New Directions in Aircraft Instrumentation

The thin cathode-ray tube and transparent screen described in the following papers may provide at least a partial answer to one of the most pressing problems involved in contemporary aircraft development — that of how to keep instrumentation abreast of advances in aircraft design. A pilot must instantaneously coordinate and evaluate many items of information. Within the limits of human capability, he must depend upon instrumentation. An examination of this problem indicated that some of the requirements could be met with a thin, transparent viewing window through which the pilot may observe the real world, or on which he may watch a representation of that world when weather or other conditions make direct viewing impossible. Such a device would also provide an answer to the problem of space limitations.

At first this was thought impossible, and a number of the approaches tried were found to be unworkable; but we fortunately learned about the development of the thin cathode-ray tube by Mr. Aiken and then, as Dr. Feldman will set forth, we were able to develop a transparent phosphor for the tube for our use. It may well establish a new direction in aircraft instrumentation — *George W. Hoover*, Commander, USN.*

Development of the Thin Cathode-Ray Tube

By WILLIAM ROSS AIKEN

The thin cathode-ray tube, invented by the author and developed by Kaiser Industries West Coast Electronics Laboratory, is described. Designed primarily for "on-the-wall," viewing, the thin tube has excellent focusing properties and permits simultaneous viewing from both sides of the display surface. The electron beam is injected along an edge of the tube and deflected twice to form a spot on the viewing surface. The physical configuration and sweeping circuits are described.

The Kaiser-Aiken thin cathode-ray tube differs radically from conventional types in that the basic building blocks which comprise a cathode-ray tube (electron gun, accelerating and deflecting structures, and display screen) are here arrayed in a novel fashion. It is this departure from the usual "in-line" arrangement that makes the principal advantage of the thin tube, its reduced size, possible. The importance of reducing the tube dimension perpendicular to the viewing screen (usually called *length*, but here perhaps more appropriately called *thickness*) is self-evident in circumstances where space is at a premium, e.g., in aircraft instrument panels. The reduction in bulk is obviously an attractive feature in many other applications also, as in TV receivers.

In comparison with conventional types, the thin tube has several other inherent advantages, particularly the powerful deflection-focusing action which makes it possible to utilize larger beam currents for a given "spot size" or to obtain a smaller spot size with the same current with improved brightness and/or resolution. Moreover, by relatively simple modifications of the basic model, the thin tube can be adapted to provide such special features as transparency, viewing of both sides of the display screen, and two or three primary color displays. The tube can, of course, be adapted to perform all the multifarious tasks that certain special display tubes can do, such as displaying characters and serving as a memory (storage) element.

Principle of Operation

Only one of a large number of possible configurations will be described (Fig. 1). The electron beam is injected along the bottom edge of the display screen, and travels in a field-free region between a set of electrodes, called horizontal deflection plates, and the bottom edge of the screen. If this edge and the horizontal deflection plates are all at the same (gun anode) potential, the beam continues all the way to the right. If 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 from left to right by sequentially lowering the voltage on adjacent horizontal deflection plates in the proper direction.

The upward deflected beam enters another field-free region, bounded on one side by the phosphor screen and on the other by a set of strip electrodes (vertical deflection plates), each of which extends all the way across the tube. If the vertical deflection plates are all at the same potential as the phosphor, the beam continues all the way to the top, but if 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. By choosing the appropriate sequence for each of the two sets of deflection plates (horizontal and vertical), the spot at which the beam strikes the phosphor can thus be made to sweep out a raster.

For practical reasons, the region of the horizontal deflection plates (primary section) is usually isolated from the region between the vertical deflection plates and the display screen (secondary section) by a transition section. The transition section comprises additional electrostatic lenses, so that it not only isolates the primary section from the secondary, but provides additional means of controlling beam focusing as well. The main reason why a transition section is necessary is that the primary section is operated at potentials of the order of the accelerating (anode) potential of the electron gun, i.e., about 1 kv, whereas the secondary section is of necessity operated at the potential of the display screen, which with present-day phosphors must be about 15 kv.

Based on an oral presentation October 7, 1957, at the Society's Convention at Philadelphia by Wm. Ross Aiken, Kaiser Aircraft and Electronics, Palo Alto, Calif. Another version of this paper, which includes a mathematical analysis of the focusing action, was published in the *IRE Proceedings* for December 1957.
(This paper was received on March 24, 1958.)

* The above opinions or conclusions are those of the author and are not to be construed as necessarily reflecting the views or possessing the endorsement of the Navy Department.

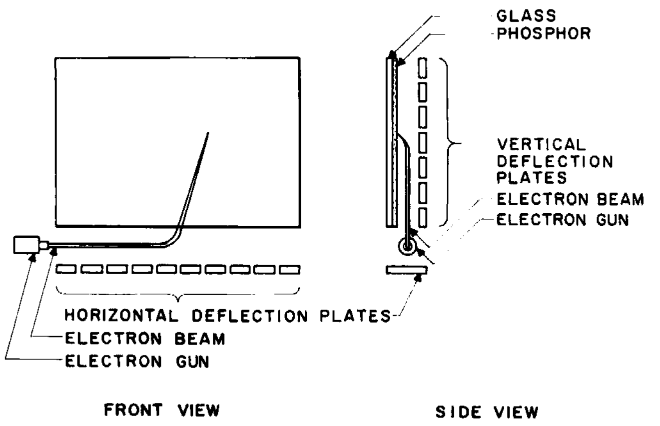

Fig. 1. Schematic diagram of operation of the thin cathode-ray tube.

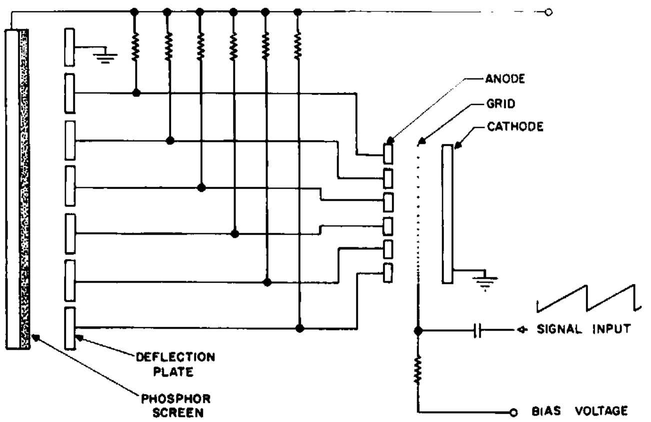

Fig. 2. Variable-mu voltage-sweep tube for secondary section

Under these circumstances, the bottom edge of the display screen cannot serve simultaneously as part of both the primary and secondary sections, and a transition section must be provided. An additional lens system is often made part of the transition section, to counteract the action of the effective convergent lens on the beam as it passes from the low-voltage primary to the high-voltage secondary section, and also to provide additional beam-focusing controls after the first deflection.

Deflection Focusing

When an electron beam of finite thickness is deflected by a uniform electrostatic field, the beam is also focused. In conventional tubes, so-called "deflection defocusing" results if the beam actually comes to a crossover as a result of this action and then diverges before arriving at the display screen. In the thin tube, deflection focusing is turned to advantage by judicious juxtaposition of the deflecting plates with regard to the beam and to the display screen.

Upon deflection by the horizontal deflection plates (primary section), the beam is brought to a focus in a plane parallel to the display screen and, if the transition section is properly designed, the cross section of the beam is changed from circular to elliptical as the beam enters the secondary section, with the major axis of the ellipse oriented normal to the display screen. The cylindrical beam traveling horizontally along the primary section thus becomes more or less a ribbon beam as it begins its upward travel.

Upon deflection by the vertical deflection plates (secondary section), the process is repeated, and the beam is again focused, this time in a vertical plane perpendicular to the display screen. The ribbon beam then becomes a pinpoint as it tends toward a crossover. If the display screen is located at a plane just before this doubly focused beam would actually come to the second crossover, a relatively small spot size at the display screen can be achieved.

The beam is not permitted to diverge after passing through the crossover toward which it tends as a result of the *first* deflection in the primary section and it may not even reach this crossover. The combined action of the transition section and of the effective lens through which the beam passes as it travels from the low-voltage primary to the high-voltage secondary section is to offset any tendency of the beam either to diverge or to converge. This action can be optimized in practice by transition-section design and by adjustment of voltages to correct for any adverse effects, including that of space-charge beam spreading.

In a conventional tube, the maximum beam current that can be focused to an acceptably small spot size (uniform over the entire display screen area) is determined mainly by the efficacy of the electron gun and focusing structure in offsetting space-charge spreading and in accommodating the electron-optical aberrations that result from the necessity for deflecting the beam through a large range of angles. It will be appreciated that in the thin tube, the design of the electron gun or the effect of beam blow-up are by no means the limiting factors in achieving small spot size. The deflection-focusing action can be used to such good effect that resolutions far in excess of those obtained in conventional tubes at comparable phosphor-voltage and brightness levels can be obtained without the expenditure of any special effort whatsoever on electron-gun design; in fact, in most of the models tested to date, standard commercially available cathode-ray tube guns have been used with excellent results.

Effect of the Exit Slot

In order to enable the deflected beam to leave the primary section, the low-voltage horizontal deflection plates, which in practice are shaped like rectangular channels in cross section, must face a slot in the direction of beam travel. This slot represents an important part of the transition section, and must be taken into consideration in the design of this section. One practical arrangement, for instance, is to provide an almost field-free region between the primary and secondary sections. In that event, the slot acts like the well-known Davisson-Calbick thin lens (divergent) and the beam actually diverges in the plane perpendicular to the long dimension of the slot; however, the divergence is offset by the action of the effective convergent lens represented by the passage from the low-voltage field-free region to the high-voltage secondary section.

In the plane of the slot parallel to the display screen, the beam converges as a result of the deflection-focusing action; it is unaffected by the slot, approaches a crossover, and would begin to diverge if it were not for the offsetting action due to the transit from low to high voltage. In the detailed electron-optical design of the transition section, factors such as space-charge spreading and the noncircular beam cross section resulting from astigmatic focusing must be taken into consideration.

It should again be emphasized that the excellent practical results obtained to date have not depended on the design of the electron gun; further improvements may well result from modifications which would serve to adapt the gun to the special application under consideration (such as providing a noncircular beam on entry to the primary section). But even with standard commercially available guns, the deflection-focusing action of the thin tube yields considerably greater definition without a sacrifice of brightness than can be attained with conventional tubes.

Sweep Voltage

Approximately 10 deflection plates are used to produce a commercial TV raster in both the primary and secondary sections. It is not necessary, as might appear at first glance, to provide, say, 525 deflection plates to produce a 525-line raster. Instead, the voltage on each deflection plate is varied monotonically

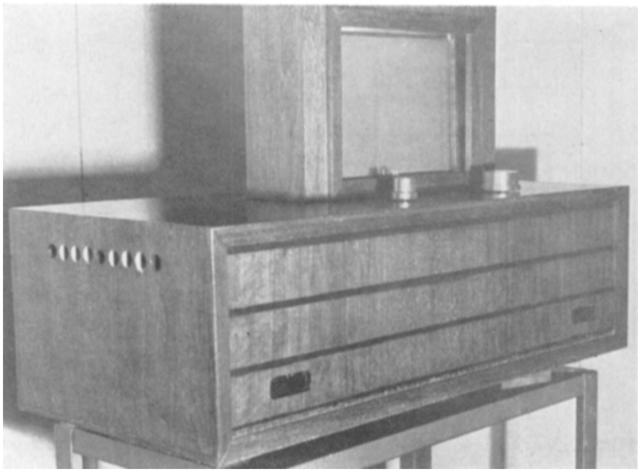

Fig. 3. Experimental TV receiver incorporating a thin tube.

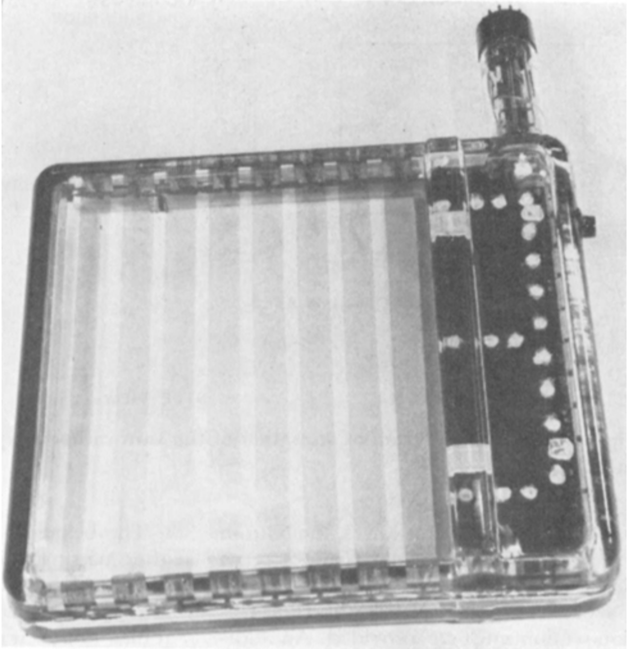

Fig. 4. Experimental sealed-off model (back view). The strips are the vertical deflection plates made from conducting material deposited on the inside of the glass envelope.

from full voltage to near zero, in such a way that as one plate approaches zero potential, the next one begins to decrease from its full value. It is expedient to allow the voltage waveforms to overlap in time, i.e., the voltage on the second plate is caused to begin decreasing considerably before the first plate has reached zero potential, with a resultant averaging of the deflecting forces acting on the beam. Various combinations of waveforms and amount of overlap can be used to obtain good linearity.

A number of possible schemes for achieving such sequential operation have been developed. Perhaps the simplest scheme consists of connecting the deflection plates to the anodes of a multi-anode triode provided with a single variable-mu grid wound in such a way that the several anodes are located opposite a progressively tighter grid mesh (Fig. 2). A positive-going sawtooth voltage applied to this grid will cause the tube to conduct progressively from top to bottom, so that the requisite sequential operation is obtained; the resistors serve to return the plates to their initial voltage during the retrace pulse. Alternately, a series of separate tubes can be used and the several tubes differently biased to require a progressively larger grid pulse to cause conduction. A sawtooth pulse is then applied to all the grids.

Fig. 5. "Windshield" model developed for integrated aircraft instrumentation.

In another scheme, a sweep tube comprising a cathode-ray gun in conjunction with a series of targets is used with each target connected to a deflection plate. Sequential operation is obtained by deflecting the beam so that it sweeps across the targets in sequence. Resistors are again used to return the several deflection plates to their initial voltage, except that here they can do so without waiting for the retrace.

Other arrangements involve tapped pulse lines, radial beam-switching tubes, and other special devices. It should be pointed out that any electronic device intended for voltage switching in the *secondary* section must be rated for operation at voltages up to 20 kv.

Practical Results

A number of models of the Kaiser-Aiken thin cathode-ray tube have been constructed, both the continuously pumped and sealed-off types. Figure 3 shows an experimental TV receiver that can be viewed simultaneously from both sides, through the use of transparent vertical deflection plates such as can be obtained by depositing strip layers of a transparent conducting material on the back plate of the glass vacuum envelope. The tube in this particular receiver is a sealed-off model that measures 12 by 12 in. (Fig. 4). The horizontal (primary) deflection section contains 10 deflection elements, each approximately an inch in length. The vertical (secondary) section consists of 8 plates, about one inch wide, made of conducting material deposited on the inside of the back surface. Primary and secondary operating voltages are approximately 1 and 12 kv, respectively.

Another version of the tube is shown in Fig. 5. In this form, the tube is used in conjunction with the Army-Navy Instrumentation Program (ANIP) (*Aviation Age*, p. 34, Oct. 21, 1957). A transparent phosphor is used in addition to the transparent conducting plates mentioned above, so that the tube is rendered entirely transparent and can be placed in the pilot's windshield without obscuring his vision when the tube is not in use.

In the laboratory, thin tubes up to 24 in. (diagonal) have been constructed, and resolutions as great as 2000 lines (at nearly acceptable brightness levels) have been achieved. In general, the substitution of an electrostatic for a magnetic deflection system makes it possible to achieve deflection with the expenditure of less power than in conventional tubes, especially if care is taken in selecting a deflection-control scheme by which a minimum number of deflection plates is maintained in a lowered-voltage condition at any instant. By this method, a minimum amount of power is wasted in those plate resistors which are not active in beam deflection at that instant. The deflection-focusing action proves to be relatively insensitive to quite substantial variations in the deflection voltages. The percentage changes in both deflection angle and final spot size, as the primary- and secondary-section voltages are varied, turn out to be very small compared with these voltage changes. Operation of the thin tube is therefore relatively insensitive to power-supply instabilities. Moreover, since the beam is deflected through the same two angles regardless of the ultimate spot position, no aberrations such as are inherent in the variable-angle deflection systems of conventional tubes are present, nor can the effects of other aberrations or fabrication errors become very prominent. Since the beam travels only a very short distance after the second deflection, there is virtually no "lever arm" to magnify such distortions. There is neither pincushion nor barrel-type distortion.

One aberration present in these models arises from the finite value of the injection velocity in the initial direction of beam travel. The tangent of the angle with which the beam is deflected out of the primary section is equal to the ratio of horizontal velocity to vertical velocity, i.e., to the square root of the ratio of the corresponding voltages. Since the electrons must be injected with a finite (horizontal) velocity, the deflection angle is not quite a right angle, so that an uncorrected rectangular raster would appear as a parallelogram skewed at an angle that in practice falls around 80°. This aberration can be corrected by a number of methods, including positioning of the gun and transition section at the same angle with respect to the bottom edge of the display area; making a correction in the controlling signal; or immersing the primary section in a localized transverse magnetic field, such as can be obtained by means of a very simple magnetic circuit (a U-shaped bar pole piece) located outside the vacuum envelope.

Finally, methods of adapting the thin tube to two or three primary color operations have been worked out, and experimental models show very promising results, especially with regard to linearity and raster registration.

Acknowledgment

The author gratefully acknowledges the aid of Dr. Charles Susskind, University of California, in the preparation of the manuscript.

Discussion

Charles O. Probst (*Cinefonics*): Can you give us an indication of the amount of data displayed on the windshield panel, how many bits are put together and something of the nature of the information given to the pilot?

Mr. Aiken: I would like to, but this information is classified.

Stanley Dobren (*Radio Corp. of America*): Can you give an idea of the brightness with 400 lines/in. on the flat tube?

Mr. Aiken: I believe that was 40 or 50 ft-L.

Mr. Dobren: Was that a conventional phosphor or a transparent phosphor?

Mr. Aiken: That was not a conventional phosphor. The grain size of a conventional phosphor is far too large for that. We used special phosphors and also Dr. Feldman's phosphor on some of those tests.

Mr. Probst: [Apparently, some of this information was declassified subsequent to Mr. Aiken's paper. Pictures of the "contact analog" presentation on this transparent cathode-ray tube display can be found in *Aviation Week*, Dec. 30, 1957; also Apr. 28, 1958; and in *Aviation* Age, June 1958.]

Development and Applications of Transparent Cathode-Ray Screens

By CHARLES FELDMAN

The process of forming transparent luminescent screens by evaporation in a vacuum is described. The method is applicable to most of the common phosphors and yields screens having the same properties as these phosphors. Advantages of transparent screens, such as high resolution and high contrast, are discussed. Applications of the transparent screen to the Navy's flat cathode-ray tube, the daylight viewing tube and the laminated color tube are described.

THE POWDERED phosphor luminscent screens that are employed today in television and cathode-ray tubes are composed of layers of small luminescent grains whose diameters are between 3 to 8 μ. This grain structure causes the screens to be white and opaque. The luminescence produced in the screen by the electron beam is scattered laterally by the grains, limiting the resolution of the image. Ambient light falling on the screen is scattered back to the observer making the screen appear bright and thereby limiting the contrast of the image.

It is desirable, therefore, to form luminescent screens free of grains that scatter light. Such screens will be transparent, providing, of course, the crystalline material is transparent. One could, in principle, accomplish this by growing a single crystal of the phosphor having the dimensions of the TV or cathode screen desired. However, this is quite impossible with the present crystal-growing technique. One can, on the other hand, accomplish the same thing by forming the screen of grains which are too small to scatter light. To accomplish this the grains must be approximately 100 times smaller than those currently employed. The technique, described here, of thermal evaporation in a vacuum has proved to be singularly successful in producing luminescent screens of sufficiently small grain size to be transparent.[1] The luminescent screens formed by this method are thinner (0.1 to 1 μ) than the diameter of a single grain in the conventional powdered material. Figure 1

Fig. 1. The transparent cathode-ray screen

Presented on October 7, 1957, at the Society's Convention at Philadelphia by Charles Feldman, Naval Research Laboratory, Washington, D. C. (This paper was received on May 8, 1958.)