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JOVIAN RADIO EMISSION BELOW 5 MHZ

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The Voyager Planetary Radio Astronomy (PRA) experiment has been described in detail by Warwick et al. (1977) and Lang and Peltzer (1977). It essentially comprises a wide-band receiver which can be tuned to any of 198 discrete frequency channels in the range 1.2 kHz to 40 MHz, and a pair of orthogonal 10 m monopoles attached to the body of the spacecraft. In order to simplify operation, the experiment is commanded directly by the on-board Flight Data System (FDS) computer. A number of distinct modes of operation are possible. Of these we shall be concerned only with two, called General Science 3 (GS3) and General Science 2 (GS2). GS3 is a 'low-rate' mode in which the receiver steps sequentially through the 198 channels, from high frequency to low. Such a 'scan' is preceded by two status words, which act as a pair of dummy channels, bringing the total equivalent number of channels to 200. The received flux density at each channel is integrated for 25 msec; a holding period of 5 ms then follows; finally an eight bit data number (DN) which represents the integrated flux is transmitted. The receiver then steps to the succeeding channel. A complete scan thus takes six seconds. Samples are made in alternating senses of circular polarization, with the sense of polarization switching on any given channel in contiguous six second scans.

Channels 3 through 132 are equally spaced 200 kHz wide channels between 40.2 MHz and 1.2 MHz. The remaining channels are 1.2 kHz wide and are equally spaced between 1.326 MHz and 1.2 kHz. These are referred to as 'high-band' and 'low-band' respectively.

GS2 is a comparitively rare 'high-rate' mode. In this mode, data are sampled according to the following scheme: a pair of pre-chosen channels (usually either contiguous or equal, depending on frequency) are sampled simultaneously in opposing senses of circular polarization. Integration continues for 100 milliseconds. A 40 microsecond hold follows. The data are transmitted sequentially, 70 microseconds apart, concurrently with the next observation, which is at the same frequency pair. This continues for 24 seconds, at which time the sequence is reputed for a second 24 seconds with another frequency pair.

Figure 1 is a typical dynamic spectrum obtained by the Voyager 1 PRA experiment near Jupiter closest approach. The top panel represents received flux density, with darker areas representing increased flux densities. The lower panel shows polarization, with dark areas right circularly polarized and light ones left circularly polarized. Note that high-band emissions are usually strongly polarized, whereas low-band ones are everywhere unpolarized. Dynamic spectra such as Figure 1 are useful in displaying gross features in the emission, and for performing long-term statistical analyses (e.g. to determine the rotation period of the planetary magnetic field). Detailed information comes from the high-rate data, such as are shown in Figure 2. This plot shows 48 seconds of GS2 data; the left- and right-circularly polarized data are shown separately, as is the polarization. Each vertical line comprises 400 consecutive data points. Figure 3 is an alternative method of displaying the same data. The Figure comprises an 800 x 800 array of pixels, with 256 levels of grey. Each pixel represents a single DN. The different polarization states are not separated in this Figure, so that consecutive pixels are of alternating polarization. A single horizontal line in Figure 3 is thus directly equivalent to a LH and RH vertically aligned pair of lines in Figure 2. Figures 2 and 3 demonstrate that structure exists in the Jovian decametric emission on time scales of seconds or less. Such detail is obviously invisible to GS3 low-rate data scans. In order to examine such detail, plots in the form of Figure 2 have been produced for all the high rate data surrounding both Voyager-Jupiter encounters. During this production, two major facts concerning the GS2 data emerged. Firstly, no usable GS2 data were transmitted by Voyager 2. Figure 4 shows a plot of typical Voyager 2 GS2 data obtained near Jupiter closest approach. Spacecraft interference almost completely obliterates the Jovian signals. A signal enhancement technique was attempted, but this resulted in no major increase in the usability of the data. Secondly, Voyager 1 data (which, by contrast, was of a uniform high quality) was obtainable only for the period preceding encounter and for a few days after encounter. Later data were transmitted by the spacecraft, but apparently were never archived, due to budgetary constraints. (J.W. Warwick, private communication, 1982). Consequently, the GS2 Jupiter database is only about a-quarter of the size that might otherwise be expected. The usable database comprised a total of 870 48 seconds 'frames'. These frames are generally referred to by the time of acquisition, as recorded by the onboard FDS clock, which counts modulo 60 in units in which 48 seconds corresponds to 0.01 counts. (i.e. times which differ by unity according to the FDS clock are separated by 48 minutes of real time). Table I shows the frequencies used by the GS2 data mode for the Voyager 1 Jupiter encounter period.

Several of the GS2 frames had an appearance similar to that of Figure 5, in which short, repeated pulses of unpolarized emission were visible. We have termed this form of emission 'P' bursts, and have attempted to examine some of its major properties. We have divided those frames which have evidence of P bursts into two categories: high quality and low quality. High quality frames are those in which the P emission is well-defined and generally persists throughout a 24 second frequency pair. Low quality frames show pulse-like behavior, but poorly defined, and often persisting only for a relatively small fraction of a particular 24 second sample. Figures 6 and 7 provide series of examples of high quality and low quality frames respectively, in order to give an idea of the difference between the respective categories. In all 54 and 24 frames were placed in the categories. Tables II and III provide a listing of the contents of the two categories.

In many cases, a series of consecutive GS2 frames were taken. This enabled us to examine relatively long trains of P bursts. The first example of P bursts occurs in frame 15731.54 acquired on February 11th, about three weeks prior to Jupiter encounter (Figure 8.) Note from Table II that this was the first in a sequence of eight high quality frames. The pulses are visible only in the second 24 seconds of the frame, corresponding to a frequency of 560 kHz. This is true in all examples of P bursts until February 23rd, when the GS2 observation frequencies were changed (Table I), beyond which time P bursts were not visible in the data.

A first step in attempting to understand P bursts was to try to correlate their occurrence with features in GS3 dynamic spectra. Periods of GS2 data acquisition appear in such spectra as white data dropouts. Figure 9 shows a typical dynamic spectrum containing a period of GS2 data acquisition, in which data intense P burst activity was apparent. Unpolarized emission is apparent in the spectrum throughout this period. This is usual for much of the time prior to Jupiter encounter. Unpolarized emission is thus frequently observed in the low-frequency GS2 data. Relatively few observations, however, include any significant degree of P mode emission. On several occasions, P burst either commence or conclude during GS2 data acquisition. The onset and conclusion of P burst 'events' is relatively sudden (Figure 10). Post Jupiter encounter dynamic spectra based on GS3 data are similar to pre-encounter spectra, with one important difference--low-band emissions are always strongly polarized. The sense of polarization is not constant,

[illegible]

[illegible] experiment [illegible] frequency [illegible] us to distinguish between two plausible [illegible] for P bursts: namely, whether emission occurs [illegible] over a range of frequencies near 1 MHz (a 'broad-band' [illegible]), or whether, like L bursts and S bursts, they are narrow-band emissions which exhibit a frequency drift (the 'narrow-band' model). In fact, apart from the [illegible] and frequency of occurrence [illegible] indistinguishable from [illegible] frequency [illegible].

[illegible] are not included. Also included are [illegible] III longitude (1965 epoch), and the apparent phase of Io as seen from the spacecraft. No pattern is obvious in the Io phases, but the system III longitudes appear to be lumped together into a series of distinct groups; this is an artifact: GS2 data were returned approximately [illegible] system III system, and so

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such grouping is to be expected.

Many of Jupiter's higher frequency radio emissions have a component which is strongly influenced by the phase of Io, relative to the observer. We have used an harmonic dial method (Chapman and Bartels, 1943) to determine if the occurrence probability of P events is a function of the phase of any of the Galilean satellites or sub-spacecraft system III longitude. Figures 11 plot the information for Io phase and system III longitude on harmonic dials. We obtain values of p_c, the probability of chance occurrence that the centroid of the points lies at least as far from the origin as the observed centroid of 0.177 and 0.615 respectively for these two cases. Neither of these values is significant at the 5% level (contiguous data were combined into a single datum prior to the construction of the harmonic dials). Results for the other three Galilean satellites are also not significant. Consequently, there is no evidence that the phase of any Galilean satellite has any influence on P emissions. Figure 11a, however, reiterates the apparent connection between P bursts and system III longitude. It is noteworthy that no high-quality P bursts are ever seen near 112 degrees, when the spacecraft also returned GS2 data (this longitude was sampled a total of 14 times). There is, therefore, the possibility of apparent system III modulation of the events, in the form of a lack of them around 112 degrees. This may perhaps be due to occultation of the source.

Effective sampling of the 560 kHz, 1 kHz wide channels occurs every 140 microseconds in the GS2 mode. Clearly, oversampling is thus taking place. Figure 12 demonstrates this, by showing a small portion of frame 16009.53 which contains an excellent example of P bursts. The shape and width of the noise background is indicative of highly oversampled data. For the same bandwidth, signal to noise varies as the square root of integration time. Figure 13 shows the same data as Figure 12, with 20 data points integration, thus giving an effective sampling rate of ~0.5 kHz. Events are clearly visible above the noise now. They are highly periodic, of very uniform flux, and symmetric. From a knowledge of spacecraft-Jupiter geometry, we can estimate the typical flux density of a P burst as $\sim 2.10^{-20}$ W m^{-2} Hz^{-1} at the standard distance of 4.04 AU (this value is based on an examination of several high-quality P burst frames). This value is too low to be detected from near Earth orbit. Consequently, there is little hope of extending the P burst data set in the foreseeable future.

As of this date, no plausible theoretical explanation of P bursts has been developed.

Table I

Voyager 1 GS2 frequencies

July 6 1978	7.99 MHz , 0.56 MHz
Feb 23 1979	9.52 MHz , 26.1 MHz
Mar 20 1979	0.10 MHz , 0.12 MHz

Table II

High-quality Jovian P bursts

1. 15731.54 through 15732.01
2. 15803.52
3. 15851.04
4. 15851.07
5. 15855.56, 15856.03
6. 15863.26, 15863.28
7. 15865.57
8. 15856.27
9. 15880.46, 15880.48
10. 15893.10 through 15893.17
11. 5900.41 through 15900.45
12. 15905.40, 15905.41
13. 15910.33
14. 15960.11
15. 15975.08, 15975.09
16. 15984.58 through 15985.00
17. 16009.53

Table III

Geometry and PRF of P burst groups

Group	III	Io	PRF (Hz)
1.	39.73	198.04	2.276
2.	326.83	325.93	0.861
3.	327.48	218.38	2.028
4.	257.10	286.30	2.625
5.	38.60	319.20	1.292
6.	255.00	9.40	1.584
7.	327.50	26.20	1.125
8.	40.10	43.00	1.292
9.	37.90	126.50	2.505
10.	38.89	211.44	1.662
11.	256.24	262.46	1.000
12.	40.10	296.05	2.646
13.	181.50	328.90	1.902
14.	181.50	305.40	2.292
15.	255.56	46.05	1.313
16.	181.03	112.67	1.653
17.	183.40	282.20	3.042

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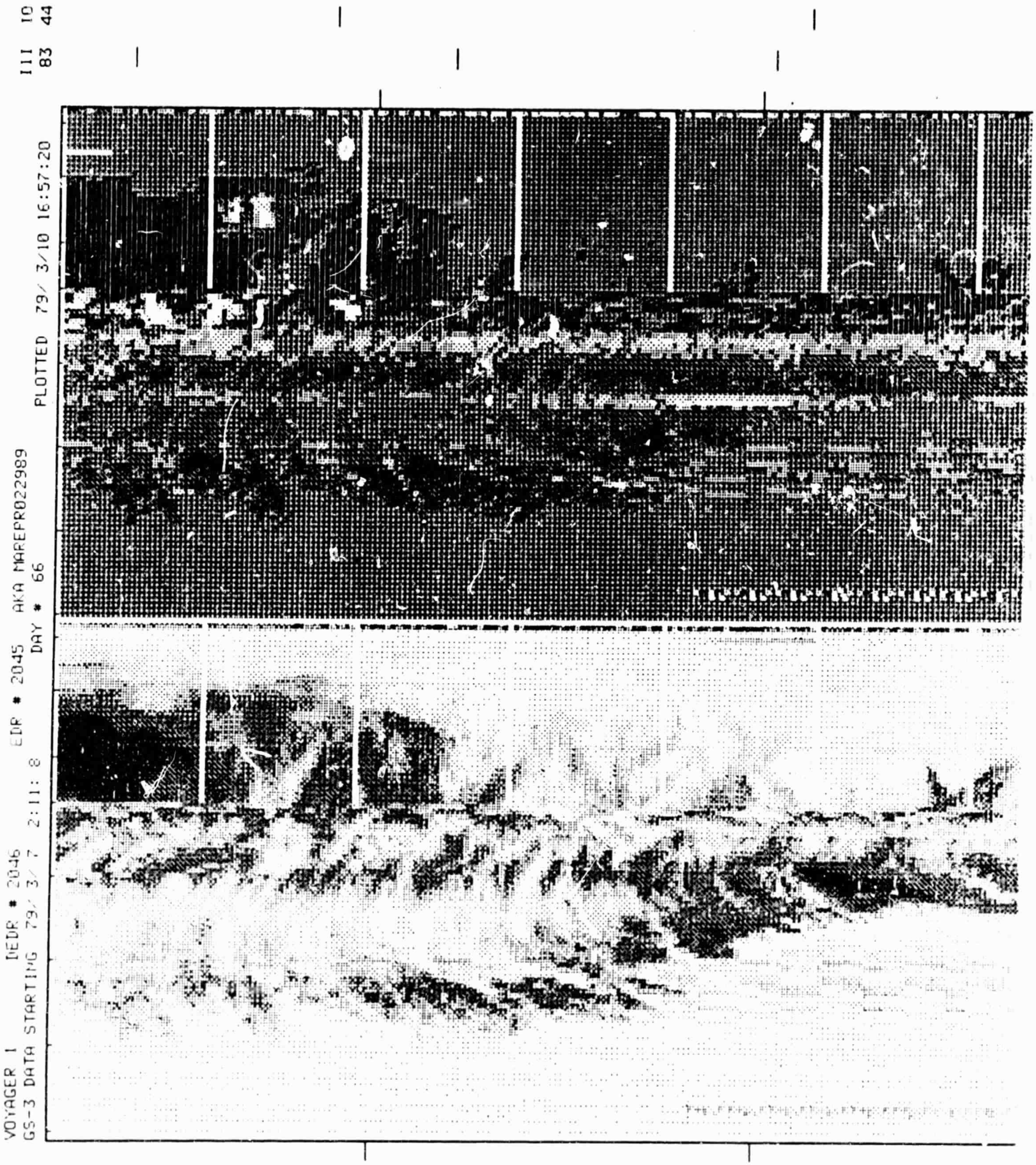

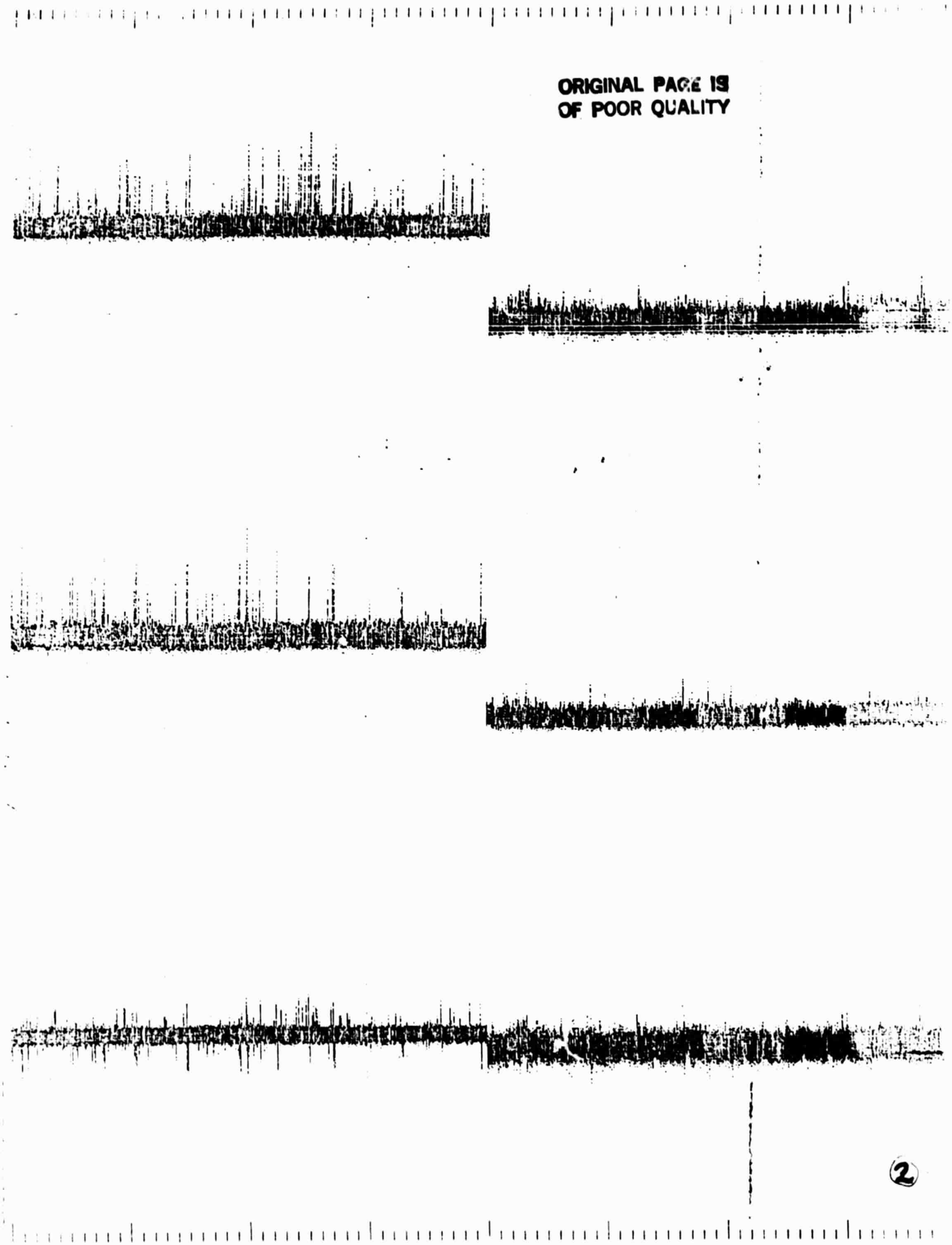

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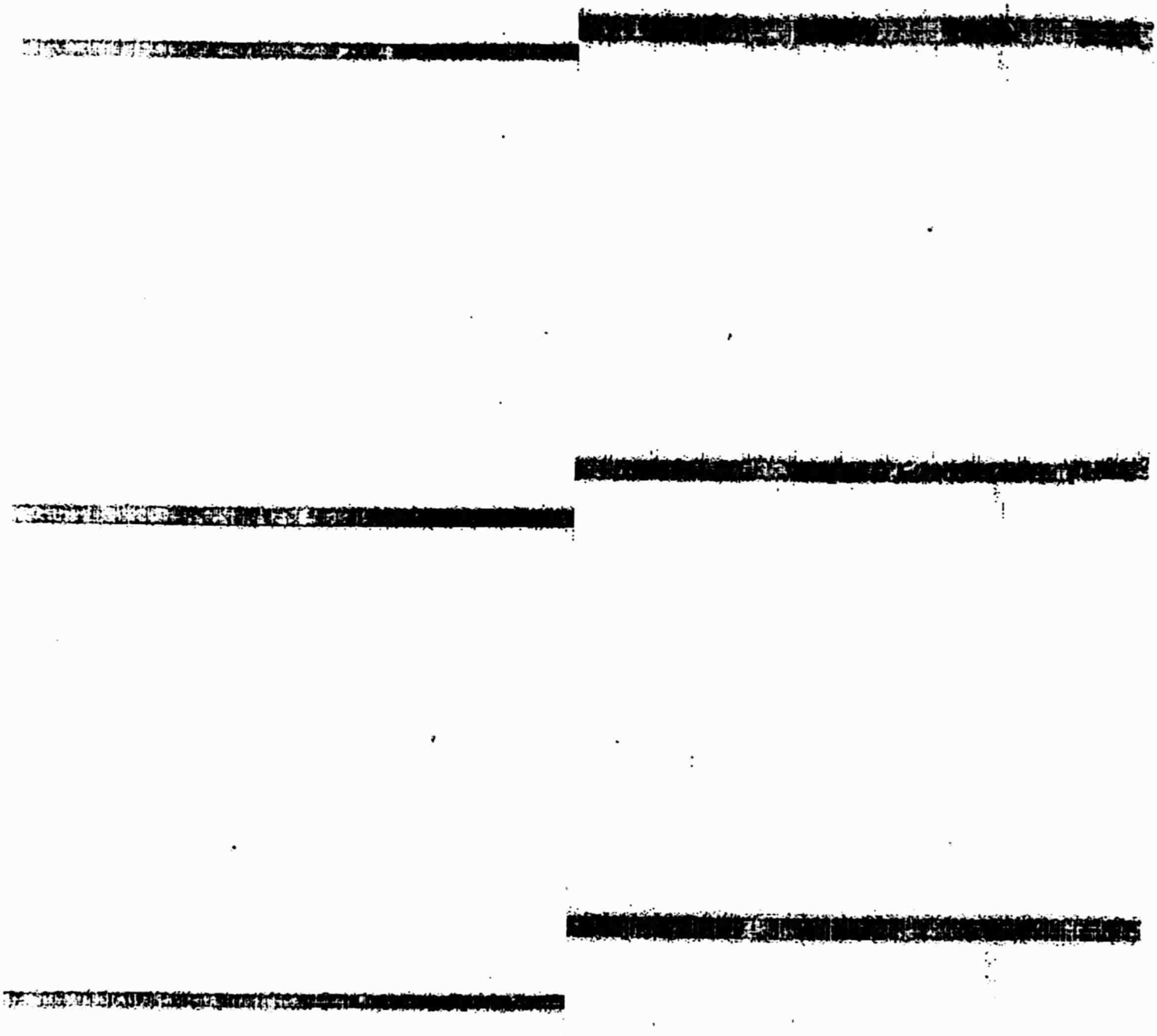

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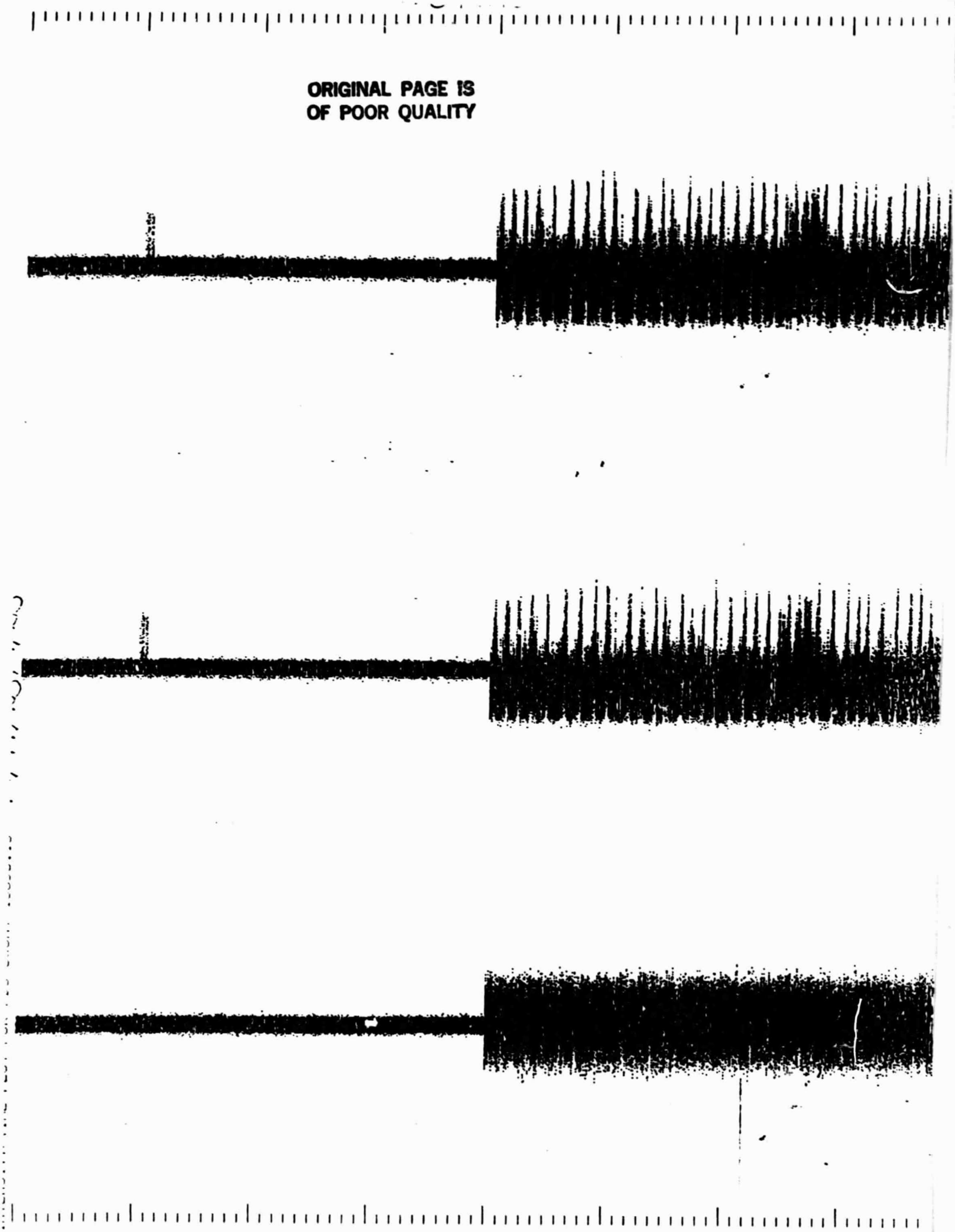

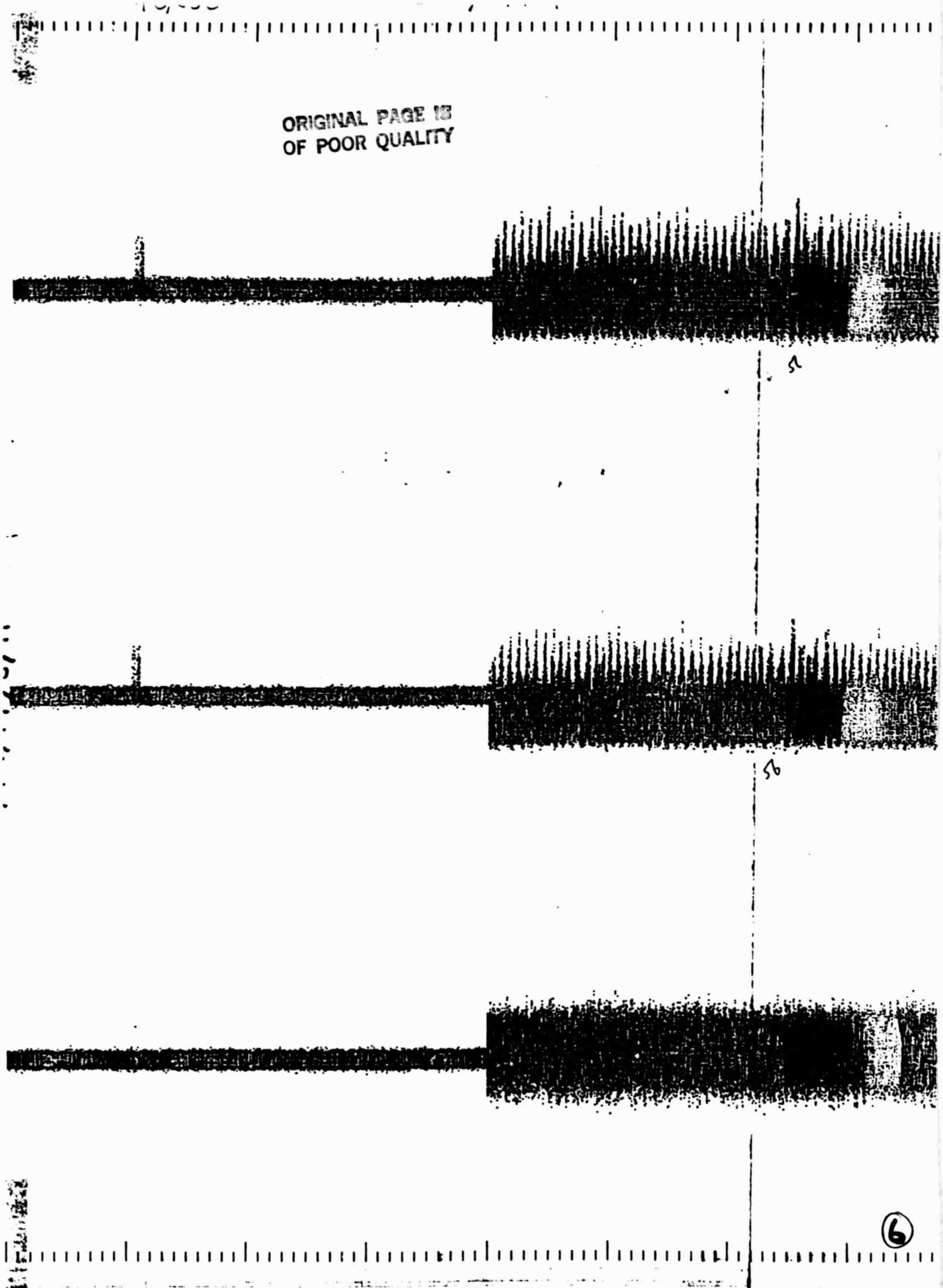
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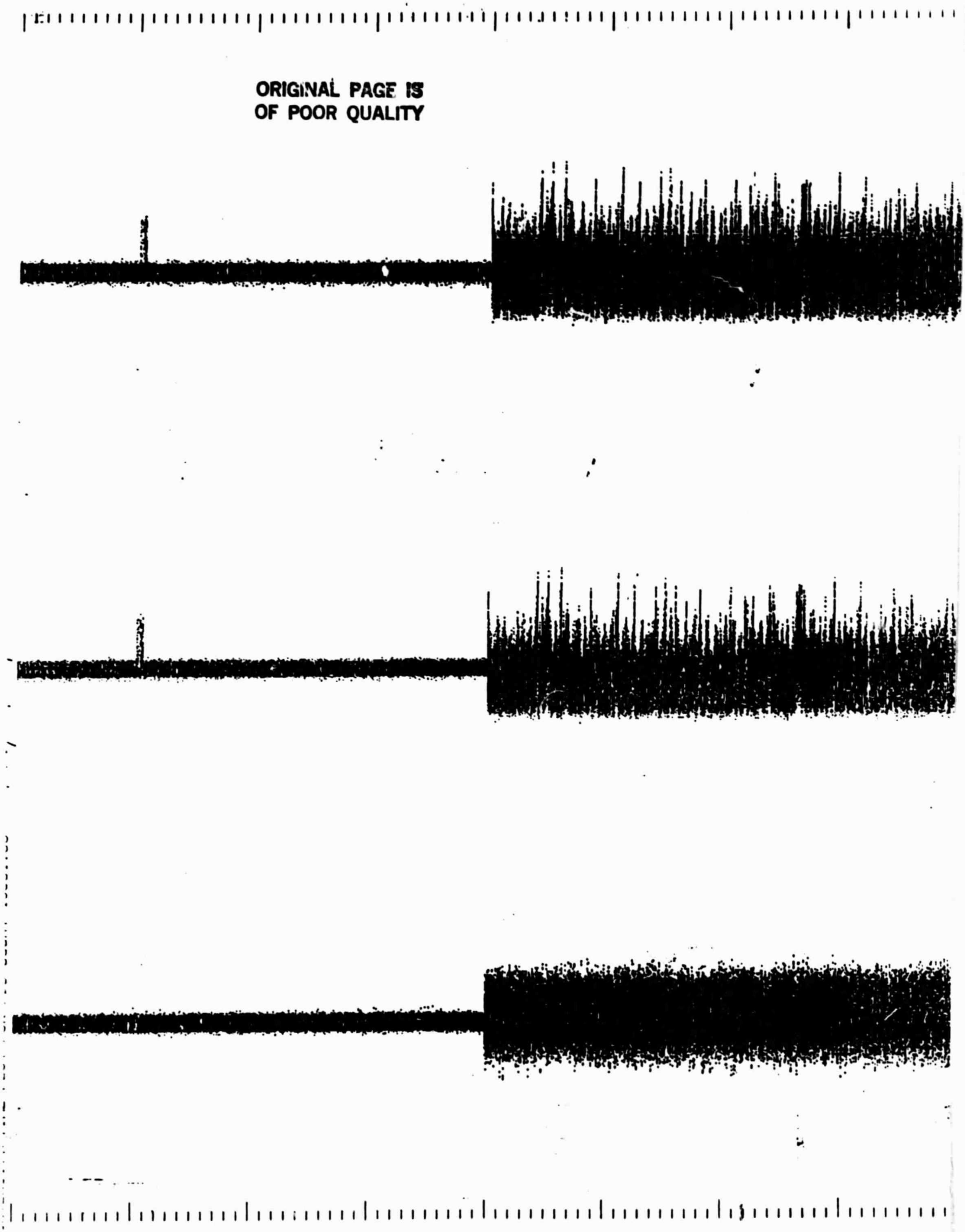

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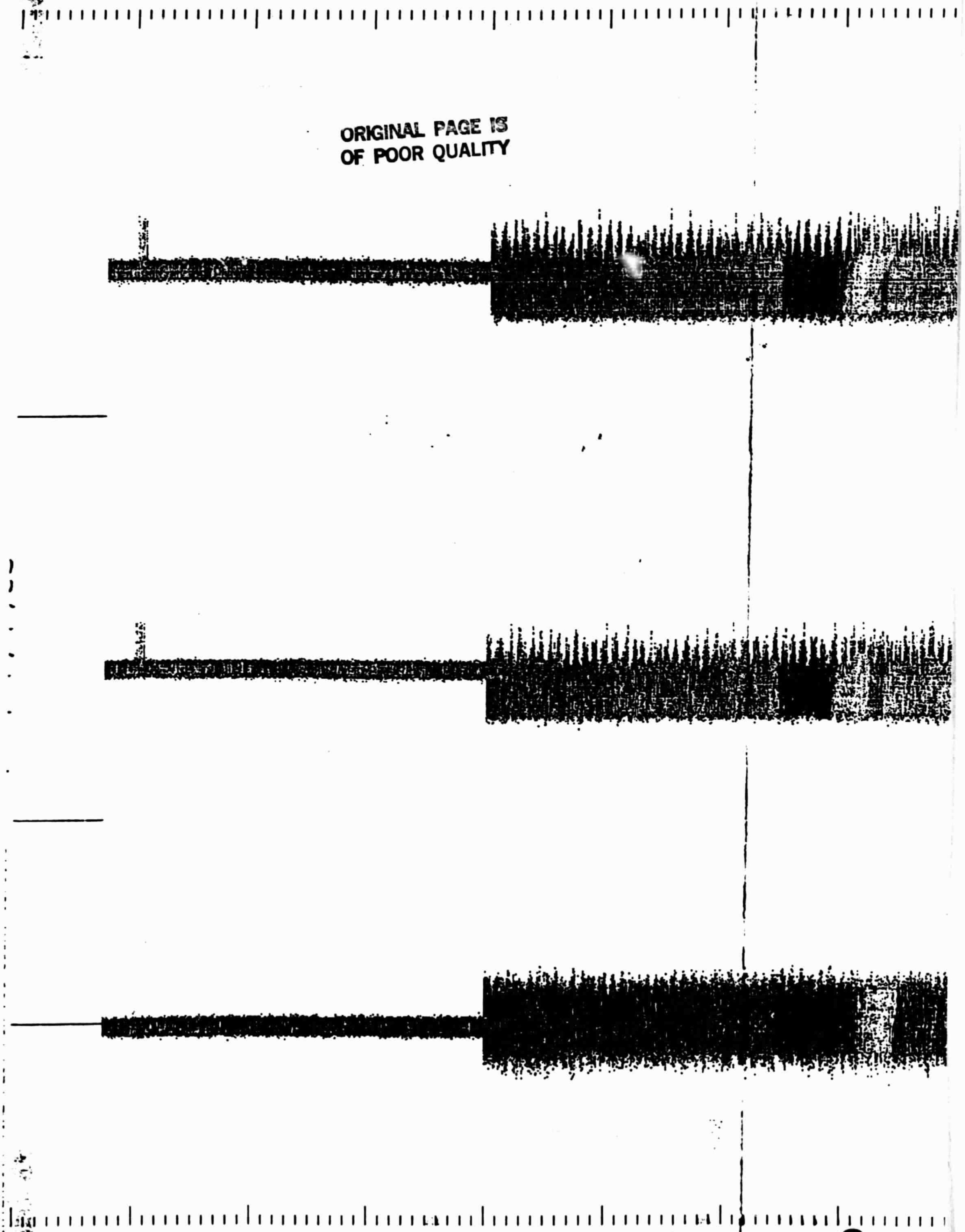

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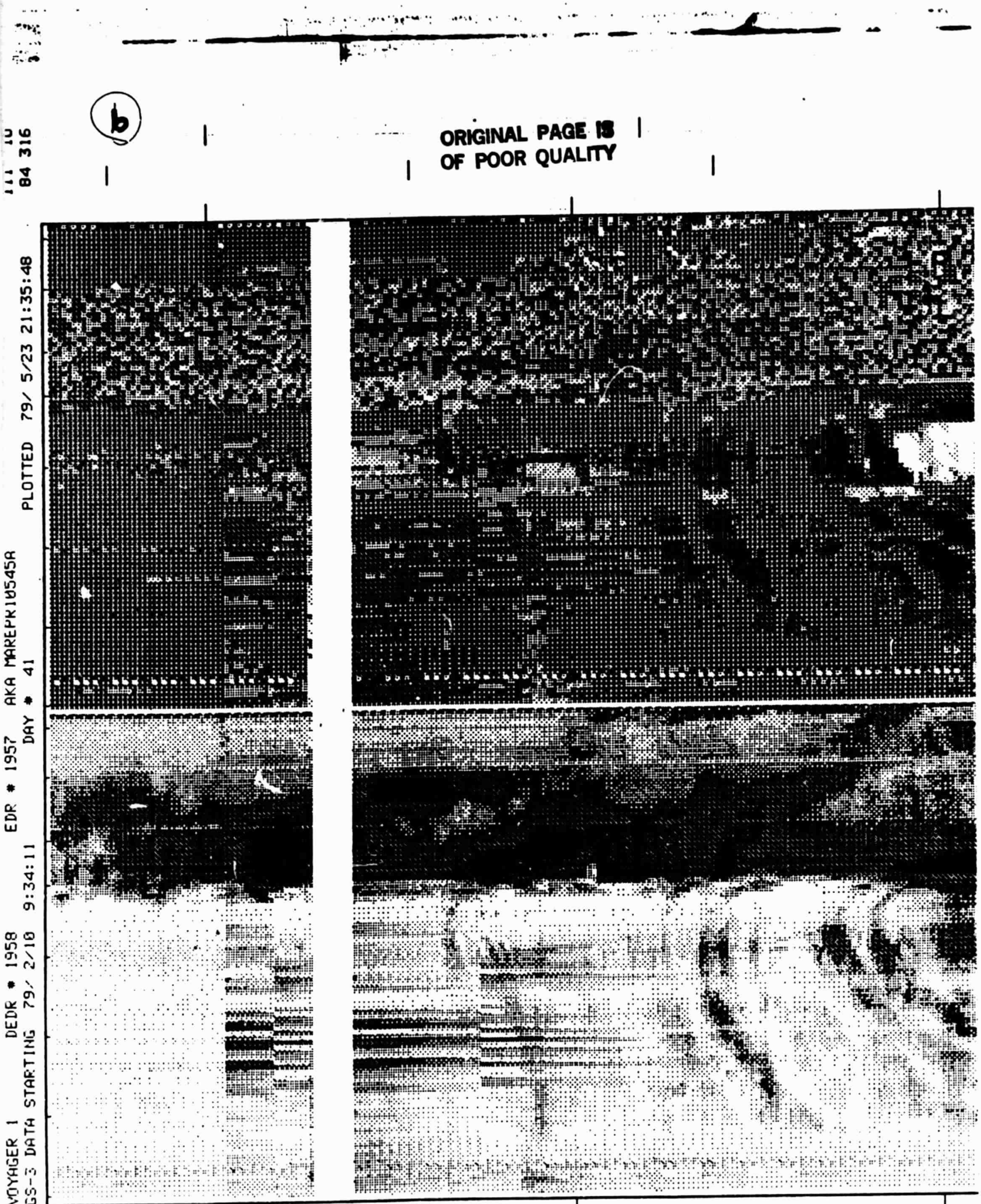

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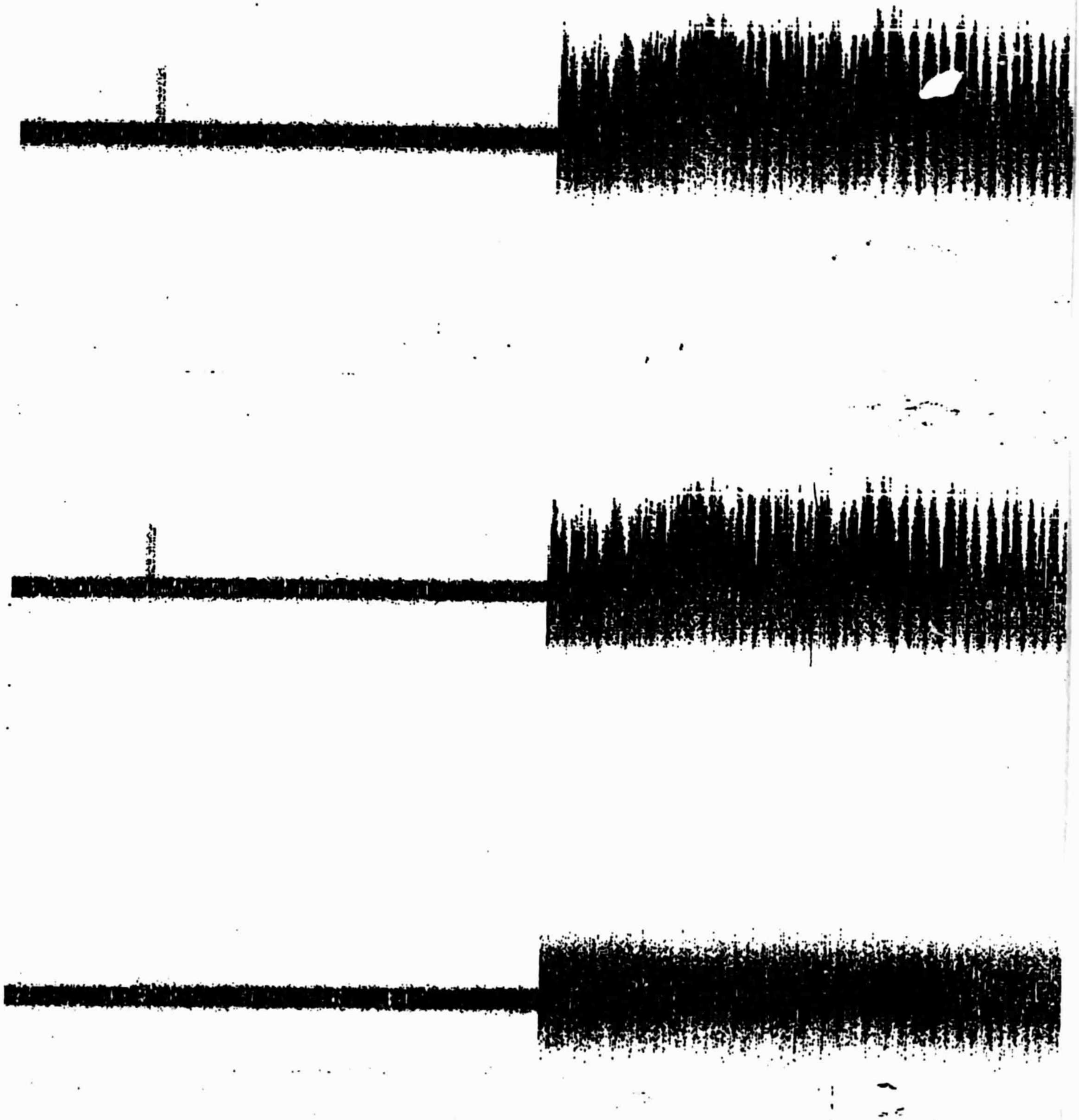

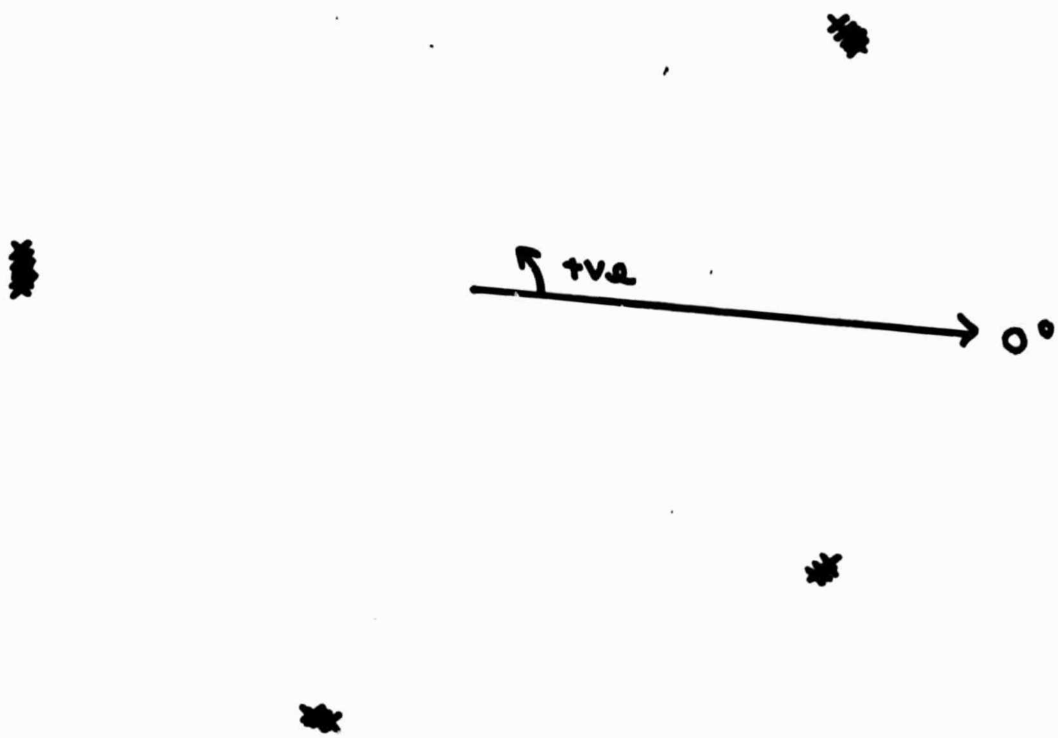
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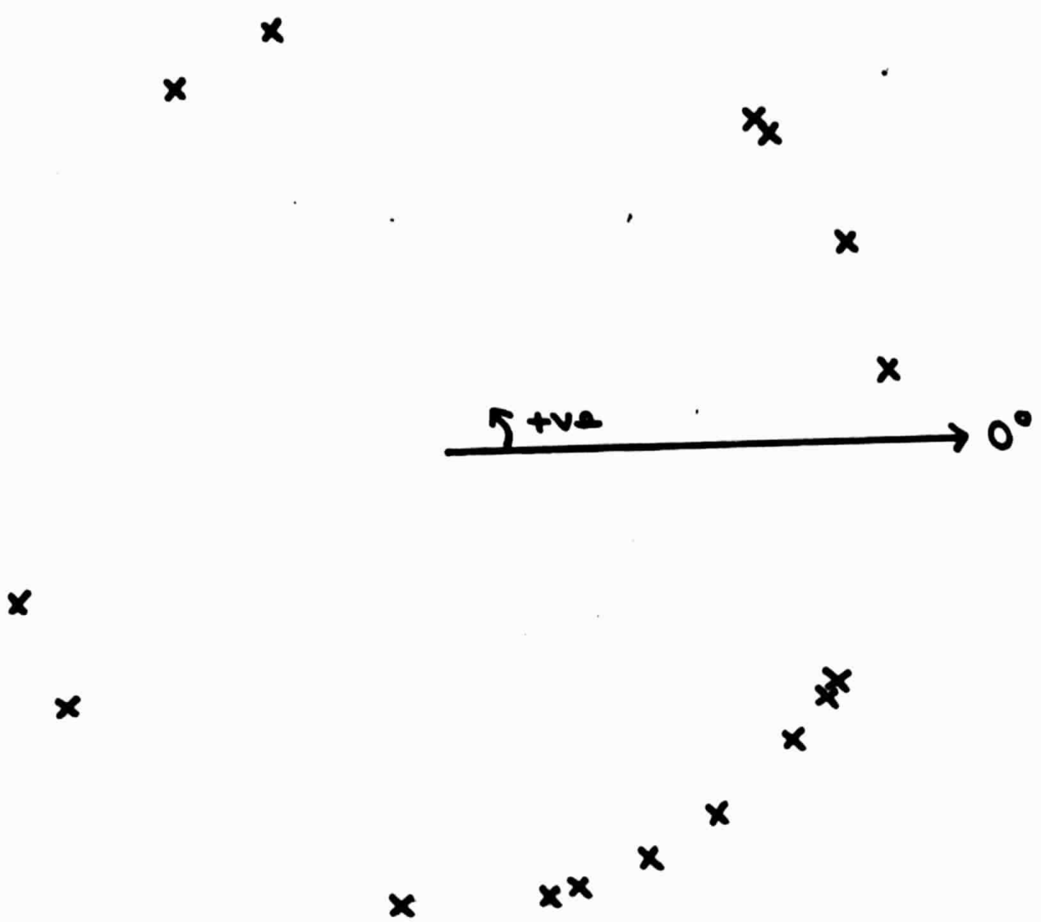

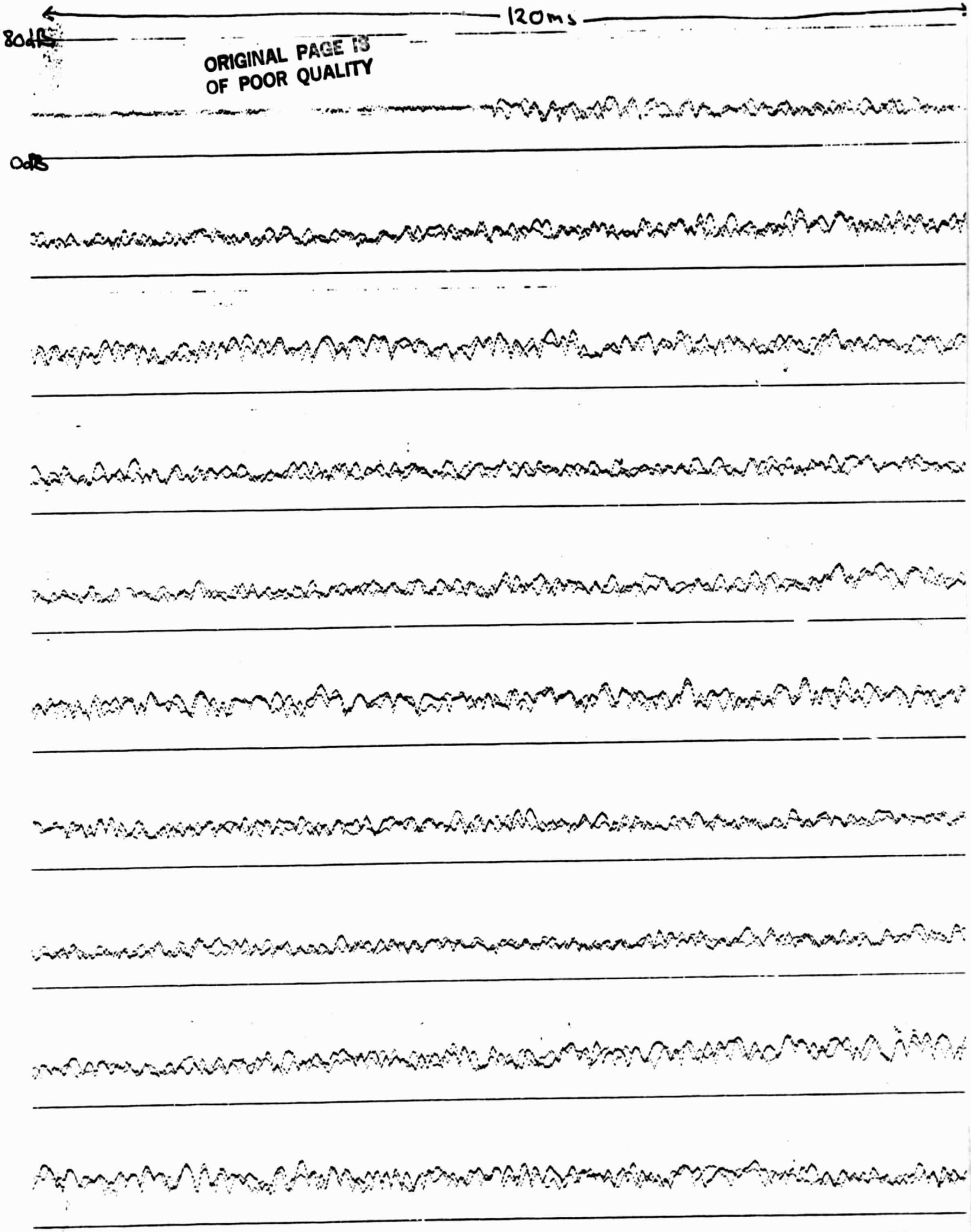
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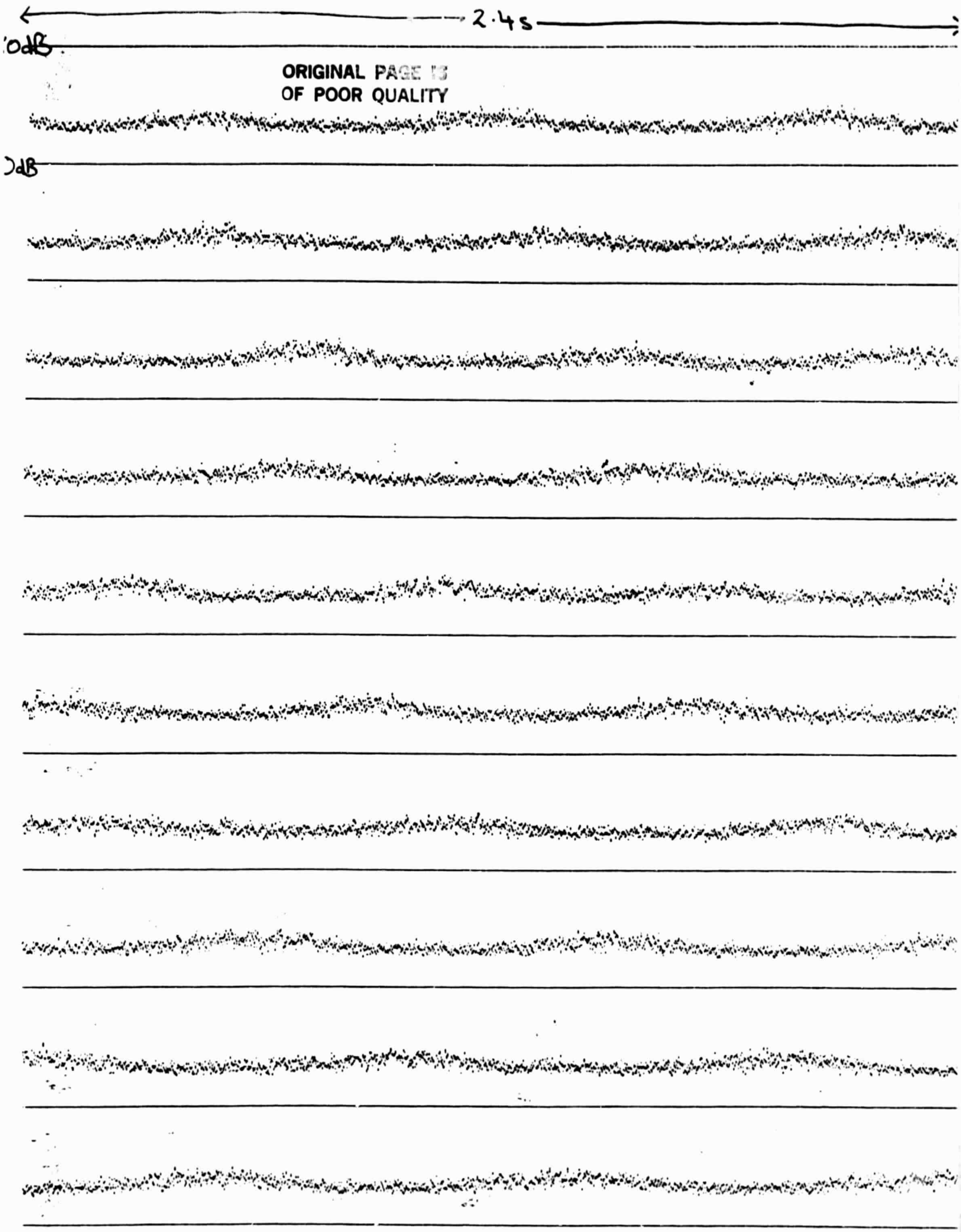
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