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ABSTRACT

A system for the direct recording of track positions in spark chamber experiments is described. The system uses a Vidicon television camera as the digitizing device that records the track positions in digitized form. This information, as well as that received from other electronic devices in an experiment, is held temporarily in a core storage and subsequently transferred onto magnetic tape in a format suitable for further analysis by computer.

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I. INTRODUCTION

The large output of spark chamber events recorded on film and the subsequent labor involved in their analysis by use of manually operated digitizing machines has prompted the development of faster and more accurate data-processing devices.

The problem of automatic digitization of tracks from spark chambers is considerably simpler than in the analogous case of bubble chambers. Simplification of spark chamber tracks is possible because the selection of events is counter controlled and hence the desired track is accompanied by few, if any, accidental tracks. Furthermore, since in many spark chamber applications the useful tracks form straight lines or arcs of a circle (if the chamber is in a magnetic field), the "pattern recognition" aspects of an automatic scanning device used for bubble chamber pictures reduce to the simpler case of a position-digitizing device with provisions for rejecting obvious background, or random sparks. In the approach we follow here, this last task is left to the versatility of the computer, which sorts out and compiles the digitized information.

The digitizing system we describe below consists of a Vidicon television-camera tube with associated electronic circuits built into an electrostatically and magnetically shielded assembly that can operate in an environment of spark chamber and accelerator electrical noise. At present the system is designed to store the locations of two sparks per gap per view of the chamber (this number does not include the often-present spurious corner and edge sparking, which can be gated out). The digitization is done by using standard 20-Mc scalers, which record the positions of the sparks relative to a system of fiducial slits located at the extremities of each chamber view. The digitized information is temporarily stored in a 6000-bit magnetic-core buffer and then transferred onto magnetic tape for subsequent processing by the 7090 computer.

From the description given below it is clear that the same Vidicon camera can serve also as the digitizing device to analyze spark chamber pictures that are taken with a suitable format of views and fiducials. It is also clear that the accuracy, speed, and data-handling capacity for which we are now aiming is not the maximum attainable with existing electronic components and techniques; we recognize that it is also possible to achieve greater versatility, although at greater cost and with more complications, by designing the system to be "on-line" to a computer.

The digitizing logic of the scanner, described in the following sections, requires a format of the various spark chamber views in which the images of all the plates appear parallel to one another on the faceplate of the Vidicon. The simplest case utilizing this format is that of a single multigap spark chamber with two perpendicular stereo views projected in a parallel array by mirrors.

Now in preparation at the Berkeley 184-inch cyclotron is an experiment to determine proton polarization from π-p scattering. The spark chamber is used to analyze the angular distributions of the proton after it is scattered from a carbon converter placed in front of the chamber.

II. VIDEO DIGITIZING CAMERA

General Description

A Vidicon camera is employed because of its high resolution, image-storage ability, and simplicity of operation. The operation of the Vidicon is illustrated in Fig. 1. The sensitive element consists of a photoconductive layer deposited on a transparent conducting surface. This layer is charged to a homogeneous negative potential by a low-velocity electron scanning beam. Illuminated portions of the target become discharged; the signal output from the Vidicon is obtained when the electron scanning beam recharges these spots. The charging current is then measured across the anode resistor that is at the input of the video amplifier. This amplifier has a gain of 30 with a bandwidth of 10 Mc and is mounted in close proximity to the Vidicon anode in order to minimize the stray capacity and noise pickup.

The Vidicon camera is well shielded, both electrostatically and magnetically. Figure 2 shows the concentric electrostatic and mu-metal magnetic shields that enable the camera to operate in magnetic fields up to 50 G, without affecting the low-velocity electron scanning beam of the Vidicon. Since the Vidicon stores the optical image it receives on the anode photoconductive layer for many milliseconds, it is possible to delay the start of the scanning and digitizing cycle until the electrical transients produced by the spark chamber discharge have disappeared. In our case this delay period is 20 μsec, and the electrostatic shielding is more than sufficient to prevent any transients from feeding through to the core storage.

Figure 3 shows the two views of a 10-gap spark chamber as "seen" by the Vidicon. Sparks are digitized by scanning the Vidicon parallel to the image of the spark chamber plates. The fiducial arrangement consists of illuminated slits placed on both ends of the spark chamber. The left-hand slits are stopped down so that they mark the central region of each spark gap. As the sweep proceeds in the slow-sweep direction, the first video signal, from a left-hand slit, sets the digitizing logic so that digitization starts on the following fast sweep. If a spark is present, a 20-Mc scaler is turned on when the sweep passes over the spark and is turned off when the sweep passes over the right-hand fiducial. A 50-μsec fast-sweep time is used; thus our quantitizing error is 1 part in 1000. At present, two scalers are available for digitization and they may be used to digitize either two sparks per gap, or one spark per gap and the total gap length. To improve accuracy, the digitizing is repeated twice in each gap; the average of these two sweeps is delivered to the buffer store.

The signal that turns the digitizing scalers on and off is obtained from a gated discriminator. This discriminator is set to trip at a level of 50 mV on the output of the video amplifier after two differentiations that produce a "zero crossover pulse." The first differentiation—with a time constant of 160 nsec—trips the amplitude gating pulse, which is set at a safe level above the noise background. The second differentiation—with a time constant of 50 nsec—produces the zero crossover pulse. These pulses are shown in Fig. 4. A spark is distinguished by the digitizing logic from a fiducial-slit pulse by the requirement of a further gating pulse that is correlated in time with the sweep pulse, and thus with the spatial position of the fiducial slits. This gating-pulse logic also minimizes triggering on spurious random sparks by requiring that the digitized sparks be in the vicinity of the scintillation counter that triggered the chamber, as shown in Fig. 3. These internal gating signals are adjusted by intensification of the corresponding portions of the sweep on a monitor scope that is simultaneously displaying the spark chamber image. This same scope is also used in monitoring the alignment of the digitizing sweeps parallel to the spark chamber plates; the two digitizing sweeps are intensified and can be located at the center of each gap.

Once an event has been digitized, it is necessary to erase completely (i.e., recharge the Vidicon target). To accomplish this erasure, the electron beam is defocused and the beam current increased. Three 5-msec sweeps of the Vidicon target are made immediately after an event has been digitized, and thereafter periodic recharging scans are made during the off-gate time of the cyclotron beam. The slow-sweep sequence of scan, erase, and recharge is shown in Fig. 5.

At present we are using a 250-line scan. The sweep speed is 50 μsec and has a 10-μsec flyback. The scanning time is thus 15 msec; an additional 15 msec is required per complete erasure and recharging. With the Vidicon tube (RCA 7263A) that we are now using, the signal level has decayed to ≈ 50% of the initial value at the end of the full scan.

Performance Tests

We have tested the Vidicon camera and digitizing logic, both with illuminated grid lines and with cosmic rays triggering the 10-plate spark chamber referred to above. These tests show an average signal-to-noise ratio greater than 10 to 1 while the camera, 20 ft from the chamber, is operated with an 85-mm lens set at an f/8 aperture. The spark chamber was filled with the usual (90% Ne)-(10% He) mixture, and the energy per spark was ≈ 0.05 joule.

Under these operating conditions, spark positions were reproducibly located to an accuracy of better than 0.1% of the full sweep, with a drift of 0.14% over a 24-h period. Two sparks could be resolved and their positions digitized if their relative spacing were ≥ 1% of the full-sweep length. These figures do not represent the limiting resolution and reproducibility of the Vidicon tube; they are a measure of the over-all performance of this system and include some noise and drift from the video amplifier.

It is worthwhile to point out here that it is possible to shorten considerably the present 30-msec dead time per event by using existing faster electronics such as 100-Mc scalers. Furthermore, the dead time per event would remain the same if a number of Vidicon cameras were used simultaneously to scan various sets of parallel plates in a complicated experimental array. This can be done by providing each camera with its own digitizing scalers and staggering the read-out time for each set of scalers—which takes only a few microseconds—and utilizing the time between sweeps for this purpose.

III. DATA PROCESSING

The data-recording system used with the Vidicon digitizer is called "Alpha 63." It has been designed as a general-purpose system, capable of being used in many different types of experiments. In a spark chamber experiment, it accepts data from the several associated sources as events occur, at a random rate. It puts the data into a prearranged format and transfers it to a magnetic-core buffer store. When the buffer store is filled, the information is recorded on magnetic tape. The format of the recorded information is suitable for direct entry into a computer such as the IBM 7094.

The block diagram of Fig. 6 shows Alpha 63 and three of the external data sources that it services. These are: (a) the Vidicon digitizer, (b) the scintillation counters and associated electronics, and (c) accumulative scalers and manually controlled data registers. Data from the third source are recorded only twice for each experimental run of several hundred or several thousand events, and produce what is known as an identification record.

Figure 7 shows the format of the recorded data for one event from the first two sources above. For a 10-gap spark chamber, the data are contained in 14 computer words. Each of these words contains 36 bits, as is typical of the IBM 7090 series of computers. Two-thirds of the first word is used as event identification. The details of this portion are shown in Fig. 7(b). The first 15 bits contain the serial number of the particular event. Bits 16 through 24 contain other information, such as the number of the scintillation counter that detected the particular event.

The remaining 13 1/3 words contain as many as 40 addresses (10 gaps × 2 sparks per gap × 2 views) of the particular event. These addresses are placed in a fixed, prearranged format. Such a format eliminates the requirement of recording gap identification with each address and thereby reduces the required number of bits. As shown, the first two 12-bit words contain the binary addresses of the first and second sparks found in the first gap, first view. When either the second or both sparks are missing the corresponding 12-bit words contain all zeros. The second two 12-bit words contain the binary addresses of the first and second sparks found in the second gap, first view, etc.

Details of the 12-bit address words are in Fig. 7(c). Ten bits contain the binary address, giving a capacity of 1024 possible spark positions. Two bits provide a code that can indicate, for example, if more than two sparks were found in the gap, or if the 10 bits contain the "fiducial address." The latter represents the distance between the start and stop fiducial marks, and is used as one of the means of calibrating the system. One feature of the system is that the first and last recorded events of a run are automatically used as calibration events. At these times, the digitizer is commanded to digitize the distance between the fiducial marks. This indicates to the computer the extent of the active area of the chamber and allows it to check for drifts in the digitizing system.

In Fig. 6, the block labeled "data combiner" controls the sequence of occurrences during the storage of an event. When the fast electronics detects the signature of a desired type of event, it fires the spark chambers and signals the data combiner. The latter first inhibits further collection of data and then transfers the 24 bits of event identification into the buffer store. Next it signals the Vidicon digitizer to commence digitizing the addresses of sparks in the chamber and simultaneously connects the output of the digitizer to the input of the buffer store. The digitizer then issues the forty 12-bit words containing the spark addresses and erases the Vidicon target. When finished, the digitizer signals the data combiner, resets its data registers, advances the event-serial-number register by one, and removes the inhibit condition on the fast electronics. The fast electronics now searches for another event.

The buffer store has a capacity of 512 12-bit words. When the store is filled to capacity by the data from 12 events, the contents are transferred in a block onto the magnetic tape. During the 25 msec required for the transfer, the data combiner inhibits further acquisition of data.

The format of the data on the tape is similar to that in Fig. 7(a) except that the words are broken into characters of 6 bits plus one odd-parity bit each. The 12 events are recorded without separation. In computer terminology, this comprises one data record. Each record contains 1,088 characters. At a writing density of 800 characters per inch, a record therefore occupies 1.25 inches of tape plus an 0.75-inch record gap. A 2400-foot reel of tape has a capacity of 175,800 events.

At the start and finish of each experimental run an identification record is put on the magnetic tape. At the start, its purpose is to record the serial number of the run for the benefit of the computer. At the end of the run, it contains the accumulation of several monitor scalers and other manually entered conditions of the run.

In systems of this size, it is essential to have readily available facilities for testing and monitoring. Means for monitoring the operation of certain critical parts and of the over-all performance are needed. Methods of simulating input signals to some of the blocks should be provided. Then, while building the equipment (or in case of malfunction), one can separate it into its functional parts and work on them separately. And during an experiment, one can reassure oneself regarding the operation not only of the spark chamber but of the electronics as well. Some of the facilities of this type that are built into the digitizer and Alpha 63 are described below.

The Vidicon and digitizing logic have several visual monitors, one of which is called an analog monitor scope. It is similar to a television monitor set in that it presents the video information from the Vidicon camera tube, but it also has other important features. The z axis (intensity) of the analog monitor CRT can be activated by several signals besides the raw video. One source of activation is the amplitude discriminator in the video chain following the Vidicon tube. Whenever a Vidicon signal exceeds the threshold of this discriminator, a spot on the analog monitor brightens to indicate that a potential spark has been discovered. As a second feature the particular horizontal sweeps actually engaged in searching for and digitizing sparks can be intensified. Also the positions of gates that activate the digitizer in only certain parts of the sweep can be shown on the analog monitor.

A second visual monitor is called the digital monitor. The magnetic-tape unit has both a write and a read head. The read head scans the digital information on the magnetic tape a few milliseconds after it is recorded. A parity check is made at this time. The digital monitor interprets the data read by the read head, performs a digital analog conversation, and plots on a CRT the positions of the sparks as detected, digitized, and recorded. The display is a temporary one, but because of the persistence of the CRT, can be seen for at least 15 seconds. It is repeated each time a data record is put onto tape. Reasonable-appearing displays on the digital monitor are assurances that the entire system is operating properly.

The visual readout block (a third visual monitor) is a device for monitoring data either from the data combiner or from the characters read from the magnetic tape. The data is displayed on three banks of 36 lamps each. Using the visual readout, one can compare the data bit by bit as recieved from the fast electronics and after being read from tape.

The reliability achieved with Alpha 63 has been gratifying. It was constructed entirely with silicon transistors (mostly 2N706) and diodes. When used recently with a Bevatron experiment, it ran continuously for several months with only one circuit fault, caused by a transistor failure. Since approximately 4500 transistors were used, this represents a transistor failure rate of the order of 0.01% per 1000 hours for the transistors.

A possible alternative to the data-recording system described would be one using an on-line computer, thereby bypassing the magnetic tape recording process.

As presently used, the Alpha 63 system is capable of recording information from the 10-gap chamber at a rate of about 30 events per second. About 30 msec per event is contributed by the Vidicon and digitizer and about 25 msec per 12 events by the time to transfer by buffer store to tape. The latter time is short compared to the Vidicon dead time. Thus, from the standpoint of speed alone, there is little advantage in using an on-line computer.

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Figure Captions

Fig. 1. Cross-section view of a Vidicon tube.

Fig. 2. Vidicon camera removed from its shield.

Fig. 3. Two views of a 10-gap spark chamber as seen by the Vidicon camera. The fast (horizontal) sweep is from left to right; the slow (vertical) sweep is from top to bottom.

Fig. 4. Single spark signals from the Vidicon camera. Upper, after one differentiation; lower, after two differentiations.

Fig. 5. Slow-speed sequence as planned for cyclotron use.

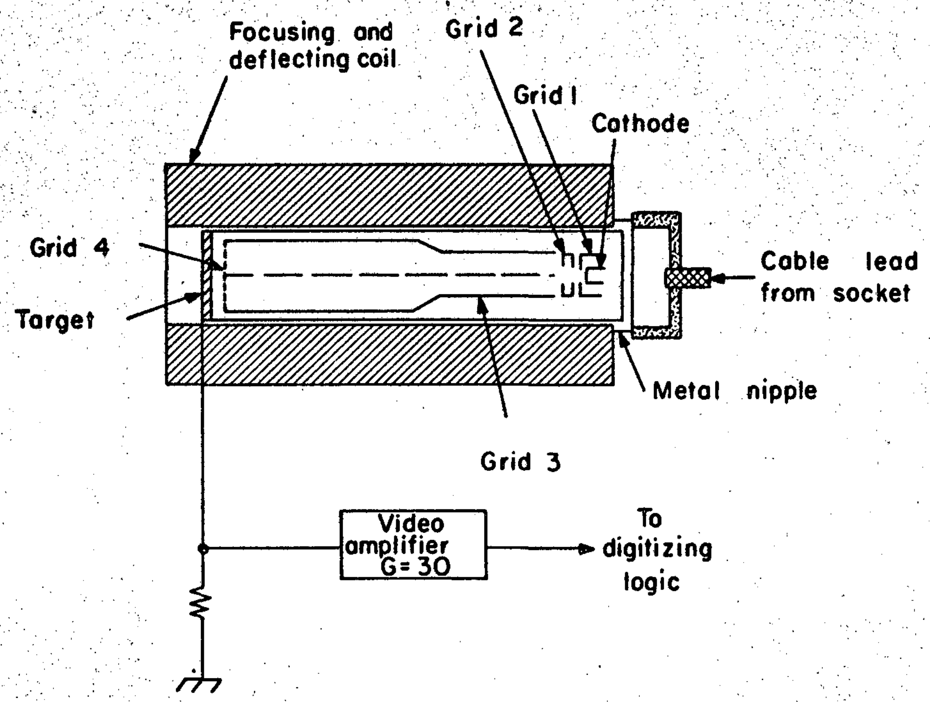
Fig. 6. Block diagram of the Alpha-63 data-processing unit as used with a Vidicon digitizing unit.

Fig. 7. Format of recorded data for one event from the Vidicon digitizer and the scintillation counters.

(a) Format of an event partial record. Numbers refer to gap/view/spark numbers, e.g., 922 is data of gap 9, view 2, spark #2.

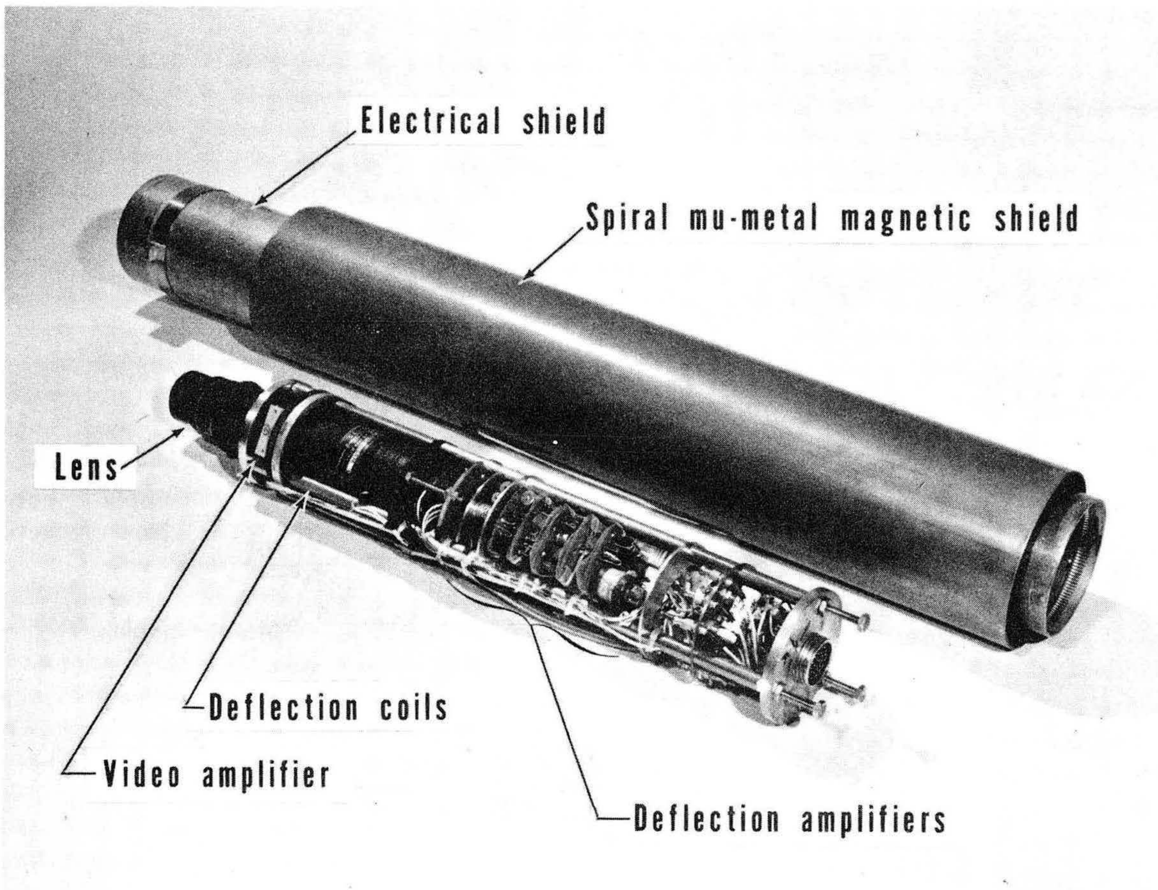
(b) Event-identification word.

(c) Spark-address word.



MU-33463

Fig. 1.


Electrical shield
Spiral mu-metal magnetic shield
Lens
Deflection coils
Video amplifier
Deflection amplifiers

ZN-4294

Fig. 2

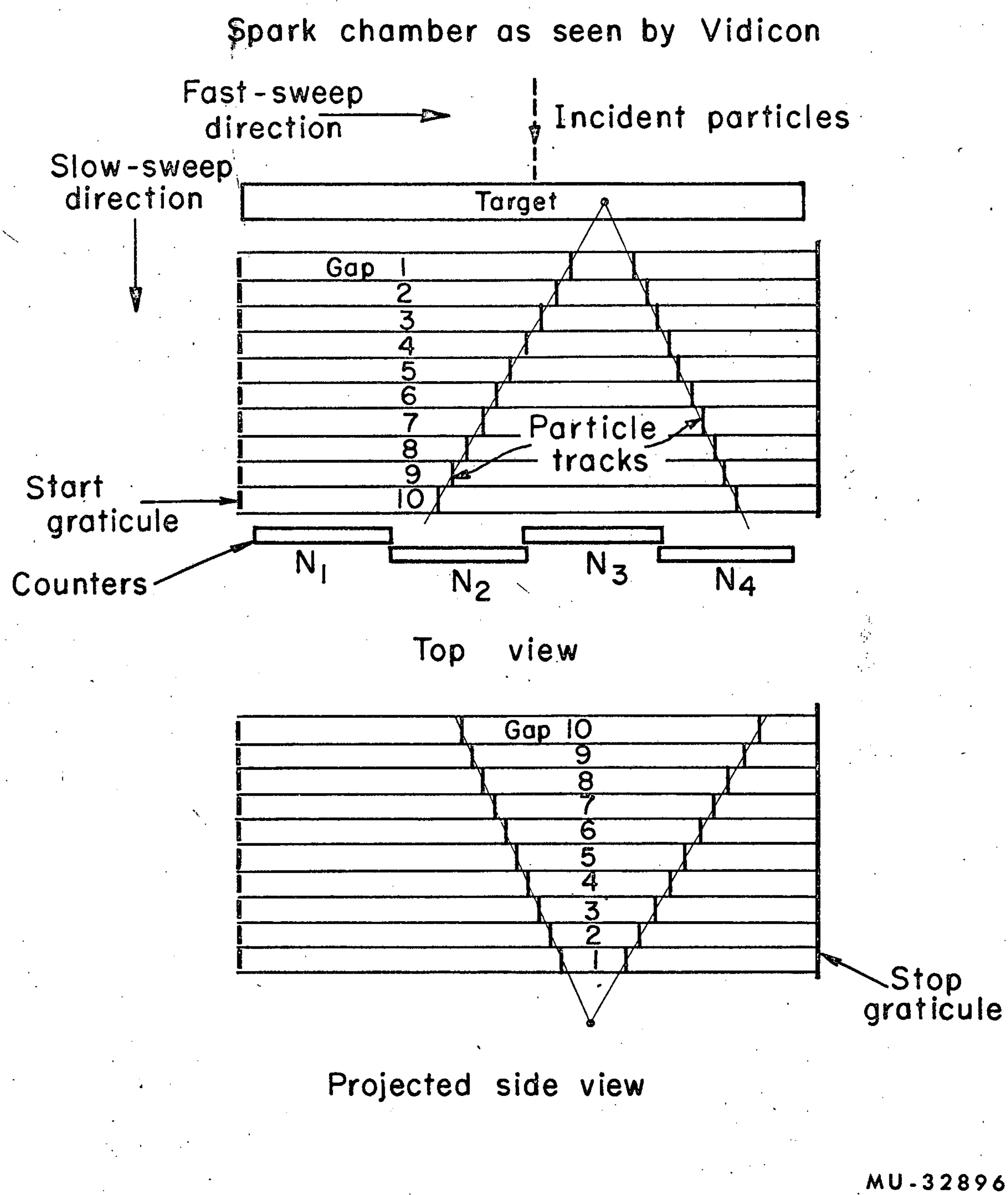

Spark chamber as seen by Vidicon
Fast-sweep direction
Incident particles
Slow-sweep direction
Target
Gap 1
2
3
4
5
6
7
8
9
10
Particle tracks
Start graticule
Counters
N1
N2
N3
N4
Top view
Gap 10
9
8
7
6
5
4
3
2
1
Stop graticule
Projected side view
MU-32896

Fig. 3.

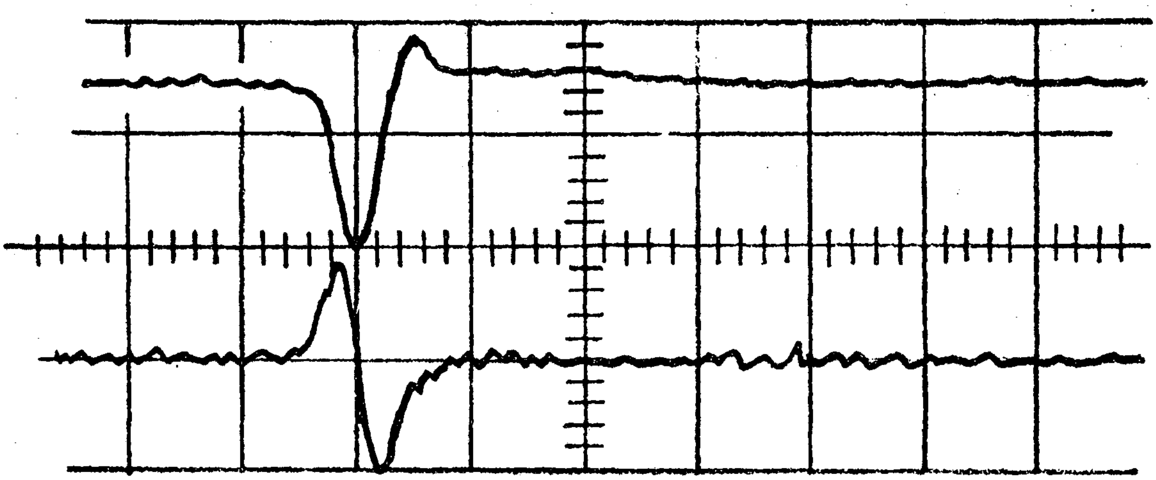


Fig. 4

MU-33464

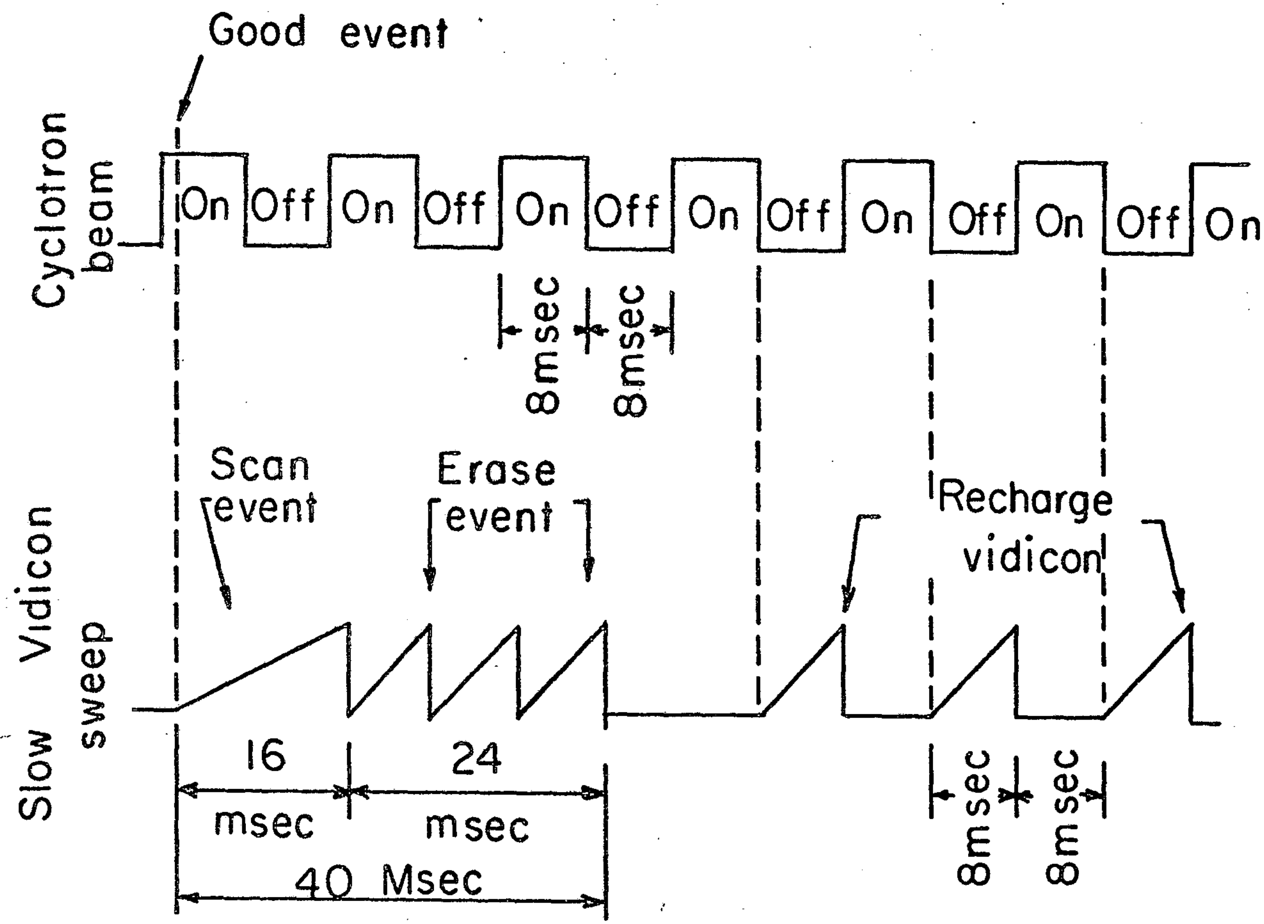


Fig. 5

MUB-2875

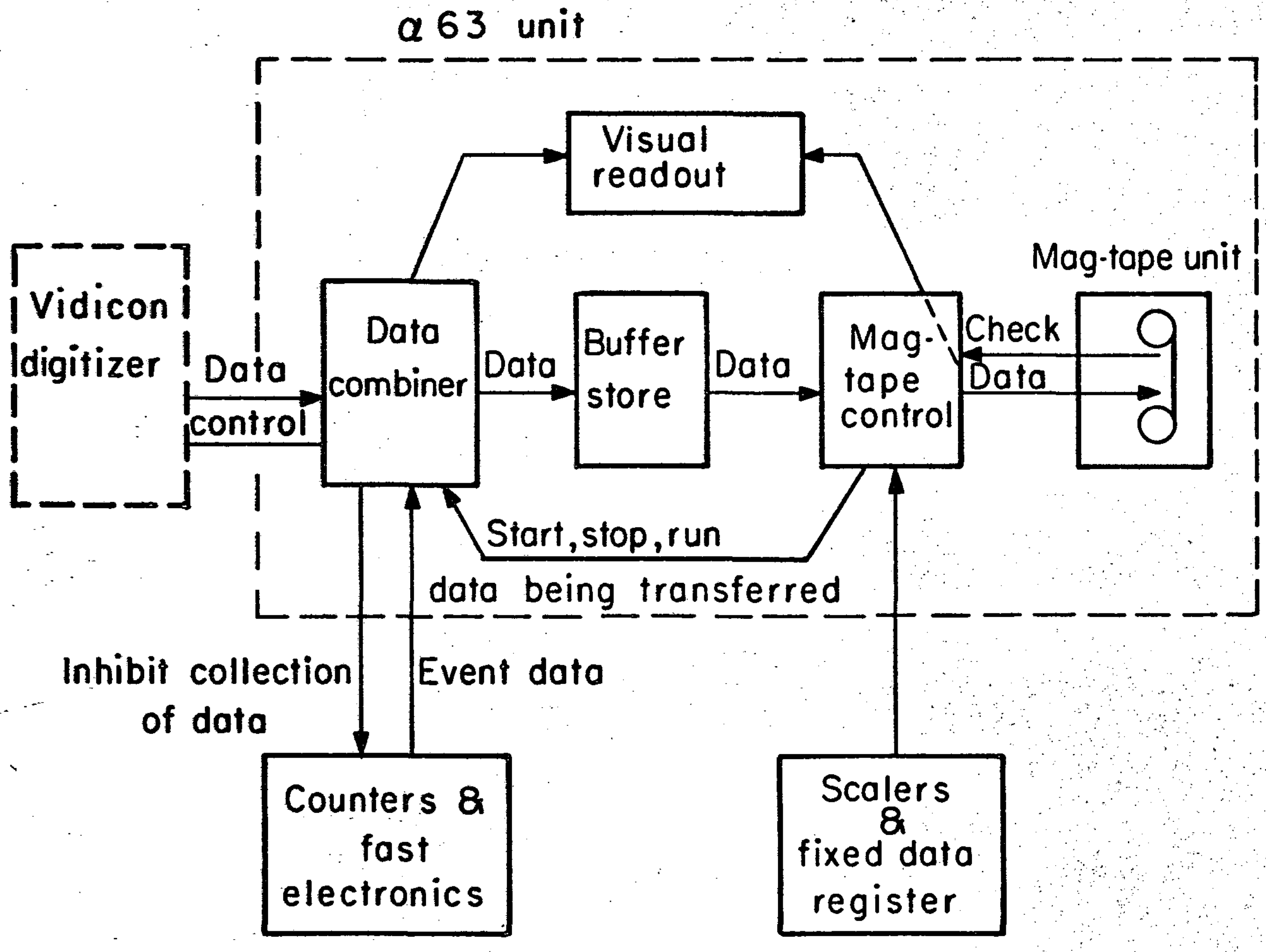
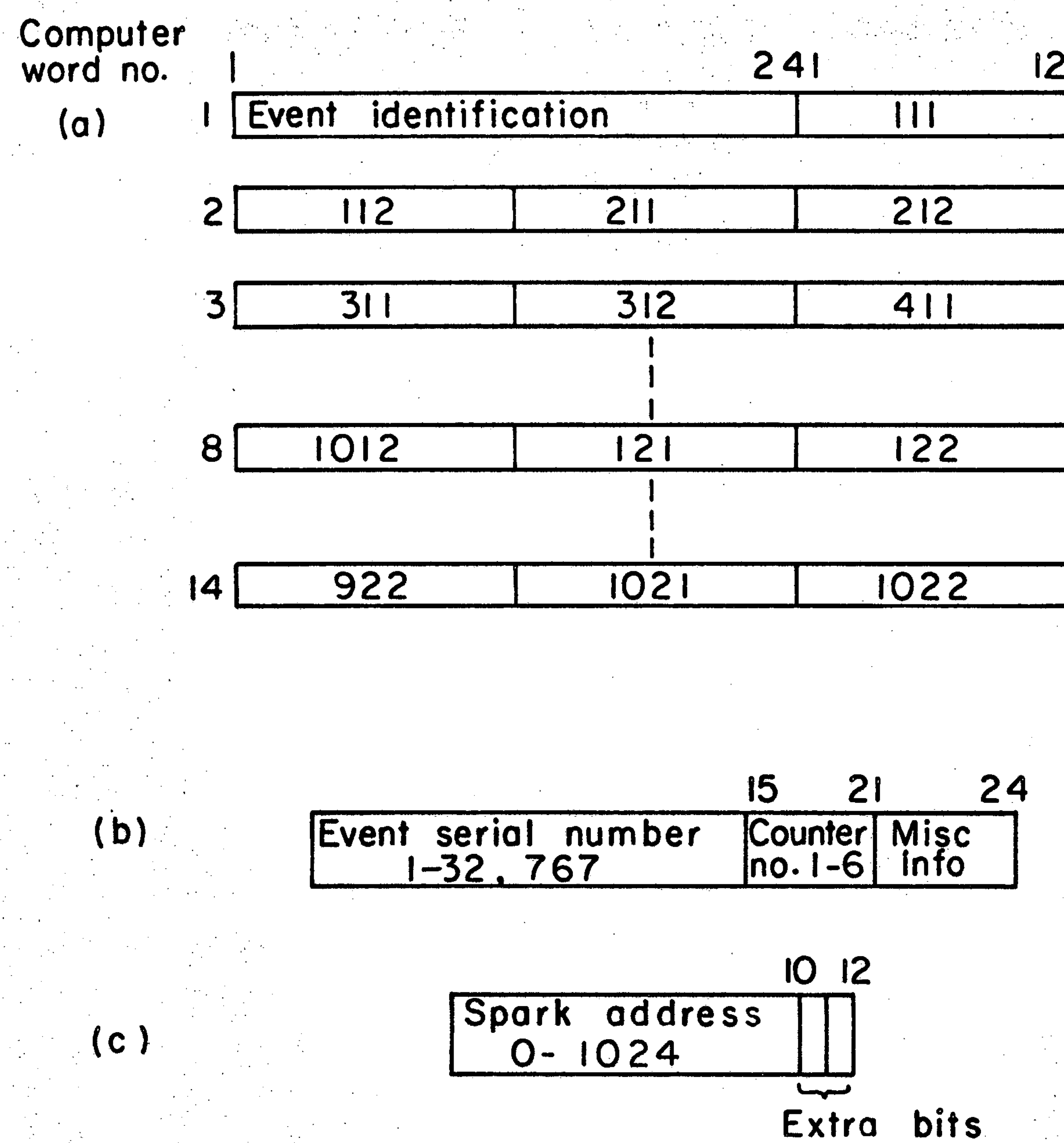


Fig. 6.

MUB-2876



MUB-2877

Fig. 7.