AUTOMATIC DIGITIZATION OF SPARK CHAMBER EVENTS BY VIDICON SCANNER

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PART I : (presented by V. Perez-Mendez)

PART II : (presented by F. Kirsten)

I. Vidicon camera and digitizing logic

1. INTRODUCTION

The large output of spark chamber events recorded on film and the subsequent labour 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 spark chamber tracks is considerably simpler than in the analogous case of bubble chambers. The simplifications stem from the fact that the selection of spark chamber 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 fall on straight lines or arcs of a circle (if the chamber is in a magnetic field), the "Pattern Recognition" aspects of an automatic scanning device to be 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 accomplished by using existing Lawrence Radiation Laboratory 20 Mc/s 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 pictures of spark chambers 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 aiming at present 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, as 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 face-plate of the vidicon. The simplest case utilizing this format is that of a single multi-gap spark chamber with two perpendicular stereo views projected in a parallel array by mirrors. A polarization experiment is under preparation at the Berkeley 184-inch cyclotron, in which the proton of polarization from a π-p scatter is determined by using the spark chamber to analyze the angular distributions of the proton after scattering from a carbon converter placed in front of the chamber.

2. VIDEO DIGITIZING CAMERA

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 and 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/s 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. Fig. 2, shows the concentric electrostatic and mumetal magnetic shields which 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 μs 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 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/s 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 μs 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 either to digitize 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 and 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 which produce a "zero cross-over pulse". The first diffentiation - with a time constant of 160 ns - trips the amplitude gating pulse which is set at a safe level above the noise background (10 mV). The second differentiation - with a time constant of 50 ns - produces the zero cross-over pulse. These pulses are shown in Fig. 4. A spark is distinguished by the digitizing logic from a fiducial-slit pulse by requiring a further gating pulse which is correlated in time with the sweep pulse, and thus with the spatial position of the fiducial slits. This gating-pulse logic is also used to minimize triggering on spurious random sparks, by requiring that the digitized sparks are in the vicinity of the scintillation counter that triggered the chamber, as shown in Fig. 3. Adjustments of these internal gating signals is accomplished by intensifying the corresponding portions of the sweep on a monitor scope that is simultaneously displaying the spark chamber image. This monitor 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 centre of each gap.

Once an event has been digitized it is necessary to erase completely (i.e., recharge the vidicon target). To accomplish this the electron beam is defocused and the beam current increased. Three 5 ms sweeps of the vidicon target are made immediately after an event has been digitized and the reafter 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 μs, with a 10 μs flyback. The scanning time is thus 15 ms; an additional 15 ms are required per complete erasure and recharging. With the RCA 7263A vidicon tube 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 better than 10 to 1 while operating the camera 20 ft from the chamber 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 hour period. Two sparks could be resolved and their positions digitized if their relative spacing was ≳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 overall performance, including some noise and drift from the Video amplifier.

It is worthwile to point out here that it is possible to shorten considerably the present 30 ms dead time per event by using existing faster electronics such as 100 Mc/s 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 only takes a few microseconds - and utilizing the time between sweeps for this purpose.

DISCUSSION

VERNON: Could you say something about the absolute resolution of sparks ? I thing you mentioned you had photographs also.

PEREZ-MENDEZ: If one assumes a start graticule in one place and a spark in another, then one can say to what accuracy this distance is measured. If one repeats the measurement and then also an hour later and so on, the question is what is the spread in timing. We have done this with a time to height converter and arrived at a certain spread which was 25 nanoseconds. Of course, this is a combination of effects in the electronics and of the vidicon and of the sweep stability of the vidicon and of how well the zero cross-over really picks up the centre of gravity of a spark.

VERNON: So, with a resolution of one part in 2000 one is happy to scan fiducial lines at any arbitrary time, just comparing their position in space with what you measure, but, as I find it, this unfortunately is not the case with tracks. Depending on how careful I am, the resolution varies between one part in 2000 and one part in 1000 or 500 for tracks. I am wondering since you have the same sort of triggering system as I do whether you don't have the same sort of trouble as due to the variation in spark intensities; if you have two tracks instead of one track, the overall change in intensity changes the triggering stability a little bit.

PEREZ-MENDEZ: Well I can answer the question partially in the following way. First of all when we did these tests we changed the light intensity of a slit; that is we just varied it systematically by factors of two until finally the light intensity was such that the gating discriminator was just on the verge of triggering; when you were close to this position then the resolution curve widened up. Then we made some tests with sparks and also took pictures of them. Since the sweep is slightly non-linear we had provision for a calibration scale placed on the chamber - that is the calibration scale is fed into the computer and it is there once and for all. We admit an error in the calibration scale so you can see that it was digitizing well but we did not have an absolute comparison.

GELERNTER: Is there any reason why in order to erase the previous event you can't increase the beam current in the vidicon and also increase the sweep speed ?

PEREZ-MENDEZ: Well we do that, as a matter of fact, because the erasing cycle takes only 8 milliseconds so we defocus the beam and increase both the current and the sweep speed, but then we talked to the RCA people and they told us that irrespective of how much we increased the current the photo-conductive layer absorbed only so many electrons and you do not accomplish a complete erasure. Now I don't understand the physics of this phenomenon but they assure me that this is so, and that it doesn't really matter at what rate - I am quoting the RCA people - they claim that it doesn't really matter at what rate you erase providing you go through a number of erase cycles; that is if you do three erase-cycles at 100 megacycles they say it is as good as having three erase-cycles at 20 megacycles.

GELERNTER: I would guess that they don't understand the physics of the situation either or else they would have solved the problem.

PEREZ-MENDEZ: We intend to look into this when we finally get around to speeding up the entire cycle but we have not done it yet. That is we wanted to make the system work at a certain time so we have followed what RCA recommended to us.

ROBERTS: I don't remember you saying anything about the linearity of the sweep and the consequent accuracy of determination of position of a spark. You said something about the resolution. Not about the accuracy.

PEREZ-MENDEZ: What we have done in our chamber is the following. The sweep can be made accurate to not much better than about 1% and for a while we spent some time trying to flatten out this curve but we couldn't get it better than 1% from linearity. However, it is quite convenient if a metal bar with little strips of reflecting scotch-light is put in certain places on the chamber and one shines light on it and in this way calibrates the vidicon. It picks up these objects remarkably well, and then one can put as many of these calibration marks as one wants and, at the start of a day's run, one sweeps through it to record the positions and these coordinates are fed into the computer. If one likes, one can also make the graticules of small strips of scotch-tape although there may be some reflections in the lenses. But it is a cheap way of making whole systems of graticules because one needs only a single flash lamp by the camera and then as many of these little strips of scotch-light to indicate to the vidicon where to start and where to stop. This again emphasises something that Dr. Vernon said, that you can use existing chambers and then take the scotch-light and a razor blade and, by cutting the strips out, it is adapted for vidicon use.

HINE: Continuing this question of linearity, are you sure a single calibration like that is valid all over the screen ? Is it stable on an hour by hour basis ? Could I also ask almost the same question of Dr. Vernon ? Is the relation between his current and spot position as accurate as it would appear from his talk ? Is his hysteresis an indication that the spot position doesn't quite seem to follow the controlling current.

PEREZ-MENDEZ: First of all about the stability. We have two sweep generators, one which generates fast sweeps and one which generates the slow sweeps. In principle they are independent and any one sweep is as good as another. If you like, one can put calibration marks at one end of the chamber and one at the other end and interpolate in between. You can put as many of these calibration marks in the dead spaces between the gaps of the chamber as you wish.

HINE: Have you been doing so ?

PEREZ-MENDEZ: For test purposes we have put one on either end only. The next question about reproducibility. Naturally it would certainly be very desirable not having to perform this calibration every 10 minutes, and these tests demonstrate this is possible because we left the vidicon running for about 20 hours overnight and then looked at the resolution curve. We saw that it only spread out about 50%; that is, it had increased from 25 to about 35 nsec over a 24 hour period.

VERNON: In response to the other question, the absolute spatial position of a fiducial line, for example, where you know the position in space, changes, in my system, by about half a per cent of the whole scan due to hysteresis. I think it can be removed if I just remove the hysteresis causing elements in the system.

WEINSTEIN: Regarding the absolute number of bits you need to record, have you considered representing the position of the second spark with the binary number for the first spark subtracted, to get a very much reduced number of bits for recording and analysis.

PEREZ-MENDEZ: No not really. There are many schemes one can use, but then one worries about how errors are accumulated if, for example, there is a missing spark. After all, the reason for having say ten plates in a chamber instead of two is that the chamber sometimes misses sparks and what one really wants to record is a straight line where the particle went, and one expects to have one gap miss occasionally and still get a good straight line. So we did not want to bias the data by requiring one measurement to be dependent on another.

PART II

II. Digitized data compiler

The data recording system used with the vidicon digitizer is referred to as "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 arranges 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: 1) the vidicon digitizer, 2) the scintillation counters and associated electronics, and 3) 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 the case of 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. 7b. 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 remainder of the 14 words contain up to 40 numbers (10 gaps x 2 sparks per gap x 2 views) for a 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. In the cases where 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. 7c. Ten bits contain the binary address, giving a capacity of 1024 possible spark positions. Two bits contain a code which 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 caused to be 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 additionally allows it to check for drifts in the digitizing system.

In Fig. 6, the block labelled "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. It then 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 1024 12-bit words. When filled to capacity by the data from 12 events, the contents of the store are transferred in a block onto the magnetic tape. During the 25 ms 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. 7a, 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 1088 characters. At a writing density of 800 characters/in., a record therefore occupies 1.25. of tape plus an 0.75 in. 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 purposes. Means of monitoring the operation of certain critical parts and of the overall 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 electronics but of the spark chamber as well. Some of the facilities of this type which are built into the digitizer and Alpha 63 are described below.

The vidicon and digitizing logic have what is referred to as 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 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 is brightened 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 which may be used to 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 at least 15 s. 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 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 received 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 by-passing the magnetic tape recording process.

As presently used, the above system is capable of recording information from the 10-gap chamber at a rate of about 30 events per second. About 30 ms per event is contributed by the vidicon and digitizer and about 25 ms 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 A cross-section view of a vidicon camera

Fig. 2 The vidicon camera removed from its magnetic shield. The deflection amplifiers are on the central printed-circuit cards. The lens is to the left, and the video amplifier card is just visible between the lens and the deflection coil

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

Fig. 4 Signals from the vidicon camera. That of a single spark: (upper) after one differentiation; (lower) after two differentiations

Fig. 5 The slow sweep sequence

Fig. 6 A block diagram of the Alpha 63 data processing unit as used with a vidicon camera

Fig. 7 Format of: (a) An event partial record; (b) Event identification word; (c) A spark-address word

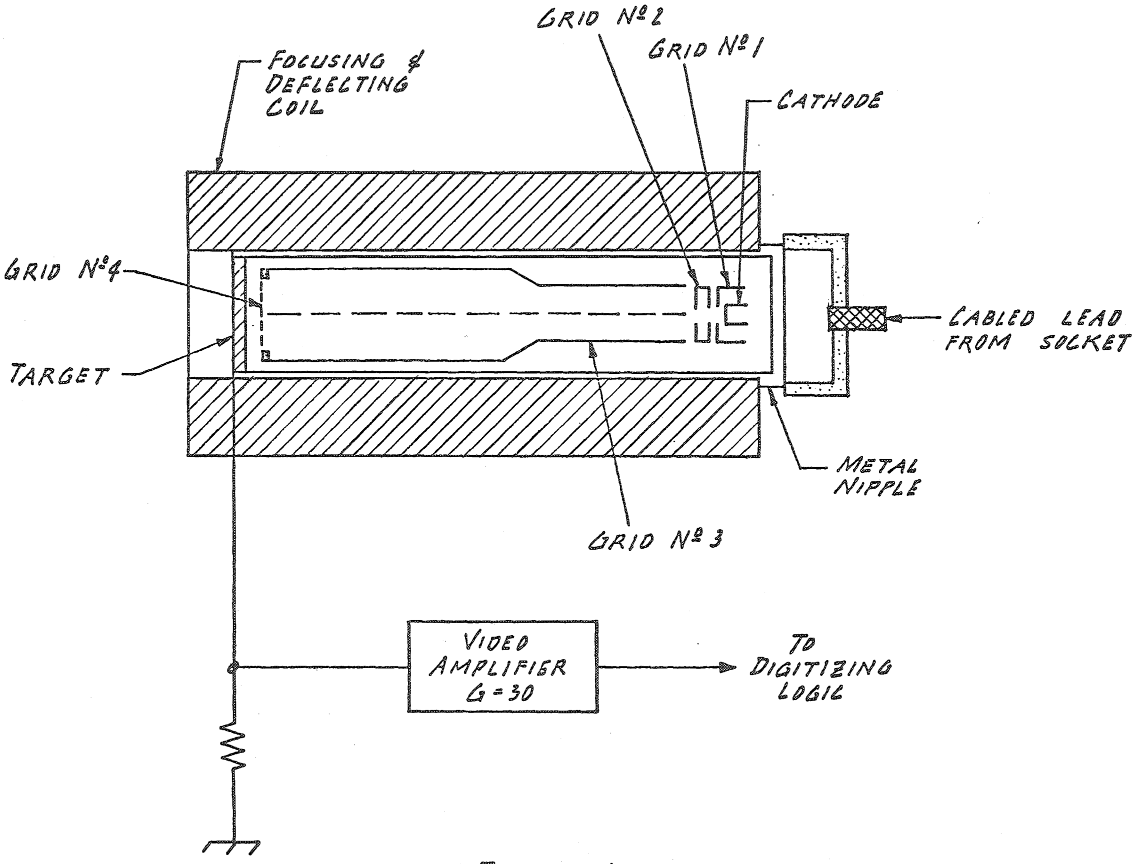


FIGURE 1.

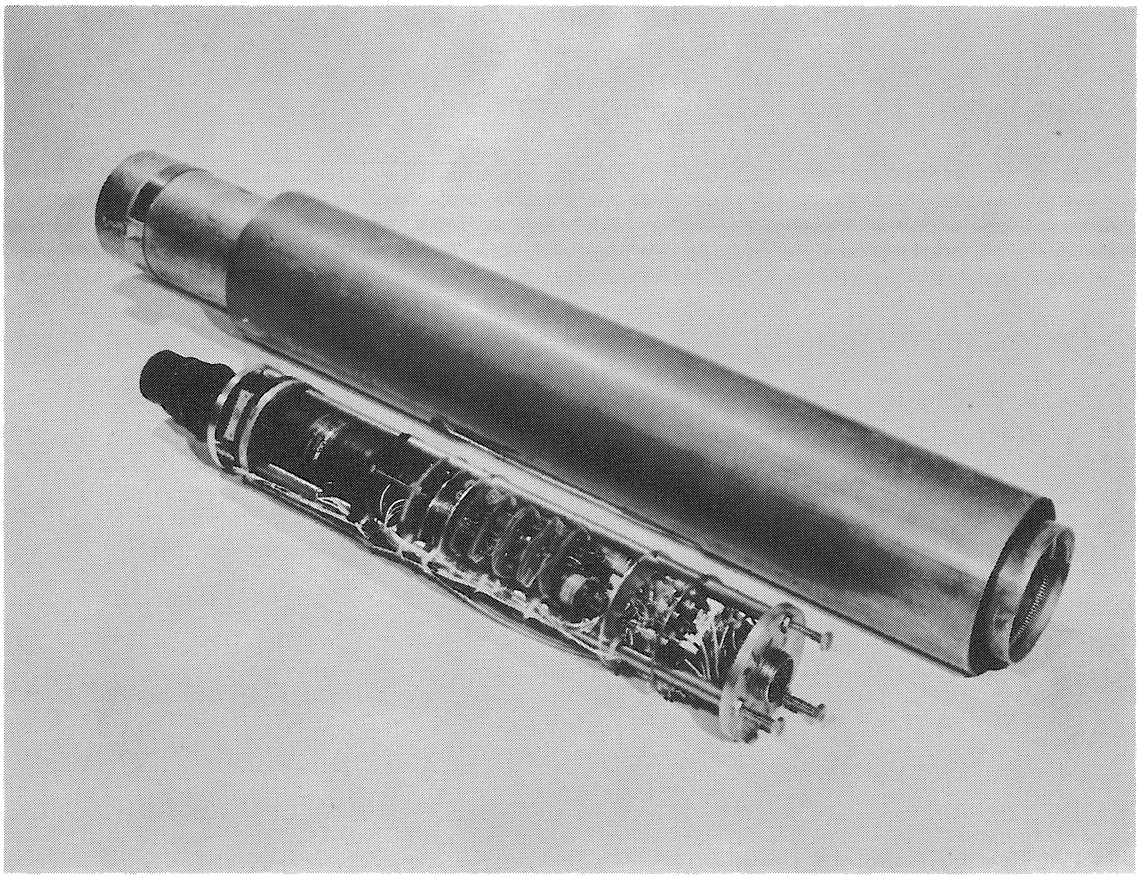


Fig. 2

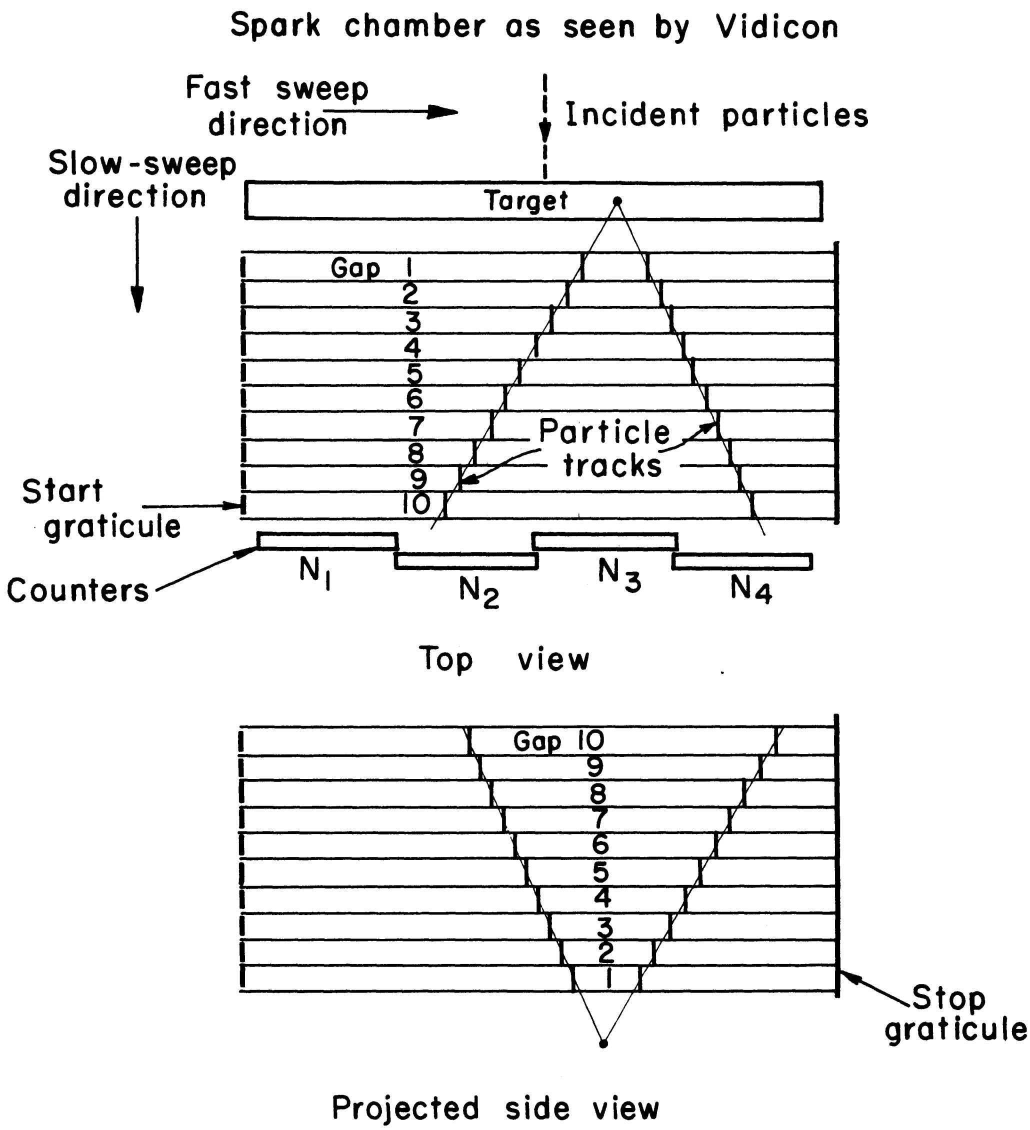

Spark chamber as seen by Vidicon
Fast sweep direction
Incident particles
Slow-sweep direction
Target
Gap 1
2
3
4
5
6
7
8
9
10
Particle tracks
Start graticule
Counters
N_1
N_2
N_3
N_4
Top view
Gap 10
9
8
7
6
5
4
3
2
1
Stop graticule
Projected side view

Fig. 3

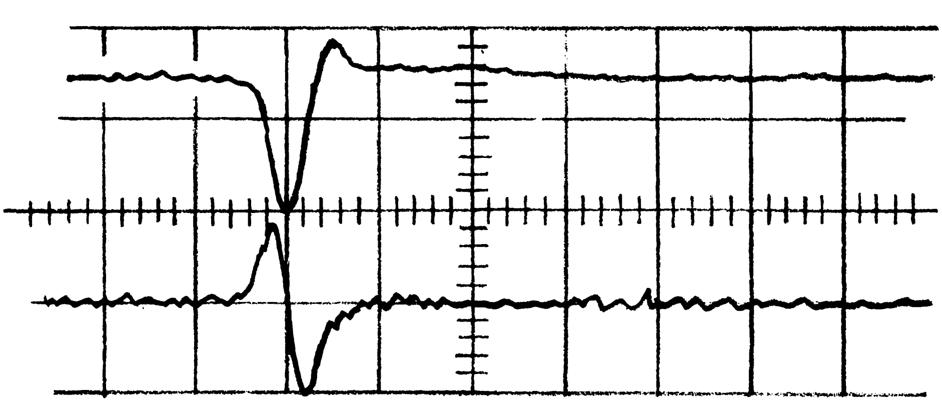


Fig. 4

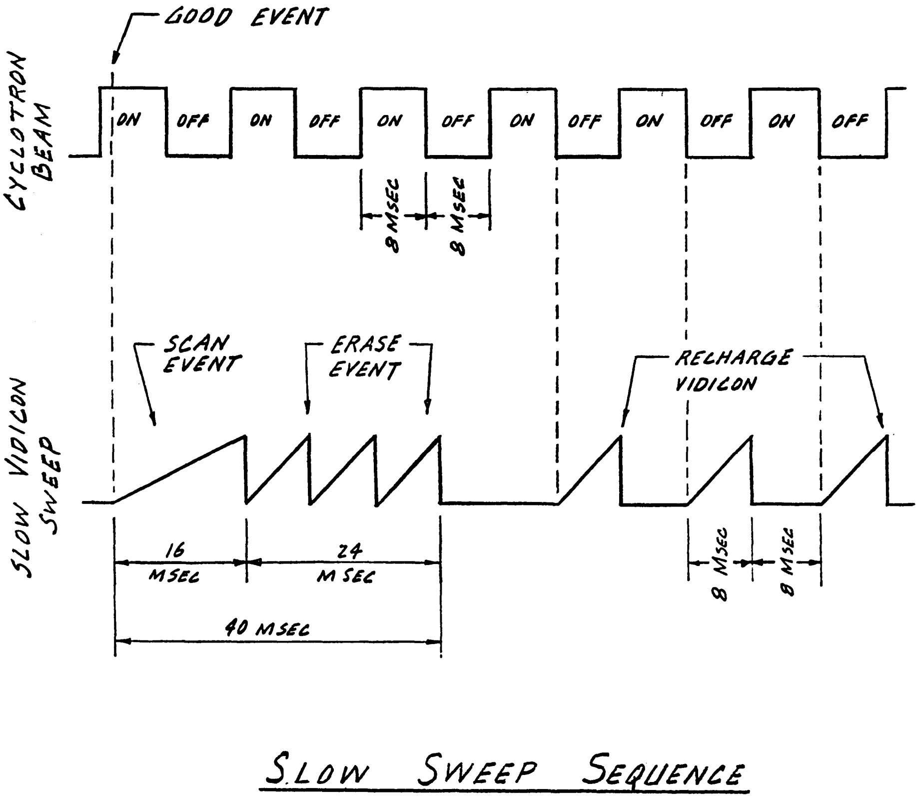

GOOD EVENT
CYCLOTRON BEAM
ON
OFF
8 MSEC
SLOW VIDICON SWEEP
SCAN EVENT
ERASE EVENT
RECHARGE VIDICON
16 MSEC
24 MSEC
40 MSEC
8 MSEC
SLOW SWEEP SEQUENCE

Fig. 5

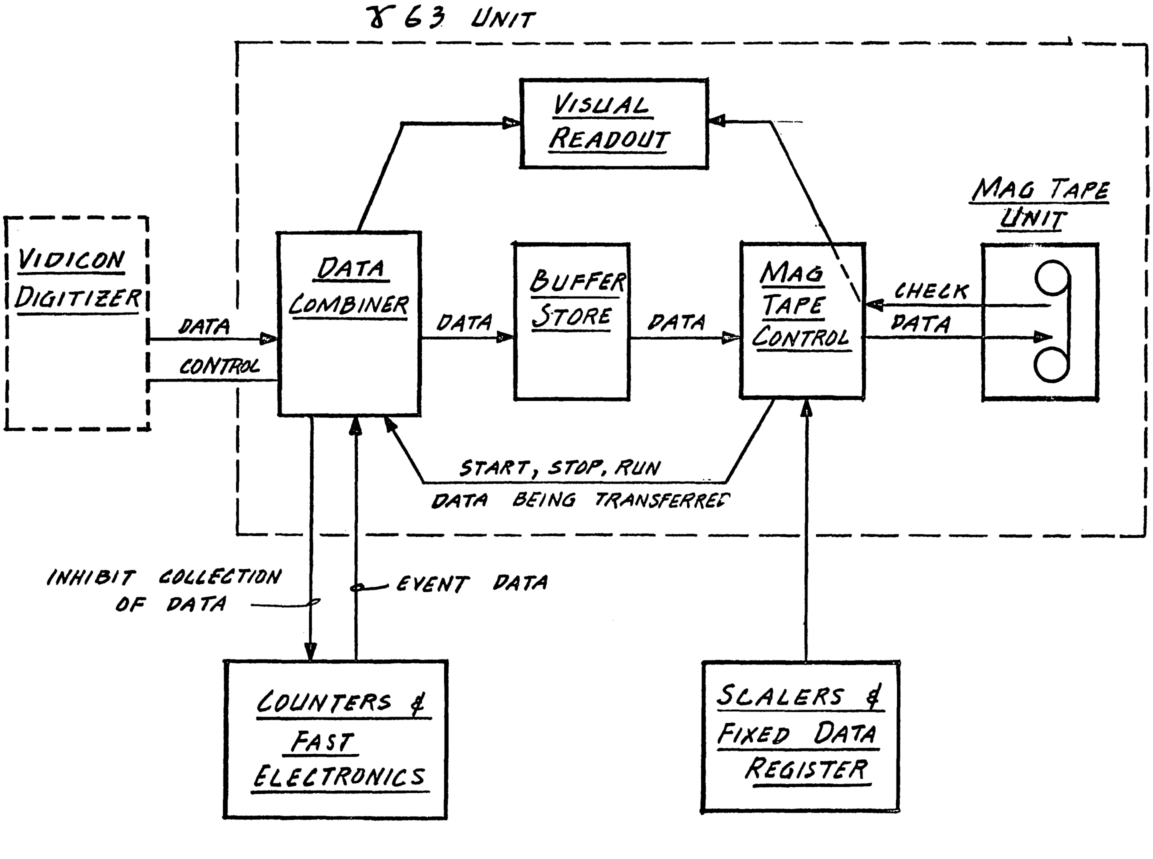
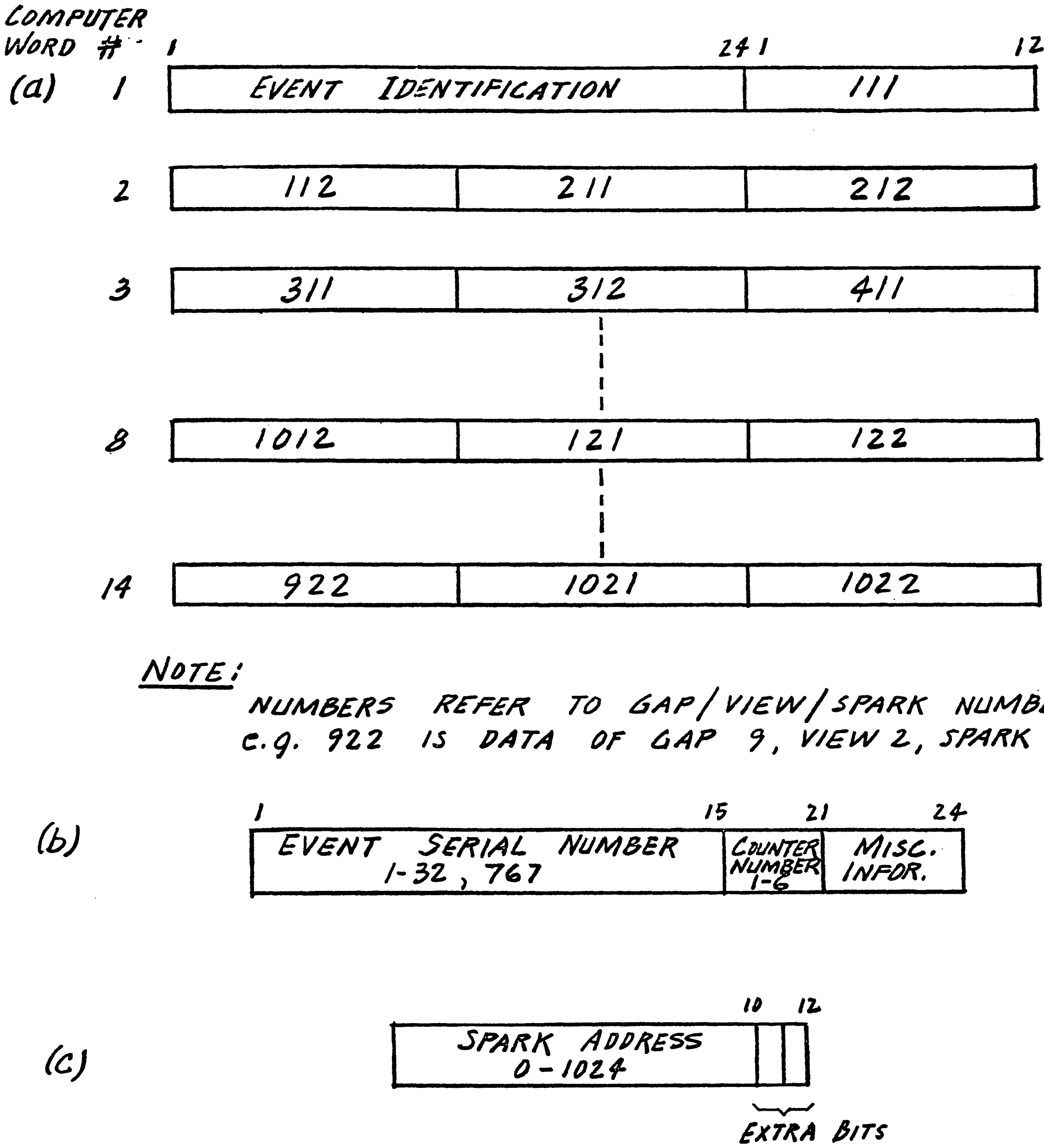

γ 63 UNIT
VISUAL READOUT
MAG TAPE UNIT
VIDICON DIGITIZER
DATA
CONTROL
DATA COMBINER
DATA
BUFFER STORE
DATA
MAG TAPE CONTROL
CHECK
DATA
START, STOP, RUN
DATA BEING TRANSFERRED
INHIBIT COLLECTION OF DATA
EVENT DATA
COUNTERS & FAST ELECTRONICS
SCALERS & FIXED DATA REGISTER

Fig. 6



FORMAT OF (a) AN EVENT PARTIAL RECORD; (b) EVENT IDENTIFICATION WORD (c) A SPARK ADDRESS WORD.

Fig. 7

DISCUSSION

GELERNTER: Have you ever considered or felt the need for digitizing and storing the intensity of the spark as well as its position ?

KIRSTEN: Well we had of course considered it - I believe this idea was originally presented by yourself several years ago and we have of course noticed it. We originally thought that we would provide several extra bits for each spark to indicate intensity, but we have not done this in this experiment since, presumably, we are dealing with a single track only and the intensity is not important. But if one is concerned with cases where there are several sparks it certainly would be useful as a means of separating the data from the various sparks.

GELERNTER: Were there technical problems that prevented you from recording intensity ? All you really have to use is some kind of threshold when you integrate the signal.

KIRSTEN: No the technical problems haven't stopped us simply because we haven't tried them, but I don't know of any reasons why it couldn't be done.

HINE: Could I ask my question about costs ?

KIRSTEN: In this case, I believe that the data handling electronics from the data compiler to the magnetic tape control has cost us approximately $ 50,000. The tape unit itself is not included since we are leasing this.

HINE: Is that including labour ?

KIRSTEN: That's including labour, parts and the time used to test the system.

HINE: What about the earlier part of the electronics, with the scalers, the control sets of the vidicon and so on ? Is that in the $ 2000 that was mentioned ?

KIRSTEN: No it is not. To duplicate units I believe would require in the order of $ 5000 per unit and also you would need one digitizing unit for each vidicon camera. The development cost of course is then much higher in this case.