

The Iconoscope TV Camera at W6BM, Berkeley

John Staples, W6BM

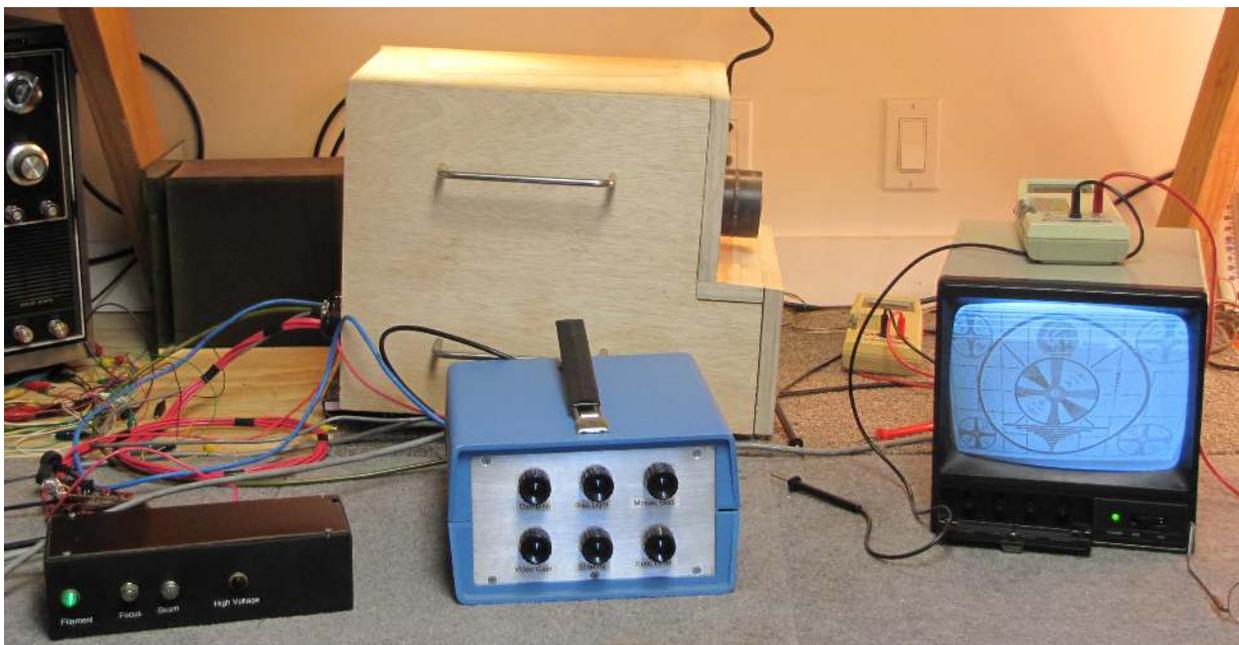
1. Background

The mechanical television era, dating from the early 1920's, used mechanical scanning technologies (discs, lenses and mirrors) to rasterize the subject with resolution from 30 lines, 12.5 frames per second, ultimately to 240 lines, 50 progressive frames per second by the middle '30's. The scanning can proceed from left-to-right, or from top-to-down, as in the original Baird system. Each scan line comprises 30 to hundreds of pixels, which defines the resolution in the direction of the scan line.

As each pixel element in the scene is scanned by one-by-one, the time exposure of each element is only the short time the scanner dwells on that pixel, requiring a high scene illumination.

If all the pixel elements of the scene can be stored in parallel, say on a 2-dimensional array of capacitors, and then each read out sequentially, the sensitivity is significantly increased. This is the basis of the iconoscope image pickup tube which stores the image on a mosaic plate of millions of individual small photosensitive capacitors which charge up individually according to the brightness distribution of the screen.

I acquired an RCA 1850A iconoscope 20 years ago from Al Jones, the founding president of the Tube Collectors Association. It was time to put this valuable tube to work in a camera, joining three known operational iconoscope (“ike”) cameras in the world. Below I report on my decisions and technical progress in this successful endeavor.



2. Construction

My goal was to produce a working camera with construction techniques that I could easily master. The camera body is fabricated of 3/4" plywood, easier for me to work with than an all-metal box which would also have easily provided the required RF shielding.

Should I use more authentic (for the '30's) vacuum-tube electronics, or go solid-state? Solid-state won out, particularly for the video circuits, as wide-band amplification is much easier to accomplish with wide-band op-amps. Also, except for the iconoscope high-voltage circuits, all DC voltages are safely less than 12 volts.

The individual circuit modules (video, deflection, power) would be constructed separately so they could be debugged easily. Most of the electronics was constructed on a proto-board, as many circuit variations were tried until a successful one was found. Then, the circuits were rebuilt on 0.1 inch perf boards and packaged in small enclosures with connectors for the cables.

As many of the components as possible would come from my extensive junkbox, some of them unlabeled transistors and FETs, which were characterized on a curve tracer, so the circuit diagram does not contain type numbers for some of the components.

Should the sync be full NTSC, or just random interlace for a 525-line picture? The current choice is random interlace scanning, so the video image cannot be captured on a video recorder. I have three NTSC sync generators, and it would be not too difficult to substitute them for the present sync generators, but it would add to the bulk of the system and hamper the portability of the equipment. That may come later.

The lens is probably from an old photocopy machine and is well-suited to the camera. It is a 2 inch, f/4 flat-field lens with an 8.5 inch focal length, with no adjustable iris. A fast lens is required, as the sensitivity of the camera is still low compared to modern cameras, and the scene requires a high level of illumination. Sunny outdoor scenes are fine, but indoor incandescent-lit scenes require a lot of light.

3. Iconoscope Tube

To increase the sensitivity of image pickup devices, the storage principle was invented. V. K. Zworykin, who first studied TV technology in his native Russia, then in the USA, mostly at RCA, developed the iconoscope tube in the late '20's as a high-sensitivity (at that time) storage-principle image tube for high-definition (at that time) television.



A lens focuses the scene on the mosaic, about the size of an index card, which consists of millions of small separate silver globules on an insulating mica substrate. The globules are treated with cesium, which renders them photosensitive, so they will emit photoelectrons when hit by light and thereby charge up. Behind the mica substrate is a full-size signal plate, connected to the video amplifier.

An electron beam scans across the mosaic, and recharges each small globule that has lost electrons, causing a signal to be capacitively coupled to the signal plate, generating the small video signal.

The actual operation is much more complex than this, which reduces the sensitivity of the iconoscope to 5% of its theoretical value, but the gain in sensitivity is enough to make the tube practical for the advent of fully electronic television.

Experimental television broadcasts in the US used iconoscope tubes up to the war, and were replaced by the superior orthicon tubes after, with the iconoscope still used in the late '40's for film pick-up.

Another tube, the image dissector, was invented in the '30's by Farnsworth, which was a non-storage tube, but with the addition of a secondary-emission signal amplifier, could produce good quality pictures, but still lacked the sensitivity to make live electronic television practical with it.

4. Design

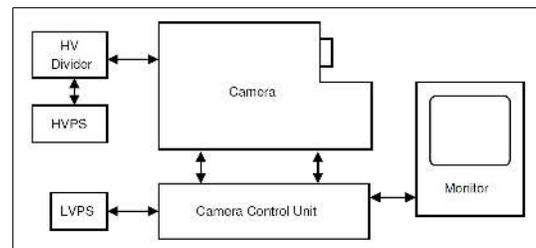
Due to the small magnitude of the video signal, the iconoscope must be fully shielded from outside interference. Broadcast stations in the 1 MHz band would produce strong interference in the image signal.

The camera body is wood, which is fully lined on the interior with a copper screen Faraday shield. All connections to the camera pass through connectors fitted with RF bypass capacitors.

Only the video preamplifier is inside the camera body. It amplifies video the signal, which is less than 0.1 microampere, at high impedance to a level that can be safely transferred on coax to the video amplifier chain. Also inside the camera housing are the deflection yoke, the high-voltage leads to the iconoscope, and the bias lights, which are used to put a uniform illumination on the mosaic which has an effect on the sensitivity and spurious signals (shading) of the iconoscope.

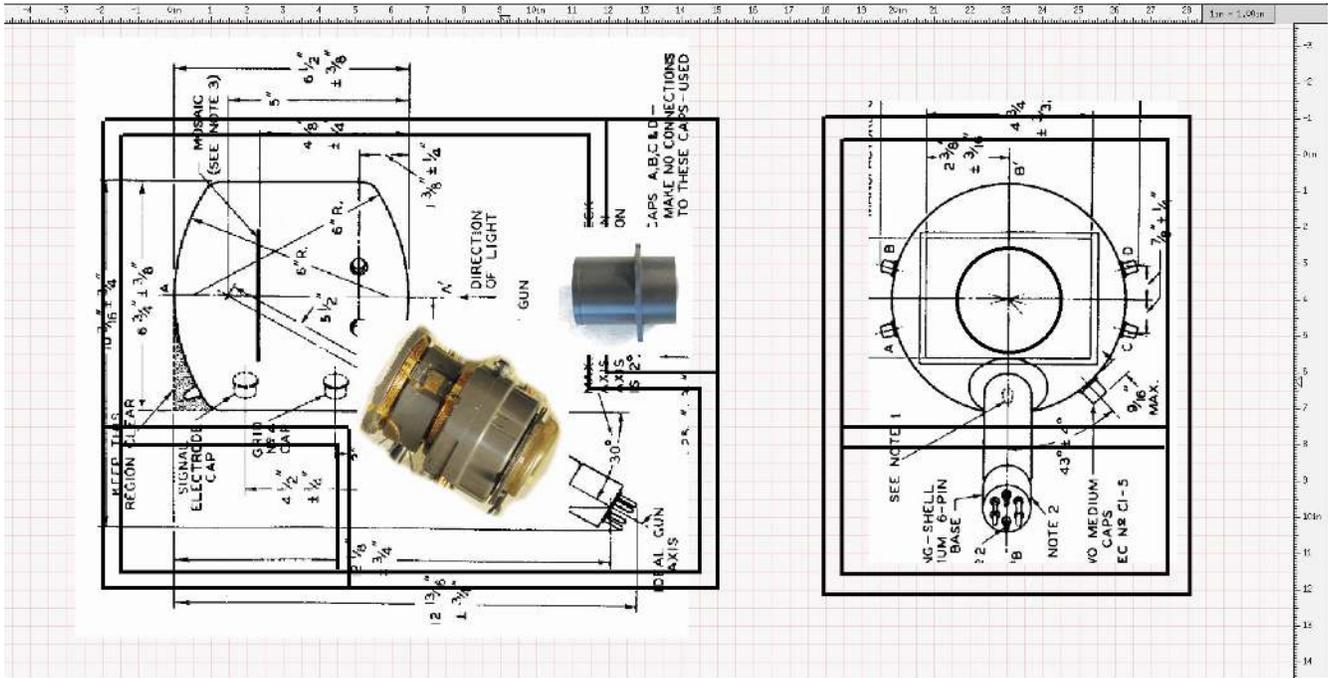
The iconoscope tube itself is wrapped with an aluminum foil shield to further prevent electrical interference from the deflection yoke from entering the tube. Shielding turned out to be the most difficult issue to solve satisfactorily, as the overall video gain is so high, the signal is so weak, and the bandwidth so large.

The circuitry external to the camera body is broken up into individual modules: camera body itself with video preamp, the video amplifier, the deflection circuits, the 1-kV HV divider chain for the iconoscope tube, and the LV and HV power supplies, along with the monitor. All modules are connected with cables and connectors.



5. Camera Body

The camera case is built of $\frac{3}{4}$ inch plywood, cut from a 2 by 4 foot piece. The camera case pieces are joined by internal bracing, so no screws are visible from outside. The figure shows the outline of the wooden case around the iconoscope, the lens and the deflection yoke, viewed from the side and from the front. The iconoscope sits on a "boat" that secures it with nylon straps to a form-fitting cradle. The cradle sits on a shelf and is attached with long bolts with wing-nuts to allow a coarse positioning of the iconoscope.



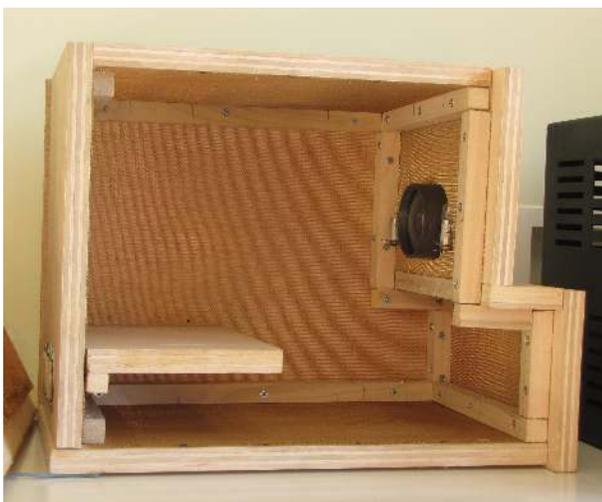
The entire case is Faraday-shielded with a copper screen completely lining the case, except for the lens opening. All the sections of the screen are connected together, and contact is made to the screen on the removable side through four banana-plug mounting points.

The internal wiring for the deflection yoke and the high-voltage to the iconoscope are shielded in braid to prevent radio interference inside the case.

Two DC-operated lamps form the bias light that can flood the mosaic with a uniform low-level light, which has a small effect on the shading signal generated by the iconoscope.



Connections to the outside of the case are through three ceramic octal sockets, where all the non-signal conductors are bypassed to ground by capacitors.



6. Lens

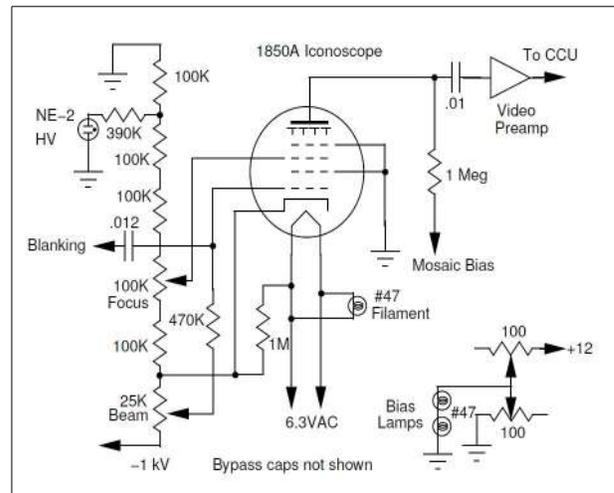
The lens is a $f/4$ flat-field lens with a 8.5 inch focal length. There is no adjustable iris. The lens probably came from an office copier.

The lens has a tight slip-fit to the hole in front of the case and is directly in line with the center of the mosaic. Focus is adjusted by manually moving the lens in the hole of the case. The range of focus is from about 3 feet to infinity.

7. Iconoscope Circuits

The iconoscope voltages include 6.3 volt AC for the heater, and a 1 kV accelerating voltage between the cathode and the mosaic. The electrostatic focus electrode requires approximately 400 volts, and the control grid (beam electrode) operates up to 100 volts negative to the cathode. Vertical blanking is supplied to the control grid.

The iconoscope is operated with the mosaic at about ground potential within a few volts, so the heater is near 1 kV negative, requiring a filament transformer with good insulation. The resistive divider is located in a separate box, with the HV introduced through a HV-connector (similar to a BNC). A resistor string drains 2 mA and contains two potentiometers for focus and beam current, on HV standoffs for safety, and indicator lamps for filament (incandescent) and HV (neon) with green and red jewels.



The high voltage is provided by a regulated 0-2 kV Power Designs 2K-10 power supply, that is controllable down to an increment of one volt. The supply is current-limited to 10 mA.

8. Video Preamplifier

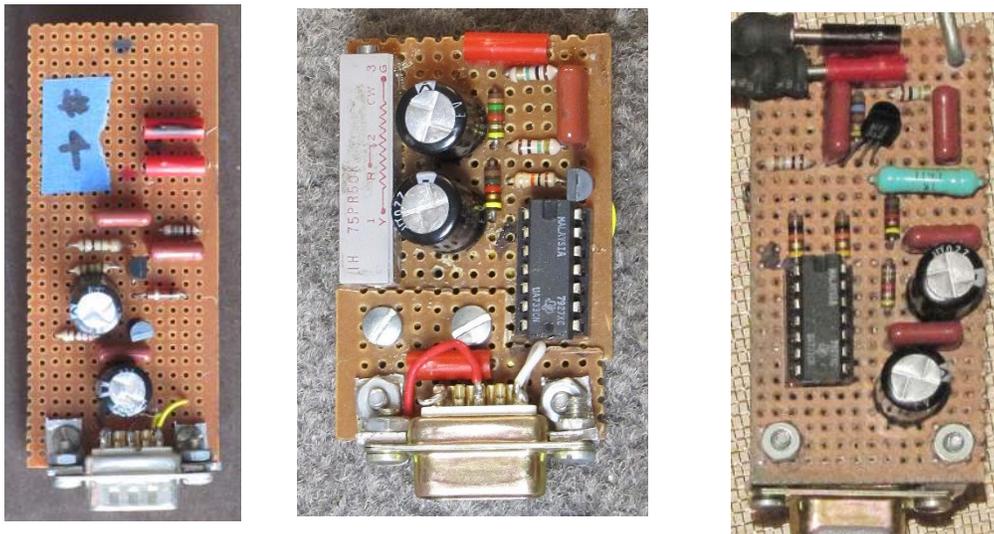
The video preamplifier is the most critical circuit element. The iconoscope video output current is a fraction of a microampere, and must be amplified to the volt level with a bandwidth of several MegaHertz.

The choice of the input resistor to the preamp is critical. As the iconoscope is a current source, the voltage developed across the resistor is proportional to the value of the resistor, so a high value will generate a larger voltage into the preamp. However, the distributed capacitance of the mosaic, the wiring, and the input capacitance of the first amplifier stage will form a low-pass filter.

The capacitance is typically 15 pF, so for a total input resistance of 0.5 MegOhm, the corner frequency is around 20 kHz, at which point the frequency response falls at 6 dB per octave above that, or around 40 dB at 4 MHz.

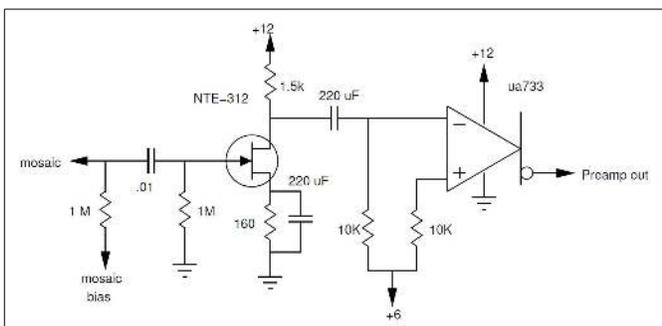
The input resistor also generates a thermal noise (Johnson noise). The voltage is proportional to the square-root of the resistance value, so the signal-to-noise ratio favors a larger resistor value, but the bandwidth favors a lower input resistor. The decision also includes the noise figure of the preamplifier itself, and with a low-noise FET input stage, the value of the input resistor has been chosen to be 0.5 Meg. This resistor is actually two 1 Meg resistors in parallel: one for the input gate of the FET, and the other one in the circuit that allows the bias of the mosaic to be changed to be a few volts of either polarity with respect to the collector ring, which is the ground reference for the iconoscope.

Much of the development effort of the camera is finding a suitable preamp circuit. The preamp is the only active circuit inside the camera body, which was swapped out frequently. To make development easier, several candidate preamps were built on a small perf board with a DB-9 power and signal connector, and mini-pin jacks for the mosaic and collector terminations to experimentally determine the best circuit.



The preamp configuration chosen for now uses an NTE-312 depletion-mode NPN J-FET in common source configuration with a 1K drain resistor. This FET is a VHF amplifier with a 10 dB power gain at 400 MHz with a 2 dB noise figure at 100 MHz. Even with high-peaking in the video amplifier circuit, the amplifier noise level is acceptably low.

The FET is followed by a ua733 op-amp, which has a frequency response to 200-400 MHz, depending on the gain setting and about a 12 microvolt rms noise level at the input. The input impedance is larger than the 1K FET drain resistor, and it can drive a few hundred ohm load.



The op-amp has both inverting and non-inverting inputs, and inverting and non-inverting outputs, which is very useful in determining the proper polarity of the video. The voltage from the iconoscope mosaic is positive-going for black, and the video polarity out of the video chain provides a negative-going black signal.

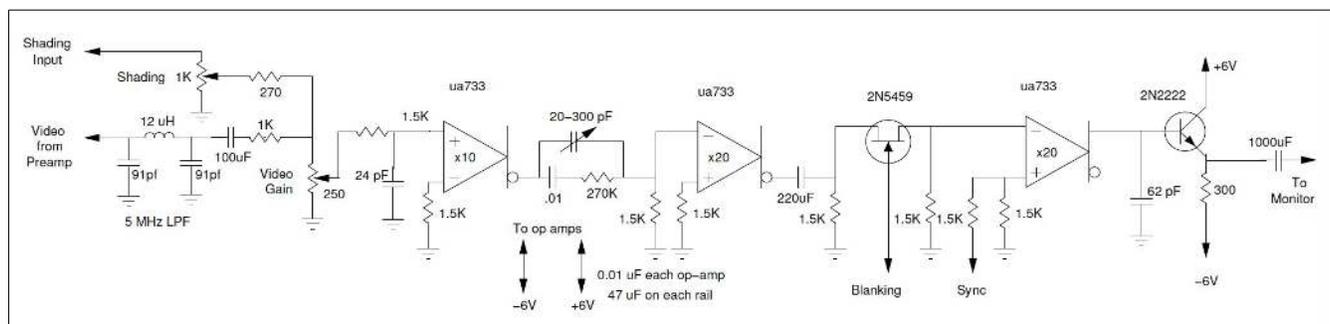
9. Video Chain

The video chain provides most of the wide-band video amplification, sync, blanking and shading insertion, video frequency response peaking and gain control.

The gain element is the ua733 wide-band op-amp, which provides a flat 200 MHz passband down to DC. Three stages of gain are used, so taming the gain block, along with the design of the preamp, is a most challenging task.

The video amplifier is built on a copper substrate perf board, with all power supply leads bypassed and run through chokes and ferrite beads, with the bypass capacitors soldered directly to the copper substrate.

The amplifier is housed in its own copper-plated box to shield it from outside RF interference. The two knobs are the video gain and sync level. Later, an additional shading level control was added.



The voltage gain per stage is adjusted with external gain adjust resistors to be between 10 and 20.

The video from the preamp and the shading generator are mixed together and regulated through the video gain control. At the exit of the first stage the frequency roll-off due to the distributed capacitance at the input of the video amplifier is compensated, with the low-frequency gain below 10 kHz attenuated some 45 dB.

The video signal is amplified by 26 db in the second stage and applied to the blanking gate, a FET that is used as a series switch. The video is further amplified by another 26 dB in the output stage, with the synchronism waveform mixed into the non-inverting input of the output amplifier.

To use a standard video monitor, the video black polarity, as well as the sync tip, is a negative-going signal. The use of the inverting or non-inverting inputs of the op-amps allows the correct polarity of all the signals to be conveniently chosen at each point along the chain. The three amplifiers are powered between the +6V and -6V rails with a lot of bypassing. The amplifiers themselves do not require stability compensation, but good circuit layout is necessary for overall stability without VHF parasitic oscillation.

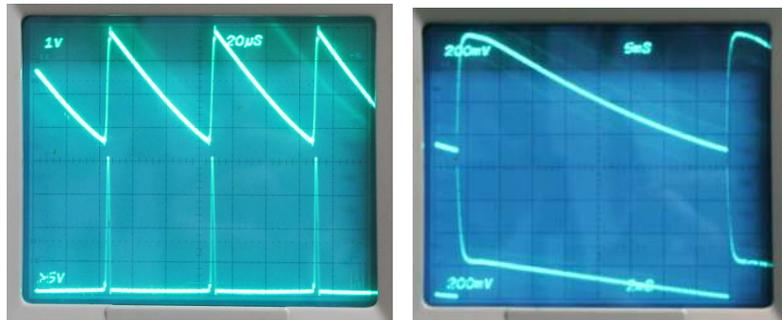
10. Deflection Yoke

The deflection yoke is of unknown origin and includes a separate set of centering coils that are not presently used. Since it is an unknown, the properties had to be determined. First, the DC resistance and inductance were measured. To determine the magnetization, a small precision-wound search coil was made and each set of deflection coils activated with a known AC current of 500 or 1000 Hz. The field along the axis at many points was measured with the search coil, and the integral magnetization calculated.



Knowing the rigidity of a 1 kV electron beam and the deflection angle of ± 0.3 radians, the peak current through the coil could be calculated, which is 100-200 mA, depending on the direction of deflection. A circuit simulation determined the voltage waveforms required, which amounted to a 500 volt pulse for the horizontal deflection coil. The vertical coil required a combination of pulse and sawtooth waveform of about 2 volts. Each current waveform is monitored by a 10 ohm resistor in the return lead of each yoke, and the horizontal current waveform was used for the horizontal shading signal.

The horizontal current (top) and voltage are shown on the left, and the vertical on the right.

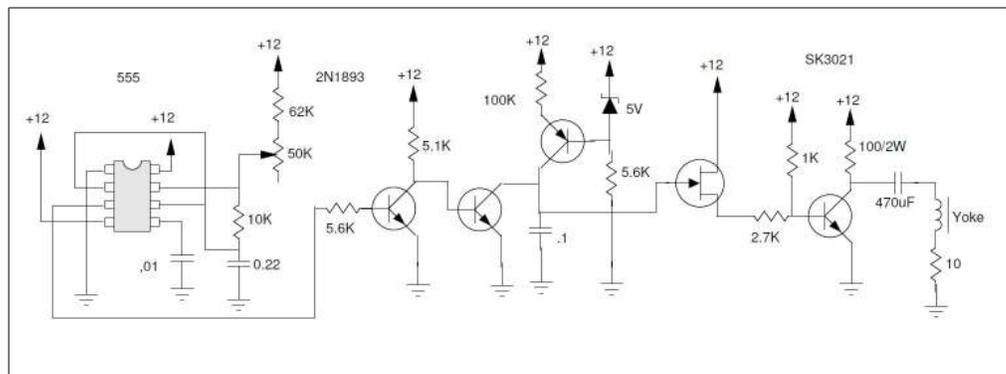


The deflection coil had to be completely shielded with grounded copper screen to reduce interference with the video signal.

11. Vertical Deflection System

The vertical deflection system is straightforward: a 555 timer generates a 60 Hz pulse waveform with a 10% duty factor.

The following inverter applies a positive reset pulse to the discharge NPN transistor. A PNP



current source supplies the constant current, producing a linear ramp on the 0.1 uF capacitor that is amplified by the FET-NPN Darlington that drives the horizontal yoke through a DC blocking capacitor. The output transistor is a SK3021 that can take a several hundred volt pulse on the collector, which is set on a heat sink. The only control is the 50K 10-turn screwdriver pot that sets the frequency.

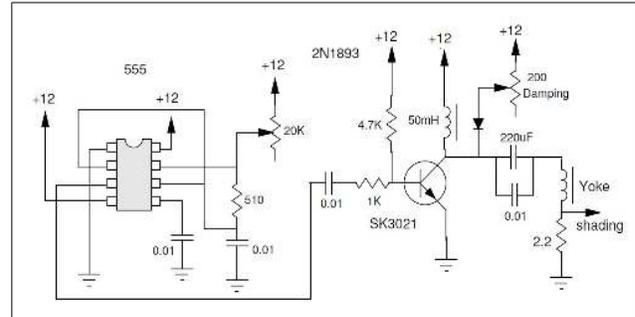
12. Horizontal Deflection System

The horizontal deflection looks simpler, but it is not.

A 555 timer generates a 15750 Hz pulse with a 10% duty factor and applies it directly to the base of the SK3021 output transistor. The transistor is biased on during the cycle, so the magnetic field in the inductor in the collector lead stores magnetic energy.

The transistor is suddenly cut off at the end of the line of sweep, producing a several hundred positive-going voltage pulse that is conducted to the horizontal deflection yoke through the DC block. The yoke presents an inductive load to the driver, so the current waveform is a linear sawtooth.

The diode and pot in the collector lead controls the overshoot (damping) of the flyback pulse.

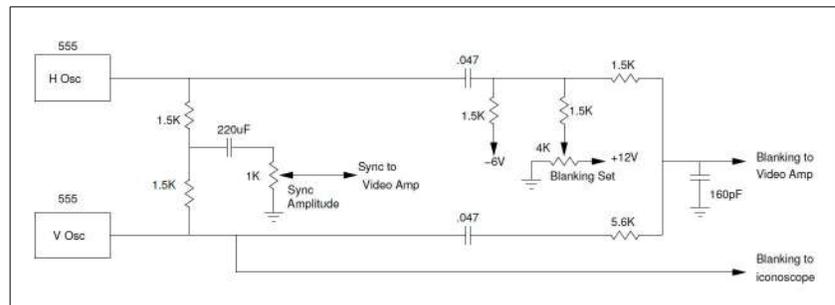


The horizontal linearity is not yet completely satisfactory, and will be worked on in the future. The horizontal sawtooth waveform taken from the 10 ohm resistor in the yoke return leg is used to provide a horizontal shading signal that is fed back to the video amplifier.

13. Synchronism and Blanking Insertion

Both sync and blanking waveforms are required and are derived directly from the pulse waveform from each of the 555 timers.

To generate the sync signal, the two signals are simply added and fed to the video amplifier output stage and the amplitude is controlled by the 1K pot.



The blanking signal is fed to the FET series switch right before the video output stage. The blanking removes a large interference pulse in the video signal during retrace that results from radiation from the deflection yoke, even through the yoke has been Faraday shielded. The 4K pot sets the DC level of the blanking pulse so that full video comes through outside the blanking period, and no video comes through during blanking. No pedestal is seen on the video signal as a result of the very simple switch configuration.

14. Power Supplies

The LV and HV power supplies are commercial units. The LV power supply is an open-frame unit supplying +12V and -6V. A one-chip TO-3 6 volt regulator supplies the +6V from the +12V supply.

The HV power supply is a regulated commercial supply that sets the output voltage with decade voltage controls with a resolution of 1 volt.

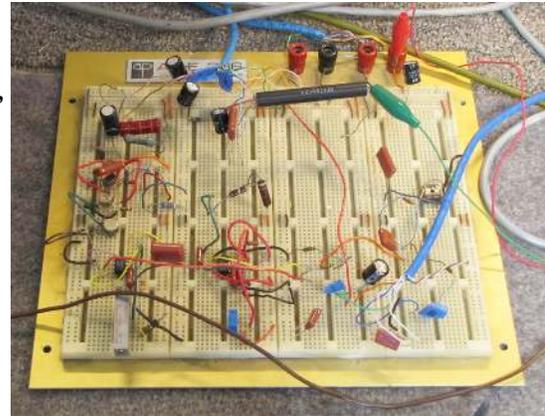
The power is supplied to the modules through various connectors, such as HV coaxial connectors, or DB-9 connector to the camera control unit.

Three octal connectors are provided on the rear of the camera providing connections to the yoke from the CCU and power and signal to the CCU. A third connector provides the high voltages from the HV divider module.

15. Packaging

The deflection and video chain are collected together in the CCU, the Camera Control Unit. During development, the deflection circuits were created on a protoboard.

After a satisfactory design was achieved, the circuits were transferred to a perf board and placed in a cabinet with connectors to the power supplies, to the camera body and to the monitor.



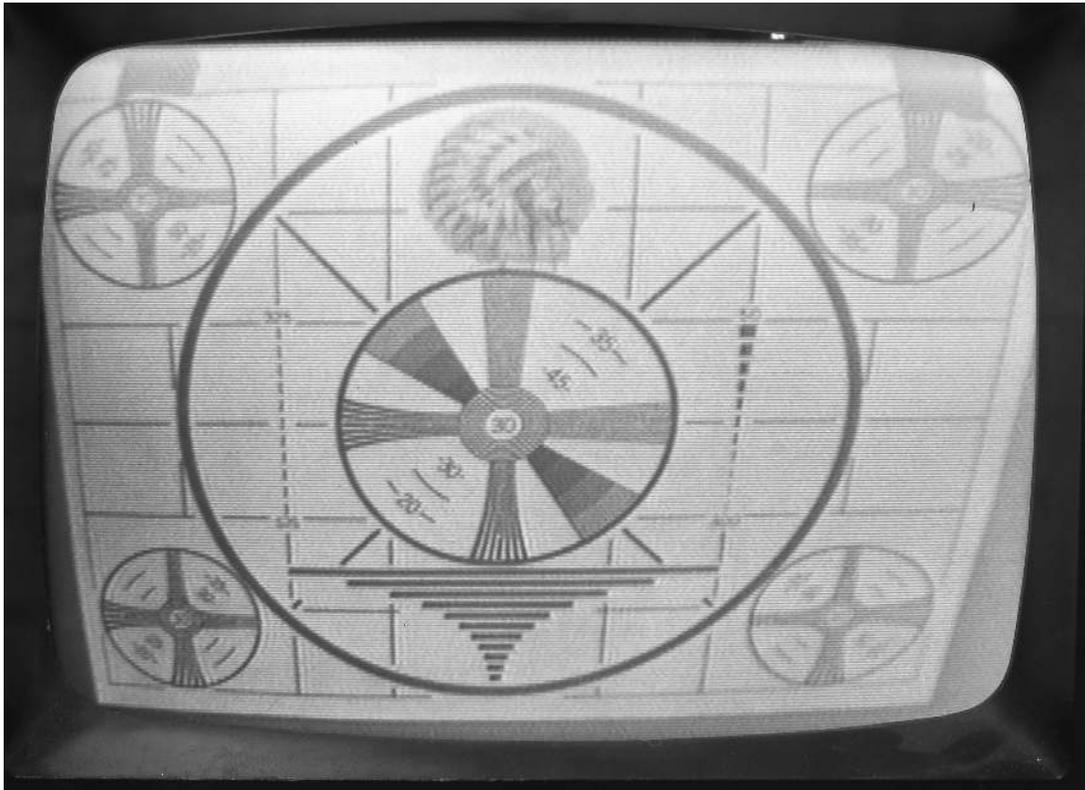
16. Performance

The performance seems to be equal to contemporary descriptions given in the 1930's report as far as image quality and lighting requirements. The 1850A iconoscope appears to be fully operational.

Lighting requirements cited in contemporary accounts indicated that an illumination of 3000 foot-candles was required, typical of outdoor sunlight on a typical spring or fall day. The iconoscope is mainly blue-sensitive, so for indoor lighting with incandescent bulbs, which are blue-poor, a lot of light was required, which was difficult for live talent.

The ultimate resolution of the iconoscope is several hundred lines. With the Indian head test pattern,

the resolution seems to be near to commercial quality. Some noise is visible in the picture, which agrees with contemporary accounts of signal-to-noise figures of perhaps 30 dB or so.





17. Future Development, Lessons Learned

That it works at all is a miracle. The video amplifier chain seems to work well, although during development, some instability issues stemming from the high-gain, wide-bandwidth amplifier chain produced some oscillations in the 50-200 MHz range, which were difficult to diagnose until a wide-band spectrum analyzer was used to find and cure the oscillation.

Complete shielding of the iconoscope and all following amplifiers is essential. RF interference from the broadcast band, as well as lamp ballasts easily sneaks in anywhere. The camera body was designed from the outset to be a Faraday cage, but additional shielding of components inside the camera body was needed.



18. The Author

Dr. John Staples, W6BM, designs and builds particle accelerators at the Lawrence Berkeley National Laboratory. He received his Extra Class ham license and First Class Radiotelephone and Radar licenses in 1958. Besides being an avid collector of vintage electronics, he has been a passionate motorcyclist for over 50 years.

All pictures were taken by the author. Distribute this note freely.