LB-1050

TRANSISTORIZED TELEVISION CAMERAS USING THE MINIATURE VIDICON

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Approved

Stuart Wm. Seeley

This bulletin describes two fully transistorized television cameras built around a new one-half inch diameter Vidicon pick-up tube. One camera provides a simple closed circuit television chain in conjunction with a home receiver. The second is designed for remote broadcast applications and is a completely self-contained television station.

Introduction

The development of a half-inch diameter vidicon has made it possible to design transistorized television cameras of small size, low weight, low power consumption and high sensitivity. Two camera equipments will be described in this bulletin. The first, which is shown in Fig. 1, alongside a commercial portable receiver, is a relatively simple unit which, in connection with any standard television receiver, will form a complete closed circuit television system. This camera, hereafter designated as the Transistorized TV Eye (abbreviated TTV) employs 19 transistors and has rather flexible power supply arrangements which will be described. The second, shown in Fig. 2, is a much more elaborate device. It is in reality a complete portable television transmitting station including a synchronizing generator, a picture monitor and a 2000 mc transmitter. Employing 72 transistors, the entire unit weighs 19 pounds including a rechargeable battery providing about five hours of operation. The term 'Creepie Peepie' seems to have received considerable popular acceptance for this type of equipment. Consequently, it will hereafter be referred to as the Transistorized Creepie Peepie (abbreviated TCP).

The Half-Inch Vidicon

This tube is shown in Fig. 3. Its dimensions may be deduced from the photograph. For use with transistor

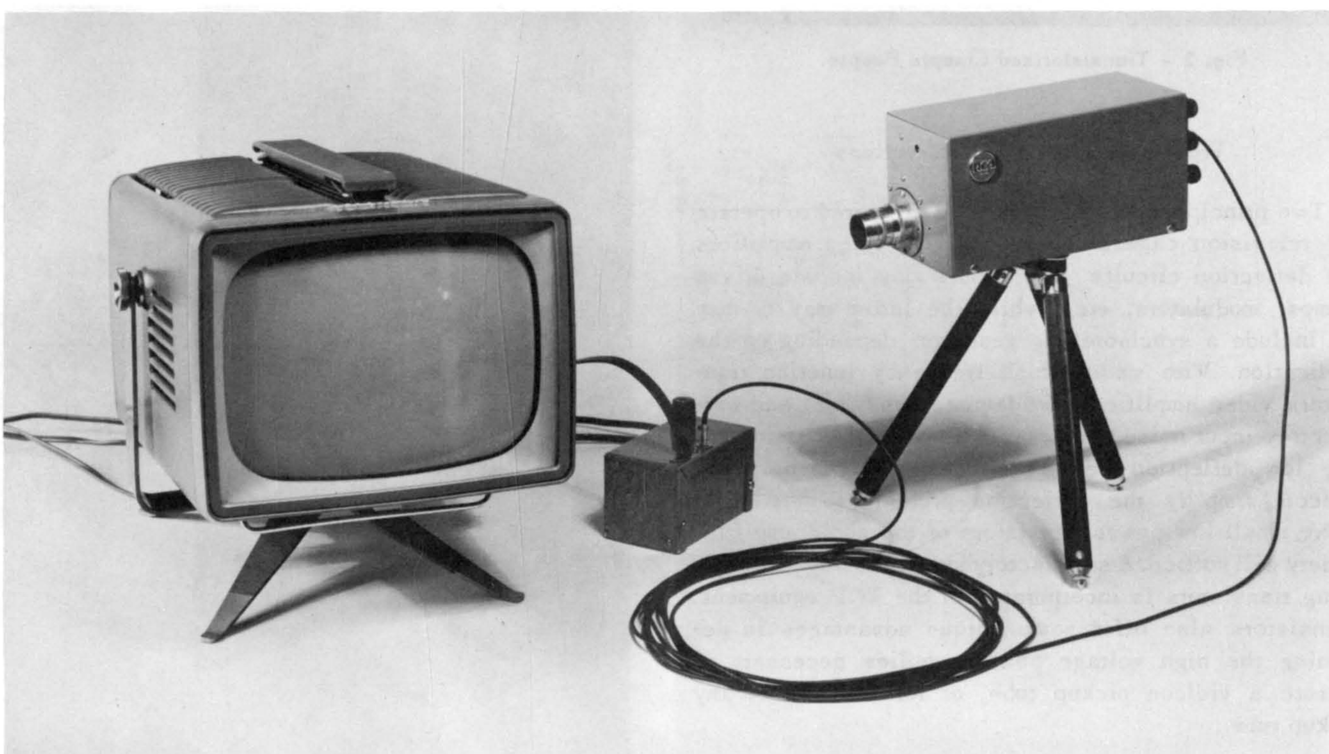


Fig. 1 – Transistorized television-eye camera.

circuits the tube has the advantage of requiring only about 20 ampere turns of deflection field. This is about one-third of the amount required by the conventional one-inch vidicon (RCA 6198). The tube may also be made somewhat more sensitive than its predecessor. As this tube is described in a companion bulletin[1], it will not be discussed further.

Fig. 2 – Transistorized Creepie Peepie.

Transistor Circuit Considerations

Two principal types of circuits are required to operate any television camera tube. They are video amplifiers and deflection circuits. The former may include driven clamps, modulators, etc., while the latter may or may not include a synchronizing generator depending on the application. With modern high frequency junction transistors video amplifiers of adequate bandwidth and satisfactory input noise characteristics may be constructed. The low deflection field requirements of the half-inch vidicon simplify the deflection problem to the point where small low power transistors of the audio amplifier variety will suffice. A satisfactory synchronizing generator using transistors is incorporated in the TCP equipment. Transistors also offer some unique advantages in designing the high voltage power supplies necessary to operate a vidicon pickup tube, or for that matter any pickup tube.

[1] *LB-1049* *A Miniature Vidicon of High Sensitivity,* by A. D. Cope.

The Transistorized TV Eye Camera (TTV)

General

The complete circuit of this unit is shown in Fig. 4 and Fig. 5 is a photograph of the camera with the cover removed. The video amplifier appears across the top, the center section depicts the deflection and blanking circuits and the power supplies are at the bottom. These various circuits will be described.

The Video Amplifier

The video amplifier must accept a signal current from the half-inch vidicon of about 10^{-7} amperes and amplify it to a level sufficient to drive the modulator in which the video information is modulated on a carrier frequency which may be adjusted to either of the two lowest VHF television channels. The camera output is thus at radio frequency and is suitable for connection

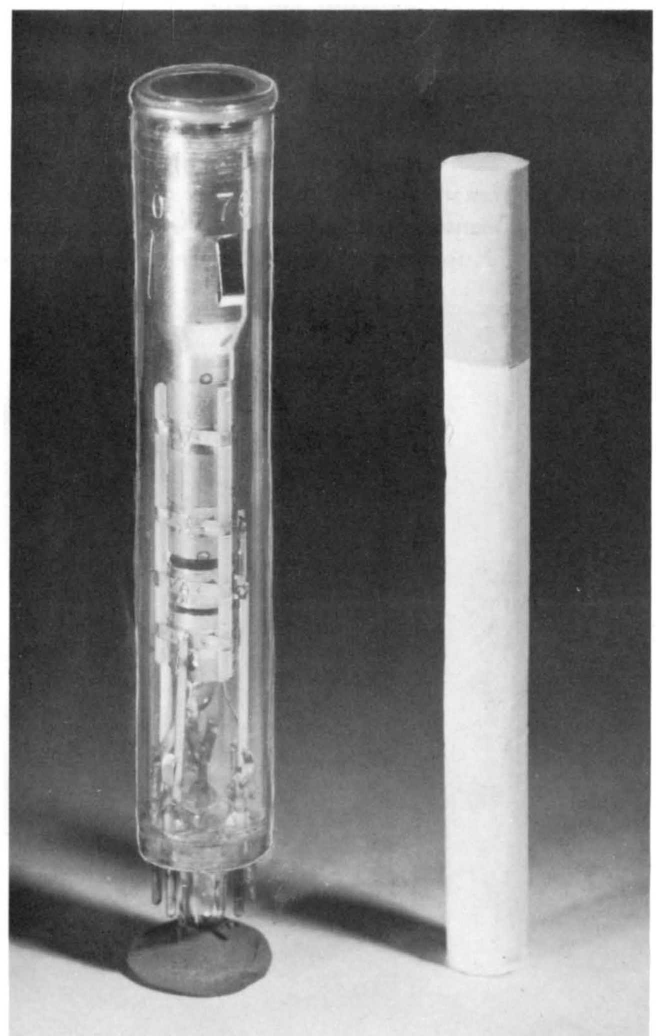


Fig. 3 – Half-inch vidicon compared with cigarette.

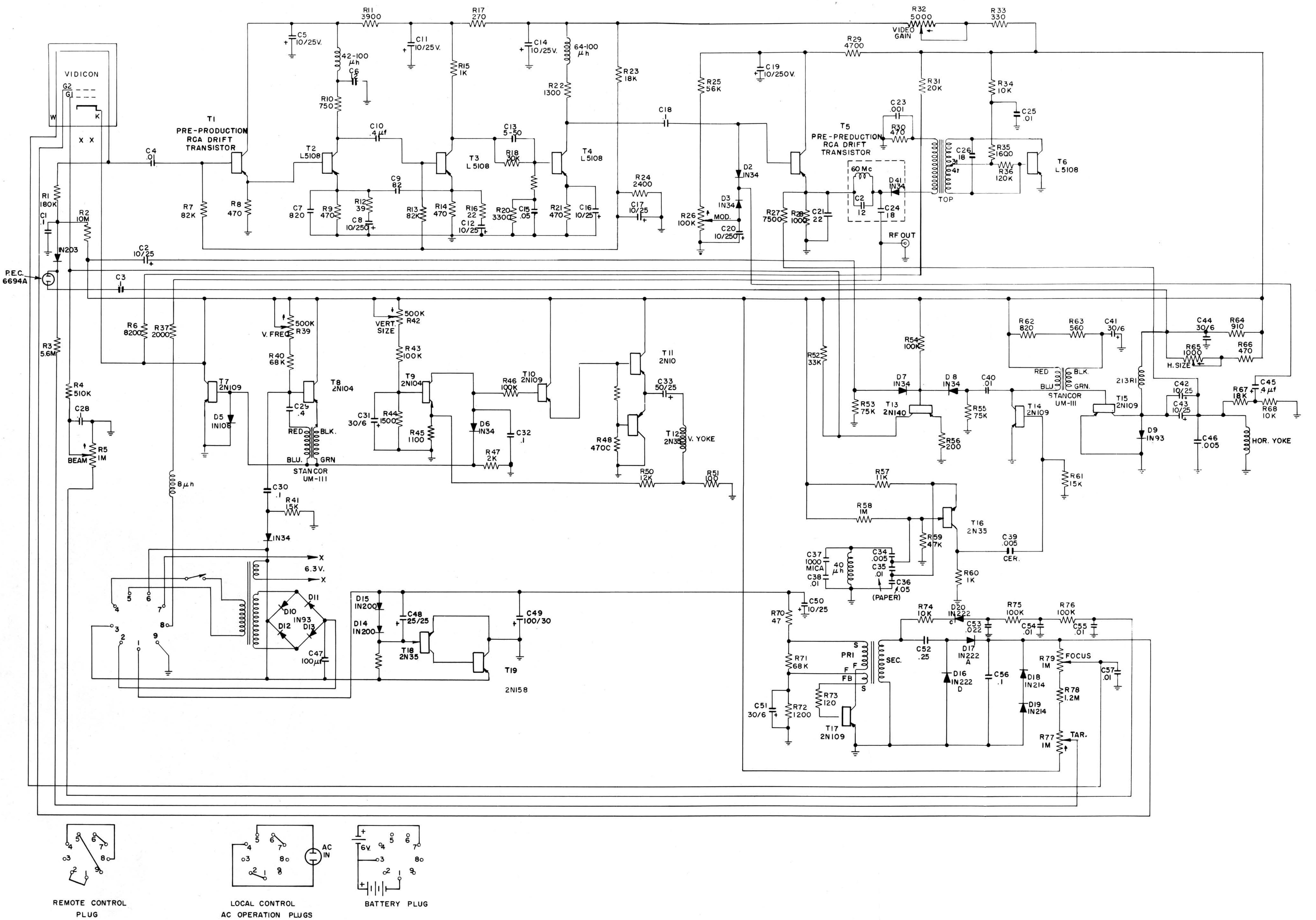


Fig. 4 – Improved transistorized camera.

directly to the antenna terminals of the associated receiver. The video bandwidth is about 4 mc.

For best signal-to-noise ratio the input impedance of the amplifier is made high even though this results in a non-uniform frequency response, i.e., a considerable high frequency roll off. The characteristics of a later stage in the amplifier are then altered in an inverse manner to produce an overall flat response. This well known technique, called *high peaking,* results in about 14 db improvement in the apparent low frequency signal-to-noise ratio. In practice, the input impedance of the amplifier is made about 50KΩ. The vidicon signal current thus develops about 5 millivolts across this load at low frequencies. The modulator requires about 200 millivolts at about 200 ohms impedance. A power gain of approximately 57 db is thus required. The *high peaker* requires about 26 db more gain adequately to equalize the falling high frequency response of the input network and it is advantageous to provide an additional 22 db of high frequency gain to compensate for the apparent spot size of the camera tube (aperture correction). The total required high frequency gain is 105 db.

The first video stage, transistor T_1, is connected as an emitter follower. It provides the required high input impedance. The output of this stage is direct coupled to the base of a second transistor, T_2. As might be expected the first transistor presents the greatest problem in transistor selection. Although other transistors may be used, an RCA pre-production drift transistor has proven the most suitable in this application due to its high input impedance, good frequency response and low noise.

The second and third stages of the amplifier must be considered together. Neglecting their emitter circuits they will be seen to be conventional a-c coupled common emitter amplifiers. A shunt peaking inductance in the collector circuit of T_2 maintains the high frequency response to 4 mc. The emitter circuits are complex. In each emitter a 470 ohm resistor (R9, R14) provides a d-c path of sufficient resistance to obtain adequate d-c stability. Such a high resistance would reduce the stage

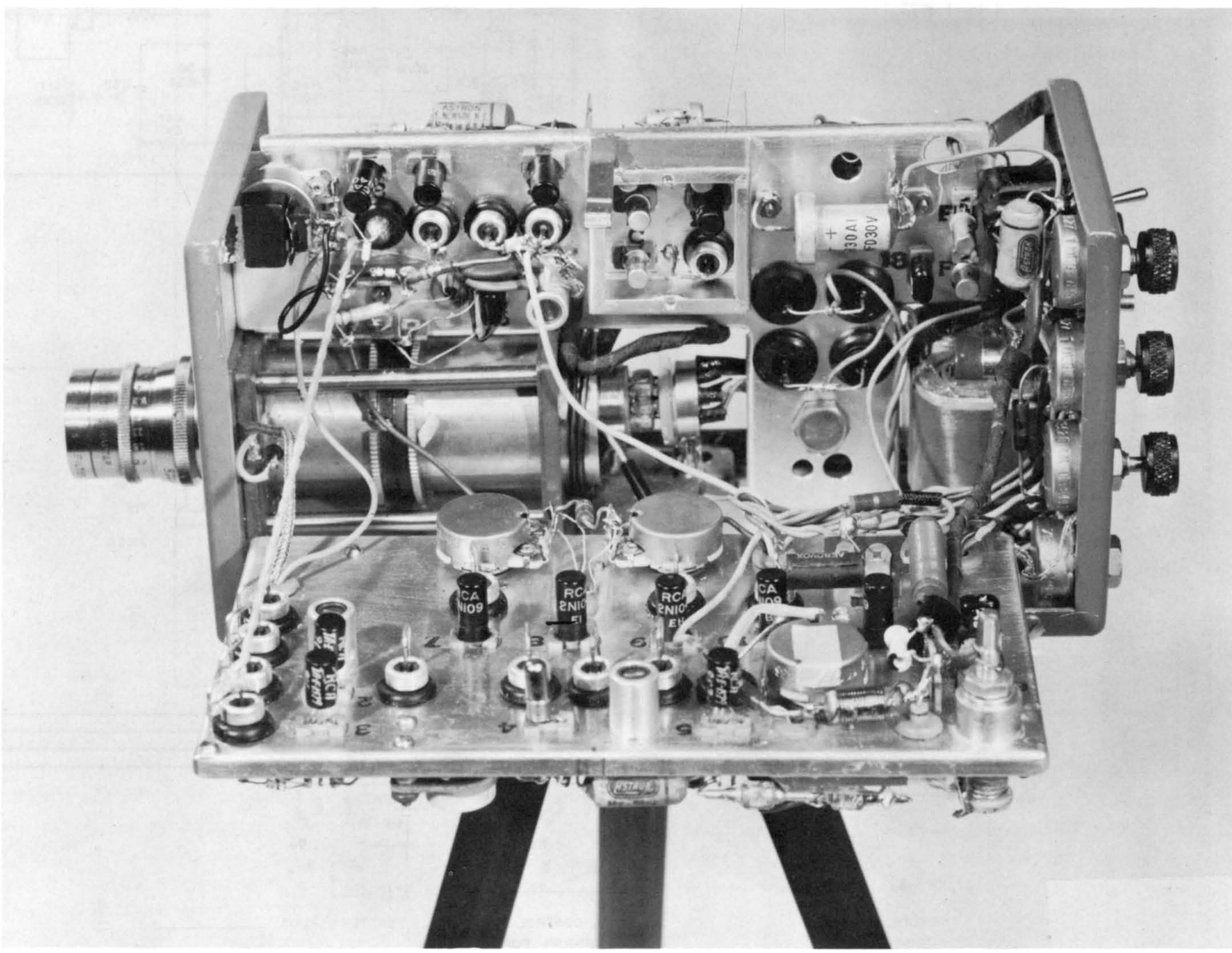


Fig. 5 – Camera interior.

gain to a very low value, however. RC networks comprising R12 and C8 and R16 and C12 are therefore shunted across these emitters. It will be noted that this does not remove all the a-c degeneration. Positive feedback at high frequencies is now applied from the emitter of T_3 to the emitter of T_2 via a capacitive divider comprising C9 and C7. This artifice sufficiently increases the high frequency gain of the circuit to provide the necessary aperture correction. Transistors T_1 and T_3 are biased by means of a common bleeder network (R23, R24) while T_2 is biased by its direct connection to T_1.

The adjustable high peaker is located between the collector of T_3 and the base of T_4. It will be seen to be a simple adjustable high frequency equalizer in which the amount of high frequency equalization is fixed by the circuit resistances and the turn over frequency adjusted by means of C13. The latter is adjusted to match the loss characteristic of the input network. In practice this adjustment is most readily carried out by observing a test pattern and visually adjusting the high peaker to minimize *trailing*.

T_4 is a conventional common emitter stage. Its emitter is by-passed and a peaking inductance in its collector maintains its high frequency gain. Bias is applied via the high peaker resistors to its base. The transmission of a good television picture imposes special requirements on the low frequency response of the system amplifiers. There are several possible solutions to this general problem. The response may be made good to d-c for example. This is usually impractical. A more usual technique is to adjust the amplifier low frequency gain and phase response in such a fashion that it will adequately reproduce a square wave at the horizontal scanning frequency and then to employ clamping or d-c restoration to reinsert the d-c component. Where space is at a premium, as in this camera, the latter technique results in much smaller coupling and by-pass capacitors. In this equipment an overall low frequency correction can conveniently be made by placing a capacitor, C15, across R20, the latter resistor being required to properly bias T_4. This one capacitor will adequately compensate the low frequency response of the amplifier through T_4 in the desired fashion.

The signal from the collector of T_4 is a-c coupled to the base of T_5 via a relatively small capacitor, C18, and a driven clamp, comprising diodes D2 and D3 sets the base potential of T_5 at the start of each horizontal line. Negative drive pulses for the clamp are derived from the horizontal deflection circuit via R67, R68 and C45. On each pulse, the diodes conduct, clamping the base of T_5 to a potential which is adjusted for optimum operation of the modulator by means of R26. DC information is thus reinserted at this point in the amplifier.

The modulator, D4, operates as a variable impedance in series with the carrier oscillator output. This impedance is caused to vary in accordance with the video information. T_6 is a transistor oscillator which is tunable from 54 to 66 mc. Oscillation is maintained by feedback from collector to base via the tuned transformer shown. Energy from the oscillator is applied to the anode of the modulator diode, D4, via a two turn coupling coil on the oscillator transformer. DC bias is also applied at the same point from a divider comprising R30 and R31. The cathode of the modulator diode is connected through a trap broadly tuned to the carrier frequency, to the emitter of T_5. By means of R26 the modulator diode is adjusted to be conducting. RF from the oscillator, T_6, now can pass through the modulator diode to the output terminal of the camera via a small capacitor, C18. Video signals at the emitter of T_5 will vary the diode impedance thus modulating the video signal on the carrier.

Synchronizing pulses are also added to the outgoing signal in the modulator. Negative horizontal synchronizing pulses from the deflection circuit are applied via R27, which imposes a negligible load on the video signal. Positive vertical synchronizing pulses from the vertical blanking amplifier, T_7, are applied to the other electrode of the modulator diode by means of R6. These circuit arrangements produce a composite output signal in which both horizontal and vertical synchronizing components are of the correct polarity with respect to the video information.

The Vertical Deflection System

A blocking oscillator, T_8, generates negative pulses across R47 at vertical frequency. During a-c operation this oscillator is locked to the power line by means of a circuit comprising D22, R41 and C30. This circuit injects the requisite amount of suitably shaped line frequency signal into the base circuit of the oscillator to accomplish this function. During battery operation the blocking oscillator runs free.

The negative pulses across R47 are amplified and inverted in T_7, the vertical blanking amplifier, and applied to the cathode of the vidicon. Landing of the electron beam is thus prevented during the vertical flyback. A portion of the output of T_7 is also used as vertical synchronization as previously explained.

Each negative pulse across R47 charges C32 via diode, D6. A linear sawtooth voltage is generated across this capacitor by allowing it to discharge between pulses through constant current transistor, T_9. The magnitude of the discharge current is adjustable by means of R42, the vertical size control. The generated sawtooth voltage waveform has a maximum amplitude of about ten volts; this limitation being set by the magnitude of the pulse available across R47.

The vertical yoke windings have a resistance of about 200 ohms and an inductance of about 57 mh. The latter is negligible. The sawtooth voltage appearing across C32 must now be coupled into these windings and must cause an accurately linear sawtooth current to flow in them. Impedance conversion is performed in the following stages as a first step in accomplishing this. T_{10} is an emitter follower direct coupled to a class B complementary symmetry output amplifier comprising T_{11} and T_{12}. R46 limits the voltage which can be applied to this system and swamps out the somewhat non-linear input impedance characteristics of T_{10} as well as raising the load impedance seen by the sawtooth generating circuit. As a d-c connection to the yoke would cause prohibitive decentering of the vidicon beam, capacitive coupling to the yoke is used. The coupling capacitor, C32, is too small adequately to reproduce the sawtooth, but space did not permit a larger unit. The application of negative feedback via R51, R50 and R45 corrects the resulting non-linearity in acceptable fashion. The available maximum peak-to-peak deflection current is about 25 milliamperes.

The Horizontal Deflection Circuit

The horizontal deflection circuit operates in much the same fashion as its counterpart in contemporary home television receives: that is to say it generates a sawtooth current waveform by periodic interruption of the current flowing in an inductance. Fortunately, transistors make better switches than vacuum tubes in that the impedance of a transistor when conducting is materially lower than that of a vacuum tube.

Transistor, T_{16}, is an oscillator operating at the horizontal scanning frequency. It is similar to a vacuum tube Colpitts oscillator. Some temperature compensation is applied in the interest of stability by means of temperature sensitive capacitor, C38. Although the waveform across the oscillator tuned circuit is a good sine wave the waveform in its collector circuit is a negative pulse. This keys on transistor, T_{14}. The large positive pulse on the collector of T_{14} is coupled into the base of horizontal output transistor, T_{15}, without inversion by the stepdown transformer shown. This cuts off T_{15}, causing a large pulse to appear across the yoke windings. This occurs during the horizontal retrace period. D9 is the usual damper diode, as in a conventional receiver. C46 adjusts the resonant frequency of the yoke system. It is chosen to lengthen the retrace period to the maximum permissible amount, as this reduces the peak pulse voltage occurring during the flyback and materially improves the efficiency of the circuit. Again d-c must be blocked from the yoke windings, hence a choke provides a d-c path for the collector current of T_{15} and capacitors C42 and C43 couple the collector to the yoke. The horizontal yoke windings have an inductance of about 1 mh and a resistance of about 3 ohms. For good linearity the L/R ratio of the yoke must be as high as possible, the figures given representing about the lowest value of this ratio permissible.

In principle, as a transistor such as T_{15} really contains a built-in diode in its collector circuit, diode D9, could be omitted. In practice, due to the relatively high forward impedance of the collector to base junction of small transistors better results can be obtained by adding an additional low impedance diode as shown. In higher power deflection circuits using power transistors the improvement due to the added diode is not as marked.

Associated with the horizontal deflection system is an additional blanking amplifier, T_{13}. The vidicon requires about 15 to 20 volts of positive blanking signal on its cathode to positively prevent beam landing during the retrace periods under all conditions of beam current and illumination. It is obviously difficult to provide this in a camera in which the maximum supply voltage is 15 volts. For this reason additional blanking is applied to the vidicon grid to reduce the beam current during the retrace intervals. Diodes D7 and D8, non-linearly mix positive horizontal pulses from T_{14} and positive vertical pulses from T_7. The resultant is applied to the base of T_{13}. Amplified negative blanking pulses at the collector of T_{13} are applied to the vidicon grid.

It will be noted that this arrangement, in conjunction with T_7, results in the application of positive vertical blanking pulses to the vidicon cathode and negative mixed blanking pulses to the vidicon grid. Thus double blanking is supplied during the more critical vertical blanking interval. The vertical blanking interval is the more critical as it encompasses a number of complete horizontal scans during the forward scanning portions of which the beam is moving relatively slowly. On the other hand during the horizontal retrace the beam is always in rapid motion and the resulting current density at the vidicon target is proportionately lower.

The High Voltage Power Supply

The vidicon requires a positive accelerating potential of about 300 volts, a positive focussing voltage adjustable from 250 to 300 volts, and a negative source of bias adjustable from zero to about minus 100 volts for beam current control. All voltages are referred to the vidicon cathode, which is near ground potential, being returned to the collector of T_7. These voltages are supplied by a transistor converter, T_{17}, operating from the minus 15 volt bus which powers all the transistor circuits of the camera. Since battery operation was one of the design objectives this scheme greatly simplifies the power and switching arrangements. Further, as the converter operates at a high frequency (15 kc) the size and weight of the required filter components is greatly reduced. T_{17} is a transistor square wave oscillator. Its operating frequency is controlled by the associated transformer. A convenient design procedure is given by Light and Hooker[2]. As a d-c to d-c power converter the efficiency is high because the transistor is operated as a switch. The waveform at the collector of T_{17} is nearly a square wave whose amplitude approaches the supply voltage. The transistor in this circuit is switched rapidly between its fully conducting state in which its current is high but the voltage across it nearly zero, and its off state in which its current is zero and the voltage across it is considerable. Under these conditions the power dissipated in the transistor is very low and overall efficiencies of 70 to 90 percent may be achieved.

The voltage at the transistor collector is stepped up in the transformer and applied to two separate rectifier systems. The first, comprising D16 and D17 is a doubler. Its output is regulated by a pair of silicon *zener* diodes, D18 and D19. Two diodes in series are used to reduce the power dissipated in each. The output voltage is adjusted to 280 to 300 volts by selection of the regulator diodes which have fairly wide tolerances as received from the manufacturer. A bleeder comprising R77, R78 and R79 then provides the necessary wall, focus and target potentials for the vidicon. The maximum current available from this rectifier system is about 800 microamperes.

Another rectifier, D20, supplies about 100 volts negative to the beam current control, R5. Resistance capacitance filters are used throughout. Note also that some decoupling is provided between the converter and the minus 15 volt bus (R70 and C50); this was necessary to prevent interference from the free-running converter from getting into the video circuits.

The Low Voltage Power Supply

The camera may be operated either from the a-c line or on batteries. The user has a further option during a-c operation; power for the camera may either be taken from the nearest a-c outlet or it may be sent to the camera from the remote viewing point over the same coaxial cable which carries the rf output of the camera. During either the local or remote a-c mode of operation the 15 volt bus which operates all the transistor circuits in the camera is energized by a low voltage regulated supply comprising power transformer, XF-1 rectifiers D10 thru D13 and transistorized voltage regulator, T_{18} and T_{19}.

During the remote method of supplying power, plug, P1, is inserted into socket, S1. This connects the primary of the power transformer across the rf output connector through a small (8 microhenry) rf choke. Power is applied to the end of the output coaxial cable remote from the camera by means of an adapter box shown in Fig. 6 which interconnects the cable and the remote receiver. Because of the great frequency separation between the camera output radio frequency (approximately 60 mc) and the power line frequency the simple chokes and capacitors shown are entirely adequate for isolation of the two signals. As the primary current of the power transformer in the camera is only about 45 ma a considerable length of coaxial cable may be used to interconnect the camera and the remote receiver.

To change over to local a-c operation, plug, P2, to which is connected an ordinary line cord, is inserted in socket, S1. The line cord is then plugged into the nearest a-c outlet.

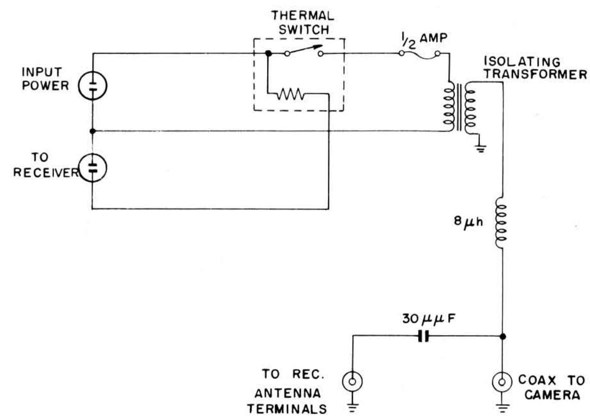


Fig. 6 – Circuit of remote adaptor for transistorized television camera.

In either of the above modes of operation transformer XF-1 steps down the incoming line voltage to about 24 to 26 volts, This is rectified by the bridge rectifier, D10 thru D13, and applied to the transistor regulator. Although this circuit looks unconventional, its action is identical to the usual vacuum tube series regulator. In this case transistor, T_{19}, is the series element and T_{18} is the amplifier. A pair of zener diodes provide the necessary voltage reference. The regulator delivers about 150 ma to the 15 volt bus and will hold the output voltage within 0.1 volt of the specified value for any input voltage between 100 and 130. It also reduces the ripple content at the output of the bridge rectifier (about 2 volts) by a factor of about 100. It will be apparent to the reader that a choke to perform this function would be prohibitively bulky.

The camera may be operated on batteries by inserting plug, P3, into S1 and connecting the appropriate batteries to the leads terminating in P3. The power supply regulator remains in the circuit to hold the voltage of the 15 volt bus constant. Although this wastes some power it greatly increases operating stability.

[2]L. H. Light and P. M. Hooker, 'Transistor DC Converter', *The Proceedings of the Institute of Electrical Engineers,* Vol. 102 p. 775 Part B (1955).

The total power consumed by the camera is about 5.2 watts during a-c operation. Of this input power about 1.5 watts is dissipated in the power supply regulator, this dissipation decreasing at lower line voltages. Another watt is used in the heater of the half-inch vidicon. About 0.5 watt is lost in the power transformer and rectifier system. The remaining 2.2 watts powers all the transistor circuits in the camera. Note that this is less than the heater power alone of many receiving type vacuum tubes.

Miscellaneous

A few details remain for discussion. The half-inch vidicon is focussed by means of a permanent magnet assembly. The latter is simply a scaled down version of a similar assembly used with the one-inch vidicon. It is easily fabricated of low precision parts and gives excellent results. Its greatest advantage is that it requires no input power. It also eliminates the coil current regulator circuit which would be required with electromagnetic focus.

A novel feature of the TTV camera is an experimental arrangement for automatically varying the camera sensitivity as a function of the ambient illumination of the scene being viewed. D21 is a photo-diode which is arranged at the proper distance behind a hole of suitable diameter in the front surface of the camera so that it *sees* a solid angle identical to that of the camera lens. Increasing light increases the current through the photo-diode. This is arranged to reduce the target voltage of the vidicon, thus reducing its sensitivity. A zener diode, D1, provides a d-c level shift in this circuit merely for convenience in selecting appropriate operating points for the vidicon and the photo-diode. Compensation for ambient illumination changes of the order of 50 to 1 may be provided by this method. The usefulness of such compensation where the camera operator is unskilled or the camera itself inaccessible is obvious.

The Transistorized Creepie Peepie

General

The TCP comprises three distinct units, the camera, the monitor (electronic viewfinder), and the backpack. The camera and monitor may be fastened together by

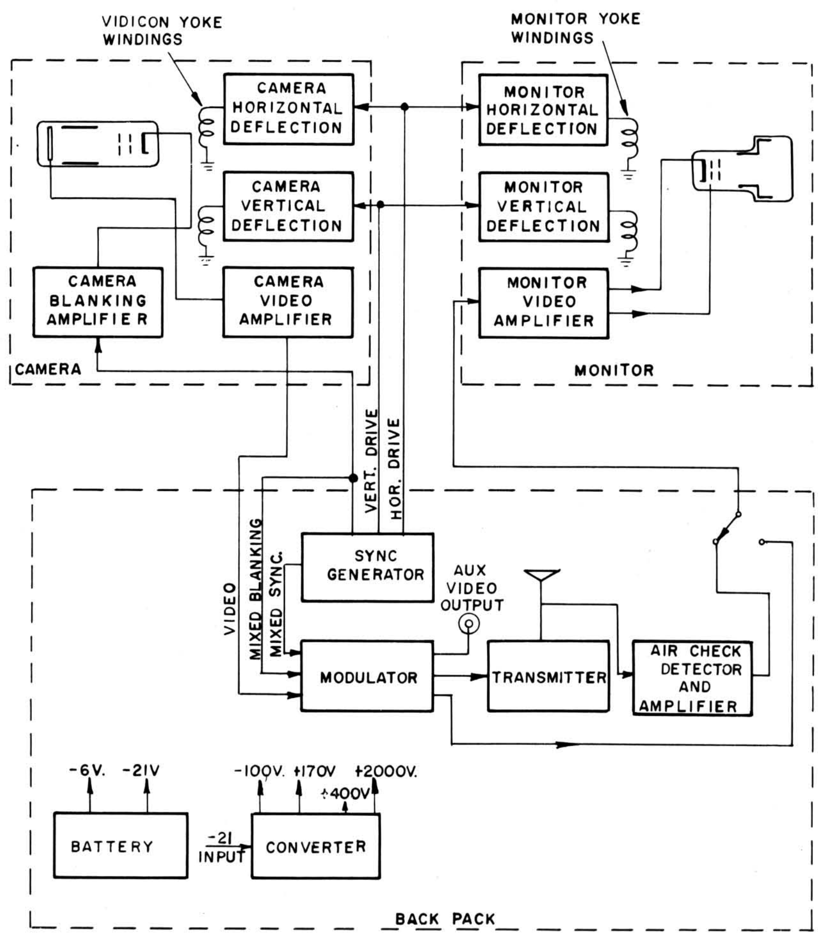


Fig. 7 – Block diagram of transistorized Creepie Peepie.

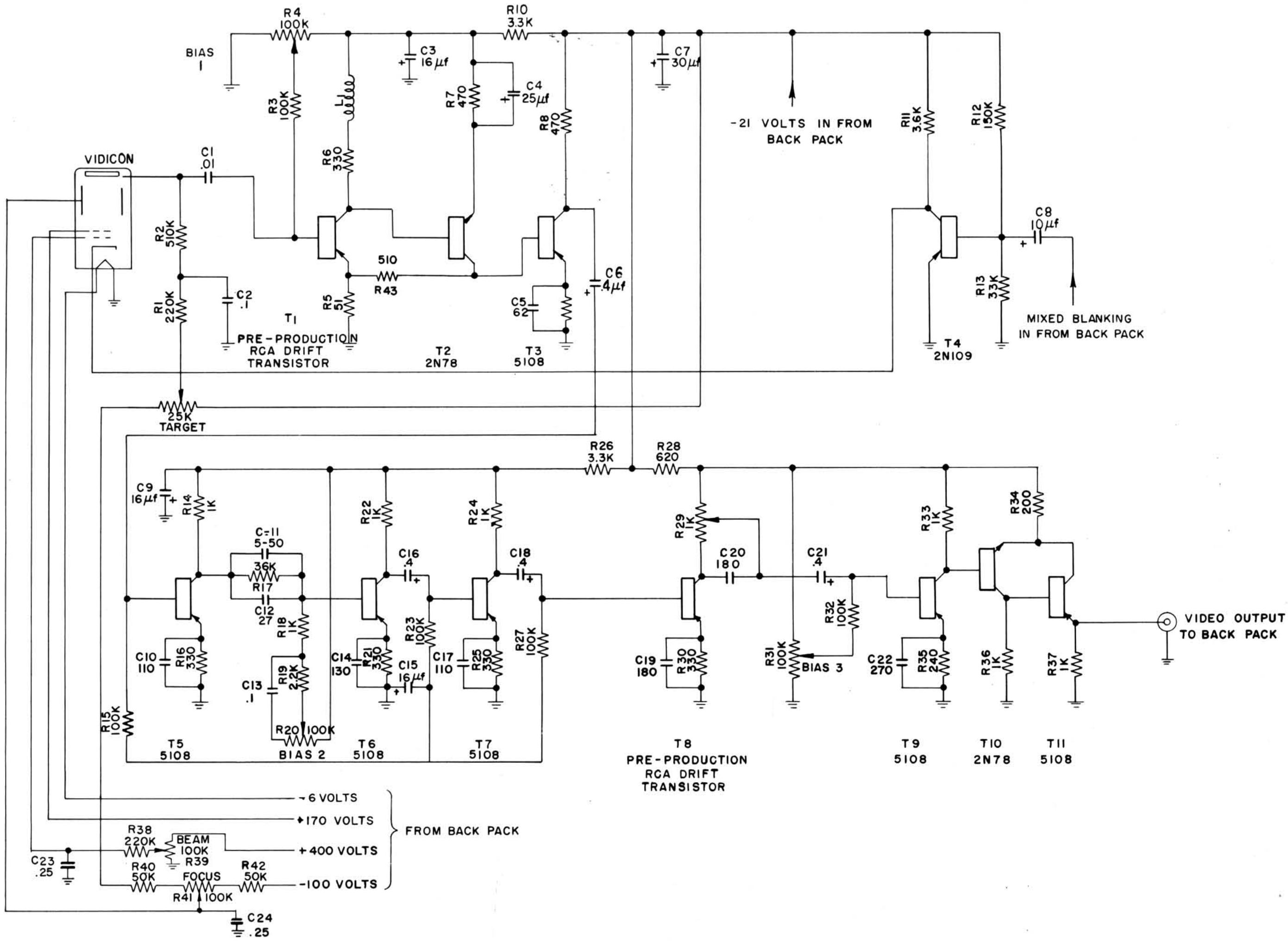


Fig. 8 – Camera video and blanking amplifier.

means of captive screws during operation, or the viewfinder may be slung around the user's neck on a suitable lanyard and viewed in a manner similar to a reflex camera. Appropriate cables are supplied for either mode of operation. For most shots the viewfinder is left fastened to the camera, but it may occasionally be advantageous to employ the other mode of operation to obtain a picture over the heads of persons in a crowd. etc.

A block diagram of the equipment is shown in Fig. 7. The camera contains a video pre-amplifier, horizontal and vertical deflection circuits and a blanking amplifier in addition to the half-inch vidicon with its yoke and focus magnet. Horizontal drive pulses, vertical drive pulses and mixed blanking pulses as well as all necessary d-c voltages are supplied to the camera over a four foot cable from the backpack. The video signal from the camera video pre-amplifier is sent back to the backpack on a coaxial conductor braided into the same cable.

The monitor contains horizontal and vertical deflection circuits and a video amplifier. Most of the space within the monitor case, which is identical in size to the camera, is taken up by the monitor tube and its deflection yoke. The tube has a one and one-half inch diameter face. Two cables are supplied with the equipment. One, a few inches in length, is used when the monitor is mounted on the camera. It interconnects plugs on the rear of the monitor and camera. The second, four feet long, is used when the monitor is dismounted from the camera. It connects the monitor directly to a duplicate plug on the side of the backpack. In either case the appropriate cable carries horizontal drive pulses, vertical drive pulses and video information to the monitor as well as all necessary d-c voltages.

A switch on the backpack permits the operator to view on the monitor either the video signal at a suitable point in the modulator or a rectified and amplified sample of the transmitter output. The latter mode of operation has proven most desirable as it gives the operator an instantaneous indication of transmitter overmodulation. The electronic viewfinder also permits the cameraman to check the vidicon electrical focus. This would be impossible with an ordinary optical viewfinder.

The backpack contains a rechargeable battery which will run the equipment for about five hours, a transistor power converter to supply high voltage for the camera, monitor and transmitter tubes, a crystal controlled synchronizing generator, a 2000 mc transmitter, a modulator amplifier in which d-c level setting, sÿnch addition, set-up addition, etc. are performed and a small auxiliary video amplifier and rectifier which samples the transmitter output. The transmitting antenna projects from the top of the backpack.

It is instructive to compare the weight, size and power data for the TCP with that for a similar vacuum tube equipment built by the authors several years ago[3]. The TCP camera with its viewfinder weighs 4 pounds. The earlier unit, which used a one-inch vidicon and a similar monitor tube, weighed 8 pounds. The backpack unit of the TCP weighs 15 pounds and is 3 by 12 by 13 inches in size. The corresponding part of the earlier equipment weighed 50 pounds and required four times the volume. The same equipment consumed nearly 200 watts of power from its batteries which would operate it for about two hours. The TCP consumes 30 watts and operates for nearly five hours on a smaller size battery.

[3]Flory, Dilley, Morgan, and Pike, 'A Developmental Portable Television Pickup Station', *RCA Review*, Vol. XIII No. 1 p. 58, March 1952.

The TCP Camera

The camera and monitor are shown with covers removed in Figs. 9 and 13. As the heat dissipated in the transistors themselves is negligible their accessibility has been sacrificed in order to make their socket connections to which the various resistors, capacitors and other components are soldered, more readily accessible. The deflection circuits occupy the small fixed chassis directly behind the vidicon assembly.

The circuit of the camera video pre-amplifier is shown in Fig. 8. The blanking amplifier is also included in this drawing, as well as the vidicon beam, focus and target voltage controls. As a higher supply voltage, 21 volts, is available in this unit the vidicon blanking amplifier presents no problem. T_4 is a common emitter amplifier which is directly connected to the vidicon

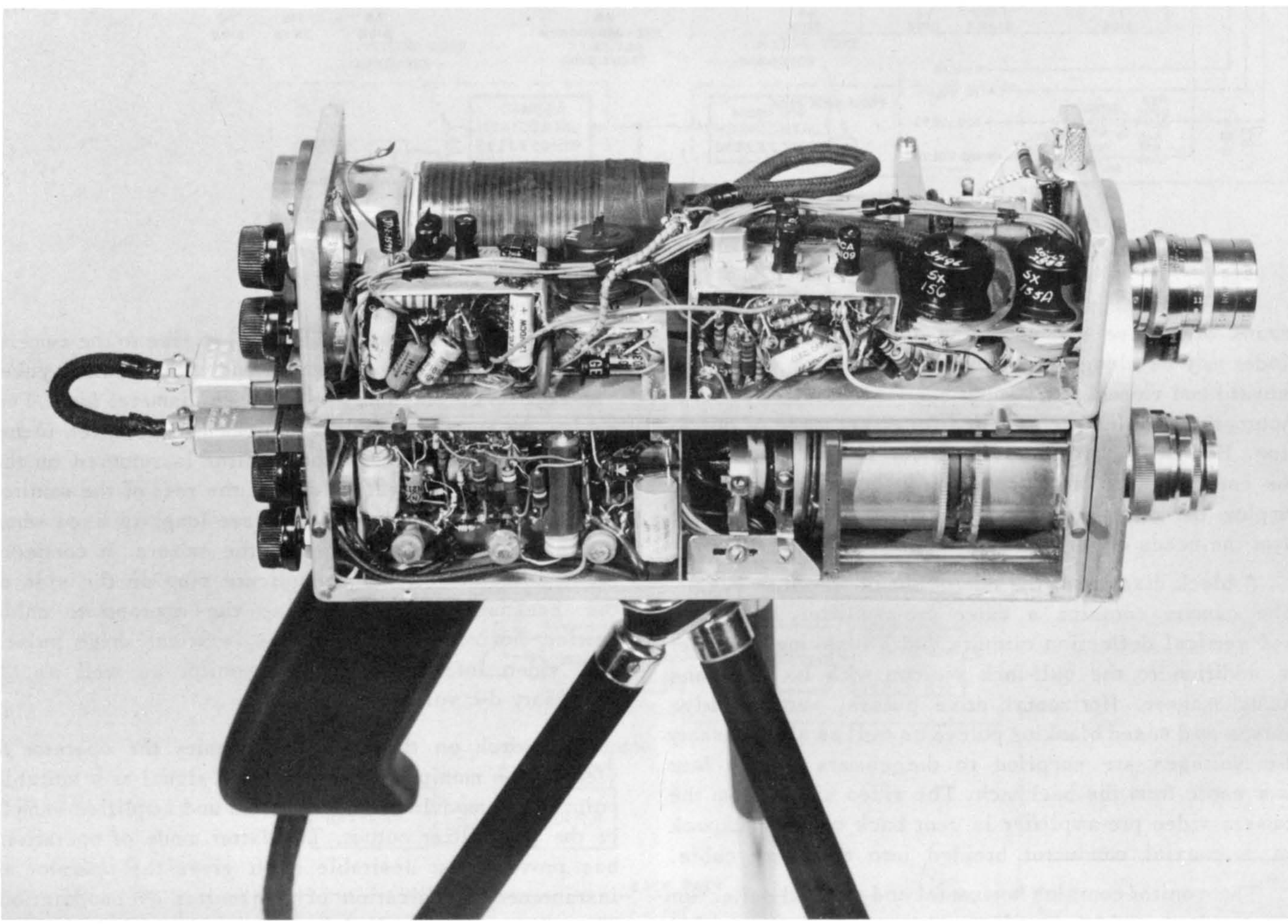


Fig. 9 – Right side of camera and monitor.

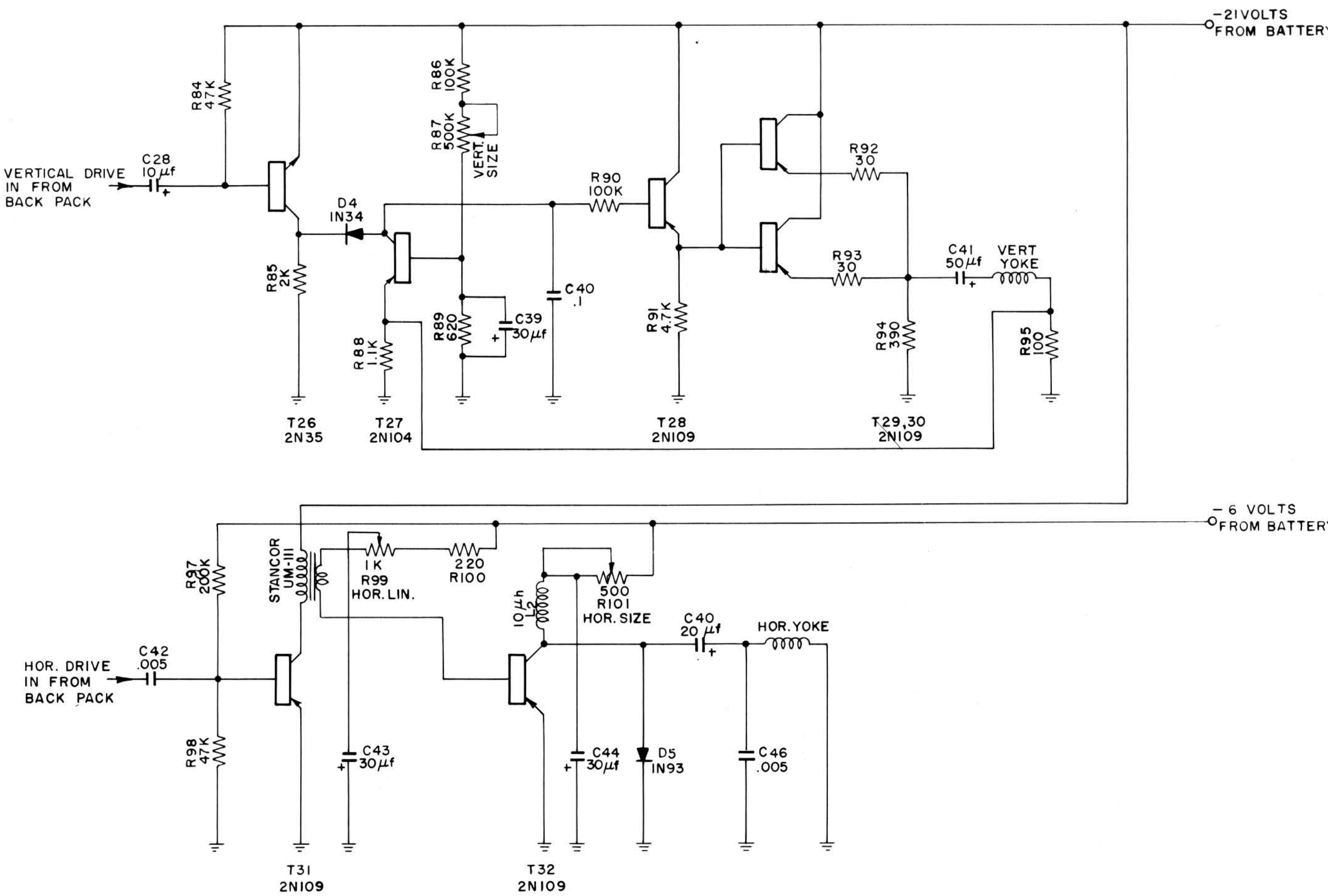


Fig. 10 – Camera deflection circuits.

cathode. Negative mixed blanking signals from the sync generator in the backpack are applied to its base. Twenty volts peak-to-peak of positive mixed blanking are available at its collector and this is adequate to prevent landing of the vidicon beam under any conditions during the horizontal and vertical retrace periods.

A somewhat different design philosophy has been adopted in this video amplifier. Basically it has been to use a liberal number of transistors in the interests of eliminating peaking coils with their inevitable need for careful adjustment. The bandwidth of this amplifier is also wider (6 mc) than that of the TTV camera.

The input amplifier employs transistors. T_1, T_2 and T_3, and exemplifies in transistors T_1 and T_2 a type of feedback pair which has been freely used in later stages, particularly in the modulator. It consists of a pair of transistors of opposite conductivities, with feedback from the collector of the second to the emitter of the first. The arrangement is d-c stable, has high input impedance, low output impedance and either output polarity may be derived from it. In this case the collector of the second transistor is d-c connected to the base of the third, T_3. The response of this circuit is maintained flat to 6 mc by means of a peaking inductance, L1, and a capacitor shunting the emitter resistor of T_3, C5. A bias control, R4, is provided to set the operating point for this circuit. This could have been fixed, but was made variable to accomodate different types of transistors. A similar reasoning governs R20 and R31.

The next stage, T_5, is an ordinary common emitter stage which drives the high peaker. Its high frequency response is maintained by means of C10. The high peaker is basically identical to that in the TTV camera with some slight differences in parameters necessitated by the increased bandwidth. Again an overall low frequency compensation is provided in this stage by means of C13.

The following four stages, T_6 through T_9 are ordinary common emitter amplifiers. They are, however, overcompensated as far as high frequency response is concerned and the cumulative effect of this overcompensation supplies the necessary aperture correction. A video gain control, R29, compensated by a small capacitor, C20, is inserted between T_8 and T_9. The last two transistors, T_{10} and T_{11}, comprise another feedback pair which drives the cable interconnecting the camera and backpack. This feedback pair will deliver about 0.5 volt of 6 mc video signal to the 75 ohm line with good linearity. In this case output is taken from the emitter of the second transistor of the pair.

The camera deflection circuits are shown in Fig. 10. They are very similar to those of the TTV camera. The sync generator in the backpack supplies horizontal and vertical drive pulses to the camera. The horizontal pulses are negative and the vertical pulses positive. The negative horizontal pulses turn on transistor. T_{31}. Amplified positive horizontal pulses appear at its collector. The remainder of the horizontal deflection circuit is identical to that of the TTV camera.

The vertical deflection circuit is driven by the positive vertical drive pulses. These are inverted by transistor, T_{26}, which drives a sawtooth generating circuit comprising T_{27} and its associated components in much the same fashion as in the TTV camera. A complementary symmetry vertical output stage is not used, the vertical drive to the yoke being provided by two paralleled emitter followers, T_{29} and T_{30}. Resistors R92 and R93 equalize the currents in the transistors. Again negative feedback is used to assist in linearizing the yoke current and circumventing the shortcomings of of the necessarily small coupling capacitor, C41. Although this output circuit is less efficient than that of the TTV camera it is more stable and exhibits less warm up drift.

The Modulator, Transmitter and Associated Accessory Circuits

Before turning our attention to the other portions of the system it seems logical to follow the principal video chain through the equipment to its eventual destination in the transmitter. The modulator and transmitter are located in the backpack and may be seen in the photograph of Fig. 16. The circuit diagram is shown in Fig. 11.

The transmitter is depicted at the upper right of this drawing. It is a self-excited cavity stabilized triode oscillator which is grid modulated. A 6442 planar triode is used. The output frequency is adjustable from 1900 to 2100 mc. The maximum output power with the voltages available in this equipment is about 0.5 watt. A video signal of 1 to 2 volts amplitude is sufficient fully to modulate the transmitter. This is supplied by transistors T_{12} through T_{16}.

Video signal from the camera pre-amplifier is available across the cable termination, R43. This is coupled into the base of transistor, T_{12}, through a relatively small capacitor, C25. A keyed clamp sets the d-c level at this point at the start of each horizontal line. This action is provided by T_{17}, which is turned on by negative mixed blanking pulses applied to its base. In somewhat unconventional fashion this also clamps the base of T_{12} during the entire vertical blanking interval. The clamping potential is adjustable by means of R61, which is bypassed by a very large capacitor, C30.

Since d-c information has now been reinserted into the signal, the following stages must be d-c coupled if this information is to appear in the output signal. By employing alternate n-p-n and p-n-p transistors a five stage amplifier of adequate stability has been constructed. The stage gains of this amplifier are not high; the large number of stages has been necessitated by the many other functions which must be performed in it. Mixed sync, for example, from sync amplifier, T_{21}, is inserted on the emitter of T_{12}. Adjustable *set-up* is inserted on the base of T_{14}, by feeding in a small amount of mixed blanking of the correct polarity at this point.

T_{12} and T_{13} form a feedback pair similar to others previously used. This circuit is advantageous here because it presents a high impedance to the clamp circuit and thus does not discharge capacitor C25. This would cause horizontal shading. T_{14} has been included to get a low impedance point from which to drive the auxiliary amplifiers, T_{18} and T_{19}, as well as the actual modulator output stage which comprises another feedback pair, T_{15} and T_{16}. This stage will deliver about 1.5 volts of video signal to the transmitter.

The remaining transistors are not in the main video chain but perform various auxiliary functions. T_{18} is an emitter follower which drives the line to the monitor amplifier when the monitor input selector switch is in the *video* position. T_{19} provides an auxiliary video output if it is desired to operate the TCP into a video line rather than use the transmitter. In this case the transmitter switch may be turned to the *off* position, which removes the load of the transmitter from the various power supplies and correspondingly reduces the total load on the battery. Transistors T_{22} and T_{23}, amplify the output of diode, D1, which rectifies a sample of the transmitter output. When the monitor input selector switch is in the *air check* position, the output of this amplifier drives the video line to the monitor.

Transistor T_{20} is a special regulator which assists in maintaining the correct operating point of the transmitter as the batteries discharge during operation. It was found that as the 6 volt portion of the battery discharged the slight change in the voltage of the transmitter heater was sufficient to upset its operating point. As regulation of the 0.9 amp. current of this heater would be a difficult task, other means to correct this difficulty were sought. It was found that a slight readjustment of the transmitter bias would accomplish the necessary correction, but that the sense of the requisite bias change was opposite to the sense of the change of heater voltage causing the trouble. Transistor T_{20} accomplishes the necessary sense reversal. Its base is connected to the six volt battery, through a network comprising R58, R70, R71

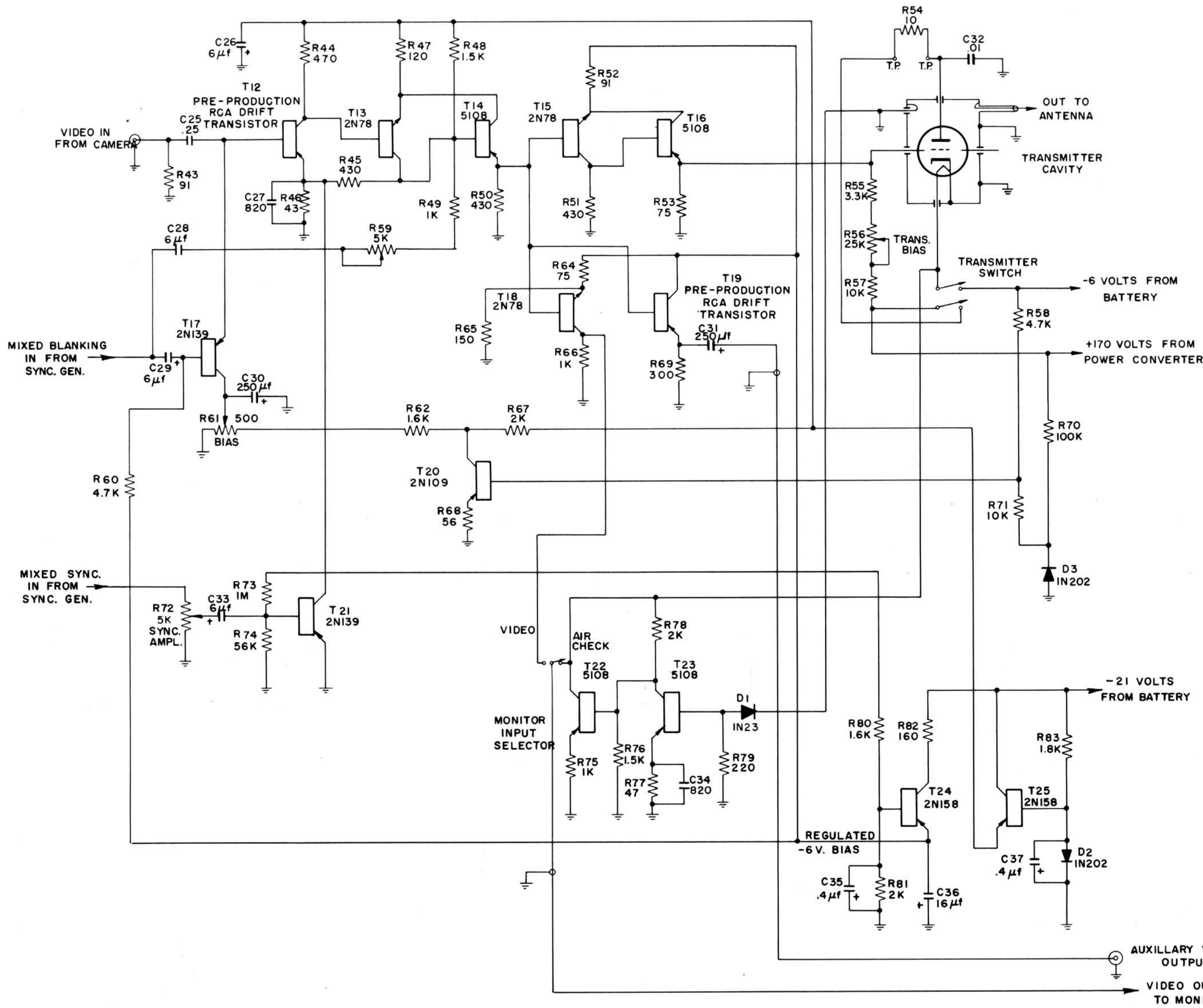


Fig. 11 – Transmitter, video modulator, and associated circuits.

and D3. This network simply sets the base potential of T_{20} at the correct d-c operating point. The collector of T_{20} is connected to the potentiometer which sets the clamp potential, thus inserting the required correction at this point. D-C degeneration in this compensating circuit is provided by R68, by means of which the loop gain of the circuit has been adjusted to maintain nearly perfect compensation during the useful operating life of the battery.

For stability reasons it is also necessary to regulate the supply voltages of all these amplifiers. Regulated buses of six and twelve volts are supplied. The twelve volt regulator comprises emitter follower, T_{25}, the base potential of which is set by zener diode, D2. The six volt regulator is T_{24}, the base potential of which is set by a potentiometer across the regulated 12 volt supply.

The Monitor

The monitor is shown in Fig. 9 and Fig. 13 and its circuit diagram in Fig. 12. No suitable commercially available cathode ray tube could be found for this unit, hence a special one and one-half inch tube was made in the laboratory. The latter is magnetically deflected and electrostatically focussed. With an ultor voltage of 2000 volts its resolution exceeds 300 lines. It fits the standard one-inch vidicon yoke and about 400 ma peak-to-peak horizontal deflection current must be supplied to this yoke to produce a raster of adequate size at the ultor voltage specified.

The deflection circuits are very similar to those in the TTV camera but employ larger output transistors. In the vertical circuit, complementary symmetry and negative

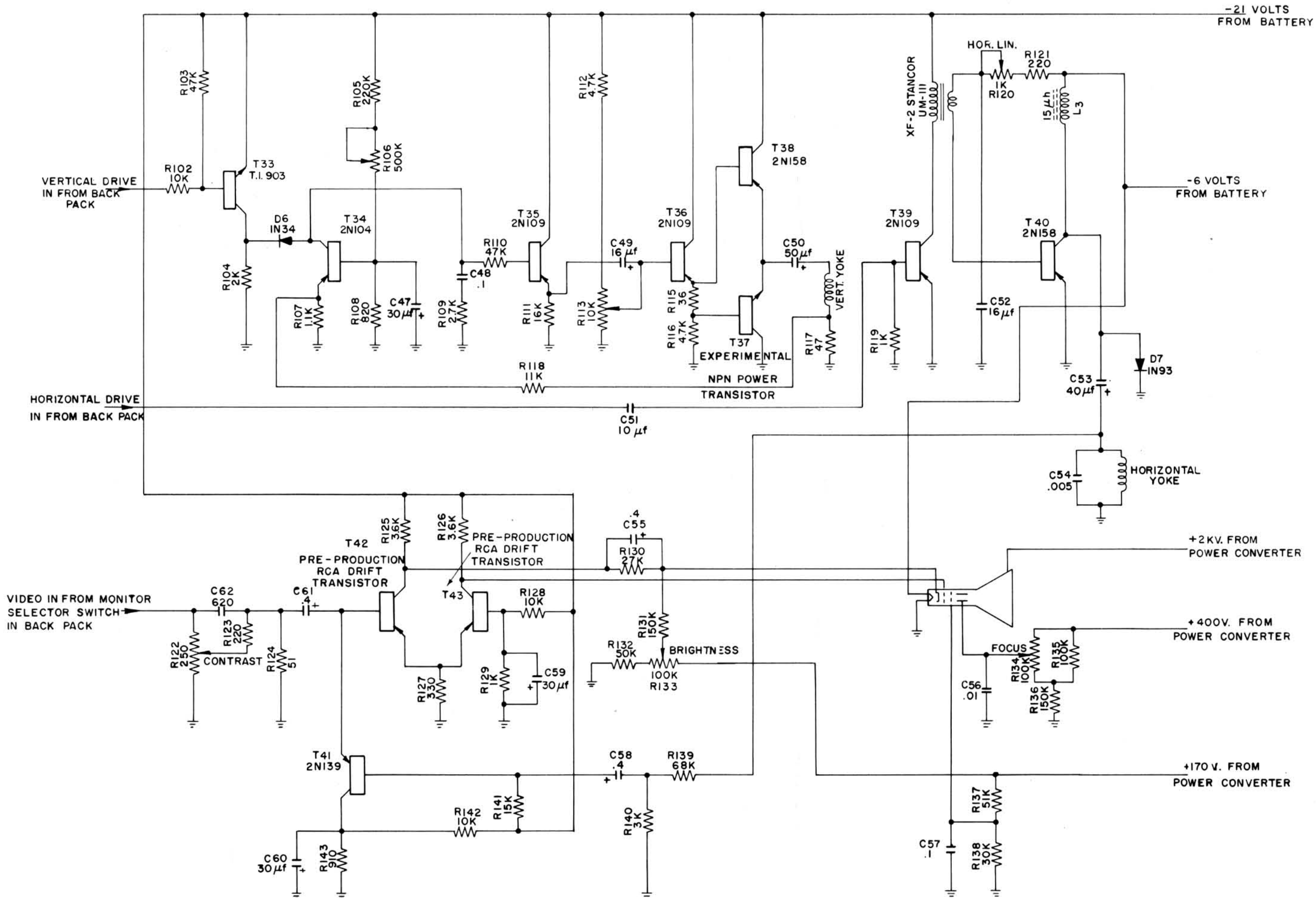


Fig. 12 – Complete monitor circuit.

feedback are used as before, In this circuit T_{37} and T_{38} are power transistors with rated dissipations of 1 watt each, without heat sinks.

Video signal from the backpack is amplified by transistors T_{42} and T_{43}. This circuit is a transistor version of the familiar vacuum tube *long-tailed pair.* It provides a pushpull output with which the cathode and grid of the monitor are simultaneously driven in anti-phase. By this means the effective video drive on the monitor is made about 35 volts peak-to-peak, a value difficult to achieve by other means due to the voltage and power limitations of available high frequency transistors. T_{41} is a driven clamp, which sets the d-c level of the monitor amplifier. It is identical to that in the modulator, except that only horizontal pulses from the monitor horizontal deflection circuit are used to drive it. Slightly better high frequency response could have been achieved in this amplifier by incorporating peaking coils in the collectors of T_{42} and T_{43}, but as the response was adequate and space limited, they were omitted.

The Synchronizing Generator

The synchronizing generator is located in the back-pack. It is in two sections, the master oscillator and divider chain comprising the first, and the waveshaping circuits and line drivers the second. Figs. 14 and 15 depict the circuits of these units, while the synchronizing generator may be seen in the photograph of Fig. 16. Only the chassis containing the master oscillator and divider chain is visible in this photograph; the wave-shaper and line amplifiers are directly behind this unit.

A crystal oscillator operating at twice the horizontal scanning frequency (31.5 kc) is the master oscillator. Transistor T_{44} in Fig. 14 is this oscillator. It is a negative resistance oscillator which makes use of the fact that if one inserts a parallel LC circuit in the emitter of a grounded collector transistor amplifier a negative resistance will appear at the base terminal of the transistor at frequencies for which the emitter load is capacitive. If a quartz crystal is now placed in the base circuit a large negative resistance thus appears in series with it if the resonant frequency of the emitter circuit is less than the operating frequency of the crystal and oscillation occurs.

Output is taken across a small resistor, R147, in the collector circuit to drive a pair of isolation amplifiers, T_{52} and T_{45}. The horizontal divider, which divides by 2, comprises transistor, T_{53}, and associated circuits. It is a blocking oscillator using an autotransformer wound on a small toroidal ferrite core. A positive pulse of a few volts amplitude and about 1.5 microseconds duration appears at the collector of T_{53} each time the blocking oscillator fires. This is called the positive horizontal trigger and is used, after some processing, to initiate the leading edge of the horizontal blanking and drive pulses.

A delayed trigger pulse is derived from transistor, T_{54}. An auxiliary winding on XF-7 drives this transistor. The waveform on this winding is a considerably distorted single cycle of a sine wave, the width of each half-cycle of which is about 1.5 microseconds. The winding is so poled that the positive going half cycle occurs first. T_{54} does not conduct during this portion of the cycle. On the following negative half-cycle, however, it does conduct, and a positive pulse is generated at its collector. This pulse is delayed with respect to the pulse from the collector of T_{53} by about 1.5 microseconds, and is used as the delayed horizontal trigger pulse. The leading edges of the horizontal synchronizing pulses and the serrations in the vertical synchronizing pulses are derived from this delayed trigger. This scheme will be seen to set the width of the *front porch* of the composite

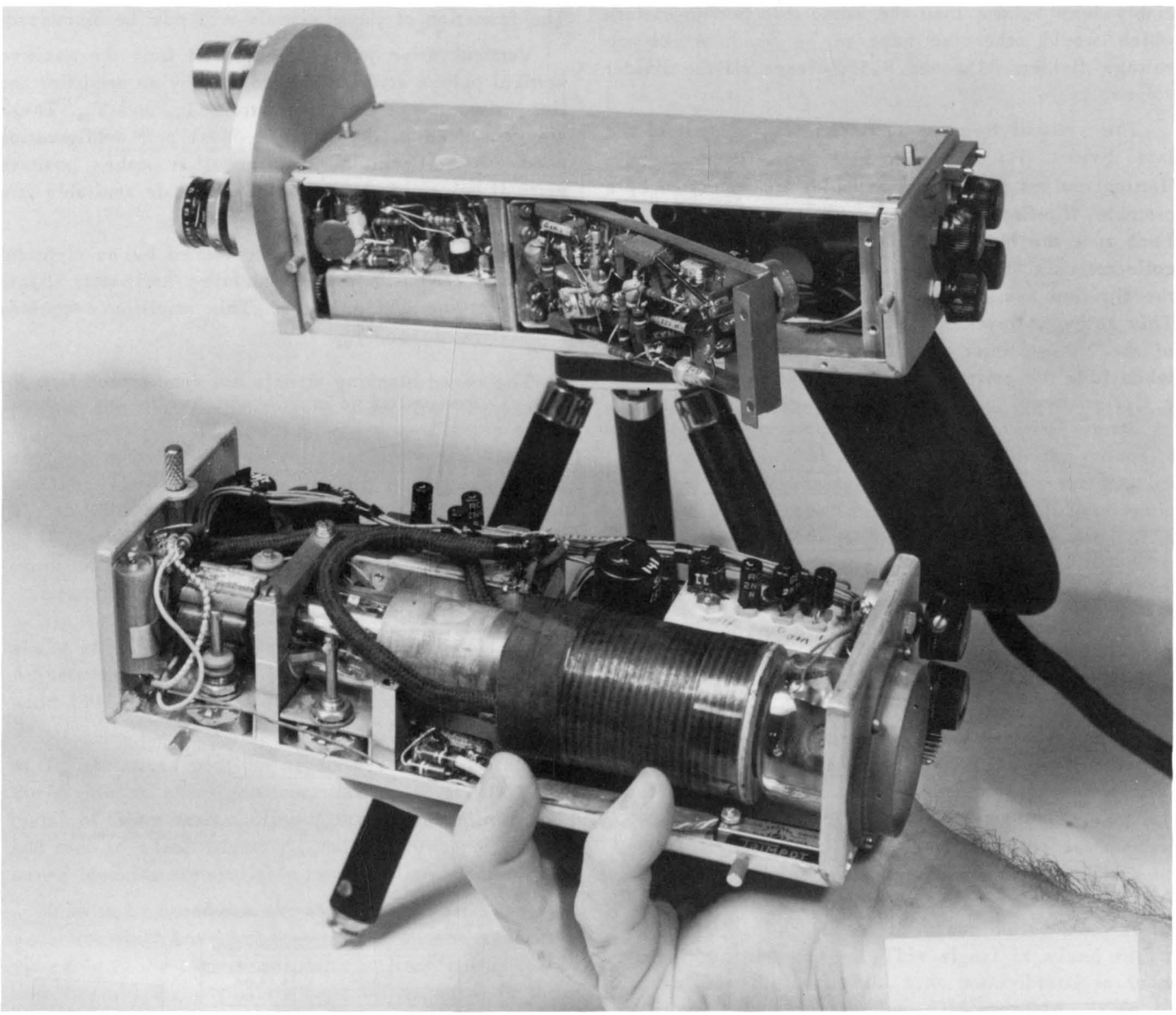


Fig. 13 – Left side of camera and monitor.

video output of the TCP at 1.5 microseconds, or the amount by which the delayed horizontal trigger lags the undelayed trigger.

The vertical divider chain comprises transistors, T_{46} through T_{49}. Each of these is a blocking oscillator in which the feedback is from collector to base, and the RC circuit which controls the repetition frequency is in the emitter. The temperature stability of this circuit is superior to that of other circuits in which the frequency determining elements are in the base circuit because it isolates these elements from the effects of the temperature dependent base to collector leakage current (I_{CO}). As space is limited in the sync generator the frequency determining elements of each divider are fixed, and the amount of sync injection has been made adjustable to control the division ratio. The small capacitors, C67, C69, C71 and C73 used for this purpose require appreciably less volume than the adjustable potentiometers which would otherwise have to be used. A common voltage divider, R156 and R157, biases all the divider stages.

The vertical frequency pulses at the output of the last divider, T_{49} are too narrow to be used directly. Vertical pulses of the desired width are generated by a bistable flip-flop comprising transistors, T_{50} and T_{51}. Each time the last divider, T_{49}, fires, a pulse from its collector cuts off T_{51}. The usual regenerative action in the flip-flop assists this and, of course, turns on T_{50}. This action is reversed on the 15th, 21st or 35th cycle of the 2H oscillator after the firing of T_{49} by a pulse taken from the collector of the second divider, T_{47} and fed to T_{50}. This scheme causes the flip-flop to generate clean positive and negative vertical pulses the width of which can be set at 7-1/2, 10-1/2 or 17-1/2 horizontal lines by adjustment of the order in which the usual divisors of 3. 5, 5 and 7 are assigned to the various dividers. The table included as a part of Fig. 14 shows the arrangement used in each case.

The output pulses from the divider chain thus consists of four kinds of pulses: positive horizontal trigger pulses, positive delayed horizontal trigger pulses, negative vertical pulses and positive vertical pulses. The waveshaper shown in Fig. 15 synthesizes the following signals from these trigger pulses.

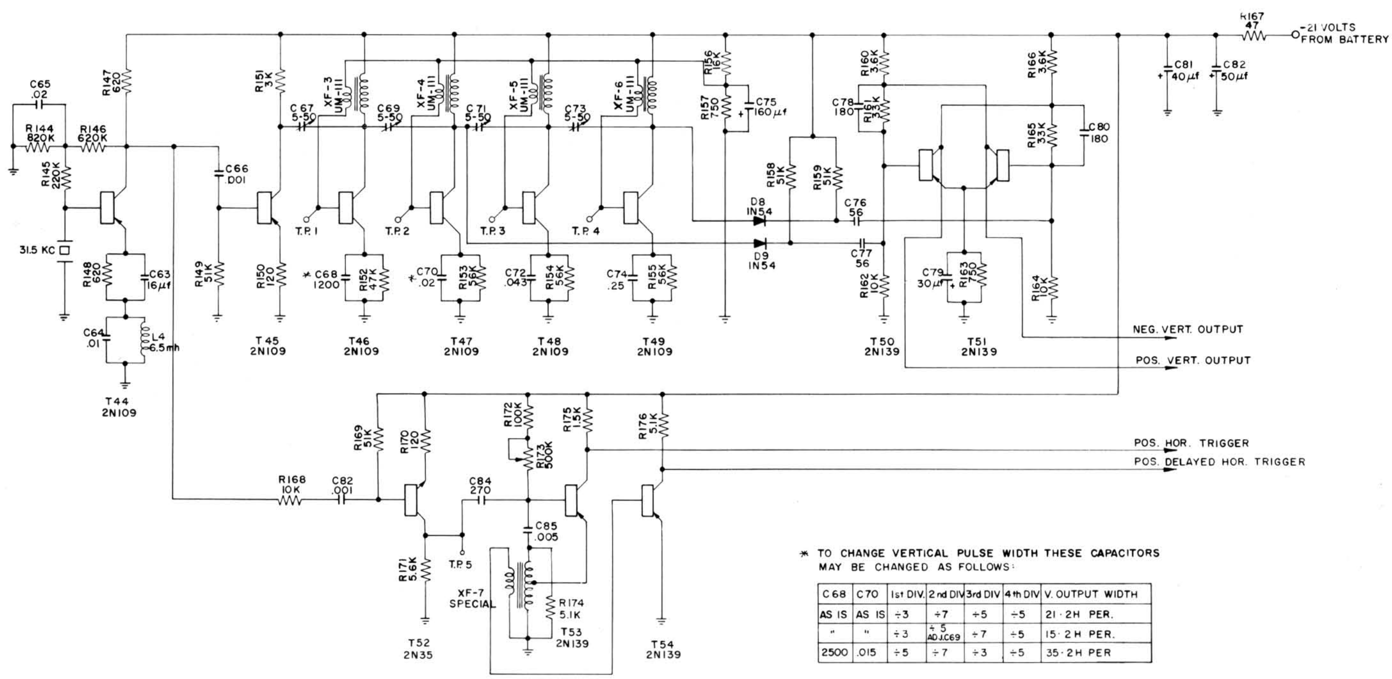
(a) Positive vertical drive pulses
(b) Negative horizontal drive pulses
(c) Positive and negative mixed blanking pulses
(d) Negative composite sync pulses.

The formation of these signals will now be discussed.

Vertical drive pulses are formed from the positive vertical pulses at the divider output by an amplifier and line driver comprising transistors T_{69} and T_{70}. These are connected in the same feedback pair configuration used in the monitor. This amplifier makes positive vertical pulses of about 5 volts amplitude available at a relatively low impedance.

Horizontal drive pulses are formed by an identical amplifier driven from the undelayed horizontal trigger pulses at the divider output. This amplifier comprises transistors, T_{67} and T_{68}.

The mixed blanking signals are synthesized from the undelayed horizontal trigger pulses and the negative



* TO CHANGE VERTICAL PULSE WIDTH THESE CAPACITORS MAY BE CHANGED AS FOLLOWS:

C68	C70	1st DIV.	2nd DIV	3rd DIV	4th DIV	V. OUTPUT WIDTH
AS IS	AS IS	÷3	÷7	÷5	÷5	21 · 2H PER.
"	"	÷3	÷5 ADJ.C69	÷7	÷5	15 · 2H PER.
2500	.015	÷5	÷7	÷3	÷5	35 · 2H PER

Fig. 14 – Synchronizing generator master oscillator and dividers.

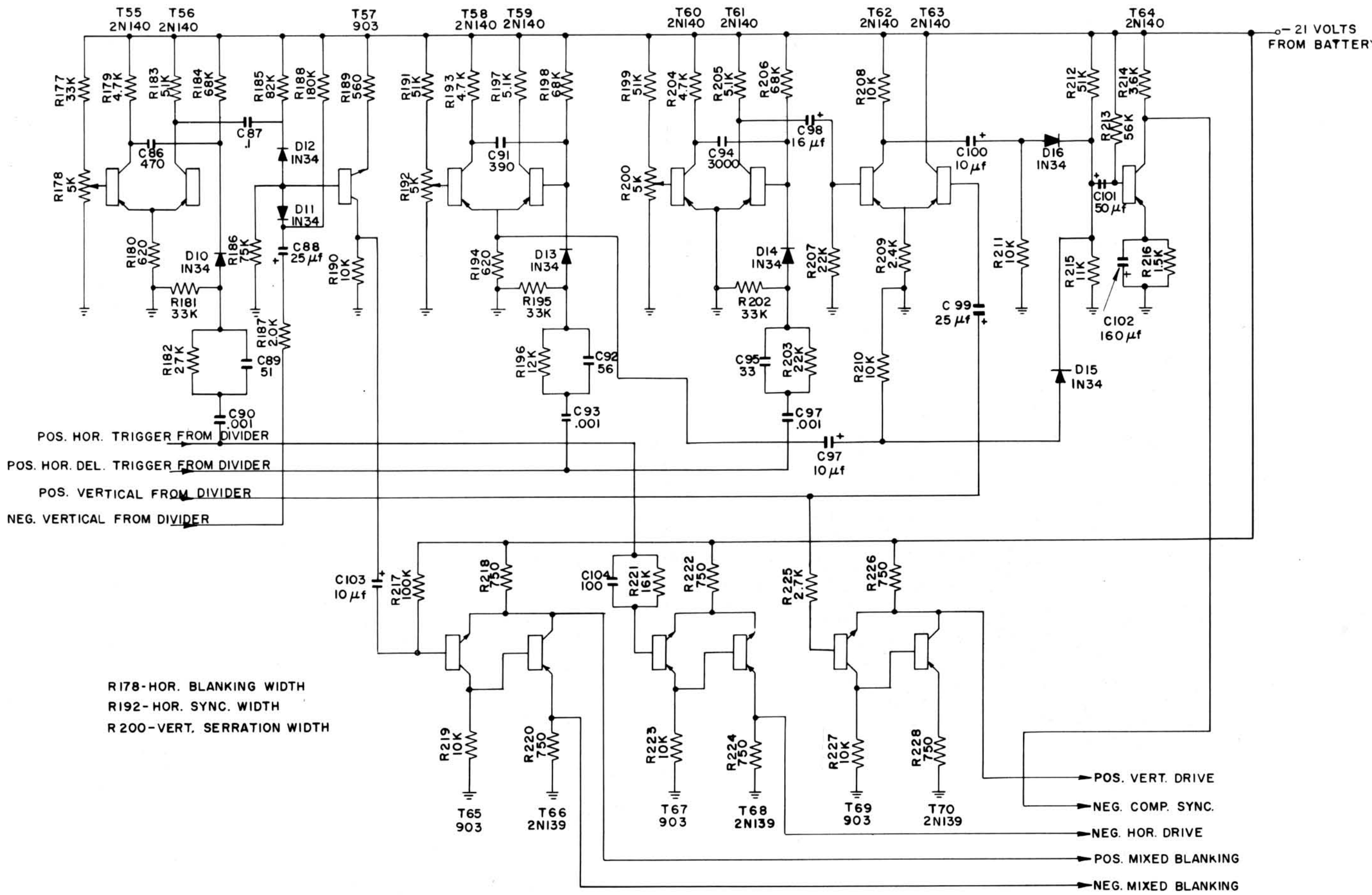


Fig. 15 – Synchronizing generator waveshaper schematic.

vertical pulses from the divider by transistors T_{55}, T_{56}, T_{57}, T_{65} and T_{66}. T_{55} and T_{56} form a monostable emitter coupled multivibrator which determines the horizontal blanking width. In this circuit. T_{55} is normally off and T_{56} on. Horizontal trigger pulses are applied to the base of T_{56} via diode, D10. Each pulse turns off T_{56} and turns on T_{55} by the usual regenerative action The circuit remains in this state for a period of time determined by the time constant, C86, R184 and the voltage at the slider of R178. It then flips back to its original state. Adjustment of R178 varies the horizontal blanking pulse width between the limits of 5 and 15 microseconds.

Negative horizontal blanking pulses from the collector of T_{56} are mixed with the negative vertical pulses from the divider in an *or gate* comprising D11 and D12. The output of this gate is applied to the emitter follower, T_{56}, and then to a line driver, T_{65} and T_{66}. Both polarities of mixed blanking are available from this line driver.

It is to be noted that the three outputs from the sync generator which have just been treated must be transmitted via cable to the camera and monitor. It is for this reason that line driving amplifiers must be provided for these signals.

The remaining transistors, T_{58} through T_{64}, are employed in generating the composite sync signal. It is non-standard in that there are no equalizing pulses, the vertical synchronizing interval is the same length as vertical blanking and there are serrations in the vertical sync pulses at horizontal frequency. The form of this signal is shown in Fig. 17

The synchronizing signals are synthesized from the delayed horizontal trigger pulses and the positive vertical pulses from the divider chain. A monostable multivibrator, T_{58} and T_{59}, similar to that used to generate horizontal blanking pulses, generates horizontal sync pulses adjustable in width between the limits of 5 and 8 microseconds. A similar multivibrator, T_{60} and T_{61}, generates serration pulses of about 40 microseconds width. The output of the serration multivibrator is gated by a serration gate comprising T_{62} and T_{61}. This gate is open only during the vertical pulses from the divider. The output of the serration gate thus consists of bursts of serration pulses which are timed to occur during each vertical pulse from the divider. This signal is mixed with the output from the horizontal sync multivibrator in another *or gate* comprising diodes D15 and D16. It is then

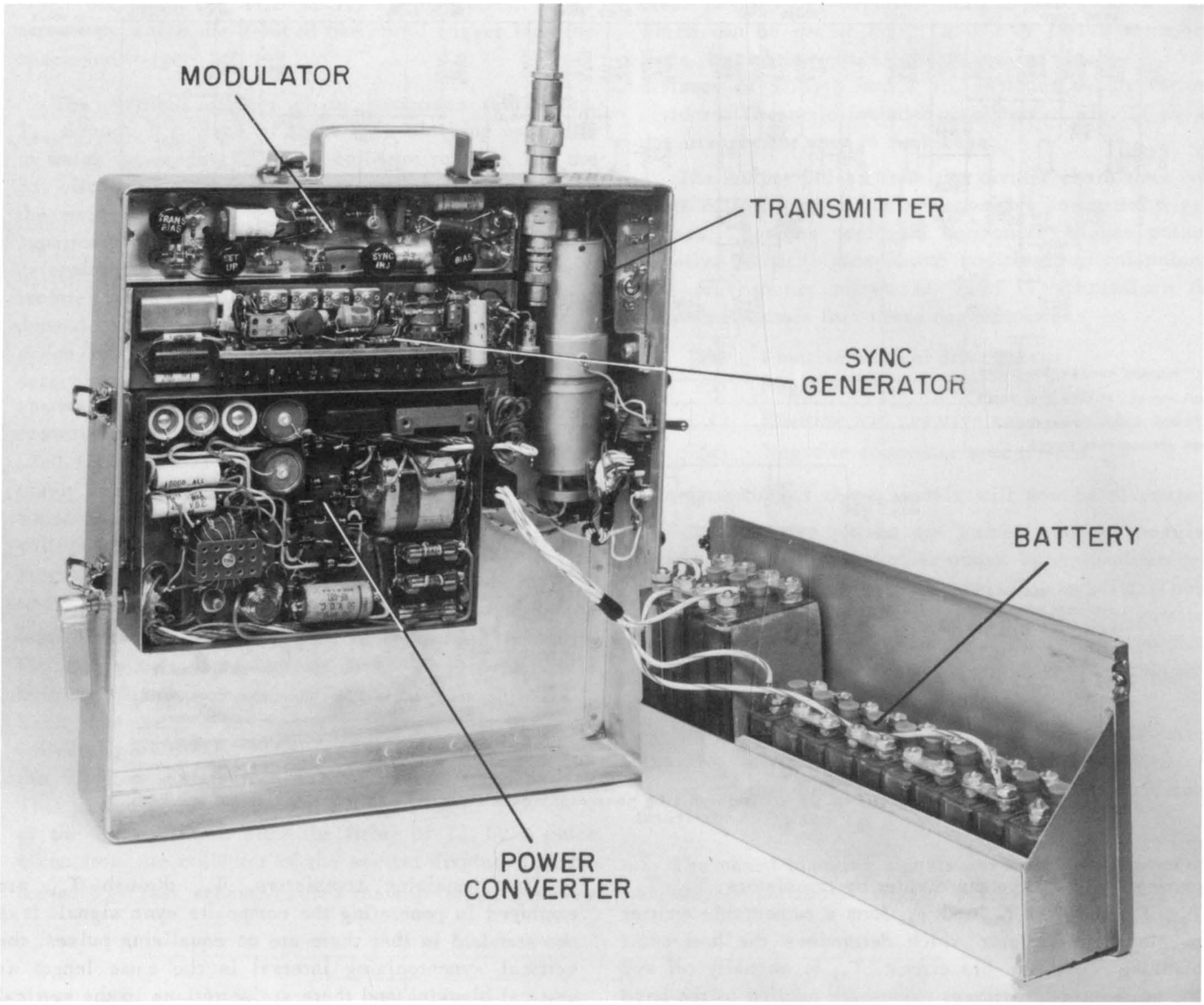


Fig. 16 – Interior view of backpack.

amplified and clipped by the sync output amplifier, T_{64}. Fig. 17 shows the various waveforms occurring in these circuits.

The Power Converter

The power converter steps up the low voltage available from the battery to the necessary high voltages to operate the transmitter, monitor and camera tubes. Advantage has been taken of the unique properties of transistors as high speed switches to achieve in the power converter a high efficiency, low weight and long life almost unattainable by any other method. The unit may be seen in the photograph of Fig. 16 and its circuit is shown in Fig. 18.

Basically two transistors are used in the power converter as a kind of power oscillator to convert d-c to a-c. The latter is then transformed up to the desired voltage levels and reconverted to d-c by rectification. As the switching speed of the transistors is high, an a-c operating frequency (1000 cycles) considerably above that of readily available commercial vibrators may be profitably employed to reduce the weight and size of the iron cored components such as transformers and chokes. Further, the operating conditions of the transistors are similar to those of the high voltage supply in the TTV camera in that their dissipation is low.

The power converter oscillator is similar to that described by Uchrin and Taylor[4], however, we have

[4] G. C. Uchrin and W. O. Taylor, 'A New Self-Excited Square Wave Transistor Power Oscillator' *Proc. IRE.* Vol. 43 No. 1 p. 99, January 1955.

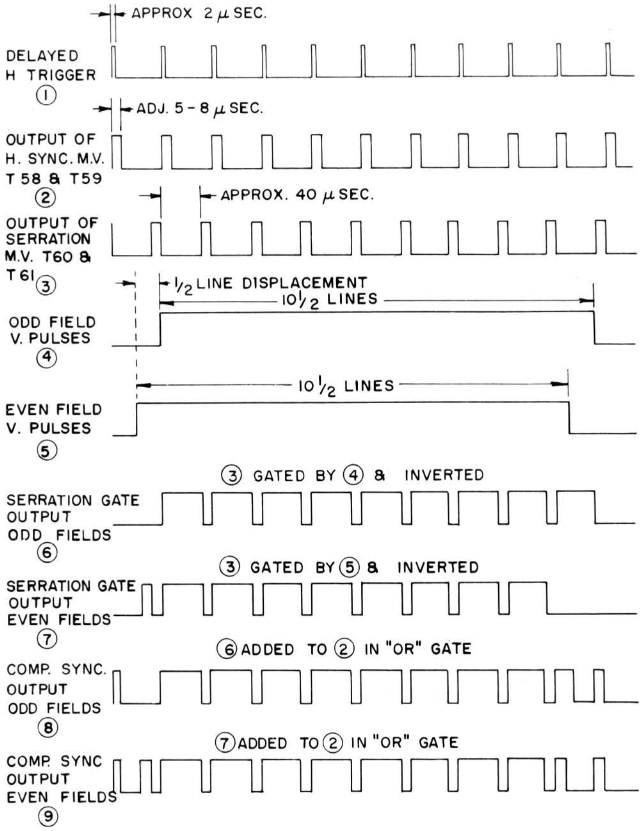


Fig. 17 – Synthesis of synchronizing pulses.

found it advantageous to slightly modify their circuit. They use a single saturable transformer both to control the frequency of oscillation and to effect the necessary voltage transformation. We separate these two functions.

In the diagram of Fig. 18, transformer, XF-8, is wound on a small toroidal core and needs to be designed to handle only the driving power for the base circuits of the transistors. A 1000 cycle square wave of about 90 volts peak-to-peak amplitude appears from collector to collector of transistors, T_{71} and T_{72}. This signal is applied to the power transformer, XF-9 which steps it up to several different voltages.

Most of the power from the converter is delivered to the plus 170 volt bus, on which the principal load is the transmitter. The latter requires about 50 ma. This is supplied by a full wave rectifier comprising diodes D20 through D23 , and filtered by L6, C115 and C116. The ultor voltage for the monitor tube, 2000 volts, is supplied by a doubler comprising D18 and D19, driven by an additional winding. The 400 volt bus which supplies accelerating and focus potentials for the vidicon and monitor is served by a tripler comprising diodes D24 through D28. The minus 100 volt bus, which is used only for bias on the vidicon, is fed by a half wave rectifier, D29. The overall efficiency of this power converter is about 90 percent.

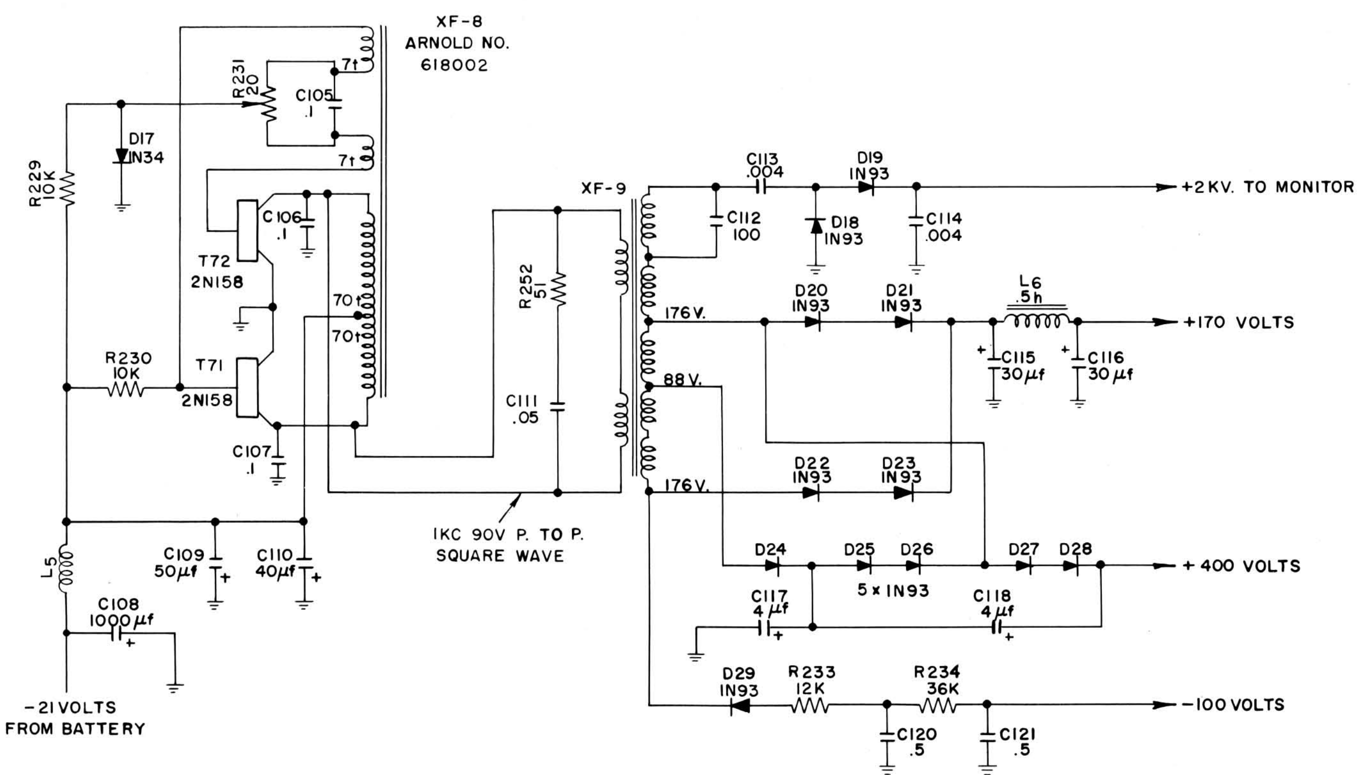


Fig. 18 – Power-converter circuit.

Miscellaneous

Primary power for the entire TCP unit is supplied by a bank of Yardney *Silvercell* batteries. Four LR-10 cells are connected in series to supply the six volt bus which powers the heaters of the tubes and portions of the horizontal deflection circuits. Nine additional LR-5 cells are connected in series with the six volt portion of the battery to power the 21 volt bus. The flat voltage characteristic of these cells during discharge is very helpful in maintaining stable operation of the more critical circuits, such as the sync generator dividers. This battery complement will run the TCP unit for about five hours, before recharging becomes necessary.

Conclusions

Two transistorized camera equipments have been constructed and extensively operated. One is a simple camera which may be attached to any home television receiver to form a complete closed-circuit television chain. The other is, in effect, a complete portable television transmitting station which will generate a picture of adequate quality for remote broadcast purposes and transmit it for a distance of about one mile. These two units show that present day transistors make possible operating performance in such equipment which cannot be achieved with vacuum tubes.

It is also of interest to note that except for the preproduction RCA drift transistors used in the video amplifiers, commercially available transistors either were used in each socket or are available for use. Near the conclusion of the development of these cameras the commercial drift transistor (RCA 2N247) was announced. The authors were able to obtain only a small sample of these units (3) before this bulletin went to press. All units would work in the circuits of the TCP, however there are indications that some revision of a few of the video circuits of the TTV unit will be necessary to obtain the best results from the 2N247 transistors.

The TTV unit potentially supplies the answer to the quest for an extremely compact low power, low cost pickup unit which could convert any home receiver to a closed-circuit TV system.

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