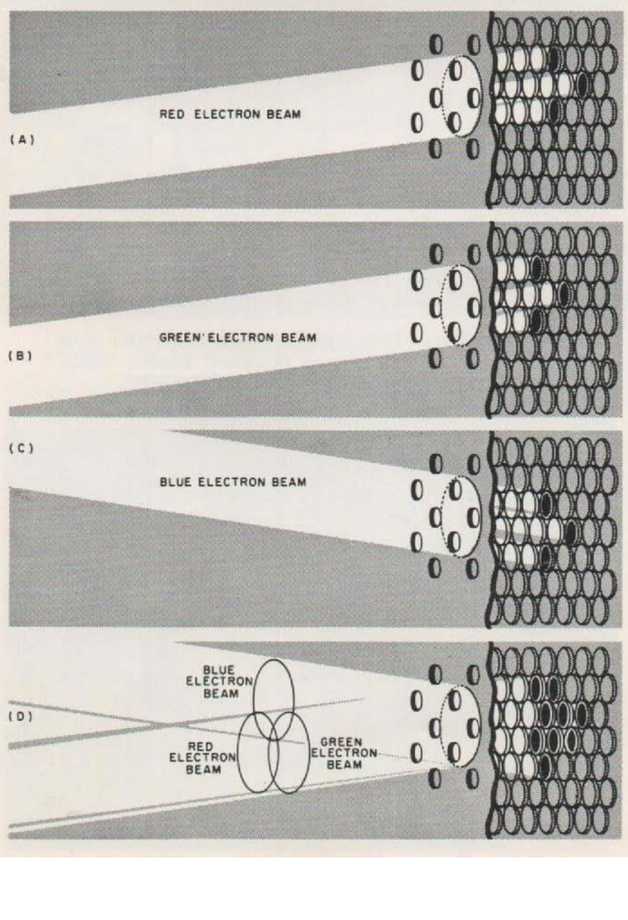
Probably the most complex device to be mass-produced for the consumer market, the color CRT requires the most exacting optical, chemical, metal-working, glass-fabrication, electronic, and assembly procedures.

MANUFACTURE OF COLOR PICTURE TUBES

By J. F. HOLAHAN / RCA Electronic Components and Devices

A COLOR-TELEVISION picture tube is an enormously complex device. Consider the problem of precisely aiming three separate electron beams at a fluorescent screen between one and two feet away. The screen is made up of nearly 1¼ million red, green, and blue color phosphor dots. The beams must pass through some 400,000 tiny holes, as small as 0.010-inch in diameter, and each beam must strike only those phosphor dots of a single color. Consider further that these three electron beams must sweep over an area of about 300 square inches, 60 times each second, and that they must maintain their relation to each other throughout. Added to all of this is the problem that the three beams can be deflected very easily even by the weak magnetic fields produced by the earth and nearby magnetized objects.

Fig. 1. The three electron beams approach the shadow mask at angles so that each beam hits its own color phosphor only.



It is obvious that some very special manufacturing techniques must be used in order to produce such a complex device, yet one that still creates accurate color pictures. This article describes the techniques used by *RCA* at its color-tube manufacturing plants at Lancaster, Pa. and Marion, Indiana.

The Color Tube

The modern color-television tube differs from a black-and-white tube in the makeup of the phosphor viewing screen, in the configuration of the electron gun, and in the presence of an additional element within the envelope, called a shadow mask. These differences are fundamentally the result of the fact that a color-picture tube is actually three complete picture tubes built within a single envelope.

Instead of a single solid layer of phosphor emitting only white light, the color-tube screen is made up of small individual dots of phosphor arranged in orderly trios. Each trio includes three dots, each of which emits a characteristic color when excited by an electron beam. Thus, the television picture may be considered to be made up of minute spots of light varying in brightness and placed very closely together so that the eye integrates them.

The primary colors used are red, blue, and green. With this system of primaries, the color tube is capable of producing a wider gamut of colors; greater, in fact, than that obtainable from either color printing or color film. (See "Colorimetry in Color Television" ELECTRONICS WORLD Dec. 1965.)

Similarly, the color-tube electron gun is really three guns combined into a single assembly. One gun creates a beam of electrons which is controlled in such a manner that it strikes only the red-light-emitting phosphor dots to paint a red picture. The beam from the second gun strikes only the blue-light-emitting phosphors and creates a blue picture. In the same way, the third gun provides the green picture information.

Between the electron gun and the phosphor screen is the heart of the color-television tube—the shadow mask. The shadow mask is a sieve-like disc containing about 400,000 holes, one hole for each phosphor-dot trio. These holes vary in diameter across the mask, according to a precise mathematical formula, from 0.010 to 0.012 inch. As shown in Fig. 1, the function of the shadow mask is to keep the three color pictures separated by shadowing two of the three arrays of phosphor dots from two of the three electron beams, while exposing the proper array to bombardment by its particular beam.

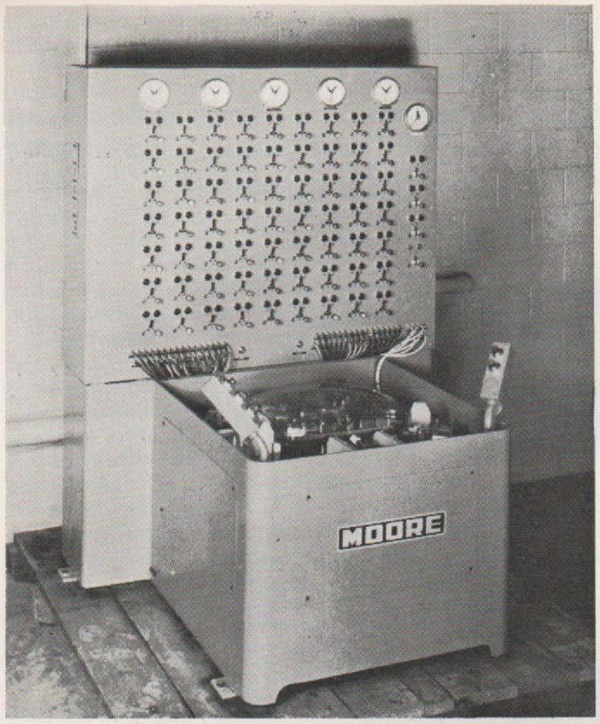


Fig. 2. Automatic gauge checks contour of CRT faceplate or panel at 125 points. Failure to meet contour is signalled by red indicator lamp on panel. One red light means reject.

Although the shadow-mask color picture tube is probably the most complex "chemelectromechanical" device ever to be mass-produced for the consumer market, it is compiling a record of reliability and long life which rivals that of its relatively uncomplicated predecessor, the black-and-white tube. How is it done? The answer lies in the almost incredible precision used in every step of color-tube manufacturing —from inspection of raw materials, creating the color tube, to packaging and shipping of the finished device.

Incoming Inspection

All parts and materials used in the manufacture of the color-television picture tube are thoroughly inspected prior to use. Individual lots are acceptance-inspected on the basis of the same statistical sampling plans used for military and government space programs. Acceptance specifications involve visual, mechanical, and dimensional standards and, in many cases, also involve laboratory tests for elemental purity as well as for exacting chemical and physical characteristics.

One of the newer pieces of inspection apparatus in use at *RCA's* Lancaster plant is shown in Fig. 2. This automatic gauge is used to measure the contour of the tube face plate or panel. The gauge checks 125 points on the face of the panel by means of small, air-regulated pressure points which have been precisely set. As the panel depresses the pressure points, red and green lights on the display board, corresponding to specific pressure-point locations, indicate whether or not the contour of the panel meets specifications. One red light is sufficient to reject the panel. Similar comparator gauges check the trueness of the panel and funnel periphery. Seal lands (the surfaces at which the panel and funnel are joined) are checked for flatness on granite plates ground and polished to a tolerance of 0.0001 inch.

Some parts and materials require even more complex inspection techniques. An example is the inspection process of nickel material used in the manufacture of the cathode, a vital component of the electron gun. At incoming inspection, an inspector removes a 2-foot section from each coil of metal, and forwards it to the laboratory for analysis. There the nickel first undergoes spectrographic analysis where concentrations of only a few hundredths of a percent of other metals present in the base nickel are determined. Since cathode performance is affected by the presence of minute quantities of several other metals in the base nickel, exact measurements are obtained through the use of a recording microphotometer. The strip is then taken to a conductometric carbon analyzer where a determination is made of the amount of carbon and sulfur present in the metal. Concentrations as low as 0.002% carbon or sulphur are readily detected.

All metals contain many microscopic inclusions of oxides, silicates, or sulfides distributed at random throughout the mass. It is often necessary to identify these inclusions to determine whether they will have an adverse effect on the life of the finished tube. By the use of an electron probe analyzer, particles as small as one-hundredth the width of a human hair can be examined and identified.

Shadow Mask

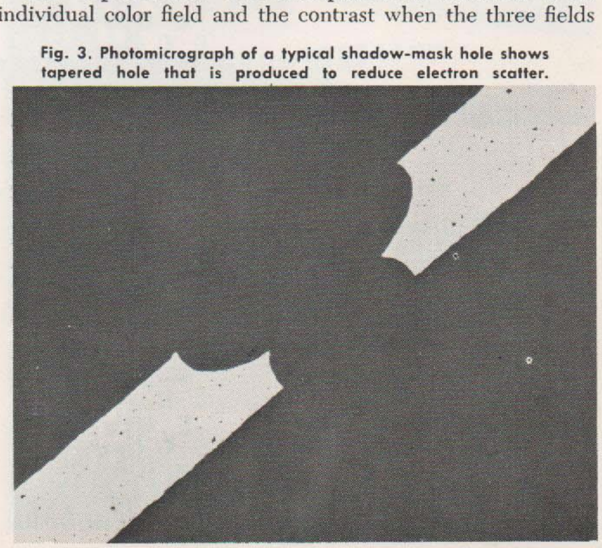
The shadow mask is manufactured by a combination of chemical, mechanical, and photographic techniques that are closely akin to photoengraving. In this process, 1000-pound coils of cold-rolled steel 0.006-inch thick (about the thickness of the cover of this magazine) and 21⅜ inches wide are first fed into a machine which chemically cleans all traces of oil, oxide, and other soil from the surface of the metal. Both sides of the strip are then coated with a thin layer of fish-glue solution which has been made light-sensitive by the addition of certain chemicals. This coating is quite similar to a photographic film in that exposure to light will produce an image. The coating applied in this machine is dried and the coated strip is recoiled on spools.

Following recoiling, the strips are fed through a manually indexed machine in which the coated strip is first sandwiched tightly between two glass sheets containing photographic patterns of about 400,000 dots. These two patterns are held in intimate contact with the coated metal by the action of vacuum, and must be perfectly aligned (from one side of the metal strip to the other) within a fraction of a thousandth of an inch. After alignment, the sensitized coating is exposed to the light emitted by two high-intensity arc lamps, and the dot pattern is reproduced on each side of the metal.

Once again the strip is recoiled and then fed into a machine where sprays of water remove the unexposed areas of coating which have remained water-soluble, then through an oven which bakes the remaining coating to a hard, chemically resistant finish. In the final processing step, the metal with its pattern of uncoated dots is fed through sprays of acid which chemically eat through the uncoated areas from both sides of the metal simultaneously to produce holes having the characteristic cross-section shown in Fig. 3.

This "tapered hole" feature improves the saturation of an individual color field and the contrast when the three fields

Fig. 3. Photomicrograph of a typical shadow-mask hole shows tapered hole that is produced to reduce electron scatter.



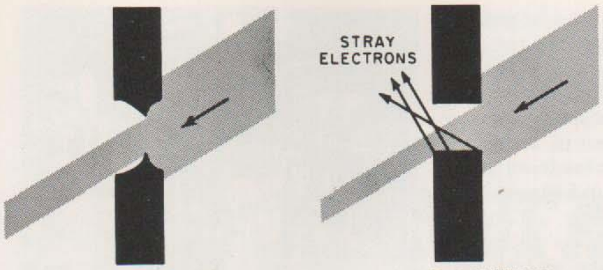


Fig. 4. Tapering the holes in a shadow mask reduces electron scatter, increases beam intensity, and achieves increased light output as well as better contrast and color saturation.

are used together to produce white. As shown in Fig. 4, tapering permits the electron beam to be transmitted through the mask without striking the side wall of the aperture. The degree of hole taper in the mask is not the same over its entire area, but maximum at the edge and gradually reduced toward the center. This gradation provides maximum taper where it is needed; that is, near the edge of the mask where the electron beam approaches at the greatest incident angle. Another advantage of the tapered holes is the fact that more of the beam is allowed to pass through the aperture, whereas the wall of the straight-sided aperture blocked upwards of 20% of the beam. Thus, tapering achieves increased light output as well as improved contrast and color saturation.

Light output is also substantially increased by grading the size of the holes over the area of the shadow mask. Holes gradually increase in diameter from the edges to the center; consequently, the central portion of the color hole feature effectively exploits the tendency of the human eye to take its impression of over-all brightness from the center of the screen

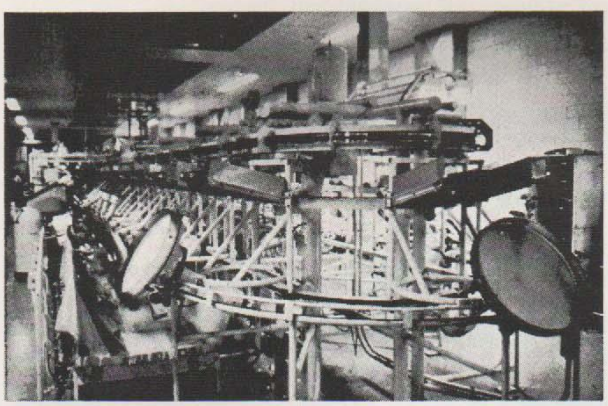
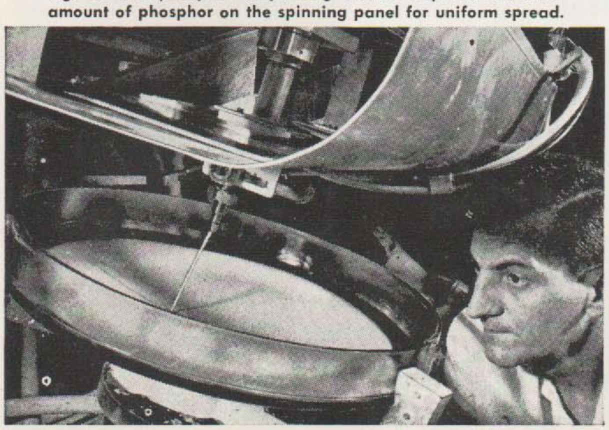


Fig. 5. Phosphor processing takes place on this semi-automatic machine. The trolley moves the CRT panels to each position.

Fig. 6. The phosphor dispensing station deposits an exact amount of phosphor on the spinning panel for uniform spread.



it is viewing. The viewer is aware not of the variation, but only of the increased brightness of the picture.

After etching and removal of the protective coating, the mask is formed into its final spherical contour, blackened, and precision welded to a rigid frame. It is then subjected to several critical inspections for size and perfection of the apertures. Each mask is checked on a light table for defects that could produce objectionable spots, streaks, or bars in the color picture. In this inspection, irregularities in the size of adjacent holes so minute as to be virtually unmeasurable can be visually detected. In addition, before forming, the masks are checked in statistically determined areas for proper hole size. The measuring instrument is a photoelectric cell device which can measure tolerance of hole size to less than 0.0001 inch. The mask is now ready for installation.

Phosphor Screening

(Editor's Note: It should be pointed out that the following discussion on phosphor screening applies to the author's company (RCA). *Other color-CRT manufacturers use different techniques for laying down the phosphors.)*

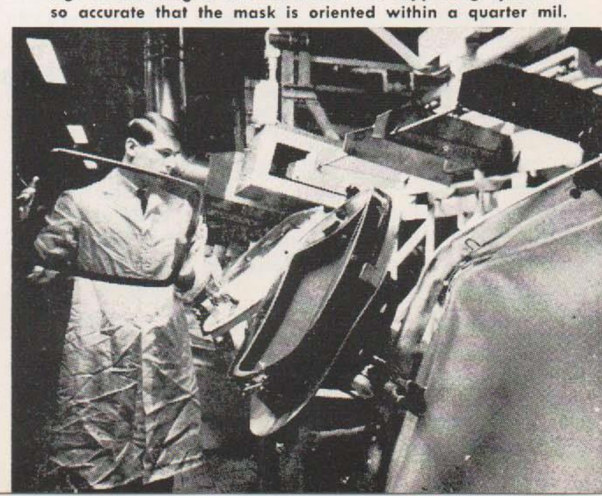
Application of the phosphor screen to the glass panel is perhaps the most critical of all manufacturing steps. Added to the usual problems of dimension control is the tendency of phosphors to behave erratically when contaminated by even trace (minute) amounts of impurities. Airborne particles of copper, for example, will make blue phosphors glow green and green phosphors glow red. As a result, screening is carried out in a very clean environment.

Each of the three dot arrays is formed in a "photo deposition" process similar to that used for the shadow mask. All processing steps are accomplished on a semi-automatic machine, such as the one shown in Fig. 5. The trolley moves the panels from position to position around the machine in an indexing manner.

At the dispensing station, shown in Fig. 6, a carefully metered amount of phosphor in the form of slurry is deposited into a spinning panel so that it spreads uniformly over the panel surface in a solid layer. At the time of dispensing, the slurry material looks much like pancake batter and contains a photosensitive additive as well as the fluorescent material. The phosphor layer is then dried at subsequent stations on the machine, and a shadow mask is installed in the panel. As shown in Fig. 7, the mask is supported by specially designed leaf springs and is readily inserted and removed. Furthermore, the supporting system is so precise that it places the mask within 0.00025 inch of the same position within the panel each time it is inserted.

The panel with its shadow mask is then placed on a device called a "lighthouse." In the lighthouse, a point source of light is properly placed with respect to the panel and mask so that the angle of approach of the light rays at the mask

Fig. 7. Installing a shadow mask. The supporting system is so accurate that the mask is oriented within a quarter mil.



aperture is the same as that which will exist for the electron beam when the tube is completed. In effect, the shadow mask acts as a "negative" in the exposing process. The areas struck by the light rays passing through the shadow mask are rendered insoluble in water by virtue of the photosensitive agent which was included in the slurry mixture.

After exposure, the panel is removed from the lighthouse, the shadow mask removed, and the panel replaced on the slurry machine for development of the first color array. Development is simply a washing operation. Those areas exposed to light are not washed away and remain on the glass; all of the water-soluble, non-exposed material is removed to leave a uniform array of phosphor dots. Final drying completes the screening of the first color field.

It is then only necessary to repeat the same process for the other two colors, each time using a different phosphor slurry, and placing the light source at a different predetermined point to represent the position of the particular electron beam activating each color.

Final Manufacturing Steps

Panels passing the screen inspection are transported by conveyor to the aluminizing operation. Here they are loaded onto cars which evaporate a 4000-angstrom layer of aluminum on the inside of each panel. The aluminum layer acts as a mirror and insures that all the light produced by the phosphors will be directed outwards toward the viewer. Because the phosphor dots are porous, direct application of aluminum would result in severe aluminum penetration of the dots and little, if any, mirror effect. Consequently, an organic buffering film is laid down to temporarily provide a mirror-like, smooth base for deposit of the aluminum layer.

Following aluminizing of the screened and filmed panel, the shadow mask is inserted and electron shields are secured to the outer rim of the shadow mask frame. These shields intercept electrons that ricochet around the outside of the mask frame and prevent them from reaching the face of the tube. The entire assembly is then baked out to remove the layer of film as well as any other organic materials.

The panel is joined to a coated funnel by means of a special sealing glass called frit. As shown in Fig. 8, the frit, made up of powdered glass mixed with the organic binder and vehicle, is dispensed on the sealing surface of the coated funnel. The funnel and panel are then loaded onto a fixture which holds the parts in accurate orientation by means of built-in locating devices. The bulb and fixture are belt-fed through a large oven in which the frit devitrifies or crystallizes to provide a vacuum-tight seal of high mechanical strength. The sealed bulb is then mated with its three-element electron gun and put through the final manufacturing steps and tests necessary to produce a finished tube.

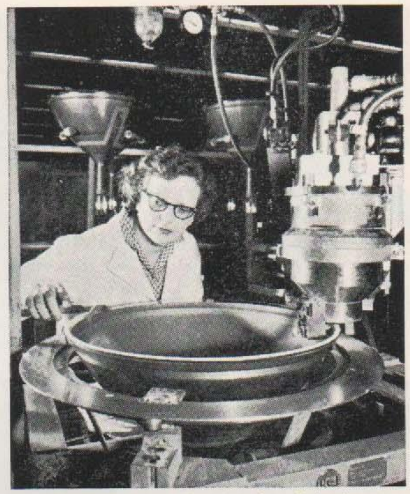


Fig. 8. The phosphor panel and shadow mask are joined to tube funnel with a soft glass called frit. Heating the junction makes permanent, strong seal.

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