Milestones in color-picture-tube development

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Frequently a company, however heterogeneous its output, becomes identified in the mind of the public with a single, best-known product. The RCA Lancaster plant's life-span has encompassed many developments of high interest to scientists, engineers, the military services, and ordinary laymen. But of all the Lancaster products, the public is most aware of television picture tubes, and, in particular, color tubes. The 19 years during which Lancaster engineers have been engaged in developing and producing color tubes has been an eventful period.

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received the BS in Physics from Providence College, and in June, 1968, Mr. Seelen received an Honorary Doctor of Business Administration degree from it. Mr. Seelen was appointed Division Vice President and General Manager, Television Picture Tube Division, of Electronic Components on August 20, 1965. Previously, he had been General Manager of the division since July 20, 1965. Mr. Seelen joined RCA in 1930 as a tube design engineer at the Harrison, New Jersey, plant. Subsequently he became Manager of the Tube Development Shop. In 1942, he organized and set up the Engineering organization and laboratories at the new Lancaster plant. In 1943, with the transfer of all non-receiving tube engineering to Lancaster, he assumed charge of Engineering Services. Seven years later, he was appointed Manager of all Laboratory Engineering at Lancaster. In 1954, Mr. Seelen became Manager of the Color Kinescope Operations Department and later returned to Harrison as Manager, Kinescope Operations. In 1963, he was appointed Manager, Television Pictube Tube Operations Department of the RCA Television Picture Tube Division, until his promotion to General Manager of the division. He is a Fellow of the IEEE and a Registered Professional Engineer in the State of New Jersey. He is a member of the Association for the Advancement of Arts and Sciencies, as well as Sigma Pi Sigma, honorary engineering fraternity. In 1955, he received the RCA Victor Award of Merit, the company's highest tribute.

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FROM THE BEGINNING, effort has been applied principally to the shadow-mask type, which appeared most suitable for development of the several forms of color tubes investigated by the RCA Laboratories. We are often asked, today, why RCA has adhered steadfastly over the years to this tube. The answer has good technical and commercial foundations: no other type has shown so desirable a combination of good performance characteristics and mass-production suitability, brought about by a long series of engineering developments. Admittedly, the three-beam shadow-mask system is less efficient than other systems as regards light output, and it has convergence complexities. But its advantages are dominant: high contrast and resolution, capabilities for uniform color fields and high color saturation (which is built into the tube), fine dot-screen structure, and moderate circuit requirements, considering both complexity and stability.

Pioneering work in color TV had been done by RCA prior to World War II, but the major advances in the commercial program occurred after 1945. An important milestone was passed in 1949 when field tests began and the first demonstrations of the RCA compatible system were held for the Federal Communications Commission. For this early work, the receivers used a separate picture tube for producing each of the three primary colors, and the three pictures were combined optically.

The next big step, then, was to provide a single, directly viewed tri-color tube. Of prime importance at this time was the fabrication of a group of such tubes to aid continued development of the RCA color TV system as a whole, and to permit additional demonstrations of the system at various stages beginning in the Spring of 1950. Ultimately, the system developed by RCA served as the "backbone" of the National Television Systems Committee recommendations, which were finally adopted by the F.C.C. late in 1953. RCA thus became the major contributor to formulation of the present national standards for color TV transmission.

Early color tubes

In addition to furnishing tubes for the RCA color program, it was, of course, an important part of Lancaster's assignment to develop the color-tube design, with a view to eventual mass production. The approach followed during this early period beginning in 1949 was to explore the potentials of the flat-screen, flat-mask system. Because accurate positioning of mask apertures with respect to the phosphor-screen dots (*register*) is extremely important, great emphasis was placed on mounting arrangements for the thin, rather flexible, metal mask. In this connection it was felt that tensioning the mask in a frame would provide greatest accuracy and stability of aperture position. As a correlative advantage, a flat screen opened up various possibilities for high-speed phosphor application: initially, silk-screening; later, letter-press or offset methods. These approaches to fabrication of mask assembly and screen required that all mask-aperture arrays be similar, and all phosphor-dot arrays be alike, within the narrow tolerances permitted by the shadow-mask system's geometry. In other words, there was a need for "interchangeability"; any mask should "fit" any screen. Another advantage of using the flat mask-screen assembly was the feasibility of adjusting relative positions of these parts for best register, as a final step before insertion into the bulbs. Many acceptable tubes of the flat mask-screen type were made. The 15GP22 was put in production in 1953, and a larger 19-inch tube of the same type was developed.

Curved screen tubes

Meanwhile, various curved-screen, curved-mask proposals had been considered. It was fully realized that a phosphor screen on the face of the bulb would be desirable because of better appearance, a larger picture in the same size bulb, and several other factors; but it was also realized that interchangeability might be difficult to attain if curved masks and screens were used. Furthermore, an interchangeable system seemed more suitable for mass production; non-interchangeability would require that each mask be mated to a particular screen, through all of the many processing steps. In addition, a problem would arise if the curved mask did not remain sufficiently stable through the heat treatments to which a vacuum tube must be subjected during fabrication.

In the fall of 1953, another tube manufacturer announced and demonstrated a tube of the curved-mask, curved-screen type. Although this tube evidenced register problems, it gave some indication that a curved mask might be reasonably stable through tube processing. RCA decided to investigate this type more thoroughly.

Earlier work had been done in the RCA Laboratories on a photographic method for depositing phosphor dots, a method well suited for screen application to a curved surface. With this background, the Lancaster program for design and construction of curved-screen color tubes was initiated late in 1953.

Among the first of these tubes were both round and rectangular samples. The round tubes used 19-inch-diameter bulbs that had a final closure of welded metal flanges presealed to the face-panel and the funnel. For the all-glass rectangular tubes, standard 21-inch, 90-degree bulbs were cut near the panel seal, and, after screen deposition and mask mounting, were resealed with a low-temperature glass frit.

These first tests were so encouraging that, within the next few months, an intensive developmental effort was being placed on curved-mask tubes. A 21-inch size was selected because of the popularity of this size in black-and-white picture tubes; a round shape was chosen for reasons of stability of bulb and mask assembly, and a metal envelope was used for flexibility in design. From this development evolved the 21AXP22, which went into production in the fall of 1954. This tube incorporated many changes in addition to the curvature of mask and screen. It not only provided a larger screen (260 square inches instead of 88-½-square-inch size of the 15GP22) but did so at a slightly decreased overall length by widening the deflection angle from 45 to 70 degrees.

Photographic application of the three phosphors to the curved face plate involved development of processing techniques for production use, as well as design and development of a special equipment called a "lighthouse". The purpose of this equipment is to provide exposure of the photosensitive phosphor layers in arrays of "dots" properly located so that they are bombarded by the respective electron beams when the tube is completed and in operation. An innovation, called a "radial correction lens", was made in the lighthouse to provide a correction by optical simulation of the electron paths. This compensation is needed because of the manner in which the deflection field acts on an electron beam, effectively changing its "source" position with increasing deflection angle.

The photographic method of phosphor deposition required development of a mask-frame assembly which could be removed from its normal position within the front end of the tube or "top-cap" and accurately replaced several times. Stability of the curved mask itself was ensured by mounting on a rigid frame; repeated, precise positioning of the mask-frame assembly in the top-cap was attained by special leaf-springs attached to the frame which engaged studs on the cap wall.

In addition, a new triple-beam gun structure, which had originally been developed for the flat-screen tubes, was introduced in the 21AXP22. This gun included magnetic pole pieces for convergence control of individual beams. In this assembly, the three guns were tilted slightly toward the axis to provide static convergence at the screen center; dynamic fields, in synchronism with the scanning frequencies, could then be applied to the pole pieces to provide the change in convergence angle needed as the beams were deflected. This development permitted accurate convergence to be obtained even at the much wider deflection angle.

The glass tube

During and following this period, both round and rectangular glass bulbs were investigated to determine whether glass was potentially desirable for either technical or commercial reasons, and to assess the problems connected with a rectangular shape. Some of the early glass bulbs using metal flanges have already been mentioned. A major improvement relating to glass bulbs occurred with the introduction of a special frit glass developed by Corning Glass Works which devitrifies, during sealing of the "top-cap" to the funnel, at a temperature low enough not to harm the phosphor or internal parts.

This development was followed by the introduction, in 1957, of the first color tube in an all-glass bulb, designated type 21CYP22. For screening this tube, a "degrouping correction lens" was introduced. This lens has an asymmetric contour superimposed on the radial correction contour to compensate for beam degrouping incidental to dynamic convergence. This latter innovation permitted enlargement of the mask apertures at the center, and increased transmission by about 40%. It also permitted a graduated tapering of the aperture walls which effectively increased transmission about 20%.

As mask material, cold rolled steel was substituted for the expensive copper-nickel alloy previously used. The aperture walls were tapered in such a way that only "knife edges" could be struck by the beams. This modification reduced electron scattering and consequently improved contrast.

The glass bulb proved advantageous in several ways. Its insulating properties simplified tube mounting problems for the receiver designer. Its mechanical stability and uniformity of face contour provided very significant improvement in register. Moreover, an improved referencing system for the lighthouse and for the frit-sealing operation also contributed to consistently good results. The mask-mounting method originally developed for the 21AXP22 was well adapted to provide the accuracy needed for this system. All of these features which provided stability and accuracy contributed significantly to improved uniformity of both color fields and white, and to greater ease of setup in the receiver. These improvements were the keys to initial commercial success in the fabrication of shadow-mask tubes.

In late 1960, another major improvement was introduced in the tube type 21FBP22. New green and red (sulfide) phosphors, having higher efficiencies and shorter persistence, supplanted those formerly used. The advantages included an important enhancement in picture brightness (about 50%), freedom from "smear" in rapid-action scenes, and better balance between the currents required from the three guns to produce white. Thus, the all-sulfide phosphor screen permitted driving to higher white-light output without serious red halo. The improvement in current balance also simplified receiver setup, particularly the adjustment of video drive for black-and-white picture reproduction. In addition, a protective window of 61% transmission filter glass was laminated to the tube face with a clear resin to improve contrast and color saturation.

Today's tubes

The last few years have seen the development of the first RCA 90-degree rectangular tube, the 25AP22, and the proliferation of its brothers and smaller cousins. The rectangular bulb shape, and particularly the higher deflection angle, have introduced additional problems requiring a higher degree of engineering sophistication for satisfactory solutions. Use of the rectangular bulb has required solution to problems of bulb stability and alignment, as well as development of completely new approaches to design and mounting of the mask assembly. Frame weight, replaceability, and thermal stability were among the factors which had to be reconsidered. A simple, inexpensive, lightweight assembly permitting good beam-to-screen register control has been developed for the entire tube family. The control of register and contrast has established a standard which has been or is now being emulated by our competitors.

Important advances have also been made in the art and science of lighthouse lens design, aided by use of a computer. We have been able to deposit phosphor dots to a higher degree of precision than heretofore thought possible. The increase in radial misregister brought about by the increase in deflection angle and the greater nonuniformity caused by factors of panel deformation and panel obliquity have required greater control. Also, higher beam degrouping factors brought about by the increase in deflection angle and the greater nonuniformity of these factors as a result of yoke characteristics also required higher degrees of control. Optimum designs of mask and lens contours have been developed for such control. We have indeed come a long way from the initial simple radial lens on a path of progress which has been vital to the success of wide-angle tubes.

Another innovation was the introduction of smaller neck size to permit use of smaller-diameter yokes. This change increased the efficiency of scanning needed for the larger deflection angle, and also reduced beam separation, thus minimizing misconvergence. Development of the small gun to fit the small neck required further improvements in beam formation and focus to maintain the quality performance of the larger gun used in the round tubes. Low-wattage heaters were developed to reduce thermal problems in the stem area. As a result, movement of parts because of thermal expansion has been reduced and convergence drift has been minimized. Einzel-lens guns have also been developed in the small size which permit fixed focus and thus simplify circuitry in portable receivers.

The development of high-efficiency red-emitting phosphors has been extremely important. The red sulfide phosphor was succeeded by yttrium vanadate in 1964 and by yttrium oxysulfide 2 years later. The yttrium-oxysulfide red-phosphor efficiency has made the "Unity Current Ratio" mode of operation a reality in the color picture tube. No longer must brightness be limited by red-gun "blooming". Now all guns may be uniformly driven to their resolution capability to provide maximum gun-screen efficiency and thus a brighter picture. Because of this permitted increase in current to the screen, the mask-frame thermal-compensating system called "Perma-Chrome" has become a necessity. Brightness has been gained without sacrificing resolution, purity, or white uniformity.

The success of these tube developments has literally echoed around the world. Our licensees in Japan and Western Europe have been tooling up to make similar tubes, and RCA itself has started up new tube plants in Scranton, Pa., Midland, Ontario, and Skelmersdale, England; in addition, our RCA plant in Puerto Rico is supplying gun assemblies.

Color picture devices in the future

We continue optimistic about the potential of the shadow-mask tube for further development, and we expect to exploit ideas not yet fully explored. People frequently ask, "Is the shadow-mask tube likely to be supplanted by some new device in the near future?" Any new device would have to show at least as good performance, and it would probably require novelty (such as a large, thin panel to be hung on the wall), but far more important than any physical qualities would be the potential for cost reduction. A replacement for the shadow-mask tube which would meet such criteria is not presently within our field of view; we feel, therefore, that advanced versions of the shadow-mask tube will be serving us for a number of years to come.

Gen. David Sarnoff's words at the first tri-color tube demonstration on March 29, 1950, still ring true:

> "Measured in comparison with every major development in radio and television over the past 50 years, this color tube will take its place in the annals of television as a revolutionary and epoch-making invention. When historians at the close of the 20th century evaluate the most important scientific developments, I will predict that this tube will be among the great inventions of the second half of this century."