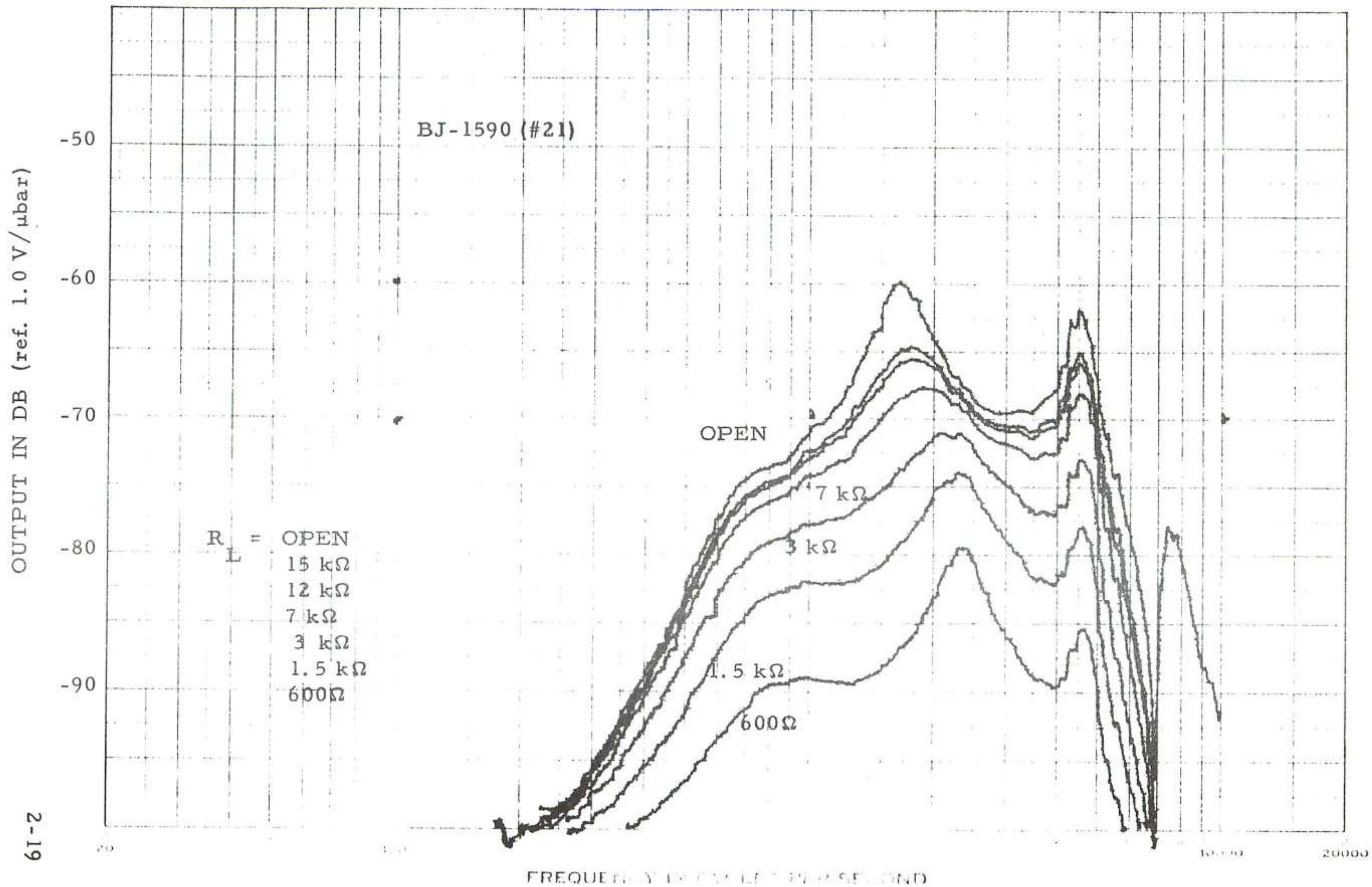

Figure 2-16. Effect of Load Impedance on Response Characteristics For the Magnetic Microphone BJ-1590 (#21)

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Measurements (cont)

B. Voltage Output at 1 kHz

General Results - The ceramic type microphones BL-1670 and BL-1671, which differ only in the location of the sound entrance, have an open circuit output of approximately -57 dB[(1)]. The ceramic microphone, BL-1680, is a very thin version of the BL-1670; this unit had an open circuit output of -61 dB[(1)]. These output values are approximately 13 dB greater than the open circuit outputs available from the BJ-1500 series magnetic microphone. The test data for the voltage outputs are included in the summary of microphone characteristics given in Figure 2-17.

Effect of Environmental Tests - The post-environmental test measurements were not made until the units had been out of the humidity chamber for approximately one day. At the time of the output measurement, there was only a slight reduction in output: approximately 1 to 3 dB. After a few days, the output returned to value measured before the environmental test. ESG reported a similar situation; except their measurement was made within two hours after the unit was removed from the humidity chamber; at that time the output was down 29 dB. After a few days, the output increased, until it was within a few dB of the original reading.

Based on these findings, it not possible to predict the performance of the ceramic type microphone under adverse humidity conditions; without further testing.

Effect of DC Bias Voltage - The output voltage increased about 5 dB with a change of bias voltage from 0.9 to 24 vDC. Most of the change in output occurred between 0.9 and 2.7 vDC. The microphone used in this test had a higher-than-average current; microphones with lower currents showed less change in output voltage when the bias voltage was changed.

(1) re. 1.0 V/μbar

Characteristic	BJ-1590 #21	BJ-1591 #22	BJ-1591 #23	BL-1670 #24	BL-1671 #25	BL-1671 #26	BL-1680 #28
Output at 1 kHz (re 1V/μb) Before Environ. Test After Environ. Test	 -71.5 dB -72.2 dB	 -70.5 dB NA	 -70.3 dB -70.8 dB	 -57.3 dB -60.5 dB	 -57.2 dB NA	 -56.8 dB -58.7 dB	 -61.2 dB NA
Signal-to-Noise Ratio BW = 200 to 5,000 Hz	 48 dB	 48 dB	 47 dB	 42 dB	 42 dB	 43 dB	 40 dB
Frequency Response (-10 dB ref 1 kHz) Low Hz High kHz	 520 Hz 6.3 kHz	 530 Hz 5.5 kHz	 520 Hz 5.5 kHz	 <100 Hz 8.6 kHz	 110 Hz 7.2 kHz	 <100 Hz 7.5 kHz	 <100 Hz 9.1 kHz
Max Excursion above 1 kHz	11 dB	9.5 dB	9.5 dB	4.5 dB	4.5 dB	4.0 dB	4.5 dB
Impedance At 100 Hz At 500 Hz At 1 kHz At 6 kHz At 10 kHz	 Not Meas. 2.5 KΩ 3.8 KΩ 12.0 KΩ Not Meas.	 Not Meas. Not Meas. Not Meas. Not Meas. Not Meas.	 Not Meas. 2.5 KΩ 3.7 KΩ 11.0 KΩ Not Meas.	 16.0 KΩ 16.0 KΩ 16.0 KΩ 10.0 KΩ 7.3 KΩ	 14.4 KΩ 14.5 KΩ 14.2 KΩ 10.2 KΩ 7.4 KΩ	 12.0 KΩ 12.0 KΩ 12.0 KΩ 9.1 KΩ Not Meas.	 12.0 KΩ 11.8 KΩ 12.0 KΩ 9.6 KΩ 7.4 KΩ
Current Drain For V_{in} = 0.9 vDC For V_{in} = 1.1 vDC For V_{in} = 1.35 vDC For V_{in} = 2.7 vDC	N/A	N/A	N/A	 17.5 μA 17.8 μA 17.8 μA 18.2 μA	 13.9 μA 14.0 μA 14.2 μA 14.8 μA	 23.5 μA 25.0 μA 25.8 μA 26.8 μA	 35.0 μA 40.0 μA 41.2 μA 42.6 μA
Output at 1 kHz (re 1V/μb) V_{in} = 0.9 vDC V_{in} = 1.1 vDC V_{in} = 1.35 vDC V_{in} = 2.7 vDC	N/A	N/A	N/A	 -62 dB -60.8 dB -60.5 dB -61.3 dB	 -58 dB -57.8 dB -57.2 dB -60.5 dB	 -65 dB -60 dB -58.7 dB -57.3 dB	 -71 dB -63 dB -61.2 dB -59.5 dB

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Figure 2-17. Summary of Microphone Characteristics

Measurements (cont)

C. Signal-to-Noise Ratio

General - The signal-to-noise measurements for the ceramic and magnetic units were made with different bandwidth conditions: wideband, 200 to 5,000 Hz, 500 to 5,000 Hz and 5 Hz. The bandwidth of the wideband condition was limited by the response characteristics of the Dual Loop AGC Module (1), the two given bandwidths by high and low pass filters and the 5 Hz condition by the bandwidth of the Wave Analyzer used to determine the spot noise characteristic of the two microphones.

The normal acoustic path to the diaphram of the microphones was blocked during the noise measurements and the unit under test was imbedded in a sphere of modeling clay to further eliminate outside noises. Unfortunately, the location of the anechoic chamber was exposed to a relatively high level of low frequency vibration due to heavy machinery on the floor above. This low frequency vibration caused a serious degradation of the overall noise figure of the magnetic type microphone. Additional tests were performed, as a result of the unexpected degradation, in an effort to provide an objective comparison between the two types of microphones.

The spot noise characteristics, 5 Hz bandwidth, for the ceramic type microphone, BL-1671 #25, are shown in Figure 2-18. The response characteristics of the microphone obtained with a SPL of 74 dB(2) are shown using the same output scale.

The spot noise characteristics, 5 Hz bandwidth, for the magnetic type microphone, BJ-1590 #21, are shown in Figure 2-19. The response characteristics are also shown using the same output scale.

(1) -3 dB points of AGC Amplifier (re. 1 kHz): 150 Hz and 5 kHz, with 6 dB/octave roll-off.

(2) re. 0.0002 dynes/cm^2

Measurements - Signal-to-Noise Ratio (cont)

Test Results - The signal-to-noise ratios of one magnetic unit and two ceramic type microphones are given below for three bandwidth conditions.

S/N RATIO IN DB (re. output at 1kHz for 74 dB SPL) (74 dB SPL = 1.0 dyne/cm^2)			
Microphone	Bandwidth		
	500-5,000Hz	200-5,000Hz	Wideband[1]
BJ-1590 #21 (magnetic)	57 dB	48 dB	34 dB
BL-1671 #25 (ceramic)	44 dB	42 dB	40 dB
BL-1680 #28 (ceramic)(thin)	42 dB	40 dB	38 dB

[1]-3 dB points of AGC amplifier (re. 1kHz): 150 Hz and 5,000 Hz w/6 dB/octave roll-off.

Discussion - The effect of a low frequency sensitivity for the magnetic type microphone was observed as the low frequency cut-off was changed from 500 to 200 Hz; a 5.5% reduction in the bandwidth resulted in a 19% degradation in the S/N figure for the magnetic unit. A similar measurement for the ceramic unit resulted in a 5% degradation in the S/N value.

A comparison of the low frequency effect on the two types of units is possible by referring to the spot noise characteristics shown in Figure 2-20 and the narrow band signal-to-noise curves given in Figure 2-21.

A comparison of the spot noise taken at 1 kHz and a 100 Hz shows that there is an increase in output of 37 dB for the magnetic unit and only a 16 dB increase for the ceramic unit. In a similar manner, a comparison of the narrow band S/N ratio at the two frequencies shows a degradation in the S/N ratio for the magnetic unit of 57 dB but for the ceramic unit there is a degradation of only 16 dB. It is assumed this difference is due to an accelerometer effect in the magnetic unit caused by the larger mass of the diaphram and armature. This causes the magnetic unit to be much more susceptible to low frequency room vibrations.

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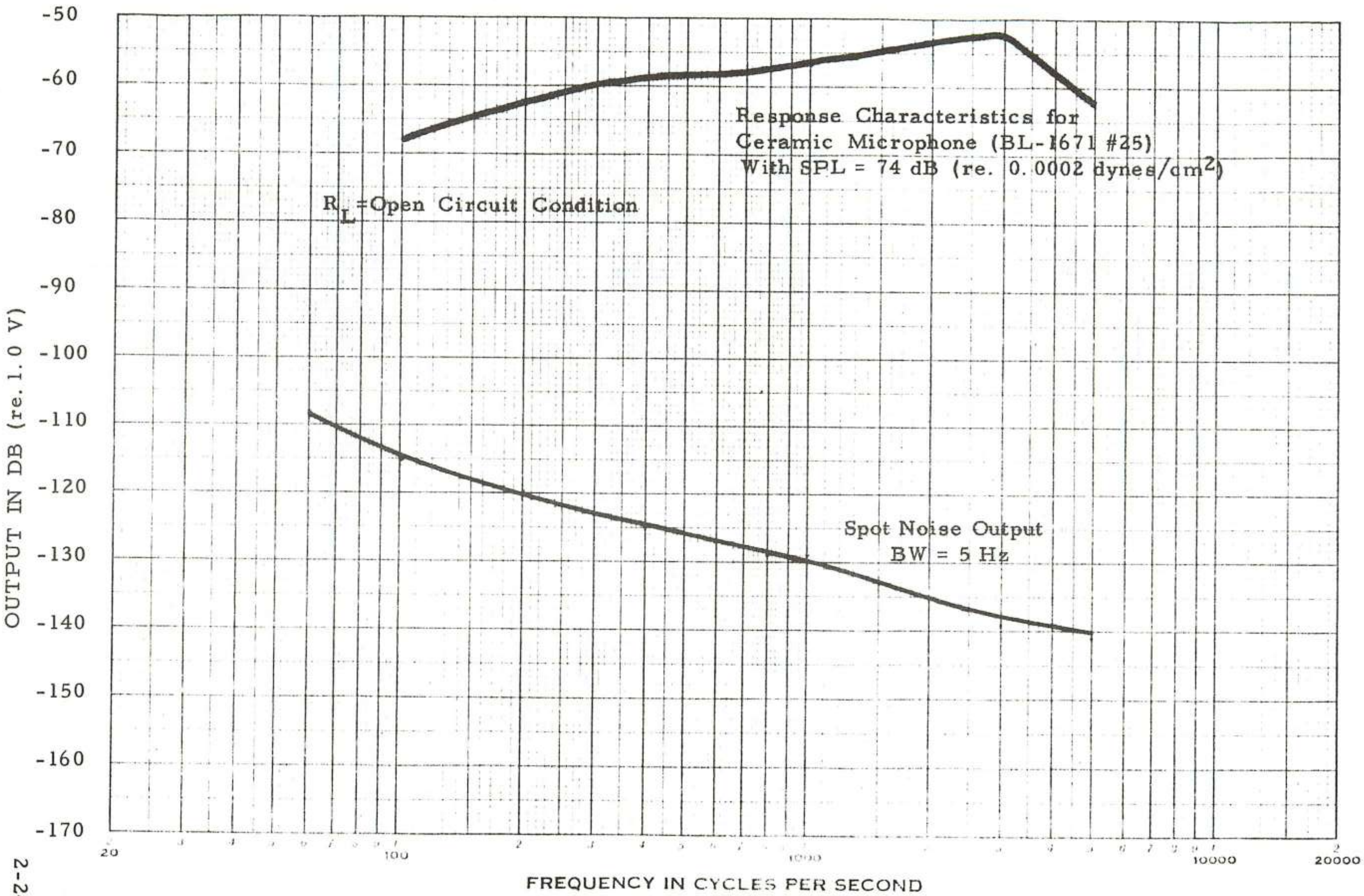

Figure 2-18. Spot Noise Output (BW=5 Hz) and Response Characteristics for Ceramic Type BL-1671 #25

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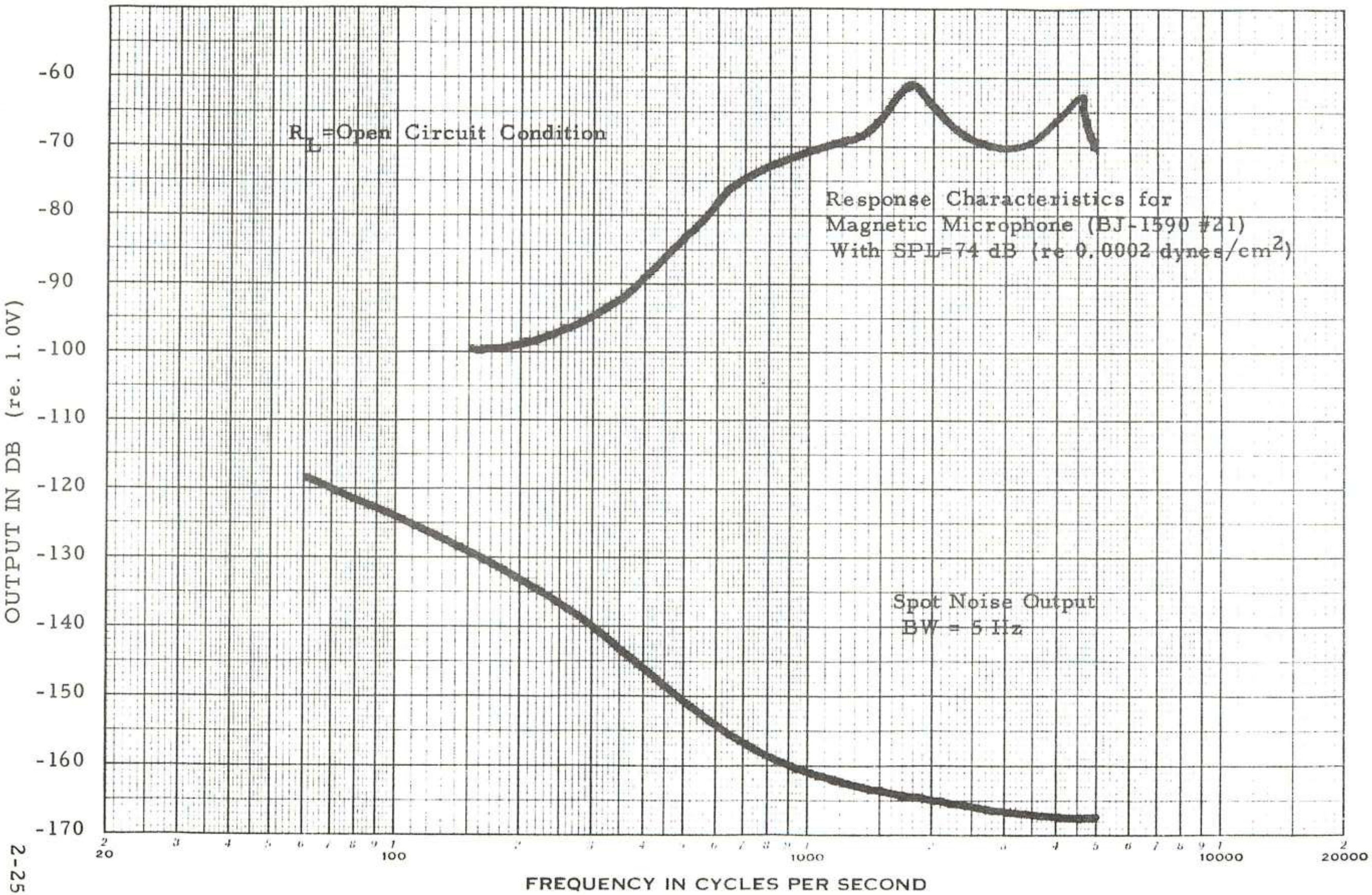

Figure 2-19. Spot Noise Output (BW=5 Hz) and Response Characteristics for Magnetic Type BJ-1590 #21

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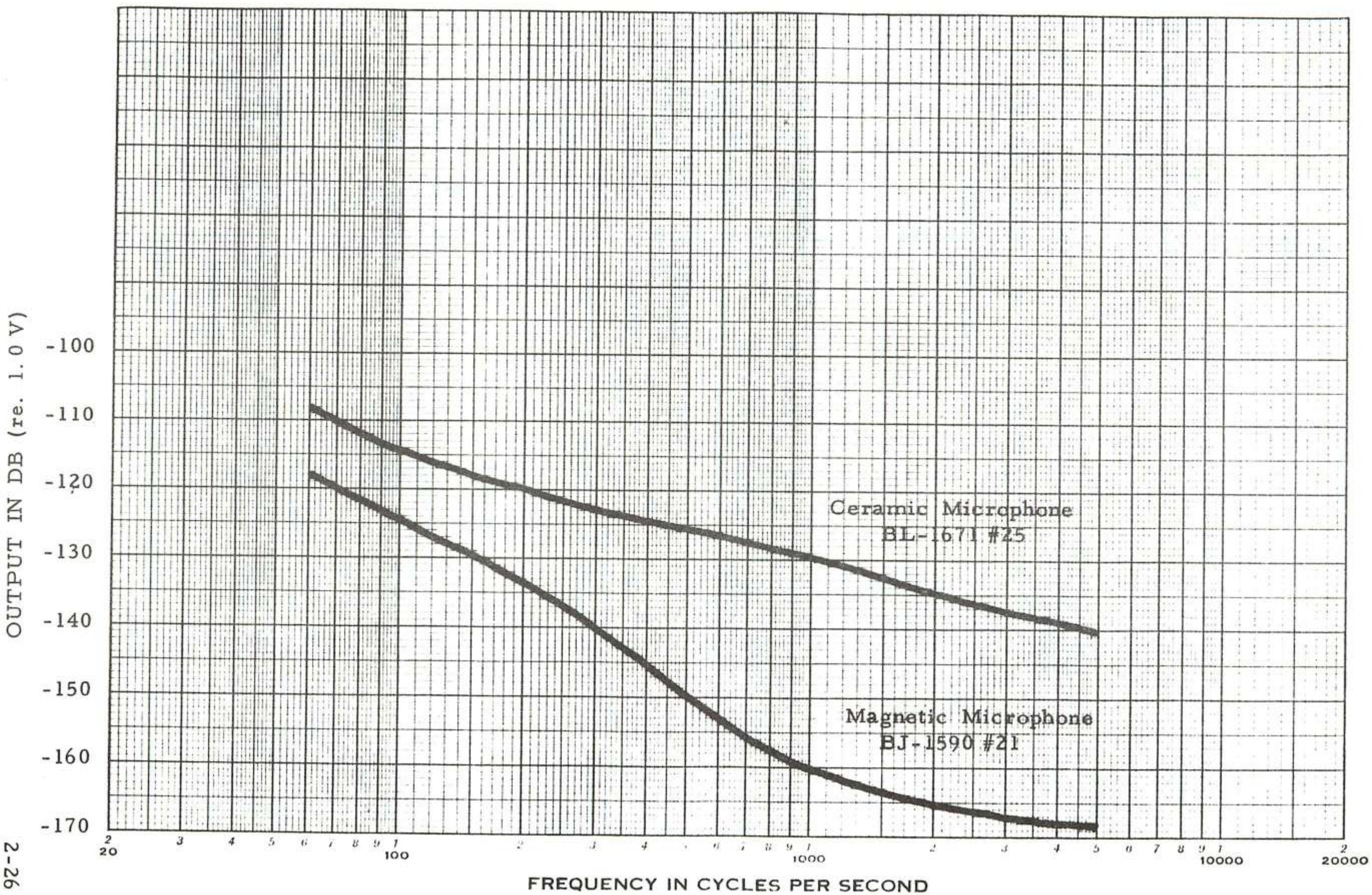

Figure 2-20. Spot Noise Outputs For Ceramic Type (BL-1671 #25) and Magnetic Type (BJ-1590 #21) Microphones

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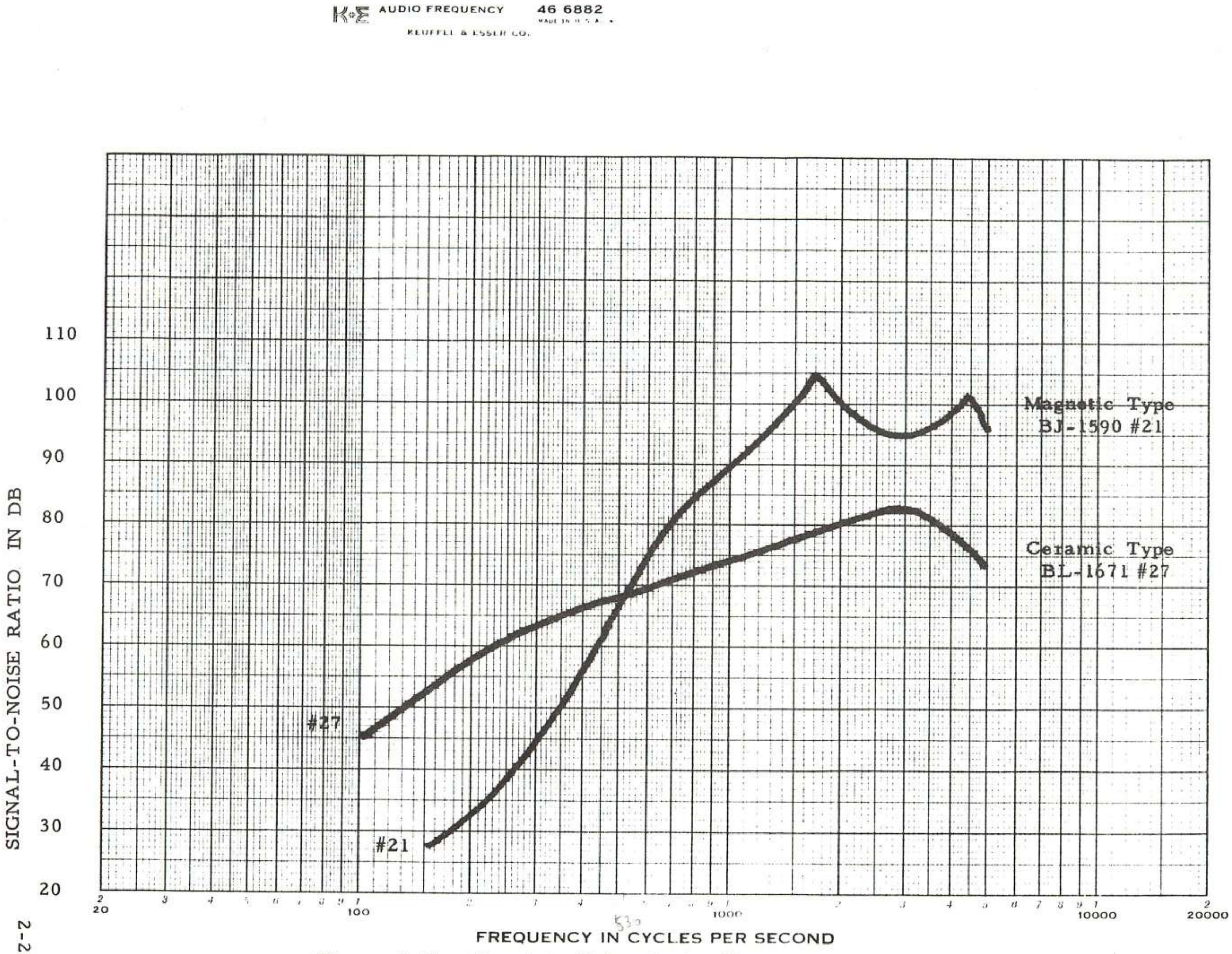

Figure 2-21. Signal-to-Noise Ratio Characteristics of the Magnetic Type (BJ-1590 #21) and Ceramic Type (BL-1671 #27) Microphones

Measurements (cont)

D. Output Impedance

General Results - The manufacturer states the impedance of the ceramic units to be nominally 12 kΩ. The results of the impedance measurements are given in Figure 2-22 as a function of frequency. The values of impedance obtained at 1 kHz would indicate that the 12 kΩ value of the manufacturer to be a minimum value. The impedance function vs frequency for the magnetic unit is shown in Figure 2-23; it is not smooth like the impedance curves shown for the ceramic units in Figure 2-22.

Effect of Environmental Test - There was no change in the output impedance due to the environmental test.

Discussion - A coupling capacitor is recommended with the use of a dropping resistor, to prevent a change of bias on the FET in the ceramic unit. A dropping resistor is usually necessary to attenuate the output of the microphone due to the relatively higher output of the FET pre-amplifier.

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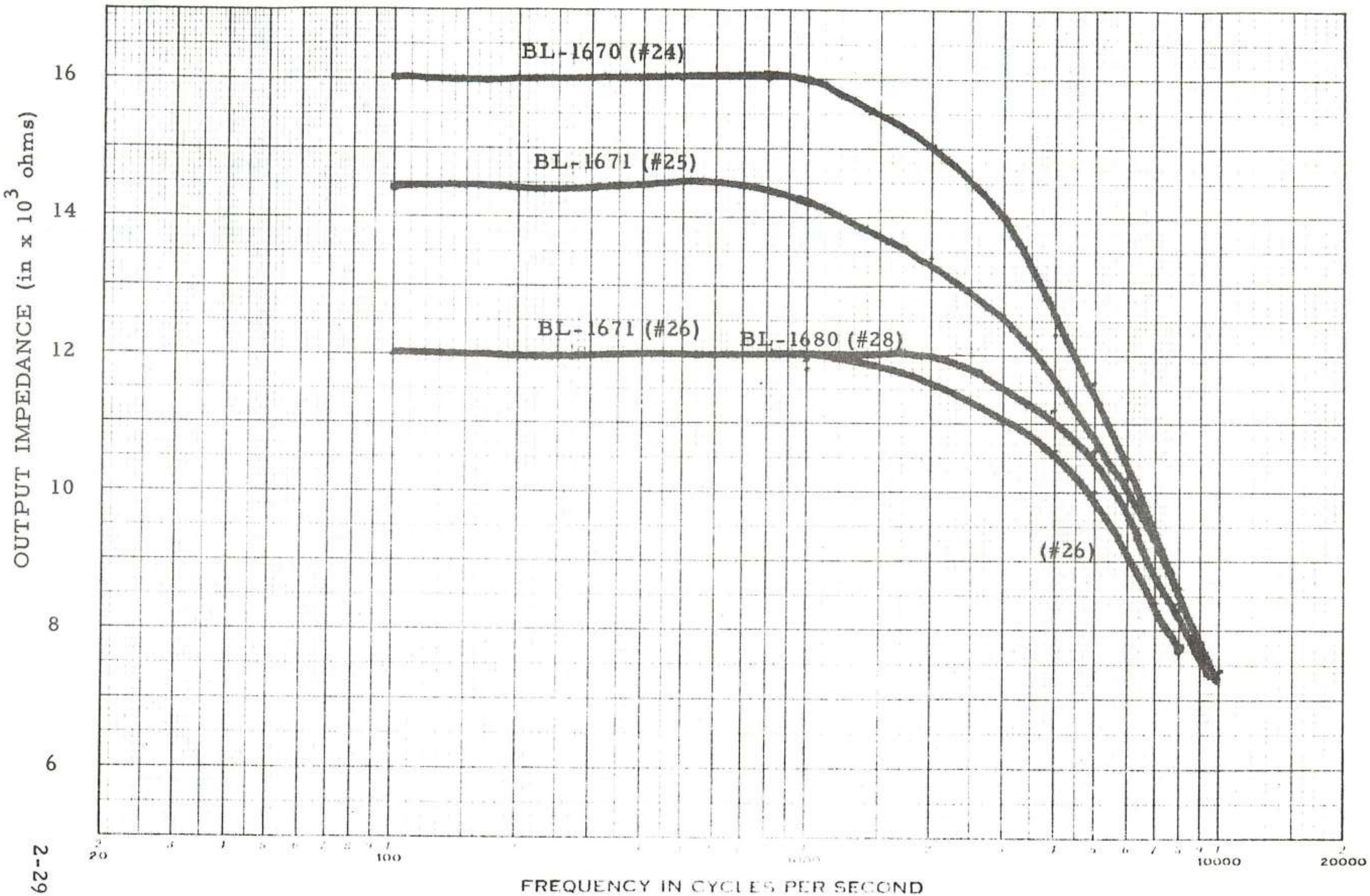

Figure 2-22. Output Impedance as a Function of Frequency For the Ceramic Microphones

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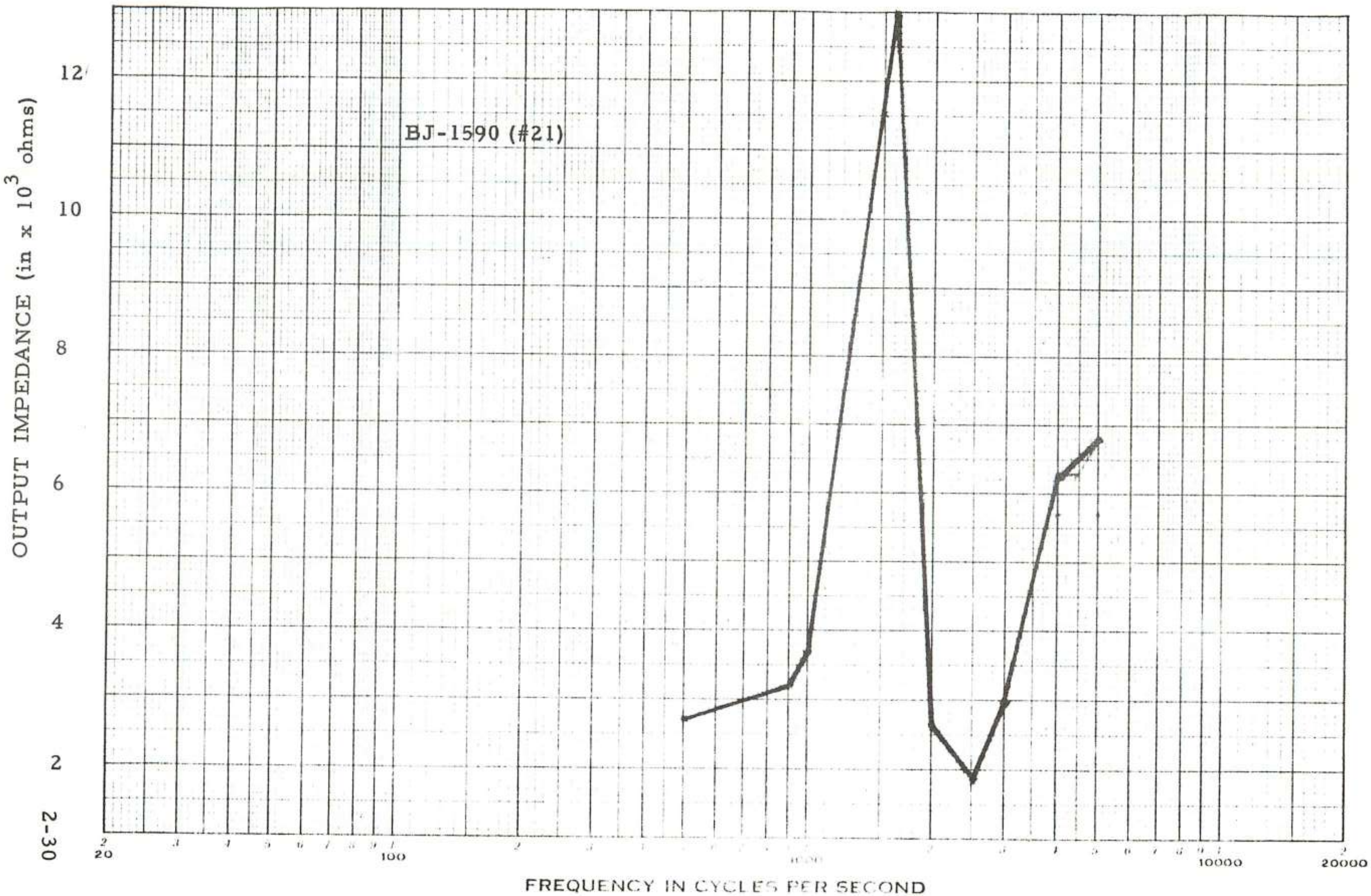

Figure 2-23. Output Impedance as a Function of Frequency For the Magnetic Microphone: BJ-1590 (#21)

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Measurements (cont)

E. Susceptibility to Magnetic Fields

General Results - There is virtually no effect of a magnetic field on the performance of the ceramic microphone. A Weller soldering gun provided the source of a magnetic field at a distance of three (3) inches from the microphone under test.

When used near the magnetic type microphone, the audio intelligence was nearly masked by the hum level picked up by the microphone. In contrast, when the ceramic type unit was under test; the audible click of the gun being triggered, was the only clue to the listener that the magnetic field was being actuated.

Measurements (cont)

F. Stability of the FET in the Ceramic Microphone

General Results - The Ceramic microphone performance appeared to be very stable when subjected to the various capacitive loads that were connected across the output terminals. Figure 2-24 shows the high frequency roll-off characteristic which occurred when the test capacitor values were connected: 0.003, 0.006 and 0.01 μf.

A typical transistor input circuit was then simulated by the use of a 1.0 μf coupling capacitor and a 20 kΩ load resistor. The performance of the ceramic unit continued to appear normal as is shown in Figure 2-25 . The 20 kΩ load resistor apparently caused some loading of the output impedance of the microphone, thus resulting in a reduction in output voltage.

Discussion - As a result of these tests, it is concluded that the only source of instability would be from an improperly decoupled microphone bias supply. These same problems exist in the design of any high-gain audio amplifier. The manufacturer has issued a Technical Bulletin, which is reproduced in Appendix A, that discusses the problems encountered when the power supply is improperly decoupled.

The tests described above were conducted using an external DC power source to provide the bias voltage; therefore showing only the effect of the various loading conditions on the performance of the ceramic microphone. During the listening test phase of the evaluation; however, the bias was derived from the power supply of the AGC Module. There was no evidence of abnormal performance when the internal power supply was used.

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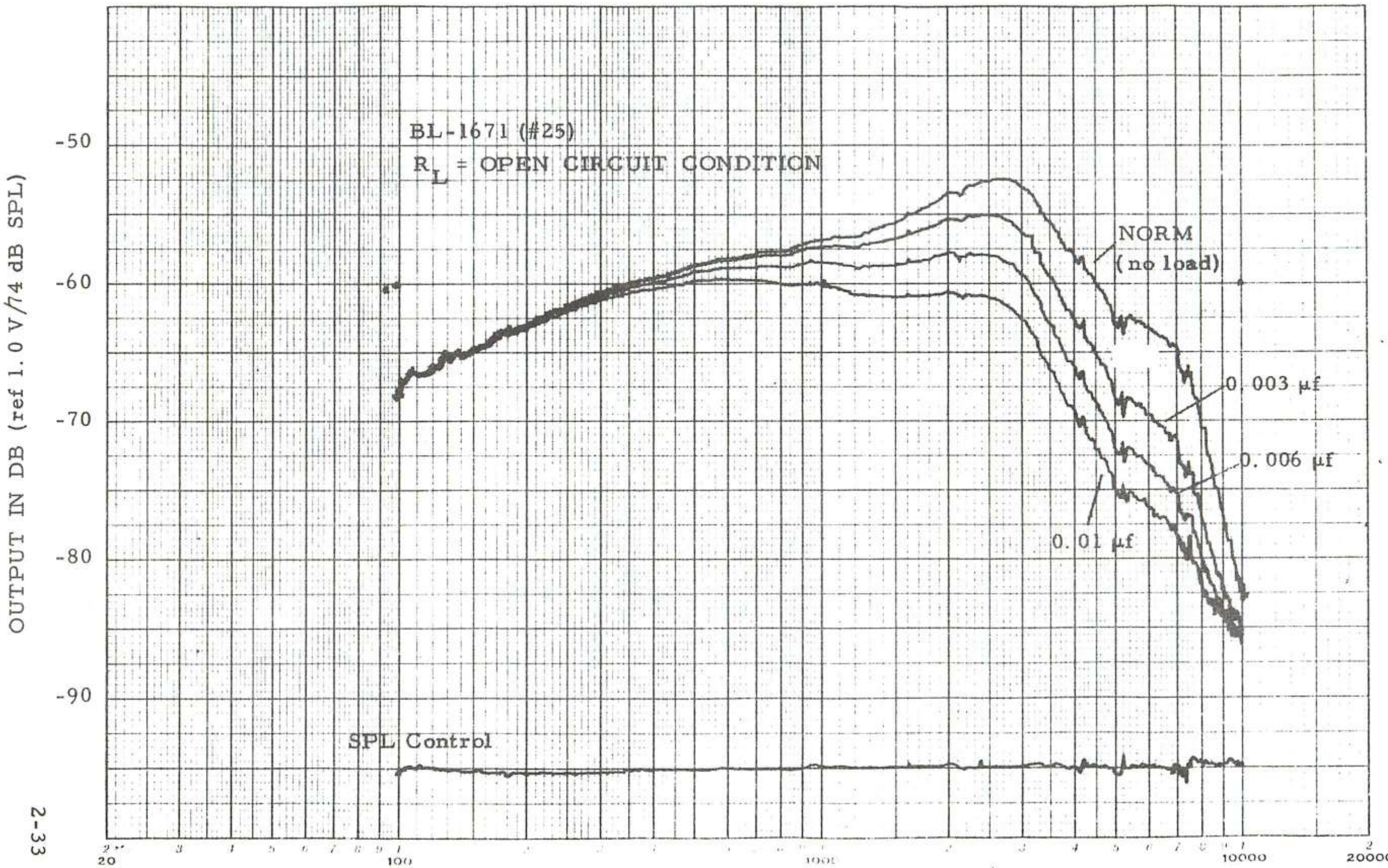

Figure 2-25. Effect of Capacitive Load on Response Characteristics For Ceramic Microphone BL-1671 (#25)

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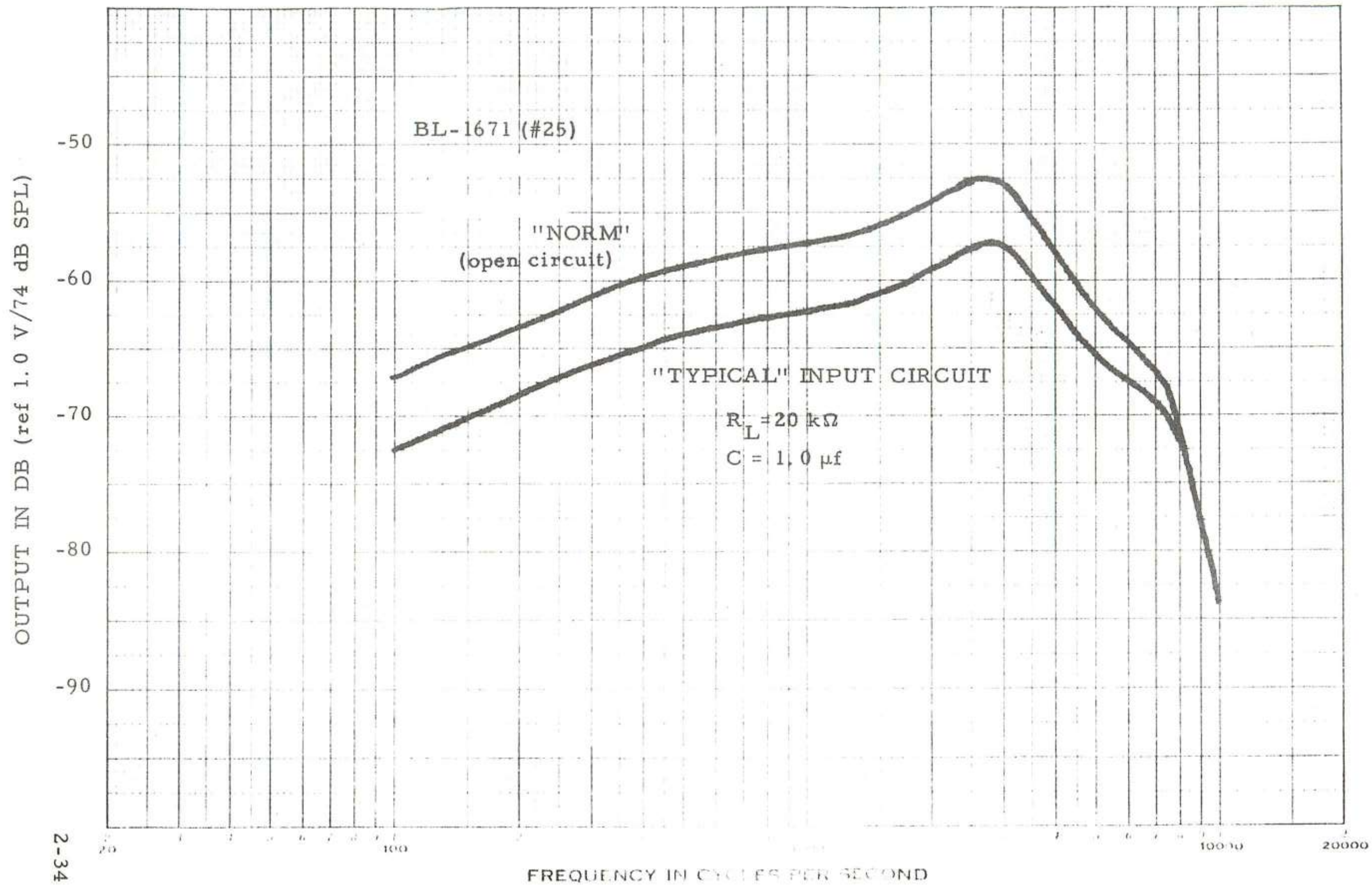

Figure 2-26. Effect of Typical Input Circuit on Response Characteristics For the Ceramic Microphone BL-1671 (#25)

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Measurements (cont)

G. Listening Test

General Results - A series of informal listening tests were performed using both the magnetic and ceramic type microphones with the SRT-60 Transmitter and the newly developed Dual Loop AGC Module.[1] The power supply of the AGC Module was used to bias the ceramic type microphone and an external supply was used for the SRT-60 phase of the test.

The quality of sound produced by the ceramic unit was very natural and the identification of the speaker was easily made. It is of interest to note that the introduction of a 500 Hz high pass filter, reduced the sound quality of the ceramic microphone to that of the magnetic type microphone. Reference to the response characteristics of the two units, Figure 2-5, shows that this effect should be expected.

The use of the Weller soldering gun as the source of a magnetic field had no effect on the performance of the ceramic type microphone. The hum pick-up of the magnetic type unit was very noticeable, but the intelligence could just be heard above the interference.

Discussion - No attempt was made to attenuate the output of the ceramic type microphone when used with either the SRT-60 or the AGC Module; and there was no evidence of overloading even when the sound source was within eight inches from the microphone. It was apparent that the ceramic unit could be used as a direct substitution for the magnetic unit, in the case of the SRT-60; provided an external bias supply were furnished. As mentioned in the ESG Report, the use of a single mercury cell, with a rating of 1000 mah, would provide the necessary bias for the ceramic type microphone for a period up to two (2) years.

[1] Developed under Contract 5089, Task 7, Work Order 9

3.0 CONCLUSIONS AND RECOMMENDATIONS

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3.1 Conclusions

The performance of the ceramic microphone appeared to be superior to the magnetic microphone in many areas. A direct substitution for the magnetic unit seems to be feasible and in most cases it would seem to be desirable.

A. Superior Characteristics

The ceramic microphone appears to be superior to the magnetic unit in the areas listed below.

1. Frequency Response - a relatively smooth response characteristic is provided by the ceramic unit from 100 Hz to 10 kHz with a peak output at approximately 3.5 kHz as shown in Figure 2-2.
2. Small Dimensions - the package size for the very thin ceramic microphone, BL-1680, is 0.22" x 0.34" x 0.08" as compared to the smallest available magnetic microphone from Knowles, the BJ-1500 series, which has the dimensions of 0.22" x 0.312" x 0.16".
3. Susceptibility to Magnetic Fields - The ceramic microphone has virtually no output due to the proximity of a magnetic field.
4. Susceptibility to Low Frequency Vibration - The ceramic unit has little sensitivity to non-airborne low frequency sounds such as transmitted in structural members of a building.
5. Effect of Electrical Loading - The response characteristics of the ceramic unit are independent of the resistive load connected across the output terminals.
6. Effective Gain - The ceramic microphone has an effective gain of 13 dB more than the magnetic microphone at 1 kHz. This characteristic allows the elimination of one stage of gain in the input circuit of the associated audio device.
7. Sound Quality - The quality of sound produced by the ceramic microphone is far superior to the magnetic unit. Due to the low frequency sensitivity (air-borne); voice recognition is enhanced.

Conclusions (cont)

B. Deficiencies

Although the ceramic microphone does appear to be a desirable direct replacement for the magnetic unit; there are some areas which will require careful consideration before a choice is made.

1. DC Bias Voltage - A DC bias voltage supply of at least 1.0 vDC with a current capacity of 50 μA is required for the ceramic units. Substitution of the ceramic unit for use with older equipment would require an external battery. In new equipment the bias voltage could be obtained from the decoupled supply voltage fed to the first amplifier stage of the device. Careful consideration must be given to the design of the decoupling circuit to insure stable operation.

2. Self Noise - The self noise of the ceramic microphone is approximately 13 dB higher than that of the magnetic unit. In very critical applications where the ambient room noise is expected to be down around 20 dB; the magnetic unit would provide superior performance over the ceramic unit.

3. Adverse Humidity Conditions - As a result of the 10-day environmental test, the ceramic microphone apparently lost sensitivity due to the high humidity. The sensitivity gradually increased until it nearly reached its pre-environmental test value; this occurred over a period of several days after the units had been removed from the environmental chamber.

   The magnetic type microphone apparently was not effected by the environmental test

   The reliability of the ceramic type microphone cannot be predicted at this time for operation in an adverse humid environment, without subjected the units to further environmental tests.

3.2 Recommendations

Based on the results and conclusions reached during this microphone evaluation; the recommendations will be given in terms of additional tests and replacement of the magnetic type microphone, where feasible, by the ceramic type microphone.

A. Additional Tests

The following tests are suggested to confirm the suitability of the ceramic microphone to replace the magnetic type microphone in terms of reliability and performance.

1. Adverse Humidity Conditions - The ceramic type microphone should be exposed to an adverse humid environment over a long period of time; with frequent performance checks during the period, to determine its reliability under such conditions.
2. High Bias Voltage - The ceramic type microphone should be exposed to bias voltages in excess of 1.35 vDC, over a long period of time, to determine what effect the higher voltage will have on the FET in the microphone. Bias voltages up to 24 vDC were used for short periods of time during the evaluation tests, with no detrimental effects.
3. Factors Leading to Instability - Further studies should be conducted to determine specifically the circuit designs that could contribute to an unstable situation when used with the ceramic unit.
4. Survey of Parameters - A survey type test should be scheduled to check the parameter values to be expected from the production run of the ceramic microphones. Ten (10) BL-1670 type units and ten (10) BL-1680 units were received from the manufacturer which are available for testing.
5. Sensitivity to Low Frequency Vibrations - A study should be conducted to determine to what degree the ceramic and magnetic type microphones exhibit an accelerometer type response; i.e., sensitivity to non-airborne sounds through the case of the microphone.

Recommendations (cont)

B. Up-Date Equipment with the Ceramic Type Microphone

Based on the limited samples tested, the ceramic type microphone is recommended for all applications where the humidity level is not excessive, the self-noise level is not comparable to the program level and where it is feasible to provide the necessary bias voltage for the FET.

Immediate substitution of the ceramic type microphone is recommended for all AC outlet applications due to the low susceptibility to magnetic fields, low sensitivity to non-airborne low frequency vibrations and small physical size.

The microphone is also recommended for agent communication applications due primarily for the improved articulation and voice recognition qualities which are made possible by an extended high and low frequency response characteristic, respectively and the low sensitivity to non-airborne low frequency vibrations.

A conditional recommendation is made for the use of the ceramic unit in audio surveillance applications pending the outcome of a survey type testing program of the microphone.

APPENDIX A

Stability of Amplifier Systems Connected to the BL Microphone

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Stability of amplifier systems connected to the BL microphone

Each of the BL-series microphones requires a biasing voltage. Since the voltage is usually supplied by connection to the amplifier power supply, the microphone power supply regulation requirements must be considered in the design of the amplifier system to avoid oscillations and other undesired side effects. The problems of stability in using the BL microphone are not new but are a repetition of the old problems of biasing a high gain transistor amplifier. It is necessary to remember that the supply regulation fluctuations can reach the amplifier input via the microphone.

In applying the BL microphone to the hearing aid amplifier, the problem can be divided into two fairly distinct classes: (1) Amplifiers containing an odd number of inverting stages, and (2) Amplifiers containing an even number of inverting stages (disregarding emitter follower, Darlington, or other non-inverting stages in each case).

Class 1: THE AMPLIFIER WITH AN ODD NUMBER OF STAGES is the simplest application because in this configuration the feedback that passes through the microphone produces degeneration in the center of the passband. Unless it contains an excessive number of coupling capacitors or is used at a very high gain, the amplifier will usually be stable. It will suffer a loss in gain as the internal resistance of the battery increases near the end of its life. This effect can be minimized by the use of a decoupling network in the supply lead to the microphone. We recommend, to prevent excessive loss in supply voltage to the microphone, that the decoupling resistor not exceed 2,000 ohms. The value of the bypassing capacitor will set the frequency above which the degeneration is to be eliminated. Thus, as battery resistance increases, the sensitivity below the frequency determined by the decoupling network will decrease.

Figure 1 shows an experiment which was run with a moderate gain, 3-stage amplifier hearing aid using a BL microphone, a BK receiver, and a battery with a 10 ohm internal resistance. The decoupling network consisted of a 2000 ohm resistor in series with the microphone, and a range of values of capacitance shunting the microphone bias terminals. The decoupling capacitance was varied from zero microfarad thru 1.5 microfarad. Then, the decoupling network was removed, and the BL microphone was biased with a separate battery of equivalent terminal voltage; this simulated an ideally decoupled power supply. It is to be noted that increasing the value of the decoupling capacitance maintained the sensitivity to a lower frequency.

Other than spurious difficulties (such as mechanical vibration transmission, acoustic leakage between the receiver and the microphone, or inadvertent "common path" coupling in the wiring), the principal cause of instability in this class of circuit is apt to be excessive phase shift introduced by series coupling capacitors in the amplifier. This can normally be controlled by not having more than two interstage coupling capacitors. Regardless of the number of coupling capacitors, however, the amplifier will be stable if the phase shift stays under 180 degrees until the loop gain due to power supply impedance feedback falls below unity. In practice, this means that only one coupling capacitor should be used to provide the basic low frequency rolloff: all other coupling capacitors should be large enough so they are unimportant (i.e., produce negligible phase shift) until the frequency is reached at which the loop gain falls below unity. The other coupling capacitors can then be used to further limit the low frequency response.

Class 2: THE AMPLIFIER WITH AN EVEN NUMBER OF STAGES is a more critical problem in that the feedback caused by battery impedance is positive and tends to produce oscillation. To assure stability, the product of amplifier transconductance (G_a), the source resistance of the battery (R_b), and the attenuation in the microphone (A_m) must be less than unity: $G_a R_b A_m < 1$. When the amplifier gain is appreciable, it may be necessary to increase the microphone attenuation in the amplifier passband to obtain stability. Since decoupling by a resistor-capacitor combination will become ineffective at a low

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enough frequency, it is necessary to deliberately decrease the amplifier gain to a safe value at and below this low frequency. This should be done by selecting one coupling capacitor to produce the needed low frequency rolloff and providing generous enough capacity in any others so that they cannot contribute a significant amount of phase shift in the frequency region where the stability is still in doubt.

The frequency responses shown in Figure 2 illustrate the effect of using too small a decoupling capacitor for the value of the dominant interstage coupling capacitor. Excessive sensitivity at a low frequency can result. The same effect is illustrated in Figure 3 where amplifier gain control has been varied on a similar set-up that has insufficient decoupling for use at the higher gain settings. With larger values of coupling and decoupling capacitors, this can be at a very low frequency (in the region of a few Hertz). The circuit values chosen for illustration place the effect within the audible band. In practice, the response anomalies may occur at very low frequencies where the effect is more likely to result from acceleration rather than acoustic signals.

The microphone output impedance and the attenuation of power supply modulation are constant and without appreciable phase shift throughout most of the audio frequency range. However, at low frequencies (between 1 and 10 Hertz), there can be a phase shift in the attenuation of as much as 60° lead. This phase shift, like the attenuation, is dependent on the internal amplifier and the circuit adjustment necessary to standardize the mid-band performance of the microphone. As frequency is lowered through this range, the output impedance of the microphone will decrease, and the attenuation of the power supply feed-through signal will increase. The two effects are related, and those devices exhibiting the higher phase shifts will exhibit greater increases of attenuation and lower very-low-frequency output impedance. The additional very-low-frequency attenuation may be only a few dB or as much as 20dB. Most devices will exhibit phase shifts and attenuations less than the above extremes. In the attenuation transition range, the internal low frequency phase shift is in the same direction as that due to the use of an additional coupling capacitor.

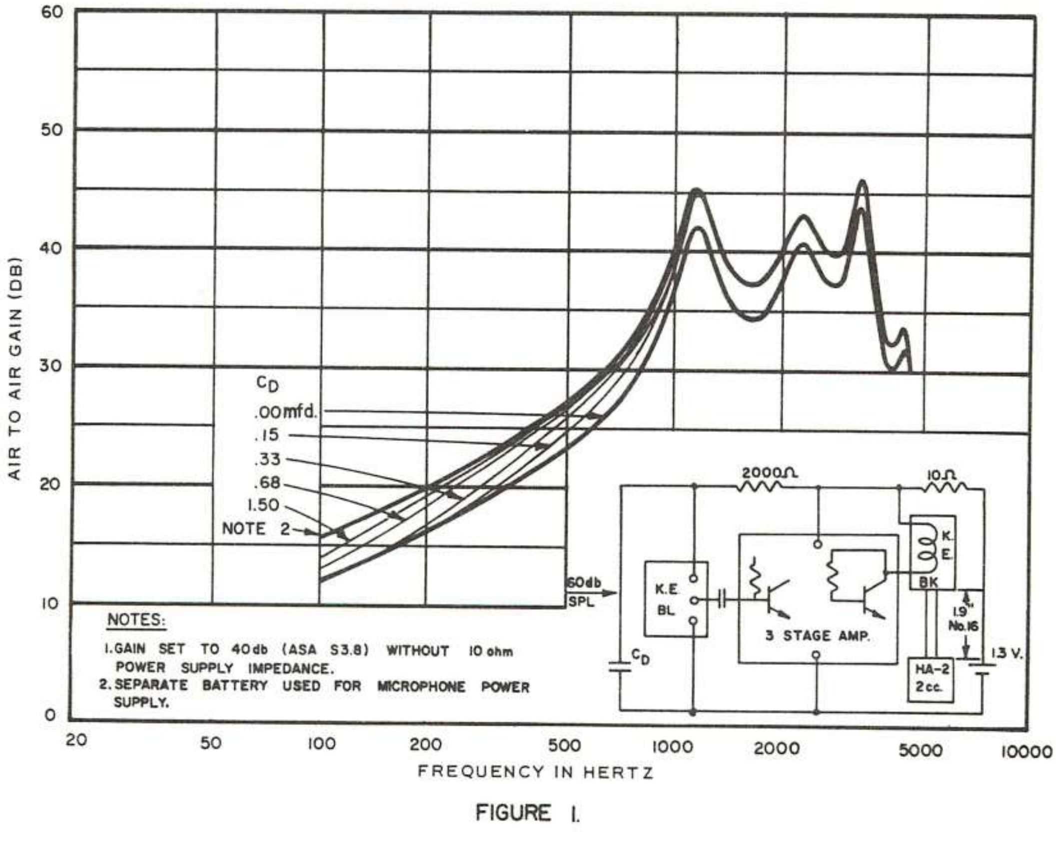

FIGURE 1.

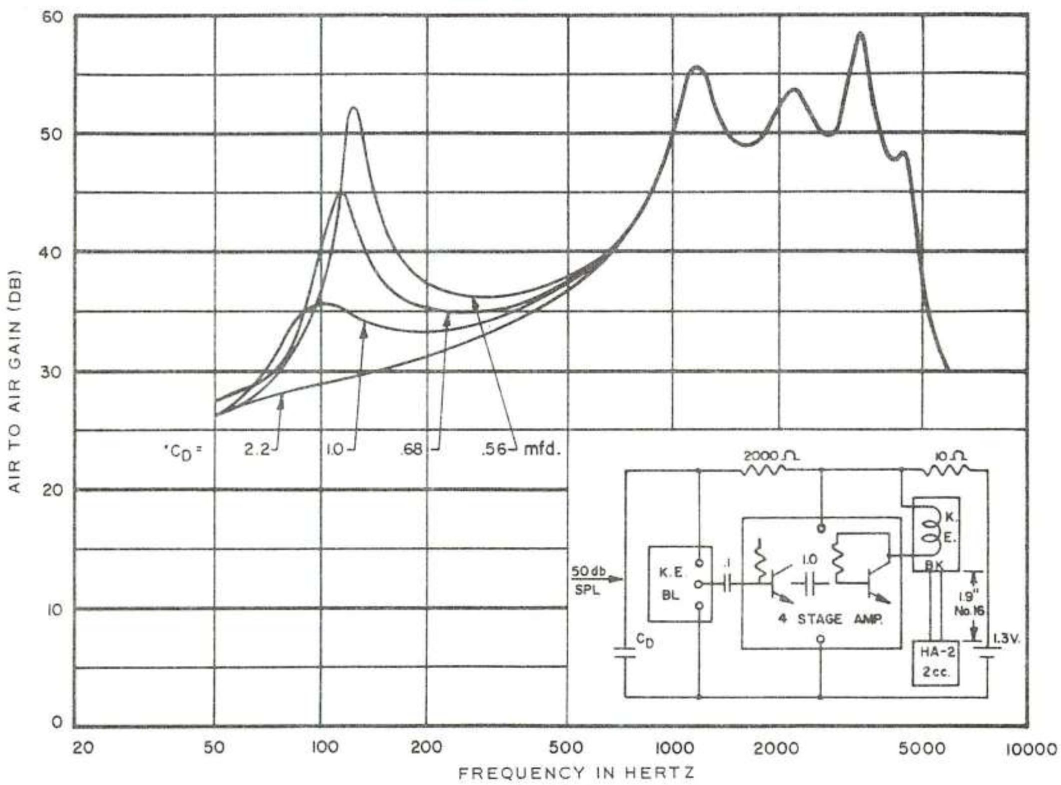

FIGURE 2.

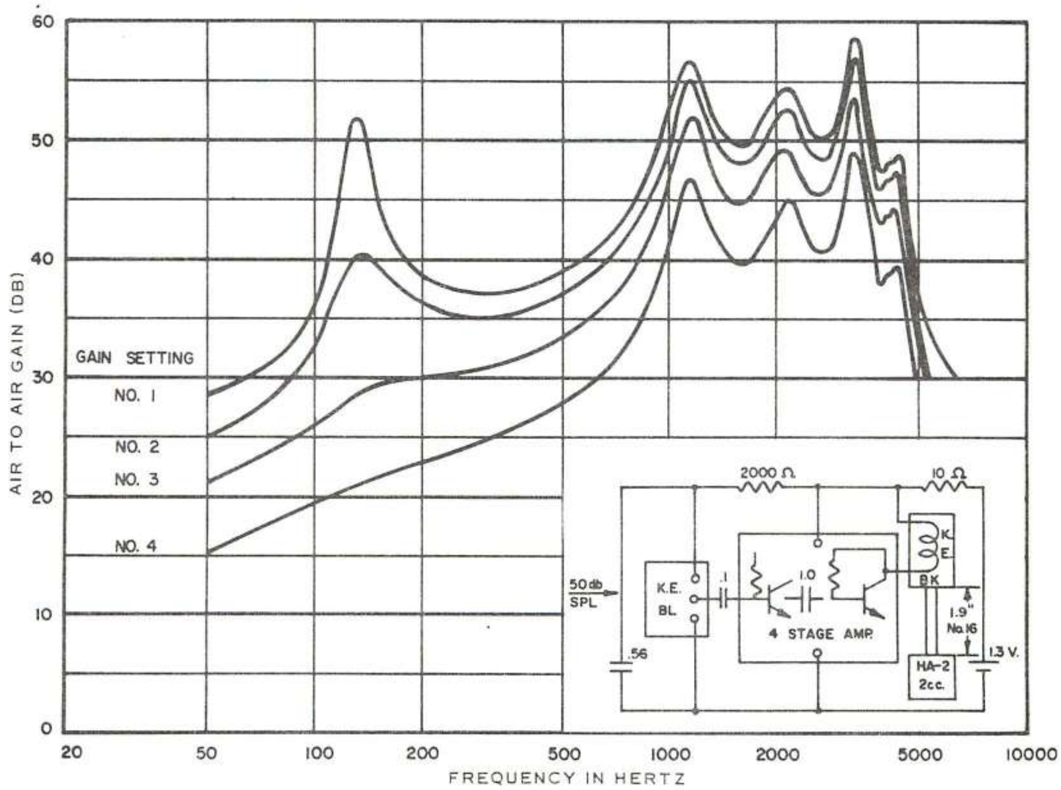

FIGURE 3.