A conventional monochrome TV camera which has been modified for color operation is being adjusted for a studio color shot.

CHROMACODER COLORCASTING

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Modified conventional monochrome TV cameras, when combined with a chromacoder, can produce standard NTSC color signals.

COLOR television delivers an impact for the advertiser which is an order of magnitude greater than that of monochrome television. It provides the viewer with greatly increased entertainment and educational values. It also provides the engineers who must plan the technical facilities for the origination of live color programs with many opportunities to conquer new technical problems. To these engineers, it is a challenge to select the equipment that will produce and transmit the highest quality color pictures—equipment that will do so with proper regard for minimum investment, minimum operating cost and maximum operating ease and flexibility. It was with these thoughts in mind that the chromacoder system of colorcasting was developed.

Sequential color television, as once approved by the FCC, posed a serious technical and economic problem in that it was not compatible. Existing monochrome receivers were unusable for this type of color and would have become obsolete. Speaking more practically, color broadcasting would not have been successful because there would not be the large number of viewers who could also see the programs in black and white. This was unfortunate since sequential color is capable of producing the highest quality of color pictures in a relatively simple and straightforward manner.

Consistent and beautiful results can be obtained with a minimum of adjustment difficulties. A sequential color camera requires only the addition of a rotating disc and some electronic modifications, which result in a unit no larger than a conventional monochrome camera. As such, the camera is both maneuverable and portable, and still utilizes the same single cable. Switching, fading, dissolving, and superimposing can be accomplished in the usual manner without extremely careful adjustment of the camera and its associated equipment. In short, sequential color appears to have all the advantages of simplified technical operation. It would not be economically feasible, however, if there were insufficient receivers, both monochrome and color, to view it. What was needed was a means of translating the sequential color signal at the studio to a signal which could be transmitted in accordance with the FCC-approved NTSC color standards. This problem has been solved by the *Columbia Broadcasting System* Laboratories, under the capable direction of Dr. Peter Goldmark, and the equipment which is being manufactured and which will be described here follows their basic concept.

Color Cameras

The latest in portable monochrome camera chains has been modified to provide sweep speeds of 180 fields and 525 lines. This means 60 red, 60 blue, and 60 green fields per second, and 47,250

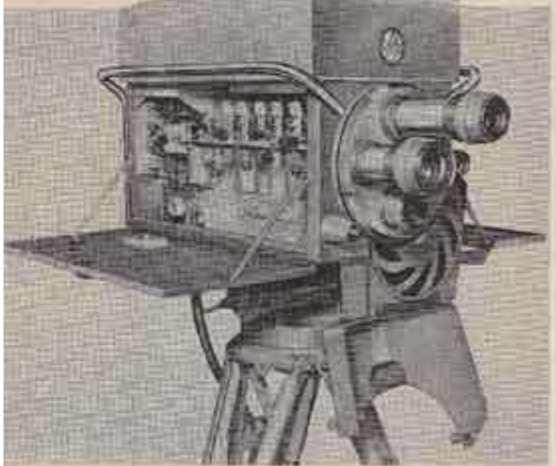

Fig. 1. Modified camera showing nine-segment color wheel in lower front corner.

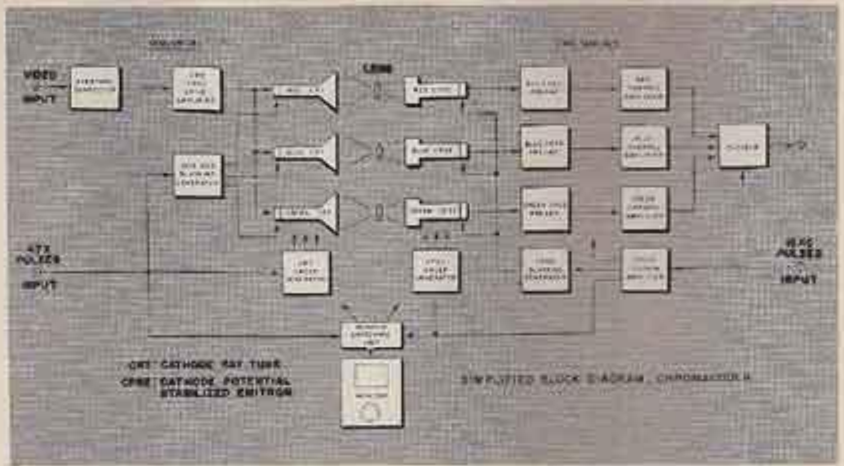

Fig. 2. Simplified block diagram of the chromacoder which converts the signal from the modified camera to a standard NTSC color signal.

scanning lines per second. To facilitate conversion to NTSC standards without moiré effects (beat patterns), the sweep yokes are rotated 90° so that the scanning lines are vertical and cross those of the conversion equipment at right angles instead of being parallel to them. The 3 by 4 aspect ratio is maintained, which shortens the length of the vertical lines and thereby lessens the high speed sweep problem.

A nine-segment color wheel about 8" in diameter is mounted in a lower front corner of the camera, between the lens turret and the image orthicon compartment. The wheel is driven by a small synchronous motor which is almost completely contained within the original camera dimensions. (See Fig. 1.) By the addition of two video amplifier stages, the camera is modified to have a 12-mc. bandwidth. The image orthicon yoke is rotated 90° and driven with new sweep circuits for the higher rates. The view-finder is modified to accommodate the wider bandwidth and higher sweep frequencies, requiring a new deflection yoke and circuitry. Color telecasting imposes a reduced latitude on the light values which may be used, and this in turn makes exposure more critical. A remote iris control has therefore been added to permit the camera control operator to adjust any camera lens opening for optimum exposure at any time without involving the cameraman. The camera control unit is similarly modified, and clamping and shading circuits are altered to suit the new frequencies. Another color wheel is installed in front of the picture monitor so that all camera control functions are performed while viewing the full color picture.

Packaged in a manner similar to the rest of the equipment is a new unit—the color mixer. It contains a gamma correction amplifier, commutator or signal separator, individual gain and setup controls, adder or mixer amplifier, and master contrast, setup, blanking, and clipping controls. It also contains the drive amplifier and phasing controls for the camera color wheel. The video bandwidth is 12 mc., and a feedback output stage provides two 1-volt outputs, one of which is used to feed the control monitor. An additional portable power supply is required with each channel to power the color mixer.

Alterations are made in the sync generator to provide the proper line and field rates which are exactly triple the original values. Two binary counters are added to obtain the 60-cycle color drive pulse which identifies the start of the red field and keeps the whole system in color synchronism. The field sequential sync generator may be operated in any of the conventional ways—locked to the 60-cycle line, sync-locked to a remote generator, or crystal-controlled. In any event, it need not have any tie with the NTSC sync generator which is always locked to the 3.58-mc. crystal.

The portable monochrome switcher can be easily modified to perform all of the same functions for four color chains that it now performs for four black-and-white chains.

Chromacoder Unit

Field sequential color pictures are fed to the scan conversion unit which *CBS* has named the "chromacoder." The primary function of the chromacoder is to convert the sequential color signal having 47-kc. top-to-bottom scan lines into three simultaneous color signals, red, blue and green, with 15-kc. side-to-side scan lines. Operation of the chromacoder is best described with reference to a simplified block diagram, Fig. 2. The conversion is accomplished by three channels, each of which carries the information on one color. Each channel consists of a display or picture tube and a pickup or camera tube.

Since information continuously flows from each of the three simultaneous RB&G output channels while it is supplied to the chromacoder sequentially—first red, then blue, then green, the equipment must perform a memory or storage function. For example, the red video is on for only 1/180 second, and is off for 1/90 second, but the output from the red channel is continuous. This memory function is achieved partly in the pickup tube, which has virtually 100% storage, and partly in the long-persistence P1 phosphor of the display or cathode-ray tube. The pickup tube will be covered in more detail later.

An aperture corrector amplifier receives the incoming sequential color signal. This amplifier is a phase distortionless high peaker which compensates for the spot size of the CRT's (cathode-ray tubes), maintaining the ultimate light level and spot size for best reproduction. The amplitude-vs.-frequency characteristic of the aperture corrector is adjustable from "flat" ±1 db up to 15 mc. to "peaked" +15 db at 15 mc. From the aperture corrector, the video signal continues to the CRT video drive amplifier—a high-gain, high-power amplifier capable of 60-70 volts grid drive for the three CRT's. The drive amplifier also has a 15-mc. bandwidth.

Drive pulses from the field sequential sync generator key the gate generator, principally the color drive pulse which identifies the red field. It turns on and off—or gates—the CRT's in their cathode circuits in synchronism with the filters in the color wheel. For example, when one of the red filters is in front of the picture tube in the camera, the red CRT is gated "on" to reproduce the red information, and the blue and green CRT's are gated "off."

A special aluminized type 7" cathode-ray tube is used which has an extra fine P1 green phosphor and a fine spot gun structure. Each tube is operated at

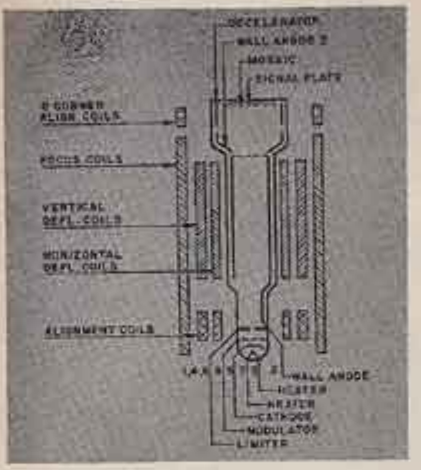

Fig. 3. The CPS Emitron with its associated scanning and field coils. It uses a charge-storage mosaic.

27-kv. potential. Special attention has been devoted to the design of the deflection yokes and sweep circuits used with the CRT's to achieve the ultimate in linearity and stability.

Each of the three CRT's is imaged with a conventional enlarging lens onto one of three pickup tubes which are CPS (cathode potential stabilized) Emitrons.

Emitron Tube

The CPS Emitron, developed in England by the *Electrical-Musical Industries Laboratories*, is a television camera pickup tube using a charge-storage mosaic. Figure 3 shows the Emitron with its associated scanning and field coils. The signal plate is separated from the mosaic by an insulating medium. The wall anode extends practically the whole length of the tube, but is made in two sections to eliminate the undesirable electrostatic coupling between the scanning coils and the signal plate. At the rear of the tube is the electron gun, comprising an indirectly heated cathode, a modulator or grid, and a limiter or first anode. The first anode has an aperture which limits the electron emission of the cathode to a narrow beam. The decelerator supplies a corrective field to overcome geometric distortion. Focus coils supply a uniform axial field, while deflection coils provide the line and frame sweep fields. Alignment coils apply a corrective field which adjusts the axis of the electron beam to coincide with the lines of force created by the focus coils.

Light striking the photosensitive mosaic (antimony caesium surface) causes photoelectrons to be emitted, and these are attracted to the wall anode. Having lost electrons proportional to the amount of light, the individual elements of the mosaic are charged positively. In scanning the mosaic, the electron beam successively discharges these elements through their capacity to the common signal plate. The circuit for signal current is completed through the load resistor, the cathode, and the beam, and the signal voltage developed across the load resistor is fed directly to the first grid of the preamplifier.

By virtue of the low velocity electron beam, the mosaic may be stabilized at a potential equal to the cathode; hence the name "cathode potential stabilized Emitron." The low velocity beam liberates practically no secondary electrons from the target so that there is no spurious shading in the picture signal. Freedom from secondary emission, together with the removal of all photoelectrons from the mosaic, results in high sensitivity and establishes a reliable black reference in the picture signal. While not as sensitive as an image orthicon, in this application where light levels are high and fully controlled, CPS Emitrons have other distinct advantages. The major ones are: unity and linear gamma (gray scale response), absence of sticking or burning in, longer life (approximately 1000 hours), minimum

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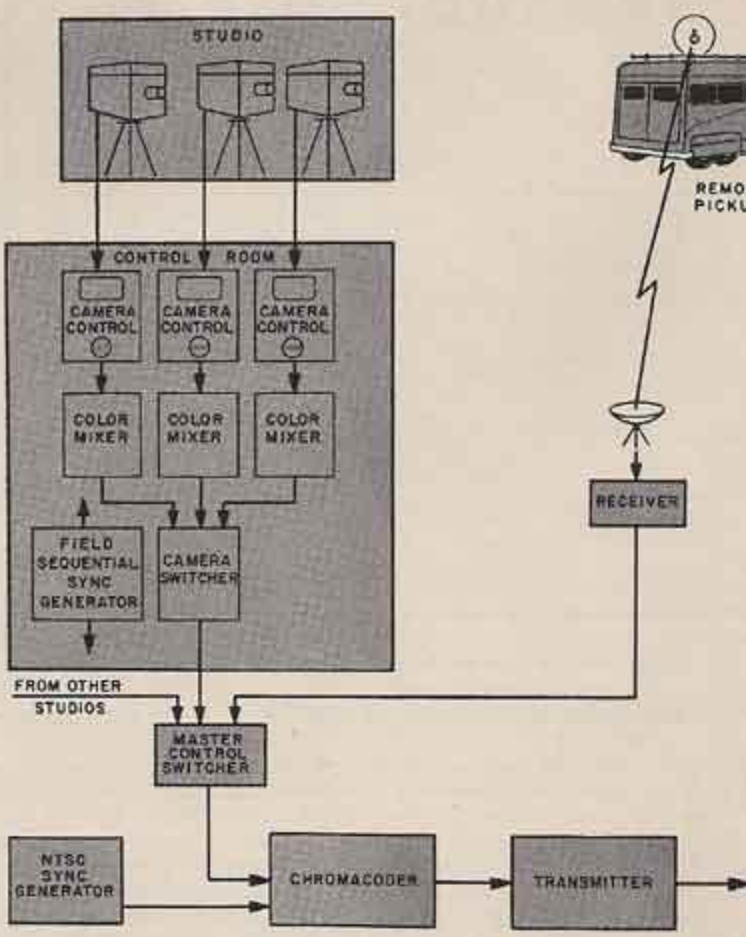
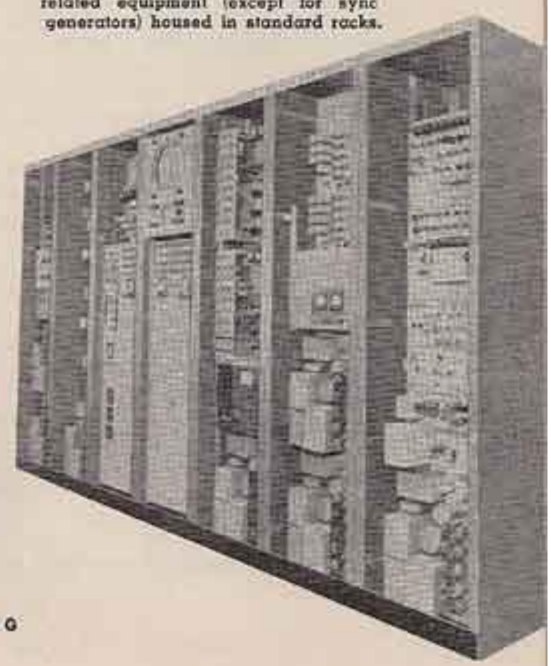


Fig. 4. Block diagram of the chromacoder system used with a number of different studio and remote cameras.

Fig. 5. Chromacoder, encoder, and related equipment (except for sync generators) housed in standard racks.



Chromacoder

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noise in the blacks, and stable operating characteristics.

Signals emanating from the CPS Emitrons go through low noise, high gain preamplifiers of feedback design to individual channel amplifiers. The channel amplifiers provide separate control of gain, setup, gamma, and clipping.

Emitrons are supplied with a composite blanking signal applied to the cathodes to extinguish the beam during retrace. This signal is formed from H and V drive pulses in the CPS Emitron blanking generator. The widths of both components of the signal are independently variable. Focus and deflection yokes specially designed to work with the Emitron are used in the chromacoder. As with the CRT sweep circuits, special consideration has been given to the circuitry of the Emitron sweep generator, linearity and stability being the prime design factors. In the chromacoder system of color television, the problem of registration appears only once, here in the rack-mounted converter, and an all-out effort has been made to simplify and stabilize the problem.

Related Equipment

The encoder receives the separate red, blue, and green signals from the channel amplifiers, and from these forms the *Y*, *I*, and *Q* signals specified by the NTSC/FCC standards. *Y* is the luminance or brightness component of the color signal, the one that is viewed on a monochrome receiver. *I* and *Q* are the "in phase" and "quadrature" signals respectively, which modulate the 3.58-mc. subcarrier in both amplitude and phase. The modulated subcarrier supplies the "chrominance" or color information. In order to detect the phase modulation of the subcarrier, a reference phase must be transmitted, and this is supplied by the "color burst" applied to the "back porch" of the composite signal by the encoder. The encoder has been carefully designed to be stable and easy to set up, with self-contained phase checking circuits.

A monochrome calibration monitor, combined with a unique switching unit, permits the observation of picture and waveform in any of the following combinations, without adjustment, at the touch of a button: R, B, G, RB, RG, BG, RBG, G-R, G-B, NTSC video, and sequential video (waveform only). Its prime function is in setting up the CRT's and CPS Emitrons for registration, linearity, level, etc.

Any existing sync generator may be used for NTSC color, but it must be locked to the color subcarrier of 3.579545 mc. rather than its own crystal or the power line. Sync generator adapters are available which provide the subcarrier frequency and a subdivided frequency of approximately 31.5 kc. to drive the existing sync generator.

For the sake of clarity, power supplies have been omitted from the block diagram. Seven regulated power supplies furnishing +285 volts at 900 ma. each are required. While most of the chassis have self-contained bias supplies, a regulated —150 volt supply is incorporated for the CRT and CPS Emitron controls. All filament transformers are supplied through an electronic 115-volt a.c. line regulator for greater operating stability. A separate, highly regulated, 12-volt d.c. source is added to provide yoke centering currents which are independent of other loads. A regulated high voltage supply of the r.f. type furnishes up to 30 kv. for the CRT's. All a.c. power required by the chromacoder, approximately 7-kva., 115-volt, 1- or 3-phase, is fed through circuit breakers for protection and ease of control.

The chromacoder, the encoder, and all the necessary related equipment, with the exception of the sync generators, are housed in seven standard racks. (See Fig. 5.) These may be located in the studio control room, or centrally in the station, remote from camera equipment.

When sequential color camera equipment is taken out on remote, only the color mixer suitcases and associated power supplies are added to the equipment required for a monochrome pickup. The extra equipment necessary to telecast parades, football games, etc., in color remains in the studio and is the same chromacoder used for studio origination. Figure 4 shows such an overall system from the remote cameras through a microwave link to the chromacoder and from studio cameras to the chromacoder. The studio sync generator is locked to the remote sync generator so that there will be no problems in switching from studio to remote or vice versa. Commercially available microwave equipment has been successfully modified to carry the wider bandwidth necessary with the sequential color signals.

Advantages

Some advantages of chromacoder colorcasting are as follows:

1. Because the cameras so closely resemble their monochrome counterparts and because the additional equipment necessary for color is housed in racks and not repeated for each camera chain, the initial investment required in a chromacoder system with two cameras is less than that for other presently used systems. As the number of cameras to be used increases, this advantage becomes even more apparent.
2. There are fewer expensive camera tubes used than in other systems, and for those which are used, cooling to give long life is no problem. Very satisfactory life has been obtained from the Emitrons in studio service in England, and longer life can be expected when they are used in rack equipment. With a two-camera system, the tube cost per hour is only 65% of that of other systems; and as the number of cameras is increased, the saving is even greater.
3. In preparation for a color show, it is necessary to set up only one piece of equipment where linearity, registration, and phase must be carefully adjusted, rather than having to go through all these steps for each camera to be used. As a result, the setup time is considerably reduced. The adjustments for strikingly beautiful color pictures are made on the sequential color camera chains where such adjustments are relatively simple. Only in the chromacoder must careful adjustments be made for color, and these are simplified because the equipment has more than ample control for all the variables encountered; the equipment has excellent stability once adjustments are made. Consistent results from camera to camera are obtained with very little effort.

There is no doubt that colorcasting requires more money, more space, and more effort than monochrome telecasting. The *General Electric* chromacoder colorcasting system, utilizing straightforward engineering design principles, allows the broadcaster to achieve the best color pictures while at the same time causing the least additional strain on his pocketbook and operating staff.

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