Reprinted from "New Scientist," Volume 10, Pages 234-236

The “Apple” tube for colour television

General use of colour television awaits a simple and inexpensive domestic receiver. Ten years’ work has now perfected a “feedback” system that determines which of three primary colours the electron beam is generating at any instant, so that the correct beam current can be applied

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Ever since colour television has been seriously considered for home service, it has been evident that the major obstacle was the development of a satisfactory, inexpensive device for displaying the picture. The display problem is considerably more difficult for colour than for monochrome (black and white) television. In a monochrome display one needs to generate a single image, roughly representative of the relative brightness of the various points in the scene. A considerable amount of spatial distortion is permissible before subjective degradation of the image is noticeable. In the case of a colour-television display, one must generate three independent images, representative of the relative intensities of three primary colours, red, green and blue at the various points in the scene. Further, since these images must be presented to the observers in almost exact registry with each other very little relative spatial distortion is tolerable. The colour-television broadcast standards that are used in the United States and are evolving elsewhere require that these images be generated simultaneously and in synchronism with each other. In addition to these requirements based on technical considerations, several additional requirements are imposed by the realities of the market-place. First, since the majority of the transmissions will continue to be in monochrome for a substantial period after the inception of colour service, a colour display must be capable of producing a monochrome picture of a quality equal to that of commercial monochrome displays. Secondly, the colour display must be sufficiently simple to manufacture and maintain that it will enable colour service to be supplied at only a small increase in cost over monochrome service. This last requirement is presently the most difficult to fulfill and is the reason why colour television is not in common use today. Numerous technical approaches to the colour-display problem have been studied in the past decade with varying degrees of success. The only technique which has been used commercially is the “shadow-mask” tube. This technique, while capable of producing a pleasing colour picture, falls short of meeting the requirements of an ideal colour display in several particulars. The technique acknowledged to have the best chance of meeting all the requirements for a commercially successful colour display is the "beam-index" technique. This approach has been studied at several laboratories. The major effort has been in the United States in the laboratories of the Philco Corporation, where the advantages of the beam-index approach were recognized early, and an intensive programme of research and development, known as the “Apple” project has been under way for over ten years. The Apple tube is a logical evolution from the conventional monochrome tube. Figure 1 shows a monochrome and Apple tube side by side. The only functional difference is in the "screen” the layer of phosphorescent materials on which the image is developed. In both cases the screen is scanned by a single beam emanating from a single electron gun. The entire screen area is scanned by a series of horizontal strokes of the electron beam. The first stroke of each image is at the top of the screen, subsequent strokes being slightly below their predecessor until the entire screen area has been covered, the entire sequence taking 1/50 second. As the beam scans the screen, the beam intensity (current) is modulated in accordance with the desired brightness of the image on a point-by-point basis, the brightness of any point on the phosphor screen being proportional to the current impinging thereon. The difference between the monochrome tube and the Apple tube is in the microscopic structure of the phosphor screen. The monochrome screen consists of a random mixture of bluish and yellowish phosphor particles, so small that they cannot be resolved by the unaided eye. These two phosphors in combination produce a white light. The Apple screen consists of an ordered array of vertical stripes of red, green and blue phosphor, which in combination also produce white light. The structure of the stripes is sufficiently fine to be unnoticeable at norma1 viewing distances. On monochrome transmissions both tubes behave in exactly the same way. The beam current modulation has a limited rate of change due to restrictions on the transmission channel so that adjacent colour stripes of the screen receive essentially equal current. Thus all parts of the image appear in black and white to the observer. When a colour picture is displayed, the Apple tube is operated in a different mode. The beam current is modulated at a much higher rate than when a monochrome picture is being displayed The red, green and blue stripes are excited independently in response to the amounts of red, green or blue light called for by the transmitted signal. In Figure 2, the upper waveform shows the variation of beam current with time when a point in the image corresponding to a red-to-white edge is being scanned. In the "red” section, the beam is being pulsed on when it is pointing at red stripes. In the white section the beam is on continuously as all stripes are scanned. The lower waveform shows the corresponding current density *v*. position on the phosphor screen. Note that the beam must be narrow enough to excite the colour stripes individually.

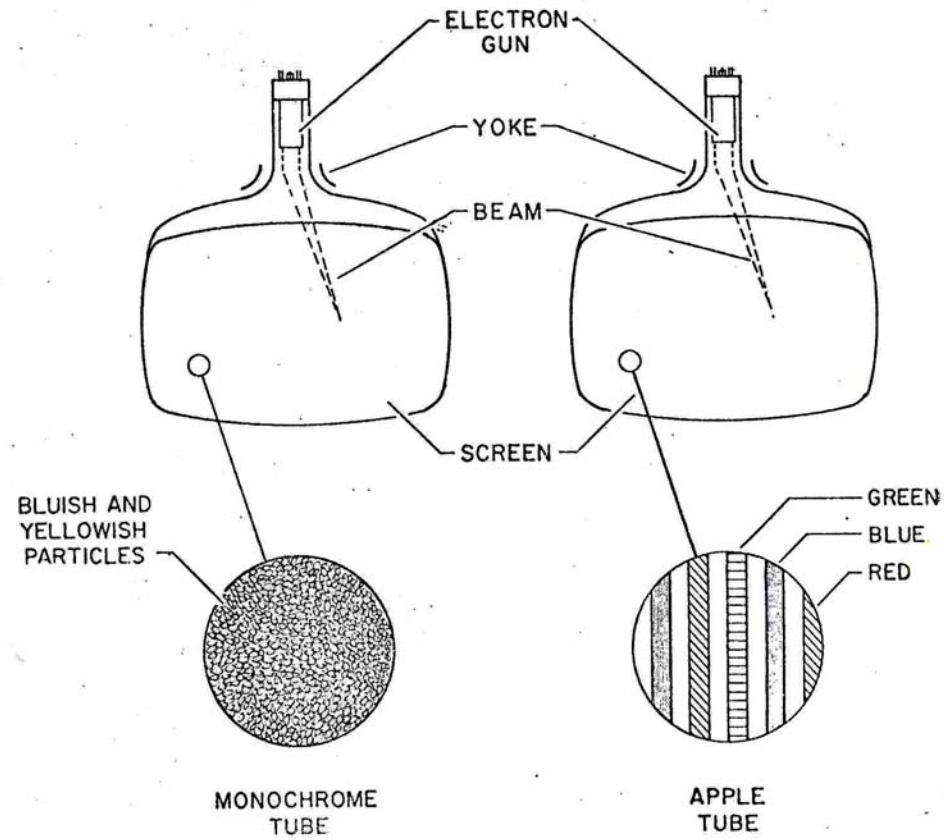

FIGURE 1. *Comparison of Apple tube with conventional monochrome tube.*

This points to one of the major problems encountered in the development of the Apple tube. At the inception of the Apple programme, the state of the art in electronic design was such that sufficiently small beams were not attainable at the beam currents needed for colour television. A large-scale study and development programme was needed to solve this one problem. The programme advanced the knowledge of electron-beam design generally and result in the design of a special gun using elliptically shaped electron optics which is more than adequate for the Apple tube. Another problem in the design of the Apple system is evident from Figure 2. that is the need for precise registry between the current density pattern and the stripe structure which constitutes the phosphor screen. The difficulty encountered here can be illustrated by a few numbers. It is seen that if the waveform is shifted slightly to the left or right, some current will land on a stripe of the wrong colour. This quickly results in a noticeable error in reproduced hue. Experience has shown that if the waveform shifts by as little as 1.4 per cent of the distance between successive stripes of the same colour, a noticeable hue error results. Since there are typically 300 sets of colour stripes across the screen, the registry must be held to one part in 20,000 of the screen width. This is impossible to attain without some form of feedback control. The development of the feedback-control technique was the major effort required in the Apple programme. In order to know the beam position relative to the screen structure with sufficient accuracy at all times, it is necessary to measure its position at frequent intervals as it scans across the colour stripes. One measurement every time the beam scans across several sets of colour stripes is sufficient if the display is handled properly. The measurement is accomplished with the aid of an "index-stripe" structure which is placed behind the colour-stripe structure. Figure 3 shows a cross-section of the complete screen structure. The colour-stripe structure is deposited directly on the glass envelope of the tube. It is backed by an extremely thin, electron permeable coating of aluminum – as is a monochrome tube screen – which serves as the anode of the electron-optic system and also increases the brightness of the image by reflecting forward that light which the phosphor radiates in a backwards direction. The index-stripe structure is deposited behind the aluminum in a known position relative

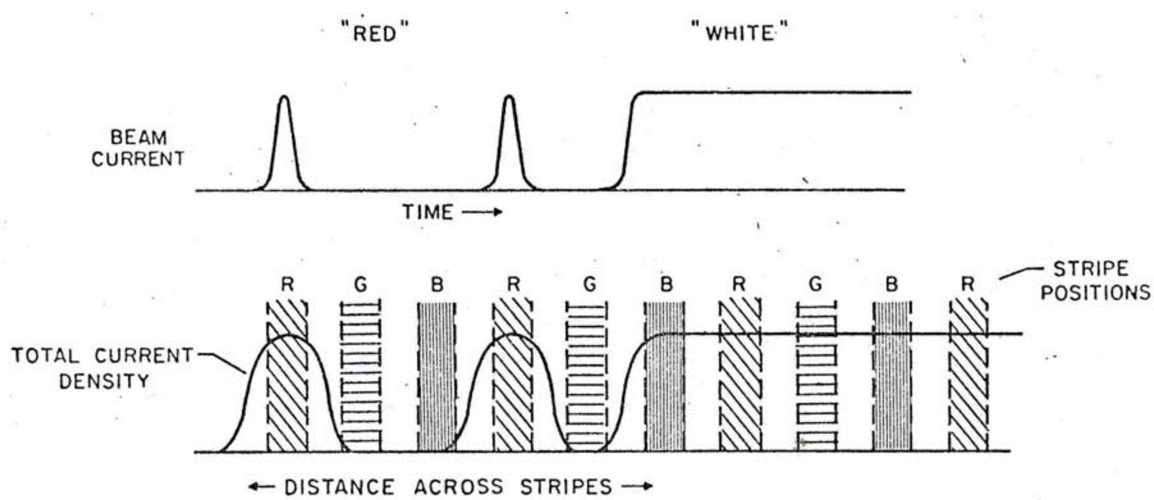

FIGURE 2. *Colour selection in Apple tube.*

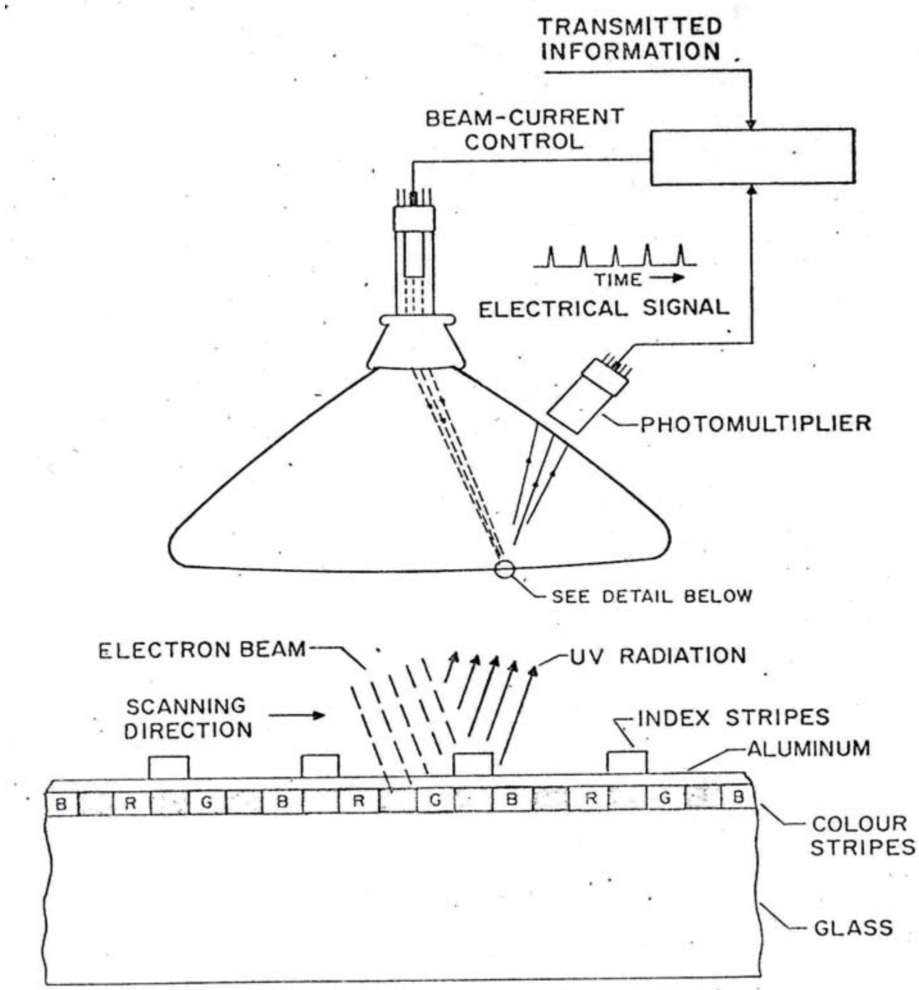

FIGURE 3. *Beam indexing mechanism in Apple tube.*

to the colour-stripe structure. The index stripes are of a phosphorescent material which emits ultra-violet radiation when bombarded by the electron beam. The ultra-violet radiation is picked up by a photo-multiplier which generates an electrical signal proportional to the incident U-V. Thus, as the electron beam scans the screen structure, the output of the photo-multiplier is a series of current pulses which occur whenever the beam crosses an index stripe. Since the relative positions of the index and colour stripes is known, one then knows, by interpolation, which portion of the colour screen is being excited at every instant. The information contained in the photo-multiplier output is combined, in external circuitry, with that information in the transmitted signal which specifies the hue to be displayed, and a new signal is generated which controls the instantaneous beam current in such a way that the red, green and blue stripes are excited in the proportions called for in the transmitted signal. There are two major problems associated with the beam-index concept for which ingenious solutions have been effected in the last several years. The first problem results from the fact that the rapid modulation of beam current needed to display saturated (pure) colours causes an apparent displacement in the position of the index stripes. For example, if the modulation is such that a large amount of current falls on the green stripes, and very little on the blue, the radiation from an index stripe between green and blue will indicate an apparent shift in the stripe position toward the green stripe (to the left in Figure 3). In other words, there is an error in index information. If all the stripes were located between green and blue stripes, they would all be shifted to the left, resulting in an index error which could not be detected or compensated. The preferred solution to the problem is to so p1ace the index stripes that there will be compensating displacement errors that will balance, regardless of the modulation on the beam. The structure illustrated in Figure 3 appears to be the best compromise considering many factors. The index stripes occur between alternate pairs of colour stripes. There are then three positions of index stripes relative to colour stripes; green-blue, blue-red, red-green. Analysis and experiment have proven that, with this arrangement, the apparent displacements of index stripes compensate for each other to within an unnoticeable error for all forms of modulation of the electron beam possible under normal operating conditions. This solution, however, introduces a new problem. The index signal is ambiguous: there are three kinds of positions, with respect to the colour stripes, at which index stripes occur, and the index signal cannot show a difference between them. The ambiguity is resolved by a special section of the index structure which exists at the start of each horizontal line scan. In this section (where beam-current modulation is prohibited) there are index stripes in only one position, green-blue. This enables the circuits to “tag” the index pulses at the start of each scan, and since they then follow in a regular sequence, their identity can be established throughout the scan without further “tagging”. The second major problem associated with the beam-index technique results from the fact that it is impractical to design - scanning system that causes the beam to scan the stripe structure at a constant rate. Whenever the stripe-scanning rate varies, there is a proportional, apparent displacement in stripe position resulting from the limitations (time delay) of the circuitry external to the tube. For a long time it was thought that considerable cost and adjustment capability would be needed in a receiver to keep the scanning rate as nearly constant as possible. This is now unnecessary since a simple circuit technique has been demonstrated to compensate the error: the variations in scanning rate are detected from changes in the index signal and the information is used to cancel the displacement error in the index pulses resulting from the variations in scanning rate. It now appears that satisfactory solutions to all of the beam-index system problems have been found. Demonstrations of the system have been made in the United States. The consensus of the observers has been that the picture quality is excellent on both monochrome and colour transmissions – definitely superior to that shown on any other display intended for home service colour television. Further, it appears that the beam-index approach will lead to a simpler and less-expensive colour receiver than any other acceptable technique.