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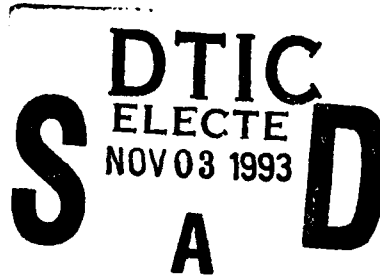


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**CATALOG OF ABSOLUTELY CALIBRATED,
RANGE NORMALIZED, WIDEBAND, ELECTRIC
FIELD WAVEFORMS FROM TRIGGERED LIGHTNING
FLASHES IN FLORIDA**

Yutaka Izumi
John C. Willett



22 June 1993

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During the summer of 1987, a rocket-triggered-lightning program was conducted at the NASA Kennedy Space Center, Florida. The rocket triggering was performed from two trigger platforms - one over water and the other over land. The propagation paths from the two sites were almost entirely over brackish water. This report presents waveform plots of the electric-field time derivative, the electric field, and the high-frequency spectral density at 5 MHz.

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Contents

1. INTRODUCTION	1
2. 1987 KSC ROCKET-TRIGGERED LIGHTNING PROGRAM	1
3. DATA PLOTS	2
REFERENCES	5
APPENDIX A: OVER-WATER PLOTS	7
APPENDIX B: OVER-LAND PLOTS	59

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Preface

We extend our thanks to Mr. J. C. Bailey, who wrote most of the basic data-analysis software, for guidance during the preparation of this report. We also thank Dr. D. M. Le Vine for his active participation in the 1987 field experiment. Special thanks are also due to Mr. William Jafferis of the Kennedy Space Center, without whose efforts the experiments would not have been possible. The experiments were carried out while the second author was at the Naval Research Laboratory, Washington, DC, supported in part by AFOSR contract F49620-86-C-0013.

Catalog of Absolutely Calibrated, Range Normalized, Wideband, Electric Field Waveforms from Triggered Lightning Flashes in Florida

1. INTRODUCTION

During the summer of 1987 a field experiment was conducted at the NASA Kennedy Space Center (KSC) in Florida to study rocket-triggered-lightning flashes. The experiment was a cooperative effort of the Office National d'Etudes et de Recherches Aerospatiales (ONERA), the Centre Etudes Nucleaires de Grenoble (CENG), the Centre National d'Etudes des Telecommunications (CNET), the State University of New York at Albany (SUNYA), and the U.S. Naval Research Laboratory (NRL). The activities of these participants are described by Eybert-Berard et al.¹ The lightning was triggered by CENG with small rockets trailing grounded wires. Currents and current derivatives were measured by CENG and CNET. High-speed photographic measurements of stroke-propagation velocities were made by SUNYA, and electric fields and field derivatives (dE/dt) were recorded by NRL. This report presents the triggered-lightning electric-field data collected by NRL.

2. 1987 KSC ROCKET-TRIGGERED LIGHTNING PROGRAM

The 1987 triggered-lightning experiment was a sequel to the 1985 KSC rocket-triggered program described by Willett et al.² In addition to the over-land trigger site used in 1985, the 1987 experiment utilized an over-water triggering platform that was located in shallow, brackish waters not far from the over-land pad, as described by Willett et al.³ and by Le Vine et al.⁴ The propagation paths from the two trigger sites were almost entirely over the brackish water at the Mosquito Lagoon. Maps of KSC showing the locations of measurements are presented in the two papers cited above.

The 1987 rocket-triggering experiment recorded electric-field waveforms from 33 return strokes in nine triggered flashes to the over-water triggering platform and 21 return strokes in seven triggered flashes to the over-land triggering site. The dates of these recordings were 30 and 31 July and 19 August 1987.

3. DATA PLOTS

The data plots of the triggered-lightning flashes for the three days are shown in the appendices. These plots use formats identical to those in the two volumes of data by Bailey and Willett⁵ and by Izumi and Willett⁶. Much of the discussion of the instrumentation and plots in these two reports is repeated below to make the present report complete. Descriptions of the instrumentation and calibrations can also be found in Willett et al⁷ and Willett et al.⁸

The data-acquisition system recorded an entire triggered-lightning flash with moderate time resolution as well as recording many of the return strokes within the flash with much higher resolution. The high-resolution data were obtained from triggered 10-bit digitizers sampling the "fast electric field" (fast E) and high-frequency energy spectral density (fast HF) at 10^7 samples per second and from 8-bit digitizers sampling the time derivative of the electric field (dE/dt) at 10^8 samples per second. Two digitizers were used to record dE/dt so that one could be operated at half the gain of the other to increase the effective dynamic range. Unfortunately, the low-gain digitizer introduced occasional artifacts in the form of one-sample-wide spikes in the digital data stream. In practice it was easy to recognize these spikes by eye, so that they did not seriously compromise data quality.

Either 4096 or 2048 samples of high-resolution data were recorded by each digitizer during each stroke, and these records will, hereafter, be referred to as the 4096 data or the 2048 data, respectively. The change from 4096 or 2048 data was made in mid-season to decrease the dead time between high-resolution records from 25 ms to 13 ms. The duration of a single triggered-lightning flash was defined by two slow digitizers that sampled the "slow electric field" (slow E) and the peak HF energy spectral density (slow HF) at 5×10^4 samples per second for a period of 1.31 s starting 492 ms before the first trigger.

The high resolution data for each triggered stroke is represented by a "fast page" in the appendices. Each fast page uses the same format. The title line comprises the date/time group, the event type (which is "triggered stroke" in all but two of these events), and, enclosed within parentheses, the fixed range of 5.16 km. The date/time group gives the time of the trigger. For example, the date/time of 211230644.229 for the first plot in the appendices is interpreted as the Julian date of 211, 23rd hour, 06th minute, and 44.229 seconds. The time used in all the figures is the universal time (UT); four hours must be subtracted to convert to Eastern Daylight Time. On the left side of the fast page are plotted the fast E (V/m) waveform at the top and the fast HF ($V m^{-1} Hz^{-1}$)² waveform at the bottom, both at a resolution of 100 nsec per sample for a total time of 0.4098 ms for the 4096 data or 0.2048 ms for the 2048 data. On the right side is plotted the dE/dt ($V m^{-1} \mu s^{-1}$) waveform at the bottom, at a resolution of 10 n/s per sample for a total time of 40.96 or 20.48 s, as the case may be. The corresponding portion of the fast E waveform (magnified) is displayed above the dE/dt waveform.

The fast pages for a given flash are followed by a "slow page", which shows the context of each event within the entire flash. The slow page title line contains the start time of the record, the date, and, in parentheses, the range of

5.16 km. The slow E (V/m) waveform is at the top, and the slow HF ($V m^{-1} Hz^{-1}$)² waveform is at the bottom, both at a resolution of 20 μs per sample for a total time of 1.31 s. The trigger times for the fast events are indicated by tick marks beneath the slow HF record.

At this point, a number of comments should be made regarding the data and the plots. The figures in the appendices are identified by the event time rather than by figure number. The linear scales of the ordinates can vary from plot to plot, since a scale appropriate to each individual waveform is selected. Whenever digitizers are saturated, the saturation levels are indicated on the plots by dashed horizontal lines. For the dE/dt waveforms, if the high-gain 100 MHz digitizer exhibits saturation, a second fast page is included for the event, showing the unsaturated data from the low-gain dE/dt digitizer. Inclusion of both records makes it easier to recognize the artifacts that were sometimes present in the low-gain data. The sign convention used throughout the report is the normal physics convention. That is, an upward electric field is produced by negative charge overhead and is positive. A normal return stroke that lowers negative charge to Earth thus produces a negative field change.

It should be noted that, because of the nature of the fast and slow integrators, there is no absolute electric-field zero. For this reason, and also to remove any electronic zero drifts from the data, zeros were computed numerically from each record. The fast and slow HF zero levels were set to the minimum value of the respective HF record. The slow E zero was equated to the average of the maximum and minimum values. The other two zero levels were determined by dividing the full records into four quadrants of identical length. The fast E zero level was equated to the average of the first quadrant, whereas the dE/dt zero level was taken as the average of the first and fourth quadrants.

All lightning waveforms presented in this report, except the slow E, have been range normalized to 100 km. The original data can be reconstructed by multiplying the fast E and dE/dt waveforms by $(100/range)$, multiplying fast and slow HF by $(100/range)^2$, and leaving the slow E alone. All the data in this report were obtained with the digitizers triggered by the fast HF signal. The HF-receiver center frequency was 5 MHz.

The data plots presented in Appendix A are the over-water, triggered-lightning data for 30 and 31 July and 19 August 1987. Those in Appendix B are the over-land data for the same three days. All data in July were 4098 data and those in August were 2048 data.

As mentioned before, nearly all of the fast plots had "triggered stroke" as the event type. There were two exceptions, however, both in Appendix A. The 4096 data with time 212211544.078 on 31 July was labeled "upward negative leader". This is the event that burned out the French current shunt on flash 8721. The 2048 data with time 231221139.772 on 19 August was labeled "leader in altitude flash". This flash 8733 resulted from an "altitude" rocket fired from the water pad whose negative downward leader struck the land pad. The early portion of the slow data from each of these flashes has been expanded to the limits permitted by the slow digitizers and presented following the respective slow page. In both plots the "0" time is the time of the first trigger and is listed in the title line above.

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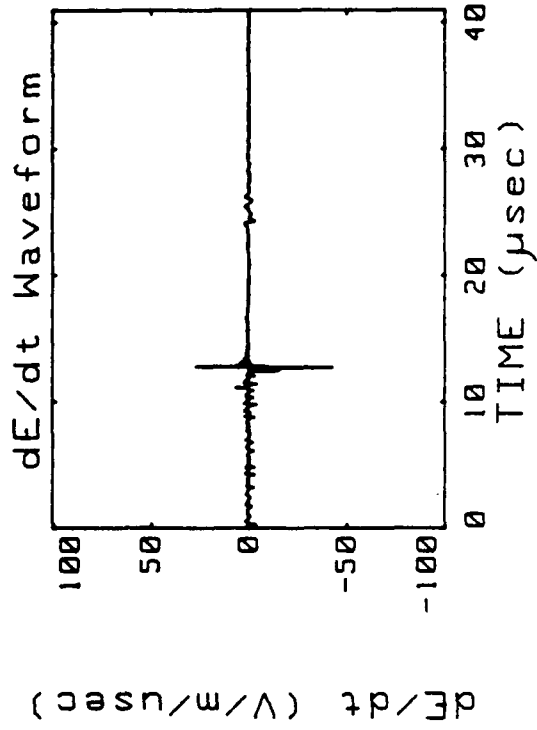
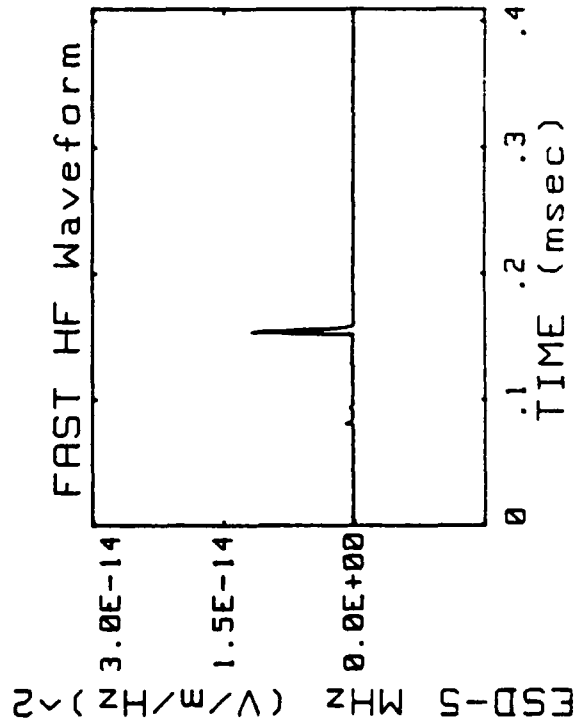
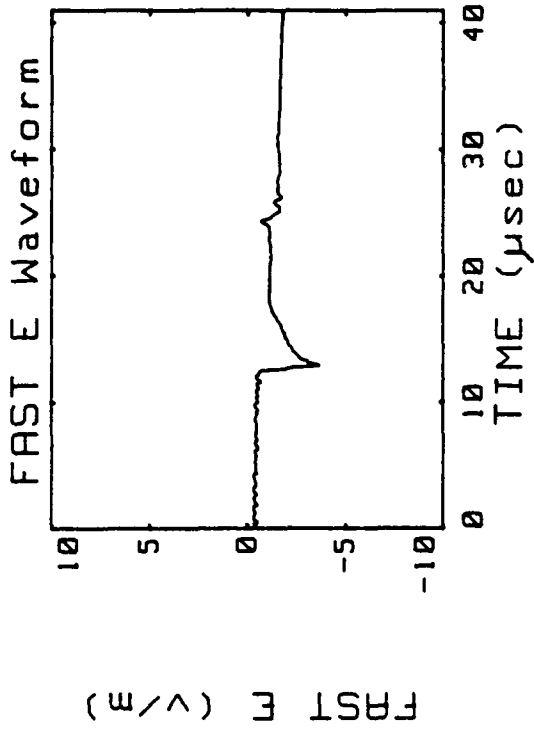
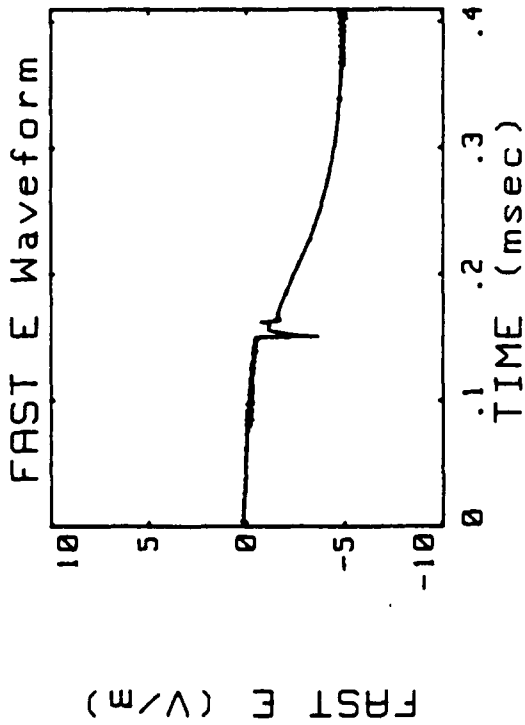
Appendix A

Over-Water Plots

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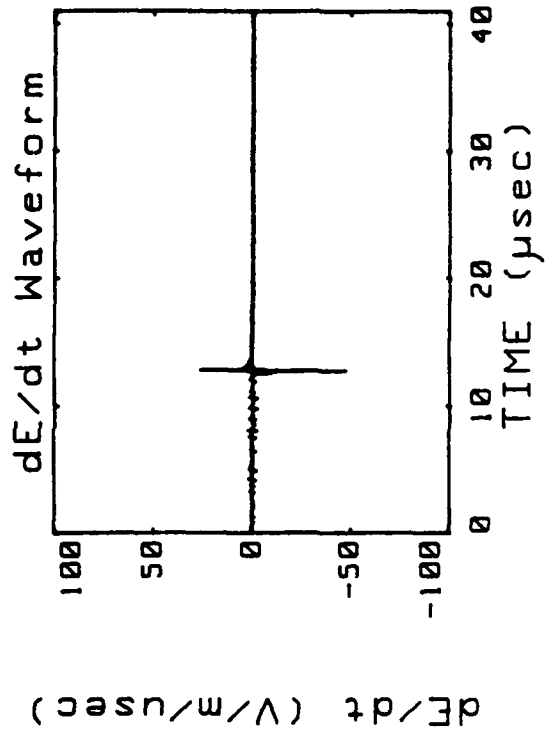
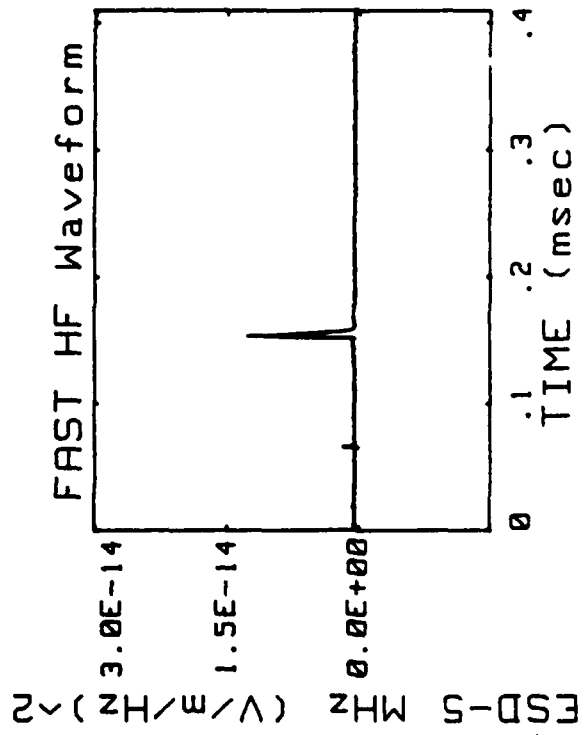
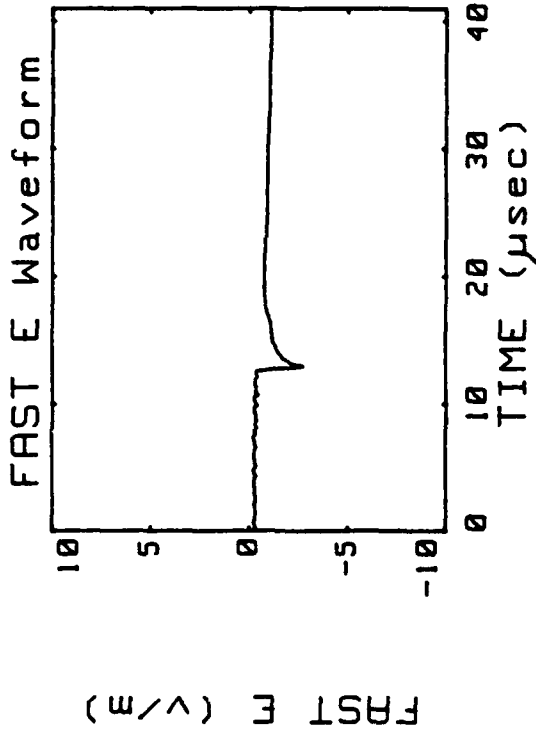
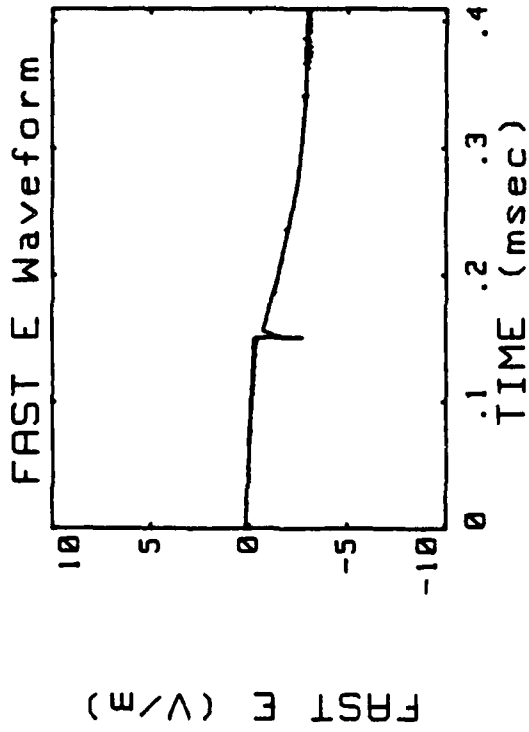
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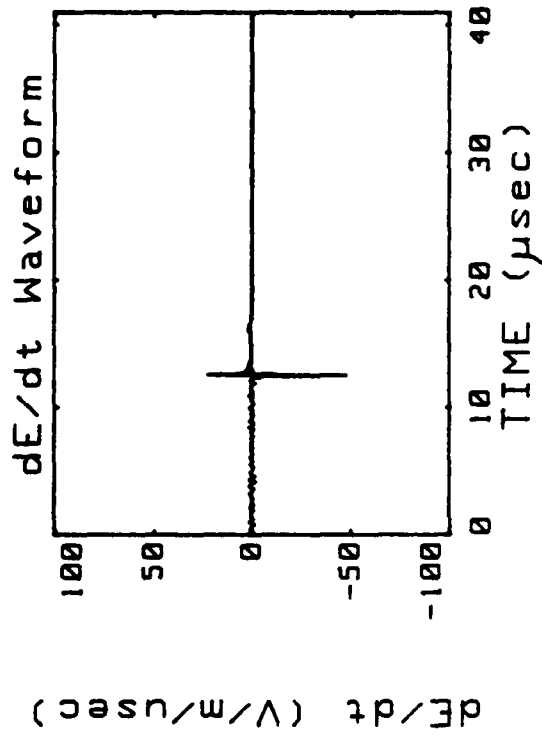
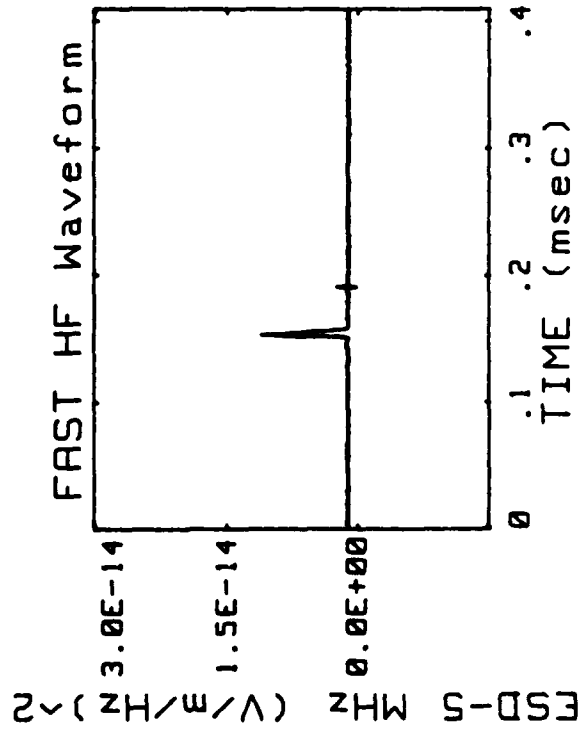
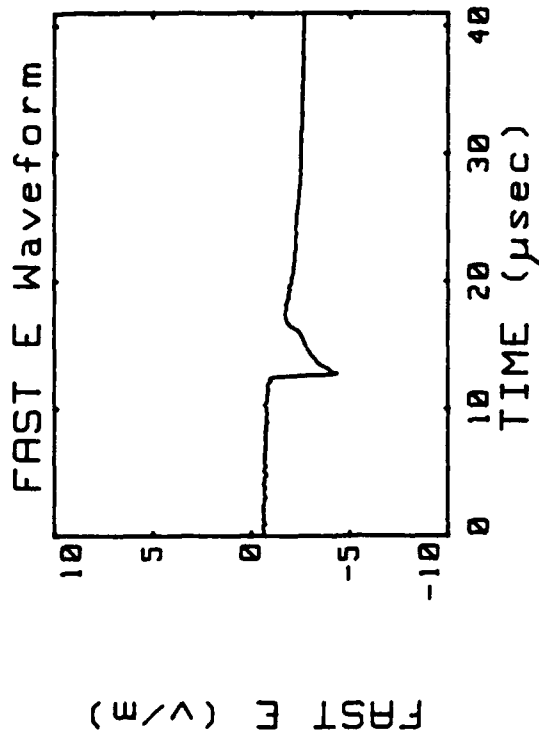
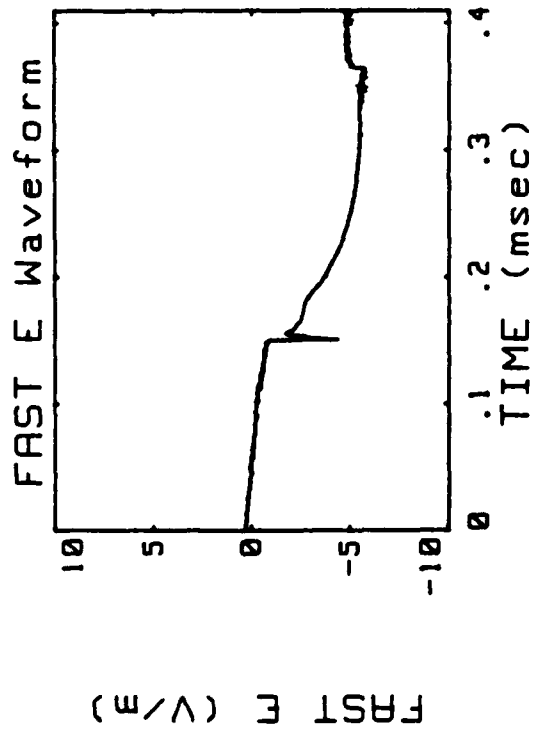
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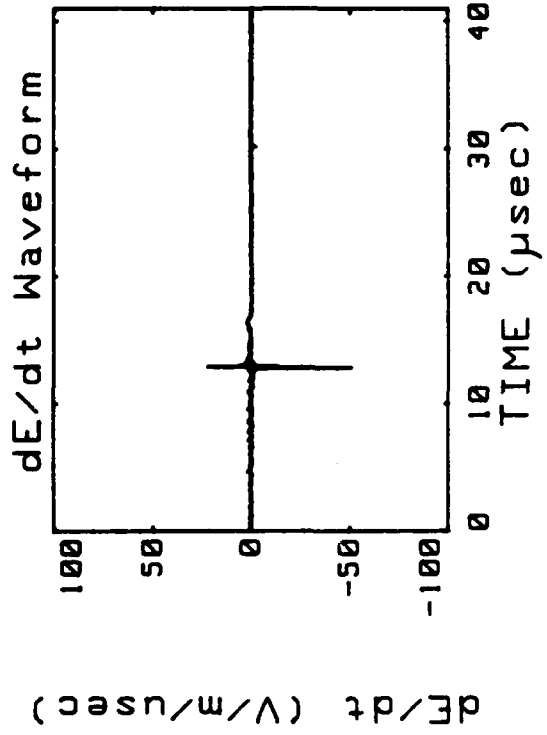
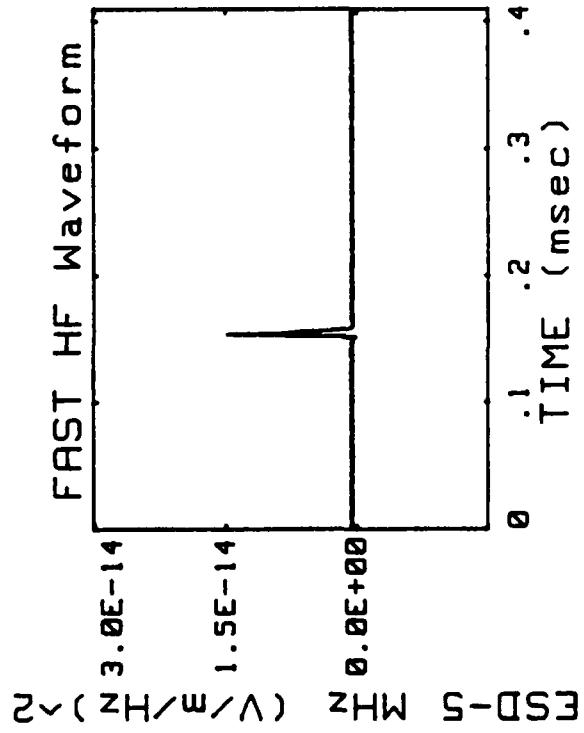
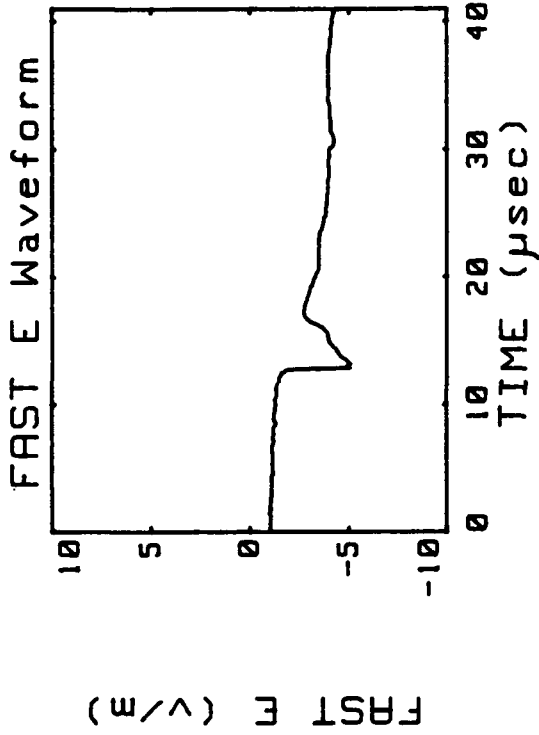
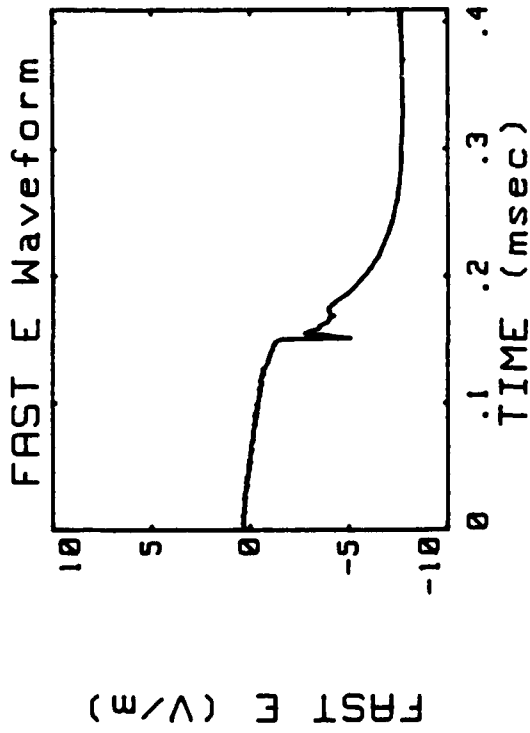
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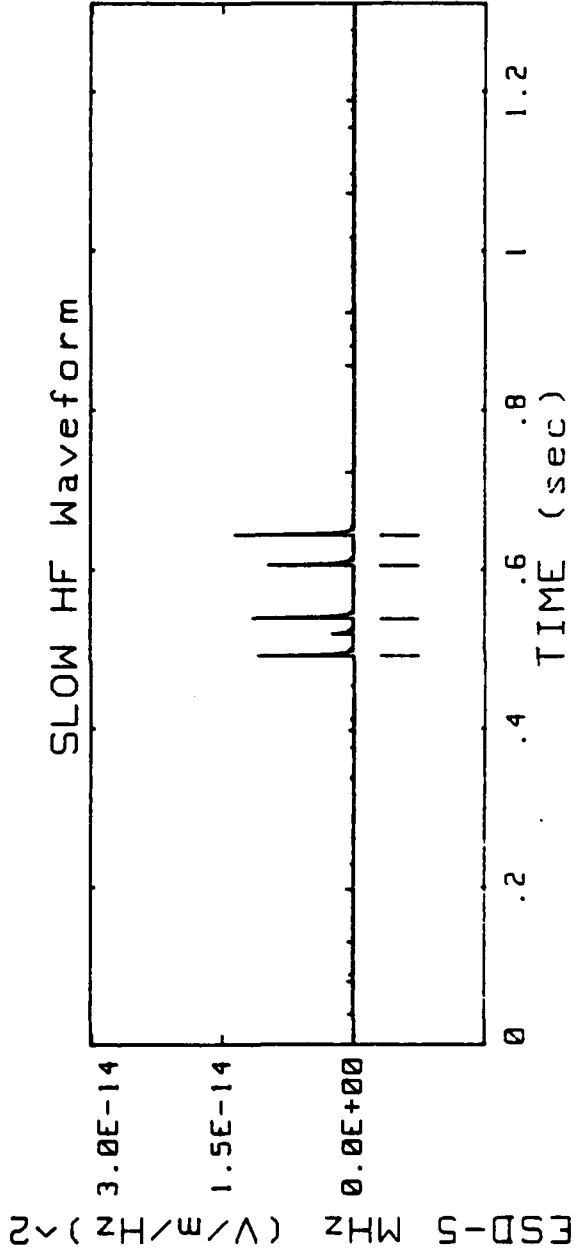
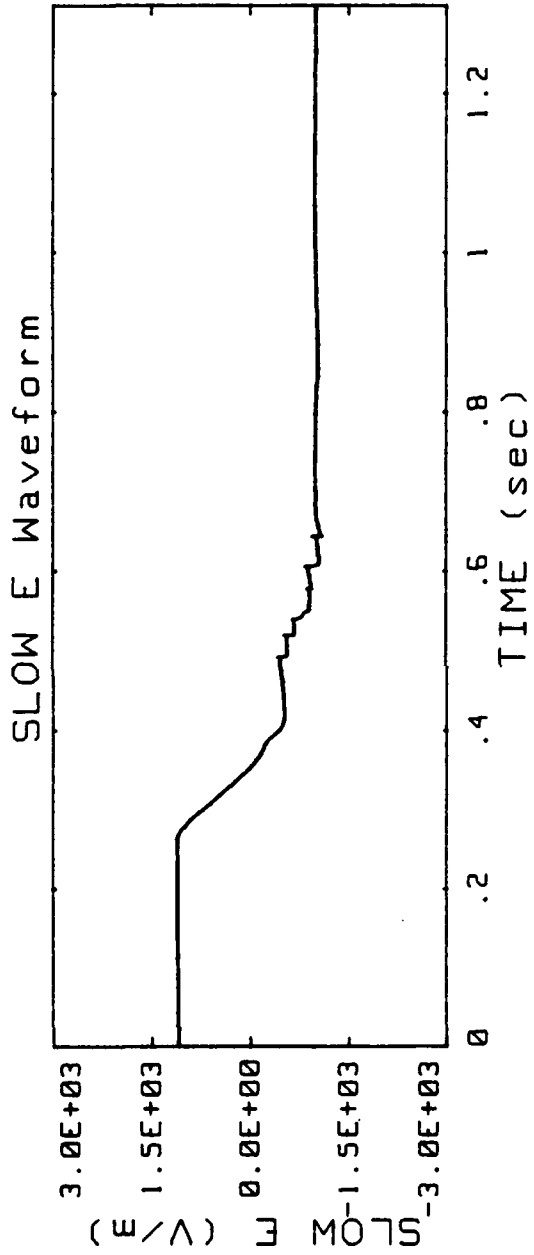


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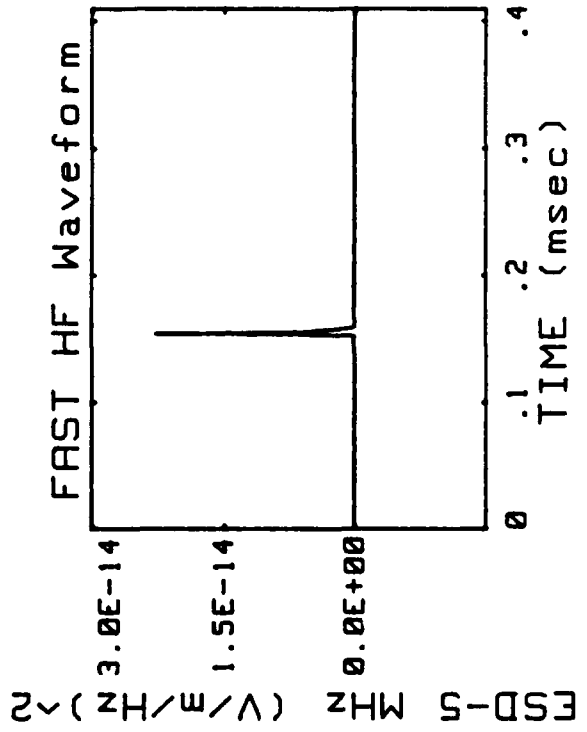
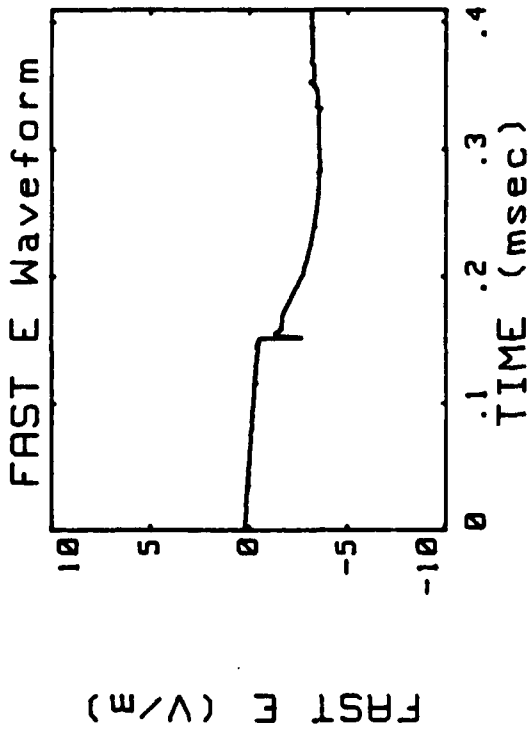
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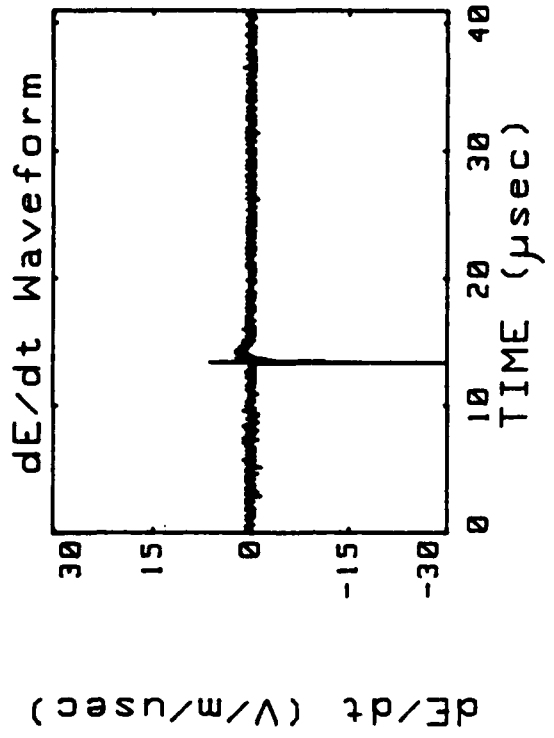
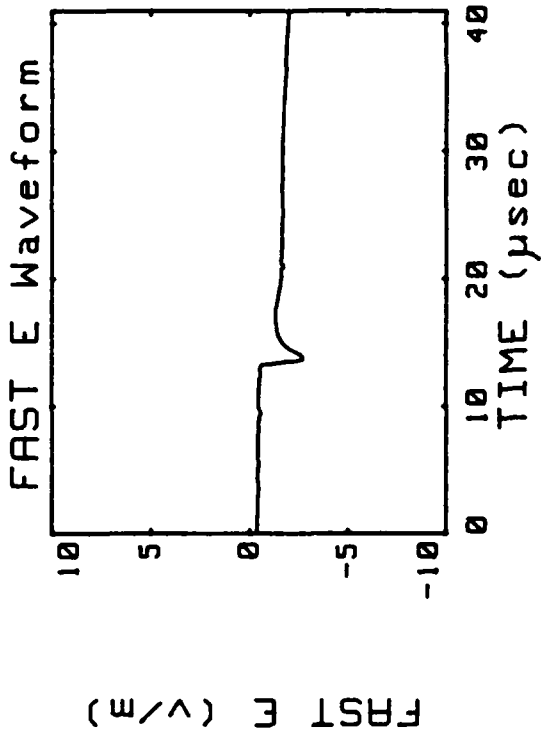
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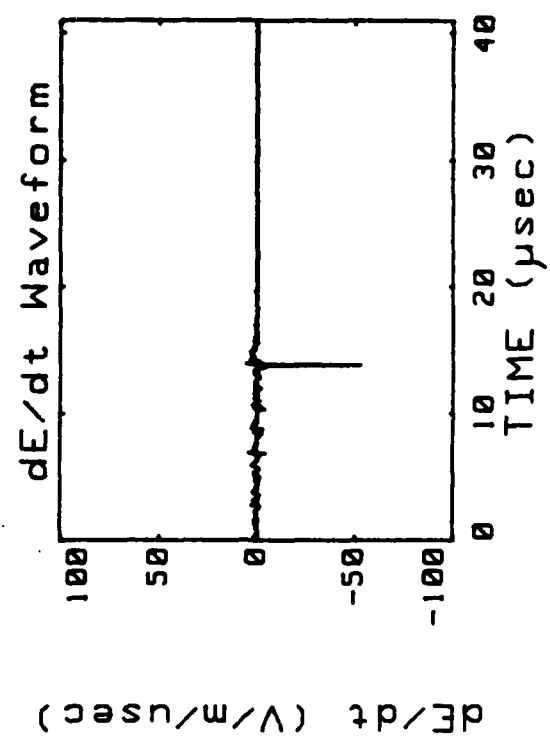
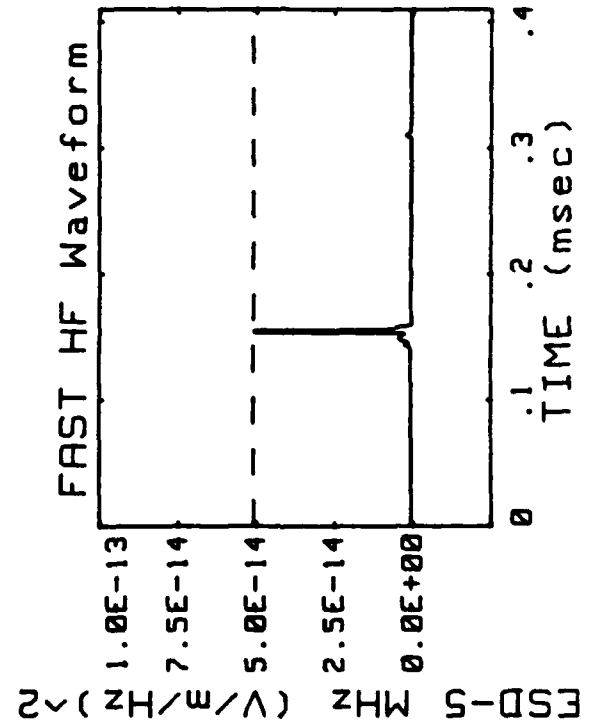
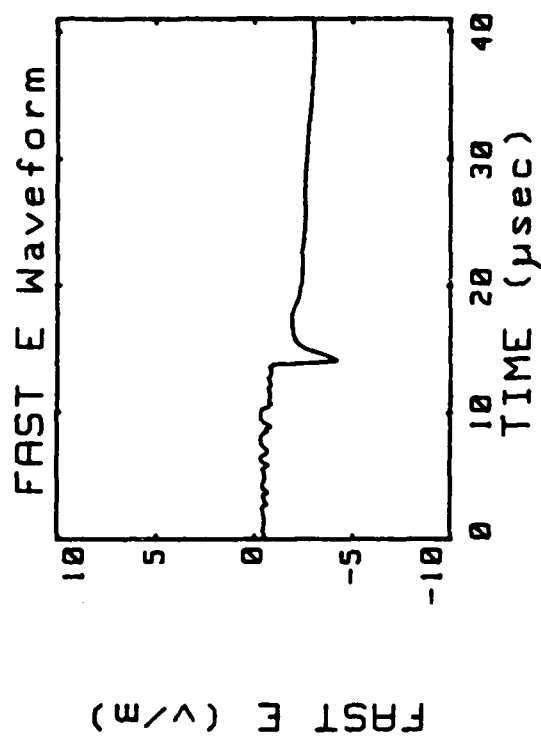
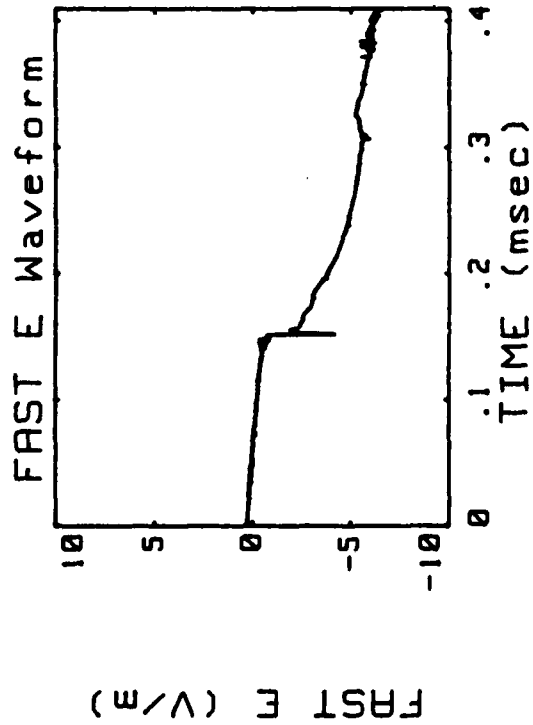


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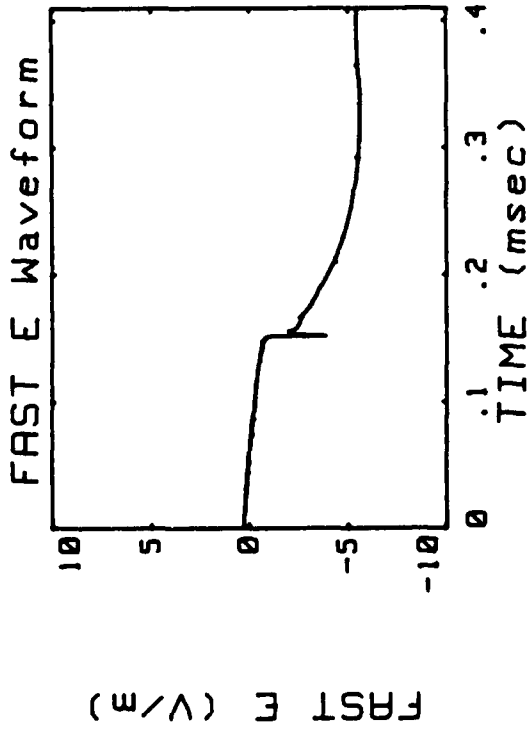


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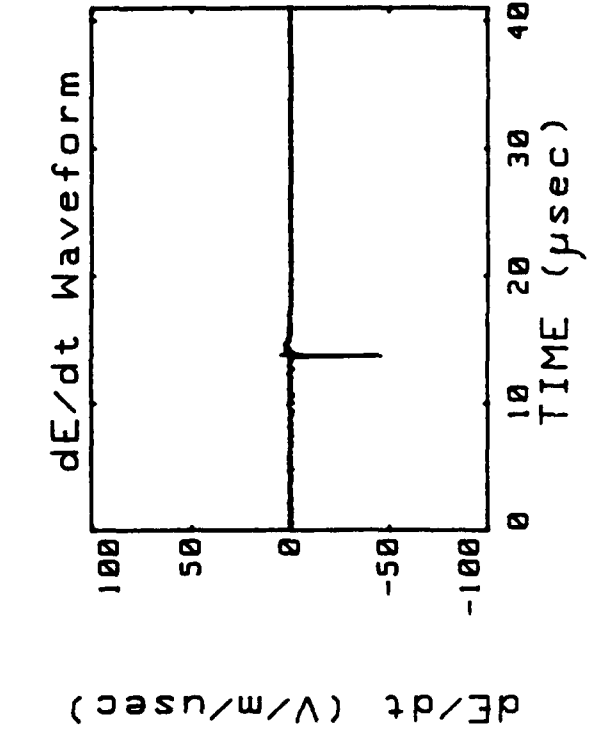
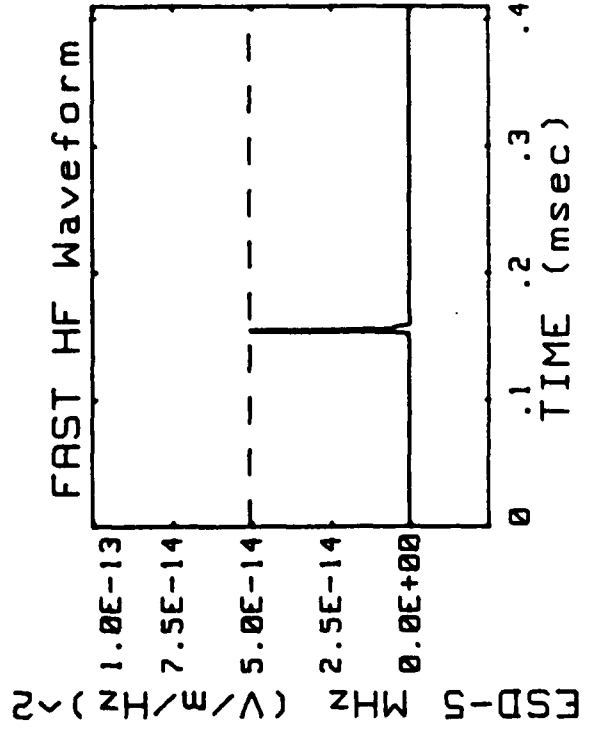
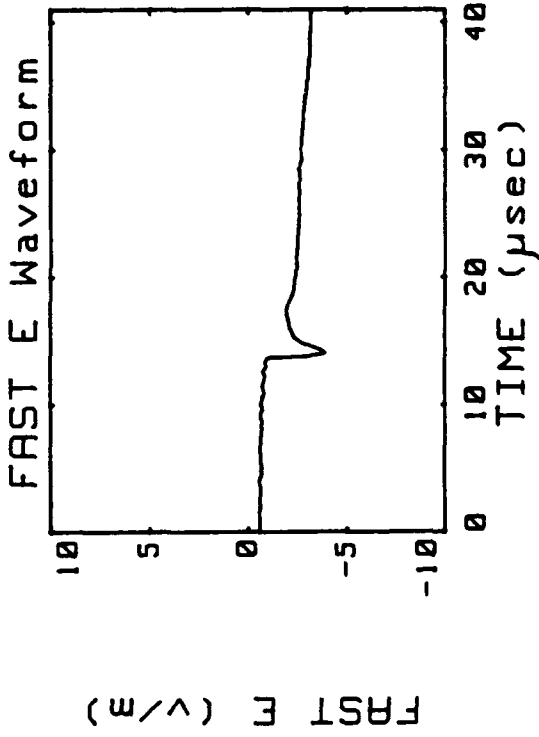
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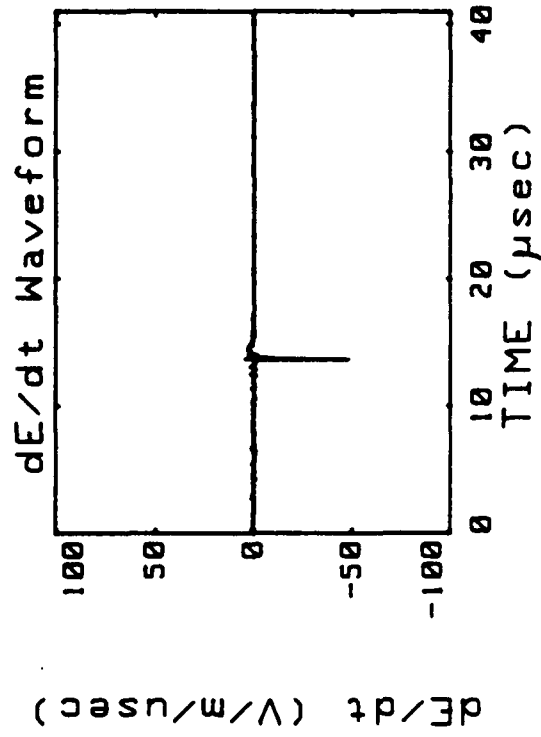
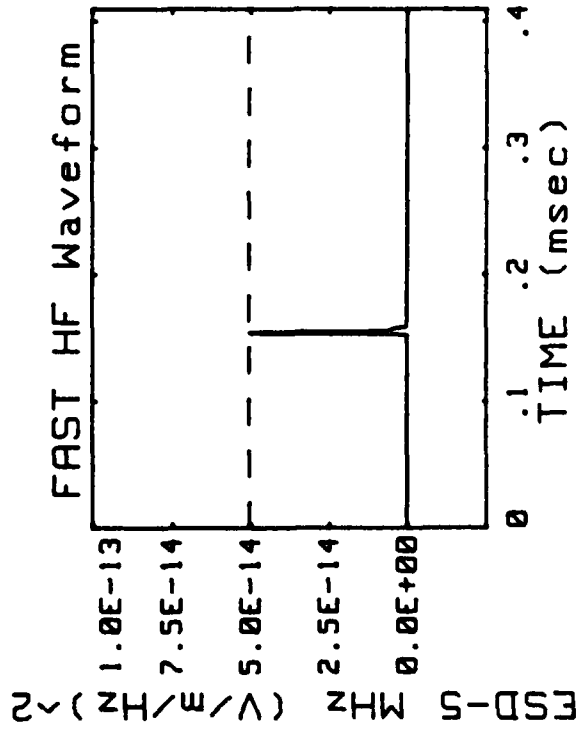
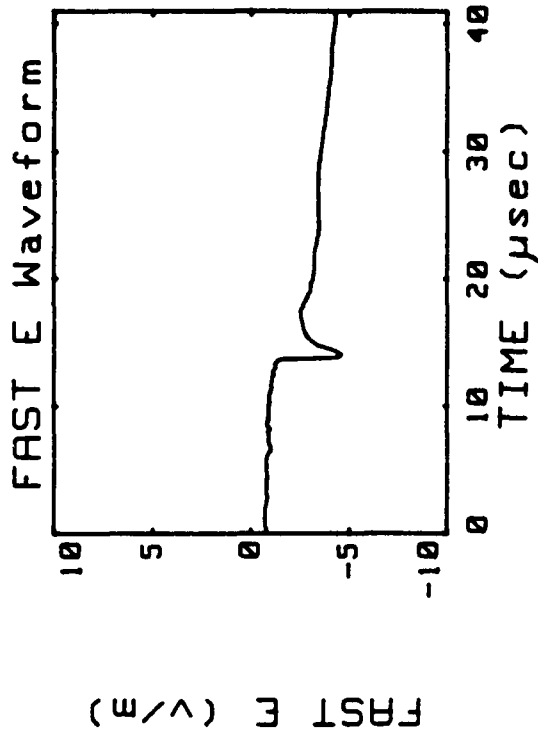
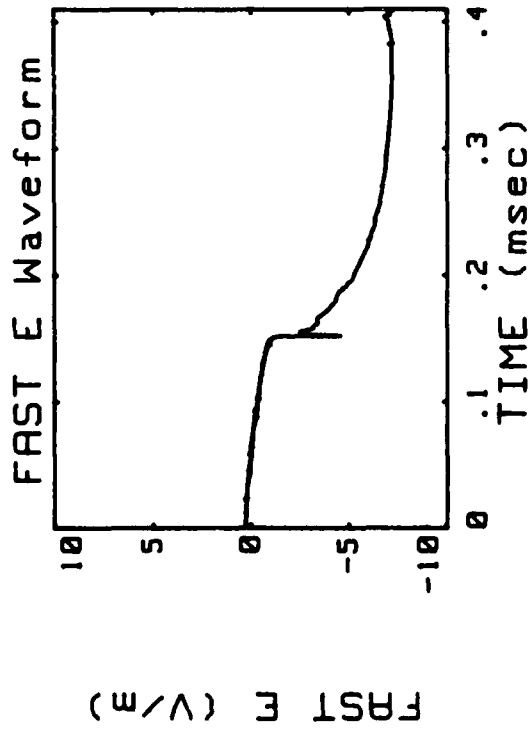


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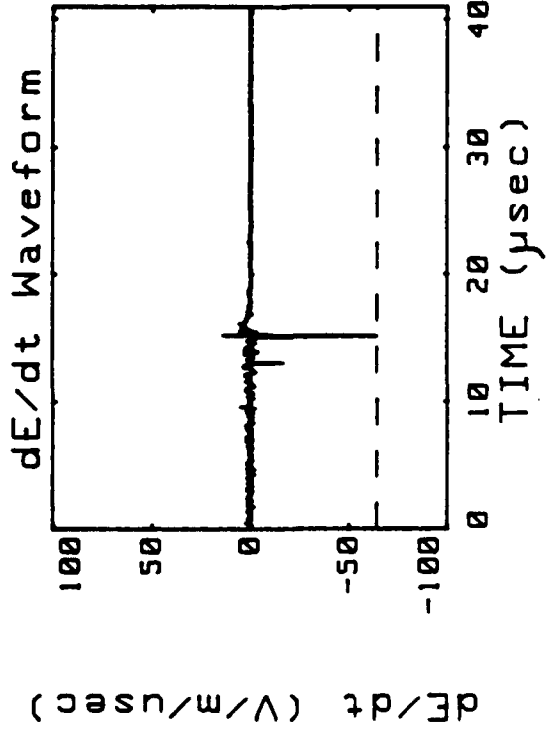
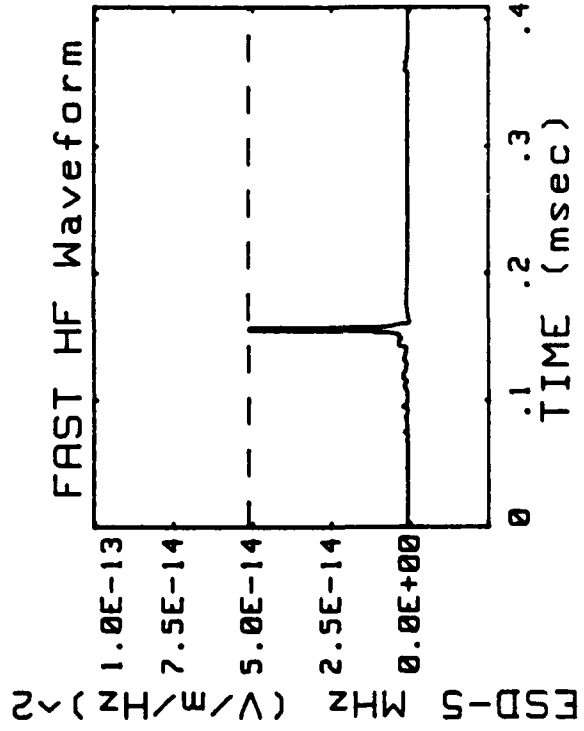
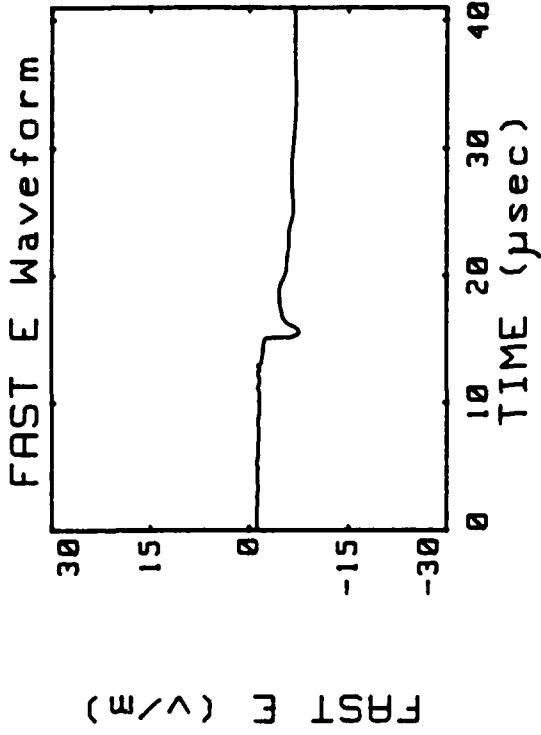
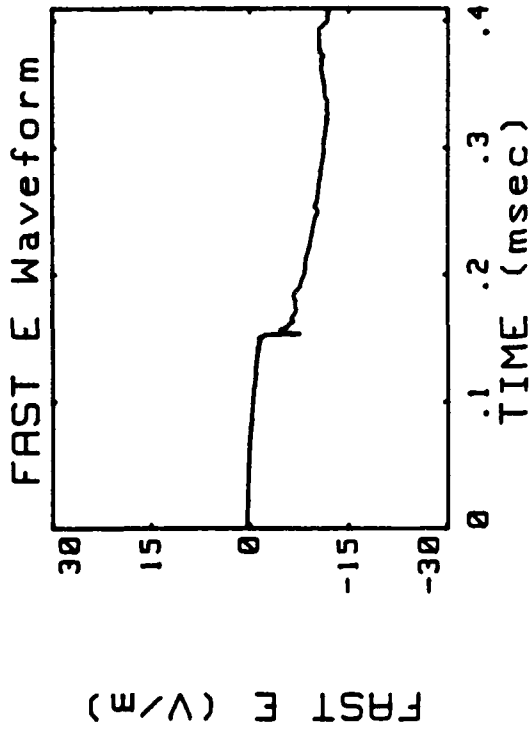
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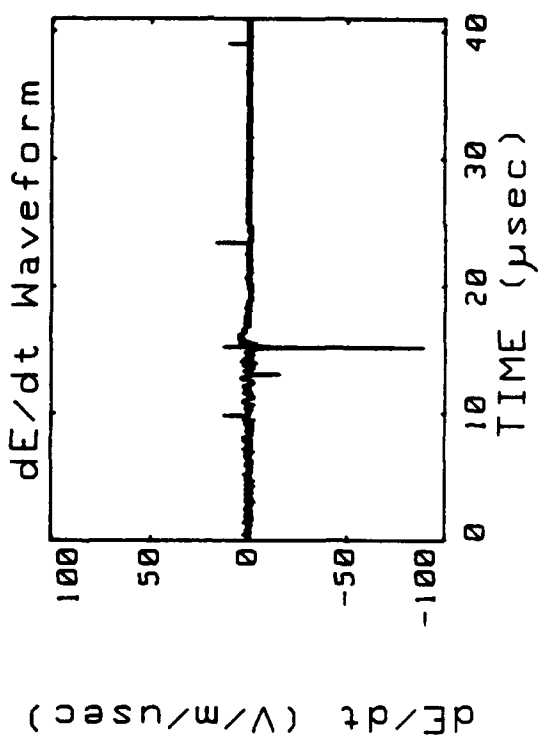
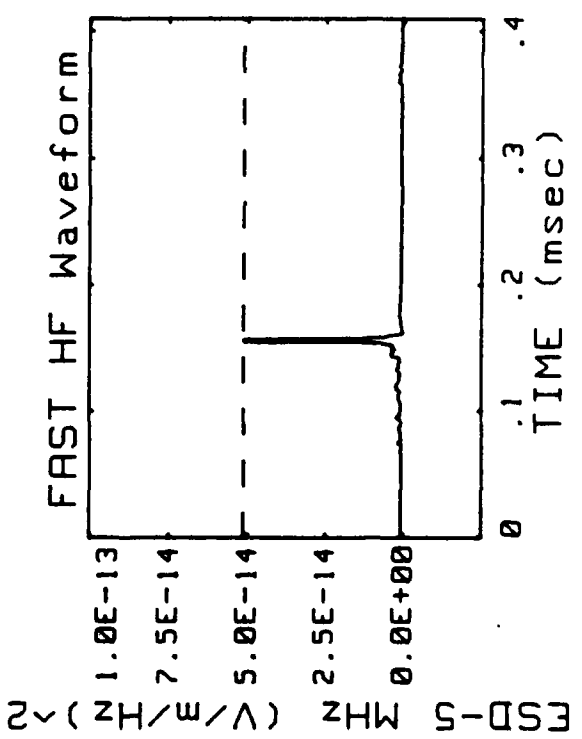
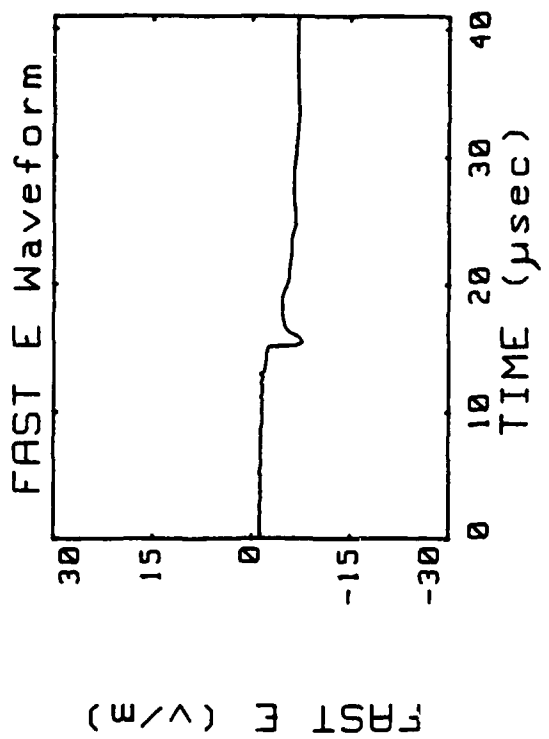
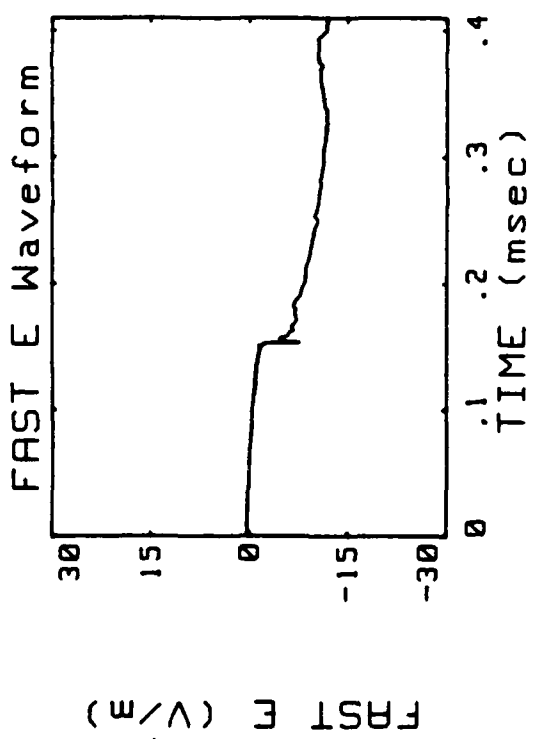
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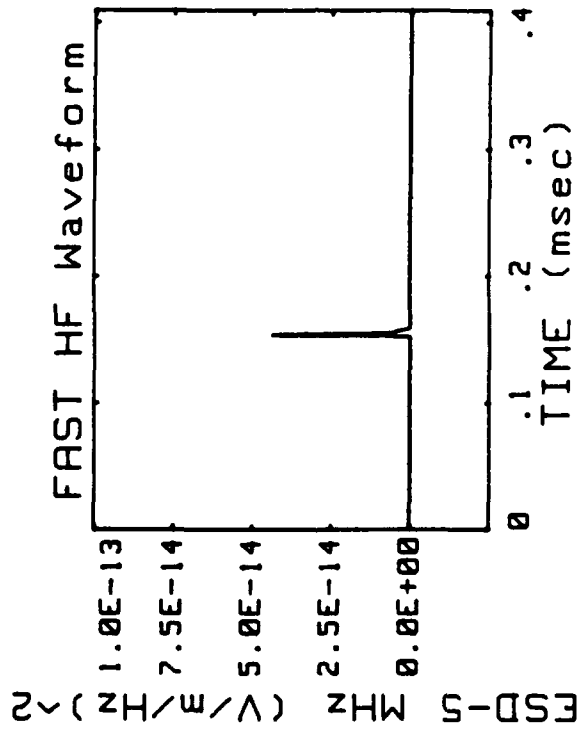
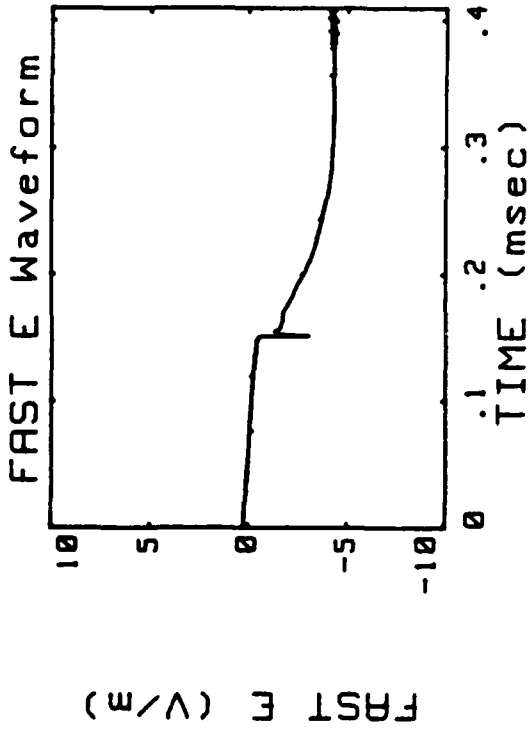


212194133.112 1987

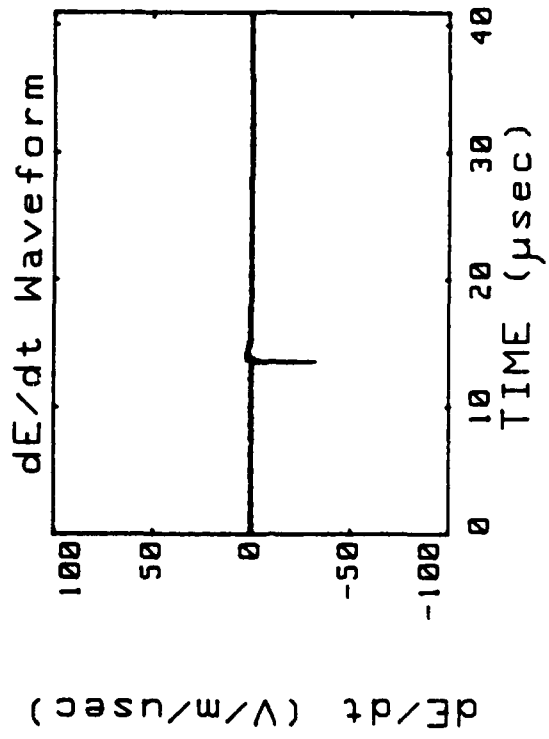
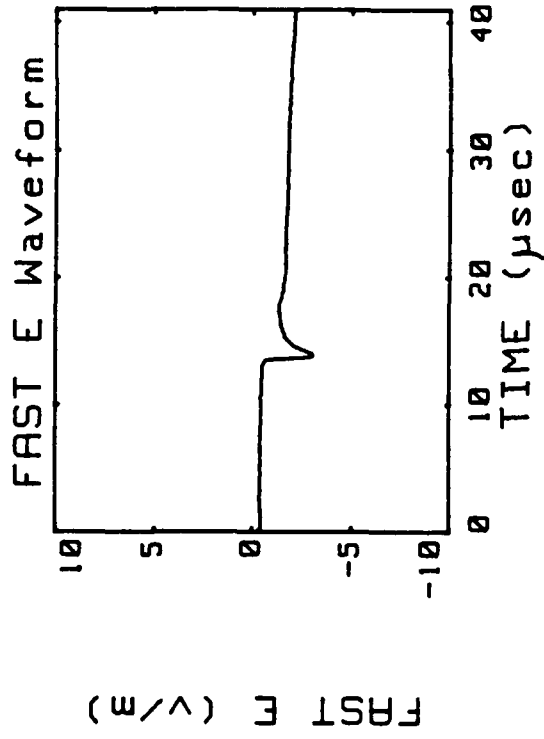
Triggered Stroke (5.16 Km)



212194133.142 1987

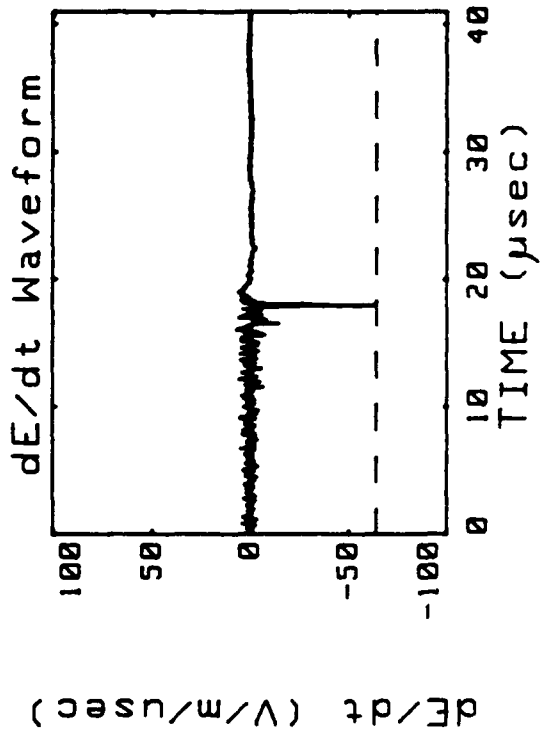
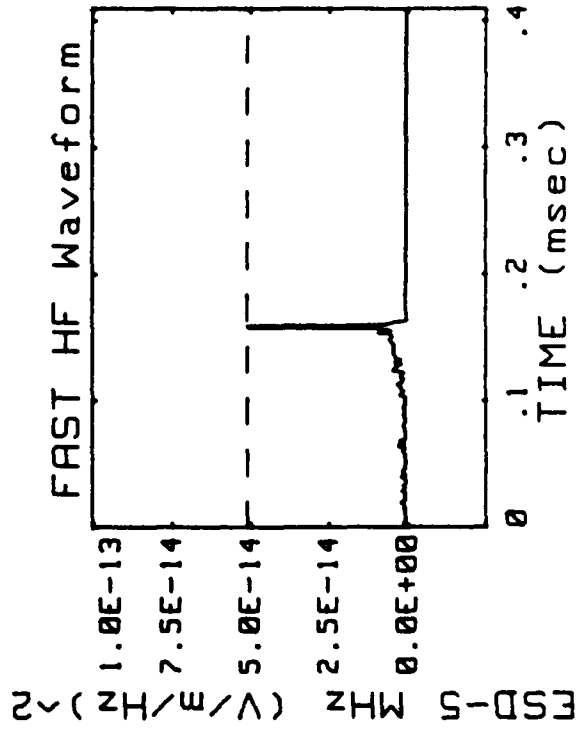
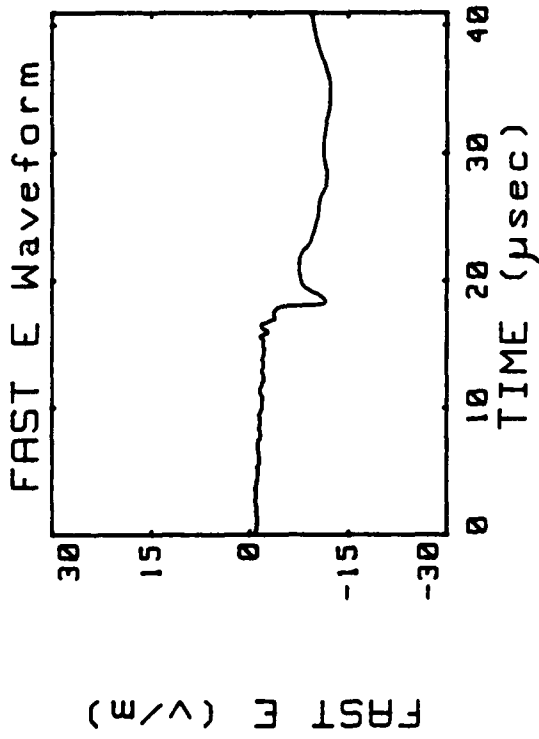
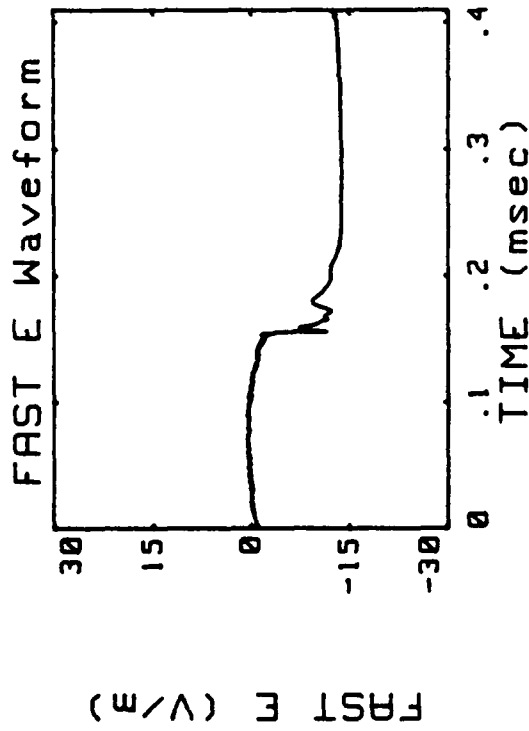


Triggered Stroke (5.16 Km)



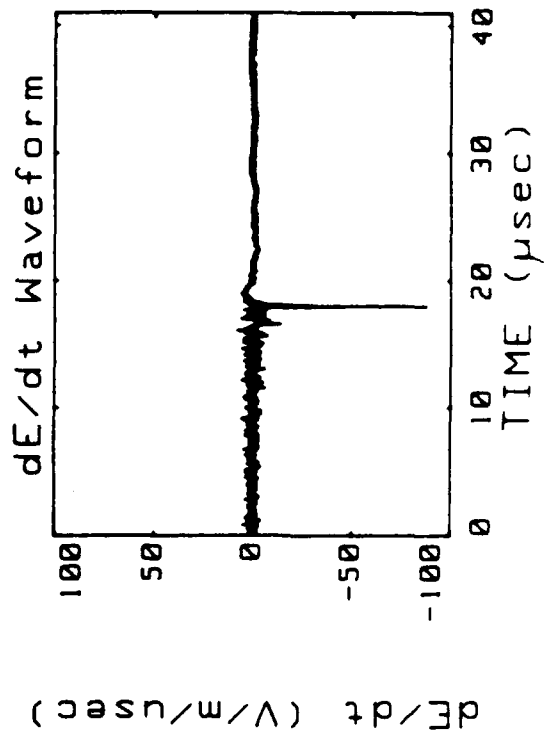
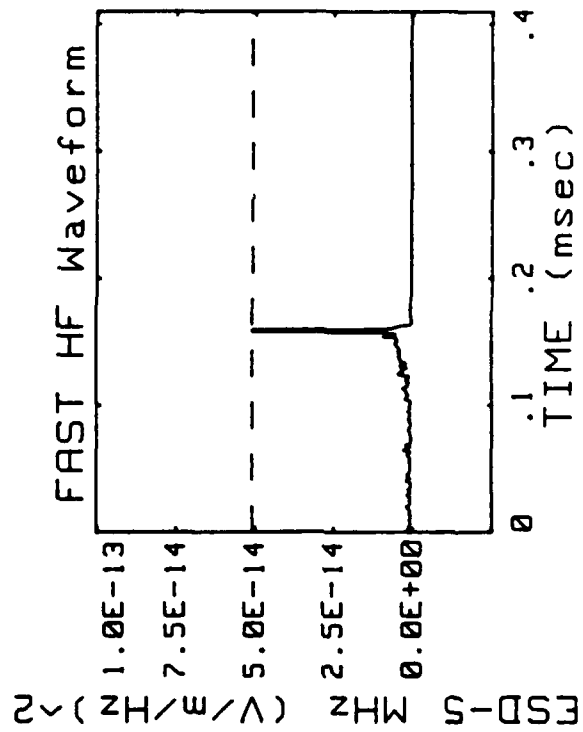
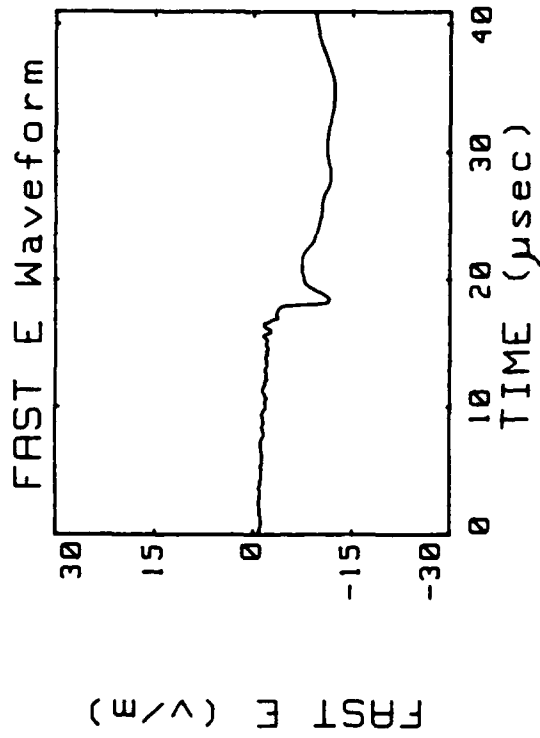
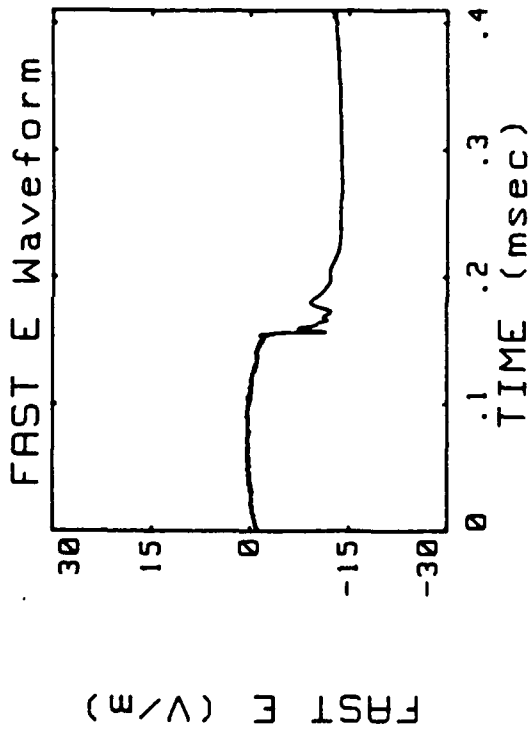
212194133.483 1987

Triggered Stroke (5.16 Km)



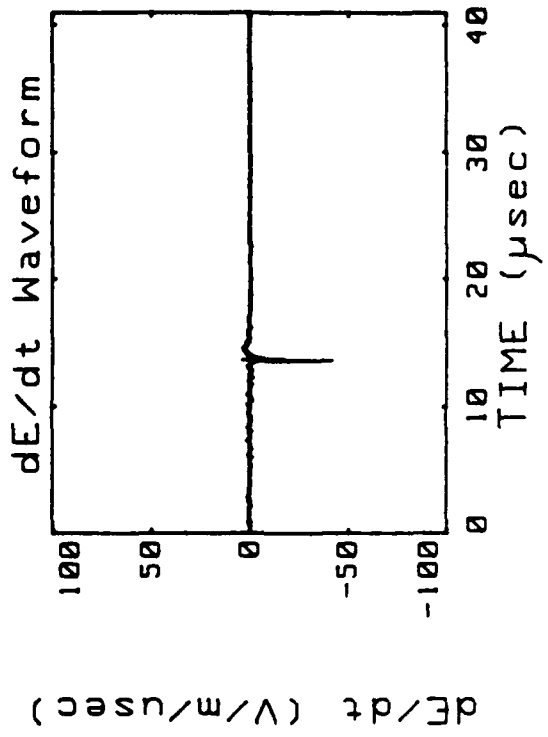
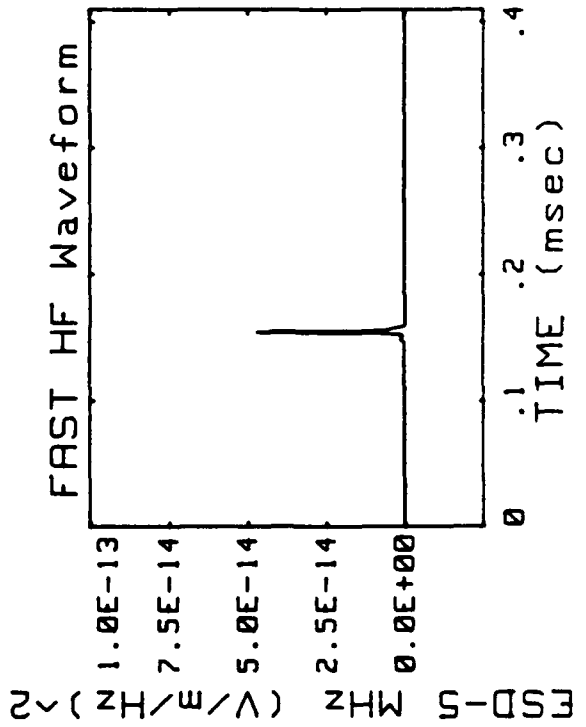
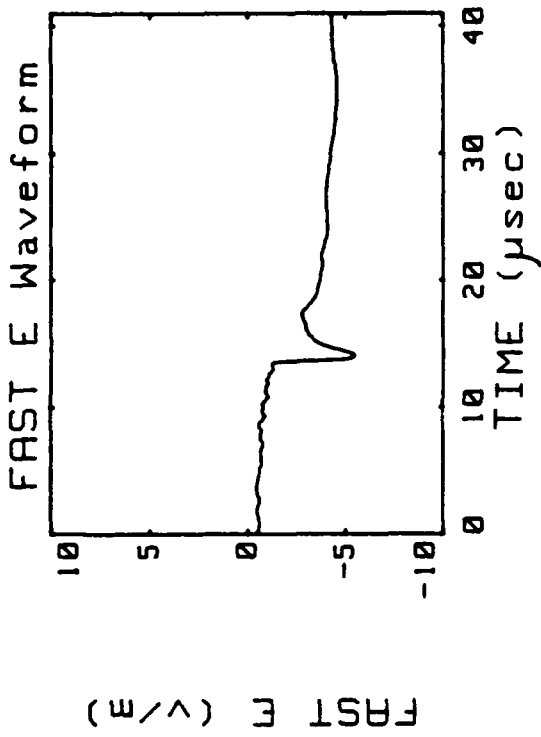
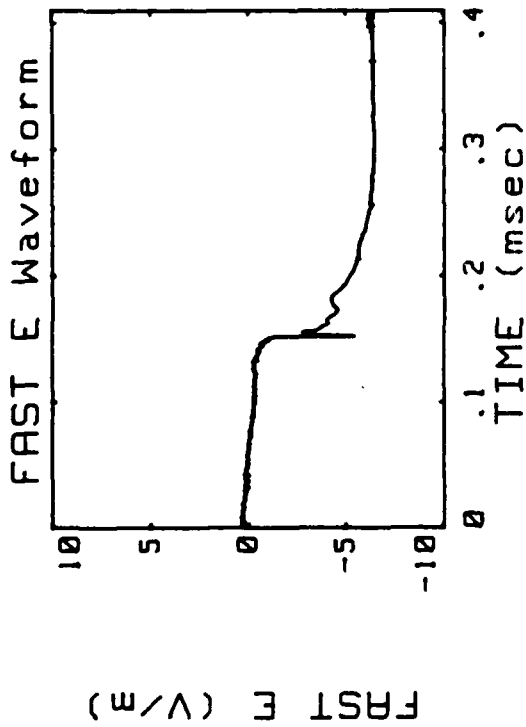
212194133.483 1987

Triggered Stroke (5.16 Km)



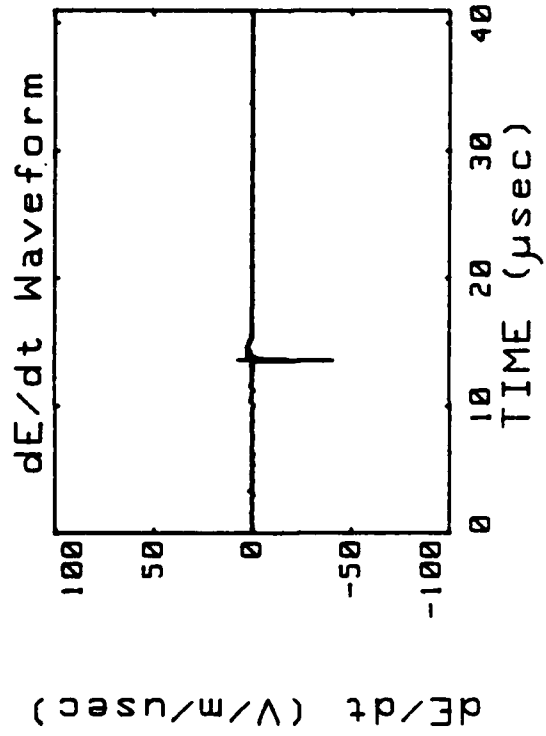
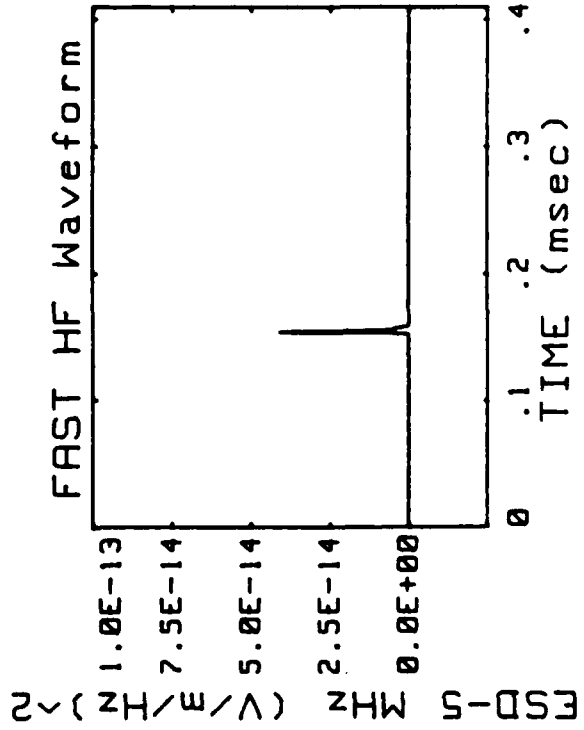
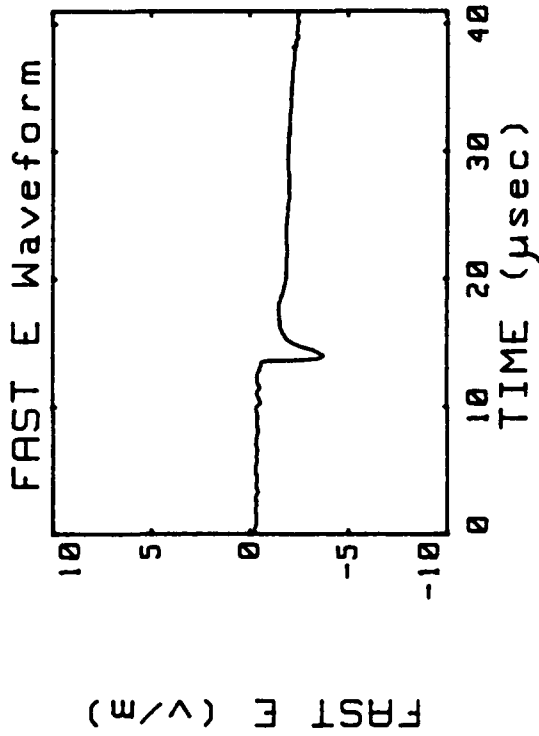
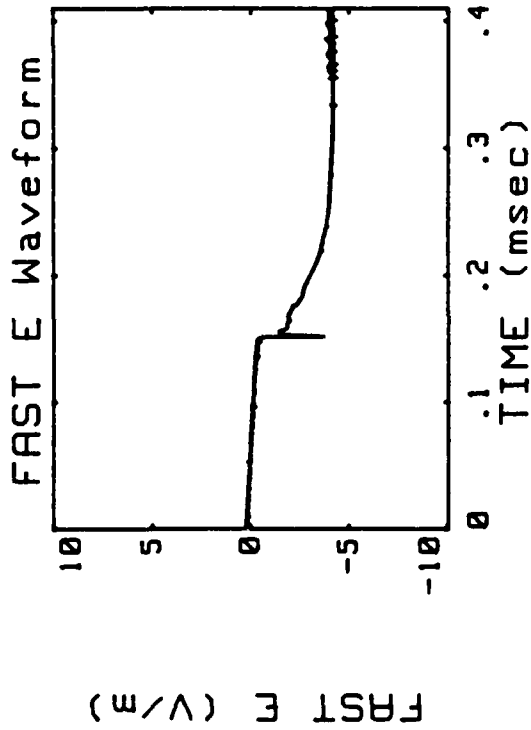
212194133.537 1987

Triggered Stroke (5.16 Km)

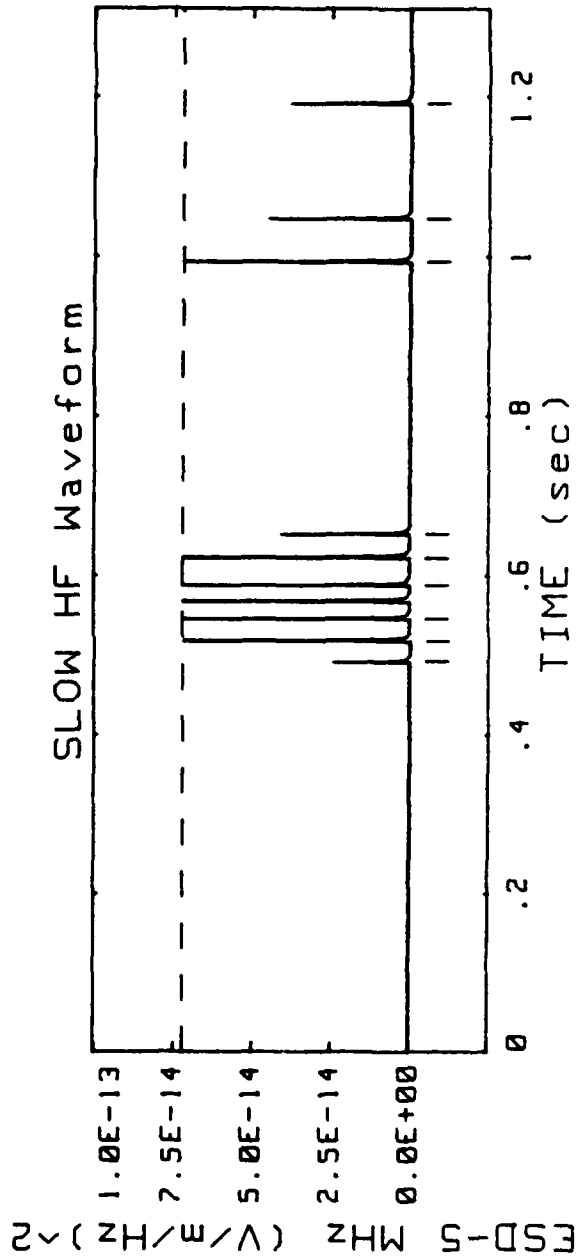
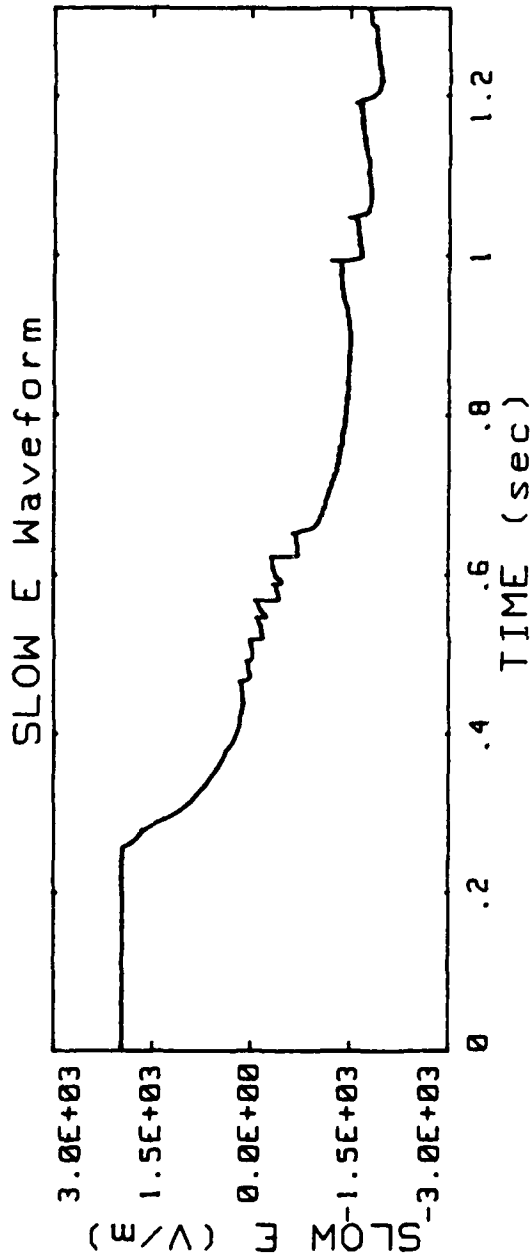


212194133.681 1987

Triggered Stroke (5.16 Km)

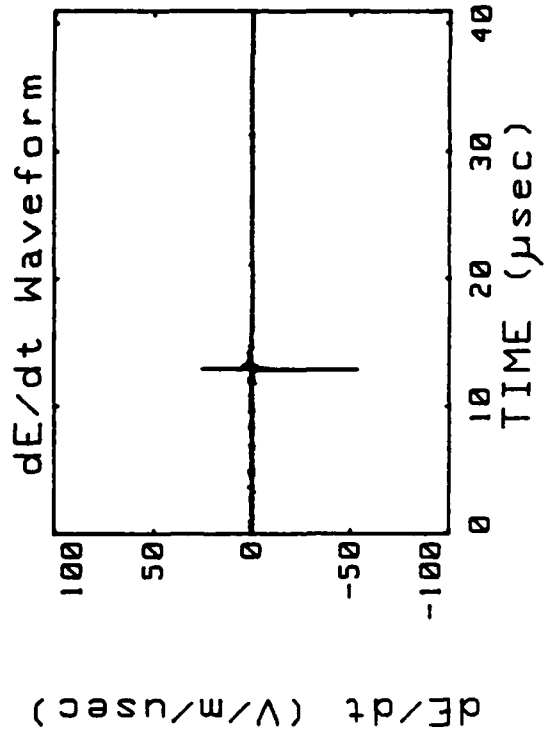
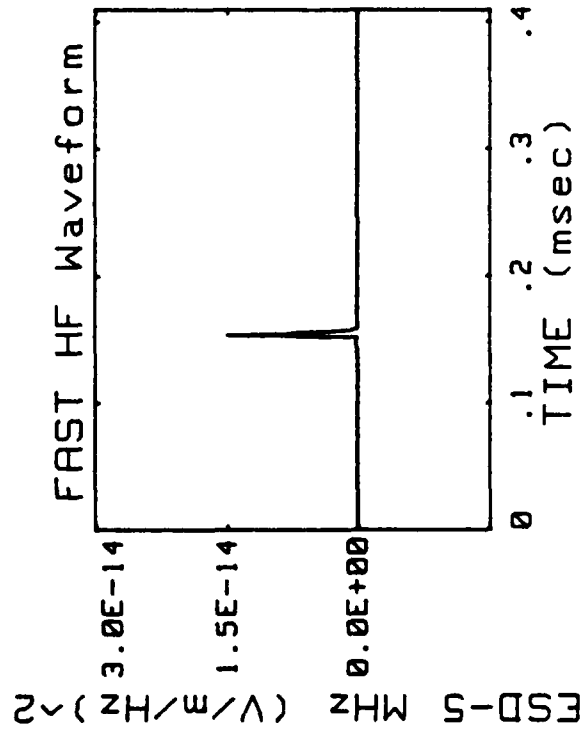
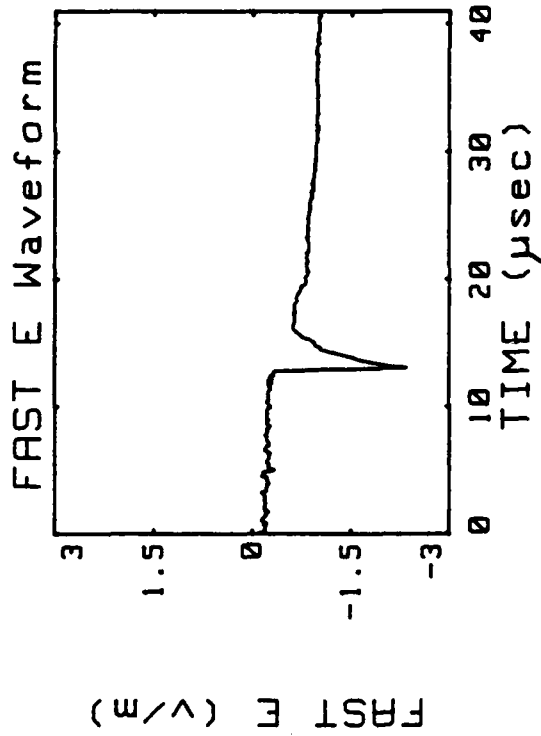
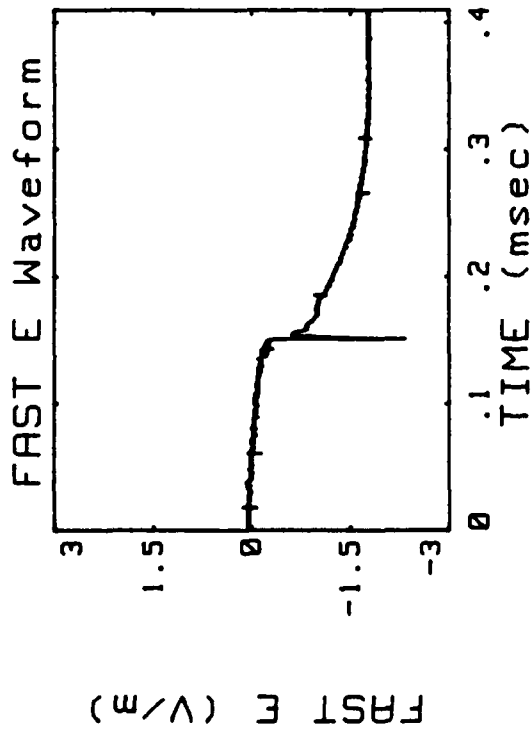


19:41:32.491 31 Jul 1987 (5.16 Km)



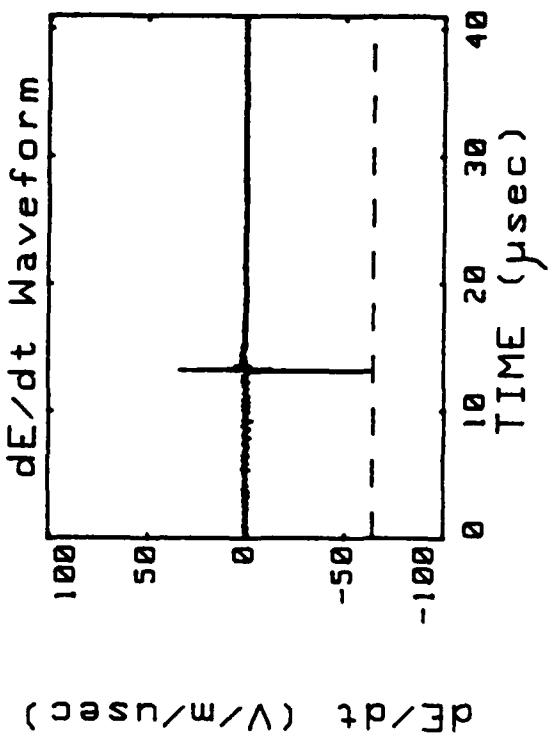
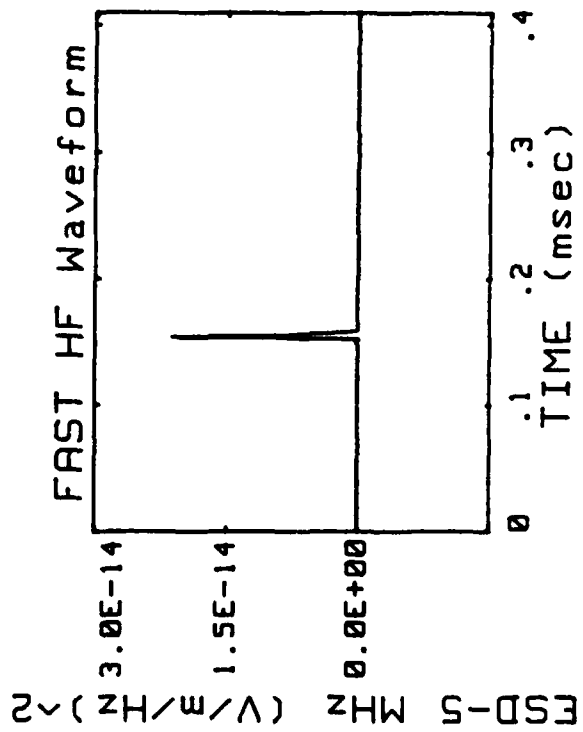
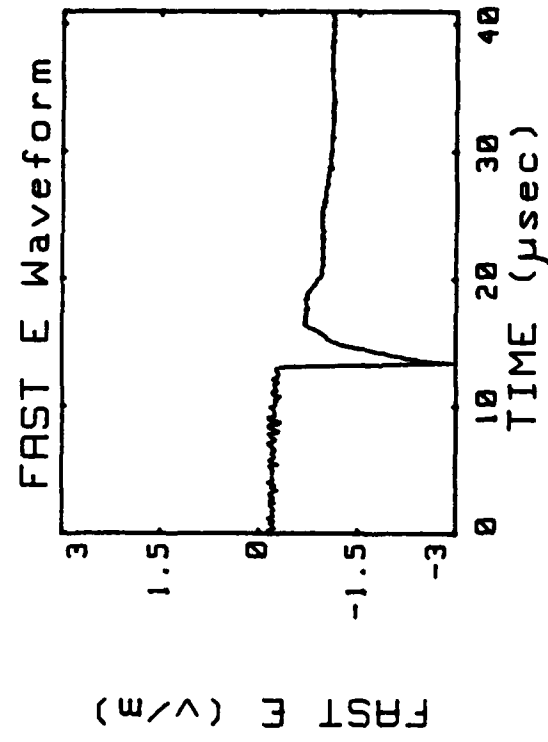
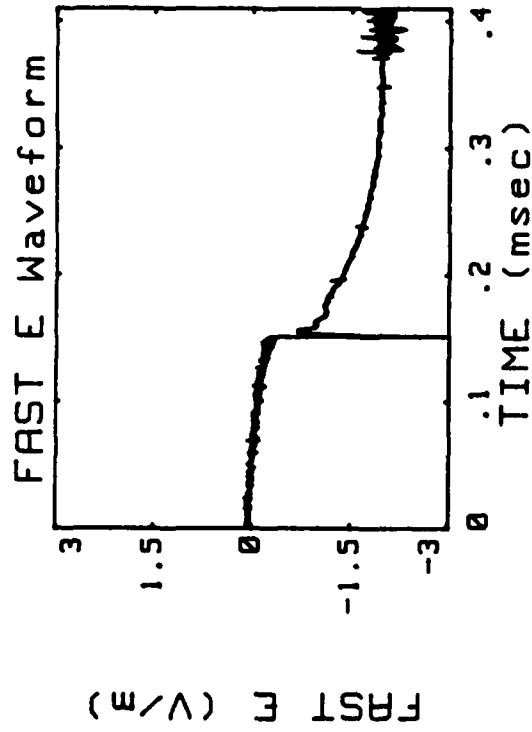
212194508.893 1987

Triggered Stroke (5.16 Km)



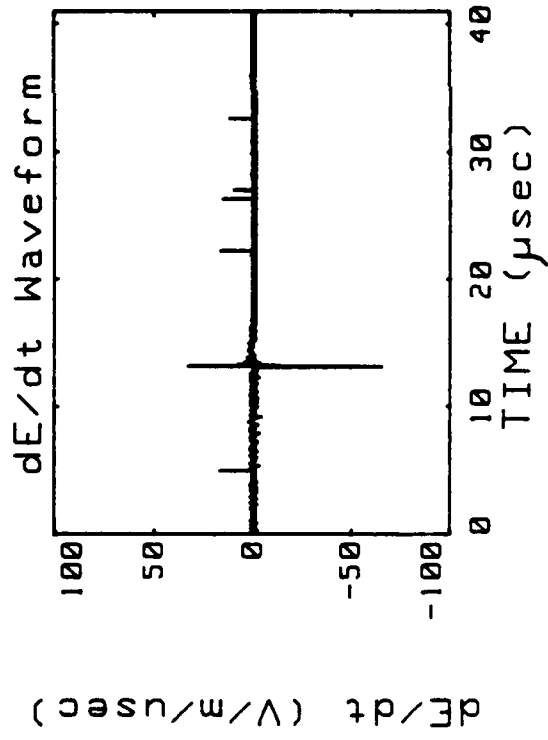
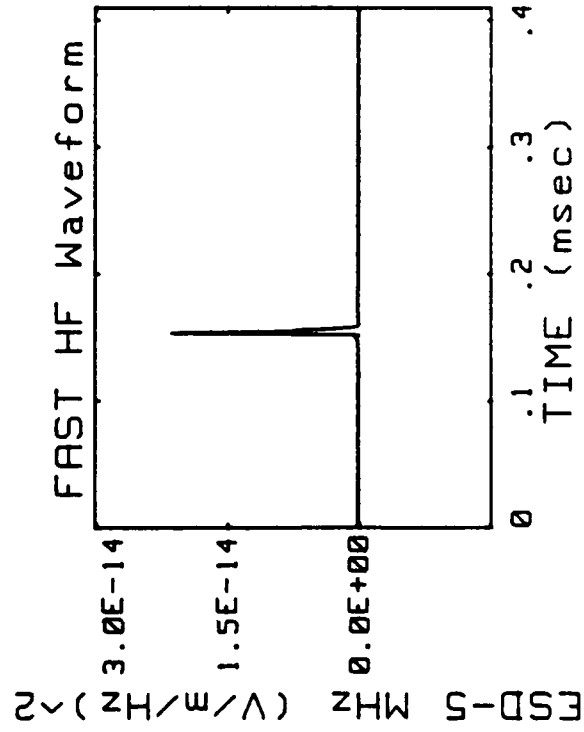
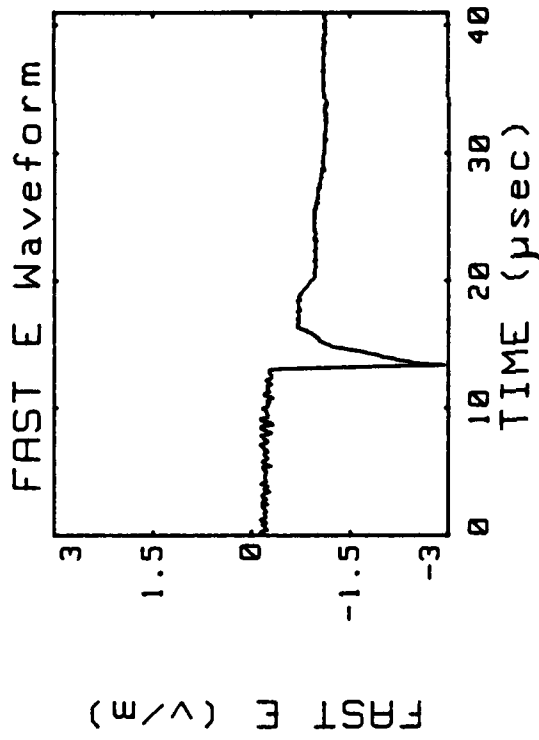
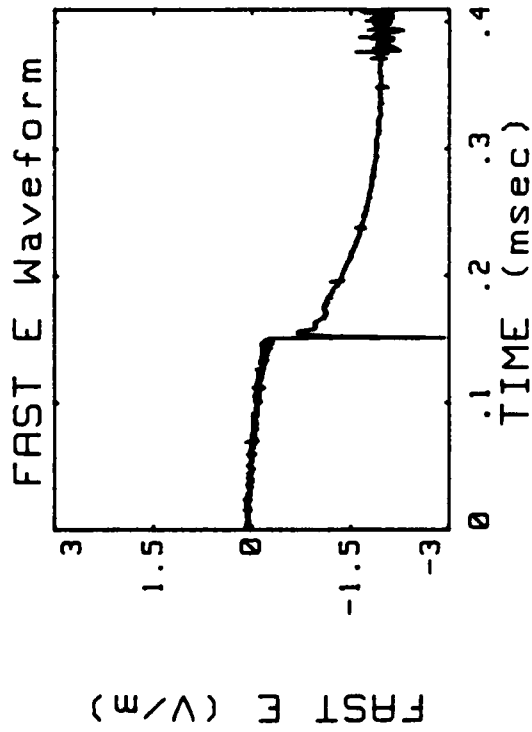
212194508.928 1987

Triggered Stroke (5.16 Km)



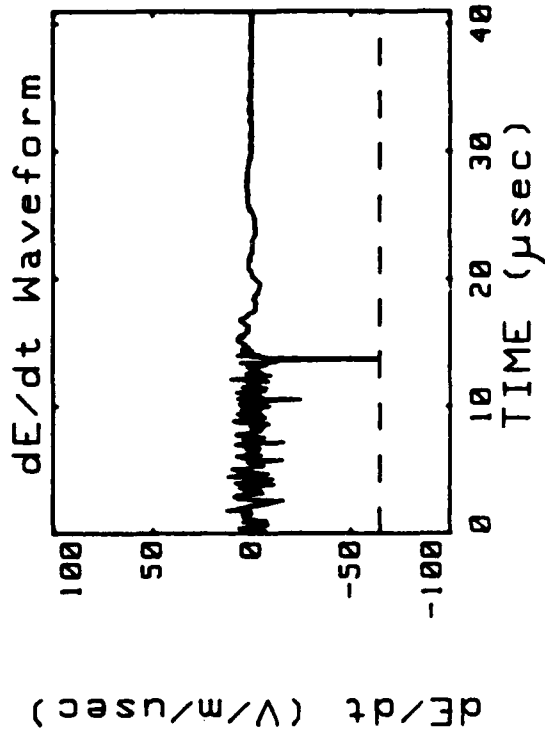
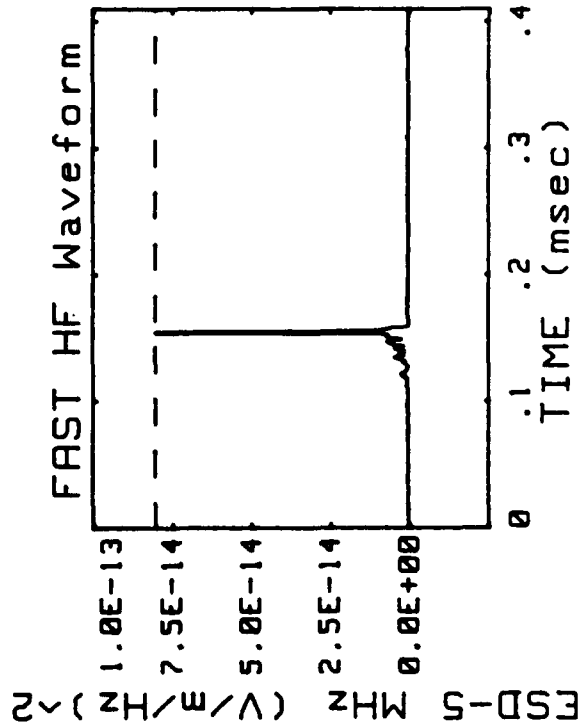
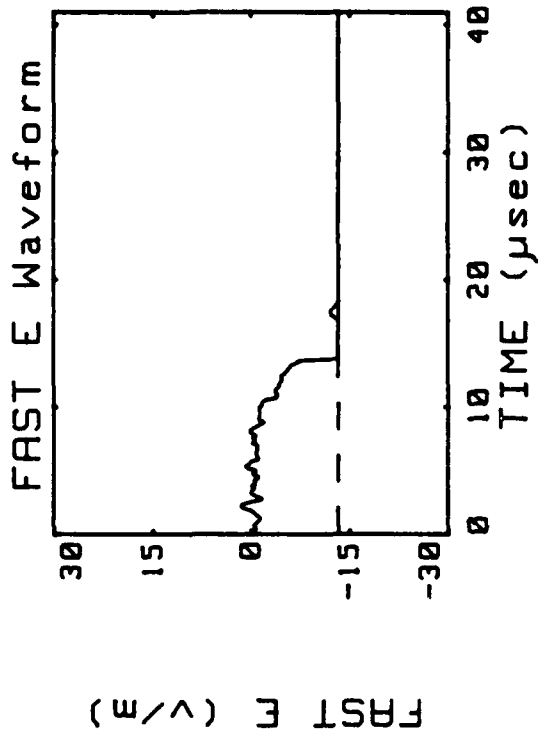
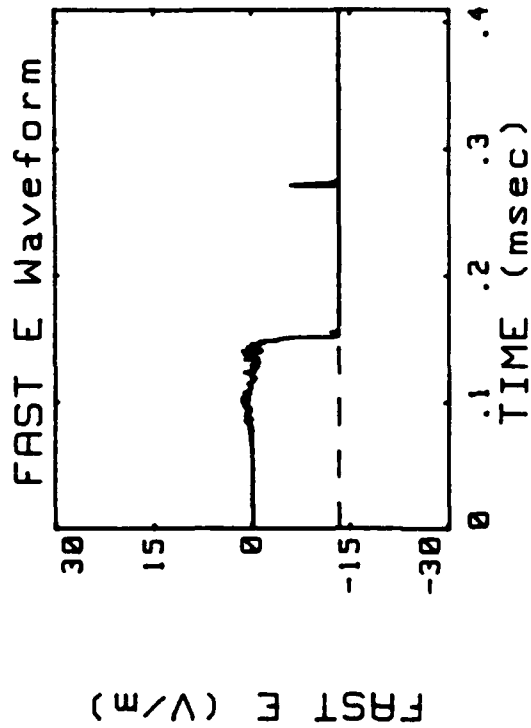
212194508.928 1987

Triggered Stroke (5.16 Km)



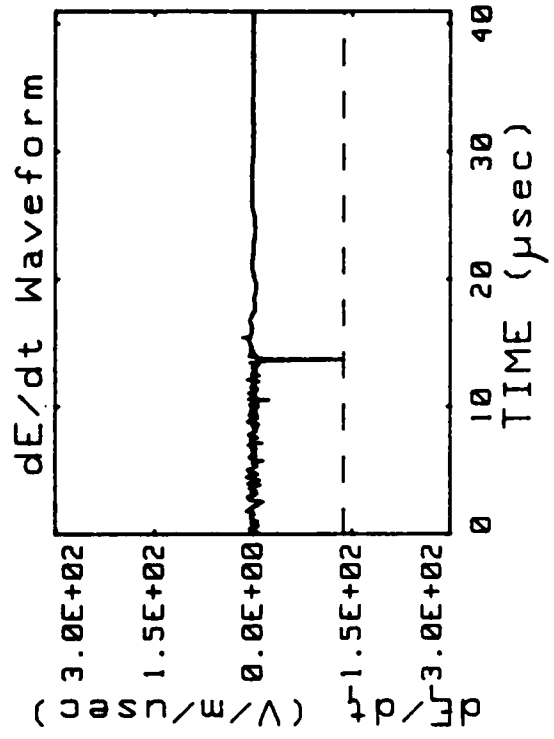
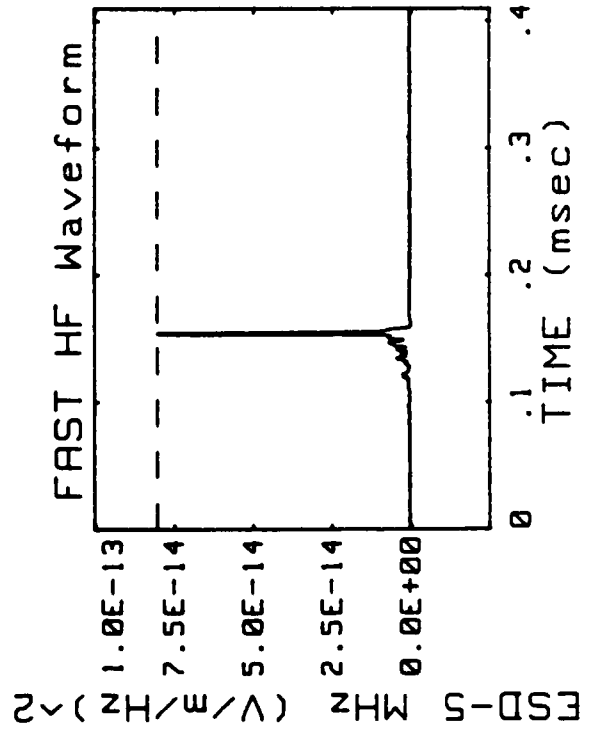
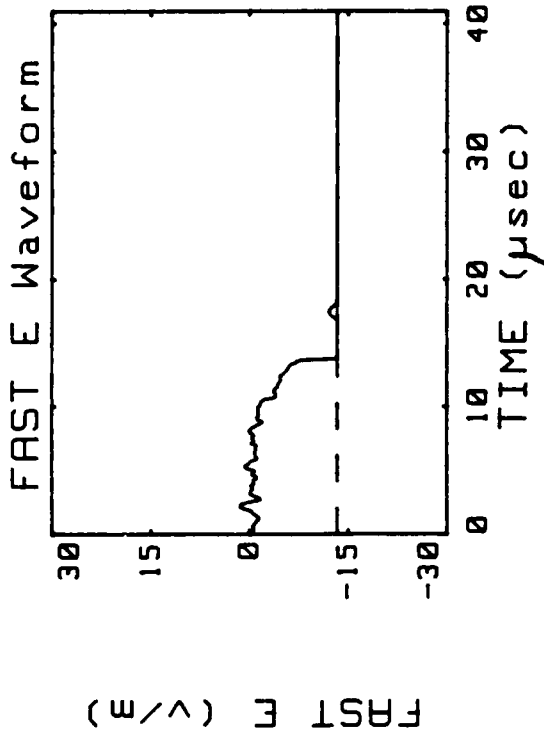
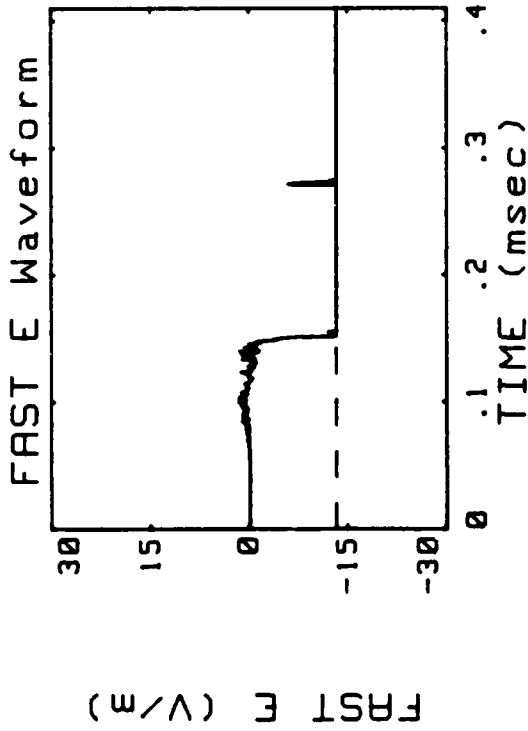
212194509.152 1987

Triggered Stroke (5.16 Km)

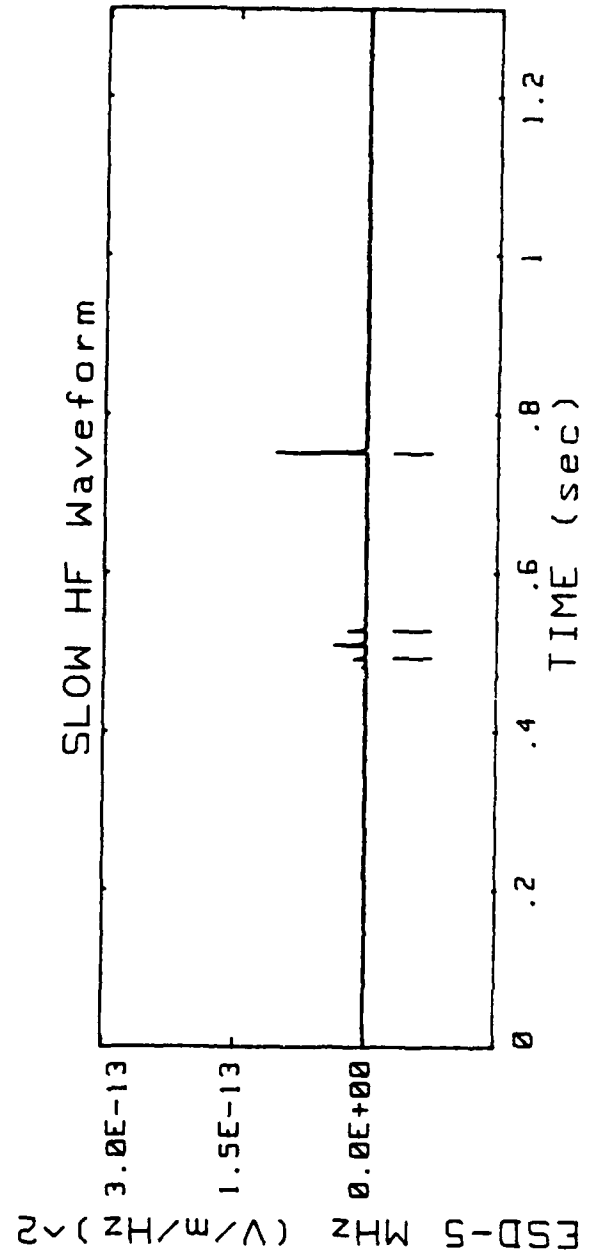
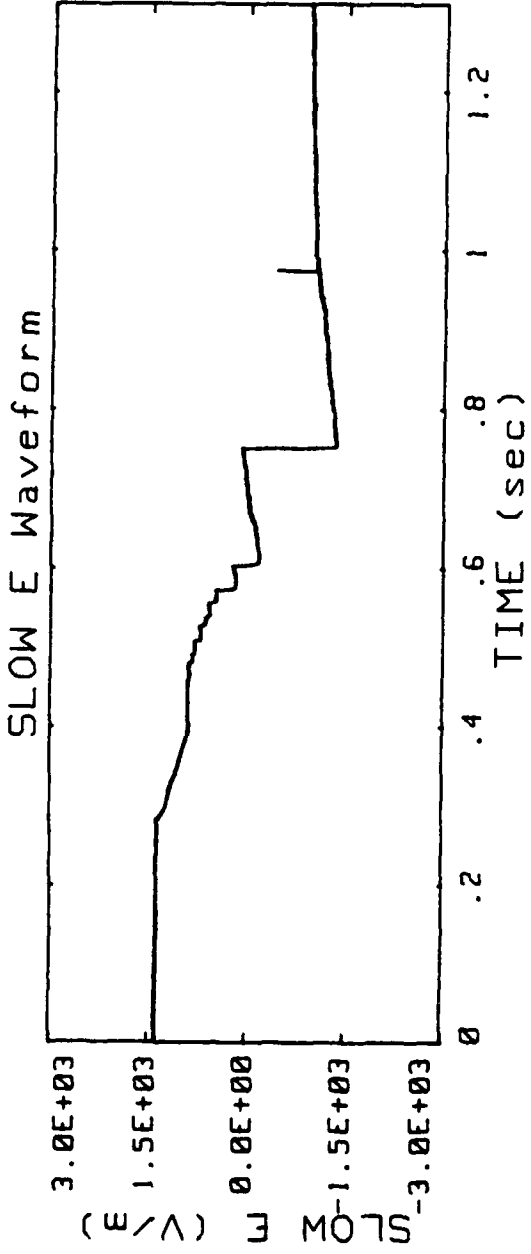


212194509.152 1987

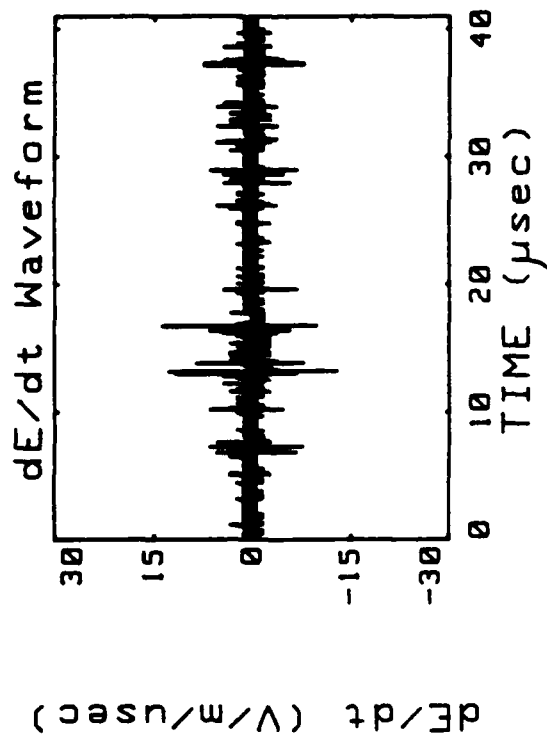
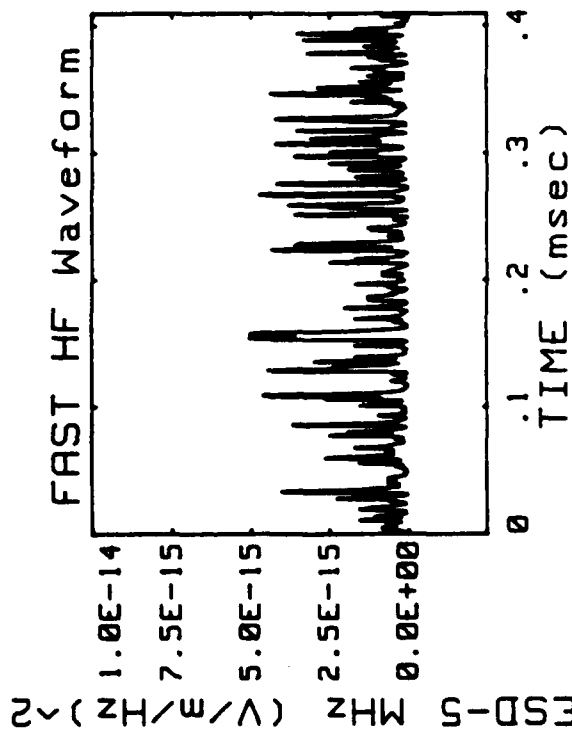
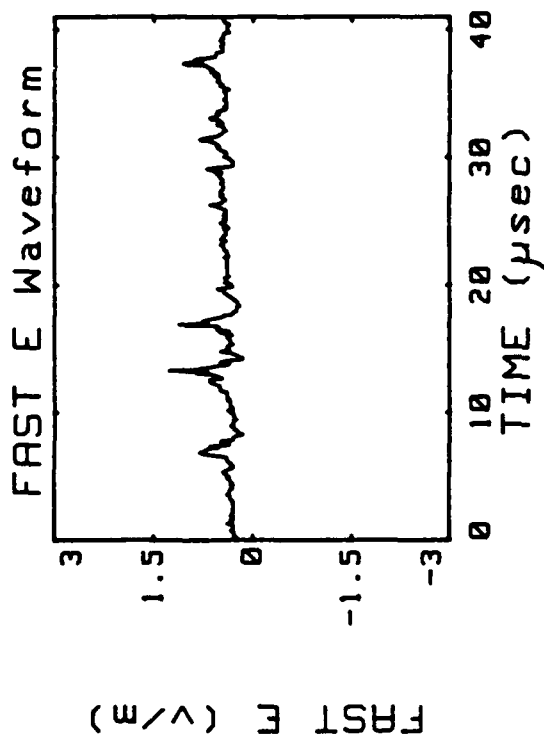
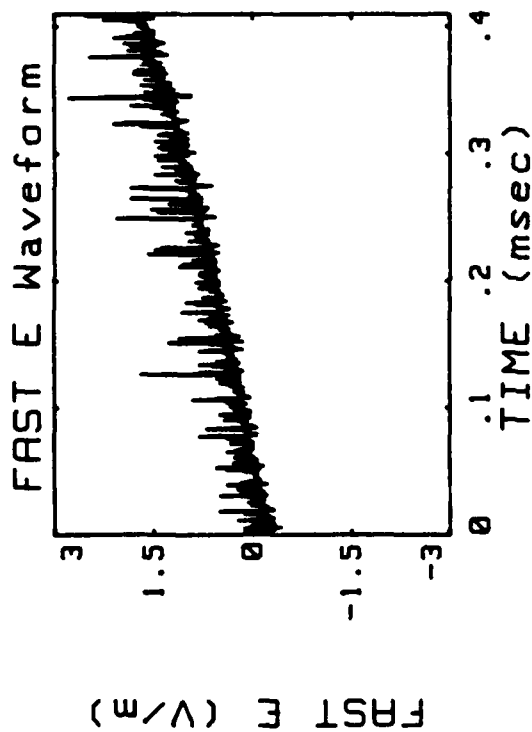
Triggered Stroke (5.16 Km)



19:45:08.402 31 Jul 1987 (5.16 Km)

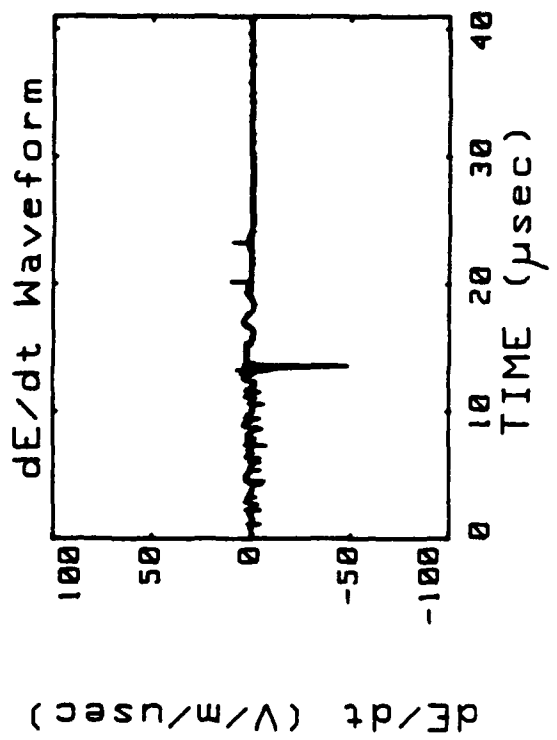
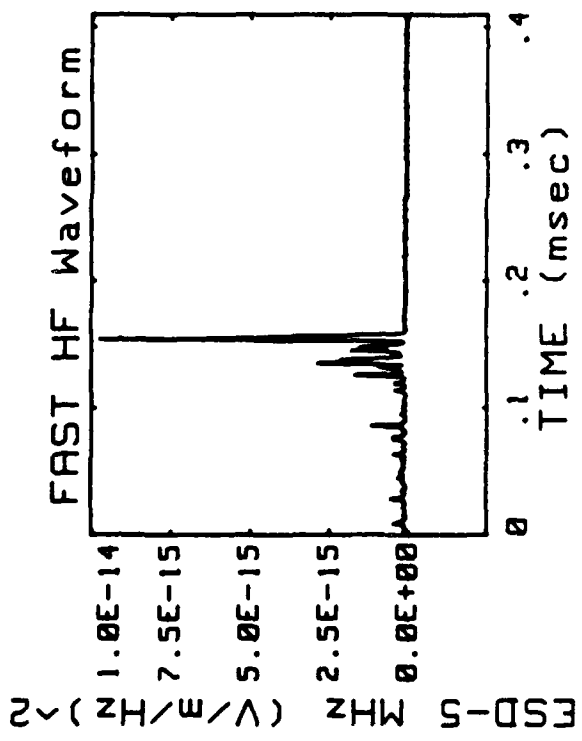
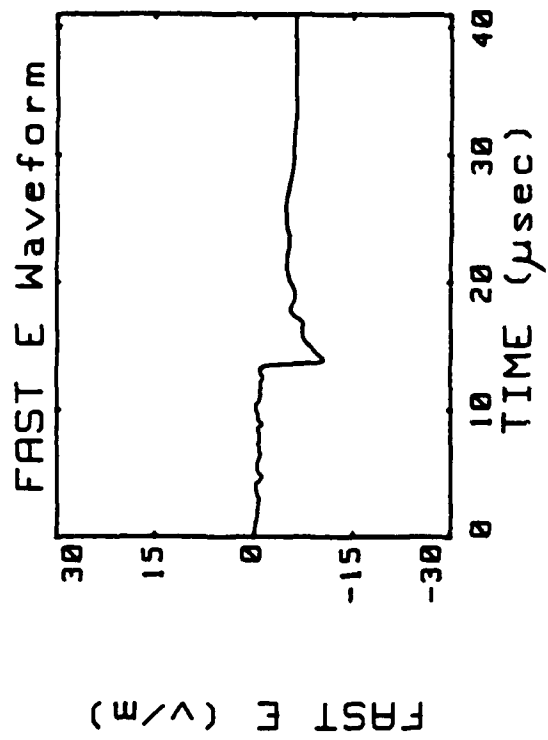
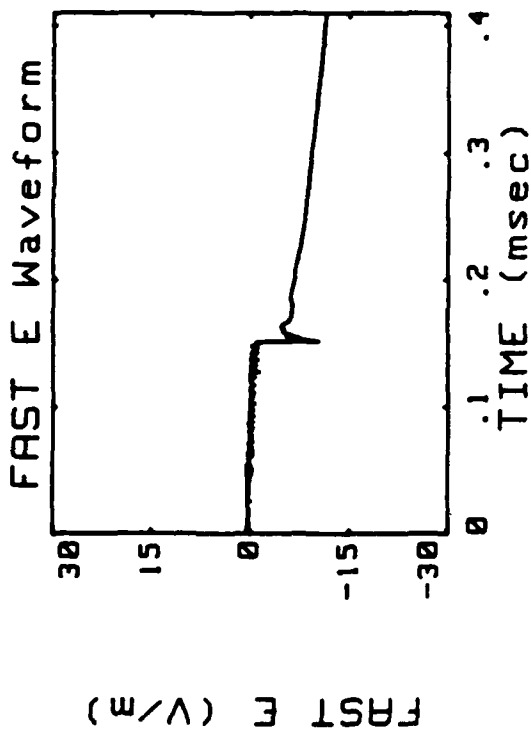


212211544.078 1987 Upward Negative Leader (5.16 Km)

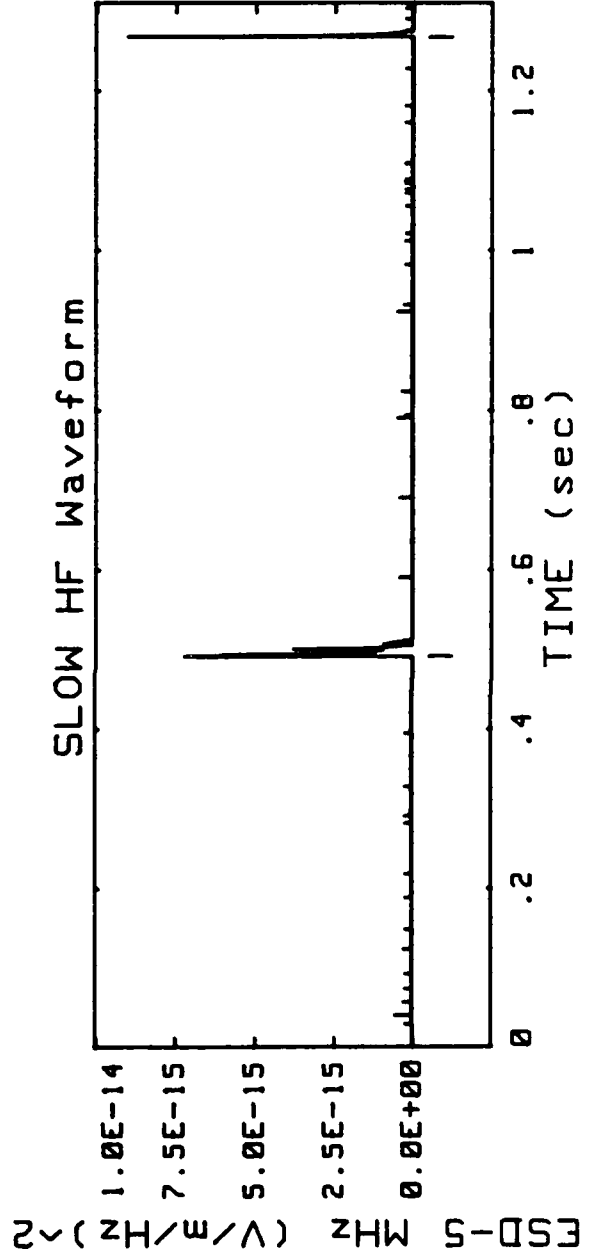
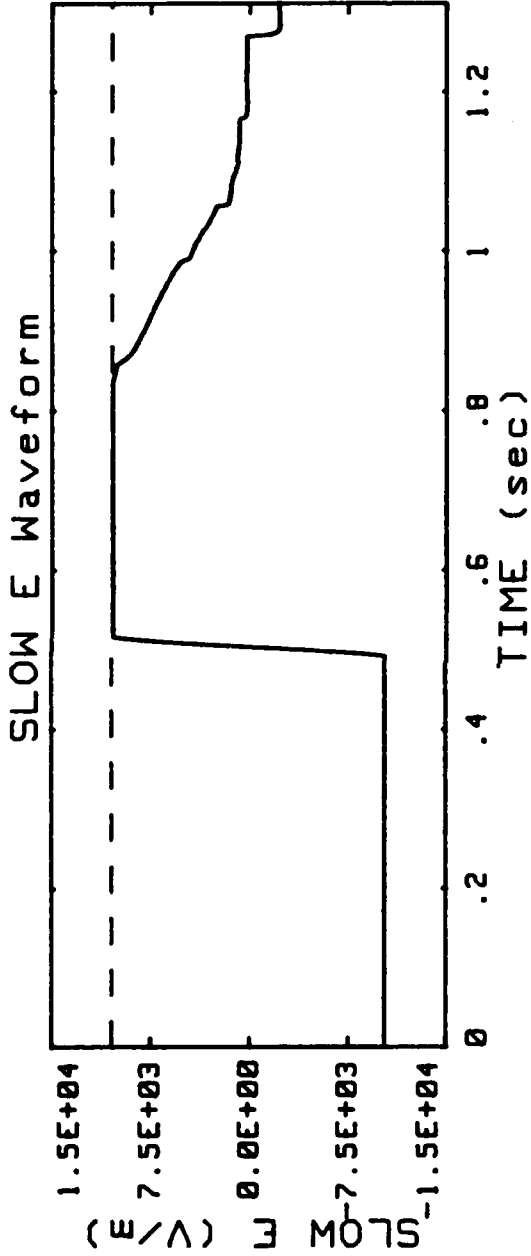


212211544.854 1987

Triggered Stroke (5.16 Km)

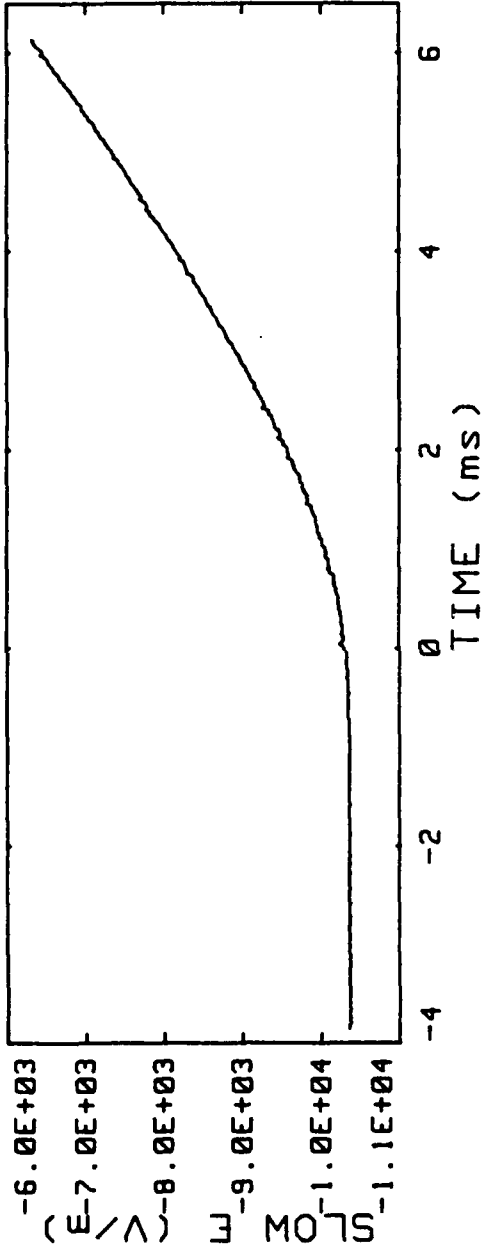


21:15:43.588 31 Jul 1987 (5.16 Km)

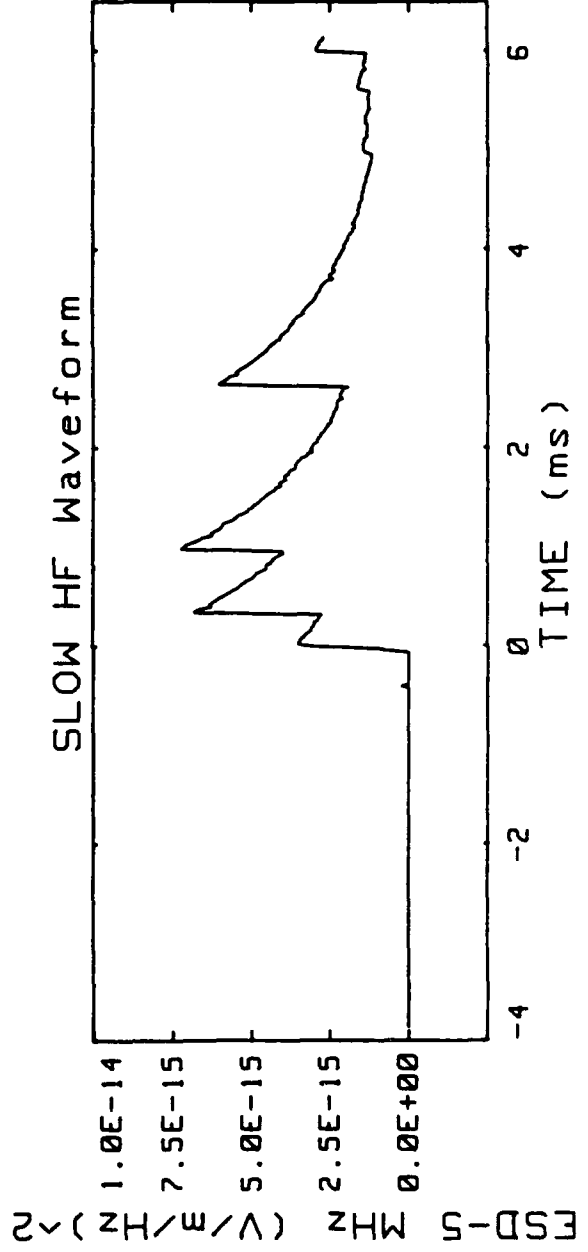


21:15:44.078 31 Jul 1987 (5.16 Km)

SLOW E Waveform



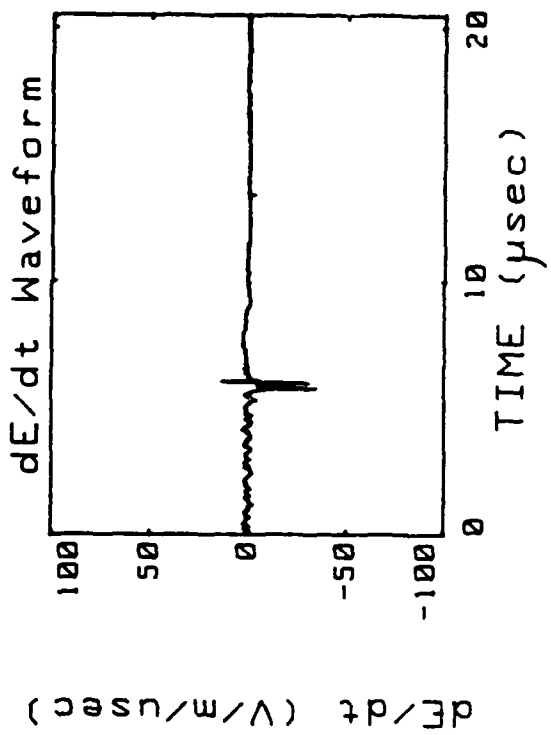
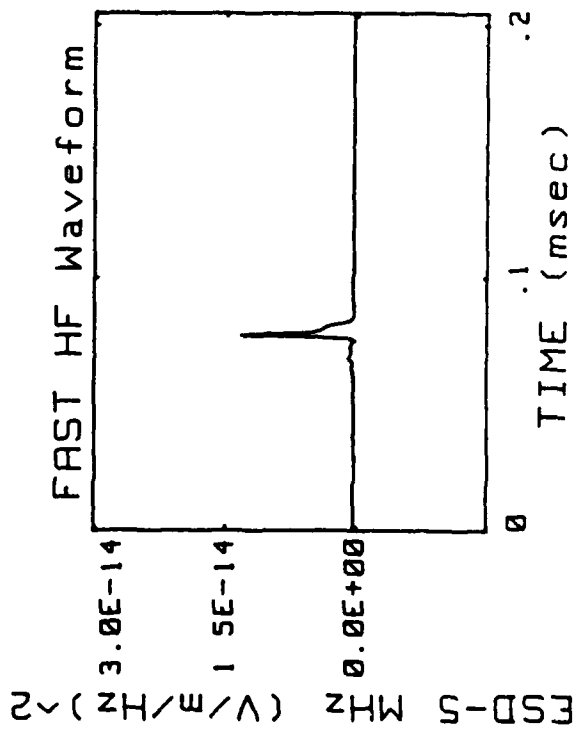
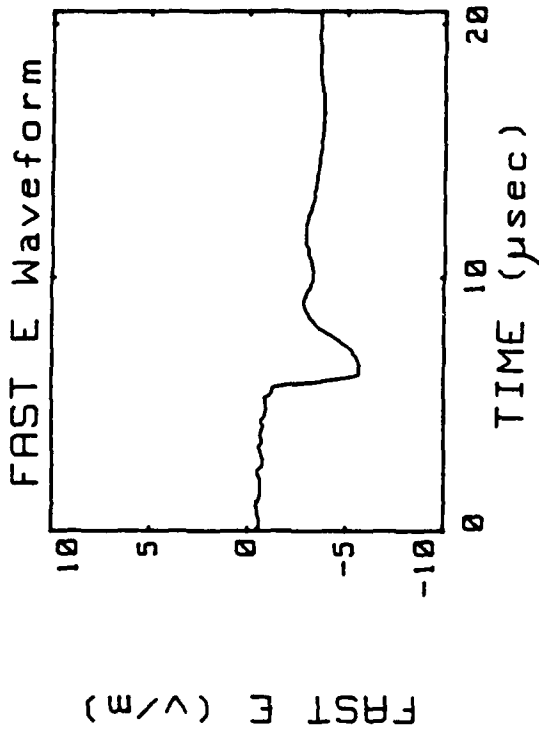
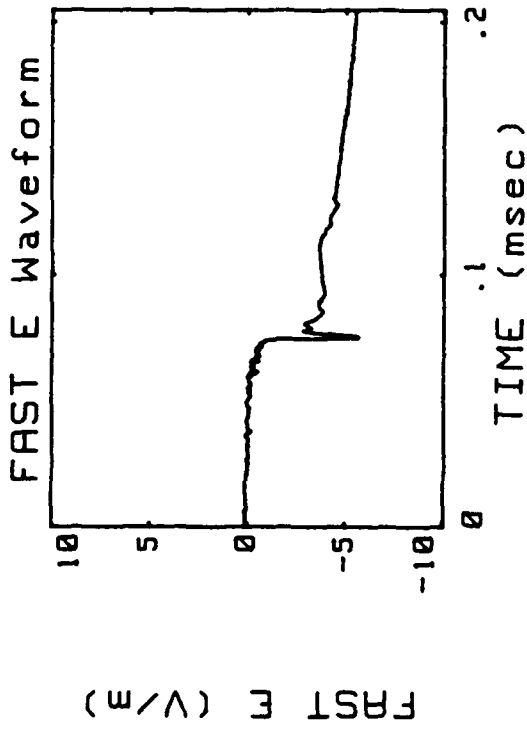
SLOW HF Waveform



2048 Data

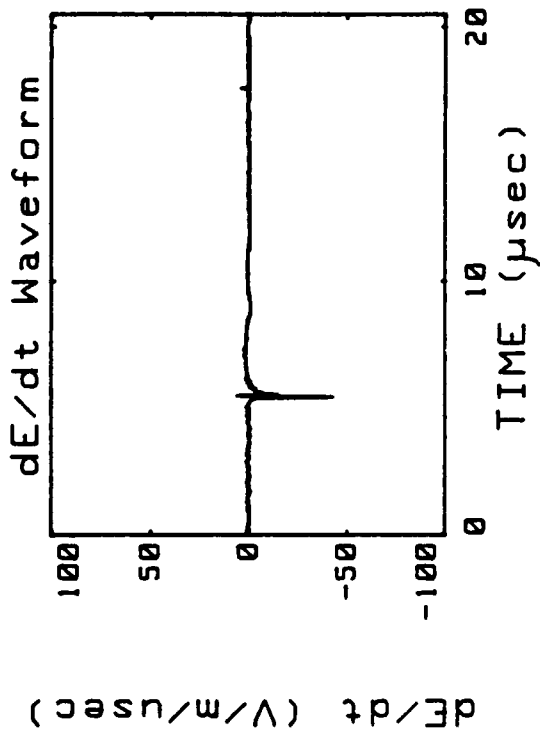
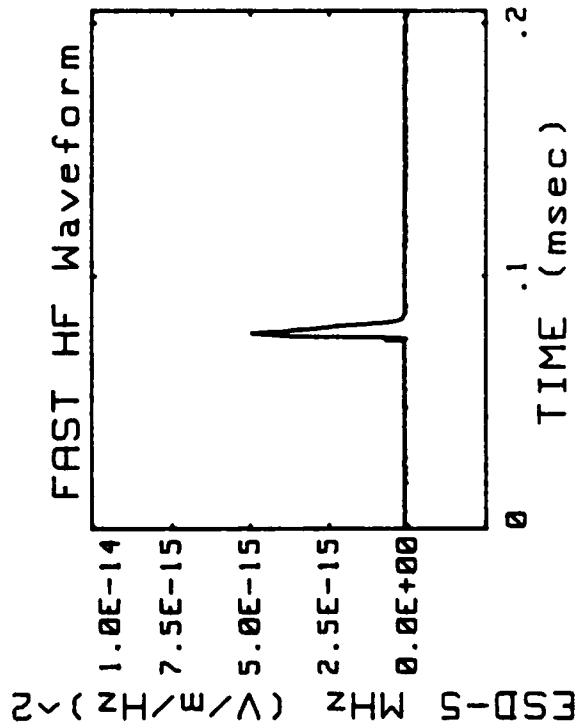
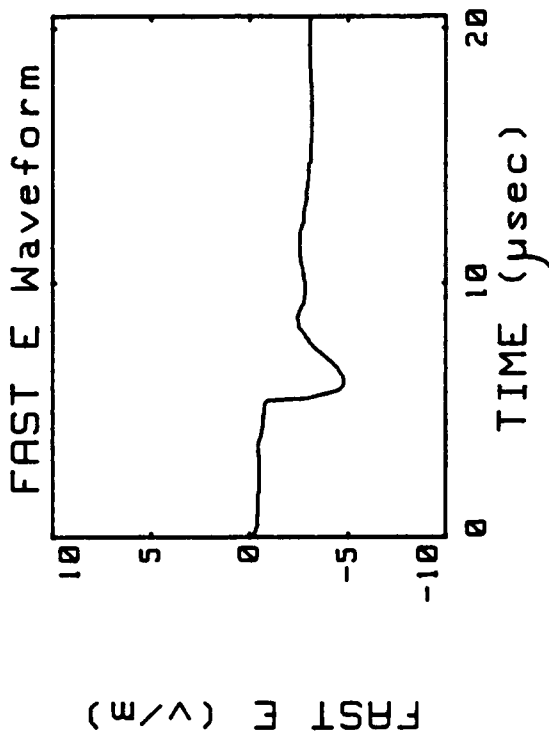
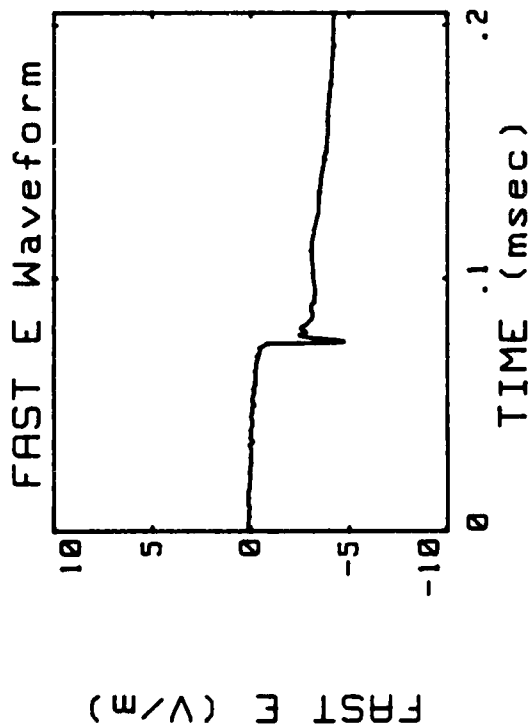
231211248.647 1987

Triggered Stroke (5.16 Km)



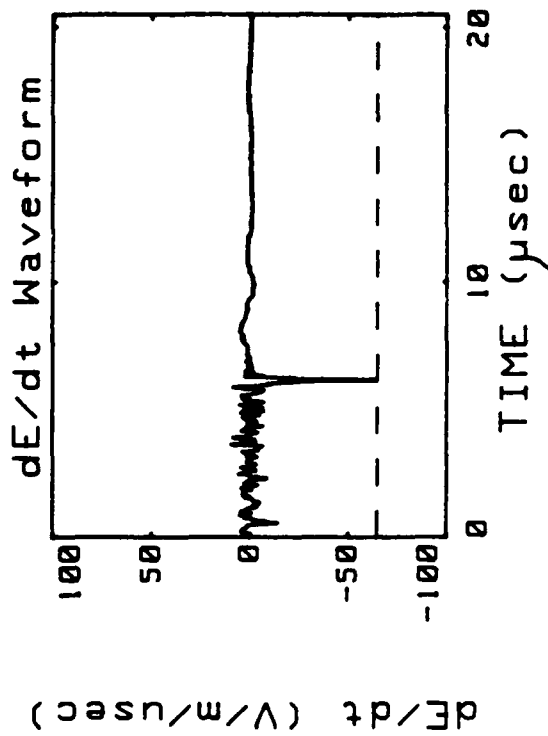
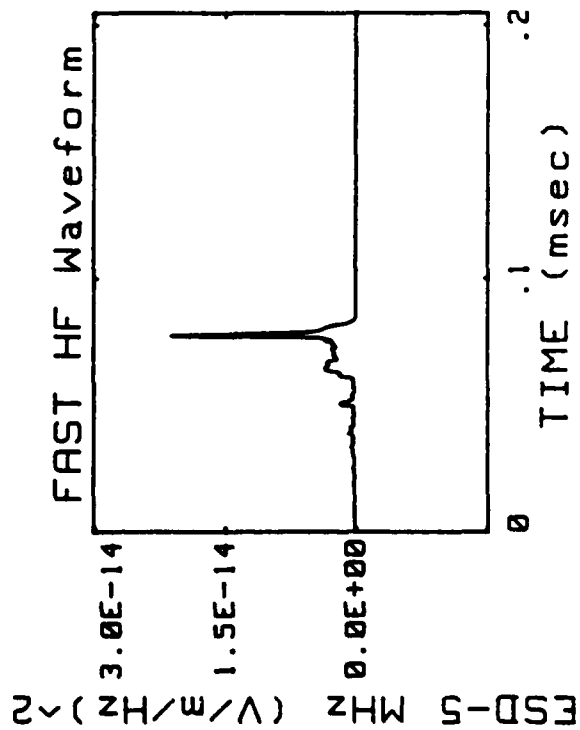
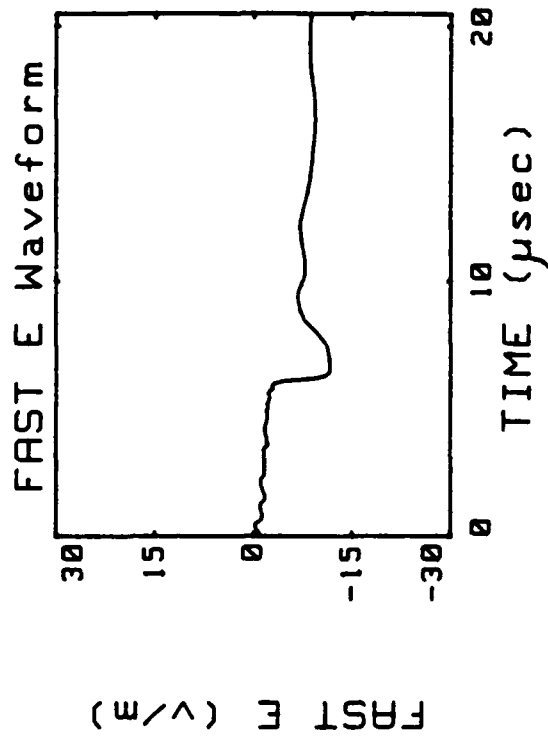
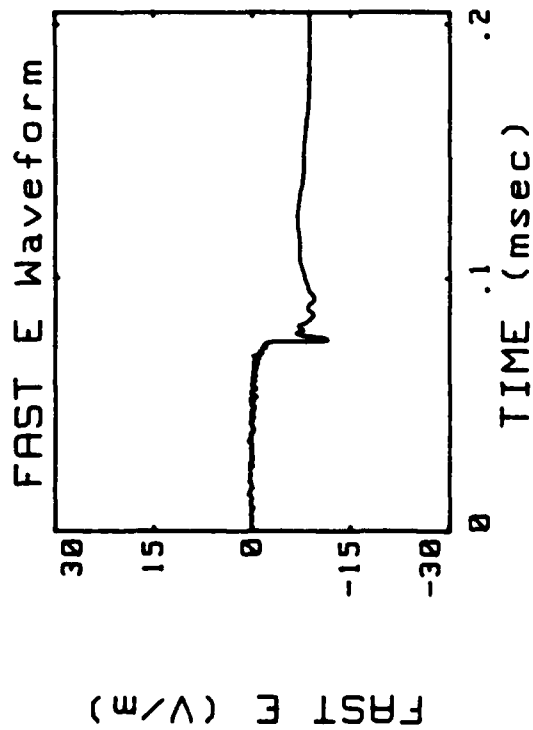
231211248.717 1987

Triggered Stroke (5.16 Km)



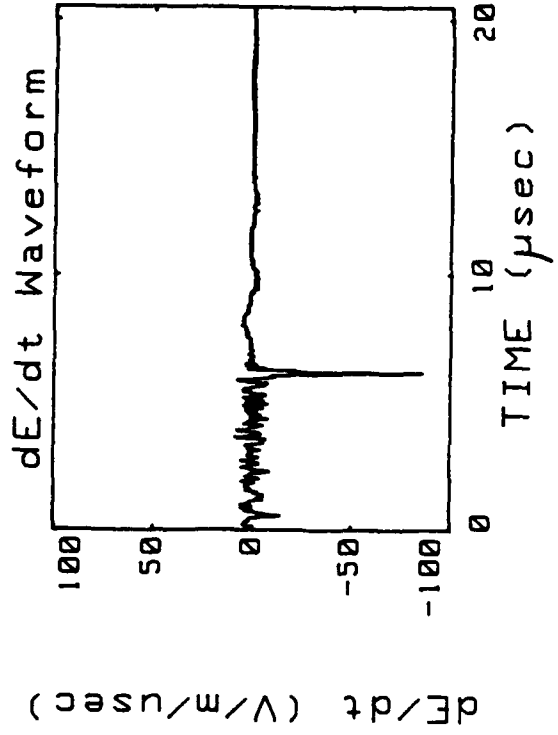
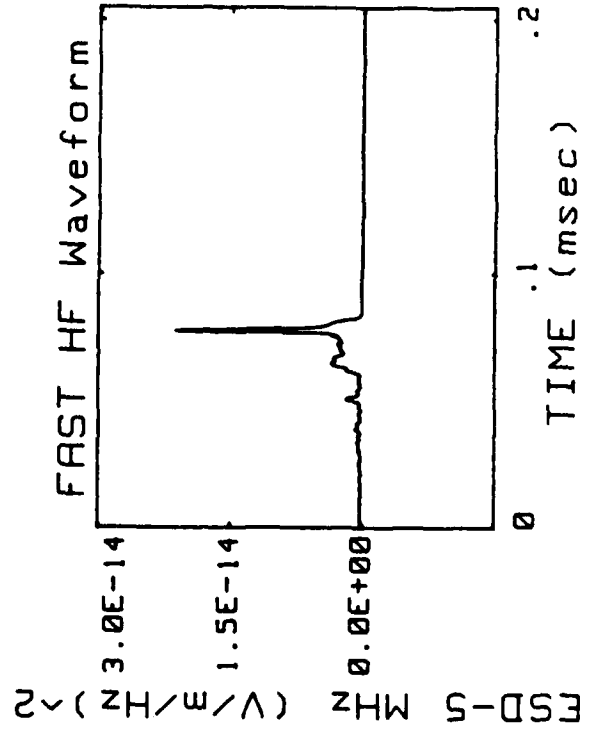
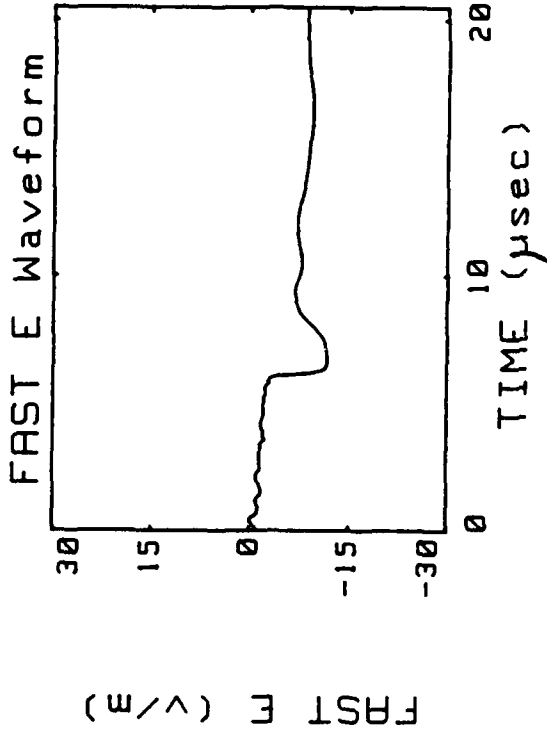
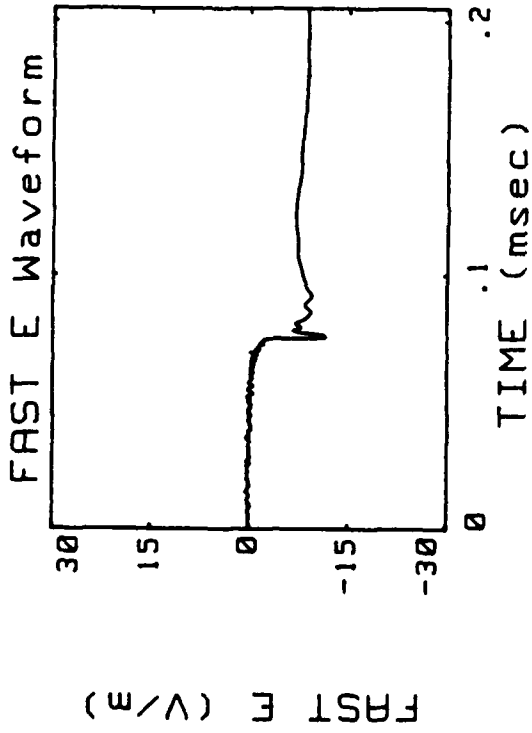
231211248.842 1987

Triggered Stroke (5.16 Km)



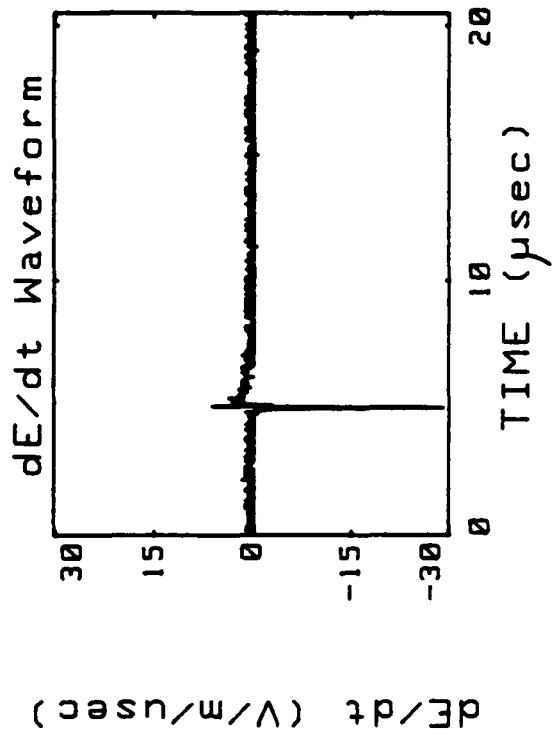
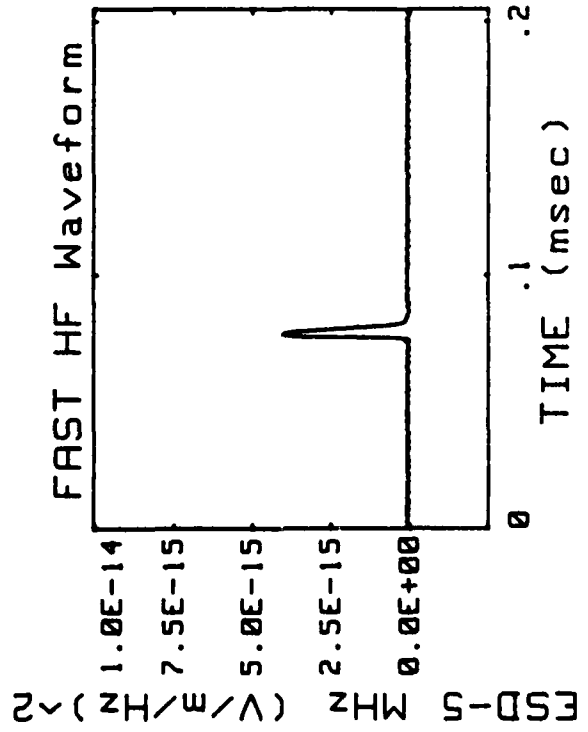
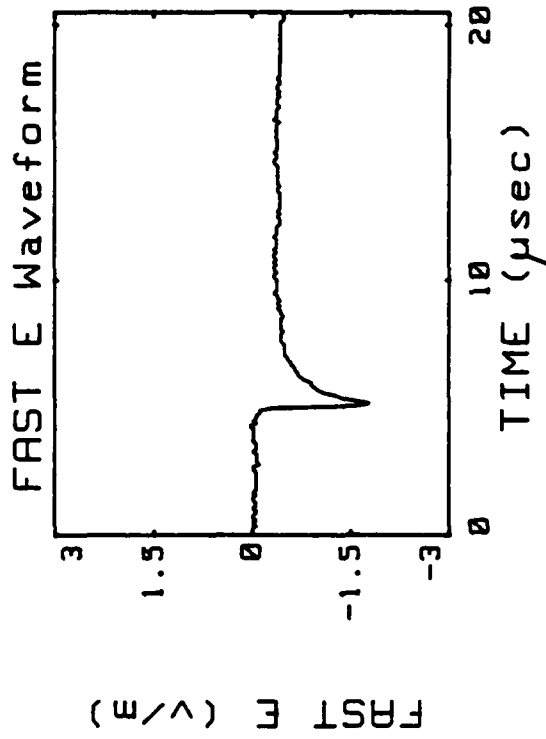
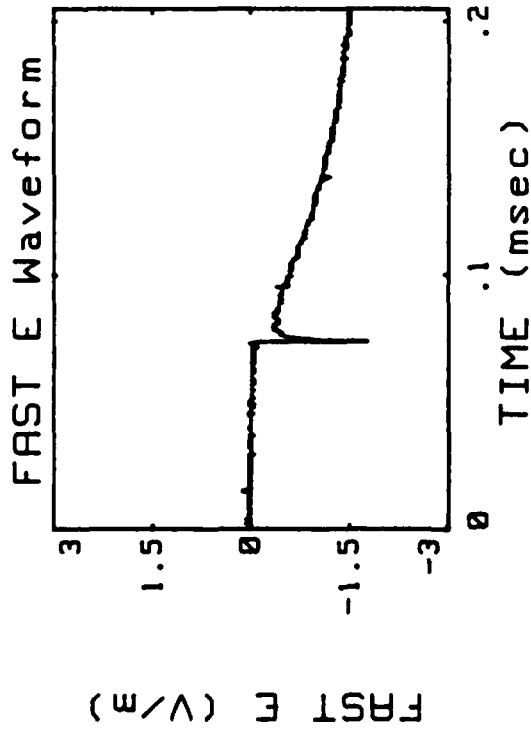
231211248.842 1987

Triggered Stroke (5.16 Km)



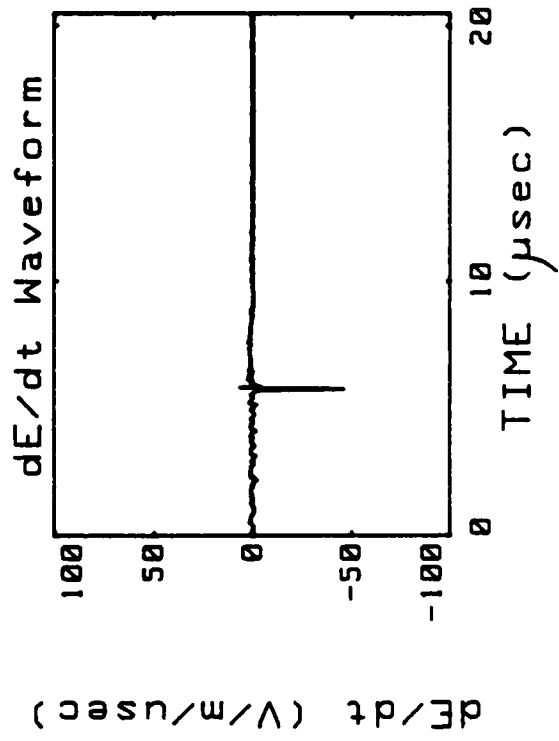
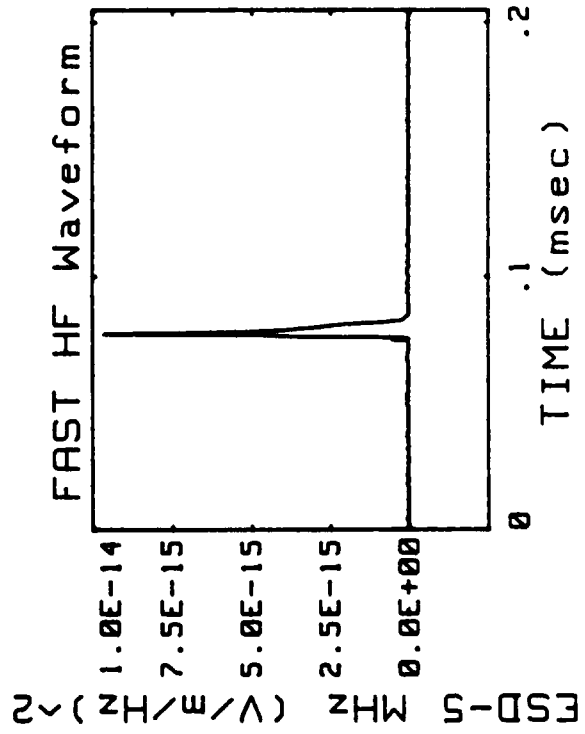
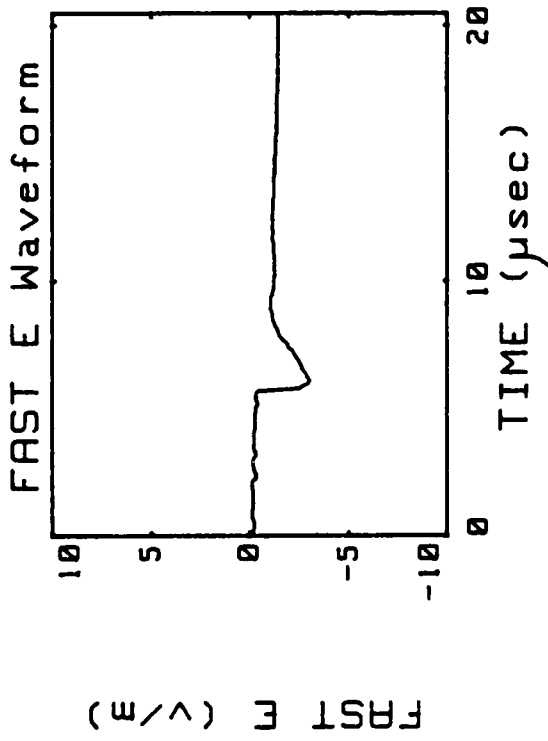
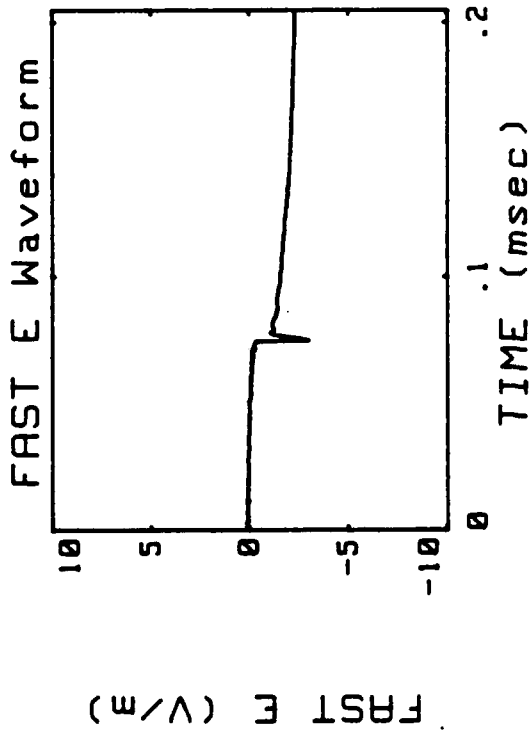
231211248.896 1987

Triggered Stroke (5.16 Km)

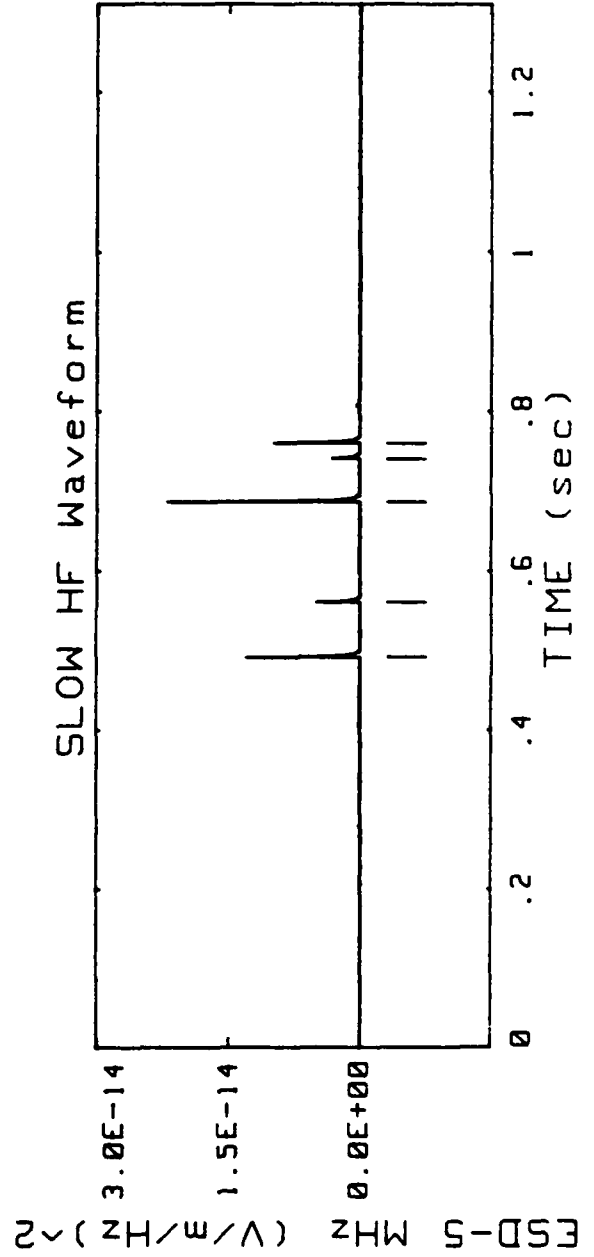
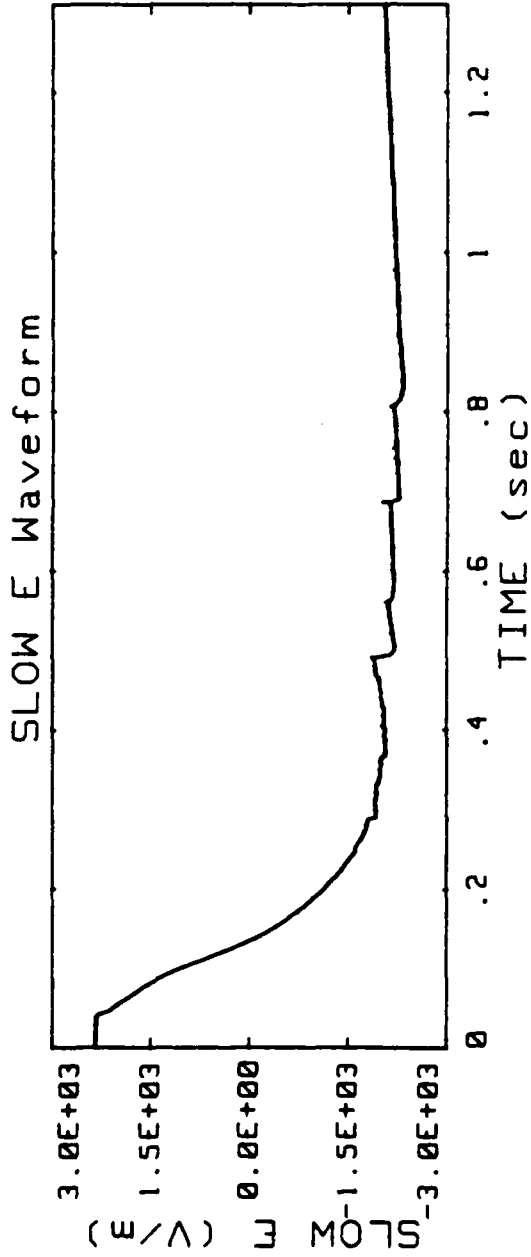


231211248.916 1987

Triggered Stroke (5.16 Km)

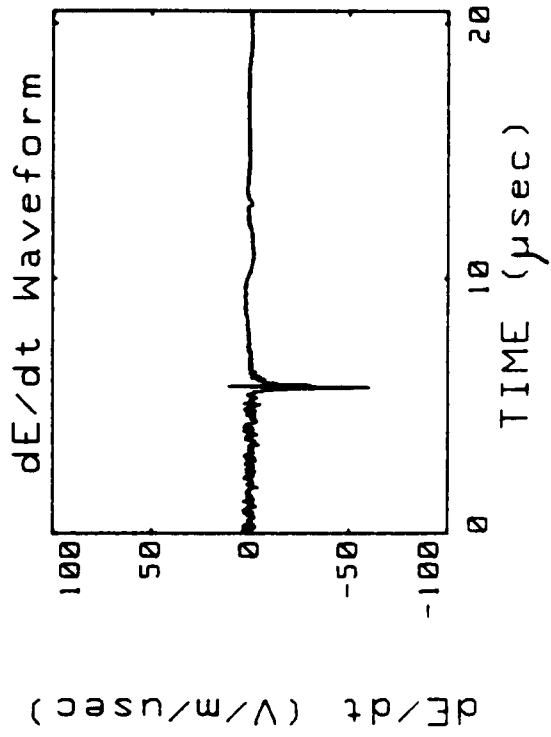
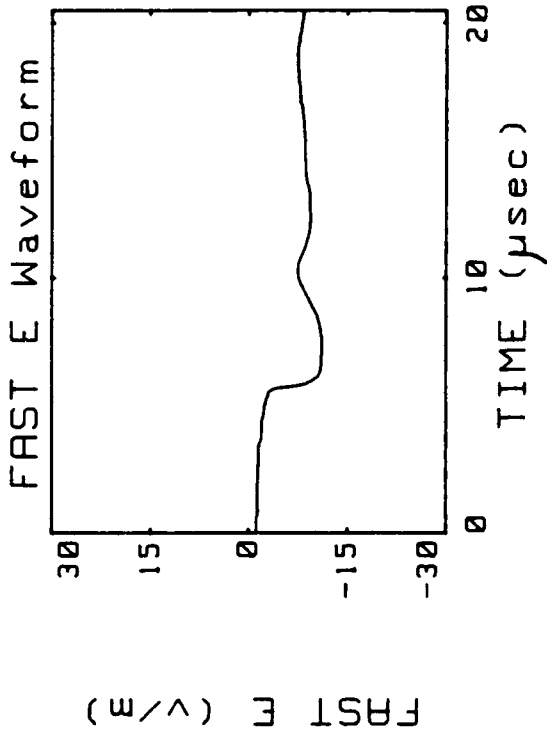
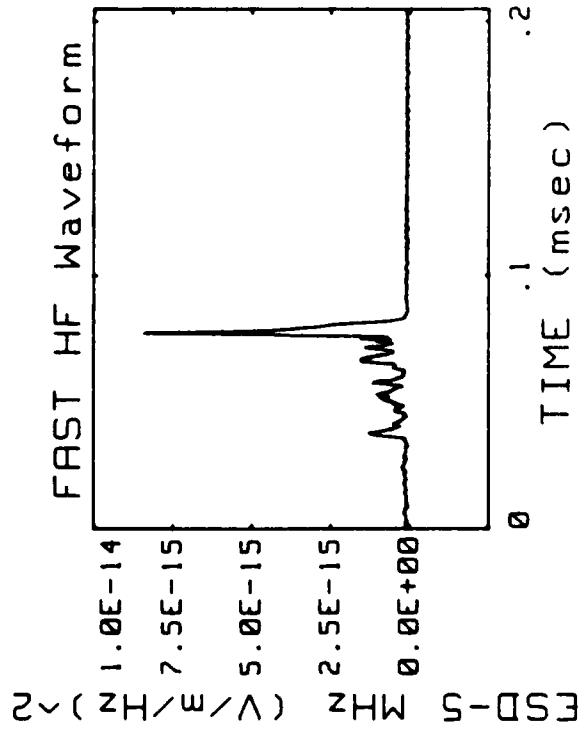
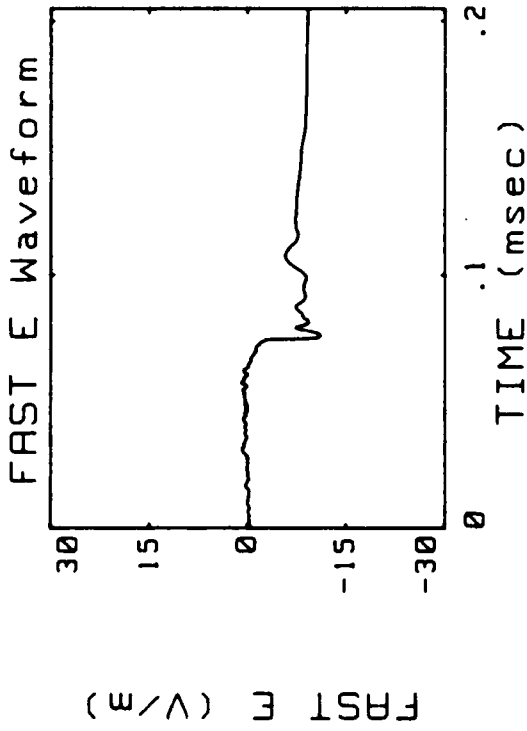


21:12:48.157 19 Aug 1987 (5.16 Km)



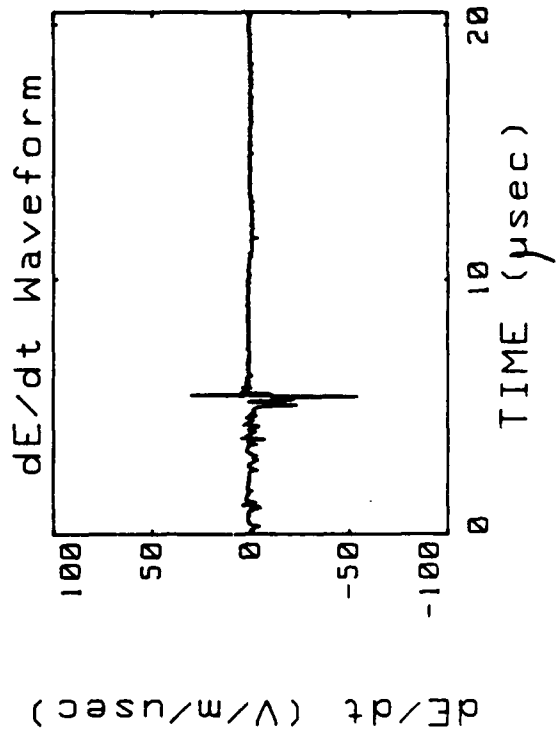
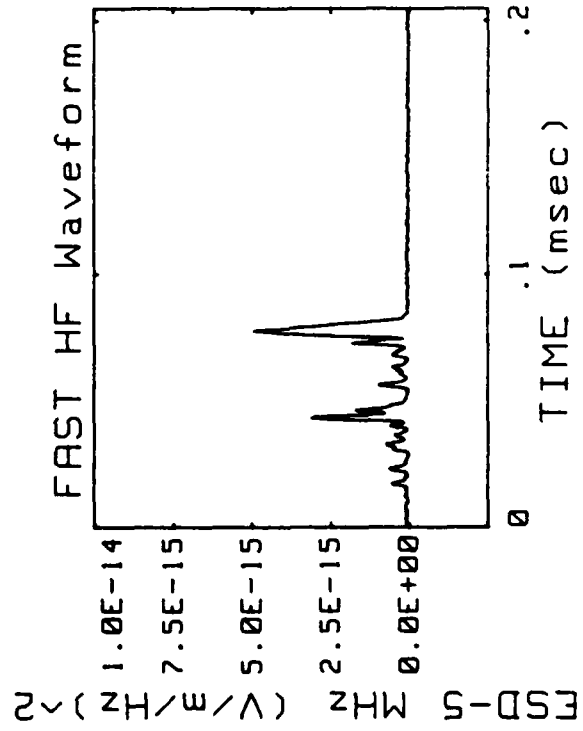
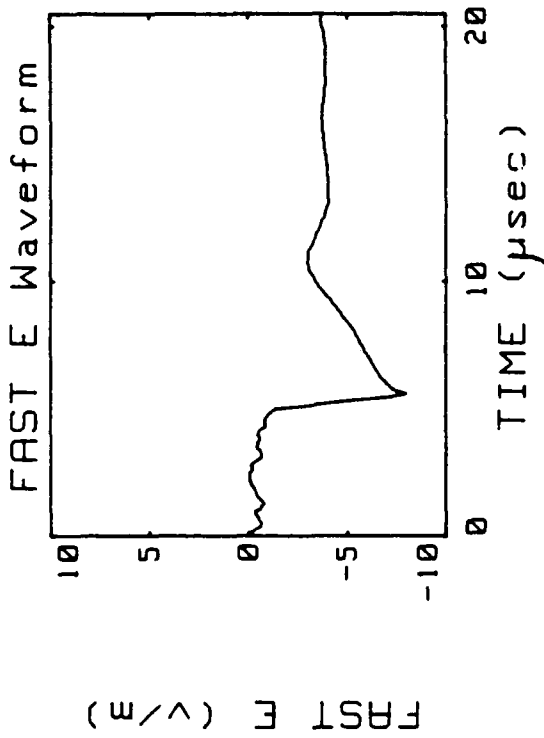
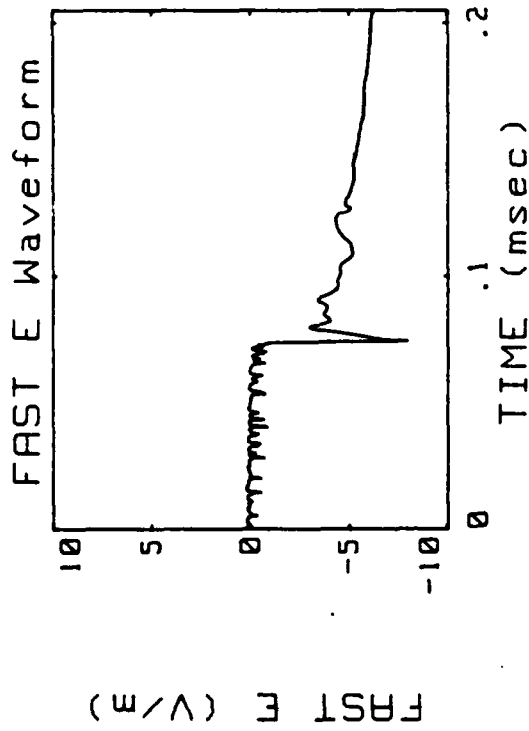
231212133.663 1987

Triggered Stroke (5.16 Km)



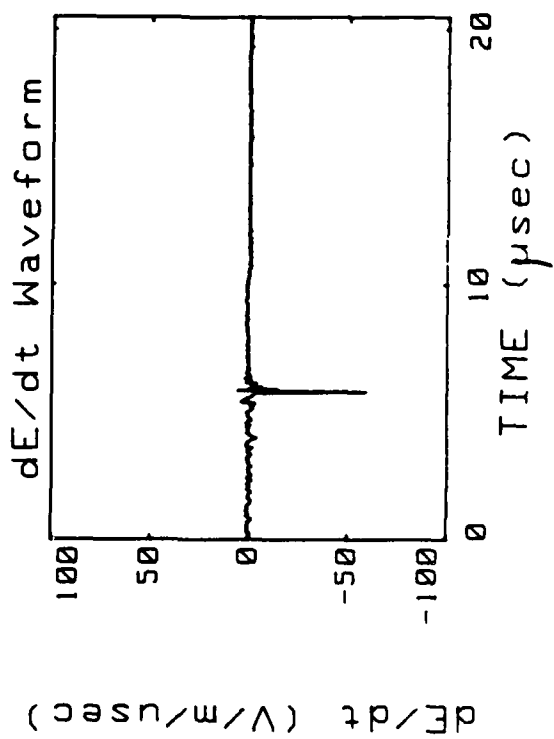
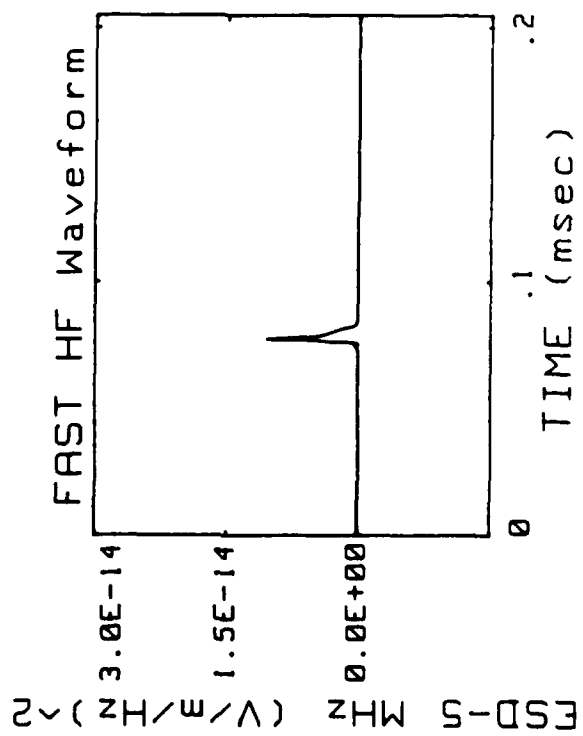
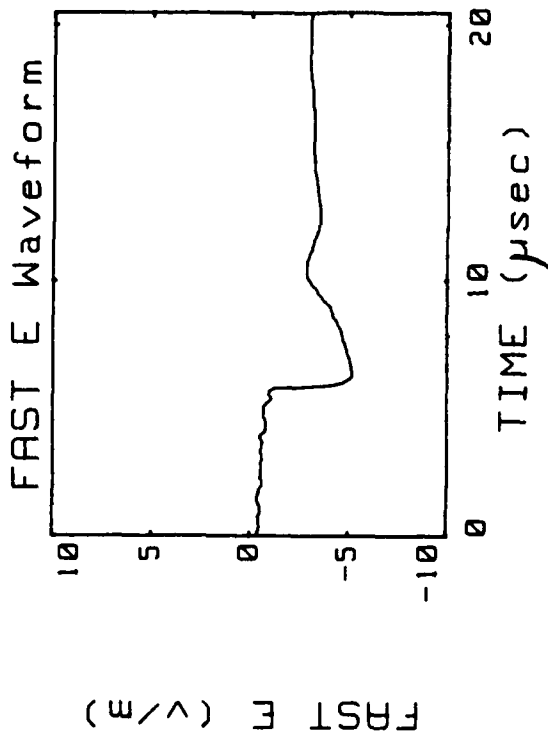
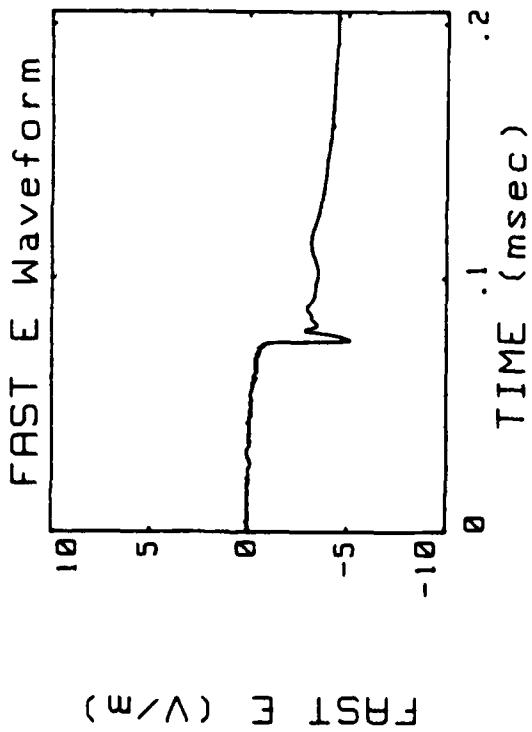
231212133.880 1987

Triggered Stroke (5.16 Km)



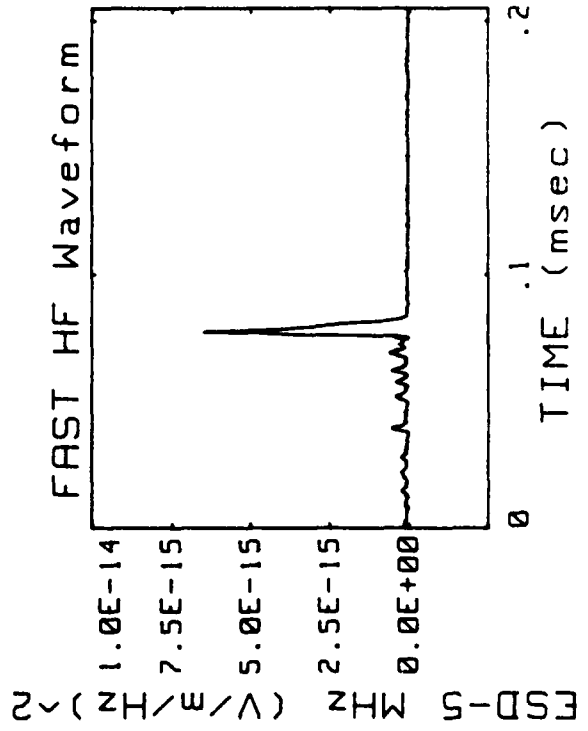
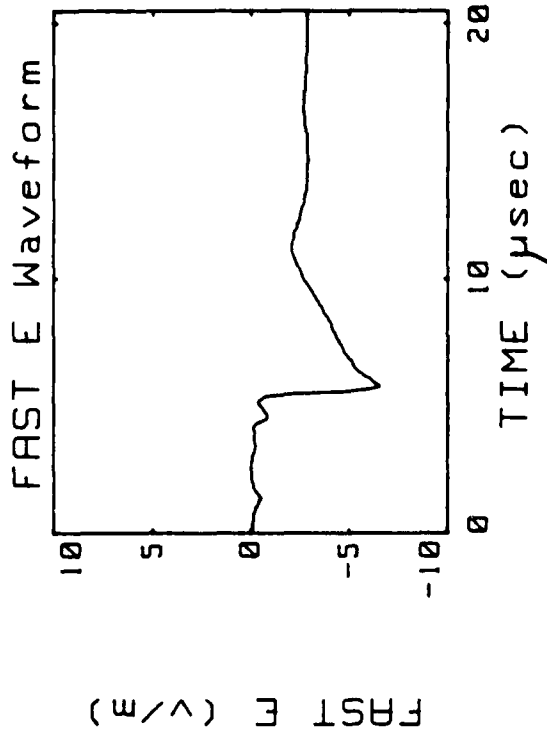
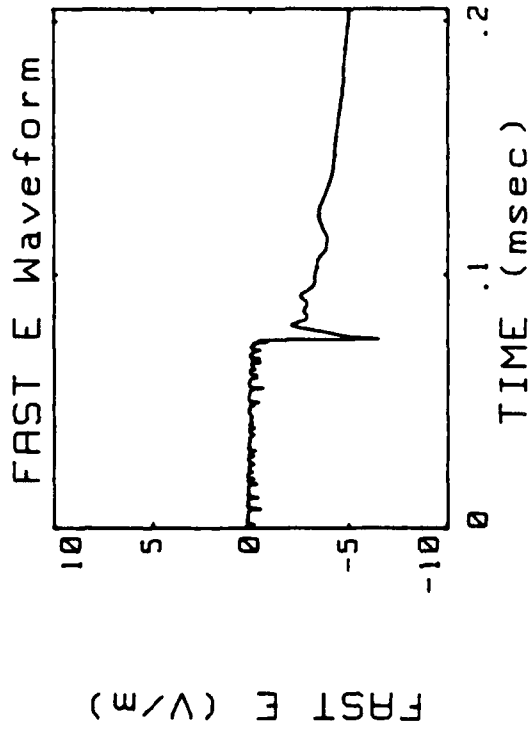
231212133.962 1987

Triggered Stroke (5.16 Km)



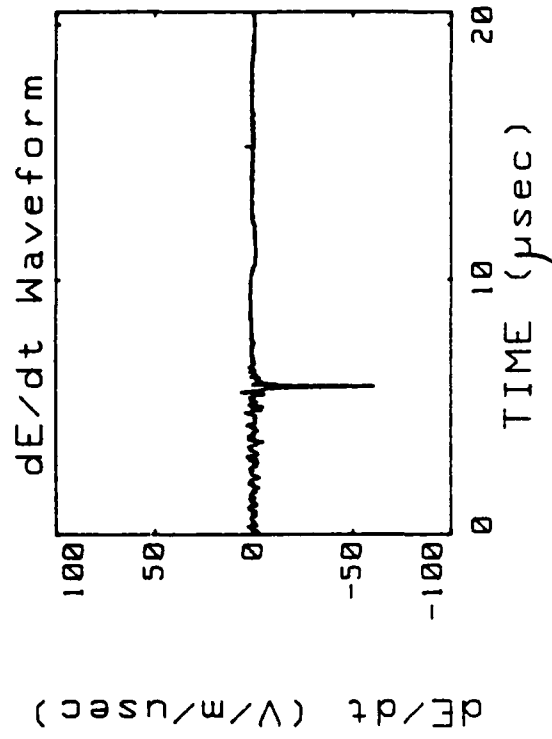
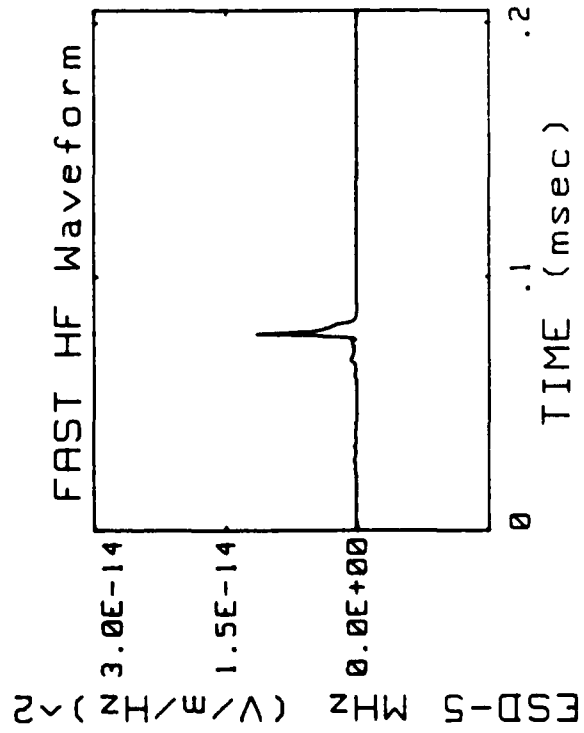
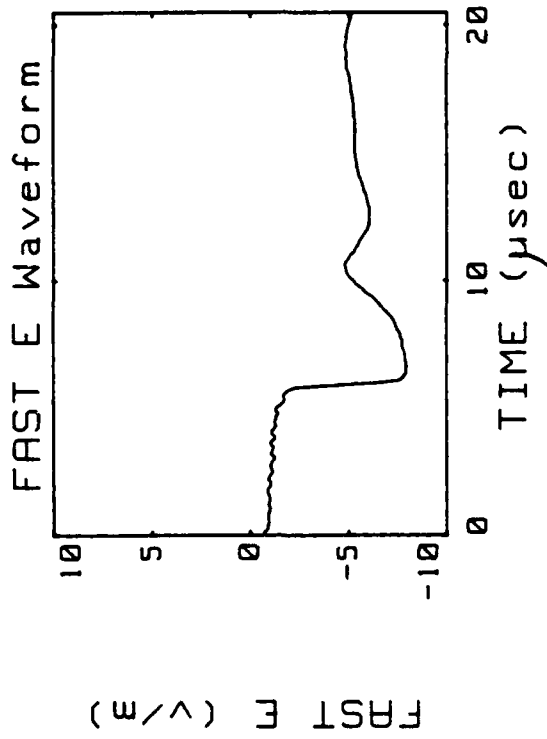
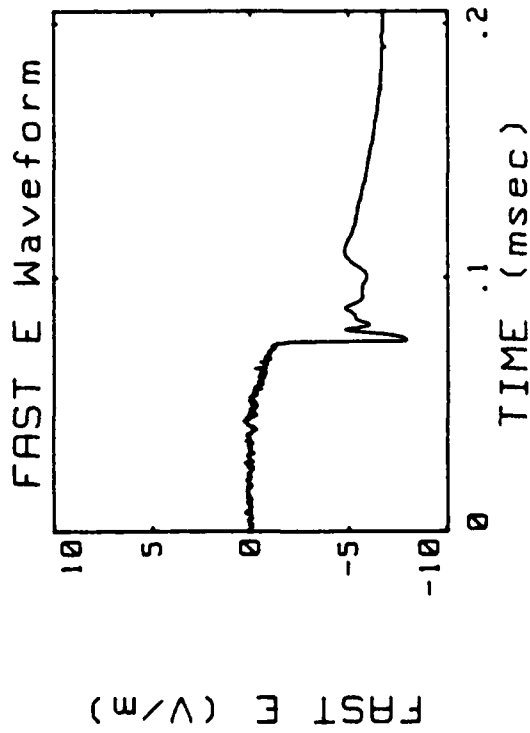
231212134.067 1987

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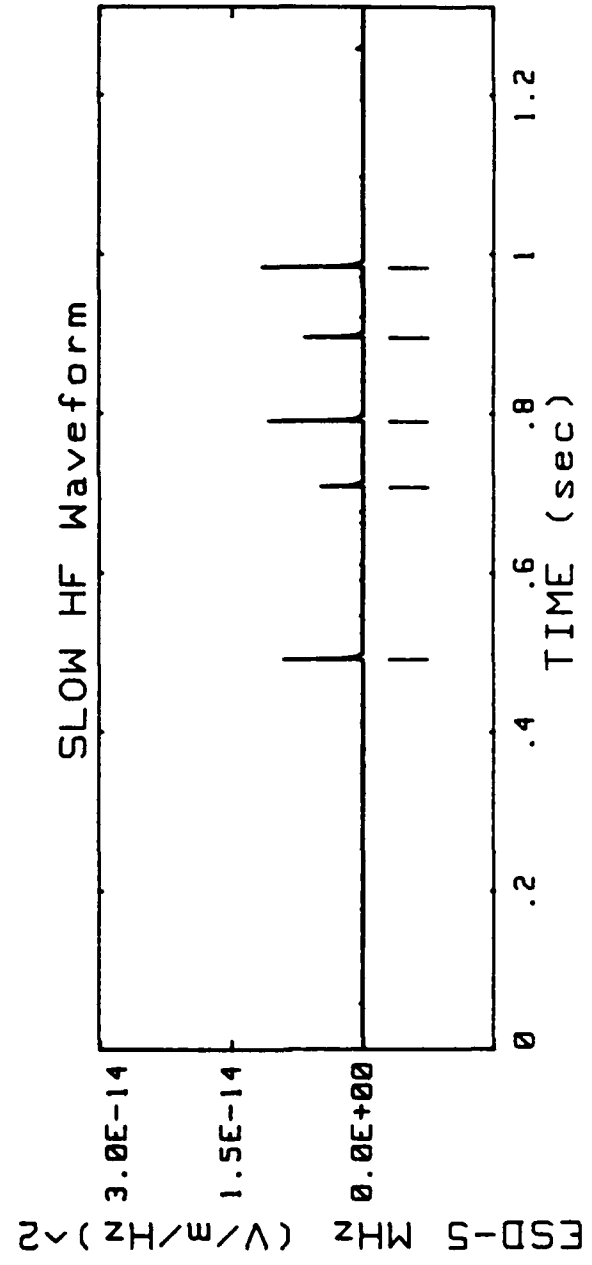
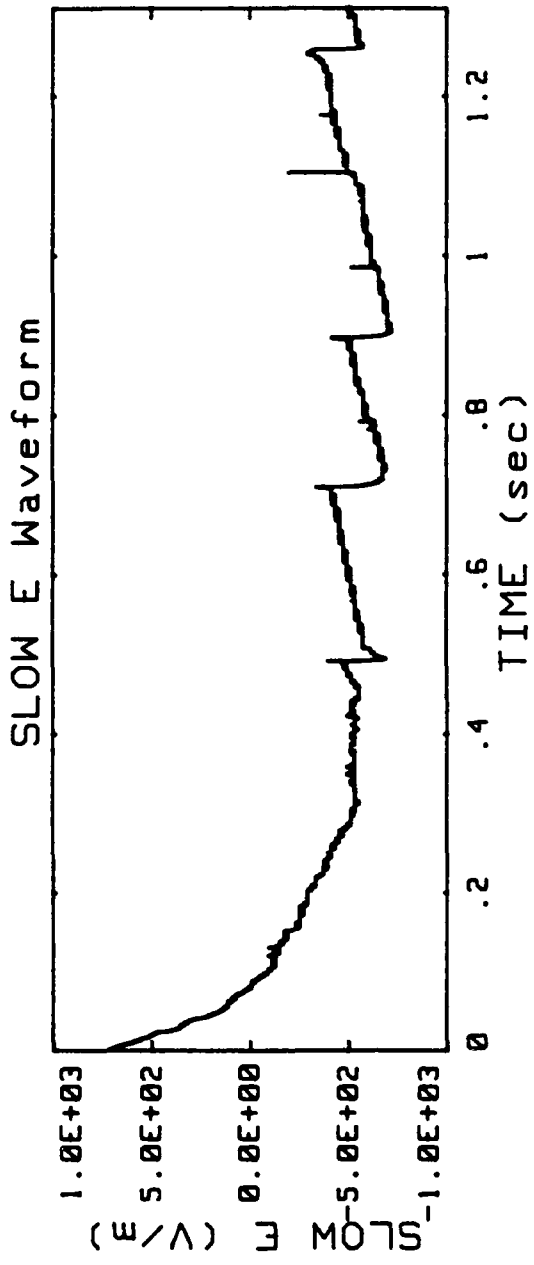


231212134.155 1987

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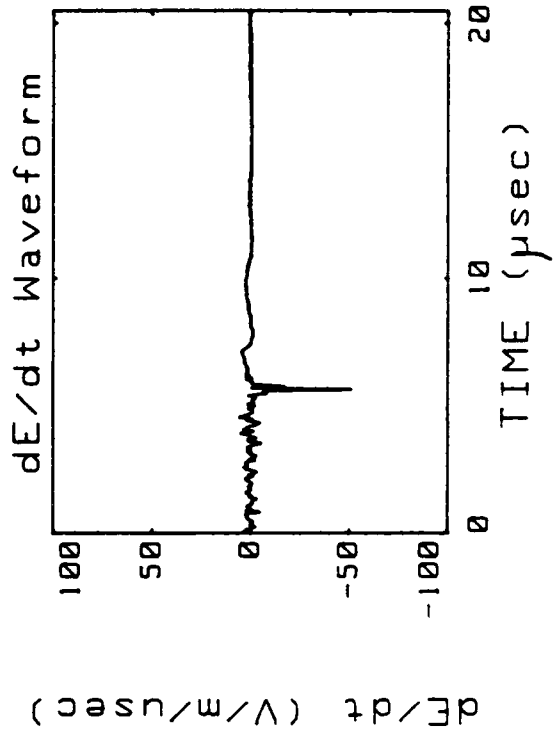
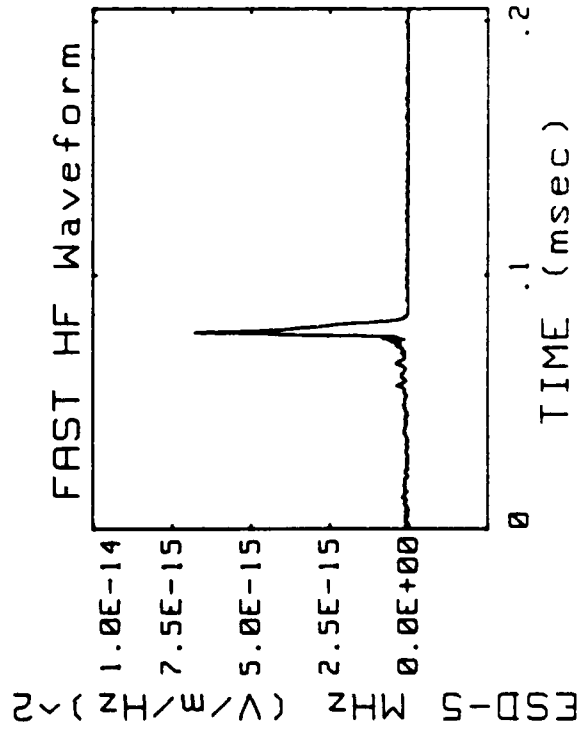
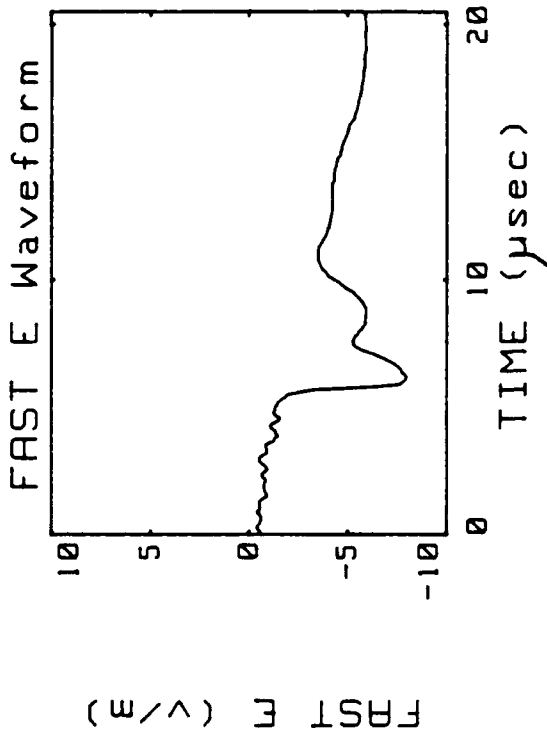
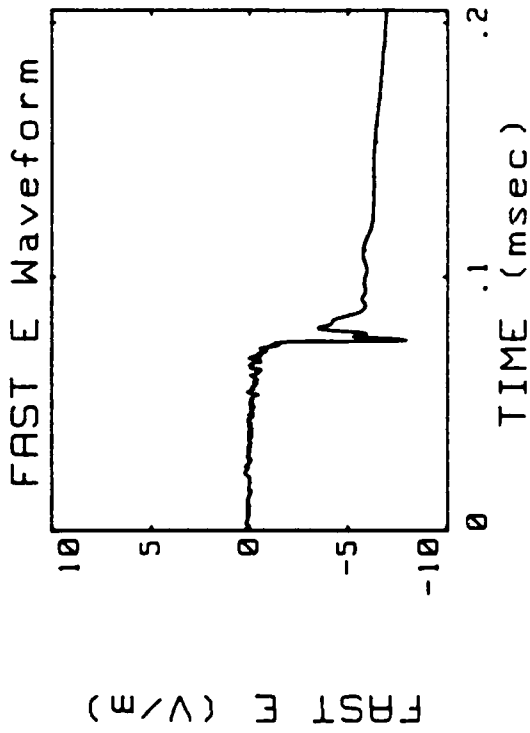


21:21:33.173 19 Aug 1987 (5.16 Km)



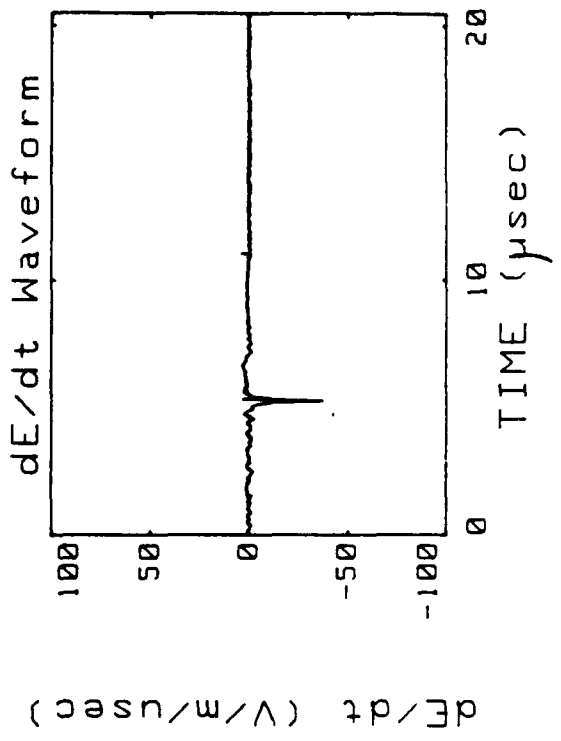
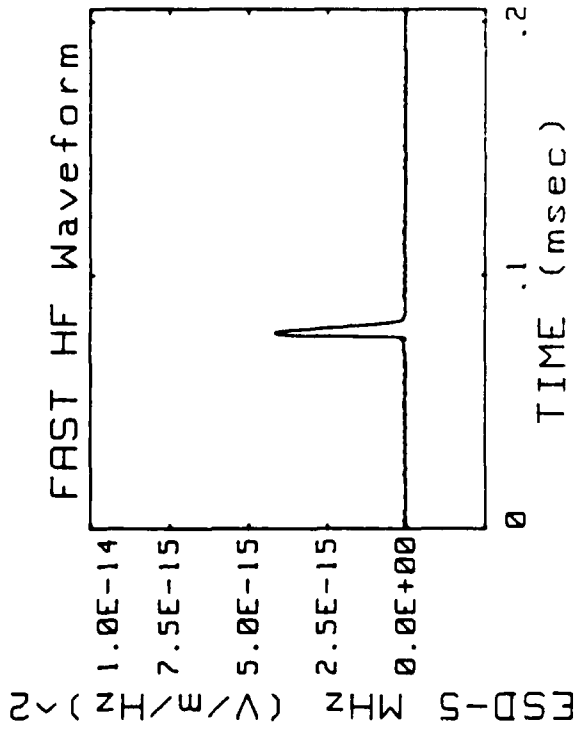
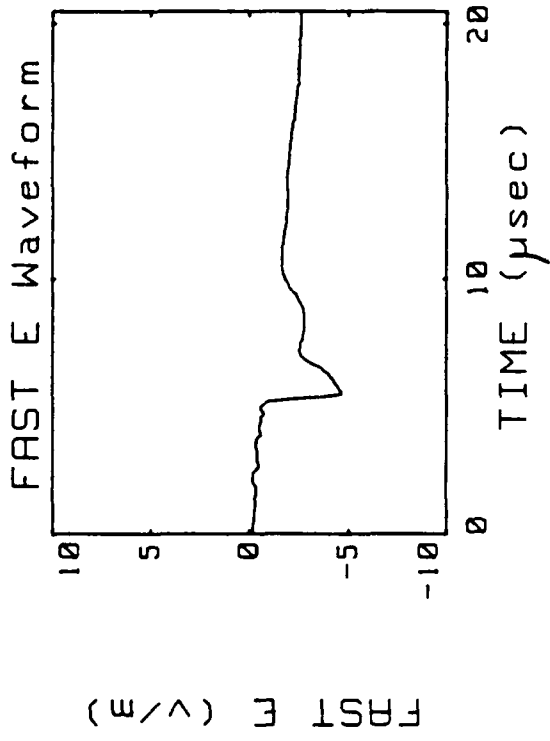
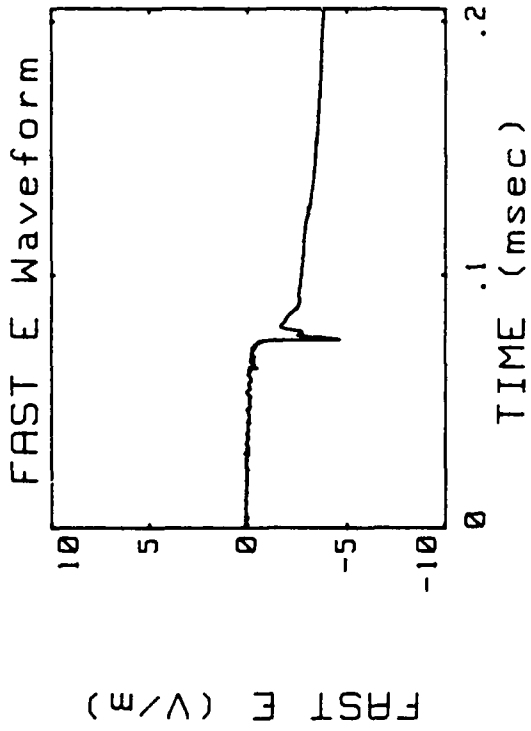
231214058.827 1987

Triggered Stroke (5.16 Km)

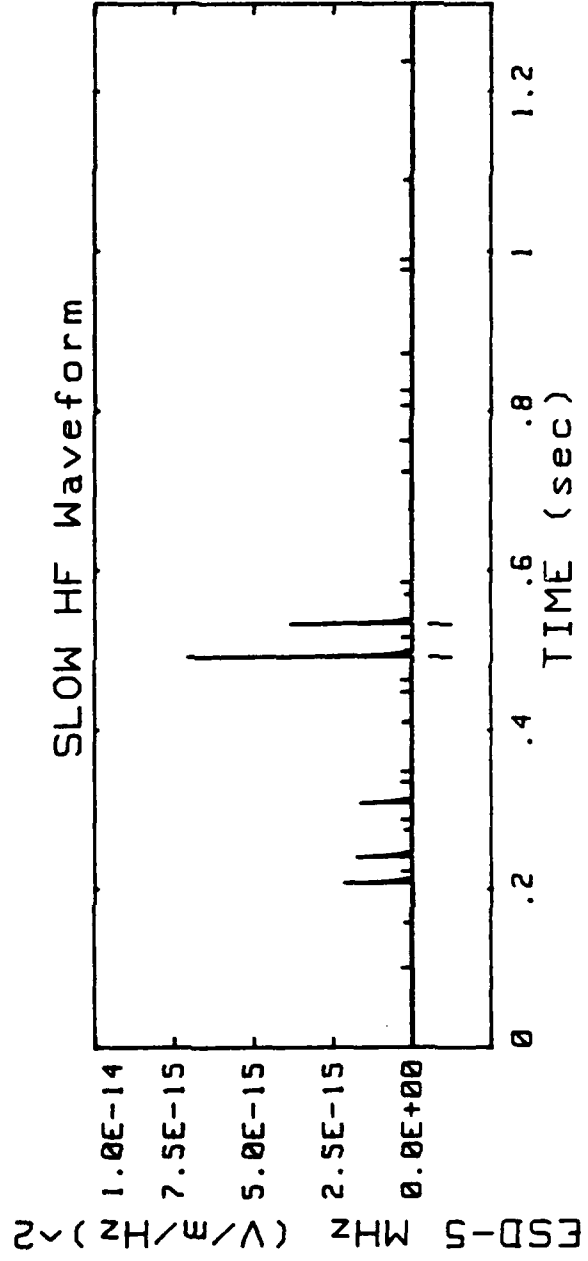
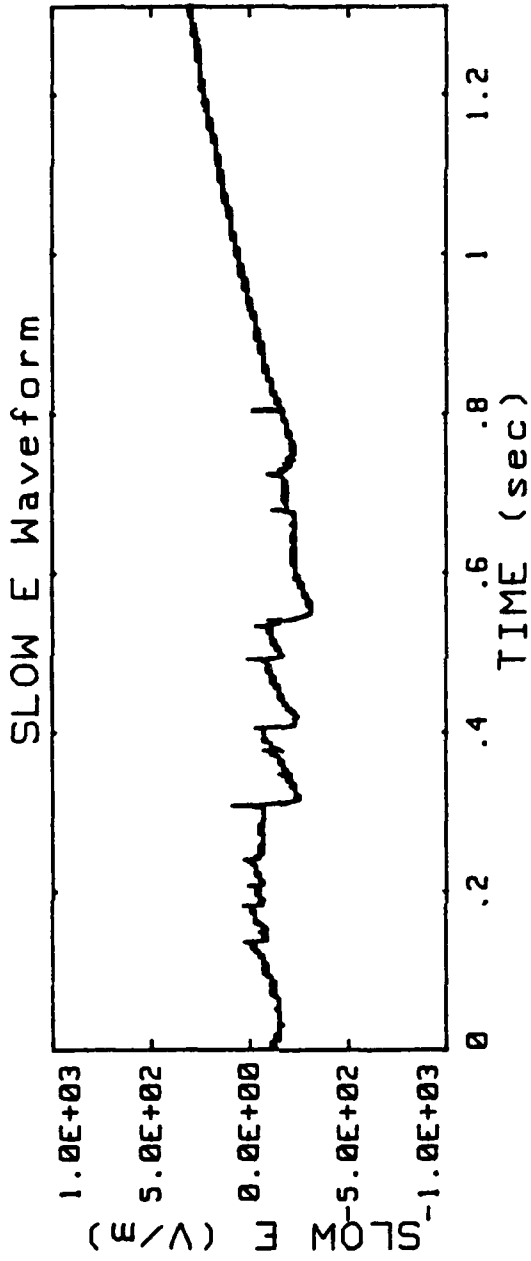


231214058.869 1987

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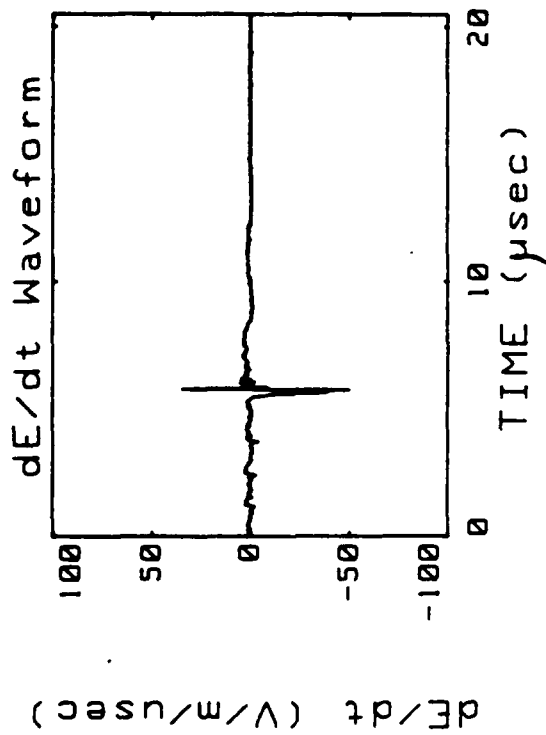
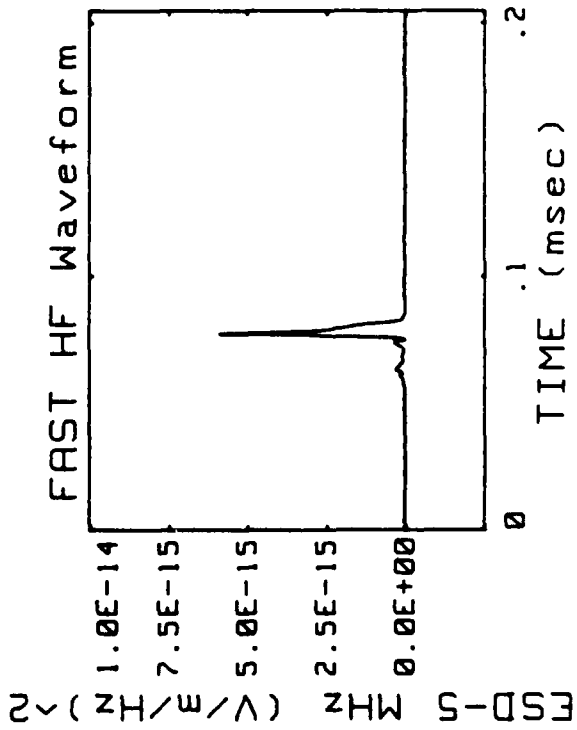
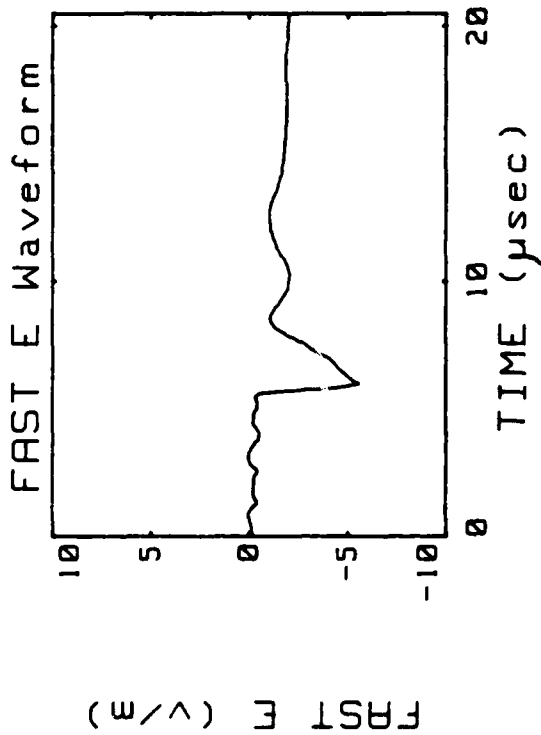
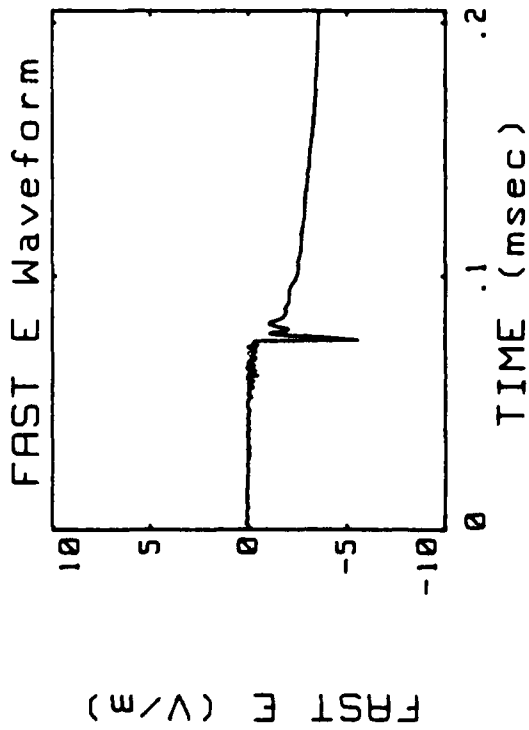


21:40:58.337 19 Aug 1987 (5.16 Km)



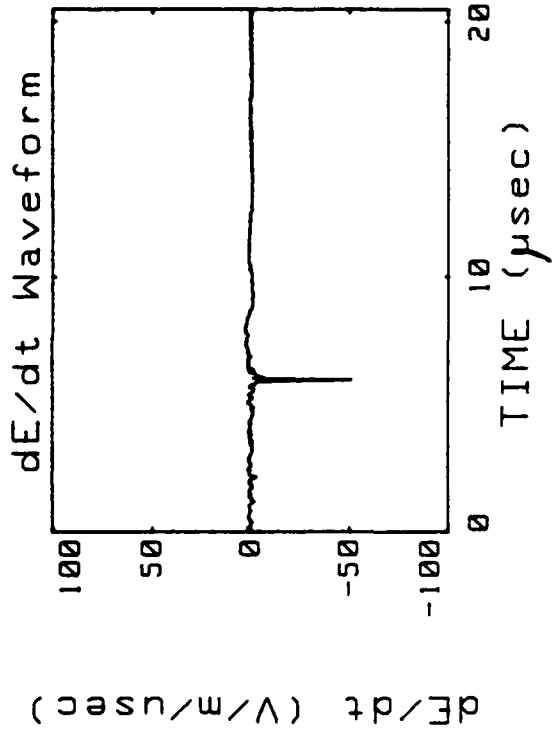
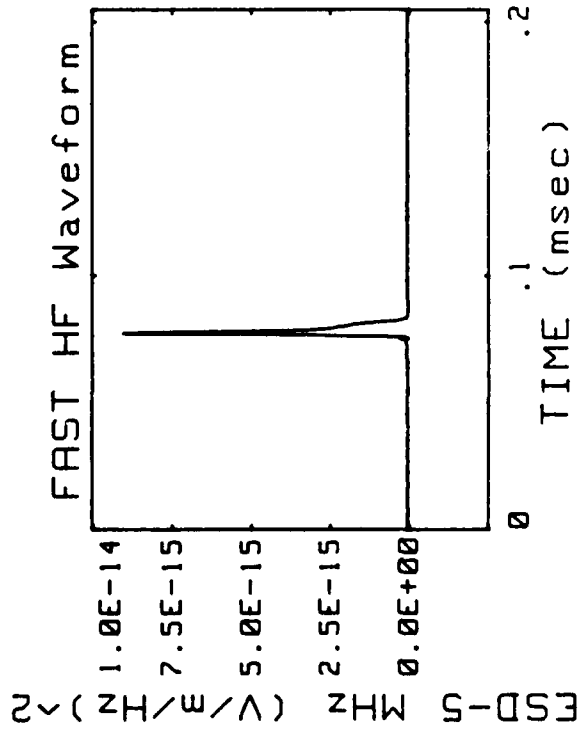
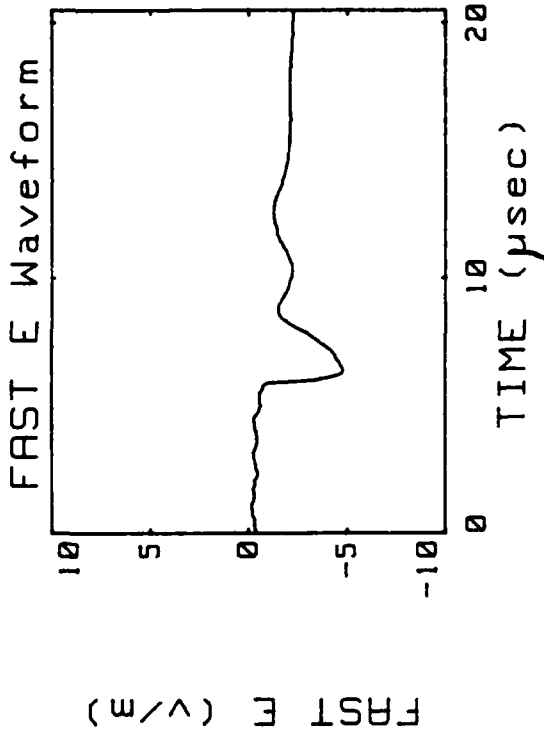
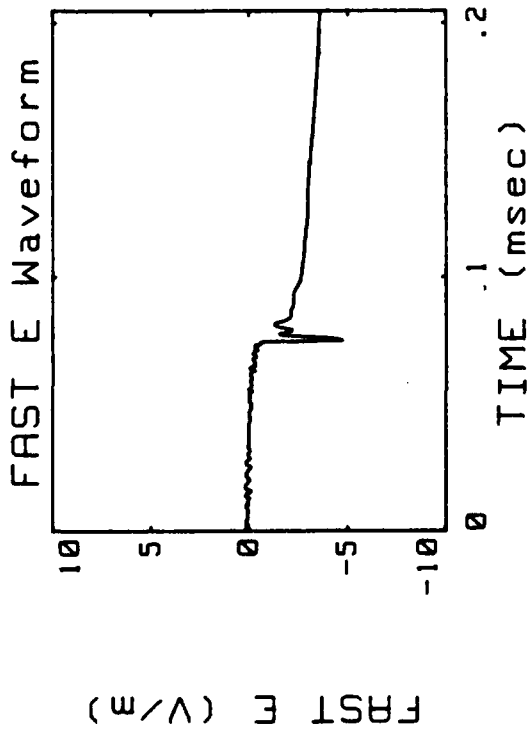
231215835.862 1987

Triggered Stroke (5.16 Km)



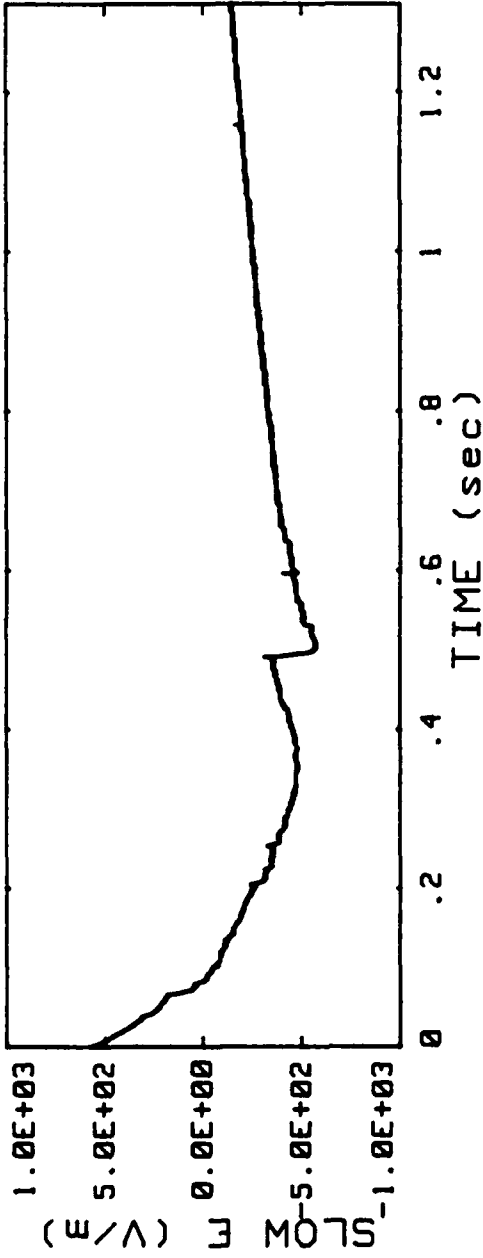
231215835.967 1987

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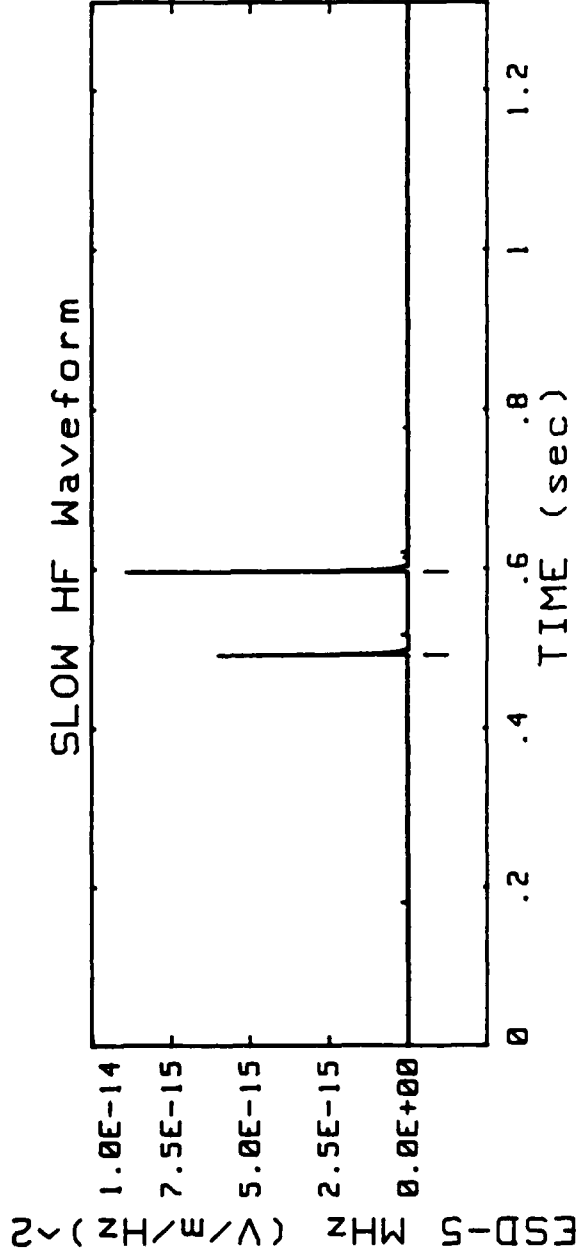


21:58:35.372 19 Aug 1987 (5.16 Km)

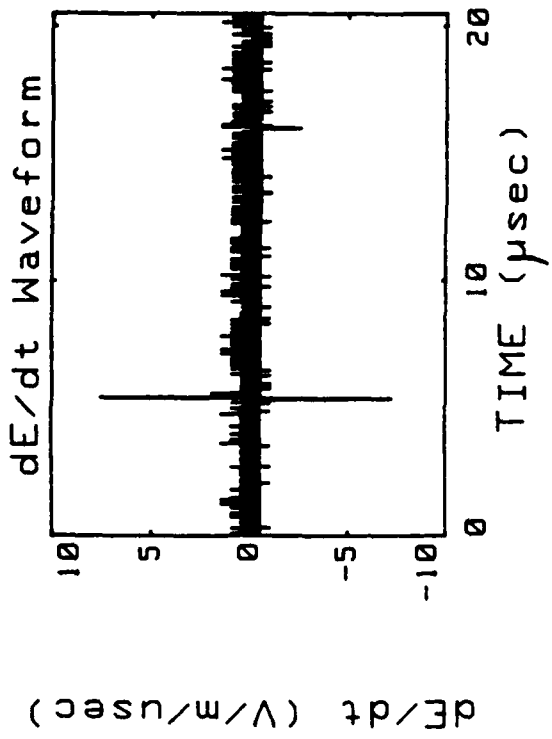
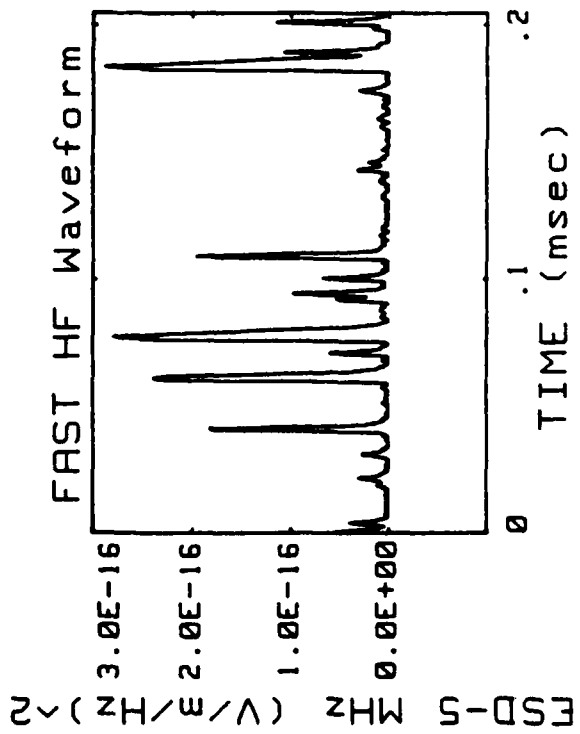
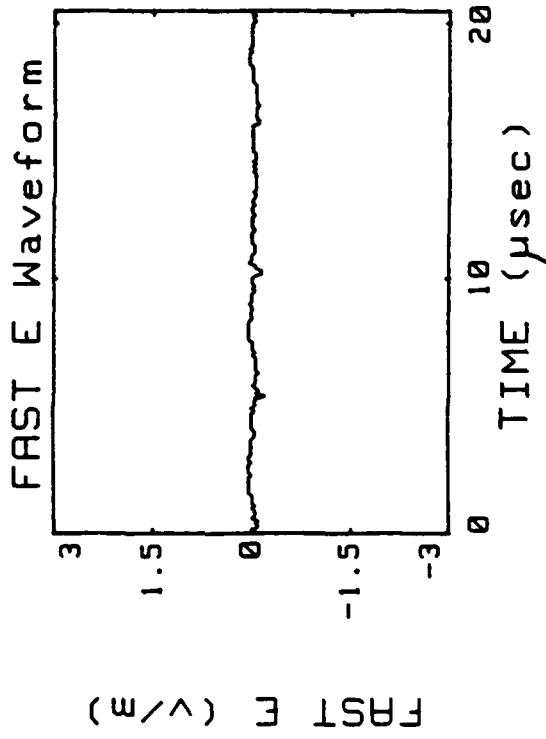
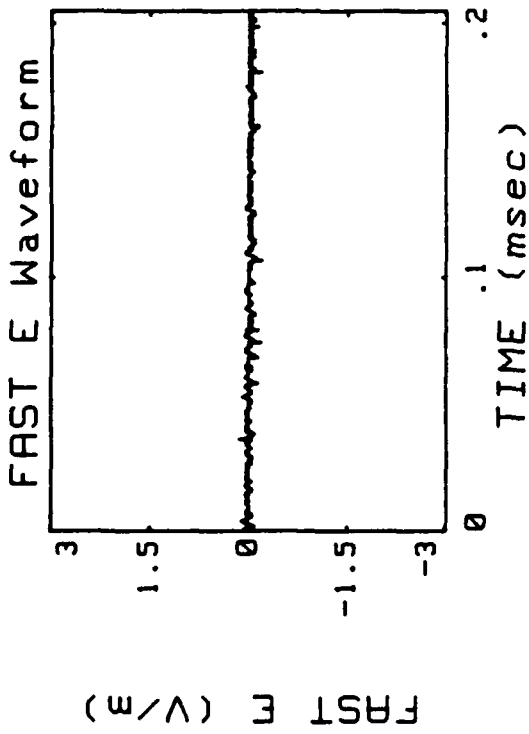
SLOW E Waveform



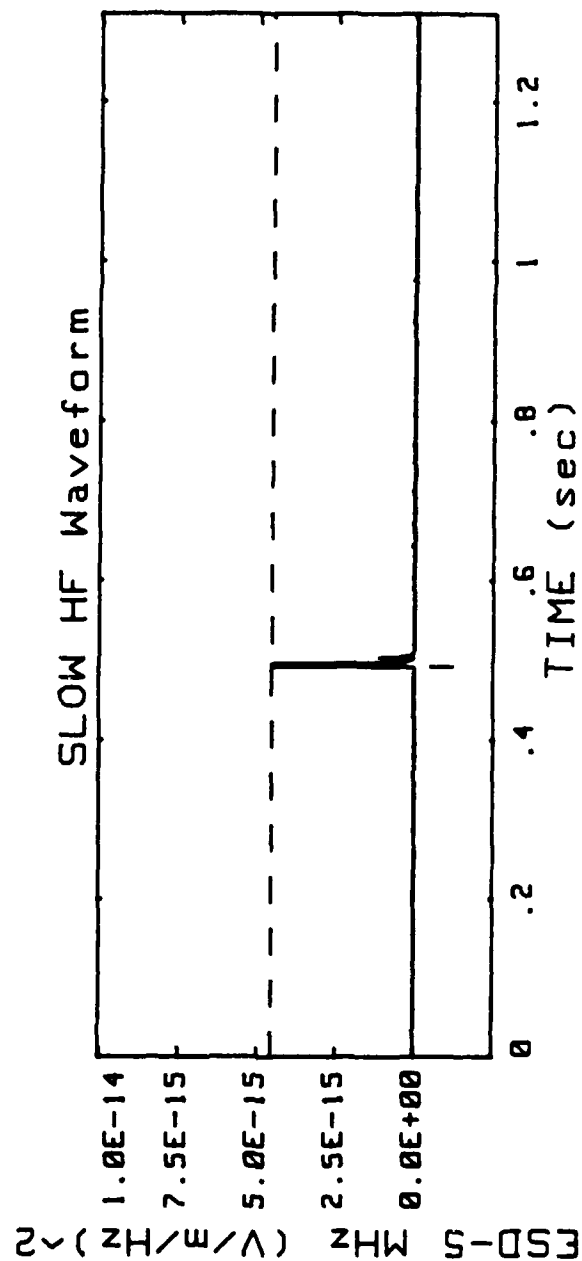
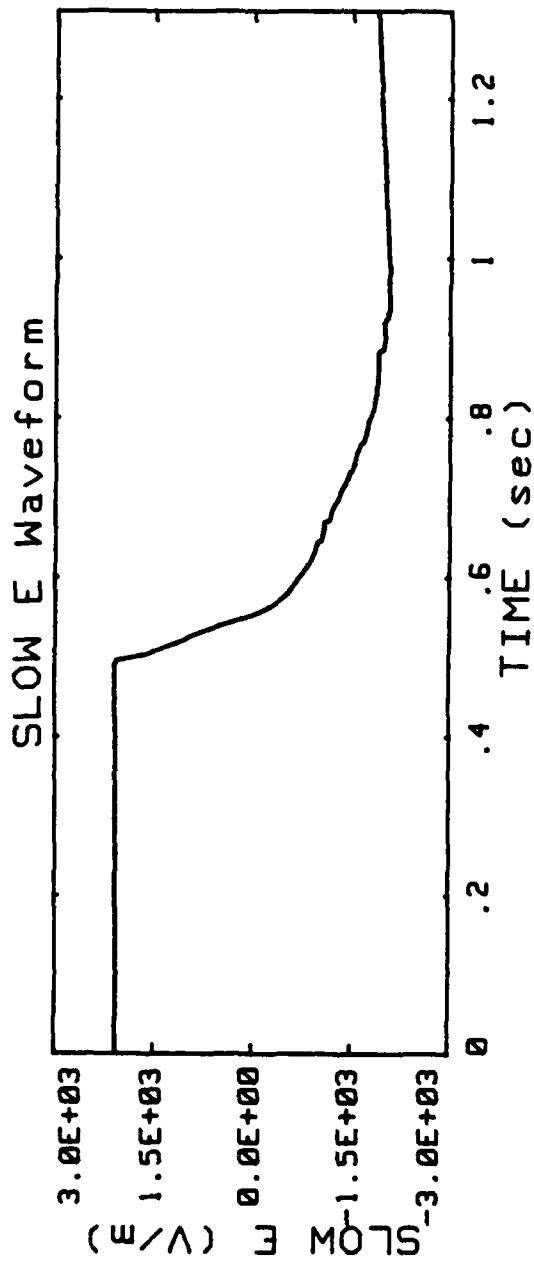
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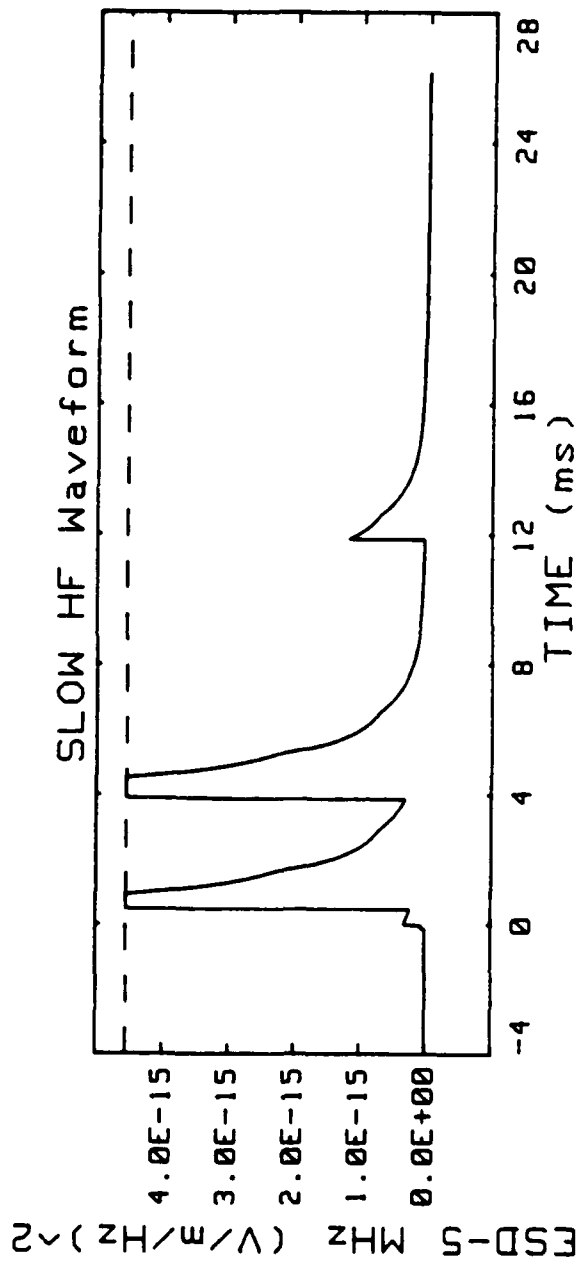
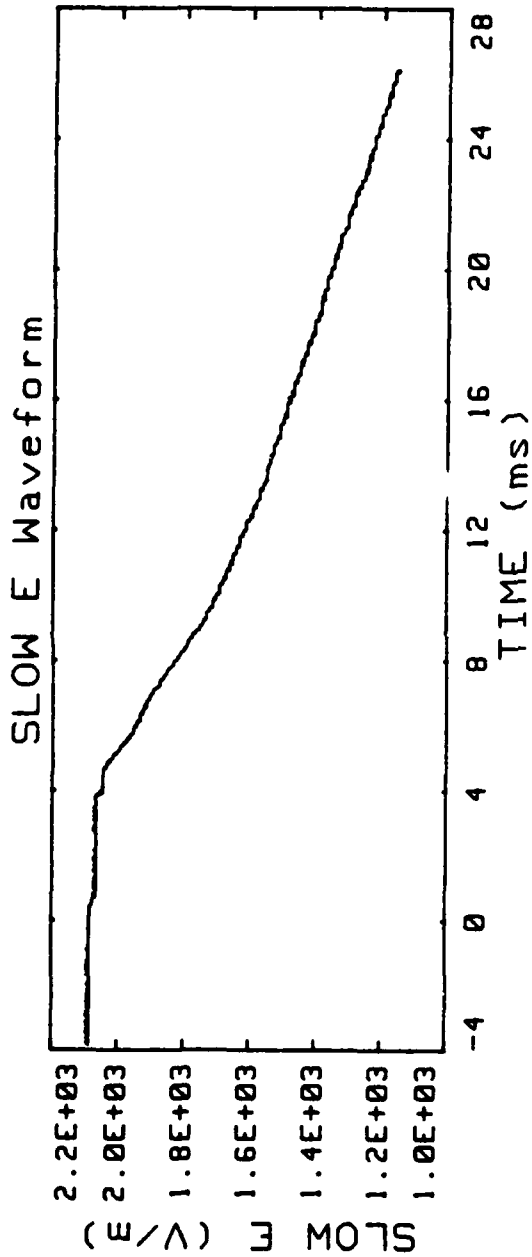
231221139.772 1987 Leader in Altitude Flash (5.16 Km)



22:11:39.282 19 Aug 1987 (5.16 Km)



22:11:39.772 19 Aug 1987 (5.16 Km)



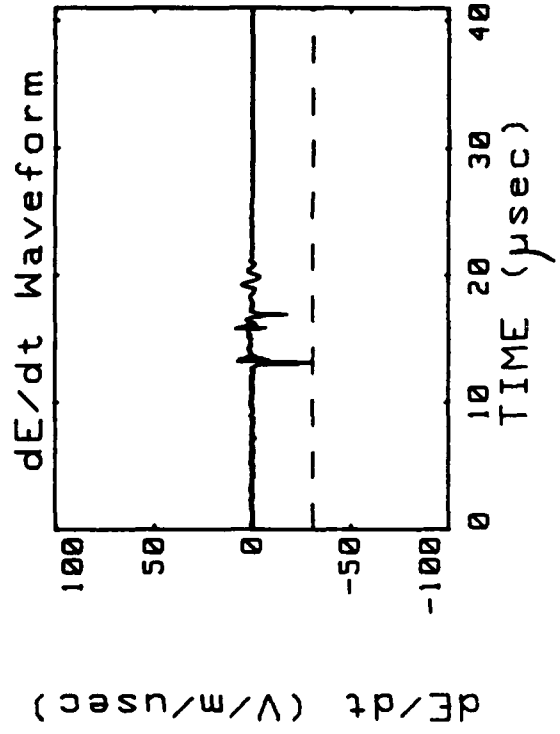
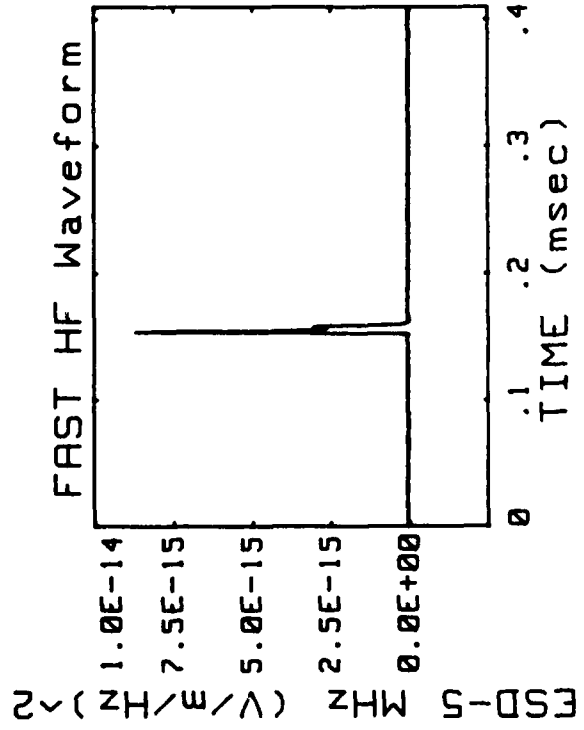
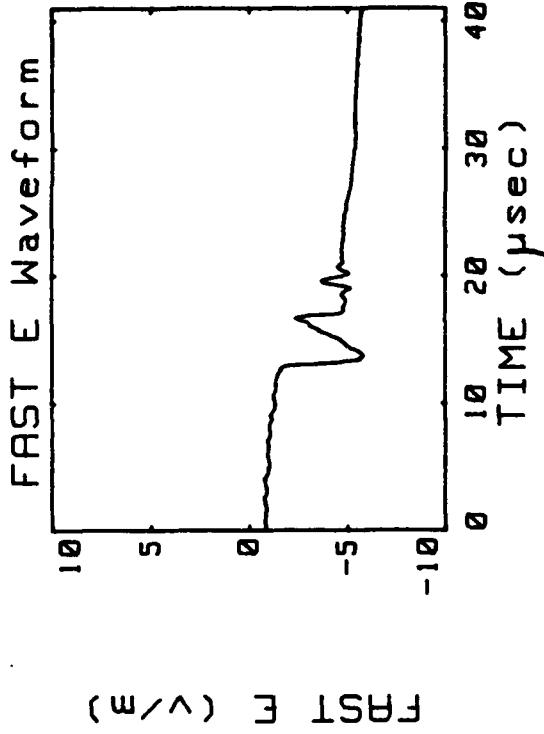
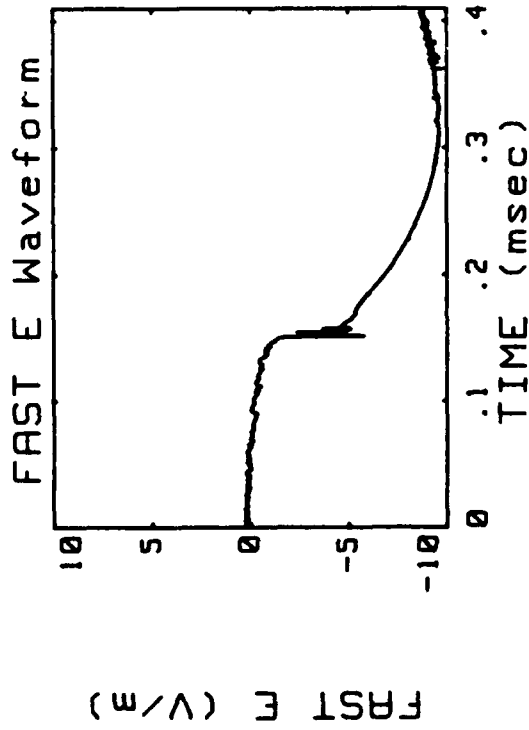
Appendix B

Over-Land Plots

4096 Data

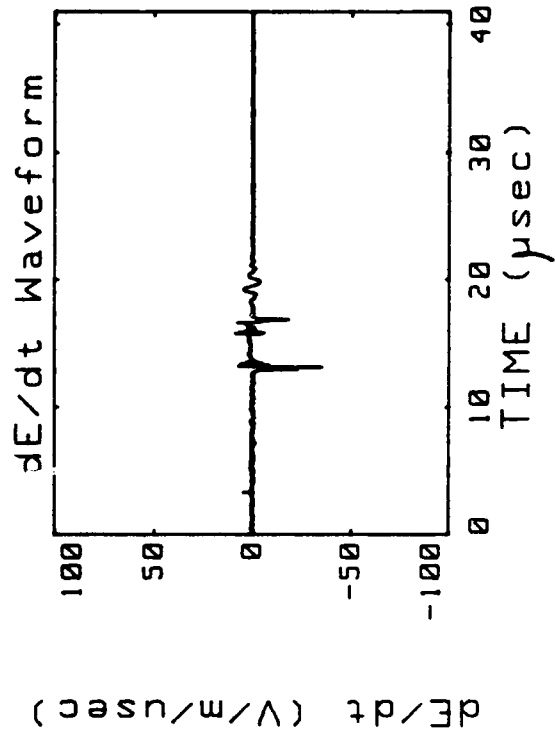
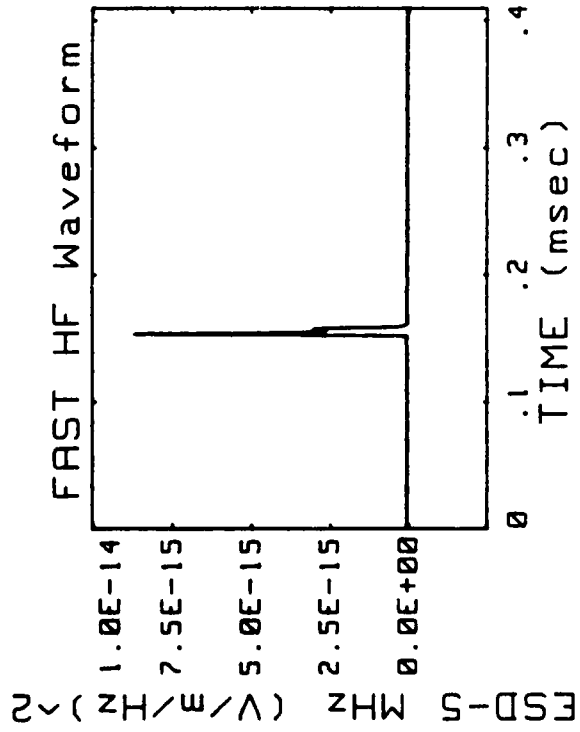
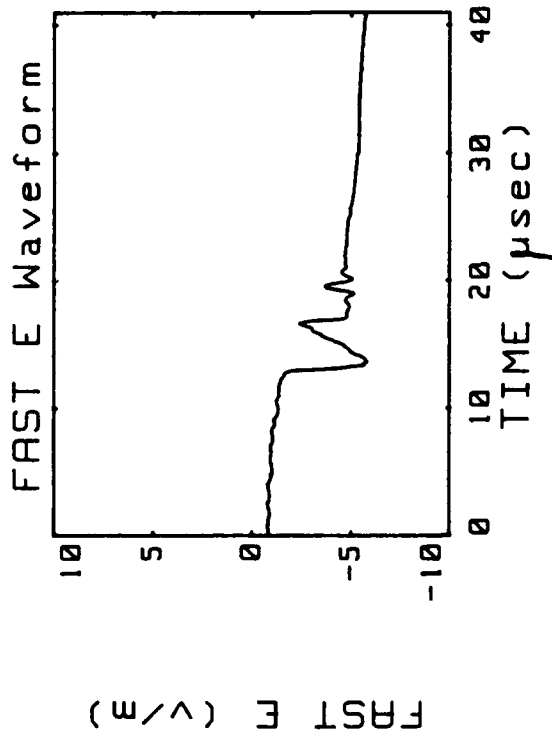
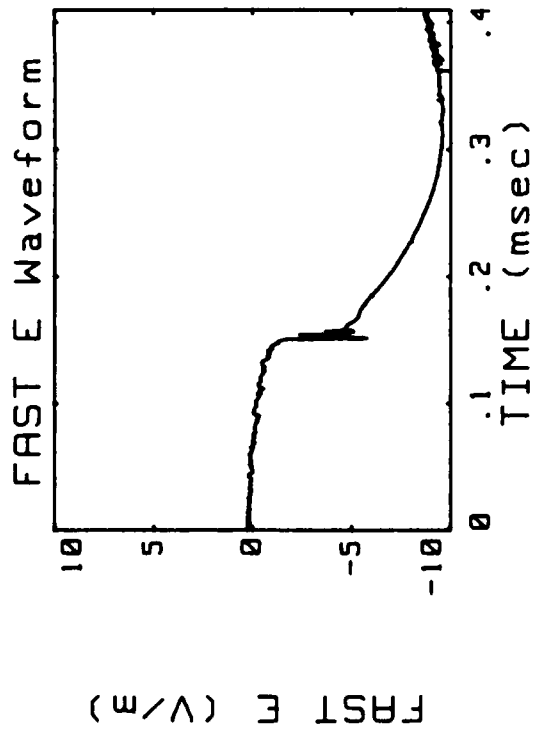
211234232.579 1987

Triggered Stroke (5.16 Km)



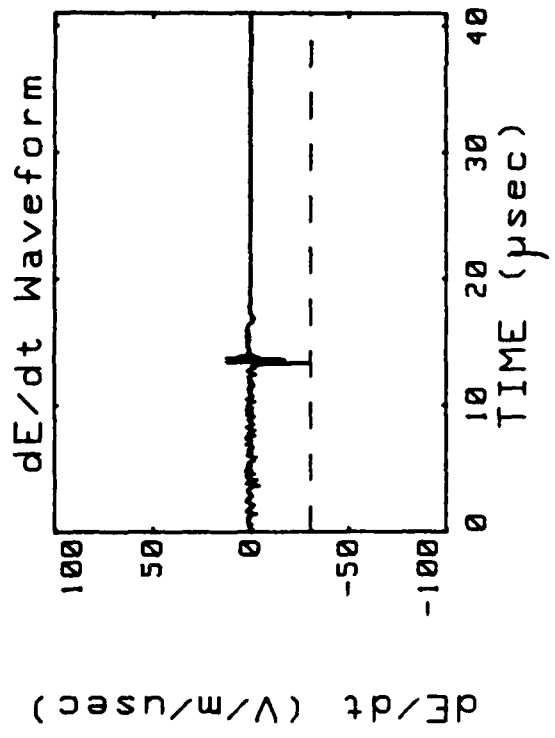
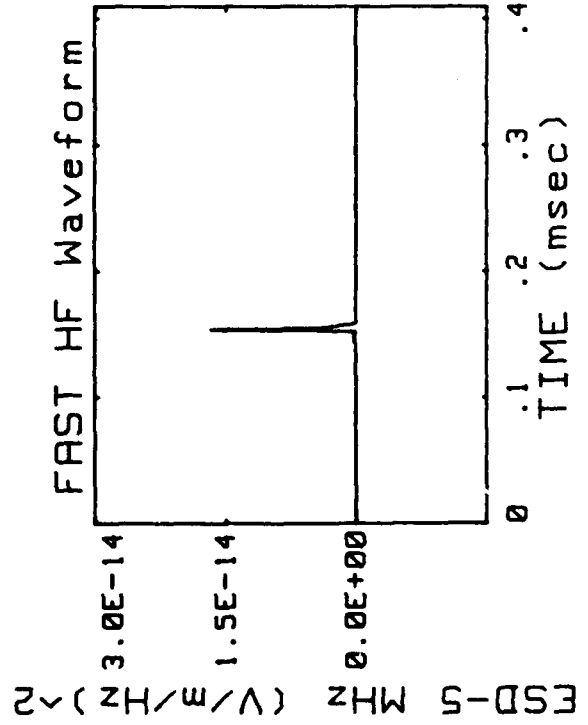
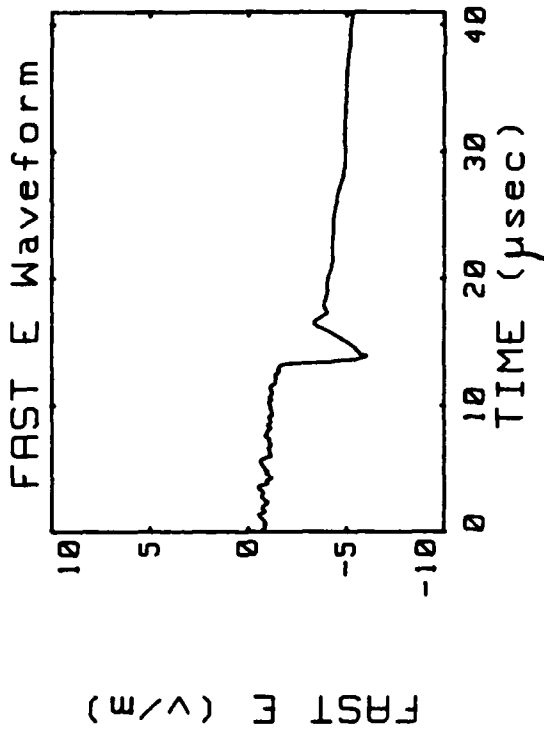
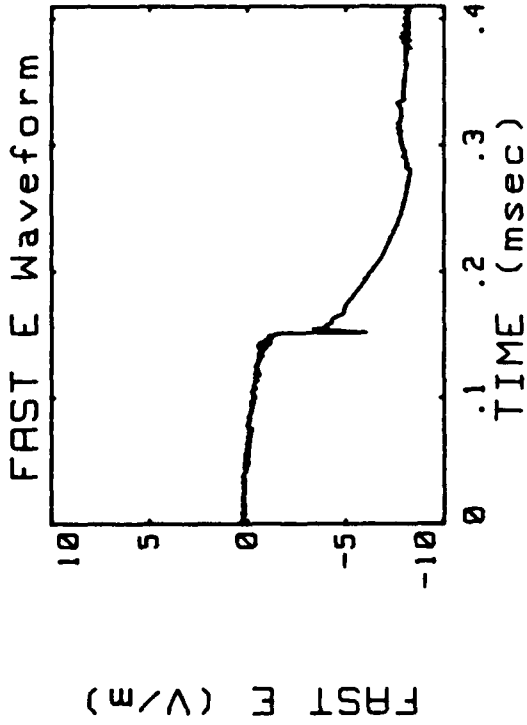
211234232.579 1987

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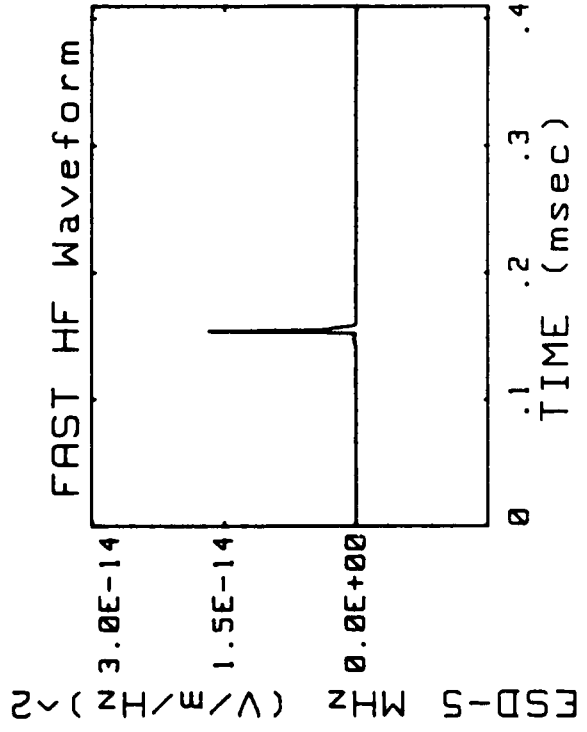
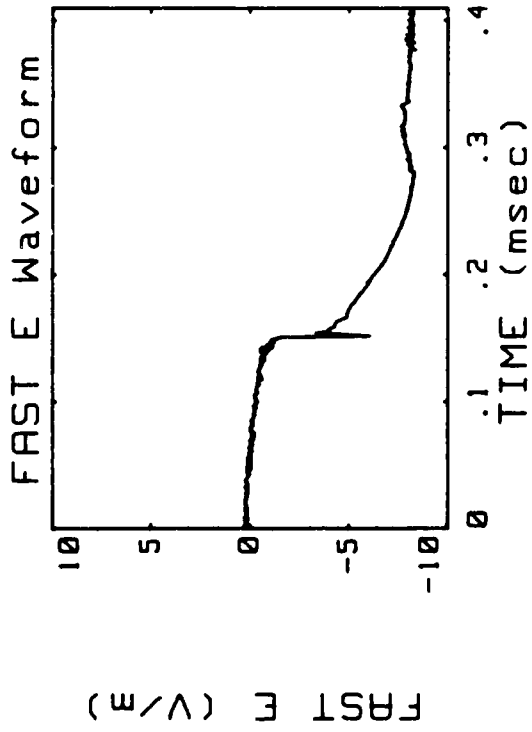


211234232.623 1987

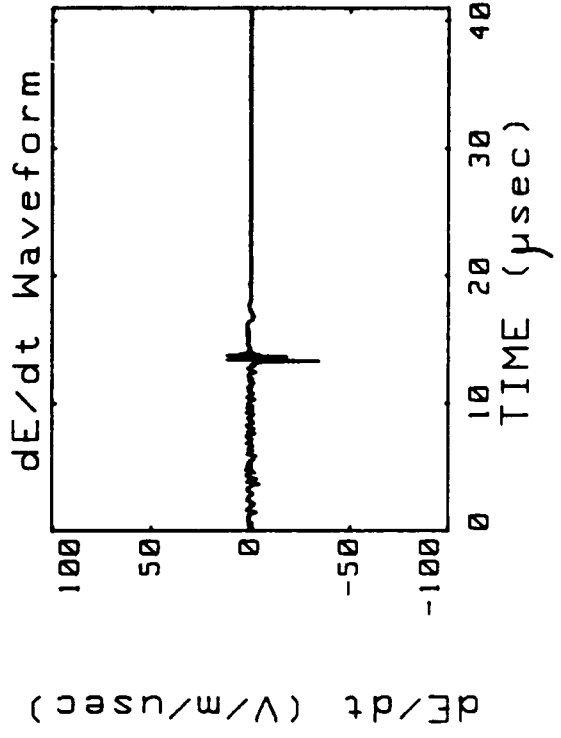
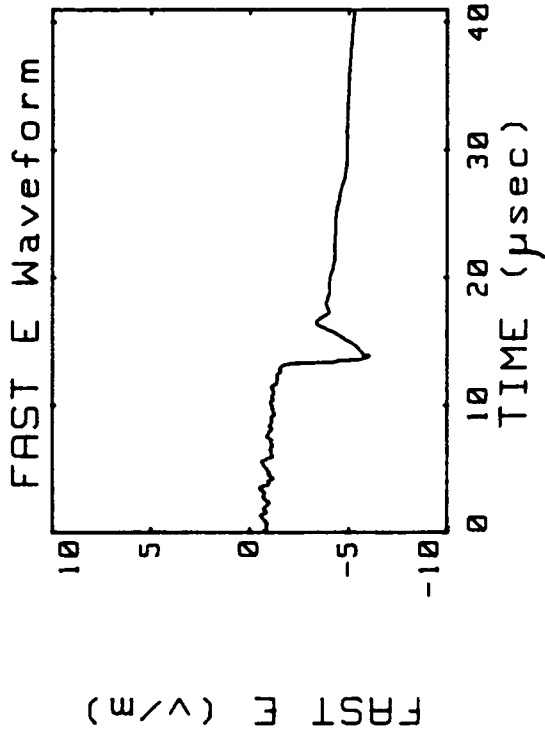
Triggered Stroke (5.16 Km)



211234232.623 1987

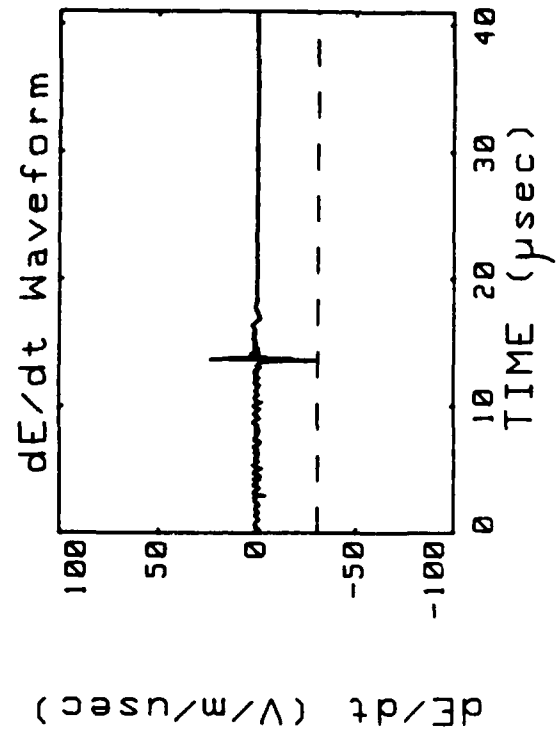
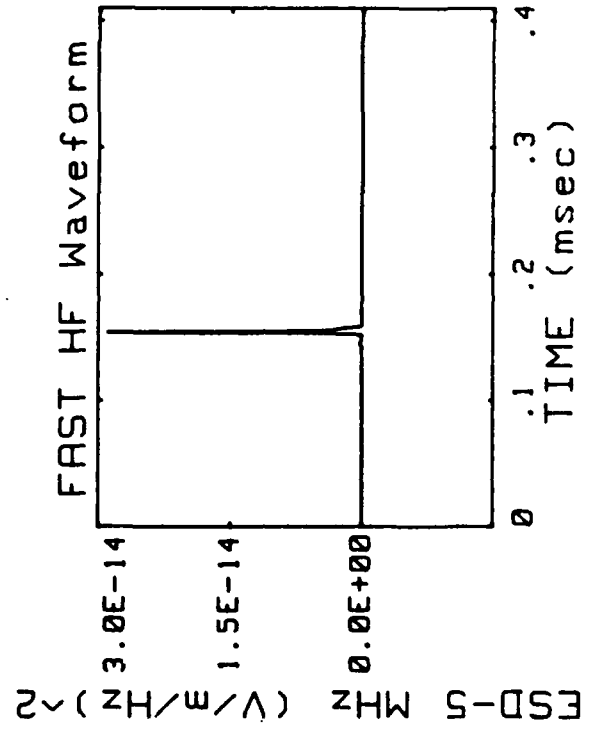
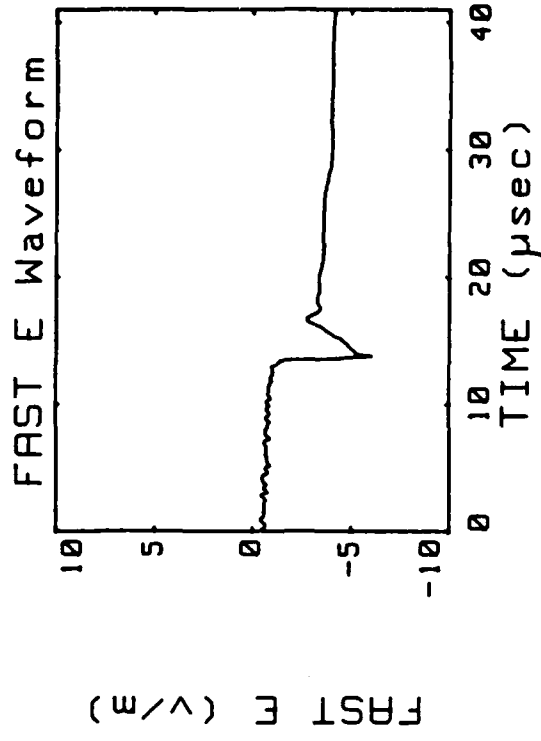
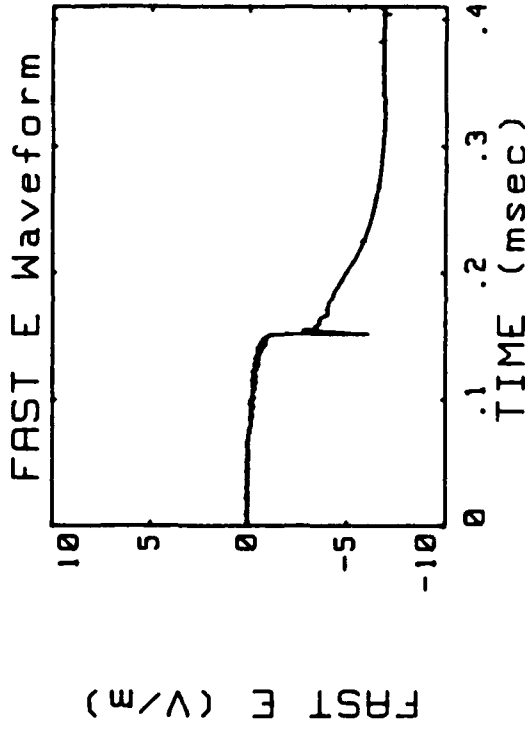


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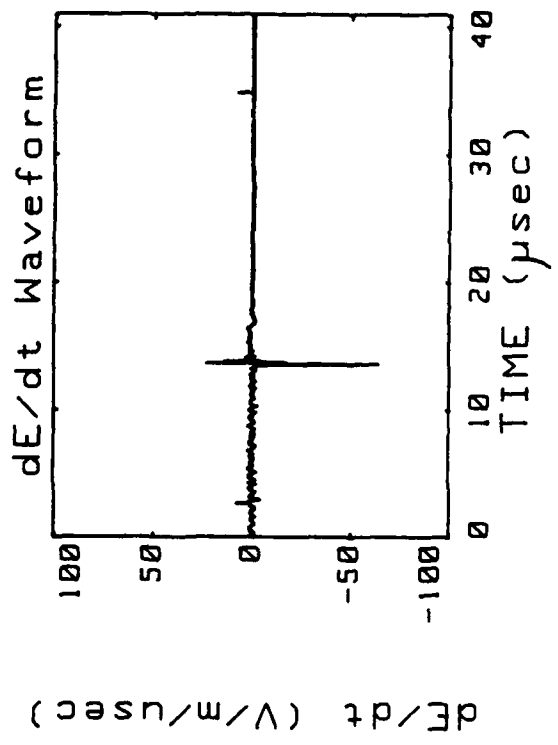
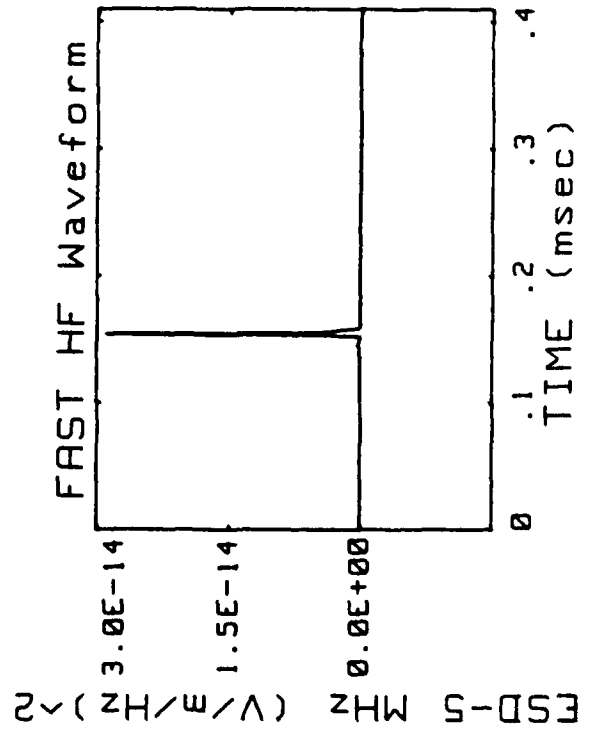
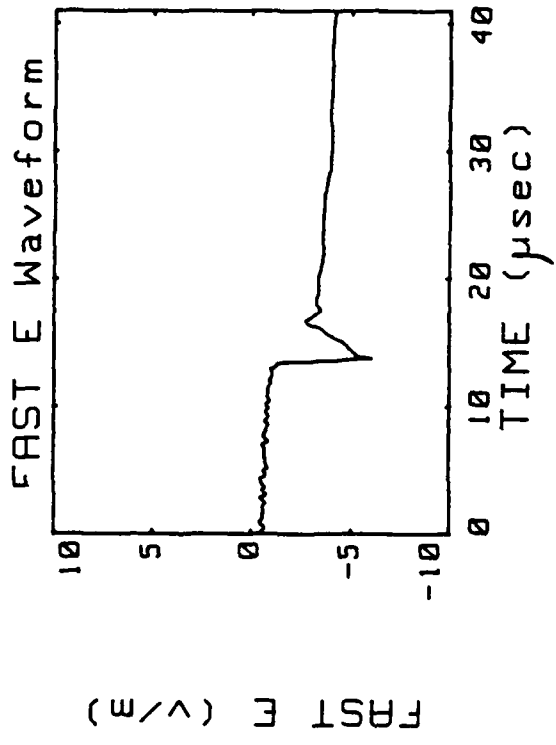
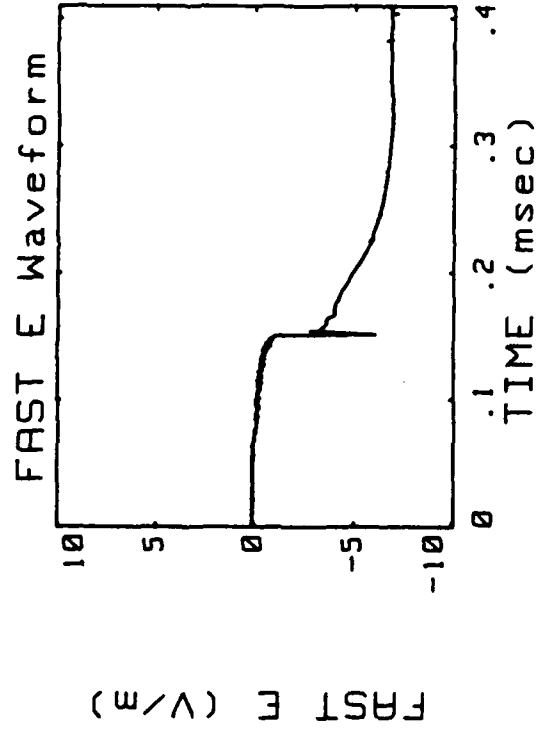
211234232.674 1987

Triggered Stroke (5.16 Km)



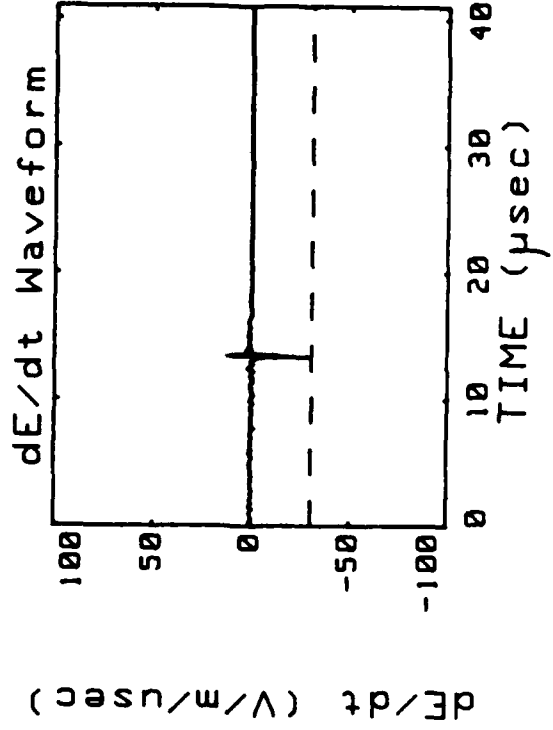
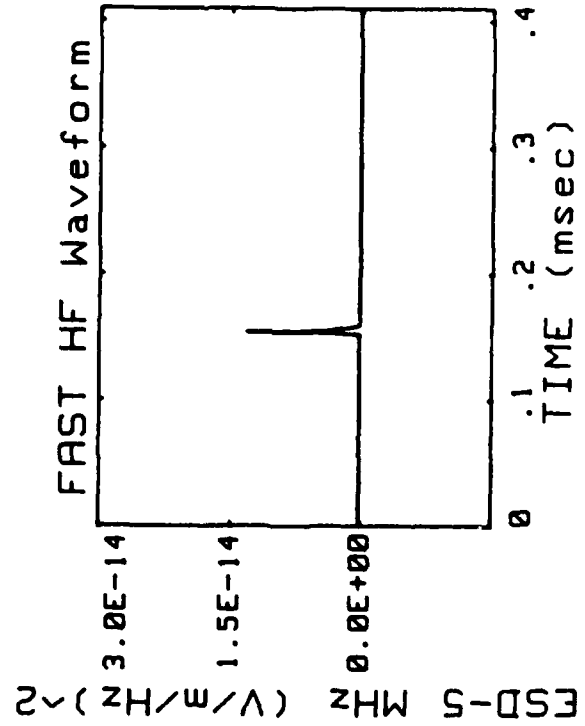
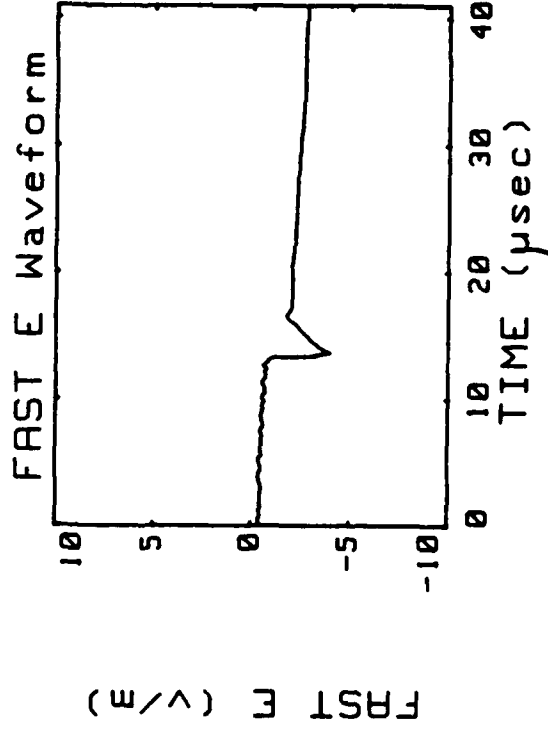
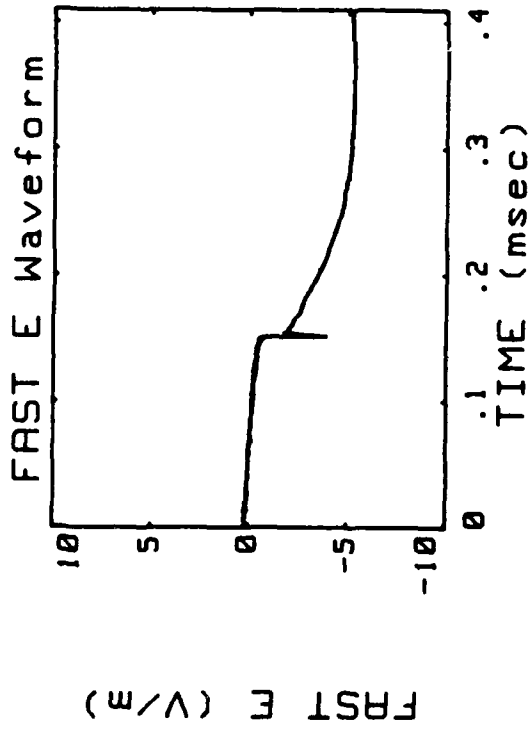
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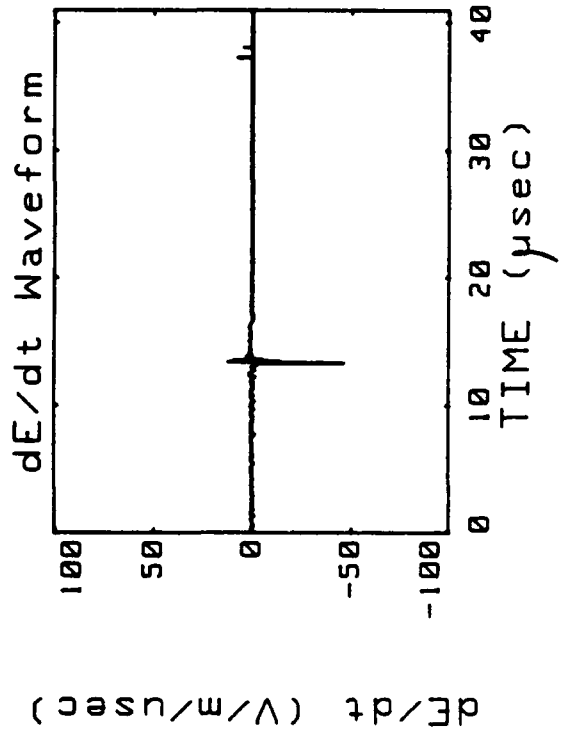
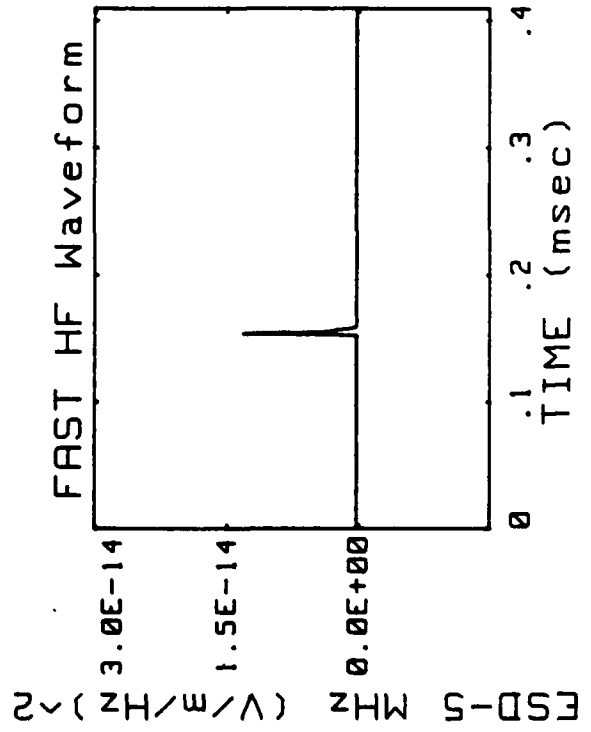
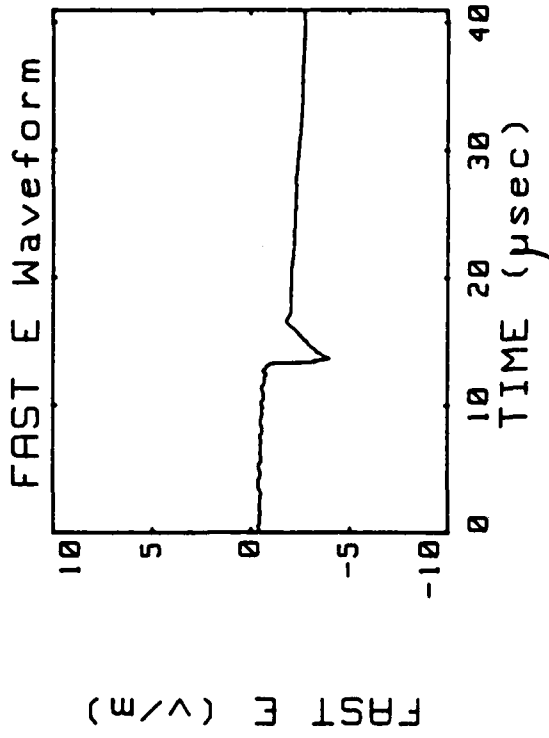
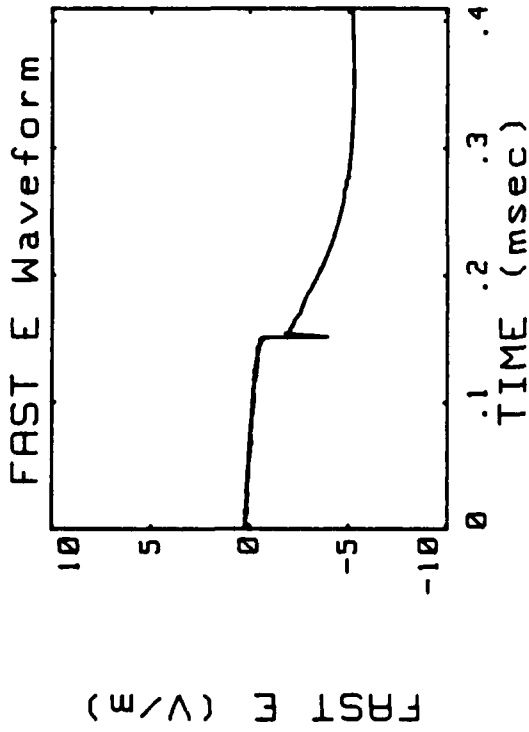
211234232.802 1987

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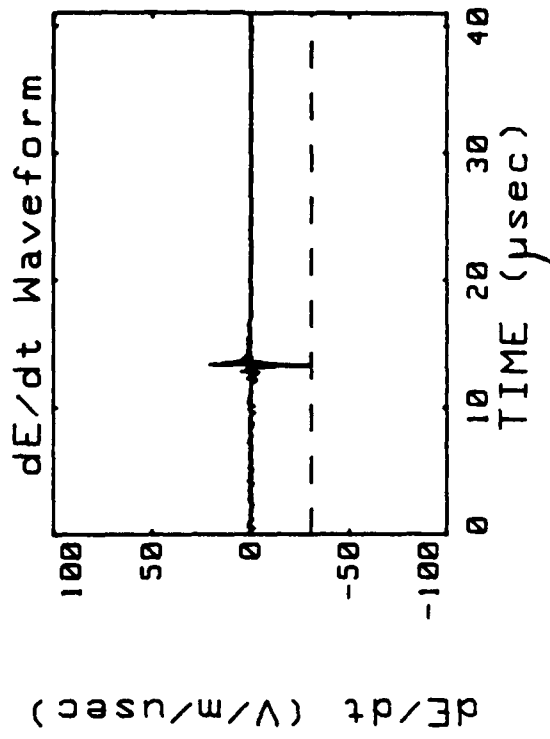
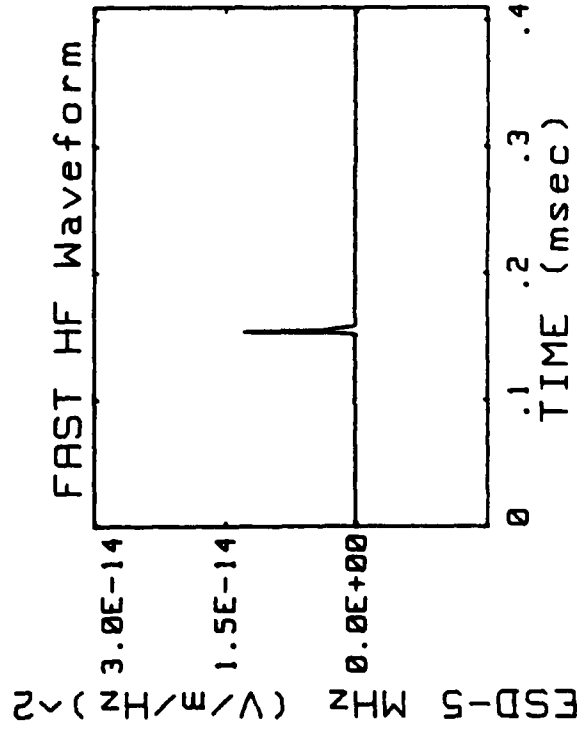
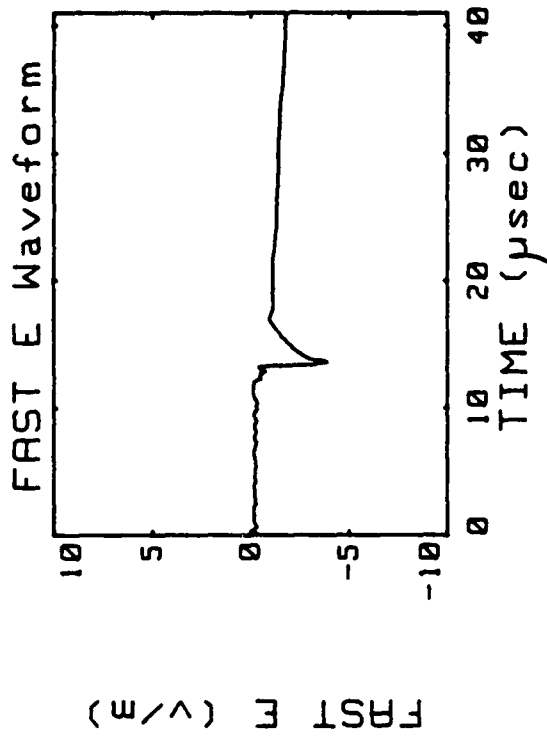
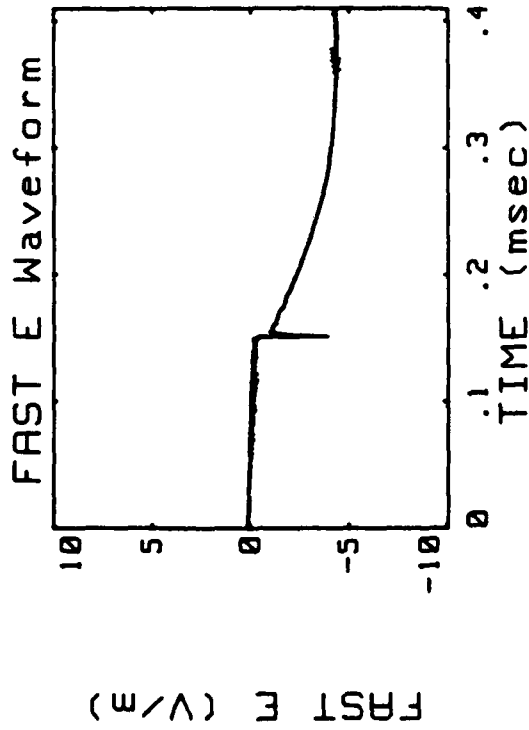
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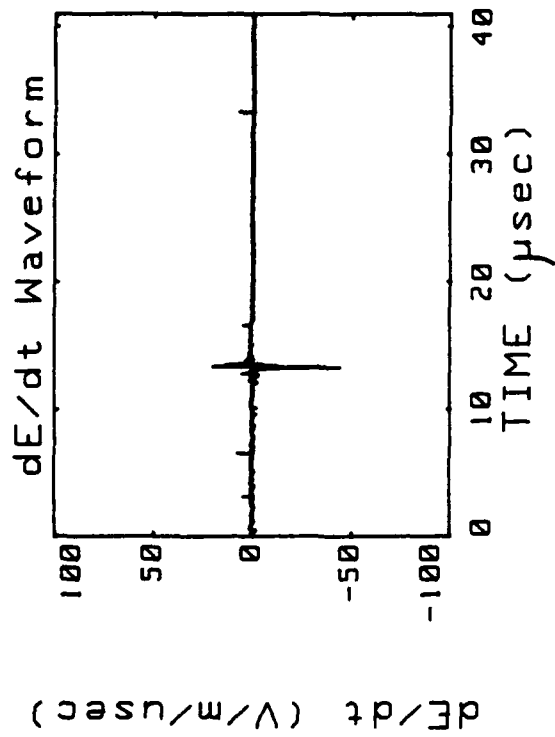
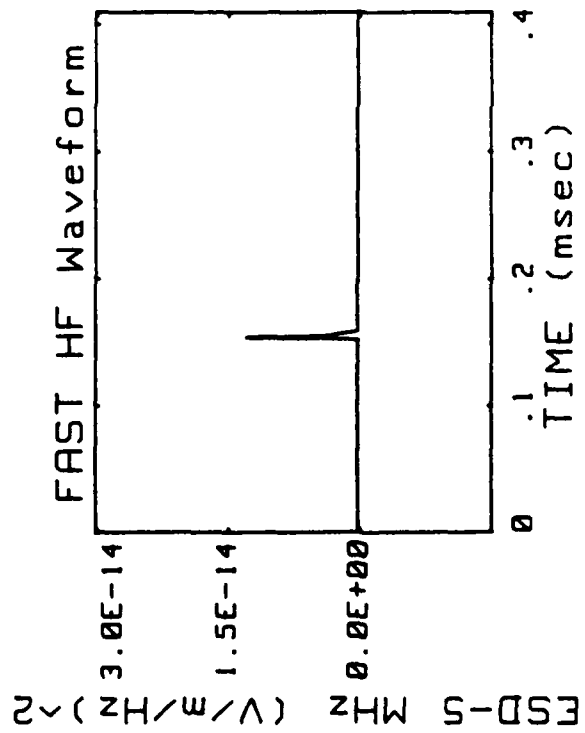
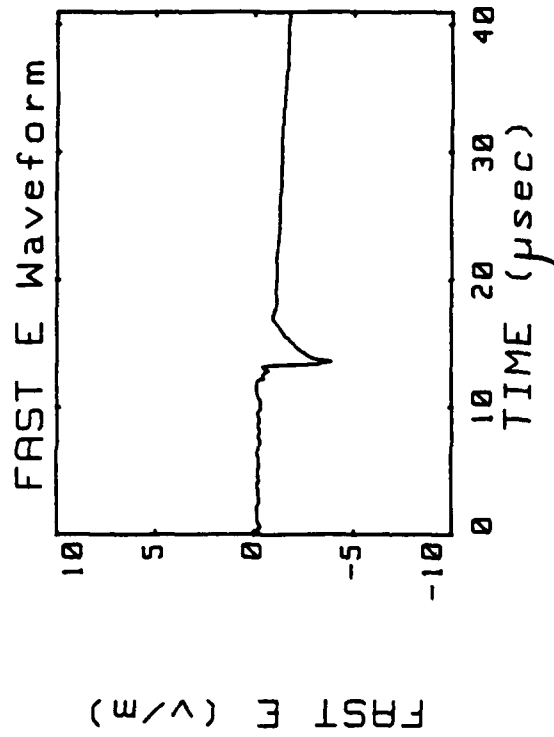
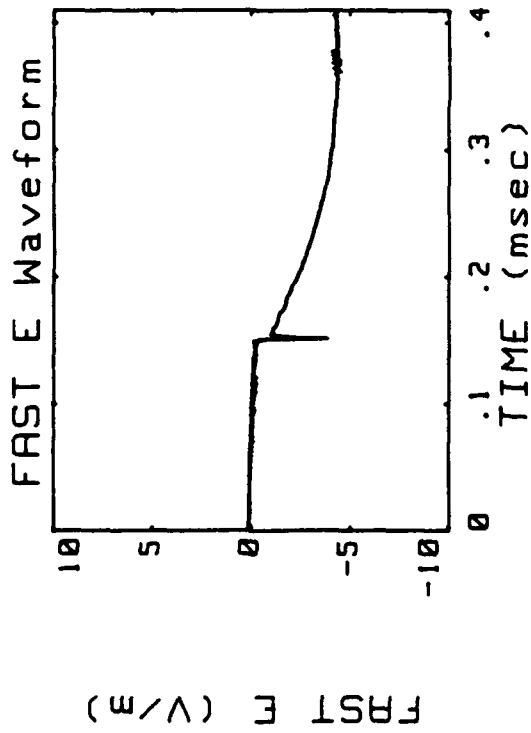
211234232.839 1987

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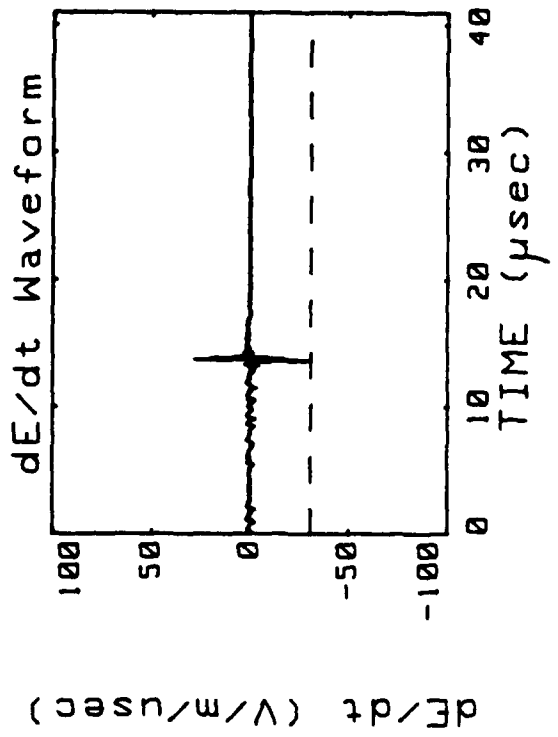
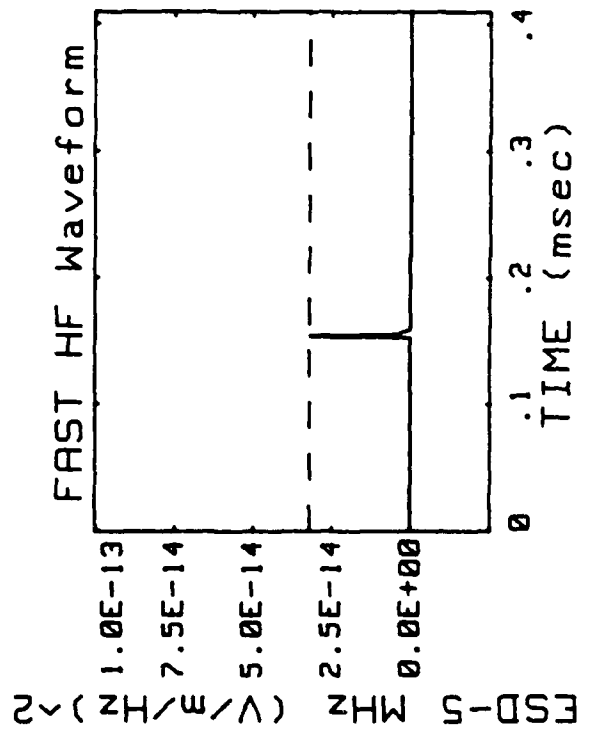
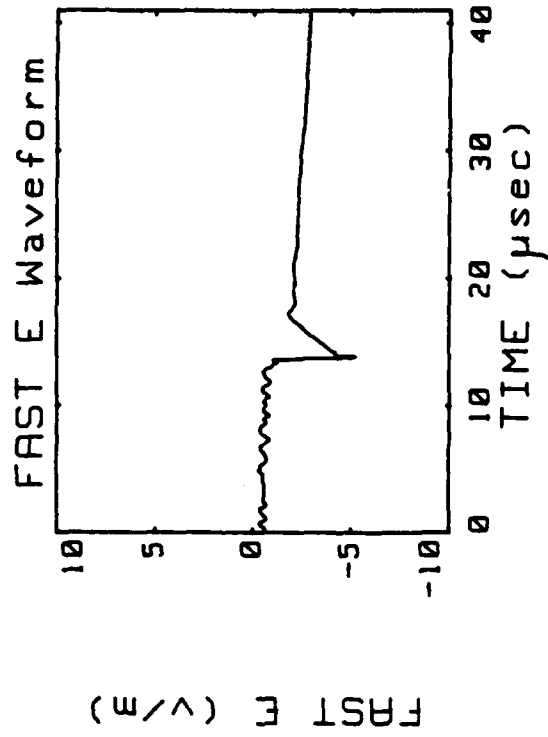
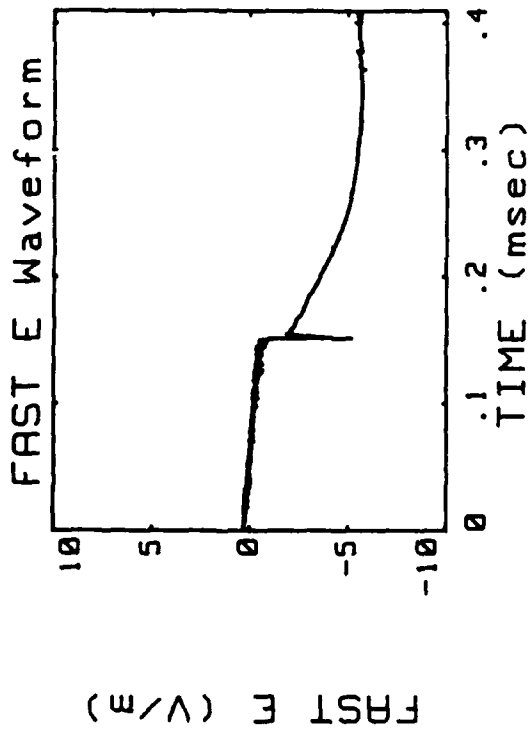
211234232.839 1987

Triggered Stroke (5.16 Km)



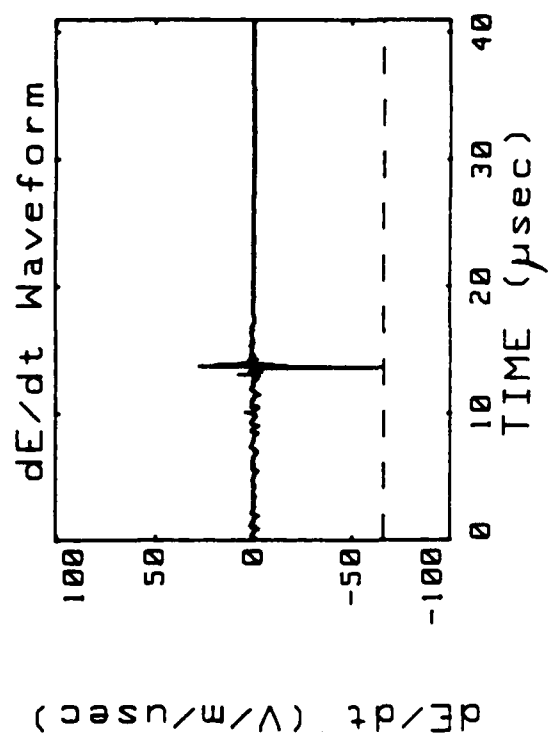
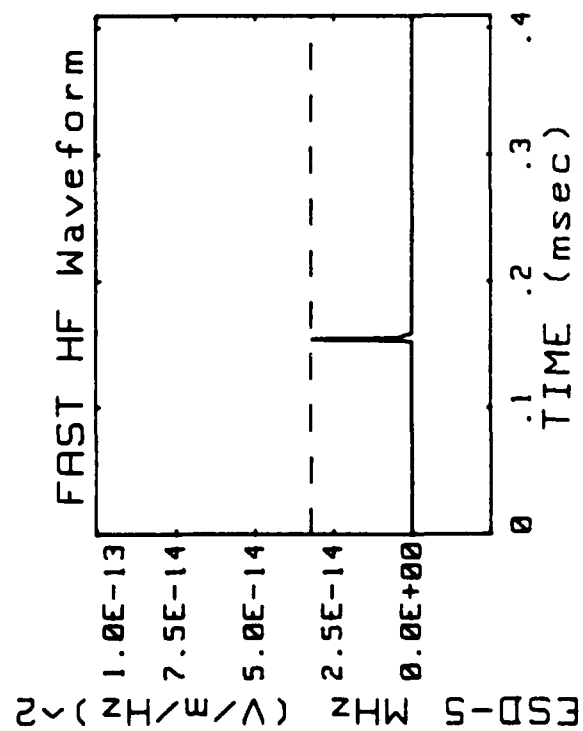
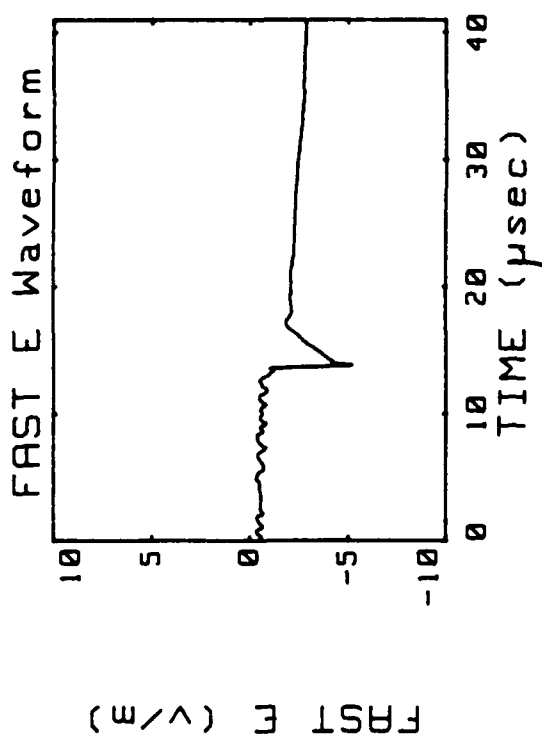
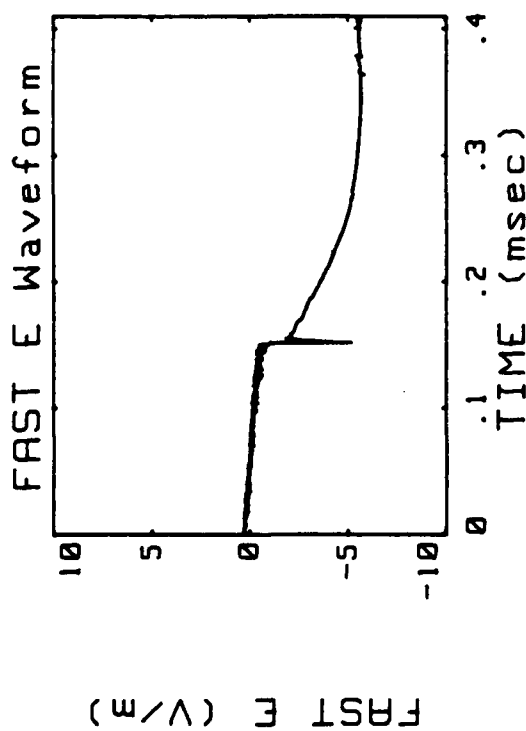
211234233.130 1987

Triggered Stroke (5.16 Km)



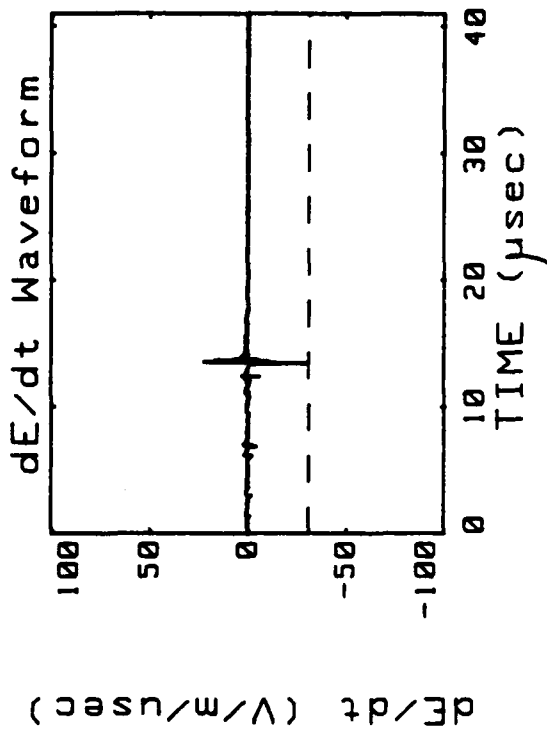
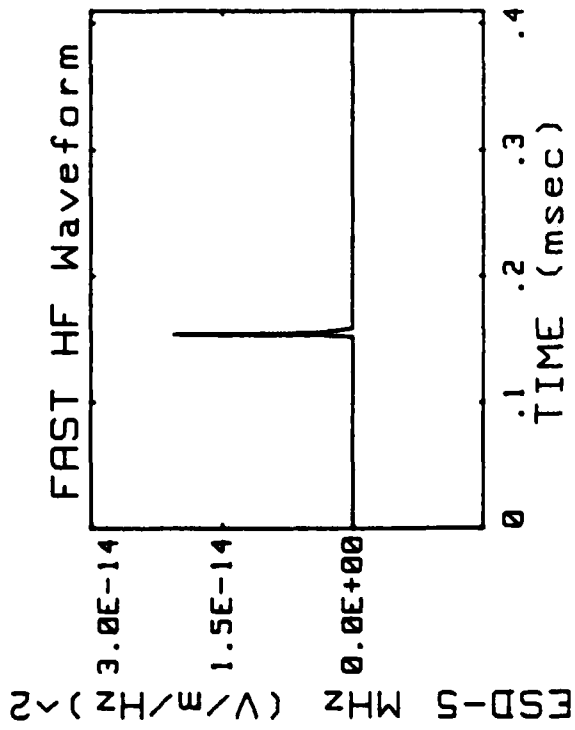
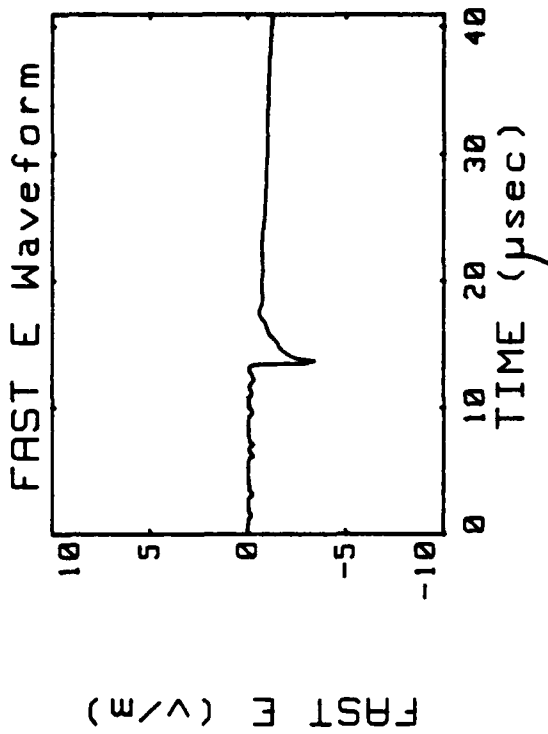
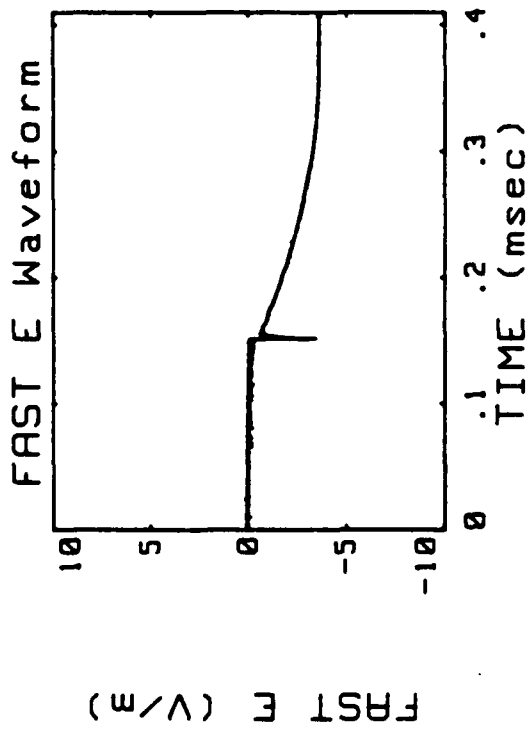
211234233.130 1987

Triggered Stroke (5.16 Km)



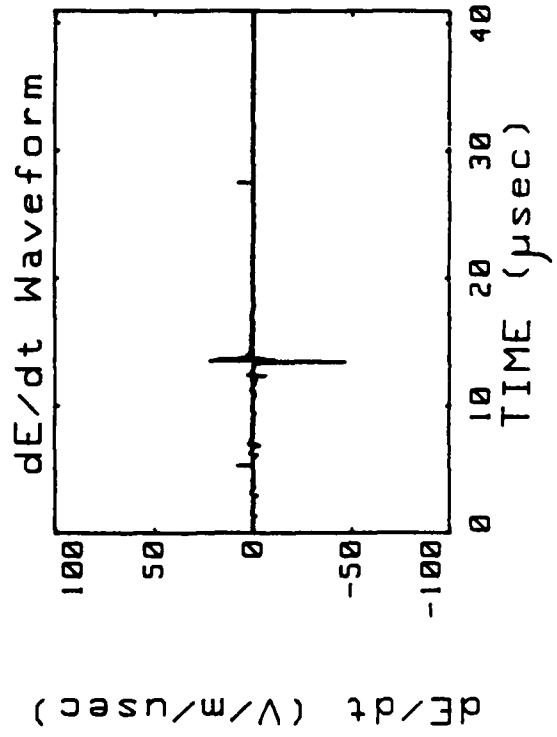
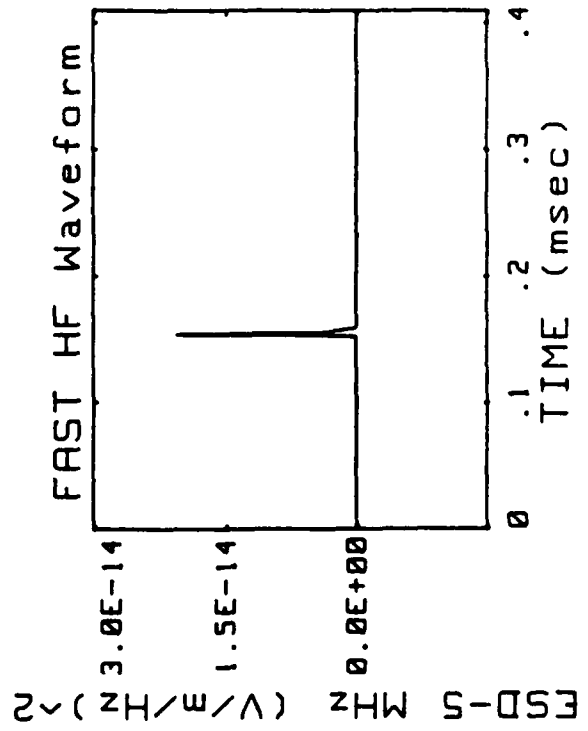
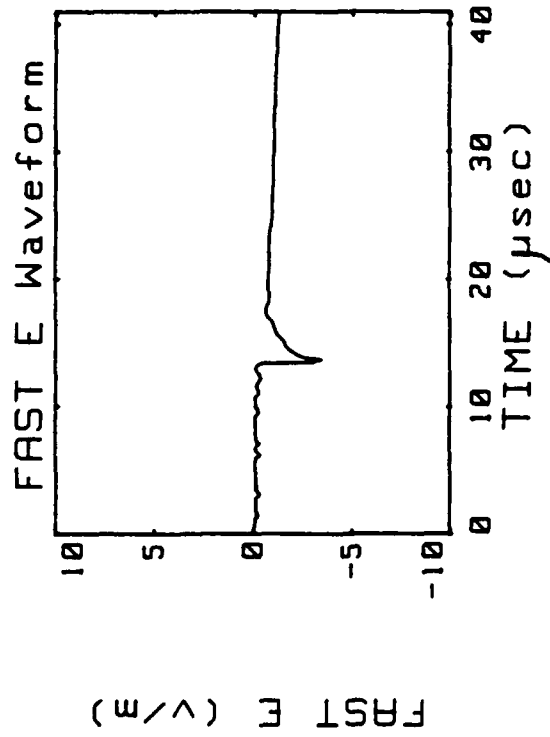
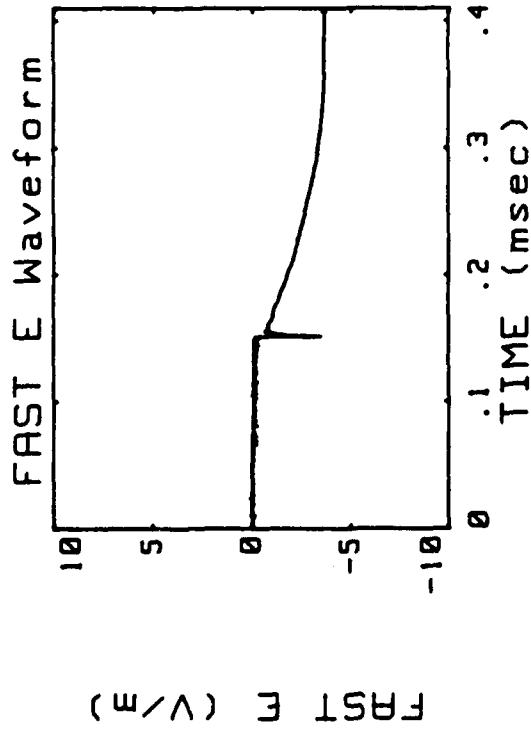
211234233.213 1987

Triggered Stroke (5.16 Km)



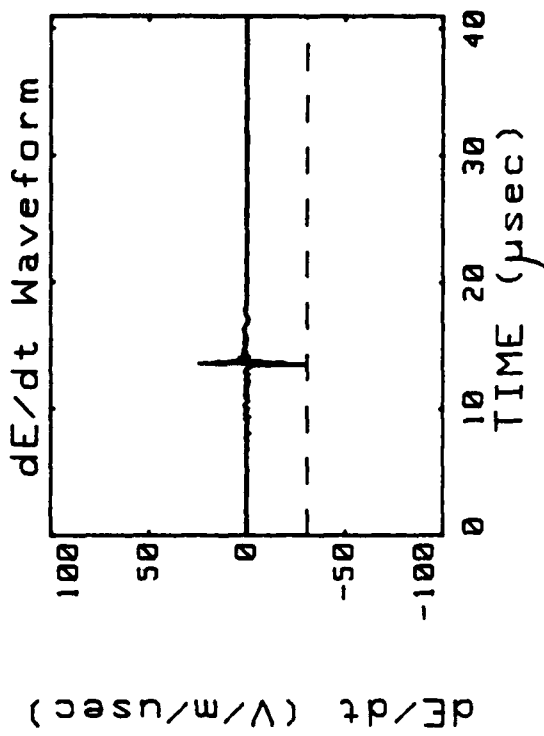
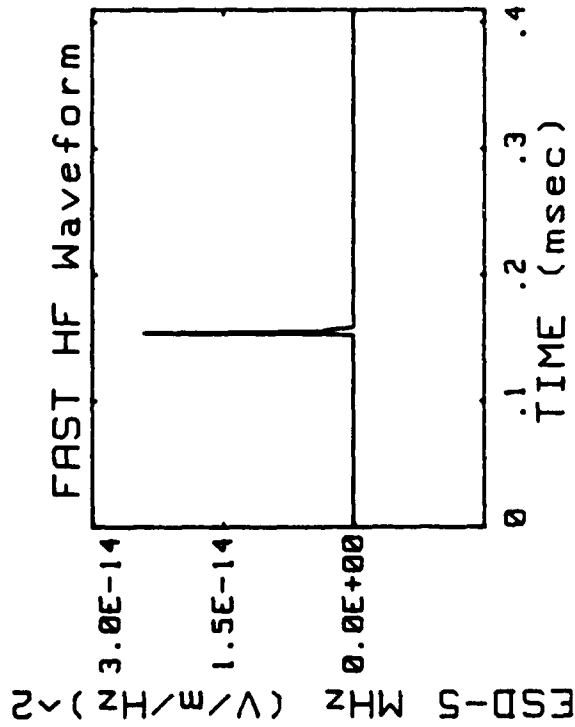
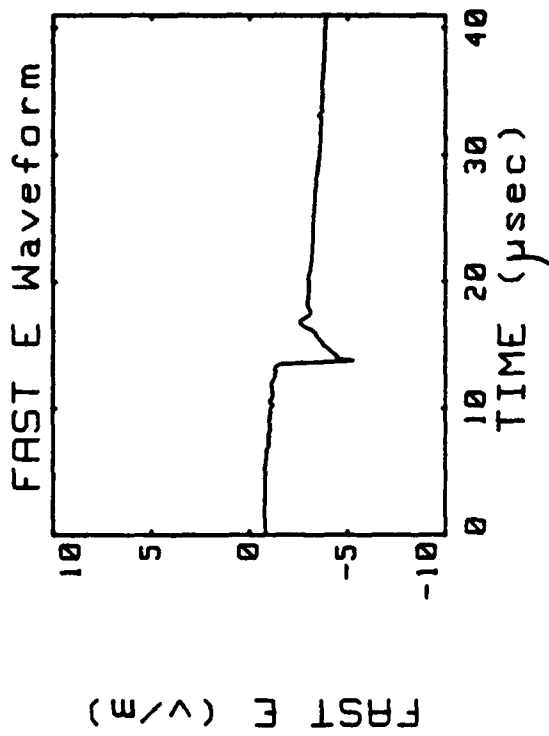
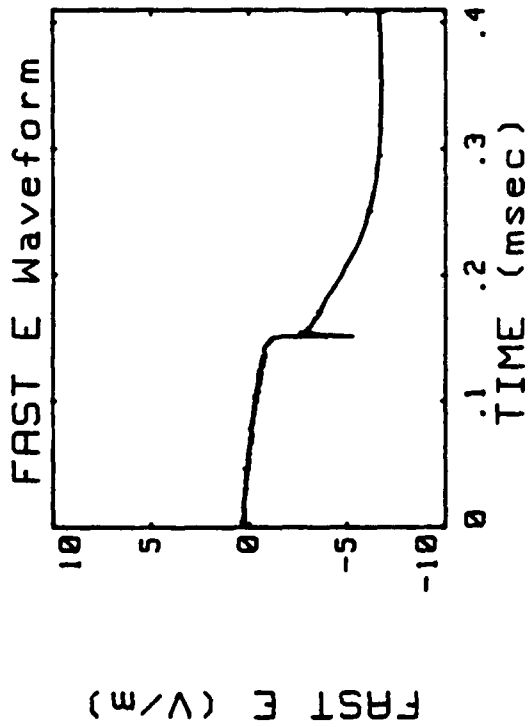
211234233.213 1987

Triggered Stroke (5.16 Km)



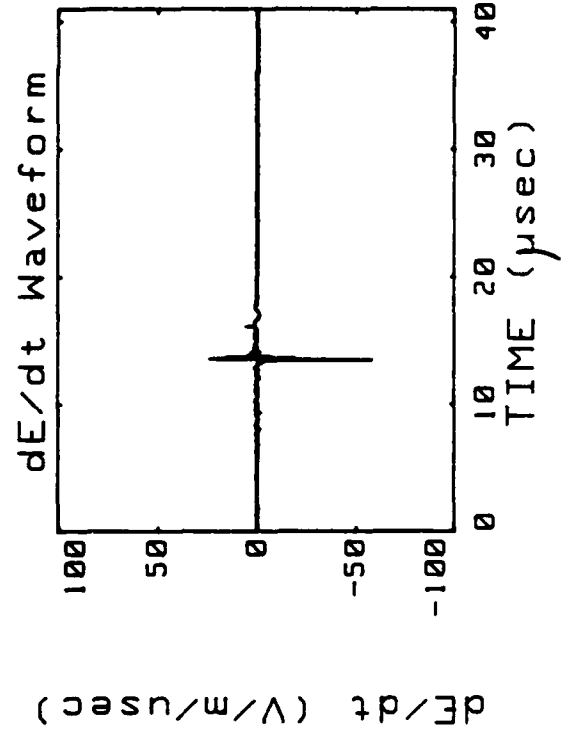
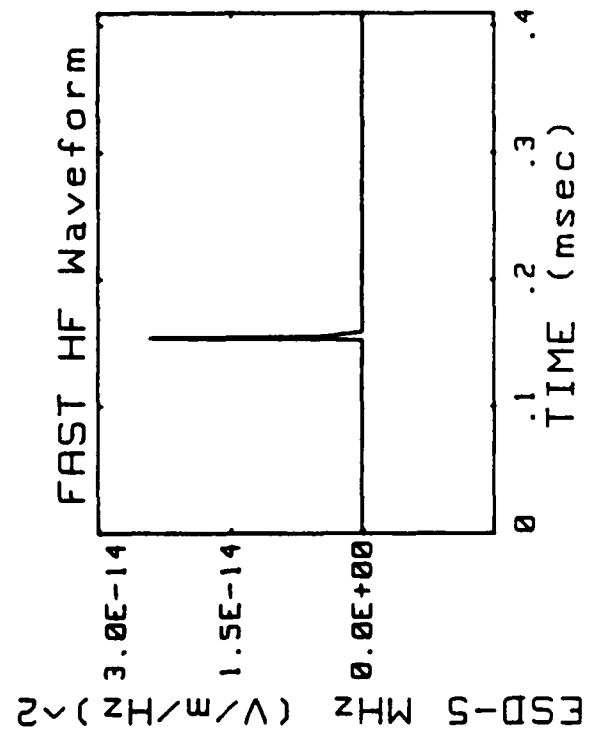
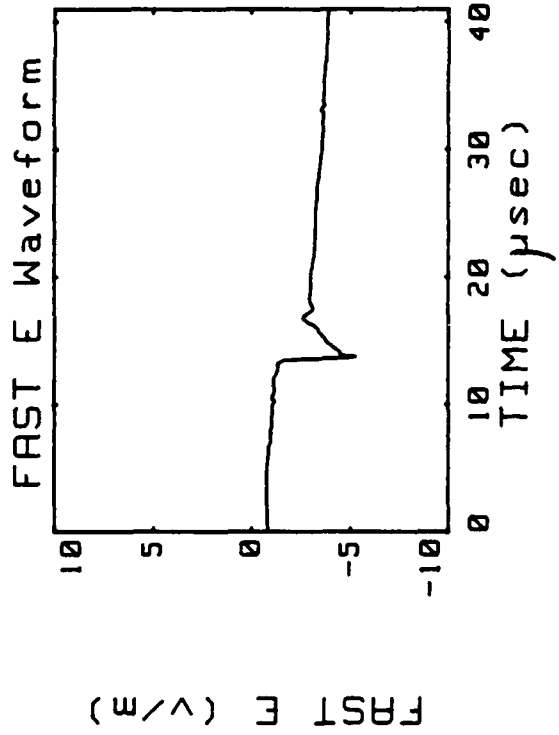
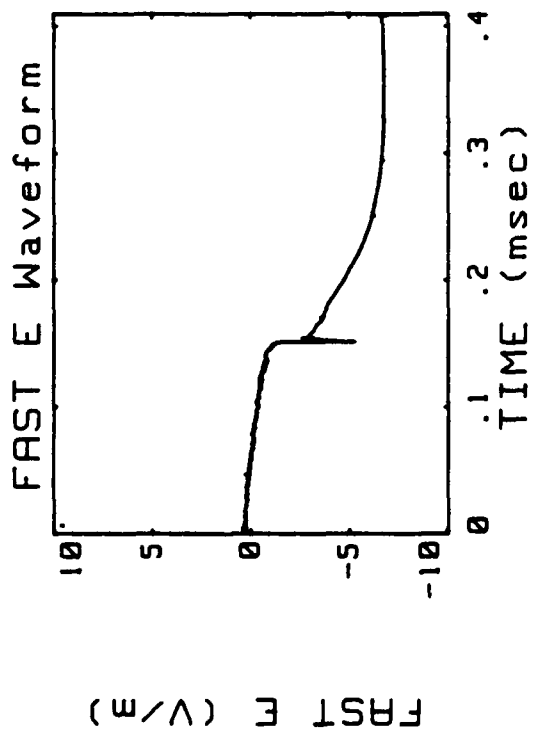
211234233.257 1987

Triggered Stroke (5.16 Km)

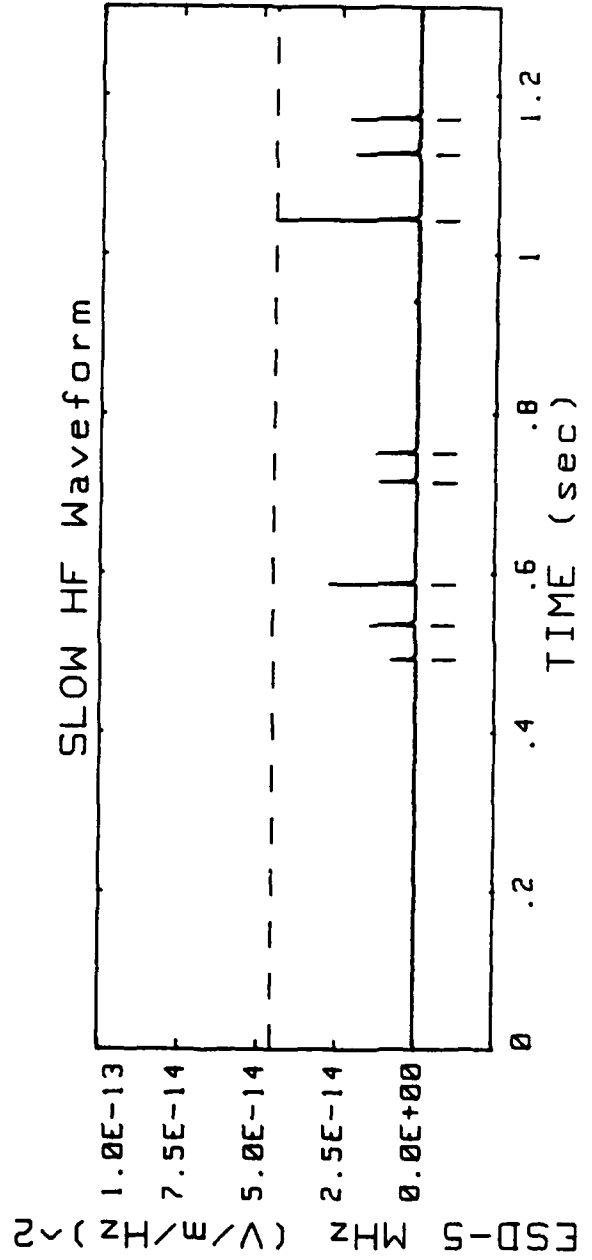
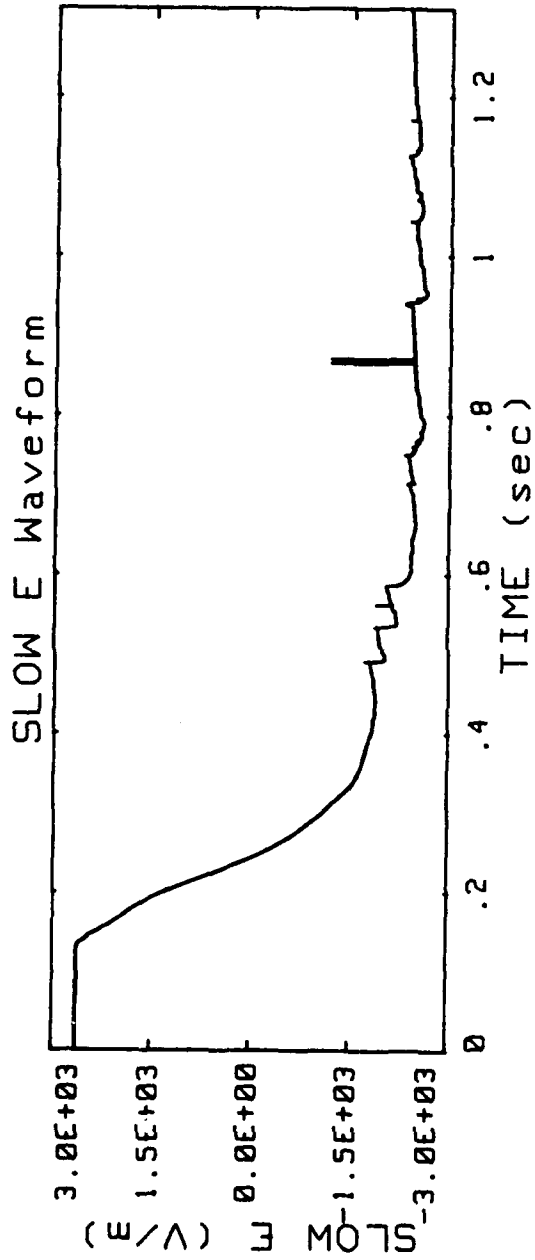


211234233.257 1987

Triggered Stroke (5.16 Km)

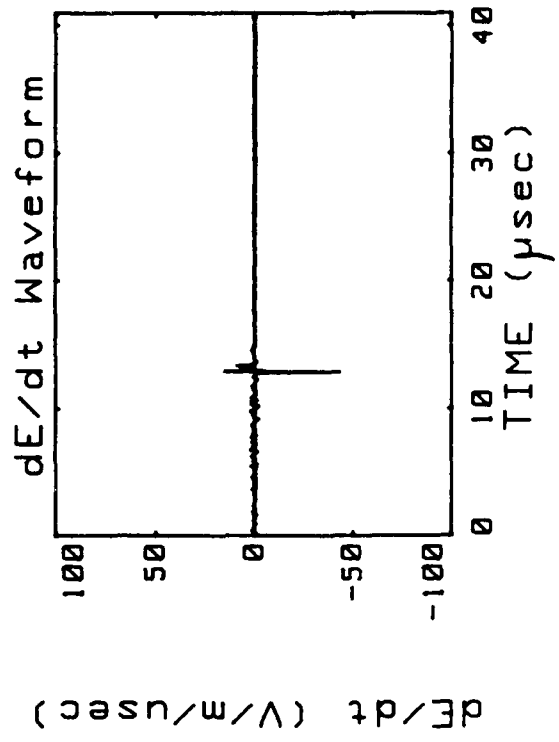
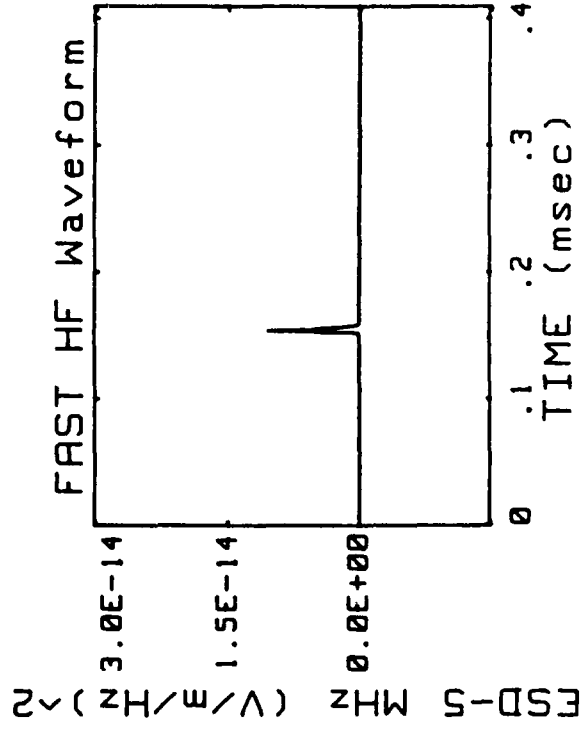
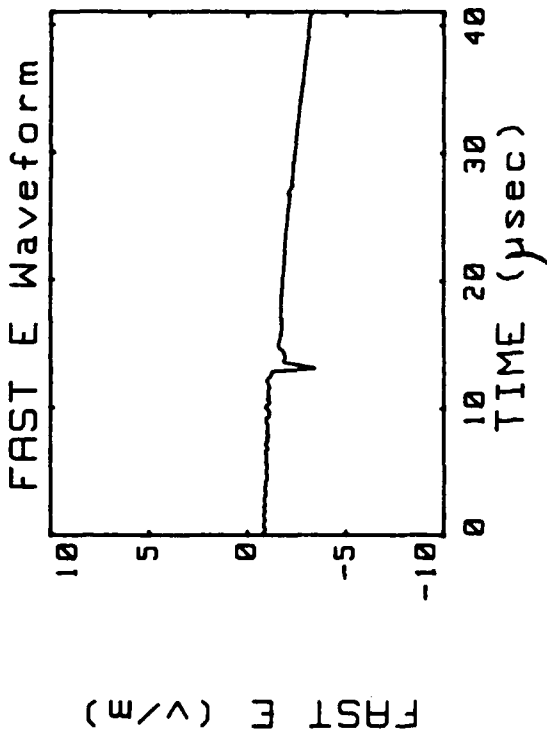
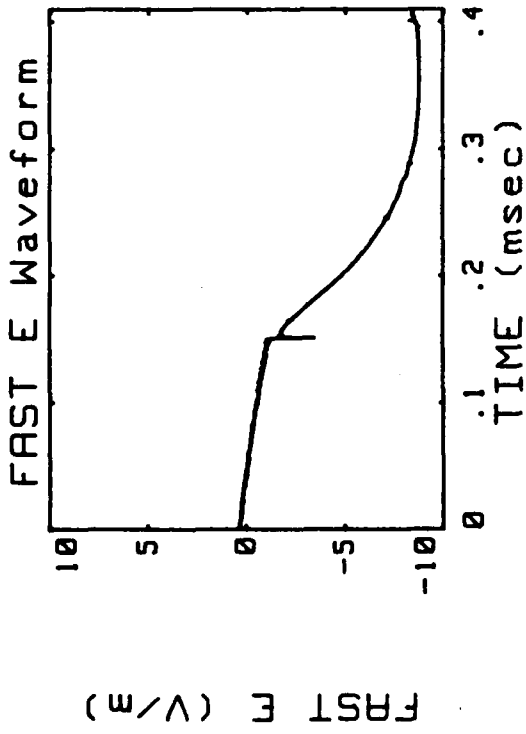


23:42:32.089 30 Jul 1987 (5.16 Km)



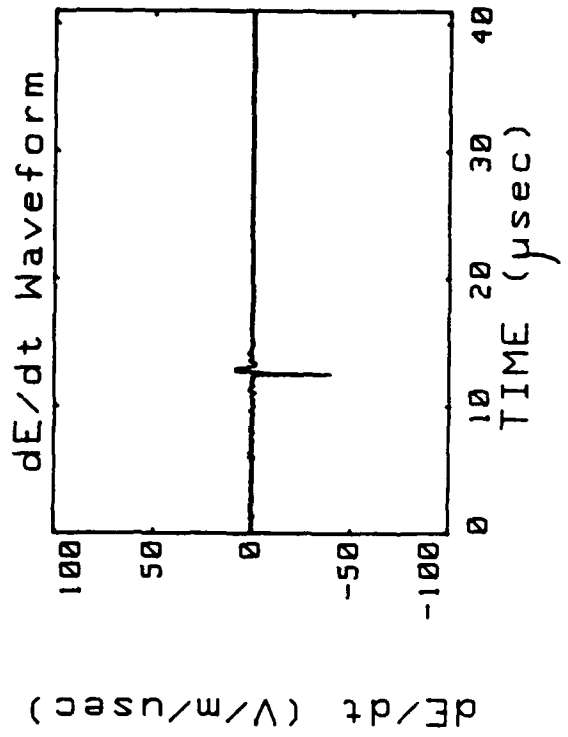
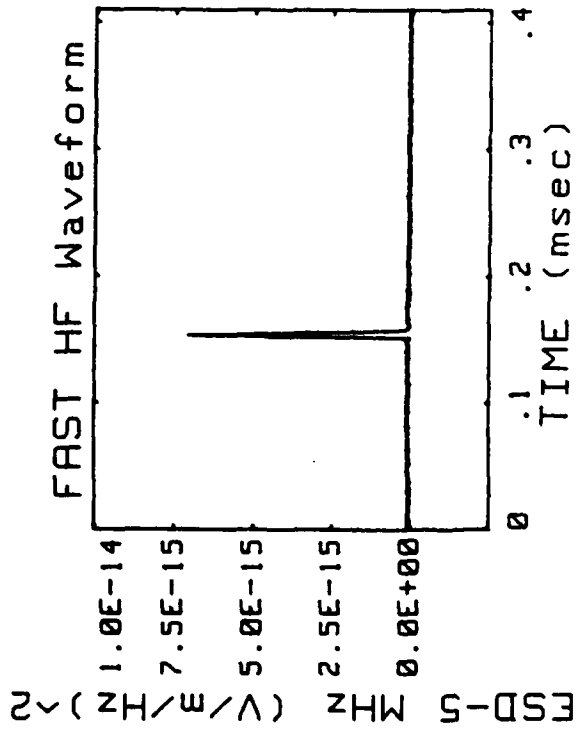
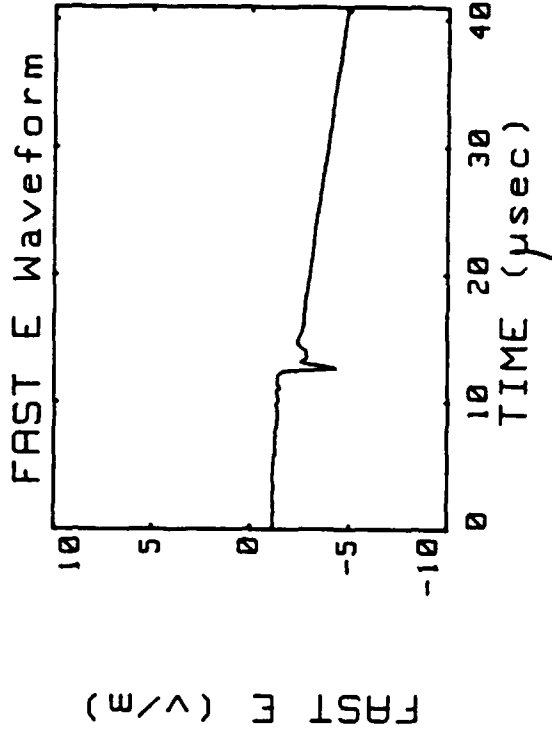
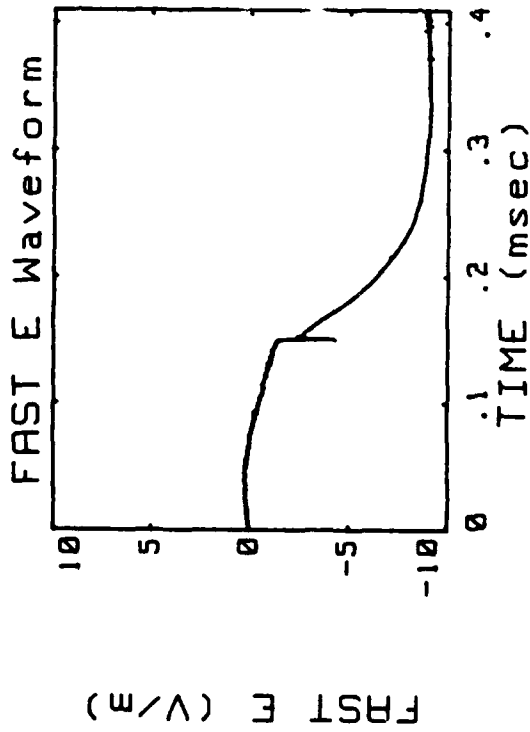
211234719.931 1987

Triggered Stroke (5.16 Km)

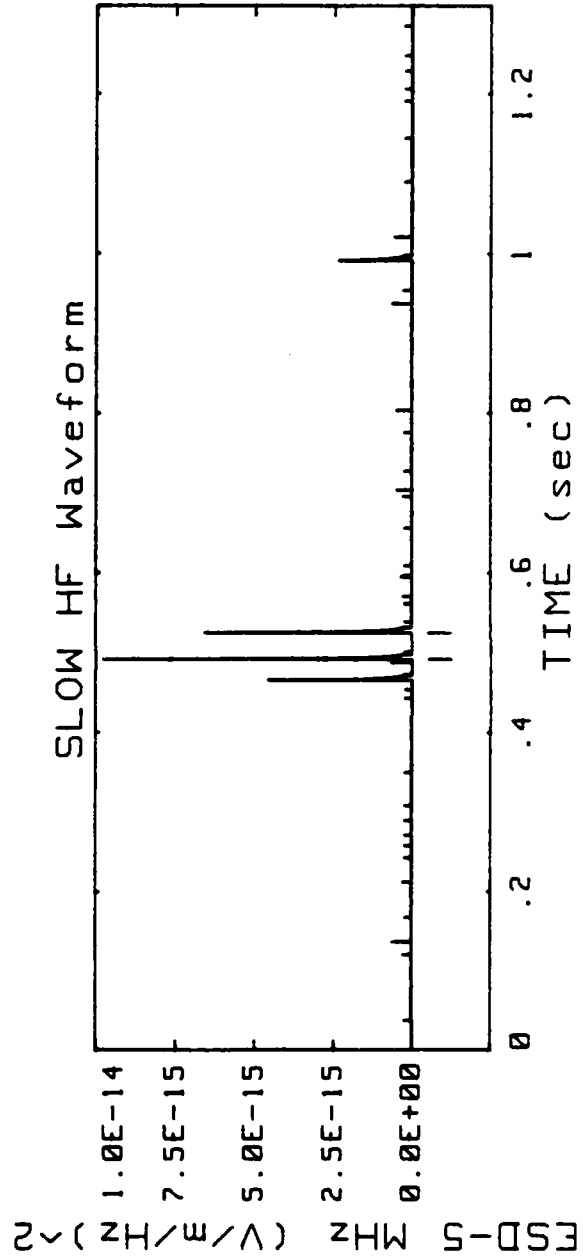
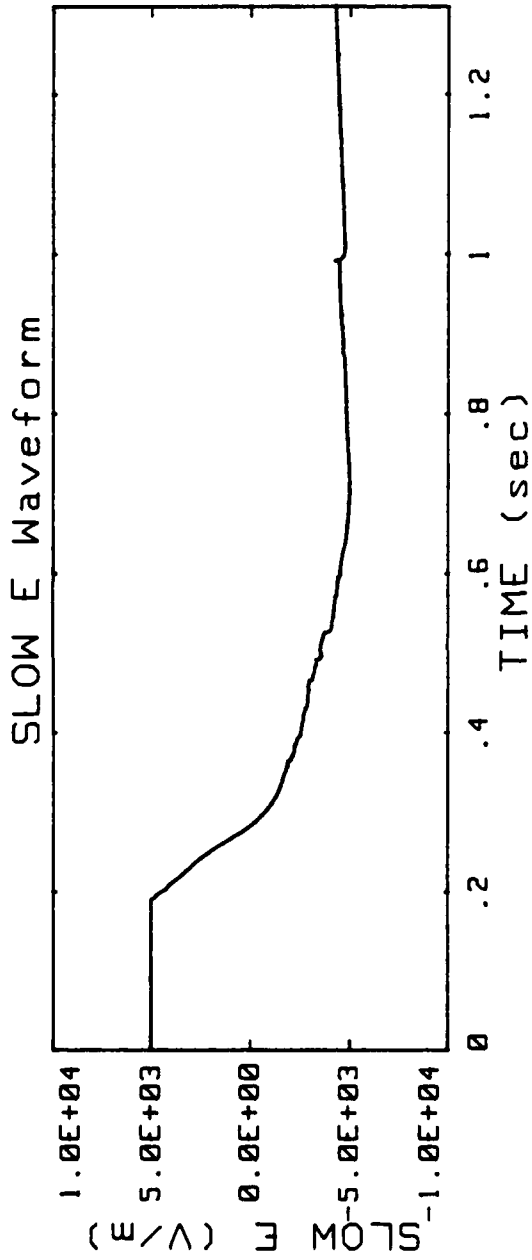


211234719.965 1987

Triggered Stroke (5.16 Km)

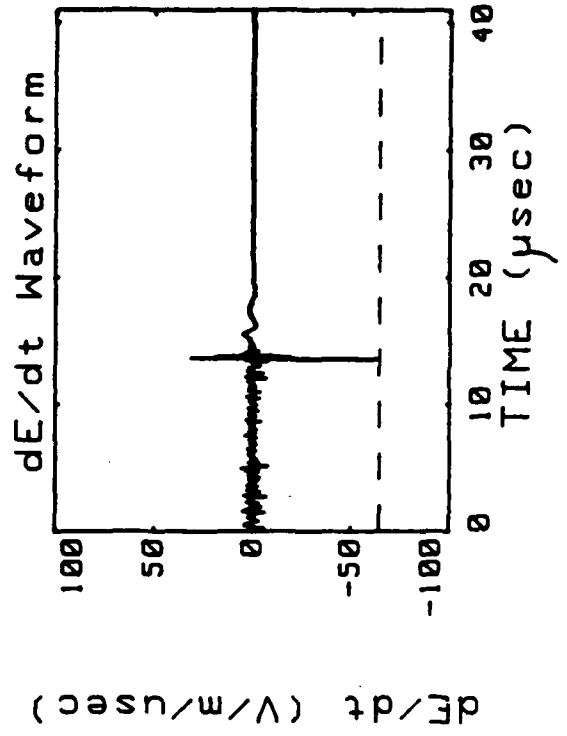
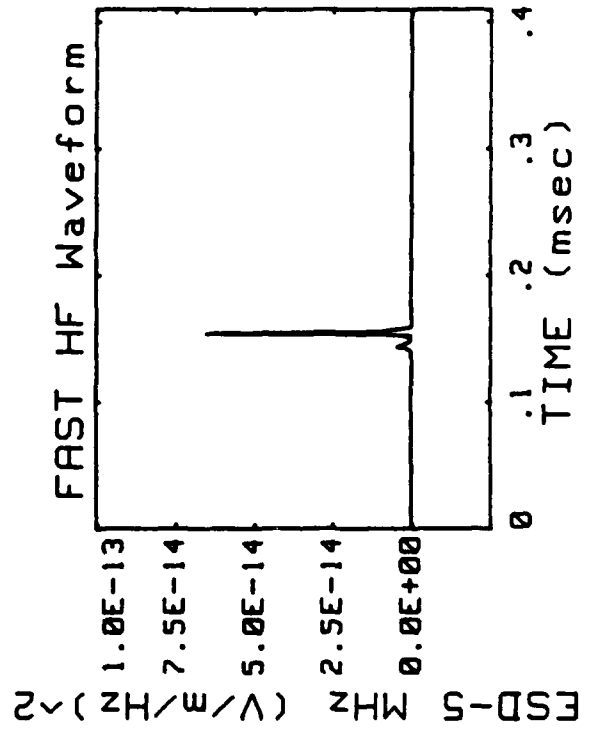
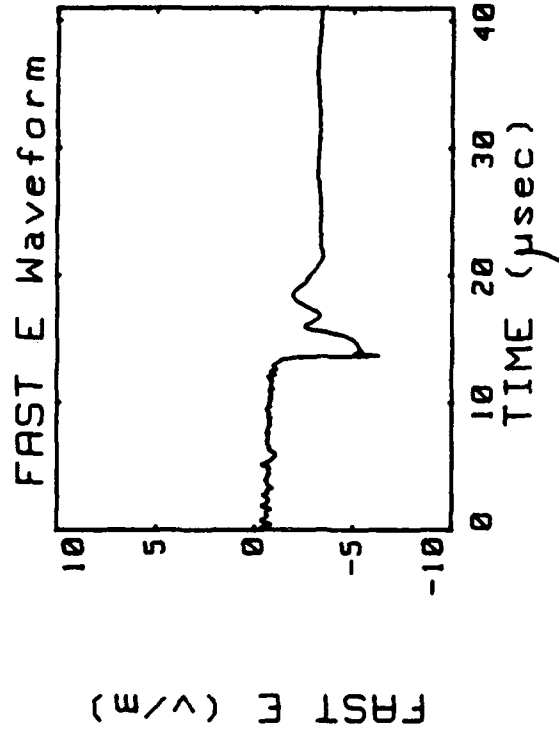
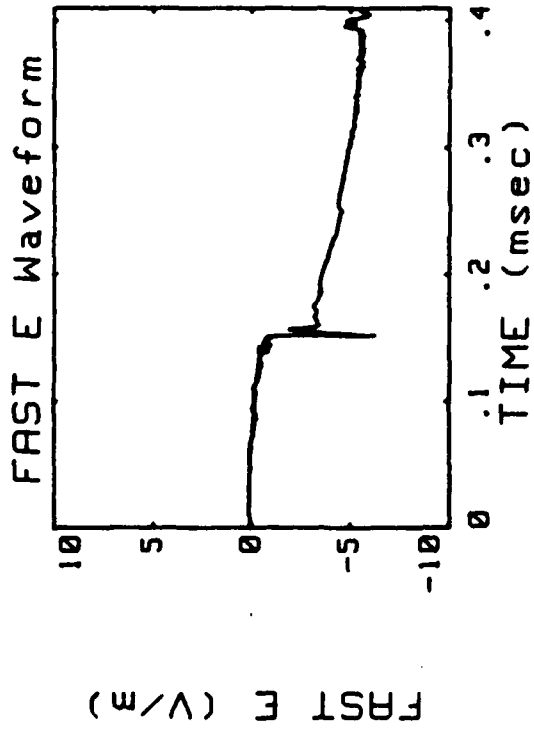


23:47:19.441 30 Jul 1987 (5.16 Km)



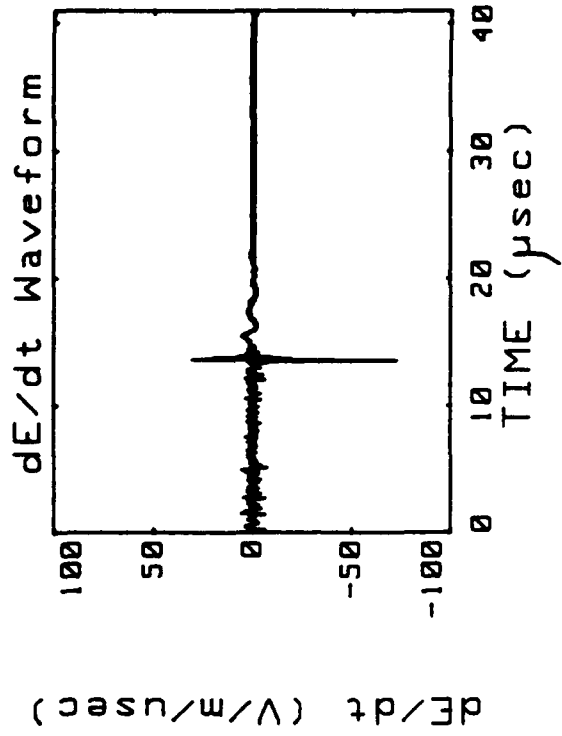
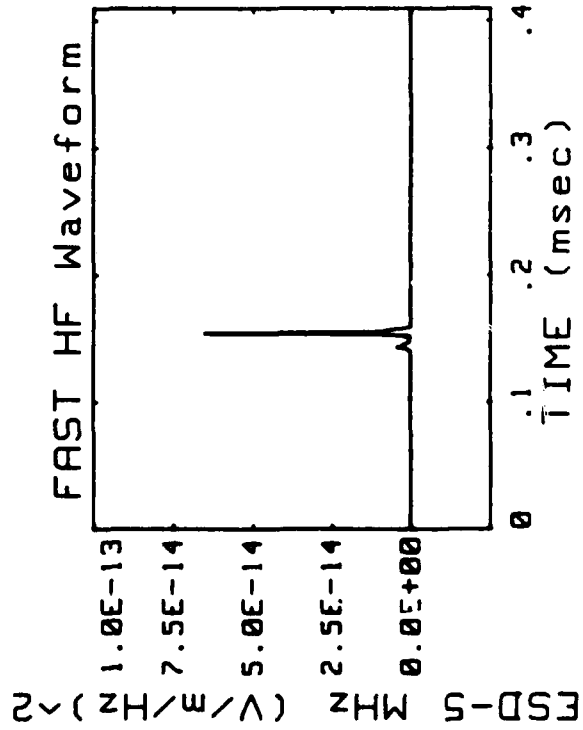
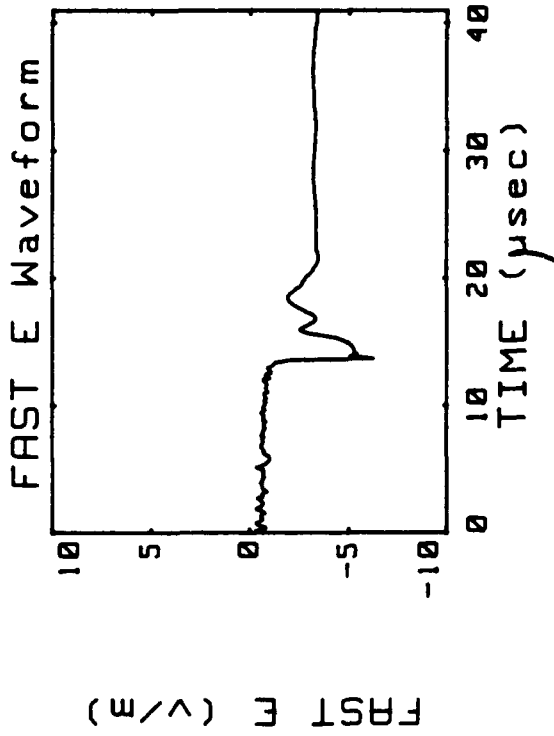
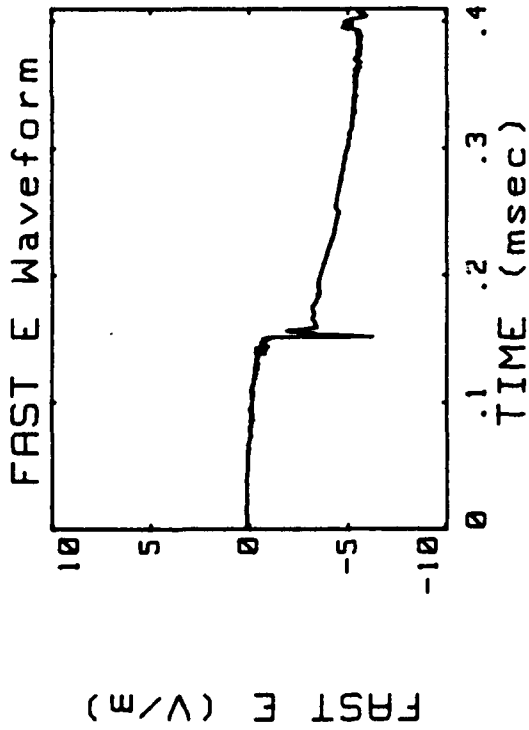
212193348.555 1987

Triggered Stroke (5.16 Km)

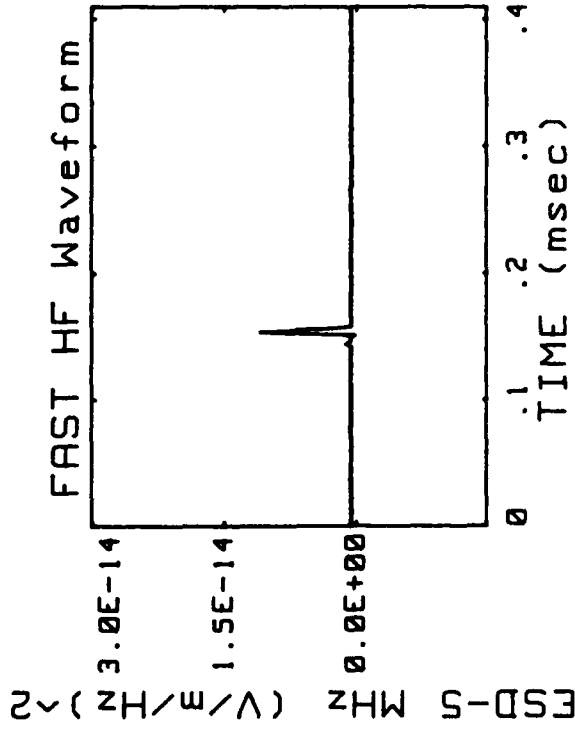
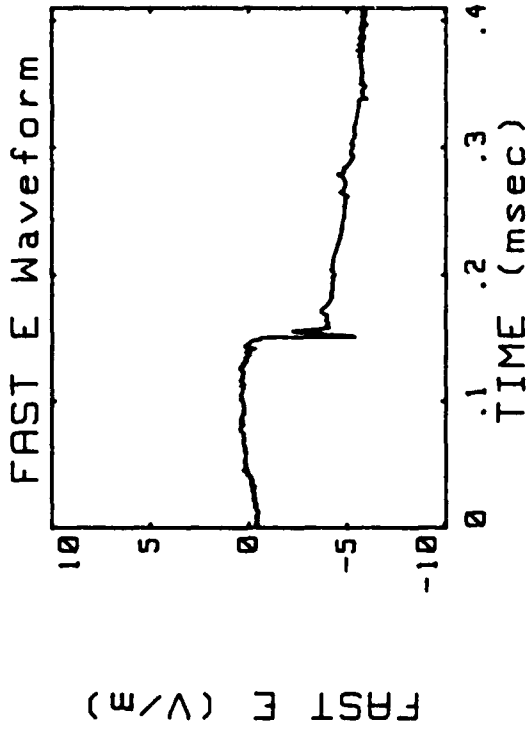


212193348.555 1987

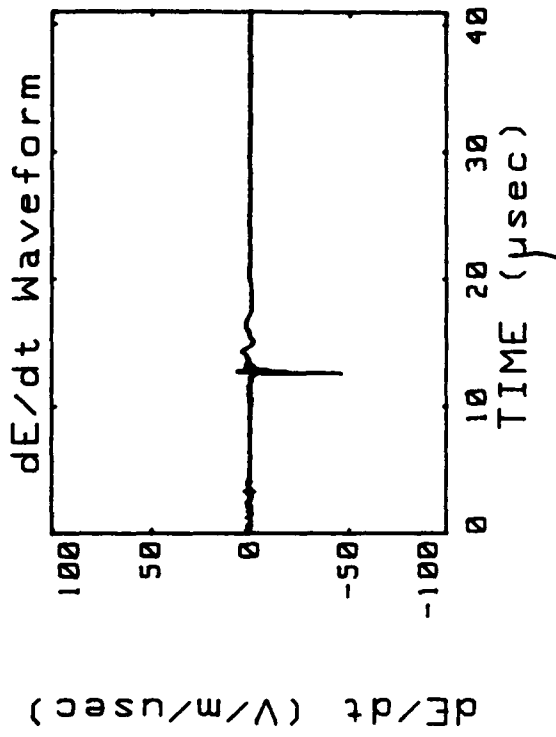
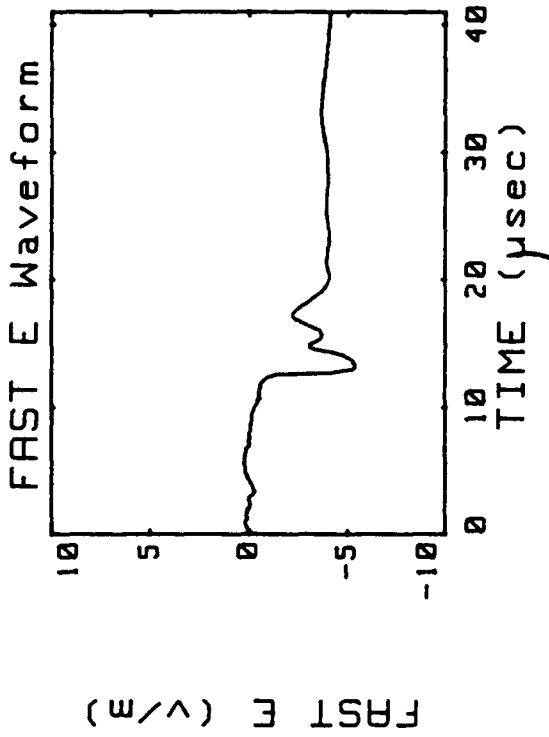
Triggered Stroke (5.16 Km)



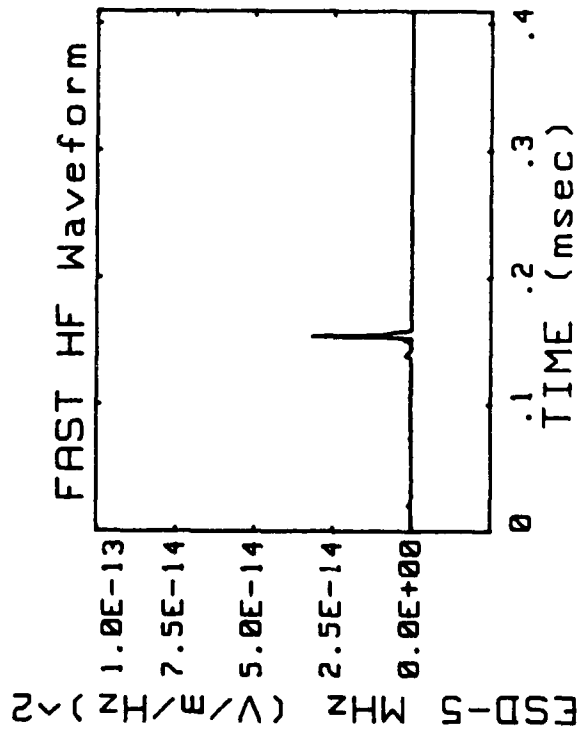
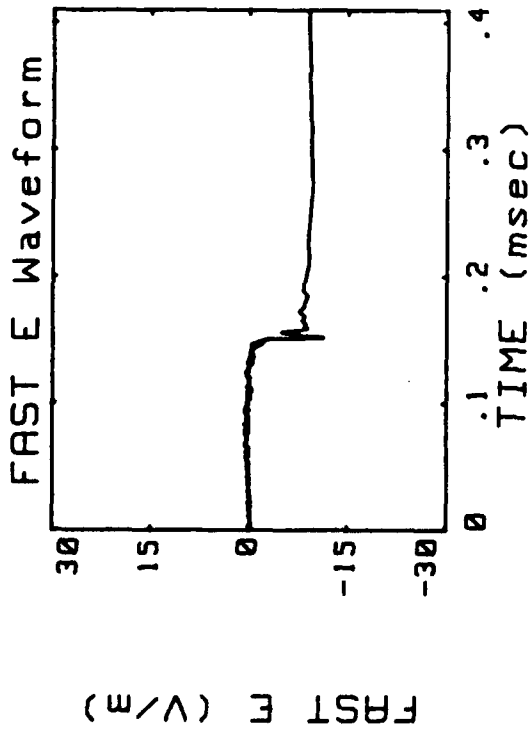
212193348.674 1987



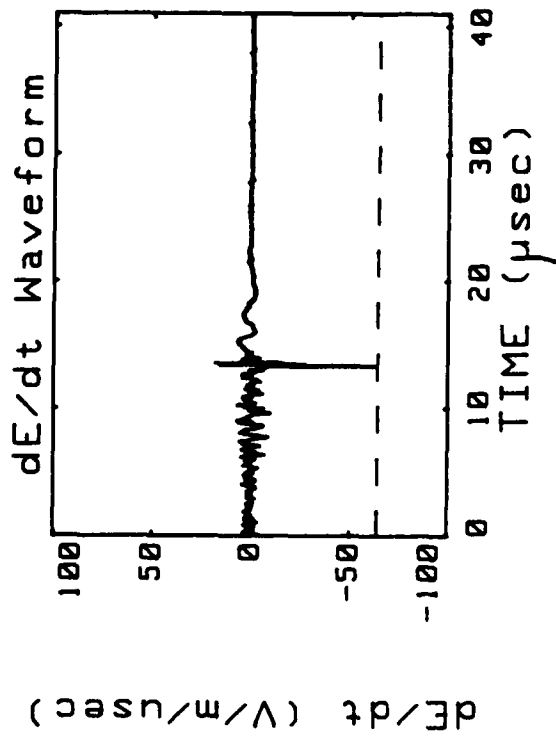
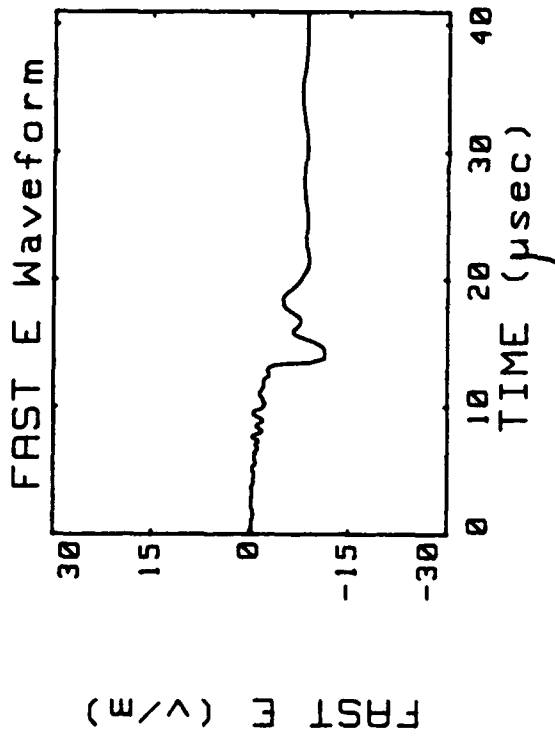
Triggered Stroke (5.16 Km)



212193349.330 1987

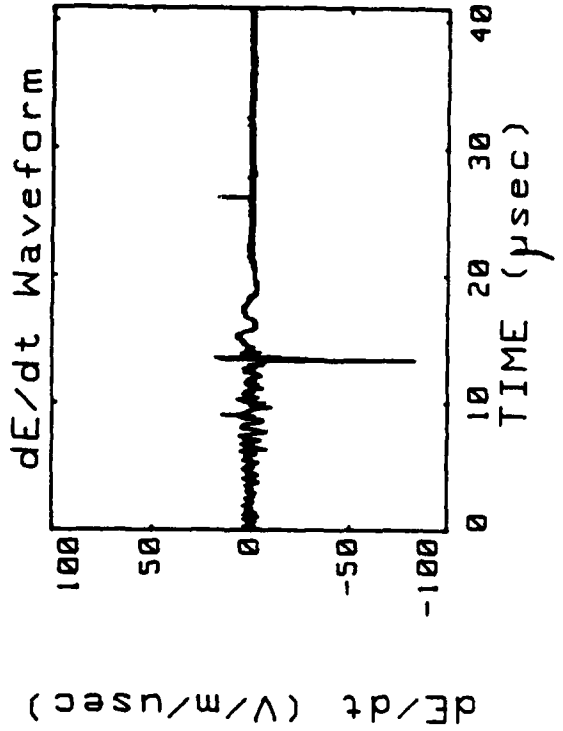
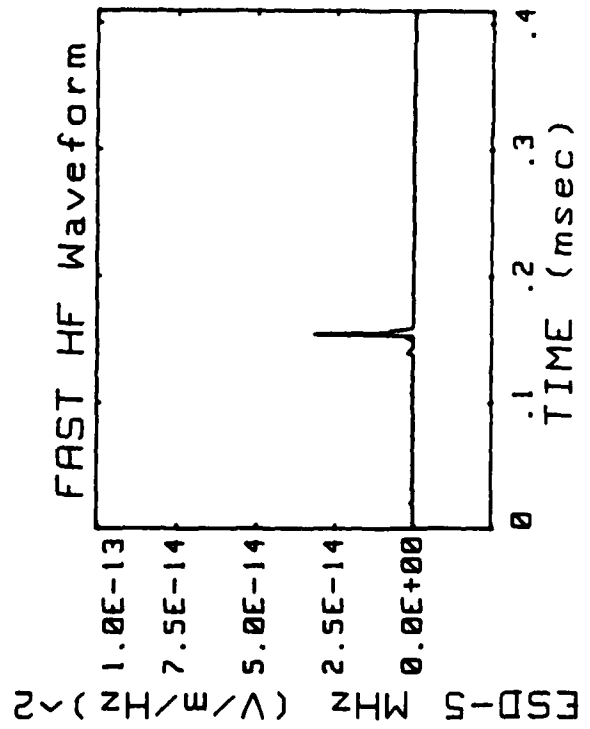
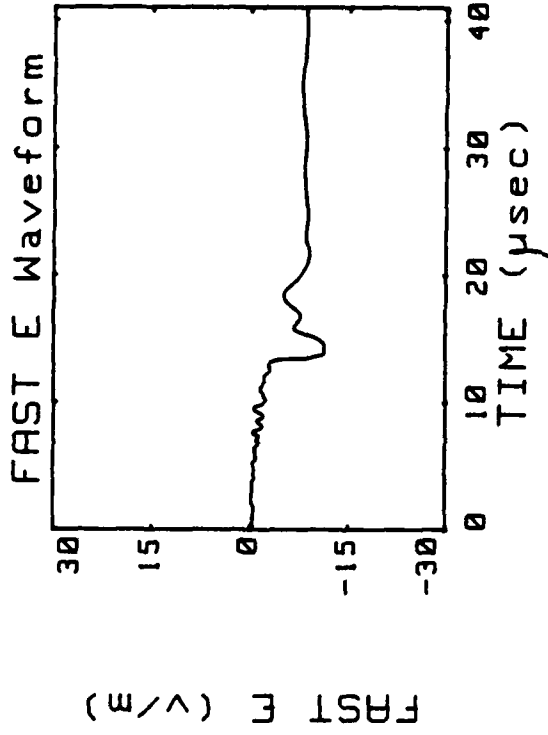
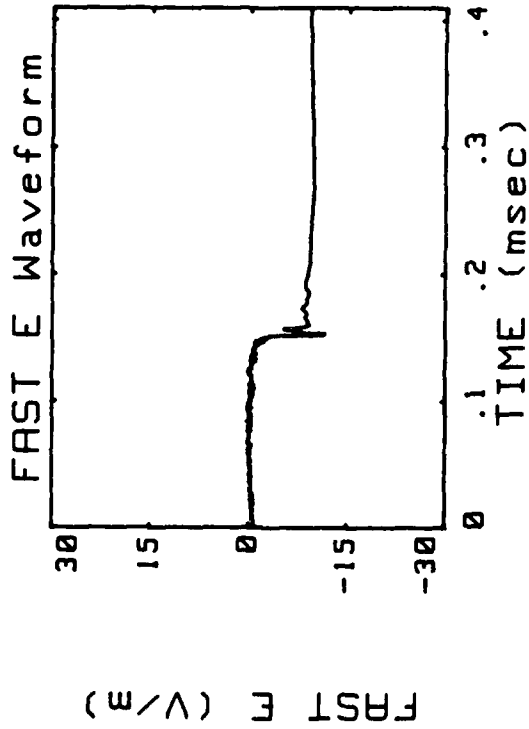


Triggered Stroke (5.16 Km)

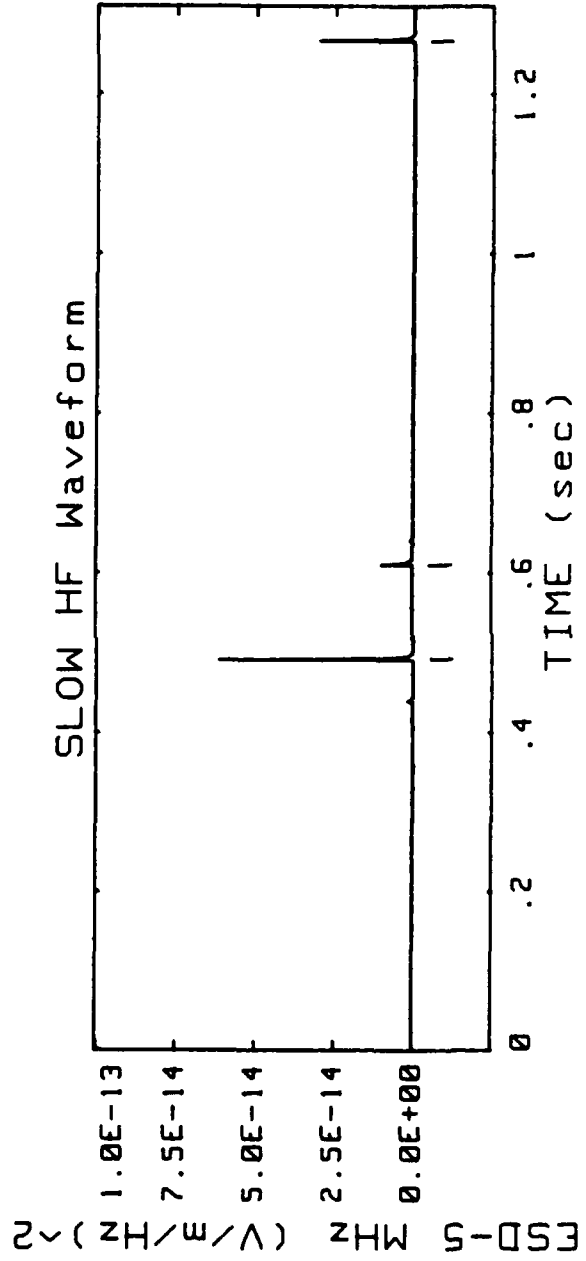
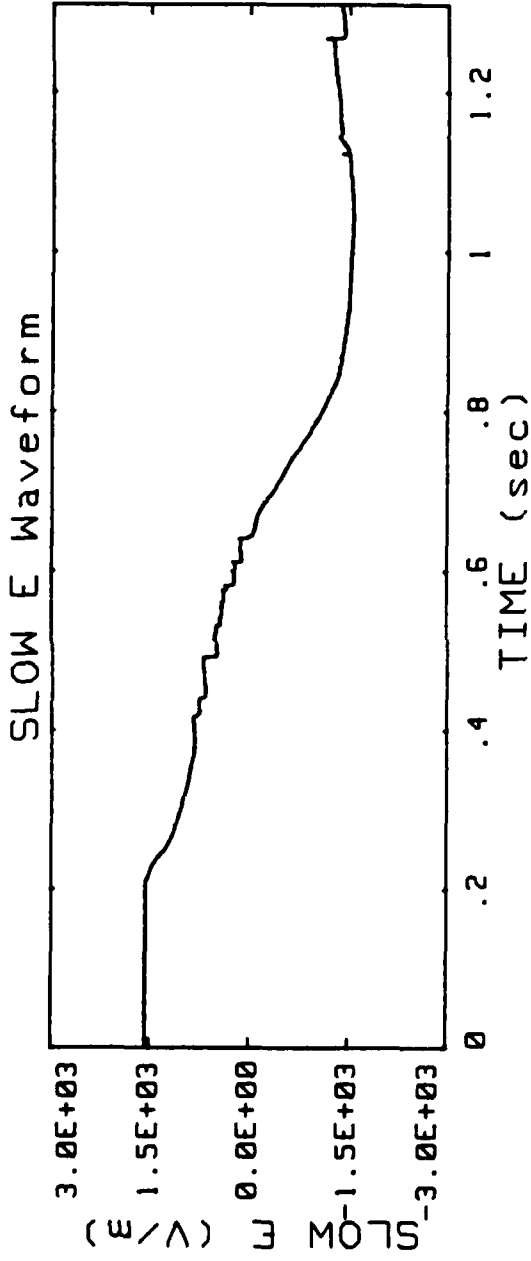


212193349.330 1987

Triggered Stroke (5.16 Km)

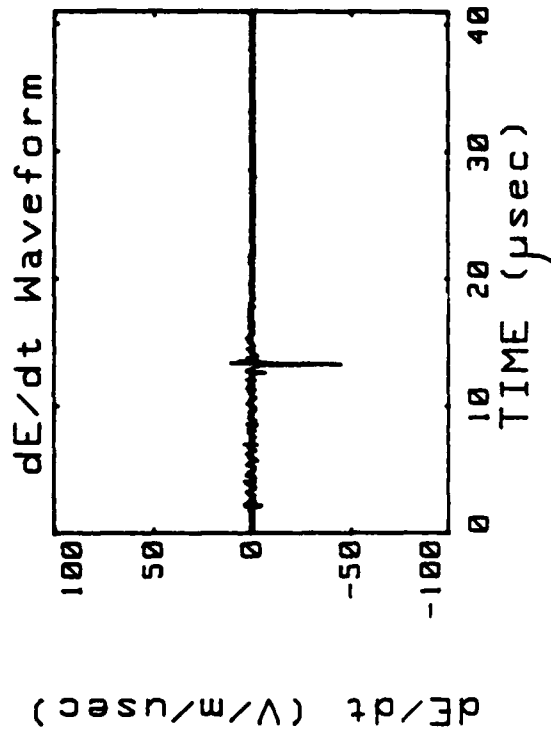
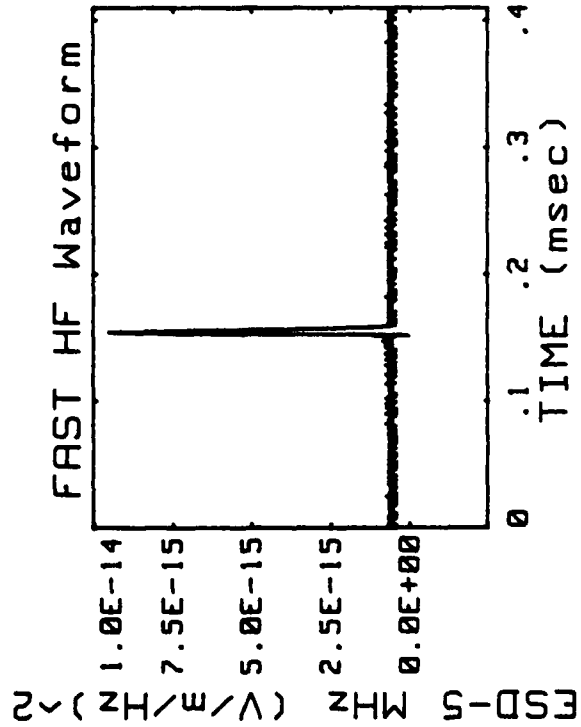
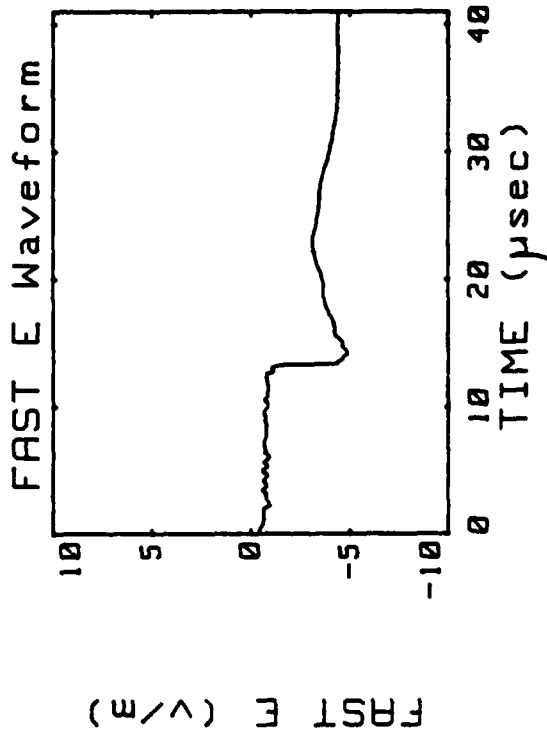
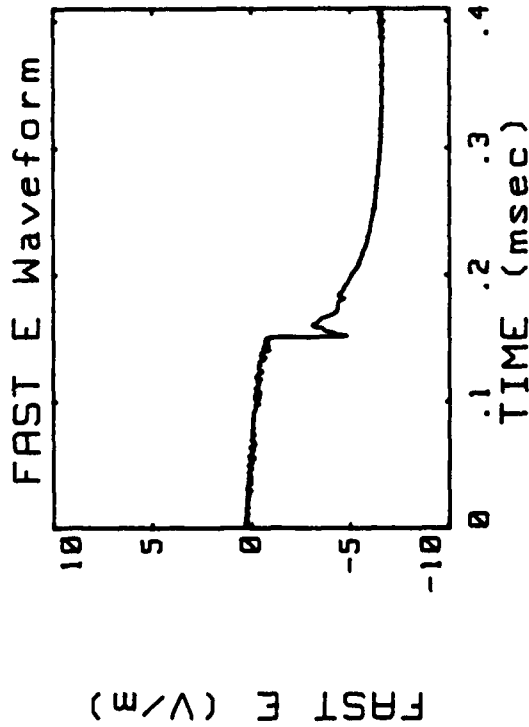


19:33:48.065 31 Jul 1987 (5.16 Km)

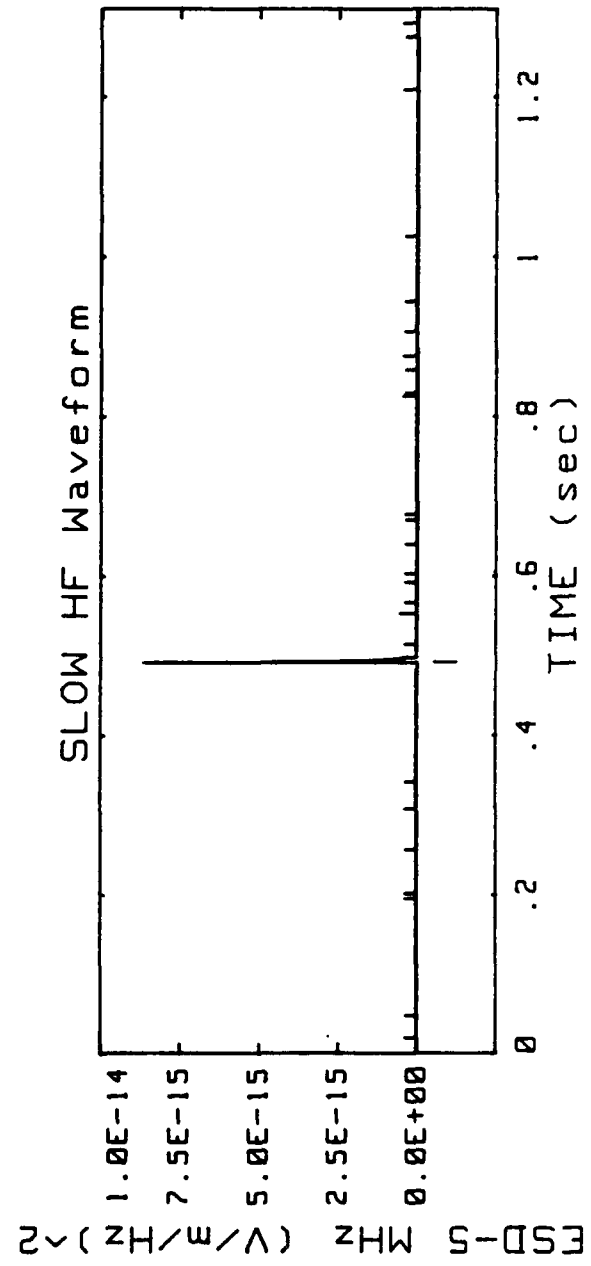
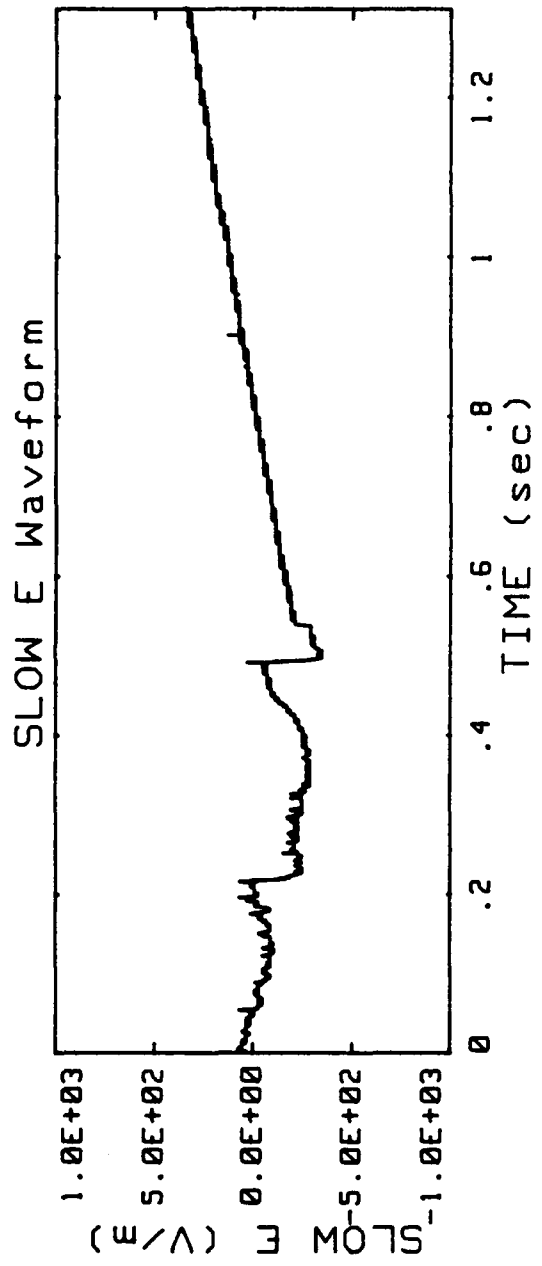


212195125.591 1987

Triggered Stroke (5.16 Km)



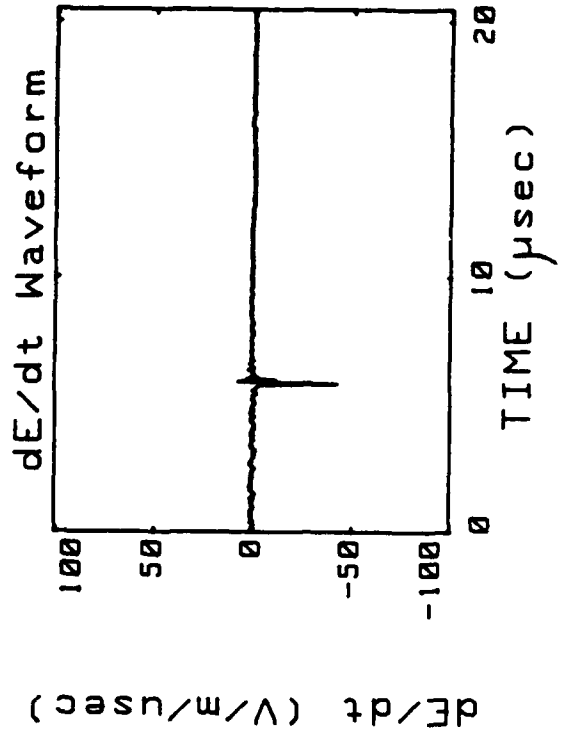
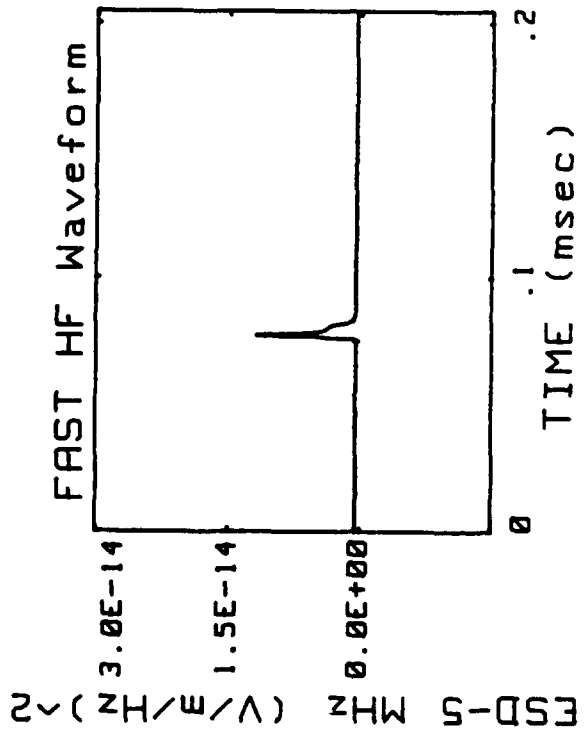
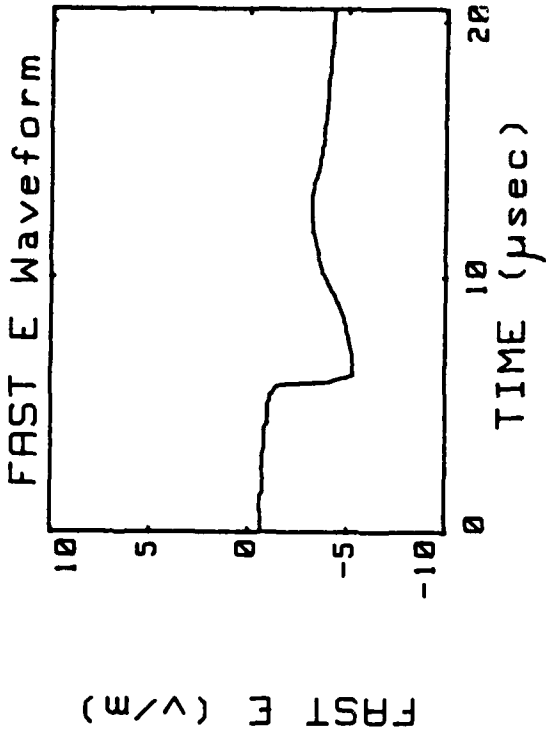
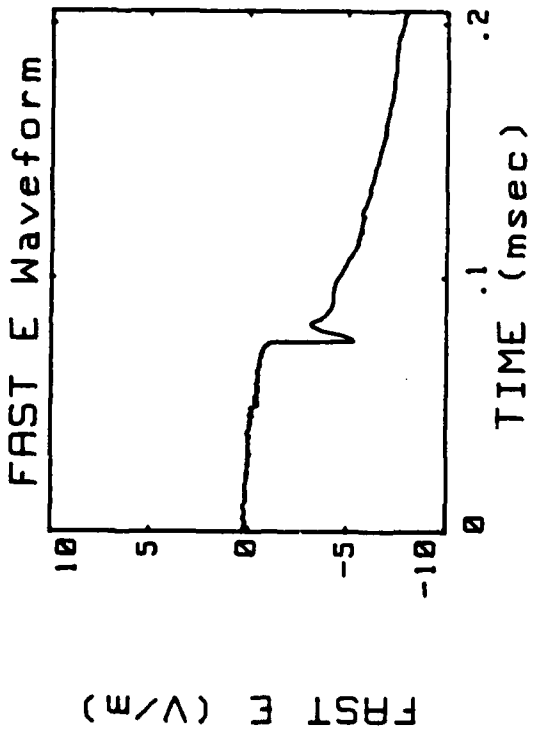
19:51:25.101 31 Jul 1987 (5.16 Km)



2048 Data

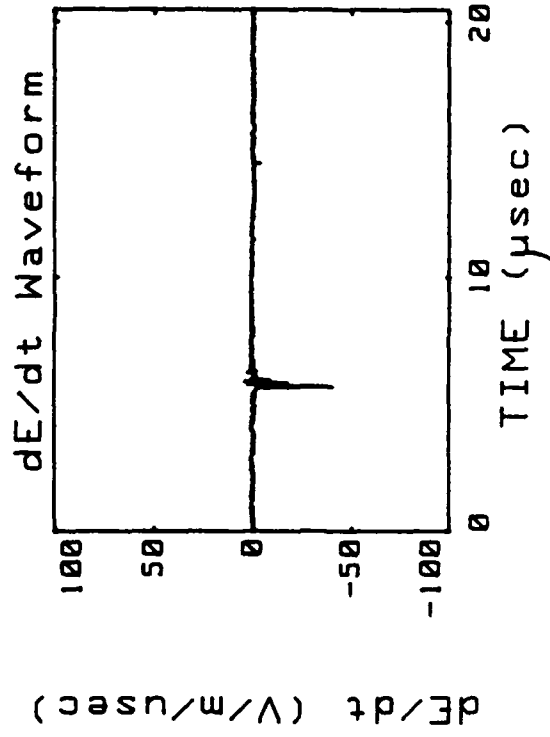
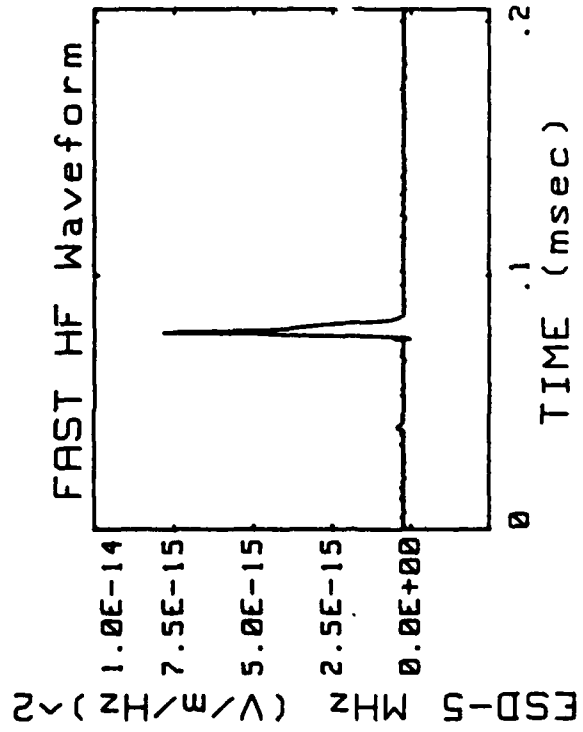
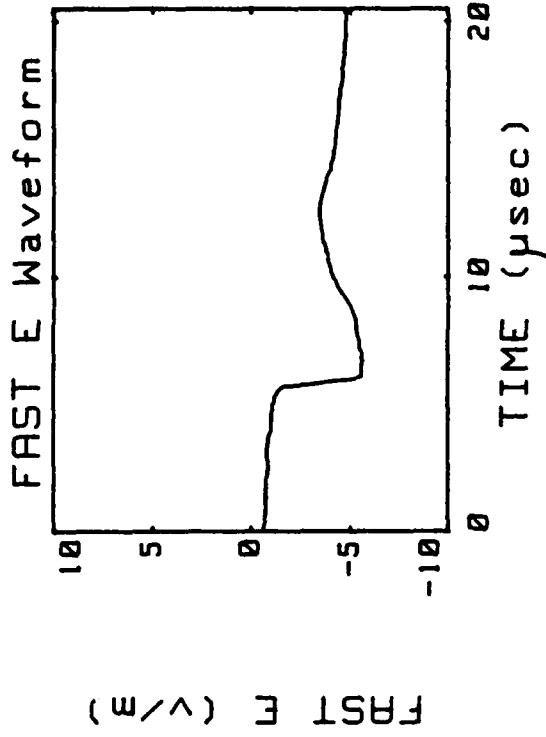
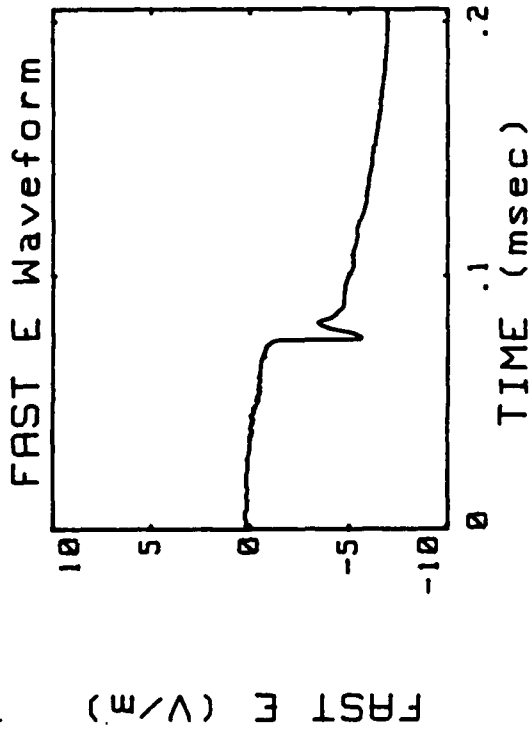
231212419.246 1987

Triggered Stroke (5.16 Km)



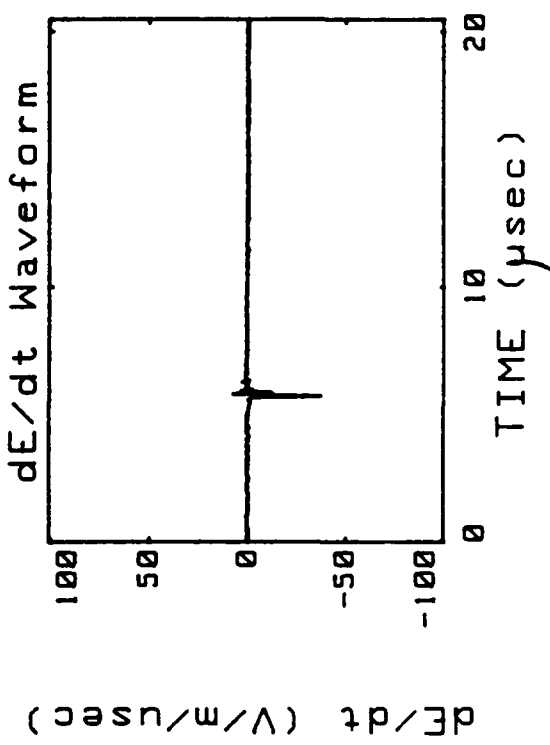
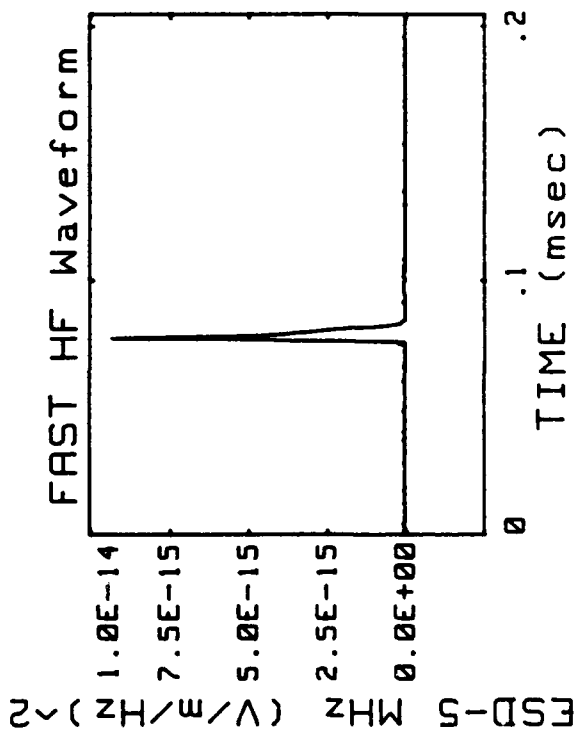
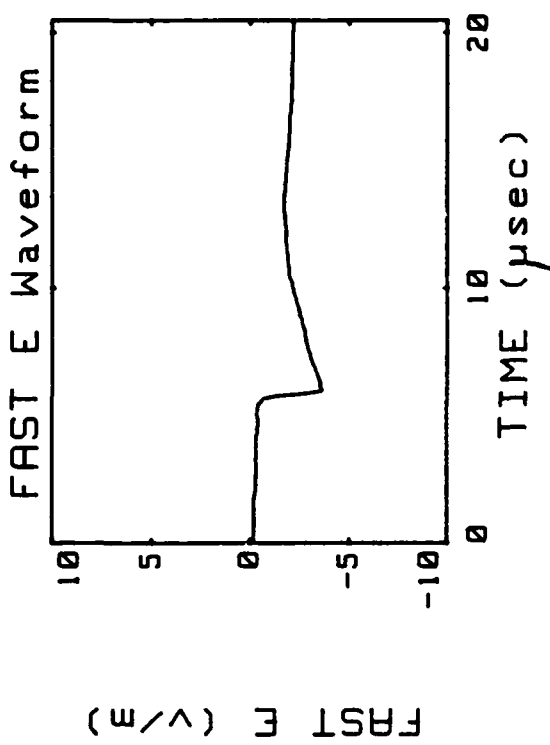
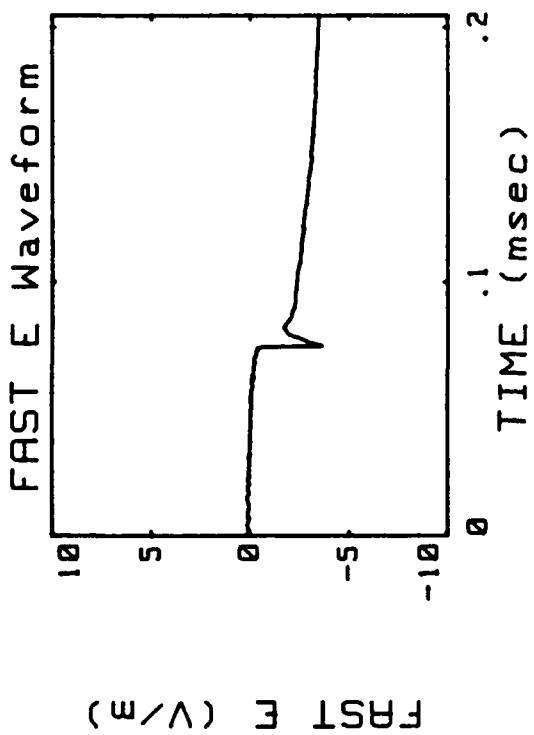
231212419.314 1987

Triggered Stroke (5.16 Km)

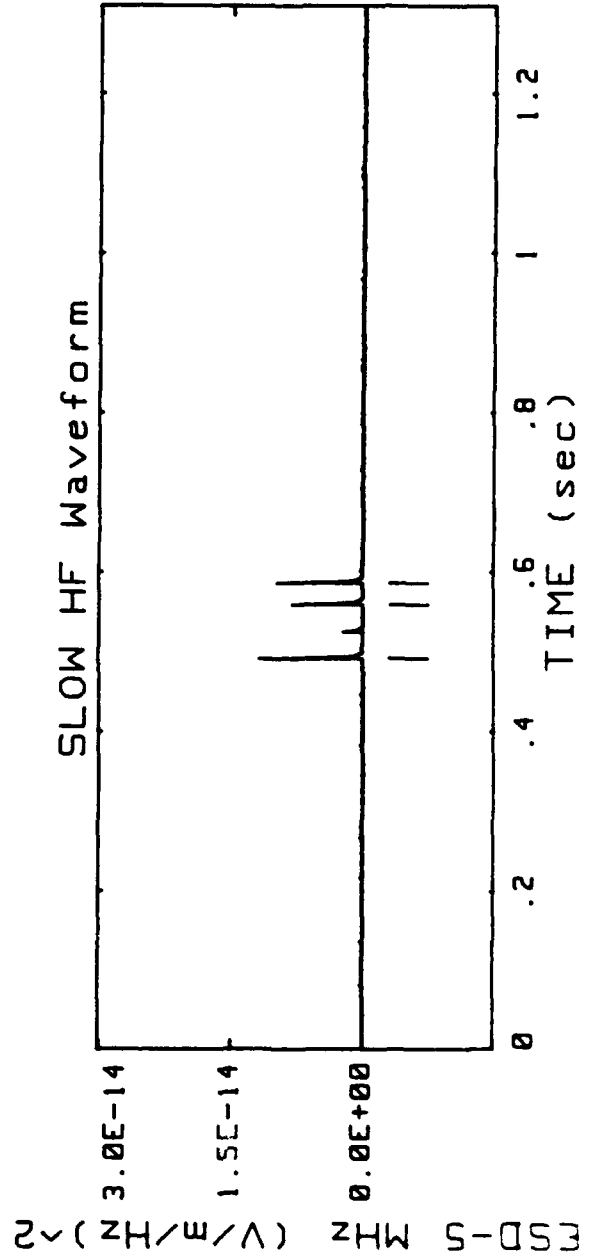
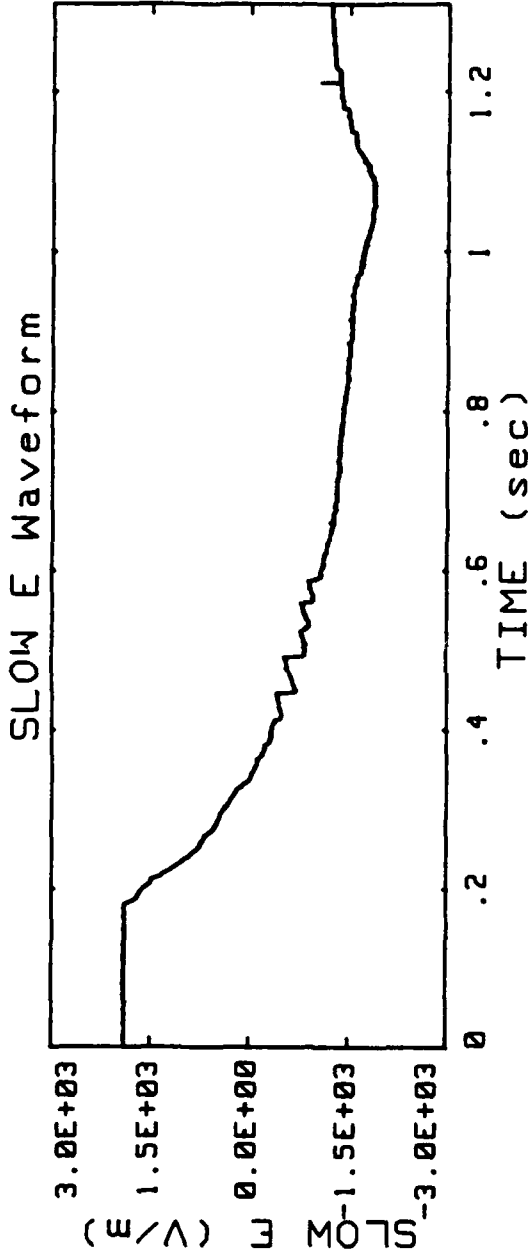


231212419.341 1987

Triggered Stroke (5.16 Km)

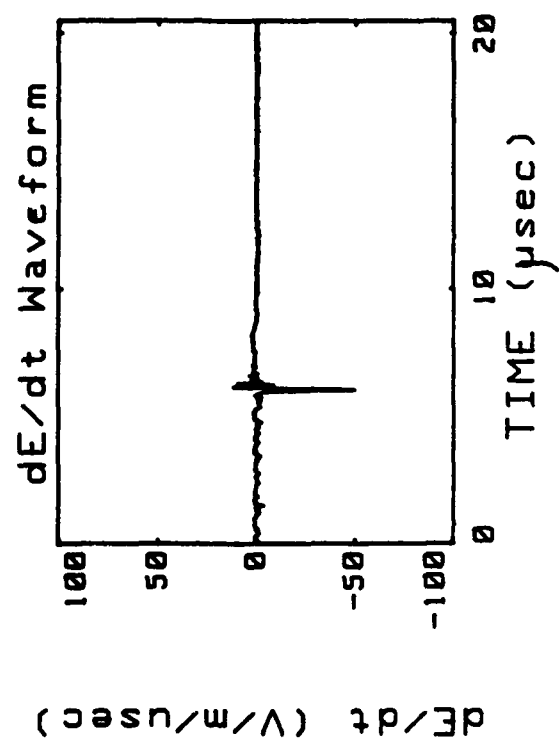
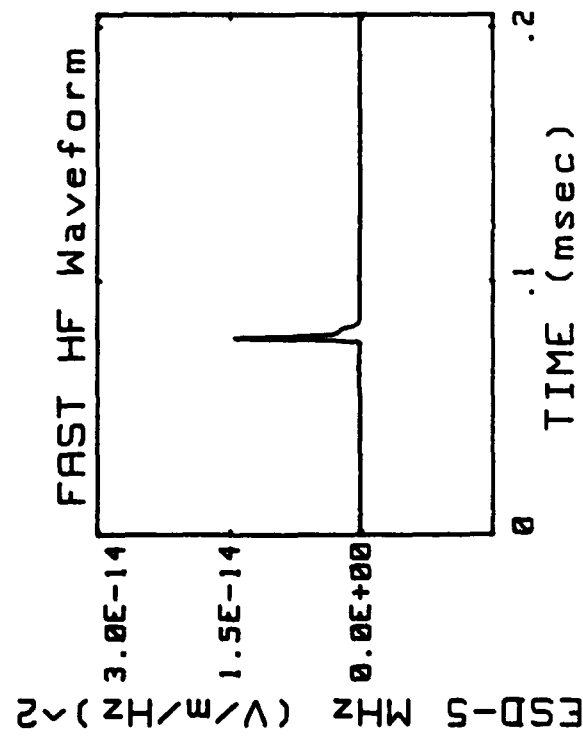
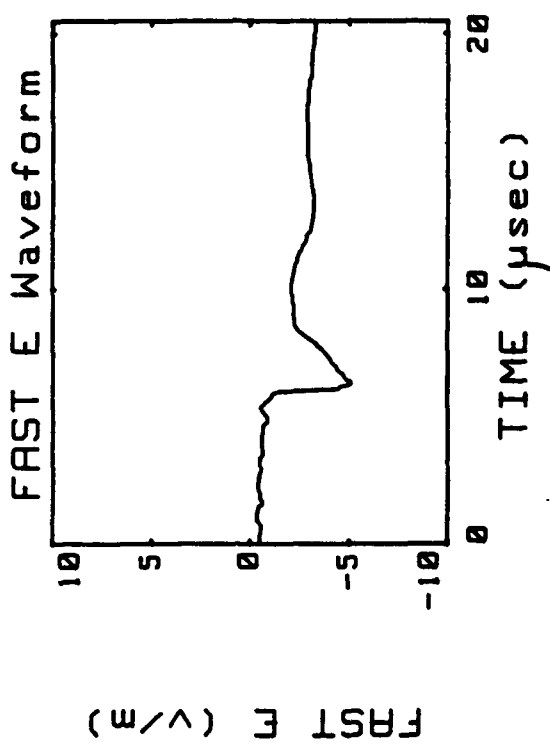
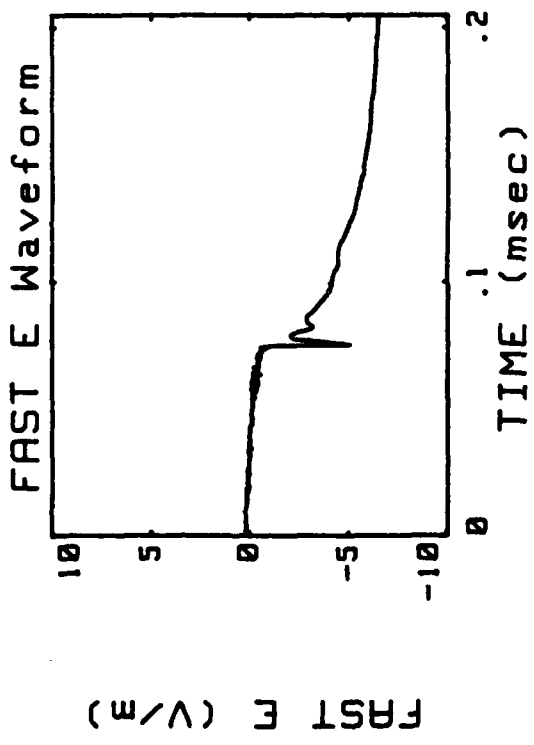


21:24:18.756 19 Aug 1987 (5.16 Km)



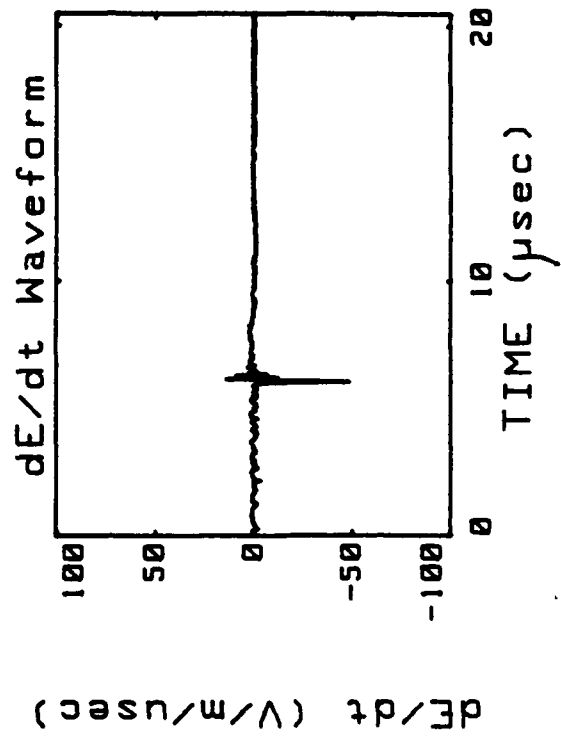
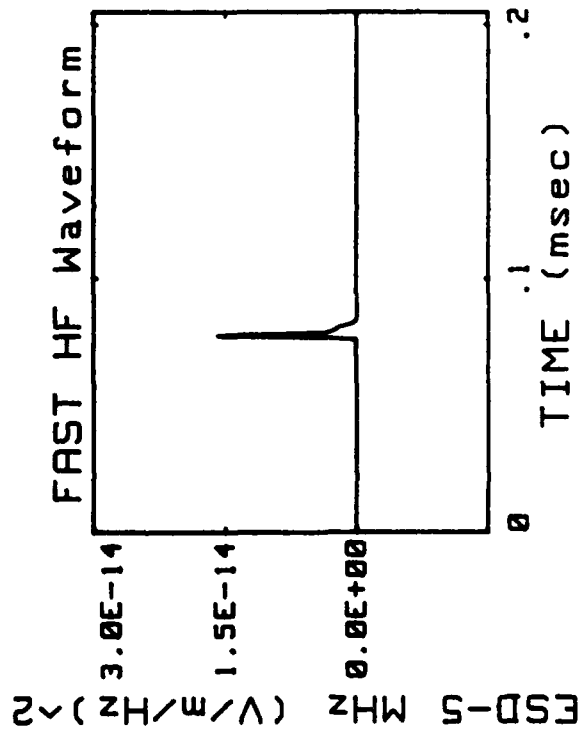
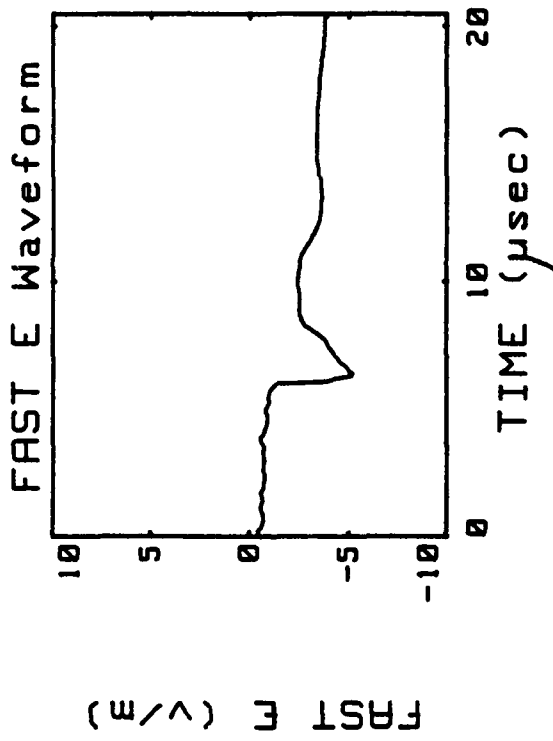
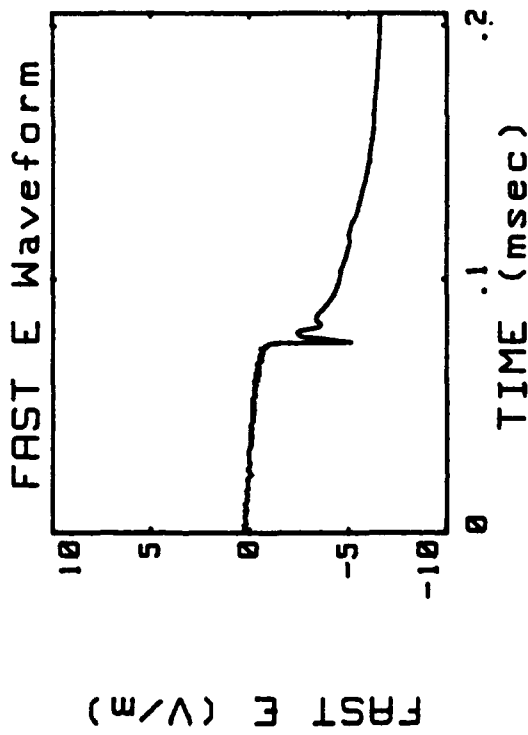
231214314.604 1987

Triggered Stroke (5.16 Km)



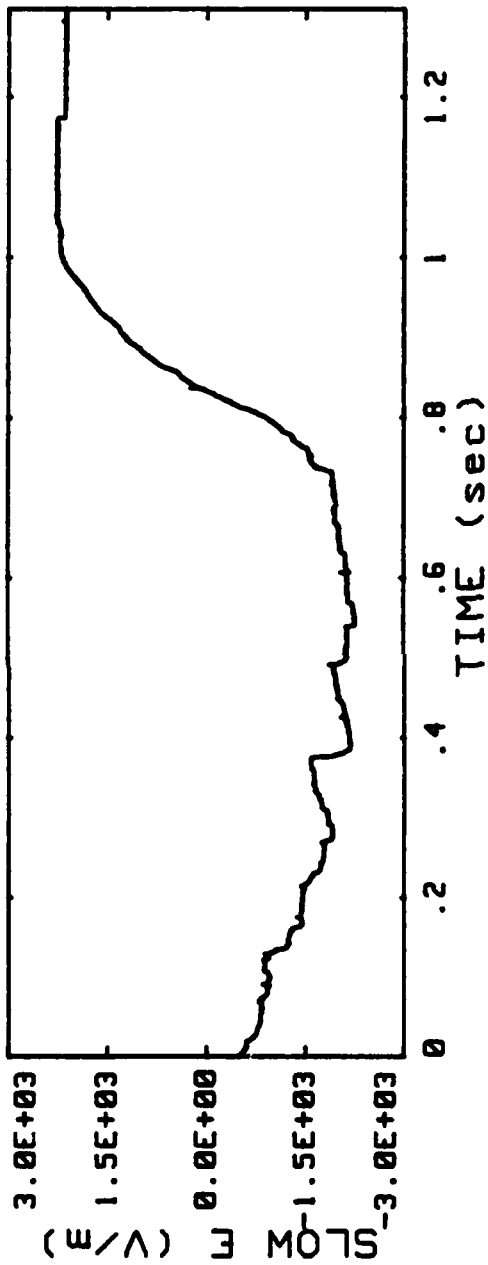
231214314.719 1987

Triggered Stroke (5.16 Km)

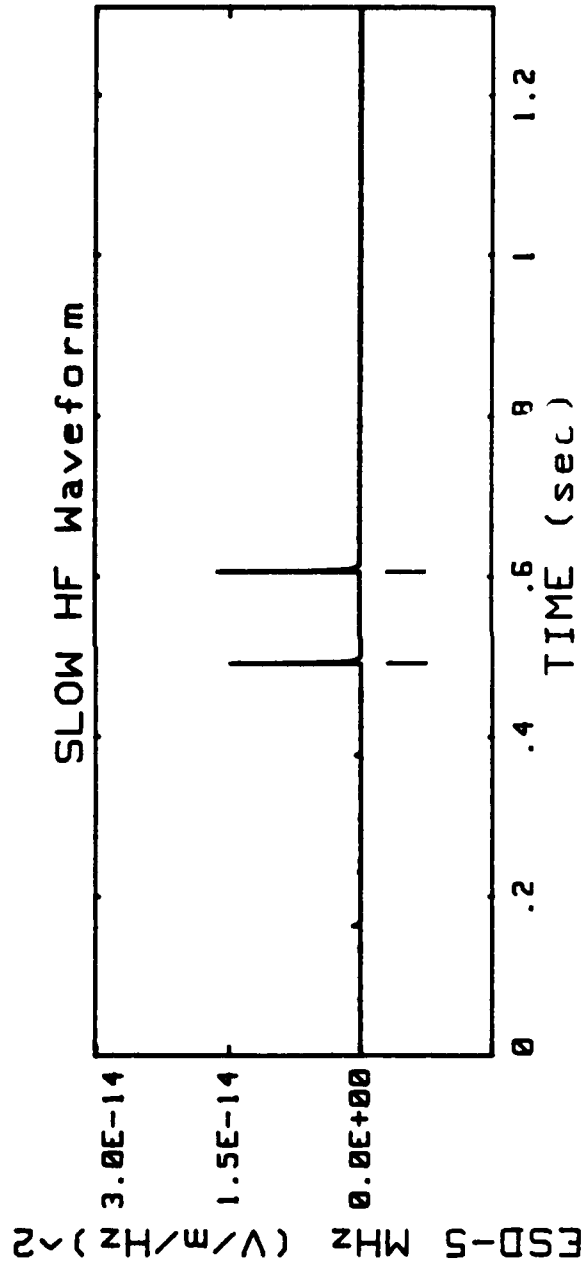


21:43:14.114 19 Aug 1987 (5.16 Km)

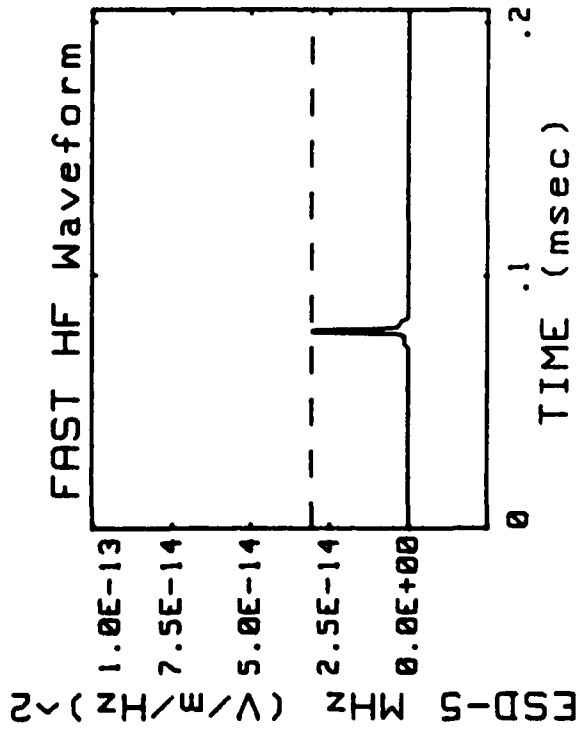
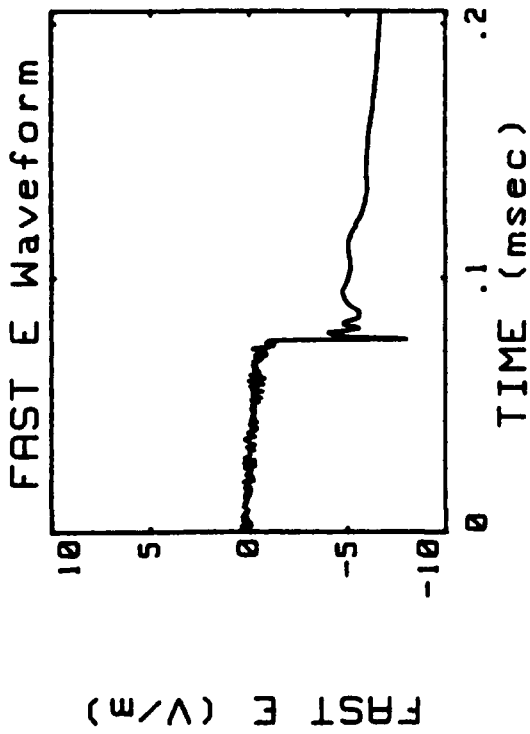
SLOW E Waveform



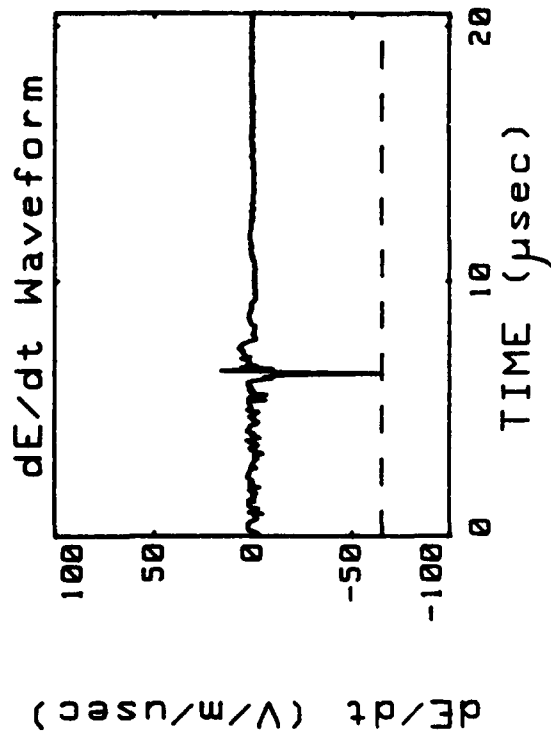
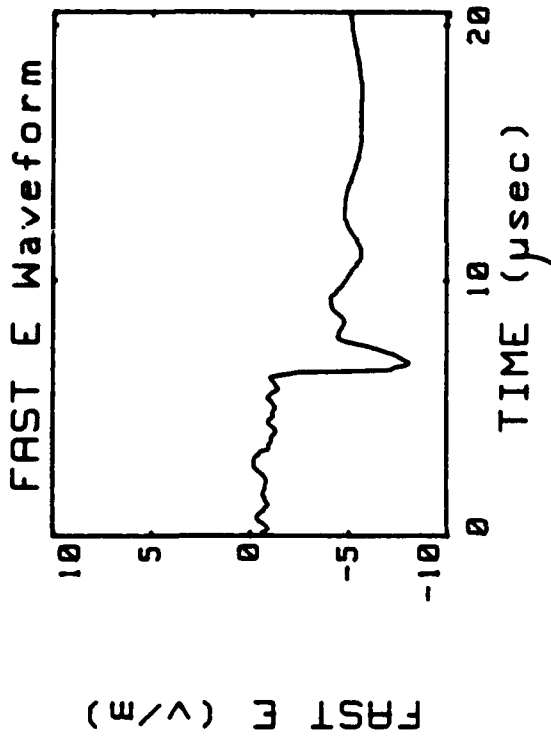
SLOW HF Waveform



231215350.660 1987

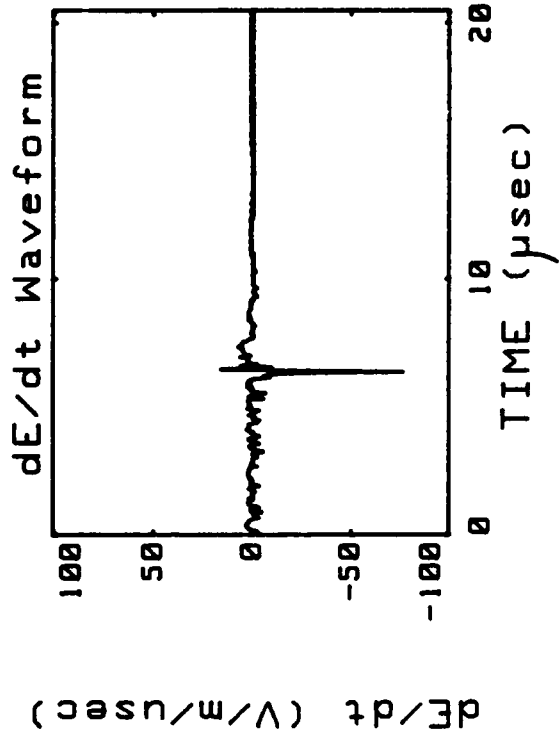
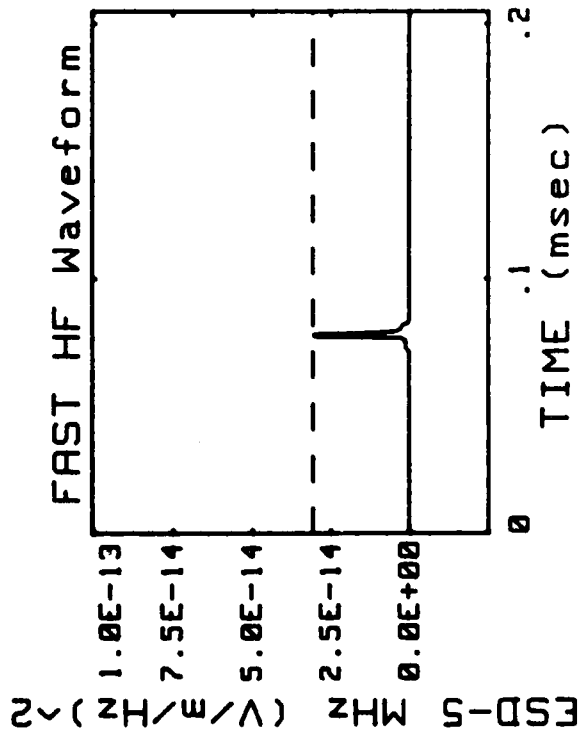
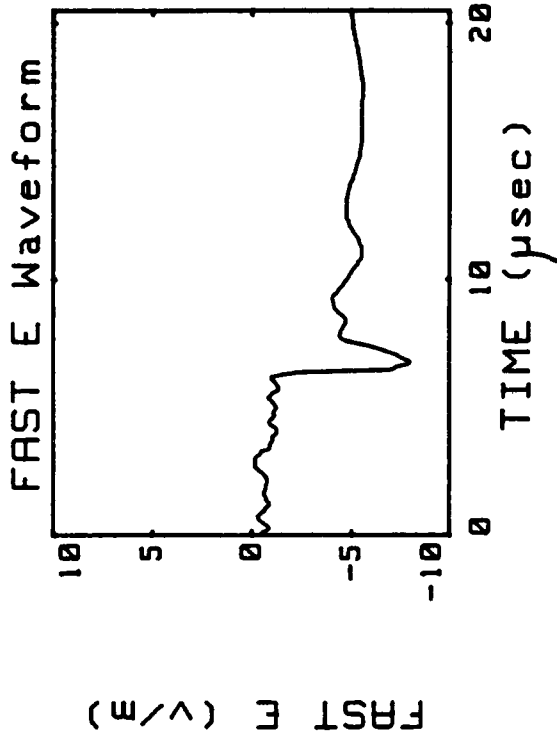
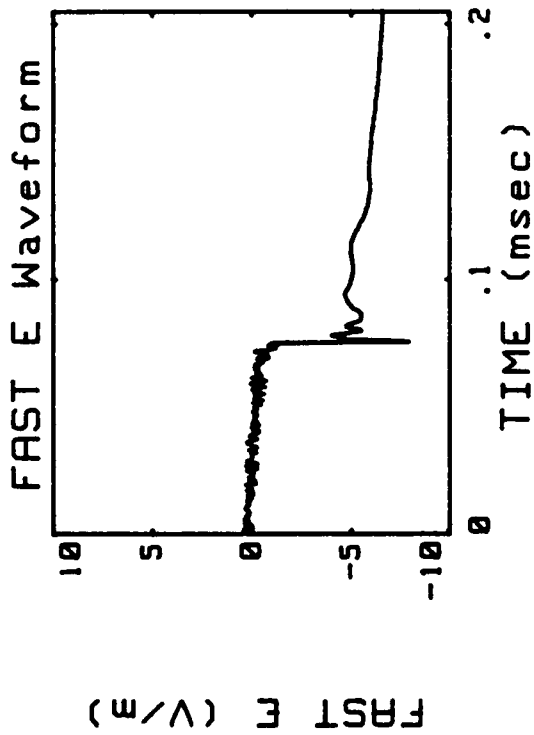


Triggered Stroke (5.16 Km)



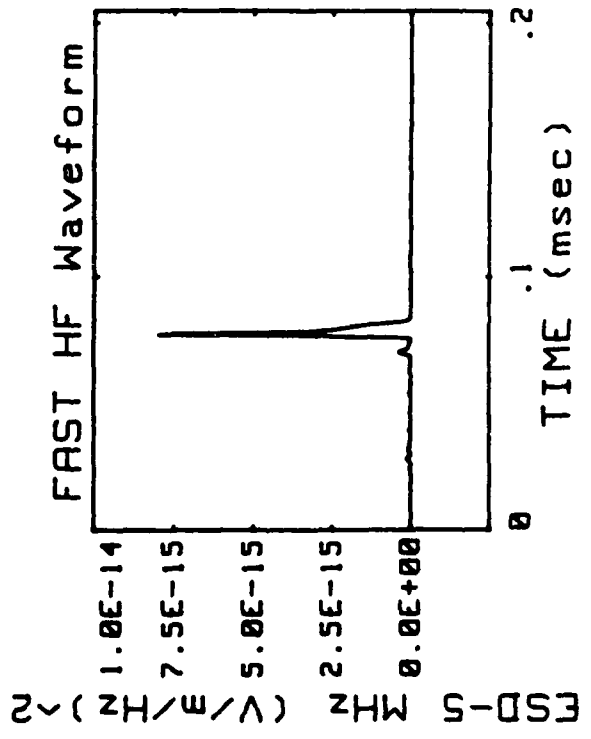
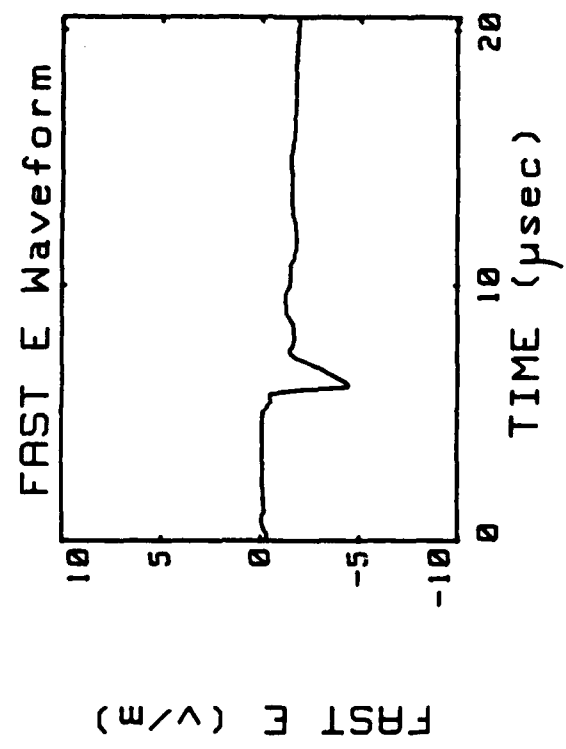
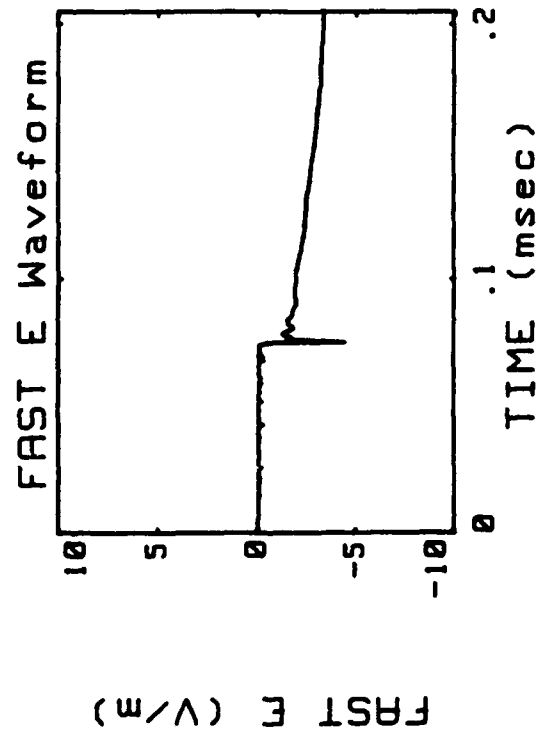
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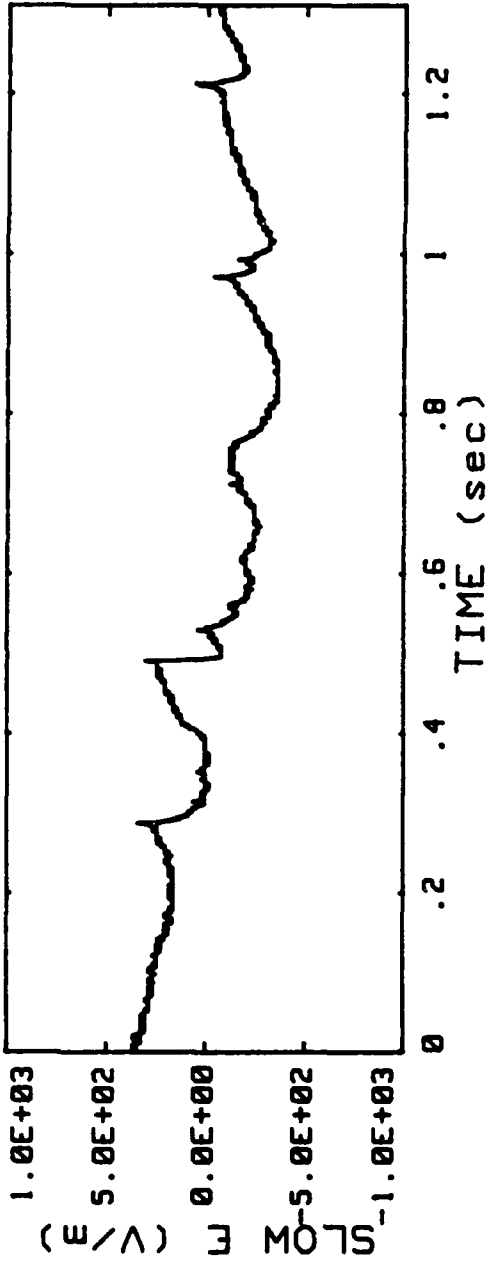
231215351.381 1987

Triggered Stroke (5.16 Km)



21:53:50.170 19 Aug 1987 (5.16 Km)

SLOW E Waveform



SLOW HF Waveform

