N-63-4-3

410016

KAISER AIRCRAFT & ELECTRONICS

Division of Kaiser Industries Corporation

West Coast Electronics Laboratory
Palo Alto, California

SUMMARY REPORT
OF KAISER ANIP PARTICIPATION
1954-1962

1 May 1963

Prepared for

Douglas Aircraft Company, Inc.

Subcontract DAC 61-102
under
Office of Naval Research
Prime Contract Nonr 1076(00)

Prepared by: Kaiser WCEL Staff

Approved by: D.J. O'Brien, Plant Manager

KAISER AIRCRAFT & ELECTRONICS
Division of Kaiser Industries Corporation
WEST COAST ELECTRONICS LABORATORY
Palo Alto, California

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I. INTRODUCTION

A. SUBCONTRACTS AND REPORTS

This report represents a summary of the work carried out between 1954 and 1962 in Palo Alto, Calif., by the West Coast Electronics Laboratory, Kaiser Aircraft & Electronics Division of Kaiser Industries Corp., as part of the Army-Navy Instrumentation Program (ANIP) aimed at developing a system of integrated instrumentation for jet aircraft. Kaiser participated in ANIP through Prime Contract Nos. Nonr 1076(00), managed by Douglas Aircraft Corp., El Segundo, Calif.; and Nonr 1670(00), managed by Bell Helicopter Corp. (now Bell Aircraft Corp.), Fort Worth, Texas. The work was carried out under the following subcontracts, listed below with the effective beginning dates:

Douglas: DAC 55-308 (28 December 1954)
DAC 59-942 (9 September 1959)
DAC 61-102 (2 February 1961)
Bell: FW-501 (1 November 1955; terminated 3 September 1957)
FW-3301 (1 December 1959)

The work was described in considerable detail in a number of quarterly and technical reports. The quarterly reports were issued in three series, one for the three Douglas subcontracts and one each for the two Bell subcontracts listed above, as follows:

Douglas QPR-Nos. 1-22, 1 December 1954-31 May 1960
Bell (FW-501) QPR-Nos. 1-6, 1 February 1956-31 July 1957
Bell (FW-3301) QPR-Nos. 1-4, 15 March 1960-14 March 1961

QPR-Nos. 2, 3, and 4 in the last series include a sizable Appendix apiece, each of them in effect a technical report, as follows:

Appendix to QPR-No 2 (15 June-14 September 1960): "Determination of EL phosphor brightness-excitation requirements."
Appendix to QPR-No. 3 (15 September-14 December 1960): "Optimum frequency distribution of control signals for a vacuumless display."
Appendix to QPR-No. 4 (15 December 1960-14 March 1961): "Use of resonant delay lines with electroluminescent cells."

During the period following the last Douglas QPR, report requirements to Douglas were met by technical reports issued at irregular intervals as the occasion arose. The following reports were issued:

TR-No. 1 (15 June 1961): "Requirements for the coincidence-pulse scanning system," by Q.H. Joy.
TR-No. 2 (30 June 1961): "Investigation of solid-state delay lines."
FR (30 April 1962): "Solid-state display research program."

The last-named report, a 107-page final report summarizing all phases of the vacuumless cross-grid EL display medium and the associated circuitry, represents the most complete description of the work done by Kaiser on this topic.

B. SEQUENCE OF PROJECTS

Kaiser participation in ANIP derived in the first instance from the invention of W.R. Aiken (then Director of Research of the Kaiser West Coast Electronics Laboratory) of a device known as the Kaiser-Aiken thin cathode-ray tube,[1] which was deemed to be suitable for service as the vertical display medium in the windshield of an aircraft cockpit. The generation of the display pattern in a "contact-analog generator" actuated by the aircraft sensors likewise became a task under the first subcontract. The first contact-analog display was derived by television-camera methods from a pattern inscribed on a metal sphere that could be moved in correspondence with changes in the aircraft attitude. This method was developed to its logical conclusion and its usefulness was successfully demonstrated in airborne tests. Preliminary mathematical considerations were also given by Kaiser to the possibility of an electronic approach during the initial phases of the Contract DAC 55-300. However, in 1956, Douglas directed Kaiser to terminate such evaluation, and to restrict all of its efforts under the contract to the development and building of an electro-mechanical system. G. H. Balding, working with Kaiser proprietary funds, approximately one year later developed an all electronic contact analog including the now well-known Kaiser FLITE-PATH system[2]. In 1958, in response to a request for bids by Douglas, Kaiser submitted a proposal, but was not successful in obtaining an award. Kaiser model #135 was purchased by Douglas early in 1959 for evaluation in a C11B flight simulator.

The other major project in which Kaiser participated was the development of a vacuumless, "cross-grid", electroluminescent (EL) display system.

The present report summarises the above Kaiser contributions, in the following sequence:

- Kaiser-Aiken thin cathode-ray tube
  - Internal structure
  - Tube envelope
  - Sweep circuitry
- Contact-analog generator (electromechanical)
- Vacuumless displays
  - Sweep circuitry
  - Panel fabrication

II. KAISER-AIKEN THIN CATHODE-RAY TUBE

A. INTERNAL STRUCTURE

The Kaiser-Aiken thin cathode-ray tube (CRT) has been described in considerable detail in the technical literature.[4,5] The brief description of the operation of the device that follows is included to facilitate an understanding of the progress that has been made in the course of the present project; the treatment is not meant to be exhaustive.

The tube's configuration differs from that of conventional CRT's in that the basic elements that comprise a display tube (electron gun, accelerating and deflecting structures, and display screen) are arrayed in a novel way (Fig. 1). The electron beam is injected along the bottom edge of the display screen and travels in a field-free region past a set of horizontal deflection plates. If they are all at the same (anode) potential the beam continues all the way to the right. When the voltage on one of the deflection plates is lowered, the beam is deflected upward. The position at which this deflection occurs can thus be moved in a continuous manner from right to left (or left to right) by a sequential lowering of the voltage on adjacent plates in the appropriate direction.

The upward-deflected beam enters another field-free region, bounded on one side by the display surface and on the other by the vertical deflection plates, each of which

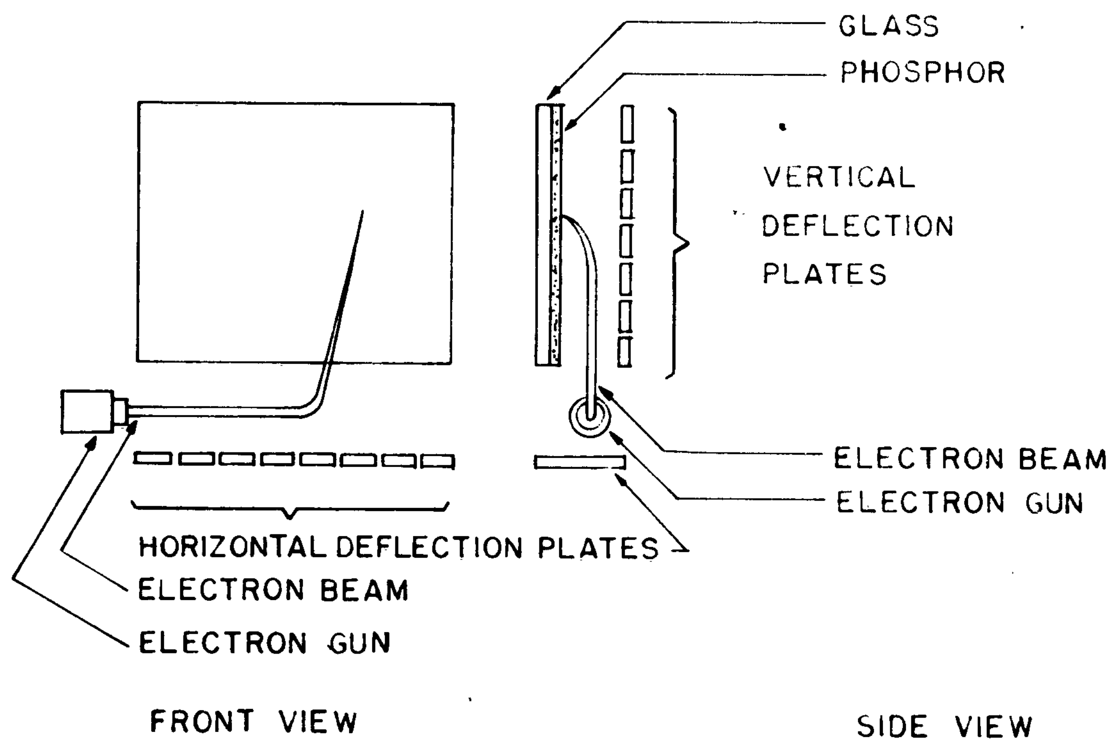


FIG. 1.--Basic configuration of Kaiser-Aiken thin cathode-ray tube.

extends all the way across the tube. If the vertical deflection plates are all at the same potential, the beam continues all the way to the top. When the voltage on one of the deflection plates is lowered, the beam is deflected into the phosphor. Again, the position at which the deflection occurs can be varied continuously by sequential variation of the voltage on adjacent deflection plates. The tube can thus sweep out a raster if an appropriate sequence for each of the two sets of deflection plates is chosen. It is not necessary to have as many deflection plates as the number of horizontal or vertical elements to be resolved, since the application of time-varying (and overlapping) voltage waveforms to the deflection plates makes a smooth deflection possible.

When an electron beam of finite thickness is deflected by a uniform electrostatic field, the beam is also focused. In conventional CRT's, an operation known as "deflection defocusing" occurs if the beam comes to a crossover as a result of this action and then diverges before arriving at the display screen. In the Kaiser-Aiken thin CRT, on the other hand, deflection focusing is actually turned to advantage and produces a powerful focusing action. As a result, it is possible to utilize larger beam currents for a given spot size, or to obtain a smaller spot size with the same current, than in conventional CRT's, with attendant improvements in brightness or resolution (or both).

Apart from the small depth, the feature that constitutes the principal reason why the Kaiser-Aiken thin CRT has been deemed suitable for ANIP purposes is the possibility of rendering the display transparent. If transparent phosphor is used and the vertical deflection plates are made of strips of conductive coating on glass, the entire display becomes transparent. In contact flight, the pilot can switch off the display and look through the tube. Used as a contact analog, the display is centered in the pilot's contact-flight field of vision. However, the present state of transparent-phosphor development is such that these materials can be processed only at temperatures that are too high to be used for deposition on the soft glasses ordinarily employed in CRT practice; hence a special insert plate made of hard glass (with a high melting point) must be employed, with the attendant structural and optical complications and partial brightness loss. Moreover, the brightness of the best transparent phosphors still does not match the values obtained at comparable ultor voltages with opaque phosphors, although this disadvantage is in part offset by the improvement in contrast resulting from a relatively smaller fraction of ambient light being reflected from a transparent-phosphor display surface than from an opaque one.

At the outset of Kaiser participation in ANIP, the feasibility of the Kaiser-Aiken thin CRT had been demonstrated by means of laboratory models in demountable vacuum systems. Television reception was possible; the picture quality was below acceptable standards from the viewpoints of frame distortion, uniformity of brightness, and uniformity of focus, but brightness levels and resolution were acceptable even in some of the earliest models. The considerable strides made in bringing the above characteristics to high levels in the course of the present program came about as a result of improvements in the internal structure and in the associated circuitry. Only the former are reported in this section; circuitry is described in Sec. II-C.

During the initial part of the program, the electrodes comprising the internal structure were essentially handmade and the strips of transparent conductive paint used for the vertical deflection plates were created by the removal of spacer strips from a continuous layer of stannic oxide deposited on the inside glass surface by the manufacturer of the tube envelope. Considerable difficulties were experienced in bringing out the relatively large number of leads to the several electrodes and in developing a reproducible, rugged structure. An early attempt to solve the former problem involved leads in the form of narrow, flat metal strips brought out between the two halves of the tube envelope (see Sec. II-B). At the same time, rugged structures were being developed with the help of vibration tests. Another problem that received much attention early in the program was the electron gun. All of the models of the tube actually delivered contained an electron-gun attachment protruding from one corner of the device, and much design effort went into making this attachment as short as possible. A moderately extensive program to develop a "bent" gun was undertaken at one time, with the objective of making the protrusion altogether unnecessary by placing the gun structure entirely within the tube envelope and causing the beam to be injected after it had undergone one or more 90° deflections; but this feature has yet to be included as part of the final design.

As the development effort proceeded, continual tests were being made to develop a structure that would be free from distortions caused by fabrication errors and from electron-optical distortions produced in dynamic operation by voltage variations. A large electrolytic tank was employed in optimizing the electron-optical design. The metal parts of the internal structures were fabricated to small tolerances and assembled with glass or ceramic spacers on special jigs. The internal structures of tubes delivered later in the program represent a tremendous improvement over the early models. It should be nevertheless kept in mind that the total design effort associated with the development of the internal structure to date has been relatively modest in comparison with, say, the effort that goes into developing a production prototype model of a storage tube or a three-color television tube. Although the bulk of the design work may be considered to be completed, there can be little doubt that further work toward developing a production model would lead to additional improvements in tube performance and reliability.

B. TUBE ENVELOPE

The Kaiser-Aiken thin CRT has always presented certain special problems in glass construction. The conventional technique of joining the face panel of a picture tube to the rest of the bulb (cone), by heating the junction, cannot be readily applied because the high temperatures involved would damage the internal structure and the display surface. This problem does not arise in conventional black-and-white CRT's, since the junction can be made before the phosphor is deposited and the gun is attached.

The program was thus faced with the problem of persuading a glass manufacturer to develop specially molded tube envelopes made in two halves, with special recesses to accommodate the internal structure and with a curvature that was large enough to withstand the considerable stresses characteristic of the special thin-tube configuration, but not so large that optical distortion would become a problem. The glass manufacturers most logically equipped to develop such an envelope were the producers of such items as television tubes and curved automobile windshields. The cost experience accumulated in the course of developing such items led to an understandable reluctance on the part of these manufacturers to undertake a modestly funded program of developing molds for any application whose run would not be numbered in at least six figures. Nevertheless a few experimental molds were developed and matching tube halves received from several manufacturers, notably the Kimble Glass Co. These tube halves were put together by means of a special glass solder ("frit") that fused at a temperature below the melting point of the glass halves but had an almost identical coefficient of expansion.

The procedure finally evolved was the following. The blanks were received from the manufacturers covered by a transparent conducting tin-oxide coating. Additional holes for the pump-out tubulation and the electron gun were drilled and polished. The glass frit, mixed in a slurry with an acrylic resin binder material, was applied to all sealing surfaces. The conducting coating was stripped on one tube half to provide the vertical deflection plates, and on the other to provide a rectangular area that was then coated with phosphor. The internal structure was inserted, the pump-out tubulation and electron gun were put into place, and the entire assembly was placed in the exhaust oven, where it was heated, sealed, and exhausted in a complex heat cycle during which the glass had to be annealed, the electron gun activated, the tube tipped off, and the getters flashed. The yield, after an initial period of experimentation, was surprisingly good and tubes were soon being delivered in several shapes. Moreover, the experience gained as a result of this program proved to be invaluable in the course of the next development.

This development, which in its way amounted to a major contribution to glass technology, was the employment of plate glass for tube envelopes. In view of the difficulties experienced in the design of molds on a very limited budget by manufacturers for whom such an endeavor was at best a marginal operation, the decision to employ plate glass for the Kaiser-Aiken thin CRT might appear to have been the obvious one in retrospect. Costly molds would be eliminated and optical distortions would be minimized. Nevertheless, it should be recalled that this decision was made by Kaiser in the face of contrary advice from all representatives of the glass industry who were consulted. The fact that this aspect of the project was brought to a successful conclusion despite the unanimous discouragement of industrial glass experts must be reckoned as an important by-product of the total Kaiser effort, and one whose effects on U.S. industrial practice still remain to be assessed.

In the plate-glass version of the tube, the two face plates are simply rectangular pieces of plate glass, joined together by a thin ribbon of glass that is bent into a frame shape in a prior operation. The three glass pieces are joined together in a single operation by a frit method similar to that described above. Electrical contacts through the vacuum envelope are made by means of narrow strips of conducting paint. The fabrication procedure has been perfected to a point at which failures ascribable to the glass envelope are rare. Current models of the Kaiser-Aiken thin

CRT are all made of plate glass. The model shown in Fig. 2 has a viewing area of 8 x 6 in. and may be viewed from back and front; as transparent phosphors are developed that are capable of being deposited on "soft" glass, this version can be made wholly transparent. The only disadvantage in comparison with the molded glass envelope is a slight increase in weight. As the area of the face plates is increased, the stresses on their centers produced by the pressure differential between atmospheric pressure and vacuum have to be counteracted by an increase in the plate thickness; since this thickness is necessarily uniform over the entire face plate, a relatively heavier assembly results.

C. SWEEP CIRCUITRY

The purpose of the sweep circuitry is to generate the voltages that must be applied to the deflection electrodes in order to cause the beam spot to progress uniformly. The "horizontal" and "vertical" circuits, though essentially equivalent, perform under different operating conditions. For a raster of the television type, for instance, the horizontal sweep takes place at anode voltage (typically 1 kv) and line-scan frequency, whereas the vertical takes place at ultor voltage and frame frequency. Since the ultor is usually the phosphor display surface, brightness requirements dictate the use of a voltage of 12-15 kv, which creates a problem even at the relatively low frame frequency. Finally, the circuits must be so arranged that waveforms on

FIG. 2.--Recent model of Kaiser-Aiken thin cathode-ray tube employing plate-glass envelope.

adjacent electrodes overlap, to compensate for the discrete nature of the deflection electrodes.

All of these requirements may be met by circuits comprising vacuum tubes. Sweep circuitry of this type was used in the initial demonstration models and remains the most acceptable type to date. The problems associated with this type of circuitry have been solved. However, it is recognized that this scheme, which necessitates the use of one vacuum tube for each deflection electrode, is by no means the simplest that could be conceived, and efforts directed toward the development of a simpler method were undertaken throughout the duration of the project.

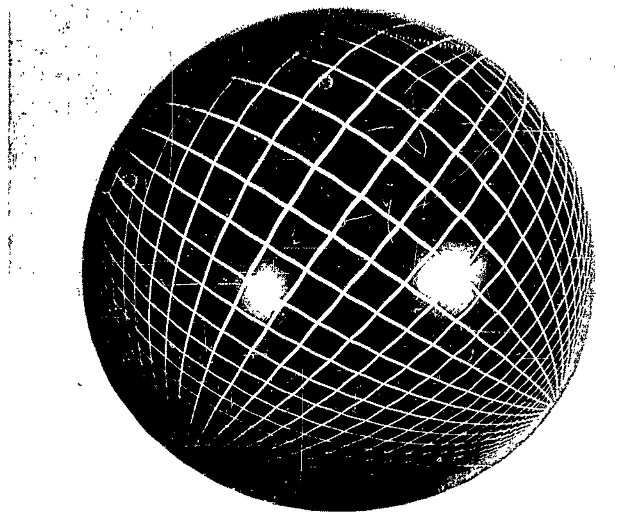
An additional problem associated with the vacuum-tube sweep circuitry early in the program was the realization that no suitable tube capable of operating at the high ultor voltages was commercially available for vertical deflection. The principal difficulty inherent in the operation of tubes containing oxide-coated cathodes at high voltages is that any positive ions formed by collisions between electrons and remaining gas molecules strike the cathode with enough force to destroy the oxide coating. To deal with this problem, a special ion-trap tube was developed by Kaiser.[6] This tube, the 6IT6, is now commercially available on special order and represents yet another by-product of Kaiser participation in ANIP.

Vacuum-tube, gaseous, and solid-state devices all played a part in attempts to replace the scheme of one tube per deflection electrode. Several approaches proved to be promising, but none of these attempts was really carried far enough to permit a final evaluation of their relative merits.

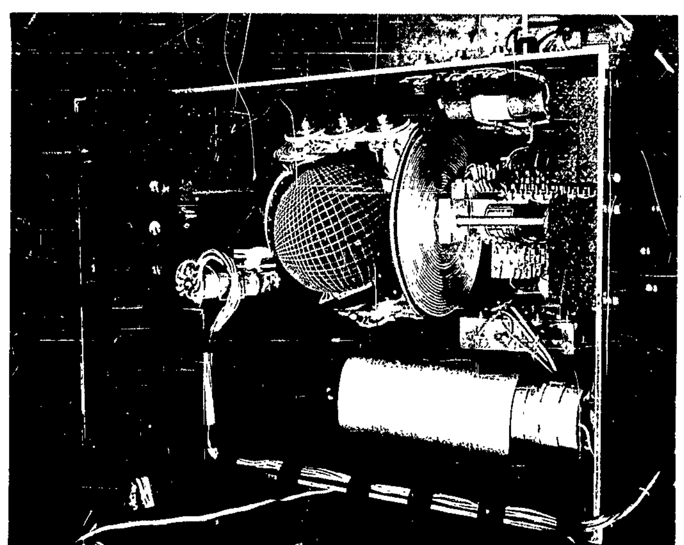
A vacuum tube that was conceived to meet the requirements of both the horizontal and the vertical sweeps (one tube for each) was a switching tube containing several target electrodes (one for each deflection electrode) arranged in a circular array, with the switching function performed by an electron beam caused to rotate by electrostatic means. In the gaseous-tube approach, the progression of the deflection waveform from one deflection electrode to the next depended on the progress of the length of the glow region along a long gas-filled tube, which served as a light source for a row of photoconductive elements employed as switches. The solid-state approach dispensed with light source and photoelectric elements and depended instead on a voltage transmission line for sequential operation. Although none of these efforts was carried sufficiently far to produce a scheme that would compare favorably with the multiple-vacuum-tube approach, enough work was done to simplify considerably any future evaluation of the relative merits of the several alternatives. Such an evaluation would, of course, have to take into account advances in the state of the art in such rapidly developing fields as solid-state technology.

III. CONTACT-ANALOG GENERATOR (ELECTROMECHANICAL)

The electromechanical contact-analog generator developed by Kaiser during participation in the ANIP Program, comprises a system in which television camera methods are employed to produce visual cues for display on a cathode ray tube such as the Kaiser-Aiken tube. The picture to be displayed was produced from the video pulse train output of a phototube picking up light that originated from a flying-spot scanner and was reflected from a specially inscribed metal sphere (Fig. 3) that was rotated in accordance with the aircraft attitude. Additional cues were likewise produced by video-camera means, with the help of small CRT's suitably masked to produce the requisite patterns. Video mixing was employed to combine and to position the several cues. Changes in altitude were produced by operating upon the sweep circuits of the flying-spot scanners so as to shrink or magnify the final display, in accordance with a scheme that has been described in the literature.[7] Perhaps the most important of the features of the electromechanical contact-analog that were to be forerunners of corresponding features in the all-electronic system was the method by which forward motion was simulated. Representation of forward motion was obtained by causing the display to be gradually expanded away from the horizon line (perspective being maintained) until one of the horizontal cross lines assumed the position of the



(a)



(b)

FIG. 3.--Electromechanical contact-analog generator. (a) Inscribed metal sphere; (b) complete assembly.

one below it; whereupon the display was caused to shrink abruptly into its original configuration and the process was repeated.

Prototype models of the electromechanical contact analog were brought to a relatively high degree of perfection and were successfully subjected to flight tests.

IV. VACUUMLESS DISPLAYS

A. OBJECTIVES OF PROJECT

This project aimed at developing a practical method of dealing with the well-known problem of illuminating a solid-state "cross-grid" display at video rates.* Such solutions as had been attempted previously had been unable to cope with the very large capacitive load represented by such a panel. The major contribution made at this Laboratory (a novel method of exciting the grid wires, coupled with certain innovations in the exciting circuitry) may well point the way toward the first practical solution of a problem that has stumped the industry for the past 15 years.

A second problem associated with the use of cross-grid displays is the elimination of crosstalk and background illumination arising from partial excitation along the entire line that is being energized. To the extent that minimization of such background illumination depends on the method of excitation, the technique to be described is inherently superior to other methods that have been proposed. However, it is recognized that such problems are largely the result of limitations in the characteristics of present-day

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*A cross-grid display consists of a set of closely spaced parallel wires separated from a second set oriented at right angles to the first by an electroluminescent panel; any intersection may be illuminated by energizing the two wires that form it with voltages of opposite polarity. The wires may take the form of thin strips of conducting paint deposited by screening or photographic techniques; however, they are referred to as "wires" throughout this report.

phosphors. In a display medium with a highly nonlinear dependence of light output on excitation voltage, the problem would disappear. No attempt to develop a more tractable light-producing medium was made in the course of the present project, which was devoted entirely to the controling circuitry; however, the method used at this Laboratory for fabricating suitable panels is described in Sec. IV-G.

B. COINCIDENCE-PULSE METHOD

The coincidence-pulse method invented by W.R. Aiken depends on the phenomenon of a pulse being introduced at one end of a delay or transmission line, traveling along the line, and being absorbed by a terminating impedance at the other end. If another pulse is similarly introduced at the other end, the two pulses meet at some intermediate point and create a pulse there with a magnitude equal to the sum of the magnitudes of the two pulses. By varying the time at which the pulses are generated, the location at which the coincident pulse occurs can be varied: the delay line acts as a multiple-output AND gate. With appropriate circuitry, sequential switching by electronic means is achieved. Brightness control is obtained by varying the magnitude of one pulser output at video rates.

A possible scheme is to employ two double pulsers with outputs of opposite polarity, one to feed pulses at the two ends of a delay line whose taps are connected to the vertical wires and the other to the horizontal. To illuminate successive intersections, the two pulsers must be carefully synchronized, so that the positive and negative coincident pulses arrive at the intersections simultaneously. The development of a method of insuring this "simultaneous coincidence" of all four pulses was the first important breakthrough made in the course of the project. Briefly, the method is to design for simultaneous coincidence at the center of the display and then to vary the pulse phasing for other positions by retarding one pulser of each pair while advancing (by an equal amount) the other pulser of each pair. In this way, the time of coincidence does not vary with pulse-pair separation.

C. "DIGITAL" CONNECTION

The simple scheme described above would require pulser and delay-line bandwidths in the kilomegacycle range for operation at video frequencies. A technique for substantially reducing the bandwidth requirements, the so-called "digital" connection, represents the second important breakthrough of the project. Instead of applying a pulse between one of, say, 100 wires and a continuous conducting back-up strip (behind the phosphor), the wires are grouped so that every tenth one is interconnected (i.e., 1, 11, 21, 31, etc., are connected together; 2, 12, 22, 32, etc., are connected; and so forth); and the back-up strip is broken up into 10 segments, one behind wires 1-10, one behind 11-20, etc. Instead of a delay line with 100 taps, two delay lines with

10 taps each are used, one connected to the groups of wires and one connected to the segmented back-up strip. A wire is energized by simultaneous application of power (of opposite polarity) to a "units" tap on the delay line connected to the wires and a "tens" tap on the delay line connected to the segmented back-up strip. For instance, wire 23 is energized by exciting the 21-30 "tens" tap negatively and the 3 "units" tap positively. In this way, 10-tap delay lines replace 100-tap ones, with resulting greater accuracy of digital operation and considerable reduction in complexity.

Crosstalk, which may be caused by a poorly shaped pulse, still remains a problem. For instance, if in the above example the "tens" delay line partially energizes the adjacent (31-40) circuit, wire 33 may also be energized. A possible remedy might be doubling the number of back-up segments and halving the number of wires served by a single back-up segment. Then energizing the 21-25 segment by a poorly shaped pulse might be safely allowed to energize partially the adjacent 16-20 and 26-30 segments as well, since neither backs up a 3 wire, so that no crosstalk can result.

The "digital" connection reduces the number of taps required on each delay line to the square root of the number of wires, making order-of-magnitude reductions in the requirements for bandwidth and pulse width possible. As an example, for a standard television system with a resolution (not number of raster lines) of 350 lines and 30 frames/sec, the straightforward connection would require delay lines with a total delay of 64 ns and a bandwidth of 2,310 Mc; and a pulse width (at 50-percent amplitude) of 0.2 ns. In the "digital" connection, the total delay is the same, but the bandwidth is reduced to 124 Mc and the pulse width is increased to 3.4 ns. These requirements are still formidable, but at least appear to be feasible in the present state of the art.

Another aspect of the "digital" connection that should not be overlooked is that although the present system is controlled by analog signals, the nature of the connection is such that it is directly applicable to digital control, which makes the scheme particularly attractive for computer applications.

D. DISPLAY PANELS

During the course of the project, several experimental panels were constructed, including a 1 x 40 cross-grid display, a 9 x 9 large-scale model, a 40 x 40 cross-grid display, a 1 x 100 bar graph, and a 100 x 100 cross-grid display. The results obtained with each of these devices are described in this subsection.

1. 1 x 40 CROSS-GRID DISPLAY. This device was constructed early in the program as a non sophisticated version of a working unit built by Kaiser prior to award of the contract. The display device was used for test purposes in the initial stages of development and later as a demonstration model.

2. **9 x 9 LARGE-SCALE MODEL.** This device was a wall-mounted model 3 x 5 ft in size comprising 9 wires in each direction, which was constructed as a means of determining whether pulses of nanosecond width could be generated, controlled, and added along wires as specified. The model was used largely in testing pulsers (cf. Sec. IV-F). Since no phosphors capable of being excited with nanosecond pulses were available at the time, flashlight lamps were used at the intersection to demonstrate the method. The experiments were successful and adequate control of the lights was attained.

3. 40 x 40 CROSS-GRID DISPLAY. Tests conducted with this device represented the turning point of the project. Both x-y and raster scan were demonstrated with this model, which also proved to be an important means of evaluating pulser and delay-line performance.

Two pulse generators produced double pulses at 15.75 kc; the outputs of each generator were applied to two 20-μsec delay lines, suitably phased to provide a continuous scan as described in Sec. IV-B. The phasing was accomplished by a variable-delay network that causes one of the pulses applied to the 20-μsec delay line to lead the 15.75-kc reference by 10 μsec and the other to lag by 10 μsec at the beginning of each sweep; as the sweep progresses, the complementary lead and lag are incrementally reduced to zero and then increased in opposite directions to complete the sweep. Through a count-down circuit, one delay line receives pulses at 1/40-th of the rate of the other, to produce a raster scan similar to television scan.

The "simultaneous coincidence" described in Sec. IV-B was achieved in this model by sampling the output of one delay line and using the resulting signal to trigger the pulse generator connected to the other delay line.

The device was also used for x-y scanning of the sort produced by a conventional oscilloscope. In this application, the count-down circuit used in raster scanning is removed. The waveform to be displayed is used to modulate a 1.2-Mc oscillator whose output passes through a detecting circuit, where the signal is separated into its positive and negative components that are then integrated to reproduce the original signal as two complementary (positive and negative) signals, which in turn are applied to the variable-delay circuits in one of the pulse generators. A sine wave displayed on the 40 x 40 cross-grid display is shown in Fig. 4. If both the horizontal and vertical circuits are modified in this fashion and time-base signals are applied to both, it is possible to produce Lissajous patterns; such patterns were generated and recorded in dynamic variation on motion-picture film.

4. 1 x 100 BAR GRAPH. This device was constructed for the purpose of making evaluation tests on the "digital" connection described in Sec. IV-C. The connection minimizing crosstalk was used: wires in groups of 10 and the back-up plate in 20 segments corresponding to 5 wires per segment.

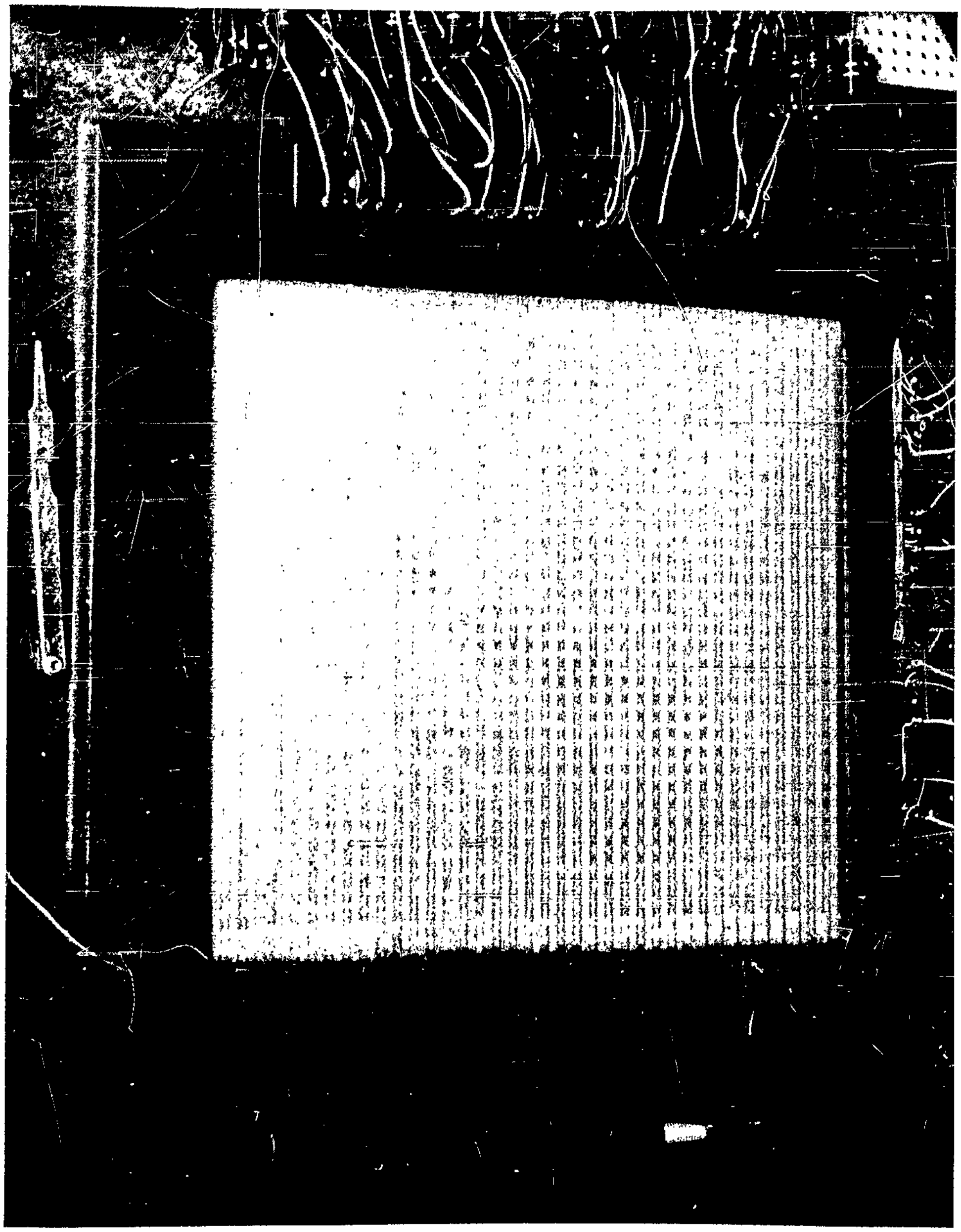

FIG. 4.--Sine wave on 40 x 40 display.

The device thus represented a one-dimensional version of a complete display and served to determine such design characteristics as pulse repetition rate, amplitude, and coincidence, as well as stability and sensitivity. (A sensitivity of 100 mv per division was achieved.) In addition, the bar graph may have direct applications as a special-purpose display system with the following characteristics:

(a) Good contrast ratio.

(b) Small package size.

(c) Low power consumption (i.e., low heat generation).

(d) Simple switching circuitry using standard components.

(e) Good linearity.

5. 100 x 100 CROSS-GRID DISPLAY. This was the most elaborate display device constructed in the course of the project and demonstrated the feasibility of the "digital"-connection scanning scheme for large displays. For demonstration purposes, a slow frame rate (16.7 sec) was chosen. The decimal arrangement of wires and back-up plates (both in groups of 10) was used, with steps of 10 used between the delay lines for simplicity: 16.7 and 167 msec for the "units" and "tens" sweeps of one delay line, and 1.67 and 16.7 sec for the other. Design emphasis was placed throughout on standardization of circuits, with a view to making mass production on a microminiaturization scale feasible. The number of different types of functional circuit blocks was reduced to six.

The results obtained with this device substantially accomplished the stated objective of developing a basis for a practical commutating system of switching a cross-grid display at video scanning rates.

E. DELAY LINES

In connection with the development of a practical means of scanning the cross-grid display by the method described above, various special delay lines were investigated and evaluated, including a nonlinear, a solid-state, and a bifilar delay line. These studies are briefly described below.

1. NONLINEAR DELAY LINE. This type of line has been under study as a result of its ability to transform a sine wave into a sawtooth waveform with a very steep wavefront.[8] It was of interest to the present project as a means of sharpening the pulses for the purpose of obtaining higher resolution. The nonlinearity is in the response to signals of varying amplitude. The line typically consists of series inductances and shunt capacitances, with a biased diode inserted in series with each capacitance. One scheme that was studied was the replacement of the lumped elements by a distributed line made of a ferroelectric material such as barium titanate, but the high fields necessary to realize the nonlinear properties of such materials (of the order of 80 v/mil) and the large dielectric losses at high frequencies were deemed to be insurmountable obstacles to the success

of such an application.

The investigation of the nonlinear line was cut short by the development of special nanosecond-pulse techniques, as described in Sec. IV-F.

2. SOLID-STATE DELAY LINE. The basic configuration investigated consisted of flat parallel conductors with a material of high dielectric constant placed between the conductors. The experiments were aimed at determining the maximum achievable bandwidth and the ranges of impedances and delays attainable. Lines of this configuration are physically rugged and can be tapped at points that are not necessarily evenly spaced (as in a lumped-constant line) and whose number can be made arbitrarily large, as limited only by the physical considerations of making electrical contacts. Typical characteristics achieved were delays of the order of 30 ns/ft, characteristic impedances of 10-20 ohms, and bandwidths up to 200 Mc. It is believed that further investigation of such delay lines would reveal a number of interesting applications.

3. BIFILAR DELAY LINE. The basic configuration consists of two separate conductors wound in the same direction around a dielectric mandrel, so that a bifilar helix results. The effect of winding two conductors in this manner is to increase the delay time by about 15 per cent above the straight two-wire configuration. Typical characteristics obtained were delays of the order of 100 μsec and

characteristic impedances of 50-100 ohms. However, the bifilar line in this form was found unsuitable for the proposed application, largely because of difficulties associated with tapping the line and obtaining a ground reference for the tapped voltage; since the "ground" wire is carried alongside the other throughout the length of the line, no ac ground is obtained except at the ends of the line.

F. PULSERS

1. NANOSECOND PULSE TECHNIQUES. Four basic methods of generating nanosecond pulses were evaluated for the present application. The first was the method of standard triggered blocking oscillators. Such circuits were found to be unsatisfactory for the generation of pulses of the required amplitude (and shorter than 100 ns) on low-impedance delay lines.

The second method consisted in using silicon transistors in the avalanche mode, and likewise proved to be unsatisfactory.

The third method involved the use of the nonlinear delay line described in Sec. IV-E-1 above and also turned out to be unsatisfactory owing to (a) the high impedance of the line, (b) the limited bandwidths of the voltage-variable capacitors ("Varicaps"), and (c) their relatively low voltage swing.

The fourth method was the most successful for producing nanosecond pulses. An oscillator operating between 1 and

10 Mc was used to drive a solid-state diode via a capacitive coupling network; the positive half cycle forward-biases the diode, but the reverse-biasing action of the negative half cycle is delayed and then takes place very abruptly, giving rise to a sharp pulse. (This action is sometimes called the "Boff" effect after its inventor.[9]) This method is limited only by the characteristics of the diode (i.e., speed and power dissipation) and is doubtless capable of even further improvement.

2. DESIGN OF MICROSECOND PULSERS. Since the delay lines developed in the course of the project were not capable of propagating nanosecond pulses without serious deterioration, a parallel program of pulser design at microsecond pulse widths was undertaken. Commercially available delay lines could then be used to demonstrate the operation of the system. Several pulser designs were undertaken.

The first approach was that of driving a "slave" output stage with a low-impedance source, such as an emitter follower or cascaded emitter followers ("Darlington pair"), to minimize loading of the input signal. This circuit suffered from the basic problem of unavailability of a transistor for use as output "slave" that would have a sufficiently high collector-voltage rating to yield the required output voltage and at the same time a low enough storage time so that sharp pulse rise and fall times could be maintained; this problem proved to be insurmountable. Some improvement in rise time was obtained by the use of a four-layer switching diode in series with the collector of the output "slave" transistor, but the fall time was still poor and was aggravated by overheating of the transistor junction, which tended to increase the storage time. Insertion of an inductor or a high-speed saturable reactor for the purpose of reducing the overheating by reducing the turn-off time brought about no improvement, since it resulted in a damped wave train at the switching diode that generated several pulses in place of one and thus contributed to the heating.

The circuit that finally proved to be satisfactory utilized a triggered blocking oscillator, which has the inherent advantage for the present application of providing a symmetrical waveform. The design requirements on the transistor to be used were high gain-bandwidth product, high collector-voltage rating, low collector-to-emitter saturation resistance, insensitivity of beta to collector-current variations, and low storage time. The requirements on the transformer to be used were small physical size and good accessibility, high efficiency of core material at the frequencies under consideration, low insertion loss, and low leakage inductance, distributed capacitance, and IR drop.

The transistor ultimately selected had a gain-bandwidth product of 60 and a saturation resistance of 0.3 ohms at 500 ma. The storage time was not quite low enough and made it difficult to produce an output pulse shorter than about 2 μsec. The pulse width was ultimately brought to a controllable range of 0.5-4 μsec by the substitution of a silicon mesa transistor, which also had a somewhat higher gain-bandwidth product and thus less heating, since the device can reach saturation more quickly.

The blocking oscillator is the only circuit that seems to be capable of meeting the stringent requirements that (a) output-pulse magnitude must be in excess of the voltage rating of commercially available transistors, (b) the rise and fall times must be faster than those available with medium-power transistors, and (c) the storage time must be small, which eliminates available high-power transistors. The blocking oscillator essentially eliminates all these problems because of its use of a transformer in conjunction with regenerative feedback. Moreover, it provides the following advantages: stable operation, less stringent requirements on the trigger source, very small turn-on delay times, insensitivity to normal load variations, fixed and controlled rise and fall times, fixed pulse width, high efficiencies (of the order of 90 per cent), low average-power consumption, low heat generation, correct impedance matching to load, small package size, and the use of standard components.

G. PANEL FABRICATION

During the present investigation, techniques for fabricating phosphor panels were developed that permitted microsecond-pulse excitation at acceptable brightness levels. Although no systematic study of the techniques employed in the fabrication of such panels was undertaken, the laboratory techniques may be of interest and are briefly summarized below.

A commercially available glass substrate coated with stannic-oxide transparent conducting film was used and conducting strips were created by electric-arc etching of 0.1-in. spacer strips. A layer of U.S. Radium No. 3663 phosphor was deposited from a water suspension of the phosphor and its binder; the length of time during which the suspension is allowed to settle controls the thickness of the phosphor. Next, a film of dielectric material with high dielectric strength is sprayed onto the panel. The second (opaque) set of strips is formed by vacuum evaporation of pure aluminum through a mask, and a protective plastic film coating is then sprayed over the aluminum. Lastly, metal contacts are attached to the ends of the strips for external connections.

Apart from the limitations of the phosphor itself, the principal problem encountered in the preparation of panels by the above techniques was the relatively high resistance of the transparent conductive elements. This problem could be doubtless overcome by an appropriate research effort directed toward minimizing the resistance.

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