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AN INTEGRATING STORAGE DISPLAY MONITOR WITH DARK-TRACE TUBE FOR NUCLEAR TWO-PARAMETER SPECTRA

by

D. RIEB and W. STÜBER

1966

Joint Nuclear Research Center
Geel Establishment - Belgium

Central Bureau for Nuclear Measurements - CBNM

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SUMMARY

The necessity and possibility of a monitoring device for sorted display of unsorted nuclear event data during or after their recording on magnetic tape are discussed. A dark-trace storage tube is proposed for this purpose and the main characteristics of such a tube are studied. The operation and the circuits of a developmental storage monitor are described.

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Introduction

In many nuclear experiments a distribution function of certain properties of nuclear events is measured. For this the range of interest is divided into a lot of small steps or increments, called "channels". This distribution function, the "spectrum", will be multidimensional, if several characteristics of each event are measured simultaneously. Especially in these "multiparameter experiments" the necessary number of channels can be very high, exceeding by far the possibilities of great multichannel analyzers (1000 to 4000 channels).

Besides the use of a multichannel analyzer with an extra large memory [1], or a computer with channel reduction facilities [2] or of an associative memory technique [2,3], one possibility to dispose of a sufficient number of storage channels is the use of a magnetic tape recording system which has a virtually unlimited storage capacity [4]. Sorting of the recorded data is done off-line after the experiment by means of a sorting memory of normal size. If the number of experiment channels is m and the number of memory channels is n, the magnetic tape has to be scanned $\frac{m}{n}$ times in order to sort all recorded data. Magnetic tape recording is the most economical method for storage of large channel numbers, but it has a rather prohibitive drawback: as the data are only recorded but not sorted during the experiment, there is no possibility to monitor the build-up of a spectrum to check that the experiment is running correctly. For the same reason preparation of experiments and optimization of the necessary experiment conditions is very difficult and troublesome. Therefore, to exploit the economy and huge data storage capability of the magnetic tape system, there is a stringent need for a relatively simple sorting and integrating display unit, which shows the gradual growth of a spectrum by the data written onto the magnetic tape. This unit should have the capability of displaying simultaneously the contents of

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$10^5 - 10^6$ channels; a reduced accuracy concerning the number of counts per channel can be allowed.

A normal sorting memory with display facilities, as is used in multichannel analyzers, can be adapted to the task by first sorting the whole spectrum with low resolution, feeding groups of 100-1000 incoming experiment channels to each memory channel, and later on sorting with high resolution only a small interesting part of the spectrum. The disadvantage of this procedure is not only that several measuring steps are necessary to measure all interesting parts of the spectrum, but also that the first survey measurement of the whole spectrum can yield a misleading picture. As in this case each memory channel shows only the average of a greater number of experiment channels, narrow peaks will appear lower than wide peaks of equal height, or might even disappear completely in the "background".

Much better with regard to these drawbacks is the 'twinkle-box" method [5], which is especially suited for two-parameter spectra. There the beam of a cathode ray oscilloscope is deflected in the x- and y-directions proportional to the address number of the x- and y-parameter of an incoming nuclear event, and is pulsed on for a short time, giving a short light flash on the fluorescent screen. The screen is viewed by a photographic camera for a long time and all the light flashes are integrated on the film, building up a picture of the spectrum, with the x- and y-coordinates giving the addresses and the blackening of the film representing the number of counts per channel (map display). This simple system would be almost ideal for monitoring purposes, if it could show the spectrum while it is growing; but as this is not the case with photographic methods, the twinkle box is not well suited for monitoring.

The photographic integration can be avoided and the spectrum picture can be made visible during operation, in case a direct view storage cathode ray tube is used, having a viewing screen with storage and integration properties [6]. The feasability of a direct-view integrating storage monitor depends mainly on certain properties of the storage tube, especially line resolution, storage time and integration accuracy. The channel resolution of a storage monitor is determined by the ratio of the usable storage area to the area of one stored dot and can certainly reach a value of 10^5, perhaps even 10^6. But to realize this in practice, the location of each channel on the screen of the tube must be accurately defined and stable, i.e. the analog deflection has to be of very high stability. The storage time of the tube should be as long as possible to get a good integration over a long period, because a multiparameter-experiment can last many hours or even days. But in practice a slow fading of the picture probably can be tolerated. Then the tube will work more like a ratemeter, giving a picture of the counting rates in all channels, which certainly need not be a disadvantage. The most important problem with the storage monitor is the count-storage and display accuracy. Though such a monitor is not a measuring instrument, it must give a certain degree of quantitative information concerning the number of counts per channel. The accuracy limit set by the tube is due to nonuniformity of integration efficiency over the screen. An even more severe limit might be that the human eye is not well suited to judge differences in brightness or blackening quantitatively. Therefore an additional light measuring device could be advantageous. To aid the eye also a storage tube with a threshold display characteristic would be favourable, making visible only those channels which exceed a certain number of counts (contour display). The map display is best suited to two-parameter experiments, but can be adapted also to three-parameter data. In this case the storage area must be divided into a lot of sub-areas, which display x-y cuts through the three-dimensional spectrum in different heights, so that each sub-area corresponds to one channel of the third parameter. In practice this will be feasible only with large storage screens.

A storage display can be advantageous also for large sorted spectra, as a non-storing display will not give the impression of a standing picture, if the display cycle time becomes too long with large numbers of channels. In this case integration and gray-scale capabilities of the storage tube are not of great importance, because the spectrum is already sorted and a channel-content selection for contour-display can be made by an external device.

Among the different storage tubes available the dark-trace tube is the simplest and least expensive one; therefore such a tube has been investigated for its usefulness for monitoring purposes. The electronic circuits developed for a dark-trace monitor can be used with minor modifications also for other tubes.

1. General properties of storage tubes

There exist two different kinds of direct-view storage tubes: the dark-trace tube and the charge-picture storage tube. Types with electrostatic or with magnetic deflection are available of both kinds. Though magnetic deflection is not as fast as electrostatic deflection, tubes with magnetic deflection are preferable because they can better be adapted to transistorized equipment.

1.1. Dark-trace storage tube

This tube differs from an ordinary television picture tube only with regard to the picture screen. The fluorescent screen is replaced by an alkalihalogenide screen, the colour of which is changed permanently from white to violet on all places, where the screen has been hit by the electron beam. In contrast to other cathode-ray tubes the picture is not self-illuminating, but can be seen only with external illumination of the screen. A written picture will fade away very slowly, but can be visible for several days. An erasure of the picture is possible within 30 - 60 seconds by electrically heating the screen.

1.2. Charge-picture storage tube

This tube has a fluorescent screen and the picture looks like that of an oscilloscope tube. A charge picture written by the electron beam can be stored on the isolating surface of a mesh electrode between the electron gun and the screen. A flooding electron current flowing through the meshes to the viewing screen is controlled by the charges on the storage surface, thus generating a luminous projection of the charge distribution on the storage electrode. As the bias voltage of the mesh electrode can be controlled externally, it is possible to shift the cut-off point of the storage surface, so that e.g. only the highest peaks of the "charge mountains" are visible. This will increase strongly the accuracy of visual "channel-content" readout, and gives a distinct advantage over the dark-trace tube. A charge picture will be conserved for several days without viewing. When the picture is viewed by means of the flooding electrons the charge picture is destroyed within some minutes by positive ions in the tube. Therefore viewing is only possible for short time intervals; but of course the picture can be conserved on a photo. Erasure of the stored picture is possible in a fraction of a second by a positive voltage pulse to the storage mesh.

2. Investigation of a dark-trace storage tube, type LORENZ AS 17-21

The investigated tube has magnetic deflection and electrostatic focussing. The picture screen is rectangular, with a useful area of 8 x 12 cm^2. Two tubes have been tested, giving practically the same results. For the magnetic deflection a television deflection yoke, type AS 70-3, was used, the vertical deflection coils of which had been modified to give the same deflection sensitivity as the horizontal coils.

As the blackening of the screen by the electron bombardment is not very intense and therefore somewhat difficult to measure, this property has not been measured directly. Instead of this, polaroid-photographs have been made of several screen pictures and have been compared with a known gray-scale on a photo. Though this is not a very accurate procedure, it is quite adequate in our case, as in practice an integrated spectrum on the viewing screen will also be evaluated visually.

The written pictures are composed of many single points, arranged in form of squares of 0.22 cm^2 size or as a lattice of horizontal and vertical lines, which are written automatically by means of the electronics to be described later. For photographing the screen was illuminated from the back-side through the tube bulb by four incandescent lamps of 15 W each. This is more convenient than illumination from the front-side, and can be permitted because it has been found that the visual impression of the contrast of a written picture is the same for incident and for transcident light. As the maximum light absorption of the written spots on the screen lies in the yellow-green wavelength region, a green filter pane has been placed before the screen. For practical reasons all measurements have been made with a screen voltage of 8 kV.

The screen is susceptible to burning by the electron beam and therefore the charge deposited by one single scan must not exceed 5 $\mu As/cm^2$ [7].

2.1. Gray scale and integrating capability

When the electron beam deposits a charge on the screen of a dark-trace tube a dark spot is generated. The contrast K of this spot to its surroundings for incident light can be defined and measured as

$$K = \frac{I_o - I_c}{I_o} \qquad (1)$$

where I_c is the light intensity reflected from the dark spot and I_o is the light intensity reflected from the white screen before this spot was generated. For transcident light a similar expression for the light absorption can be given.

In the documentation of the manufacturer [7] a relation between contrast K and charge density σ [AS/cm^2] is given for an accelerating voltage of 10 kV. This curve is reproduced in fig. 1 and can be approximated by the following expression,

$$K\,[\%] = 15 \ln (1.5\,\sigma + 1) = 34{,}6 \lg (1.5\,\sigma + 1) \qquad (2)$$

σ in μAS/cm^2.

For low values of the charge density σ, the contrast increases almost linearly with σ, whereas for high values the contrast varies with the logarithm of the charge density. According to [7] a sharp contrast step from 0 to 2 % is just visible.

To give an impression how a certain contrast looks, a gray scale is shown in fig. 2 with steps of 5 % contrast increase from 0 to 60 % (and then to 100 %) contrast. This contrast staircase has been made by photographing the illuminated tube screen successively 20 times, while an opaque object before the screen was shifted one step to the right after each exposure. So the film has received on different spots $\frac{20}{20}, \frac{19}{20}, \frac{18}{20}, \ldots$ of the integral quantity of light. Fig. 2 shows that a contrast of 5 % is hardly visible and 10 % is clearly visible. The same is true for contrast differences at other contrast values. Therefore, if we want a picture with several discernible contrast levels, we cannot use the linear region of the storage characteristic, but are forced to work in the logarithmic region. For the difference of two contrast levels K_1 and K_2 in this region we can derive an approximate expression from eq. (2),

$$K_2 - K_1 \approx 34{,}6 \lg \frac{\sigma_2}{\sigma_1} \qquad (3)$$

This means that for the discernible contrast difference of 10 % the corresponding charge densities will have a ratio $\frac{\sigma_2}{\sigma_1} = 1.95 \approx 2$. As the contrast is proportional to the accelerating voltage according to [7], for the same contrast difference this ratio will be 2,30 at 8 kV and 1.61 at 14 kV (which is the maximum rated voltage for this tube). With regard to a quantitative judgement of the deposited charges by visual inspection of the screen picture these are poor values, and it is advisable to use always the highest rated voltage. Therefore, measurements with 8 kV accelerating voltage give a somewhat too pessimistic picture of the tube's capabilities.

The situation becomes even worse with integration. Measurements show that a certain amount of charge gives less contrast on the screen when it is deposited in small successive portions compared with a deposition by one single "shot". This can be seen in fig. 3, which shows from left to right 3 squares written with 10 scans of 0.45 $\mu As/cm^2$ each (interval between two scans 1.2 sec.), with 1 scan of 4.5 μ AS/cm^2, and with 20 scans of 0.45 μ AS/cm^2 each, resp. The charge has been deposited by 4096 beam current pulses per scan of 12 μA, with a duration of 2 μs in the first and third case and of 20 μs in the second case. Under these conditions about twice the charge is needed with integration to give the same contrast as with single scan.

The gray-scale characteristic is also worse with integration. Fig. 4, upper row, shows 8 squares, which have been written with 1, 2, 4, 8, 16, 32, 64, 128 scans respectively, each scan depositing a charge of 0.3 $\mu As/cm^2$ on the screen. It can be seen that a charge ratio of 1:4 gives a contrast difference of about 10 % only.

For high contrast values the gray-scale characteristic must come to a certain saturation, as the contrast cannot exceed 100 %. No measurements have been made above 50 % contrast, but at least up to this value the logarithmic characteristic remains valid. Therefore the tube can display at least 6 different contrast levels (inclusive zero). The writing efficiency, i.e. the contrast generated by a certain charge, has been found to be constant all over the screen within the limits of the poor measuring accuracy.

2.2. Storage time

A picture written on the screen is not absolutely stable, but fades away slowly. The velocity of this process depends on external influences, especially temperature and light incident on the screen. It has been found that a "single shot" contrast is more resistant against these influences than the same contrast made by integration.

In fig. 4 the lower row shows the same picture as the upper row, but has been written 17 hours before the photo was taken. During this time the screen has been held in almost complete darkness. Comparison with the upper row shows that the contrast has faded for about one contrast level, corresponding to a factor 4 in charge density. The same result has illumination of the screen with the four 15 W lamps for about 1 minute or with the dispersed room light for about 2 hours.

2.3. Resolution

According to [7] the line-width is 0.12 to 0.16 mm for beam currents of 10 to 20 µA. This is valid only for a defined sweep speed, because the beam current density is not homogeneous over the diameter of the beam. Therefore, the apparent line width depends also on the deposited charge, so that it is not possible to give an accurate fixed value. It has been found, that dots written with a good contrast (about 30 %) by a beam current of 12 µA just come in touch with one another if they have a center distance of 0.16 mm. This would mean that 500 x 750 = 375.000 channels are possible on the 8 x 12 cm^2 screen area. But at the left and right edge of the screen the beam cannot be focussed equally sharp as in the center, and therefore it is advisable to use only an 8 x 8 cm^2 area of the screen, which means 500 x 500 = 250.000 channels.

2.4. Deflection stability

The deflection stability depends mainly on the quality of the deflection yoke and its mechanical fixation. It has also been found that there exists a definite distance between cathode and yoke, where the deflection stability has a maximum, at least with that yoke used for the tests.

Fig. 5 shows the results of a temperature test. Two test lattices have been written on the screen, the first one at a temperature of 28°C (tube and yoke) and the second one at 52°C. A shift of 0.4 mm can be observed on the left part of the picture, which was reversible and reproducible. This instability can probably be improved by a better mechanical fixation of tube and yoke.

2.5. Nonlinearity of deflection

The lines in fig. 5 should be linear, but this is not the case. The picture shows a distinct pincushion distortion, which is due to the fact that the screen is not part of a sphere's surface, but is flat. So the distance from the center of deflection to the edge of the screen is greater than to the center of the screen. Though this distortion can be avoided by using a deflection yoke with pincushion correction, a certain degree of distortion will always exist. For measuring purposes it is advisable therefore not to use an external graduation on the tube, but to write electronically a calibration lattice onto the screen. This would avoid also any parallax error.

2.6. Necessary voltage stability

The only voltage which influences the beam deflection is the accelerating voltage of the screen. Calculation and measurement show, that a small voltage change of b % gives rise to a change of the deflection distance from the center of $-\frac{b}{2}$ %. If a deflection stability of 0.1 % of the whole deflection length over the screen is required, the accelerating voltage must not change more than 0.4 %.

3. Layout and operation manner of a storage monitor

Fig. 6 shows a simplified block-diagram of a monitor unit with display storage tube. As already mentioned, for each incoming nuclear event a constant charge increment has to be placed at the proper spot on the storage screen. This spot is determined by the (preferably two) measured parameters of the event, which have been digitized in binary form as an address number. For two-parameter events it is convenient to attach the address part of one parameter to the horizontal (x) direction and the address part of the other parameter to the vertical (y) direction.

The arrival of a coded event is indicated by a read-in command pulse. Then the x- and y-adress parts are accepted by 10-bit registers, equivalent to a storage capacity of 1024 x 1024 channels. (This is 2 x 2 times too high for the resolution of the dark-trace tube , but has been chosen to see better the resolution limit of the tube). The binary numbers stored in the x- and y-registers are converted to proportional current levels by two digital-to-analog converters. These "address-currents" are amplified by two dc-current amplifiers, and the amplified output currents are fed to the x- and y- deflection coils, respectively. When the magnetic deflection fields have settled, the electron beam is pulsed on for a short time to deposit a charge increment on the storage screen. The pulse duration can be altered by a switch, so that the number of pulses necessary to reach a good contrast value can be adapted to the experiment requirements. 100 pulses per channel will be very satisfactory; in this case the statistical error is only ± 10 %, which is much better than the visual readout capability. For quick monitoring during experiment set-up certainly 10 pulses per channel will be sufficient. Though the statistical error is ± 32 % in this case, it will be hardly visible on the dark-trace screen, particularly as the eye will diminish the importance of the statistical error by averaging over several adjacent channels.

Besides the event storage a calibration lattice facility has been provided. 16 horizontal and 16 vertical lines composed of a sequence of points can be written automatically. As this takes place via the input registers, all nonlinearities and long-time instabilities of digital-to-analog converters, dc-amplifiers, and of the deflection yoke will be made ineffective by this calibration. Of course, the stability during one experiment cycle must be in accordance with the required resolution.

The maximum acquisition rate of the developmental monitor for equidistant events is only 3000 events/sec. But as multiparameter-rates are normally low and the statistical time distribution of events can be derandomized by a buffer store, this should be sufficient in most cases.

4. The building blocks of the developmental dark-trace monitor

4.1. Deflection amplifier

The high channel resolution of the storage tube should not be diminished by instabilities in the beam deflection; this requirement determines the necessary stability of the analog working deflection circuits. Therefore the deflection amplifier has been designed for high gain stability and low dc-drift. This has been attained by a strong negative feedback and by a differential amplifier input stage with relatively low collector current. But especially the dc-drift would be reduced further by using transistors with extraordinary high current gain in the input stage (e.g. 2N 2484).

The amplifier can supply positive and negative output currents of up to 1A and has a current gain of 200. The open-loop gain (without feedback) is about 5.10^5. The nonlinearity, i.e. the maximum deviation of the input - output current characteristic from a mean straight line, is $\pm 3.10^{-4}$ referred to the peak to peak swing of 2 A. This is negligible compared with the nonlinearity of the deflection system. A change of the ambient temperature from 23°C to 60°C causes a relative increase of the gain of 3.10^{-4} and an additional output current drift of 1.6 mA. This drift is equivalent to an 8 μA input current change or to a deflection shift on the screen of 8.10^{-3} cm. The rise time of the output current pulse through the deflection coil (L = 1,5 mH, R = 1 Ω) in response to an input current step is dependent on the amplitude, because the output transistor is always driven to saturation in the first moment, due to the nature of the applied feedback. The most critical case for the storage monitor is a jump of the beam from one edge of an 8 x 8 cm^2 field to the other edge. The time needed for the corresponding current jump from

+ 0,8 A to - 0,8 A is 150 μs. This can only be speeded up by using a higher supply voltage or a deflection yoke with lower inductance (and correspondingly higher current need). Probably an improvement will also be possible with another deflection yoke, as the one in use obviously is not an optimum design with regard to deflection sensitivity.

The circuit diagram of the amplifier is shown in fig. 7. The amplifier input needs positive and negative currents, but as the digital-to-analog converter can supply only positive currents, a negative bias current is fed from the - 24 V power supply to the input via R1 = 6.6 KΩ. For this reason the - 24 V-supply has to be highly stabilized. The base of the right transistor of the input differential amplifier is not grounded, but set to about + 1 V; so the input of the amplifier is also at + 1 V. This is necessary for a good functioning of the DA-converter. The output stage of the amplifier, a complementary push-pull class B amplifier, has an inductive load by the deflection coil. As this leads to high-frequency oscillations, a CR circuit has been attached to the output, making the output load ohmic by fulfilling the condition $R = \sqrt{\frac{L}{C}} = R_2$. Because suitable pnp silicon power transistors were not available, 6 transistors, 2N 1131, in parallel and with separate emitter resistors have been used instead of a power transistor. Via resistor R_3 1/200 of the output current is fed back to the input.

4.2. Digital-to-analog converter

As the event addresses are coded in binary form, strictly speaking the DA-converters are binary-to-analog converters. The conversion is executed by adding binary weighted dc-currents, which can be switched on or off via diodes by voltages from the corresponding bits. Fig. 8 shows the circuit diagram of the 10-bit converter.

As $2^{10} = 1024$ steps must be discernible, the error of the converter should be less than 5.10^{-4}; this stipulates the use of high-precision metal-film resistors. To minimize the influence of diode voltage drop changes a high supply voltage of 100 V has been chosen, which has also to be constant to better than 5.10^{-4}. For proper functioning the converter needs at its output a low load resistance and a constant positive voltage of 1 V. This has been provided for by the deflection amplifier. The current level of the converter has to be chosen according to the input current drift of the deflection amplifier, which in our case is 8 µA for a temperature change of 37°C. As such large temperature changes will not occur in practice, a smallest converter step of 8 µA is sufficient for good stability.

4.3. Digital circuits for read-in and calibration

A detailed blockdiagram (fig. 9) and a time diagram (fig. 10) show the functioning of the digital circuits. The circuit diagram is given in fig. 11. There are two modes of operation : "event read-in" and "calibration lattice generation".

4.3.1. Event read-in

The arrival of an event address is marked by a start pulse at SM, which triggers the univibrator (one-shot) U 1 via a Schmitt trigger ST 1. U 1 triggers the delay univibrators U 2 and U 3. After 2 µs U 2 gives a reset pulse to the two 10-bit input registers via A 2, and after 4 µs a pulse from U 3 via amplifier A 3 opens the input gates for a parallel read-in of the waiting address information into the flipflops X 1 ... X 10 and Y 1 ... Y 10 of the address registers. The gating pulse also triggers a delay univibrator U 4, which triggers univibrator U 5 after 200 µs. This delay time is necessary for the deflection currents to reach

their steady state values. The pulse width of U 5 can be controlled in 4 steps; thus the number of pulses needed to reach maximum blackening on the screen can be changed. The U 5 pulse is amplified to a positive 24 V pulse, which blanks the electron beam. When U 5 switches back, U 2 is triggered for the second time, but as U 1 is not triggered now partial reset is made, i.e. flipflops X 1 ... X 9 and Y 1 ... Y 9 are reset and flipflops X 10 and Y 10 are set. In this way the deflection currents are set to about zero, which brings the power consumption of the deflection amplifiers to a minimum.
An automatic delayed reset (AR) is provided, which brings all flipflops to the correct state, when the supply voltage is switched on.

4.3.2. Calibration lattice generation

To write a calibration lattice several connections have to be changed. In the block diagram this is made by switches, but in reality these switches are gates, controlled by an external switch. The program can be started by a pushbutton T 1 and runs in the beginning like an event read-in. But instead of the read-in gates now flipflop FF 2 is triggered, which switches on a 3 Kc/s multivibrator. This multivibrator triggers via a gate flipflop X 3 of the X address register. As the register flipflops are not isolated from each other, but are connected as a binary counter, the X register begins to count the multivibrator pulses. By each pulse also U 4 is triggered and a dot is written onto the storage screen. When a line of 256 dots is completed, X 10 switches Y 7 via gate G 3, thus shifting the following line upward for 1/16 of the complete picture height. After 16 equidistant horizontal lines an output pulse from Y 10 switches flipflop FF 1, which opens gates G 4 and G 6 and closes gates G 3 and G 5. So the roles of the x- and y- counter are reversed, and now 16 vertical lines are written. When with the 16th vertical line the whole lattice is completed, X 10 switches back FF 1, which causes a reset for FF 2. In this way the multivibrator is stopped, and partial reset is made for the input registers. For one lattice 8192 dots have to be written, which takes about 2.7 seconds.

5. Test results of an experimental storage monitor

The tests were made with a picture area of about 8 x 8 cm^2. The maximum channel number is limited by the tube to 512 x 512. In this case the dots just begin to overlap.

At normal room temperature stability and reproducibility is good; shifts of calibration lattices were not observable. The identification of the address number of an interesting dot can be done with an uncertainty of at most 1/4 of the calibration line distance. In our case that means 8 out of 512 channels in each direction. But as it is no problem to write a much more dense lattice, in principle the uncertainty can be avoided completely. The sole difficulty might be, that the calibration lines will not be clearly visible at dark spots on the screen, i.e. in the region of high spectrum peaks.

To get a certain impression how the dark-trace monitor will display a two-parameter spectrum, artificial "spectrum peaks" with a two-dimensional Gaussian distribution have been integrated on the storage screen. The Gaussian peaks were generated by two pulse-height converters for the x- and y-direction, which were fed by electrical pulses with superimposed electrical noise from two independent noise sources.

Fig. 12 shows 7 Gaussian peaks, containing 10^4, 2.10^4, 4.10^4, 10^5, 2.10^5, 4.10^5 and 10^6 counts, respectively. Each peak has a diameter of 20 channels at half its maximum height, which has been measured by means of a multichannel analyzer in x- and y-direction. With this knowledge the probable number of counts in each channel of a peak can be calculated. For the center channel of a two-dimensional Gaussian peak with a FWHM-diameter of Z channels we find the following relation between the number of counts C in the center channel and the number of counts K in the whole peak

$$C = \frac{0{,}883}{Z^2} \cdot K \qquad (4)$$

For the lowest peak with 10^4 counts the probable number of pulses in the center channel is 22.1. As each beam pulse has deposited a charge of 12 μA x 2 μs on the channel area of $2.2 \; 10^{-4}$ cm^2, the center channel has got a charge density σ = 2.4 μAS/cm^2. The values for the other peaks are correspondingly greater, proportional to their total number of counts. The correspondence between the peak blackening and the test results in fig. 4 is adequate. The calibration lattice on fig. 12 has a mesh size of 32 x 32 channels.

As could be expected from the foregoing measurements, it is not easy to estimate the number of counts by visual inspection. With a real spectrum this will be still more difficult. Probably a ratio of 10 : 1 of peak to "background" or of a peak to a valley between two peaks will be necessary to perceive clearly the peak or the valley. There, photographic integration will be much in advantage, because the light integration characteristic of the film is linear, at least within a certain range. For comparison fig. 13 shows a "twinkle-box" photo with 5 Gaussian peaks of 10^4, 2.10^4, 4.10^4, 10^5, 2.10^5 counts, respectively. In a real spectrum a 2 : 1 ratio of peak to background will certainly be sufficient to let the peak become discernible.

The tests have shown, that we can get a usable picture of a spectrum on the dark-trace screen, if 512 x 512 channels are to be stored. With an input of 256 x 256 channels the picture is unsatisfactory in its contrast. The reason is that the dots are so small that they are almost invisible from some distance. So the eye integrates the blackening over a certain area containing several dots, and if there are blank areas between the dots the contrast impression is strongly diminished. Of course, the contrast can be improved by defocussing the beam to get a larger dot, but as this is possible only to a limited extent the problem arises again with 128 x 128 channels. Therefore some other measures must be taken to increase the dot size, e.g. beam wobbling or writing 2 x 2 or 4 x 4 dots respectively on each channel spot.

During the integration of a spectrum the storage screen must be held in darkness, because at low event rates the normal room lighting will be sufficient to inhibit the growth of a picture. But this is no severe disadvantage, as observation of the growing picture during short time intervals is tolerable.

6. Conclusions and prospects

The investigations have shown that a monitoring unit with a dark-trace storage tube for sorted display of unsorted two-parameter spectra is feasible but not satisfactory. The maximum number of resolvable channels is limited by the tube, not by the electronics, to 512 x 512. The stored channel identification capability can meet all requirements owing to the electronically written calibration lattice, which can be made as close-meshed as necessary. The tube gives a certain outline of the spectrum in form of a map display, but the channel content determination capability is poor. This is due to the logarithmic integration characteristic and the low attainable contrast. Probably the utility of the dark-trace monitor could be improved considerably by an objectively measuring spot blackening indicator. Without such a device the monitor is only able to show to a certain extent that data gathering is going on and that the address coding and storing electronics works correctly. Visual inspection of the stored spectrum picture cannot give the degree of quantitative information which is desirable for preparation and monitoring of a two-parameter experiment.

The dark-trace tube will probably be favourable in a storage display unit for large sorted spectra with electronic channel-content selection for contour display, as in this case a good gray scale presentation is not necessary. There the economical advantages will outweigh the technical disadvantages, because the dark-trace tube costs only one fourth of a charge picture storage tube of comparable size and needs a much less complicated power supply.

The human eye is much more sensitive to differences in colour than to differences in light intensity or contrast. Therefore a display would be favourable which varies the colour of each channel dot corresponding to the number of counts in that channel. But as there exists no storage tube which can change the emitted light colour dependent on the deposited charge, a colour display can be made only from a sorted spectrum by means of a colour television tube and a store with very fast read-out, e.g. a disc storage device.

So it looks that a satisfactory integrating storage display monitor can be built only with a charge picture storage tube, having a linear integration characteristic within a certain range and a variable display threshold for contour display. The informations on integration capability, gray-scale range and storage time available from the manufacturers of these storage tubes make it probable, that such tubes will give much better results for our purpose than the dark-trace tubes. Due to the storage mesh however, the dot size of the charge picture storage tube is larger than that of the dark-trace tube. This has the advantage that a single channel dot is better visible, and the disadvantage that a larger tube is necessary to get the same channel storage capacity. Considering this an investigation of a charge picture storage tube is in preparation, which has a useful diameter of 8 1/2", allowing for a spectrum picture of about 16×16 cm^2. A storage capacity of 250.000 channels can be expected.

Acknowledgements

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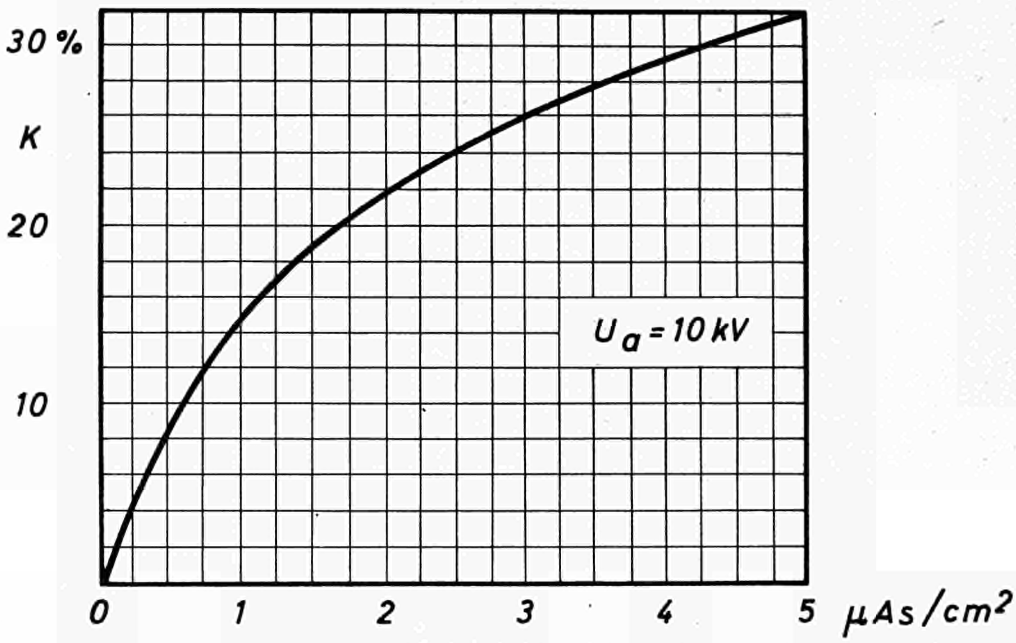

Fig.1 Contrast K vs. charge density σ
for single scan [7].

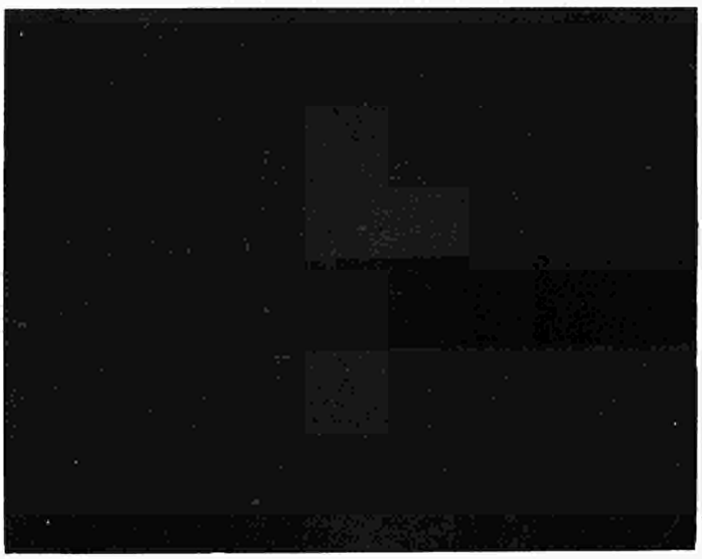

Fig.2 Gray scale with 5% contrast steps.

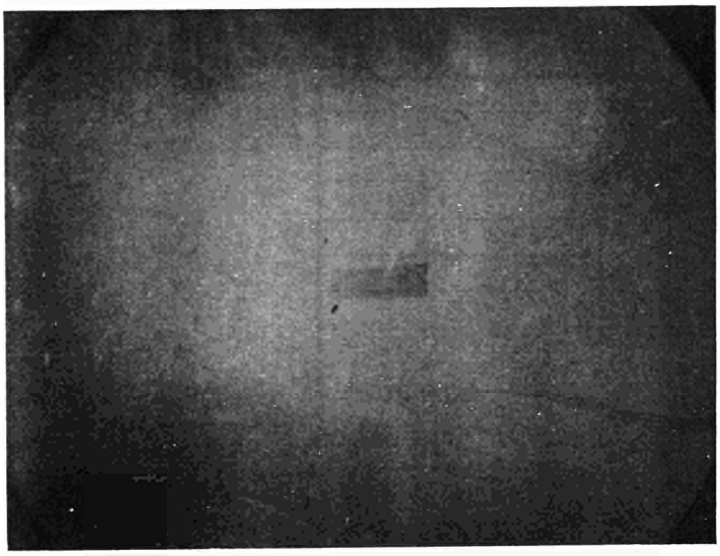

Fig.3
Comparison of integration with single scan contrast.

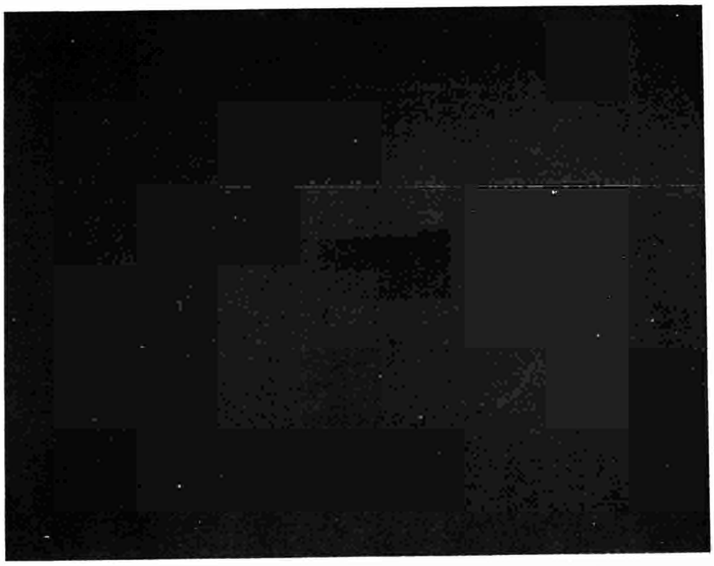

Fig.4
Integration contrast with charge steps of factor 2.
upper row : fresh
lower row : 17 hours old

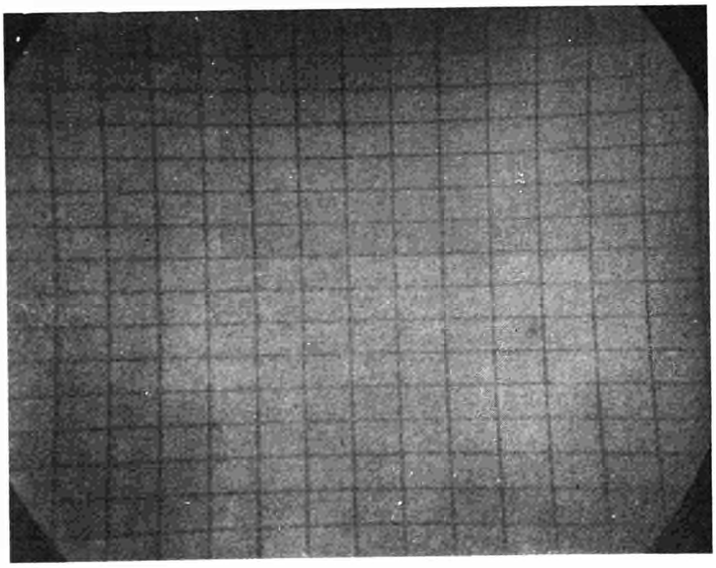

Fig.5
Congruent test lattices at 28° and 52°C.

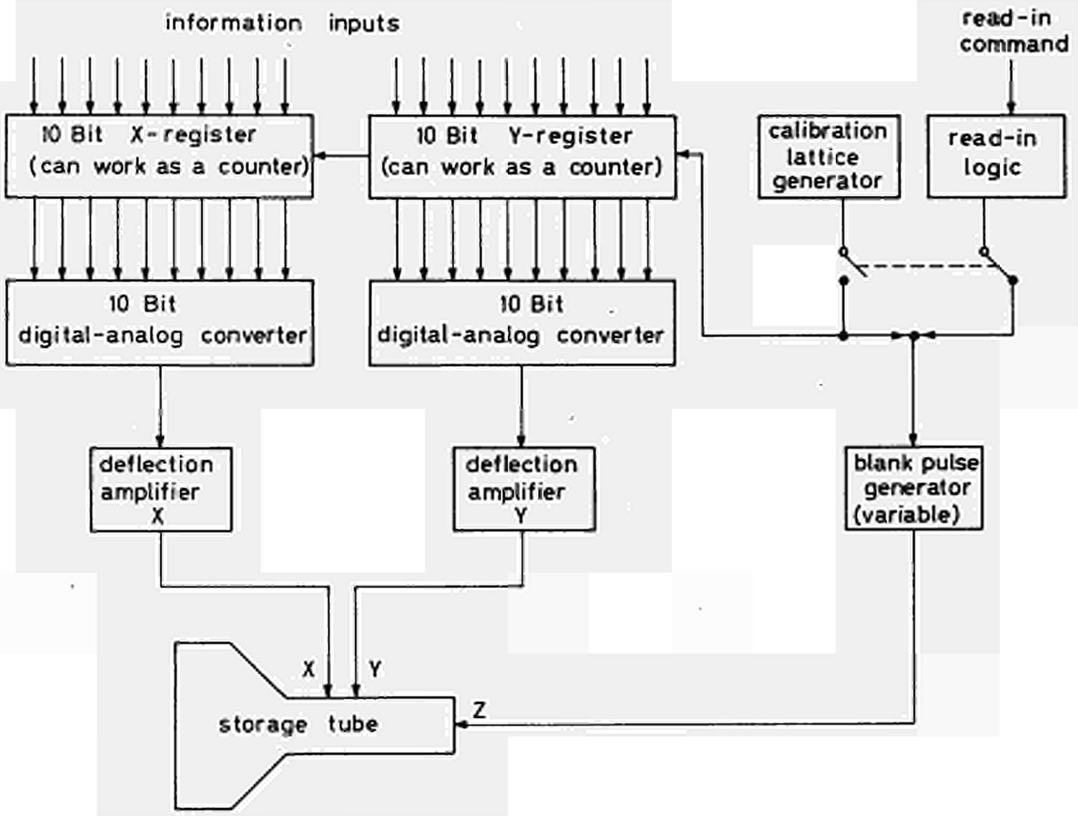

Fig.6 Simplified block diagram of a storage monitor

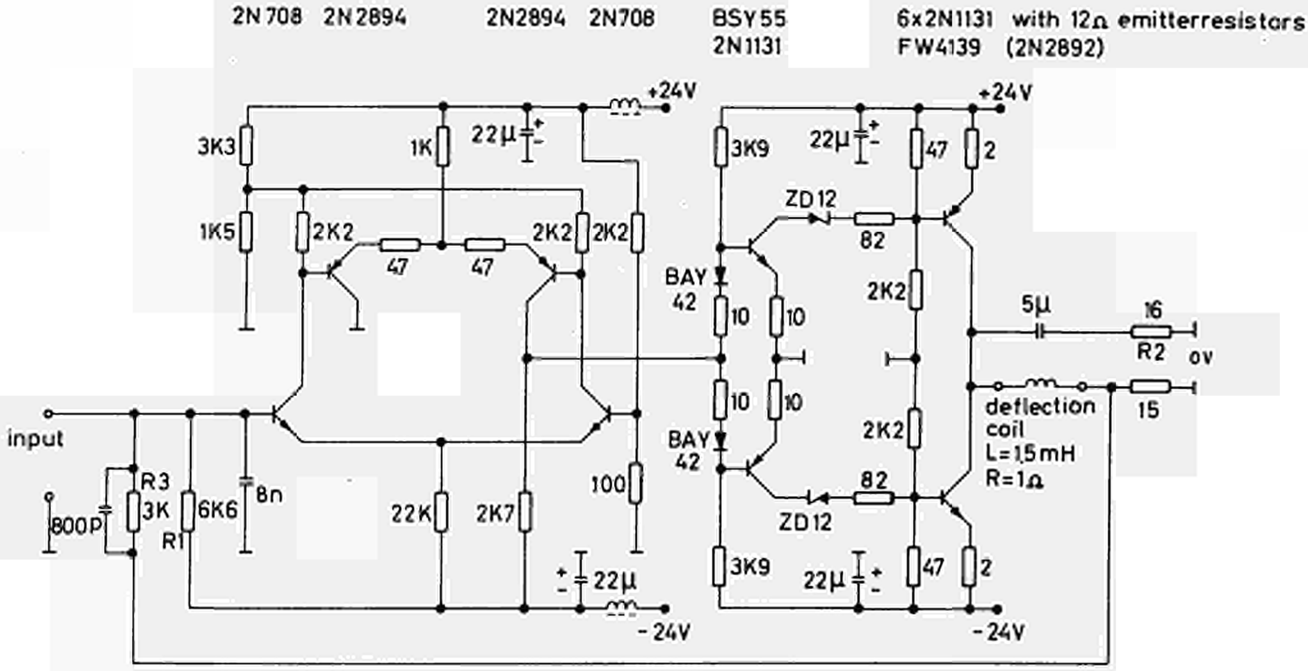

Fig.7 Deflection current amplifier, circuit diagram.

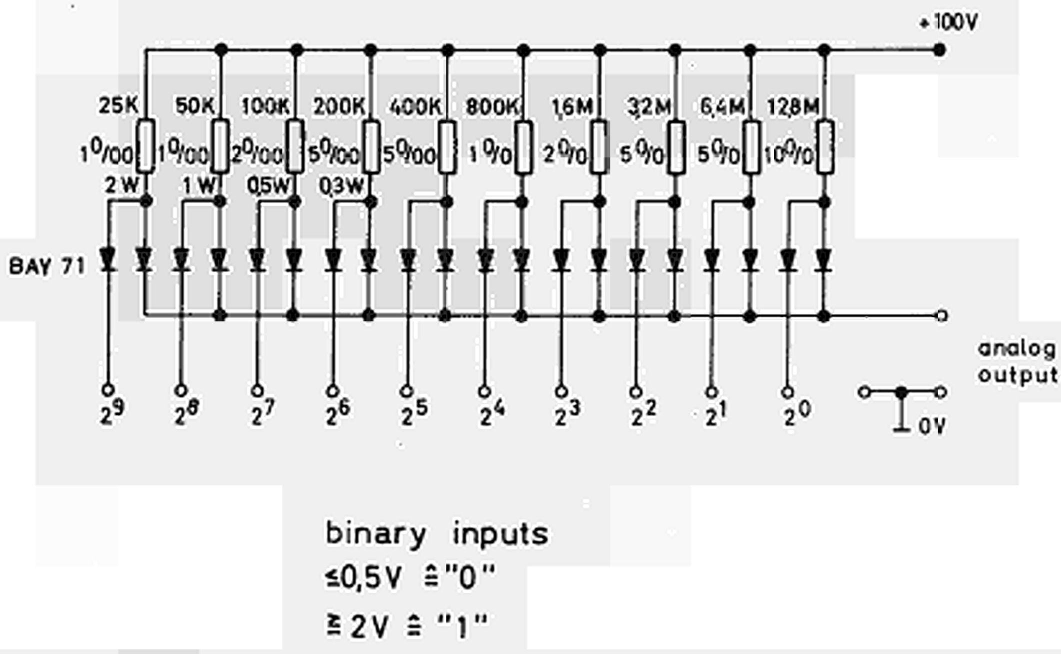

Fig.8 Digital-to-analog converter, circuit diagram.

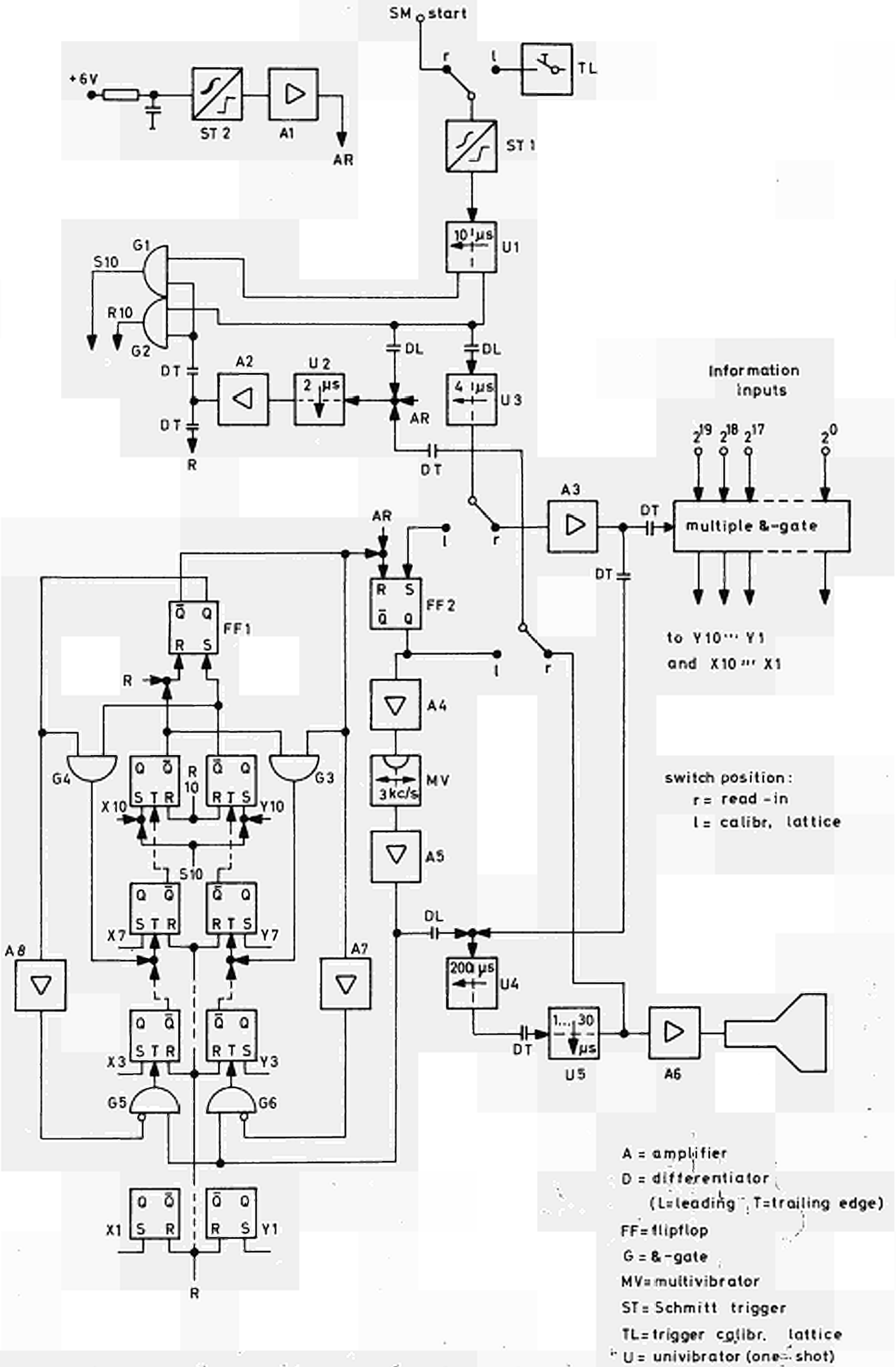

Fig.9 Read-in logic, block diagram

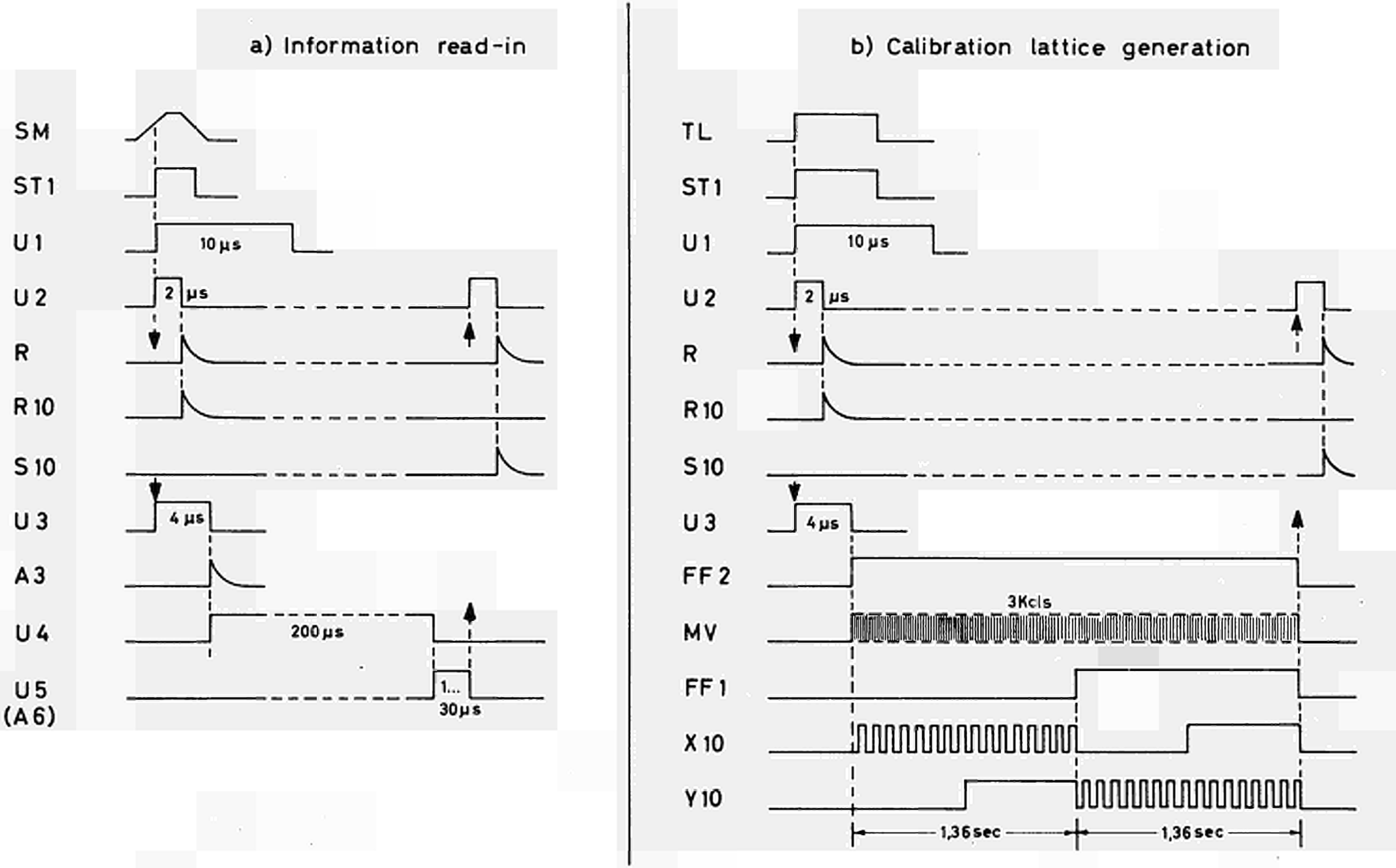

Fig.10 Timing diagram

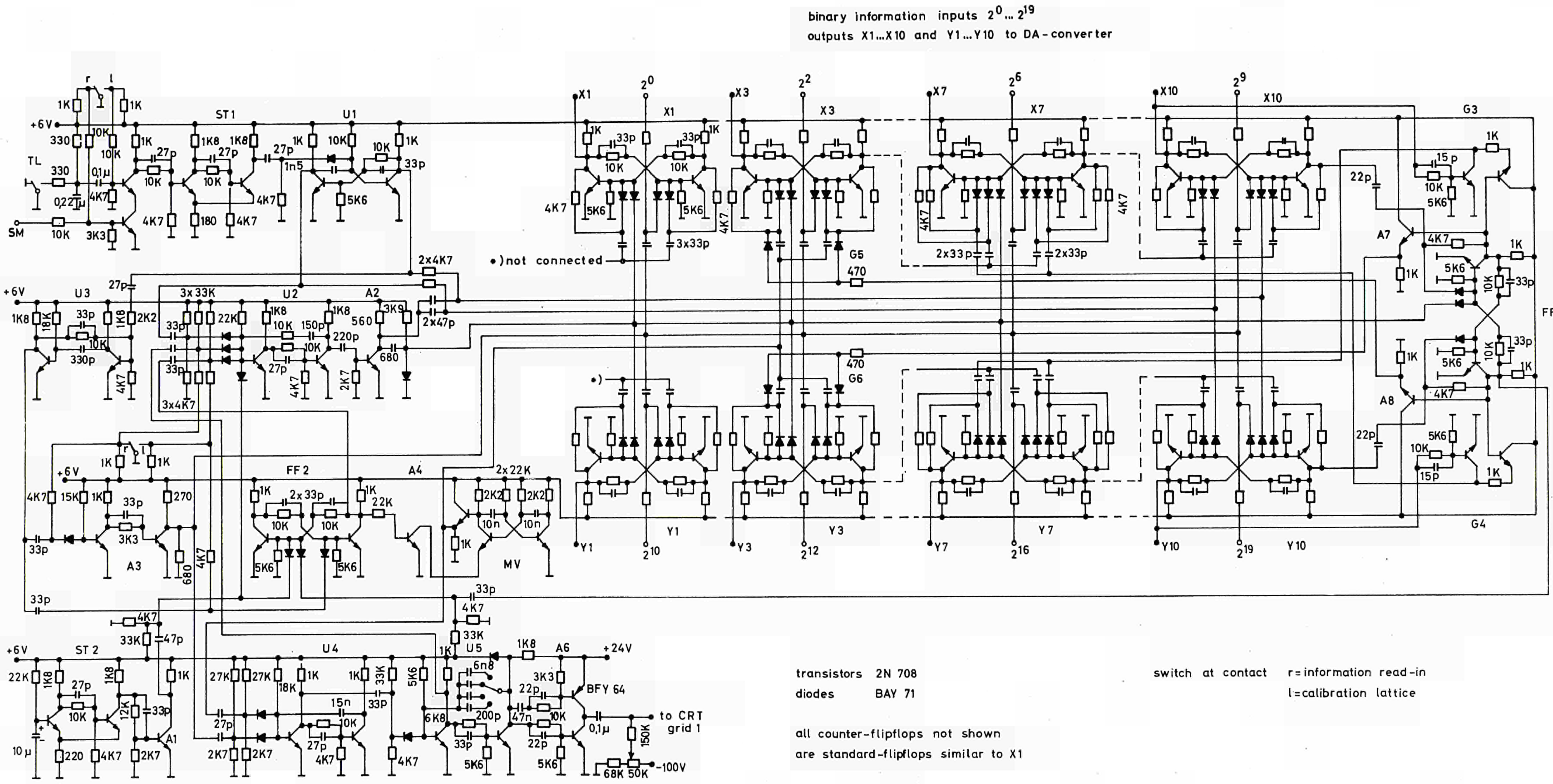

Fig.11 Read-in logic, circuit diagram

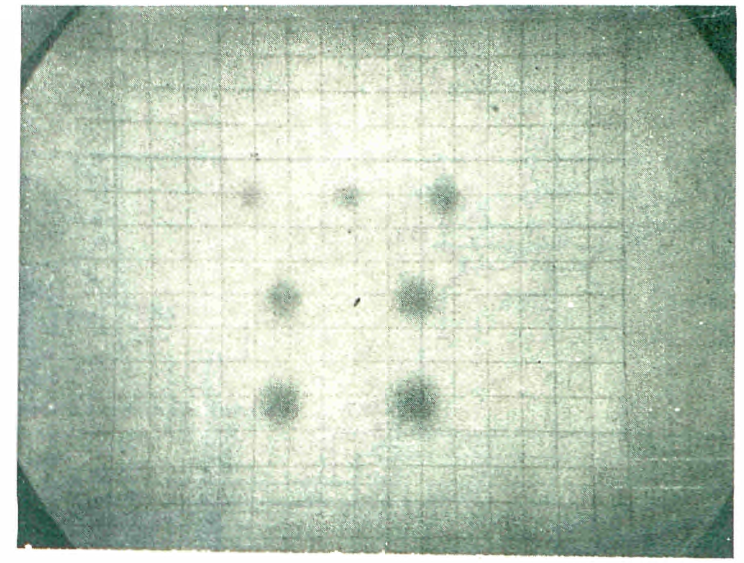

Fig.12
Gaussian peaks on the dark-trace screen with
$10^4, 2.10^4, 4.10^4$
$10^5, 2.10^5$
$4.10^5, 10^6$ counts

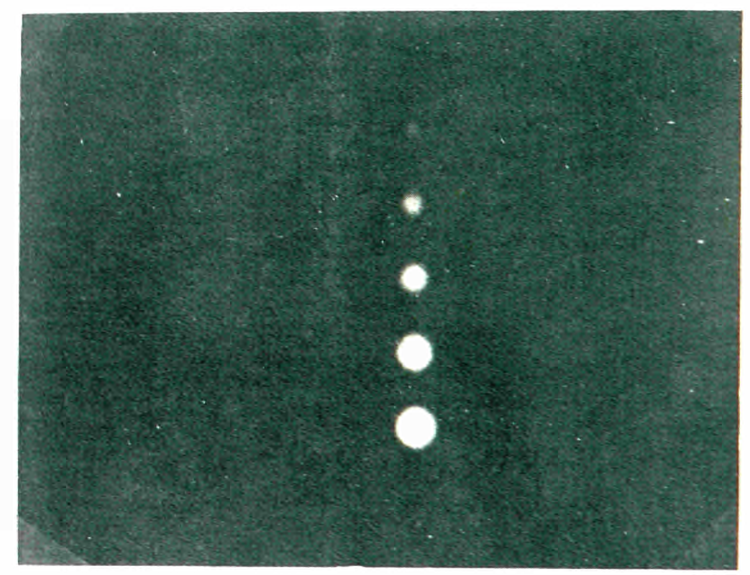

Fig.13
"twinkle-box" photo of Gaussian peaks with
10^4
2.10^4
4.10^4
10^5
2.10^5 counts

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Alfred Nobel

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