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Direct Observation of Primary PUE Signals

M. J. Brennan

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Collider Accelerator Department
Brookhaven National Laboratory

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Experimenter(s) J.M. Brennan and L.A. Ahrens

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Subject Direct Observation of Primary PUE Signals

Introduction

Measurements were made to characterize the performance of the PUE system in order to guide thinking about a possible upgrade of the system. The PUE system functions by measuring the induced charge on short plates placed circumferentially around the beam within the vacuum chamber at 72 locations around the ring. To function usefully, the system must produce reliable information with a high degree of precision and absolute accuracy. Technically, the challenge to this goal arises from two basic areas. One is the wide frequency swing and bunch length variation during the cycle; the other is the noise environment and remoteness of the processing electronics to the sensing devices.

An attempt was made to look in detail at the critical points in the system to see just what are the noise sources and how they couple into the signal path. The apparent implication of this study is that most of the hardware in the vacuum chamber and the 78 miles of coaxial cable between the ring and control room can be preserved. But, the internal wiring (within the vacuum chamber) should be upgraded to an impedance-matched arrangement using either coaxial cables or strip-line techniques and the processing electronics should be replaced with modern circuitry capable measuring orbits on a turn-by-turn basis or averaging over many turns for enhanced resolution.

One long-standing shortcoming of the PUE system is the lack of high quality data on the absolute location of the plates. There are no easy solutions to this problem. Some improvements in the locating jigs and fixtures are possible but since there is no way to measure with precision the location of the plates once the vacuum chamber is closed, the burden of reliability will ultimately fall on the individuals doing the alignment and assembly. The alternative of trying to make a "goof-proof", verifiable system seems prohibitively expensive.

Observations

Signals were observed as close as possible to the pick-up plates by connecting 10 kΩ resistors right at the vacuum feedthrough connector of PUE L-8. Ten megaohm, 14 pF scope probes then connected a fast storage oscilloscope (in the first run) or waveform digitizer (second run) to the 10 kΩ resistors. A schematic diagram of the system is shown in Figure 1. The scope was observed in Building 914 and the control room via CCTV. The digitizer was read out in real time directly to a video monitor and stored data was transferred to a graphics terminal via an RS-232 data link. The F-20 wideband wall current monitor was observed simultaneously as an indicator of the true bunch profile.

Typical waveforms are shown in Figures 2 and 3. The first observation is that there is nothing pathologically wrong with the PUE signal. The baseline is well behaved with no trailing disturbance from one pulse influencing the next. What was observed, however, was a tendency for internal structure within the bunch to stimulate resonances or ringing in the PUE signal. Figure 4 is an example where the tight bunch (10 ns FWHM) near transition has excited an internal resonance(s) in the PUE which greatly distrorted the signal. Figure 4 represents the limit of the storge scope and CCTV technique. A better look at the signal was obtained in the second run with the digitizer in the ring. Figure 5 is a digitizer wavform output at essentially the same point in the cycle. The higher resolution (one sample per nanosecond) reveals even more structure. The digitizer waveform shown in Figure 6 is from the earlier point in the cycle (same as Figure 2) and shows much less distortion. It is clear that the fidelity of the PUE signal depends on the detailed structure of the bunch charge distribution. The most likely cause of distortions and ringing is the non-impedance matched cabling arrangement and termination scheme.

The cabling arrangement was probably chosen for economic reasons. But the termination scheme follows from the basic decision that the PUE signal should reveal the beam charge, as opposed to current, waveform. This decision might be reconsidered when planning an upgraded system, especially in light of the fact that another device (the wall current monitor) is much better suited to seeing the charge signal and the PUE system does not require the charge signal in order to measure orbits.

Another possible cause of distortions in the primary PUE signal is the induced voltages that are caused by the impedance seen by the wall image currents in crossing the insulated beam pipe flanges. The wall current crossing the flange drives the downstream vacuum chamber up in voltage proportionally to this impedance. The chamber itself has capacitance and inductance to the outside world and so the wall-current induced voltage pulse will generate a very complicated response. The plates of the PUE will see (capacitvely couple) this voltage variation and respond, in turn giving distortion and ringing. This leads to the infamous RC networks which were installed to absorb energy from the chambers and damp its response to the wall current.

Some attempt was made to see the current in the RC network of L-8 simultaneously with observing the PUE signal. To do this, the RC network that connects the chamber to the magnet via 50 Ω was extended out of the magnet fringe field on a 50 Ω cable and the current monitored with a fast current probe. The results of this test are shown in Figures 7 and 8, which corresponds to PUE signals shown in Figures 5 and 6 respectively. It is clear that at least some of the high frequency structure seen in Figure 5 is correlated to currents that have gotten onto the outside of the chamber via the insulated flange.

It is important to note that the insulated flanges are "defeated" at each PUE chamber by a copper strap across the gap. The prescription for installing RC networks calls for a copper strap at the inside of the flange but a series 16 Ω - 0.05 μF network at the outside edge. So for some frequencies (d.c.), the insulated flange is defeated and for some high frequencies it is not completely.

Given the short duration of the study period (4 hours) and difficulties with access to the ring, it was not possible to explore systematically this effect of the strap and RC network on the PUE signal.

An imporant test for a future study would be to try to determine if some improvement of the PUE signal would arise from a completely conducting flange joint. This can be done by adding more strap around the joint and observing the PUE signal and the RC network current.

Finally, some attempt was made to assess the extent of signal degradation between the ring and the control room. Unfortunately specific measurements were not possible because we could not simultaneously measure in the ring and upstairs (we had only one digitizer). But by using the wall current monitor as a guide, similar signals were observed. Figure 9 is the PUE signal that arrives upstairs. It has passed through some RC filtering, a 100 into 1 impedance ratio pulse transformer, and 1700 feet of RG-62U cable. Not surprisingly, it is attenuated and heavily smoothed. One would not expect, and does not see, any fine structure similar to Figures 5 and 6. The relevant questions to ask are, has any necessary information been lost and has precisely the same thing been done to the other member of the $\pm x$ or $\pm y$ pair? The answer to both questions is probably no.

No information necessary to extract orbits has been lost, but a faithful picture bunch charge has been lost. Whether or not this is a problem depends on whether one is asking the PUE to reveal bunch shapes or just to obtain orbits. The designers of the PUE system apparently wanted to see bunch shapes because the next element in the system is an active device that "restores the high frequency components". This is done by passing the signal through a high-pass filter that attempts to be the complement of the cable attenuation and then amplifying the result in a frequency independent stage. The output of this circuit is shown in Figure 10. Clearly high frequency components are now present but by their randomness, it seems dubious that they accurately represent what has been lost between Figures 5 and 9. What has been lost irretrievably, however, is signal-to-noise ratio. Attenuation and re-amplification must reduce the signal-to-noise ratio by at least the noise factor of the amplifier. So, the desire to use the PUE's to measure orbits and also see bunch structure has in fact cost something, i.e., signal-to-noise ratio.

Future studies time should be devoted to two areas. One is the effect of the insulated flanges on the PUE; the other is studying the possiblities of using a matched system and sending the bipolar signal to the control room on the existing RG-62U 93Ω cables.

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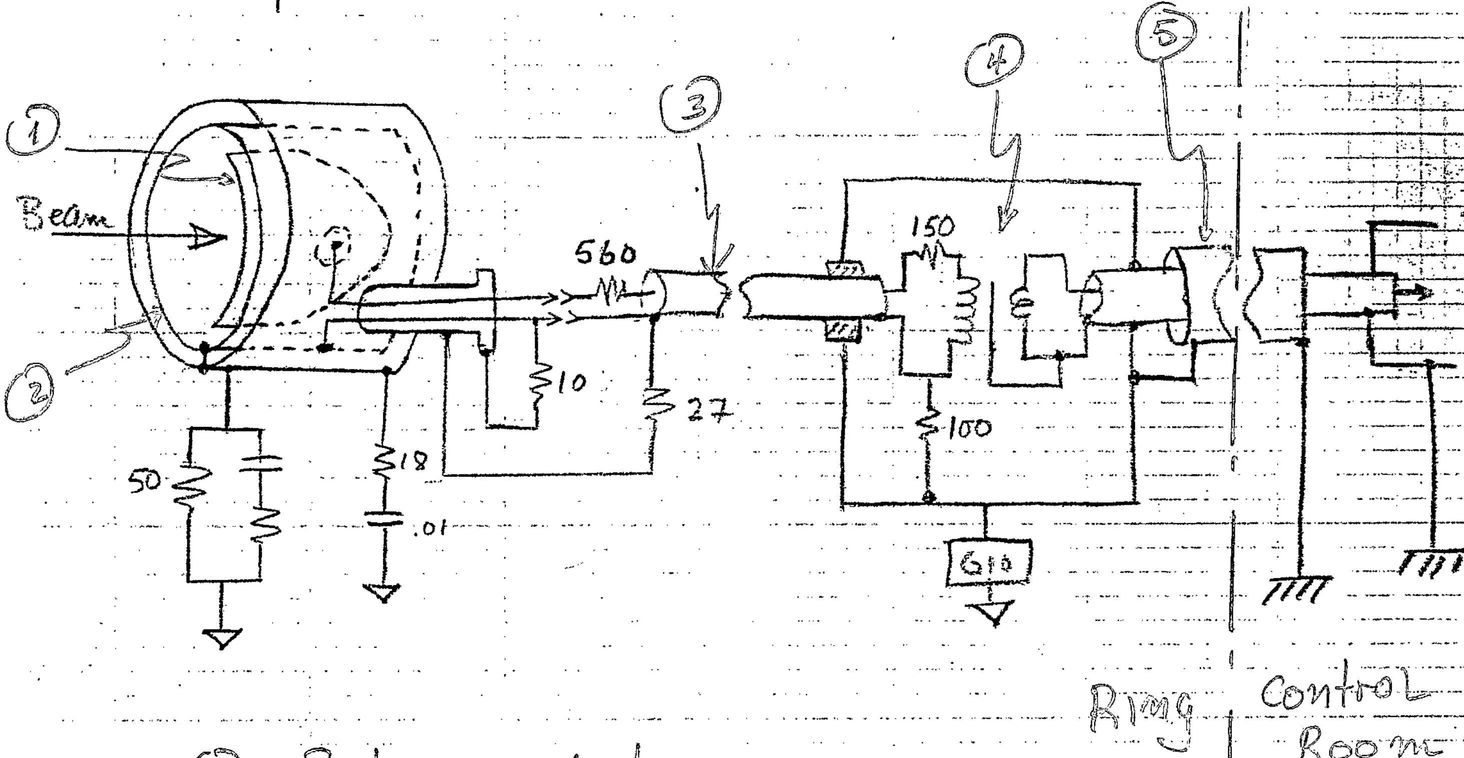

(1) Pick up plate

(2) Ground shield

(3) 2' of RG 62U, 93 Ω cable

(4) Pulse transformer, $V_{out}/V_{in} = 1/10$

(5) 1700' of RG62U between ring and control room, with double shield

Figure 1

Schematic diagram of PUE's

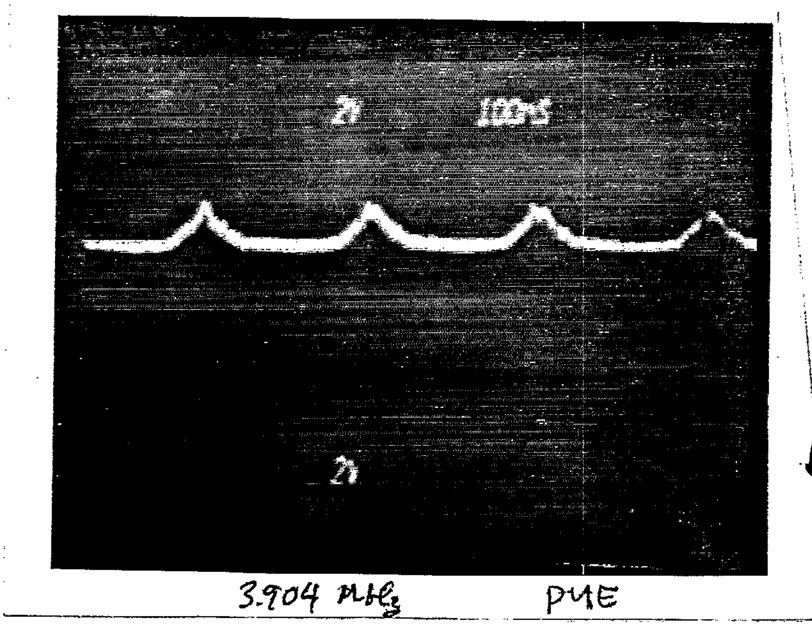

Figure 2. PUE signal.

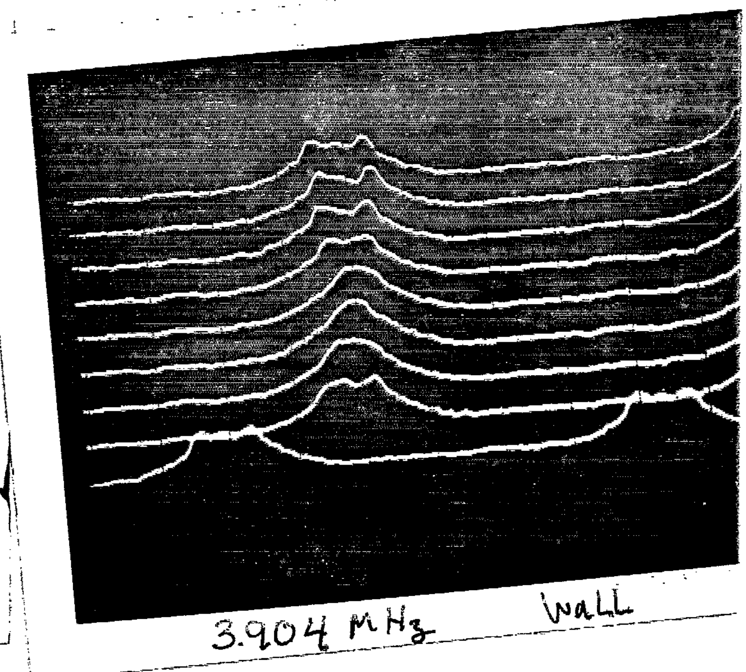

Figure 3. Wall current monitor.

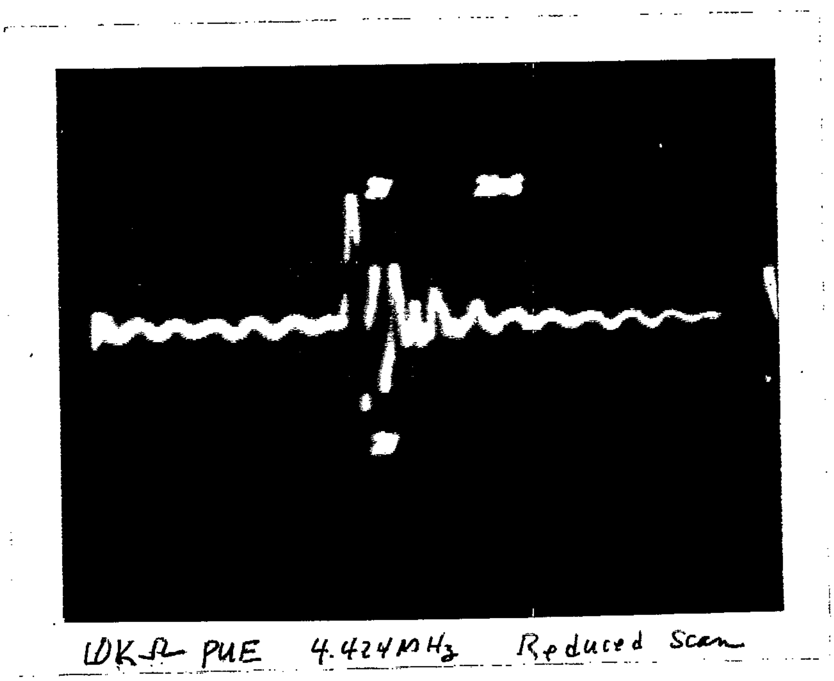

Figure 4. PUE signal near transition.

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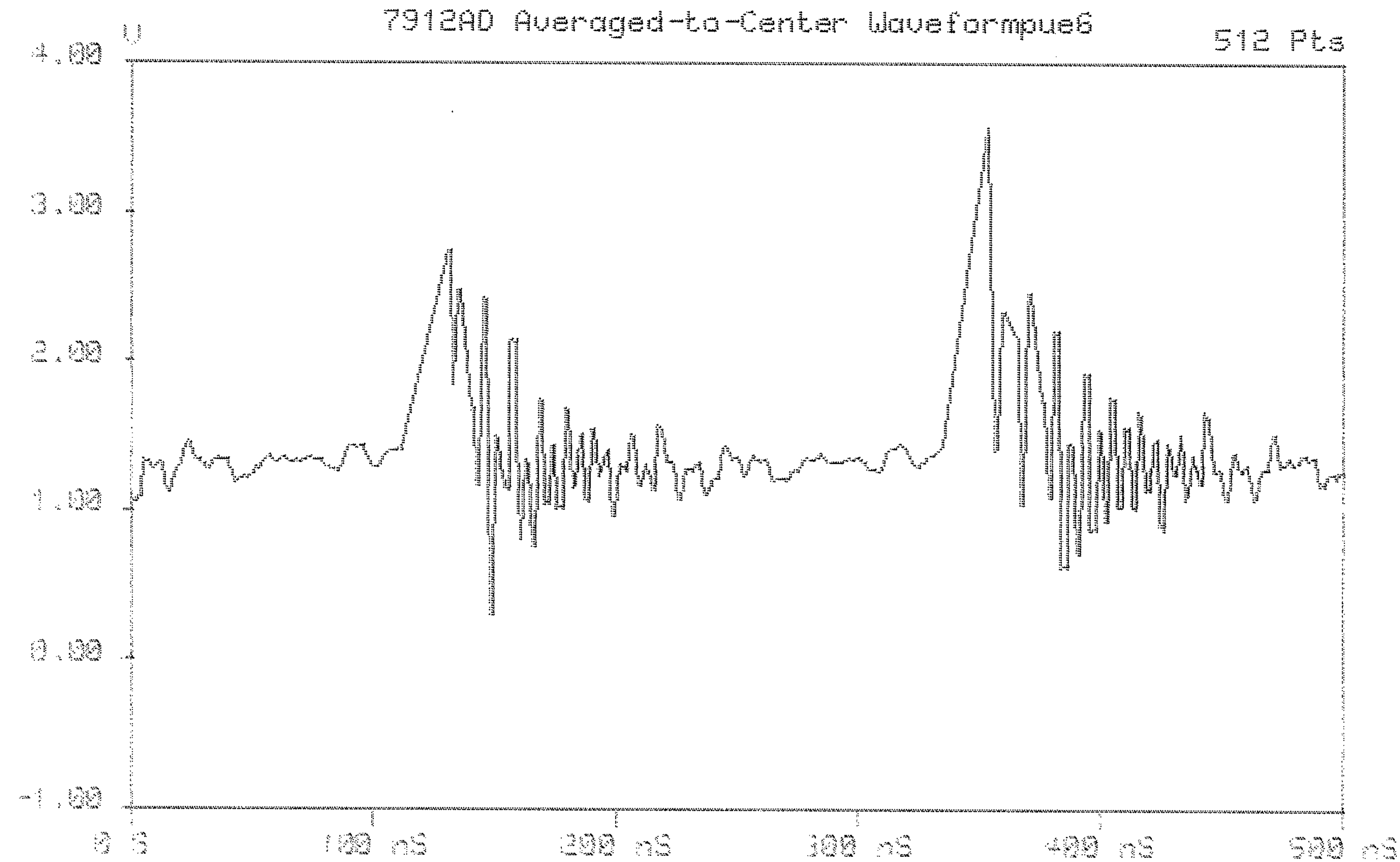

Figure 5. Waveform digitizer output of PUE signal.

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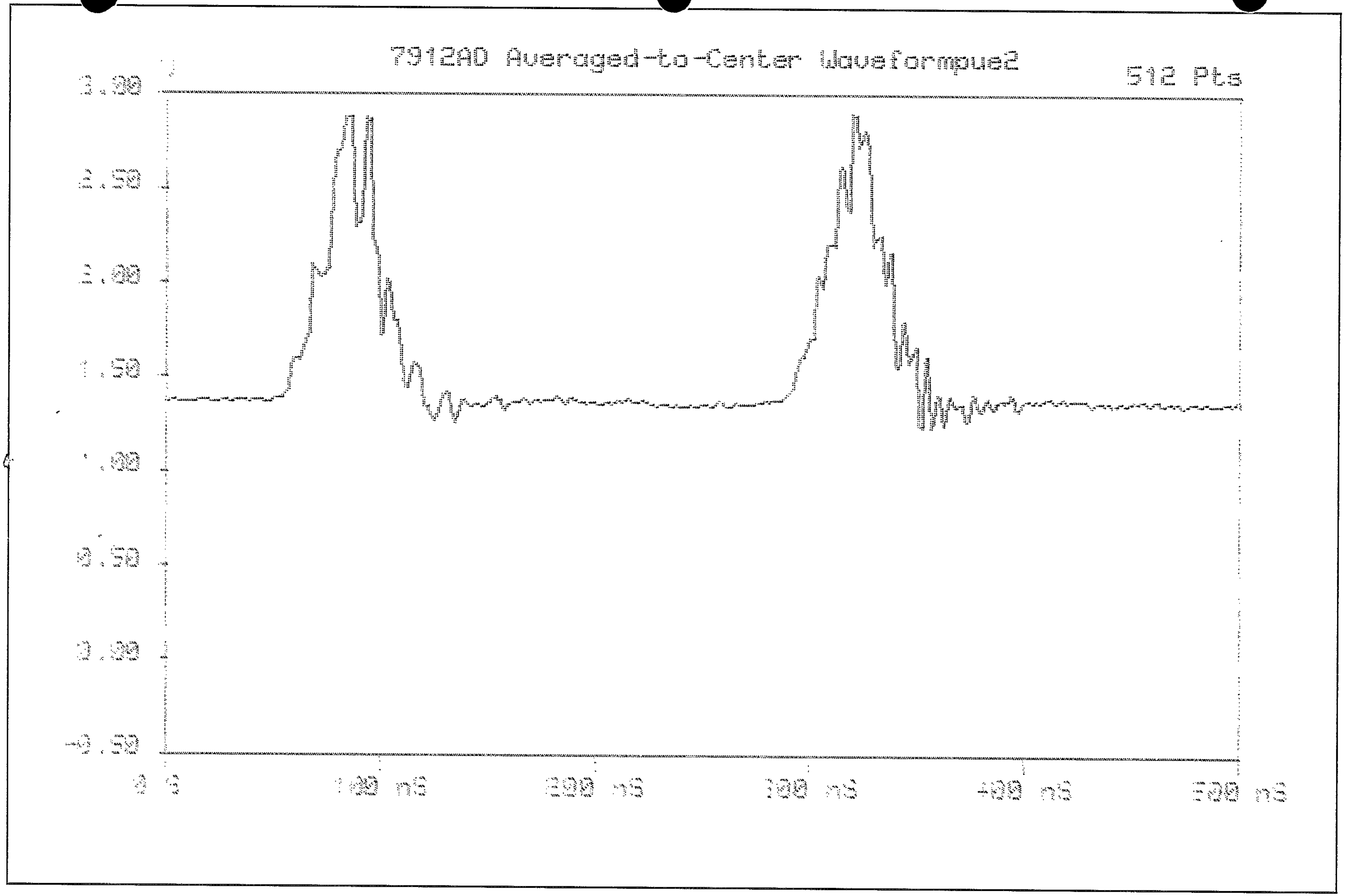

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Figure 6. Waveform digitizer output of PUE signal. Compare to Figure 1.

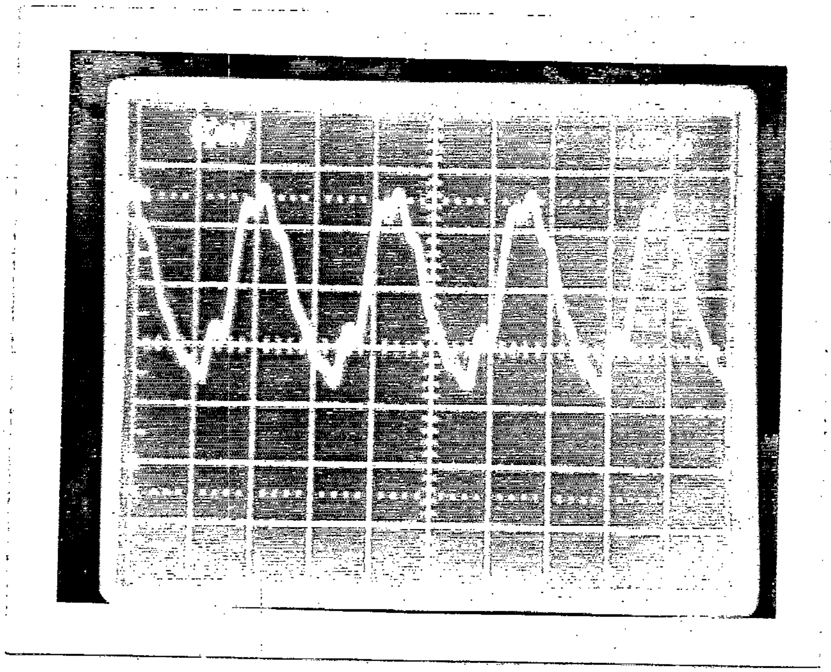

Figure 7. RC network current. Compare with Figure 5.

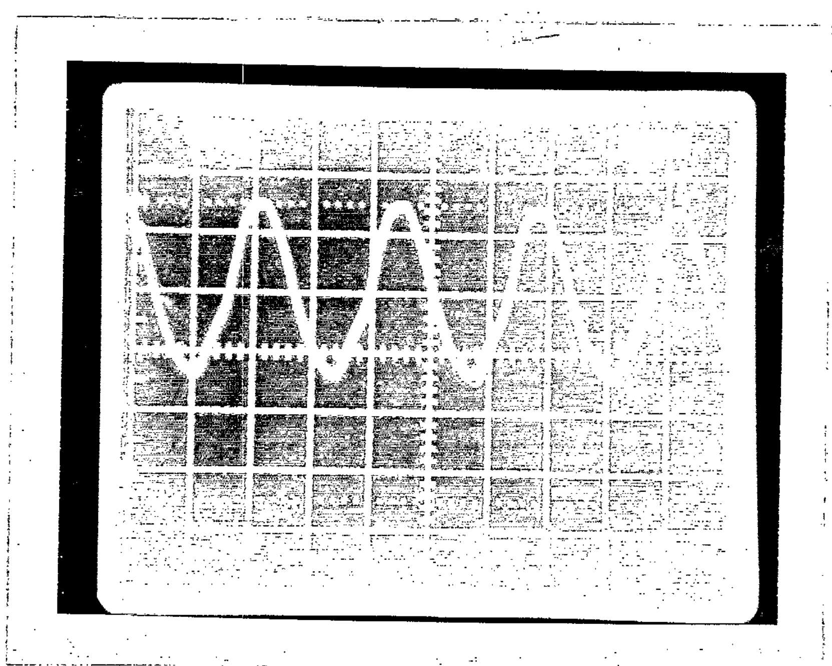

Figure 8. RC network current. Compare with Figure 6.

#8

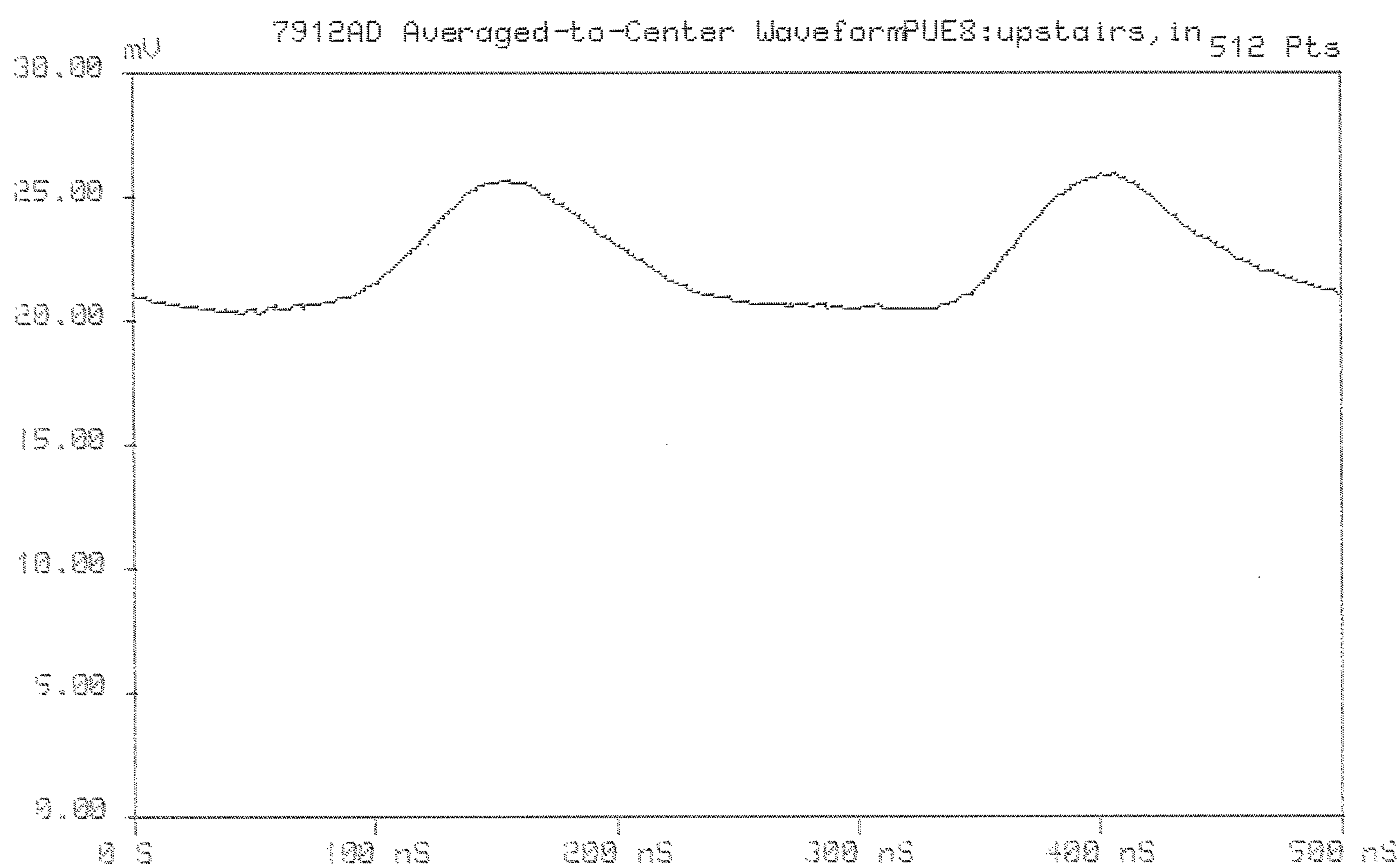

Figure 9. PUE signal as it arrives upstairs.

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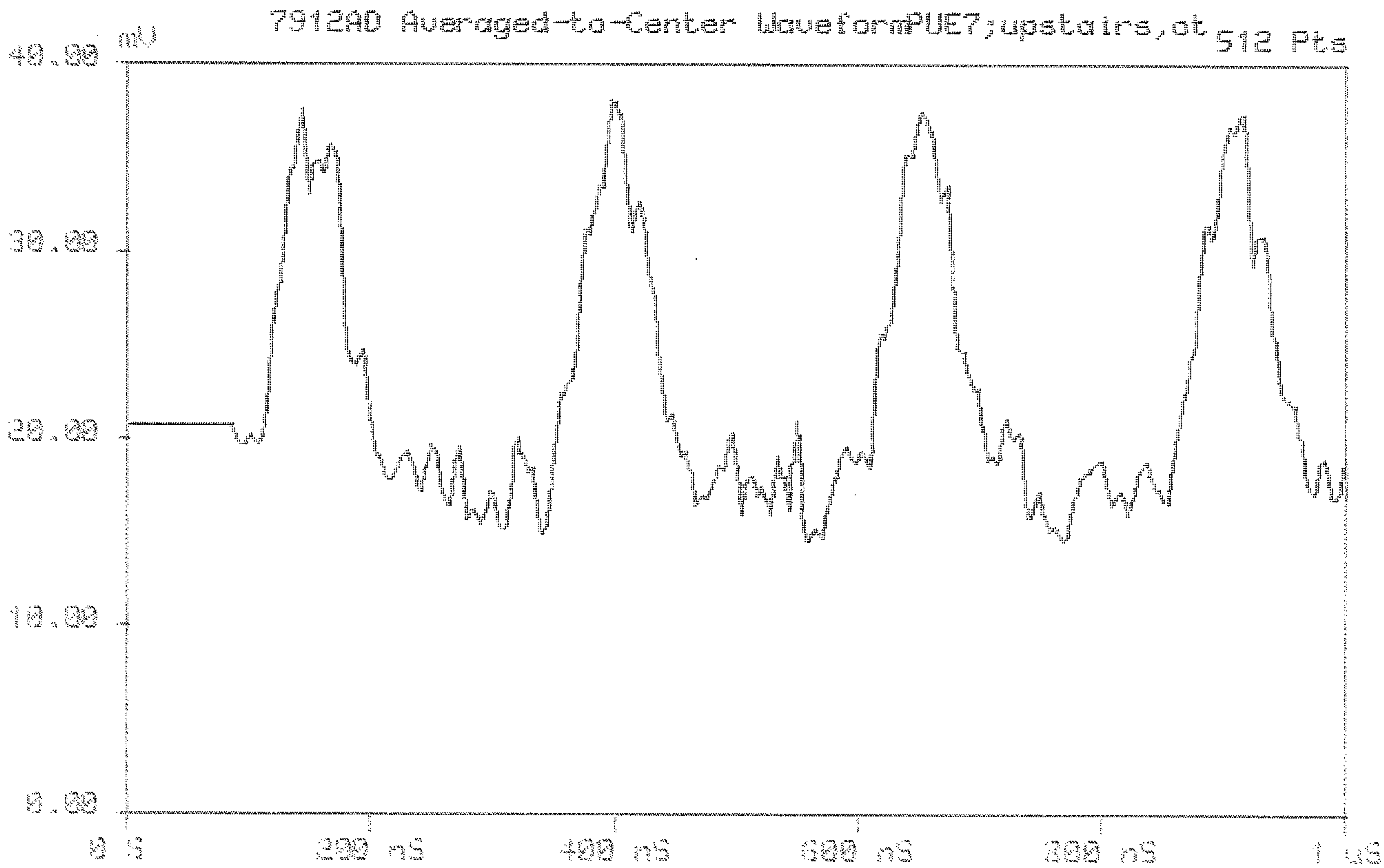

Figure 10. High frequency restorer output.

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