DESERT RESEARCH INSTITUTE
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AN INVESTIGATION OF ELECTRICAL PROPERTIES OF POROUS MEDIA

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ABSTRACT

The problem of ground-water contamination has provided a need for detailed information on ground-water quality. Well drilling and sampling provide limited information, especially when trying to delineate a ground-water contamination plume. D.C. electrical geophysical methods are being increasingly used to help delineate contaminated ground water, however, these methods provide only resistivity data. Simple resistivity is affected by many different parameters* and it is often not possible to develop a unique interpretation of the data. Complex resistivity (CR) is a method that provides considerably more information about the saturated porous medium, thus introducing the possibility of reducing the unknown parameters that affect the electrical properties of the porous medium and thereby providing a unique interpretation.

The CR method provides two curves: impedance amplitude (related to resistivity) and phase shift (related to capacitive effects), both as a function of frequency. Although CR provides much more information than a single resistivity measurement, there is not much known about how the CR responses are affected by pore geometry, pore fluid chemisty and clay content.

In this study, a laboratory measurement system is set up to allow systematic variation of parameters of interest, in order to determine their effect on amplitude and phase data. The laboratory apparatus consists of a sample holder, appropriate electrodes, and a data collection and analysis system. Experiments were conducted to vary grain size, concentration of NaCl and clay content.

*Such as pore geometry, pore fluid chemistry and clay content

Results indicate that grain size has little to no effect on amplitude or phase at any frequency for clay-free samples. Phase-shift becomes increasingly negative over the range of frequency investigation for a clay-bearing sample (3% clay content). The amplitude also becomes increasingly smaller with increased frequency for a clay-bearing sample.

Comparison of amplitude versus salinity for the clay and non-clay samples show that it may be possible to develop a modified version of Archie's Law for low salinity samples that contain clay.

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SECTION 1

INTRODUCTION

The use of geophysical techniques has become common in inves- jations of the character and extent of the ground-water source. This is especially true with respect to electrical :hods. In general these techniques rely on detecting the elec- ical response of subsurface units and then correlating this with ner geologic information such as well logs, geology, and water alysis to obtain information such as the depth to ground water, alitative estimates of occurrence and distribution of ground- ter contamination, and even estimates of the hydraulic conduc- vity of aquifers (Zody et al., 1974; Keys and MacCary, 1971; ott, 1980).

In general past measurements of the electrical response have en limited to the D.C. resistivity of the medium, which is only e portion of the electrical response. Additional information out the system can be obtained by more fully characterizing the ectrical response of a medium, which consists of two parts, real d imaginary. This can be represented by amplitude and phase. e impedance represents the total resistance (measured in ohms) flow of an alternating current and the phase shift represents e difference between the current and voltage waveforms voltage id is measured in radians, or milliradians. The impedance and iase shift can be affected by numerous properties of the porous edium and the fluid within the porous medium, and in general, oth are frequency dependent.

Although measurements of the complex electrical signal are common to ground-water investigations, they have been used by minerals exploration industry since the late 1940's (Brent,). The techniques go by such names as "complex resistivity" (Zonge, 1972) or "spectral IP" (induced polarization) (Pelton ıl., 1978).

In the past few years, emphasis in the ground-water discip- has shifted from ground-water quantity to concern about ınd-water quality. Traditional D.C. resistivity techniques l in conjunction with other methods usually provide adequate ›rmation about ground-water head levels (for unconfined ıfers). However, D.C. methods are inadequate for many prob- s in which the contaminant plume location, distribution, and nical nature are of interest because so many parameters affect D.C. resistivity. For instance, a relatively low resistivity ue can be indicative of high salinity and/or high moisture tent.

Complex resistivity investigations conceptually have the ential to reduce the number of unknowns by providing more elec- cal information. Because many parameters affect the resistiv- of a saturated porous medium it is not possible to separate individual effects with resistivity data alone. This poten- .l advantage of the CR technique arises because two sets of .bers (impedance and phase shift) for a suite of frequencies are ıerated for a particular porous medium, instead of a single .ue of resistivity that is obtained with D.C. techniques. :ause of this additional information, it may be possible to :ain actual concentration values and/or type of chemical species ıt are present in a contaminated ground-water system. One very :eresting possible use for CR is that organic pollutants may ›mically interact with earth materials to create a complex sistivity anomaly which would not be detected by D.C. resis- ity measurements alone.

Carefully controlled laboratory experiments represent an portant step in isolating and determining the complex response the fluid and chemical constituents contained within a porous medium. As a first step towards this long range goal, this study is an attempt to characterize the complex, frequency dependent electrical response of a saturated porous medium when certain parameters are varied. The parameters to be varied in these experiments include grain size, salinity and clay content. There already exists a large body of literature characterizing the complex electrical response of rocks due to the occurrence and distribution of ore materials (Wong and Strangway, 1981; Wong, 1979; Zonge, 1972; Marshall and Madden, 1959). Although most of this information is not directly transferable to the problem of groundwater contamination, it has been very helpful in the design of the present study.

SECTION 2

OBJECTIVES

This publication was produced as part of a cooperative agreement between the Desert Research Institute, University of Nevada System and the U.S. Environmental Protection Agency (EPA CR810052-01). The objectives of this task are as follows:

1) Design and build laboratory equipment to measure complex frequency dependent electrical response of a saturated porous media with accuracy and repeatability.
2) Calibrate the experimental apparatus and compare calibration results to similar experiments by other researchers.
3) Measure complex electrical response of porous media as a function of frequency for: a) samples of several different grain sizes; b) samples of saturated porous media with a range of solutions of an electrolytic solute; and c) samples with and without clay.
4) Analyze the collected laboratory data for relationships between the varied parameters and the complex electrical response.

To achieve these objectives, the project was divided into four tasks. Task one consisted of a thorough search of the literature to assess the applicability of field CR methods to ground-water quality and contamination investigations. Since these methods were developed primarily for sulphide ore body and other ore-related investigations, interpretation of field data was not expected to be directly applicable to ground-water problems. A literature search was also conducted to determine what other experimental laboratory equipment had been used for complex parameter estimation. Information gleaned from this search provided the basis for the experimental design that was chosen.

Task two consisted of building, testing and calibrating the laboratory equipment. Task three was the actual suite of experiments for the numerous parameters that were varied. Task four was the analysis and interpretation of the experimental results.

SECTION 3

THEORY AND BACKGROUND OF ELECTRICAL MEASUREMENTS

THE NEED FOR COMPLEX ELECTRICAL MEASUREMENTS

The most commonly made electrical measurement is the D.C. resistivity of a material, which represents only a portion of the electrical characteristics of a medium. There is also a capacitive property which causes a phase lag between the current and voltage. This phase lag makes it convenient to describe the electrical properties as a complex number represented as amplitude and phase. In the most general case both of these properties of the sample are considered to be frequency dependent. One simplified example of this is the electrical circuit shown in Figure 1a. We see in this case that the D.C. resistance alone is not sufficient to characterize the circuit. To fully investigate the circuit both phase and amplitude must be measured as a function of frequency. Ward and Fraser (1967) discuss that a similar situation can occur in a porous medium. Figure 1b shows two pore paths, the upper one with a clay particle and the lower one without clay. The cations are attracted to the vicinity of the clay because of its excess negative surface charge when current is applied (Figure 1c). Cations can move freely through the cation cloud but anions are blocked. This forms an ion-selective membrane and a buildup of charge. The charge buildup is analogous to the charge built on the capacitor in Figure 1a.

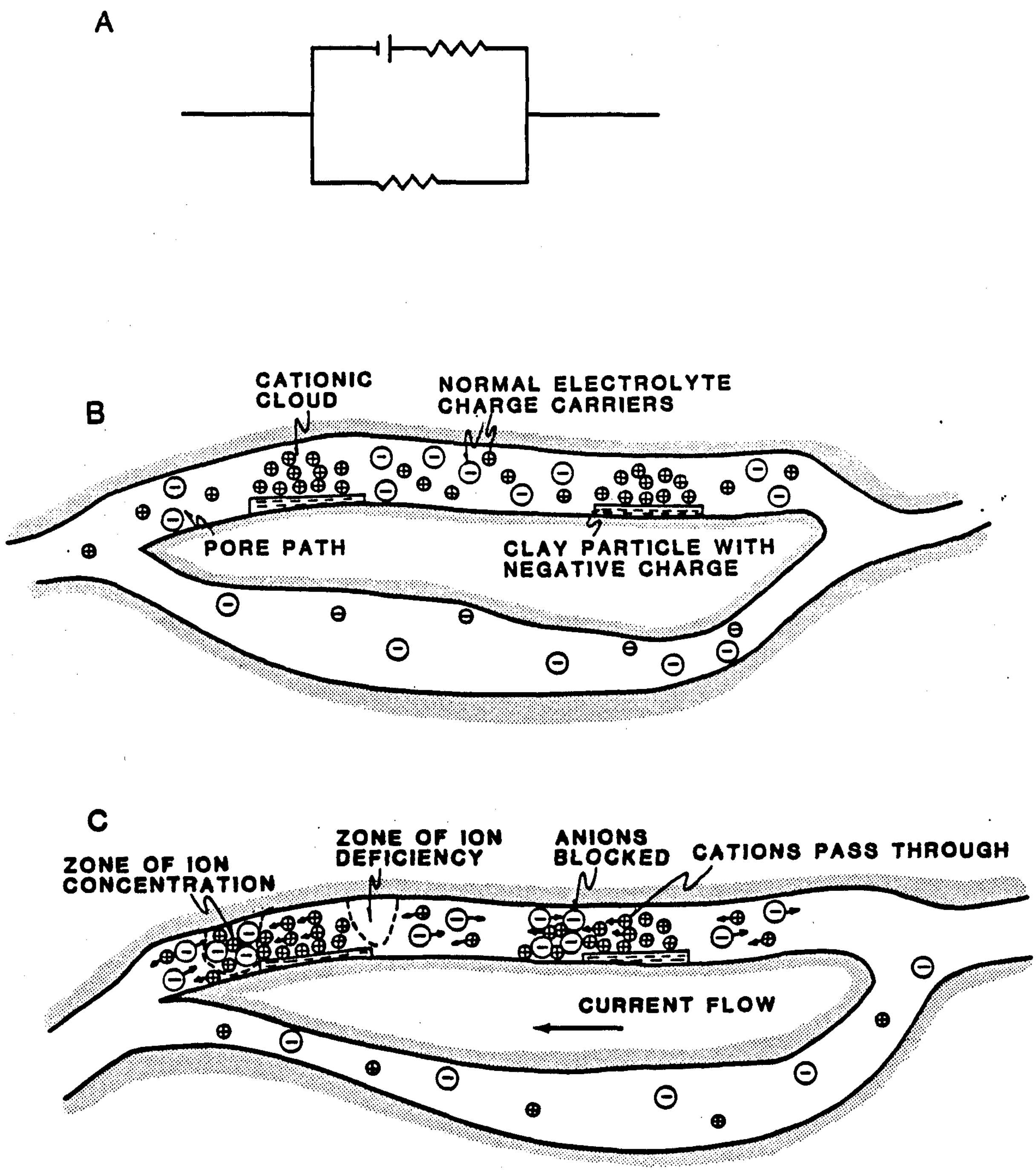

Figure 1. Electrical response of porous medium:

A. Analogous electrical circuit.

B. Charge distribution in pore without current flow.

C. Charge distribution with current flow.

(After Ward and Frazier, 1967).

CALCULATION OF COMPLEX AMPLITUDE AND PHASE

To determine the complex impedance of the sample the voltage waveform across a known resistance (V_r) and across the sample (V_s) are digitized (see Section 4). By measuring the voltage drop across the known resistance (R_r), the current can be determined utilizing Ohm's law. To characterize the sample impedance independent of the sample geometry, it is necessary to multiply by the sample length (L) and divide by the sample cross section (A_r). This is referred to as the material's intrinsic resistivity.

To obtain the complex electrical response of the sample, a sine wave was used as an input and the digitized voltages were recorded and analyzed for up to 10 harmonics. This was repeated until the frequency range of interest was covered. An alternate technique employed by Zonge and Hughs (1981) utilizes a waveform that contains numerous harmonics such as a square wave. By doing this they were able to obtain results at many frequencies by only doing one measurement. This technique can save time but it requires more data points per waveform to obtain reliable results, which causes problems in non-linear systems.

To measure the voltage waveforms across the sample and resistor, digital recording is necessary. The equipment used to do this is discussed in Section 4.

To reduce the digital data a matrix inversion method was chosen instead of a fast Fourier transform because it provides a method to calculate the variance to check data quality (Olhoeft, 1979). The data is in a series of voltages and times:

$$\begin{array}{l} V_{s_1}, V_{s_2}, V_{s_3} \; \ldots\ldots, V_{s_n} \\ V_{r_1}, V_{r_2}, V_{r_3} \; \ldots\ldots, V_{r_n} \\ t_1, t_2, t_3 \; \ldots\ldots, t_n \end{array} \qquad (1)$$

where:

n = number of digitized points

t_i = time at the ith sample

V_{s_i} = voltage reading from across the sample at t_i

V_{r_i} = voltage reading from across the resistor at t_i

These data were fitted to the following model (Olhoeft, 1979);

$$V_r(t) = V_r dc + \sum_{i=1}^{k} V_{r_i} \sin(\omega_i t + \phi_{r_i})$$
$$V_s(t) = V_s dc + \sum_{i=1}^{k} V_{s_i} \sin(\omega_i t + \phi_{s_i}) \qquad (2)$$

where:

t = time

ω_i = $2\pi f_i$

f_i = frequency of ith harmonic

ϕ_{r_i} = phase shift of the ith harmonic of the voltage waveform across the resistor relative to time 0

ϕ_{s_i} = phase shift of the ith harmonic of the voltage waveform across the sample relative to time 0

V_{r_i} = amplitude of the ith harmonic for the voltage waveform across the resistor

V_{s_i} = amplitude of the ith harmonic for the voltage waveform across the sample

$V_r dc$ = zero frequency component of the voltage waveform across the resistor

$V_s dc$ = zero frequency component of the voltage waveform across the sample

k = number of harmonics considered

These equations are Fourier series and can be used to reconstruct any periodic waveform. In this study a sine wave input was used and therefore the ideal calculated response would contain only 1 harmonic (k = 1). However, Olhoeft (1981b) suggests that measuring the change in harmonic content of the waveforms can give an indication of the linearity of the sample's response. Therefore even though a sine wave input was used, up to 10 harmonics were analyzed to check the linearity of the sample's electrical response.

Equation 2 can be set up in the following matrix form (Olhoeft, 1979).

$$\underline{X} = \underline{T}\ \underline{A} \tag{3}$$

where $\underline{T}$ is n by (1+2k), $\underline{A}$ is (1+2k) by 2, $\underline{X}$ is n by z where n is the number of digitized points and k is the number of harmonics. The components of the matrices are as follows:

$$\underline{X} = \begin{bmatrix} V_{s(t_1)}, & V_{r(t_1)} \\ V_{s(t_2)}, & V_{r(t_2)} \\ V_{s(t_n)}, & V_{r(t_n)} \end{bmatrix} \tag{4}$$

$$\underline{T} = \begin{bmatrix} 1, \sin(\omega t_1), \cos(\omega t_1), \sin(2\omega t_1), \cos(2\omega t_1)\ldots\sin(k\omega t_1)\ldots\cos(k\omega t_1) \\ 1, \sin(\omega t_2), \cos(\omega t_2), \sin(2\omega t_2), \cos(2\omega t_2)\ldots\sin(k\omega t_2)\ldots\cos(k\omega t_2) \\ 1, \sin(\omega t_n), \cos(\omega t_n), \sin(2\omega t_n), \cos(2\omega t_n)\ldots\sin(k\omega t_n)\ldots\cos(k\omega t_n) \end{bmatrix} \tag{5}$$

$$
\underline{A} = \begin{bmatrix}
V_s dc & , & V_r dc \\
V_{s_1} \cos\phi_{s_1} & , & V_{r_1} \cos\phi_{r_1} \\
V_{s_1} \sin\phi_{s_1} & , & V_{r_1} \sin\phi_{r_1} \\
V_{s_2} \cos\phi_{s_2} & , & V_{r_2} \cos\phi_{r_2} \\
V_{s_2} \sin\phi_{s_2} & , & V_{r_2} \sin\phi_{r_2} \\
\vdots & \vdots & \vdots \\
V_{s_{(1+2k)}} \cos\phi_{s_{(1+2k)}} & , & V_{r_{(1+2k)}} \cos\phi_{r_{(1+2k)}} \\
V_{s_{(1+2k)}} \sin\phi_{s_{(1+2k)}} & , & V_{r_{(1+2k)}} \sin\phi_{r_{(1+2k)}}
\end{bmatrix} \quad (6)
$$

Examination of these matrices reveals that the unknown quantities are all in Matrix $\underline{A}$. As given by Olhoeft (1979) this matrix can be determined as follows:

$$
\underline{A} = (\underline{T}^T \, \underline{T})^{-1} \, \underline{T}^T \underline{X} \quad (7)
$$

where T^T means the transpose of $\underline{T}$ and the $^{-1}$ refers to the inverse matrix. From the components of the A matrix the following quantities can be obtained.

$$
\phi_{s_i} = \text{Arc} \quad \tan \left(A_{(1+2i,1)}/A_{(2i,1)}\right) \quad (8)
$$

$$
\phi_{r_i} = \text{Arc} \quad \tan \left(A_{(1+2i,2)}/A_{(2i,2)}\right) \quad (9)
$$

$$
V_{s_i} = A_{(2i,1)}/\cos\phi_{s_i} \quad (10)
$$

$$
V_{r_i} = A_{(2i,2)}/\cos\phi_{s_i} \quad (11)
$$

These components are then utilized to obtain the magnitude of the intrinsic impedance ($|Z_{in}|_i$) and the phase shift (ϕ_i) as follows:

$$|Z_{in}|_i = \frac{V_{s_i}}{V_{r_i}} (R_r) \ (K) \tag{12}$$

$$\phi_i = \phi_{s_i} - \phi_{r_i} \tag{13}$$

The average harmonic distortion is also calculated as a measure of the linearity of the sample's electrical response by:

$$\% \text{ THD} = [\sum_{i=2}^{k}((\frac{V_{s_i}}{V_{s_1}} - \frac{V_{r_i}}{V_{r_1}}) \ 100.)^2]^{1/2} \tag{14}$$

where, % THD is referred to as the total harmonic distortion.

SECTION 4

EXPERIMENTAL DESIGN AND EQUIPMENT

The basic electrical measurement system utilized in this study is shown in Figure 2. The operation of the system is basically the same as the system described by Olhoeft (1979). The set-up has also been employed in the study by Nelson *et al.* (1982). To determine the complex impedance it is necessary to provide a current of the desired frequency in the sample. This is done by connecting a function generator to the current electrodes in the sample holder. The voltage waveform is measured by digitizing the signal at the voltage electrodes and the current waveform is measured by digitizing the voltage drop across a known resistor. The digitized data can then be processed.

SAMPLE HOLDER

An important feature of the system is the sample holder (Figure 3) and its four-electrode arrangement. The unit consists of two plexiglass reservoirs that are connected via a cylindrical plexiglass sample tube. The sample is held in place by plexiglass plates. The cylinder and sample can be removed from the reservoirs without disturbing the sample.

The four-electrode arrangement has been used for low frequency measurements below 1000 Hz (Olhoeft, 1979; Nelson *et al.*, 1982). Platinum mesh electrodes were chosen to minimize electrolytic action and were placed at each end of the sample tube where they measured the voltage drop across the sample. The current electrodes are contained in the end reservoirs. The major

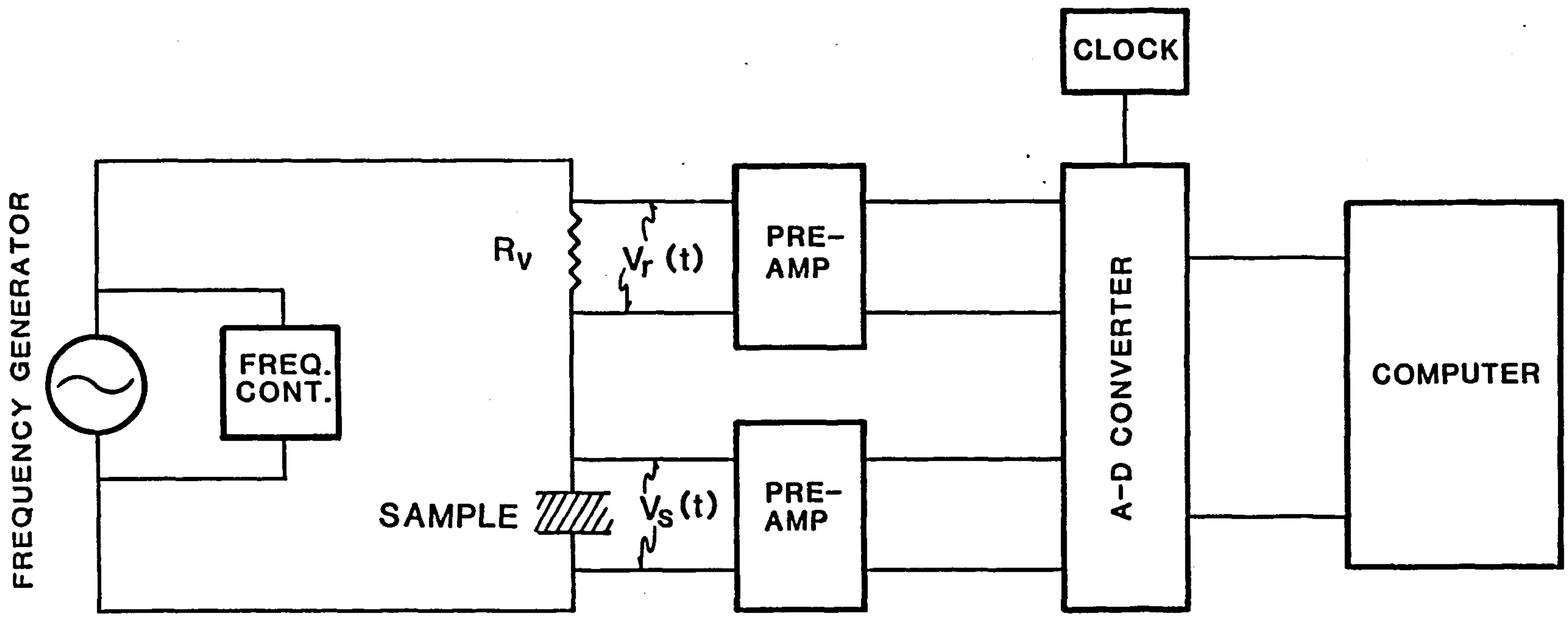

Figure 2. Experimental setup.

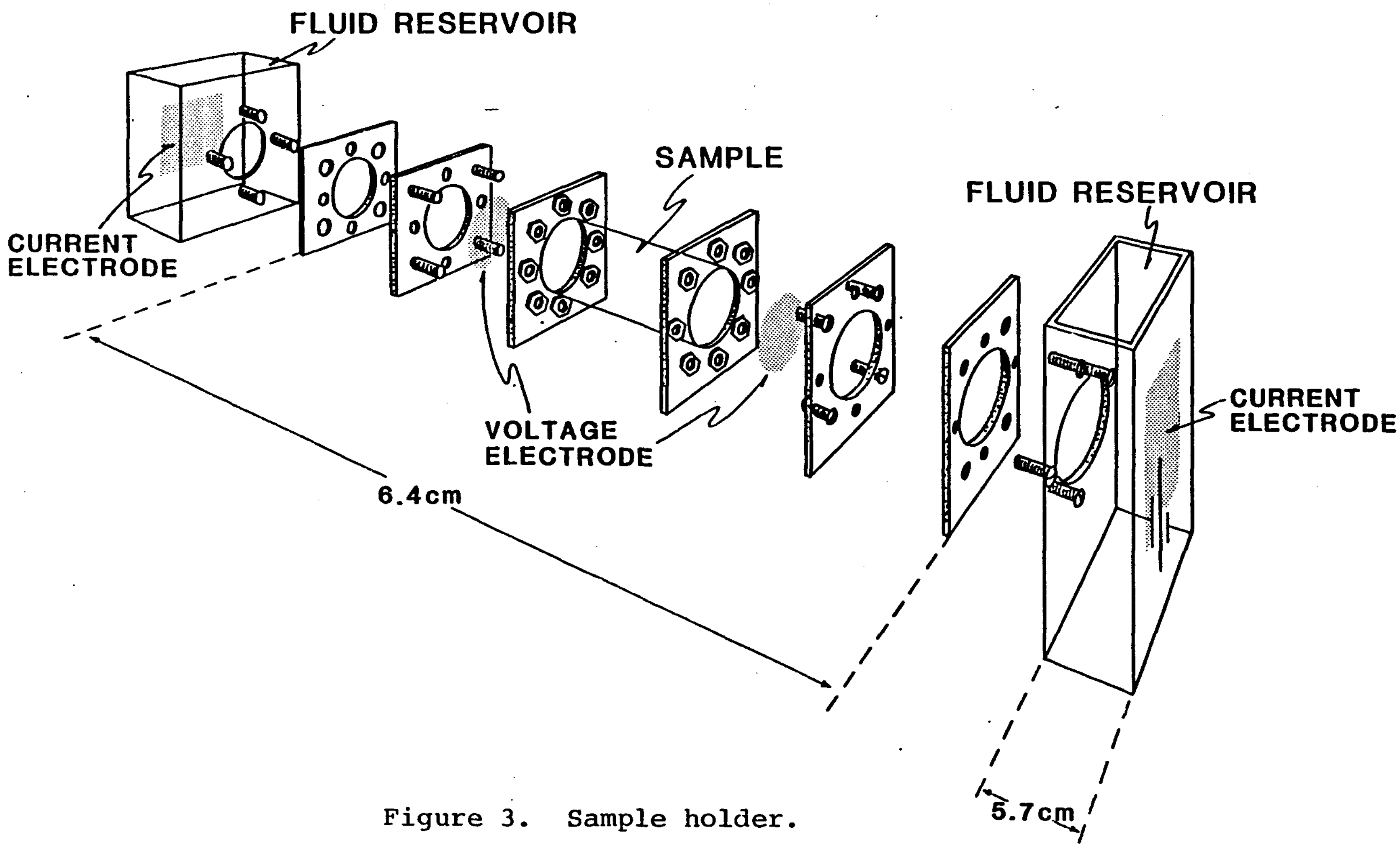

Figure 3. Sample holder.

advantage of this system is that it circumvents the problems associated with electrode polarization and other problems (Fuller and Ward, 1970).

The voltage electrodes located outside of the cylindrical sample tube can polarize if the voltage measuring device draws an appreciable current. However, the preamplifiers draw negligible current and electrode polarization is not a problem with this system. The problem with the four-electrode system is that mutual inductance occurs between the electrode and leads and may become serious above 100 Hz if the sample impedance is greater than 5000 ohm-cm. Although capacitive coupling is expected in samples with high impedance, the inductive coupling inherent in the equipment overshadows the capacitive coupling. Because resulting instrument errors are the net effect of both capacitive and inductive coupling, the instrument error will generally be referred to simply as coupling errors or interference for the remainder of this report. The resistivity of the samples used in this study effectively limits the frequency range of the measurement system to less than 5000 Hz. This is not a serious problem because CR measurements taken in the field presently fall within this range.

ELECTRICAL EQUIPMENT

A function generator was employed as the voltage source and a frequency counter was used to determine the output frequency.

A decade resistor box was constructed from resistors whose values were determined on a commercial bridge. The resistors act as the known resistance in the measuring circuit and the unit contained values from 10 ohm to 1×10^6 ohms.

Because the current density had to be kept low to ensure a linear electrical response, the resulting voltage drops were too small to be accurately detected by the A/D converter. This is especially pronounced for samples with low impedances and at low frequencies. To overcome this problem, a preamp was used.

After the voltage waveforms were amplified, they were digitized and recorded with a resolution of 0.002 volts. The A/D converter (Andromeda Systems Model ADC 11) is interfaced to an LSI 11/03 computer that controls the sampling and recording.

To minimize noise pickup, all leads were coaxial cables with grounded shields and the decade resistance box, function generator and sample holder were surrounded by a Faraday cage.

POROSITY AND CLAY CONTENT DETERMINATION

Porosity measurements were made by weighing the dry sample holder both empty and full of glass beads, the weight difference is the weight of glass, which by knowing the glass density can be converted into the volume of glass. The porosity is found by taking one minus the fraction of the volume of glass to the volume of the sample holder.

Clay content was measured as percent weight of the sample. The clay was powdered and heated at 105°C for 12 hours before weighing to insure that all free water was driven out.

METHOD OF SAMPLE SATURATION

The sample was saturated by filling the fluid reservoirs. Saturation was considered to be complete when the reservoir level remained constant and the pore fluid conductivity, temperature and pH were constant in both reservoirs, which took a few days. This process could have been accelerated had vacuum saturation been available.

SECTION 5

TESTING AND CALIBRATION

A cell constant (K), which is equivalent to L/A (defined in Section 3), was calculated based on electrical measurements of a KCl solution with known electrical properties. This was necessary since the measurement of the sample geometry was not believed to be as accurate as the electrical measurements. The resulting cell constant utilized in the measurements was 0.257 (cm^{-1}) and was frequency independent. It is interesting to note that based on geometric measurements the cell constant was calculated at 0.251 (cm^{-1}). An error of 0.03 cm in the measurement of the radius could account for this difference and it appears that the K determined by electrical measurements is a reasonable value and is probably superior to actual dimension measurements.

In order to determine lead effects, the system was calibrated by replacing the sample with a parallel resistance-capacitance (R-C) network with known values. However, the system agreed quite well with the measured values of the R-C network for resistances less than 1000 ohms. The tests with resistances greater than approximately 1000 ohms had a phase shift and impedance magnitude that deviated from the measured values. The phase shift was positive indicating inductive effects (Olhoeft, 1975). Since it was uncertain if this result was due to the mutual inductance between the leads and wiring necessary for R-C network, it was decided to test the system with NaCl solutions of varying concentrations. This better approximated the system error expected for actual samples since component leads and wires were not present.

The results of these tests are given in Figure 4. In this calibration, the coupling errors were also found above 100 Hz in samples with impedivity above about 3000 ohms-cm. On a log-log plot the slope of these lines were very close to 1.0 which is the expected result of both capacitance and inductance effects (Olhoeft, 1975).

From the standard deviation of the calibration it appears that below 100 Hz the accuracy of the phase shift measurement is within 2 milliradians of the known value. The precision of the impedance magnitude measurements appears to be within 1 percent of the reading below 100 Hz. When the impedivity magnitude is less than approximately 1000 ohms-cm these values apply up to approximately 3500 Hz. Then at 1000 ohms-cm the measurements deteriorate and the precision of the system is basically unknown, except that the precision deteriorates as impedance increases since the coupling errors cannot be removed with the equipment used in this study.

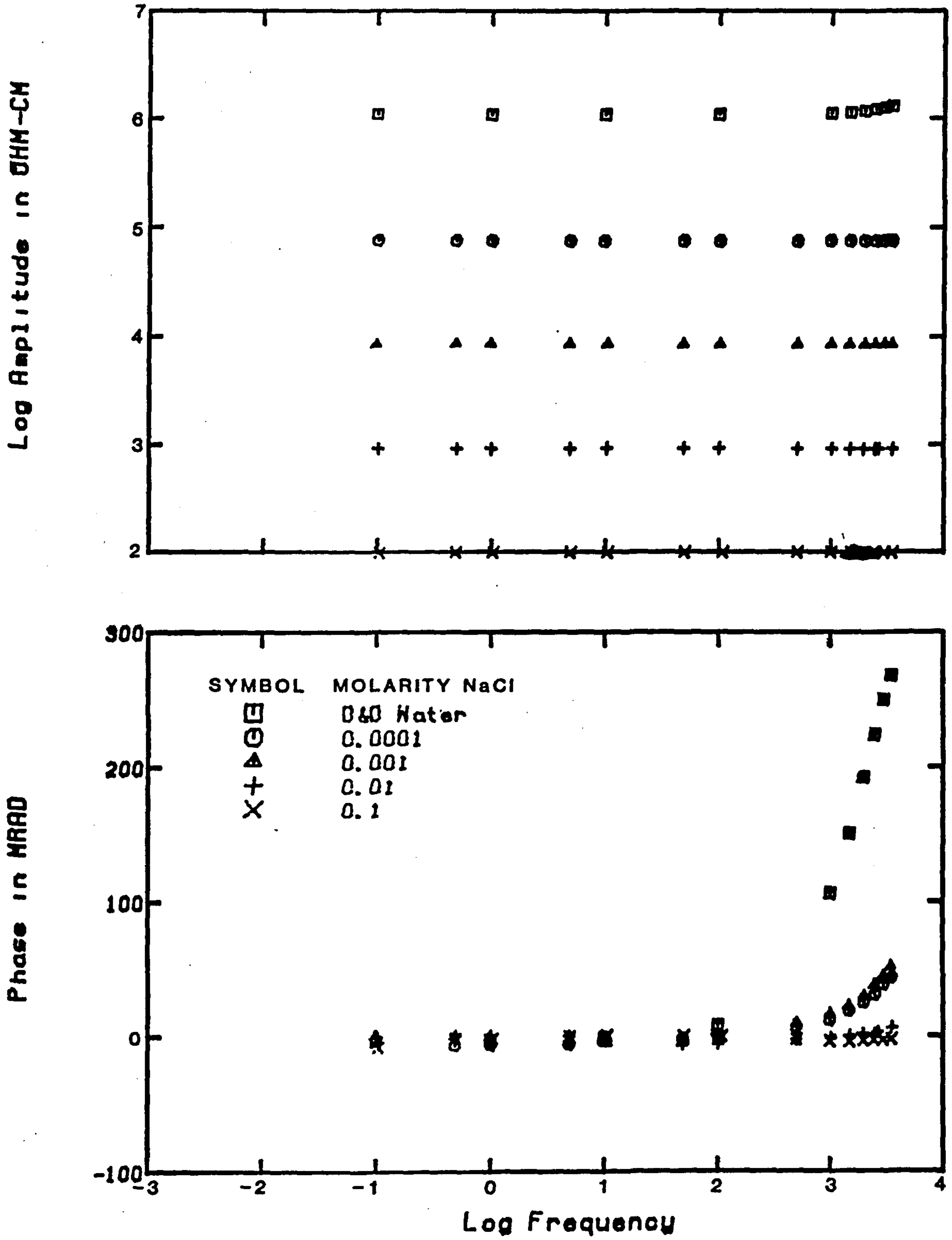

Figure 4. Calibration runs: sample holder filled with salt solution of indicated molarity.

SECTION 6

PROBLEMS ENCOUNTERED AND POSSIBLE SOLUTIONS

Once calibration was completed, the experiments were run. As problems were encountered, it was sometimes possible to make minor modifications in the equipment set up and design. (For example, a Faraday cage was installed around the sample holder to help eliminate electromagnetic inteference.) This section deals with problems encountered which required solutions that were beyond the scope of this project to solve, thus alerting future researchers to the expected problems so that they can be dealt with appropriately.

COUPLING ERRORS

At frequencies above 100 Hz there were problems with inductive coupling between the current and voltage electrodes. This was especially true when the sample impedance was above 5000 ohm-cm because the current densities were low. These effects could be reduced by an improved amplifier design and a source that would allow higher current densities.

A/D CONVERTER

The A/D converter limited the frequency range of the measurements. The maximum sample rate of 25,000 samples/second caused waveforms above 3,500 Hz to be undersampled. This undersampling increased the error and set a practical upper limit on the frequencies measured.

LOW FREQUENCY EFFECTS

The results below 0.1 Hz are of uncertain reliability. The current density was low during these readings, possibly due to the characteristics of the signal generator and/or increased interfacial impedance at the current electrodes. In either case this could have resulted in the voltage drop across the sample being to small to be accurately digitized. Other possible problems are thermal drift and slow chemical reactions. A function generator that provided constant current would help eliminate these problems.

D.C. OFFSET

A D.C. offset voltage was commonly present, probably caused by spontaneous potential, and at times this reached values exceeding 0.5 volts, which when amplified exceeded the voltage level accepted by the A/D converter (±10 volts). Much of this effect was eliminated by soldering the platinum connections with a palladium-platinum alloy; however, after amplification a D.C. offset of ±5 volts was not uncommon. This could be further reduced with a D.C. bucking circuit.

CLAYS

The clay mixtures also presented some problems. When the clay-bearing samples were initially saturated with a high salinity solution, the clays flocculated and tended to remain in place in the sample. When lower salinity solutions were added, the clay began to disperse, and it is estimated that by the time the lowest salinity solution was used, well over half of the clay had been washed from the sample.

The clay washing problem can be solved by using a recirculating reservoir and pump attached to the sample holder. The reservoir would be filled with water at the desired salinity and clay concentrations and would have a mixer to keep the clay in suspension. The pump would circulate the water-clay mixture into the sample holder (already filled with porous material). After the mixture had been recirculated through the reservoir several times, the sample holder and reservoir should have the same concentrations of salinity and clay. The pump would then be stopped and the sample holder would be disconnected from the reservoir apparatus and connected to the electrical measurement system. The procedure would be repeated for multiple clay samples. The sample holder designed for the present study would be suitable for this process because of its modular design, allowing quick connection and disconnection from the electrical and reservoir systems.

CURRENT DENSITY

During the course of the experiment a range of current densities from 0.001-10 $\mu amp/cm^2$ were used. Some problems with data collection at low current densities were noted. The voltage drop across the sample was low, which might have caused the waveform to be poorly sampled. In future studies a constant current source of variable frequency should help eliminate this problem.

DATA RECORDING

The data recording system relies on two computers operating at the same time. The data processing computer was a DEC PDP11/23 with a UNIX-based operating system, which is not capable of collecting real-time data. Therefore, the data was collected with an A/D converter that was run by a DEC PDP11/03. Frequently one of the computers went down, and measurements could not be made. The amount of time it took to prepare, measure and analyze the voltage data was also large. Each run took about one and one-half days to obtain a complete data set. Most of this time (24 hrs) was spent equilibrating the sample with the saturating solution. Future studies should allow the lengthy sample preparation and data collection times necessary for each experiment.

SECTION 7

RESULTS

DATA ANALYSIS PROCEDURES

The first step in the interpretation of the results was to evaluate and identify errors in the data that were the result of experimental procedures and equipment. This was done by examining all the data collected for individual samples and comparing them to the calibration runs. Sample data which displayed experimental and equipment errors or interference were not considered further in the analysis. (The specific data that were ignored and the rationale for doing so are discussed below.) The second step was to compare data from experiments where only one parameter had been changed, thus allowing the effect of that parameter to be investigated. This analysis is presented in the sections dealing with effects on varying parameters.

SUMMARY OF EXPERIMENTS

There were a total of 24 different experiments (or "runs") made, on four different porous medium samples. Table 1 is a summary of these runs. Appendix 1 is a set of graphs of amplitude and phase shift for each run, and Appendix 2 contains the actual data that are shown graphically in Appendix 1. In addition, Appendix 2 contains the standard deviation and total harmonic distortion data for the amplitude and phase shift data. The first three porous medium samples were pure glass beads of different grain sizes. As can be seen from Table 1, sizes of beads within

TABLE 1. SUMMARY OF THE SAMPLES USED

Experiment Run	Glass Bead dia. (mm)	% Na-Mont. by Weight	Molarity of NaCl Sat. Sol.
GB1	2.8-2.0	0	0.0001
GB2	2.8-2.0	0	0.0005
GB3	2.8-2.0	0	0.001
GB4	2.8-2.0	0	0.005
GB5	2.8-2.0	0	0.01
GB6	2.8-2.0	0	0.05
GB7	2.8-2.0	0	0.1
GB8	2.8-2.0	0	0.5
GB9	0.85-0.60	0	0.0005
GB10	0.85-0.60	0	0.001
GB11	0.85-0.60	0	0.005
GB12	0.85-0.60	0	0.01
GB13	0.85-0.60	0	0.005
GB14	0.85-0.60	0	0.1
GB15	0.15-0.106	0	0.0005
GB16	0.15-0.106	0	0.001
GB18	0.15-0.106	0	0.01
GB19	0.15-0.106	0	0.05
GB20	0.15-0.106	0	0.1
CG1	2.8-2.0	3.0	0.1
CG2	2.8-2.0	3.0	0.05
CG3	2.8-2.0	3.0	0.01
CG4	2.8-2.0	3.0	0.005
CG5	2.8-2.0	3.0	0.001
CG6	2.8-2.0	3.0	0.0005

each sample varied slightly, but the variation was limited enough so that each sample could be considered essentially uniform in size. The fourth sample was prepared as a clay-bearing porous medium, containing 3% Na-Montmorillonite by weight, mixed uniformly with large (2.2-2.8 mm) glass beads. The clay was mixed with the glass beads in such a way as to cause the clay to adhere to the surface of the glass beads. Another way to mix the clay is to fill the voids with a clay-water mixture. These two methods may give different results, as it is important to specify which is used. A number of different experiments was run on each sample, varying the salinity concentrations, as shown in Table 1.

EXPERIMENTAL ERRORS AND INTERFERENCE

In Figure 5 all of the runs for the large grain size sample have been plotted together. Similarly, all runs for the medium grain size and the small grain size are plotted in Figures 6 and 7, respectively. All the runs with an impedance greater than 5000 ohm-cm show the effects of coupling errors at frequencies greater than 100 Hz. This can be seen in Figures 5-7 as an exponential increase in phase at higher frequencies and was expected because the calibrations behaved in a similar fashion (see Section 5, Testing and Calibration). The observed phase increases are caused by coupling errors within the equipment and should not be attributed to true sample response.

The runs that have the inductance problem are the very low salinity runs, below 0.001 molarity (about 50 ppm). The coupling interference of this equipment limits the useful range of investigation to pore fluids above 50 ppm total salinity.

The total salinity found in most ground waters is higher than 50 ppm, therefore the equipment is able to measure pore fluids in and above the range found in most natural ground-water systems. The runs with serious coupling interference are therefore not considered further in the analysis.

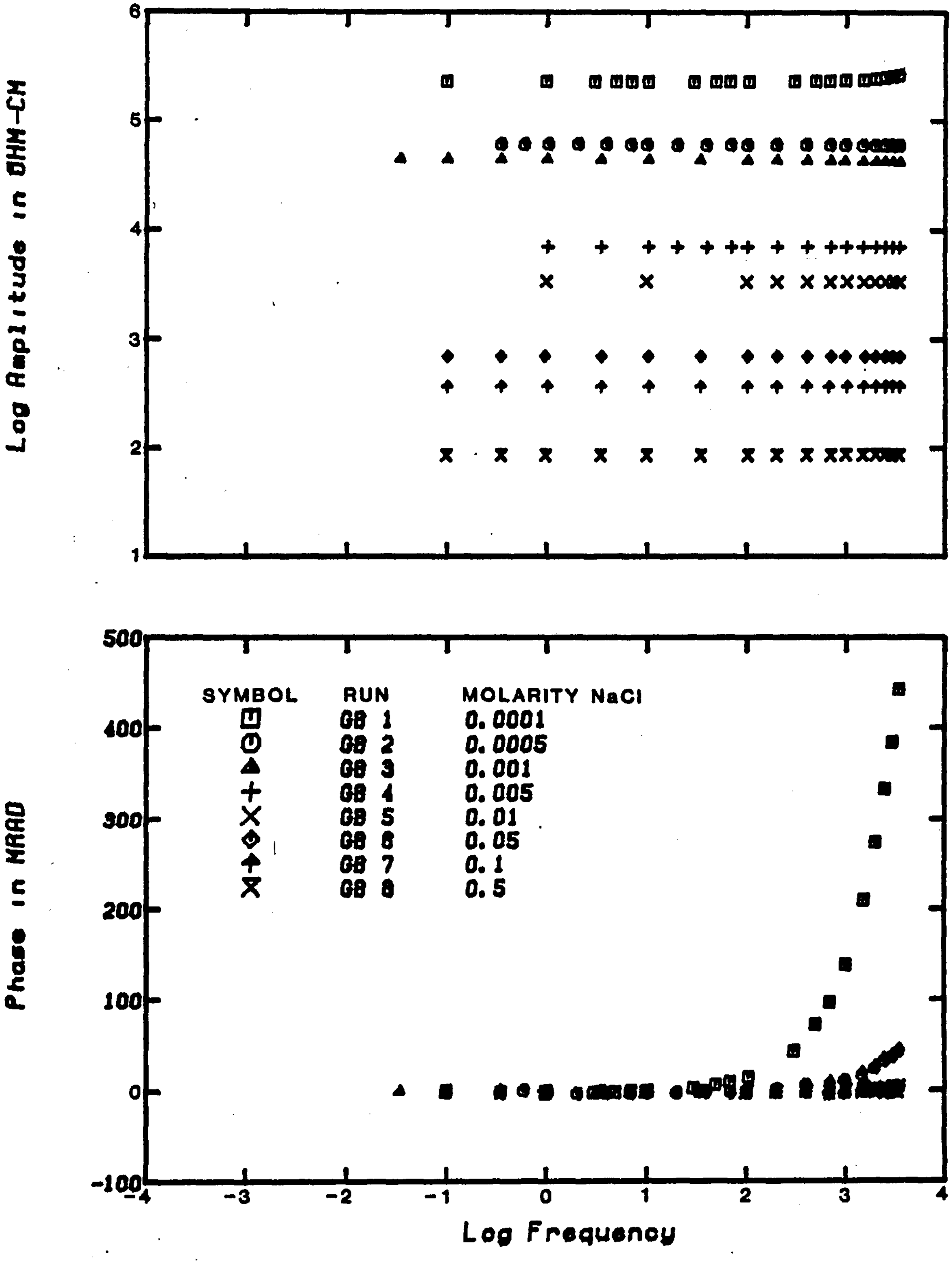

Figure 5. Large glass beads sample, without clay.

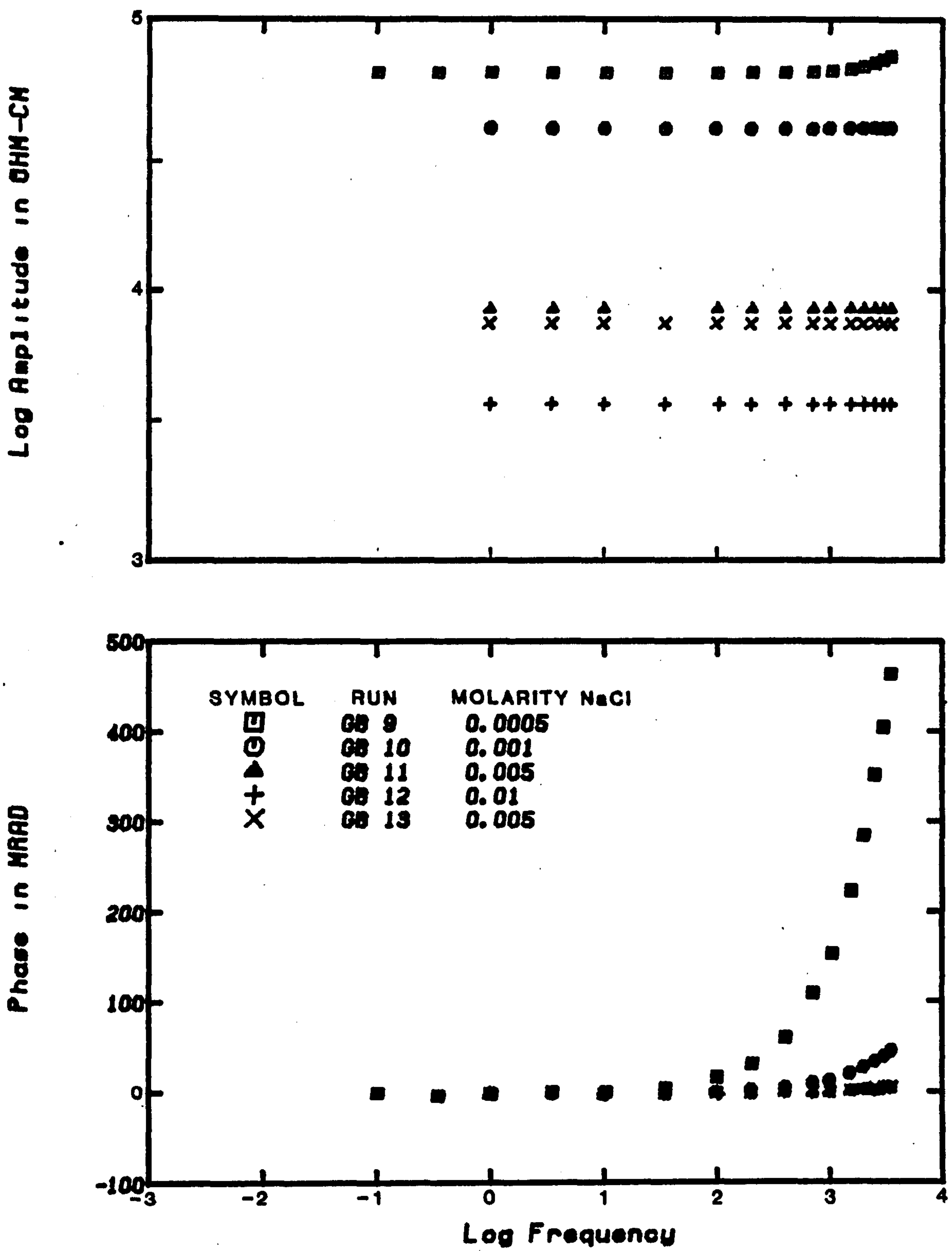

Figure 6. Medium glass beads sample, without clay.

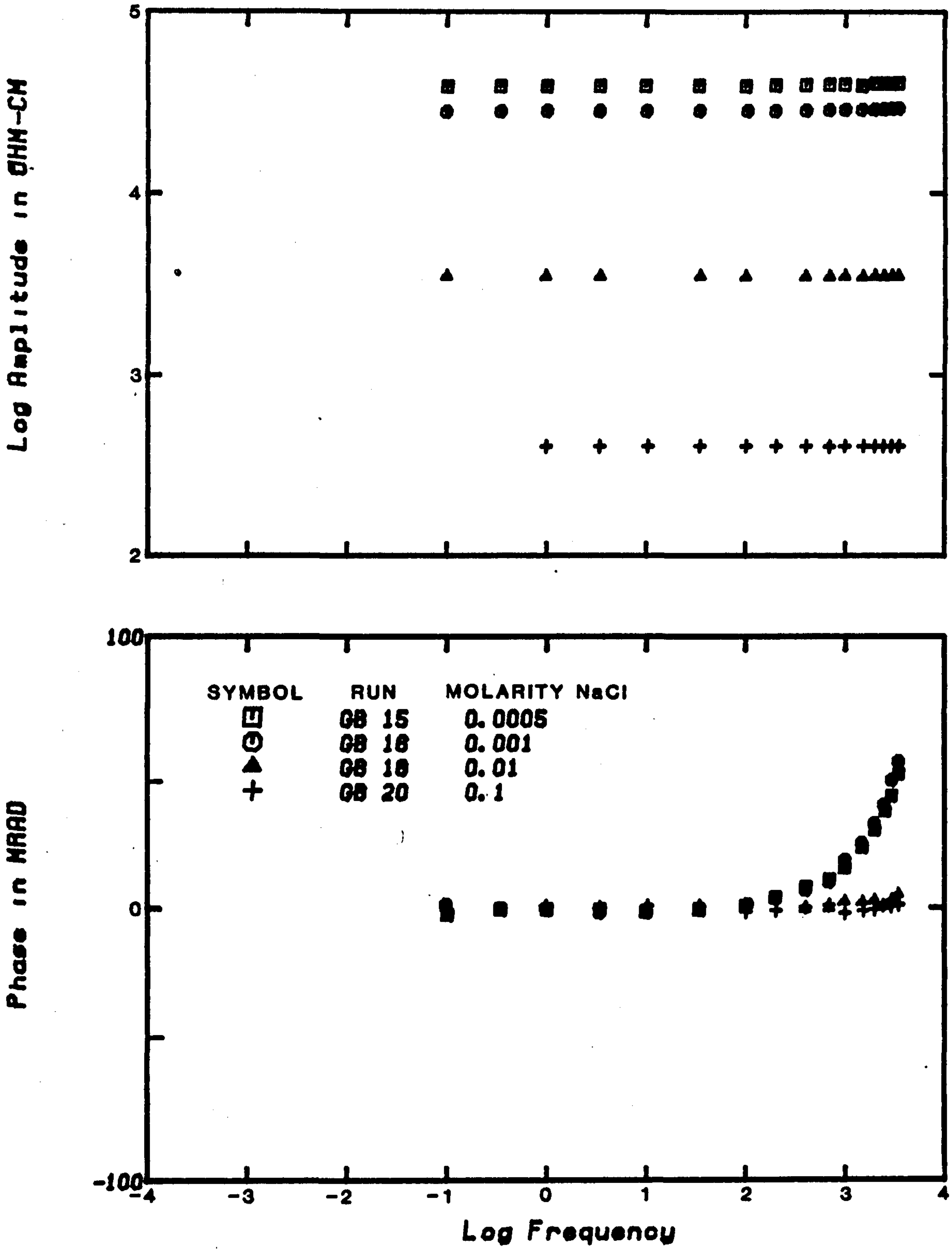

Figure 7. Small glass beads sample, without clay.

For the remaining runs on the non-clay samples, Figures 5-7 show little dependency on frequency for the phase or amplitude. This is expected because there are no polarization mechanisms in the sample and it demonstrates that the experimental setup is working quite well. The experimental results from the fourth (clay) sample in Figure 8 show the data for several runs with different concentrations of NaCl in the pore fluid. Once again the coupling errors can be seen above 100 Hz for low salinity solutions. Below 0.1 Hz there is a wide scatter in the data which can be attributed to low current densities (see appendix 2) at those frequencies, thus the voltages were too small to be adequately digitized by the equipment. In addition, at these low frequencies, the time required to make the measurements increases greatly so that temperature drift and slow electrochemical effects can also contribute to errors. There are methods that will improve the low-frequency data, such as signal stacking. One algorithm was devised to average the signal, but it proved unsatisfactory. In future studies, consideration should be given to some sort of signal processing for the important low frequency data. For these reasons the low frequency data are not considered reliable, and Figure 9 shows the data for the clay sample that are acceptable. These data will be discussed further in the following sections.

COMPARISON OF EXPERIMENTAL RESULTS WITH OTHER RESEARCH

The most obvious effect of the clay is to cause a reduction of the phase at frequencies above 10 Hz. This is expected because of membrane polarization effects and agrees favorably with Olhoeft (1981). The trend and magnitude of the effect agree with Klein and Sill (1982), however they report a positive phase shift which is in disagreement with this work and Olhoeft (1981). It is possible that the discrepancy is due to an opposite definition of the phase. The phase shift also increases with decreasing salinity, which is attributed to an increase in the effectiveness of

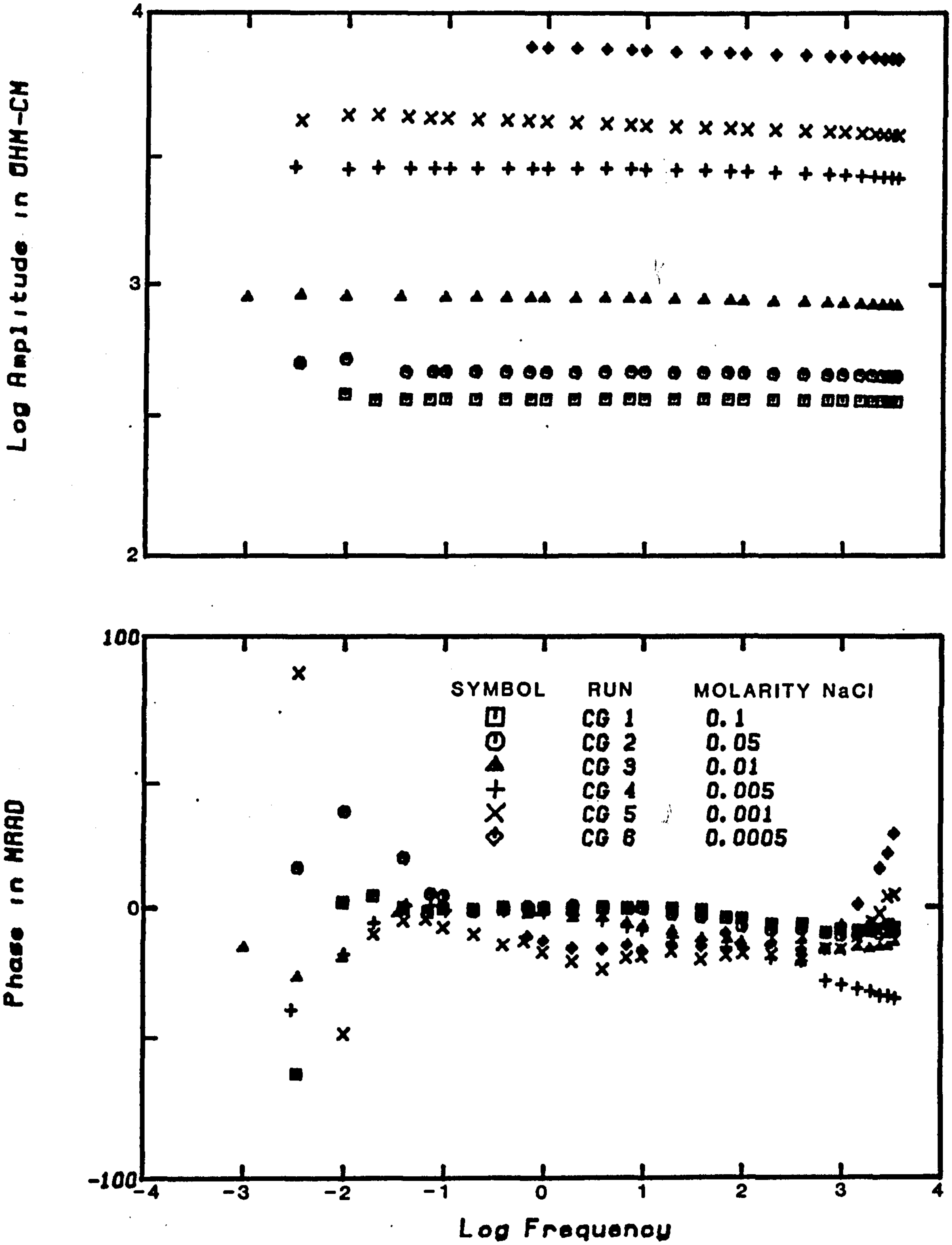

Figure 8. Sample of large glass beads with 3% Na-Montmorillonite.

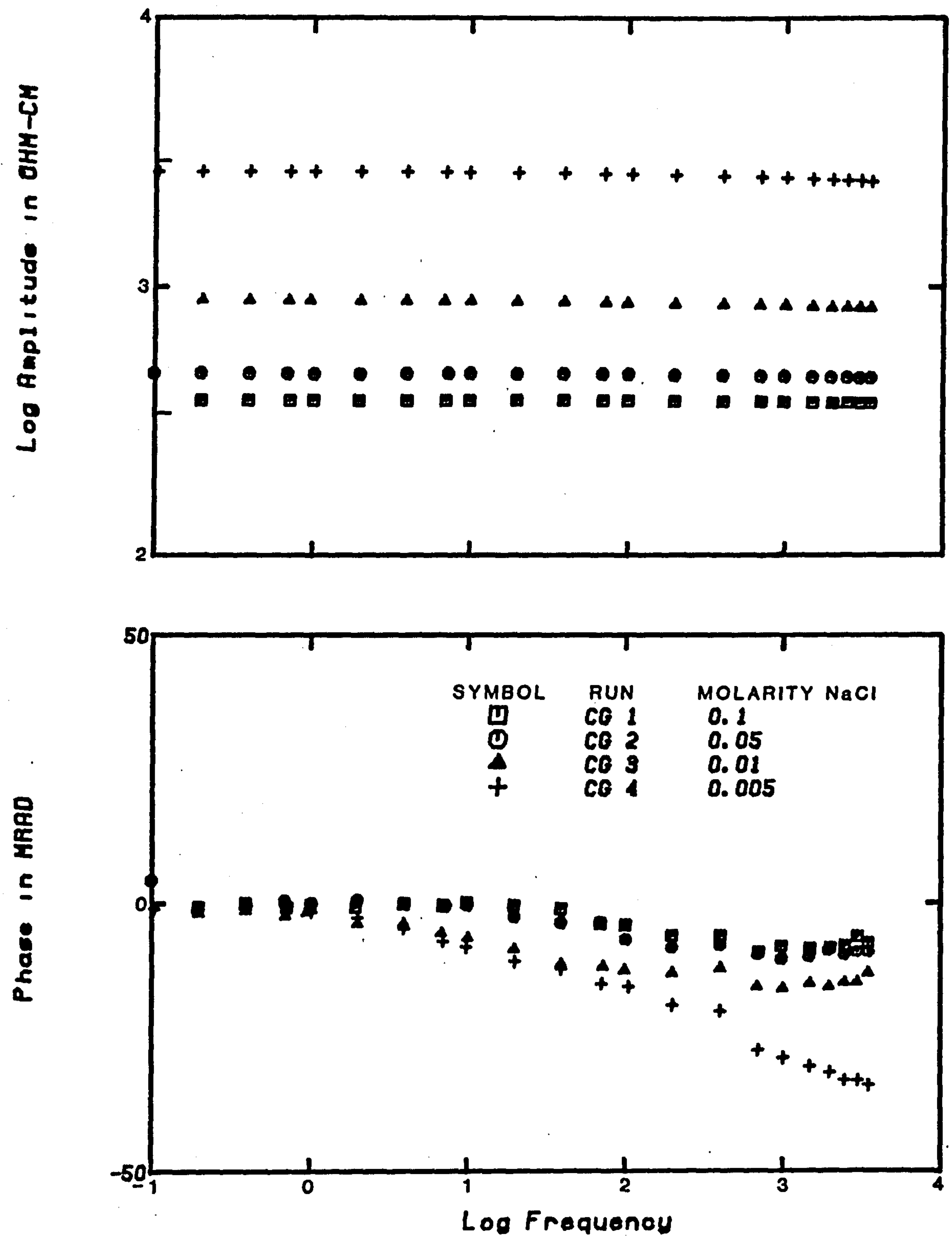

Figure 9. Selected results of sample of large glass beads and 3% Na-Montmorillonite.

clay particles to set up ion selective membranes in low salinity solutions (Ward, 1967). Another observed effect which only occurs in the clay-bearing sample is that the phase peak is shifted to lower frequencies as the salinity is decreased. This can be observed in Figure 9 and corresponds to a similar observation made by Sill and Klein (1981). There is also a small effect of frequency on amplitude. At the higher frequencies the amplitude decreases slightly. Although the small change of only a few percent is difficult to see on the logarithamic plots, it can be verified by examining the actual values in Appendix 2. This trend is in agreement with Klein and Sill (1982) and is caused by capacitive losses at the higher frequencies.

EFFECTS OF GRAIN SIZE ON AMPLITUDE AND PHASE

To investigate the influence of grain size, Figure 10 shows the results of the three clay free samples with a pore fluid concentration of 0.01 molar NaCl. The differences in amplitude are believed to be caused by a difference in the porosity of the samples due to slight differences in the grain sorting. The scale of the phase shift plot is expanded compared to the other phase graphs, thus exaggerating the scatter and the relatively small coupling errors which begin to appear above 1000 Hz. The scatter is within the expected errors of the experiment, so it is concluded that there is no effect of grain size on the phase shift in clay-free samples. This is an expected result, since the phase shift should always be small in a clay-free sample.

EFFECTS OF CLAY ON AMPLITUDE AND PHASE

In a clay bearing sample the phase shift may depend, among other things, on the distance between the ion selective membranes, which is influenced by the grain size (Ward 1967). Figure 11 is a comparison of the response of two samples of the same grain size both with and without clay. The results are shown for runs of 3

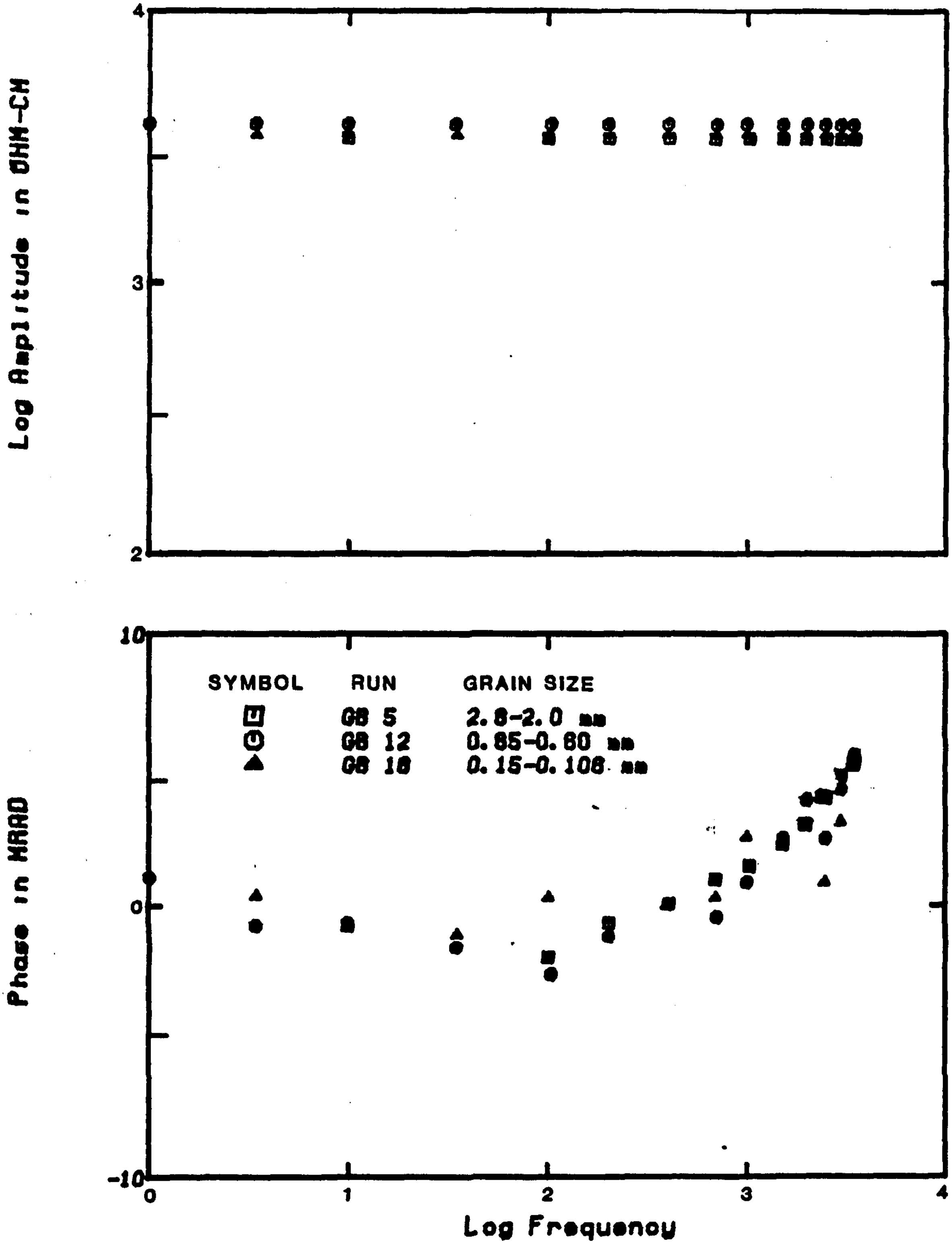

Figure 10. Effect of grain size on phase and amplitude (without clay).

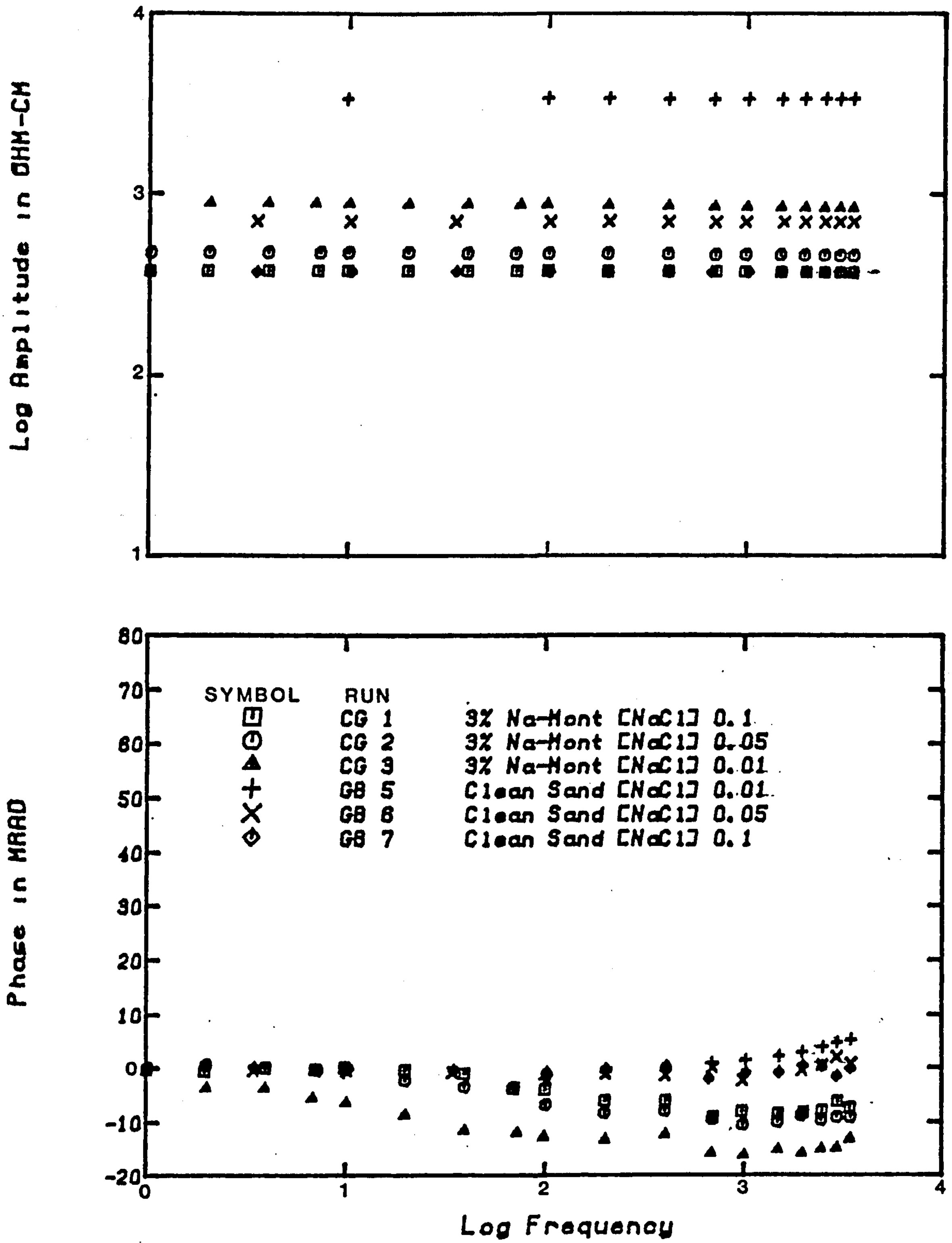

Figure 11. Effect of 3% Na-Montmorillonite on phase and amplitude.

different salinities. The clay-free sample has essentially zero phase shift while the clay sample has negative shifts. This provides encouragement for the use of the CR method to identify clay zones. Traditional resistivity methods which only measure the amplitude at D.C. cannot differentiate between a saline sand and a formation containing clay. The results here indicate that under favorable circumstances, the CR method may be able to make such a distinction. Because the method is sensitive to low clay content, which can have significant effects on the hydraulic conductivity of a formation, it is anticipated that CR may be of significant importance for hazardous waste site evaluation and other groundwater studies.

Figure 12 indicates the effect of clay content on amplitude as a function of salinity for samples of the same pore size. Because the effect of frequency on amplitude is small at low frequencies, a frequency of 10 Hz was chosen for this analysis. The clean sample plots as a straight line on the log-log plot, in agreement with Archie's Law. The clay-bearing sample also plots as a straight line, but with a smaller slope. Run CG4 falls above the straight line, however it is believed that about one-half of the clay was lost from the sample between run CG3 and CG4, thus causing the shift (see Section 6-clays). The smaller slope associated with CG4 implies that a new form of Archie's Law may be developed for porous media containing clay with pore fluid of low salinity. This form of Archie's Law may have the form:

$$\rho_B = a\phi^{-m}\left(\rho_f\right)^n \qquad (15)$$

where:

a = empirical constant

ϕ = porosity

m = cementation factor

ρ_B = bulk (formation) resistivity

ρ_f = fluid resistivity

n = constant which depends on the formation clay content

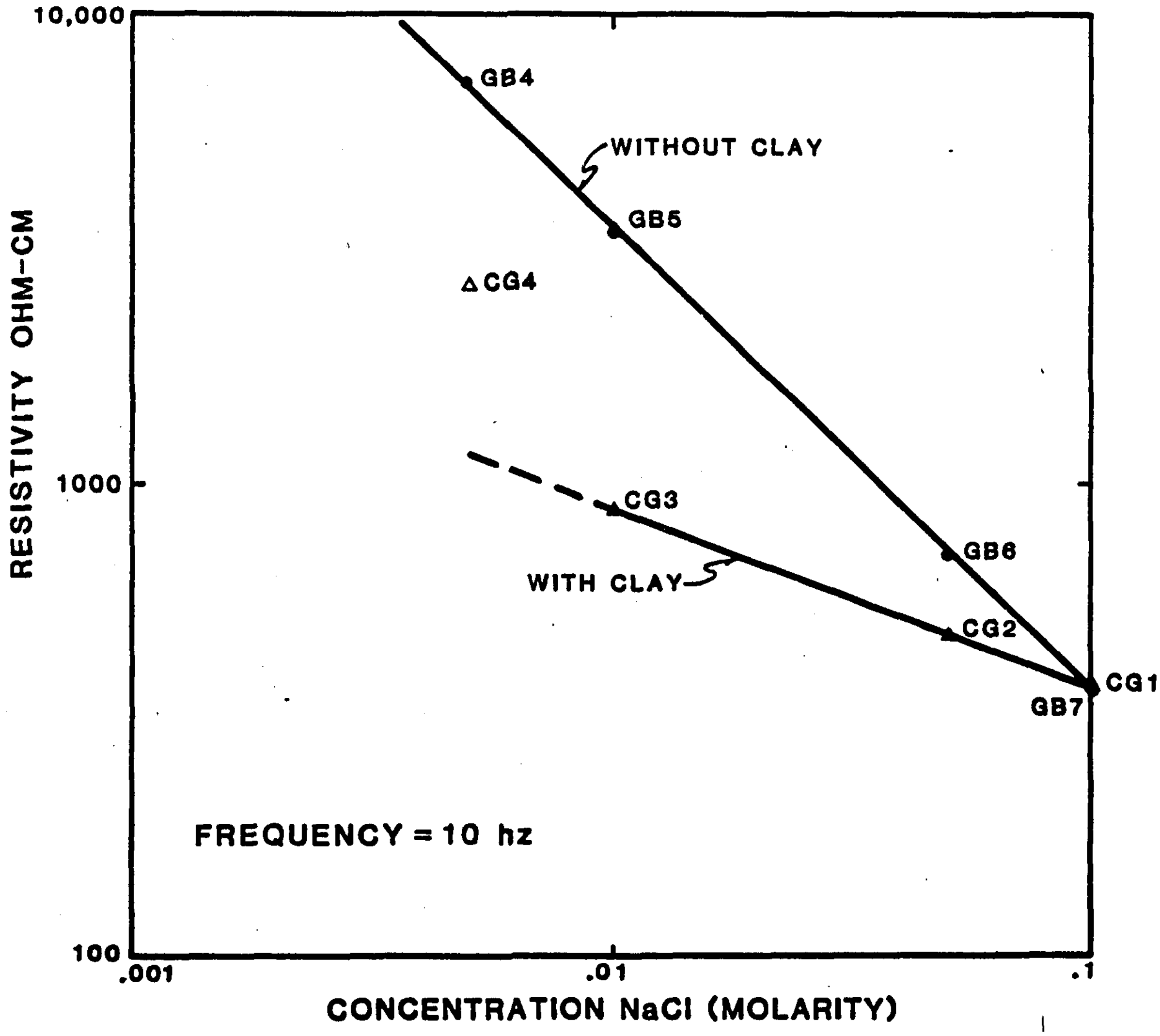

Figure 12. Effect of clay content on the impedance vs. salinity relationship.

The data from these results suggest that the fluid resistivity has an exponent greater than one for clay-bearing samples. However, because there were only three valid data points, an attempt was not made to calculate a value for n. Archie's Law is semi-empirical in nature whereas Waxman-Smits (1968) proposed a model that is physically-based. Future experiments to compare models would be simplified relative to this study because the results of this study show little to no dependence of impedance amplitude over the range of frequency normally used in the field. Thus future experiments could be conducted at one frequency.

Another significant result is that the samples have nearly identical response for pore fluids of 0.1 molarity NaCl. Unfortunately, there are no data beyond where the curves meet, so it is not possible to say what will happen at higher NaCl concentrations. It is generally assumed that clay-containing formations will have a lower resistivity than clean formations due to the additional surface conductance on the clay. Salinity may influence this effect because volume conduction through pores dominates surface conduction at high salinities.

SECTION 8

CONCLUSIONS

CONCLUSIONS

Analysis of the data collected in these experiments leads to three primary conclusions:

1. The impedance amplitude and phase data as a function of frequency agree quite well qualitatively with similar experiments by Olhoeft (1981). The agreement between this study and some experimental data by Klein and Sill (1982) is somewhat ambiguous because they report positive phase shifts in the presence of clay. This may be due to a difference in definition, rather than a real difference.
2. Amplitude/phase data are not affected by variation in grain size for clay-free samples. This result implies that hydraulic conductivity cannot be determined by amplitude/phase data because hydraulic conductivity is a function of porosity and grain size.
3. Clay-free samples have zero phase shift over the range of frequency measurement, whereas the clay-bearing sample showed increasingly negative phase shifts from about 10 Hz through 3500 Hz. The amount of clay in the sample was only 3%, which is an indication that CR measurements may be quite sensitive to clay content and therefore useful for detecting changes in hydraulic conductivity that are due to the presence of clay. Downhole CR data would be more useful than surface CR for clay-content determination for two reasons: a) the vertical changes in hydraulic conductivity are very useful in deter-

mining contaminant migration in groundwater, and b) surface measurements cannot provide the detailed resolution necessary to delineate important changes in hydraulic conductivity over a small vertical distance.

Results of this study show that the presence of clay has a significant effect on frequency dependent electrical properties of a saturated porous medium. Most well log interpretation strategies that have been used in hydrologic investigations ignore or avoid this problem, thus making the interpretations subject to significant error. The electrical effects of clay on a saturated porous medium need to be understood so that clay content and variation can be determined. Amplitude/phase data taken over a range of frequencies show promise for being able to make these determinations. Further quantitative laboratory work needs to be done to more fully understand the relationships between amplitude/phase information and clay content.

Clay content information can be derived from nuclear logging techniques. However, to apply this information in interpreting the electrical response requires an indirect relationship involving the cation exchange capacity of the clay. A model accounting for the effect of clay on amplitude that is based on phase information may be more direct. An additional advantage of CR over techniques using active sources is the elimination of the logistical problems associated with the radioactive source. The potential advantages to downhole CR over other methods may lend further weight to the recommendation to develop a better understanding of the relationship between amplitude/phase information and clay content.

The insensitivity of amplitude and phase to grain size variation provides a strong indication that hydraulic conductivity variations resulting purely from grain size variations will be detectable with downhole CR methods. It should be noted that this is true only for non-reactive surfaces. Information on grain size variation is very important for the determination of hydraulic conductivity variations, and it is recommended that other downhole methods be examined to determine their potential in this area.

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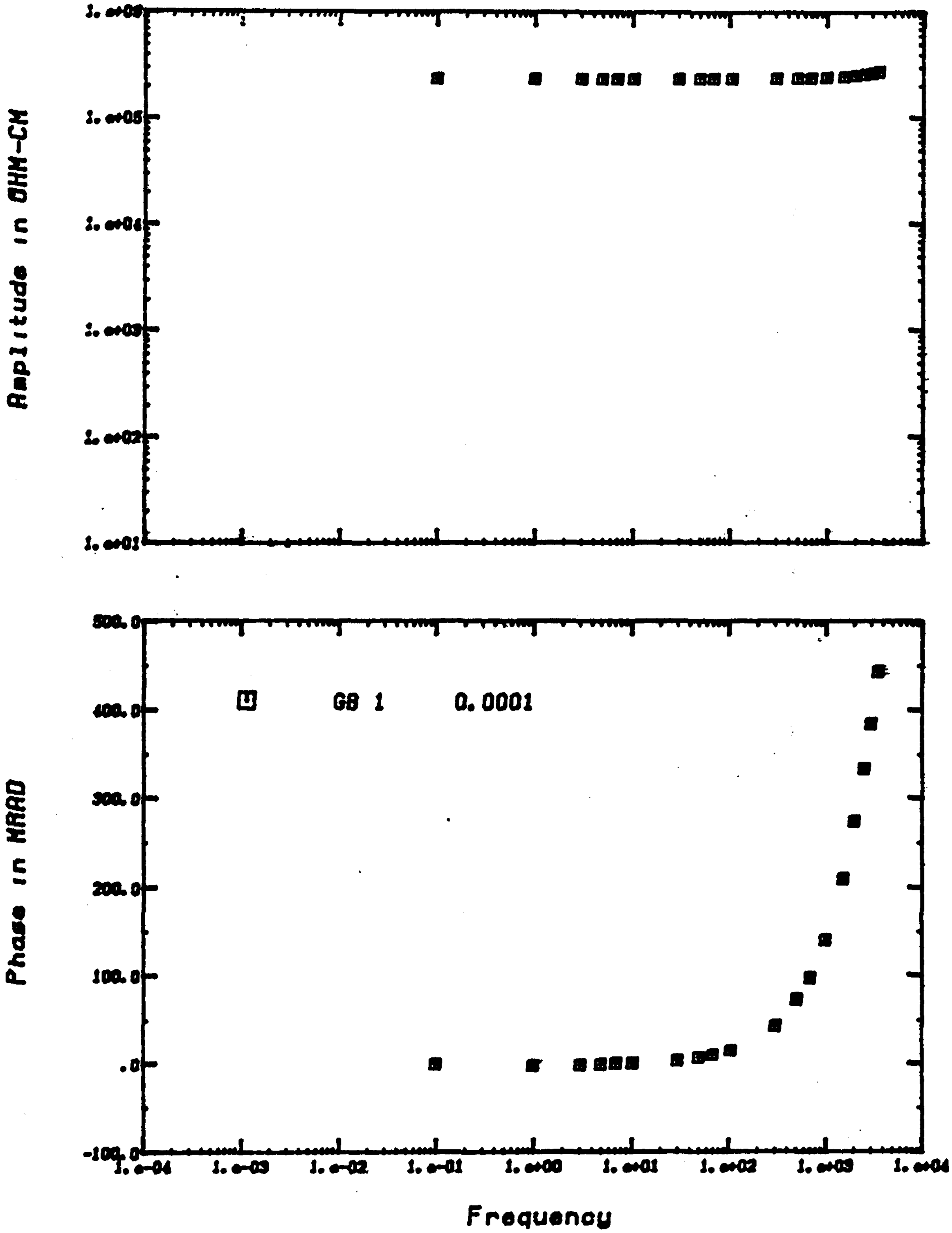
APPENDIX 1

GRAPHS OF EACH RUN



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1.e+04
1.e+03
1.e+02
1.e+01
Phase in MRAD
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400.0
300.0
200.0
100.0
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-100.0
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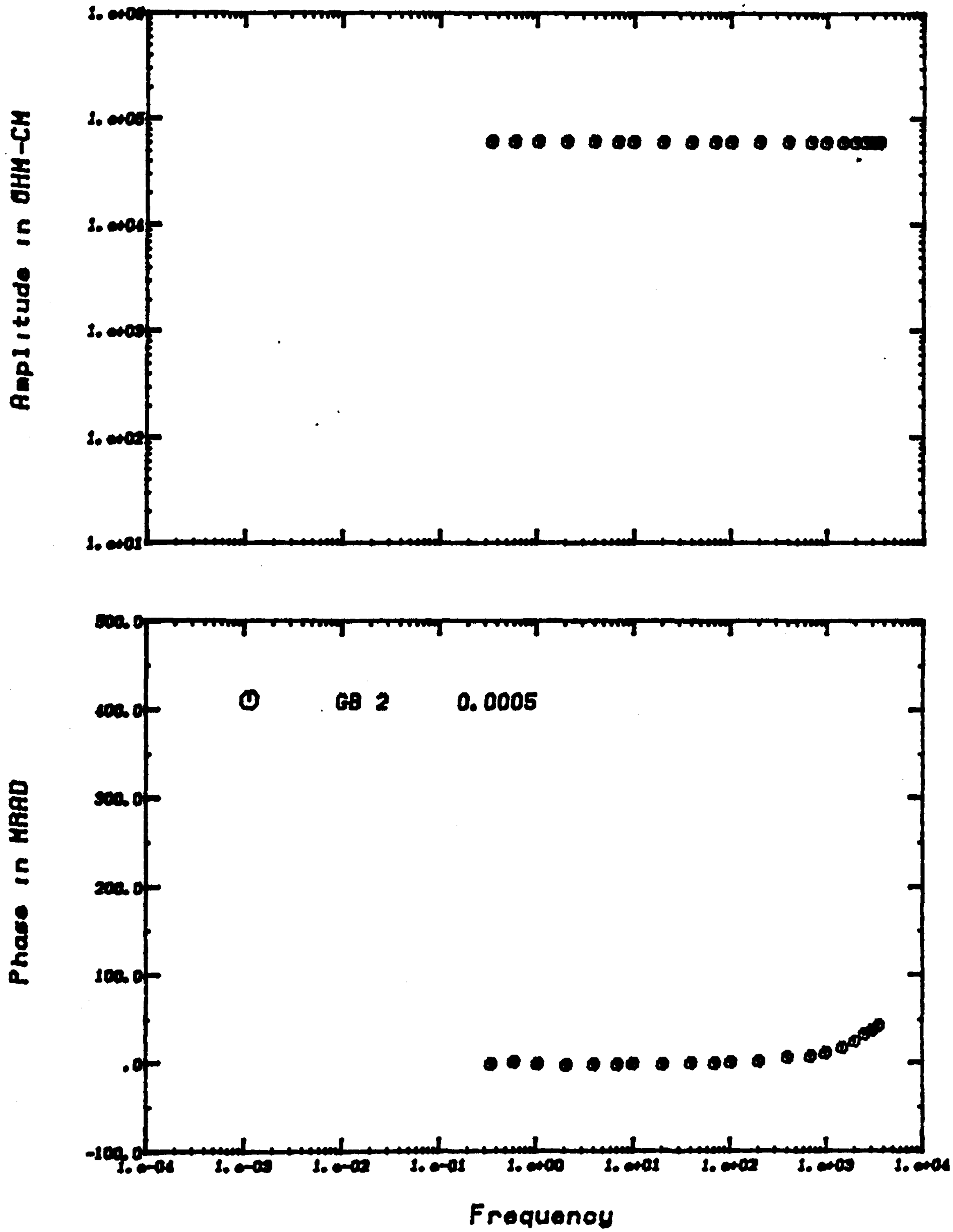
Frequency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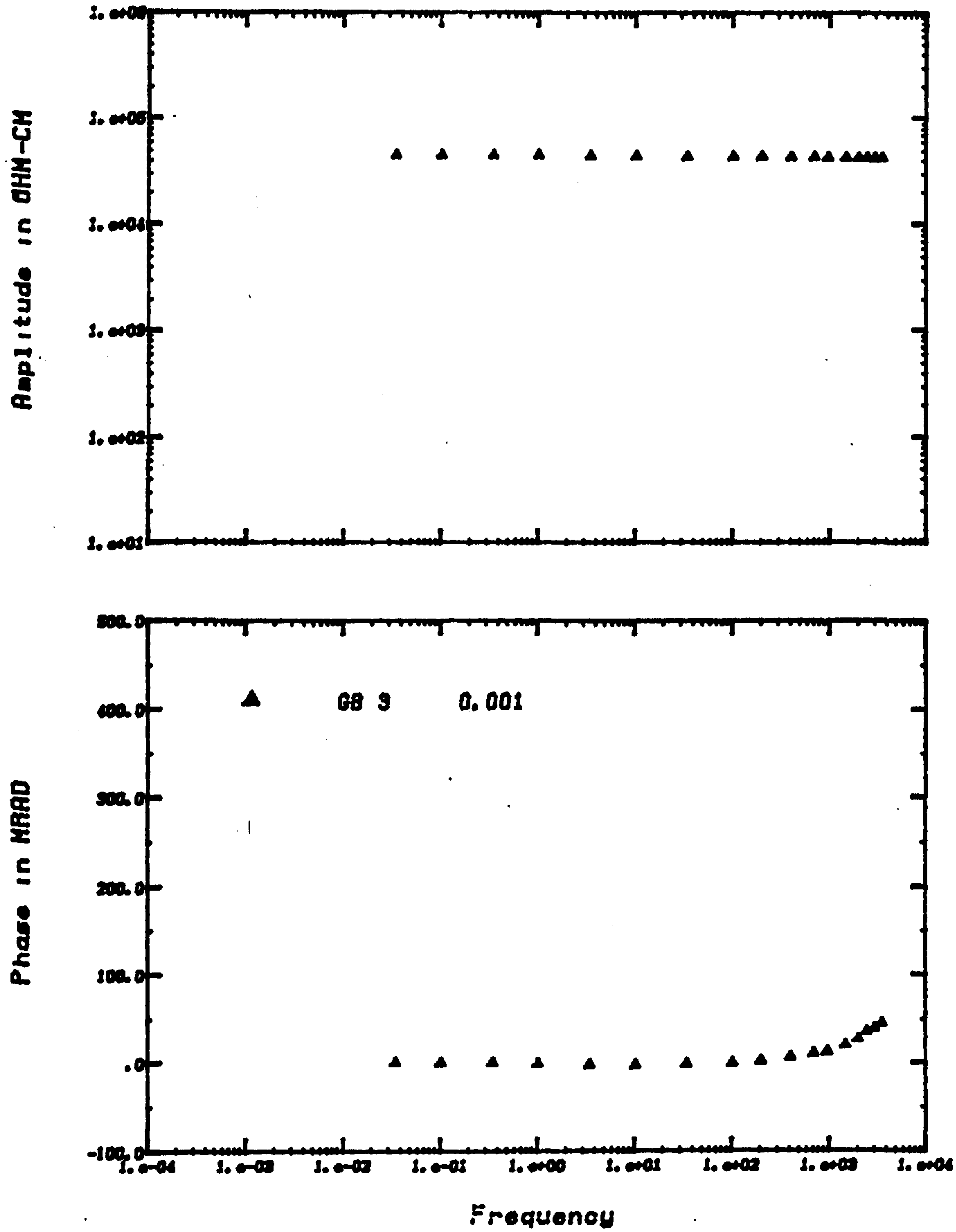
Frequency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1.e+02
1.e+01
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400.0
300.0
200.0
100.0
.0
-100.0
GB 3
0.001
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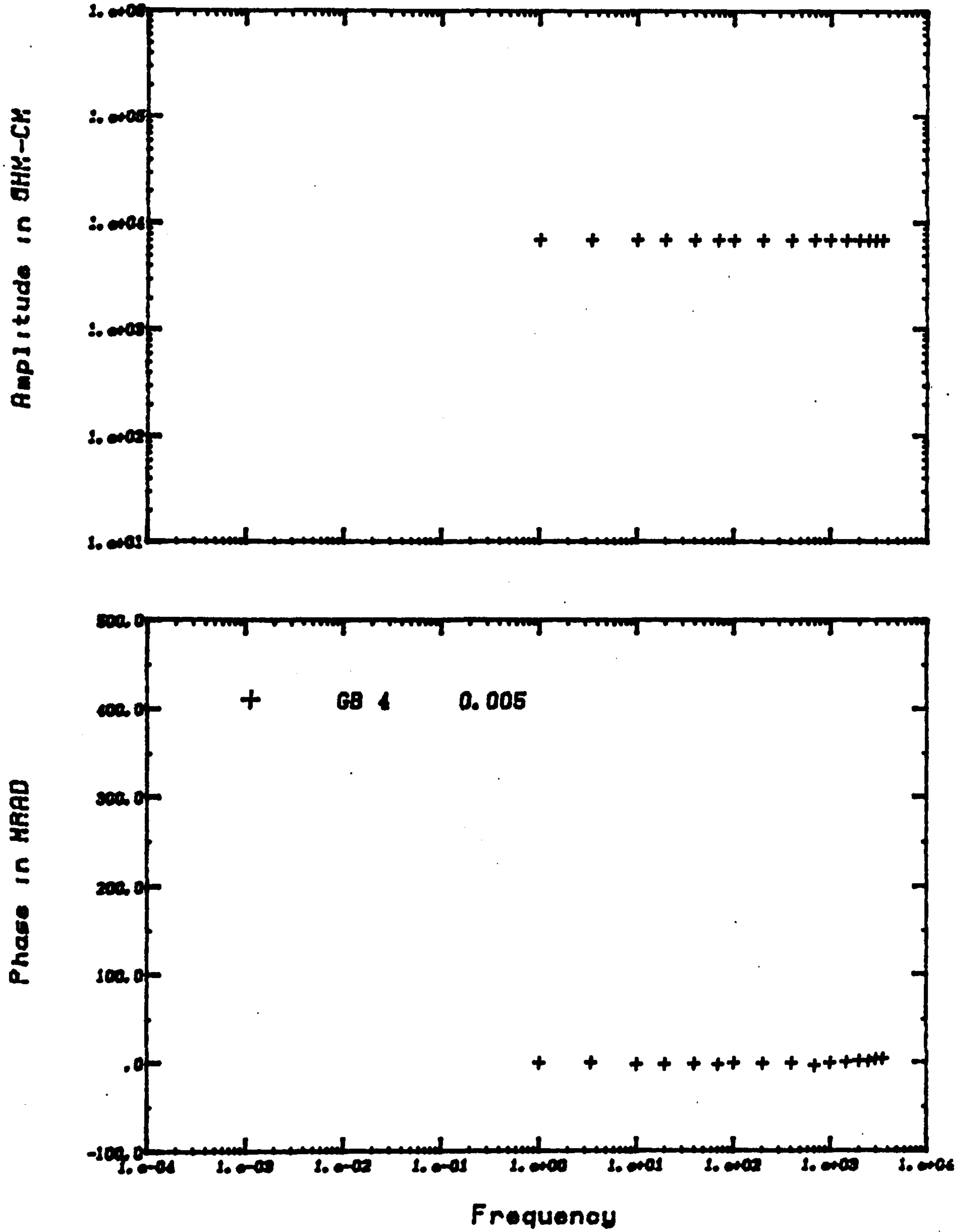
1.e+03
1.e+04
Frequency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200.0
100.0
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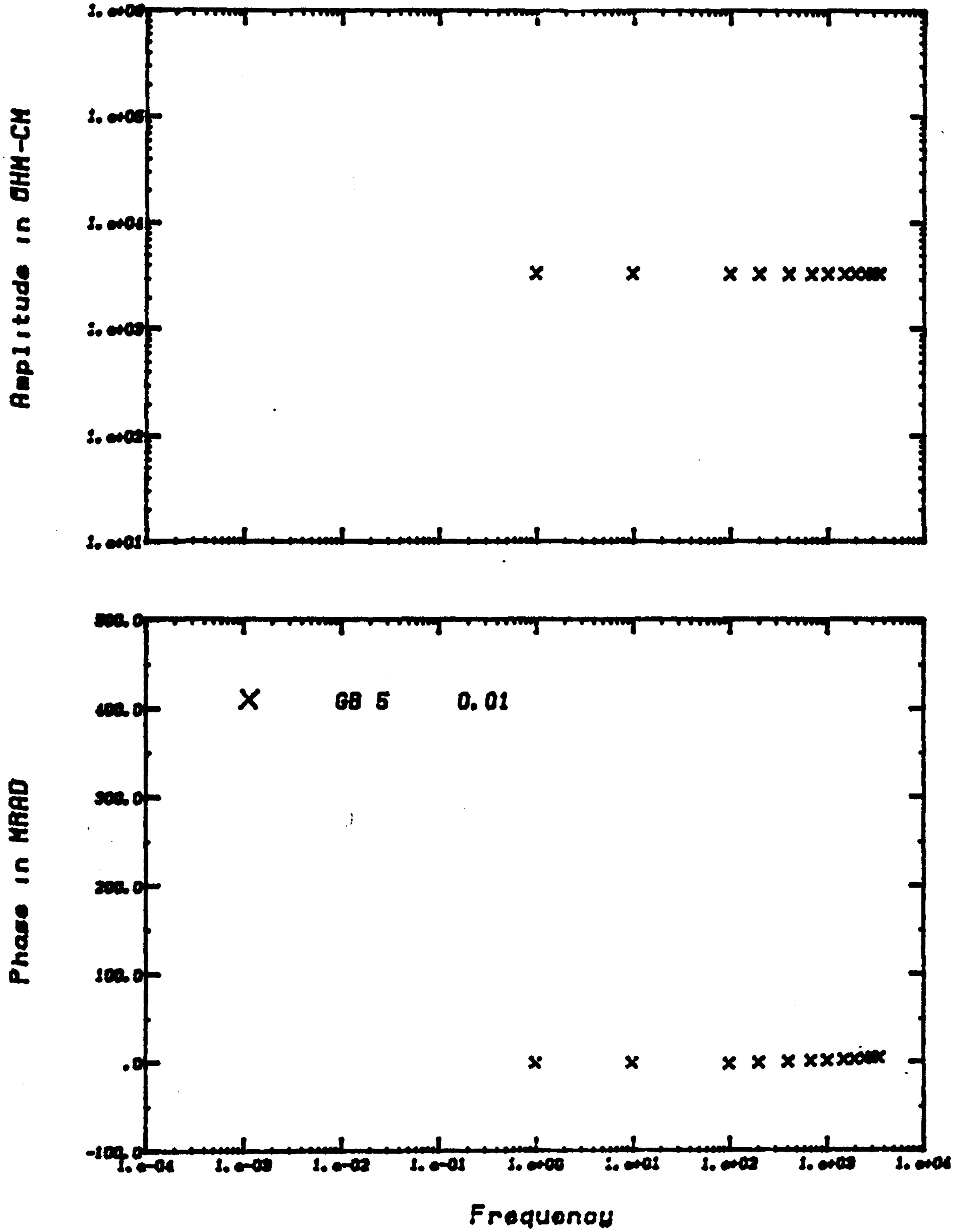
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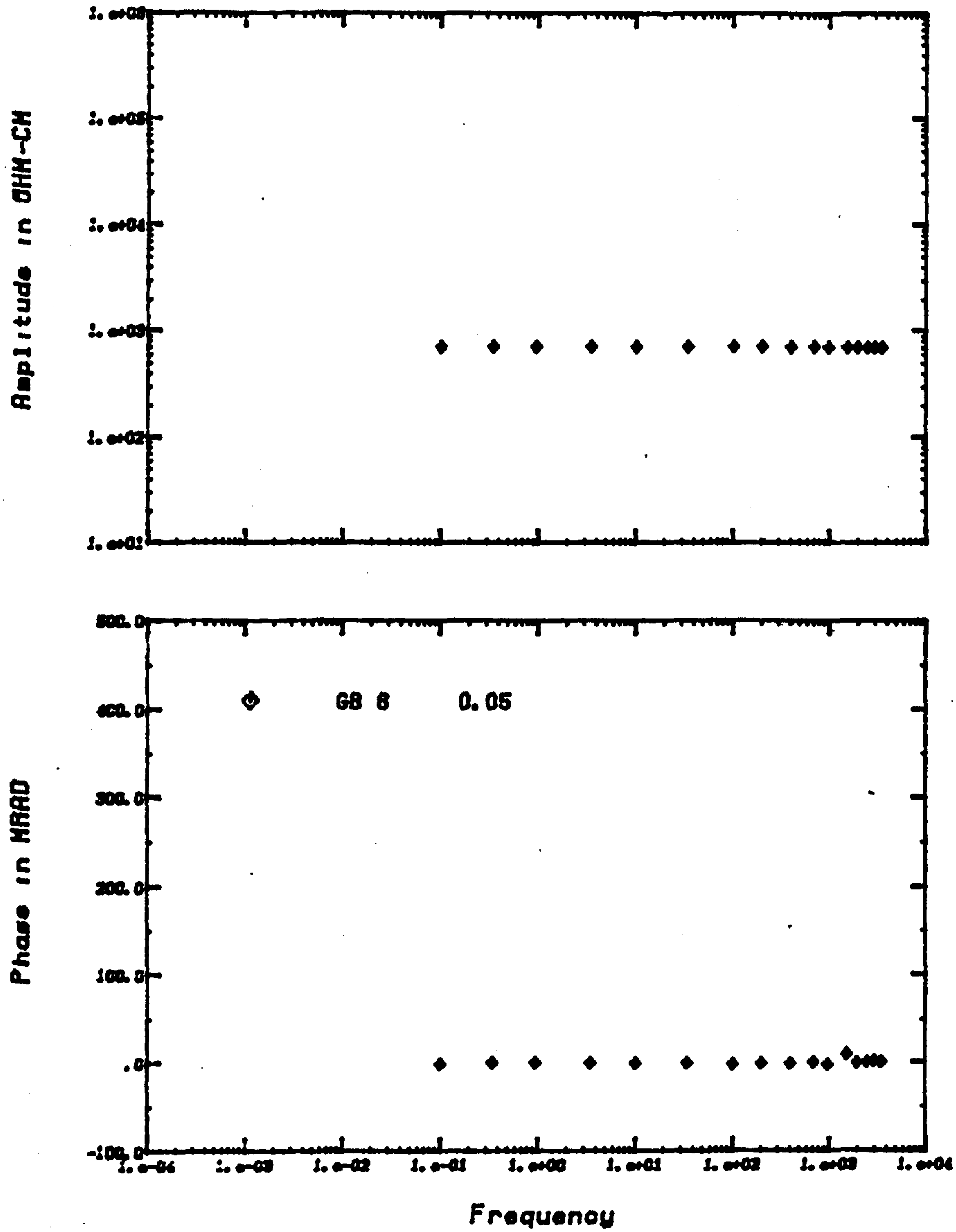
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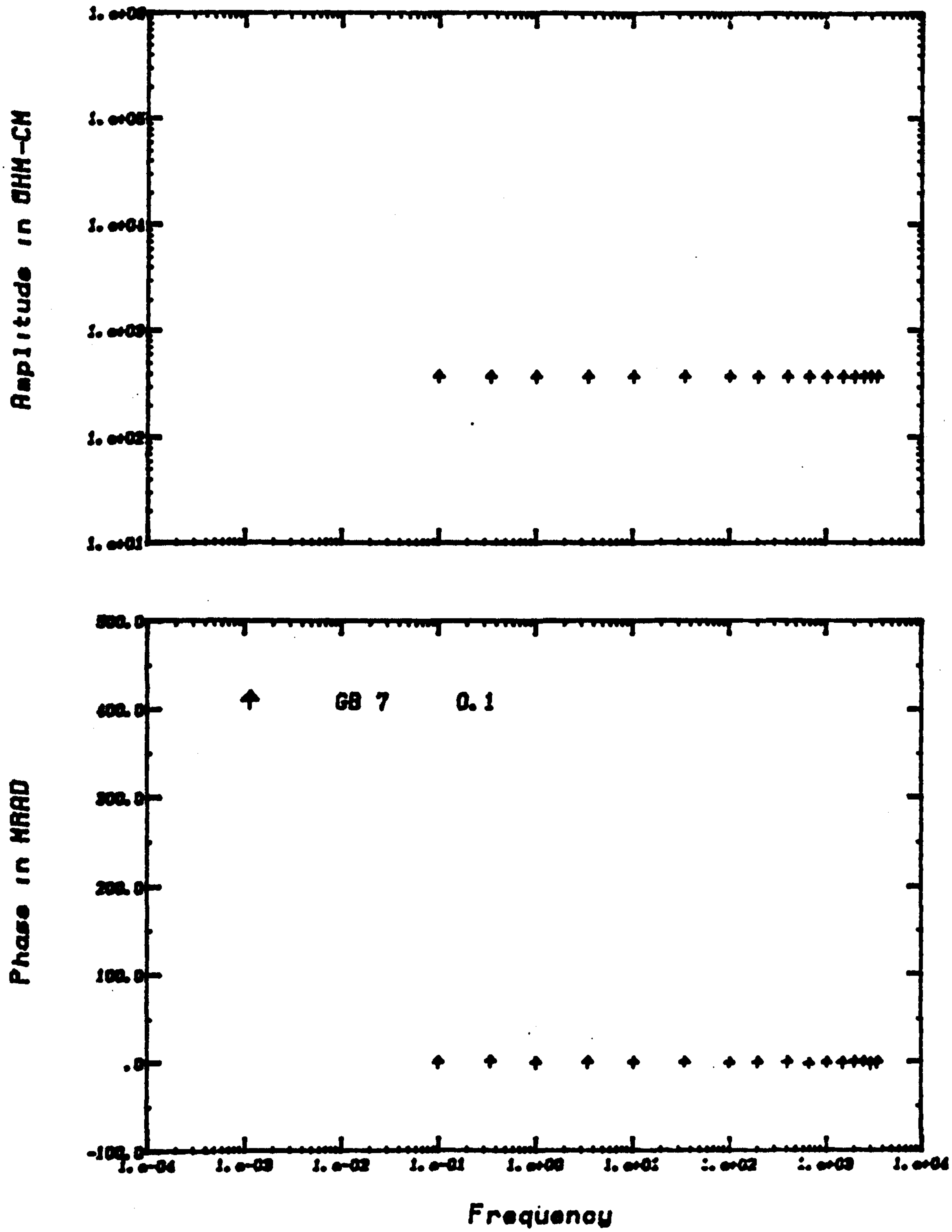

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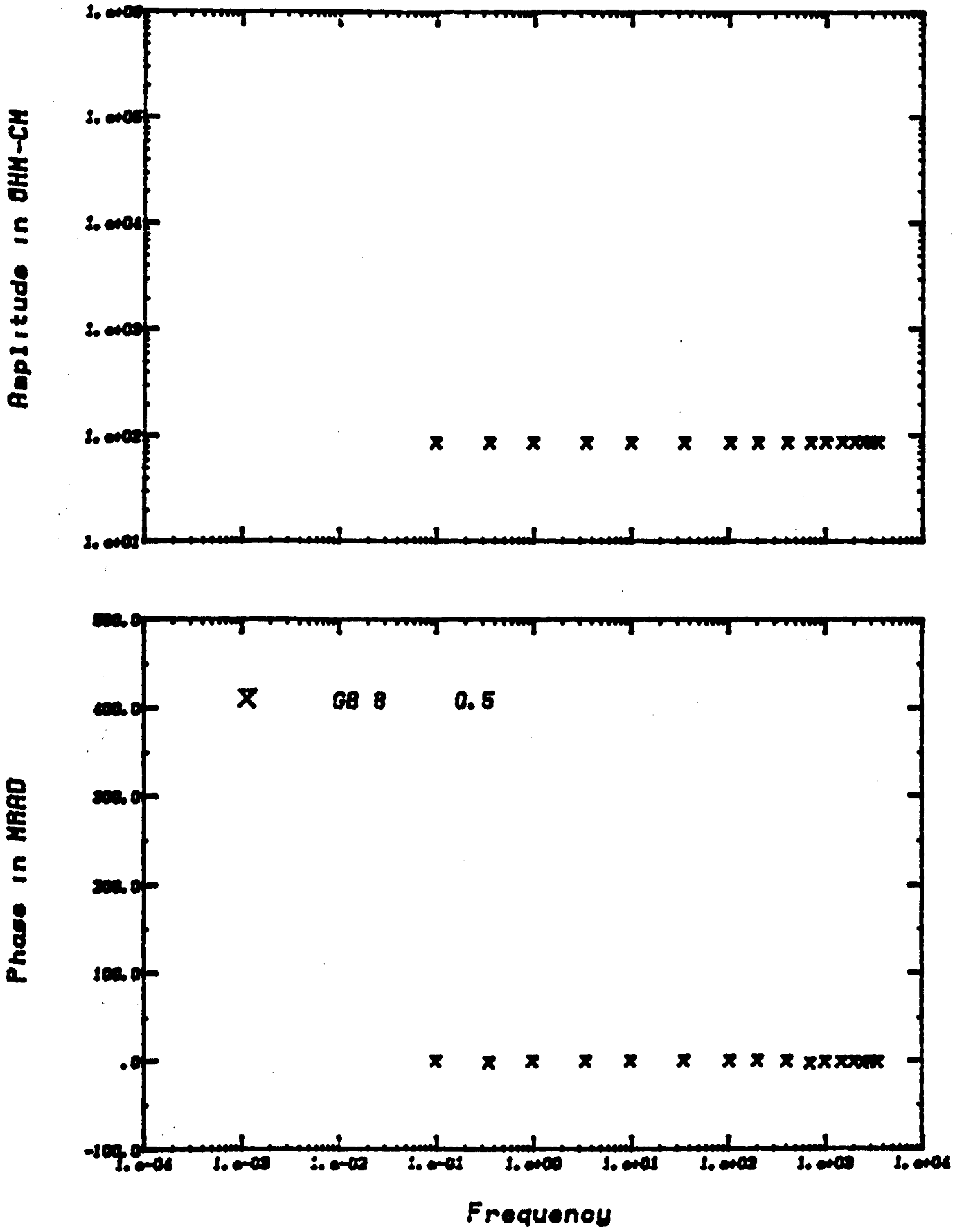
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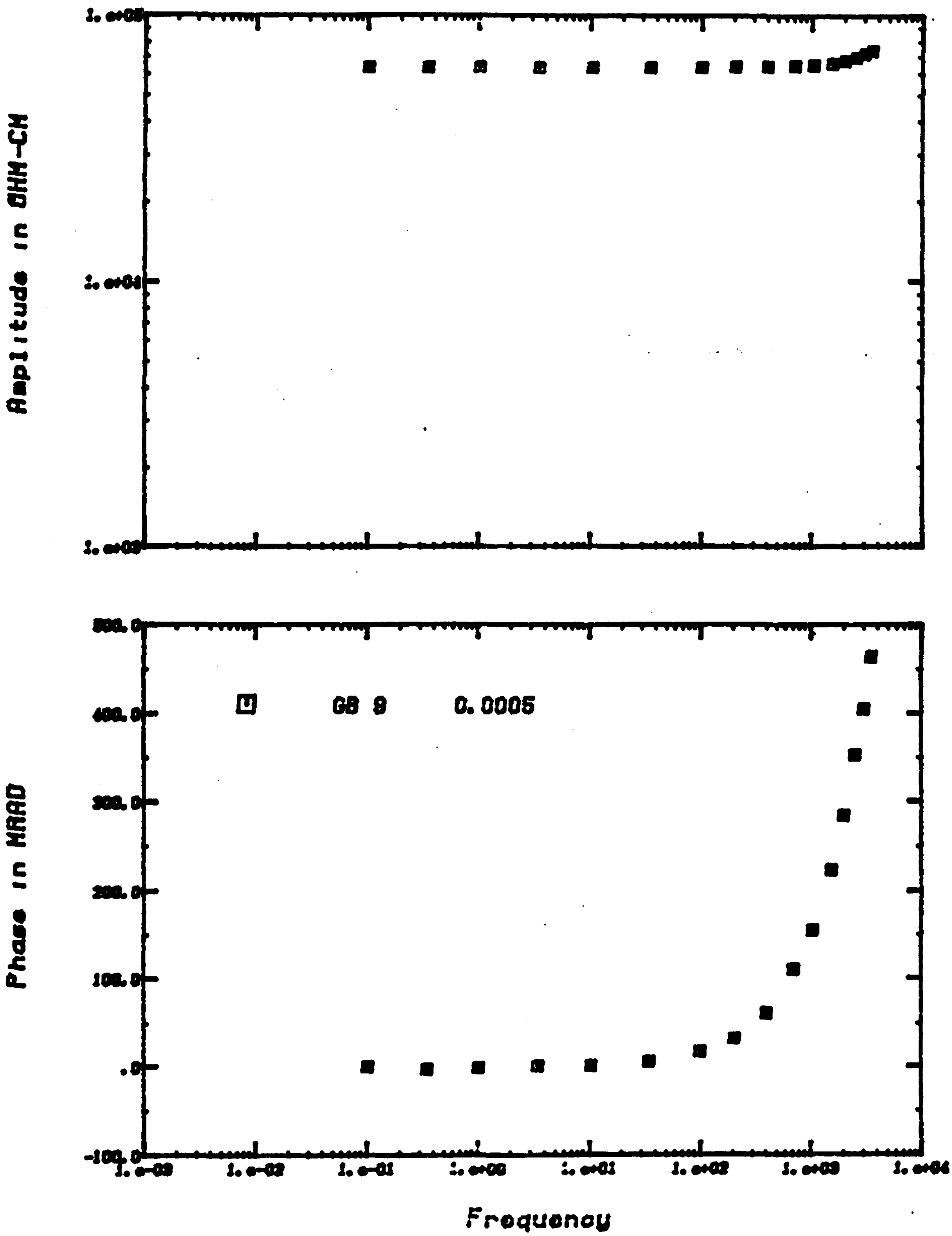

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1.e-01
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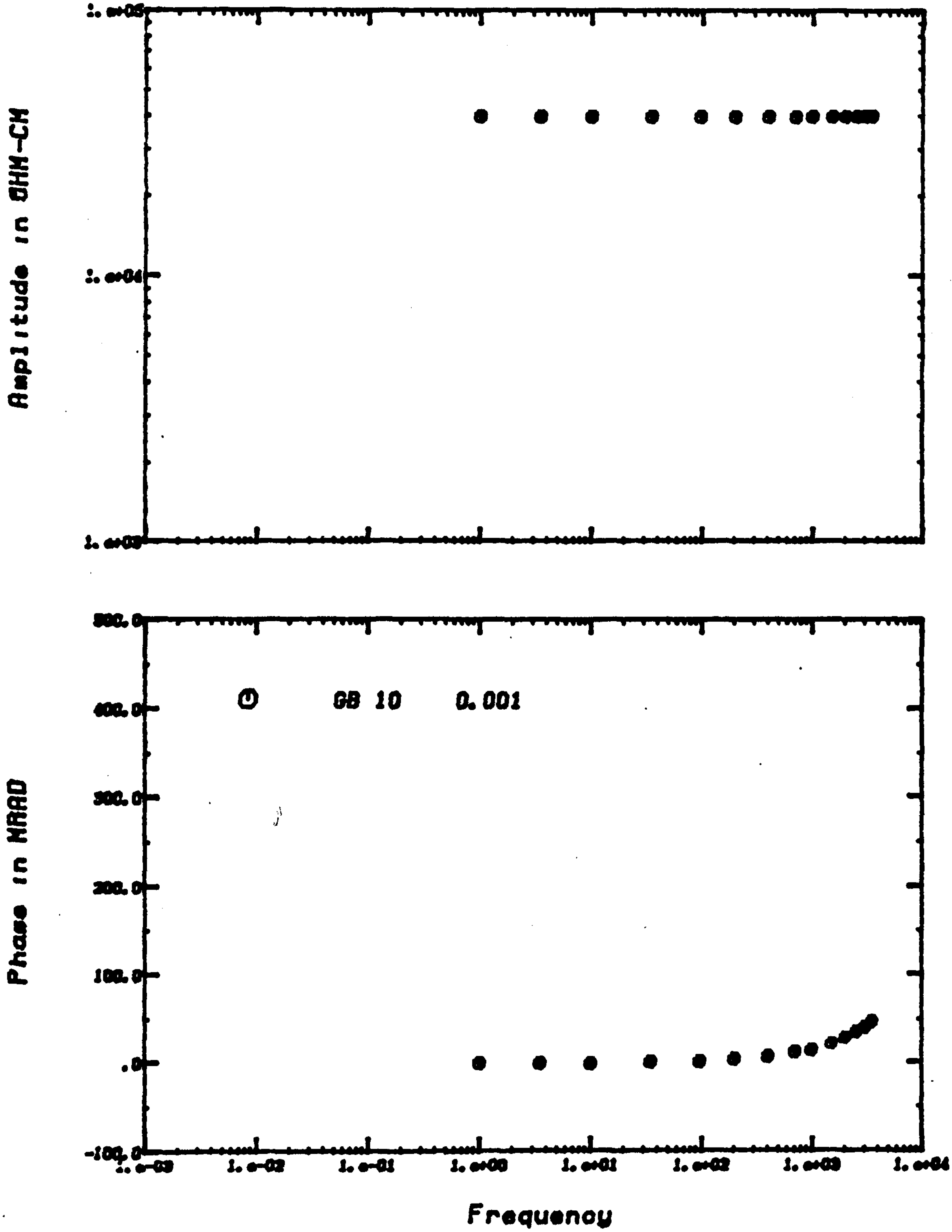
1.e+03
1.e+04
Frequency



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200.0
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.0
-100.0
O GB 10 0.001
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1.e-01
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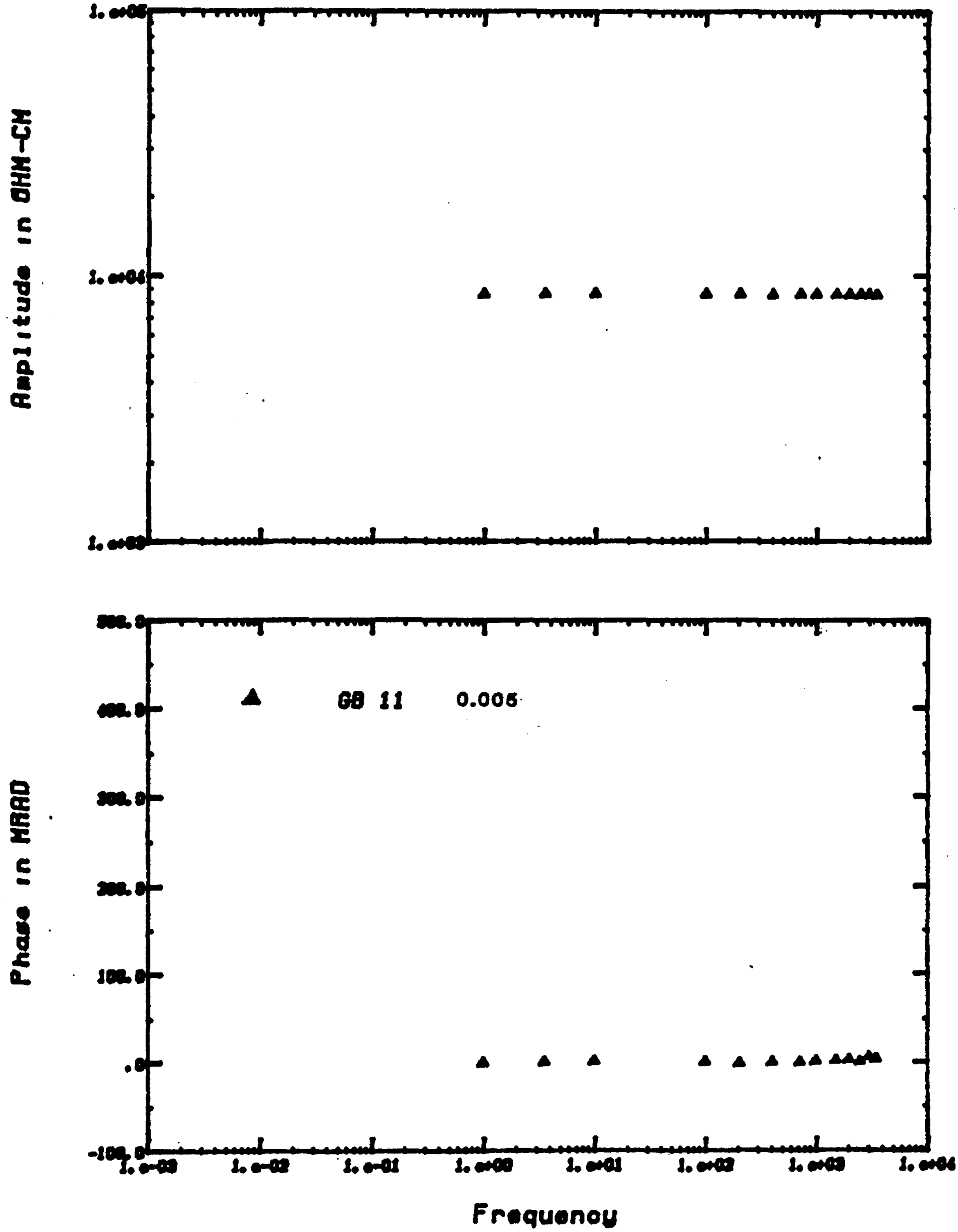
Frequency



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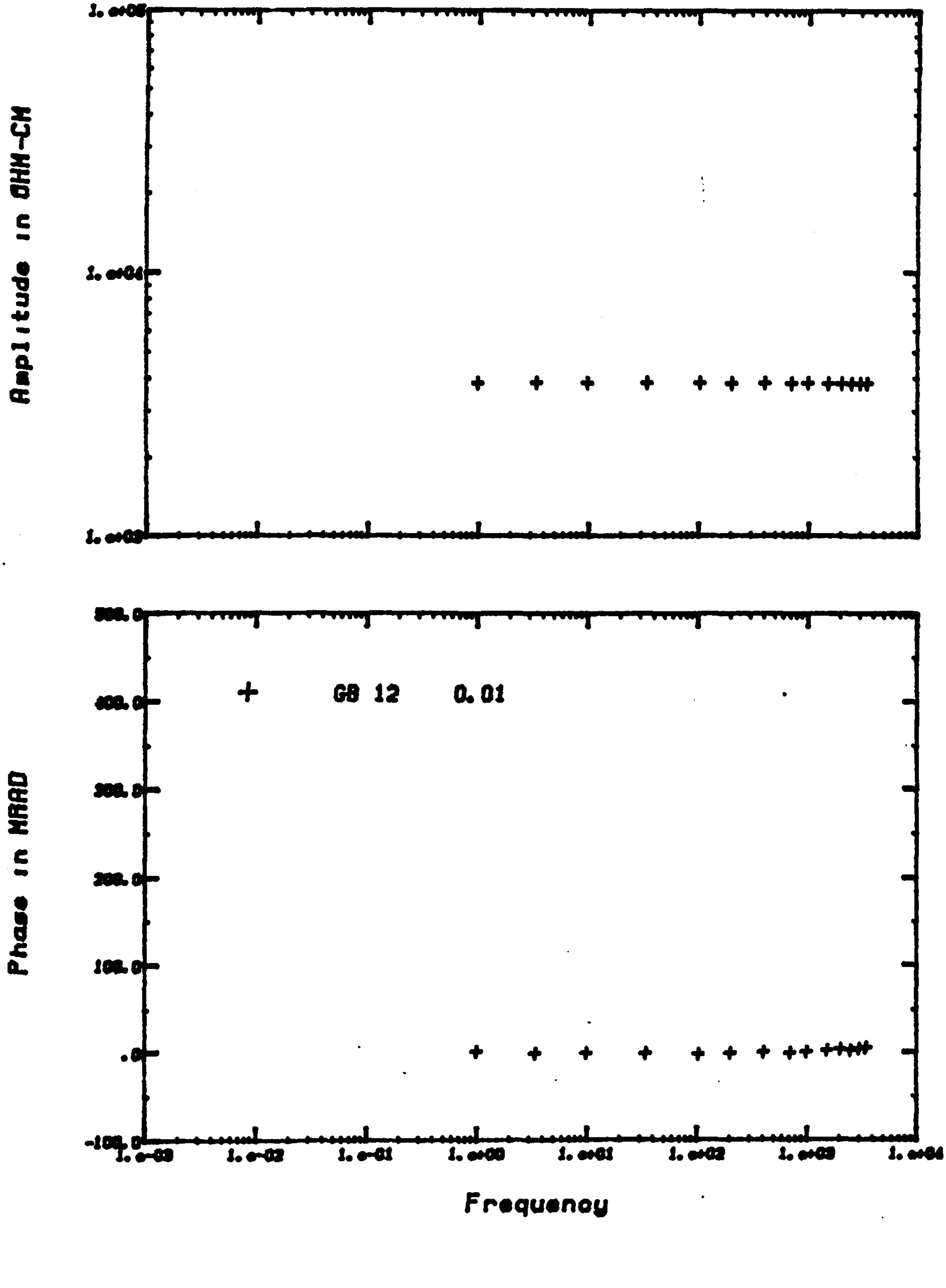
Frequency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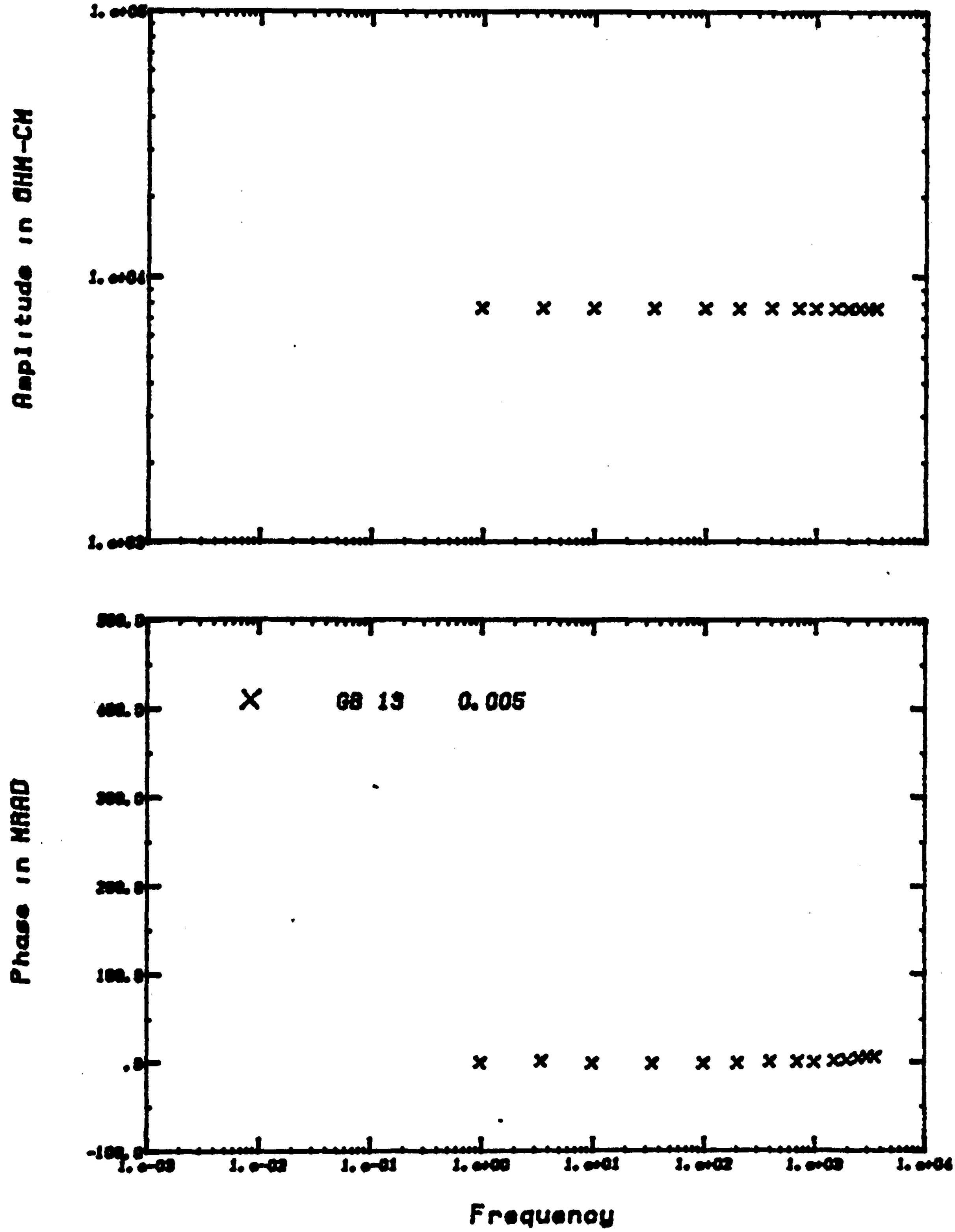
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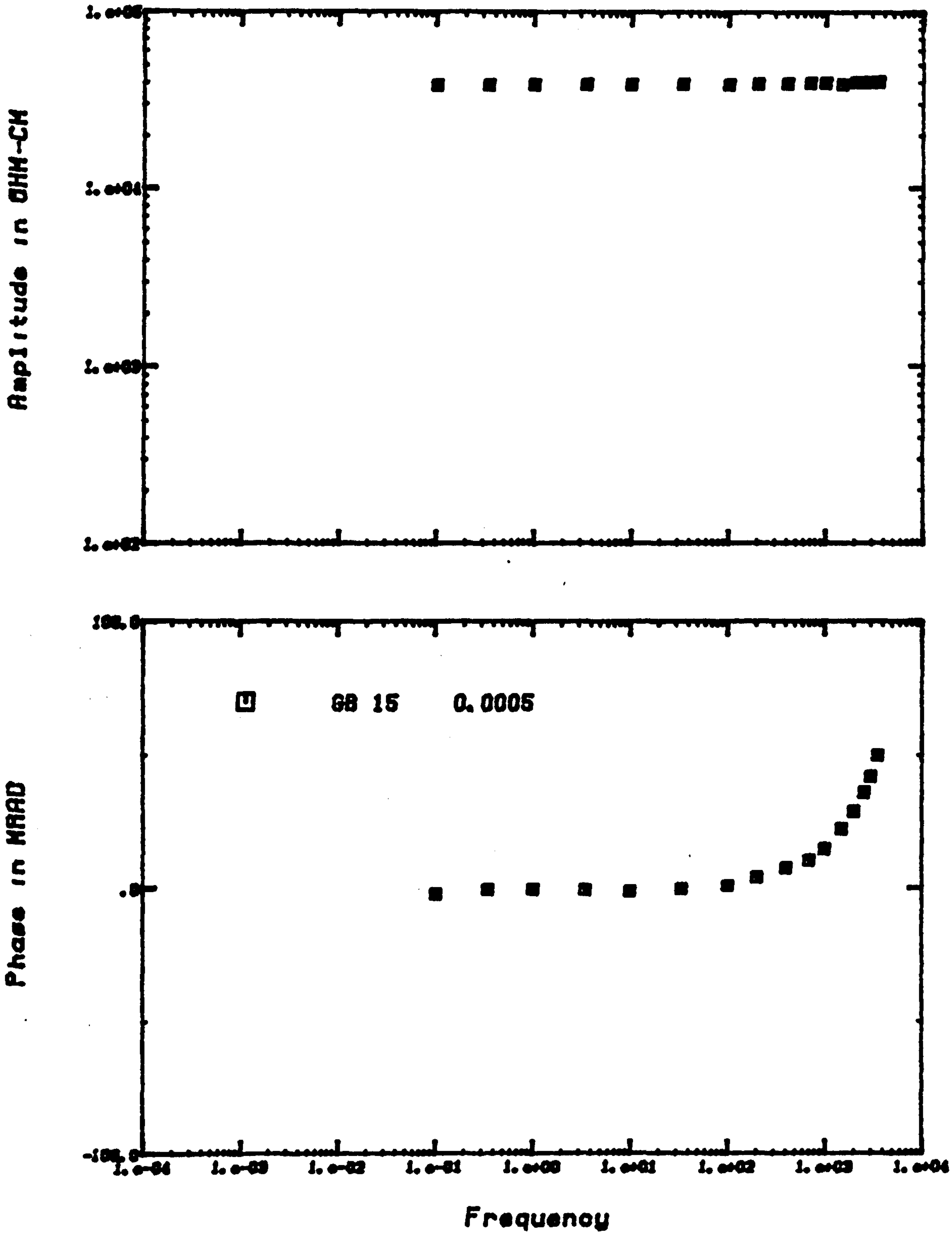
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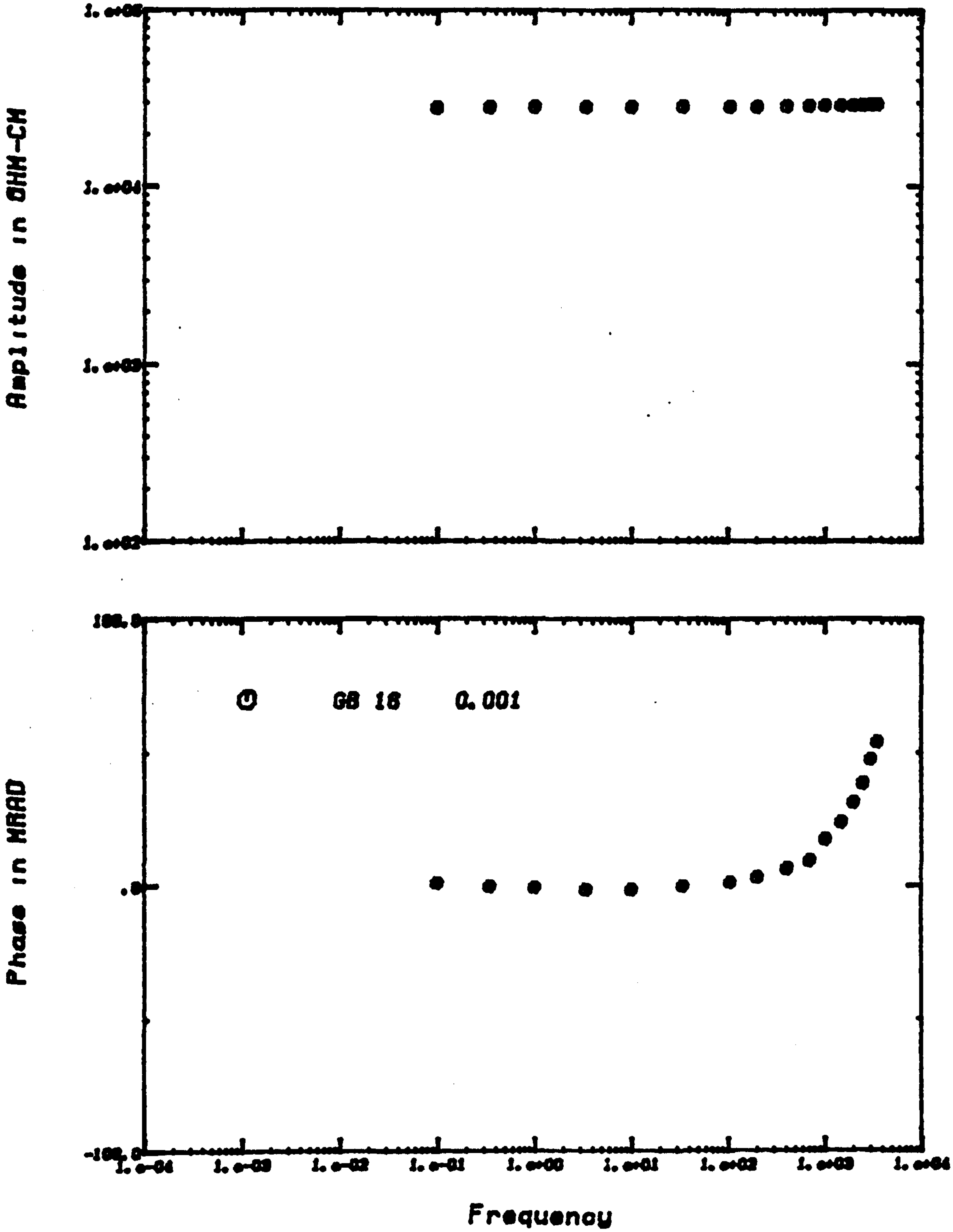
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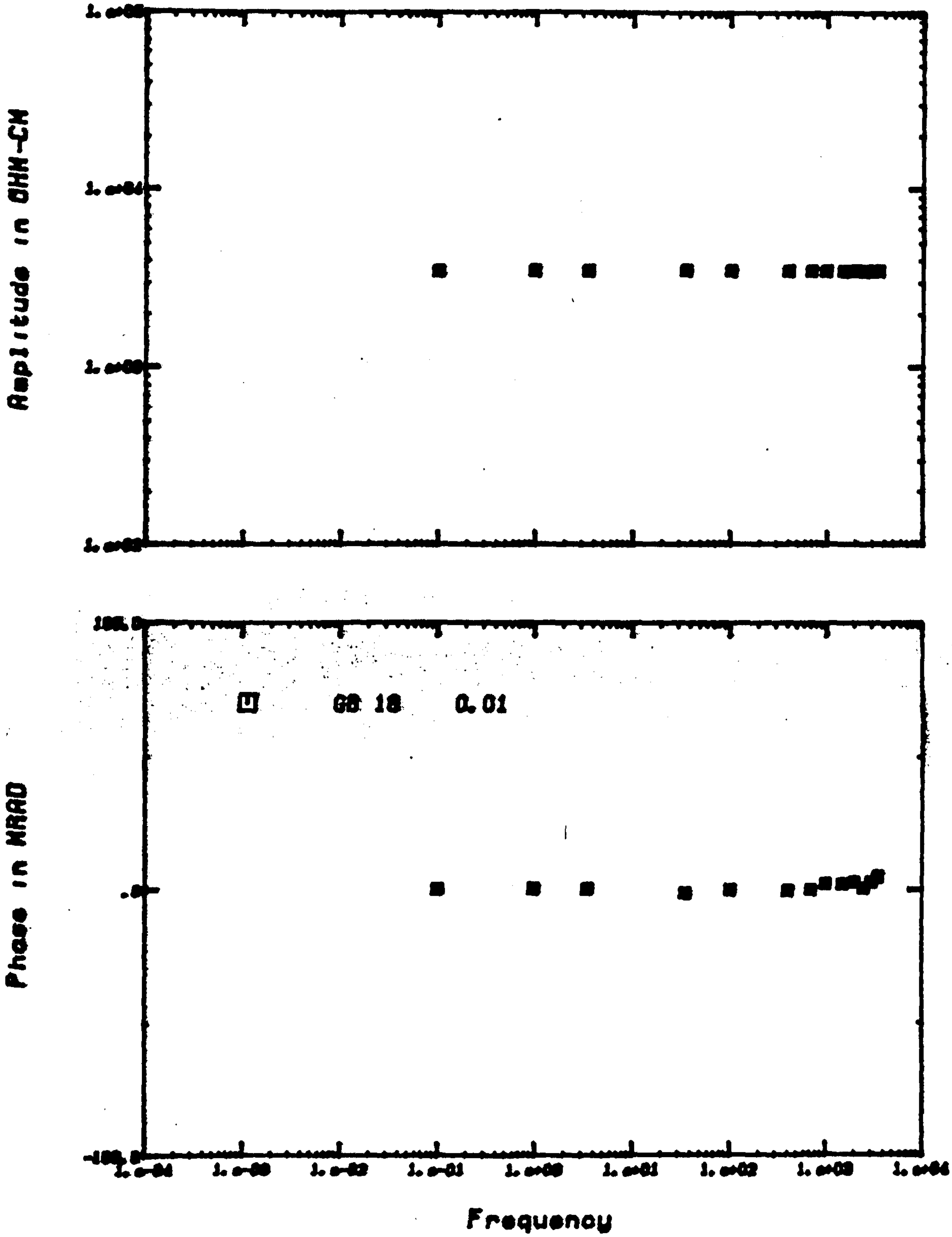
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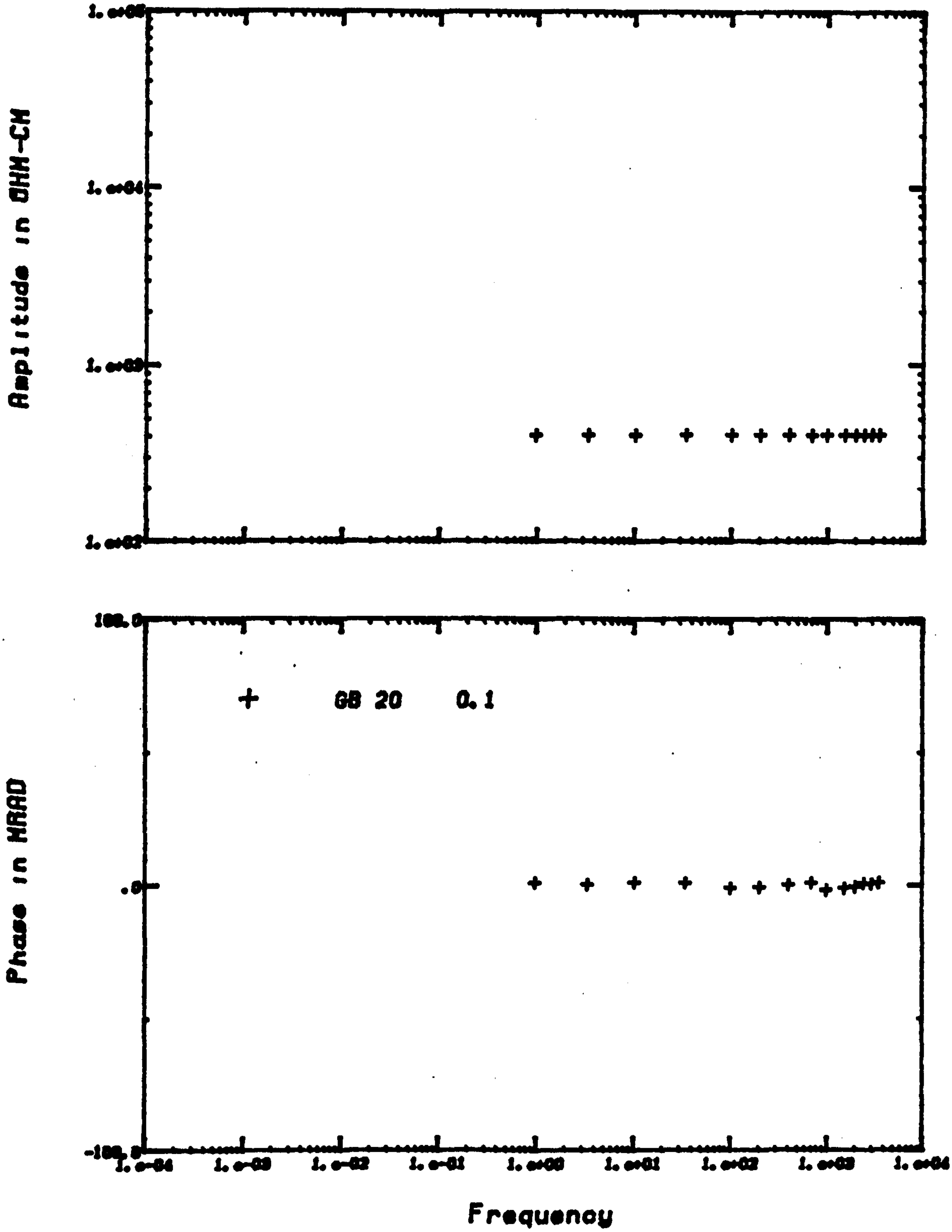

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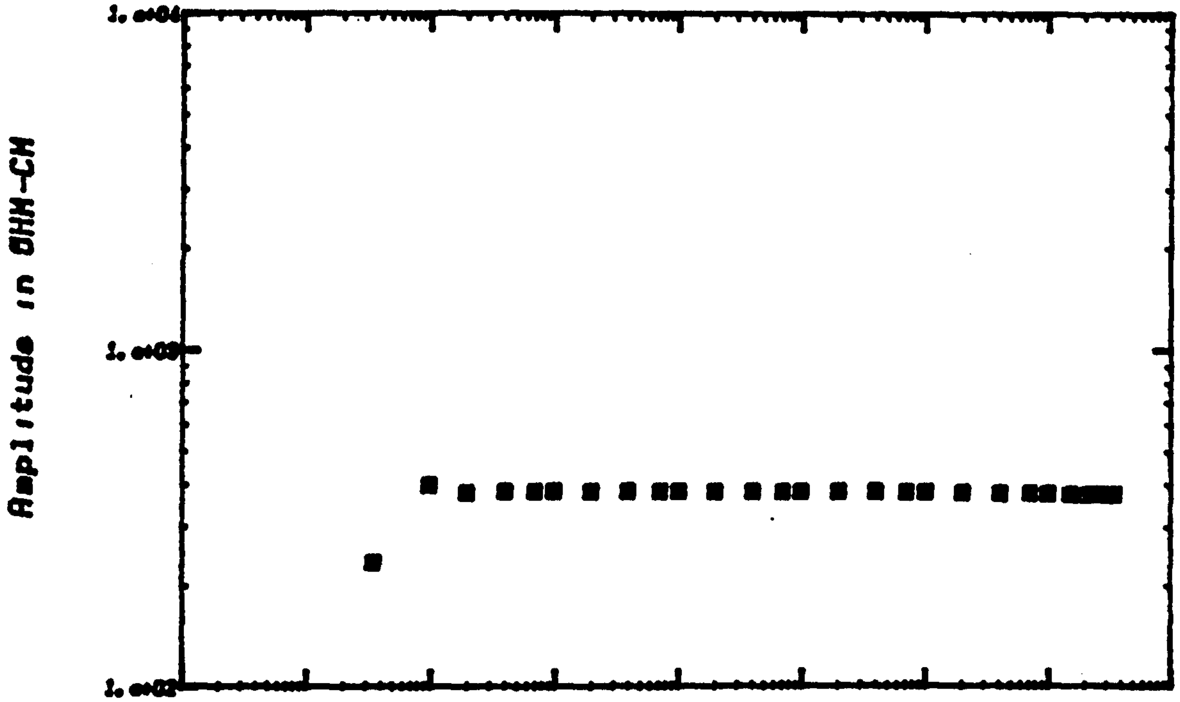

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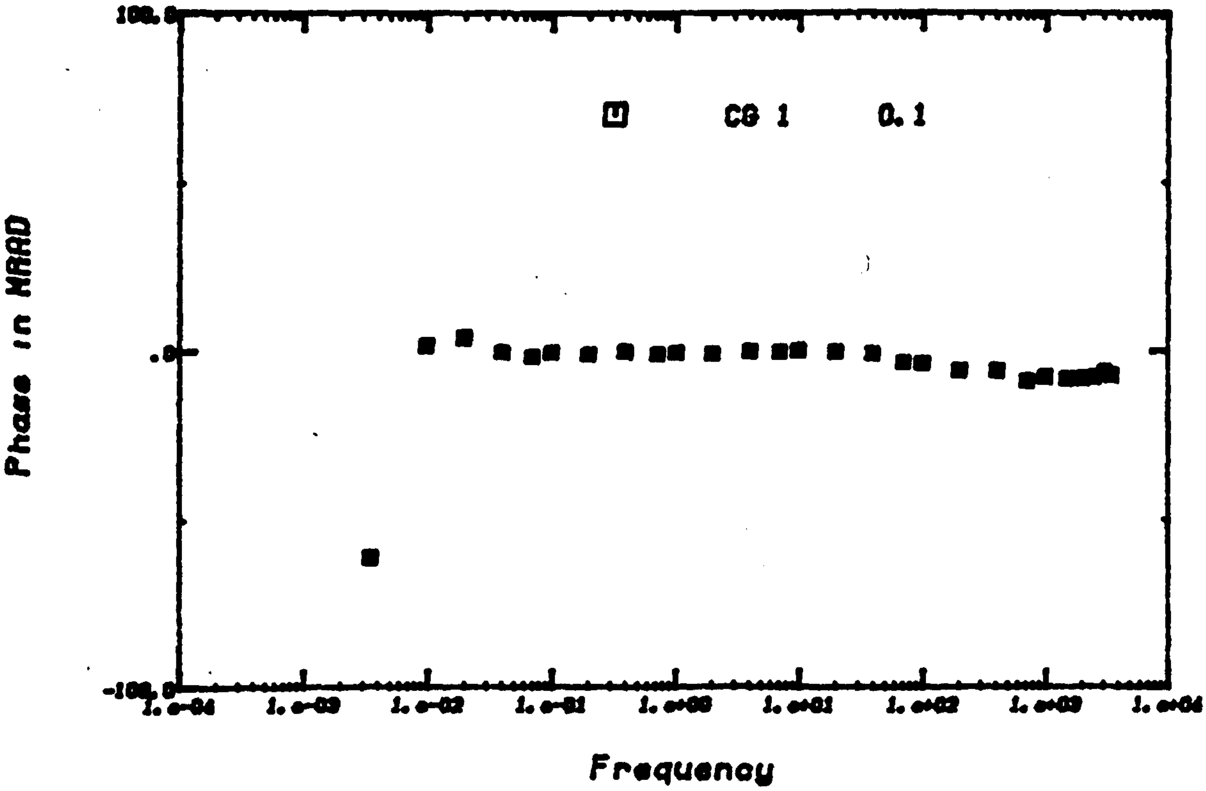

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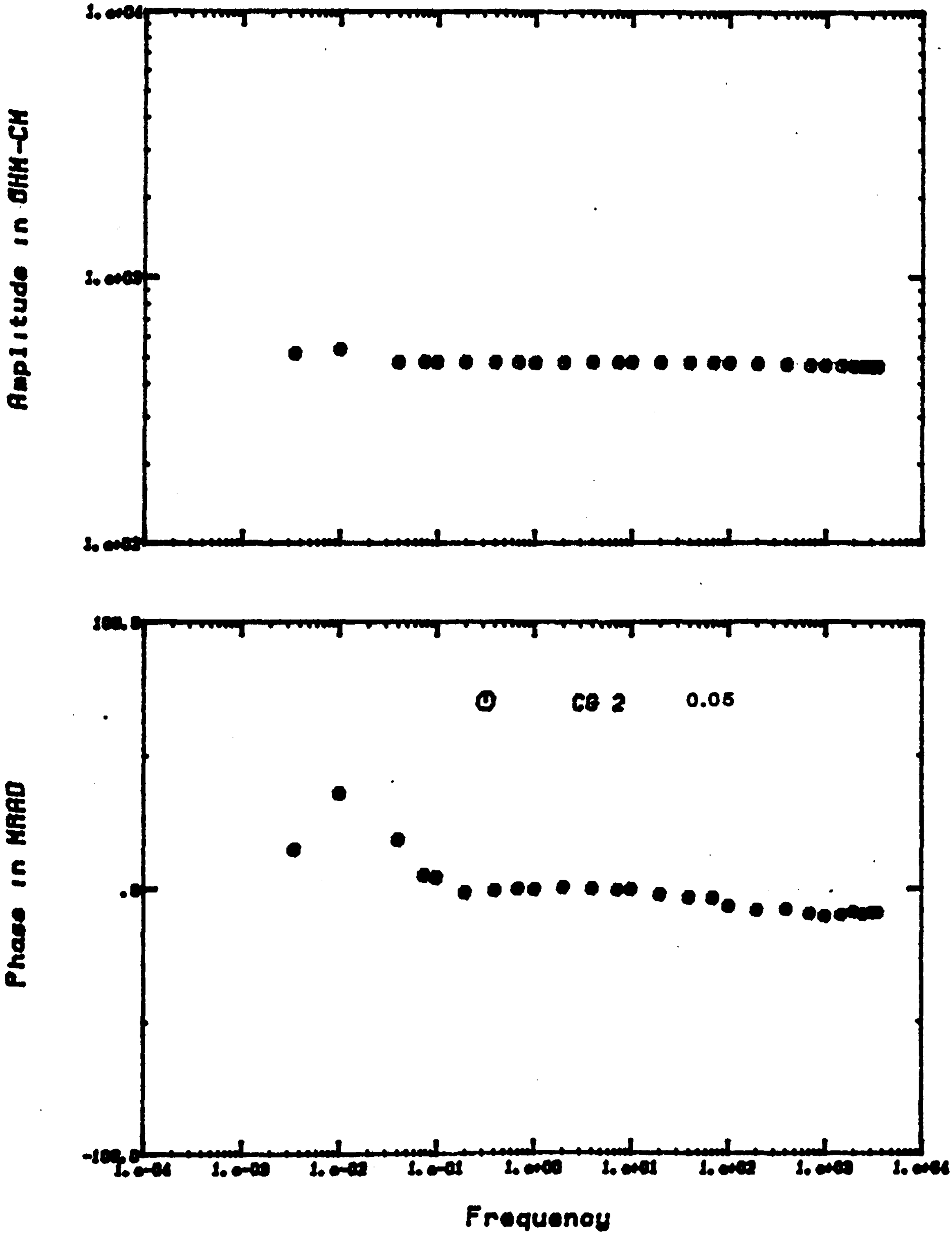
Frequency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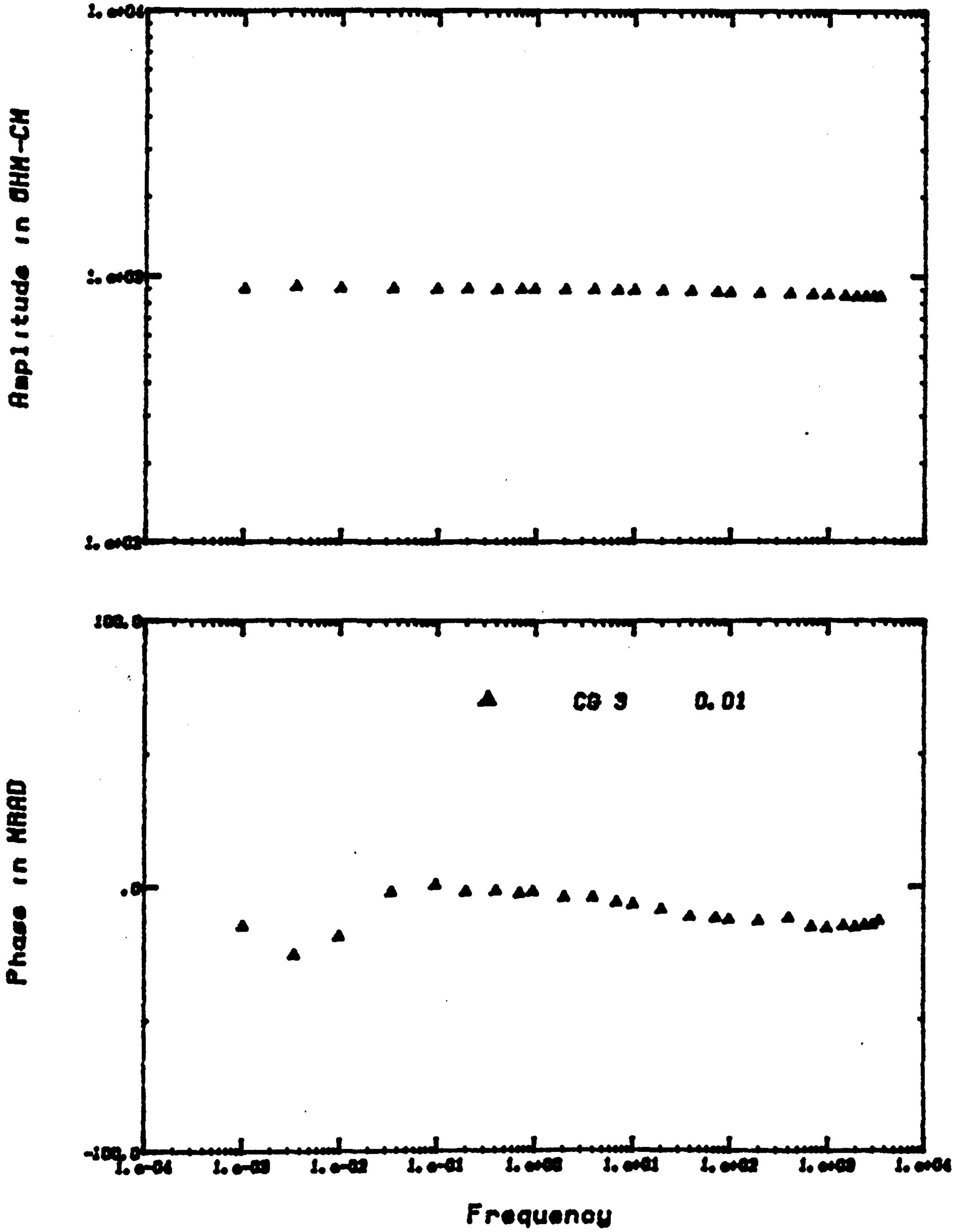
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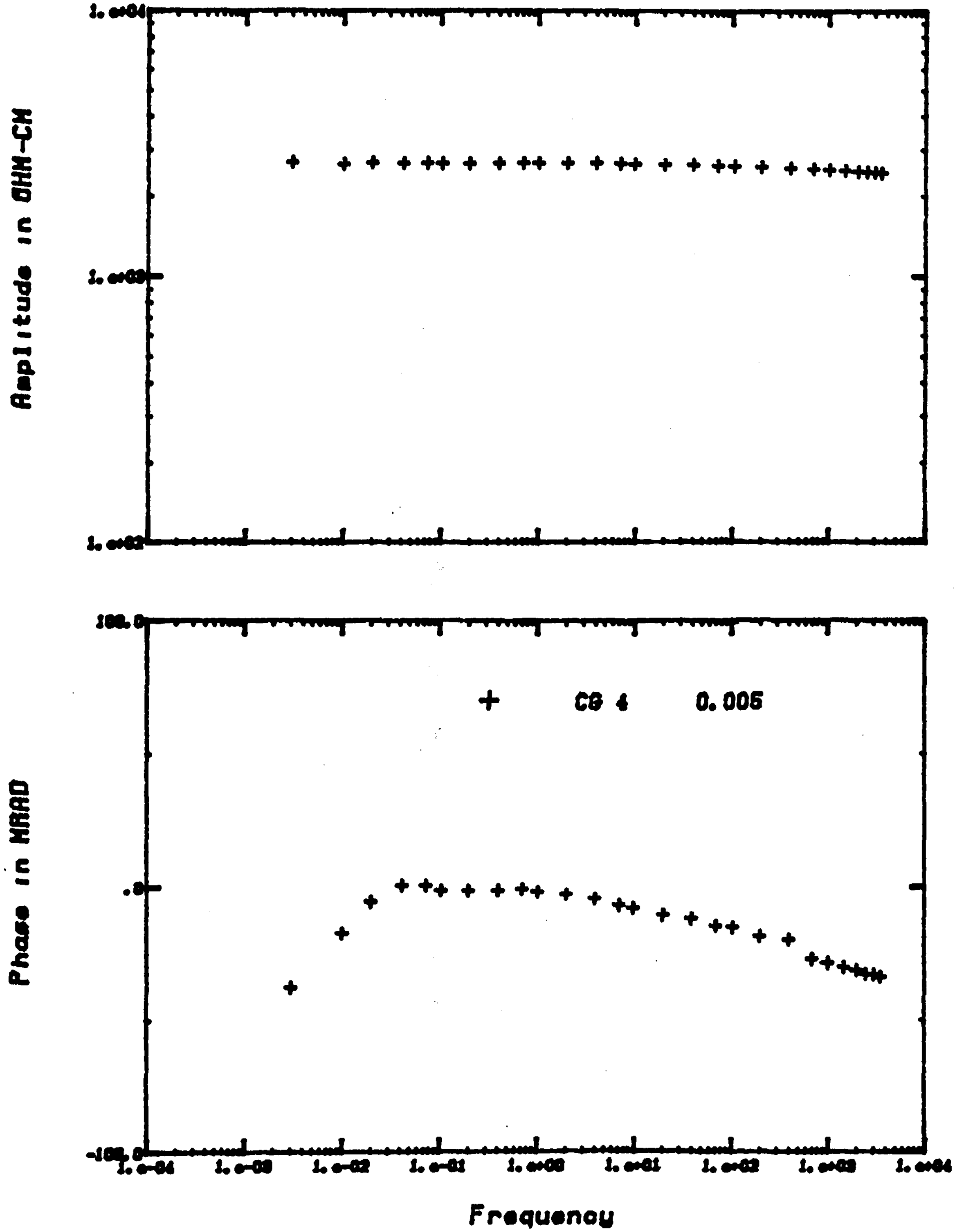
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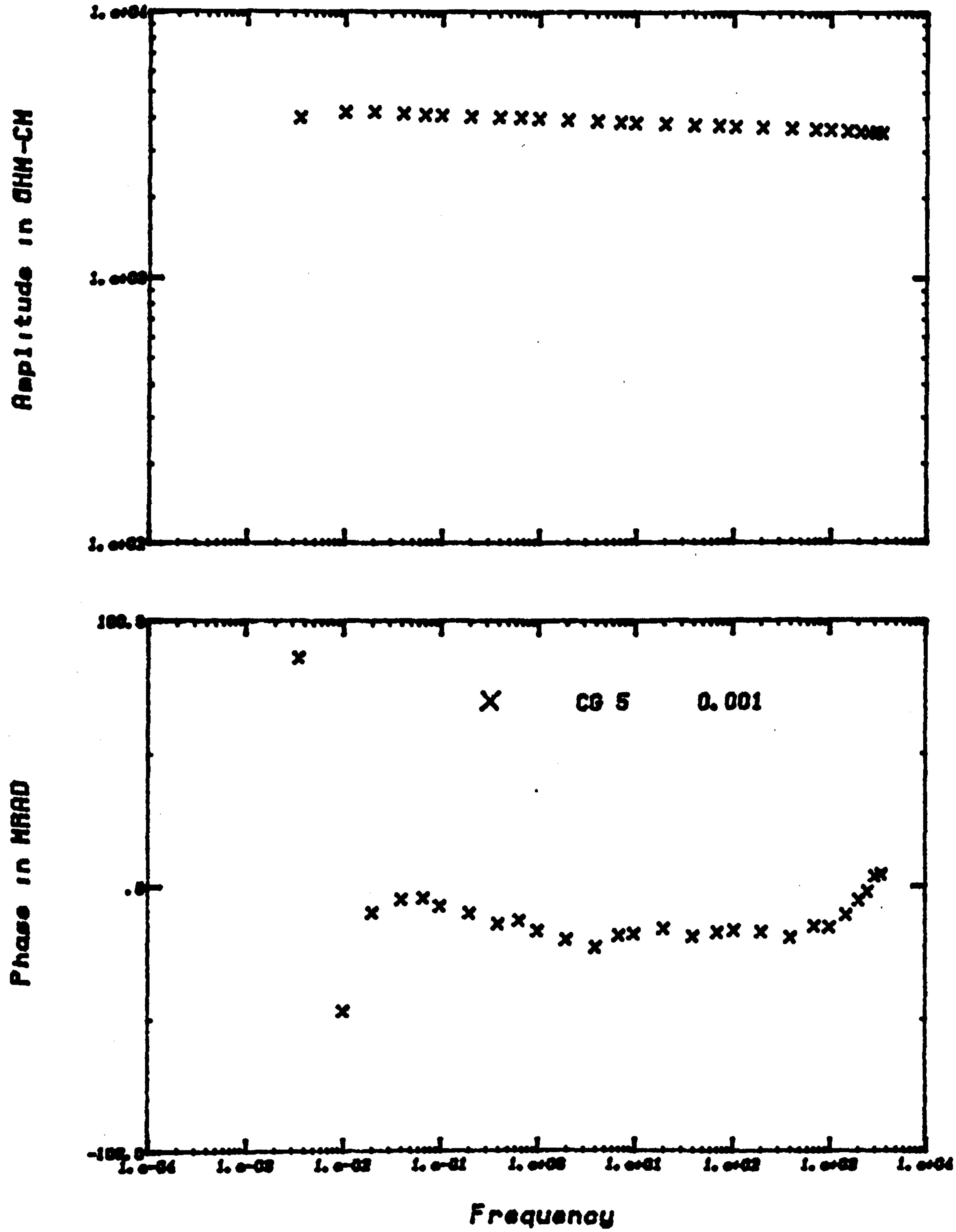
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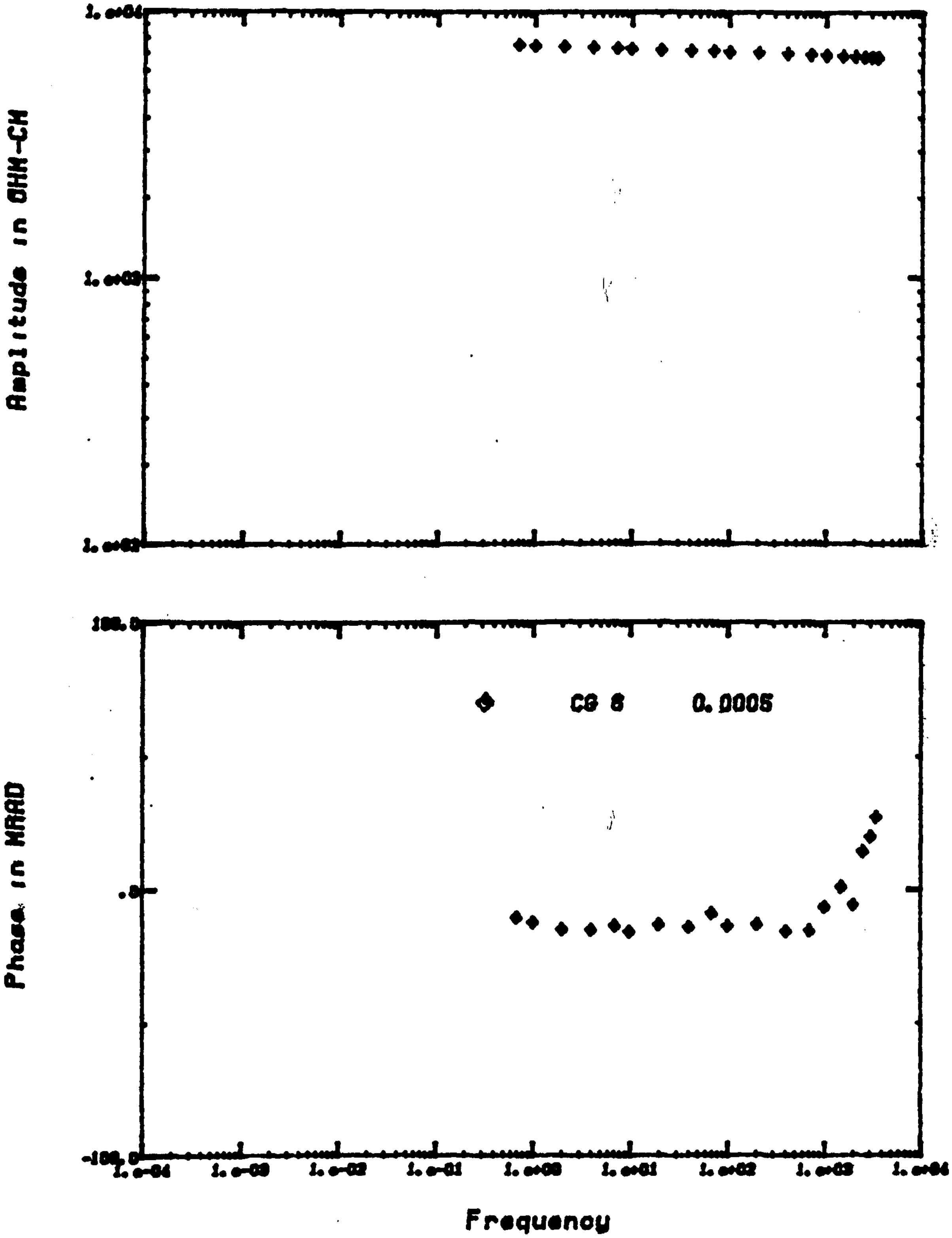
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Frequency

APPENDIX 2

LISTING OF EACH RUN

GLASS BEADS 2.8-2.2 MM DIA. FILE GB1 .0001 MOLAR NACL
RK=101820. 8/23/83 2100 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.349e+04	273586.09	607.54	442.18	.08	.101	.11e-07
.349e+04	273841.16	564.75	442.38	.08	.008	.11e-07
.349e+04	273236.72	570.12	443.95	.08	.092	.11e-07
.349e+04	273174.38	631.37	443.44	.09	.130	.11e-07
.297e+04	264984.50	544.81	385.02	.08	.069	.11e-07
.297e+04	265292.06	498.35	385.10	.07	.072	.11e-07
.297e+04	265336.50	404.61	386.56	.06	.058	.11e-07
.297e+04	264399.22	725.17	383.17	.10	.148	.11e-07
.251e+04	258430.16	488.98	336.06	.07	.060	.11e-07
.251e+04	257701.52	420.34	330.61	.06	.037	.11e-07
.251e+04	257960.80	442.85	333.46	.07	.108	.11e-07
.251e+04	256915.16	558.52	333.92	.08	.193	.11e-07
.201e+04	250747.91	829.45	273.72	.14	.054	.11e-07
.201e+04	251389.58	826.81	275.07	.14	.060	.11e-07
.201e+04	250558.92	808.81	272.57	.13	.052	.11e-07
.201e+04	250624.14	960.20	274.12	.15	.080	.11e-07
.153e+04	245934.97	671.43	210.80	.11	.040	.11e-07
.153e+04	245830.98	711.95	209.62	.12	.017	.11e-07
.153e+04	245809.55	636.65	210.83	.11	.021	.11e-07
.153e+04	245263.27	646.44	210.23	.11	.025	.11e-07
.100e+04	240681.44	498.33	139.67	.08	.071	.11e-07
.100e+04	240746.44	524.52	141.46	.09	.036	.11e-07
.100e+04	240450.20	501.21	139.24	.09	.048	.11e-07
.100e+04	239743.06	488.15	140.84	.08	.063	.11e-07
.691e+03	238324.30	357.27	97.36	.06	.031	.11e-07
.691e+03	238484.78	371.70	97.53	.06	.041	.11e-07
.501e+03	237539.31	3460.05	73.43	.63	.020	.11e-07
.500e+03	237793.45	3510.67	72.43	.64	.036	.11e-07
.303e+03	236740.56	.00	43.96	.24	.016	.11e-07
.303e+03	236737.20	.00	43.49	.24	.019	.11e-07
.107e+03	235967.88	.00	15.17	.03	.037	.11e-07
.107e+03	236184.23	.00	15.24	.03	.028	.11e-07
.694e+02	235822.14	.00	9.95	.15	.019	.11e-07
.693e+02	234850.19	.00	10.97	.14	.018	.11e-07
.499e+02	234403.56	.00	5.90	.03	.015	.11e-07
.499e+02	234383.38	.00	8.43	.03	.009	.11e-07
.300e+02	234011.67	.00	4.22	.04	.047	.11e-07
.300e+02	234134.86	.00	3.64	.05	.040	.11e-07
.104e+02	234070.33	.00	.54	.03	.033	.11e-07

.104e+02	233795.06	.00	1.07	.03	.040	.11e-07
.703e+01	233986.30	.00	.27	.03	.031	.11e-07
.703e+01	233418.50	.00	-.21	.03	.029	.11e-07
.496e+01	233796.41	.00	-.54	.03	.051	.11e-07
.496e+01	233504.81	.00	-.77	.03	.021	.11e-07
.302e+01	233180.92	.00	-.85	.03	.033	.11e-07
.302e+01	233534.88	.00	-1.45	.03	.026	.11e-07
.998e+00	233093.09	.00	-2.83	.04	.036	.11e-07
.998e+00	233250.84	.00	-.96	.03	.041	.11e-07
.999e-01	233642.45	.00	-.37	.03	.021	.11e-07
.999e-01	233751.17	.00	.28	.03	.039	.11e-07

GLASS BEADS 2.8-2.2 MM .0005 MOLAR NaCl rk=10004.ohms
8/23/83 2200 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.351e+04	60660.37	85.82	43.89	.07	.115	.65e-07
.351e+04	60579.85	100.59	41.90	.08	.067	.66e-07
.351e+04	60748.79	109.97	44.22	.08	.052	.65e-07
.300e+04	60687.04	82.34	35.90	.07	.005	.65e-07
.300e+04	60828.87	84.01	38.90	.07	.040	.65e-07
.300e+04	60692.96	92.89	38.26	.07	.042	.65e-07
.251e+04	60843.13	82.77	34.13	.06	.045	.65e-07
.251e+04	60808.21	72.10	29.41	.07	.093	.65e-07
.251e+04	60870.77	59.62	35.61	.06	.108	.65e-07
.201e+04	60835.67	179.98	24.69	.13	.014	.65e-07
.201e+04	60852.36	179.55	25.21	.12	.090	.65e-07
.201e+04	60951.73	189.93	24.24	.13	.037	.65e-07
.150e+04	60890.69	150.78	16.86	.11	.020	.65e-07
.150e+04	60929.63	158.20	18.11	.11	.077	.65e-07
.150e+04	60944.52	153.04	17.37	.11	.063	.65e-07
.100e+04	60884.40	117.41	11.46	.09	.026	.65e-07
.100e+04	60937.41	117.30	11.54	.08	.051	.65e-07
.100e+04	60806.98	118.77	10.80	.09	.063	.65e-07
.701e+03	61004.57	89.44	7.28	.06	.025	.65e-07
.701e+03	67631.95	99.38	64.42	2.91	5.072	.59e-07
.400e+03	60940.04	700.90	5.27	.50	.031	.65e-07
.400e+03	61048.92	692.56	7.53	.49	.034	.65e-07
.203e+03	61072.39	.00	2.70	.03	.035	.65e-07
.203e+03	60984.04	.00	.41	.03	.024	.65e-07
.104e+03	61297.80	.00	.40	.03	.010	.65e-07
.104e+03	61025.52	.00	.87	.03	.024	.65e-07
.705e+02	61176.85	.00	-.30	.18	.023	.65e-07
.705e+02	61179.20	.00	-.82	.17	.016	.65e-07
.402e+02	61213.16	.00	-.46	.03	.032	.65e-07
.402e+02	61327.97	.00	-.22	.02	.036	.65e-07
.204e+02	61303.26	.00	-1.30	.03	.030	.65e-07
.204e+02	61312.47	.00	-1.34	.03	.045	.65e-07
.101e+02	61350.92	.00	-1.37	.02	.023	.64e-07
.101e+02	61405.42	.00	-.66	.03	.029	.64e-07
.701e+01	61454.14	.00	-1.78	.03	.033	.64e-07
.701e+01	61492.22	.00	-2.25	.03	.027	.64e-07
.399e+01	61517.72	.00	-1.80	.03	.036	.64e-07
.399e+01	61556.09	.00	-2.47	.03	.039	.64e-07
.209e+01	61628.27	.00	-2.06	.03	.012	.63e-07

.209e+01	61609.22	.00	-2.25	.03	.019	.63e-07
.106e+01	61636.32	.00	-.91	.03	.020	.63e-07
.106e+01	61781.59	.00	-1.61	.03	.035	.63e-07
.352e+00	61752.16	.00	-1.06	.03	.041	.62e-07
.353e+00	61870.18	.00	-1.32	.07	.029	.62e-07
.970e-01	61767.32	.00	2.35	.03	.017	.62e-07
.105e+00	61899.63	.00	.53	.03	.024	.62e-07
.349e-01	58176.28	.00	6.49	1.30	2.318	.65e-07

GLASS BEADS 2.8-2.2 MM .001 MOLAR NACL RK=10004.
8/24/83 1515 hrs

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.354e+04	42678.78	72.07	45.73	.08	.011	.82e-07
.354e+04	42826.13	75.74	45.62	.07	.080	.82e-07
.354e+04	42820.40	74.53	45.88	.07	.097	.82e-07
.300e+04	42971.98	75.59	41.73	.07	.037	.82e-07
.300e+04	42962.74	64.49	38.96	.06	.045	.82e-07
.300e+04	43042.71	65.75	39.37	.06	.054	.82e-07
.249e+04	43095.10	58.73	37.33	.06	.099	.82e-07
.249e+04	43276.18	58.19	34.90	.06	.098	.81e-07
.249e+04	43188.25	65.30	36.99	.06	.024	.82e-07
.203e+04	43290.65	132.50	27.25	.13	.028	.81e-07
.203e+04	43347.11	131.40	27.54	.13	.035	.81e-07
.203e+04	43379.05	130.79	27.04	.13	.063	.81e-07
.150e+04	43458.34	105.64	20.13	.11	.023	.81e-07
.150e+04	43525.22	112.15	19.91	.11	.034	.81e-07
.150e+04	43538.35	111.40	20.49	.11	.011	.81e-07
.978e+03	43630.05	84.24	11.68	.08	.042	.81e-07
.978e+03	43695.00	78.87	11.89	.08	.021	.81e-07
.978e+03	43649.01	84.58	13.27	.08	.031	.81e-07
.704e+03	43795.46	60.67	9.95	.06	.032	.81e-07
.704e+03	43797.54	65.65	10.60	.06	.006	.81e-07
.409e+03	43825.49	514.38	6.67	.51	.037	.80e-07
.409e+03	43901.33	525.74	6.35	.52	.030	.81e-07
.204e+03	43954.87	.00	1.50	.15	.013	.80e-07
.205e+03	44319.58	.00	2.93	.17	.052	.80e-07
.104e+03	44341.72	.00	-.07	.02	.013	.80e-07
.104e+03	44338.38	.00	-.15	.02	.012	.80e-07
.349e+02	44442.69	.00	-1.16	.07	.053	.80e-07
.349e+02	44477.14	.00	-.98	.07	.015	.80e-07
.105e+02	44639.79	.00	-2.27	.02	.029	.79e-07
.105e+02	44639.12	.00	-2.03	.02	.038	.80e-07
.352e+01	44728.39	.00	-2.99	.03	.027	.79e-07
.352e+01	44771.60	.00	-.87	.02	.019	.79e-07
.103e+01	44907.26	.00	-.91	.02	.035	.78e-07
.103e+01	44943.74	.00	-.68	.03	.038	.78e-07
.352e+00	44990.43	.00	.30	.02	.024	.77e-07
.352e+00	48303.28	.00	13.82	1.67	2.837	.72e-07
.103e+00	45063.25	.00	1.05	.02	.050	.76e-07
.103e+00	45117.96	.00	-.03	.02	.048	.76e-07
.350e-01	45206.58	.00	.10	.02	.033	.76e-07
.350e-01	45275.36	.00	1.20	.03	.010	.76e-07

GLASS BEADS 2.8-2.0 MM .005 MOLAR NACL RK=996.72
FILE GB4 8/24/83 1925 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.352e+04	7054.20	10.10	4.53	.07	.047	.58e-06
.352e+04	7049.05	9.95	4.51	.08	.054	.58e-06
.352e+04	7065.57	10.71	5.05	.07	.005	.58e-06
.298e+04	7053.34	8.33	5.33	.07	.046	.58e-06
.298e+04	7051.33	9.94	1.67	.07	.018	.58e-06
.298e+04	7062.76	9.41	6.28	.07	.036	.58e-06
.250e+04	7032.03	7.55	-1.17	.07	.061	.58e-06
.250e+04	7030.86	7.35	7.73	.07	.061	.58e-06
.250e+04	7058.07	7.12	.05	.06	.161	.58e-06
.200e+04	7040.53	21.18	1.29	.14	.060	.58e-06
.200e+04	7045.48	20.15	1.19	.13	.033	.58e-06
.200e+04	7049.32	21.02	3.27	.13	.031	.58e-06
.149e+04	7036.23	17.46	.91	.11	.025	.58e-06
.149e+04	7039.16	17.67	1.27	.11	.039	.58e-06
.149e+04	7044.95	17.42	.21	.11	.020	.58e-06
.101e+04	7035.66	13.34	.74	.08	.024	.58e-06
.101e+04	7051.06	12.97	-.28	.09	.021	.58e-06
.101e+04	7044.76	13.09	-1.55	.09	.032	.58e-06
.701e+03	7037.12	9.23	-5.06	.07	.022	.58e-06
.701e+03	7034.98	9.68	-2.64	.07	.020	.58e-06
.404e+03	7033.91	81.70	-.06	.50	.027	.57e-06
.404e+03	7031.87	81.95	-.69	.51	.041	.57e-06
.205e+03	7047.32	.00	-1.15	.16	.025	.58e-06
.205e+03	7038.67	.00	-.77	.15	.022	.58e-06
.103e+03	7048.94	.00	-.37	.03	.030	.58e-06
.103e+03	7047.89	.00	-.73	.03	.008	.58e-06
.706e+02	7044.50	.00	-3.81	.15	.021	.57e-06
.706e+02	7064.26	.00	-1.14	.15	.021	.58e-06
.401e+02	7048.06	.00	-.76	.03	.022	.57e-06
.401e+02	7052.79	.00	-2.56	.03	.020	.57e-06
.201e+02	7053.94	.00	-2.41	.03	.033	.57e-06
.201e+02	7050.82	.00	-1.43	.03	.030	.57e-06
.103e+02	7059.56	.00	-2.35	.03	.028	.56e-06
.103e+02	7061.47	.00	-1.79	.03	.032	.56e-06
.350e+01	7064.04	.00	-.43	.04	.030	.56e-06
.350e+01	7060.21	.00	1.19	.04	.022	.56e-06
.103e+01	7062.17	.00	-.98	.04	.012	.56e-06
.103e+01	7065.50	.00	.31	.04	.006	.56e-06

GLASS BEADS .01MOLAR NACL 2.8-2.0 MM DIA. RK=996.72
8/24/83 2200 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.352e+04	3401.33	5.63	5.25	.07	.091	.91e-06
.352e+04	3394.71	4.89	5.23	.07	.051	.91e-06
.352e+04	3398.16	5.75	5.51	.08	.034	.91e-06
.300e+04	3394.56	4.97	3.68	.07	.036	.91e-06
.300e+04	3391.31	4.30	6.90	.07	.121	.91e-06
.300e+04	3394.58	4.91	3.96	.07	.113	.91e-06
.253e+04	3395.97	4.42	2.58	.06	.016	.91e-06
.253e+04	3397.93	5.34	4.87	.07	.066	.91e-06
.253e+04	3399.81	4.39	4.62	.06	.061	.91e-06
.199e+04	3392.73	10.23	2.98	.13	.039	.91e-06
.199e+04	3400.91	10.11	2.75	.13	.060	.91e-06
.199e+04	3395.19	10.12	3.38	.13	.066	.91e-06
.152e+04	3390.70	8.74	2.17	.12	.006	.91e-06
.152e+04	3396.81	8.28	2.19	.11	.041	.91e-06
.152e+04	3392.88	8.33	2.39	.11	.032	.91e-06

GLASS BEADS 2.8-2.0 MM DIA 0.05 MOLAR NACL RK=100.35
8/25/83 0810 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.351e+04	707.61	1.08	-.30	.07	.079	.51e-05
.351e+04	707.21	1.06	1.42	.07	.100	.51e-05
.351e+04	707.48	1.05	1.50	.07	.064	.51e-05
.298e+04	708.96	.80	3.73	.07	.092	.51e-05
.298e+04	707.53	1.08	1.16	.07	.041	.51e-05
.298e+04	707.87	.91	1.54	.07	.071	.51e-05
.251e+04	708.01	.82	-2.88	.06	.033	.51e-05
.251e+04	708.39	.73	.69	.06	.100	.51e-05
.251e+04	709.30	.80	3.85	.07	.050	.51e-05
.199e+04	708.25	2.09	1.03	.13	.013	.51e-05
.199e+04	708.17	2.09	-.62	.13	.010	.51e-05
.199e+04	709.41	2.13	-1.41	.13	.018	.51e-05
.155e+04	707.31	29.06	11.72	1.78	.047	.49e-05
.155e+04	710.69	29.10	7.68	1.77	.106	.48e-05
.155e+04	705.95	28.54	8.79	1.76	.096	.48e-05
.995e+03	707.74	1.28	-2.03	.09	.033	.51e-05
.995e+03	710.17	1.30	-1.79	.09	.034	.51e-05
.995e+03	708.96	1.32	-2.82	.09	.026	.51e-05
.703e+03	708.72	1.04	-1.32	.07	.008	.51e-05
.703e+03	711.36	.91	1.78	.06	.036	.51e-05
.404e+03	707.86	8.26	-.68	.51	.058	.50e-05
.404e+03	709.59	8.27	-1.72	.50	.014	.49e-05
.203e+03	711.05	.00	-.52	.17	.025	.50e-05
.203e+03	710.63	.00	-1.35	.15	.033	.50e-05
.103e+03	709.67	.00	-2.20	.03	.024	.50e-05
.103e+03	710.75	.00	-1.84	.04	.042	.50e-05
.348e+02	711.41	.00	-1.01	.07	.019	.49e-05
.348e+02	711.78	.00	-.37	.07	.020	.49e-05
.103e+02	710.86	.00	-1.04	.03	.076	.49e-05
.103e+02	711.49	.00	.26	.03	.068	.49e-05
.351e+01	711.67	.00	-.12	.03	.037	.49e-05
.351e+01	711.02	.00	-.47	.03	.033	.49e-05
.966e+00	711.56	.00	.00	.03	.020	.48e-05
.967e+00	711.55	.00	.12	.03	.030	.48e-05
.349e+00	708.55	.00	-1.07	.03	.018	.45e-05
.349e+00	714.21	.00	1.21	.03	.048	.45e-05
.102e+00	712.21	.00	.18	.04	.053	.33e-05
.102e+00	711.75	.00	-2.52	.04	.066	.33e-05

GLASS BEADS 2.8-2.0 MM DIA 0.1 MOLAR NACL RK=100.35
8/25/83 1220 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.351e+04	378.20	.62	1.11	.08	.060	.71e-05
.351e+04	377.41	.60	-1.40	.08	.069	.71e-05
.351e+04	377.65	.61	.31	.08	.062	.71e-05
.298e+04	378.83	.60	-.70	.07	.006	.71e-05
.298e+04	378.05	.55	-1.59	.07	.065	.71e-05
.298e+04	378.23	.49	-1.99	.06	.031	.71e-05
.251e+04	377.08	.44	1.89	.06	.064	.71e-05
.251e+04	377.01	.49	.60	.06	.034	.71e-05
.251e+04	377.03	.45	-1.26	.07	.043	.71e-05
.200e+04	377.77	1.12	.12	.13	.063	.71e-05
.200e+04	377.33	1.10	1.26	.13	.065	.71e-05
.200e+04	377.51	1.11	.13	.13	.039	.71e-05
.151e+04	377.40	.98	-.36	.11	.044	.71e-05
.151e+04	377.59	.91	-.82	.11	.026	.71e-05
.151e+04	377.37	.94	-1.25	.11	.030	.71e-05
.103e+04	376.96	.72	-1.90	.08	.049	.71e-05
.103e+04	376.36	.71	.77	.08	.044	.71e-05
.106e+04	376.83	.76	-1.34	.09	.047	.71e-05
.671e+03	376.72	.49	-1.56	.06	.029	.71e-05
.671e+03	377.05	.49	-2.06	.06	.022	.71e-05
.407e+03	376.12	4.47	1.24	.51	.021	.70e-05
.407e+03	377.48	4.48	-.33	.51	.033	.70e-05
.202e+03	377.09	.00	-.62	.18	.027	.70e-05
.202e+03	377.04	.00	.52	.17	.023	.70e-05
.103e+03	377.90	.00	-1.21	.03	.022	.70e-05
.103e+03	376.89	.00	-.38	.03	.010	.70e-05
.350e+02	377.15	.00	.09	.07	.027	.70e-05
.350e+02	377.51	.00	-.61	.07	.024	.69e-05
.105e+02	377.38	.00	.13	.03	.043	.69e-05
.105e+02	377.23	.00	-.12	.03	.034	.69e-05
.351e+01	377.18	.00	.30	.03	.027	.69e-05
.351e+01	376.90	.00	.30	.03	.035	.69e-05
.103e+01	377.40	.00	.22	.03	.031	.68e-05
.103e+01	377.49	.00	.17	.03	.027	.68e-05
.353e+00	377.66	.00	1.08	.03	.038	.61e-05
.353e+00	376.92	.00	2.13	.03	.068	.61e-05
.102e+00	378.38	.00	1.63	.04	.034	.38e-05
.102e+00	377.07	.00	.08	.04	.054	.39e-05

GLASS BEADS 2.8-2.0 MM DIA .5 MOLAR NACL RK=100.35
8/25/83 1450 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.349e+04	87.60	.18	-.98	.08	.026	.11e-04
.349e+04	87.42	.17	-1.26	.08	.045	.11e-04
.349e+04	87.82	.17	-.57	.08	.010	.11e-04
.296e+04	87.52	.15	.40	.07	.060	.11e-04
.296e+04	87.33	.17	-.27	.07	.031	.11e-04
.296e+04	87.27	.16	-1.77	.07	.051	.11e-04
.252e+04	87.53	.16	-5.51	.07	.028	.11e-04
.252e+04	87.42	.15	-3.42	.06	.161	.11e-04
.252e+04	87.38	.10	1.97	.05	.087	.11e-04
.202e+04	87.35	.26	.33	.13	.074	.11e-04
.202e+04	87.42	.26	-2.65	.13	.090	.11e-04
.202e+04	87.27	.26	-.70	.12	.068	.11e-04
.150e+04	87.62	.22	-1.44	.11	.032	.11e-04
.150e+04	87.41	.23	-.05	.11	.052	.11e-04
.150e+04	87.47	.22	-1.59	.11	.027	.11e-04
.101e+04	87.37	.17	-1.63	.08	.022	.11e-04
.101e+04	87.33	.16	-1.05	.08	.069	.11e-04
.101e+04	87.36	.17	-.42	.08	.075	.11e-04
.705e+03	87.01	.14	-2.10	.06	.059	.11e-04
.705e+03	86.89	.11	-3.87	.06	.026	.11e-04
.405e+03	86.84	1.02	.46	.51	.056	.11e-04
.404e+03	87.12	1.01	-.42	.51	.030	.11e-04
.203e+03	87.06	.00	-.28	.17	.032	.11e-04
.203e+03	87.06	.00	.65	.17	.036	.11e-04
.105e+03	87.20	.00	-.65	.03	.017	.11e-04
.105e+03	87.01	.00	1.04	.03	.021	.11e-04
.353e+02	87.15	.00	1.06	.07	.019	.11e-04
.353e+02	87.22	.00	.49	.07	.023	.11e-04
.100e+02	87.16	.00	-.46	.03	.024	.11e-04
.100e+02	87.08	.00	.91	.03	.015	.11e-04
.348e+01	87.08	.00	.58	.03	.016	.11e-04
.348e+01	87.06	.00	-.23	.03	.032	.11e-04
.988e+00	87.12	.00	.29	.03	.051	.10e-04
.988e+00	87.13	.00	.53	.03	.018	.10e-04
.352e+00	86.91	.00	-1.66	.03	.026	.91e-05
.352e+00	87.00	.00	-.51	.03	.032	.91e-05
.100e+00	87.14	.00	.21	.05	.032	.50e-05
.100e+00	86.96	.00	1.59	.05	.076	.50e-05

GLASS BEADS 850-600 UM DIA .0005 MOLAR NACL RK=101820 OHMS
8/26/83 1230 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.349e+04	74427.15	230.49	462.47	.10	.125	.16e-07
.349e+04	73965.44	284.03	467.44	.13	.160	.16e-07
.349e+04	74224.28	233.21	462.61	.11	.153	.16e-07
.299e+04	72151.42	197.91	408.73	.09	.132	.16e-07
.299e+04	71982.29	265.50	407.34	.12	.108	.16e-07
.299e+04	71870.67	230.93	400.69	.11	.097	.16e-07
.252e+04	69913.53	250.45	347.09	.11	.396	.16e-07
.252e+04	70378.24	265.00	356.72	.12	.164	.16e-07
.252e+04	69721.06	304.81	352.98	.14	.245	.16e-07
.199e+04	68068.16	290.01	284.20	.16	.044	.16e-07
.199e+04	67577.83	274.30	286.85	.15	.028	.16e-07
.199e+04	67565.57	230.26	283.79	.14	.069	.16e-07
.155e+04	66235.52	191.98	223.60	.12	.054	.16e-07
.155e+04	66356.44	260.01	226.36	.14	.036	.16e-07
.155e+04	66176.52	256.15	220.98	.14	.063	.16e-07
.105e+04	65221.03	154.90	154.74	.09	.054	.16e-07
.105e+04	65104.88	147.11	154.80	.09	.062	.16e-07
.105e+04	65185.71	202.90	154.84	.11	.045	.16e-07
.711e+03	64664.64	210.06	117.17	.11	.047	.16e-07
.711e+03	64678.77	109.67	103.91	.06	.061	.16e-07
.406e+03	64374.22	764.29	61.27	.51	.080	.16e-07
.406e+03	64136.67	766.22	61.12	.51	.084	.16e-07
.207e+03	64227.99	.00	31.80	.18	.035	.16e-07
.207e+03	64175.20	.00	32.45	.16	.048	.16e-07
.101e+03	63603.02	.00	17.02	.07	.026	.16e-07
.101e+03	63975.81	.00	17.40	.06	.018	.16e-07
.351e+02	63741.92	.00	4.34	.09	.061	.16e-07
.351e+02	63794.94	.00	6.53	.09	.047	.16e-07
.105e+02	63808.92	.00	-.02	.05	.197	.16e-07
.105e+02	63695.16	.00	2.87	.06	.161	.16e-07
.351e+01	63887.36	.00	-.99	.06	.065	.16e-07
.351e+01	63836.79	.00	1.23	.05	.043	.16e-07
.103e+01	63923.16	.00	1.04	.07	.080	.16e-07
.103e+01	63965.78	.00	-3.02	.06	.078	.16e-07
.352e+00	63693.77	.00	-.61	.06	.065	.16e-07
.352e+00	63831.72	.00	-5.30	.06	.085	.16e-07
.103e+00	63787.81	.00	2.03	.05	.054	.16e-07
.103e+00	63703.52	.00	-1.23	.07	.042	.16e-07

GLASS BEADS 850-600 UM DIA. .001 MOLAR NACL RK=10004 OHMS
8/26/83 1510 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.348e+04	40067.80	73.46	45.38	.08	.057	.88e-07
.348e+04	40055.76	87.58	47.65	.08	.052	.88e-07
.348e+04	39960.85	73.91	47.41	.07	.085	.88e-07
.302e+04	40053.11	88.05	42.69	.08	.061	.88e-07
.302e+04	39892.63	69.57	40.56	.07	.032	.88e-07
.302e+04	39934.41	71.66	39.07	.07	.059	.88e-07
.252e+04	39930.39	80.48	36.55	.08	.022	.88e-07
.252e+04	39889.00	67.44	37.40	.07	.059	.88e-07
.252e+04	40001.90	67.21	31.83	.06	.031	.88e-07
.199e+04	39870.87	128.40	29.58	.14	.050	.88e-07
.199e+04	39936.61	138.96	29.32	.14	.028	.88e-07
.199e+04	39941.62	135.68	27.38	.14	.041	.88e-07
.151e+04	39819.45	105.94	23.24	.11	.044	.88e-07
.151e+04	39852.23	102.45	20.36	.11	.033	.88e-07
.151e+04	39811.58	105.98	20.67	.11	.035	.88e-07
.997e+03	39763.80	85.58	14.07	.09	.028	.88e-07
.997e+03	39807.22	82.42	14.27	.09	.021	.88e-07
.997e+03	39859.29	75.18	13.22	.08	.016	.88e-07
.706e+03	39623.92	85.63	13.05	.08	.025	.88e-07
.706e+03	39961.00	66.32	10.71	.06	.030	.88e-07
.406e+03	39906.50	468.85	6.34	.51	.030	.87e-07
.406e+03	39615.02	467.87	6.18	.51	.028	.87e-07
.201e+03	39728.62	.00	2.62	.16	.019	.88e-07
.201e+03	39677.61	.00	4.91	.16	.034	.88e-07
.978e+02	39712.36	.00	.79	.03	.031	.88e-07
.978e+02	39706.38	.00	.56	.03	.030	.88e-07
.351e+02	39726.74	.00	.12	.07	.025	.88e-07
.351e+02	39708.65	.00	-.23	.07	.012	.87e-07
.102e+02	39732.15	.00	-2.03	.03	.018	.87e-07
.102e+02	39729.06	.00	-2.11	.03	.024	.87e-07
.352e+01	39789.45	.00	-.90	.03	.036	.86e-07
.352e+01	39758.77	.00	-.36	.03	.013	.86e-07
.102e+01	39808.27	.00	-.82	.04	.052	.84e-07
.102e+01	39806.02	.00	-.67	.03	.021	.85e-07

GLASS BEADS 850-600 UM DIA .005 MOLAR NACL RK=10004. OHMS
8/26/83 1720 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.350e+04	8589.51	33.38	8.26	.13	.059	.15e-06
.350e+04	8615.44	16.35	5.68	.08	.113	.15e-06
.350e+04	8636.32	24.94	-1.48	.10	.058	.15e-06
.301e+04	8593.74	25.78	6.54	.11	.148	.15e-06
.301e+04	8620.60	16.25	5.55	.07	.120	.15e-06
.301e+04	8631.17	17.89	7.37	.08	.063	.15e-06
.251e+04	8580.49	28.70	-4.93	.11	.592	.15e-06
.251e+04	8624.38	19.91	6.83	.08	.101	.15e-06
.251e+04	8658.46	22.31	.36	.09	.072	.15e-06
.199e+04	8619.87	30.38	4.20	.14	.164	.15e-06
.199e+04	8613.77	30.88	5.28	.15	.041	.15e-06
.199e+04	8562.07	37.23	-.89	.16	.120	.15e-06
.152e+04	8611.59	28.49	4.76	.13	.119	.15e-06
.152e+04	8610.30	26.22	2.36	.12	.106	.15e-06
.152e+04	8659.49	28.75	.01	.13	.093	.15e-06
.999e+03	8637.78	21.27	1.39	.09	.080	.15e-06
.999e+03	8638.22	21.77	.91	.10	.084	.15e-06
.999e+03	8609.26	24.55	2.62	.11	.073	.15e-06
.711e+03	8639.78	18.17	.63	.08	.096	.15e-06
.711e+03	8616.72	21.01	-.07	.09	.101	.15e-06
.403e+03	8623.13	101.53	.30	.51	.093	.15e-06
.403e+03	8608.22	101.40	.85	.51	.061	.15e-06
.205e+03	8638.11	.00	-.76	.17	.051	.15e-06
.205e+03	8643.32	.00	-1.03	.17	.044	.15e-06
.101e+03	8630.42	.00	-.88	.04	.027	.15e-06
.101e+03	8644.43	.00	2.13	.04	.093	.15e-06
.348e+02	*********	.00	2674.10	4.59	*****	.59e-07
.348e+02	32089.28	.00	745.45	2.20	*****	.57e-07
.100e+02	8629.19	.00	.23	.04	.061	.15e-06
.100e+02	8624.74	.00	1.89	.04	.048	.15e-06
.354e+01	8619.15	.00	2.23	.04	.035	.15e-06
.354e+01	8637.03	.00	.37	.04	.067	.15e-06
.100e+01	8618.91	.00	.94	.03	.050	.15e-06
.100e+01	8620.16	.00	-1.29	.04	.090	.15e-06

GLASS BEADS 850-600 UM DIA. 0.01 MOLAR NACL RK=996.72
8/26/83 1950 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.349e+04	3836.89	6.32	4.18	.08	.068	.97e-06
.349e+04	3829.99	5.92	6.31	.07	.073	.97e-06
.349e+04	3830.11	6.20	6.39	.07	.075	.97e-06
.302e+04	3829.52	5.06	6.75	.06	.024	.97e-06
.302e+04	3833.62	6.32	2.84	.07	.028	.97e-06
.302e+04	3832.60	5.94	3.19	.07	.018	.97e-06
.251e+04	3839.61	4.82	-.66	.06	.089	.97e-06
.251e+04	3829.54	4.33	6.08	.06	.050	.97e-06
.251e+04	3828.62	3.80	2.18	.06	.037	.97e-06
.202e+04	3836.03	12.27	5.45	.14	.033	.97e-06
.202e+04	3822.75	11.93	1.95	.14	.021	.97e-06
.202e+04	3827.55	11.53	4.44	.13	.030	.97e-06
.153e+04	3831.53	9.75	3.23	.11	.042	.97e-06
.153e+04	3828.86	9.73	2.19	.11	.014	.97e-06
.153e+04	3831.17	9.02	2.15	.10	.028	.97e-06
.100e+04	3836.20	6.89	.59	.08	.027	.97e-06
.100e+04	3833.40	7.29	.93	.09	.032	.97e-06
.100e+04	3832.68	7.82	1.10	.09	.023	.97e-06
.709e+03	3820.26	5.38	-4.14	.07	.019	.98e-06
.709e+03	3837.51	4.63	3.42	.06	.021	.97e-06
.405e+03	3833.00	44.55	-.80	.50	.036	.95e-06
.405e+03	3834.55	44.67	.97	.51	.021	.96e-06
.202e+03	3835.17	.00	-.80	.17	.019	.97e-06
.202e+03	3831.33	.00	-1.46	.15	.029	.97e-06
.105e+03	3840.60	.00	-2.44	.03	.016	.97e-06
.105e+03	3834.76	.00	-2.63	.03	.031	.97e-06
.345e+02	3840.01	.00	-1.43	.07	.021	.97e-06
.345e+02	3839.78	.00	-1.57	.07	.032	.97e-06
.100e+02	3843.29	.00	-.79	.03	.016	.97e-06
.100e+02	3842.60	.00	-.35	.03	.020	.97e-06
.346e+01	3846.43	.00	-.83	.03	.024	.97e-06
.346e+01	3848.25	.00	-.47	.03	.021	.96e-06
.101e+01	3836.99	.00	.70	.03	.014	.95e-06
.101e+01	3841.02	.00	1.43	.03	.029	.95e-06

GLASS BEADS 850-600 UM DIA 0.005 MOLAR NACL RK=996.72 OHMS
8/28/83 1610 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.354e+04	7629.90	13.13	7.28	.09	.088	.58e-06
.354e+04	7636.61	12.86	7.02	.09	.110	.58e-06
.354e+04	7613.28	12.52	5.69	.08	.120	.58e-06
.300e+04	7599.43	8.94	6.77	.06	.085	.58e-06
.300e+04	7622.13	10.95	7.69	.08	.095	.58e-06
.300e+04	7614.42	11.44	6.64	.08	.098	.58e-06
.252e+04	7629.35	7.95	2.40	.06	.026	.58e-06
.252e+04	7626.61	8.55	5.54	.07	.077	.58e-06
.252e+04	7628:70	10.42	8.17	.07	.083	.58e-06
.196e+04	7629.61	21.49	3.38	.13	.121	.58e-06
.196e+04	7603.28	22.19	4.77	.13	.049	.58e-06
.196e+04	7621.65	22.37	2.17	.13	.055	.58e-06
.152e+04	7619.99	20.27	1.77	.12	.026	.58e-06
.152e+04	7634.36	19.04	2.67	.11	.016	.58e-06
.152e+04	7612.66	19.86	1.29	.11	.022	.58e-06
.101e+04	7631.17	14.40	1.47	.09	.042	.58e-06
.101e+04	7610.43	13.89	.45	.09	.023	.58e-06
.101e+04	7615.97	14.04	.45	.09	.012	.58e-06
.710e+03	7632.68	3.46	3.19	.03	.027	.58e-06
.710e+03	7647.03	3.92	-.47	.03	.022	.58e-06
.401e+03	7627.17	87.90	1.57	.50	.031	.58e-06
.401e+03	7634.22	88.45	.56	.50	.031	.57e-06
.202e+03	7621.35	.00	-.67	.17	.030	.58e-06
.202e+03	7375.64	.00	-17.21	.96	1.483	.58e-06
.100e+03	7621.37	.00	-1.39	.03	.030	.58e-06
.100e+03	7635.69	.00	.59	.03	.033	.58e-06
.349e+02	7630.10	.00	-1.12	.07	.015	.57e-06
.349e+02	7624.97	.00	-.81	.07	.022	.58e-06
.996e+01	7652.92	.00	-1.10	.03	.022	.56e-06
.996e+01	7650.76	.00	-1.27	.03	.024	.56e-06
.348e+01	7456.97	.00	-33.09	.92	1.636	.57e-06
.348e+01	7645.52	.00	1.60	.03	.020	.55e-06
.991e+00	7636.86	.00	.31	.03	.016	.55e-06
.991e+00	7638.60	.00	-.65	.03	.032	.55e-06

GLASS BEADS 850-600 UM DIA 0.1 MOLAR NACL RK=100.35 OHMS
8/28/83 1825 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.353e+04	656.81	1.21	-.45	.09	.090	.57e-05
.353e+04	658.82	1.21	.52	.09	.081	.56e-05
.353e+04	656.17	1.41	1.62	.09	.131	.57e-05
.298e+04	657.04	.96	2.50	.07	.009	.57e-05
.298e+04	656.05	.88	2.05	.07	.026	.57e-05
.298e+04	659.27	1.02	-.14	.08	.110	.56e-05
.249e+04	657.30	.83	.00	.07	.091	.57e-05
.249e+04	657.69	.69	2.37	.07	.037	.56e-05
.249e+04	658.03	.87	-4.29	.08	.074	.56e-05
.200e+04	658.12	1.98	.92	.14	.010	.56e-05
.200e+04	657.64	1.88	1.26	.13	.055	.56e-05
.200e+04	657.66	2.03	1.83	.14	.022	.57e-05
.151e+04	657.56	1.65	-.78	.11	.051	.56e-05
.151e+04	657.79	1.70	.87	.11	.040	.56e-05
.151e+04	657.75	1.71	-1.24	.12	.026	.57e-05
.104e+04	656.13	1.28	2.30	.09	.029	.56e-05
.104e+04	656.66	1.31	.03	.09	.047	.56e-05
.104e+04	657.92	1.26	-1.14	.09	.053	.56e-05
.697e+03	654.27	.89	-1.48	.07	.036	.56e-05
.697e+03	656.88	.97	.36	.07	.022	.56e-05
.402e+03	656.24	7.70	-.80	.51	.031	.55e-05
.402e+03	658.19	7.54	1.56	.50	.042	.56e-05
.200e+03	657.53	.00	-.81	.16	.029	.55e-05
.200e+03	657.95	.00	1.21	.16	.017	.55e-05
.106e+03	657.14	.00	-.73	.03	.023	.55e-05
.106e+03	656.90	.00	-2.18	.03	.038	.55e-05
.350e+02	657.73	.00	.23	.07	.029	.55e-05
.350e+02	658.07	.00	1.32	.07	.015	.55e-05
.992e+01	657.72	.00	.57	.03	.017	.54e-05
.992e+01	657.72	.00	.72	.03	.016	.54e-05
.352e+01	656.76	.00	-1.05	.03	.019	.54e-05
.352e+01	657.33	.00	-.34	.04	.021	.54e-05
.102e+01	656.67	.00	.24	.04	.019	.53e-05
.102e+01	657.29	.00	-.02	.04	.023	.53e-05

GB15

GLASS BEADS 150-106 UM DIA .0005 MOLAR NACL ACIDIFIED
RK=10004. OHMS 8/29/83 1800 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.353e+04	40716.74	72.25	50.36	.07	.015	.14e-06
.353e+04	40698.96	76.06	49.13	.08	.048	.14e-06
.353e+04	40694.25	62.60	49.99	.07	.057	.14e-06
.298e+04	40610.84	60.83	42.24	.06	.027	.14e-06
.298e+04	40491.22	65.66	41.26	.07	.045	.14e-06
.298e+04	40519.45	62.33	41.73	.07	.038	.14e-06
.255e+04	40570.20	63.98	36.86	.06	.052	.14e-06
.255e+04	40515.92	64.05	35.62	.06	.052	.14e-06
.255e+04	40526.51	61.06	35.50	.06	.049	.14e-06
.201e+04	40491.75	121.27	28.97	.13	.016	.14e-06
.201e+04	40438.32	122.34	28.29	.13	.023	.14e-06
.201e+04	40401.06	118.24	29.30	.12	.047	.14e-06
.148e+04	38179.66	81.40	21.40	.09	.013	.14e-06
.150e+04	39907.68	97.46	23.19	.11	.016	.14e-06
.150e+04	39925.52	105.42	22.53	.11	.024	.14e-06
.998e+03	39850.27	88.60	15.36	.09	.025	.14e-06
.998e+03	39790.86	74.66	14.14	.08	.018	.14e-06
.998e+03	39782.44	74.38	14.78	.08	.051	.14e-06
.701e+03	39887.41	47.62	11.19	.06	.024	.14e-06
.701e+03	39802.33	58.31	9.72	.06	.026	.14e-06
.404e+03	39607.36	462.93	6.44	.51	.015	.13e-06
.404e+03	39557.01	459.90	9.05	.50	.027	.14e-06
.202e+03	39520.18	.00	3.32	.17	.015	.14e-06
.202e+03	39473.87	.00	4.84	.17	.025	.14e-06
.104e+03	38565.91	.00	1.11	.03	.010	.14e-06
.100e+03	39370.91	.00	.67	.03	.027	.14e-06
.344e+02	39262.84	.00	-.07	.07	.008	.14e-06
.344e+02	39211.52	.00	-.43	.07	.056	.14e-06
.100e+02	39159.47	.00	-.60	.03	.017	.14e-06
.100e+02	39150.21	.00	-1.65	.03	.021	.14e-06
.350e+01	39136.74	.00	-.47	.03	.032	.14e-06
.350e+01	39063.88	.00	-.13	.03	.025	.14e-06
.102e+01	38954.71	.00	-.22	.03	.027	.13e-06
.102e+01	38923.91	.00	-.11	.03	.022	.13e-06
.348e+00	38827.40	.00	.49	.03	.020	.13e-06
.348e+00	38756.34	.00	-.18	.03	.026	.13e-06
.103e+00	38675.07	.00	1.76	.03	.034	.13e-06
.103e+00	38526.02	.00	2.02	.03	.010	.13e-06

GLASS BEADS 150-106 UM DIA .001 MOLAR NACL RK=10004. OHMS
8/29/83 2010 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.352e+04	29589.99	64.84	53.98	.08	.108	.16e-06
.352e+04	29515.40	58.42	53.93	.08	.014	.16e-06
.352e+04	29505.95	54.77	54.38	.08	.074	.16e-06
.301e+04	29535.93	52.32	48.11	.07	.061	.16e-06
.301e+04	29480.97	65.20	45.42	.08	.031	.16e-06
.301e+04	29385.40	56.34	48.82	.07	.006	.16e-06
.249e+04	29410.79	50.03	37.46	.06	.073	.16e-06
.249e+04	29293.46	57.87	36.60	.07	.052	.16e-06
.249e+04	29284.79	51.03	41.35	.07	.036	.16e-06
.199e+04	29282.46	92.35	31.71	.13	.027	.16e-06
.199e+04	29221.60	100.16	31.06	.14	.031	.16e-06
.199e+04	29187.80	104.85	31.29	.14	.058	.16e-06
.149e+04	29165.33	84.91	23.21	.12	.027	.16e-06
.149e+04	29106.20	74.44	24.66	.11	.016	.16e-06
.149e+04	29072.78	75.15	24.23	.11	.039	.16e-06
.101e+04	29046.17	62.03	15.64	.09	.035	.16e-06
.101e+04	29009.92	50.74	18.82	.08	.016	.16e-06
.101e+04	28935.72	63.58	18.34	.09	.034	.16e-06
.695e+03	28916.55	30.37	8.93	.05	.020	.16e-06
.695e+03	28903.06	44.50	10.39	.06	.019	.16e-06
.404e+03	28785.66	338.19	6.66	.51	.026	.16e-06
.404e+03	28803.14	338.43	7.00	.51	.041	.16e-06
.201e+03	28689.46	.00	2.87	.17	.032	.16e-06
.201e+03	28649.99	.00	4.15	.17	.032	.16e-06
.106e+03	28598.29	.00	1.69	.03	.013	.16e-06
.106e+03	28558.98	.00	1.32	.03	.012	.17e-06
.347e+02	28554.96	.00	.10	.07	.026	.16e-06
.347e+02	28523.49	.00	-.40	.07	.014	.16e-06
.102e+02	28537.92	.00	-1.92	.03	.036	.16e-06
.102e+02	28476.88	.00	-.63	.03	.020	.16e-06
.347e+01	28500.29	.00	-.75	.03	.021	.16e-06
.347e+01	28463.26	.00	-1.96	.03	.014	.16e-06
.102e+01	28441.93	.00	-.74	.03	.007	.16e-06
.102e+01	28407.09	.00	-.01	.03	.008	.16e-06
.349e+00	28345.99	.00	.61	.03	.024	.16e-06
.349e+00	28285.52	.00	-.32	.03	.017	.16e-06
.100e+00	28155.29	.00	2.37	.04	.026	.16e-06
.100e+00	28035.94	.00	.61	.03	.014	.16e-06

GLASS BEADS 150-106 UM DIA 0.01 MOLAR NACL RK=996.72 OHMS
8/30/83 1315 HRS JGH

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.350e+04	3522.33	5.55	5.12	.08	.078	.12e-05
.350e+04	3521.92	5.87	5.62	.07	.010	.12e-05
.350e+04	3521.88	5.77	7.39	.07	.037	.12e-05
.299e+04	3526.84	5.10	3.11	.06	.066	.12e-05
.299e+04	3521.99	5.68	2.88	.07	.045	.12e-05
.299e+04	3525.41	5.07	4.79	.06	.034	.12e-05
.249e+04	3510.58	3.91	.89	.05	.060	.12e-05
.249e+04	3512.27	4.17	8.05	.06	.051	.12e-05
.249e+04	3519.90	4.08	6.58	.06	.097	.12e-05
.200e+04	3516.55	10.08	2.95	.13	.027	.12e-05
.200e+04	3511.98	10.47	2.66	.13	.024	.12e-05
.200e+04	3517.55	10.69	3.83	.13	.033	.12e-05
.151e+04	3510.68	9.01	2.40	.11	.053	.12e-05
.151e+04	3516.26	9.11	2.43	.11	.010	.12e-05
.151e+04	3510.91	8.93	3.16	.11	.021	.12e-05
.999e+03	3512.56	6.50	2.54	.09	.018	.12e-05
.999e+03	3516.16	6.95	.98	.09	.035	.12e-05
.999e+03	3510.62	6.89	1.24	.08	.036	.12e-05
.700e+03	3505.77	4.94	.32	.05	.023	.12e-05
.700e+03	3520.96	4.54	-.21	.05	.036	.12e-05
.400e+03	3510.30	41.00	-.04	.51	.019	.12e-05
.400e+03	3505.28	40.83	.03	.50	.019	.12e-05
.199e+03	3511.60	.00	-1.24	.15	.023	.12e-05
.199e+03	3506.64	.00	.46	.17	.018	.12e-05
.102e+03	3509.77	.00	.33	.03	.020	.12e-05
.102e+03	3514.50	.00	-.59	.02	.016	.12e-05
.351e+02	3511.36	.00	-1.32	.07	.024	.12e-05
.351e+02	3513.47	.00	-1.04	.07	.044	.12e-05
.998e+01	3515.93	.00	-.63	.02	.041	.11e-05
.998e+01	3516.82	.00	.09	.02	.024	.11e-05
.349e+01	3509.95	.00	.42	.02	.022	.11e-05
.349e+01	3513.41	.00	.72	.02	.030	.11e-05
.994e+00	3509.03	.00	1.10	.03	.033	.11e-05
.994e+00	3509.58	.00	.56	.03	.025	.11e-05
.346e+00	3504.53	.00	-.09	.03	.009	.11e-05
.346e+00	3501.23	.00	-.74	.02	.021	.11e-05
.101e+00	3501.77	.00	.56	.03	.009	.11e-05
.101e+00	3498.16	.00	.36	.03	.021	.11e-05

GLASS BEADS 150-106 UM DIA 0.05 MOLAR NACL RK=100.35 OHMS
8/30/83

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.353e+04	785.82	1.17	.13	.06	.021	.63e-05
.353e+04	785.78	1.14	.57	.07	.009	.64e-05
.353e+04	785.78	1.14	.57	.07	.009	.64e-05
.297e+04	785.80	1.06	.27	.06	.047	.63e-05
.297e+04	786.22	1.15	1.03	.06	.013	.63e-05
.297e+04	784.96	1.05	1.95	.06	.031	.64e-05
.250e+04	783.79	.87	-1.85	.05	.100	.64e-05
.250e+04	786.52	.71	-1.81	.05	.019	.63e-05
.250e+04	785.02	.91	.91	.05	.134	.63e-05
.201e+04	784.24	2.32	1.57	.14	.043	.63e-05
.201e+04	784.45	2.28	-.63	.13	.053	.63e-05
.201e+04	784.51	2.33	.14	.13	.051	.63e-05
.150e+04	785.47	1.96	.70	.11	.014	.63e-05
.150e+04	784.70	1.93	1.71	.11	.032	.63e-05
.150e+04	784.89	1.96	.62	.12	.029	.63e-05
.996e+03	783.72	1.41	-1.31	.08	.018	.63e-05
.996e+03	784.56	1.43	-.67	.08	.027	.63e-05
.996e+03	784.60	1.43	-.05	.08	.024	.63e-05
.706e+03	783.85	1.05	-1.52	.06	.026	.63e-05
.707e+03	781.55	.97	-5.15	.06	.030	.63e-05
.407e+03	784.88	9.41	.89	.52	.012	.63e-05
.407e+03	783.62	9.10	-.94	.50	.059	.62e-05
.201e+03	784.79	.00	-.91	.16	.036	.62e-05
.201e+03	785.16	.00	-.64	.16	.031	.62e-05
.999e+02	785.00	.00	.60	.03	.025	.62e-05
.999e+02	786.55	.00	-2.11	.03	.035	.62e-05
.348e+02	785.70	.00	-.15	.07	.030	.61e-05
.348e+02	784.60	.00	.64	.07	.069	.61e-05
.974e+01	783.22	.00	.06	.03	.034	.61e-05
.974e+01	785.49	.00	.30	.03	.021	.61e-05
.347e+01	785.05	.00	.42	.03	.023	.61e-05
.347e+01	783.50	.00	.79	.03	.028	.61e-05
.100e+01	784.44	.00	.94	.03	.021	.60e-05
.100e+01	783.59	.00	.81	.03	.018	.60e-05

GLASS BEADS 150-106 UM DIA 0.1 MOLAR NACL RK=100.35

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
3540.	407.1	0.6	1.3	0.1	0.07	10.
2980.	407.2	0.6	0.9	0.1	0.05	10.
2470	406.9	0.5	1.0	0.1	0.05	10.
2010.	407.2	1.2	-0.3	0.1	0.04	10.
1540.	407.1	1.0	-0.8	0.1	0.02	10.
1000.	407.0	0.8	-1.6	0.1	0.02	10.
702.	405.4	0.6	1.2	0.1	0.02	10.
404.	407.0	4.75	0.5	0.5	0.02	10.
205.	407.1	0.0	-0.6	0.2	0.02	10.
103.	407.5	0.0	-1.0	0.0	0.02	10.
35.0	407.0	0.0	0.9	0.1	0.03	10.
10.5	406.4	0.0	1.0	0.0	0.03	10.
3.47	406.4	0.0	0.2	0.0	0.03	9.7
1.00	405.7	0.0	0.9	0.0	0.03	8.6

GLASS BEADS 2.8-2.0 MM 3 % WT NA MONT 0.1 MOLAR NACL RK=100.35
8/31/83 1410 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.347e+04	374.73	.69	-7.45	.08	.062	.73e-05
.347e+04	375.27	.55	-6.96	.07	.029	.73e-05
.300e+04	374.44	.44	-4.35	.06	.028	.73e-05
.300e+04	375.31	.46	-7.58	.06	.036	.73e-05
.250e+04	376.58	.58	-9.55	.07	.055	.73e-05
.250e+04	375.33	.43	-5.91	.06	.080	.73e-05
.201e+04	360.63	22.32	-90.91	1.90	4.348	.73e-05
.201e+04	375.52	1.13	-8.05	.14	.052	.73e-05
.150e+04	376.45	.93	-8.02	.11	.044	.73e-05
.150e+04	376.22	.94	-8.58	.11	.058	.73e-05
.987e+03	377.41	.74	-7.29	.08	.014	.73e-05
.987e+03	377.19	.73	-8.56	.09	.025	.73e-05
.706e+03	379.32	.51	-9.88	.06	.019	.72e-05
.706e+03	379.15	.57	-8.08	.07	.019	.72e-05
.404e+03	379.85	4.42	-5.97	.50	.030	.72e-05
.404e+03	378.98	4.42	-5.91	.50	.034	.72e-05
.200e+03	380.89	.00	-5.77	.16	.015	.71e-05
.200e+03	380.51	.00	-6.07	.17	.013	.71e-05
.101e+03	382.15	.00	-4.93	.03	.017	.71e-05
.101e+03	381.65	.00	-2.94	.03	.027	.71e-05
.704e+02	381.53	.00	-3.86	.15	.025	.70e-05
.704e+02	381.71	.00	-3.30	.15	.040	.71e-05
.398e+02	382.19	.00	-.91	.03	.022	.70e-05
.398e+02	382.22	.00	-.88	.03	.042	.70e-05
.200e+02	382.26	.00	-.42	.03	.021	.70e-05
.200e+02	382.14	.00	-.11	.03	.038	.70e-05
.100e+02	382.18	.00	.06	.03	.026	.70e-05
.100e+02	381.77	.00	.29	.02	.035	.70e-05
.708e+01	381.83	.00	-.52	.04	.021	.70e-05
.708e+01	381.41	.00	.05	.04	.017	.70e-05
.400e+01	381.20	.00	-.30	.03	.024	.70e-05
.400e+01	380.91	.00	.48	.03	.048	.70e-05
.199e+01	381.27	.00	-.67	.03	.058	.69e-05
.199e+01	381.13	.00	-.27	.03	.026	.69e-05
.102e+01	381.35	.00	-.33	.03	.039	.68e-05
.102e+01	381.11	.00	-.08	.03	.019	.68e-05
.719e+00	381.02	.00	-.17	.03	.020	.67e-05
.719e+00	381.79	.00	-.95	.03	.029	.67e-05
.396e+00	381.65	.00	.29	.03	.028	.62e-05

.396e+00	382.11	.00	-.16	.04	.018	.62e-05
.198e+00	381.42	.00	-1.19	.04	.025	.51e-05
.198e+00	381.58	.00	.07	.04	.026	.51e-05
.993e-01	382.59	.00	-.61	.06	.039	.35e-05
.993e-01	382.41	.00	.15	.05	.021	.35e-05
.696e-01	380.34	.00	.86	.07	.041	.28e-05
.696e-01	382.16	.00	-3.50	.07	.060	.27e-05
.398e-01	380.99	.00	3.10	.13	.183	.18e-05
.398e-01	382.29	.00	-3.12	.11	.164	.18e-05
.197e-01	386.21	.00	17.39	.31	.210	.95e-06
.197e-01	372.65	.00	-8.38	.32	.254	.95e-06
.985e-02	398.54	.00	2.07	.82	.501	.51e-06
.347e-02	234.94	.00	-61.21	7.42	8.024	.19e-06
.101e-02	485.23	.00	3274.90	6.73	*****	.55e-07

GLASS BEADS 2.8-2.0 MM 3 % NA-MONT 0.05 MOLAR NACL RK=100.35
8/31/83 2300HRS JGH

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.350e+04	465.24	.86	-7.64	.09	.083	.62e-05
.350e+04	464.51	.77	-10.18	.08	.020	.62e-05
.299e+04	464.31	.65	-9.79	.07	.117	.62e-05
.299e+04	464.66	.61	-8.02	.07	.091	.62e-05
.249e+04	466.84	.56	-7.40	.07	.055	.62e-05
.249e+04	465.43	.53	-11.42	.07	.050	.62e-05
.197e+04	466.75	1.41	-9.06	.13	.049	.62e-05
.197e+04	466.69	1.41	-8.23	.13	.023	.62e-05
.149e+04	467.70	1.18	-9.82	.11	.027	.62e-05
.149e+04	468.12	1.16	-9.86	.12	.032	.62e-05
.997e+03	470.31	.84	-11.24	.08	.039	.62e-05
.997e+03	468.95	.87	-9.28	.08	.024	.62e-05
.701e+03	471.51	.58	-7.02	.07	.038	.62e-05
.701e+03	467.65	.57	-11.52	.07	.027	.62e-05
.402e+03	472.83	5.51	-8.92	.50	.028	.60e-05
.402e+03	472.49	5.41	-6.55	.50	.016	.61e-05
.200e+03	474.77	.00	-7.98	.15	.027	.60e-05
.200e+03	475.18	.00	-8.26	.16	.012	.60e-05
.102e+03	476.92	.00	-5.78	.02	.036	.60e-05
.102e+03	477.09	.00	-7.44	.02	.015	.60e-05
.697e+02	478.87	.00	-4.83	.15	.028	.59e-05
.697e+02	478.22	.00	-4.76	.15	.023	.59e-05
.398e+02	478.71	.00	-3.02	.03	.017	.59e-05
.398e+02	480.06	.00	-3.52	.03	.034	.59e-05
.201e+02	479.69	.00	-2.31	.03	.011	.58e-05
.200e+02	479.65	.00	-2.14	.03	.031	.58e-05
.101e+02	479.48	.00	.28	.03	.051	.58e-05
.101e+02	480.66	.00	-.39	.02	.032	.58e-05
.731e+01	480.43	.00	.03	.04	.027	.58e-05
.731e+01	479.66	.00	-.60	.04	.020	.58e-05
.400e+01	479.98	.00	.57	.03	.025	.58e-05
.400e+01	480.18	.00	-.44	.03	.021	.58e-05
.202e+01	479.92	.00	.88	.03	.015	.58e-05
.201e+01	479.64	.00	.50	.04	.038	.58e-05
.103e+01	479.99	.00	.75	.13	.024	.57e-05
.103e+01	479.86	.00	-.49	.12	.034	.57e-05
.693e+00	481.18	.00	.74	.03	.023	.56e-05
.693e+00	480.72	.00	.34	.04	.022	.56e-05
.400e+00	481.11	.00	.12	.04	.037	.53e-05

.401e+00	480.91	.00	-.48	.06	.047	.53e-05
.198e+00	481.82	.00	-1.46	.04	.041	.45e-05
.198e+00	482.45	.00	-.78	.04	.025	.45e-05
.100e+00	481.75	.00	4.42	.07	.039	.33e-05
.745e-01	481.99	.00	5.15	1.34	.059	.24e-05
.398e-01	480.09	.00	18.38	.11	.108	.17e-05
.101e-01	536.68	.00	35.50	.98	.927	.17e-05
.348e-02	517.39	6.04	14.75	.40	.501	.18e-05

.400e+00	897.84	.00	-.67	.03	.025	.22e-05
.201e+00	898.97	.00	-1.50	.03	.006	.22e-05
.201e+00	898.82	.00	-1.96	.03	.015	.22e-05
.984e-01	898.84	.00	.98	.03	.015	.21e-05
.348e-01	902.80	.00	-1.83	.06	.085	.17e-05
.100e-01	905.11	.00	-18.58	.20	.140	.85e-06
.353e-02	917.06	.00	-25.65	.32	.224	.93e-06
.103e-02	899.14	.00	-14.79	.71	.381	.87e-06

CG4

GLASS BEADS 2.8-2.0 MM 3% NA-MONT 0.005 MOLAR NACL RK=996.72
9/6/83 1145 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.352e+04	2468.77	3.64	-33.90	.07	.051	.25e-05
.352e+04	2468.60	3.53	-33.83	.06	.025	.25e-05
.301e+04	2479.81	2.92	-33.54	.05	.035	.25e-05
.301e+04	2478.15	3.02	-32.42	.06	.017	.25e-05
.249e+04	2488.40	2.71	-30.65	.05	.045	.25e-05
.249e+04	2489.46	2.87	-35.09	.05	.045	.25e-05
.200e+04	2503.10	7.46	-31.18	.13	.006	.25e-05
.200e+04	2502.13	7.44	-31.55	.13	.015	.25e-05
.149e+04	2517.53	6.15	-30.26	.11	.019	.25e-05
.149e+04	2516.13	6.11	-30.32	.11	.015	.20e-05
.102e+04	2534.18	4.84	-29.12	.08	.021	.20e-05
.102e+04	2536.55	4.72	-28.54	.08	.018	.20e-05
.702e+03	2551.49	3.52	-27.35	.06	.013	.20e-05
.403e+03	2569.95	29.69	-20.12	.50	.028	.20e-05
.201e+03	2596.89	.00	-18.97	.17	.012	.20e-05
.106e+03	2616.39	.00	-15.56	.02	.019	.19e-05
.715e+02	2626.51	.00	-15.08	.15	.013	.19e-05
.398e+02	2638.15	.00	-12.18	.02	.016	.19e-05
.202e+02	2651.59	.00	-10.79	.02	.009	.19e-05
.988e+01	2661.64	.00	-8.13	.02	.006	.18e-05
.705e+01	2667.66	.00	-6.96	.03	.014	.18e-05
.398e+01	2672.30	.00	-4.45	.02	.012	.18e-05
.202e+01	2674.95	.00	-2.46	.02	.018	.18e-05
.103e+01	2675.10	.00	-1.47	.02	.009	.18e-05
.715e+00	2672.23	.00	-.51	.02	.019	.18e-05
.400e+00	2675.64	.00	-.91	.03	.024	.13e-05
.199e+00	2676.83	.00	-.87	.03	.013	.13e-05
.105e+00	2676.22	.00	-.88	.03	.033	.13e-05
.738e-01	2682.02	.00	.95	1.20	.035	.12e-05
.420e-01	2686.78	.00	.96	1.07	.050	.11e-05
.200e-01	2693.43	.00	-5.31	.08	.079	.94e-06
.102e-01	2654.64	.00	-17.31	.21	.169	.65e-06
.304e-02	2703.55	.00	-37.72	5.28	.278	.16e-06

CG5

GLASS BEADS 2.8-2.0 MM 3% NA-MONT 0.001 MOLAR NACL RK=10004
9/6/83 1440 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.348e+04	3530.62	15.36	4.36	.14	.302	.36e-06
.348e+04	3536.40	15.96	4.97	.15	.033	.36e-06
.299e+04	3552.98	11.30	6.48	.11	.055	.36e-06
.299e+04	3557.43	11.85	1.60	.11	.122	.36e-06
.250e+04	3569.72	10.89	1.68	.11	.107	.36e-06
.250e+04	3558.07	12.38	-3.84	.11	.130	.36e-06
.204e+04	3563.43	20.05	-4.03	.20	.070	.36e-06
.204e+04	3585.83	13.99	-6.46	.15	.145	.36e-06
.150e+04	3600.18	13.13	-9.96	.14	.085	.36e-06
.150e+04	3607.46	10.52	-11.54	.12	.056	.36e-06
.101e+04	3640.39	10.86	-12.15	.11	.072	.36e-06
.101e+04	3633.02	8.50	-18.88	.09	.062	.36e-06
.704e+03	3647.86	8.42	-15.34	.08	.054	.36e-06
.403e+03	3668.68	43.13	-19.60	.51	.042	.35e-06
.202e+03	3708.72	.00	-17.44	.16	.036	.35e-06
.106e+03	3728.05	.00	-17.02	.06	.039	.35e-06
.716e+02	3764.08	.00	-17.72	.17	.049	.35e-06
.399e+02	3788.59	.00	-19.28	.06	.037	.35e-06
.201e+02	3809.48	.00	-16.24	.06	.131	.35e-06
.998e+01	3845.97	.00	-18.21	.06	.032	.35e-06
.701e+01	3860.92	.00	-18.62	.07	.075	.35e-06
.400e+01	3904.03	.00	-22.96	.06	.008	.34e-06
.199e+01	3944.02	.00	-19.96	.06	.062	.34e-06
.100e+01	3983.11	.00	-16.63	.06	.052	.33e-06
.647e+00	4008.83	.00	-12.62	.06	.063	.33e-06
.396e+00	4033.05	.00	-13.75	.06	.033	.33e-06
.200e+00	4053.19	.00	-9.60	.07	.032	.33e-06
.988e-01	4096.77	.00	-7.02	.10	.076	.33e-06
.665e-01	4106.47	.00	-3.87	.12	.061	.33e-06
.398e-01	4146.22	.00	-4.39	.18	.221	.33e-06
.200e-01	4206.84	.00	-9.41	.30	.297	.32e-06
.101e-01	4195.97	.00	-46.36	.49	.541	.30e-06
.349e-02	4011.28	.00	86.62	1.21	1.447	.24e-06

CG6

GLASS BEADS 2.8-2.0 MM 3% NA-MONT. 0.0005 MOLAR NACL RK=10004.
9/6/83 1900 HRS

FREQ (hz)	IMP MAG (ohm-cm)	S.D. (ohm-cm)	PHASE (mrads)	S.D. (mrads)	THD (%)	J (amp/cm^2)
.346e+04	6768.23	12.86	26.49	.07	.069	.29e-06
.346e+04	6770.64	17.43	27.78	.09	.065	.29e-06
.299e+04	6772.44	16.93	19.55	.08	.091	.29e-06
.299e+04	6768.58	12.42	20.14	.07	.055	.29e-06
.250e+04	6790.51	12.61	13.70	.07	.178	.29e-06
.250e+04	6750.28	19.45	15.13	.10	.181	.29e-06
.200e+04	6841.18	22.13	6.81	.13	.077	.29e-06
.200e+04	6820.57	24.24	4.80	.14	.027	.29e-06
.150e+04	6851.46	19.85	.06	.12	.049	.29e-06
.150e+04	6866.98	17.65	2.32	.11	.069	.29e-06
.101e+04	6913.94	15.35	-6.80	.09	.060	.29e-06
.101e+04	6890.70	13.72	-6.28	.08	.078	.29e-06
.697e+03	6931.44	18.46	-15.51	.09	.034	.29e-06
.403e+03	6998.57	83.04	-15.86	.51	.040	.28e-06
.202e+03	7047.91	.00	-13.11	.17	.024	.28e-06
.101e+03	7087.62	.00	-13.84	.06	.023	.28e-06
.696e+02	7142.54	.00	-9.19	.16	.023	.28e-06
.400e+02	7169.39	.00	-14.33	.06	.030	.28e-06
.199e+02	7212.22	.00	-13.47	.06	.021	.28e-06
.991e+01	7278.14	.00	-16.08	.06	.032	.28e-06
.704e+01	7303.92	.00	-13.91	.06	.028	.28e-06
.399e+01	7356.75	.00	-15.40	.06	.023	.28e-06
.199e+01	7415.41	.00	-15.01	.06	.005	.27e-06
.101e+01	7466.27	.00	-12.32	.06	.018	.27e-06
.684e+00	7504.33	.00	-10.50	.06	.022	.27e-06
.396e+00	7534.48	.00	-7.82	.06	.088	.26e-06
.198e+00	7557.36	.00	-5.46	.03	.038	.26e-06
.102e+00	7608.34	.00	-2.81	.03	.032	.26e-06
.706e-01	7610.44	.00	-2.48	.03	.045	.26e-06
.399e-01	7639.37	.00	-.31	.03	.015	.26e-06
.211e-01	7701.75	.00	6.47	1.21	.031	.24e-06
.992e-02	7808.69	.00	6.48	.08	.077	.25e-06
.347e-02	8275.25	.00	-69.97	1.01	1.034	.21e-06