Two Systems of COLOR TELEVISION

A statement of the relative merits of the sequential color system shown by CBS and the simultaneous system demonstrated by RCA, from the standpoint of performance, required standards, and needed research

By DONALD G. FINK

RECENT INTEREST in the color versus black-and-white television controversy has centered on two color systems, demonstrated by the Columbia Broadcasting System and the RCA Laboratories.

The CBS system, which has been described at length in these pages[1,2] is a typical example of the sequential method, in which images in the three primary colors are sent one after the other on a single r-f carrier. The RCA system, demonstrated recently and briefly described in these pages last month[3], is typical of the simultaneous method, in which images in the three colors are sent at the same time on three carriers. The sequential and simultaneous systems have been referred to as mechanical and electronic systems respectively but these are not significant designations, since either system can be operated electronically.

In preparation for the FCC hearing on color television which began December 9th last, the comparative merits of the two systems were studied by television specialists on committees of the Radio Technical Planning Board and the Radio Manufacturers Association. This article is a summary of their findings as revealed at the hearing, plus observations on economic factors not considered by the RTPB and RMA groups.

The Two Systems

The sequential system is characterized by the fact that the transmitted signal contains information about one primary color only at any instant of time, the three primaries following one after another.

The cameras thus far used with this system are of the mechanical type, i. e., they use a rotating disc carrying three color filters.

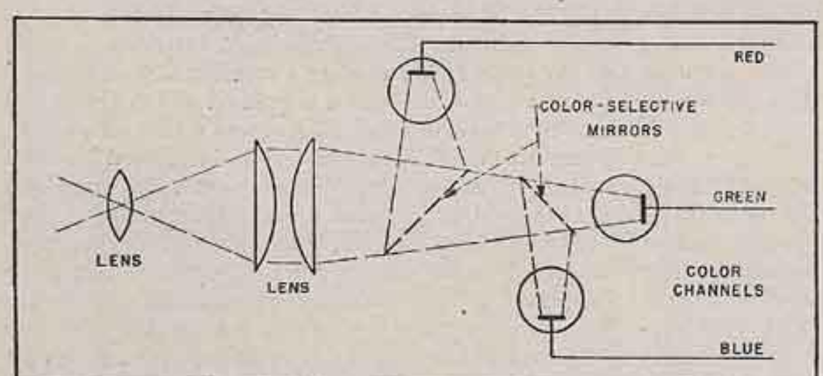


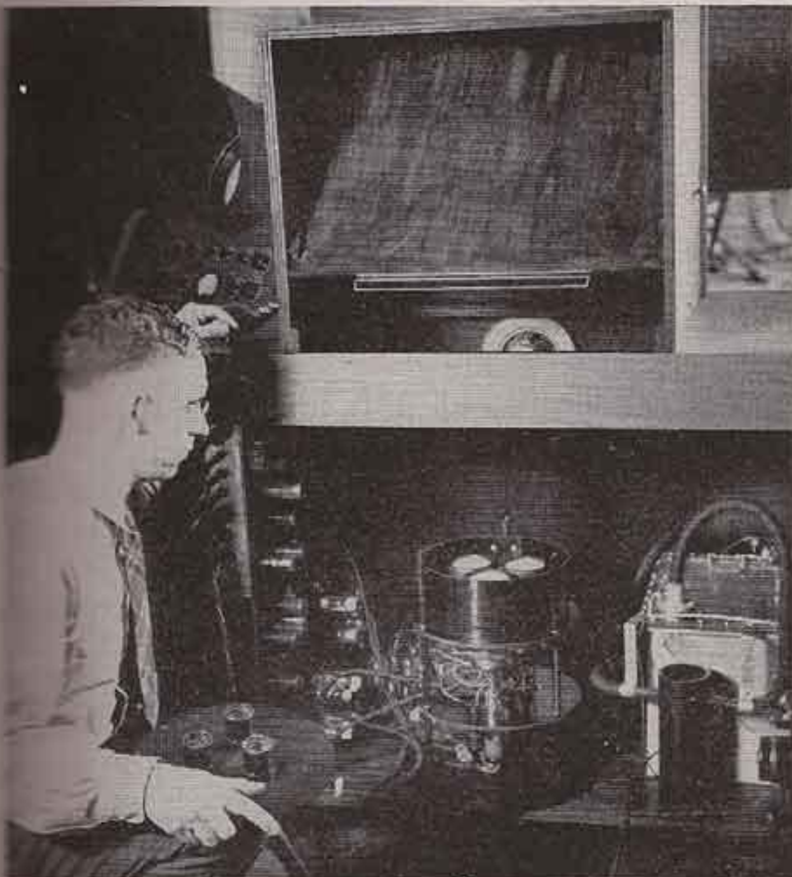
FIG. 1—Beam-splitting camera arrangement for deriving three colored images from color-selective mirrors. This type of camera can be used in either system, with the mosaics keyed sequentially or operating simultaneously

In place of the rotating disc, however, it is possible to employ a beam-splitting arrangement like the simultaneous-type camera, and three photosensitive elements (phototubes or mosaics), each with a different fixed color filter. The photosensitive elements may be keyed on and off in sequence, producing a sequential signal without using moving parts.

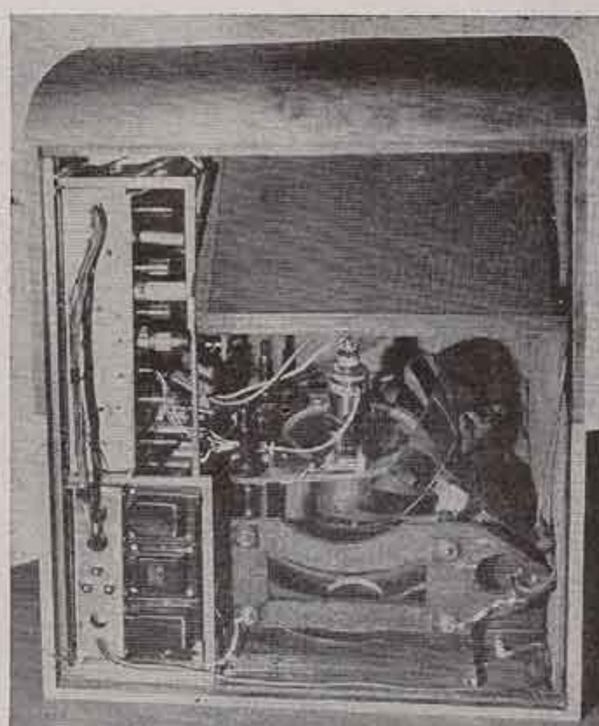
In the receiver the signal actuates a single cathode-ray tube in front of which rotates a synchronous color disc like the one used at the transmitter. Here, also, the mechanical disc may be replaced by three cathode-ray tubes, each fitted with a fixed color filter and arranged so that the images may be projected in register on a viewing screen. The c-r tubes are in this case keyed on and off in synchronism with the studio camera.

The simultaneous system uses three carriers or sub-carriers. The image is perceived either by three cameras, each with a different fixed color filter and each feeding a separate channel, or by a beam-splitting device, Fig. 1, which breaks the image into three colored images, each feeding a separate phototube or mosaic. In either event, three signals are generated simultaneously and are fed through three separate channels.

At the receiver, the three carriers are received separately either by employing three separate i-f amplifiers or by employing wave filters before the second detector,



Corresponding elements of sequential and simultaneous projection receivers. The CBS receiver (below) uses a single five-inch cathode-ray tube with a cup-shaped filter disc. The RCA receiver (at left) employs three separate three-inch tubes with projection lenses



and applied to three picture tubes, each fitted with a different fixed filter (or using colored phosphors). The three images are projected on a screen in register.

The simultaneous system is thus an electronic one, with elements like the elements of an electronic sequential system. The difference is that in the simultaneous system all channels are working at once, rather than one after the other as in the sequential system.

Different as the two systems may appear at first glance, they have many performance characteristics in common. Both are capable of rendering the same fidelity of color transmission, provided that the same color filters are used in each system. Both employ approximately the same bandwidth in the ether spectrum, since the sequential system requires one wide-band carrier while the simultaneous system uses three narrower carriers. Both are capable of about the same broadcast coverage, when operated in the same region of the spectrum, since the separate transmitters of the simultaneous system can develop higher power over the narrower band, but only at the expense of using three sets of tubes. If all these tubes are combined (in a ring oscillator circuit, for example) in the single transmitter of the sequential system, they can provide approximately the same power over the wider band and hence produce equal signal strength contours.

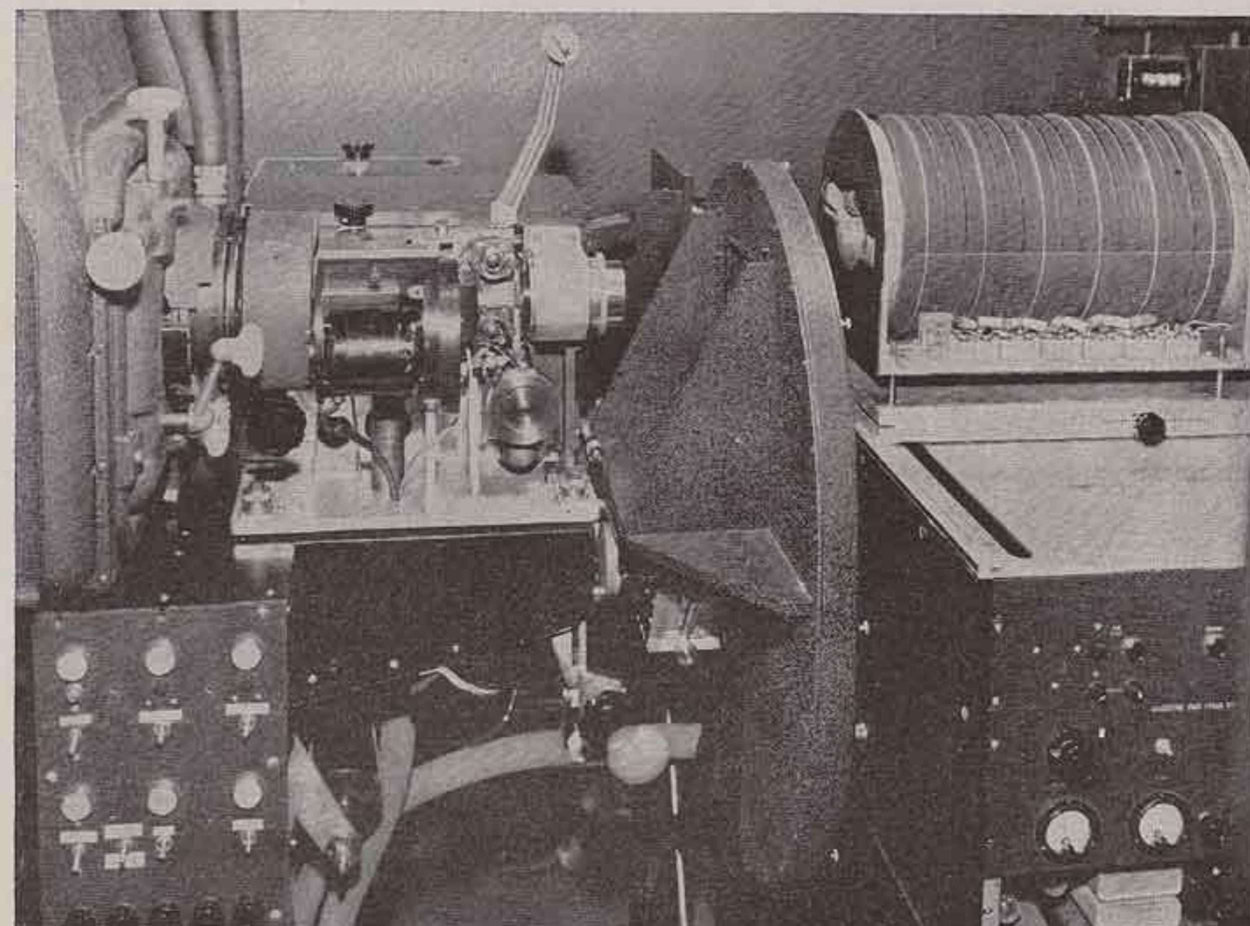
Picture-Repetition Effects

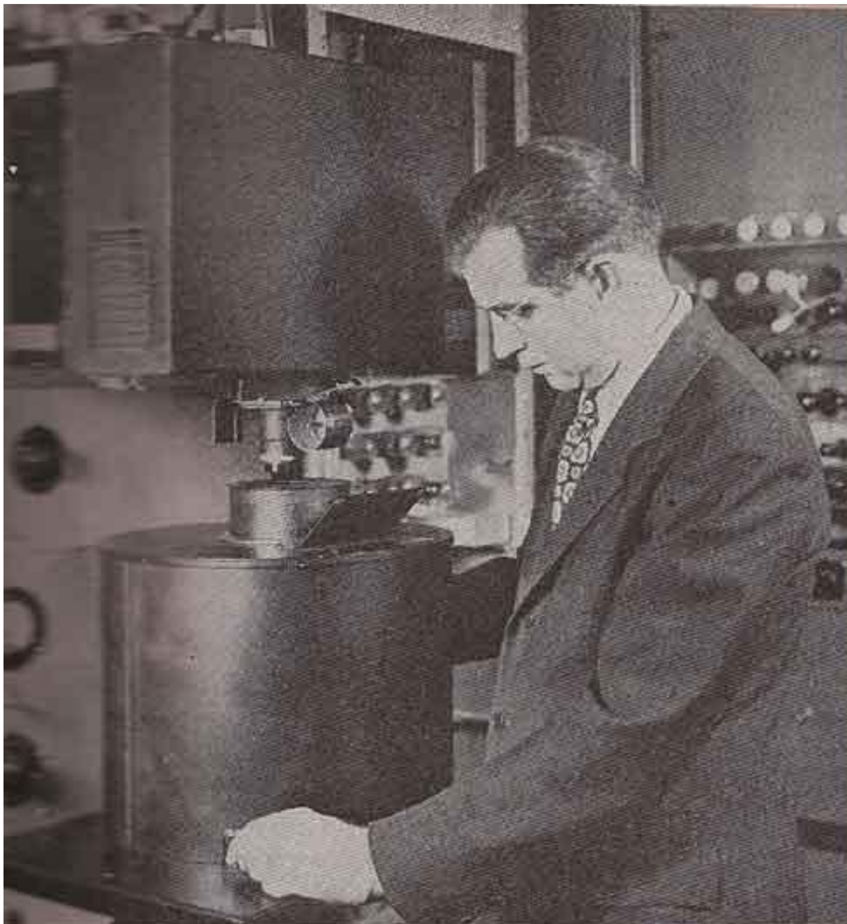
The two systems display different requirements when the picture-repetition effects (flicker, color break-up and color fringing) are considered. In the black-and-white system, the flicker problem has been attacked by setting the picture repetition rate at 60 fields per second (30 frames per second). At highlight picture brightnesses up to about 50 foot-lamberts (somewhat brighter than the brightest television pictures now available to the public, and high enough to be received satisfactorily in a well-lighted room), and when phosphors having normal decay rates are used, there is no apparent flicker in the black-and-white system. At higher brightnesses there is some doubt that the 60-field rate is high enough but it suffices for foreseeable needs.

In the sequential color system the flicker problem is complicated by the fact that the light from one color field must disappear substantially completely before the next color filter is positioned before the c-r tube. This implies the use of rapid-decay phosphors, and consequently higher apparent flicker. To overcome this tendency, and to assure smooth blending of the colored images, it is necessary to transmit the sequential color images at a field rate well above 100 per second. The rate originally adopted by CBS was 120 fields per second (40 color frames per second), and this was later raised to 144 fields per second (48 color frames). Since flicker is observable at brightnesses of 50 foot-lamberts or better with this rate, some engineers have urged that the field rate be set at 180 per second (60 color frames per second). In the latter case, the pictures are sent at three times the rate of the black-and-white images, and the bandwidth required is three times as great. It thus appears that the sequential system requires a video bandwidth of from 2.4 to 3 times the black-and-white figure, for a picture of equal objective resolution.

In the simultaneous system, the blending of colors is inherent and a much lower field rate is permissible. In addition, phosphors of slower decay may be used, and this

Corresponding film pick-up devices in the two systems. Below: CBS unit uses film projector (left), a color wheel (center), and a single image dissector pick-up tube (right). The RCA equipment (on right-hand page) uses a flying-spot raster scanner located below a housing containing a beam splitter with three multiplier phototubes





further lowers the flicker threshold frequency. Thus a rate of 60 fields per second in a simultaneous system may be expected to give flicker performance superior to that of a sequential system operating at 180 fields per second. Each of the three channels in the simultaneous system would have a bandwidth, for pictures of equal resolution, of 60/180 or one third that required for the sequential system. Under these conditions the total bandwidth required is the same in the two systems except that space for guard bands, to separate the three channels, must be allowed in the simultaneous system.

The other picture-repetition effects, color break-up and color fringing, are basically different in the two systems. In the simultaneous system, since all colors are presented continuously, there can be no color break-up as such, whereas in the sequential system break-up may be caused by movement of the eyes. Many observers, perhaps the majority, have a tolerance for color break-up, and it is not considered a serious factor in any event. Color fringing, the third effect, is also not present in the simultaneous system, but a similar effect due to lack of register among the three simultaneous images may be present. Hence the two systems are comparable in this respect.

Other Pertinent Factors

A factor of great importance in the progress of the art is the compatibility of color television standards with the present black-and-white standards. Here the simultaneous system has a clear advantage. If a simultaneous field rate of 60 per second is chosen, the scanning standards of each of the images are identical to the black-and-white standards. Hence the color images may be received, in black-and-white, on a standard present-day black-and-white receiver. This is done by using a frequency converter to tune the black-and-white receiver to the green image of the color transmission, which contains nearly all of the black-and-white values of the colored image.

The sequential system cannot be so accommodated to existing black-and-white standards. Thus the choice of the simultaneous system with a field rate of 60 per second would greatly ease the transition from black-and-white to color. Such a choice implies a total bandwidth (three simultaneous channels) somewhat greater than that for a 180-field sequential system, and considerably wider than that for a 144-field sequential system, which many consider to be adequate. Here, again, a situation exists which tends to place the two on a par. In the sequential system, since a single channel of fixed width is employed and all colors are scanned at the same rate, the same amount of information is necessarily sent in all three colors. Stated differently, if the bandwidth is chosen to accommodate the most detailed color, green, the same bandwidth is reserved to transmit detail in red and blue, despite the fact that less detail may suffice in the latter colors.

In the simultaneous system, on the other hand, the bandwidth provided for each color may be tailored to meet the detail requirements of the eye. It is well known in physiological optics that, except at very high brightness levels, the eye can resolve much less detail in a blue image than it can in an identical green image. Thus it is possible to restrict the bandwidth for the blue channel, and possibly to a lesser extent for the red channel also, without apparent loss of resolution in the color picture*. If this is done, and the extent to which it is possible has not yet been accurately determined, the bandwidth required for a simultaneous system will not exceed, and it may even be less than that required for a sequential system of the same resolution, even when guard-band space is provided in the former system.

Still another question is the relative ability of the two systems to pick up images directly from live subjects. Both systems have been demonstrated on film and lantern

* A similar saving of bandwidth might be achieved in the sequential system by scanning the colors at different rates, that is, allowing more scanning time for green than for red and blue, but this would introduce serious apparatus problems, particularly with respect to interlacing, color balance and flicker, and probably is not a practical procedure.

slides; no demonstrations have been given of live pickup with the simultaneous system. Until the latter event occurs, conclusions must be tentative. But it can be assumed that the register problem in the live-pickup simultaneous camera can be solved as satisfactorily as it has been in the receiver, and it may be expected that the performance will be about the same as regards color rendition.

In the sequential camera the mosaic must be completely discharged at the end of each color field (every 1/180th second in a 180-field system) to avoid carry-over of one color into the next. Since the storage time is thus reduced, the sensitivity of the sequential camera must inevitably be lower than that of the simultaneous camera, in which mosaic storage can be employed through the whole frame interval (comparably, 1/30th second). Whether or not this will prove an important advantage to the simultaneous system depends, of course, on the extent to which the producer uses dimly-lit scenes. The sensitivity of the image orthicon, which may be used in either color system, is so great that it may provide sufficient margin to give adequate performance in the sequential system with any light level likely to be encountered. Finally, it must be remembered that a sequential signal can be produced from a simultaneous camera by keying the color images in and out in sequence, so the most sensitive camera available could be applied to either system.

The above comparisons are based on equal resolution, that is, the same number of resolvable picture elements in the color picture produced by the two systems. To make full use of this resolving power, scanning aberrations must be minimized. Such aberrations are present in both systems.

In the sequential system, the frame rate is not synchronous with the 60-cps power source, even when operated at 180 sequential fields. Thus hum and spurious fields within the receiver must be carefully removed by filtering and shielding. In the 60-field simultaneous system, on the other hand, each image is synchronous with the 60-cps power source but the three images must be accurately registered one over the other on the camera and on the receiver viewing screen. It appears that with the use of a single deflection generator for all three c-r tubes, and with proper care in aligning and centering the beams, this effect may be minimized.

At the receiver one fundamental difference, and several less fundamental ones, appear in respect to the picture brightness. The fundamental difference arises in the fact that in the sequential system there is only one light source on at a time, operating sequentially with different colors, whereas in the simultaneous system three light sources operate at once. Hence, all other factors being equal, the simultaneous picture will be approximately three times as bright.

Received Picture Brightness

In the equipment thus far shown the brightness advantage of the simultaneous receiver is even more pronounced, because colored phosphors are used. Such phosphors generate far more light, from a given accelerating voltage, than does a white phosphor in conjunction with a colored filter (the average light loss of the colored filters is from 85 to 90 per cent). However, this is not a fundamental difference, since a sequential signal

Combined membership of the RTPB television panel and color television subcommittee which prepared evidence for recent FCC hearing. Seated at far end of table are D. B. Smith, chairman of RTPB Panel 6, and D. G. Fink, chairman of the subcommittee conducting color television studies. Others are, seated left to right, R. E. Shelby, NBC; W. E. Bradley, Philco; F. J. Bingley, TBA; Axel Jensen, Bell Labs; R. B. Dome, GE; Leonard Mautner, DuMont; G. L. Beers, RCA. Standing, left to right: H. G. Boyle, NA Philips; W. T. Wintringham, Bell Labs; P. J. Larsen, SMPE; P. C. Goldmark, CBS; E. M. Roschke, Zenith; A. Packard, Colonial; Curtis Plummer, FCC observer; J. E. Keister, GE; F. R. Norton, Bendix; A. A. MacDonald, Westinghouse; J. D. Schantz, Farnsworth; Pierre Mertz, Bell Labs; A. N. Murray, consultant; A. V. Loughren, Hazeltine; A. E. Newlon, Stromberg-Carlson; H. E. Kallman, Telicon; W. F. Bailey, Hazeltine; R. D. Kell, RCA; George Town, Stromberg-Carlson; J. D. Reid, Crosley; T. T. Goldsmith, Jr., DuMont; George P. Adair, FCC chief engineer, observer; H. G. Miller, Federal

can be used with three projection tubes with color phosphors, the tubes operating in sequence, in which case the sequential system would produce a picture one third as bright as the simultaneous system. But the three-to-one advantage of the simultaneous system cannot, it seems, be entirely eliminated.

The colored phosphors thus far used do not have equal luminosities so to secure proper saturation in the reds, a vernier optical red filter is added to the red tube. This limits the overall brightness of the system to about 50 percent of the value possible if an equally-luminous red phosphor were available.

Color Rendition

Color filters of the best type (those covering the widest area on the color triangle) can be employed at transmitter and receiver in either system, so both systems have the same ability to render color values. But if color phosphors are used in the simultaneous receiver this will be true only if the colors of the phosphors cover an equally large and similarly placed area on the color triangle. Furthermore, the color produced by the phosphor must be constant irrespective of changes in brightness.

Whether or not these requirements can be met is not known, but in view of the vastly improved control over phosphor characteristics, only minor losses are to be expected. Development of phosphors will assure bright projected pictures in the simultaneous system.

A proposal, affecting color rendition, has been made to reduce the flicker in the sequential system. This is to use primary color filters covering a somewhat smaller area on the color triangle (so-called low-flicker primaries) and having more nearly equal luminosities. These have been demonstrated by CBS and do reduce the flicker on a 144-frame sequential system so that it can be used at a brightness sufficiently high for viewing comfortably in a lighted room. The low-flicker primaries do not cover as large a region of the color triangle in the purple region and hence the rendering of purple tones is not as exact as with the standard primaries.

One final aspect of overall system performance, relating to r-f propagation, is the relative effect of multipath transmission. In the sequential system there is but one carrier, and the multipath effects (which are usually frequency-selective in appearance) are present, in effect, only once. In the simultaneous system there are three carriers, and the effect of multipath will be present in three separate groups of sidebands. Also since multipath effects depend on instantaneous carrier phase, and since the relative phases of the three carriers may vary, the multipath effects will presumably be different on the three colors. It might thus appear that multipath effects would be more serious in a simultaneous system. But such a contention is hard to support without a thorough field test.

Equipment Comparisons

In general, the sequential system may employ simpler equipment than the simultaneous, since only one camera, transmitter, antenna, receiver, i-f amplifier, and picture tube are required. The circuits throughout are wideband and therefore somewhat more expensive than a single narrowband circuit, but there is only one of them.

In the simultaneous system, three photosensitive surfaces or tubes are required in the camera each with associated amplification and modulation channels. A single wide-band transmitter modulated jointly by the carriers or sub-carriers might be used. At the receiver a joint r-f amplifier stage may be used and even a joint i-f amplifier. But somewhere in the receiver, either in the i-f amplifier or before the second detector, separation of the three carriers must be performed. Thereafter individual video amplifiers and separate picture tubes for each color are required. Also, for the present at least, there seems to be no adequate method of combining the simultaneous colors except by the projection method, which implies an optical system of high aperture and also requires high intrinsic brilliance on the c-r tubes.

All these factors point to an expensive receiver, compared to a direct-viewed sequential receiver. However, the price of a sequential *projection* receiver might not be substantially less than the simultaneous projection receiver, since the same projection system is required, and the synchronous motor-driven filter disk involves costs not present in the simultaneous equipment. Beyond these generalizations it is difficult to predict costs failing actual production of comparable receivers.

Summary

From the foregoing analysis it appears that the sequential and simultaneous systems offer equal promise in many respects. Both can provide good color rendition, free of flicker provided suitable standards are chosen. Such standards would entail about the same bandwidth requirements and coverage potentialities. But the inescapable conclusion is that one system or the other must be adopted; they are not compatible with one another.

If a color television system is to be a logical extension of the black-and-white system, the simultaneous system offers greater promise, but the equipment costs of this system will probably be greater, at least initially. Perhaps the greatest objection to the simultaneous system, so far as can be seen at present, is the difficulty of producing an inexpensive direct-viewing receiver.

Finally there are many questions which can best be answered by tests, in the laboratory and in the field, concerning propagation effects and the ultimate requirements of picture brightness and associated flicker phenomena. Coincidentally with this test program, new devices can be expected to appear which will show clearly the relative trend of costs, which in the long run must determine the extent to which either system can be used by the public.

References

(1) Color Television on Ultrahigh Frequencies, ELECTRONICS, p 109, April 1946.
(2) Where Color Television Stands, ELECTRONICS, p 104, May 1946.
(3) All Electronic Color Television, ELECTRONICS, p 140, December 1946.