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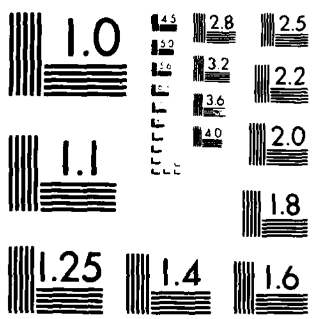

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FC EFI-1

EMP FACILITIES INTERACTION

1 MARCH 1980

FIELD COMMAND
DEFENSE NUCLEAR AGENCY
ALBUQUERQUE, NEW MEXICO, 87115

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TRESTLE	EMP
HPD	Interaction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Electromagnetic Interaction of EMP facilities on Kirtland AFB was investigated and evaluated. Personnel safety from a physiological viewpoint is addressed and energy comparisons made.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTINUED)

1. INTRODUCTION:

In a September 1979 message, HQDNA expressed concern over potential electromagnetic interaction between the Advanced Research Electromagnetic Pulse Simulator (ARES) and TRESTLE EMP facilities. In a subsequent message, HQAFSC Andrews AFB, MD extended this concern to include all EMP facilities located at Kirtland Air Force Base, New Mexico.

There are four major EMP facilities that are of interest in this potential interaction. Three are under the control of the Air Force Weapons Lab (AFWL) and one is under the control of the Field Command, Defense Nuclear Agency (FCDNA). The AFWL facilities are the Horizontally Polarized Dipole (HPD), Vertically Polarized Dipole (VPD), and TRESTLE. The FCDNA facility is the ARES. These four facilities are constructed within a close proximity of one another (see figure one), thus generating a possible interaction in the far field. The TRESTLE and ARES facilities are bounded wave simulators and the HPD and VPD are radiating simulators. Each facility was designed to do a specific job by producing horizontally or vertically polarized $\vec{E}$ fields. TRESTLE and HPD are horizontally polarized, and the ARES and VPD are vertically polarized. Within design limitations, these facilities produce $\vec{E}$ field strengths up to 100 Kilovolts per meter (KV/m). Each simulator, bounded or not, radiates outward from its own source. These outward radiations could potentially cause several problems.

a) Personnel Safety Hazards.

b) Test Object Degradations.

c) Introduction of false triggers in test instrumentation.

d) Generation of unusable EMP environments.

e) Introduction of false data records.

f) Test support equipment damage or upsets.

Beginning the second week of October 1979, FCDNA personnel began an extensive investigation into the EMP facility interaction. The objectives of the investigation were to determine:

a) Is there an EMP interaction problem?

b) What is the extent of the interaction?

c) What is the potential impact on test operations?

d) What corrective actions are needed?

This report discusses FCDNA findings, corrective actions, and makes recommendations for potential ARES users.

EMP FACILITIES LOCATION

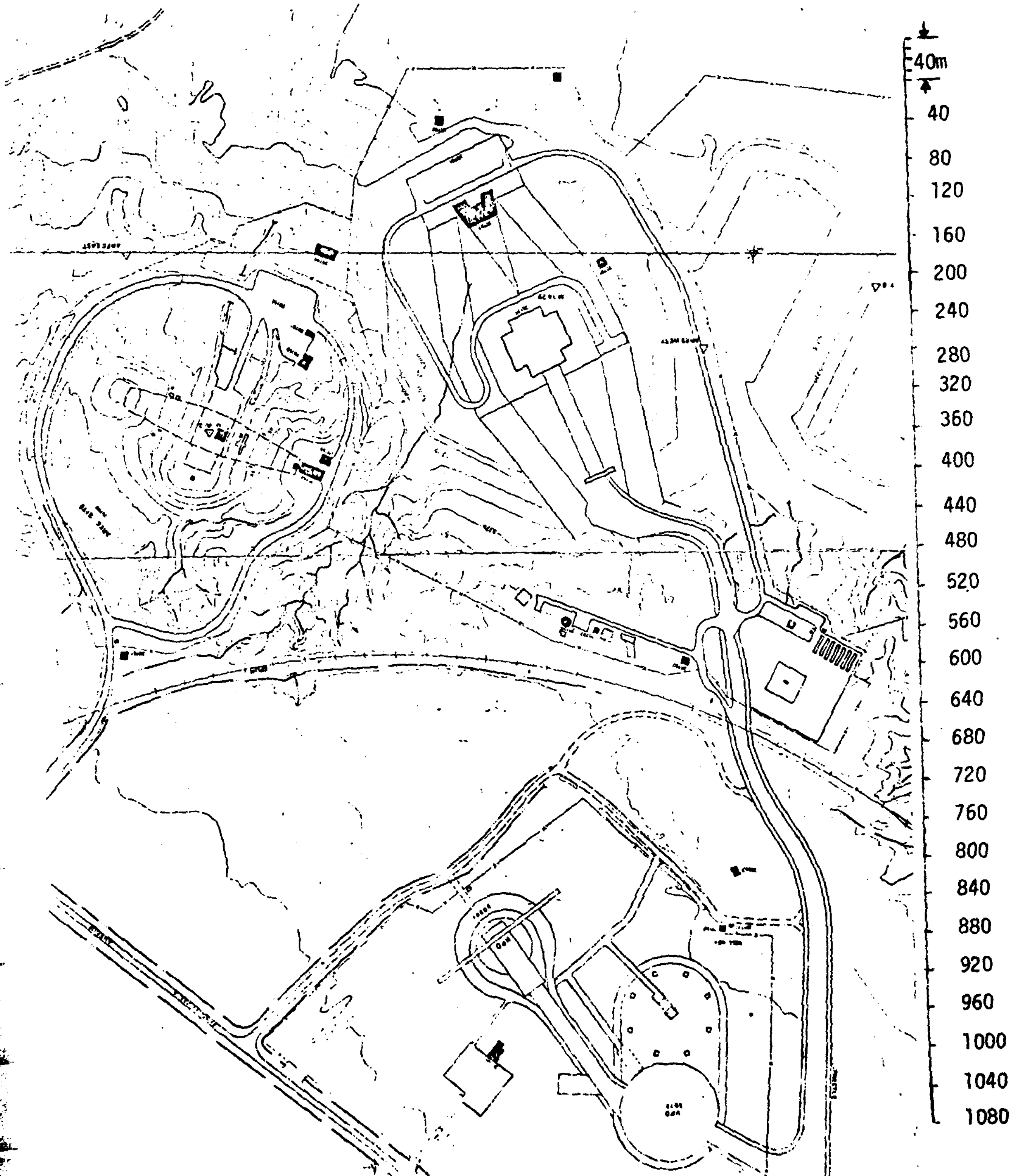


FIGURE 1-1

2. SAFETY:

The question of safety in a simulated High Altitude EMP (HEMP) test environment is an area where very little information is available. Most documentation deals with standardized safety procedures associated with accomplishment of the daily workload. Only a small amount of information is available that attempts to directly relate unique Electromagnetic Pulse (EMP) hazards to the propagating Electromagnetic (EM) field. One very good reference is AF regulation 161-42 dated 7 November 1975 and titled "Radio-frequency Radiation Health Hazards Control." This document defines the acceptable $\vec{E}$ field level for personnel exposure as less than or equal to 100 KV/m and describes the most probable hazard as "Startle hazard due to a reflex response."

Standard safety procedures will minimize the startle hazard. Standard safety procedures include but are not necessarily limited to:

a) No personnel are permitted inside of the working volume during pulser operations.

b) Working volume is monitored by closed circuit television.

c) Safety railings are installed at all levels of the isolation support stand (ISS).

Although the above precedures work well for control of personnel during local pulser operations, it does not prevent the possibility of personnel being present at the time that EMI from another facility arrives. These personnel could be reconfiguring the test object for the next series of test points. It is during this time that personnel are the most vulnerable and is the reason for making the measurements shown in Table 2-1 and graphically displayed in Figures 2-2, 2-3, 2-4, and 2-5. The currents shown are peak values.

Figure 2-1 illustrates the configuration used for measuring the current flow between a missile umbilical cable and the metallic portion of the missile skin. Provisions were made for grounding the Zipper Tubing containing the umbilical cable, and the missile skin. The symbol (S) represents a Tektronix 485 oscilloscope and isolation box used to photograph the current waveform. R was varied from 0-100K ohms and current measurements were made. Existing conditions and measured results are displayed in Table 2-1.

Although the amount of data is limited, there is sufficient data for a simple determination of the potential hazard. The following criteria were used to analyze the data:

a) Data discussed in section five of this report indicates that the EMI levels at ARES from other facilities are 1 KV/m or less with 1.5 KV/m as worst case if TRESTLE is operated at 100%.

b) Measurements at 250 V/m are related to 1.5 KV/m by the factor 1500/250 = 6.

c) A typical resistance for the human body is 1 KΩ - 1 MΩ.

d) Minimum lethal current for a human being is 1/10 amp flowing through the heart for 1 second at a frequency of 60 hz. (References 1, 2, 3, and 4 of this section verify (c) and (d), see figure 2-6).

e) A typical pulse duration is .7 micro-second.

f) R may represent the human body if personnel were to place themselves between the umbilical cable, etc and the missile.

g) Curve number 1 of Figure 2-5 and Figure 2-2 are worst case.

COMPUTATION OF ENERGY LETHAL TO HUMAN BEINGS

$$\text{Energy}_{1K}\ (U) = I^2\ R\ t \qquad (2\text{-}1)$$

$$= (.1)^2(1000)(1)\ \text{Joules (J)}$$

$$= (.01)(10^3) = 10\ \text{J}$$

Lethal range of energies for current flow through the human heart is 10 Joules or more

COMPUTATION OF ENERGY FOR CRITERIA f OF THIS SECTION

The current waveform of the ARES is a double exponential of the form:

$$i(t) = A(e^{-\alpha t} - e^{-\beta t}) \qquad (2\text{-}2)$$

where:

$$A = \text{amplitude (amps)}$$

$$\alpha = 2.3/^{t}\text{decay}$$

$$\beta = 2.3/t_{rise}$$

$$t_{decay} = 700\text{ns}$$

$$t_{rise} = 5\text{ns}$$

If the rms value of current is computed using the following:

$$I_{RMS} = \frac{A}{\sqrt{T}} \sqrt{\int_{-\infty}^{\infty} (e^{-\alpha t} - e^{-\beta t})^2 dt} \qquad (2\text{-}3)$$

where:

$$T = t_{rise} + t_{decay}$$

$$t_{rise} << t_{decay}$$

$$T \doteq t_{decay}$$

Carrying out the integration yields an RMS current of approximately 0.4A amps.

The maximum power transfer theorem states that "Maximum power is transferred to the load with $Z_{load} = Z_{source}$." This implies that maximum energy (U) is transferred when $I = I_{SC}/2$.

Therefore:

$$U_{max} = ((I_{SC}/2)(.4)(6))^2 \times Z_{source} \times \text{ pulse duration} \quad (2\text{-}4)$$

$$= ((4.93)(.4)(6))^2 \times 600 \times .7 \times 10^{-6} \text{ J}$$

$$= 58.8 \text{ mJ} \qquad (\text{For } \vec{E} = 1.5 \text{ KV/m})$$

The power transferred to the worst case human body impedance is therefore:

$$U = (I_{1000} \times .4 \times 6)^2 \times 1 \times 10^3 \times .7 \times 10^{-6} \text{ J}$$

$$= (3.8 \times .4 \times 6)^2 \times 1 \times 10^3 \times .7 \times 10^{-6} \text{ J}$$

$$= 58.2 \text{ mJ} \qquad (\text{For } \vec{E} = 1.5 \text{ KV/m})$$

These energies are much less than the minimum amount considered lethal to a human being. However, these energies do support the startle hazard hypothesis.

This simple interpretation is not intended to be a rigorous proof that a hazard does or does not exist. It does point out that a potential hazard does exist and that personnel could possibly become the inadvertant load between two potential surfaces. Until a rigorous study can be done, facility users should be aware that this hazard exists and that precautions should be taken.

SAFETY CURRENT MEASUREMENT CONFIGURATION

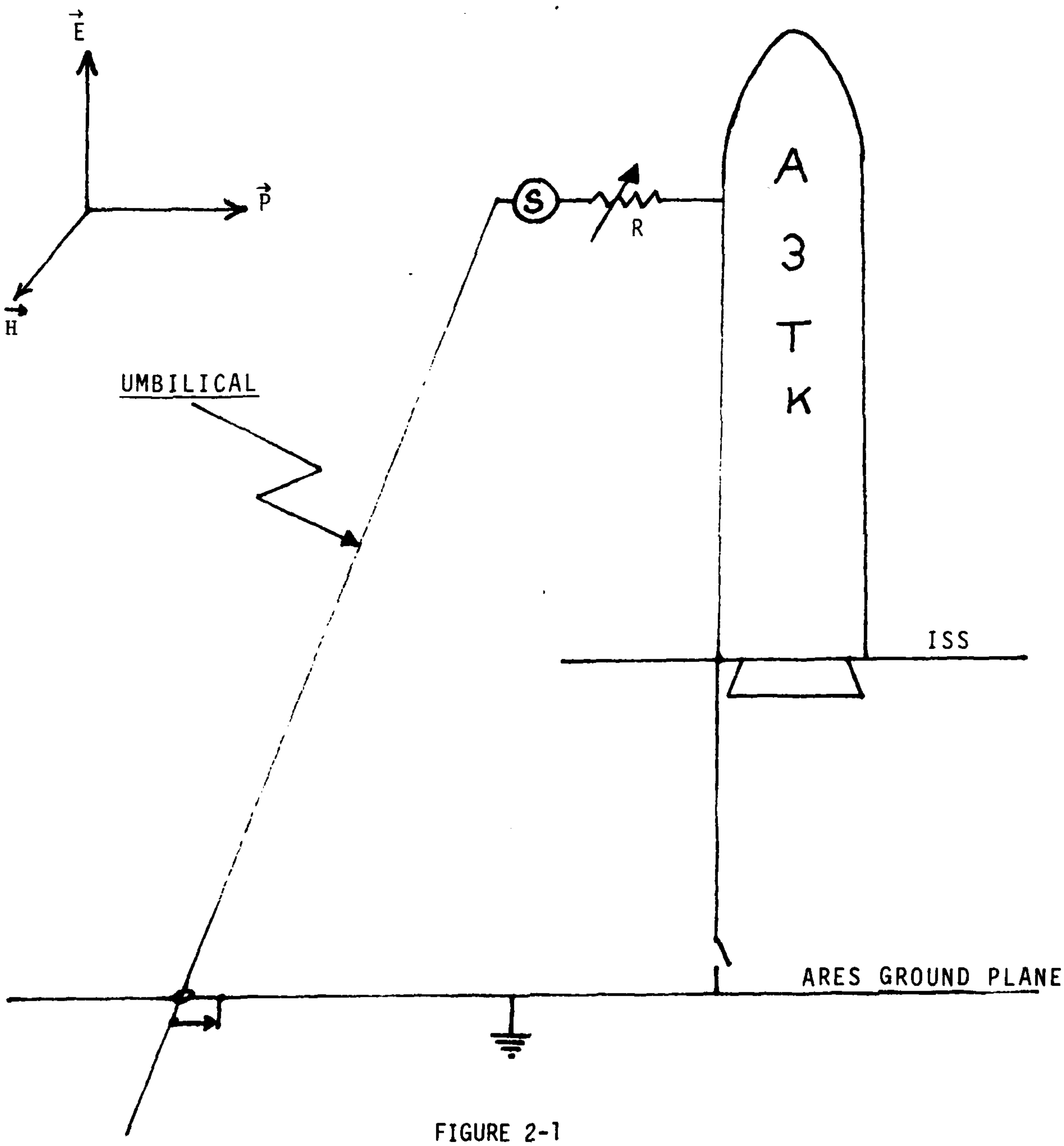


FIGURE 2-1

A3TK UMBILICAL CURRENT

(Missile and Zipper Tubing Grounded)

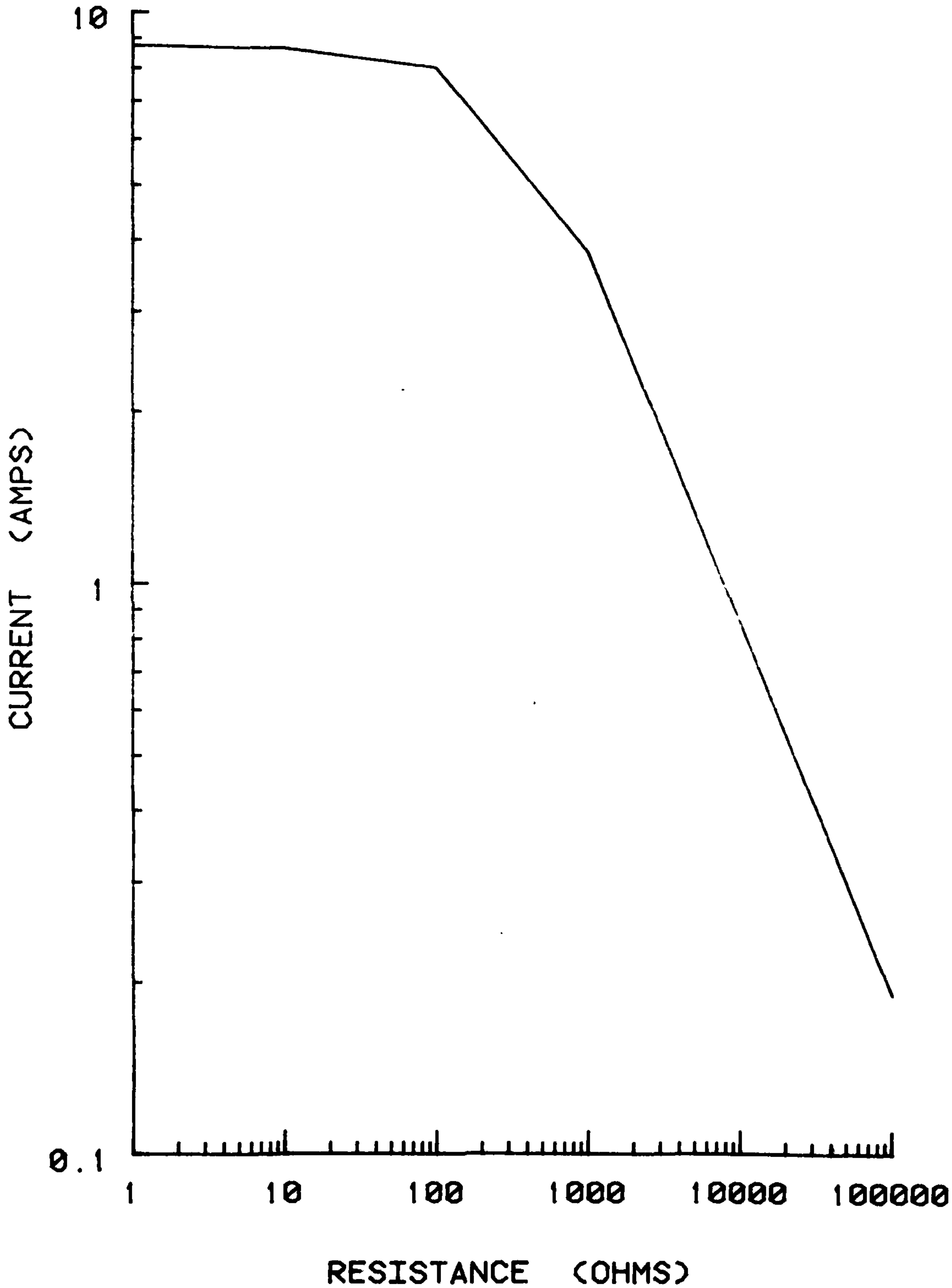


FIGURE 2-2

A3TK UMBILICAL CURRENT

(Missile Grounded: Zipper Tubing Ungrounded)

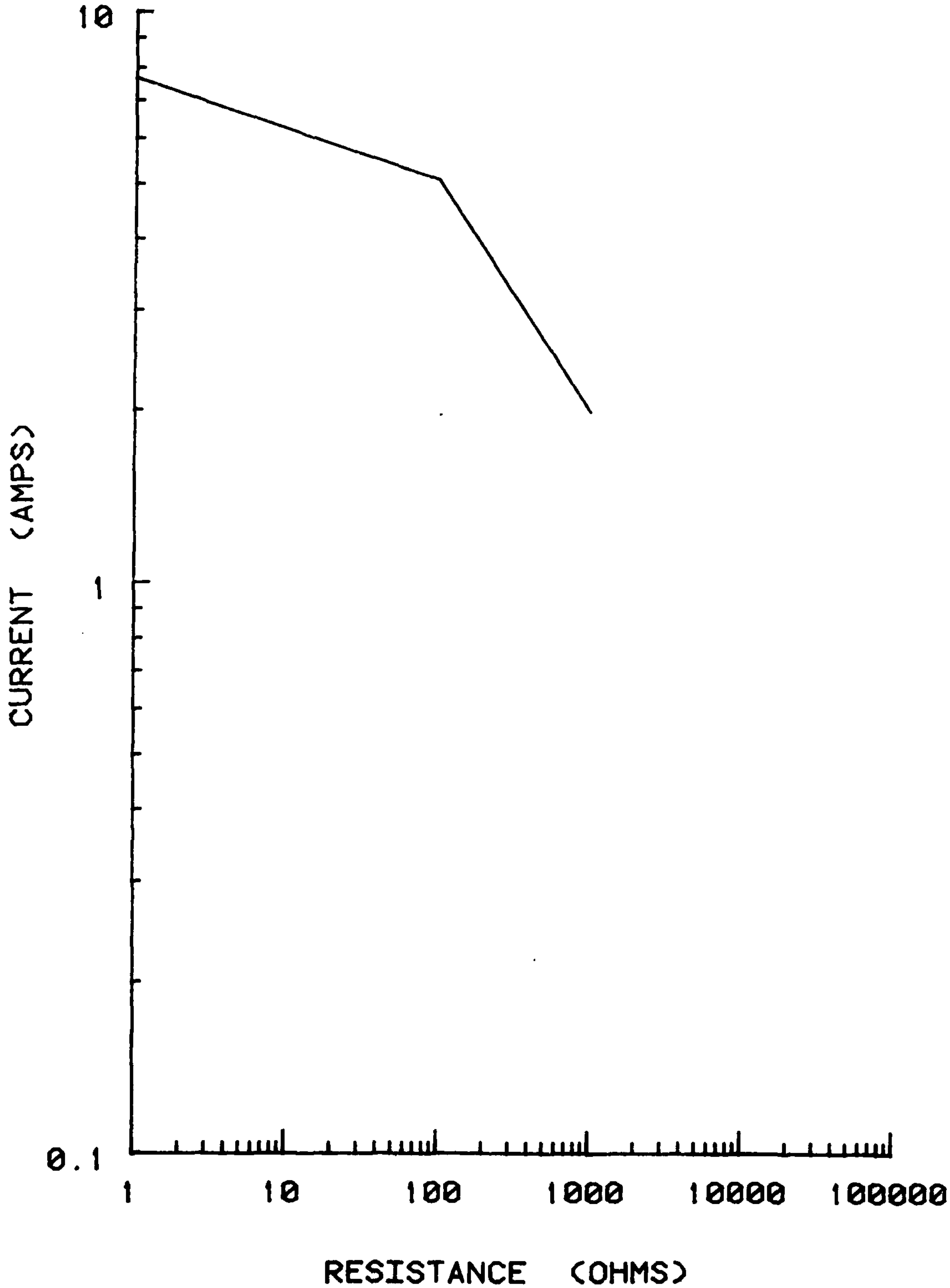


FIGURE 2-3

A3TK UMBILICAL CURRENT

(Missile and Zipper Tubing Ungrounded)

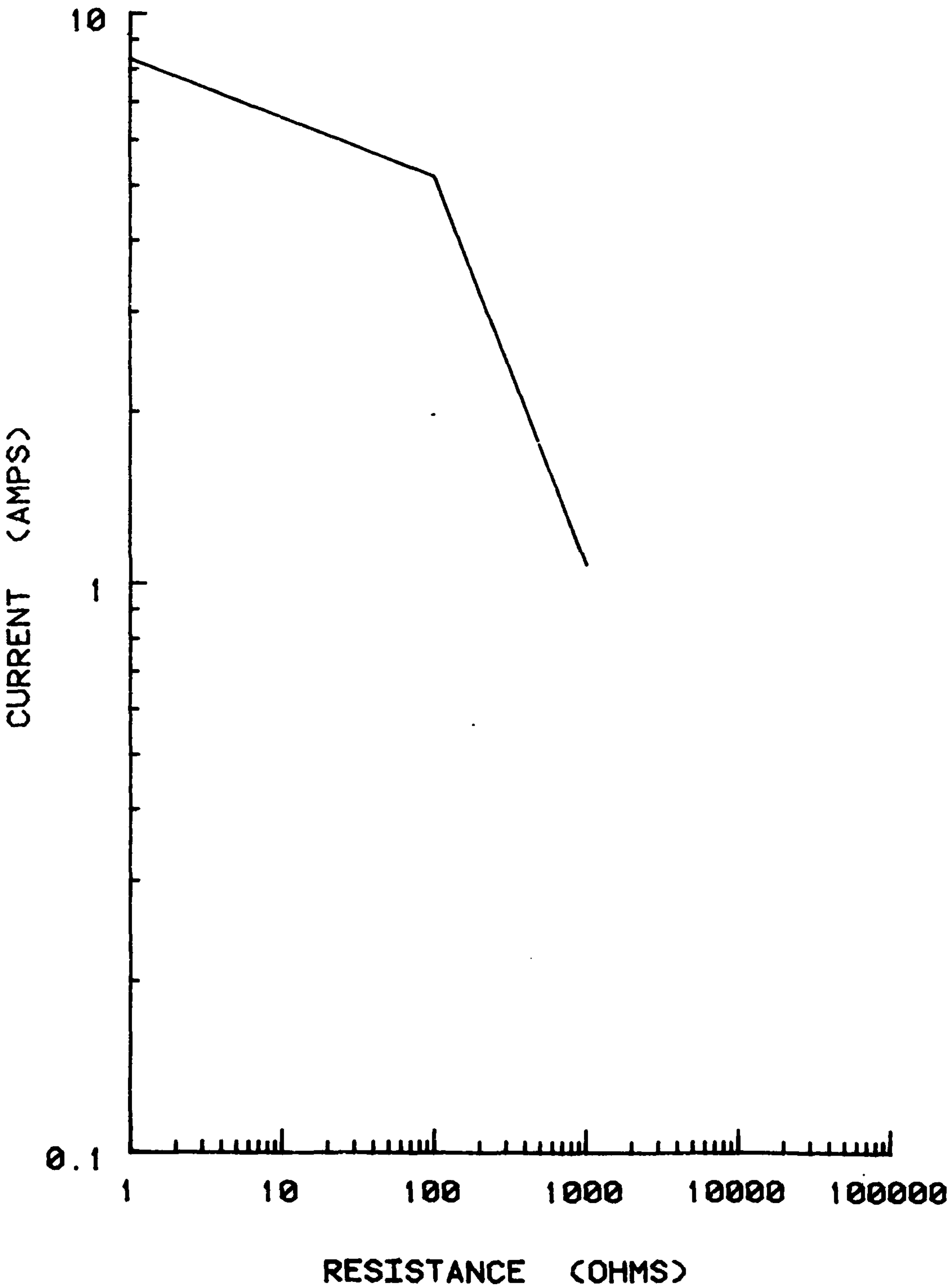


FIGURE 2-4

A3TK UMBILICAL CURRENT

(COMPOSITE)

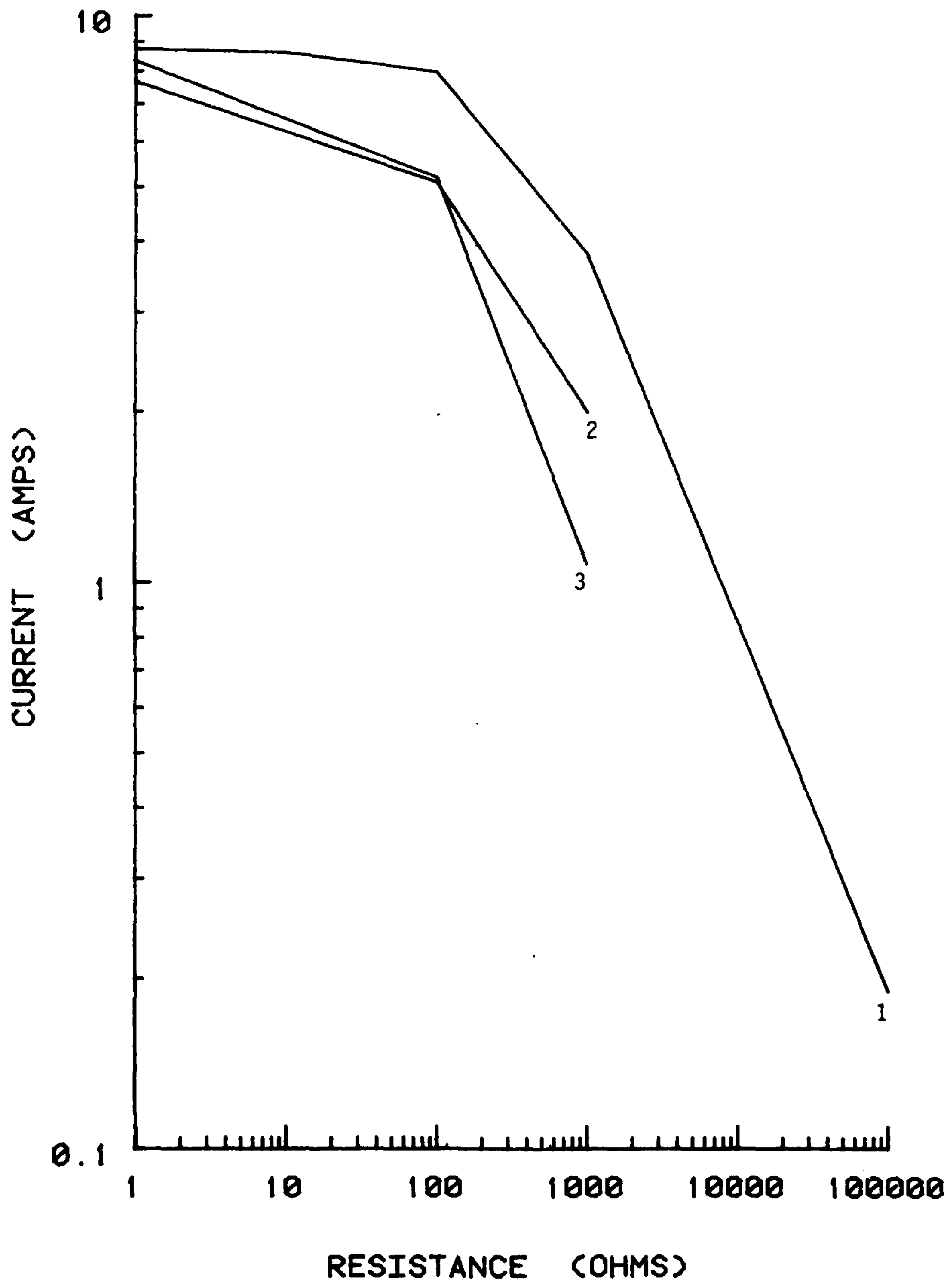
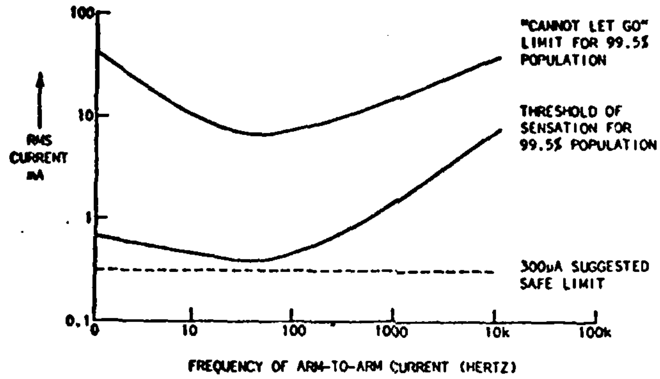
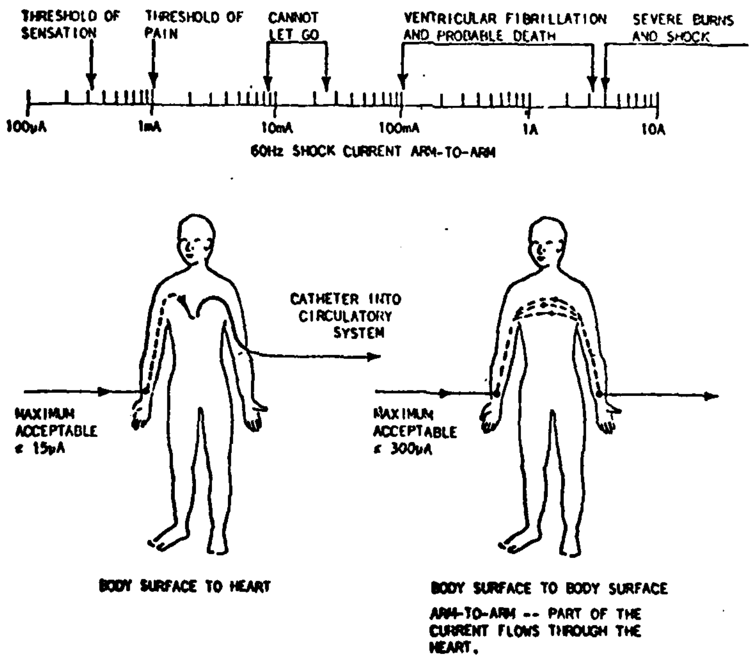


FIGURE 2-5



Physiological effects versus current frequency.



Physiological effects of 60Hz electric current.

FIGURE 2-6

TABLE 2-1

Safety Current Measurements
(E = 250 V/m)

MEASUREMENT	R (Ω)	SINGER PROBE	I (Peak amps)	f_o(MHz)
	(1) Missile and Zipper Tubing Grounded			
I_{sc}	0	94430-2	9.86	4.5
I_{10}	10	94430-2	8.62	4.0
I_{100}	100	94430-2	8.0	3.7
I_{1000}	1000	94430-2	3.8	3.08
I_{100K}	100,000	94430-2	0.19	2.597
	(2) Missile Grounded; Zipper Tubing Ungrounded			
I_{sc}	0	93686-4m	7.65	----
I_{100}	100	94430-2	5.1	3.1-3.7
I_{1000}	1000	94430-2	2.0	4.24
	(3) Missile and Zipper Tubing Ungrounded			
I_{sc}	0	93686-4m	8.33	2.1
I_{100}	100	94430-2	5.3	2.1
I_{1000}	1000	94430-2	1.08	2.17
	(4) Missile Ungrounded; Zipper Tubing Grounded			
I_{100}	100	94430-2	10.6	2.66

3. INSTRUMENTATION AND TEST OBJECT IMPACT:

The data collected and discussed in section 5 indicate that there is interaction, but that there are no fields present that are of sufficient strength to influence the test object in any manner that would degrade test data or test object performance.

During the fielding of two EMP hardening verification tests conducted during FY 78, 79, and 80, there were no documented or observed false trigger pulses in the instrumentation system. However, based on a correlation of TRESTLE and ARES pulser logs, there were several high voltage pulser (EMP-45) pre-fires that were attributed to TRESTLE induced environments. These pre-fires have in no way degraded test performance.

Concern has been expressed that simultaneous firings of any two of the simulators mentioned would generate unusable environmental data. This concern should be dismissed as inconsequential. Two observations are used to validate this recommendation:

a) A simultaneous application of dual EMP environments would require sub-microsecond timing between the two facilities and is therefore highly improbable. If this does happen, the data could be viewed as test object response to a multiple-source EMP environment.

b) The test object EMP environment is recorded on each shot. This means that a test object response to a known recorded environment has been obtained.

There is also some concern over possible generation of false data records. Previous testing at ARES has shown absolutely that no false data records have been generated. This is directly attributable to the fact that the ARES data system is protected against the ARES simulator environment and any reflected signals.

4. TEST SUPPORT EQUIPMENT IMPACT:

Experience with the A3TK test at the ARES (FY79-80) has shown that some user furnished test support equipment could be sensitive to spurious signals induced inside of the Data Acquisition Control Complex (DACC) as a result of reradiation from umbilicals, drop cords, or power cords that extend into the working volume at the time an EMI pulse arrives. These cords are not present during ARES pulse application. Data gathered show that these inadvertant antennas are the major source of interaction problems between the EMP facilities. The multitude of jobs that must be accomplished prior to actual ARES pulser firing make inadvertant antenna configuration control necessary. These inadvertant antennas are necessary for the pre-pulse system configuration changes. However, the post pulse test equipment configuration may require fewer conducting lines for data extraction from the test object. This is the most critical time that an extraneous field must not be applied if unprotected conductors are exposed to the EMP field. During this time period, data could be lost if the support equipment is upset.

The A3TK test conducted at ARES had some specific pieces of test support equipment, located in the DACC, but external to the permanent screen room, that are sensitive to the fields and signals described in section 5 of this report. The specific descriptions of these equipments are irrelevant. It is sufficient to know that equipment external to the screen room may need protection from low-level EMP fields and that data links from the test object may need protection during the post-ARES pulse configuration. The ARES EMP-45 pulser, at maximum output, generates a free field of approximately 500 V/m within the DACC. Information contained in this report can be used by a potential user to determine whether user furnished equipment is in need of additional protection.

The following fixes have been installed at ARES by FCDNA specifically for the A3TK test support equipment, however, these fixes are applicable to any test conducted at ARES:

a) Capacitor filters have been installed at power outlets inside of the DACC.

b) Zipper tubing has been installed so as to shield the umbilical cables extended from the unprotected DACC into the working volume.

c) A portable screen room has been installed in the DACC and sensitive equipments have been placed inside.

The following coordination techniques have been used to good advantage in coordinating time slots in a standard workday between ARES, VPD, TRESTLE, and HPD when quiet times are needed by either:

a) Telephone contact is maintained throughout pulser operations.

b) Radio net contact is maintained using hand held radios.

c) Personal contact has resulted in a good working rapport and arrangment of the few quiet times needed during the A3TK test.

There are two additional fixes that can still be done to increase ARES hardness to EMP:

a) Place three-phase filters in the main power distribution.

b) Place the environment trigger on a lockout circuit if it becomes necessary. However, there is presently no need for this simple fix.

5. DATA

Although a large volume of data has been gathered, only eight sets are presented here. These eight sets are typical, demonstrate that there is a potential interaction problem, and show that the potential problems have been minimized. The entire volume of data is available upon request to FCDNA, attention FCTMS.

Figures 5-1 and 5-1-1 are the time and frequency domain plots of the TRESTLE waveform that is present in the center of the ARES working volume on the ground plane. The TRESTLE reference sensor measured an $\vec{E}$ field of 86 KV/m. The measurement was made using an MGL-1 $\dot{B}$ sensor. A peak field strength of 1 KV/m is observed. Obviously, there is some interaction from TRESTLE into ARES.

Figures 5-2 and 5-2-1 are the time and frequency domain plots of the HPD waveform located approximately 30 feet above the ARES ground plane at test object position. This measurement was also taken with the MGL-1 $\dot{B}$ sensor. A peak field strength of approximately 100 V/m is observed adjacent to the ARES test object. There is some interaction from HPD into ARES, however, it is very low level and has proven to be inconsequential.

Figures 5-3, 5-3-1, 5-3-2, and 5-3-3 are time and frequency domain plots of measurements made to determine the effectiveness of shielding the missile umbilical cables and then grounding the shielding to the ARES ground plane. These measurements were made using a Singer 93686-4m current sensor. The measurements were made by inserting the umbilical and zipper tubing through the sensor and measuring the current flow first with the zipper tubing ungrounded and second with the zipper tubing attached to the ARES ground plane. The TRESTLE pulsers were charged to 3.5 MV each during this measurement. A marked decrease in current amplitude was observed after the zipper tubing was grounded. This demonstrates an extremely effective method of shunting unwanted currents away from ARES test objects. Two dominant frequencies of 3.0 and 10.0 MHz are observed in figures 5-3-1 and 5-3-3. The corresponding wavelengths are 100m and 29.7m. These wavelengths approximate closely four times the length of the umbilical cable when it is ungrounded and then grounded. The conclusion drawn from this information is that the umbilical cable is acting as a quarter wavelength antenna and coupling energy from sources external to ARES into the ARES test object and equipment and that this effect can be minimized by using an effective shielding technique.

Figures 5-4, 5-4-1, 5-4-2, and 5-4-3 illustrate that energy is coupled into the ARES DACC when TRESTLE is pulsed. The TRESTLE pulsers were charged to 4 MV each for this data set. Figure 5-4 shows the TRESTLE waveform observed in the ARES DACC and measured at the north wall ac outlets. A peak voltage of approximately 75 volts is observed. Figure 5-4-2 illustrates the effectiveness of placing capacitor filters at the wall outlets. Capacitors with a value of 0.1 microfarads and a peak voltage rating of 1000 volts were used to filter the spurious voltages. A maximum peak of approximately 6 volts was observed after placement of the filters. This simple method can be used to harden test site power distribution systems against spurous signals from other facilities. Equipment upsets after filtering were minimal. The dominant frequencies in figures 5-4-1 and 5-4-3 have wavelengths that approximate four times the distance between the commerical power line poles at the facility.

Figures 5-5, 5-5-1, 5-5-2, and 5-5-3 demonstrate that power cords of other types of cables that extend into the ARES working volume during TRESTLE pulser discharge furnish another point of entry of EMI into the ARES DACC and test support equipment. These cords are not present during ARES pulser discharge but are essential for test object reconfiguration and may be present during pulser operations at other facilities. These cords could cause equipment upsets by passing spurious signals through the power lines or by reradiation of EMI into the DACC. Dominant frequencies approximate four times the length of the heater and drop cords. This data set was taken with 1 trestle pulser charge to 4 MV.

Calculations show that VPD levels approximate those of TRESTLE. For an approximation of VPD levels in ARES, consider the following:

$$\vec{E} = K \frac{V}{R} \qquad (5\text{-}1)$$

V is the VPD pulser charge voltage, measured in volts. R is the distance from the VPD pulser to the ARES test object. K is an experimentally determined, dimensionless constant based on previous VPD mapping data and is equal to Ø.36.

Considering the maximum charge voltage on VPD as 1.6×10^6 volts, the $\vec{E}$ field in the ARES working volume would be:

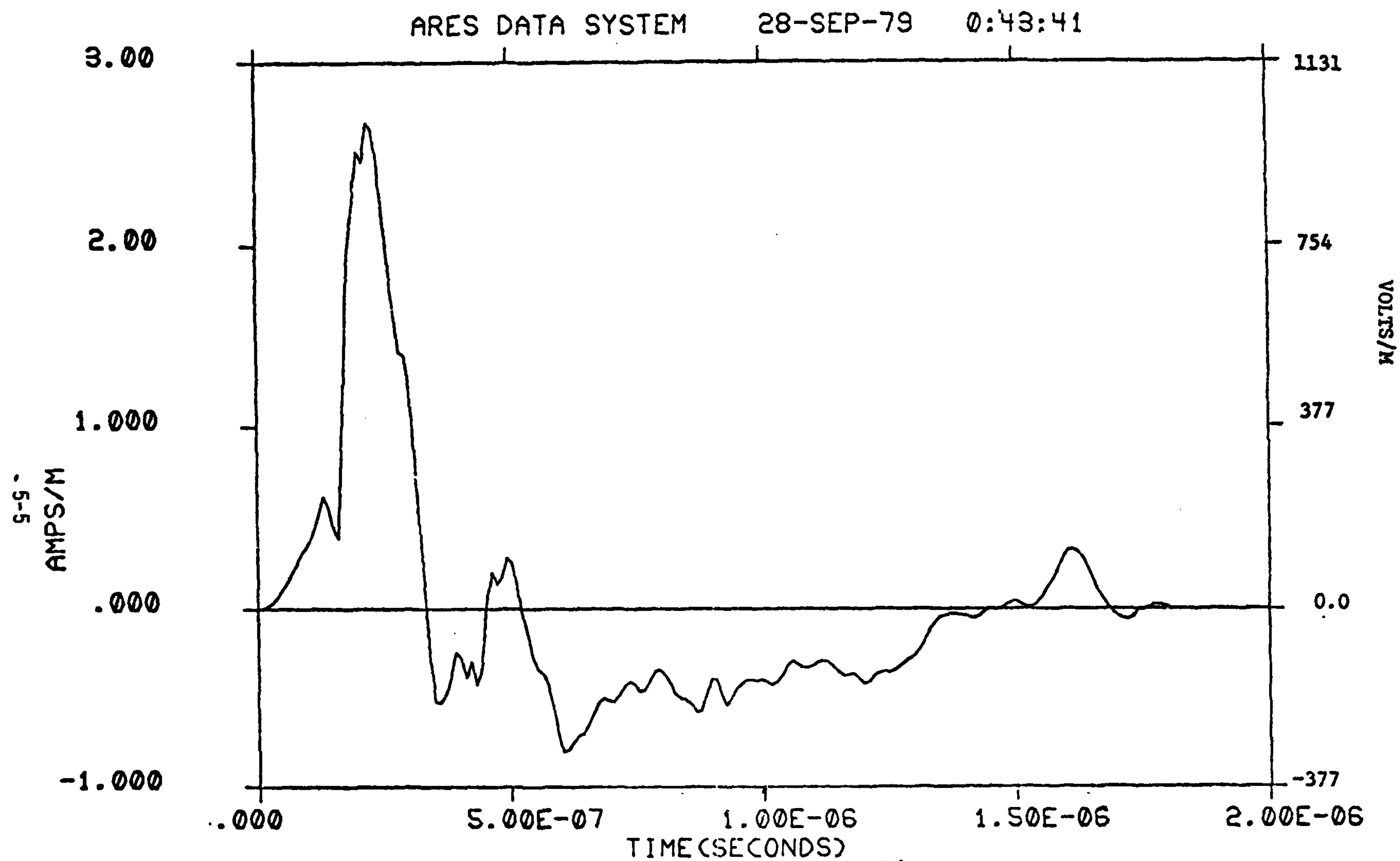
$$\vec{E} = \frac{.36 \times 1.6 \times 10^6}{7.6 \times 10^2} \ \frac{V}{m}$$

$$= 7.58 \times 10^2 \text{ V/m}$$

$$= 758 \text{ V/m}$$

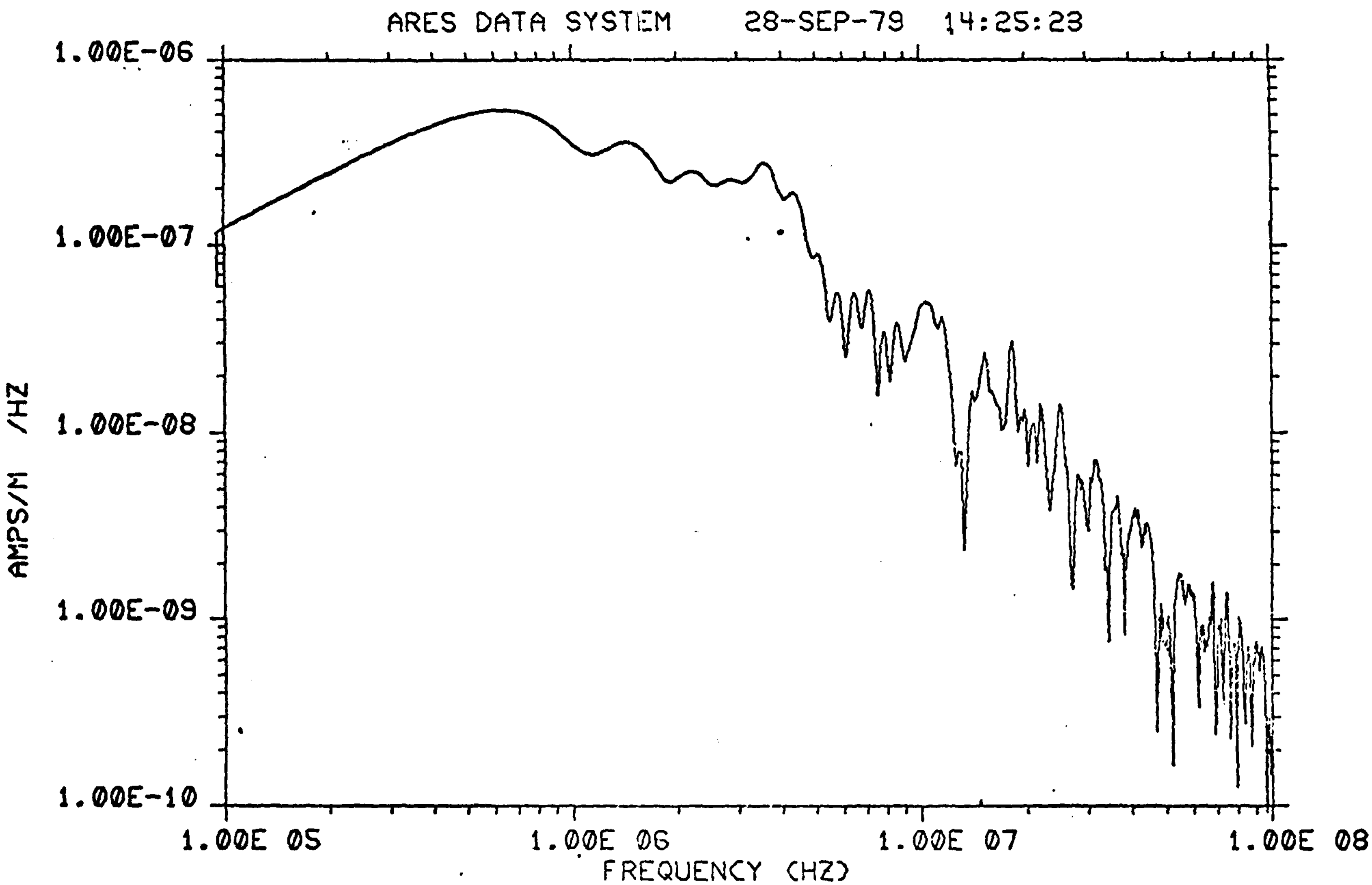
This approximation is a line of sight (LOS) approximation. It must be understood that the ARES working volume and test object are below LOS. This could attenuate VPD EMI even more. Measured TRESTLE levels thus far in the ARES working volume have a peak value of 1000 V/m.

Data has been collected and calculations have been verified. This data is available upon request.



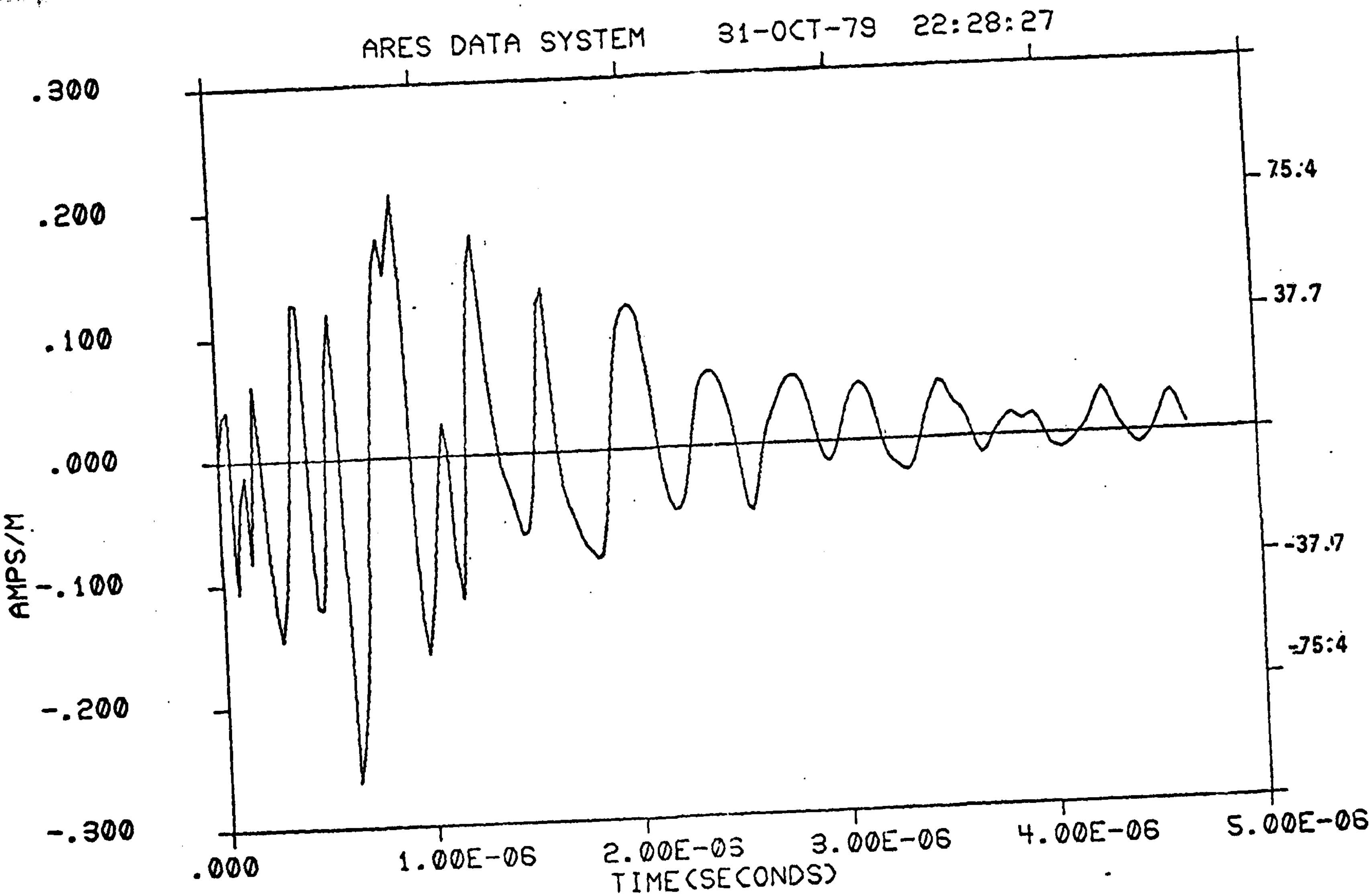
SOURCE: TRESTLE (86 KV/M)
MEAS LOC: GROUNDPLANE CENTER OF ARES WV
PROBE: MGL-1

FIGURE 5-1



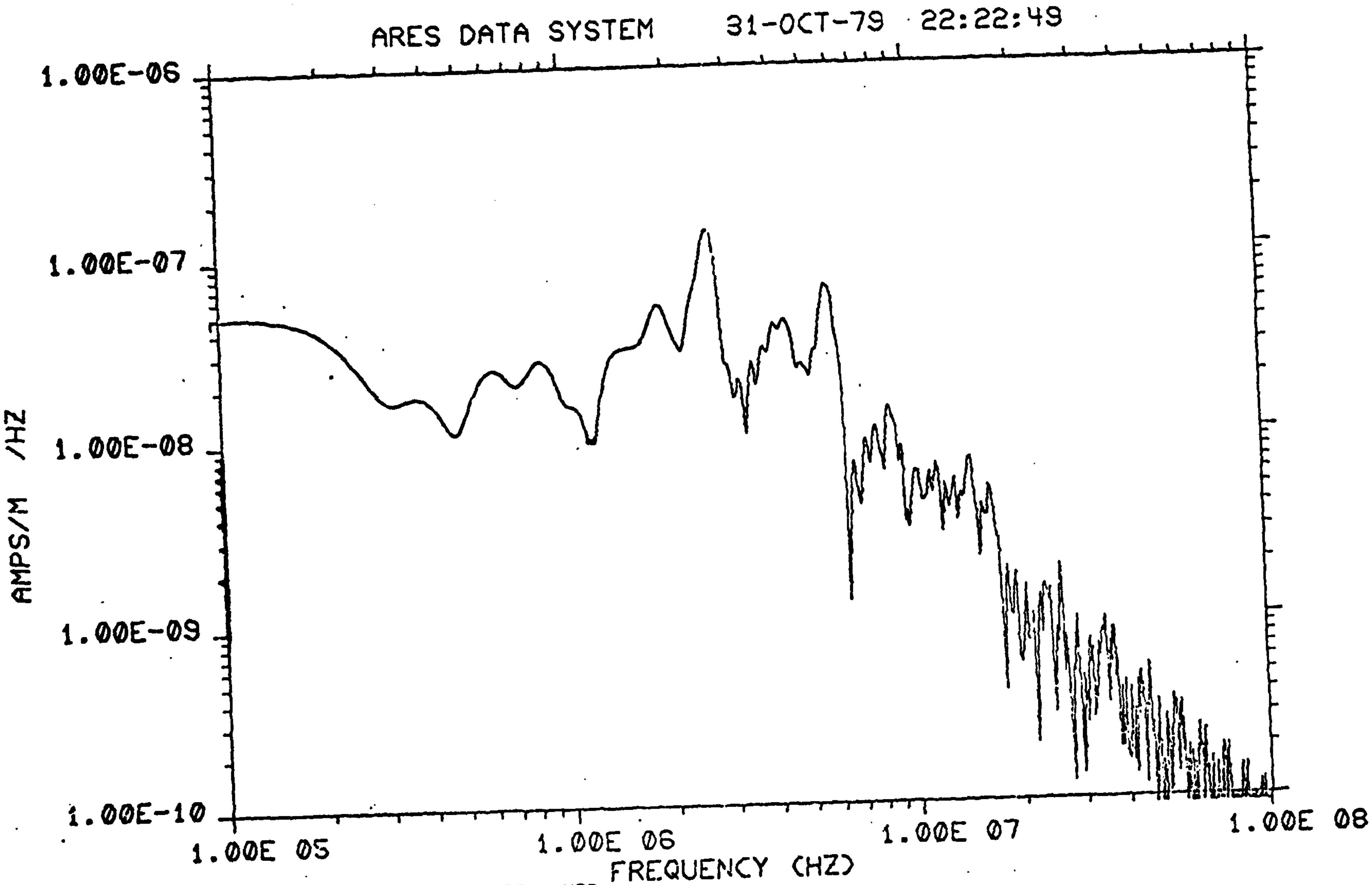
SOURCE: TRESTLE (86 KV/M)
MEAS LOC: GROUNDPLANE CENTER OF ARES WV
PROBE: MGL-1

FIGURE 5-1-1



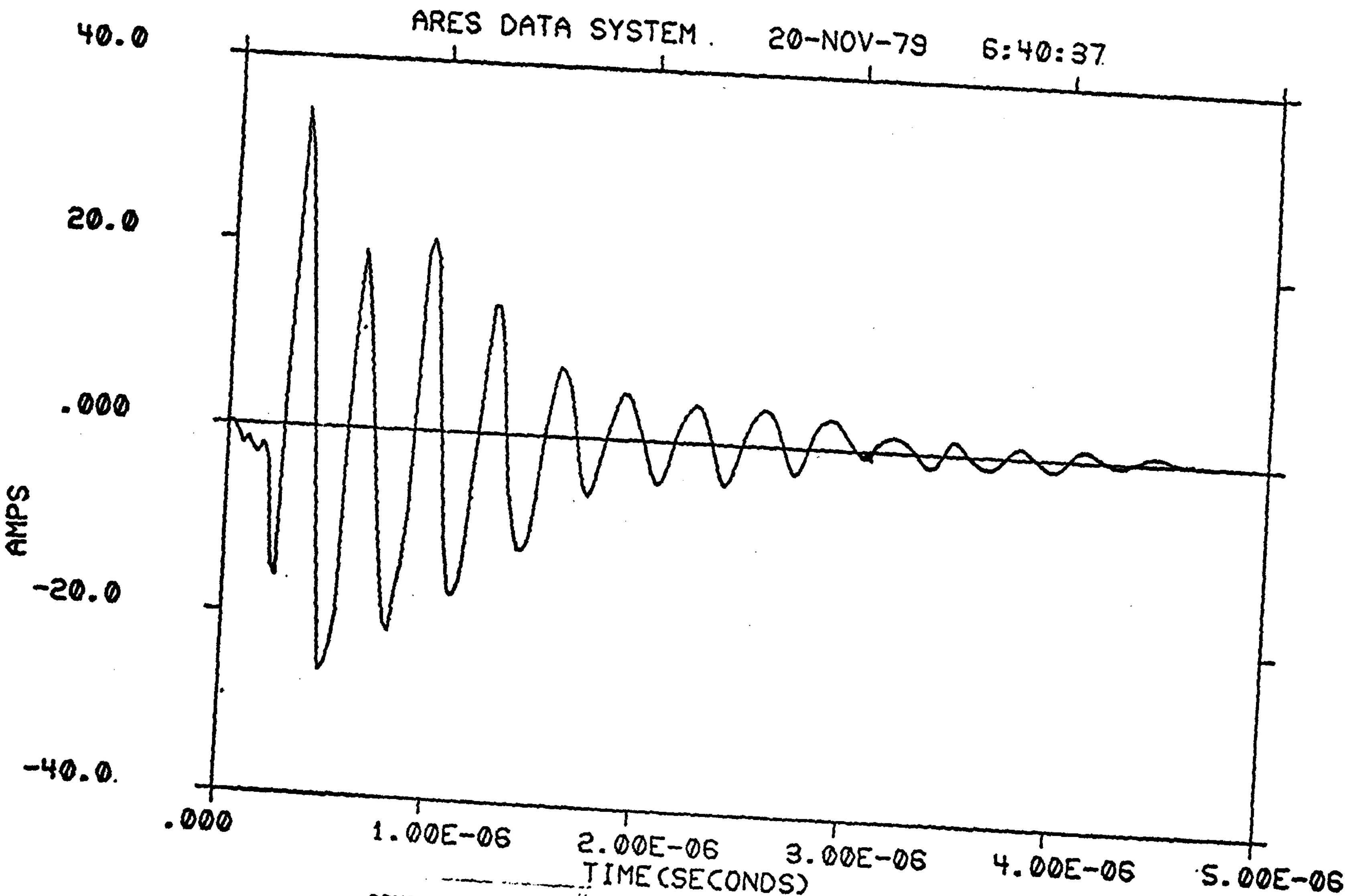
SOURCE: HPD
MEAS LOC: C4 ISS LEVEL 3
PROBE: MGL-1

FIGURE 5-2



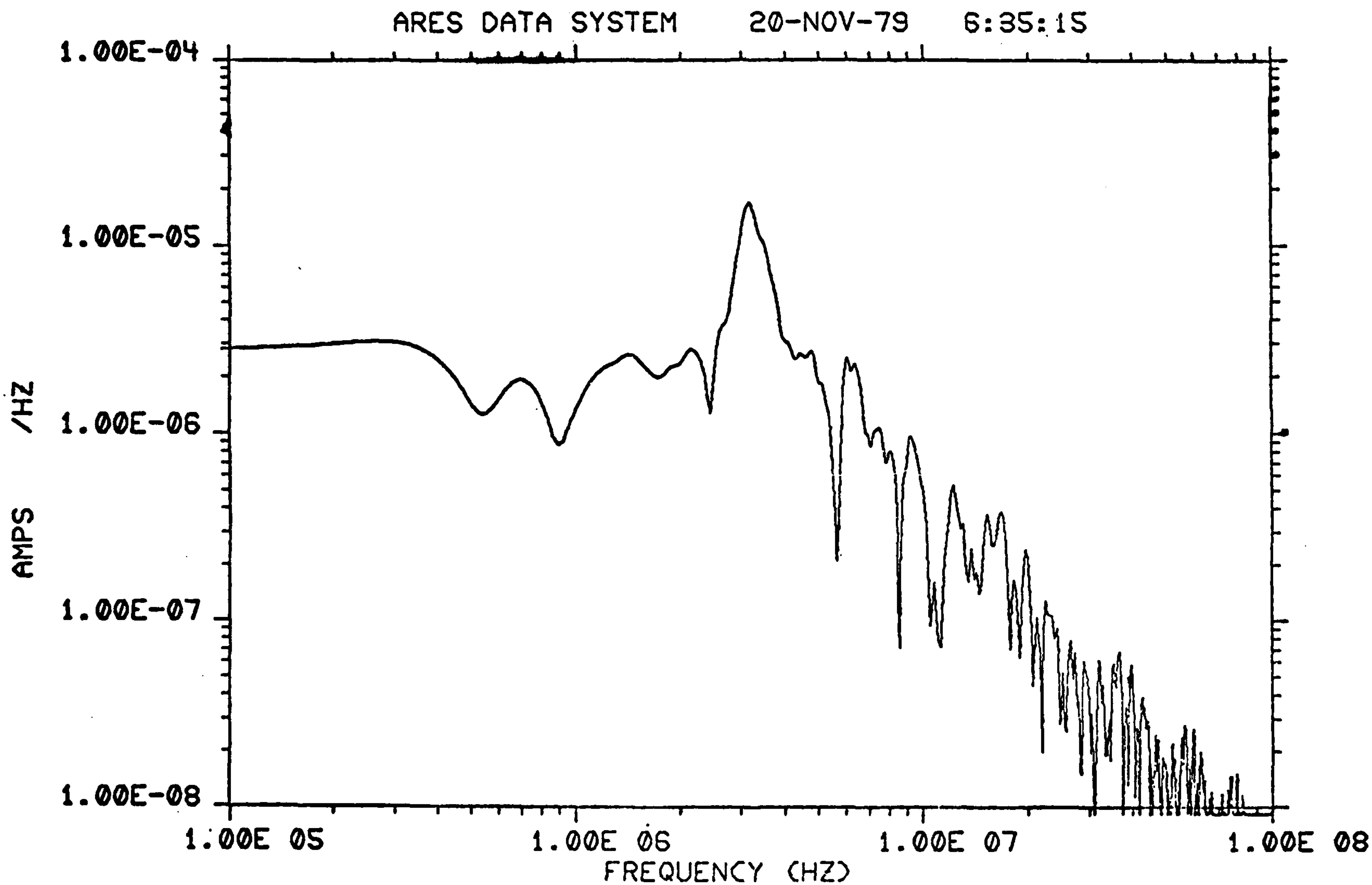
SOURCE: HPD
MEAS LOC: C4 ISS LEVEL 3
PROBE: MGL-1

FIGURE 5-2-1



SOURCE: TRESTLE (ZIPPER TUBE UNGROUNDED)
MEAS LOC: DACC MANWAY (UMBILICAL CURRENT)
PROBE: S-504

FIGURE 5-3

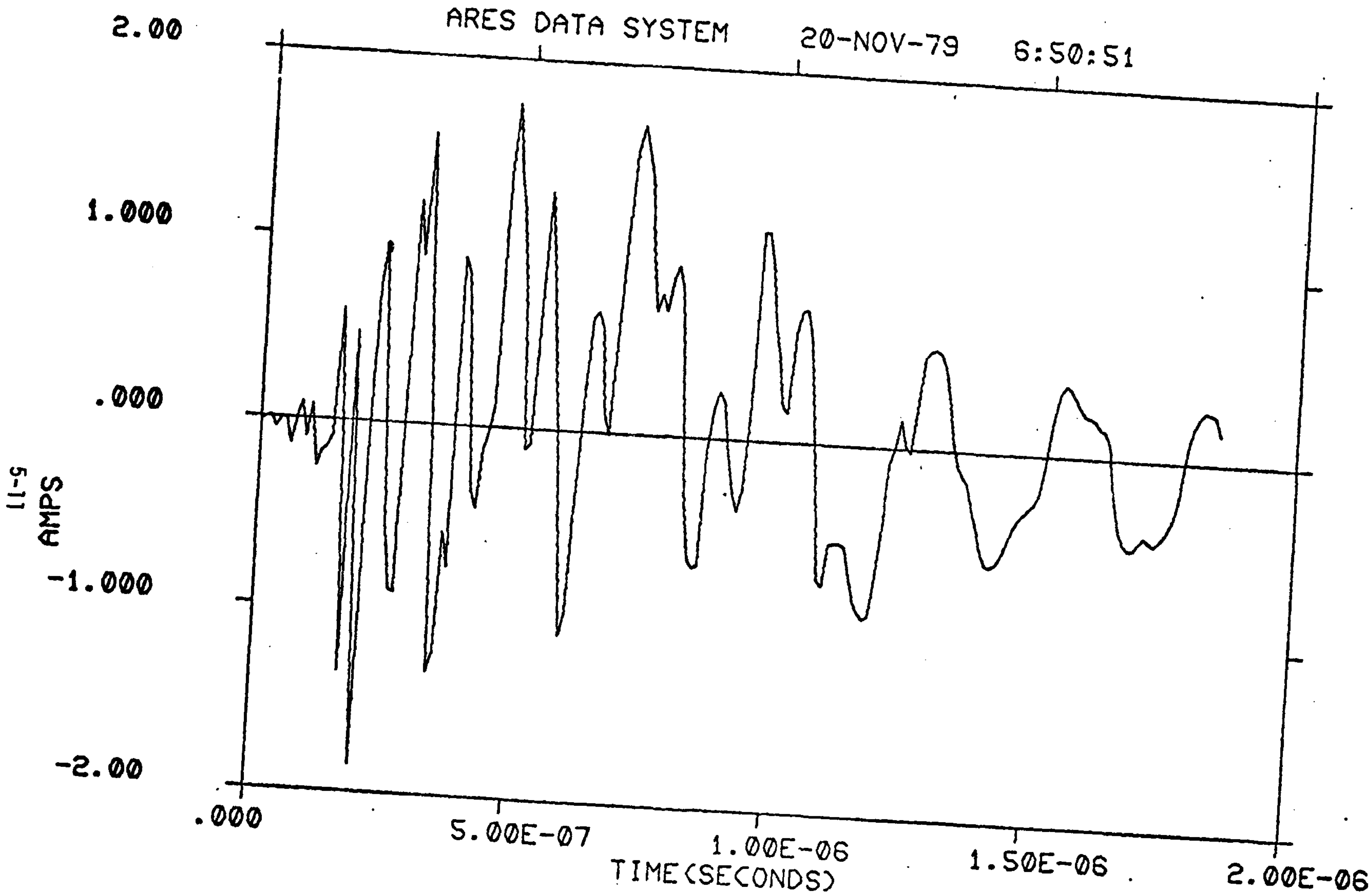


SOURCE: TRESTLE (ZIPPER TUBE UNGROUNDED)

MEAS LOC: DACC MANWAY (UMBILICAL CURRENT)

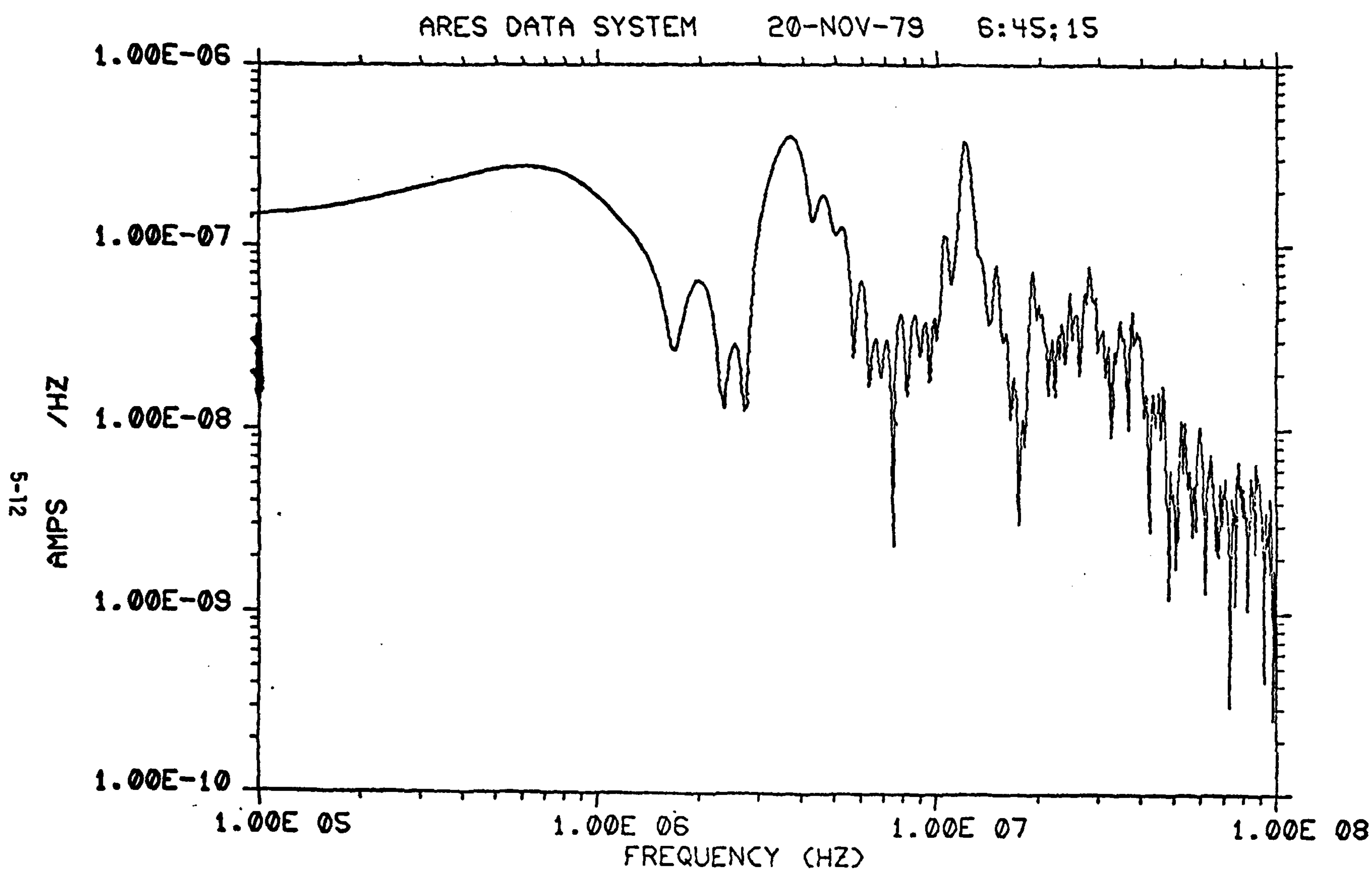
PROBE; S-504

FIGUIRE 5-3-1



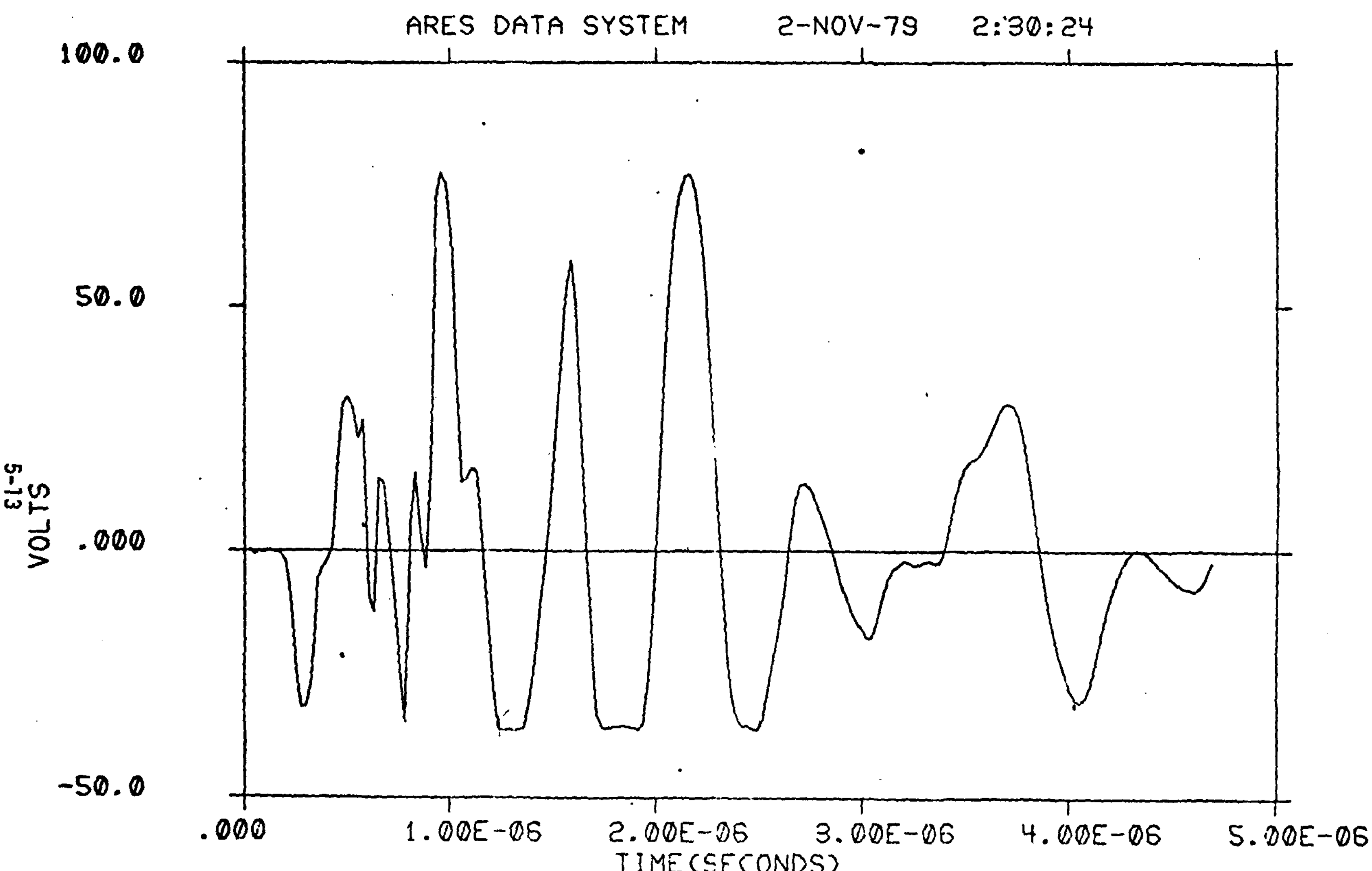
SOURCE: TRESTLE (ZIPPER TUBE GROUNDED)
MEAS LOC: DACC MANWAY (UMBILICAL CURRENT)
PROBE; S-504

FIGURE 5-3-2



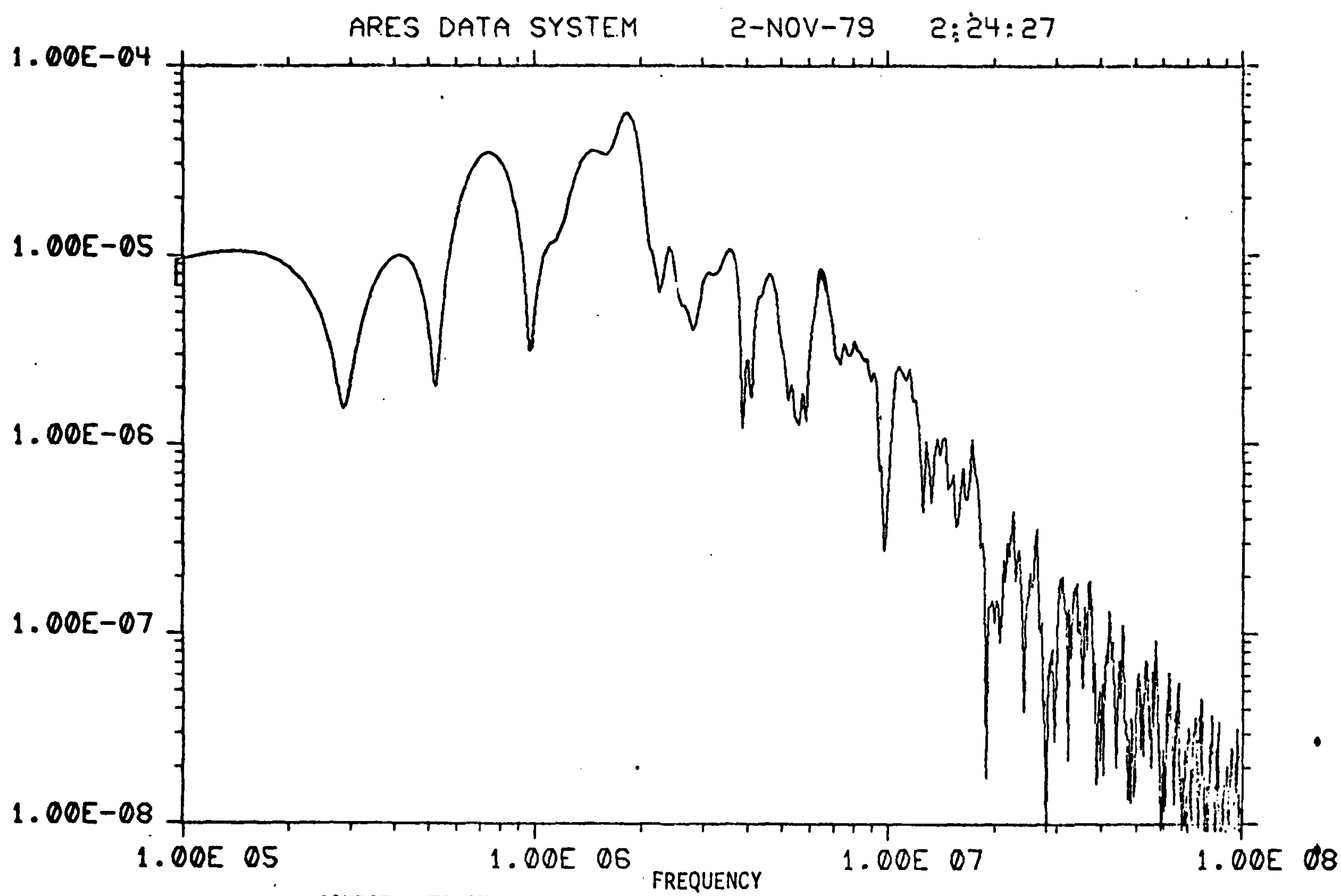
SOURCE: TRESTLE (ZIPPER TUBE GROUNDED)
MEAS LOC: DACC MANWAY (UMBILICAL CURRENT)
PROBE; S-504

FIGURE 5-3-3



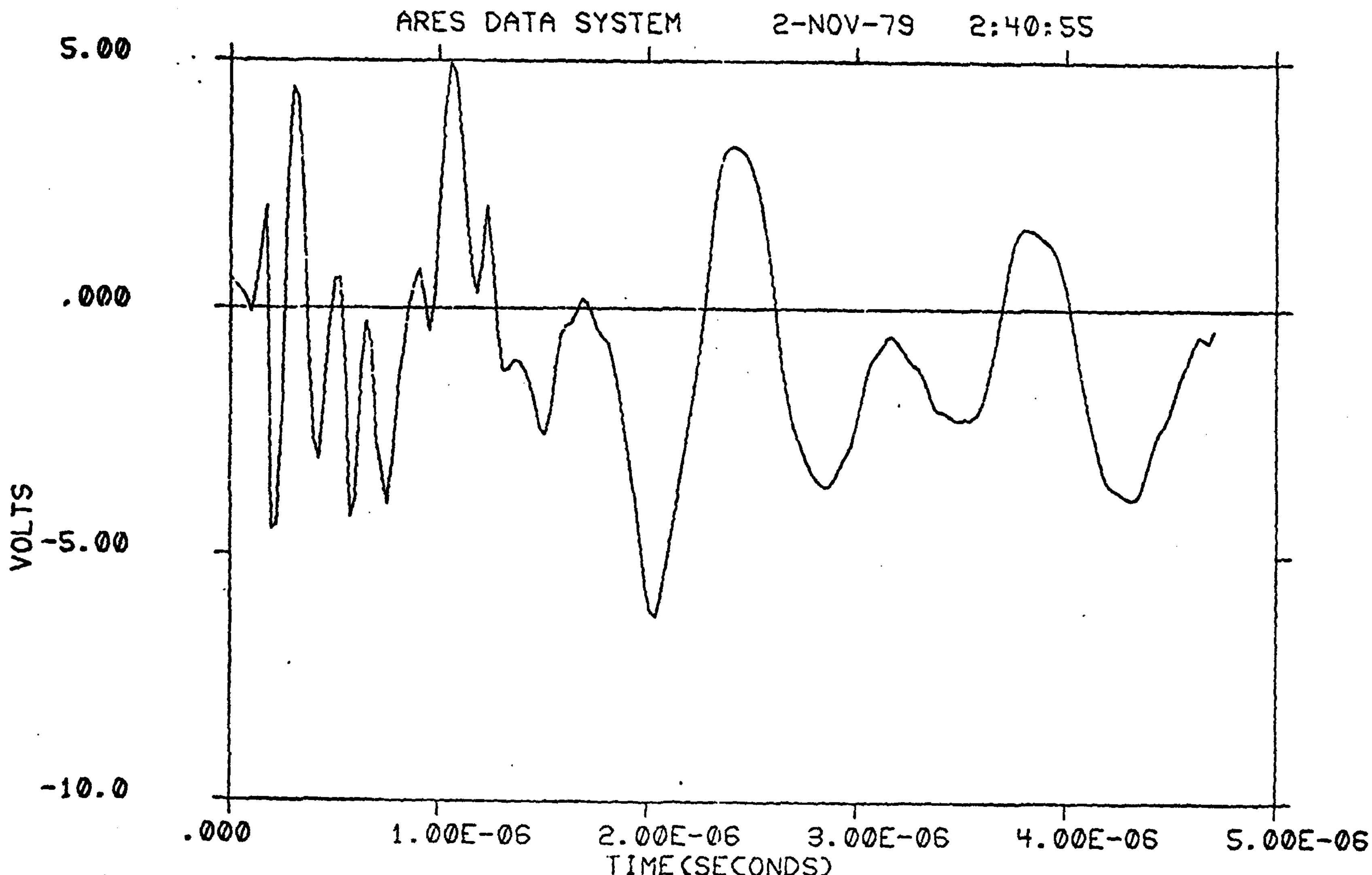
SOURCE: TRESTLE
MEAS LOC: DACC NORTH WALL AC OUTLET (UNFILTERED)
PROBE: TEK 485 SCOPE

FIGURE 5-4



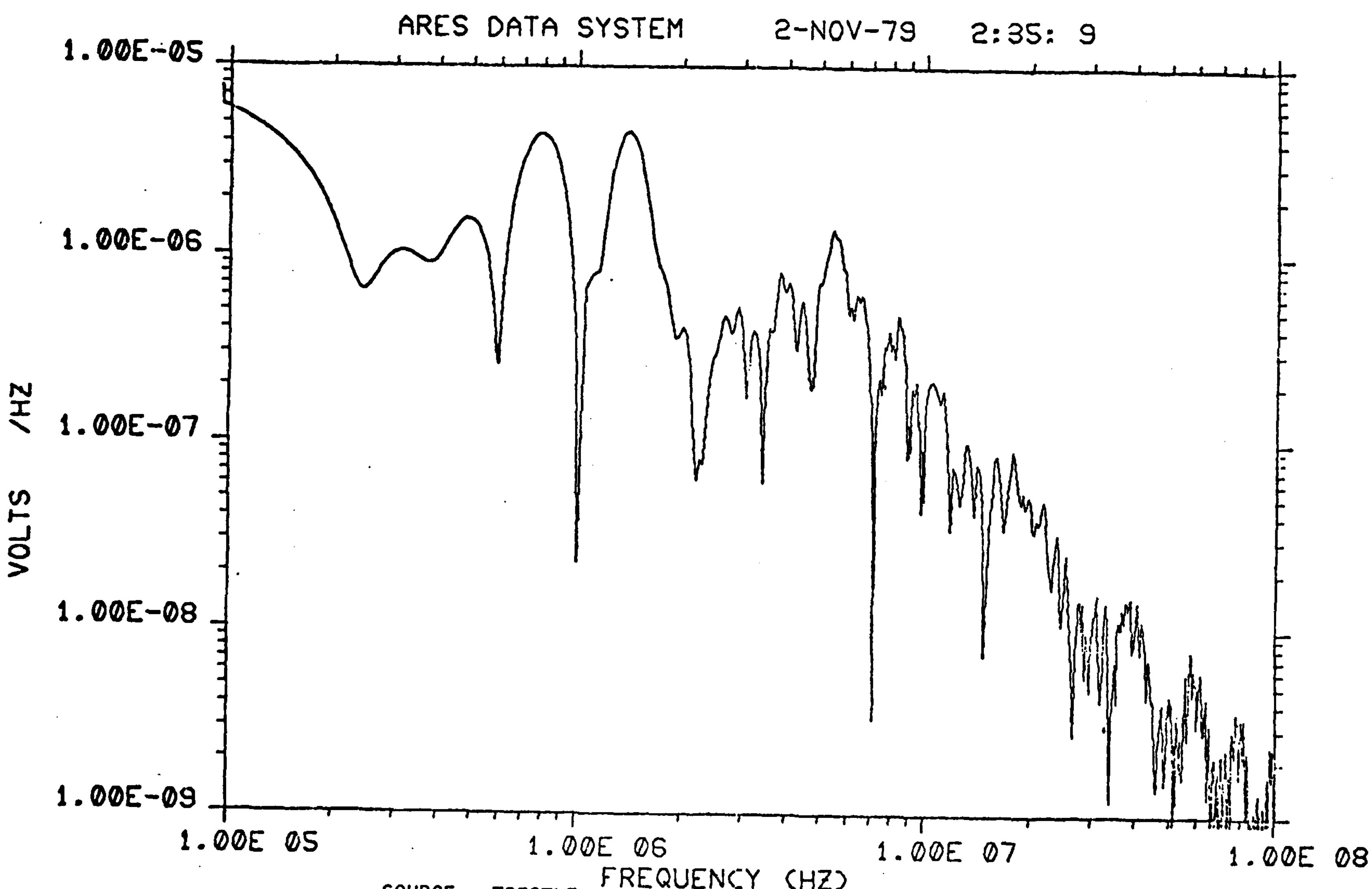
SOURCE: TRESTLE
MEAS LOC: DACC NORTH WALL AC OUTLET (UNFILTERED)
PROBE: TEK 485 SCOPE

FIGURE 5-4-1



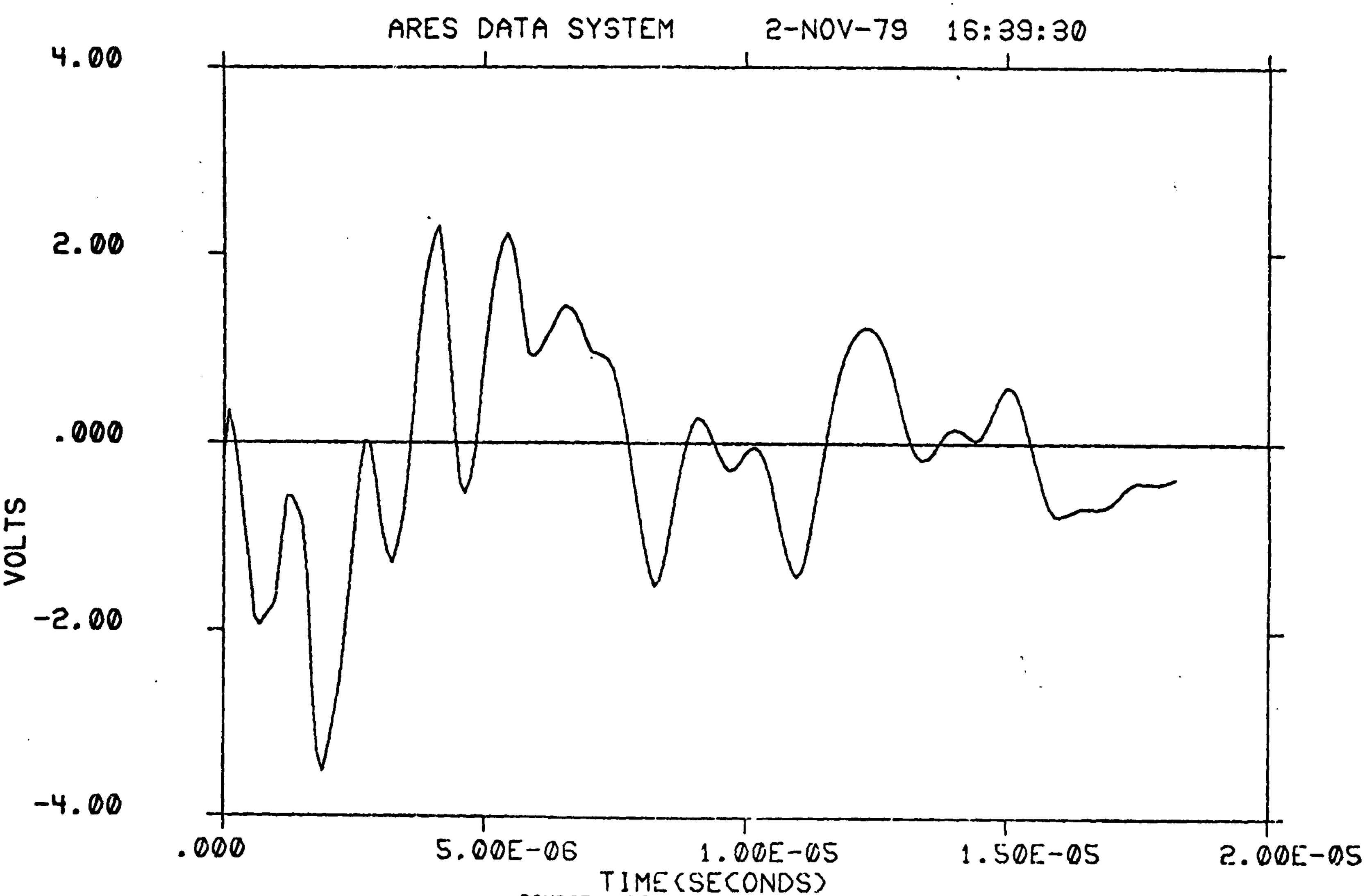
SOURCE: TRESTLE
MEAS LOC: DACC NORTH WALL AC OUTLET (CAP FILTERS)
PROBE: TEK 485 SCOPE

FIGURE 5-4-2



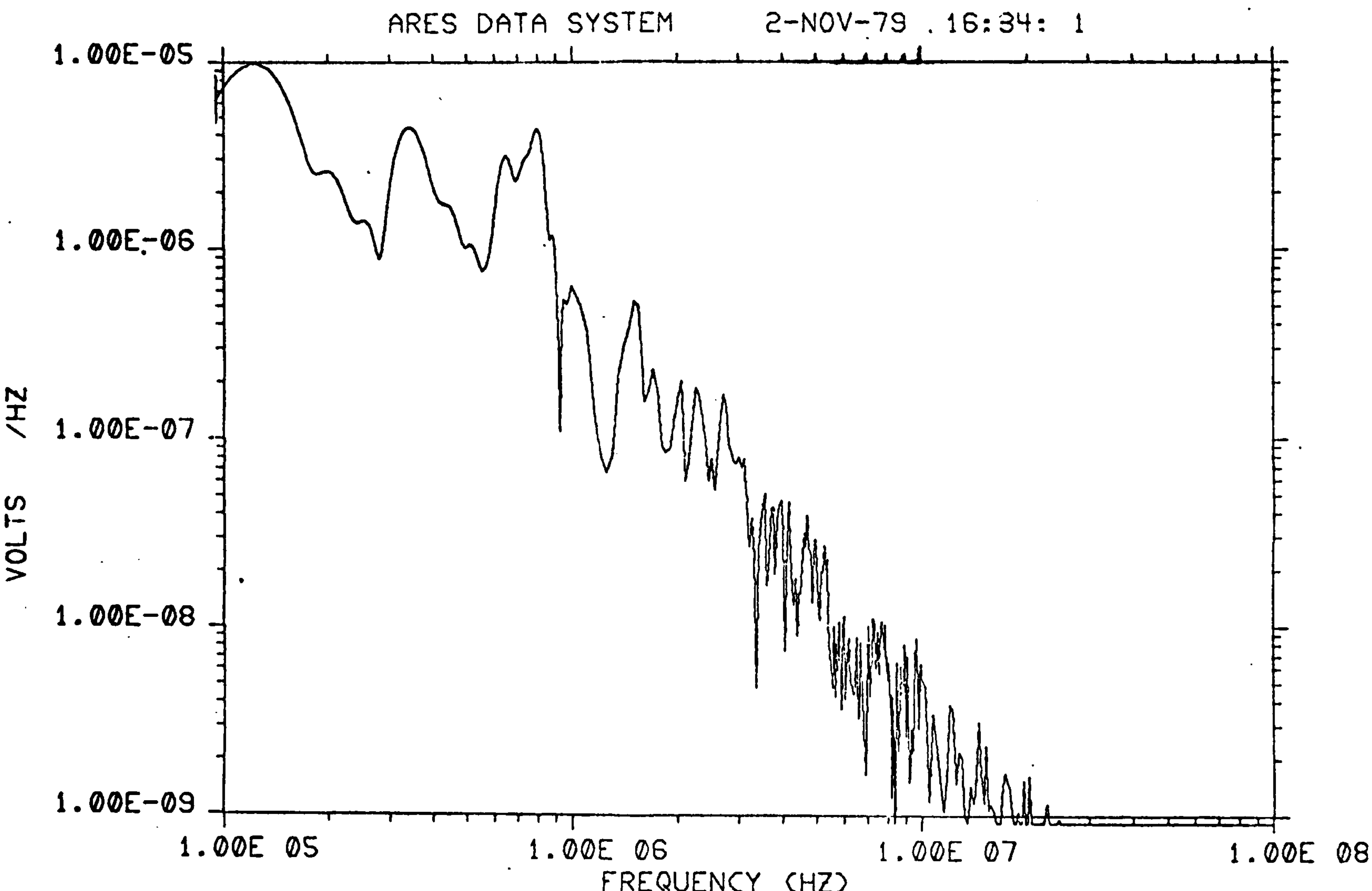
SOURCE: TRESTLE
MEAS LOC: DACC NORTH WALL AC OUTLET (CAP FILTERS)
PROBE: TEK 485 SCOPE

FIGURE 5-4-3



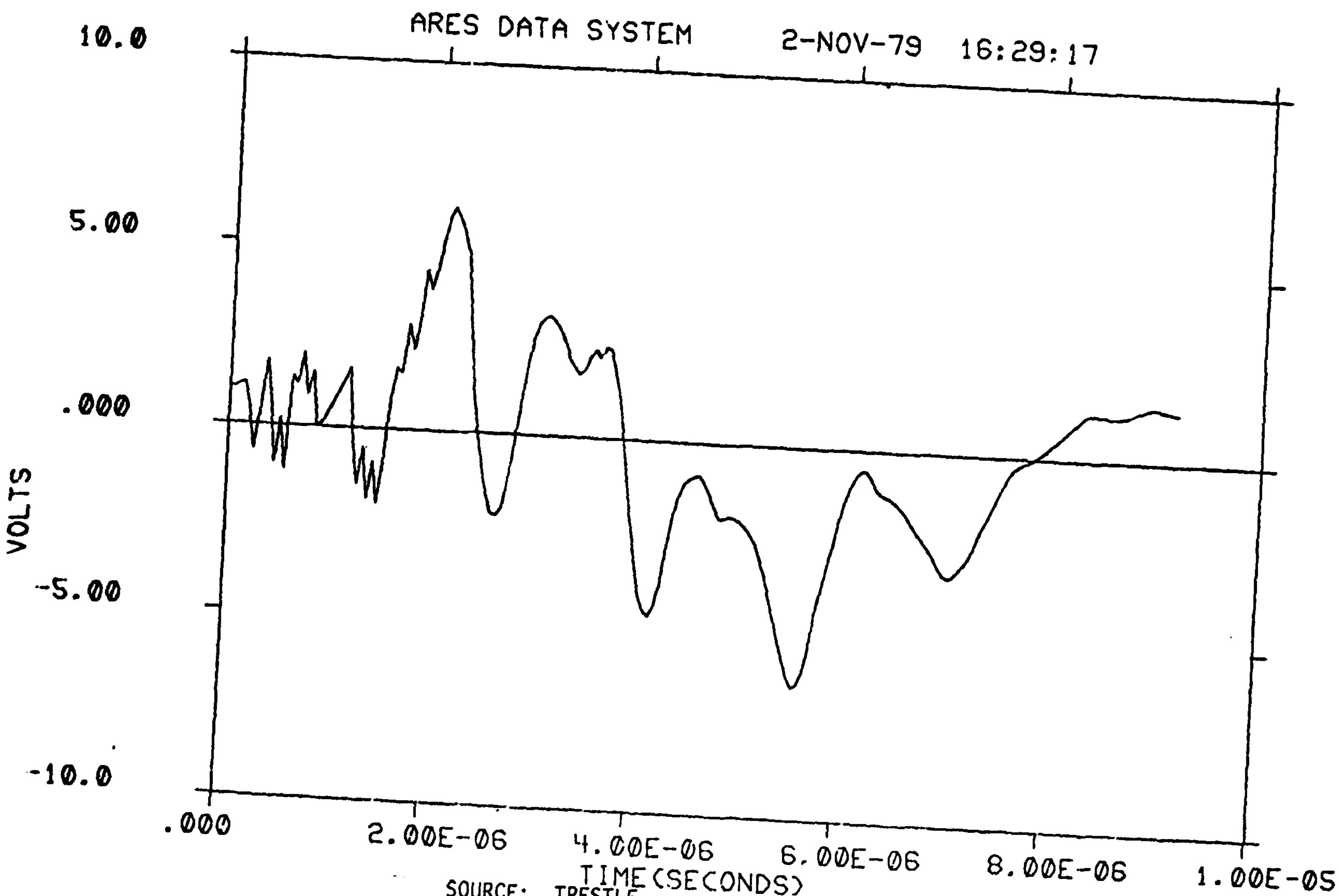
SOURCE: TRESTLE
MEAS LOC: EAST WALKWAY (NO ELEVATOR CABLE)
PROBE: X10 Voltage TEK 485 Scope

FIGURE 5-5



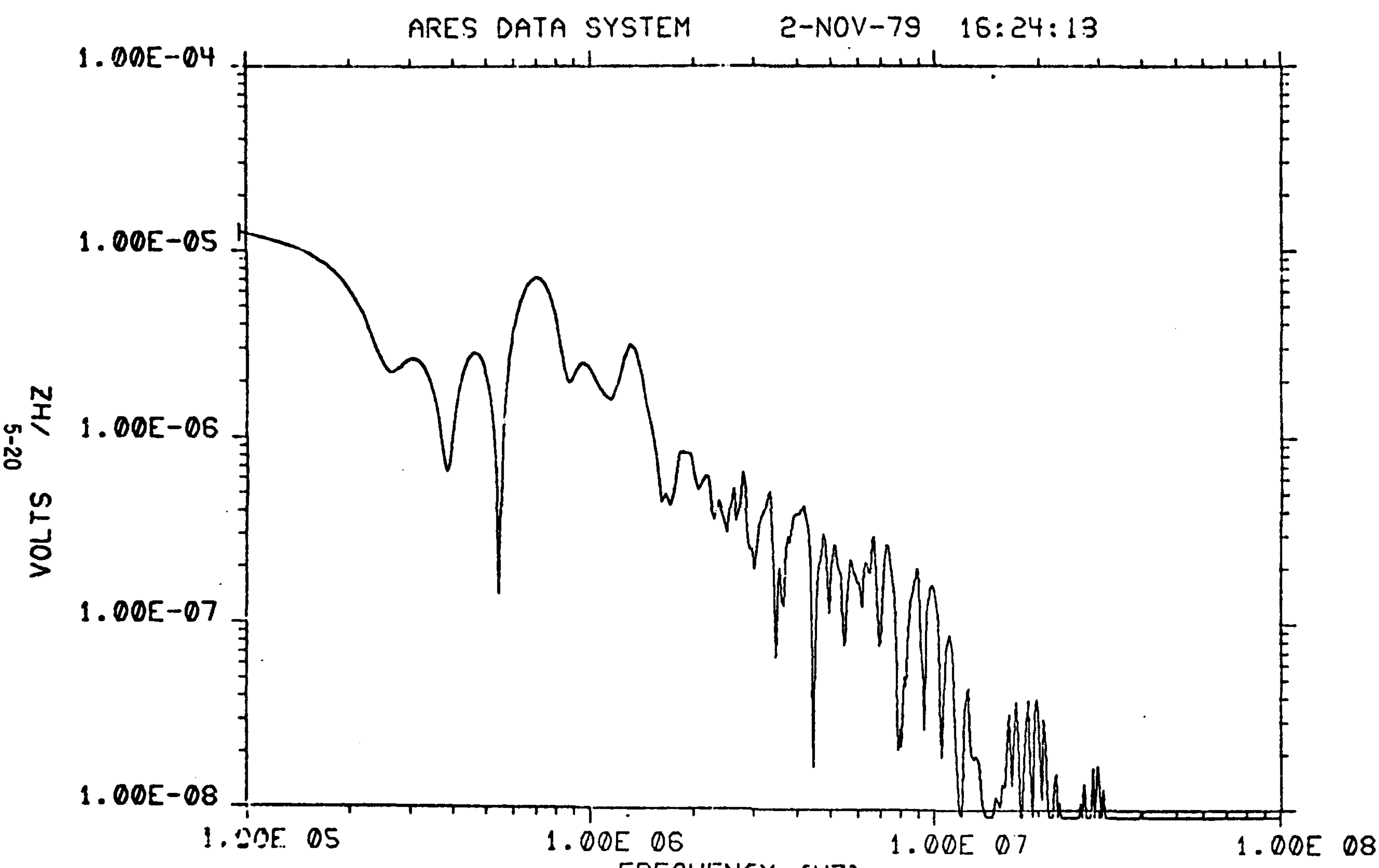
SOURCE: TRESTLE
MEAS LOC: EAST WALKWAY (NO ELEVATOR CABLE)
PROBE: X10 Voltage TEK 485 Scope

FIGURE 5-5-1



SOURCE: TRESTLE
MEAS LOC: EAST WALKWAY (ELEVATOR CABLE)
PROBE: X10 Voltage TEK 485 Scope

FIGURE 5-5-2



SOURCE: TRESTLE
MEAS LOC: EAST WALKWAY (ELEVATOR CABLE)

FIGURE 5-5-3

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS:

SUMMARY:

Data presented in this report confirms that some facility EMP interaction does take place. However, the interaction of other facilities with ARES is minimal and can be readily remedied. Three major points of entry (POE) have been defined and appropriate steps have been taken to minimize any problems. The three POEs are:

a) Commerical Power Lines

b) Umbilical Cables

c) Heater and Drops Cords

These POEs can be and have been EMP hardened by placement of filters and shielding described in section four of this report. If quiet times are needed by either facility, they need only minimal coordination.

CONCLUSIONS:

- Standard safety procedures and coordination techniques employed at all facilities can eliminate any personnel safety problems.

- Inadvertant antennas act as quarter wavelength antennas to couple EMI into the ARES DACC.

- Mutually exclusive operation of the involved facilities is not required.

- Tests can be conducted in ARES independent of ongoing tests in other facilities.

RECOMMENDATIONS:

- Potential ARES users develop a conscientious program of configuration control over inadvertant antennas.

- Potential ARES users place added protection devices at the input to equipment identified as sensitive to the EMP levels described in this report.

- Potential ARES users provide shielding for all inadvertent antennas in or near the ARES working volume.

- FCDNA coordinate quiet times as necessary to eliminate equipment problems described in section four of this report.

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3) Strong, "Biophysical Measurements," Tektronix, Inc., 1970.

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