Synchronizing The COLOR WHEEL

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Fig. 1. Color converter with motor control, saturable reactor, and alternator.

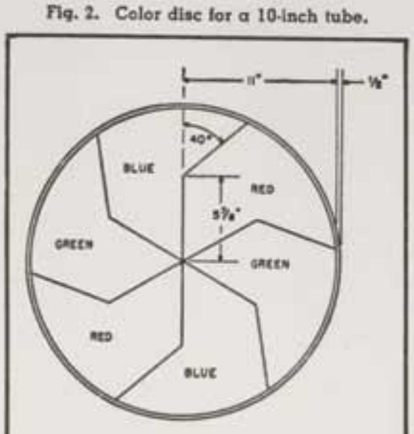
Covers both manual and automatic methods and includes complete details on the CBS system.

SINCE the inauguration of regular commercial broadcasts using the *CBS* color television system, many technicians have become interested in constructing converters or adapters to receive pictures in color. This article covers one of the most tricky aspects of this conversion, *i.e.*, the method of keeping the color wheel rotating at exactly the right speed.

In order to receive *CBS* color transmissions in black and white, the horizontal and vertical sweep frequencies of the receiver must be changed to 29,160 and 144 cps respectively. When this is done a black and white picture can be seen. To inject color, a rotating disc or drum must be placed in front of the picture tube. Since the drums for this purpose are not yet available we shall discuss only the disc or color wheel. The diameter of the disc must be slightly more than twice the diameter of the picture tube and this fact limits practical color wheels to 12 inch picture tubes at the present. In order to inject color into the black and white picture, the color wheel contains blue, green, and red filters which appear in front of the picture tube at the same time as the corresponding filter appears at the camera. As shown in Fig. 2, the color wheel contains six segments, two of each primary color. The shape of the color segments is chosen to cover a maximum screen area and keep the wheel diameter to a minimum. Since the wheel has to rotate at 1440 rpm it must be constructed to provide the least wind resistance and to prevent buckling or flapping. Commercially available color wheels are made by laminating the color filters between two sheets of clear plastic. This provides a fairly rigid disc, slightly more than 1/16 inch thick. For anyone constructing a disc we would advise a similar procedure, using a good plastic cement and clamping while drying. Needless to say, the sequence of colors must be correct. The colored filters must be the same shades as those used in the studio. *CBS* has recommended two sets of filters. One set consists of blue, green, and red filters made up of *Monsanto "E."* Set No. 2 comprises a blue filter of *Eastman* #47 (1/2 density), a green filter of *Monsanto* #61 (4/3 density), and a red filter of *Eastman* #26.

With the No. 2 set of filters the face of the picture tube should be covered with a yellow, *Eastman* #6 filter. This is not part of the color wheel but is taped or glued to the tube permanently. All of the filters are manufactured either by the *Monsanto Chemical Corp.* or *Eastman Kodak Corp.*, and should soon be available to the trade. If other colored filters, having either a different hue or light transmission characteristic are used, incorrect colors will result. The loss of color fidelity will be especially pronounced in such mixed shades as flesh and pastel colors.

Fig. 2. Color disc for a 10-inch tube.



A few words should be said here about the limitations of the *CBS* system in order to keep the experimenter from needless work. Depending on the brightness of the picture, flicker will be experienced unless there is absolutely no 60 cycle hum in the video or sweep sections. Color ringing, the effect of different colors appearing when a particular object moves quickly, is also inherent in the system. Color break-up will occur when you blink your eyes, tilt your glasses, or make any swift motion with the head. In this event the three primary colors become visible for an instant. Another thing to expect is lack of brightness. The light losses through the colored filters may amount to as much as 90%, requiring a really bright picture. This can be achieved by using an aluminum backed screen such as the 10FP4 uses, and operating the tube at about 12 to 15 kv. Turning off the room lighting will also help. As a final warning we should mention the effect of the color of the picture tube screen on the final color picture. As every service technician knows, it is rare to find two tubes that have exactly the same screen color. A wide range of purple, blue, and yellowish white is found among picture tubes. Since the screen light provides the "white" of the color picture, its color will have a considerable effect on the final picture. With the identical color wheel, entirely dif-

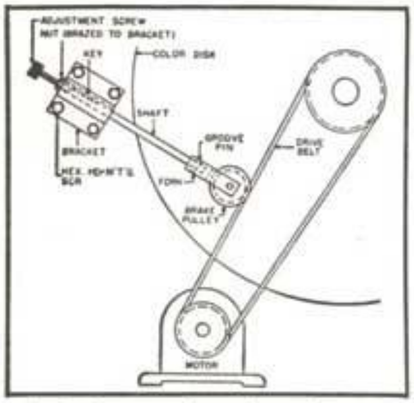


Fig. 3. One type of speed control system.

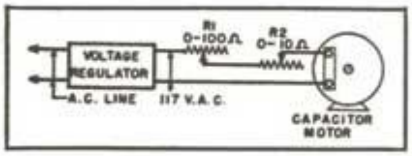


Fig. 4. Simple manual speed control circuit.

ferent flesh tones, pastel shades, and mixed colors will be obtained if different picture tubes are used. The best compromise is to select a picture tube having as pure white screen as possible.

As mentioned before, the speed of the color wheel is 1440 rpm. If only one segment of each color were used, the speed would have to be doubled. But since the six segment wheel is the most practical we will consider only a wheel speed of 1440 rpm. To get a motor operating at that exact speed is quite difficult. Most motors are designed to operate between 1600 or 1800 rpm unless they have been especially designed for a particular application. It is true that most a.c. motors can have their speeds adjusted by varying the supply voltage but this is not a practical way to get a speed of 1440 rpm since a lot of power would be wasted and the motor would operate under unfavorable conditions. Experience has shown that the best arrangement is one where the wheel is driven through gears or belts with a suitable ratio to provide proper wheel speed while operating the motor at its rated voltage and speed. For home use, a single-phase, a.c. motor is suitable. Depending on the size of the wheel and the friction that must be overcome, this motor can be either a condenser, inductance starting, or a shaded pole type. The last type is suitable for very small wheels since it has a rather low starting torque. The size of motor used again depends on the load and on the availability. In general, anything between 1/20 and ⅛ hp. can be used. At the time of writing several manufacturers are preparing to merchandise motors and control units for the *CBS* system and these, of course, are sure to do the job correctly.

Before describing the different methods of controlling the speed of the color wheel we should mention one more important thing to watch. "Color phase" means the relation between the color filters at the receiver and transmitter. For example, if at the transmitter the red picture is scanned while the blue filter is in front of the picture tube at the receiver, wrong color phase results. The singer's lips will be blue, her hair green instead of black, and her skin may have a purple tinge, etc. It is possible to lock the wheel in at the correct speed of 1440 rpm and still get incorrectly colored pictures if the color phase is wrong. *CBS* receivers have a simple cutout switch to overcome this. The a.c. is cut off for an instant, slowing the wheel down just enough to catch the right color phasing again.

Manual Speed Control

The simplest method of controlling the speed of the color wheel is to control the voltage at its driving motor. The capacitor type a.c. motor usually used for this purpose is quite sensitive to voltage changes. It would therefore appear simple to connect a variable resistor in series with the motor and adjust it by hand until the speed is just right and correct color pictures appear. Unfortunately, even the least voltage change may shift the motor speed ever so slightly but enough to lose color synchronization. One solution is to connect a constant voltage transformer between the motor and the a.c. line, and then keep adjusting the rheostat until the proper speed is reached and maintained. This system is quite feasible for experimental purposes where constant adjustment is not objectionable. In Fig. 4 the electrical circuit for such a scheme is shown. Note that two power type resistors are used, one for rough and the other for vernier adjustments.

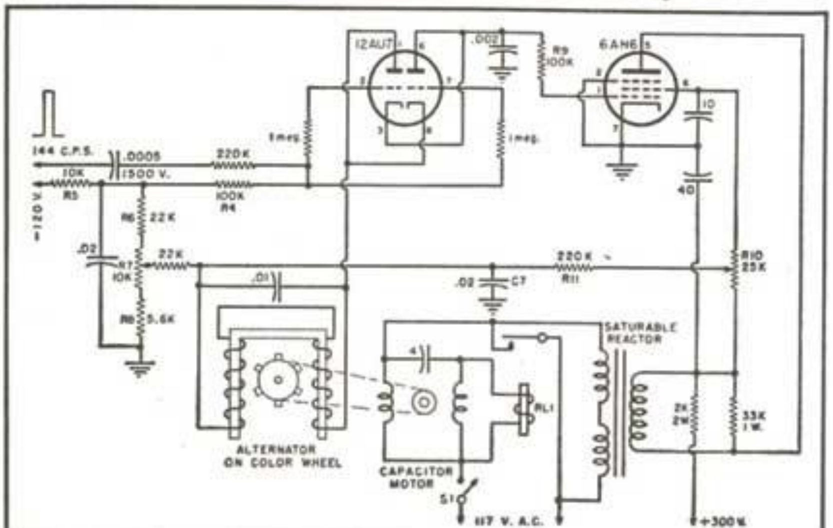
Another scheme for keeping the color wheel synchronized manually is shown in Fig. 3. To maintain constant a.c. voltage at the motor a constant voltage type of transformer should be used. The actual speed adjustment is made by controlling the load the motor must pull. The original arrangement of motor speed, pulleys, and wheel speed is such that the device runs slightly faster than the correct speed. When the brake pulley is then pressed against the belt, as shown in Fig. 3, the load is increased and the motor speed is correspondingly decreased. The pressure on the brake pulley is determined by the position of the screw pressing down on it and this permits a pretty exact adjustment. In actual operation we have found that this mechanical control method is somewhat better than the electrical method, although the latter permits controlling the wheel from anywhere in the room, a feature which the screw arrangement does not permit. It should be emphasized, however, that either method is usable only for experimental work and not at all suitable for commercial color receivers or converters.

The photograph of Fig. 7 shows a small color wheel with a rather simple manual speed control. The vertical motor shaft has a driving pulley mounted at the upper end. The rim of this pulley provides friction drive for another disc mounted at a right angle to the motor pulley on the wheel shaft. The control is provided by the bottom lever which actuates a screw arrangement forcing the motor shaft slightly up or down. The up or down motion determines the speed ratio between the motor driving pulley and the disc mounted on the wheel shaft. It changes the disc diameter against which the rim of the motor driving pulley works. Fig. 7 is a small viewing unit designed by *Celomat Corp.*, with *Monsanto* filters, and used in earlier days of the *CBS* color television system.

Automatic Speed Control

There are many different schemes available for industrial motor control, but few of these are applicable for the *CBS* color system. The main require-

Fig. 5. Circuit diagram of the CBS color disc synchronizing system.



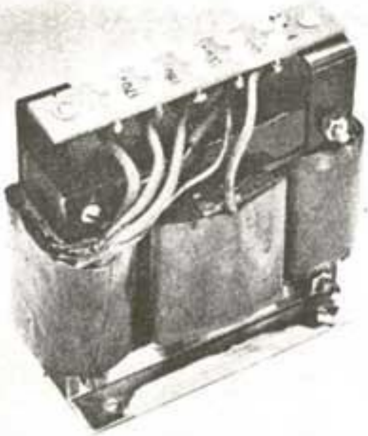


Fig. 6. The saturable reactor used by CBS in its color system.

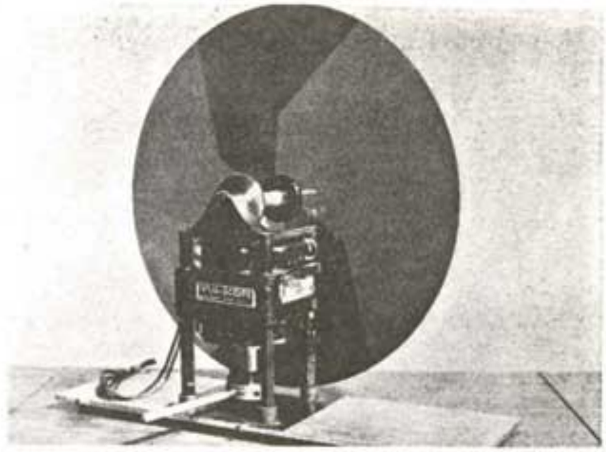


Fig. 7. Celomat Corp.'s manually-controlled color disc assembly.

ment here is that the motor speed be absolutely correct and not even a few degrees of phase difference or slippage can be tolerated. Another limiting factor in *CBS* color receivers is that the motor must be capable of operating from a single phase 60 cycle source and its speed should not vary with variations in line voltage. Many technicians felt that it would be easiest to use a motor operated from a 144 cycle source and then supply its power by amplifying the vertical synchronizing pulses. Unfortunately the current required for any suitable motor would run to several amperes and only a few transmitting type tubes that could supply so much current are available. The required "B plus" supply and the tubes themselves make this economically unfeasible.

Before going into other possible solutions of the problem, we would like to present the *CBS* method for automatic color sync. The circuit for this system is shown in Fig. 5. At the first glance it becomes apparent that this system uses two conventional vacuum tubes, a capacitor motor, and a saturable reactor. The saturable reactor is a device rarely used in radio work and therefore merits some explanation. The inductance of any iron core coil depends on the magnetic flux in the iron core. The relation of flux and coil current can be represented by a curve which rises gradually and then levels off. If the core and coil are so designed, the knee of the curve can be made either sharp or gradual. In a saturable reactor two coils are wound on one iron core. One coil is the control coil and only d.c. is passed through it. This d.c. controls the amount of flux in the iron core. The second coil is used in series with the a.c. line and represents an impedance to 60 cycle a.c. The inductance of this coil, therefore its impedance, depends on the iron core flux which, in turn, is controlled by the d.c. through the first coil. In actual operation the a.c. coil acts as a variable resistor in series with the motor and the amount of resistance is determined by the d.c. control voltage across the d.c. winding on the saturable reactor core. Refer to Fig. 4 and note that the motor speed is controlled by a series resistance R_1 and R_2. In the automatic circuit of Fig. 5, the series resistance is represented by the two-section coils at the left of the saturable reactor core while the controlling action is provided by the right hand coil and its associated networks. An over-all view of a commercially-built saturable reactor, as used by CBS, is shown in Fig. 6.

When the "off-on" switch is closed, the relay contacts will be closed and the saturable reactor will be shorted out. The full a.c. line voltage is applied to the capacitor type motor which then starts and gathers speed. The motor drives the color wheel through a belt and pulley arrangement so designed that at the approximately correct motor speed the color wheel runs at 1440 rpm. A small alternator is mounted on the shaft of the color wheel. This is effectively an a.c. generator having two stationary field poles and six rotating segments. As each segment passes between the poles it changes the magnetic flux between poles and thus a voltage is induced in the field windings. Each segment represents a segment of colored filter in the color disc. Thus the resulting a.c. induced in the alternator field coil will be an indication of the speed of the color wheel. Depending on the design of the alternator field and segments, the voltage obtained can be in the form of pulses very similar to the vertical sync pulses in the color TV set. In Fig. 5, one side of the alternator is connected to the plate and second cathode of the 12AU7 phase comparer. The 144 cycle vertical sync pulse is connected to the control grids of both sections of the 12AU7. The voltage divider, R_5, R_6, R_7, and R_8, serves to establish the fixed bias on the grids of the phase comparer tube. R_7 is usually called the "color phase control" because it sets the relationship between the sync pulse and the pulse picked up from the color wheel by the alternator. R_{10}, R_{11}, and C_1 further help in setting the d.c. operating level for the phase comparer. R_{10} is usually labeled "anti-hunt control" because it is adjusted to permit smooth action of the entire circuit. The operation of the 12AU7 as a phase comparer is basically not much different from the action of the 6AL5 phase detector in the "Synchrolock" a.f.c. system (*RCA* 630). The 6AH6 control tube obtains its grid bias through R_9, the 12AU7, and resistors R_5, R_6, R_7, and R_8. The bias voltage depends on the setting of the "anti-hunt" and the "color phase" controls and, most important, on the current passed through the 12AU7. Since this current is dependent on the phase relationship between the sync pulse and the alternator pulse, this will control the bias on the 6AH6. The 6AH6 control tube is a simple d.c. arrangement with a fixed plate current which flows through the d.c. winding of the saturable reactor. The only factor which will vary the plate current will be a variation in the grid bias. Whenever the grid bias becomes more negative, less plate current flows and the saturable reactor contains less flux. Reduced to the familiar terms of the horizontal a.f.c. circuits found in present TV receivers the action of this circuit is as follows: the incoming sync pulses are compared with the locally generated pulses. An error voltage is developed which is used as grid bias for the control tube. The plate current variation of the control tube, due to the error voltage, determines the impedance in series with the motor.

Once the motor has reached approximately full speed the relay opens its contacts and the saturable reactor is connected in series with the motor. The immediate reduction in line voltage at the motor results in reduced speed. If the speed is much below the correct one, the 12AU7 phase comparer will not be able to correct it. It may take a few seconds until the motor speed is near enough to the correct one so that the automatic control circuit can take effect. The reason for shorting out the saturable reactor during the starting period is that a relatively large starting current is required which would develop a large voltage across the reactor coil and greatly reduce starting

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The Color Wheel

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efficiency. It should be pointed out that the 12AU7 phase comparer can develop error voltage if the wheel is too slow or if it runs too fast. In one instance the error voltage will be more negative than the steady-state bias, in the other instance it will be less negative. The technician must adjust both the "color-phase" and the "anti-hunt" control carefully when the color wheel is in sync so that slowing or speeding of the wheel will be corrected properly. If it appears that on slower speed the control circuit tends to slow it up even more, connect the leads now going to pins 3 and 6 of the 12AU7 to pins 1 and 8 and *vice versa*.

In some early models the *CBS* sets used modifications of this circuit, some containing a magnetic brake winding on the motor to bring it closer to the correct speed. Other versions include a d.c. relay, operated through a selenium rectifier and filter, several different ways to reduce the motor speed permanently, and a special button which cuts the a.c. off for an instant to take care of the eventuality that the motor locks in at the wrong color phase. We have omitted these modifications here and presented only the essential features of this circuit. At the time of writing the circuit shown in Fig. 5 is the basic system used in the first *CBS-Columbia* receivers and most of the other projected models announced to date.

The saturable reactor method seems to be the most widely used at the present time, but other automatic systems are under consideration. The one which shows the most promise so far is one using a synchronous motor. This is a type of motor which is not affected by the magnitude of the a.c. line voltage but runs in relation to the supply frequency. The motor used in electric clocks is of that type. Such motors can be operated only at a speed which is a multiple of the line frequency and for 60 cycle operation the most widely used has a speed of 1800 rpm. Assuming that we have a motor which will run at exactly 1800 rpm and will change its speed only as the 60 cycle line frequency is changed, the problem is to have it drive the color wheel at 1440 rpm. The obvious solution would be a set of gears. Aside from the expense, the noise and vibration of most gear arrangements makes this impractical for our purpose.

A rim drive arrangement similar to that used in phonomotors is not practical because of wobbling and the general construction of the color wheel. The best solution is a V-belt drive with pulleys of proper proportion. Most V-belt arrangements have considerable slippage which can't be tolerated in this application. Thus it may be advantageous to use a toothed belt and pulleys having internal notches. For experimental purposes a regular V-belt will be satisfactory, but if this system is used in a commercial set, a toothed belt may be required. If the motor pulley, running at 1800 rpm, has a diameter of 2 inches, the pulley on the wheel rotating at 1440 rpm must have a diameter larger by the same ratio as the speed difference.

$$\frac{1800}{1440} = 1.25$$

$$2 \times 1.25 = 2.5 \text{ inches}$$

Thus the correct diameter for the pulley mounted on the color wheel shaft is 2½ inches. This is the inside, or useful, diameter for both pulleys.

At the present time the *CBS* color telecasts originating in New York are synchronized to the local a.c. line. Use of a 60 cycle synchronous motor is therefore entirely practical in this locality. However, in suburban areas where the power is furnished by a different company and may not be synchronized to the same mains as the *CBS* station, a synchronous motor may show phase slippage and lose the correct synchronization.

The third type of automatic speed control for the color wheel makes use of a gas filled electron tube, the thyratron. This is a tube which permits very small changes in grid voltage to control large plate currents. In modern industry this type of tube is used as a power rectifier and the grid controls the amount of current passed. Since the output of a thyratron is a pulsating d.c. it is usually used in conjunction with d.c. devices. For our application it is possible to utilize a low-voltage d.c. motor such as the 12 or 24 volt types presently available on the surplus market. The motor speed is directly proportional to the d.c. voltage supplied and this voltage can be controlled by the thyratron. The grid bias for the thyratron could be obtained from a phase comparer and alternator as described previously and shown in Fig. 5. By proper selection of circuit components the bias can be set so that the amount of current passed by the thyratron is sufficient to run the motor at the proper speed. To obtain the correct d.c. voltage for the motor, a stepdown transformer is connected between the a.c. line and the thyratron. It is understood that the motor speed and the correct 1440 rpm rotation of the disc must be correlated by means of suitable pulleys just as in the previous systems. The cost of thyratrons, stepdown transformers, and the right d.c. motors is hardly less than the cost of the components used in the saturable reactor system. Both systems perform equally well but until a lot more units have been built and tested it is impossible to say which method of synchronization is better. It should be emphasized again that to date no manufacturer has produced any color receivers in production quantities nor has any particular design been proven superior. Experimentation and development are still the order of the day rather than mass production.

In conclusion we would like to describe a complete unit, such as shown in Fig. 1, that can be put in front of a set adapted for the *CBS* system and used to inject color into the picture. The color wheel itself, its diameter slightly more than twice the diameter of the picture tube, is the largest item in the converter. For silent and efficient operation, the shaft of the wheel should be mounted in a very fine, silent type ball or roller bearing. The color wheel housing can be either square or round, but should be completely closed so that the air inside rotates with the wheel thereby reducing noise and wobbling. A screen cut-out is located in the housing where the picture tube shows through. In some instances the outer screen cut-out contains an enlarging lens to produce a bigger picture. It should be kept in mind, though, that such a lens will reduce the brightness by introducing additional light loss and will restrict the viewing angle somewhat. The motor and belt driving mechanism are usually located on the side facing the TV set and have an additional cover and housing. The motor mounting is usually a rubber base or else vibration-proof rubber washers are used to eliminate vibration and noise. The use of a thick housing for the belt and pulleys also helps reduce noise.

For commercial use the *Webster Corp.* of Chicago has announced some converter models similar to the one described before. These models employ accurately balanced color wheels, special motors, drive mechanisms that are practically noiseless, and an automatic control system based on the use of a saturable reactor. Other companies are working on the design problems for a good color converter but there is room for the ambitious technician or experimenter who can come up with some novel solutions to these problems.

Although building and adjusting a color wheel may seem involved, it can provide valuable training for the tyro color technician. —30—