Beam-index cathode-ray tubes

BY HENRI DOYEUX AND WILLIAM R. HOUSE

THE IDEA OF the beam index in color cathode-ray tubes (CRTs) has been discussed for decades. It was at the heart of Philco's Apple System – a 1950s effort to produce a high-quality, full-color picture tube at a lower cost than was possible for other color-tube types. But Apple and all of the other early development efforts stumbled over the same obstacle – the beam-index approach required faster electronic circuits than were readily available at the time. But the electronics finally caught up. In the early 1980s, Sony was able to produce the first commercial beam-index product – a video projector.

How beam-index tubes work

A color beam-index CRT is similar to a monochrome tube in all respects except for the faceplate [Fig. 1]. In particular, there is only a single electron gun for all three colors, and there is no shadow mask.

The screen is composed of red, green, and blue phosphor "triads" arranged in vertical stripes. (The different-colored stripes can be deposited with different widths to enhance a particular color or to balance a particular combination of phosphors.) These stripes are covered by a conventional aluminum layer on their inward-facing side. On this layer of aluminum, stripes of a low-remanence phosphor – the index phosphor – are photolithographically printed parallel to the stripes of color phosphor. Commonly, there is one index stripe for every two color stripes, but the detector-circuit design determines the actual choice in each case.

The beam-index tube is scanned in a conventional television mode. When the electron beam excites the index phosphor, it produces a luminous signal inside the tube. This signal is captured by a photodetector, whose electrical output allows precise tracking of the beam's position on the screen and synchronization of the multiplexed video signal [Fig. 2]. There are two ways to implement this synchronization: (1) the time at which the video signal is delivered can be varied while the beam's scan velocity is held constant, or (2) the scan velocity itself can be varied. In either case, the R, G, and B signals are sent to the beam control grid sequentially and at the exact instant that will cause a beam of the proper intensity to strike the appropriate color-phosphor stripe at just the right time.

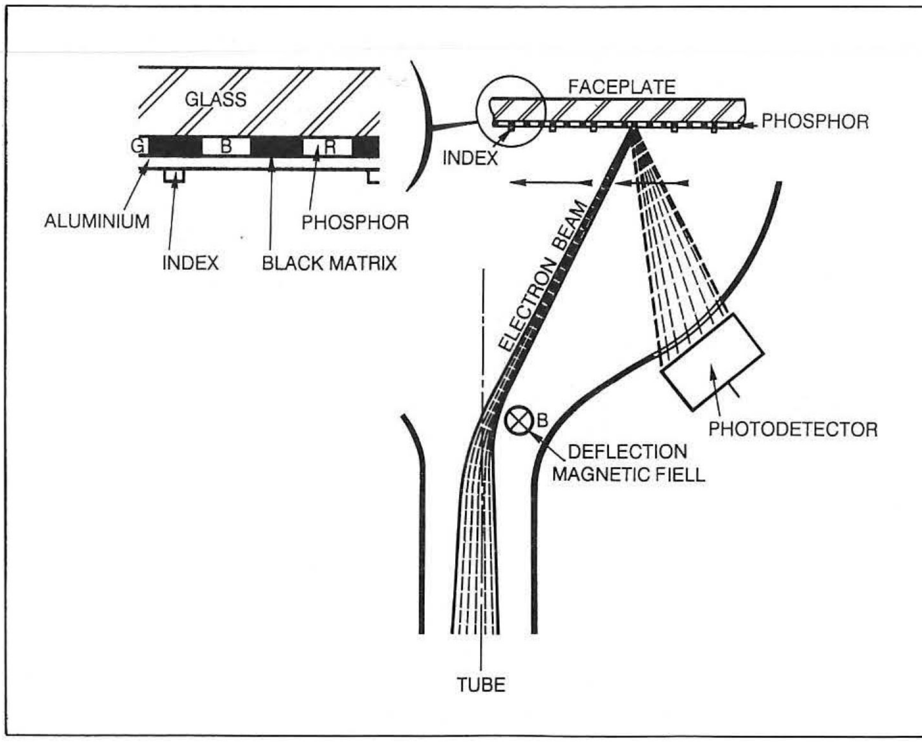

Fig. 1: Except for the faceplate, the construction of a color beam-index CRT is similar to that of a monochrome tube. In particular, there is no shadow mask.

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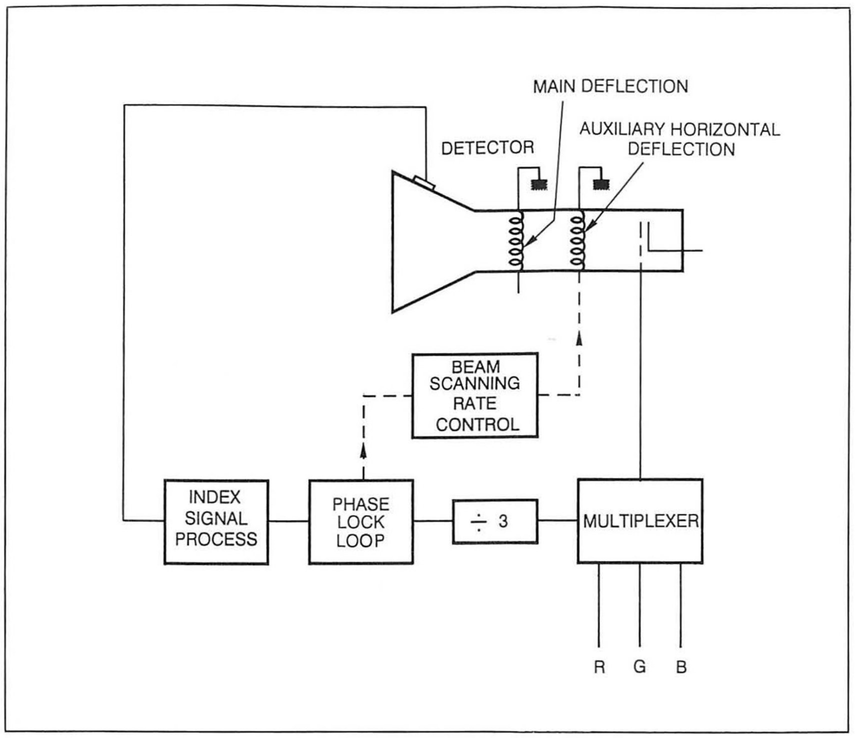
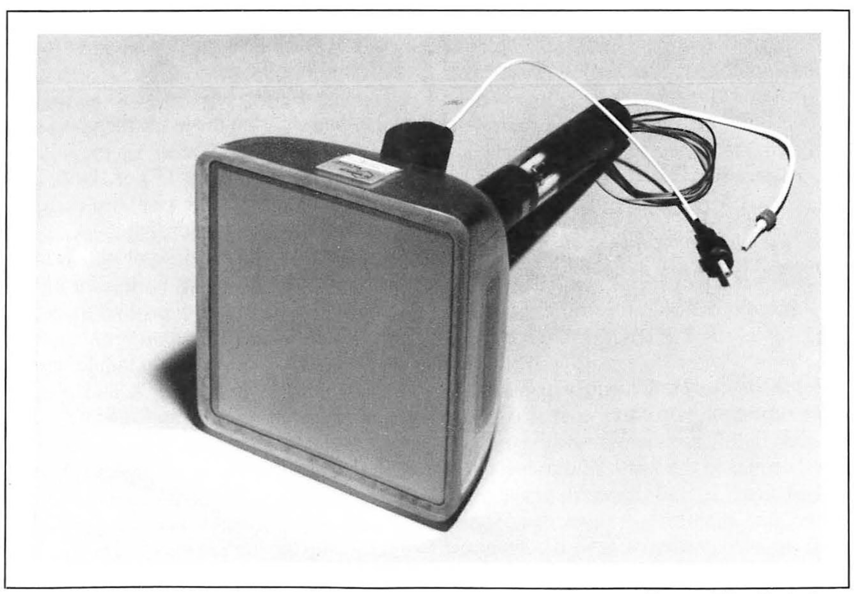


Fig. 2: The beam-index tube is scanned like a conventional television tube. When the electron beam excites the index phosphor, it produces a luminous signal inside the tube. This signal is captured by a photodetector, whose electrical output allows precise tracking of the beam's position on the screen and synchronization of the multiplexed video signal. The R, G, and B signals are sent to the beam control grid sequentially and at the exact instant that will cause a beam of the proper intensity to strike the appropriate color-phosphor stripe at just the right time.



Thomson Tubes Electroniques

Fig. 3: Beam-index color cathode-ray tubes are currently being manufactured for aircraft cockpit displays. This one is Thomson's model TH 8139 with a 6 × 6 in. screen.

Why bother?

Beam-index systems offer several advantages over other approaches to making color tubes:

- *The relative ease* with which special custom formats can be developed.
- *Increased brightness,* since most of the beam energy produces light. In conventional tubes, more than 80% of the beam energy is absorbed by the shadow mask.
- *Higher resolution* than shadow-mask tubes at equal brightness.
- *No color shift* from the expansion of a shadow mask as it heats up.
- *The feasibility* of making miniature color CRTs.
- *Minimal perturbations* from external magnetic fields and mechanical vibrations.

Applications

Beam-index tubes are well suited to applications where brightness and ruggedness are of high value – notably head-down displays (HDDs) in combat aircraft cockpits. Because their basic construction is so similar to that of monochrome tubes, little prevents them from being made in the same physical format as virtually any monochrome tube. This makes them particularly well suited to retrofit programs in military aircraft where a monochrome display of a specific format must be replaced by a rugged color display [Fig. 3]. For a civilian application, Matsushita has even produced a 77-mm-thick, flat beam-index tube that has the screen almost parallel to the electron gun. The tube was designed to fit in airplane seatbacks for individual in-flight viewing.

Competition

Despite the existence of penetration screens and other color-CRT technologies, it is against shadow-mask tubes that beam-index CRTs are most often compared. And the shadow-mask CRT is undoubtedly the most widely used technology for airborne color displays. It is found, for example, in the cockpits of commercial aircraft such as the Boeing 757 and the Airbus 320.

Shadow-mask technology has the advantage of being well known – each year it is incorporated in millions of CRTs for computer monitors and domestic television. Unfortunately, there are many applications where it is not satisfactory. The color-selection mask makes the tube relatively sensitive to mechanical vibrations, and the mask also absorbs more than 80% of the beam energy. As the tube's output luminance is increased, the mask heats up.

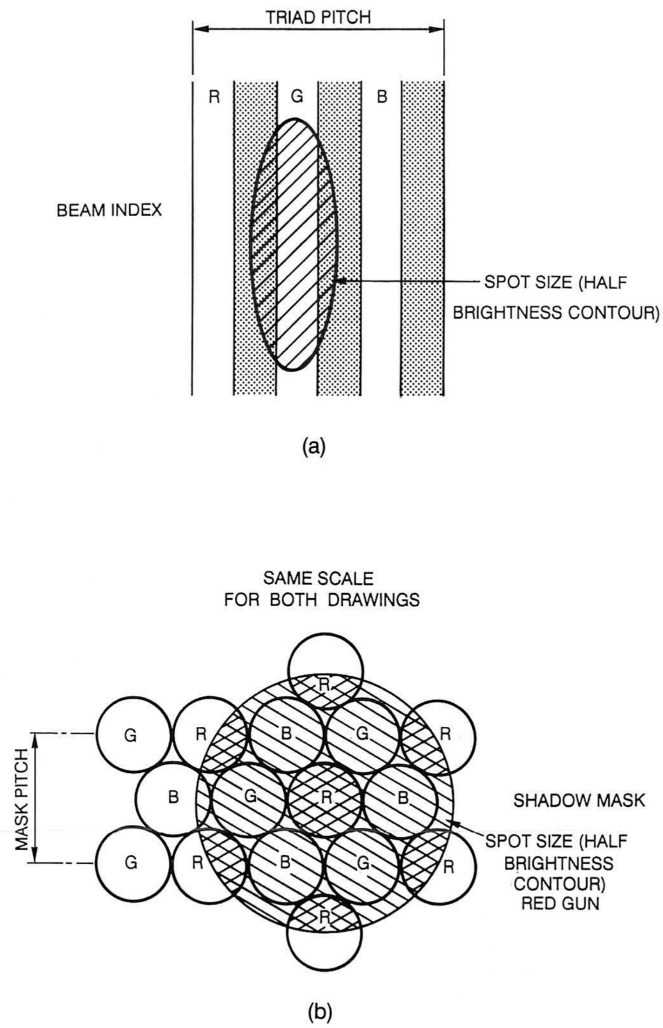


***Fig. 4:** The triad pitch in a typical beam-index tube (a) is often twice the triad spacing in an equivalent shadow-mask tube (b). But the spot size in a shadow-mask tube is often more than two triads. As a result, the useful resolutions provided by the two technologies are equivalent.*

If it becomes hot enough, the mask deforms with serious consequences for color selection and purity.

The resolution debate

Beam-index tubes are brighter in small formats than their shadow-mask competitors, but it is often said that this extra brightness is offset by reduced resolution. This is an error, but it is an easy one to make. Let's see why.

For satisfactory color purity in beam-index tubes, the horizontal spot size (measured at half-luminance) must be approximately equal to the width of one color phosphor stripe, and the width of the pixel is therefore the width of this stripe [Fig. 4(a)]. In a shadow-mask tube the situation is quite different. Color purity is guaranteed by the mask, but the interaction between the phosphor dot pattern and the scan raster can produce a moiré interference pattern. To avoid this, the electron beam must cover between two and three triads. As a result, the color pixel's diameter is not the triad pitch, as might be expected, but more than twice that value [Fig. 4(b)].

A beam-index tube, for example, with a 6 × 6 in. faceplate and a triad pitch of 0.4 cm can produce a luminance of 1000 fL. The spot half-width is about 100 μm. A shadow-mask tube having a 6-in.-sq. faceplate can produce about 500 fL, with a mask pitch of 0.2 mm. The pitches—triad pitch and mask pitch—are very different, but the useful resolutions are virtually identical. For screen sizes similar to the one in this example, the beam-index tube can be about twice as bright as the shadow-mask tube for identical resolutions.

Brightness vs. resolution

For maximum brightness and resolution, the phosphor stripe would have to be excited at maximum beam current throughout its full width, but no further. To leave the beam on for as long as possible over the color stripe without losing color purity, the rise time must be as short as possible. In addition, video-signal commutation must be sufficiently fast and sufficiently well synchronized with the beam's displacement. (In our 6-in.-sq. example, video commutation is less than 5 nsec and synchronization precision is about 5 nsec.) To increase brightness, the electron spot is lengthened vertically to a maximum height of about one triad pitch, which maintains a vertical resolution roughly equal to the horizontal resolution.

The beam-index tube presents a crisper image than the shadow-mask tube because each pixel is represented with a modulation transfer function (MTF) of 100%. This is the result of each pixel not exceeding the width of one color stripe.

The horizontal electron-spot dimension must remain as narrow as each color phosphor stripe if color purity is to be maintained. This limits the beam current, and thus the maximum attainable luminance. Reducing the pitch in our 6 × 6 in. example tube, for instance, from 0.4 to 0.3 mm reduces the maximum luminance from 1000 to about 500 fL if gun performance is unchanged.

Improving gun performance is the key to improving resolution and brightness, and this is the main goal of present development efforts.

To make spot sizes smaller, it is necessary to improve cathode emissivity. Not only must the current be high, but it must be emitted from the smallest possible area of the cathode so that the crossover area remains as small as possible. Dispenser cathodes, developed by Thomson Tubes for spaceborne microwave transmitting tubes, do just that. These cathodes are made from a substrate of porous tungsten that is impregnated with barium. It provides an eightfold increase in current density compared to the usual barium-oxide cathodes, and it does so with an even longer life.

Brightness vs. screen size

For a given pixel pitch and degree of color purity—that is, for a particular spot size and the maximum possible current at this spot size—the brightness is almost inversely proportional to the scanned surface because the beam power density is inversely proportional to screen area [Fig. 5]. It follows from this that, at the present state of the art and for the resolutions normally required, beam-index tubes offer overall performance that is superior to that of shadow-mask tubes for sizes up to 5 in. in diagonal. Above 5 in., the choice depends on whether brightness or resolution is the deciding criterion—unless a demanding bulb format makes the beam-index tube the only possible solution.

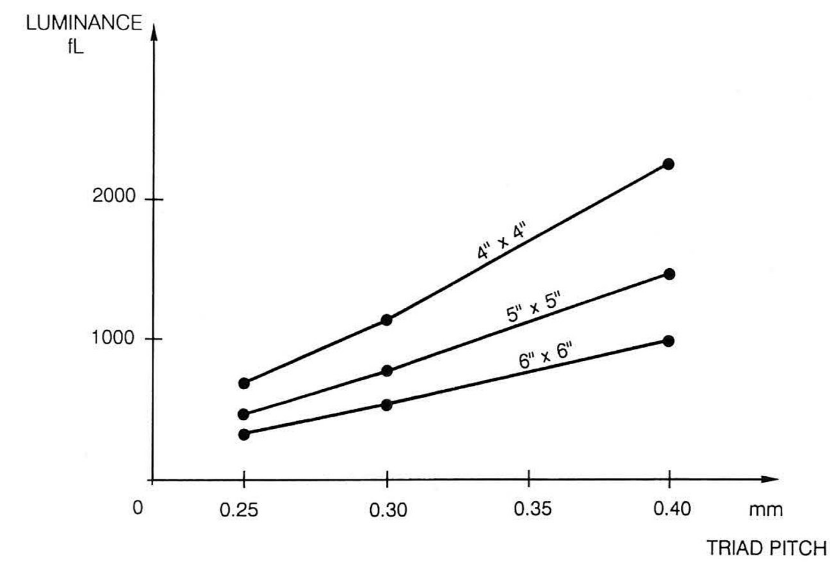


***Fig. 5:** For a given pixel pitch and degree of color purity, the brightness is almost inversely proportional to the scanned surface because the beam power density is inversely proportional to screen area.*

How black is black?

Despite its impressive strengths, the basic operating principle of beam-index tubes establishes a significant limitation. To maintain the triggering of the indexation loop, the beam current cannot be decreased below a certain value called the dark current. Therefore, parts of an image that should be "black" will actually have a low-level background luminance. In the case of a 6 × 6 in. tube fitted with a solid-state detector, the necessary background level is currently about 1 fL. This value is high for applications such as night flying. (Using a variable transmission filter is one way to solve the problem.)

The background illumination is determined by the emitting strength of the index phosphor, the photodetector's sensitivity, and the signal-to-noise ratio of the index-signal-processing circuits. To reduce the dark current, the index phosphor is chosen to match the spectral response of the detector. This phosphor must also have very short persistence compared with the period of the index signal. The two most commonly used phosphors are P46, with a decay time of 100 nsec and a peak wavelength of 560 nm, and P47, with a decay time of 80 nsec and a peak wavelength of 400 nm. The most commonly used detectors are photomultiplier (PM) tubes and fast solid-state detectors (PIN photodiodes). PM tubes are too bulky for many airborne applications; the PIN diodes are generally used for HDDs.

To help in signal detection, the inside of the bulb is usually coated with a reflective layer of aluminum. A "porthole" in the aluminum layer allows light to reach the photodetector. Internal reflections increase the light flux through the porthole, and improve the uniformity with which the index signal is detected at different spot positions.

Developers continue to improve the efficiencies of both the index phosphor and the photodetector, but the processing circuits can also contribute to reducing the background level even further. Advances in digital electronic technology, in particular, enable the photodetector signal to be separated more easily from any background noise. The limits to development have not yet been reached in any of these areas.

A technology ascending

Beam-index technology is currently in full development, and further improvements are expected in several areas including:

- *Improvements in gun design* with consequent improvements in the brightness-resolution compromise.
- *A decrease in background luminance* resulting from improvements in the detection chain—index phosphor, photodetector, and signal processing.

But the beam-index tube is already a solution for avionics applications, such as HDD and color CRT retrofits, and for any other use where ruggedness and format adaptability are determining factors.

A promising application is high-resolution, small-format color displays, where no other technology provides a satisfactory solution. One-and-a-half-inch camera viewfinders have already been fabricated, although resolution is still limited to 129 triads. Current achievements with the guns of miniature monochrome tubes for helmet-mounted displays augur well for miniature color tubes with good resolution. ■