INCREASING INTEREST IN CLOSED-CIRCUIT TV and the public acceptance of color have created a need for a lowcost color camera. A complex, high-quality broadcast color camera can cost $90,000 or more. Although recent developments have brought the cost down for educational and industrial use, prices are still out of range for most amateurs and experimenters.

The camera described in this article was developed on the premise that an advanced experimenter or amateur could build a color camera without getting into extremely complex mechanical, optical, or electrical problems. All parts are easy to obtain. The two videcon tubes are standard low-cost black and white types. Color filters are low-cost and available at any glass company. To keep the cost, weight, and size to a minimum, a small black and white TV set is used to supply all voltages and scanning signals to the camera head. The camera uses only 12 transistors in addition to the black and white TV set. The optical system is extremely simple. The cost of the camera, excluding the case, is approximately $400.

Color processing

There is a little known process of using only two colors instead of three to generate color images. This theory dates back to 1914 when William F. Fox and William H. Hickley patented a color motion picture process involving a red filtered scene shown alternately with a green filtered scene projected in black and white only while the red filtered scene was projected through a red filter. The effect was later independently re-discovered by Dr. Edwin H. Land in 1955. This phenomenon has since become known as the Land Color Theory after articles by Land appeared in the proceedings of the National Academy of Science in 1959 and the May, 1959 issue of Scientific American. Dr. Land found that the human eye can perceive scenes in full color when the image is filtered through long- and short-wavelength filters, then recorded separately on black and white photographic film.

To recover the scene in full color, it is then only necessary to project the scene recorded on the two separate photographs, with a long wavelength light source illuminating the long wavelength photograph, and a short wavelength light source illuminating the short wavelength photograph. In Land’s process, the colors in the scene arise not from the choice of wavelengths, filters, or overall brightness levels, but rather from the interplay of longer and shorter wavelengths over the entire scene.

My camera system is similar to Land’s process. The two color filter wave lengths correspond to the wave length or combination of wave lengths, generated by the three illuminating phosphor colors in a conventional color picture tube. The filter for the long wavelength image, centered at
approximately 650 millimicrons, is red. The short wavelength filter, centered at approximately 475 millimicrons is cyan, a bluish-green. In effect the two color channels are a combination of the three primary colors. Inputs to the green and blue color difference amplifiers of the color monitor are combined, allowing the blue-green phosphor dots to produce cyan, corresponding to the cyan or short wavelength filter in the camera head. The red color difference amplifier and the red phosphor dots of the color monitor handle only the signal from the red or long-wavelength tube.

Colors hold true over a wide range of different red, green and blue images due to the interplay of the red and cyan signals. In fact, the only camera operating color controls are the red and cyan lens iris adjustments. The receiver contrast control may also have to be re-adjusted depending upon lighting conditions. The color receiver tint and color-level controls have no effect in this arrangement since the signal is not encoded to a NTSC signal.

Tests indicate that NTSC color encoding can be done by feeding the cyan signal to the combined blue and green color inputs, and sending the red to the normal red input of a commercial NTSC color encoder. With this arrangement, the camera output could be video taped or transmitted by a ham TV transmitter.

Extensive testing of both the conventional three-tube color system and the simpler two-tube system indicates of course, that the two-tube system cannot duplicate three-tube performance in all respects. The main difference being some averaging of colors along the junction point of the blue-green spectrum, some difficulty with shades of yellow and some hues of magenta. However, the system produces surprisingly good color. The colors are rich and vivid. Blues are blue, greens are green, and reds are red. Complex colors such as skin tones, browns, hair colors, etc. are reproduced well.

The advantage of using only two tubes instead of three, at least for the home experimenter or low-cost application, far outweighs the relatively minor additional color discrepancies encountered with the two-color process. These advantages include:

Camera registration, the art of overlapping images to perfectly coincide, is much simpler. The camera can be built with one-third less parts.

Camera sensitivity is greater since light must be divided only two ways instead of three. Optics are much simpler allowing the use of a simple cube prism to split the incoming light in two directions.

**How It Works**

Figure 1 is a block diagram of the entire camera system. Light from the scene first passes through a cube prism. The prism itself absorbs approximately 40% of the light. Approximately 50% of the remaining light is bent 90 degrees to the red lens. The prism is available from Edmund Scientific Co. The cyan camera lens gets a straight through view of the scene. Both camera lenses are Cosmicar 25 mm, available from Denson Electronics Corp. The prism must be placed before the objective lens so the glass in the prism won't affect the focal length of the lens. The color filters are placed between the lens and vidicon face plate.

The cyan filter consists of two layers of Plexiglas green No. 2414. The red

![Diagram](image-url)

**FIG. 1—BLOCK DIAGRAM of the camera head. Operating voltages and sync signals are supplied by a black-and-white TV receiver.**
filter is Plexiglas red No. 2423, one layer thick. Both yoke and focus coil assemblies are available from Denson Electronics. This assembly also contains the alignment magnets which are used to register the two images. These yokes are built to very close tolerances and register well. Don't be tempted to substitute another type of yoke.

Again, referring to the block diagram, the black and white TV feeds horizontal, vertical, scan, blanking, -12 volts, +300 volts, and 6.3 VAC to the camera heads. The output of the cyan vidicon is fed to the cyan preamp. A vertical sync pulse is added and the video amplified to approximately 1 volt VP-P. This output also forms the luminance signal and is fed to the color monitor's luminance amplifier to provide the black and white information. The cyan preamp also feeds the cyan amplifier where the signal is inverted and raised in amplitude to drive the grids of the G-Y and B-Y amplifiers. The grids are coupled together with a .5 μF capacitor.

The cyan preamp output is also fed to the sync clipper where the vertical sync pulse is inverted and sent to the color monitor's sync separator. The horizontal sync pulse is fed separately to the sync clipper in order to prevent contamination of the blue and green amplifier in the monitor. The red preamp output drives the red amplifier, which in turn drives the R-Y amplifier. The sync clippers, cyan amplifier, red amplifier and a -18 volt power supply are located in the color monitor so that all signals may be sent to the color monitor on a single 4-conductor cable. A multi-conductor cable is used between the black and white TV set and the camera head. This 2-piece configuration also allows the camera to be used hand-held. The camera head weighs 18 lbs.

Many camera builders will want to include the small black and white TV in the camera case to act as a view finder. The horizontal sync will have to be re-applied to the TV sync separator for operation as a view finder.

Do not use an AC-DC type TV with this project because of the shock hazard involved. A square sun shade on the front of the camera prevents stray light from striking the prism in bright sunlight. Paint the inside of the camera case black. The camera case is not commercially available and may be constructed out of sheet aluminum.

I found the easiest method of mounting the parts for mechanical alignment is to build each camera head as a separate unit. After both heads are tested and operate correctly, lay both heads and the prism on a wood mounting board. The camera is initially registered and adjusted mechanically, optically, and electrically while laying on its side. Remember, for good registration, every optical and electrical parameter—focal length, distance, scan amplitude, yoke alignment, optical and electrical focus adjustments—must exactly match the other channel. Finally, when all electrical adjustments and tests are complete, screw down the heads and mount the prism. The whole camera assembly is then placed inside the camera case. All camera tests and registration adjustments are made using a standard TV test pattern with a series of vertical color stripes glued to the top of the test pattern. The colors I use are red, orange, yellow, dark green, light blue, dark blue, and magenta.

Next month we will cover the camera heads, circuit details, modification of the two TV sets, adjustments registration, and final check out.
by GARY DAVIS

LAST MONTH WE PRESENTED THE color processing, block diagram, and general layout of a low-cost color TV camera. This month we will cover the camera heads in detail, including adjustments and registration.

The vidicon tube
Each camera head consists of three basic units. The vidicon-tube assembly, the video preamp and the deflection components. Before we discuss the camera circuitry, let's briefly examine the operation of a vidicon image pick-up tube. The tube contains a signal plate of a conducting metallic film, so thin that it is transparent. One side of this plate is coated with a thin layer of photo-conductive material, such as amorphous selenium. The optical image is focused on the opposite side of the signal plate. The photo-conductive material is scanned with an electron beam originating at the vidicon cathode.

The scanning beam deposits just enough electrons on each spot that itouches, to reduce the potential of that side of the metallic film to the cathode potential. However, during the interval

FIG. 2—PREAMPLIFIER for the cyan and red video channels. All components above the dotted line, except where noted, are duplicated for red video channel. A black-and-white TV receiver supplies the operating voltages, sync and blanking signals to the camera head.
CAMERA
$400

tetails and camera
overed. Next month,
the camera head to a color monitor

between successive scans, a charge
leaks through the photo-conductive
material in proportion to the illumina-
tion. The charge deposited on any par-
ticular spot of the photo-conductive
material the next time it is scanned, is
equal to the electrons that have been lost by leakage since the last
passage of the beam. The total current
of the electron beam and the capaci-
tance of the photo-conductive material
is in series with the external load res-
sitors.

The preamp

In this camera so much light is ab-
sorbed by the color filters and prism,
that only a very low level of light
actually strikes the vidicon photo-con-
ductive surface. Therefore, the video
amplifier must work with a very low
signal-to-noise ratio. The schematic
diagram of the preamp circuits are
shown in Fig. 2. Transistor Q1 should
be a low-noise type 2N4126, and may
have to be individually selected for
low-noise content after the camera is in
operation. One should not be satisfied
with the signal-to-noise ratio until with
nuisance illumination, the pictures are
about as noise-free as those received
from a local commercial TV station.
It will probably not be necessary to in-
dividually select the other amplifier
transistors.

The video amplifier should be
mounted inside a metal box to shield
the amplifier from extraneous signals.
It is important to use short leads and
the amplifier should be mounted on the
focus coil assembly so that the signal
lead from the vidicon target connector
to the video preamplifier input is no
longer than one inch in length. In deal-
ing with low signal levels at the vidicon
output, ground loops and sufficient
grounding between components be-
comes extremely critical. A general
rule would be to ground everything
possible with short ground leads, in-
cluding the lens mount and the lens.
Good results with my camera were ob-
tained with an unshielded wire for a
target lead. However, in metropolitan
areas or areas with strong RF signals,
a shielded wire may be necessary.

Vertical sync is added to the cyan
signal through diode D1 at Q1. The
addition of vertical sync slightly tilts
the video waveform. However, it has
negligible shading affect on the picture.
Capacitors C10 and C12 boost the
high-frequency response to increase
the upper frequency limit of the entire
video amplifier. Low-frequency nega-
tive feedback is introduced to each
stage individually by connecting the
bias resistor to the collector load resis-
tance. This arrangement further en-

FIG. 3—COLOR AMPLIFIERS and sync circuit. The video and sync outputs are connected
directly to the color difference amplifiers and sync separator of the color monitor.
Deflection and focus assembly

Due to the fact that the red camera head sees a mirror image of the actual scene, the phase of the deflection signal to the red yoke must be taken into consideration. Focus coil windings for both vidicon tubes should have the purple wire grounded (see Figs. 2 and 4), and the white/purple wires connected to −12V. On the vertical windings, yellow is not used. White wires are connected to their respective height controls R18 and R19. The green wires are connected together and common to T1. On the horizontal windings, the red wires are connected together. The cyan black wire is connected to point A2. The red channels' black wire is grounded. Both gray wires of the electrostatic shield should also be grounded. The blue wires are not used. With this wiring arrangement, the deflection assembly should be mounted with the focus coil lead exit-holes for the cyan channel opposite the mounting board. The red-channel focus coil lead exit-holes should be next to the mounting board. This arrangement applies to type CV101-1547 deflection assembly available from Densron Electronics.

The vertical deflection coils require 6 V P-P for proper deflection as shown on waveform B1. Each horizontal deflection coil requires 30 to 40 V P-P as shown on waveform A2. It should be noted that for proper operation, the camera requires waveforms and voltage amplitudes as shown. They are supplied by a small B/W monitor.

Blanking and sync

Transformer T1 supplies both the vertical sync and the vertical blanking signal. The center tap of the 2K secondary is grounded. Phasing should be observed with an oscilloscope insuring that the positive-going pulse is applied to test point C1. Capacitor C9 stretches the pulse and sets the amplitude to 7 V P-P. Capacitors C6 and C7 then apply the blanking pulse to cut off the vidicon cathodes during vertical retrace. C8 may have to be selected for use with some types of vidicons if black retrace lines appear in the picture. The other half of the secondary feeds a negative-going vertical sync pulse to diode D1. Polarity of diode D1 should be observed as shown on the schematic. A horizontal sync pulse is taken from point A2 and fed to the monitor separately.

Initial vidicon tube adjustments

The following adjustments are made with all voltages and scanning signals applied to the camera from the B/W monitor. Potentiometer R3 serves as a focus control. Initially, the beam control R9 should be adjusted for maximum resistance. The target control should be adjusted for about 40 to 50 volts at the center terminal. The focus control should be set about midway. The beam control should be adjusted until the beam of light and dark areas appear.

(continued on page 74)
The objective of this process is to get the magnetism levels at a low enough point so that all registration and centering adjustments for both the yokes can be made by simply rotating the alignment rings. With both camera heads in proper focus optically and electrically, it will be necessary to loosen the yoke hold-down screws, Fig. 4, to allow rotation of the yoke within the focus coil, to correct for vertical axis errors. It should also be remembered that exact positioning of the lens mount will alter the axis of the lens, changing the apparent vertical or horizontal centering in relation to the other channel.

The best construction approach will probably be to simply build each camera head as a black and white unit, thoroughly testing it without using the prism or color filters. When results are satisfactory, initial color registration can be attempted. Insert the color filters behind the lens mount. The edges can simply be taped in place. Be sure to allow the camera to warm up sufficiently before performing registration adjustments. Place the test pattern in front of the prism at the minimum distance at which you want the camera to focus. Adjust both lenses for nearest focus. Slide the cyan vidicon tube back and forth until the sharpest focus is attained. Re-adjust the electrical focus for sharpest image. Then using the adjusted cyan image as a reference, slide the red vidicon back and forth for best focus. Tighten the vidicon tube clamp (see Fig. 4). Adjust red electrical focus for sharpest image. Adjust the red alignment magnets to bring both images in register. It will be necessary to rotate yoke, adjust vertical scan amplitude and perhaps select values for resistor R22 for best registration. It will be necessary to repeat adjustments several times initially. The above adjustments can be made while viewing the picture in either cyan or red. When it is necessary to view a single channel, simply close the iris on the undesired channel.

**Final color adjustments**

As mentioned last month, the easiest way to adjust color is by adjusting the lens iris controls on a white test pattern with color stripes. Both images together should produce a good white from the test pattern. When the proper levels are set, the other colors should appear in the correct order. The only discrepancy will be with yellow, which may appear as a yellowish-beige. To insure good color fidelity, the red, blue and green controls on the color monitor must be adjusted to produce a per-
fect gray raster with the camera on and operating, but with both iris controls closed. These adjustments will of course, be critical due to the fact that the tint control has no effect with this particular setup. Due to the high amount of light loss through the prism (each tube receives only 30% of incoming light), a very high amount of illumination will be required for good color fidelity. I use No. 2 photo-flood bulbs. If the scene has a slight pinkish cast, or the yellow appears too pink, it is possible the light bulb is too close to the subject. The camera sensitivity could be greatly increased with a higher efficiency prism or perhaps a mirror optic system which would overcome much of the light loss encountered with the present prism.

It is anticipated that some camera builders may be able to locate high efficiency prisms or low light loss semi-silvered mirrors. It is possible by using a more complex mirror arrangement to put both camera heads in line, thereby making a somewhat smaller and more compact camera. Inasmuch as this is the first known home experimenter or amateur type of live color camera, it is recognized that many modifications, changes and improvements could be incorporated by individual camera builders. For example, by using the camera in conjunction with a commercial N.T.S.C. color encoder, some inherent color deficiencies may be correctable.

Next month we will cover construction of the color monitor sync circuits, red and cyan amplifiers, as well as modification of the two TV sets for use with the camera.

Ultrasonic measurement system will aid medical researchers

A new ultrasonic measuring system developed recently by RCA will provide medical researchers with previously unavailable precise measurements of ultrasonic diagnostic devices. In doing so, it may increase and speed up the use of ultra-high-frequency sound in detecting malignancies in human tissue.

Ultrasonic techniques have been preferred for many types of research because they enable body tissue features to be observed that can't be seen by X-ray or optical techniques. But up to now, researchers had no way of knowing precisely the intensity of the waves they were using. This created difficulties in determining exactly what effect increasing or decreasing the intensity or frequency of the sonic waves had in detecting malignancies or tissue malformations.

To measure the output of an ultrasonic transmitter with the new technique, it is placed in a water tank containing a gold-plated pellicle 15 cm in diameter and a few millimeters of a meter thick. The pellicle, or membrane, is so thin as to be transparent to sound and follows exactly the microscopic motions of the water that make up the sound waves passing through it, vibrating in proportion to the intensity of the sound waves reaching it.

Its motion are sensed by scanning a laser beam across the pellicle horizontally and vertically. The reflected beam is minutely altered (phase-modulated) by the pellicle's vibrations. An interferometer compares the modulated beam with an unmodulated reference laser beam and produces electric signals that can be measured by conventional electric meters.

When the system is used to measure ultrasonic waves passing through tissue, the waves are transmitted through or reflected from the specimen and imaged, or focused, onto the pellicle by plastic acoustic lenses. The pellicle is so tightly coupled to the water that its vibrations at any point are determined by the amount of sound that reaches that point. That amount depends on how much sound was imaged through the specimen. Mapping the small motions of the pellicle with the laser interferometer technique provides an image of the specimen on the cathode-ray display tube.

With a 15-milliwatt laser, the system has a potential sensitivity of about 5 nanowatts-per-square-centimeter, corresponding to a membrane displacement of .007 anstroms at 1.5 MHz. The system has a wide frequency response—about 0.5 MHz to approximately 10 MHz.

INTERNATIONAL FM 2400CH FREQUENCY METER for testing mobile transmitters and receivers

- Tests Predetermined Frequencies 25 to 1000 MHz
- Extended Range Covers 950 MHz Band
- PIN Diode Attenuator for Full Range Coverage as Signal Generator
- Measures FM Deviation

The FM-2400CH provides an accurate frequency standard for testing and adjustment of mobile transmitters and receivers at predetermined frequencies.

The FM-2400CH with its extended MHz. The range covers 25 to 1000 frequencies can be those of the radio frequency channels of operation and/or the intermediate frequencies of the receiver between 5 MHz and 40 MHz.

Frequency Stability: ± 0.005% from +50° to +104°F.

Frequency stability with built-in thermometer and temperature corrected charts: ± 0.00025% from +25° to +125° (0.00025% special 450 MHz crystals available).

Self-contained in small portable case. Complete solid state circuitry. Rechargeable batteries.

FM-2400CH (meter only) ...................... $95.00
RF crystals (with temperature correction) ... 24.00 ea.
RF crystals (less temperature correction) .... 18.00 ea.
IF crystals ................................ catalog price

Write for catalog!
Build this COLOR TV CAMERA

Concluding this series, we show you how to modify the two receivers that are to be used as the sync source and color monitor.

by GARY DAVIS

The horizontal yoke drive pulses are obtained from a second unused winding tap on the flyback transformer. This tap provided the correct waveform, but at double the needed amplitude. As the flyback transformer on this set is a sealed unit with only the taps exposed, the camera horizontal yokes were wired in series and connected to the tap through a 2 μF capacitor. On other sets, different approaches must be taken. Two possible approaches are shown in Fig. 6. Transformer T2 consists of ten turns of well-insulated hook-up wire, loosely wound around the flyback. On most sets the voltage amplitude is approximately 4V P-P per turn. The voltage at the output of T2 must be exactly correct, as added resistive elements such as width controls would alter the horizontal waveform. The horizontal deflection coils could be connected in parallel, or by doubling the number of turns on transformer T2, they could be wired in series. Each horizontal deflection coil requires 30 to 40V P-P for proper deflection. Figure 6 should serve only as a starting point. Some added experimenting may be necessary. All generated waveforms should be checked with an oscilloscope to observe amplitude and waveform polarity. All waveforms should be close to those shown on the waveform chart before proceeding. It is important that the modifications do not affect normal operation of the TV set, as it can be used as a monitor until you are ready to modify the color receiver. It is also convenient if the set can still be used as a regular TV when the camera head is disconnected. Details of the sheetmetal case are shown above.

(continued on page 73)
Color monitor

The color receiver I use is a RCA CTC31 chassis. All part references mentioned can be found in the RCA Field Service Guide for RCA Color TV Receivers 1969-1970, Volume 3, #ERT-202. The modifications described here cover the RCA CTC31 chassis only. However, they outline the general procedure necessary to modify a typical color receiver so that it may be used as the color monitor.

Four separate signals are fed to the receiver: cyan video, red video, horizontal sync and vertical sync which is mixed with the cyan video in the camera head. The cyan video signal serving also as the luminance signal is connected directly to the set's video path immediately after the video delay line. This is point AE on the circuit board PW700. The second video IF amplifier tube V204 should be removed from the set to prevent noise from the tuner from mixing with the added luminance signal.

The cyan signal is amplified and inverted by transistor Q6 to drive both the G-Y and B-Y amplifier grids simultaneously. The grids are joined together by a .5 μF capacitor so the signal arrives at pin 9 of both 6GH8-A tubes, V701 and V704-a. The red signal is amplified and inverted by transistor Q5, then sent to the grid of the R-Y amplifier-pin 9 of V707-a.

Sync circuits

The negative-going vertical sync pulses contained in the cyan signal saturates transistor Q7 (see Fig. 3). This inverts the pulse and provides an 18V P-P vertical sync signal. Transistor Q8 is saturated by the incoming horizontal sync pulse fed separately from the camera head. The common collector load resistor R29 provides the 18V P-P composite sync signal which is applied to the sync separator-tube grid—Pin 9 or the 6GH8-A, V206-b.

Although many sets will accept signals similar to those described above, other sets may require signals of different amplitude and color signal phase. A general guide when modifying your set would be to simply observe correct amplitude and picture phase with an oscilloscope while the set is tuned to a commercial color TV station. Then try to insert the red, cyan, and sync signals from the camera and amplifier unit at similar amplitudes and phases at their respective points. Single stage phase inverters may be added in the red, cyan, and sync circuits if necessary, or the signal amplitudes may be altered as required for your particular set.

COLOR TV CAMERA

I have finished reading the first two parts of the construction article on building a color TV camera that appeared in the July and August, 1975 issues of Radio-Electronics.

I already ordered the parts and am waiting for them to arrive. The assembly looks fairly easy and not to complicated. However, there is one area that is not fully clear. This is the assembly of the vidicon, deflection yoke, lens and filter. The interior photos in the July issue shows the preamp assembly mounted over this assembly. Can you help?

Thanks for another interesting and useful project.
C. A. STROBEL
New York, N. Y.

You are absolutely right! The interior photos do not show this assembly and there is nothing in the third and final part of this article that will help clarify this. So, we contacted Gary Davis and he was kind enough to provide some photos. They appear above.

How about the rest of our readers. Drop us a line and let us know how you're making out with this project.—Editor

Courtesy of Gary Davis