TOPICS IN COLOR TELEVISION

by

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THE DESIGN OF RECEIVER COLOR WHEELS FOR USE IN FIELD SEQUENTIAL COLOR TELEVISION SYSTEMS

Introduction

In the CBS field sequential system of color television, the camera views the televised object through a set of rotating color filters; that is, the camera sees in cycles first a red image, then a blue image, then a green image.

At the receiving end, the cathode-ray tube screen is viewed through a similar set of filters so that the eye sees the red, blue, and green image components in such rapid sequence that the three primaries are added by the retentivity of the eye to give the impression of the image in full color.

Purpose

Because of the lack of published information this paper was written to show how a color wheel was designed for use in a field sequential color television system.

Method of Design

In the design of the color wheel, the primary problem was to determine the shape of the filters needed in a rotating opaque disc in order that the scanning beam could be seen as it moved across the raster. Later it was learned that the disc need not have been opaque. Since the size of the raster, the relation of the center of the color wheel to the raster, and the number of segments in the color wheel were known, the shape of the filters necessary in the rotating disc could then be determined in the manner illustrated in the following example.

As a six hundred r.p.m. synchronous motor was available, and since by our choice of standards each field occupied a time of 1/120 second, then the color wheel had to have twelve segments. Each segment therefore had to occupy an angle of 30 degrees. Drawn to scale were the raster and the center of the color wheel in relation to the raster. Also the radial OB was drawn as shown in Fig. 1.

During the time of one field the disc rotated through 1/12 of a revolution or 30 degrees. Since there were 262½ horizontal lines in one field (5), the rotation of the disc during the scanning of one horizontal line was $\frac{1}{262\frac{1}{2}}$ x 30 degrees. This small rotation of the disc was neglected. Because the horizontal scanning of one line took only $\frac{1}{15,750}$ second (4), it was assumed that the horizontal scanning of one line occurred instantaneously.

The position of the radial OB was considered at a time t_1. It was assumed that the horizontal scanning of the first line occurred during this instant. Thus it was obvious that there must be a thin filter element in the disc from A to B so that the beam could be seen as it moved across the tube face.

Then time t_2 was considered, when the last line of the raster was being scanned. This scanning occurred when the disc had rotated through an angle of $30(\frac{262\frac{1}{2}-n}{262\frac{1}{2}})$ degrees, with n representing the number of horizontal lines in the vertical blanking interval.

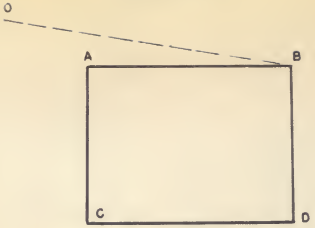


Fig. 1. [illegible] the raster and the [illegible] of the color wheel in [illegible] the raster.

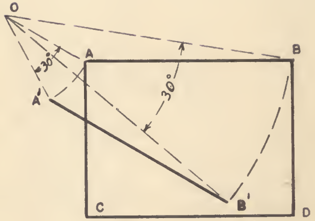


Fig. 2. The [illegible] of [illegible] time [illegible].

During these n lines no picture was being transmitted and consequently these had to be subtracted from $262\frac{1}{2}$. Since the magnitude of n was usually 15 to 22 (5) the term $\frac{n}{262\frac{1}{2}}$ was neglected, and consideration was given the last line of the raster as it was being scanned 30 degrees later than the first line. It was apparent that a filter element had to exist in the disc in such a position that the scanning action from C to D could be seen. The filter element through which the scanning action from A to B was seen had meanwhile moved downward to A^1B^1 as shown in Fig. 2. At this point two filter elements had been established, one at the beginning of the scanning process and one at the end.

For seeing the scanning action somewhere between these two limits, additional filter elements had to exist somewhere between A^1B^1 and CD. The filter element necessary to see the center line EF in the act of being scanned was determined as shown in Fig. 3.

Other filter elements could then be determined in a similar manner. The addition of the filter elements necessary to observe all of the lines as they were being scanned produced the shape of the entire filter. This shape is shown in Fig. 4.

If the disc contained filters, such as shown in Fig. 4, that were spaced at 30-degree intervals around the disc, the scanning of successive fields could then be observed. By placing a red filter in the first segment, a blue filter in the second segment, and a green filter in the third segment, one could see the scanning of the raster in three different colors as the disc rotated. By virtue of the persistence of vision, these three colors combined

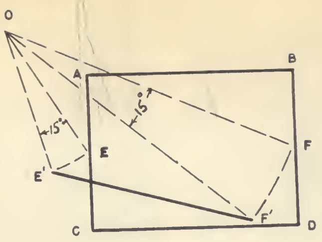


Fig. [illegible]. This figure [illegible] the [illegible] [illegible] through which [illegible].

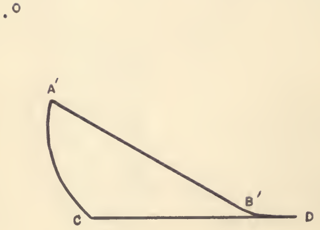


Fig. 4. The shape [illegible] [illegible].

additively to produce a color television picture.

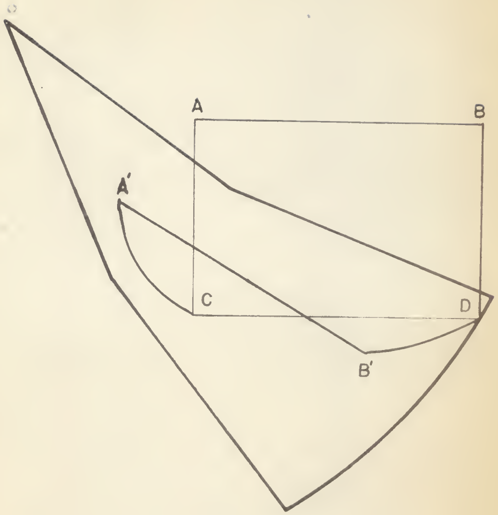
Since no light was viewed through the remainder of the disc, a little thought showed that the remainder of the disc need not have been opaque.

In practice it was found that the easiest procedure in constructing a color disc was to construct the disc of colored segments in such a manner that the area shown in Fig. 4 was included in each segment. The determination of the shape of these segments was completely arbitrary.

On Figs. 5 and 6 are shown the shapes of segments of two types of color wheels which are commonly used in color television systems (2). Also on these plates the relationship of these segments is shown to the basic filter which was necessary to observe the scanning action. It should be noted that the shape of the basic filters in Figs. 5, 6, and 7 is different than that shown in Fig. 4. This difference serves to illustrate the dependence of the shape of the basic filters upon the number of segments in the color wheel, the size of the raster, and the relation of the center of the color wheel to the raster.

Figure 7 shows the design of one segment of a six-segment disc for the same size raster and for the same relation of the center of the wheel to the raster.

No dimensions are given on the Figs. 5, 6, and 7 because the segments can have any shape provided only that the area A^1B^1 CD can be included on one segment.



O
A
B
A'
C
D
B'

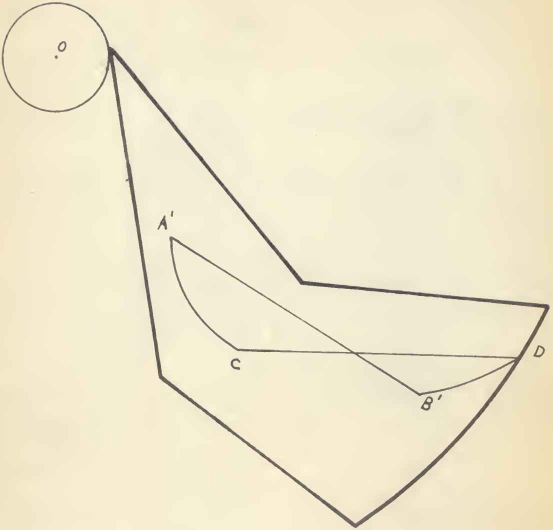


Fig. 6. A [illegible] of segment where the [illegible] of the segment is tangent to a [illegible] with O as [illegible].

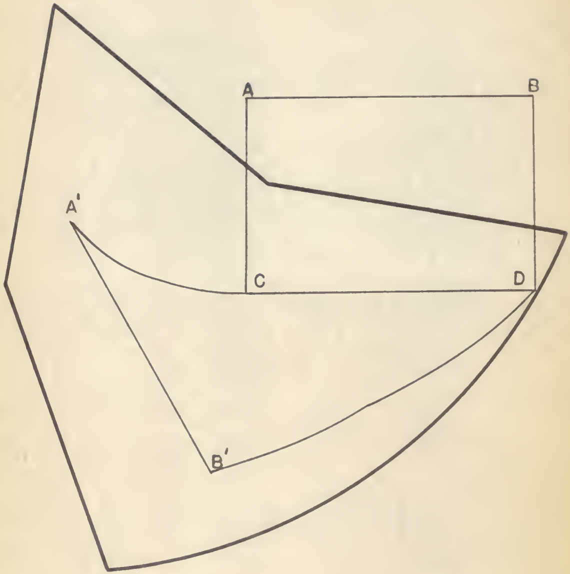


Fig. 6. A design of a segment for a six
[illegible]

A VIDEO GAIN SWITCHING CIRCUIT FOR USE IN A FIELD SEQUENTIAL COLOR TELEVISION SYSTEM

Introduction

In the CBS field sequential system of color television, the observer views the televised picture through a set of rotating filters. He sees first a red image, then a blue image, and then a green image in such rapid sequence that the primary colors are added by the retentivity of the eye to give the impression of the televised object in full color. Each image lasts for $\frac{1}{120}$ of a second.

Purpose

In color television it is frequently desirable to be able to vary the intensity of any one of the three colors composing the picture. That is, it should be possible to change the gain of the video system for each field. To achieve this purpose a video gain switching circuit was developed at Kansas State College during the summer of 1951.

Method of Development

The gain switching could be accomplished in two ways:

(1) by electro-mechanical means, whereby the gain of the video system could be switched at a time determined by means of a cam on the shaft of the color wheel.

(2) by an all-electronic system, whereby the gain of the video system could be switched by voltages derived from asymmetrical

multivibrators which were synchronized by the vertical drive pulses (120pps) and a color drive pulse (40pps).

An all-electronic system was chosen because it was felt that a more positive control of the switching time could be attained. It was also felt that by electronic gain switching, the switching time would be much shorter than could be realized with any electromechanical system.

During the development of the necessary circuitry, the following objectives were kept in mind:

(1) reliability and simplicity of operation

(2) use of a minimum number of components

(3) negligible interaction between the gain controls of different colors.

Since it was desirable to preserve the high-frequency components in the picture, it was necessary to keep the interelectrode capacitances of the video stages as small as possible. Therefore it was decided to send the video signal through a single amplifier--whose gain was switched for every field-- rather than to switch the video signal to different amplifiers, each with a variable gain, and then recombine the signals.

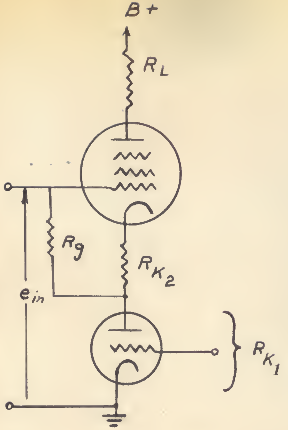
To change the gain of a single amplifier, two methods were considered. The first method was that of varying the cathode resistor in a video stage. It was felt that by switching the cathode resistance in a video amplifier, the gain would be varied by changing the amount of inverse feedback.

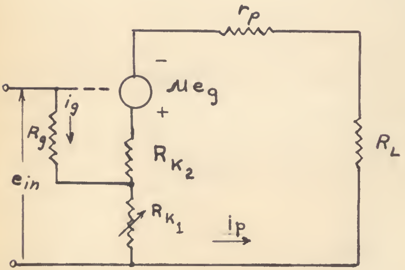
The circuit shown in Plate I was considered.

EXPLANATION OF PLATE I

Fig. 1. The schematic diagram of a gain switching circuit.

Fig. 2. The equivalent circuit.


B +
R L
R g
R K 2
e in
R K 1


r p
−
μ e g
+
i g
R g
R K 2
R L
e in
R K 1
i p

The following equations were obtained by adding voltages around a loop.

(1) $e_{in} = e_g + i_p\,(R_{k2} + R_{k1}) + i_g\,R_{k1}$

(2) $\mu\, e_g = i_p\,(R_{k1} + R_{k2} + r_p + R_L) + i_g\,R_{k1}$

The equation for the output voltage was

(3) $e_o = -i_p\,R_L$

The current ig was neglected because it was very small. Then these three equations were solved to obtain the gain of the amplifier.

(4) $$A = \frac{e_o}{e_{in}} = \frac{-R_L\,\mu}{(R_{k1} + R_{k2})\,(1+\mu) + r_p + R_L}$$

The following typical values were substituted into equation (4).

$$R_{k1} = 100$$
$$\mu = 5\cdot 10^3$$
$$r_p = 10^6$$
$$R_L = 2\cdot 10^3$$
$$R_{k2} = 800$$

R_{k2} was chosen as 800 ohms because this is the lowest plate resistance of any vacuum tube available.

$$A = \frac{-5\cdot 10^3 \;\cdot\; 2\cdot 10^3}{.9\cdot 10^3(1+5\cdot 10^3) + 10^6 + 2\cdot 10^3} = \frac{-10\cdot 10^6}{5.5\cdot 10^6} = -1.82$$

This method was abandoned because of the low gain available from the video stage.

The second method, that of varying the screen voltage of the video amplifier, held promise of a successful solution.

According to Chaffee (3) the current through a pentode is

(5) $i_b = f\,(e_{c1}, e_{c2}, e_b)$

The variation of the plate current, second and higher order terms in the expansion being neglected, is given by equation (6).

$$(6)\quad di_b = \left.\frac{\partial i_b}{\partial e_{c1}}\right|_{\substack{e_{c2}, e_b \\ \text{constant}}} de_{c1} + \left.\frac{\partial i_b}{\partial e_{c2}}\right|_{\substack{e_{c1}, e_b \\ \text{constant}}} de_{c2} + \left.\frac{\partial i_b}{\partial e_b}\right|_{\substack{e_{c1}, e_{c2} \\ \text{constant}}} de_b$$

By definition

$$(7)\quad \left.\frac{\partial i_b}{\partial e_{c1}}\right|_{\substack{e_{c2}, e_b \\ \text{constant}}} = g_{pg1} \qquad de_b = e_p$$

$$\left.\frac{\partial i_b}{\partial e_{c2}}\right|_{\substack{e_{c1}, e_b \\ \text{constant}}} = g_{pg2} \qquad de_{c1} = e_{g1}$$

$$\left.\frac{\partial i_b}{\partial e_b}\right|_{\substack{e_{c1}, e_{c2} \\ \text{constant}}} = \frac{1}{r_p} \qquad de_{c2} = e_{g2}$$

By substituting the values from equation (7) into equation (6), the following equation is obtained.

$$(8)\quad i_p = g_{pg1}\, e_{g1} + g_{pg2}\, e_{g2} + e/r_p$$

Since the switching of the screen voltage occurs only between fields, during any single field $de_{c2} = e_{g2} = 0$. The current generator $g_{pg2}\, e_{g2}$ then produces zero current during any field.

The equivalent circuit of the pentode is shown in Fig. 9.

The definition of g_{pg1} was given in equation (7) as

$$g_{pg1} = \left.\frac{\partial i_b}{\partial e_{c1}}\right|_{e_{c2},\ e_b \text{ constant}}$$

Plate II shows the variation of g_{pg1} with respect to E_{c2} for various values of E_{c1}. The graph is drawn for the 6AC7 vacuum tube (7).

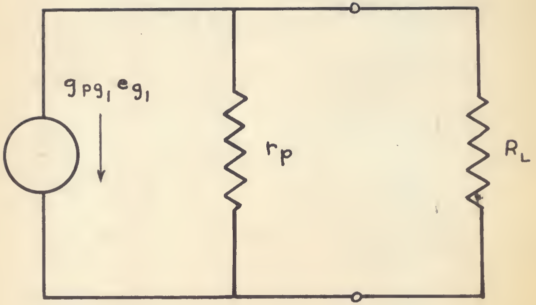
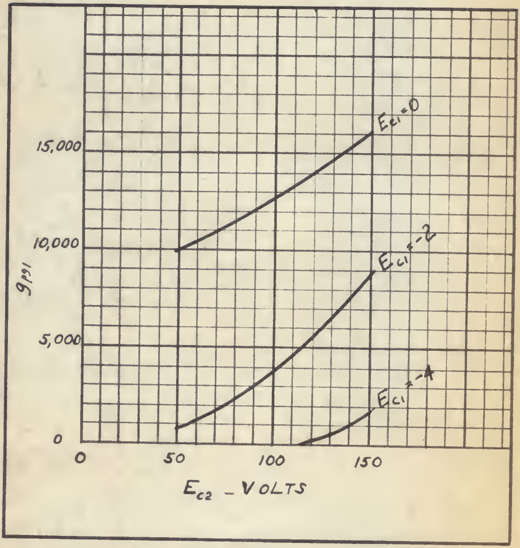


Fig. 4. The equivalent circuit of a pentode.

EXPLANATION OF PLATE II

Plot of g_{pg1} vs E_{c2} for various values of E_{c1}.

These data are for a 6AC7 vacuum tube with B + of 250 volts.


15,000
10,000
5,000
0
g_{pg1}
$E_{c1}=0$
$E_{c1}=-2$
$E_{c1}=-4$
0
50
100
150
E_{c2} – VOLTS

In order to preserve linearity in the video signal it is evident from Plate II that the video signal should be small. Since g_{pg1} increased with E_{c2}, the gain of the pentode could be changed by varying the screen voltage. Such a characteristic formed the basis upon which the gain switching circuits were developed.

The problem which remained was that of devising a circuit which would apply during each field a different voltage to the screen grid of the video amplifier. It was also necessary that the operator be able to change the voltage on the screen grid during any field in order that he might exercise control over the intensity of any one of the color image components in the picture. Since synchronized asymmetrical multivibrators were suited to this purpose, they were adopted for use.

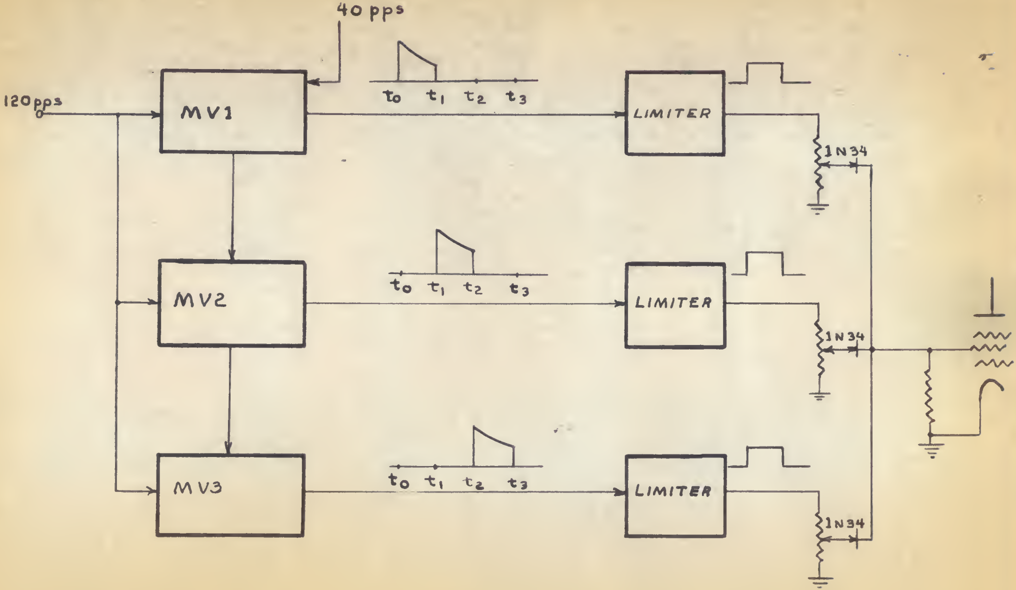
Plate III shows a block diagram of the circuit.

The multivibrators were adjusted so that the first multivibrator produced a positive pulse from time t_o to time t_1, t_1-t_o being equal to the length of duration of one field. When the first multivibrator triggered, it would trigger multivibrator number two. When multivibrator two triggered, it would produce a positive pulse from time t_1 to time t_2. At time t_2 the second multivibrator would trigger multivibrator three, resulting in a positive pulse from time t_2 to time t_3. These pulses were fed into limiter circuits which were used to produce square pulses. Gain controls were inserted at this point so that varying amounts of the square wave of voltage could be obtained. These square waves of voltage were then fed through crystal diodes to the screen

EXPLANATION OF PLATE III

A block diagram of the entire gain switching circuit.

PLATE III


40 pps
120 pps
MV1
MV2
MV3
t0 t1 t2 t3
t0 t1 t2 t3
t0 t1 t2 t3
LIMITER
LIMITER
LIMITER
1N34
1N34
1N34

grid of the amplifier. The purpose of the crystal diodes was to isolate the gain controls from one another, thereby preventing interaction.

The multivibrators were designed according to conventional multivibrator theory (1). The 6SL7 vacuum tube was chosen for use in this circuit because it is a readily available high-mu, duo-triode tube. A single stage of the multivibrator is shown in Fig. 10.

The negative pulse on grid four tends to turn off tube T2. Since, however, the negative pulse on grid one lasts longer than the negative pulse on grid four, the net effect is that T1 will be turned off and tube T2 will conduct. The plate of T1 will assume a voltage of B and condenser C_1 will charge through resistor R_5, thereby creating a positive voltage on grid four. The waveform of this voltage is determined by the time constant of C_1 and R_5. During the time T2 conducts, a positive voltage appears across the cathode resistor R_6. This is the voltage which is sent to the video tube's screen grid by way of the limiter and gain control.

The positive voltage on grid four will keep T2 conducting until the next vertical drive pulse turns off tube T2. When the current through T2 is cut off, the voltage on the plate of T2 goes to B . Condenser C_2 then starts to charge through resistor R_2, causing a positive voltage to appear on the grid of T1. Because of the positive voltage on its grid, tube T2 is made to conduct, thus reducing its plate voltage. This negative pulse of voltage

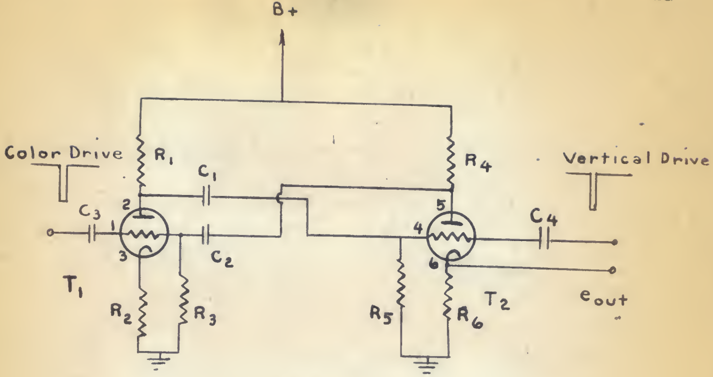


Fig. 10. A multivibrator circuit.

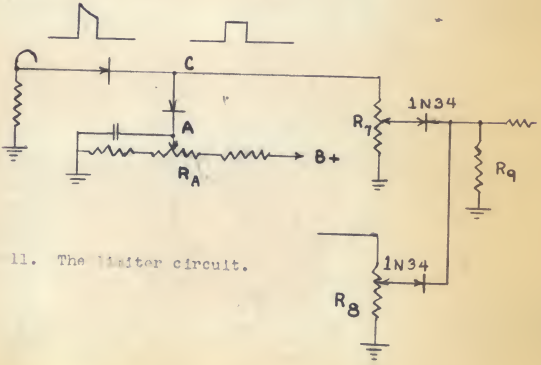


Fig. 11. The limiter circuit.

on the plate of T2 is sent through a small condenser to the grid number one of the following multivibrator, causing T3 to stop conducting. This pulse is analogous to the color drive pulse but occurs $\frac{1}{120}$ of a second later. Such action causes multivibrator two to produce an output pulse of positive voltage $\frac{1}{120}$ of a second after that produced by multivibrator one. In a similar manner multivibrator three produced a positive voltage during the third $\frac{1}{120}$ of a second. The vertical drive pulses were used to trigger the multivibrators to insure that the beginning and the end of the positive output pulses occurred during the time of the vertical drive pulses.

On Plates V and VI are shown the waveforms of the pulses on all of the elements of the first multivibrator.

The pulses from each multivibrator were fed into separate limiter circuits which clipped off the top portion of the positive pulse and produced a pulse with a flat top. The circuit which accomplishes this function is shown in Fig. 11.

A positive voltage is present at point A, the magnitude of this voltage determined by the setting of potentiometer R_a. Whenever the input voltage is more positive than the voltage at point A, the two crystal diodes conduct, thereby limiting the voltage to V_a. By setting R_a properly, a square wave of voltage can be obtained at point C. This square wave is then fed into a gain control R_7. The positive voltage determined by the setting of R_7 then appears across R_9 since the crystal diode acts as a short circuit in that direction. This positive voltage, however, cannot

EXPLANATION OF PLATE V

The photographs of waveforms on tube T_1.

Fig. 1		p-to-p volts	E_b
	Plate	240	325
Fig. 2		p-to-p volts	E_{cls}
	Grid	400	-10
Fig. 3		p-to-p volts	E_{ks}
	Cathode	120	24

Fig. 1

Fig. 2

Fig. 3

EXPLANATION OF PLATE VI

The photographs of waveforms on tube T_2.

Fig. 1		p-to-p volts	E_b
	Plate	300	130
Fig. 2		p-to-p volts	E_{cls}
	Grid	250	-29
Fig. 3		p-to-p volts	E_{ks}
	Cathode	1.05	.17

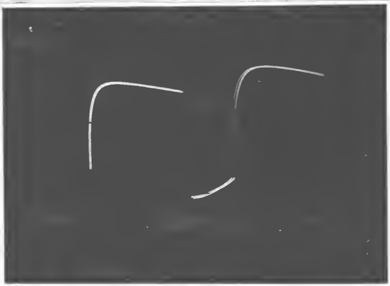


Fig. 1

Fig. 2

Fig. 3

appear across R_8 because the other crystal diode acts as a very high impedance in the reverse direction.

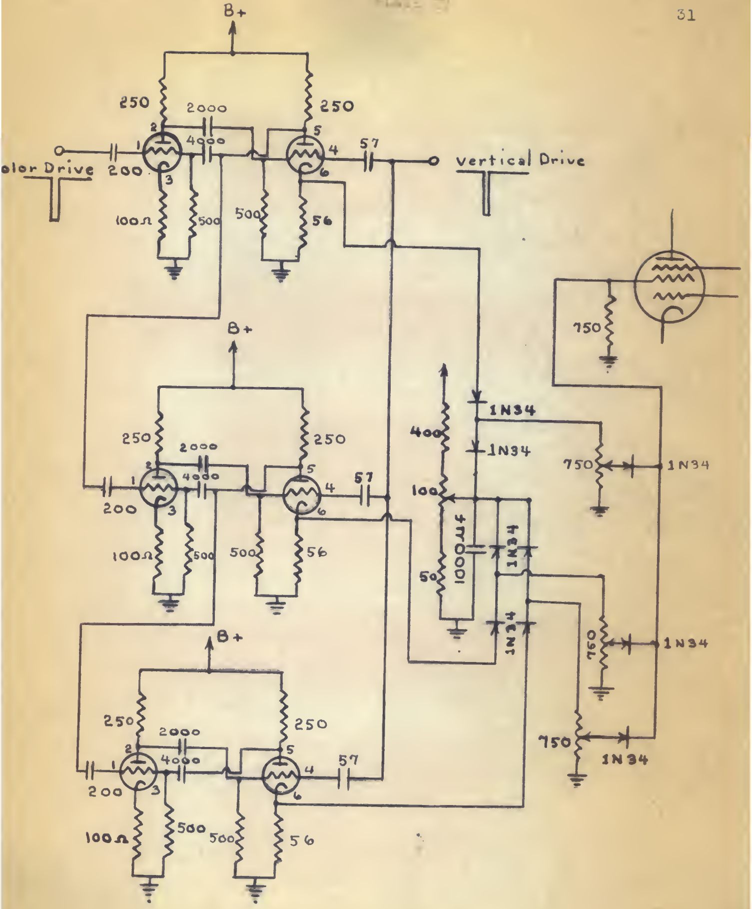
A complete circuit diagram is given in Plate IV.

Conclusions

The author conducted the research work during the summer of 1951. Since that time an improved method of gain switching has been published (6). After reviewing this new information, it was evident that these new circuits had some advantages over those used by the author. These advantages were better stability and reliability in generating the positive pulses. In view of these features, it was decided to use the new circuitry in the color television system which is being constructed at Kansas State College. While only the topology of the new circuits is available, the author is presently engaged in determining the circuit constants and in building these circuits.

EXPLANATION OF PLATE IV

The complete schematic diagram of the gain switching circuit.


B+
250
2000
250
4000
57
olor Drive
200
Vertical Drive
100Ω
500
500
56
B+
750
1N34
400
1N34
250
2000
250
750
1N34
4000
57
100
200
4000
100Ω
500
500
56
1N34
50
750
1N34
1N34
B+
250
2000
250
750
4000
57
200
1N34
100Ω
500
500
56

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OF AGRICULTURE AND APPLIED SCIENCE

1952

TOPICS IN COLOR TELEVISION

The research reported in this thesis was done in connection with the color television project being conducted at Kansas State College.

THE DESIGN OF RECEIVER COLOR WHEELS FOR USE IN FIELD SEQUENTIAL COLOR TELEVISION SYSTEMS

In the CBS field sequential system of color television the cathode-ray tube is viewed through a set of rotating color filters; that is, the observer sees in cycles first a red image, then a blue image, then a green image.

The rotating filters were designed in such a manner that the scanning beam could be seen as it moved across the raster. The shape of these filters was a function of the size of the raster, the relation of the center of the wheel to the raster, and the number of filter segments in the color wheel.

The design method was checked by constructing a color wheel and by using it under actual operating conditions. The performance was satisfactory.

A VIDEO GAIN SWITCHING CIRCUIT FOR USE IN A FIELD SEQUENTIAL SYSTEM

In color television it is frequently desirable to be able to vary the intensity of any one of the three colors composing the picture.

The problem was that of devising a circuit which would apply during each field a different voltage to the screen grid of the video amplifier. It was also necessary that the operator be able to change the voltage on the screen grid during any field in order that he might exercise control over the intensity of any one of the color image components in the picture. Since synchronized asymmetrical multivibrators were suited to this purpose, they were adopted for use.

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The gain switching circuit which was discussed in this thesis was built in August, 1951, and was found to be satisfactory.