# A Beam-Indexing Color Picture Tube – The Apple Tube*

G. F. BARNETT†, MEMBER, IRE, F. J. BINGLEY†, FELLOW, IRE, S. L. PARSONS†, G. W. PRATT†, MEMBER, IRE, AND M. SADOWSKY†

*Summary* – This paper describes the Apple color picture tube, its dimensions, materials of construction, deflection and focus systems, and the geometry and deposition of the phosphor and secondary-emissive screen materials. The construction and operation of the electron gun, which produces two independent beams of very small cross section from a single cathode, are described in detail. Life test data and pilot production experience are discussed.

## INTRODUCTION

THE APPLE concept as described in the previous paper places some very special requirements on the cathode-ray tube. The essence of the Apple development has been to design a tube in which the task of maintaining tight tolerances is relegated to the manufacturing equipment rather than to the tube itself, where it would have to be faced every time a tube is made.

Corresponding to the many possible variations of Apple color systems, there are an equivalent number of variations of Apple tube designs. Rather than attempt to consider these in general terms, it is considered wiser to describe a specific representative example, the type of tube used in a system described in the previous paper and utilizing the circuits to be described in the following paper.

The Apple color picture tube (see Fig. 1) may be generally described as an all-glass, 21-inch rectangular picture tube providing 260 square inches of useful screen area, having a diagonal deflection angle of 74 degrees, and using magnetic focusing and deflection.

More specifically, the color television display system described in the previous paper requires a picture tube that meets the following requirements:

1) The Apple tube must have a luminescent screen made up of vertical stripes of red, green, and blue phosphors that are sufficiently close together to be visually unresolvable at normal viewing distances and yet far enough apart to permit resolution of each line by the writing beam.

2) Enough triplets must be present to resolve all of the detail conveyed by the luminance component of the signal.

3) The phosphors must be so chosen that satisfactory primary colors are produced when individually excited and a satisfactory white occurs when they are excited equally.

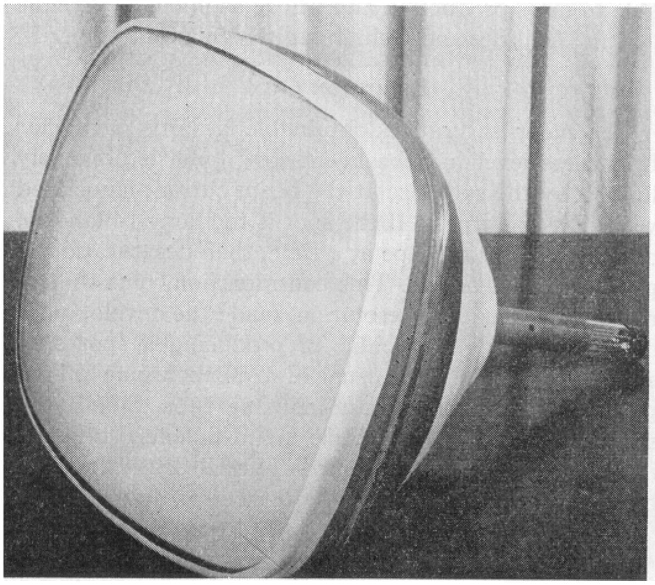

Fig. 1 – Apple tube.

4) The spacing of triplets: must be varied and the lines bent so that maximum circuit economy can be achieved by matching the triplet pitch at all parts of the raster to the normal sweep speed. This helps ensure constant index frequency all over the raster.

5) The lines must have sharp edges and constant width if accurate complimentary colors are to be produced.

6) There must be secondary emission index-producing stripes as an integral part of the screen. The tube should be aluminized to improve the efficiency at high operating voltages and to provide a low secondary emission base for the index material.

7) The tube must have two electron beams, a writing beam and a pilot beam. These beams should be made to track each other so that the variations in the horizontal component of separation at the fluorescent screen is small. The pilot beam can be a low-current, low-resolution beam.

8) The index lines must have the same period as the color triplets and the position of the index lines with respect to the triplets must be varied in a predetermined fashion to be explained later.

9) Since the Apple tube utilizes the entire 260 square inches of the tube face for visible picture area, it is necessary to extend the index lines a slight distance

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* Original manuscript received by the IRE, June 4, 1956; revised manuscript received, June 28, 1956.

† Res. Div. and Lansdale Tube Co., Philco Corp., Philadelphia, Pa.

beyond the visible raster on at least two sides to be sure to get an index signal at all points.

10) The writing beam must be small enough to resolve a single color line at a peak current of 1500 microamperes, including the effect of the spot motion during the time the peak current flows.

In addition to these special requirements arising from the system itself, it is desirable that the tube be amenable to mass production and utilize as much as possible existing facilities and techniques in its manufacture.

## ELECTRON GUN

The color saturation obtainable at any particular brightness level in a beam-indexing tube is obviously limited by the spot size at the beam current associated with that brightness. If the spot is too large to land on one primary color stripe at a time, then desaturation of primary colors occurs. This consideration, plus that of reasonable structural resolution, made the development of an electron gun capable of producing a spot substantially smaller than usual in a monochrome tube a prime necessity for a beam-indexing tube. Small spot size is obtained in the Apple beam-indexing tube by ingenious utilization of electron optical principles, and by maximum simplification of the electron optics.

The electron gun is essentially of magnetic focus, triode design. Magnetic focusing was chosen over electric focusing for two reasons. First, for any particular tube-neck diameter, magnetic focusing permits the use of a larger lens diameter than does electric focusing. The beam diameter being the same in either, less aberration occurs in the larger lens. Second, the external magnetic lens can be accurately aligned to the electron beam after the tube is assembled, reducing tube scrap from gun misalignments.

The focused spot size has, as one limitation, the size of the first crossover of the electron beam. An extensive investigation was conducted to determine the effect of electrode configuration on the formation of the first crossover. Equipotential plots were made of many configurations of elements using a resistor network to simulate, on a greatly enlarged scale, the fields that would exist between the electrodes involved. Ray traces made, utilizing these field plots, *indicated the diameter and current density variation of the crossover vs electrode configuration and potential.* These studies confirmed that there were no limits on crossover diameter precluding the development of a practical beam-indexing tube, but that a cathode loading higher than usual in picture tubes would be necessary to achieve this small crossover.

The required crossover diameter is secured by close cathode-to-grid spacing, small grid aperture diameter, and a thin grid aperture as shown in Fig. 2. Techniques were developed which made extremely close cathode-to-grid spacings possible by using a spacer ceramic which is lapped top and bottom to a specified height. The cathode-support ceramic is also lapped flat on one side, and the dimension from this surface to the top of the uncoated cathode is closely controlled. Cathode-spray thickness is also closely controlled.

The writing-grid aperture is 0.020 inch diameter, and the beam has a bogie cutoff of 150 volts. The pilot-beam aperture is 0.014 inch diameter, and produces a bogie beam cutoff of about 50 volts. The grid aperture is made electrically thin by countersinking the hole so as to leave the cylindrical portion only 0.001 inch thick.

This combination, then, of small, countersunk grid aperture and close cathode-to-grid spacing, is primarily responsible for the small diameter first crossover, which is imaged on the screen by the simple electron optics described above and results in greatly reduced spot size.

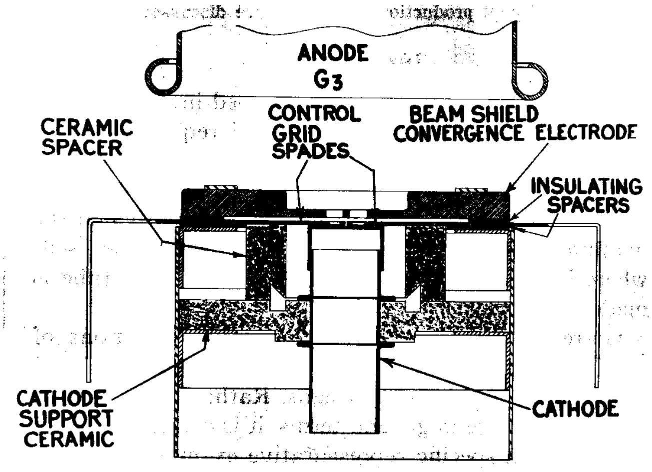

Fig. 2 – Schematic line drawing showing gun details.

The second requirement is that the two beams track each other. Since one beam is used to tell where the other beam is, the relative position of the beams must be known at all times. When this positional relationship of the two beams follows a predictable law throughout scanning, the beams are said to track. In order that this tracking relationship be independent of manufacturing variations in deflection yokes, the two beams must traverse the same portion of the deflection field at the same time. For the yoke designed for use with this tube, the optimum situation is for the two beams to originate as closely together as possible and cross each other at the center of deflection.

The two beams are formed close together by using a single cathode and two separate, coplanar control grids, each with its aperture close to the end of the piece, the ends being separated by 0.002 inch. The center-to-center separation of the two beams at the grid plane is only 0.029 inch.

Convergence of the two beams so as to cause them to cross at the center of deflection is obtained by a field lens type of convergence electrode. This lens slightly bends the two beams toward each other without any appreciable focusing effect. The convergence electrode is actually part of the beam shield whose function will now be described.

The third special requirement of this beam-indexing tube arises from the need for preventing the control voltage of one beam from affecting the intensity or position of the other beam.

Without shielding, a signal applied to the control grid of one beam was found to produce both deflection and intensity modulation of the other beam. However, a simple shield *between* the two beams in the region just above the grid apertures effectively eliminates beam *crosstalk* as a limitation of the functioning of the system.

The beam shield takes the form of a thin, flat disc having two small holes with a bridge of metal between them. This beam shield is *not* a conventional accelerating electrode, and every attempt has been made *not* to have it perform any accelerating function. If the beam shield is operated at such a potential as to accelerate the electron beam, it obviously becomes an electron lens of very small diameter. The beam would fill a substantial portion of this lens with resulting aberration.

Reduction of lens action is accomplished by operating the beam shield at its average free-space potential and by keeping it thin. By field plots of the equipotentials in the region above the control grids, it was found that the equipotentials in this region are relatively flat and so are not appreciably distorted by a thin disc such as the beam shield. When operated at 600 volts the beam shield is, at worst, a very weak lens and produces only minor aberrations.

## LUMINESCENT SCREEN

The luminescent screen of the Apple tube consists of a repeating array of red, blue, and green vertical stripes. The stripes are not contiguous but have 50 per cent duty factor; that is, the spaces between the lines are as wide as the phosphor lines themselves. The spaces between the lines are filled in with a guard band made of a dark-colored, nonluminescent material. The presence of this band insures accurate line width, improves color saturation, and enhances contrast under normal ambient light by reducing the reflectivity of the screen.

Correct white balance is built into the screen of the Apple tube by adjusting the relative efficiencies of the blue and green phosphors by the addition of varying amounts of nonactivated material so that scanning of the screen with a constant, unmodulated beam produces white.

The phosphor array is not quite the simple structure of repeated lines described above. The triplet pitch, as mentioned above is varied to match the normal sweep speed as shown in Fig. 3. Another example of matching the screen geometry to the electron optics is the progressive curving of the phosphor lines from center to edge. This is much exaggerated in the drawing of the figure. The slight pincushioning corrects for the small amount of corner twist in the relative positions of the two beams caused by certain field parameters in the deflection yoke.

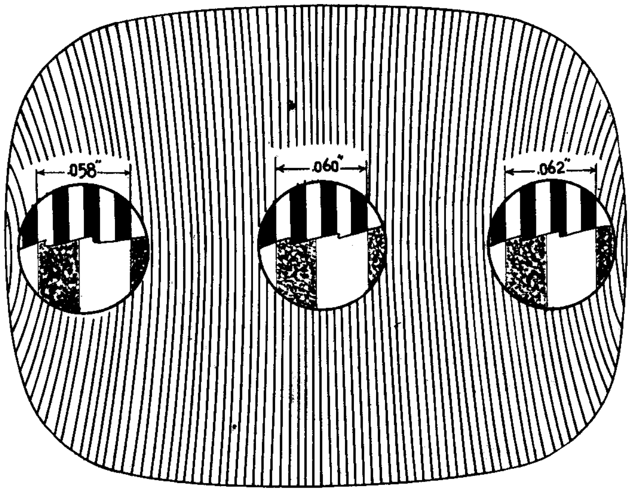

Fig. 3 – Line drawing showing details of screen structure.

The guard bands and phosphor lines are placed on the inside of the tube face by a photoresist technique using dichromate sensitized polyvinyl alcohol.

In order to cancel out any variations in the glassware of the tubes and thus increase possible glassware tolerances, the array of lines is placed on the face of the tube by a light projection system, schematically diagrammed in Fig. 4, in which the optical paths are made as nearly like the electron paths as possible. Thus, the projection lens has its optical center at the electron center-of-deflection. In order to make the exposure, the bulb is

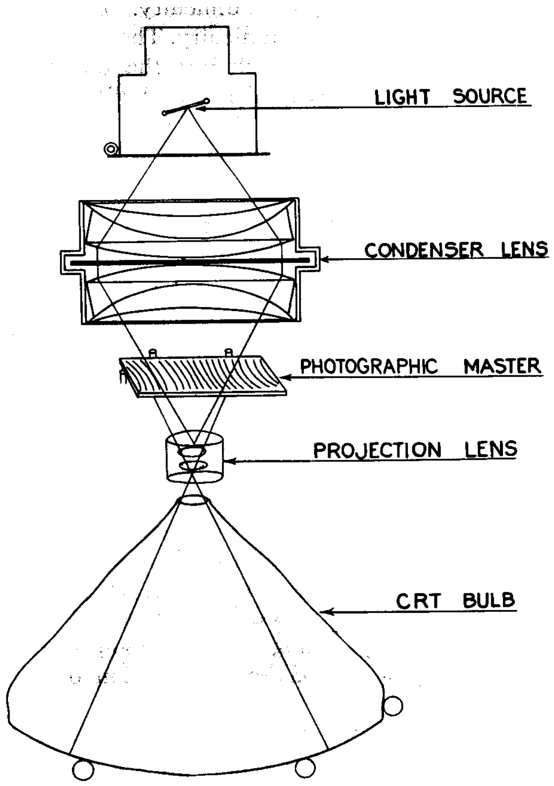

Fig. 4 – Schematic line drawing of projection system.

open at a point where a flared neck with a flare diameter of about 2½ inches may be sealed to the funnel.

The exposure equipment consists of:

1) a high pressure mercury-are light source,
2) a wide aperture condensing lens,
3) a wide angle projection lens,
4) a kinematic mounting for positioning the bulb, and
5) a precision photographic line master.

The light source is conventional.

While of special design, both the condensing lenses and projection lenses were designed and produced using well-known techniques.

The kinematic mounting device, which permits simple, precise relocation of the bulb in the projector, uses six fixed, hardened steel balls. Three of them are in contact with the face of the bulb; two are in contact with one long side of the panel, and one with one short side. Relocation with 180° rotation is avoided by observing the location of the anode contact button.

The precision with which the phosphor lines can be placed on the tube with respect to each other depends upon the stability of the projecting equipment, accurate bulb-repositioning, and the precision of the line masters. Once the proper line masters have been prepared, however, precise reproductions of the tube luminescent screens are achieved without difficulty. The precise screens are achieved without difficulty. The precise relative position of the lines is built into the glass photographic masters and thus need not, be built into each tube.

A complete discussion of the preparation of the photographic line masters would require too much time to be covered in detail here. It has entailed the design and construction of unique equipment and the development of a number of unconventional techniques. With this equipment precision linear rulings on glass or metal are converted into sets of properly distorted photographic masters, one each for red, blue, green, black, and index line deposition.

During exposure from the inside or gun side of the face plate, hardening of the resist occurs from the surface down toward the glass as exposure proceeds. If the phosphor and photoresist were mixed, an absolutely uniform layer would have to be deposited; otherwise, heavy sections would be under-exposed and not affixed to the glass, or if the exposure were long enough to ensure complete adherence of all desired areas to the glass, the phosphor particles acting as a dispersing medium, would reduce the precision and delineation of detail possible in the line pattern.

These difficulties are eliminated by first coating the bulb face plate with a film of clear photoresist which is then exposed. The exposed photoresist film is coated with a phosphor slurry, dried, and washed off. The unexposed areas of resist wash off readily, carrying phosphor from these sections with them. The exposed areas remain, holding a uniform layer of phosphor which adheres to the exposed resist lines.

The dark guard bands are applied first using the above described process but substituting a dark, non-cathodo-luminescent material for the phosphor. The red, blue, and green lines are then applied, one color at a time, using the appropriate photographic masters, and completely filling the spaces between the dark guard bands.

## INDEX STRUCTURE

The final unique feature of the beam-indexing color tube is the index structure which provides the required continuous monitoring signal. This signal is generated by the difference in secondary emission between an array of magnesium oxide stripes applied to the gun side of the aluminized screen and the bare aluminum between these stripes as shown in Fig. 5. There are two contact buttons on one side of the tube envelope, and one of these is connected to the screen aluminum coating, making it possible to maintain the screen potential at approximately 27 kilovolts.

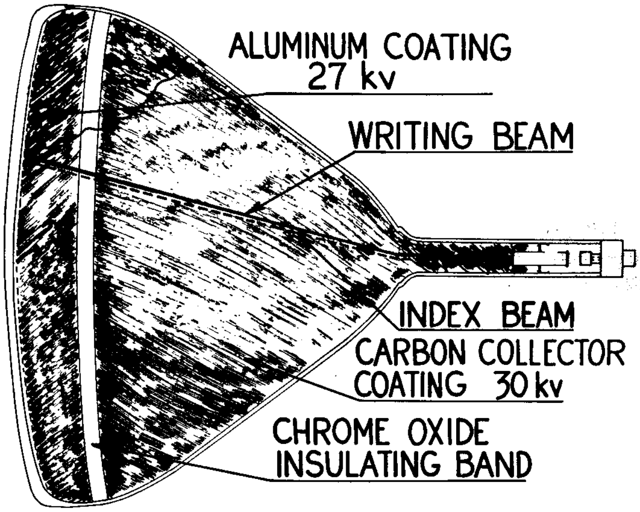

Fig. 5 – Cross section of Apple tube.

The second contact button connects to the bulb coating which is maintained at 30 kilovolts. The 3 kilovolt differential between screen and bulb coating results in collection of the secondary electrons from the screen by the bulb coating.

The screen is aluminized in conventional fashion. An organic lacquer film is then applied by a simple flow-on technique to the gun side of the aluminum film. The lacquer strengthens and protects the aluminum during the application of the magnesium oxide stripes. The magnesium oxide stripes are applied to the lacquered aluminum in exactly the same way the phosphor lines were applied to the glass, except that a different photographic master is used.

There is one magnesium oxide stripe per triplet. The index stripes are on a 40 per cent duty factor, that is, 40 per cent of the triplet width is magnesium oxide, 60 per cent bare aluminum. This has been found to give the maximum fundamental component index yield. The distortions built into the index lines, while related to the distortions built into the phosphor lines, contain a corrective component, the controlled displacement of the index stripes, to compensate for index transit-time variations and tracking variations. Transit time varies enough to produce a phase shift of over 90º at side-band frequency between the center and edge of the screen. Making the transit time uniform is more difficult and expensive than moving the index structure laterally enough to compensate for it.

An interesting feature of the testing of the beam-indexing tube is the examination of the index structure. This may be done in detail by simply using the tube as though it were a monoscope and displaying the secondary emission pattern of the screen and index structure on a monitor tube.

## PILOT PRODUCTION AND LIFE TEST

Several years of development work and many months of pilot production activity on the Apple tube have demonstrated its reproducibility in manufacture. Equipment requirements, other than those required for the screening operation, are only those required to manufacture monochrome tubes.

Extensive, long-range life tests have failed to show any signs whatsoever of index-deterioration with either shelf life or operating lifetime up to 10,000 hours. In fact, *no* measurable changes in index yield for the whole screen or any part of it, have been noticed on any of several hundred life-test tubes.

Cathode emission problems at present loadings are not substantially different from monochrome tubes, and are believed to be less troublesome than might be encountered in tubes having more internal hardware, or multiple guns.

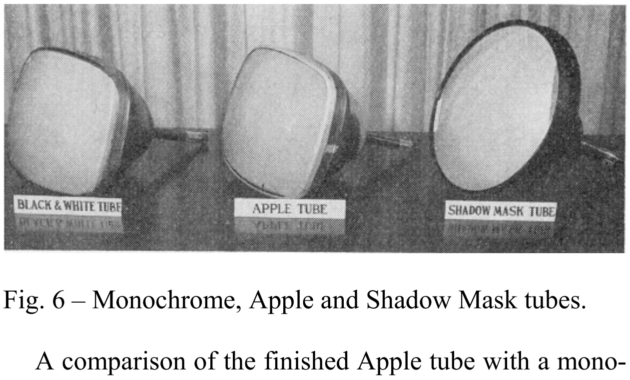

Fig. 6 – Monochrome, Apple and Shadow Mask tubes.

A comparison of the finished Apple tube with a monochrome tube, as in Fig. 6, shows the same size envelope for the same size picture. Compared to the other color tubes, the Apple tube presents the largest picture size in proportion to the envelope size.

No metal sealing flanges are present, and no new techniques or equipment for making large panel funnel seals are required by the tube manufacturer.

The electron gun, shown in Fig. 7, is more like a monochrome gun that it is like any multiple beam gun used in other types of color reproducing tubes.

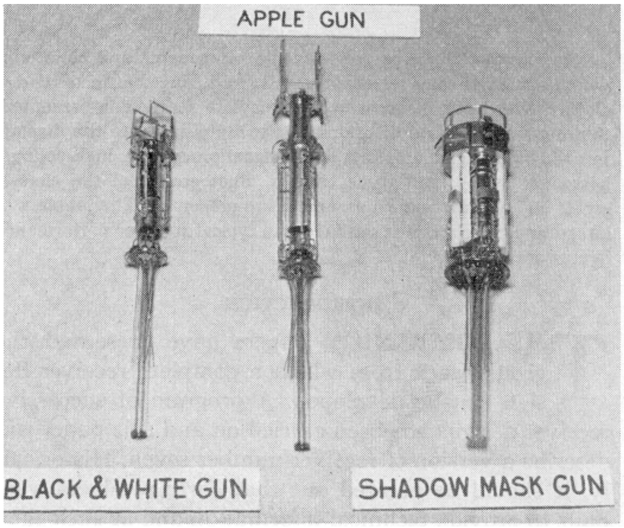

Fig. 7 – Monochrome, Apple and Shadow Mask Guns

## Conclusion

In conclusion, the beam-indexing color picture tube is believed capable of producing high-quality mono-chrome and full-color pictures. Resolution and bright-ness are outstanding.

In the opinion of the authors the tube permits potentially lower-cost manufacture than other types of color tubes.

Its manufacturability and life potentiality have been demonstrated to be satisfactory.

## Acknowledgement

A major development work such as the Apple tube project requires the assistance and cooperation of a substantial number of persons over an extended period of time, and thanks and acknowledgement are due to many who cannot specifically be mentioned by name. Specific mention can be made only of a few whose contributions were unusually outstanding and who have been identified with this project over a considerable period of time. Early original suggestions came from C. Bocciarelli, A. Rittmann, and J. Tiley of the Philco Research Department. P. D. Payne and G. R. Spencer of the Philco Tube Development laboratory made many suggestions embodied in the present tube design or processing. H. R. Colgate, in charge of the pilot-plant engineering group of the Lansdale Tube Company, was instrumental in reducing to production practice many new techniques.