Cyclotron beam pulser for particle time-of-flight experiments*

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ABSTRACT

The energy resolution in time-of-flight experiments performed on a cyclotron is limited by the reaction product flight times of approximately 60 ns associated with the beam microstructure. A scheme for eliminating $N-1$ out of every N micropulses from the external beam has been developed for the Michigan State University Cyclotron. The internal beam is stopped on a collimator on the first one-half turn by applying a d.c. voltage to a radially deflecting plate located in the dee between the ion source and collimator. A 60 ns wide pulse, synchronised with the dee voltage, but with $1/N^{\text{th}}$ the repetition rate cancels the d.c. deflection voltage allowing single micropulses through the collimator. Beam currents of 1 μA time-average have been obtained with pulse widths of 0·4 ns at one-tenth the rf repetition rate. By removing a set of phase selecting slits inside the cyclotron, time-average currents of 10 μA have been obtained at 10% duty cycle with pulse-widths of approximately 1·5 ns.

1. INTRODUCTION

Time-of-flight experiments require very short bursts of particles with long waiting periods between bursts. Cyclotrons produce such short beam pulses, but the repetition rates, typically of the order of 50–100 ns, are often too high. It is possible to eliminate some of the bursts by sweeping the beam across a collimator synchronously with the orbital frequency in such a manner that only one out of N micropulses pass through the collimator and reach the experimenter's target. This can be done in two ways: by blocking the external beam or by stopping the beam near the ion source. The former has the great disadvantage that the beam thrown away activates whatever it hits and

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produces annoying background for the experimenter and a health hazard for the accelerator operations group.

At the Michigan State University Cyclotron, $N - 1$ out of N particle micropulses are stopped by a collimator on the first one-half turn by applying a d.c. voltage to a radially deflecting plate located in the dee between ion source and collimator (see Fig. 1). A 60 ns wide pulse, synchronised with the dee voltage but with $1/N^{th}$ the repetition rate, cancels the d.c. deflection

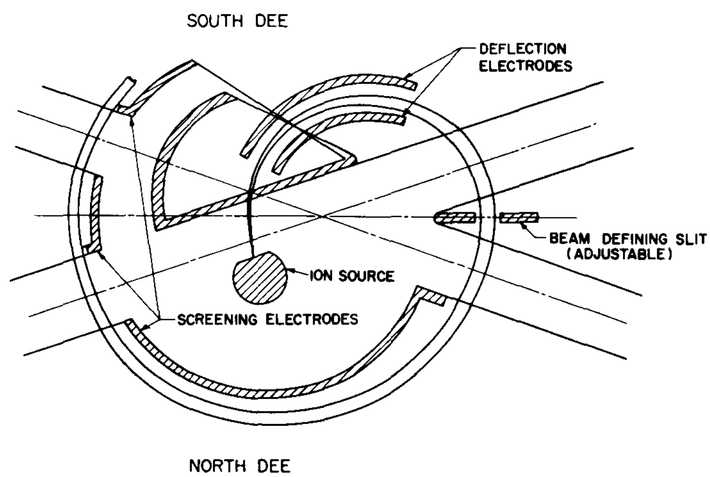

Fig. 1. Plan view of dees, dummy dees, one-half turn beam defining slit, ion source, puller and deflection plates

voltage allowing single microbursts of particles through the collimator. Eliminating unwanted pulses near the cyclotron centre greatly reduces the internal circulating beam current for a given peak current on target.

2. ELECTRONICS

A block diagram of the pulser electronics which consists of a frequency divider, variable delay line, pulse generator, amplifier, and assorted pulse-amplitude regulators is shown in Fig. 2. While the frequency divider used at present is a divide-by-ten fast pre-scaler, any type of divider can be used provided the time jitter in the output pulse is smaller than a few nanoseconds. The variable delay serves to adjust the position of the pulse relative to the dee voltage so that the d.c. voltage on the deflection plates is cancelled when the beam is passing through.

Signals from the delay trigger a pulse generator[2] that delivers a 40 V, 50 ns wide pulse, to a preamplifier. The preamplifier (Fig. 3) is a variable gain untuned amplifier feeding an inverting 200 Ω to 50 Ω transmission-line-type transformer. The gain is varied by adjusting the grid bias; this is used as the pulse amplitude regulating element.

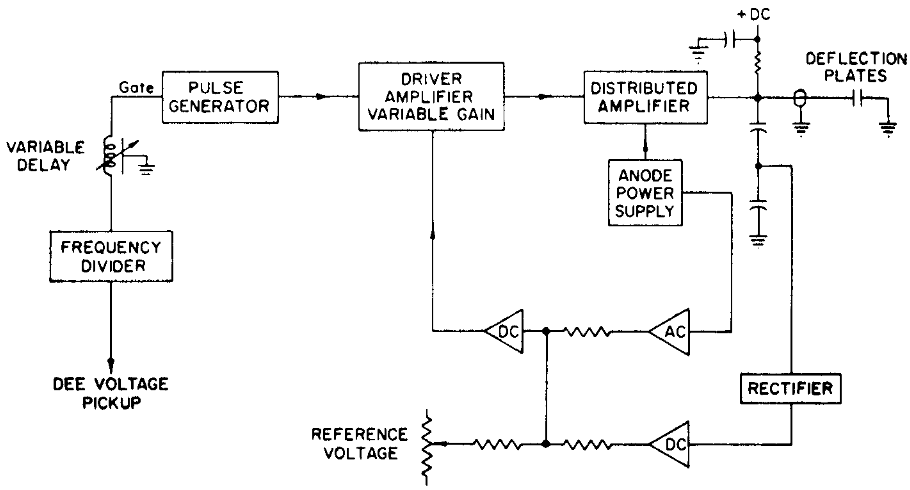

Fig. 2. Block diagram of pulser electronics

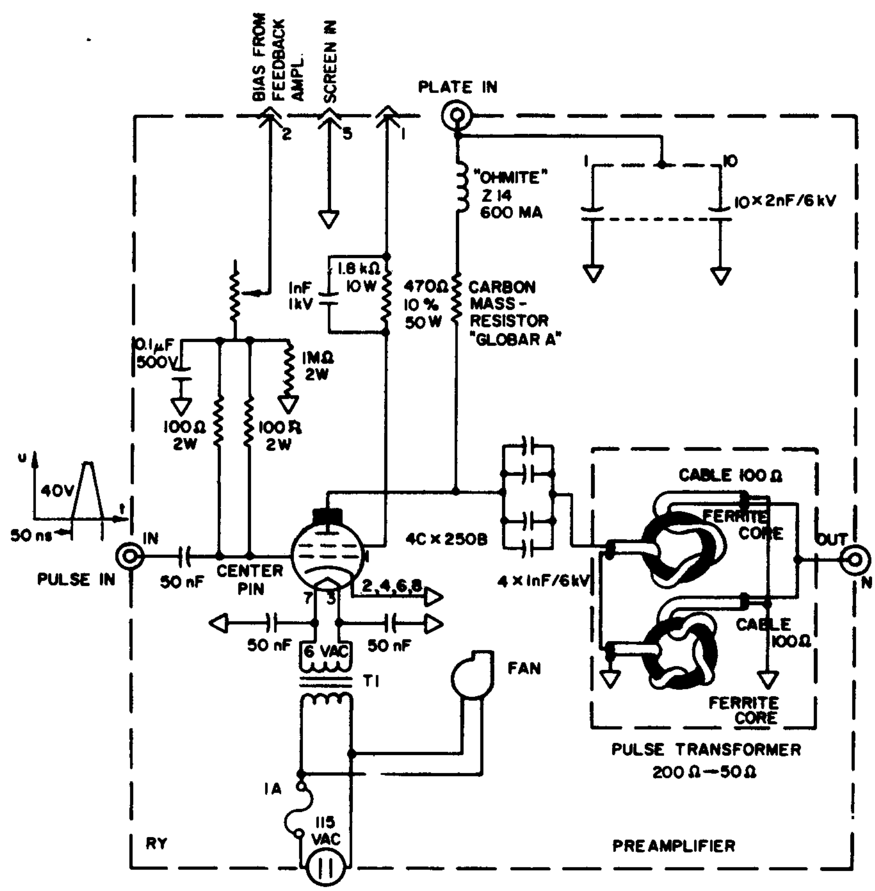

Fig. 3. Schematic diagram of the preamplifier

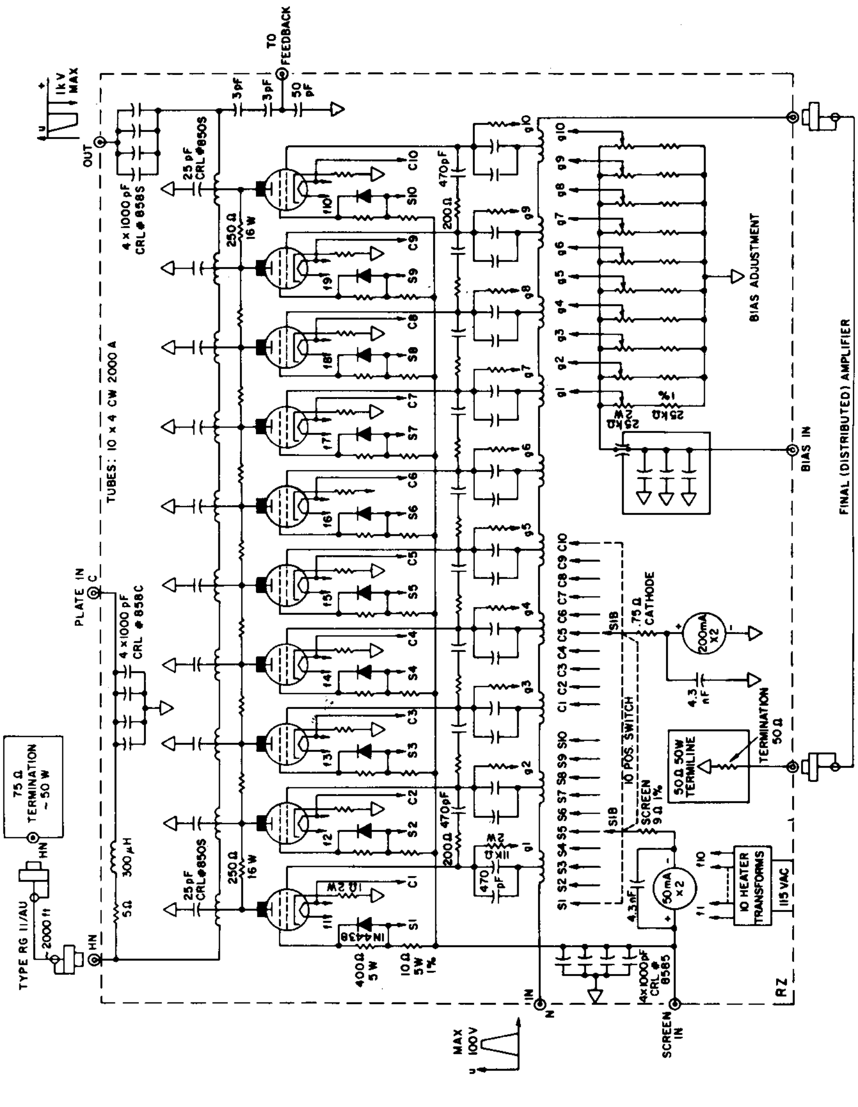

Fig. 4. Schematic diagram of the distributed amplifier

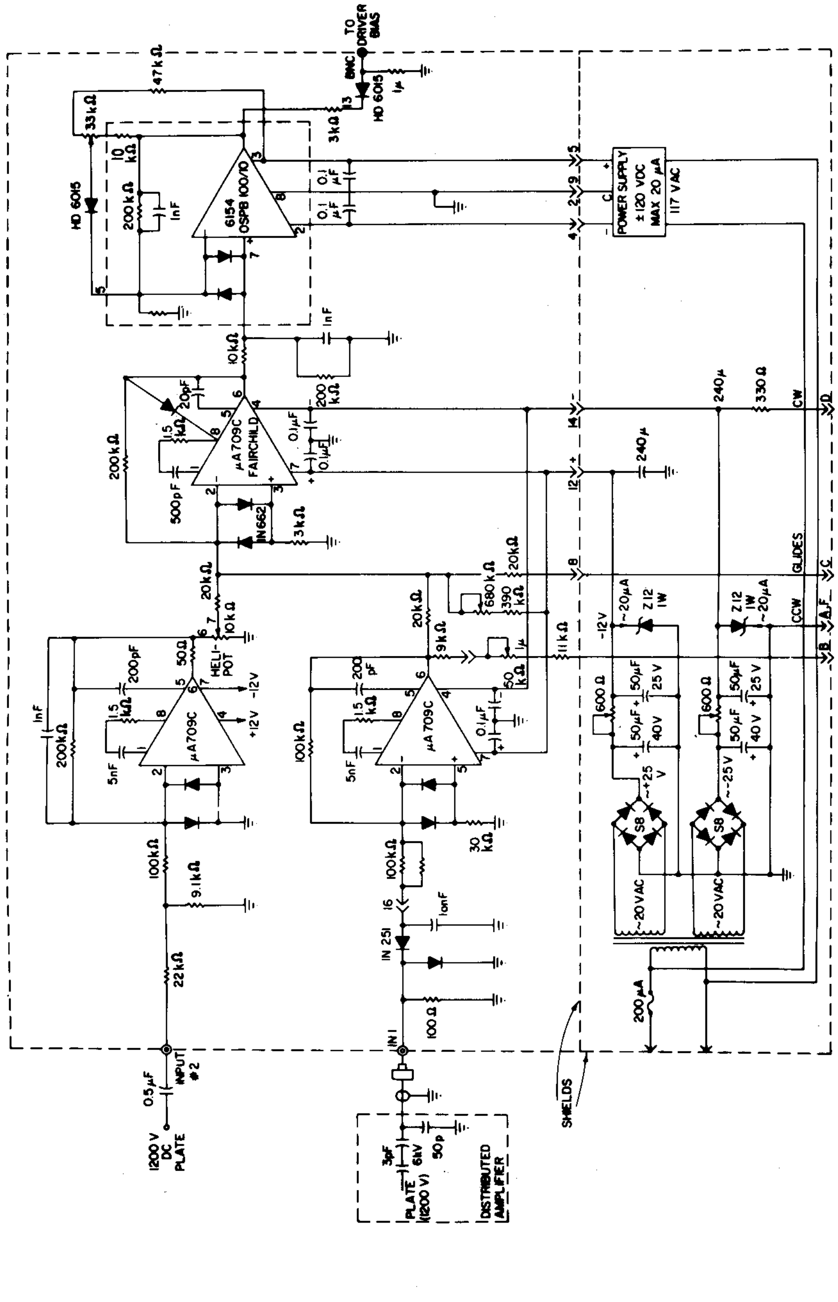

Fig. 5. Schematic diagram of the feedback amplifier

The distributed amplifier in the final stage (Fig. 4) operates with 10 parallel 4CW2000A tubes interconnected by lumped-constant delay lines and is capable of delivering 20 A into a 75 Ω transmission line. Because the deflection plates represent an open-circuited load to the transmission line, reflection produces a 3000 V pulse at the plates. The grid and plate delay lines are built from a design used at the Princeton-Pennsylvania Accelerator.[3] To simplify construction and to improve symmetry, each delay line consists of two parallel lines of twice the desired impedances: 100 Ω for grid line and 150 Ω for the plate. The reflected pulse from the deflection plates is dissipated in the back terminating resistor of the anode line.

Fig. 5 shows the feedback circuit that varies the grid of the preamplifier. Pulses from the anode are rectified by a peak detector and filtered by a 150 Hz low-pass filter. It was found that most of the 360 Hz ripple on the output comes from the distributed amplifier anode power supply. Thus, by summing a ripple

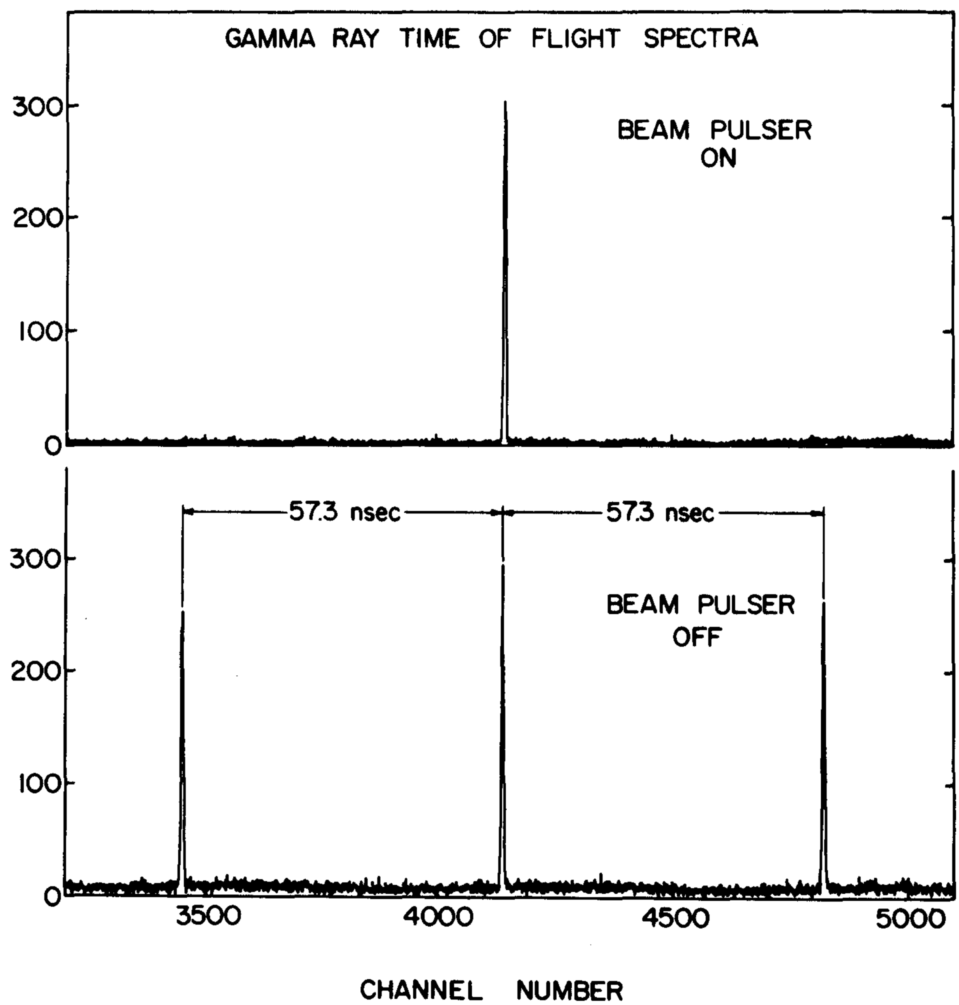

Fig. 6. Time spectrum of gammas produced by protons striking an external target. Upper figure with the pulser on; lower with the pulser off. Pulse shape discrimination was used to eliminate neutron background

signal from the anode power supply with the signal from the pulser output, stable, ripple-free pulses are produced.

The pulser is connected to the deflection plates through a 75 Ω coaxial cable inside the dee stem and a 75 Ω strip-line lying along the inside bottom of the dee. The positive d.c. deflecting voltage is applied to the same line through an RC de-coupling network.

3. RESULTS

Tests on the operation of the pulser were first made with the dees removed from the cyclotron. The 14 ns risetime pulses, observed on a sampling oscilloscope showed no appreciable ringing or overshoot. With a pulse width of 60 ns *(FWHM)*, the top of the pulse was flat to within a few percent for the period of time that the beam spends between the deflection plates. Since the beam responds to the time-average electric field in the gap, flatness of the pulse is not essential. However, any 'rounding' of this pulse does make phasing relative to the dee voltage more critical.

Beam tests with the pulser were made using a standard time-of-flight (TOF) electronic set up. γ-rays produced when the beam strikes a target are detected by a fast scintillator. The resultant signal was used as the 'start' pulse for a time-to-amplitude converter (TAC). The stop signal was the same pulse used to trigger the pulse generator. The output from the TAC was shaped and displayed on a multi-channel analyser. A spectrum was obtained that showed the time distribution of particles striking the target. The time resolution of the TOF electronics was sufficient to indicate particle pulse widths on target of 0·2 ns (corresponding to approximately a 1° phase width). Fig. 6 shows a TOF spectrum taken with an external proton beam. The lower figure gives data taken with the pulser off, showing γ-rays produced in the target at sharply defined times determined by the orbital frequency of acceleration. The spectrum in the upper half of Fig. 6 taken with the beam pulser on, clearly indicates that proton pulses have been effectively removed. The pulser was being operated at one-tenth the rf frequency and so nine out of every ten beam pulses were eliminated. (Only a portion of the spectrum has been shown in Fig. 6 to emphasise the clean removal of unwanted beam pulses.)

Provided the cyclotron is set up carefully to optimise extraction efficiency, operation of this beam pulser is stable, often running for periods of two hours without any adjustment of amplitude or delay. Preliminary measurements of the effect of the pulser on the phase width of the beam indicated no distortion of the particle pulse to within the resolution of the TOF electronics (0·4 ns *FWHM* phase width with and without the pulser). Beam currents of 1 μA time-average have been obtained with the 0·4 ns pulse width and one-tenth the rf repetition rate. By removing a set of phase selecting slits inside the cyclotron, time-average currents of 10 μA were measured with pulse widths of approximately 1·5 ns.

ACKNOWLEDGEMENTS

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DISCUSSION

Speaker addressed: W. P. Johnson (MSU).

Question by R. Jahr (P.T.B. Braünschweig): What voltage did you use across the deflector plates?
Answer: About +600 V d.c. with a corresponding negative pulse.

Question by R. W. Müller (A.E.G.): Does the amplifier work into a matched line, and how is it terminated?
Answer: There is a coaxial cable running through the dee stem, then a strip line from the edge of the dee to the dee tip. The line has 75 Ω impedance and it is not terminated, so that if 300 V are applied the reflection will result in 600 V at the plates.

Question by H. Schweickert (Karlsruhe): What sorts of insulators do you use?
Answer: The deflection electrode is mounted on a boron nitride insulator and the strip-line is made from ordinary copper-clad printed circuit board.

Question by M. E. Rickey (Indiana): Can you compare the performance of this system with the alternative of a gridded ion-source controlling pulse transmission by grid bias, as is done at Boulder, Colorado.
Answer: I have no experience with a gridded ion-source pulser, and cannot make a comparison.

Comment by W. R. Smythe (Colorado): The University of Colorado shielded grid ion-source performs as well as the MSU deflection system. They both remove the unwanted pulses completely. It should also be pointed out that both systems depend critically on achieving single turn extraction. It does no good to accelerate a single bunch of internal beam if the extraction system is going to deliver it in several slices as successive beam pulses.

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