MEASUREMENT NOTES

NOTE 25

DETERMINISTIC ERROR ANALYSIS APPLIED TO EMP SIMULATOR DATA ACQUISITION

II. APPLICATION TO AIRCRAFT TEST DATA

March 1978

L. Simpson

J. F. Prewitt

L. D. Scott

Mission Research Corporation

Albuquerque, New Mexico 87108

ABSTRACT

The deterministic error model described in Measurement Note 24 has been implemented on the ADSET* system. Analysis of a selected set of electric field, surface current, and internal cable current measurements, taken during a recent aircraft test at the ATHAMAS-I simulator, is presented. Frequency domain error curves are presented together with the resulting data bandwidths for each data set. It is found that upper bandwidth limits are determined by signal-to-noise ratios, while lower bandwidth limits are determined predominantly by base line error and lack of frequency resolution resulting from finite record lengths. Most of the electric field and surface current density measurements are found to have well-defined bandwidths, while measurements of internal cable currents are valid either over several discrete frequency ranges, or are not usable at all. This last result means that attempts to form external-to-internal transfer functions with these data will have little success.

---

*ADSET - a dedicated computer-based EMP data conversion, storage retrieval, and processing system.

1. INTRODUCTION

In Measurement Note 24, a deterministic error model was described which is applicable to the acquisition and analysis of data obtained at an EMP simulator. This note presents the application of this error model to data taken at the ATHAMAS-I simulator during a recent aircraft test. A selection of 24 data records were made available to the authors for analysis: four electric field measurements, seven surface current density measurements, and eleven internal cable current measurements. Particular emphasis is given here to (1) the identification of dominant error sources at the high and low ends of the frequency spectrum, (2) the sensitivity of the combined error to individual error contributors, and (3) the bandwidth of reliable frequency domain information.

2. DESCRIPTION OF ERROR TERMS

The principal contributors to time domain error in a well implemented test are (ref. 1):

(1) base line shift

(2) base line rotation

(3) noise

(4) truncation

(5) instrumentation measurement errors (amplitude and sweep speed)

Base line shift and rotation are combined in one base line error parameter. A base line rotation gives rise to an error in the spectrum that is less than the error calculated assuming that the maximum rotational offset is a base line shift. The base line shift and truncation errors were estimated from the time domain plots of each data record.

The data analyzed are all available in the ADSET data library. Signal-to-noise ratios were given in the ADSET characterization record for 20 of the 24 data records. For one of the four remaining data records, #00005, a noise measurement was found having the same test point and instrumentation numbers. The calculated S/N for this measurement was 160:1. The percent error of the frequency domain amplitude for this data

1. Scott, L. D., Deterministic Error Analysis Applied to EMP Simulator Data Acquisition, Air Force Weapons Laboratory, Measurement Note No. 24, June 1977.

record was calculated using both this value of the S/N and a more conservative estimate of 32:1. From the time domain plots of the other three records, a 32:1 S/N ratio was adopted as a conservative estimate.

Based upon MRC's previous experience with EMP simulator data, it had been determined that with good quality control (QC), time domain amplitude errors of integrated measurements were 10.4% and for nonintegrated measurements were typically 6.0%. Sweep speed errors with instrumentation Auto Cal* were typically one percent or less.

3. CONTRIBUTION OF INDIVIDUAL SOURCES TO TOTAL ERROR

To illustrate the contribution of individual errors to the total error measurement, a series of calculations were made on the data record #00522, which has significant amplitude, sweep speed, base line shift, truncation, and noise errors. For this data record, the calculations were made setting all the error parameters except one to zero. The result of these calculations are given in figures 8, 9, 10, 11, and 12. From these figures it is readily seen that the base line shift dominates at low frequencies and the noise error at high frequencies. Truncation and amplitude errors will tend to bound the error envelope only in the frequency range of 1 - 10 MHz when the base line shift is small and the S/N large. With good QC, sweep speed errors should be small and the error envelope in general will be dominated by noise errors at high frequency.

To study the two dominant error sources, base line shift and noise, a number of deterministic error analysis (DEA) calculations were made varying these two parameters. The effects of changing the noise-to-signal ratio can be seen for data record #00005 in figures 3 and 4.

*Auto Cal - computer based calibration procedure used with DASET (Data Acquisition System for EMP Testing).

Again this analysis illustrates that the error due to base line shift tends to dominate at low frequencies and noise error at high frequencies. The bandwidth of usable spectral information is essentially governed by these error terms and the length of the data record itself. The transform of a finite time record is limited at low frequencies by the resolution resulting from the finite length of the record and at high frequencies by the time interval between samples.

4. GENERAL CLASSIFICATION OF SPECTRAL CHARACTERISTICS

For ease of description, the spectra of the 24 data records examined can be divided into three categories--the first being a spectrum with significant information whose spectral properties are reliable over a fairly wide bandwidth. The second type of spectrum is characterized by significant information over several discrete frequency ranges. The third type of spectrum is one whose spectral information is not useable. Under this categorization there were eight data records whose spectra fall into category 1, eleven whose spectra fall into category 2, and five spectra that were not usable according to the DEA analysis (i.e., error across the entire band $\geq$ 100%).

5. DISCUSSION OF DEA FOR EACH OF THE 24 DATA RECORDS

Table 1 is a summary of the time domain error parameters adopted for each of the 24 data records along with the spectral classification of each, the usable bandwidth of the spectrum, and the predominant error contributors at high and low frequencies. It can be seen that in half of the usable spectra, the low frequency cutoff is determined by the length of the data record. If low frequency information is desired, then the data length must be extended to greater times. The data length can be extended by a change in sweep speed, or by some knowledge of the response behavior (e.g., can the signal be assumed zero for late times from physical arguments?). Given sufficient data record length, the principal ways to improve the low frequency spectral reliability are to increase S/N and minimize base line shifts. It would appear from this sample of data that all the records are noise limited at less than 80 MHz with the exception of a few large amplitude spectral features.

Table 1

	Data Record No.	Amp Error (%)	Sweep Speed Error (%)	Base Line Error (%)	Truncation Error (%)	N/S (%)	Spectral Type	Band-width MHz	Low Fre-quency Cutoff	High Fre-quency Cutoff
		Time Domain Error Parameters								
Electric Field	#00005	10.4	1.0	1.5	1.0	0.63	1	2-63	Record Length	Noise Error
	#00013	10.4	1.0	2.5	1.0	3.2	1	2-55	Record Length	Noise Error
	#00021	10.4	1.0	2.3	1.0	3.2	1	2-50	Record Length	Noise Error
	#00022	10.4	1.0	1.0	1.0	3.2	1	1-43	Record Length	Noise Error
Surface Current Density	#00439	6.0	1.0	2.4	7.3	13	2	1.1-6.8 8-16	Base Line Error	Noise Error
	#00522	6.0	1.0	3.4	7.8	10	1	1.1-16	Base Line Error	Noise Error
	#00713	6.0	1.0	2.7	1.0	3.2	1	.2-20	Record Length	Noise Error
	#00637	6.0	1.0	11.3	1.8	5.0	2	1.4-4.0 6.0-16	Base Line Error	Noise Error
	#00756	6.0	1.0	9.7	1.9	14	1	.2-12	Base Line Error	Noise Error
	#00554	6.0	1.0	1.0	13.5	7.9	1	.2-20	Record Length	Noise Error
	#00477	6.0	1.0	7.3	1.0	18	2	.2-9.8	Record Length	Noise Error

Table 1 (Continued)

	Data Record No.	Time Domain Error Parameters: Amp Error (%)	Sweep Speed Error (%)	Base Line Error (%)	Truncation Error (%)	N/S (%)	Spectral Type	Band-width MHz	Low Fre-quency Cutoff	High Fre-quency Cutoff
Internal Cable Current	#00345	6.0	1.0	1.0	10.2	11	2	2.3-8.2	Noise	Noise Error
	#00458	6.0	1.0	1.0	5.0	13	2	1.0-1.7 12-15	Record Length	Noise Error
	#00371	6.0	1.0	1.0	3.4	25	3	---	---	---
	#00411	6.0	1.0	1.2	5.4	6.3	2	0.5-5.4 7.5-19	Record Length	Noise Error
	#00370	6.0	1.0	6.4	3.0	25	3	---	---	---
	#33455	6.0	1.0	5.5	1.5	13	2 (marginal)	Peaks	Base Line & Noise	Noise Error
	#00283	6.0	1.0	5.3	4.2	32	3	---	---	---
	#00286	6.0	1.0	1.0	5.4	32	3	---	---	---
	#00369	6.0	1.0	1.3	5.3	32	3	---	---	---
	#00418	6.0	1.0	1.3	3.0	6.3	2	.7-37	Base Line & Noise	Noise Error
	#00560	6.0	1.0	1.0	7.6	7.9	2	.7-9.1	Base Line & Trunca-tion	Noise Error
	#00552	6.0	1.0	2.8	14.3	7.9	2	4.2-11.7 12.8-26	Base Line & Trunca-tion	Noise Error
	#00569	6.0	1.0	3.7	15.3	7.9	2	3.0-22	Base Line & Trunca-tion	Noise Error

Note that all four electric field measurements are of spectral type 1, and have usable bandwidths from 2 MHz to approximately 50 MHz. The seven surface current density measurements are divided equally between spectral types 1 and 2, and have bandwidths from approximately 1 MHz to 15 MHz. Finally the internal cable current measurements are divided about equally between spectral types 2 and 3--more than half of the internal current measurements are unusable if the signal-to-noise ratios given in the characterization record are valid.

An example of each of the three measurement types is given in figures 1-15. The plots are organized in the following fashion:

(1) A plot of the time domain record.

(2) A plot of the FFT of the data.

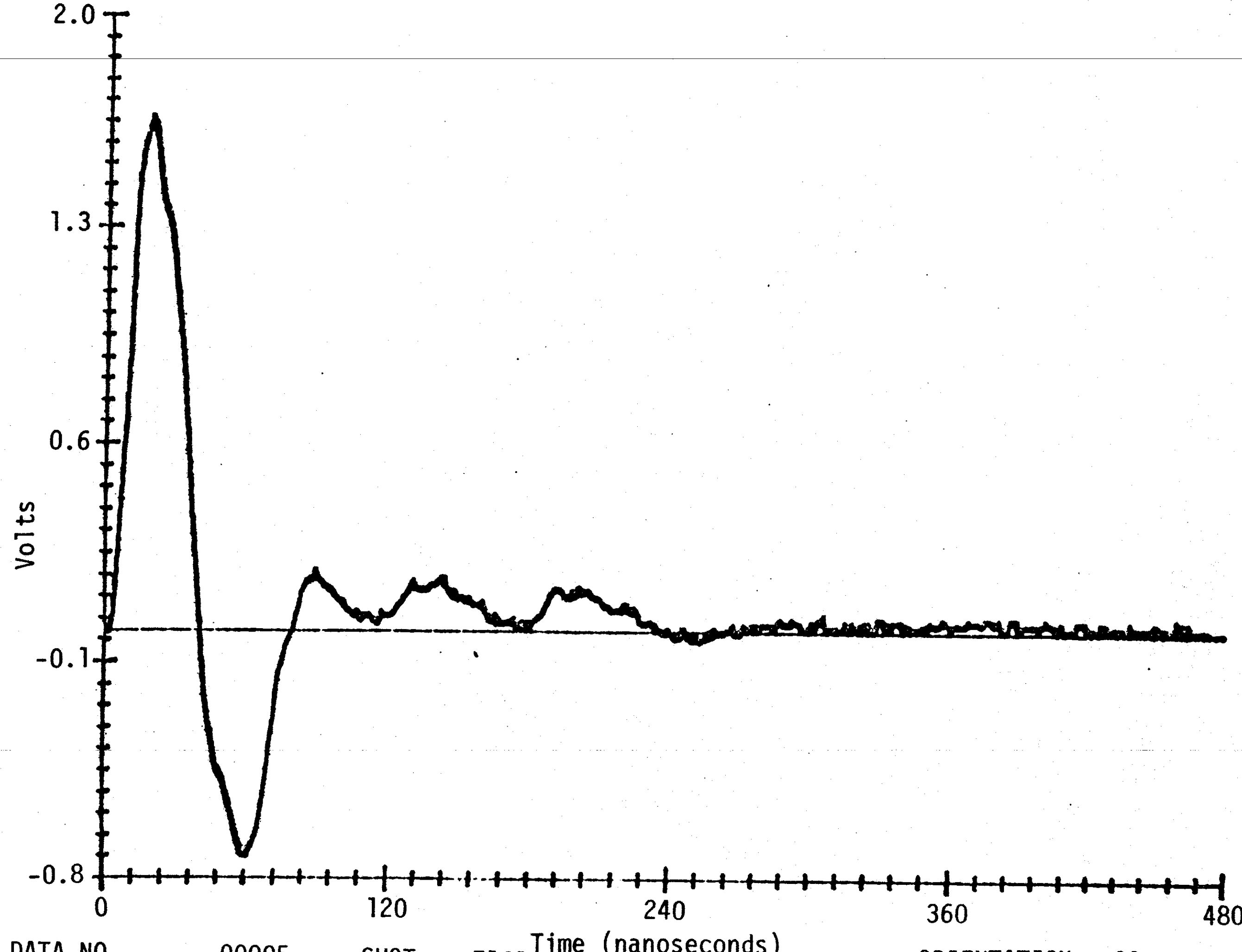
(3) A plot of the percent error of the spectrum.

(4) Additional plots of the percent error where one or more of the error parameters has been changed.

6. CONCLUDING REMARKS

The calculated percent error is to be treated as the envelope of the maximum error in the frequency domain amplitude. It is useful in determining the reliability of the spectral content of a data record with the given assumptions about the magnitudes of the errors. For the most part conservative estimates of these error parameters were made. More information might allow one to improve the estimate of these parameters and subsequently to more accurately characterize the reliability of the spectral information.

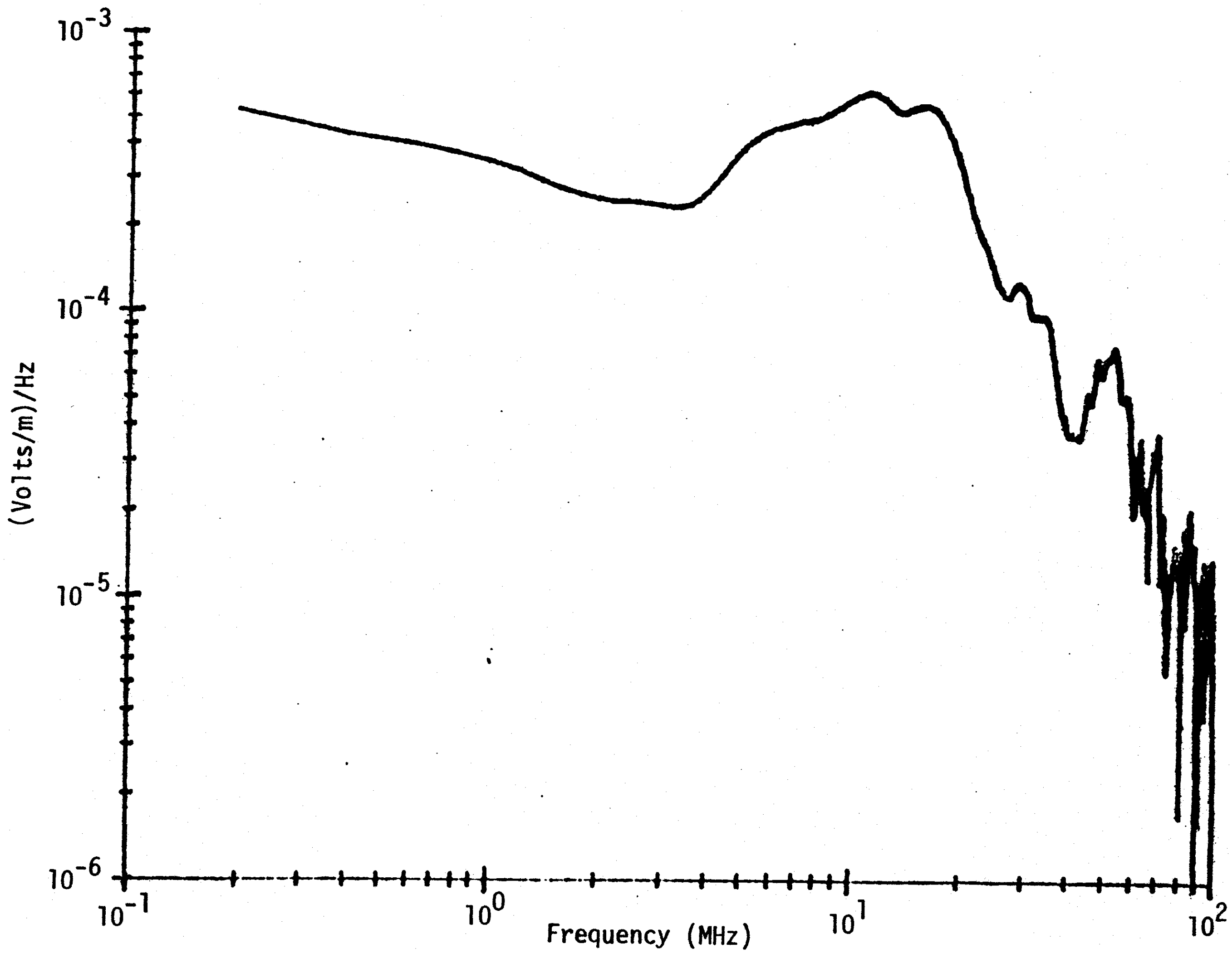
An important aspect of the above data analysis is the determination that the internal current measurements are of limited validity. Consider what this determination means if external-internal transfer functions are desired for this aircraft--more than half of the desired transfer functions cannot be used, while the remainder are valid only over several limited frequency ranges. If we envision a testing program whose purpose is the determination of such transfer functions, a weak link such as the internal current measurements discussed here can obviate the entire test program, including good field measurements, surface current and charge density measurements.



DATA NO. 00005 SHOT 7191
SENSOR NO. 0009 MEAS. NO. EX
INST. NO. M701
TEST POINT NO. 0300

ORIENTATION 00
TEST ITEM POS. +00 +05 +30
CONFIGURATION 000
ENVIRONMENTAL LEVEL 126

Figure 1. Time Domain Plot of Data Record 00005

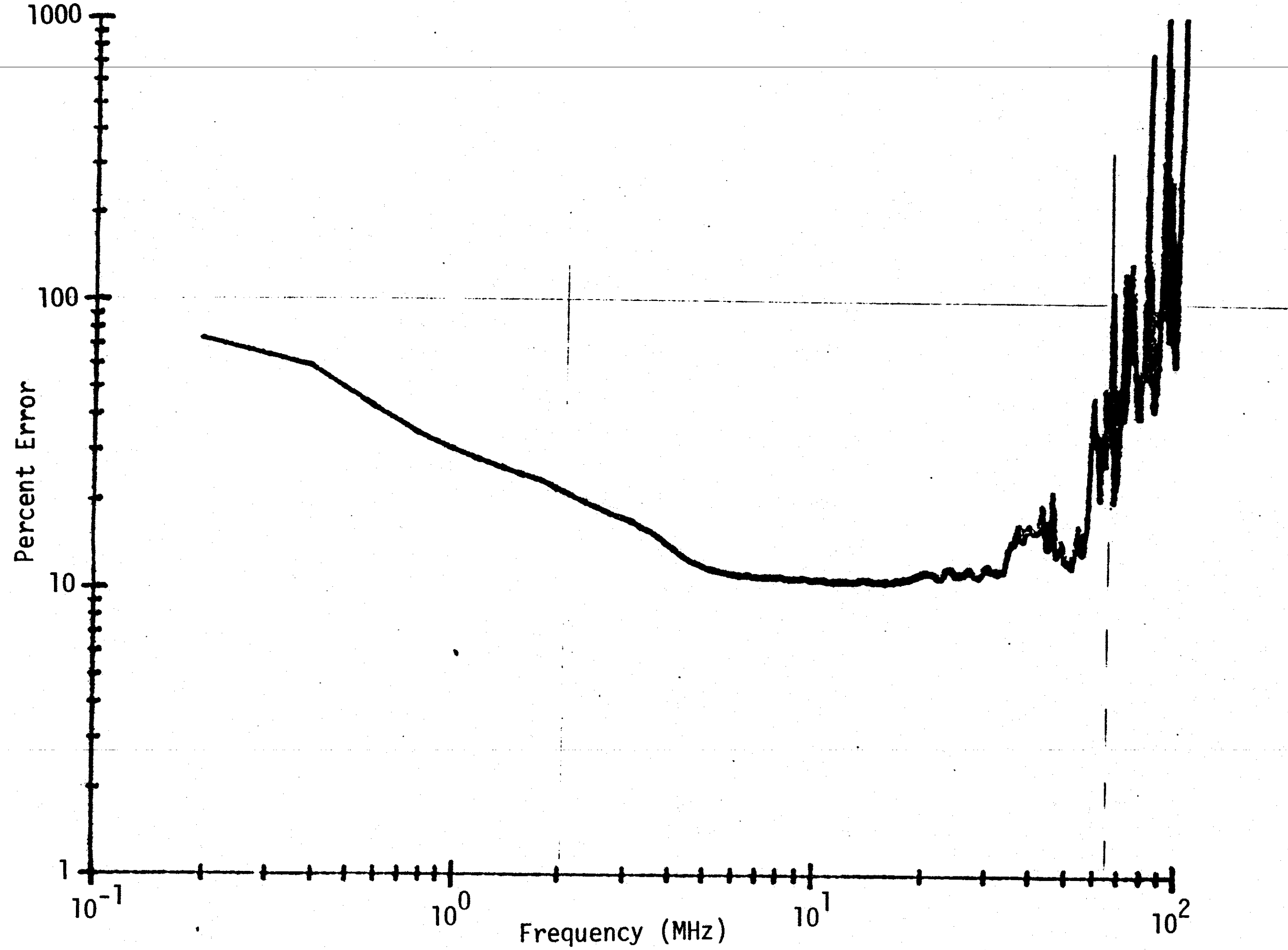


DATA NO. 00005
SENSOR NO. 0009
INST. NO M701
TEST POINT NO. 0300

SHOT 7191
MEAS. NO. EX

ORIENTATION 00
TEST ITEM POS. +00 +05 +30
CONFIGURATION 000
ENVIRONMENTAL LEVEL 126

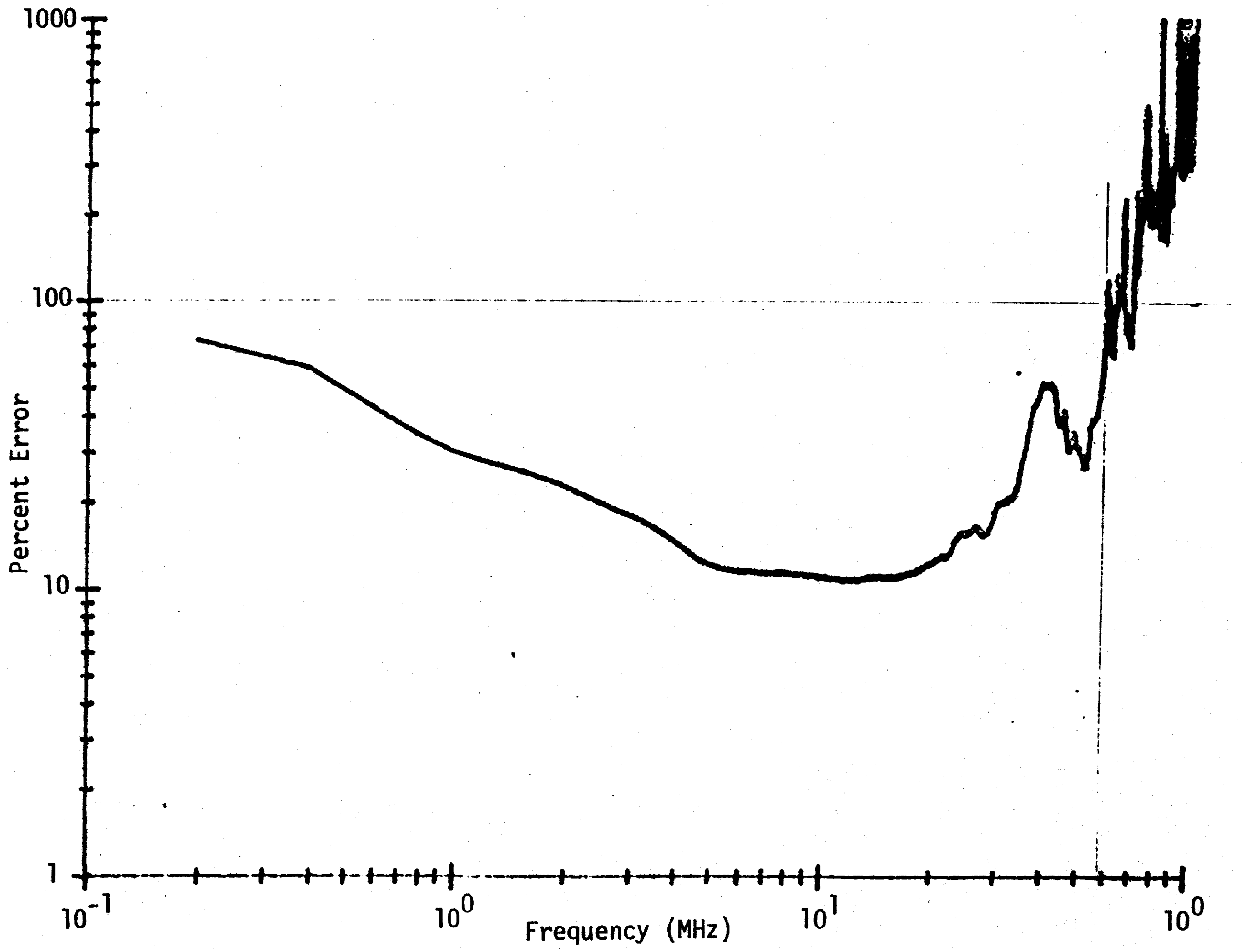
Figure 2. FFT of Data Record 00005



DATA SET NO. 00005
% AMPLITUDE UNCERTAINTY 10.400
SWEEP SPEED UNCERTAINTY = 1.000
PERCENT OF BASE LINE = 1.500

PERCENT TRUNCATION = 1.000
NOISE-TO-SIGNAL RATIO = .631E-02
DELTA T = 2.500

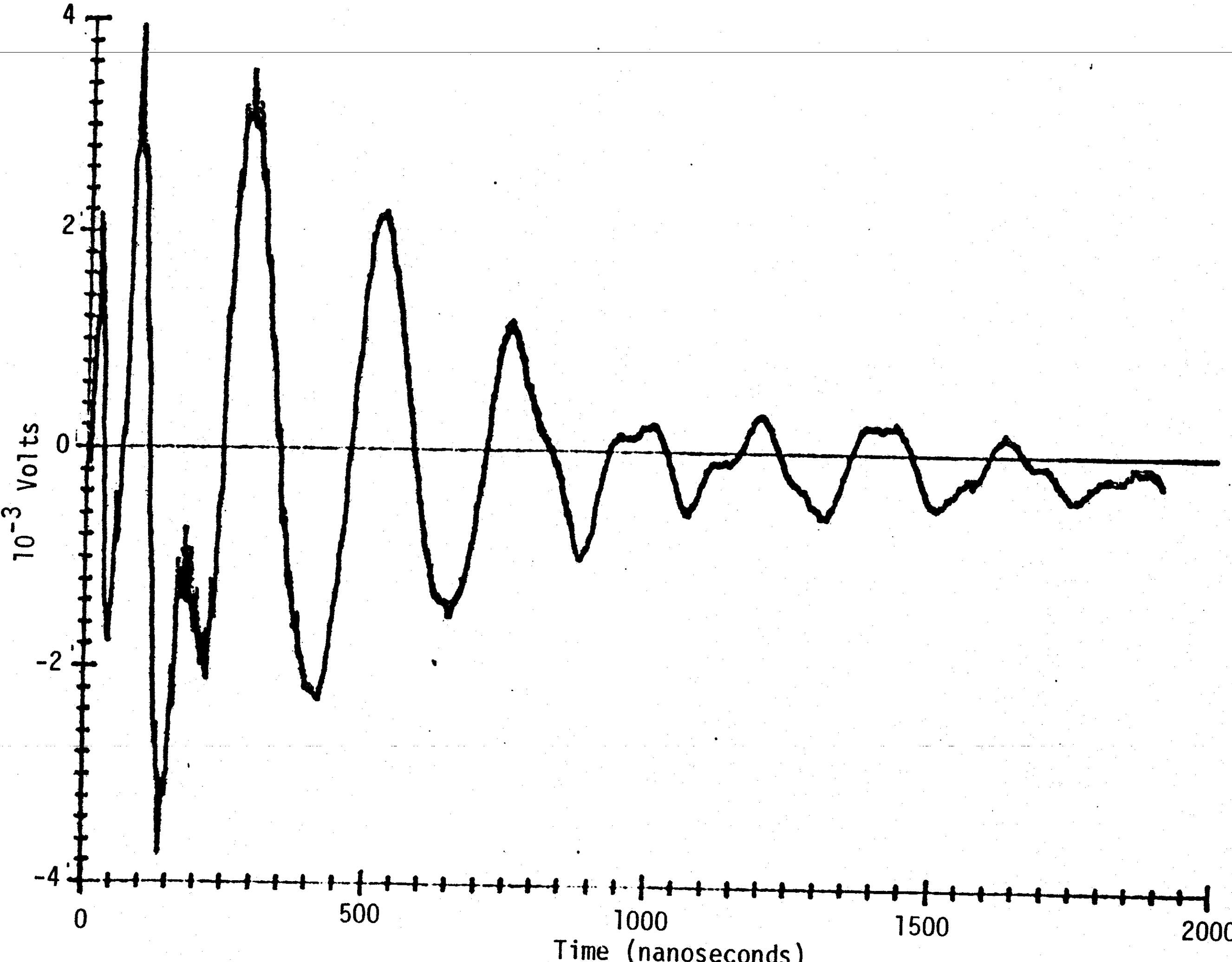
Figure 3. Plot of Percent Error of Spectrum of 0005



DATA SET NO. 00005
% AMPLITUDE UNCERTAINTY 10.400
SWEEP SPEED UNCERTAINTY = 1.000
PERCENT OF BASE LINE = 1.500

PERCENT TRUNCATION = 1.000
NOISE-TO-SIGNAL RATIO = .316E-01
DELTA T = 2.500

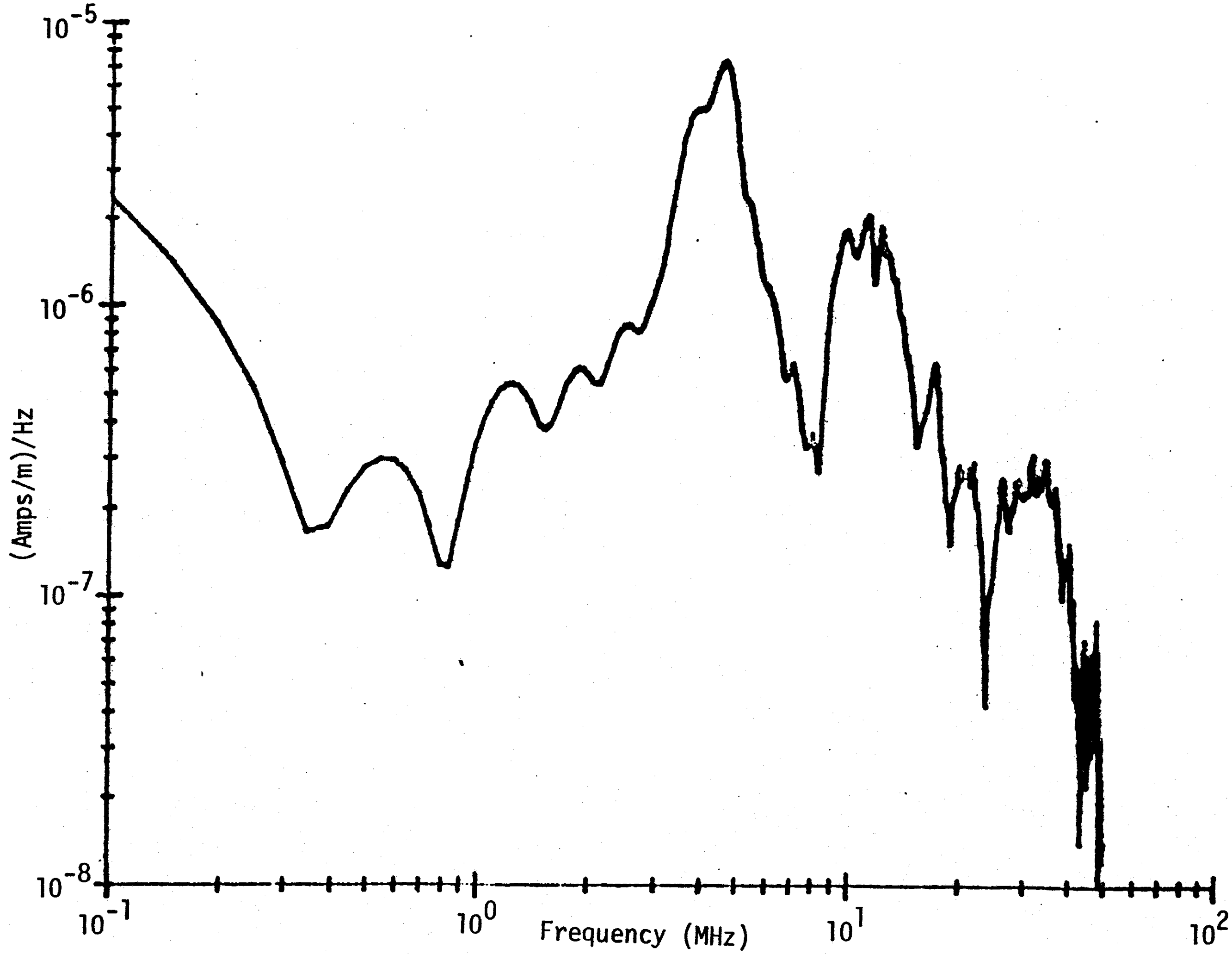
Figure 4. Plot of Percent Error of Spectrum of 00005 (N/S changed from -44. to -30. dB)



DATA NO. 00522 SHOT 7706
SENSOR NO. 0027 MEAS. NO. JA
INST. NO. 7624
TEST POINT NO. 0107

ORIENTATION 00
TEST ITEM POS. +00 +03 +30
CONFIGURATION 004
ENVIRONMENTAL LEVEL 126

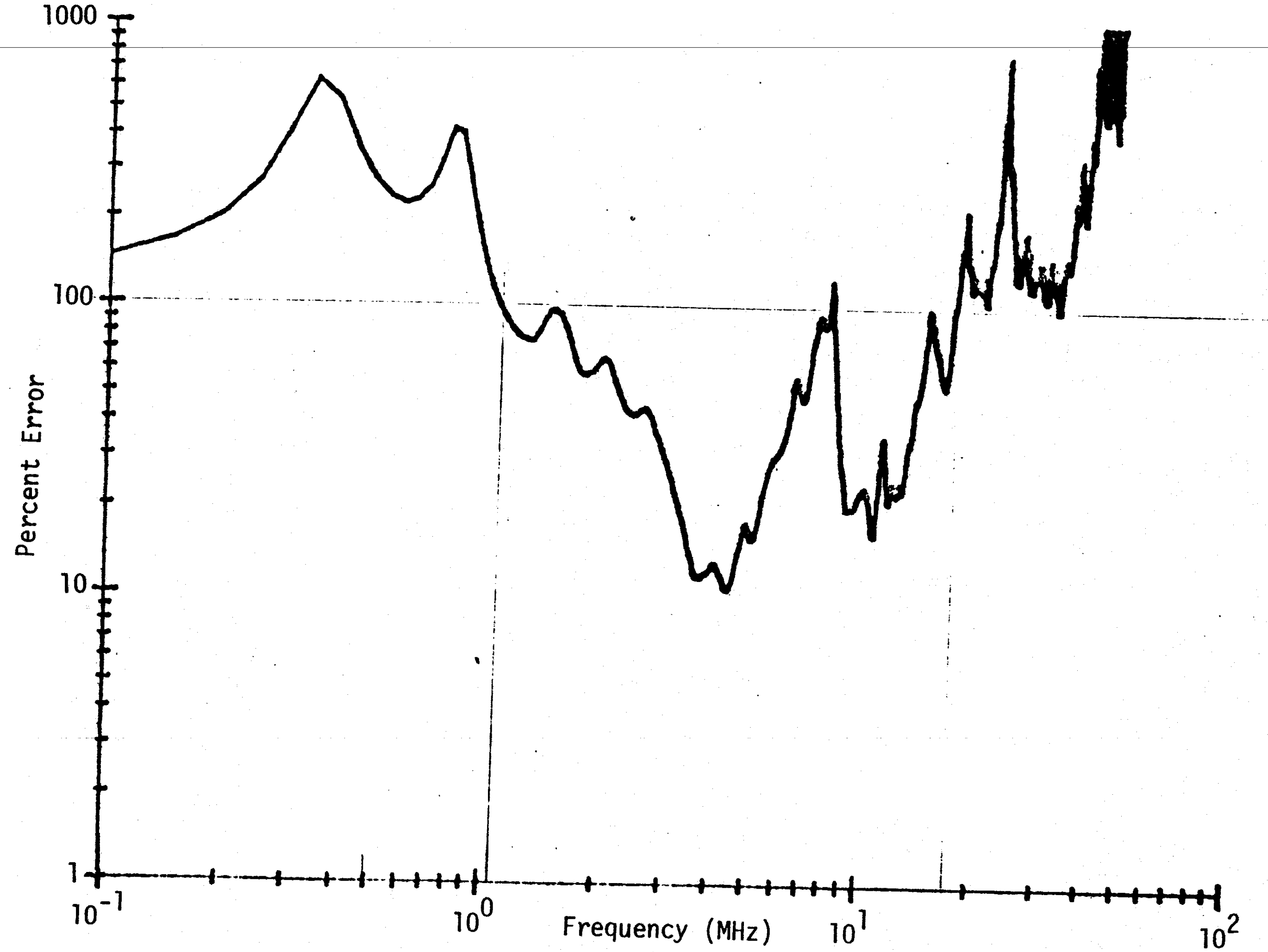
Figure 5. Time Domain Plot of Data Record 00522



DATA NO. 00522 SHOT 7706
SENSOR NO. 0027 MEAS. NO. JA
INST. NO. 7624
TEST POINT NO. 0107

ORIENTATION 00
TEST ITEM POS. +00 +03
CONFIGURATION 004
ENVIRONMENTAL LEVEL 126

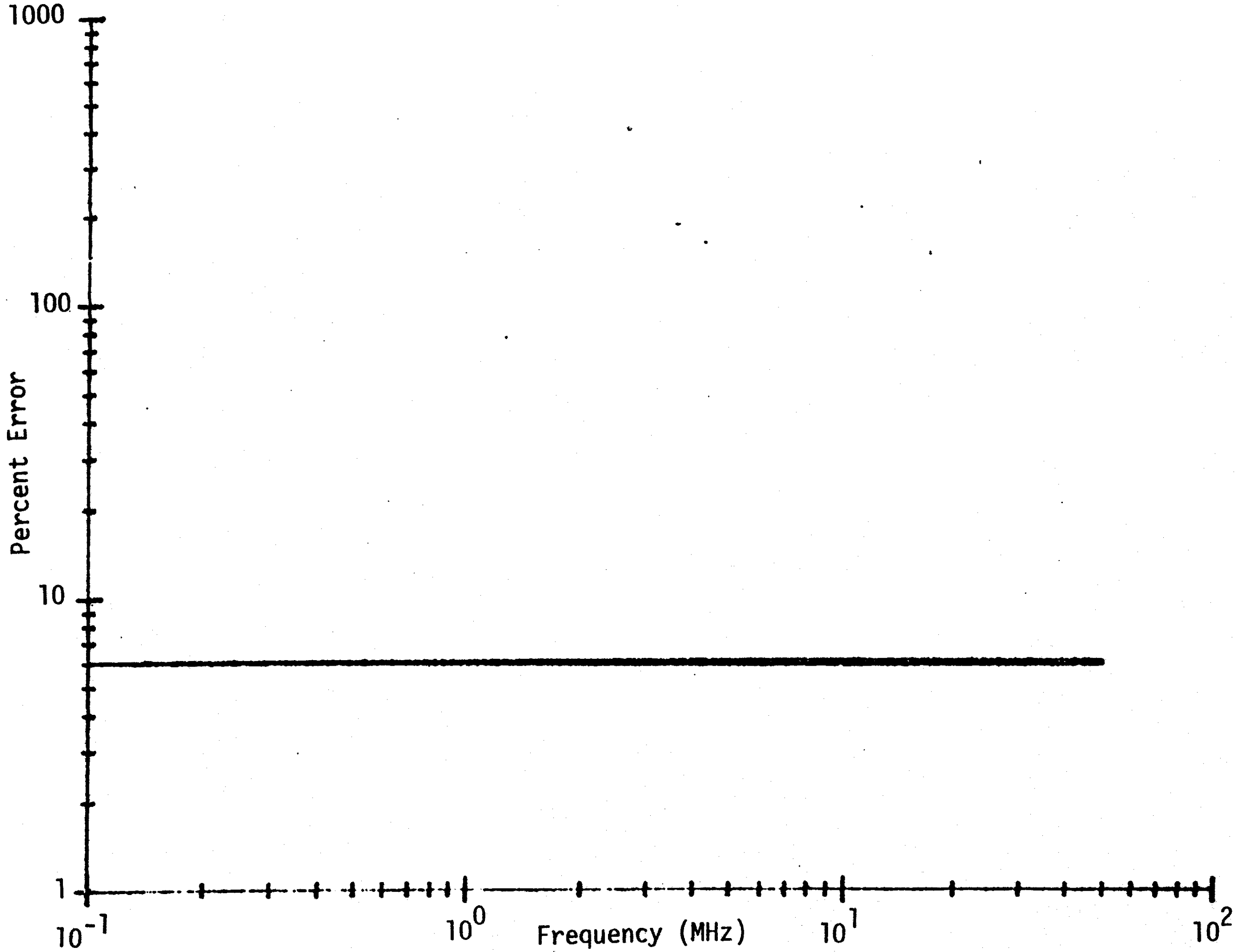
Figure 6. FFT of Data Record 00522



DATA SET NO. 00522
% AMPLITUDE UNCERTAINTY 6.000
SWEEP SPEED UNCERTAINTY = 1.000
PERCENT OF BASE LINE = 3.400

PERCENT TRUNCATION = 7.800
NOISE-TO-SIGNAL RATIO = 100E+00
DELTA T = 9.999

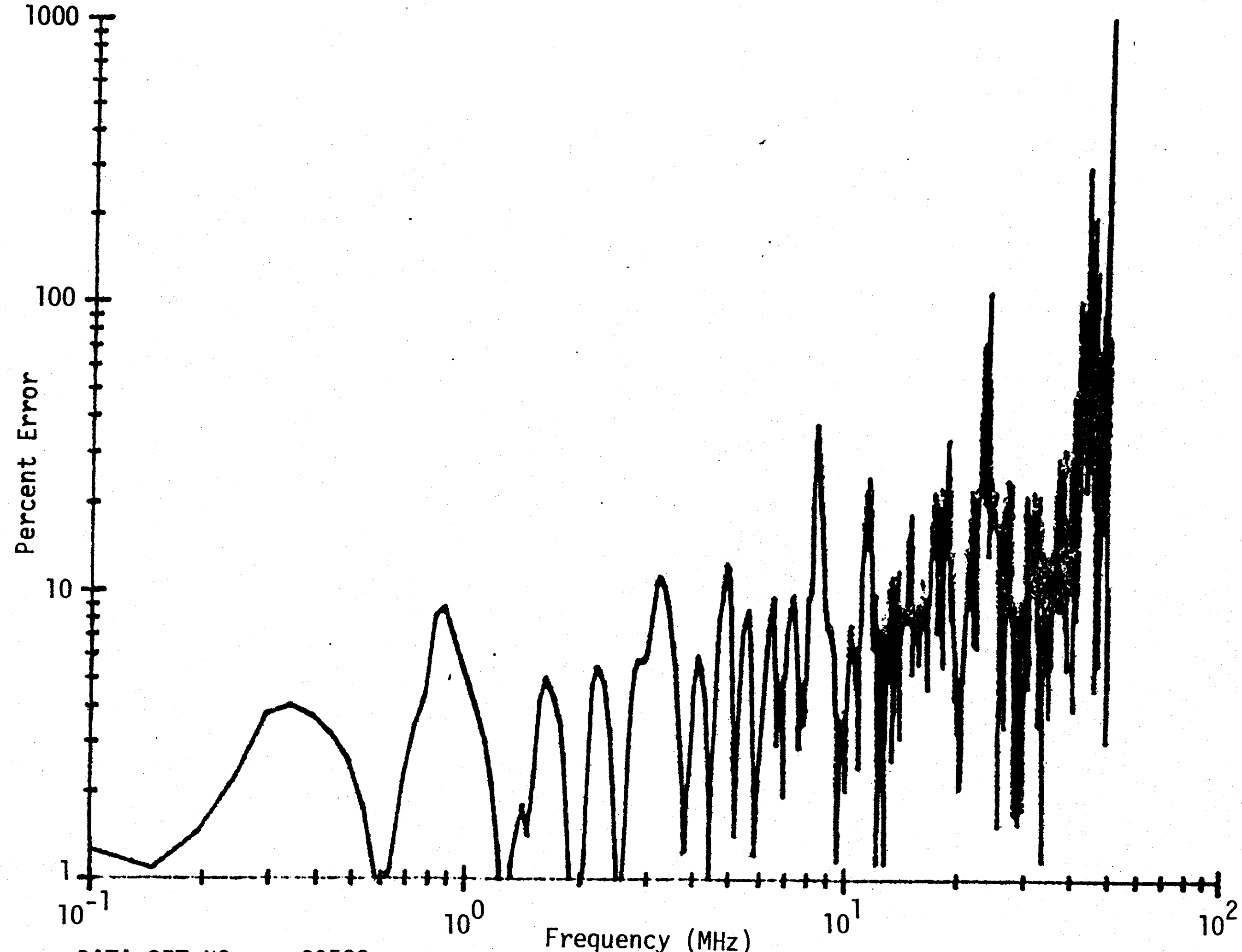
Figure 7. Plot of Percent Error of Spectrum of 00522



DATA SET NO. 00522
% AMPLITUDE UNCERTAINTY 6.000
SWEEP SPEED UNCERTAINTY = 0.000
PERCENT OF BASE LINE = 0.000

PERCENT TRUNCATION = 0.000
NOISE-TO-SIGNAL RATIO = 100E-09
DELTA T = 9.999

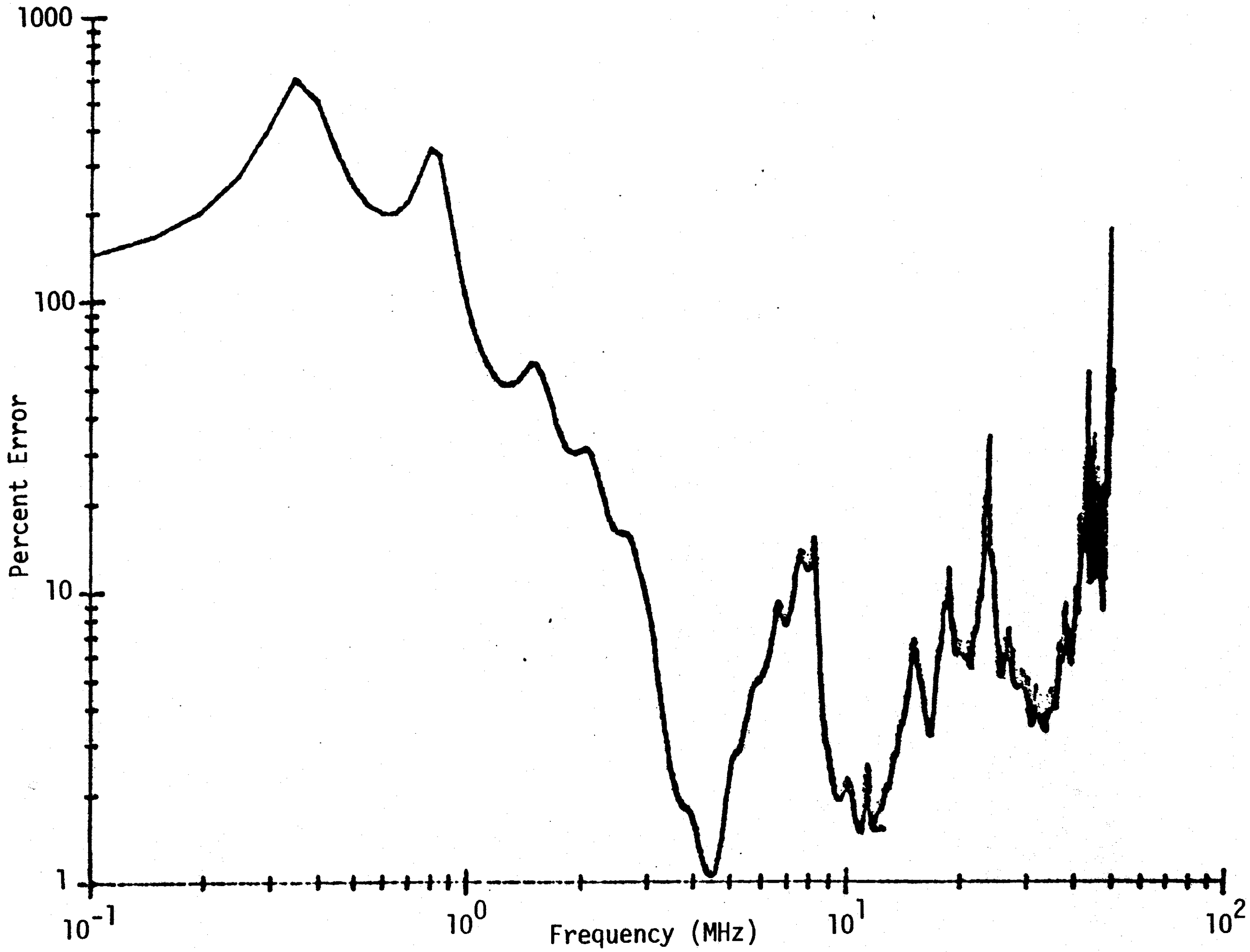
Figure 8. Plot of Percent Error of Spectrum of 00522
(All error parameters except amplitude set to 0.)



DATA SET NO. 00522
% AMPLITUDE UNCERTAINTY 0.000
SWEEP SPEED UNCERTAINTY = 1.000
PERCENT OF BASE LINE = 0.000

PERCENT TRUNCATION = 0.000
NOISE-TO-SIGNAL RATIO = .100E-09
DELTA T = 9.999

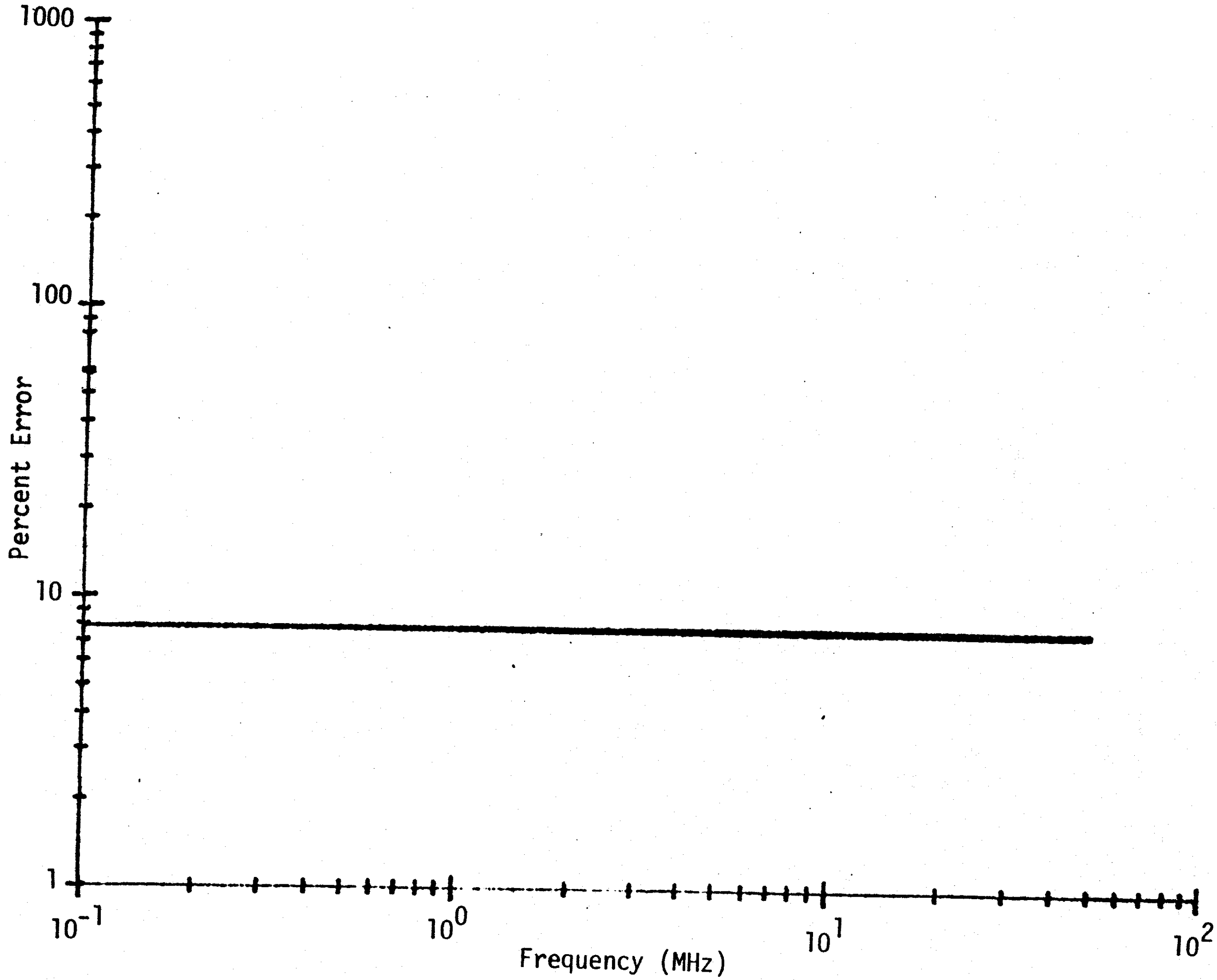
Figure 9. Plot of Percent Error of Spectrum of 00522
(All error parameters except sweep speed set to 0.)



DATA SET NO. 00522
% AMPLITUDE UNCERTAINTY 0.000
SWEEP SPEED UNCERTAINTY = 0.000
PERCENT OF BASE LINE = 3.400

PERCENT TRUNCATION = 0.000
NOISE-TO-SIGNAL RATIO = 100E-09
DELTA T = 9.999

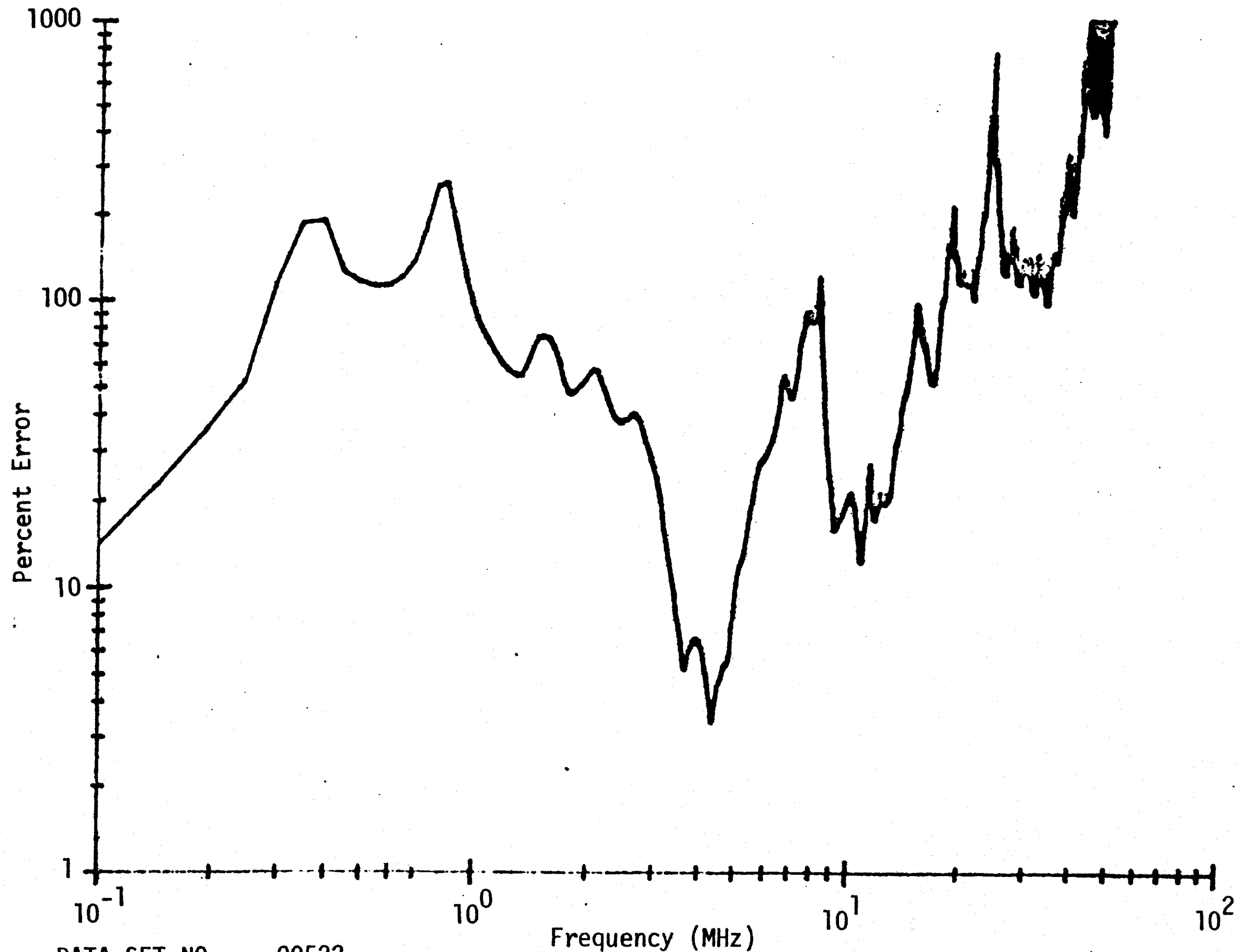
Figure 10. Plot of Percent Error of Spectrum of 00522
(All error parameters except base line set to 0.)



DATA SET NO. 00522
% AMPLITUDE UNCERTAINTY 0.000
SWEEP SPEED UNCERTAINTY = 0.000
PERCENT OF BASE LINE = 0.000

PERCENT TRUNCATION = 7.800
NOISE-TO-SIGNAL RATIO = .100E-09
DELTA T = 9.999

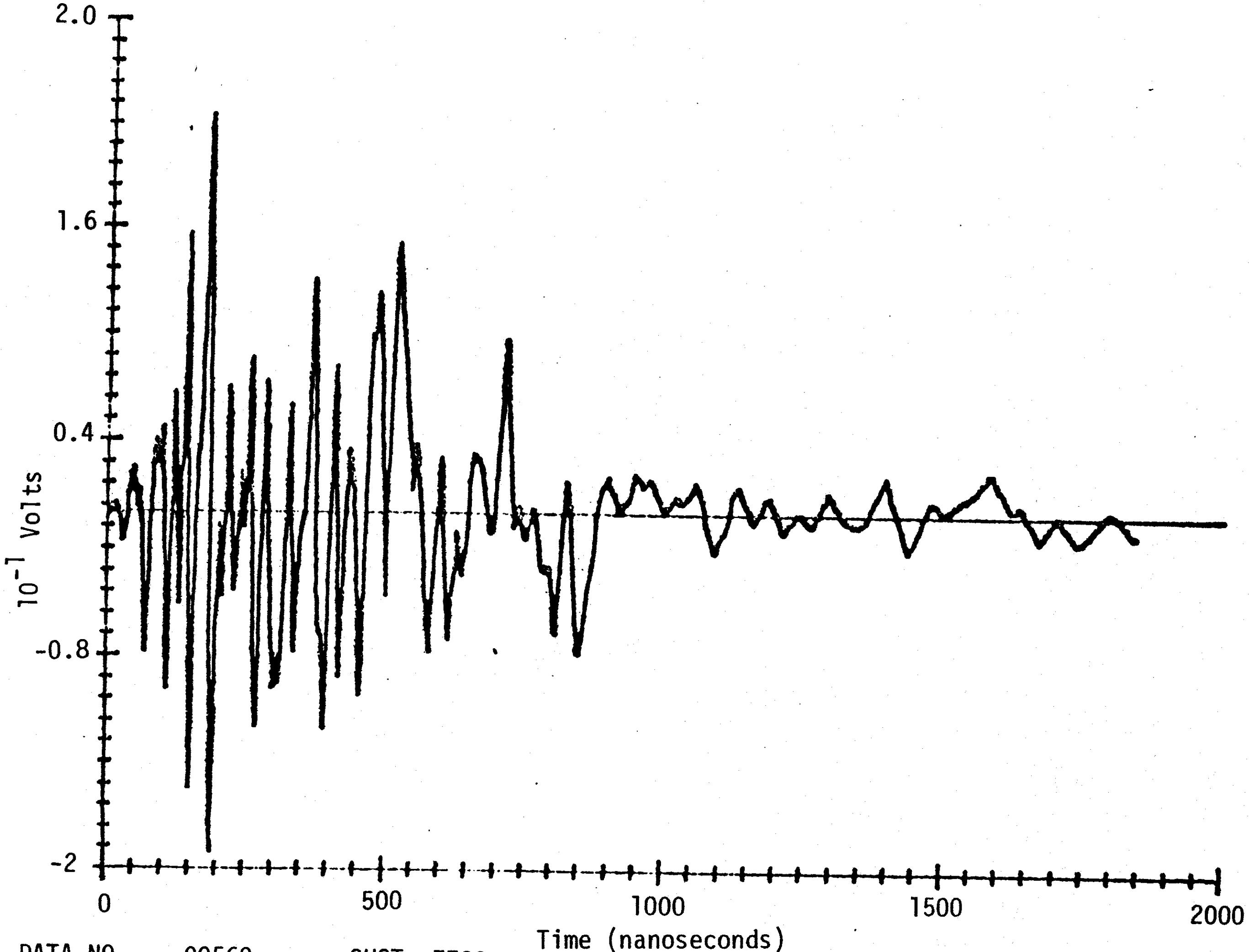
Figure 11. Plot of Percent Error of Spectrum of 00522
(All error parameters except truncation set to 0.)



DATA SET NO. 00522
% AMPLITUDE UNCERTAINTY 0.000
SWEEP SPEED UNCERTAINTY = 0.000
PERCENT OF BASE LINE = 0.000

PERCENT TRUNCATION = 0.000
NOISE-TO-SIGNAL RATIO = 100E+00
DELTA T = 9.999

Figure 12. Plot of Percent Error of Spectrum of 00522
(All error parameters except N/S set to 0.)

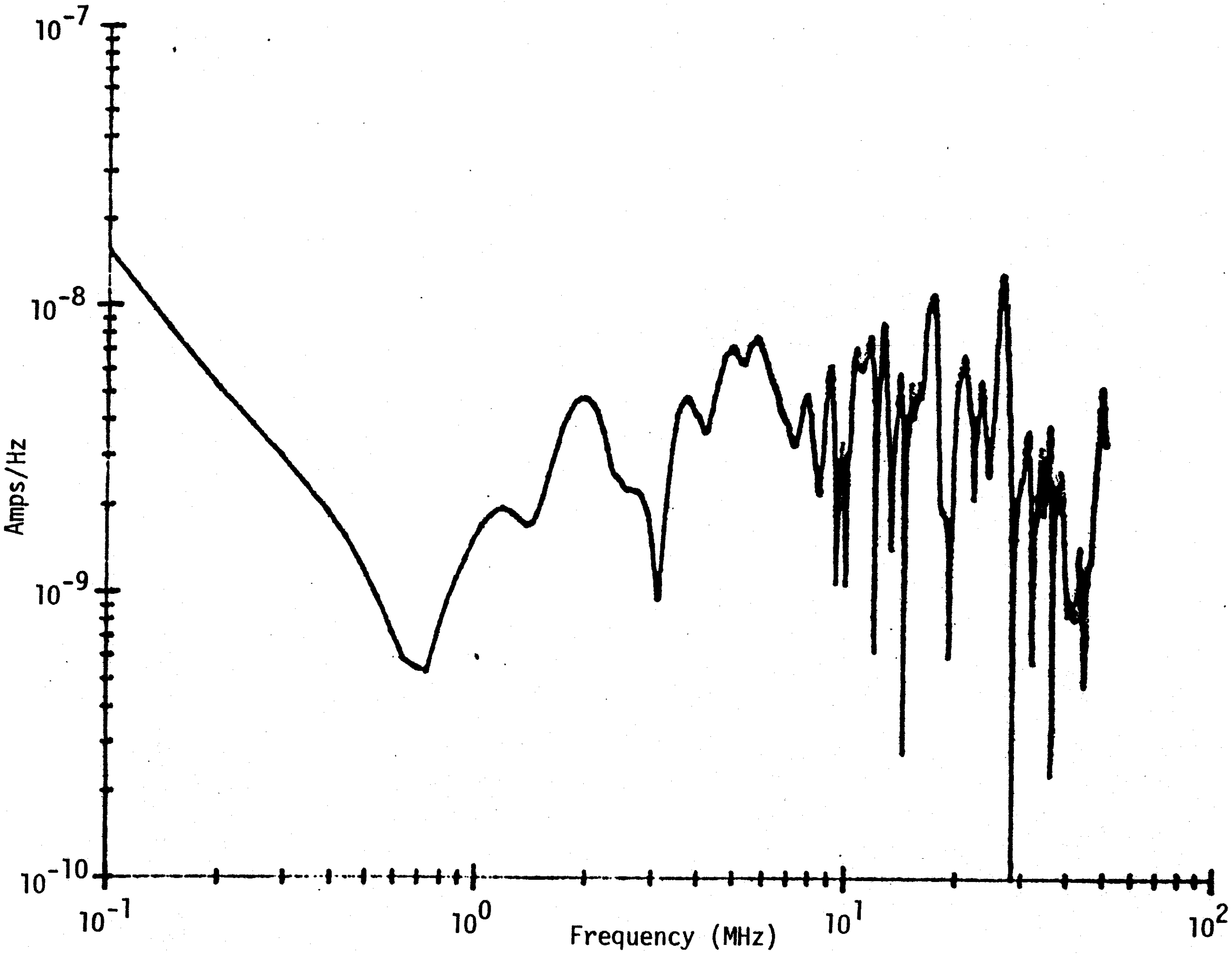


DATA NO. 00560
SENSOR NO. 0037
INST. NO. 7624
TEST POINT NO. 3093

SHOT 7730
MEAS. NO. IL

ORIENTATION 00
TEST ITEM POS. +00 +03 +30
CONFIGURATION 004
ENVIRONMENTAL LEVEL 123

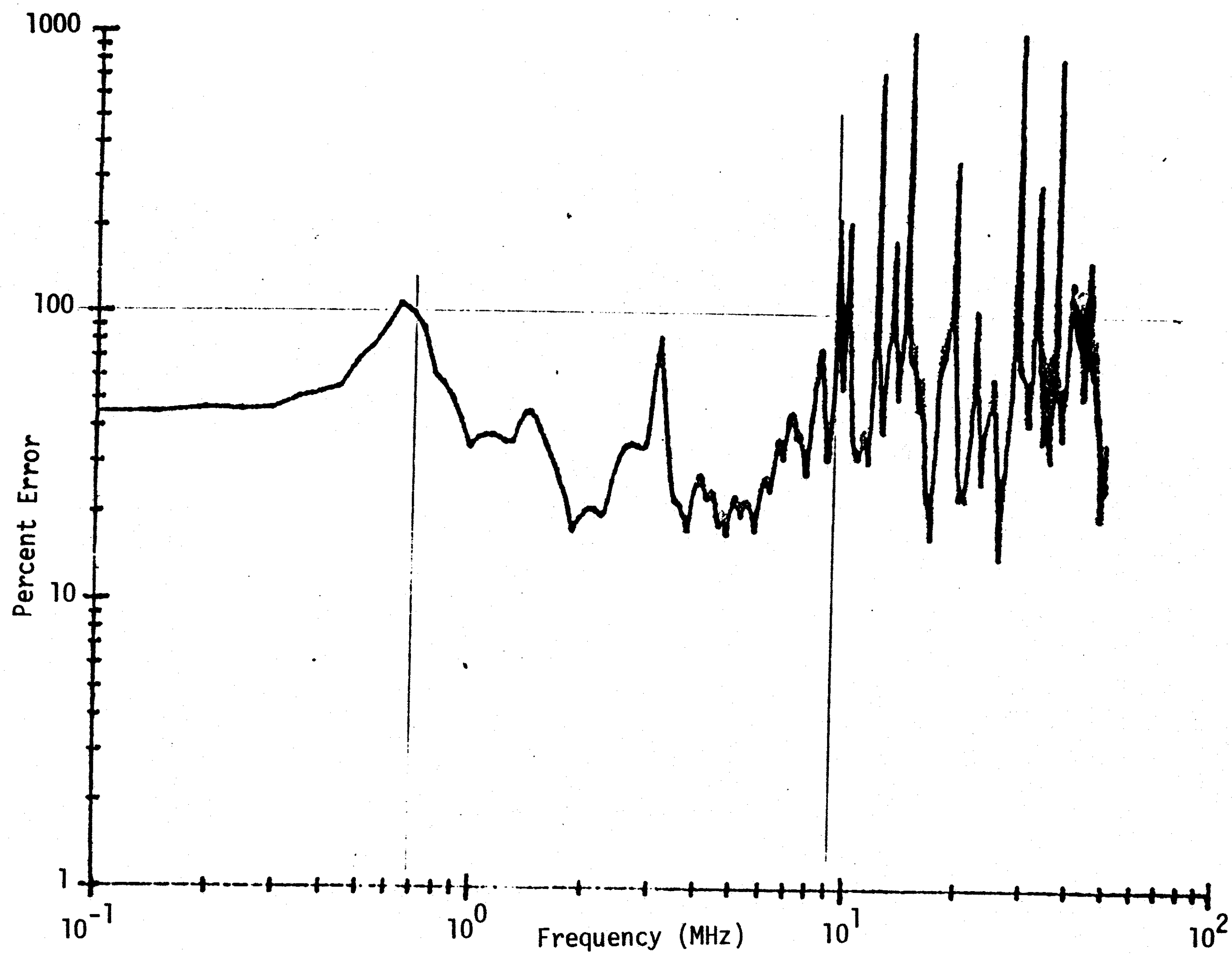
Figure 13. Time Domain Plot of the Data Record 00560



DATA NO. 00560 SHOT 7730
SENSOR NO. 0337 MEAS. NO. IL
INST. NO. 7624
TEST POINT NO. 3093

ORIENTATION 00
TEST ITEM POS. +00 +03 +30
CONFIGURATION 004
ENVIRONMENTAL LEVEL 123

Figure 14. FFT of the Data Record 00560



DATA SET NO. 00560
% AMPLITUDE UNCERTAINTY 6.000
SWEEP SPEED UNCERTAINTY = 1.000
PERCENT OF BASE LINE = 1.000

PERCENT TRUNCATION = 7.600
NOISE-TO-SIGNAL RATIO = 794E-01
DELTA T = 9.999

Figure 15. Plot of the Percent Error of the Spectrum of 00560