

# THE CT-100 COMMERCIAL COLOR TELEVISION RECEIVER

BY

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*Summary*—This paper describes the first commercial color-television receiver produced by RCA. The receiver employs 37 receiving-type tubes, two selenium rectifiers, one silicon crystal, two germanium crystals, and one color kinescope. The receiver was designed to operate on the compatible color standards approved by the Federal Communications Commission on December 17, 1953. It is fully compatible—that is, once the receiver has been tuned, it will accept either color signals or the conventional monochrome signals with no further adjustment.

## INTRODUCTION

**M**ODEL CT-100 is a color-television receiver using the 15GP22 kinescope. This kinescope is of the shadow mask type, enclosed in a round glass envelope, and giving a picture with a diagonal of approximately 12 ½ inches. A production quantity of the receivers was turned out early in 1954. This run showed that compatible color receivers could be built using normal factory techniques.

The CT-100 is designed to receive color-television signals of the type set forth in the compatible color standards adopted by the Federal Communications Commission on December 17, 1953. These signals include luminance, hue, and saturation information.

These are the three independent quantities which represent the video information necessary to reproduce color pictures.<sup>1 2</sup> The luminance information is essentially the same as the video signal in a monochrome transmission, and when displayed on a monochrome receiver, it gives a picture which is almost indistinguishable from a regular monochrome picture. The hue and saturation information is carried by a 3.579-megacycle subcarrier. The phase of the subcarrier relative to a synchronizing burst determines the hue, and the amplitude of the subcarrier relative to the luminance signal determines the color saturation.

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<sup>1</sup>G.H. Brown and D.G.C. Luck, "Principles and Development of Color Television Systems," *RCA Review*, Vol. 15, pp. 144-204, June, 1953.

<sup>2</sup>D.H. Pritchard and R.N. Rhodes, "Color Television Signal Receiver Demodulators," *RCA Review*, Vol. 14, pp. 205-226, June, 1953.

In order to recover all of the video information, certain important receiver characteristics are necessary: the high-frequency response through the color demodulators must extend to at least 4.1 megacycles, and the phase characteristic must be linear. Also, the over-all amplitude characteristics must not vary or color saturation will be incorrect.



Fig. 1—The CT-100 color television receiver.

A block diagram of the color receiver is shown in Figure 2. The individual red, green, and blue video signals are derived by matrixing in the box labeled "video." The only new functions shown, compared to a black-and-white receiver, are color synchronization and convergence; however, closer tolerances are required of most of the other functions.

The r-f tuner is a UHF-VHF turret type. This unit provides independent adjustments for each channel and, therefore, consistent performance between channels. Experience has shown that tighter factory test limits can be held using such a unit.

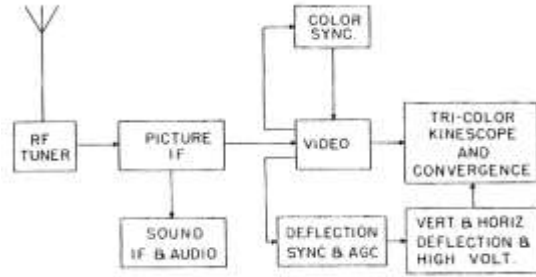


Fig 2.—Block Diagram of the CT-100

In order to facilitate manufacture, the set was designed to consist of a main chassis and three subassemblies: r-f; i-f; audio, and vertical deflection; and horizontal deflection-high voltage. These subassemblies are bolted together to form a single unit (Figure 3).

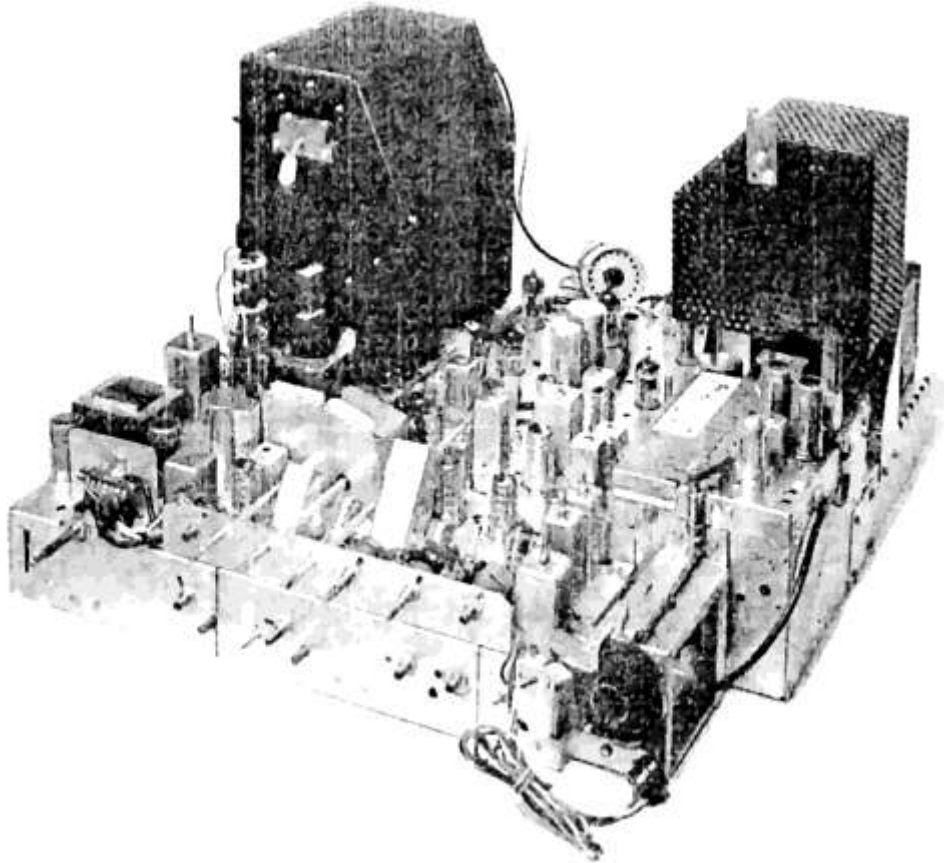


Fig. 3—Chassis of the CT-100

The kinescope is secured to the cabinet. To assist in adjusting the kinescope, the top of the cabinet was made removable (Figure 4). Also, by removing the control pencil box, other controls needed for setting up the kinescope are accessible.

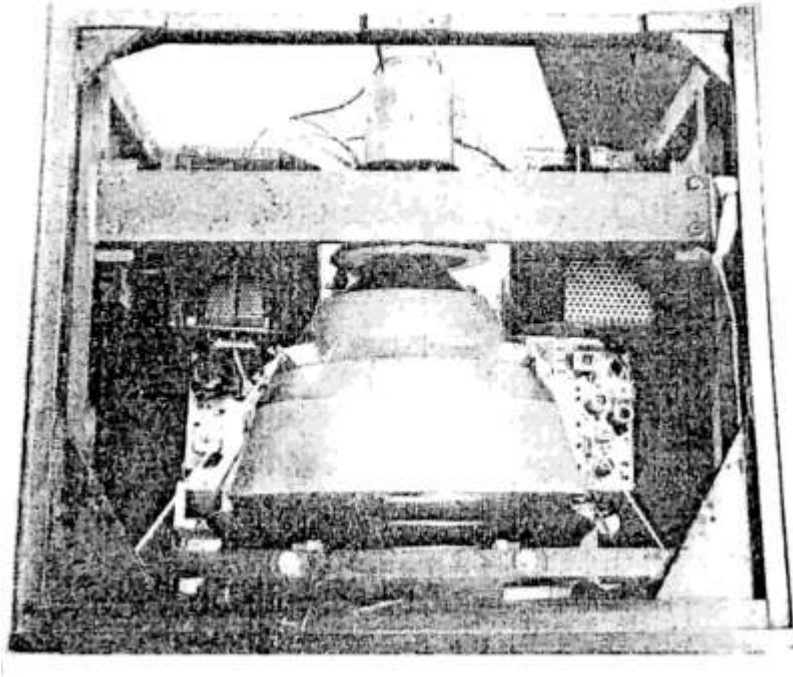


Fig. 4—Top view with the cover removed, showing how the kinescope is mounted.

In addition to the normal black-and-white controls, the receiver incorporates two new customer controls under the control panel—hue and color saturation. The d-c focus and convergence controls are accessible at the sides of the cabinet.

To minimize radiation of color subcarrier frequency and harmonics, a metal back as well as a metal chassis bottom shield is used.

An intercarrier sound system is employed.

The receiver operates on 117 volts, 60 cycles, and is rated at 475 watts.

The cabinet dimensions are 40 inches high by 28 inches wide by 30 5/8 inches deep, and the set weighs 175 pounds.

Maximum brightness of 20 to 30 foot lamberts is attainable. Noise free operation is obtained from an 800 to 1000 microvolt signal and the receiver will synchronize on a signal as low of 15 microvolts. The schematic diagram is shown in Figures 5 and 6.

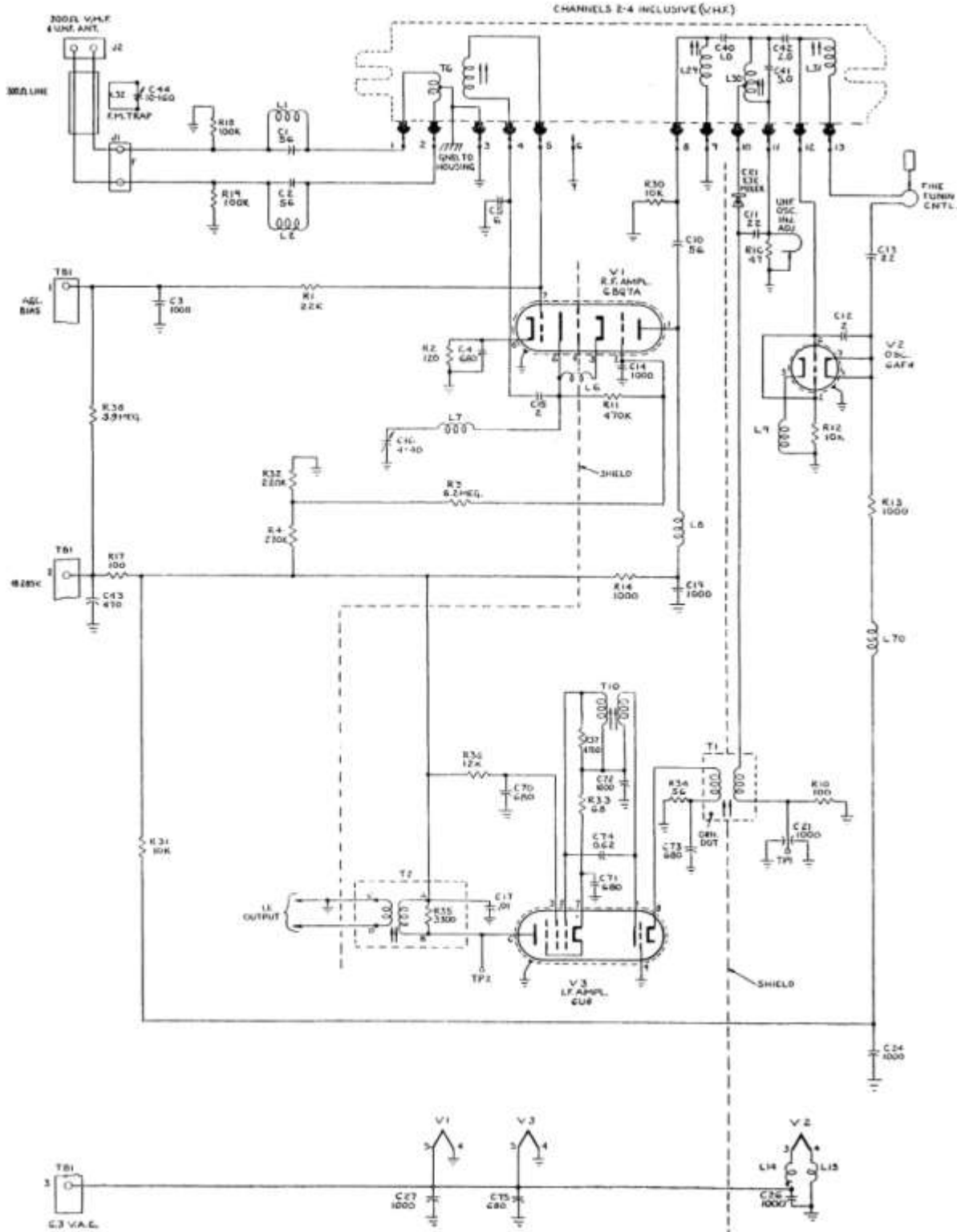


Figure 5a—Schematic diagram of the tuner with channels 2-4 strip inserted

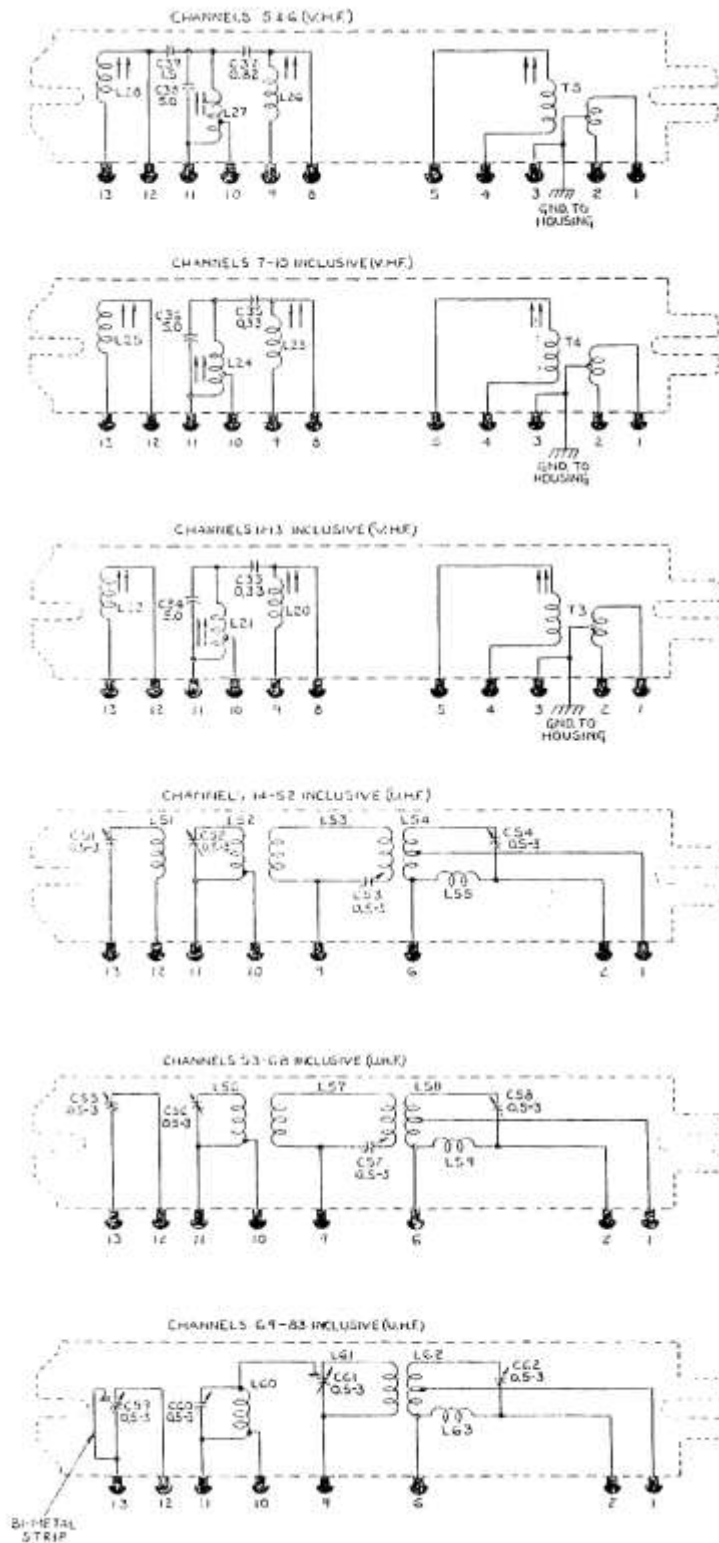


Figure 5b—Strip assemblies for channels 5-83

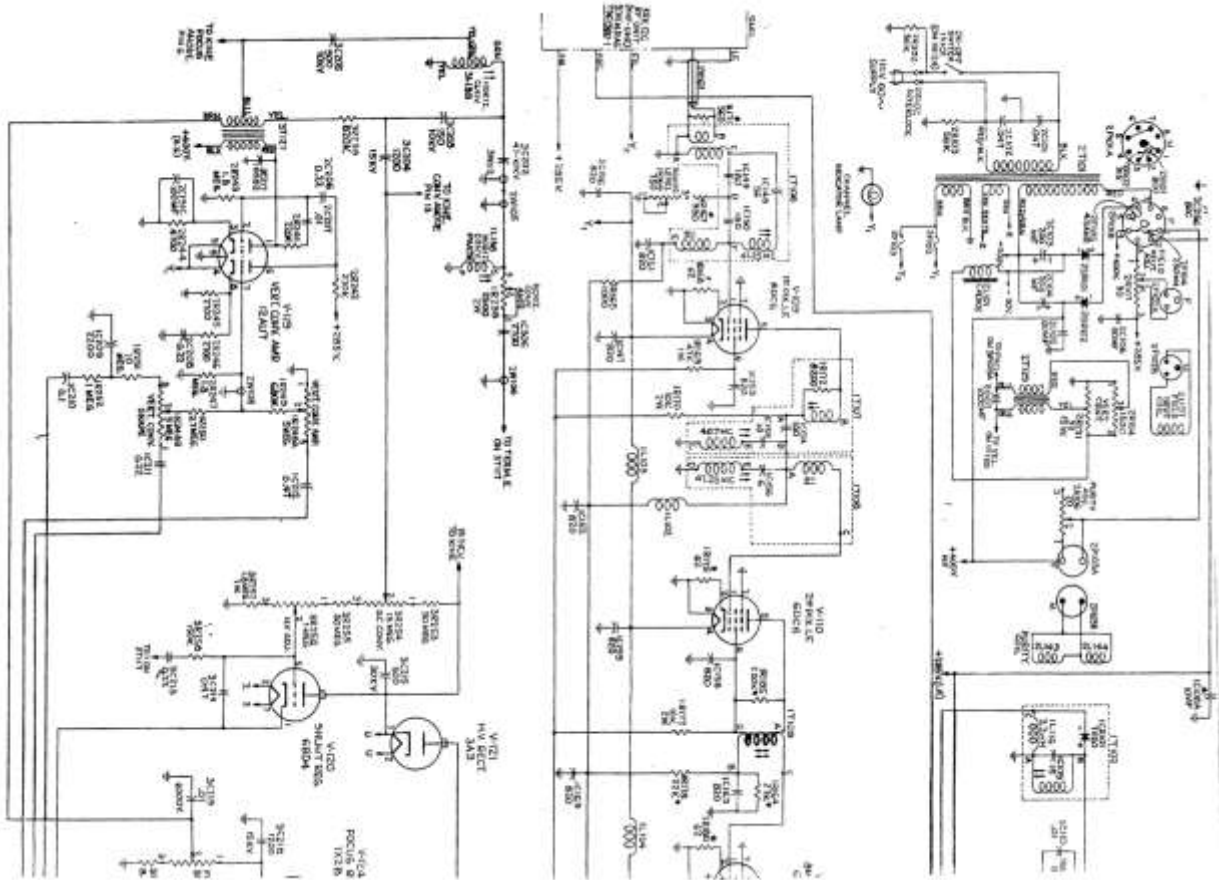


Figure 6a—Schematic diagram of the CT-100

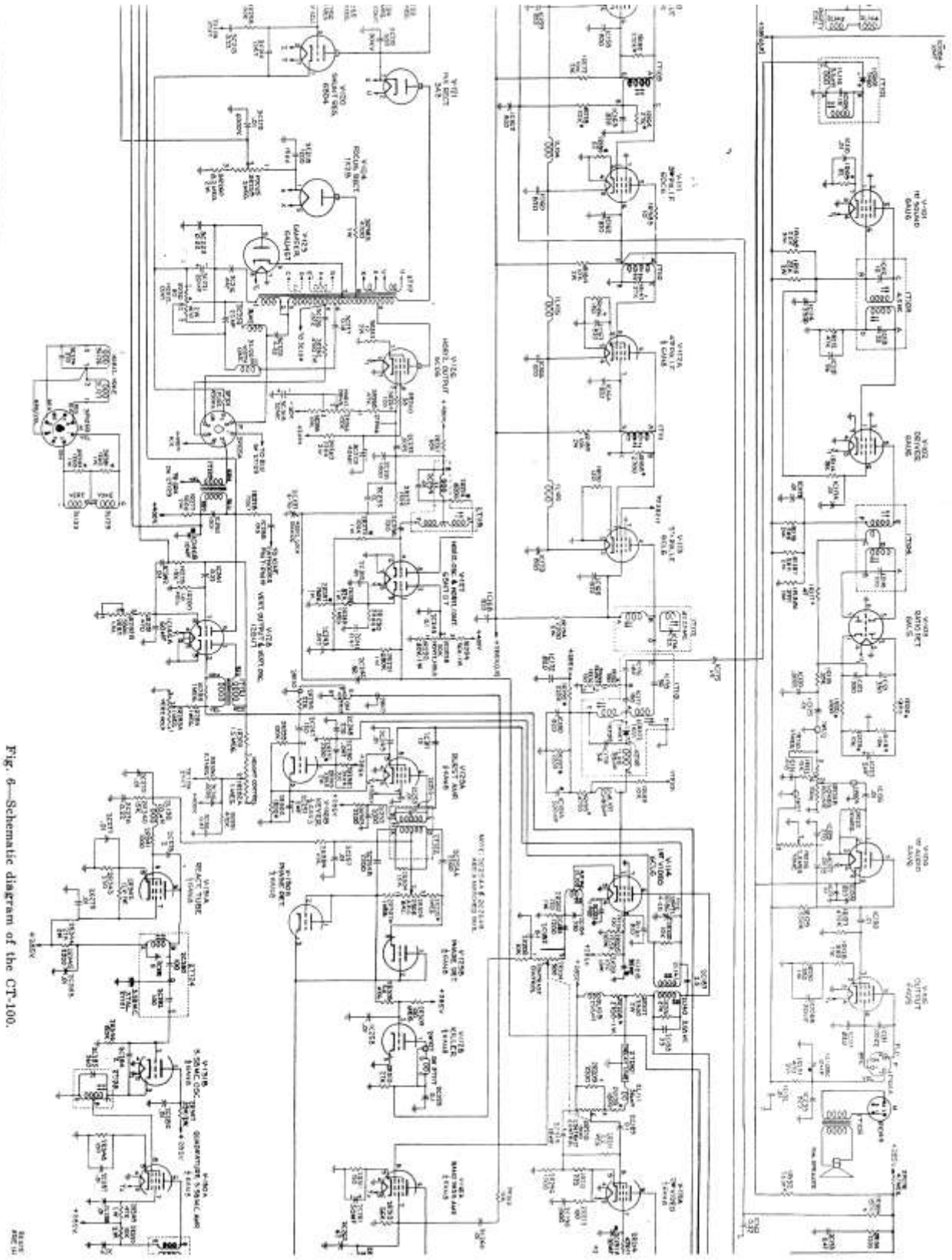


Fig. 6—Schematic diagram of the CT-100.

Figure 6b—Schematic diagram of the CT-100 (continued)



T-100.

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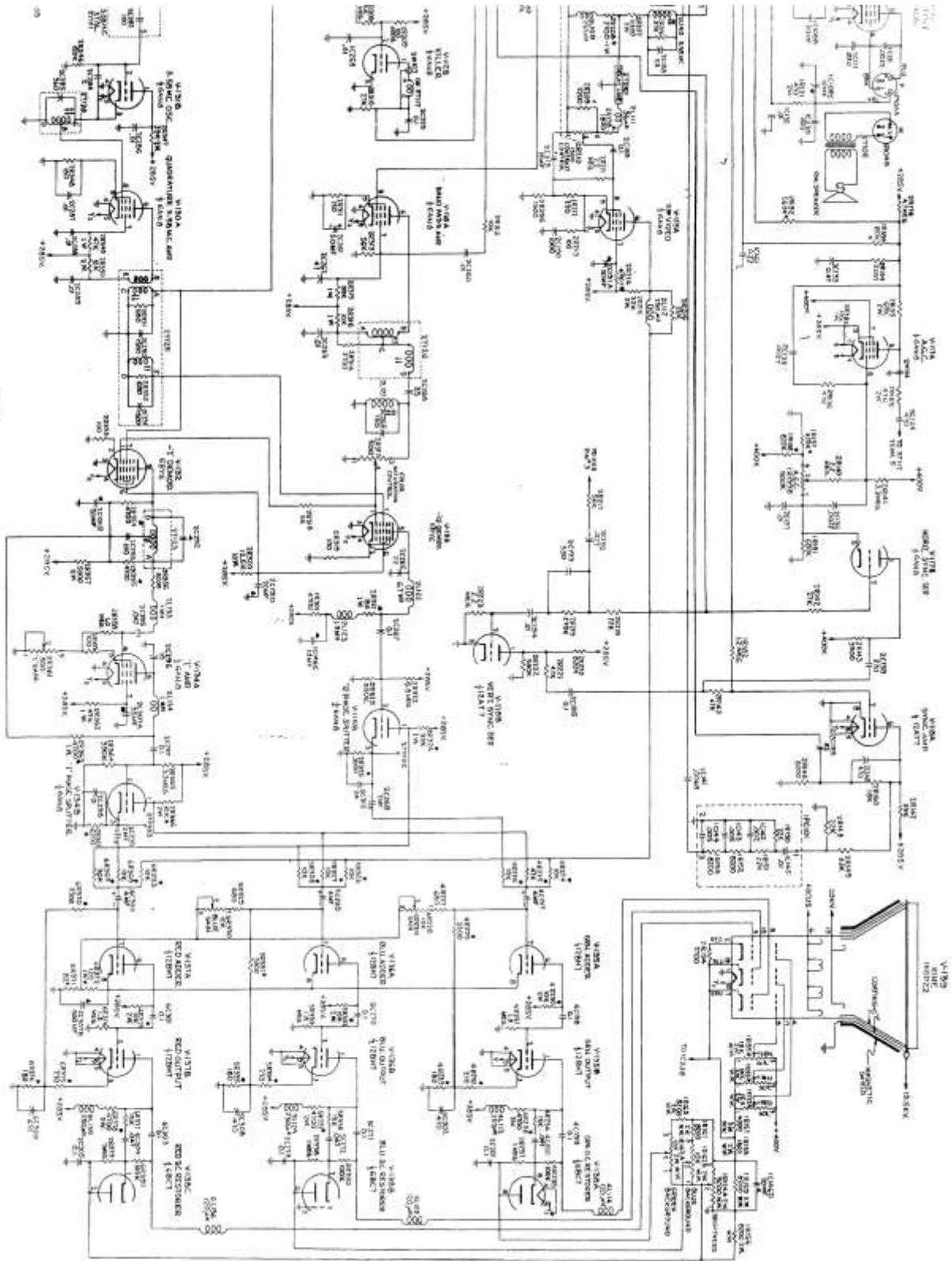


Figure 6c—Schematic diagram of the CT-100 (continued)

## CIRCUIT DESCRIPTION

### *Tuner*

The r-f tuner is a three-tube, sixteen-position, turret-type tuner capable of covering any 16 of the VHF and UHF television channels, and providing a 40-megacycle i-f output. The tube complement consists of a VHF r-f amplifier, a VHF-UHF oscillator, and an i-f amplifier. A silicon crystal is used in the mixer circuit for both VHF and UHF. In the VHF range, a low-noise r-f amplifier feeds a crystal mixer which is followed by a low-noise i-f stage. For UHF the arrangement is similar except that there is no r-f amplifier.

### *VHF Circuits*

The antenna input circuit consists of a link-coupled, single-tuned circuit with the 300-ohm balanced antenna input tapped down for impedance match. However, the constants and configuration have been selected to provide optimum noise factor for all channels rather than perfect impedance match between the antenna circuit and the r-f amplifier. Traps are placed in series with the primary of the input transformer to provide i-f attenuation. A tuned section of 300-ohm transmission line is mutually coupled to the input line to provide attenuation of signals in the FM broadcast band.

The r-f amplifier is a dual triode especially designed for driven-grounded-grid operation. It has the gain and stability of a pentode and the noise factor of a triode. Low output-to-input capacitance minimizes local oscillator feed-through. To prevent detuning of the input circuit with change in grid bias because of Miller effect and to improve the noise factor of the amplifier, a capacity bridge type of neutralization is used. The output of the r-f amplifier contains a capacity-doubled double-tuned circuit. The secondary is tapped for desired amplitude characteristic in accordance with the loading of the crystal diode. This low-noise silicon crystal mixer feeds a tuned bifilar transformer in the grid circuit of the i-f amplifier. Oscillator injection for the mixer is obtained through capacity coupling on the lower VHF channels, and mutual inductance coupling on the upper VHF channels.

The oscillator employs a temperature-compensated Colpitts circuit. Tuning is accomplished, as in the other r-f circuits, by switching in the correct inductance to resonate the tank circuit to the proper frequency. A fine-tuning control, located concentrically on the channel selector shaft, permits vernier adjustment of the local oscillator frequency.

### *UHF Circuits*

On UHF, the 300-ohm balanced antenna input, which is the same as that used for VHF, is tapped into a triple-tuned preselector circuit. The output of the circuit is tapped for the crystal mixer circuit. Oscillator injection is obtained by means of an adjustable inductance in the ground side of the mixer circuit. The output of the mixer circuit is the same as for VHF.

The UHF oscillator circuit corresponds to that used for the VHF range except that the tuning for the required channel is accomplished by using a variable capacitance in series with an inductance. The capacitance is preadjusted for the correct oscillator frequency.

### *Picture i-f Channel*

The picture i-f amplifier is designed for a 45.75-megacycle picture carrier, 42.17-megacycle color subcarrier, and a 41.25-megacycle sound carrier. The amplifier consists of seven stages. The second detector uses a germanium crystal and is operated at six volts peak output level in the interest of linearity. The over-all sensitivity is approximately 14 microvolts across the antenna terminals for six volts peak at the second detector.

The noise factor of the tuner on UHF is determined primarily by the loss in the crystal mixer and the noise contributed by the first i-f amplifier following the mixer circuit. Therefore, a low-noise, grounded-grid triode-driven pentode is used for the first i-f stage. The cathode of this stage is fed from the crystal mixer by means of a single-tuned circuit. A double-tuned circuit is used as the interstage coupling between the plate of the triode and the grid of the pentode. The output network of the pentode is a link-coupled, bridged-T, m-derived, band-pass circuit with a rejection trap tuned for accompanying sound (41.25 megacycles). In order to reduce cross modulation, the sound carrier is attenuated as early as possible in the i-f amplifier.

The first picture stage employs an m-derived, band-pass circuit with one rejection trap tuned for the desired skirt selectivity on the sound-carrier side (40.70 megacycles) and the other to the adjacent sound carrier (47.25 megacycles).

The second, third, and fourth picture i-f stages form a staggered triplet with the second and fourth stages tuned to the high- and low-frequency sides, respectively, of the passband. The third stage is tuned to approximately the center of the band.

The staggered triplet provides a means of compensating for production variations in the over-all amplifier, since each stage will affect a different portion of the passband.

The fifth picture i-f stage uses a bridged- $\pi$ , m-derived, band-pass circuit and a mutually coupled absorption trap. The rejection traps are tuned for accompanying sound (41.25 megacycles) and adjacent sound (47.25 megacycles).

Curves of the individual stages are shown in Figure 7. The over-all curve is shown in Figure 8.

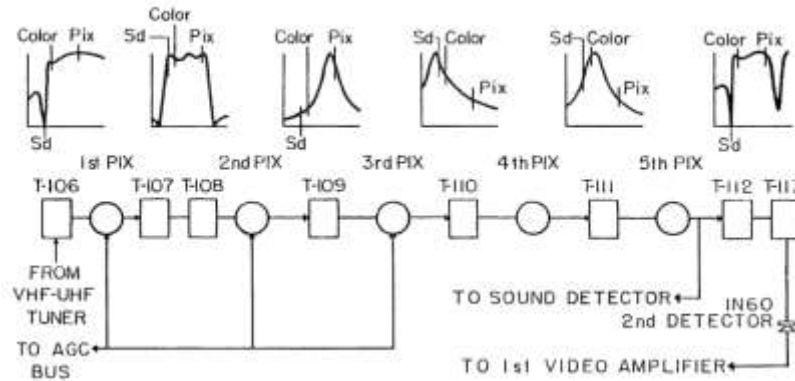


Figure 7—Block diagram of the picture i-f channel with individual stage selectivities.

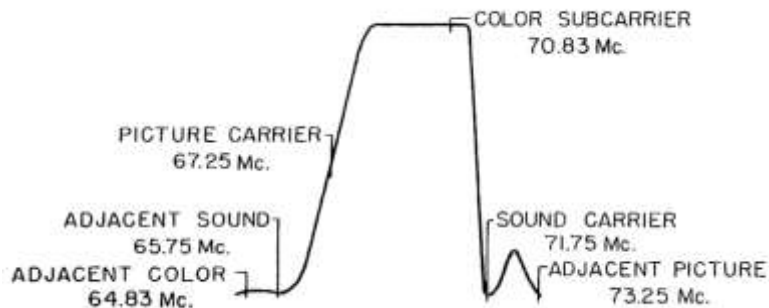


Figure 8—Over-all r-f - i-f response on channel 4 (66-72 megacycles).

### *Sound i-f and Audio Channel*

In most monochrome intercarrier sound receivers, the sound take-off is after the second detector. Also, it has been found that the optimum ratio of picture carrier to sound carrier at the detector should be approximately 15 to 1. However, in order to reduce the 920-kilocycle beat between sound carrier and color subcarrier so that it does not appear on the face of the kinescope, it is necessary to provide much greater attenuation of the sound. In the interest of sound gain, sound information should be taken off as late as possible in the i-f amplifier. In the CT-100, it is taken off after the fifth picture i-f tube. The required additional sound rejection is obtained by bridging the m-derived, band-pass circuit for maximum sound rejection.

The sound i-f detector is a germanium crystal diode feeding a single-tuned circuit in the grid of the 4.5-megacycle sound i-f amplifier. The output circuit is a high-impedance, double-tuned, band-pass transformer. Following is the driver for the ratio detector, which is operated with low screen voltage and grid leak bias in order to provide amplitude-modulation rejection.

The ratio detector employs a double triode in a balanced detector circuit. The output from the ratio detector is fed to the first audio amplifier. A normal single-ended system is employed for the output.

### Video

The video section consists of a luminance channel, chrominance channel, and a matrix which combines the two channels. A block diagram is shown in Figure 9.

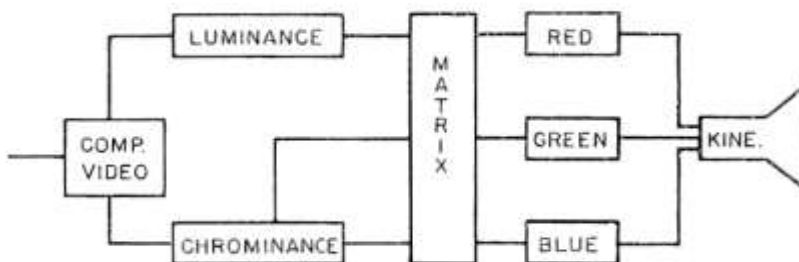


Figure 9—Block diagram of the video section.

The luminance ( $Y$ ) channel serves a purpose substantially similar to that performed in standard monochrome receivers—that of amplifying the luminance information to a level satisfactory for application to a kinescope. The only difference here is that the information is applied to the kinescope via the matrix.

The chrominance channel serves to recover the information contained in the color subcarrier and its accompanying sidebands. By the process of synchronous detection, two signals are recovered from the color subcarrier. These signals are called  $I$  (in phase) and  $Q$  (quadrature phase). Both the  $I$  and  $Q$  channels are band-limited according to FCC signal specifications. The  $I$  channel passes information up to approximately 1.5 megacycles. While band-limiting of these channels prevents crosstalk, it necessitates equalization of signal delay time among  $I$ ,  $Q$ , and  $Y$ .

The matrix provides simultaneous red, blue, and green signals by combining predetermined proportions of  $Y$ ,  $I$ , and  $Q$  information for application to the kinescope grids.

### Luminance Channel

The first video amplifier provides both polarities of video, 4.5-megacycle attenuation by means of a cathode trap, and color subcarrier attenuation by a trap in the plate circuit. The grid is d-c coupled to the second detector load circuit which is raised slightly positive by a voltage divider. This biases the first video for more linear operation.

Sync-positive wideband video at the plate provides the luminance ( $Y$ ) channel signal as well as the burst, sync, and AGC (automatic gain control) signals. The burst is taken off by

capacity coupling a single-tuned circuit to the color subcarrier trap. Sync and AGC information are taken off just below the color subcarrier trap at a high video level. The luminance ( $Y$ ) information is tapped down in the plate circuit to match the impedance of the  $Y$  delay line. This delay line provides about 1.0 microsecond time delay for the luminance signal to effect time coincidence with the chrominance signals at the matrix junction point. The  $Y$  delay line is terminated in a network containing a potentiometer used as the contrast control in the  $Y$  channel. Ganged to this control is another potentiometer which is located in the cathode circuit of the first video and serves as the contrast control in the chrominance channel. These controls are mechanically coupled so they track from minimum, which is zero contrast, to maximum, keeping a constant ratio between luminance and chrominance for all contrast settings.

The  $Y$  section of the contrast control varies the signal applied to the second video amplifier. This stage amplifies the  $Y$  information to the level necessary for matrixing.

These video stages incorporate conventional series or shunt coil peaking in the late circuits and  $RC$  peaking in the cathodes.

#### *Chrominance Channel*

The chrominance signal from the cathode of the first video amplifier is fed to the band-pass amplifier. The plate circuit of this stage contains the band-pass filter which removes the low-frequency components of the signal and retains the region of the color subcarrier and its sidebands. This filter has a bandwidth of approximately 2.4 to 5.0 megacycles, and is terminated by a potentiometer which serves as the color saturation control.

During each burst interval the band-pass amplifier operates in conjunction with the "color killer." The "killer" stage is held at cutoff by negative d-c voltage developed by the burst phase detector. In the absence of burst, that is a standard black-and-white transmission, the "killer" stage conducts and biases the band-pass amplifier the cutoff, thereby assuring that no signal information passes to the demodulator grids via the band-pass filter.

Demodulation of the chroma signal is accomplished by two synchronous detectors; color subcarrier frequencies are applied to the outer grids while the chroma signal from the arm of the band-pass terminating potentiometer is applied to the inner grids.

The detected  $Q$  signal appears at the plate of the  $Q$  demodulator and is band-limited by a 0.5-megacycle low-pass filter. This signal is fed to the  $Q$  phase splitter whose outputs provide the positive and negative  $Q$  signals necessary for matrixing.

The proper ratio of  $I$  to  $Q$  signals is adjusted by a degeneration control in the  $I$  amplifier circuit.

### *Matrix and Output*

Fixed resistances are used in the matrixing. The adder and output stages for each color are combined in a twin triode.

D-C restoration is applied to the red, blue, and green output signals by a triple diode tube. The plate return circuits for these three restorers are arranged in a bridge circuit which is adjusted in such a way as to maintain proper tracking of the three kinescope grid bias values throughout the range of the master brightness control.

### *Deflection Synchronization*

The synchronization signal is obtained from the plate circuit of the first video amplifier and is d-c coupled to the grid of the horizontal separator and a-c coupled to the grid of the vertical separator. Horizontal and vertical sync are added in the grid circuit which serves the function of sync amplifier and clipper. Variable clipping as a function of signal strength is obtained by connecting the grid resistor of the sync amplifier to the screen grid of the third picture i-f amplifier. Improved noise immunity in the vertical-deflection circuit is obtained by coupling negative noise pulses from the screen of the fifth picture i-f to the grid of the vertical-sync separator. The output of the sync amplifier is used for both horizontal- and vertical-sync information, vertical being fed through a printed integrator circuit proper shaping before being applied to the vertical-deflection oscillator grid.

### *Automatic Gain Control*

The AGC amplifier derives its control voltage from the cathode of the horizontal-sync separator. The magnitude of this voltage, together with the AGC control, determines the bias on the AGC tube. Plate supply is obtained from a horizontal kickback pulse, capacitively coupled to the yoke tap. The AGC tube conducts only at pulse time and is nonconducting during the remainder of the cycle. Negative voltage is obtained by charging the plate capacitor and is applied to the i-f and r-f grids through suitable filter networks. A diode serves as a clamp on the r-f bias delaying the r-f bias for improved signal-to-noise ratio.

### *Horizontal Deflection and High Voltage*

The horizontal-deflection system supplies the kickback pulses used in various circuits as well as the high-voltage potentials and horizontal scan. The horizontal-deflection output tube is driven by an oscillator and automatic frequency control circuit similar to that used in many monochrome receivers. A protective circuit which supplies fixed bias to the output tube grid is incorporated to protect the circuit against damage by failure of the horizontal-drive signal.

The ultor voltage is supplied by a single high-voltage rectifier rectifying the kickback pulse and is controlled by a shunt regulator. A high-voltage control which is part of the high-voltage bleeder varies the bias to the control grid of the high-voltage shunt regulator to adjust the

high voltage. This type of regulation keeps a constant load on the high-voltage system. In order to maintain the static convergence potential at a fixed ratio with respect to the ultor voltage, the d-c convergence control is used as part of the high-voltage bleeder.

The focus voltage is derived from a separate rectifier tapped further down on the horizontal-deflection transformer, and the focus control is part of the bleeder on this rectifier.

Two separate windings, one them tapped, provide kickback for “killer” bias rectification, band-pass keying, burst keying, and horizontal-deflection dynamic convergence signal.

The horizontal-deflection yoke is a-c coupled to the transformer. It is a series-connected yoke tapped up on the transformer so that both sides of the yoke carry pulse. This arrangement balances out much of the yoke ringing. In order to provide electrical centering to this arrangement and to keep centering current out of the transformer, two separate chokes are needed to connect in the centering control. One of these chokes is variable and serves as a width coil.

Since the yoke is tapped relatively high on the horizontal-deflection transformer, the vertical-deflection yoke has been isolated from a-c ground by a bifilar choke to prevent loading of the kickback pulse by the capacity between the horizontal- and the vertical-deflection windings in the yoke.

### *Vertical Deflection*

Vertical deflection is supplied by a dual triode, the first half being a blocking oscillator and the second half driving the vertical-deflection yoke section by means of an output transformer. Electrical centering is also used.

### *Color Synchronization*

In order to recover the color information, it is necessary to generate a local subcarrier of proper frequency and phase. To accomplish this, phase reference information is transmitted as a component of the composite color signal. This color synchronizing information is transmitted in the form of a “burst” of approximately eight cycles of the color subcarrier frequency and appears immediately following each horizontal synchronizing pulse in the composite signal.

This burst is separated from the composite signal and is used in establishing the proper phase relationship between the transmitted signal and the local subcarrier. This subcarrier is generated by a quartz crystal oscillator whose exact frequency and phase is controlled by a reactance tube. The reactance tube derives its control information from an error signal proportional to the difference in phase between the transmitted burst and the local crystal oscillator output.



This color synchronizing channel includes a keyer wave-shaping stage, a keyed burst-amplifier stage, a phase detector, a crystal oscillator, a reactance tube, and a 3.579-megacycle amplifier.

The burst-amplifier stage is driven from a single-tuned coil coupled to the first video amplifier plate. A trimmer across the single-tuned coil provides hue control. The keyer tube is driven by a negative pulse derived from the horizontal deflection voltage. A positive flat-topped pulse from the plate is coupled to the low side of the burst input coil. The cathode of the keyer is connected to the cathode of the burst amplifier and bypassed providing an automatic adjustment of keying level.

The plate transformer of the burst amplifier has a high-impedance primary and a bifilar secondary tightly coupled to the primary. With a turns ratio of 6 to 1, the output is approximately 60 volts peak-to-peak of burst on either side of the secondary center tap.

The phase detector uses the triodes of two separate tubes connected as grid-cathode diodes with the plates connected to the grids. The phase detector compares the phase of the incoming burst signal with the phase of the locally generated signal. This locally generated signal is one output from a double-tuned transformer. The output of the phase detector is a d-c error voltage which is the reactance tube control signal.

The reactance-tube stage is of the capacitive type.

Operating the oscillator as a cathode follower has the basic advantage of eliminating the spurious oscillation to the reactance-tube plate coil. For this type of circuit to oscillate, it is necessary for the cathode circuit to be resonant at a frequency lower than that of the crystal resonance. If the cathode circuit is tuned between the crystal resonance and the reactance plate coil resonance, it can then only oscillate at the crystal frequency.

The 3.579-megacycle double tuned transformer amplifier is driven from a tap on the oscillator cathode coil. A coupled transformer in the plate circuit yields low-impedance 3.579-megacycle voltages of the proper phase displacement for the demodulators. A tightly coupled tap from the primary provides *I*-phase color subcarrier to the *I* demodulator and reference phase color subcarrier to the phase detector. The secondary provides *Q*-phase color subcarrier to the *Q* demodulator.

### *Tri-Color Kinescopes*

The tri-color kinescope, as used, is a simultaneous color display device. Structurally, the tube consists of three electron guns mounted with their axes parallel to the central axis of the tube, and spaced 120° apart. The focus electrode potential is adjusted to cause the beams to focus at the phosphor dot plate. All three beams pass through an electrostatic lens system, whose

potential is adjusted to cause the three beams to converge at the phosphor plate. The three beams are electromagnetically deflected by a common yoke.

The control adjustments associated with the kinescope are of two categories, namely, static and dynamic.

Purity, center convergence, cutoff, and background tracking are all static adjustments. The purity adjustment permits alignment of the electron beams so that each beam falls only on the proper color dots.

Successful operation of a master background control requires that some provisions be made for the differences in the three phosphor efficiencies and also for the variation in gun characteristics. With the brightness control at maximum clockwise position the screen potential potentiometers are adjusted to give a gray low-light.

The low-light bias tracking is done by the blue and green dividers across the top portion of the master background potentiometer.

Center convergence of the three beams is done by adjusting the d-c potential of the convergence electrode for best super-positioning. Any residual error is due to mechanical inaccuracies of the gun alignments and is corrected for by the use of the individual beam convergence magnets.

#### *Dynamic Convergence*

Since the phosphor plate and the shadow mask are flat surfaces, the distance the beams must travel from the deflection plane to the central area of the aperture mask is less than the distance they must travel when deflected away from central area. If the potential on the convergence electrode which was necessary to produce center convergence remained unchanged, the deflected beams would cross over before reaching the phosphor plate. To correct this condition, it is necessary to modulate the d-c potential on the convergence electrode in such a manner as to produce a larger convergence electrode voltage as the deflection angle increases. Since the tube focus is changed by the dynamic convergence voltage, it is also necessary to modulate this electrode.

The dynamic convergence and focus modulation voltages, each having the proper waveform, amplitude, and synchronism with deflection, are produced by linear addition of a variable shape vertical parabola with a variable phase horizontal sine wave. The composite alternating output voltage is coupled to the kinescope convergence electrode and focus electrode through the respective output taps.

The vertical-deflection dynamic convergence amplifier circuit combines, shapes, and amplifies the parabola and sawtooth waveforms derived from the vertical-deflection circuit for application to the kinescope.

Sine-wave horizontal dynamic waveform is derived from two cascaded tuned circuits excited by horizontal kickback.

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L.R. KIRKWOOD received the B.S. degree in Electrical Engineering in 1930 at Kansas State University. He joined the RCA Victor Division at that time to do design and development work on radios and phonographs. In this activity he made numerous fundamental contributions to the art and acquired many patents. His wartime assignments took in development of radar, navigation, and communications equipment for both Army and Navy. Following this, he did some of the very early color systems and receiver work for RCA, after which he returned to commercial radio engineering as manager of the department. In 1950, he became manager of the Color Product Development Section and organized this new activity. From 1950 to date, he directed and took part in all the receiver developments for color as well as take part in all major demonstrations and field tests. Mr. Kirkwood is a member of Phi Kappa Phi, Sigma Tau, Lambda Chi Alpha, and is a Senior Member of the Institute of Radio Engineers.



ALTON JOHN TORRE received the B.S. degree in Electrical Engineering in 1943 at the University of Oklahoma, after which he joined the RCA Victor Division. His early work at RRCA was connected with the design and development of airborne radar equipment. Following the war, his activities transferred to the home instrument field where he did design and development work on radio receivers. At present, he is manager of electrical engineering for the Color Product Development Section of which he has been a member since 1950. In this activity, he has taken part in practically all field tests and demonstrations as well as all color television receiver developments leading up to the commercialization of color. Mr. Torre is a member of Tau Beta Pi, Sigma Tau, Eta Kappa Nu, is a Senior Member of the Institute of Radio Engineers, and a registered engineer in the State of New Jersey.