An Improved Cathode Ray Tube Storage System*

by

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Introduction

Several years have passed since Williams and Kilburn[1] first described their method of storing digital information as charge patterns on the phosphor screens of common cathode ray tubes.

Since then many computers have been built using this form of storage. Considerable research has been carried out to further the understanding of the storage phenomena[2,3] and to improve the storage tubes themselves. Yet this type of memory is still faced with two rather severe limitations. The first one is spot interaction or spillover. Thus if a single spot on the cathode ray tube screen is referred to repeatedly, the information in adjacent spots may be altered. A measure of the storage systems susceptibility to this type of failure is the "read-around ratio", or the number of times a single spot may be consulted before the adjacent spots have to be regenerated to avoid loss of information. Needless to say a low read-around ratio limits considerably the usefulness of a storage system.

The second type of difficulty encountered is caused by the presence of flaws or imperfections on the cathode ray tube screen, of such characteristics that they will not store information. These imperfections are usually very small even when compared with a beam diameter and it is relatively easy to position the charge pattern so that none of the flaws interacts with any of the storage spots. It is however quite difficult to maintain a high enough long term stability to insure that the raster of storage spots does not drift onto one of these flaws with a resultant loss of information.

The ability of the electrostatic memory tube to retain its information in the presence of flaws on the phosphor screen is somewhat dependent on the mode of operation of the tube.

Thus the various systems presently in use (dot-dash, double dot, defocus-focus, etc.) all show different susceptibility to flaws. As a rule, however, those systems which show a high resistance to flaws have a low read-around ratio and vice versa. Because of this, efforts to improve cathode ray tube storage systems have largely been centered on producing improved storage tubes with better focus and deflection characteristics and with storage screens free of flaws[4].

A parallel effort has been carried out at the Institute for Numerical Analysis to devise a modification of the Williams' principle of storage which has resulted in improvements not only in spillover, but also in resistance to flaws. Before describing this new system, however, it is well to review briefly the principle of charge storage in the conventional dot-dash system both under normal operating conditions and as affected by spillover.

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The Dot-Dash Storage System

Normal Operation

The major components of a cathode ray storage system include the storage tube itself with a pick-up electrode in the form of a wire screen added to the face of the tube, an amplifier for the restoration of signal levels, and beam control and deflection circuits. The pick-up electrode is capacitively coupled to the phosphor screen inside the cathode ray tube so that sudden changes in charge distribution on, or in the vicinity of, the phosphor result in a transient voltage signal at the input to the amplifier.

Consider now how such transient voltage changes may be generated. When an electron beam of proper energy is directed at a specific spot on the phosphor screen, the area directly under the beam charges positively with respect to its immediate surroundings due to emission of secondary electrons.

After a short time interval an equilibrium potential distribution is reached somewhat like that shown in Figure 2. Under these conditions the number of secondary electrons arriving at the collector each instant just equals the number of primary electrons in the beam. After the charge distribution of Figure 2 has been established it will remain intact although the electron beam is turned off as the phosphor screen is an excellent insulator. If the beam is now turned on and off repeatedly, a signal like the one in Figure 3(C) is developed at the input to the amplifier.

The initial negative going portion is due to the appearance of an electron cloud in the vicinity of the pick-up screen when the beam is turned on, and the later positive going portion is due to the dissappearance of this electron cloud when the beam is turned off. No changes take place in the charge pattern on the phosphor screen since an equilibrium potential distribution had previously been established at this spot. The times for the generation and dissappearance of the electron cloud are extremely short so that the shape of the output signal is largely determined by the transient response of the amplifier.

Consider next what takes place when the electron beam is turned on and moved slowly, say to the right. The new areas which come under direct bombardment of the beam, charge rapidly to a positive equilibrium potential, and the positively charged areas which are emerging from under the beam will slowly be discharged by the capture of secondary electrons, to the average potential of the surroundings. Thus the resultant effect is that the potential peak at X moves more or less intact to the position Y as shown by the dotted lines in Figure 2. If the beam is again directed to position X and turned on, the equilibrium potential peak has to be re-established. This occurs very rapidly and for a while both the peaks at X and Y may co-exist. However, as the beam is kept on, the secondary electrons from spot X gradually discharge the potential peak at Y down to the average potential level of the surroundings. The signal developed at the pick-up plate during this sequence of events is shown in Figure 3(A). The initial going positive peak is due to the recharging of the spot X to an equilibrium potential and the following negative peak due to discharging of the neighboring positive surfaces at Y. The two signals shown in Figures 3(A) and 3(C) are those taken to represent a binary "one" and a binary "zero" respectively in this storage system. When sampled at the time indicated by the short pulse shown in Figure 3(B), the "one" signal is positive and the "zero" signal is negative.

Effects of Spillover

With the ideal signals as shown in Figure 3 it is hard to see how a "zero" could possibly be misinterpreted as a "one" or vice versa, and normally, of course, this does not happen. A difficulty arises however when the electron beam is repeatedly referred to a single spot on the cathode ray tube screen. Under these conditions the "dot" or "zero" signals of the adjacent spots are progressively altered as shown in Figure 4 (A, B and C). Actually there exists a continuous distribution of signals changing gradually from the ideal signal as shown in Figure 4(A) to the highly distorted form of Figure 4(C), depending on how often the action spot is referred to before the adjacent spots are regenerated. The signal shown in Figure 4(C) resembles a "dash" or a "one" signal very closely and certainly at the time of the inspection pulse the signal is positive. It would therefore be interpreted as a "one" instead of a "zero" and permanently changed to the "one" or "dash" type of a signal. Spillover has now taken place.

But what causes the "dot" signal to change its shape? The most plausible explanation is as follows: The ideal "dot" signal is due to the appearance and dissappearance of an electron cloud in the vicinity of the pick-up plate as the beam is turned on and off. It is critically dependent on the fact that the area on the phosphor directly under the beam must previously have been charged up to an equilibrium potential (Figure 2). If this area has been fully discharged as in the case of the "dash" signal an initial positive instead of a negative going voltage is obtained.

The discharge of a positive potential peak is accomplished by its capture of secondary electrons from a nearby source; i.e., an electron beam is turned on in its vicinity. The emission of secondary electrons from any given area however is not sharply confined. Some of the electrons go to the collector while others tend to rain down on the most positively charged areas in the vicinity of the electron beam. Surely the density of this rain of secondary electrons must decrease as one moves away from the beam spot. However, if the beam is kept on long enough the cumulative effect of this rain of secondary electrons is sufficient to at least partially discharge the positive potential areas in a neighborhood, spanning perhaps over several storage spots.

If these partly discharged potential peaks are those of stored "dots" or "zeros", a distorted signal is obtained. This is because the "dot" signal, normally due only to the electron cloud, now has superimposed upon it an additional signal due to recharging of the phosphor screen back to its equilibrium potential. The more severe the discharge of the "dot" equilibrium potential peak due to stray secondary electrons, the more severe a distortion is encountered until at last a practically fullfledged "dash" signal is obtained as shown in Figure 4(C).

The Improved Storage System

It was shown above that the dot signal is quite vulnerable to distortion and that in severe cases this distortion is such as to make the dot signal indistinguishable from a normal dash signal at the time of an inspection pulse. In less severe cases discrimination can only be made by careful amplitude comparison of the two signals, the normal dash signal then being of larger positive amplitude than the distorted dot.

As both the dash and the dot signals can be positive at the time of an inspection pulse, it seems that the initial portion of the signal waveform is perhaps not the best characteristic to rely on for discrimination between the two signals. Better results might be obtained if one could afford to wait and inspect the signals at some later instant. This delay requires that the electron beam is kept on for a longer time interval before a decision is reached as to whether one has a dot or a dash type of signal. When the beam turn-on pulse is lengthened the dot signal changes its character to that shown in Figure 5(B). It still is caused solely by the transient presence of an electron cloud in the vicinity of the pick-up plate and as such can properly be interpreted as the differentiated waveform of the beam turn-on pulse itself. The shape of the dash signal on the other hand is only slightly affected and is as shown in Figure 5(A).

In the conventional storage systems the inspection pulse comes at time t_1. In the system proposed here, however, the inspection pulse is moved to the later time of t_2. Discrimination between the dot and the dash signal is on the basis of whether the signal at time t_2 is zero or positive (dot signal), or exceeds a certain minimum negative amplitude (dash signal).

For ideal waveforms the maximum amplitude difference between the dot and the dash signals is somewhat greater at time t_1 than at t_2 so that the proposed change may not seem to be much of an improvement. For signals distorted by spillover however, the reverse certainly is true. Figures 6 and 7 show how the dot signal of the modified system is affected by spillover. The two oscillograph traces shown in each picture are those of the distorted signal together with an undistorted signal shown for comparison.

As would be expected the negative peak at t_1 dissappears and in the worst cases changes to a positive peak which rivals in amplitude the initial positive peak of a normal dash signal. The amplitude difference between the distorted dot and the normal dash signals has at the time t_1 shrunk almost to the vanishing point. On the other hand consider the amplitude difference at time t_2. The dot signal is still positive at this time; the dash signal is negative and as will be shown later has changed very little. The amplitude difference between the two signals at t_2 instead of getting smaller has actually increased. No difficulty is therefore encountered in discriminating between the two signals even under severe conditions of spillover.

Figure 8 shows a dash signal affected by spillover. The features which make it differ from a normal dash are a somewhat larger positive peak and a slightly decreased negative peak. The decrease of the amplitude of the negative peak is of some concern as it could eventually if severe enough cause a "one" signal to be interpreted as a "zero" and thus cause spillover. This amplitude decrease however has been found to be very small and only by purposely defocusing the beam while continuously consulting a single spot could it be made severe enough to cause misinterpretation.

In the conventional dot-dash system the various design parameters have been carefully chosen to enhance the generation of a large initial positive peak for the dash signal. In the modified system, however, this peak is not made use of. Some of the design parameters besides the length of the beam turn-on pulse have therefore been changed to favor the generation of a large negative dash amplitude at the time of the inspection pulse (time t_2, Figure 5). In particular the sawtooth or the twitch signal, which is applied to the deflection plates to produce the dash display has been shortened from four to approximately one and one-half microseconds. In the conventional dot-dash system, the purpose of the sawtooth deflection voltage is to cause the beam to move slowly away from the dot position (position X, Figure 2), and by these means cause the potential peak at that point to be discharged. This process normally takes about four microseconds. When only one microsecond is allowed, those surfaces that come under the beam are charged to a positive equilibrium potential as before. However, now there is time only for but a slight discharge at the trailing edge of the beam. Hence the two potential storage patterns will probably be somewhat of the nature shown in Figure 9. Now when the beam is again turned on at position X there will be a small initial positive signal peak due to charging of the phosphor surface back up to equilibrium potential followed by an enhanced negative peak caused by the slower discharge of the large shaded positive area of Figure 9.

Test Results

Several single cathode ray tube units have been tested in the system just described. The amplifiers and gating circuitry used were those presently in use on the SWAC with the one modification that the signal output from the amplifier was inverted. This was done to facilitate gating of the dash signal which then could be done in the same manner as on the standard SWAC system.

Among the cathode ray tubes tested were some which had been withdrawn from the SWAC memory system because of excessive spillover and some which were currently in use.

Direct comparison of results of spillover tests indicate that improvements in read-around ratios for poor tubes may range from three to four. On good tubes the tests were less conclusive as the maximum read-around ratio obtainable on the test set was 256.

However, under these conditions the modified system always performed at least as well or better and in no case was a lower read-around ratio obtained on this system than on the standard dot-dash system.

Flaws

The second major limitation of a cathode ray tube memory is that of flaws as mentioned earlier. Apparently there exist on the phosphor surface minute specks of foreign or damaged material whose secondary emission characteristics are such as to severely attenuate the initial positive portion of the conventional dash signal. A typical flaw signal is shown in Figure 10. The raster has been purposely positioned so as to give maximum attenuation of the initial positive peak and as may be seen from the photograph it is almost completely missing. A "one" could therefore not be stored at this spot in the conventional dot-dash system. Figure 11 shows the signal obtained from the same flaw area when the raster was so positioned as to give a minimum amplitude for the negative peak of the dash signal. The amplitude of the negative peak has decreased only about 10% and the modified system stored perfectly both "zeros" and "ones" at this point.

Indeed it was found after testing several flaw areas on several cathode ray tubes that as a rule the negative going peak of the dash signal was very much less affected by flaws than the initial positive peak of the dash.

It should be pointed out though that there still exist flaws which would not store information in either system.

Conclusions

A modification of the standard dot-dash cathode ray tube storage system has been described. It appears from tests on single cathode ray tube units that this system is superior to the conventional system with respect to spillover and resistance to flaws.

Acknowledgment

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References

1. F. C. Williams and T. Kilburn, "A Storage System for Use with Binary-Digital Computing Machines," Journal IEE, Part IIIA, Vol. 96, p. 81, March 1949.

2. C. V. Parker, "Charge Storage in Cathode Ray Tubes," Proceedings of the IRE, Vol. 39, Number 8, p. 900, August 1951.

3. T. Kilburn, unpublished work on cathode ray tube storage phenomena, received at the Institute for Numerical Analysis in December 1951.

4. National Bureau of Standards Electronic Computers Laboratory, "First Quarterly Progress Report of the Research Program for Improving Cathode Ray Storage for Computers," NBS report, November 1952.

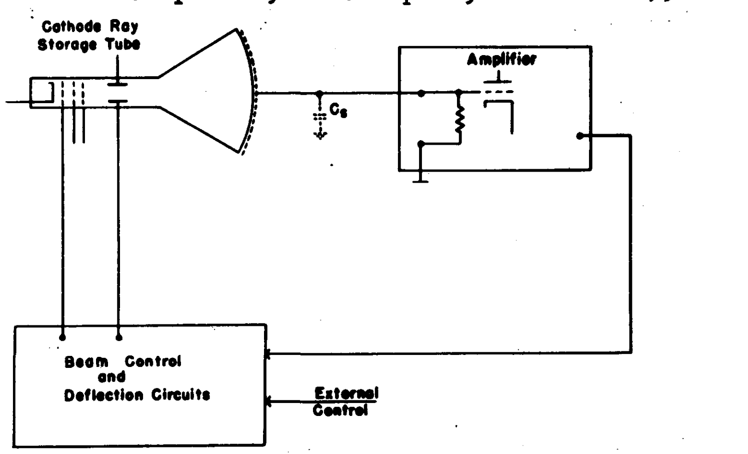

Figure 1.
Basic Elements of a Cathode Ray Tube Storage System

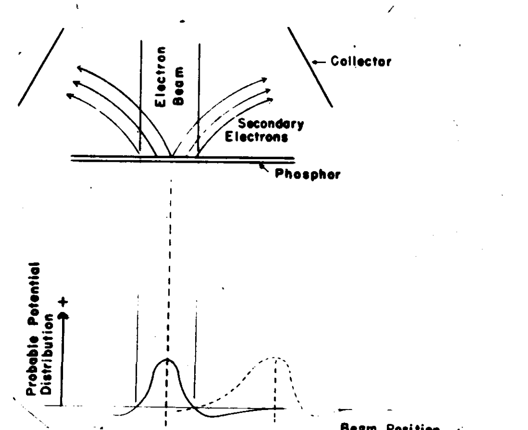

Figure 2
Probable Potential Distribution Across a Storage Cell.

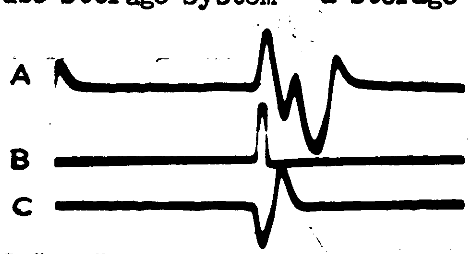

Figure 3. Typical "One" and "Zero" Signals for a Conventional Dot-Dash Storage System

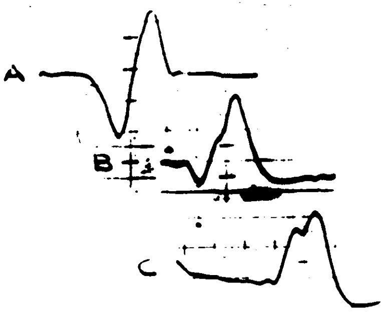

Fig. 4
Progressive Distortion of the Dot Signal as Caused by Spot Interaction.

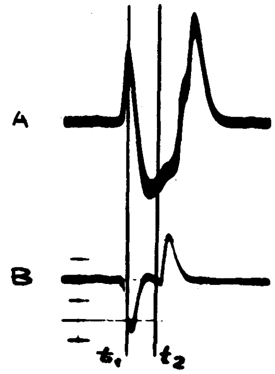

Fig. 5
Typical "One" and "Zero" Signals for the Modified Dot-Dash Storage System.

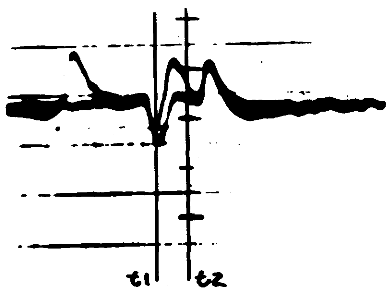

Fig. 6
Distortion of the Dot Signal, by Spot Interaction for the Modified Dot-Dash Storage System.

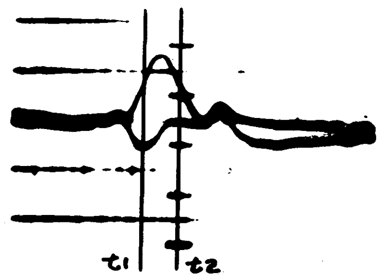

Fig. 7
Severe Distortion of the Dot Signal in the Modified Dot-Dash Storage System.

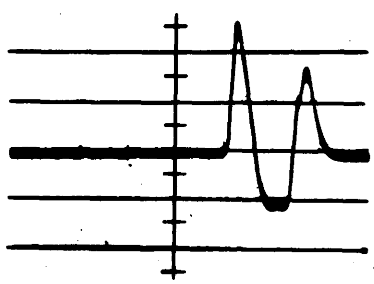

Fig. 8
Distortion of the Dash Signal by Spot Interaction.

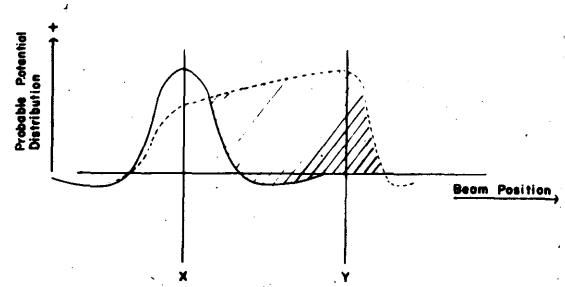

Fig. 9
Probable Potential Distribution Across a Storage Cell for the Modified Dot-Dash System.

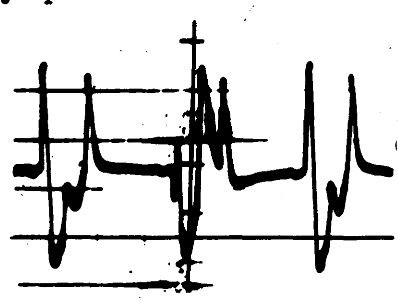

Fig. 10
Dash Signal from a Flaw Area. Storage Raster Positioned to Give Minimum Positive Dash.

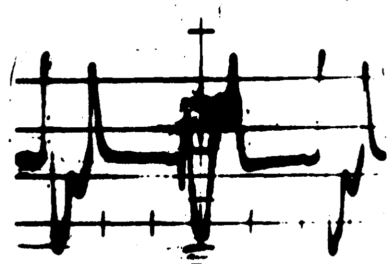

Fig. 11
Dash Signal from a Flaw Area. Storage Raster Positioned to give Minimum Negative Dash.