CATHODE-RAY DISPLAY OF DIGITAL COMPUTER OUTPUTS

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Abstract

A system in which the output of a digital computer is displayed as an arbitrary character on a memotron tube is described. Two sequences of pulses, each consisting of 25 pulses equally spaced in time, each either positive or negative, and all of equal magnitude, are applied to X and Y counters. Each pulse either increases or decreases the contents of the counters by one. The digital data in each counter are then converted to analog data which is applied to the deflection plates of the tube. Eight types of basic lines are traced on the screen and the characters are built out of these basic lines by continuously tracing them one after another in the proper sequence. Details of linking the system with an existing computer are described. Some advantages of the system are: (*a*) it does not involve any critical and complicated adjustments, (*b*) the shape of characters can be easily changed, (*c*) the operation of the system is mainly digital, and (*d*) the character is written as a continuous trace.

Introduction

A CATHODE-RAY display system has been built to function as an auxiliary output unit for the T.I.F.R. Digital Computer. Graphical as well as textual display is possible. A report[7] has already been published describing the design of a small-scale unit that was assembled to evaluate the proposed scheme. While the logical scheme of the final system is essentially similar to that described therein, the present paper gives the logical as well as engineering design and main features of the completed unit in greater detail.

The electro-mechanical nature of operation of input and more markedly the output organs of electronic digital computers render their faster operation difficult and cumbersome. A purely electronic system of output (say, on a CRT screen), while getting over this difficulty, has numerous other advantages.

A1

An analog representation is possible by applying to the CRT spot deflection voltages proportional to the outputs to be displayed. A binary representation of numbers is also possible, while it is desirable to be able to display alpha numeric outputs directly. An ideal combination would be graphical and textual display facilities.

The system, besides being fast, is very convenient for certain types of problems. Tracing of trajectories and graphical display of mutually dependent variables are examples. Programme checking during the initial run can be done by monitoring certain key locations by graphical display.

REVIEW OF EXISTING METHODS

Graphical display of digital outputs involves only digital to analog conversion and is straightforward. Character display is possible by various methods.

Electro-mechanical display[1].—This, perhaps the earliest system for character display, uses specially shaped rotating condenser vanes to vary the capacitance in an RC potential divider to generate a modulated R.F. signal. The vanes are so shaped that demodulation results in waveforms, which, when applied to the deflection plates, form the desired character on the screen. The condenser vane shapes for any character are obtainable by graphical methods.

Magnetic core output printer[2].—Each character is formed of selected points in a rectangular array, and is traced by feeding a sequence of spot intensification pulses as the array is scanned. The intensification sequences are generated in a rectangular coincident current memory matrix, each core corresponding to a point in the array. Interrogation of the cores is in the same order as scanning of the array. Each of the output windings, one per character, threads only some of the cores and gives an output only when the spot is at corresponding points in the array. The system is simple but signal to noise ratio is likely to be low due to possible non-cancellation of outputs in half excited cores. The character is not traced as a continuous line.

Delay line system for symbol display[3].—Decoding and recoding networks are used to obtain for each character a corresponding parallel code which is converted into a serial pulse sequence by delay lines. These pulse sequences are integrated to obtain deflection voltages which are combinations of linear sweeps. The disadvantage is that anything more than a very simplified character shape will unduly complicate the system.

Fourier system[4].—At the M.I.T. has been developed an analog device to write each character as a continuous trace. The X and Y deflection waveforms are obtained from the character shapes. The waveforms are generated by Fourier Synthesis, and all characters are treated as closed loops for convenience, the unwanted portion being blanked out by an inhibiting pulse. Fourier analysis of the waveforms is done graphically. They are synthesised out of the first five harmonics of a basic 30 KC. frequency. Correct amplitudes of the Fourier components are obtained in the secondaries of transformers by applying constant amplitude sine and cosine voltages to the primaries of transformers, the turns ratio being the deciding factor. Addition is carried out by connecting the secondaries in series. Tuned circuits shock excited into oscillation provide the basic frequencies. The disadvantage is that the system is of a purely analog operation, and changes in character, size and shape are cumbersome. A large number of display characters is also difficult to have since each character requires a large number of secondary windings for each harmonic for accuracy in amplitude.

Charactron.—A special tube with a built-in stencil where the shapes of all characters are cut out, the charactron, is also useful for character display. For display the beam is directed to the region where the desired character is cut out so that the focused beam forms an image on the screen. The system is not at all flexible.

REQUIREMENTS OF A NEW SYSTEM

The requirements to be met by a CRT output system for maximum utility and reliability are as follows:—

(1) *Simplicity.*—The system should not involve critical and complicated adjustments.

(2) *Flexibility.*—Later alterations of character shapes should be possible and easy.

(3) *Digital operation.*—On view of reliability, the system should be digital in operation to a maximum extent.

(4) *Continuous trace of characters.*—For ease of recognition, it is preferable to have the character as continuous line rather than as a scanned pattern or arrangement of points.

GENERAL DESCRIPTION

The display system presently being described traces characters as formed of straight lines. These are restricted to the eight types of basic lines, four

along the four axes and four along the diagonals (Fig. 1), since they are the easiest to form. The lines can be seen to be formed by unit deflections along

FIG. 1. (a) The eight types of basic lines. (b) Character 2 as displayed in the system.

one or both the axes. The series of unit deflections along both axes necessary to trace any given character of a given size can be determined from the character shape and expressed as ternary sequences of finite length, so that any character can be traced within a maximum number of " steps ". Blanking out of certain of these lines in any character is possible by means of a spot intensification pulse sequence. For simplicity in operation all characters are traced beginning from a common starting point, blanking out the steps during which the spot comes to the desired starting point of a character. The spot intensification pattern is made identical for all characters. For example, a character requiring one blanked step—four unblank—and one blank step is fitted into a common pattern where the 2nd, 4th and 9th steps are blanked, by holding the spot stationary in the 1st, 4th, 7th and 8th steps.

The schematic diagram of the system is shown in Fig. 2. The ring counter is driven by a central clock. Each state of the ring counter corresponds to one step in the character tracing. During each step a constant current pulse is applied to the primary of an associated transformer. Since the transformers are excited successively at equal intervals of time, any sequence of +ve and —ve pulses can be obtained by connecting secondaries of chosen transformers in the proper polarity. A system displaying n characters needs at most $2n$ secondaries per transformer.
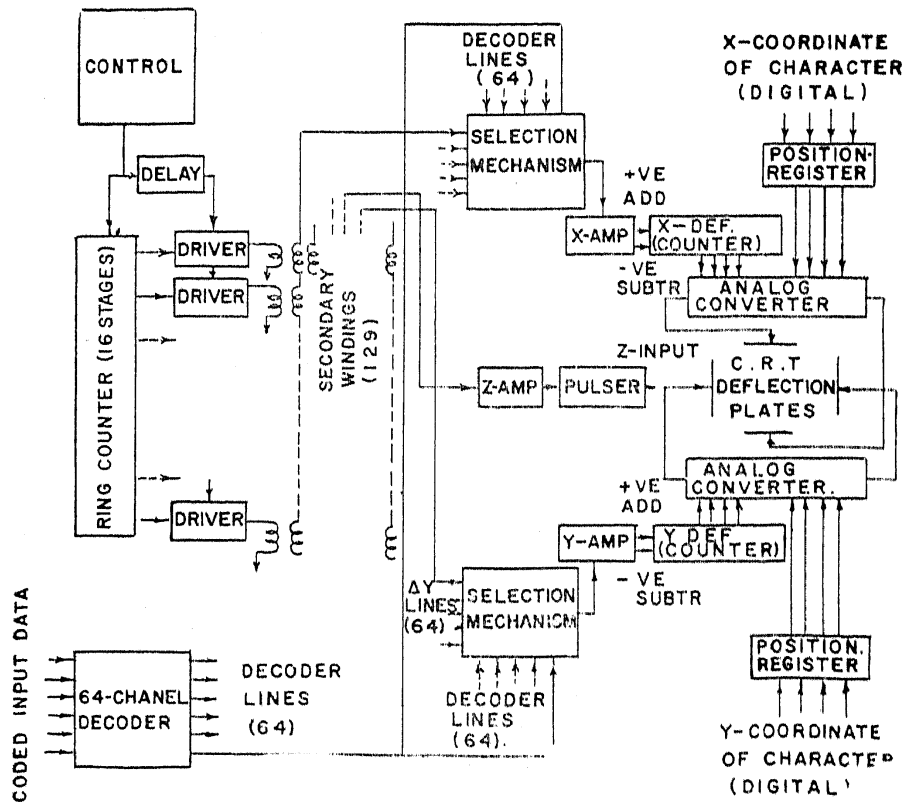
FIG. 2. Schematic diagram of the CRT display system.

The X and Y pulse sequences for each character are obtained in two output lines. Depending on the input to the character specifying decoder, the proper pair of output lines is selected and their outputs fed to the X and Y amplifiers. The X and Y pulse sequences are fed to the add-subtract counters whose contents specify the less significant bits in the co-ordinates of the CRT spot. A positive pulse causes the counter to add and a negative pulse to subtract. All eight types of basic lines can be generated by giving the proper pulses to the X and Y counters. The more significant bits specifying character placement are given by deflection registers. Conversion into analog voltages is effected in digital to analog converters, whose outputs are connected to the deflection plates.

A separate pulse sequence gives the common intensification pattern for all patterns. This is amplified and fed to the CRT control grid.

For graphical display, since the co-ordinates are all specified, they are contained in the deflection registers and converted into proportionate voltages, A.S. counters having no control over spot deflection,

Circuit Details

Ring counter[5].—The ring counter functions as the sequencing control for serial excitation of the transformers. During any clock period the transformer associated with the flip-flop in the set state gets excited. The ring counter should have as many stages as the maximum number of steps necessary to trace any character.
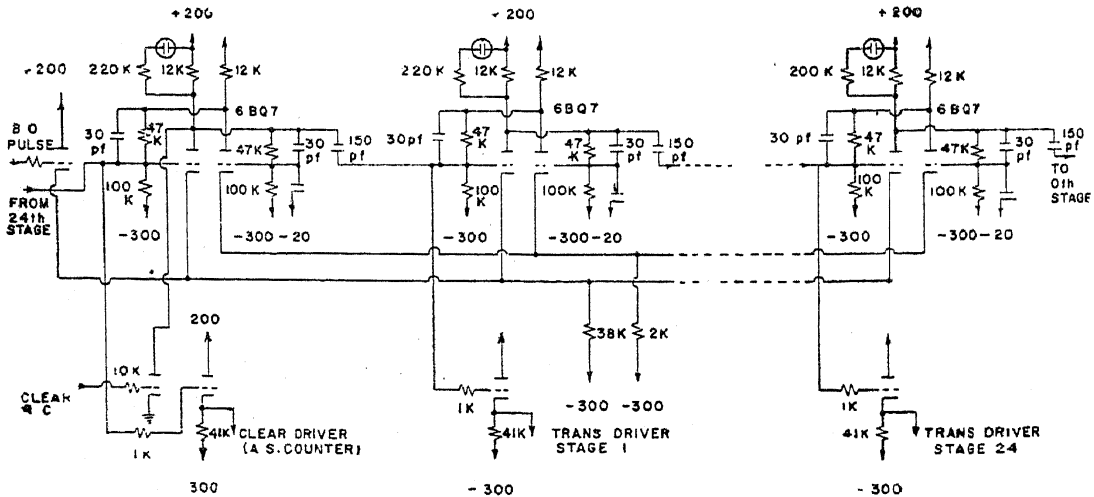

Fig. 3. Ring counter.

The conventional ring counter used in scale of ten circuits is not stable if operated with more than 10 flip-flops per ring. A condition for stability is that not more than one flip-flop be in the set state, left-hand tube conducting. This is ensured by having the right-hand and left-hand cathode resistances (to which the respective cathodes are all brought together) bear a ratio of $(n-1):1$, all flip-flops drawing equal currents. The voltages on the conducting and non-conducting grids are V_c and V_n, so that the latter are at a negative bias $V_b = V_c - V_n$, which is proportionate to the current drawn by the conducting tubes. In case two tubes are in the set condition and $(n-1)$ in the reset state, the currents drawn are $i/2$ and $i(n-1)/(n-2)$. While the reset flip-flops are in nearly the same conditions as before, the non-conducting tubes in the set flip-flops (right-hand tubes) are at a bias of $V_b/2$, the grid voltages being $V_c - V_b/2$ instead of $(V_c - V_b)$, all cathodes being at V_c. If this state is to be unstable, $V_b/2 < V_c'$, where V_c' is the cut-off bias for the tube. This is not possible since for reliable operation of a flip-flop $V_b \gg V_c'$.

A better method is to fix the r.h. cathode voltage at $V_c - V_b/2$ by preventing the r.h. grids from rising above $V_c - V_b/2$ by limiting diodes, as shown in Fig. 3. In case only one flip-flop is set, the grid is at $V_c - V_b$ or

at a negative bias of $V_b/2$ which keeps it cut off, while 2 set flip-flops cause the grid voltage to rise to $V_c - V_b/2$, making these tubes conduct so that such a state is ruled out.

The counter is driven by a $-$ve pulse at l.h. cathode which resets the " set " flip-flop. The coupling condenser, acting as a transient memory, sets the next stage at the end of the driving pulse.

Transformer drivers and transformers.—The R.C. flip-flop outputs are connected to constant current generators which are normally off. A common transformer driving pulse causes the driver connected to the flip-flop in the off state to draw a constant current pulse through the associated transformer. In a complete cycle the transformers get excited in a fixed sequence, once each. The transformers are used to generate pulse sequences for display of characters, the necessary digital information being wired in. Having numetal core, each transformer has a 100 turn primary and 64×2 secondaries of 3 turns each. Ternary pulse sequences associated with any character can be generated by connecting in series, with due attention to polarity, secondaries of properly chosen transformers.

Decoder and selection gates.—A 64-channel diode matrix decoder activates one of 64 character lines specified in a six bit binary code. Selected and non-selected line voltages are 100 and 70, respectively. Selection is by diode gates, the wanted pulse sequence being given through a conducting diode while all others are reverse biased.

X-Y Amplifiers.—The $+$ve and $-$ve pulses obtained from selection gates are separated and amplified. A counting pulse is applied at the add or subtract input of the A.S. counter depending on whether the amplifier input is $+$ve or $-$ve.

Add-subtract counters.—The (X or Y) counter contents increase or decrease by 1 depending on whether a counting pulse arrives at the add or subtract input, *i.e.*, whether the amplifier input pulse was $+$ve or $-$ve.

In the common scale of 2 counters a change of state in one digit stage (during counting) triggers the next. A change of state from 0111 to 1000 in such a counter takes place in a series of steps (0111 $\rightarrow$ 0110 $\rightarrow$ 0100 $\rightarrow$ 0000 $\rightarrow$ 1000) due to carry delay. This results in undesirable over-shoots and under shoots in the spot deflecting waveforms, their magnitudes and duration determined by the carry delay in the counter and the response time of the Digital to Analog converter. Carry delay should thus be minimised.

A double rank counter developed for use as a shift counter in the T.I.F.R. Digital Computer,[6] suitably modified for bi-directional counting, is employed (Fig. 4).
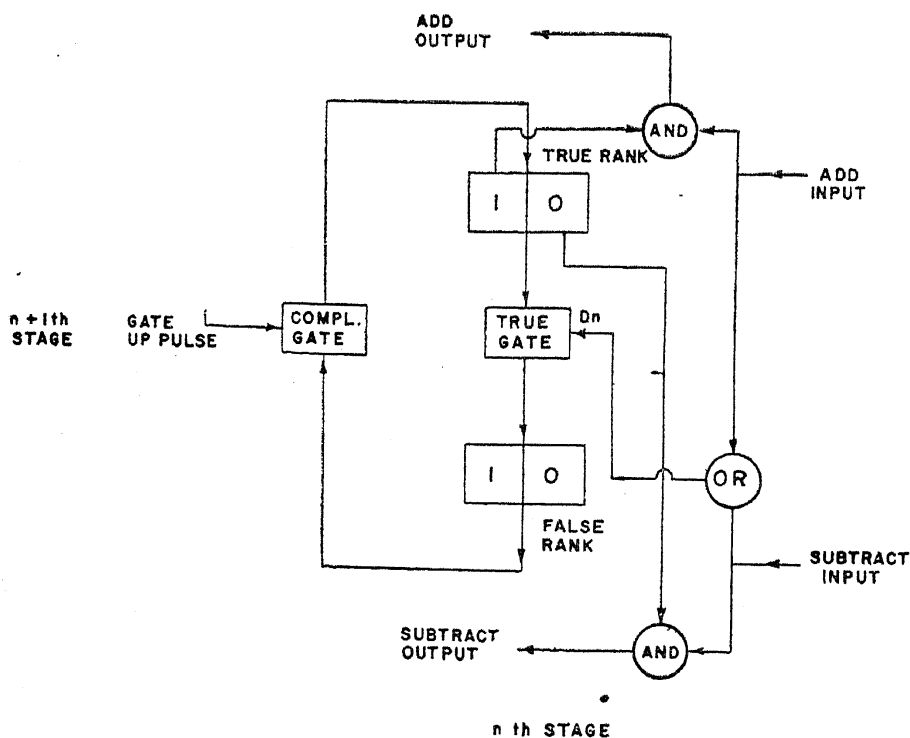

FIG. 4. Add-subtract counter (logical diagram).

Digital to analog converters.—The analog converters consist of a set of constant current generators drawing currents bearing ratios of powers of 2, each generator corresponding to a digit stage in the input. Depending on the input, currents in each stage are switched between two summing resistors. The push-pull type of output is taken across the two summing resistor points as in Fig. 5.

The following modifications are necessitated:—

(i) The response times of a cathode follower are different for $+$ve and $-$ve pulses. A change from 0 to 1 appears faster than one from 1 to 0 for $+$ve logic as seen from the converter. A number like 0111, for instance, will change through 1111 to 1000 for addition counting, giving rise to over-shoots. Therefore, identical cathode followers are used in the push-pull inputs so that one level rises while the other falls.

(ii) Character size is varied by having two constant current generators per stage, one of which can be switched on or off depending on whether a large or a small character is wanted, by means of a gating tube.
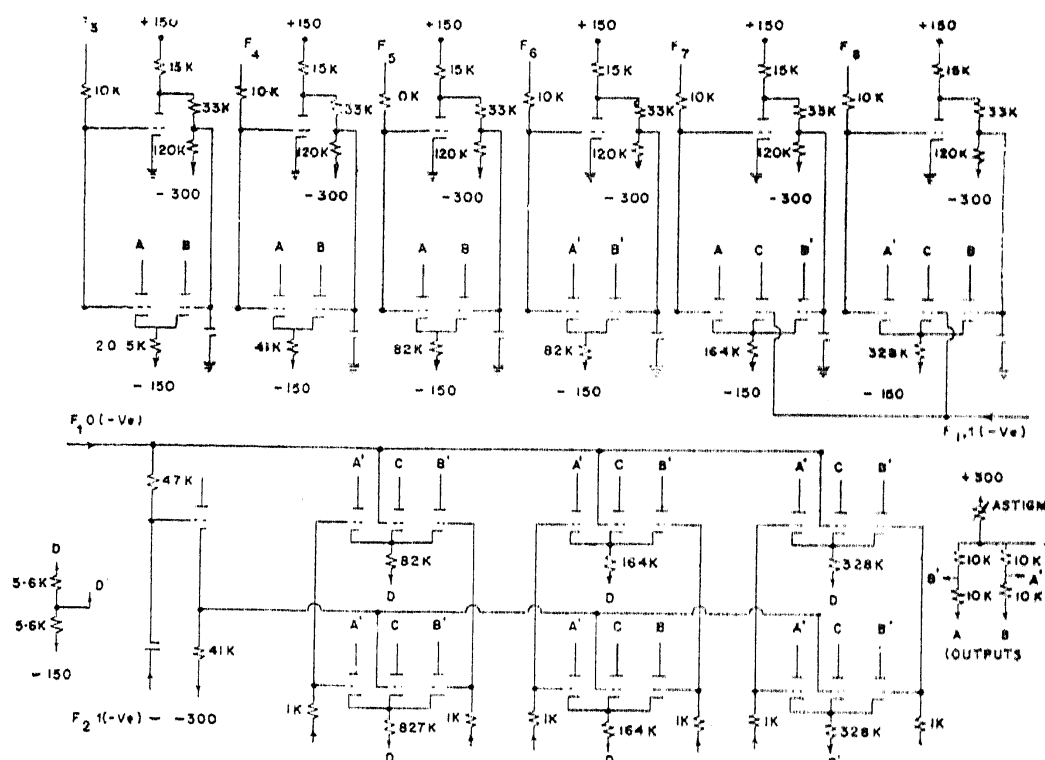
FIG. 5. Analog convertor (identical for X and Y).

(iii) Character positioning is determined by superimposing a D.C. voltage on the deflection waveforms. An extra set of constant current generators with suitably chosen currents are connected to the same summing resistances. Inputs to these specify character position. These are also useful for curve plotting, with a few additional less significant stages.

(iv) The ratio between the currents drawn by the most and least significant stages is 2^n. This wide range is narrowed by increasing the less significant stage currents and drawing them through corresponding fractions of the summing resistors.

(v) Astigmatism of the CRT spot is corrected by varying the mean potential of one pair of deflection plates with respect to the other. The summing resistance return voltage is varied by introducing a series variable resistance through which switching tube and current generator currents are all drawn. The resultant drop is very nearly independent of input conditions.

(vi) The time of transit of the CRT spot from one point to another should be finite and constant and equal in the X and Y systems. This is done by capacitive loading of the outputs.

Spot intensifier (Fig. 6).—The pulse sequence representing the spot intensification pattern common for all characters is amplified and applied
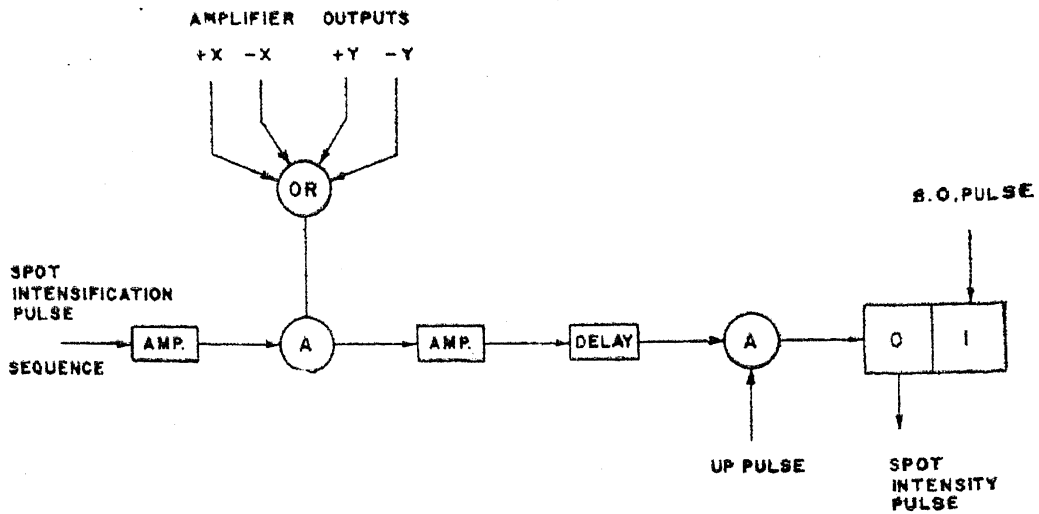
FIG. 6. Spot intensifier (logical diagram).

to the CRT so that the spot is illuminated only during certain steps. The spot is blanked out if there is no motion during any step, *i.e.*, if there is no output at both outputs of either the X or the Y amplifier. The logical diagram of the spot intensifier is as shown. The " OR " gate output serves as a strobe pulse since the X and Y amplifier outputs are sharp. The amplified pulse puts the flip-flop to 0 at the time of arrival of the " gate up " (A.S. counter) pulse, *i.e.*, exactly when the spot movement starts. The B.O. pulse for the next step puts the flip-flop back to 1. The spot is thus intensified only during the time it takes to move from one point to another.

Memotron and auxiliary circuits.—The memotron which functions as the display organ is a special purpose tube with " infinite " persistence developed at the Hughes Aircraft Corporation. In addition to the electrodes in a conventional tube, there is a dielectric coated storage mesh near the viewing screen. When a trace is written on the viewing screen the storage mesh retains the +ve charge pattern due to secondary electron emission caused by the high velocity electrons. A secondary electron " collector mesh " absorbs these electrons. A flood gun provides a steady stream of low velocity electrons over the entire area of the viewing screen, which pass through the storage mesh only in the positively charged regions, illuminating the original trace. Losses due to leakage and electron absorption are compensated for by secondary electron emission caused by the small fraction of flood electrons that strike the mesh. Erasure is accomplished by quickly lowering the collector voltage and allowing it to return slowly to the normal value.

Analog convertor outputs are directly connected to the deflection plates.

INTEGRATION OF THE CRT DISPLAY UNIT WITH THE COMPUTER

The contents of the M.Q. register specify display details like character code, positioning and size. For graphical display the co-ordinates of the points to be displayed are made available. It has been found sufficient to specify the co-ordinates of points to be plotted to an accuracy of six binary places.

There are two sizes of characters so that the usable part of the screen is divided into 8×8 cells each of which can accommodate a big character or 16×16 sub-cells to contain as many small characters. A cell or sub-cell is specified by the co-ordinates of its center point and needs 4 bits for either co-ordinate. It should be ensured that there is no overlap while using small and big characters.

The information to be supplied by the computer for a display order consists of 1 bit to specify whether graphical or character display is needed, 6 bits each for the X and Y co-ordinates of the point to be plotted in case of graphical display, 1 bit to differentiate between small and big characters, 6 bits to select 1 out of 64 available characters for display and 4 bits each on the X and Y co-ordinates to place the characters in one out of 16×16 possible positions. An optimum allocation of bits in the display specification is shown alongside (Fig. 7).

		F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}
FUNCTION		1		X CO-ORDINATES						Y CO-ORDINATES						WASTE			
CHARACTER	BIG	0	1	X SUBCELL				WASTE		Y SUBCELL				CHARACTER SPECIFICATION					
CHARACTER	SMALL	0	0	X SUBCELL				WASTE		Y SUBCELL				CHARACTER SPECIFICATION					

FIG. 7. Bitwise split up of information.

CONTROL UNITS

Control interconnections.—For meaningful operation of the display unit, the main control of the computer should be connected with the display unit control. For simplicity and reliability of operation there should be a minimum of interlocking between the two. The necessary digital information

is made available in the M.Q. before a display order is given. A start of operation pulse given by the main control initiates display sequencing. A " display on " pulse stops the main computer for the duration of a display cycle.

The control operations in a display cycle are different for graphical and textual display and listed as under:

Function plotting.—

(i) Presentation of the digital input information to analog converter.

(ii) Brightening the spot after a sufficiently long time to allow for the finite response time of the converters.

(iii) Transmitting an end of operation signal to the computer.

Character tracing.—

(i) Setting of the relevant circuits to their proper initial status after arrival of the start signal.

(ii) Generating driving pulses for converters and other circuits during every step.

(iii) Giving an end of operation signal after completion of the cycle.

Thus, for character tracing initial setting consists of:

(i) Zero setting of the ring counter for proper initiation into the display cycle.

(ii) Setting of the A.S. counter to the initial state. This is necessary at start and at the beginning of every display cycle even for repetitive tracing.

The following pulses are generated during every step of the character display cycle:

(i) Clock pulse to advance the ring counter by a single step.

(ii) A transformer driving pulse to excite the corresponding transformer during each step.

(iii) A step strobe pulse to sample the outputs of the X-Y amplifiers to minimise noise. The amplifier outputs serve as false to true gating (gate down) pulses for add and subtract counting.

(iv) Gate up pulses for information transfer from false to true rank.

A completion of operation signal is generated at the end so as to stop the cycle and signal the computer,

Control logic.—The logical diagram is as shown in Fig. 8. Flip-flop F_1 controls the blocking oscillator and remains in state 1 for the duration of
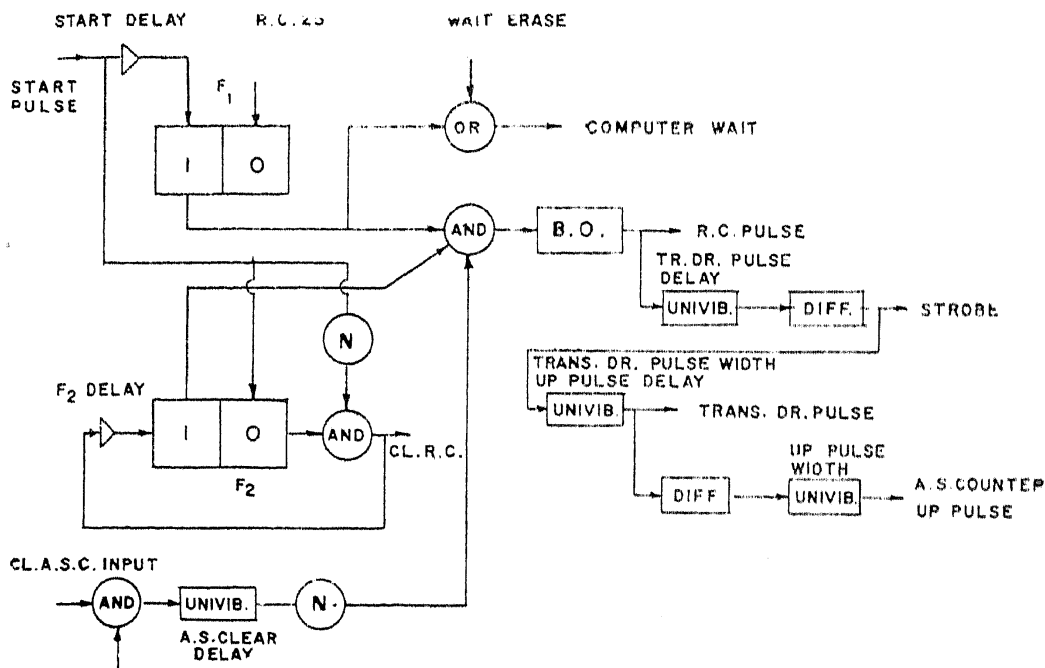

FIG. 8. Control logic.

the display cycle. It is put to zero by the last ring counter pulse. F_2 is used for initial clearing of the A.S. counters. The start of operation pulse puts F_1 to 1 and F_2 to 0. The delay D is to rule out the combination 11 due to difference in switching speeds of the flip-flops since that would open the B.O. before R.C. and A.S. are cleared. F_2 turns to 1 after R.C. is cleared. The Cl. R.C. output is inhibited for the duration of the start pulse to prevent excitation of 0 and 1 inputs of F_2 simultaneously. Repetitive tracing is possible by inhibiting the " set F_1 to 0 " pulse.

Erasure.—Erasing written information is done by giving a particular combination in the M.Q. This pulses the erase saw tooth generator during the third step.

CONCLUSION

The unit has been built and tested. It will be seen that all the requirements enunciated at the beginning have been met with. The unit has worked reliably with scarcely any component or valve failure apart from a few crystal diodes over a trial run of around two months. In each case fault finding was very simple and quick, presumably due to the system organisation. There

wasn't a single failure when the system was put on after being idle for over two weeks. Figure 9 is a photograph indicating use of the system for textual and graphical display. The auxiliary output facility should prove very beneficial in several types of problems.
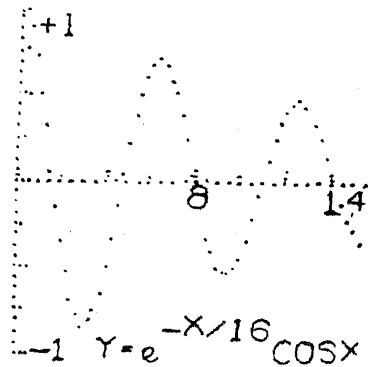

FIG. 9. Photograph of typical display.

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