ACCELERATOR EXPERIMENT: Tune vs. Intensity in the Booster

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1. The beam was accelerated to 8 GeV with a normal cycle. The Linac ran at high-intensity mode. The debuncher was on. Two turns were injected. The accelerated beam was held at the constant intensity of 100 mA, that is 1.5×10^{12} ppp injected. Without any further tuning of the ensemble: Linac, 200-MeV line and Booster, the tunes were measured by detecting spontaneous coherent motion during the first 100 μs. The fractional part of the two tunes is displaced in Fig. 1 versus charge at injection. Typical variation of the current from pulse to pulse was 5%. No intensity dependence is noticed in this range. Indeed only a change of at most one part over one thousand in the fractional tune was expected in this range. The tune measurement accuracy was of about ± 0.0015, as also one can see from Fig. 1.

2. By acting on elements of the 200-MeV line, it is possible to enlarge the beam, coherently with dipoles and decoherently with quadrupoles, and get it scraped before it is injected in the booster or in the booster itself. Since the available aperture is, in this way, filled up, the beam size remains unchanged, while the intensity decreases by increasing either the dipole kick or the quadrupole defocussing effect. The results are shown in Figs. 2, 3, 4 and 5. The elements of the 200-MeV line used are, respectively, VT9, HT9, Q7, Q7. The charge was detected at

50 μsec and the tunes at 60 μs, with exception of Fig. 5 where the tunes were measured at 200 μs. The dependence with the intensity is quite noticeable for the vertical tune, and seems to be absent for the horizontal tune. The slope of tune versus intensity is exactly the same in all four cases.

3. The Booster was then run DC with no RF. All the other conditions remained unchanged. Tunes were again displayed versus intensity with the same techniques. The results are shown in Fig. 6 (Q7, tunes at 80 μs), Fig. 7 (Q7, tunes at 200 μs), and Fig. 8 (HT9, tunes at 200 μs). In all three cases charge was detected at 80 μs. The slope of tune versus intensity is the same in all the three cases, but somewhat smaller than in the previous cases with bunched beam.

4. What we measured is, clearly, the <u>coherent tune shift</u> due to the beam image fields. The coherent tune shift has been calculated by J. Laslett[1]. The formula is

$$\Delta\nu = -\frac{N r_p R}{\pi\nu\gamma}\left[(\alpha_M+\alpha_E) + \frac{\alpha_E}{B\beta^2\gamma^2}\right]$$

where $\Delta\nu$ is the tune shift and

N, protons per turn	1.5×10^{12}
r_p, proton classical radius	1.5347×10^{-16} cm
R, average machine radius	7547.17 cm
ν, no. of betatron oscillations	6.8
$\beta = v/c$ (for 200 MeV kinetic energy)	0.56616
$\gamma = 1/\sqrt{1-\beta^2}$	1.2132
$\beta^2\gamma^2$	0.4718
$r_p R/\pi\nu\gamma$	0.0447×10^{-12} cm^2

and B is the bunching factor, which is 1 for coasting beam and 0.50 for bunched beam.

From these numbers we derive

B	0.5	1
$\Delta\nu/N$	-0.022×10^{-12}	-0.017×10^{-12}
$\alpha_M+\alpha_E+\dfrac{\alpha_E}{B\beta^2\gamma^2}$	0.49	0.38

and from this

$$\alpha_E = \frac{\xi_1}{h^2} = 0.0519 \text{ cm}^{-2}$$

$$\alpha_M = \frac{\xi_2}{g^2} = 0.218 \text{ cm}^{-2}$$

where ξ_1 and ξ_2 are the two Laslett image coefficients, h is the "equivalent" vacuum chamber half aperture and g is the "equivalent" magnet gap half aperture.

By taking h = 3.5 cm and g = 1.75 cm we get

$$\xi_1 = 0.636 \qquad \text{and} \qquad \xi_2 = 0.668$$

which are very close to the value calculated by Laslett

$$\xi_1 = \xi_2 = \frac{\pi^2}{16} \sim 0.617 \text{ (!)} .$$

Thus the measurement seems to be in excellent agreement with the theory. Nevertheless, one should note that the magnets extend only over 60% of the machine circumferance and the vacuum pipe over the remaining 40.

A.G. Ruggiero

1. J. Laslett: "On Intensity Limitations Imposed by Transverse Space-Charge Effects in Circular Particle Accelerators". Proceedings of the 1963 Summer Study on Storage Rings, Accelerators and Experimentation at Super-High Energies, Brookhaven, page 325.

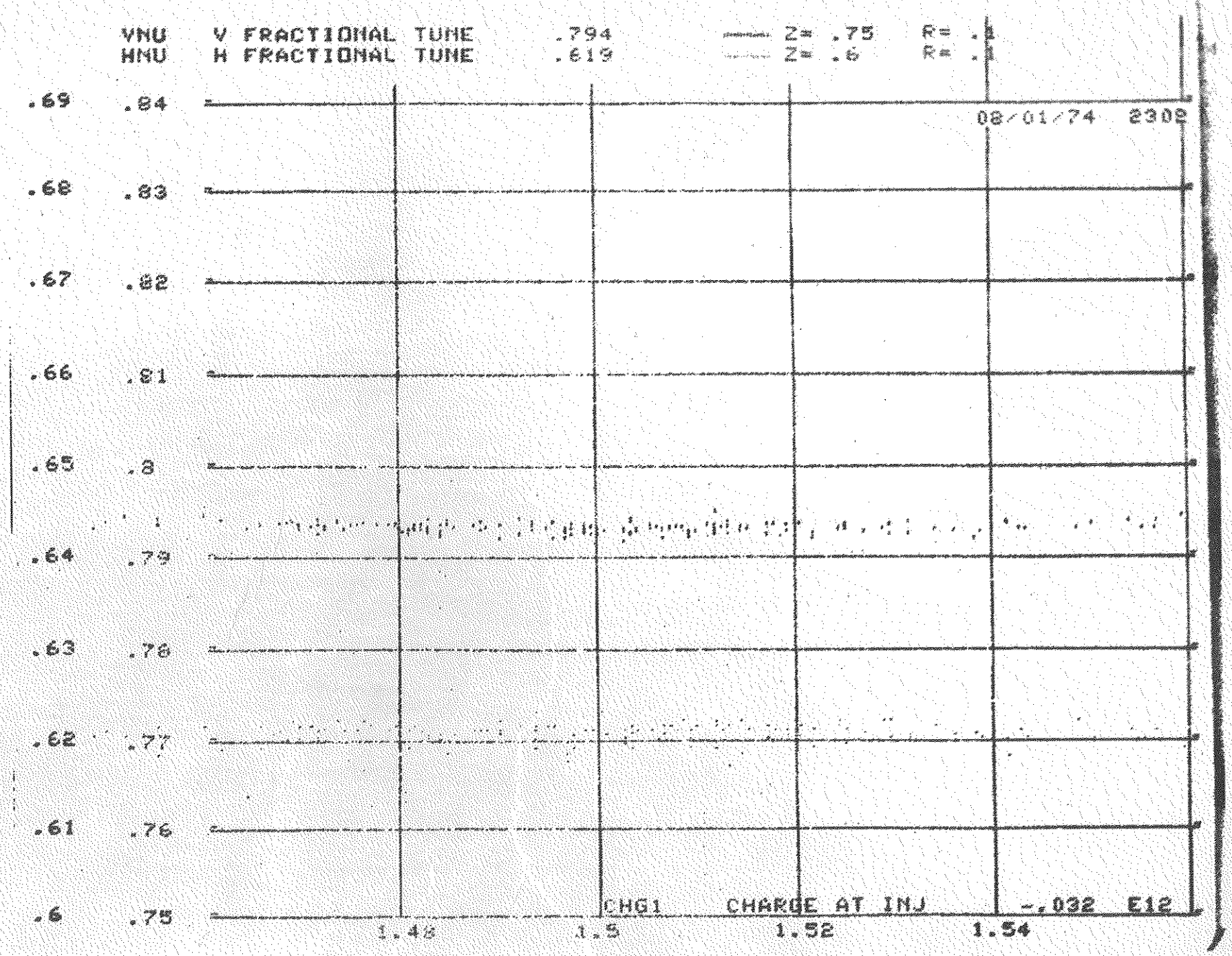

Figure 1

EXP-65

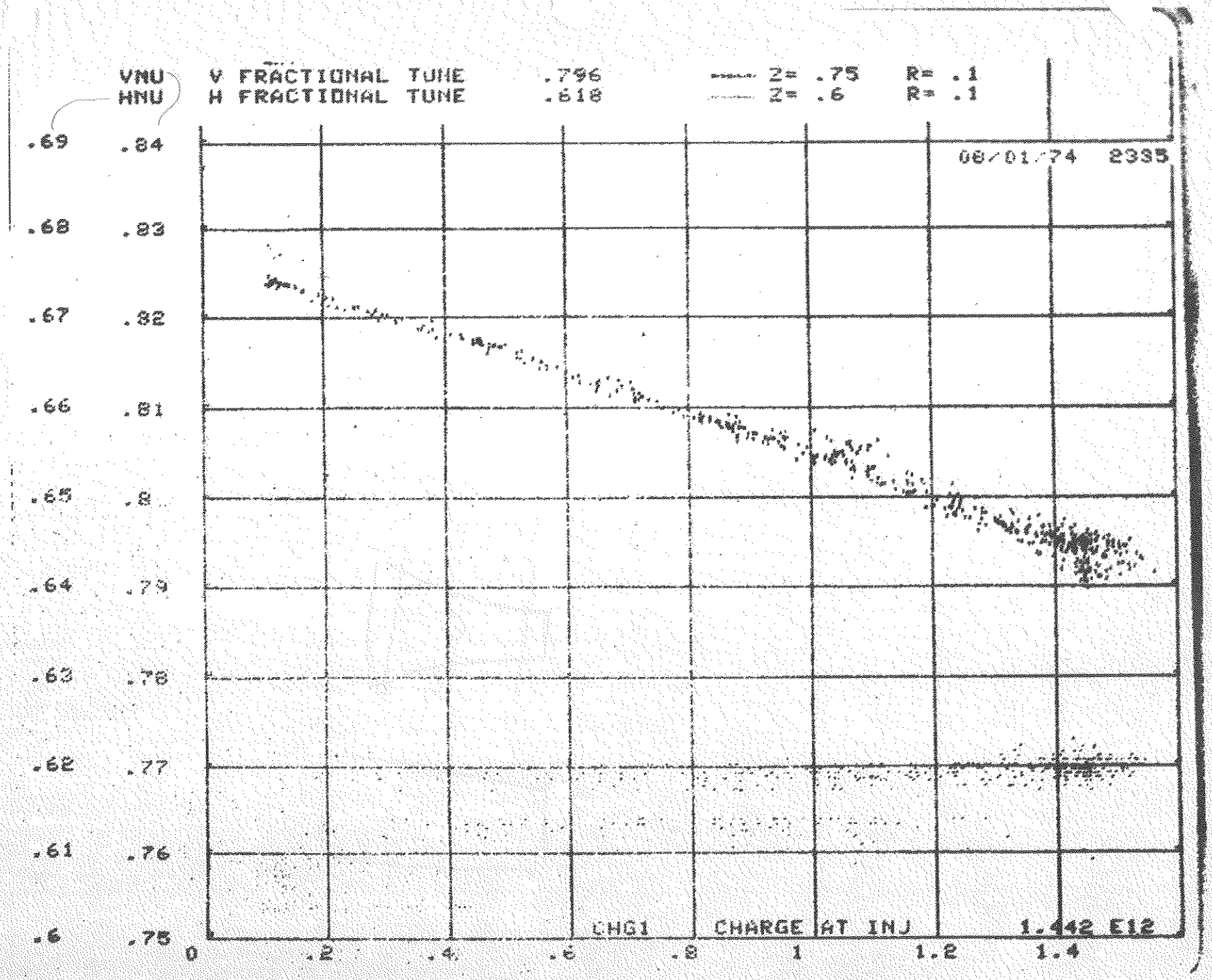

Figure 2

EXP-65

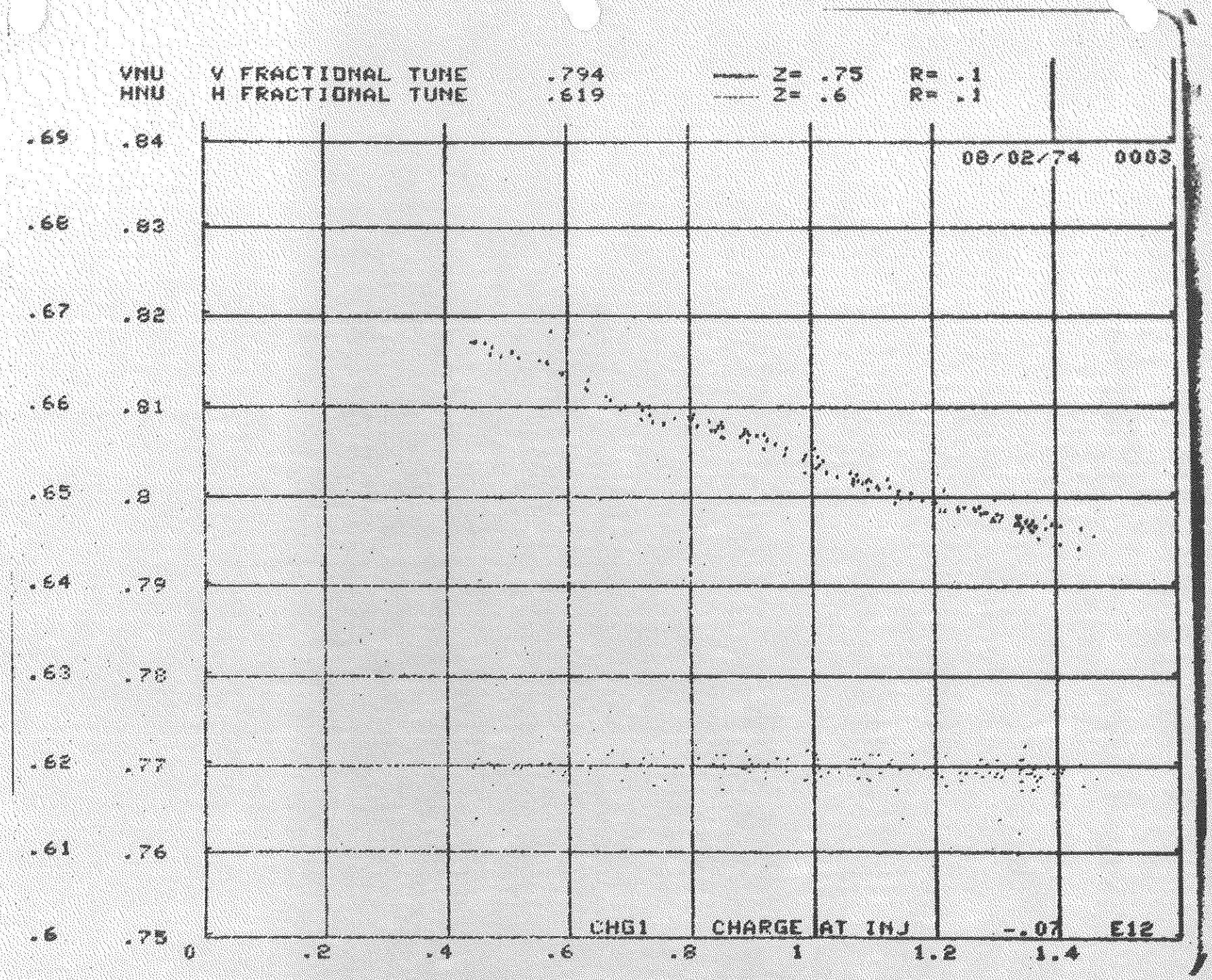

Figure 3

EXP-65

Figure 4

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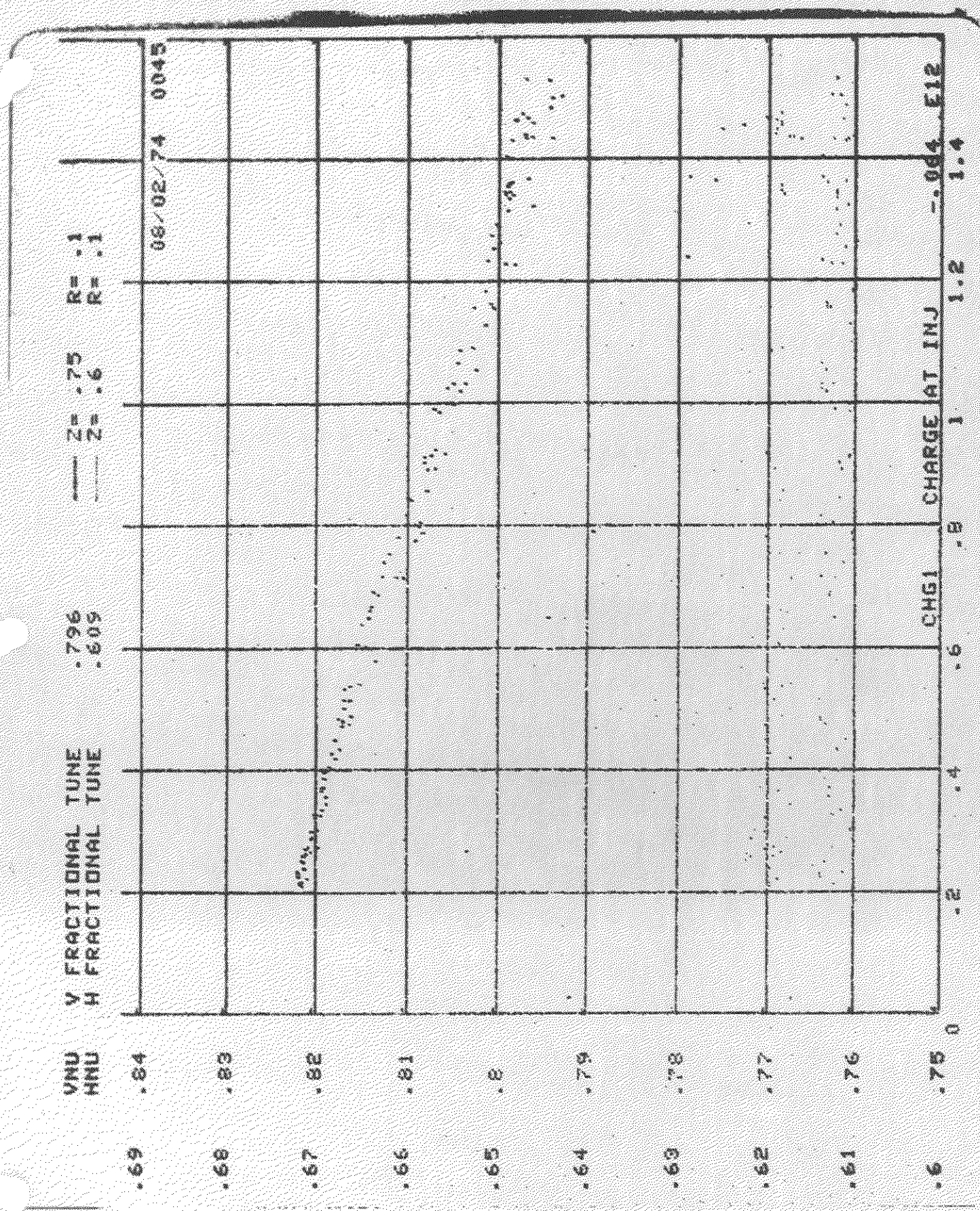

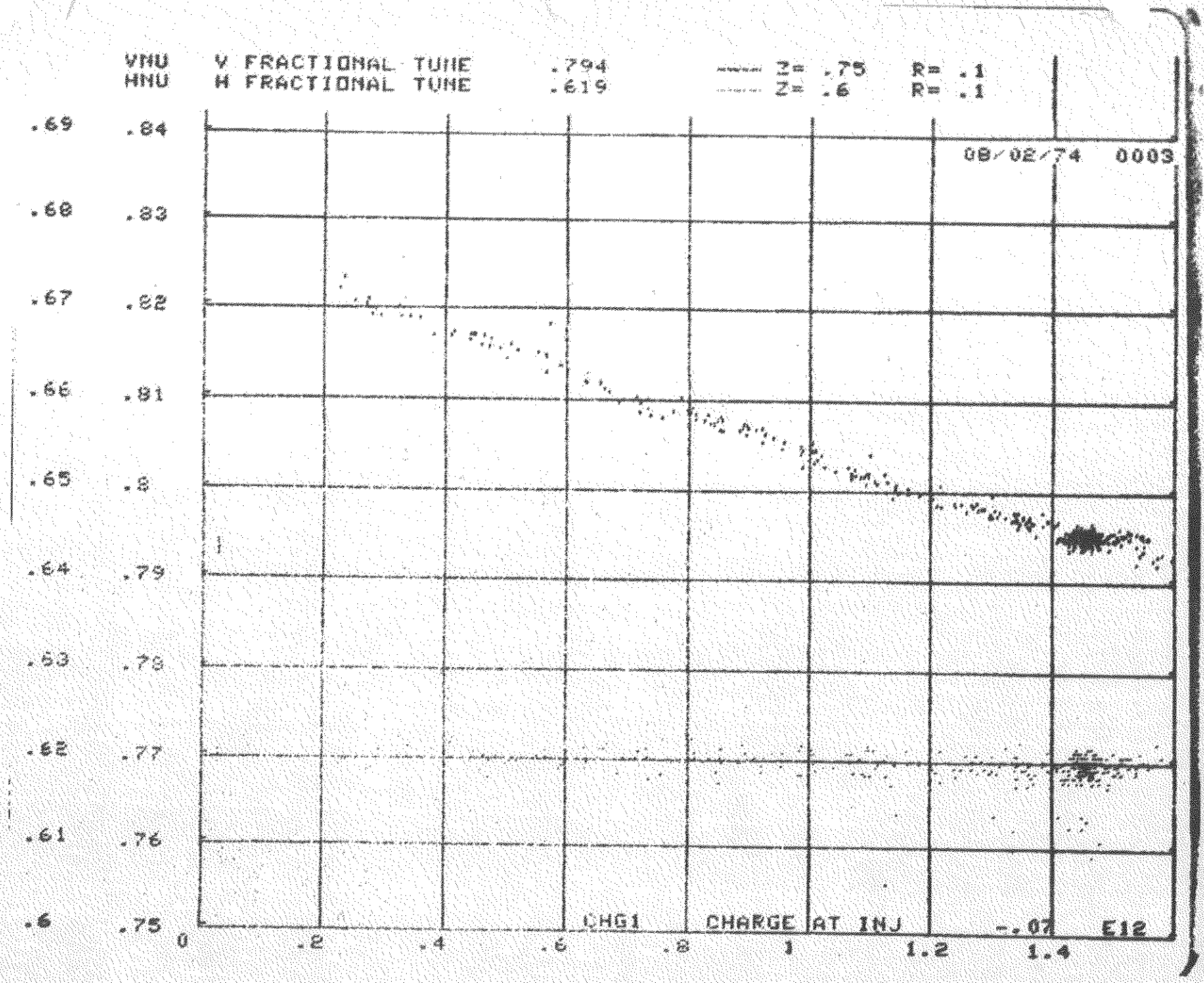

Figure 5

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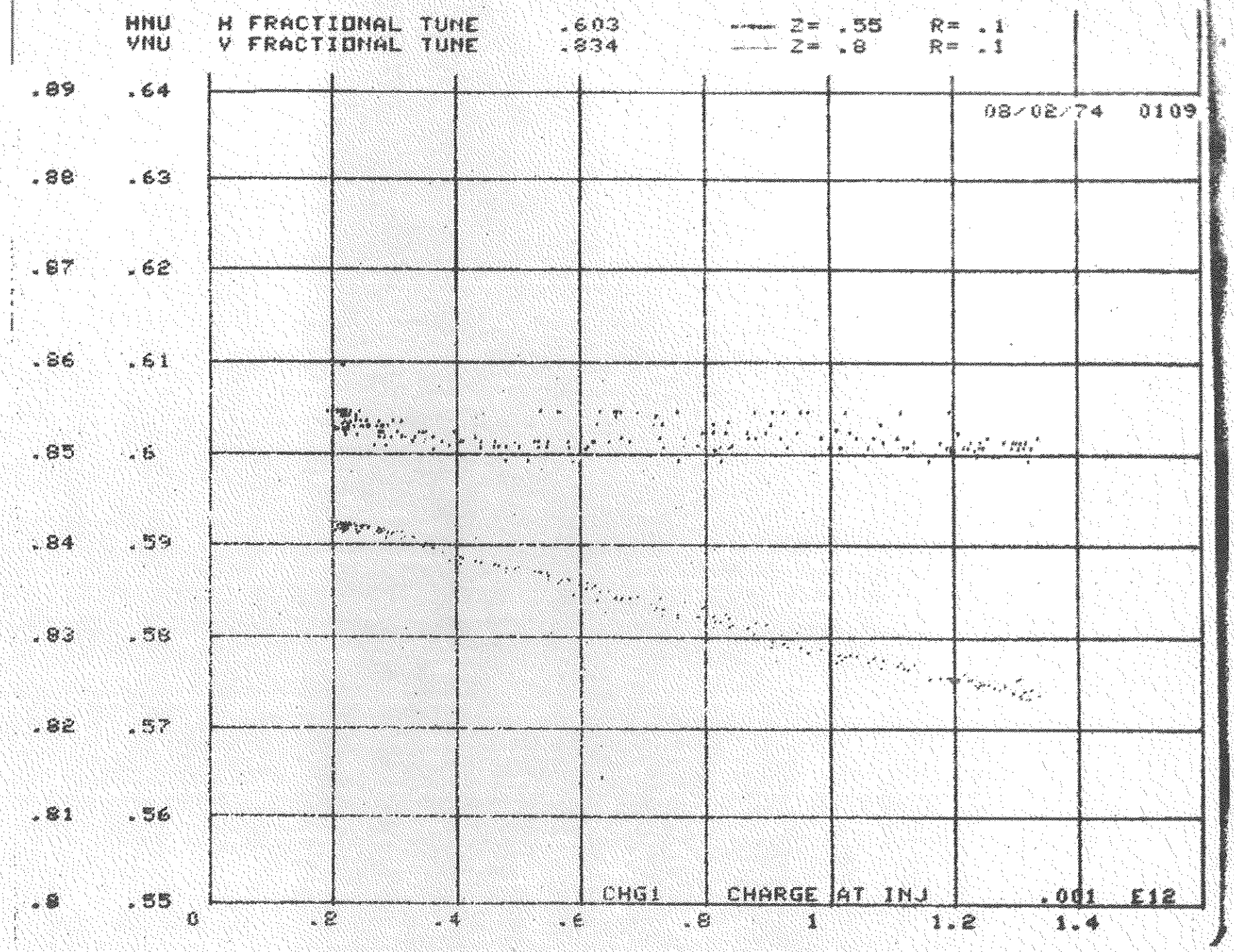
Q7 tune ~ charge 80 μs 2018



Booster DC

Figure 6

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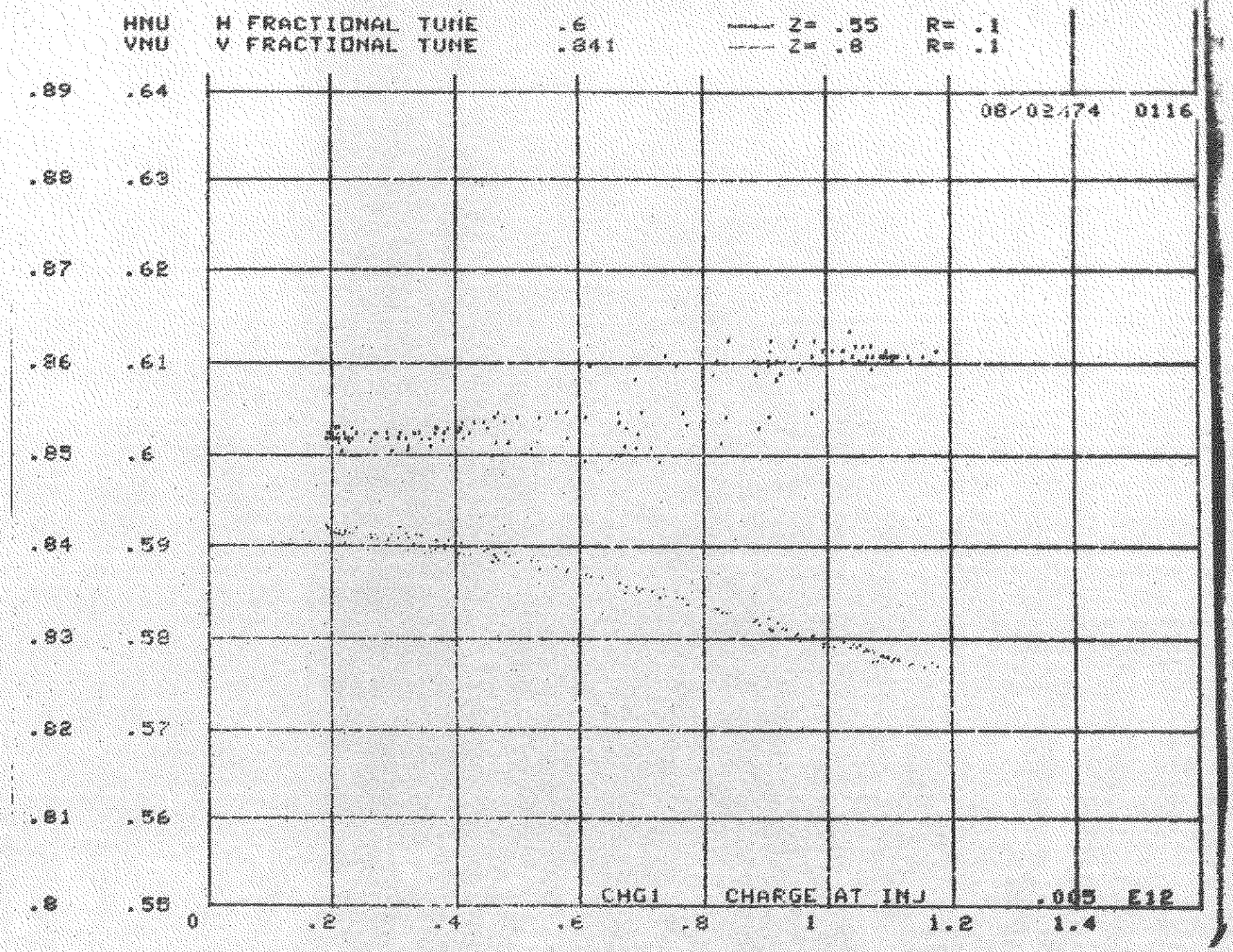

Figure 7

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Q7 200 p3 Booster DC

Figure 8

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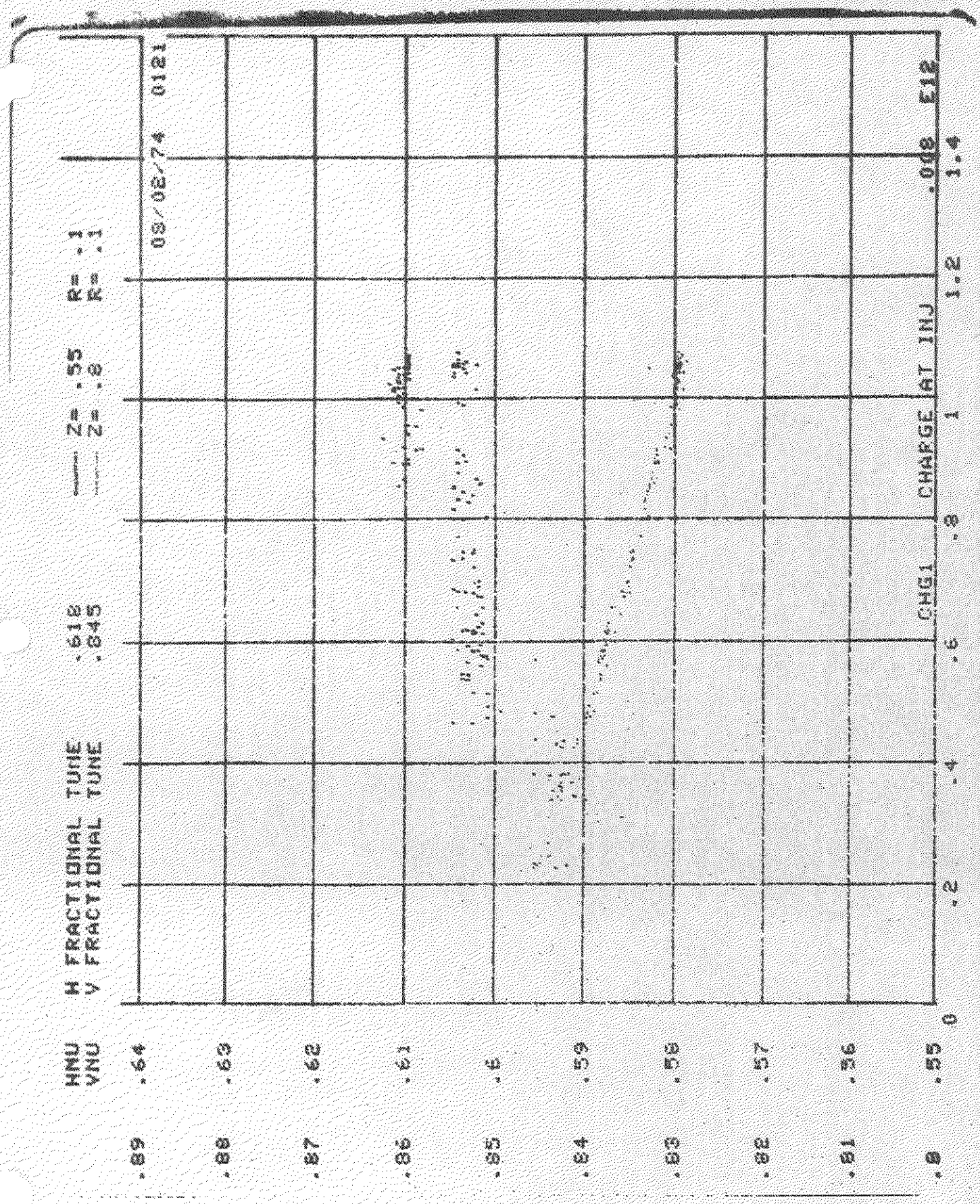

30x

R=4

21

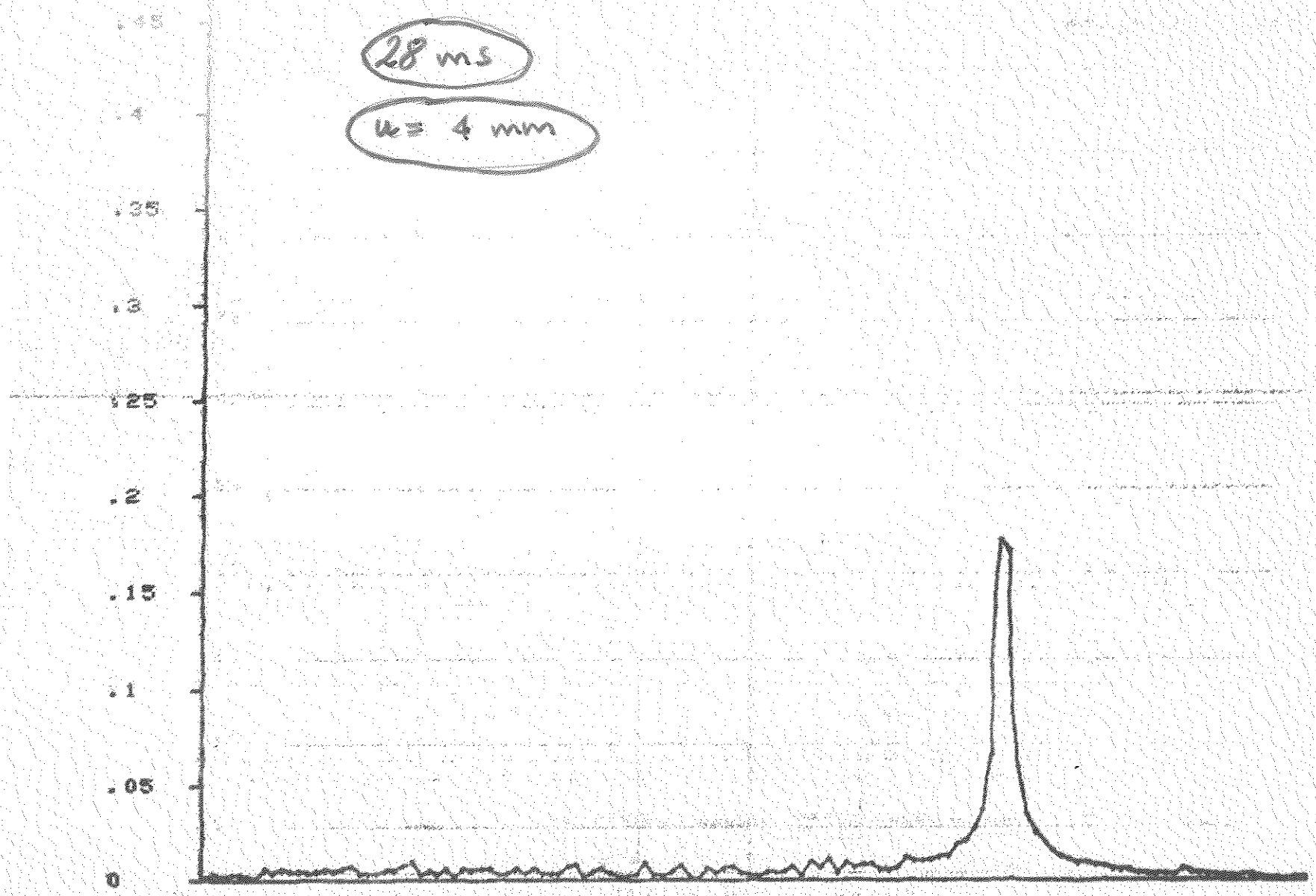

FIG. 13