Image-Converter Systems With Fast Image Group Repetition Rates

PAPER C—5

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Three different types of image-converter cameras have been designed over the past several years with various characteristics but all emphasizing fast exposure rates. The three cameras all use the Mullard converter tube type 1201 with the short-persistence blue phosphor for photographic recording. The first camera produces a sequence of six rectangular images having an aspect ratio of about 5 : 1. The exposure time of 0.4 μsec was used and a fixed exposure interval of 5 μsec. This camera takes one group of six exposures at a time with a relatively long recovery time.

The second camera has considerably advanced characteristics. This camera makes six exposures on a single frame at rates varying from 2 × 10⁶ to 2 × 10⁴ exposures/sec. The frame rate extends from zero to 5000, the upper limit depending on exposure rates. Exposure durations have these values: 0.1, 0.3, 1.0, 3.0 and 10.0 μsec. Repetition-rate and exposure-time duty cycle may not exceed 20%. Deflection of the image takes place on both axes, producing two rows of three exposures.

The third and latest camera design is similar to the second, having exposures of 0.1, 0.3, 1.0, 3.0 and 10 μsec and corresponding exposure rates of 2 × 10⁶ to 2 × 10⁴ exposures/sec. The sequence pulse and shutter pulse generator is very similar; however, the sweep is wholly on one axis and therefore similar to that of the first camera described. The mechanism of sweep generation is quite different, however, the basic sweep form being generated by a diode-pump counting circuit. Displays of 4 or 8 images may be selected.

THREE different types of image-converter cameras have been designed over the past several years having various characteristics but emphasizing fast exposure rates. The three cameras all use the Mullard converter tube type 1201, usually with the shortest persistence blue phosphor for photographic recording.

The Mullard 1201 image-converter tube uses electrostatic and electromagnetic focusing and electromagnetic deflection. The tube has a conical-cylindrical electrode, called the grid, mounted axially between the photosensitive cathode and the fluorescent screen. In operation there are a variety of grid potentials relative to the cathode that will produce a focused image in conjunction with a suitable axial magnetic field. Use of these different operating points results in different values of image magnification between cathode and screen. The useful range of linear magnification is between 1 and 4½. To deflect images across the screen, a magnification of about 3½ is used and the cathode image area is correspondingly restricted. This is the least magnification one is able to use and avoid cutting off the deflected image by the grid structure.

Earliest "Framing" Image-Converter Camera

The first camera design produced a sequence of six rectangular images having an aspect ratio of about 5:1. These were displayed one above the other on the screen and photographed by a single-frame camera. This display requires image deflection in one axis only. The sweep circuit was designed around the deflection coil as a resonant circuit which established the exposure repetition rate for the camera. Exposures were required at intervals of 5 μsec, resulting in a resonant frequency of the deflection coil circuit of 200 kc/sec.

The coil is resonated with a parallel capacitor at its required frequency. When the camera is tripped the coil circuit is shock excited by discharging a large capacitor into it by firing a thyratron. The resulting current and voltage waveform are shown in Fig. 1. The voltage waveform is unipolar, resulting in an increase in coil current with every cycle. This produces a current staircase waveform which will give the desired deflection sequence, since the image position is directly proportional to the coil current. The initial position of the image is biased to one side of the screen by small permanent magnets.

Several circuit features may be of interest. First, a feedback circuit is required to supply the deflection circuit losses because otherwise the voltage and current waveforms will damp out too quickly. It should be noted that a small triode is sufficient in spite of the deflection coil current of 2.5 amp/step. Second, a switch triode is required to gate the first so that the circuit will remain quiescent until fired, otherwise the circuit may break into oscillation at any time since it has no net losses.

A third item of interest is the diode placed across the deflection coil circuit, poled in such a way as to conduct

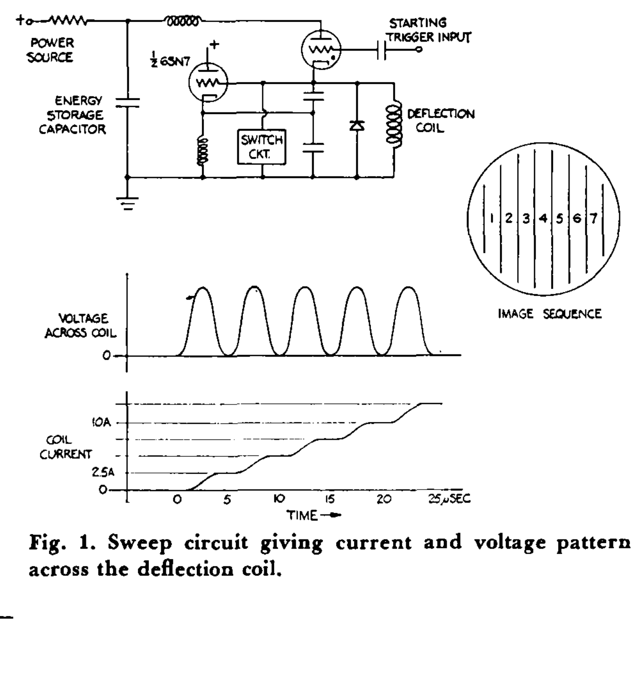

Fig. 1. Sweep circuit giving current and voltage pattern across the deflection coil.

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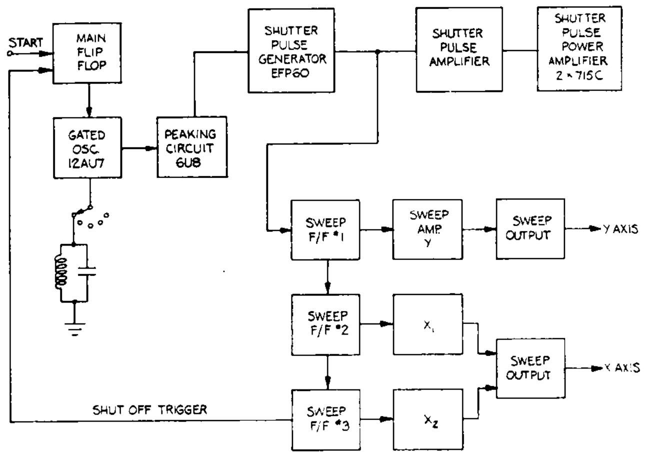

Fig. 2. Block diagram of improved framing image-converter camera.

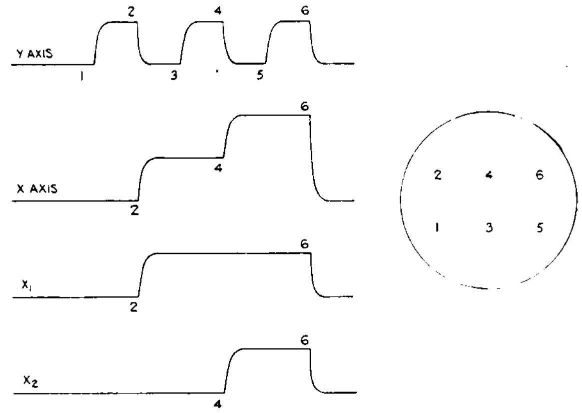

Fig. 3. Sweep current waveforms for six-image rectangular array.

if the coil voltage attempts to reverse. When conducting, the diode effectively short circuits the coil and holds the coil current constant briefly while the exposure is made. The diode makes adjustment of the feedback in the deflection circuit completely noncritical since any excess is clipped off.

The shutter pulses are triggered off by a circuit driven by the deflection coil voltage. A phase shifter is provided to allow adjustment of the shutter pulses to coincide with the constant portions of the deflection current steps. The shutter pulse generating circuit is a conventional hard tube modulator producing 3-kv flat-topped pulses of 0.4-μsec duration which are applied to the image-converter-tube cathode. The grid is grounded and the anode is operated at +3 kv.

No attempt is made to stop the circuits when the required number of exposures has been made. The deflection circuit simply carries the image off the screen and the oscillations die out before it returns. The number of images produced is determined by the initial voltage to which the energy storage capacitor is charged.

All the power supplies have very low current capabilities since they simply charge capacitors which supply all the energy during the exposure sequence.

An Improved "Framing" Image-Converter Camera

The second image-converter camera has considerably advanced characteristics. This camera makes six exposures on a single frame at rates varying from 2×10^6 to 2×10^4 exposures/sec. Exposure durations have the following values: 0.1, 0.3, 1.0, 3.0 and 10.0 μsec. Repetition rate and exposure duration are independently variable within the limitation that the exposure duty cycle may not exceed 20%. Deflection of the image takes place on both axes, producing two rows of three exposures. Additional modes of operation provide for a single undeflected exposure per input trigger at rates up to 2×10^4/sec, and a linear sweep along the y-axis with a total sweep-duration range from 2 to 400 μsec.

In the framing mode the basic pulse sequence is established by a ringing oscillator started by an input trigger as shown in Fig. 2. The oscillator contains five tuned circuits, one of which is selected to give the desired repetition rate. The oscillator output is converted to triggers which are used to trigger the shutter pulse generator and the sweep generator.

The shutter pulses are produced by an EFP60 secondary emission pentode using plate-to-cathode feedback. The three shorter exposure pulse lengths are established by current-fed lumped-constant delay lines in the plate circuit. The two longer exposure pulses are controlled by RC feedback. The positive pulse output is taken from the dynode and further amplified in a 715 tetrode cathode output amplifier. It is then fed to a pair of 715C power amplifiers. The output pulse at 6-kv amplitude is directly coupled to the cathode of the image-converter tube. The grid and screen are tied together and connected to the anode supply.

By tying the grid to the screen at the image-converter tube, we were able to obtain substantially less distortion than in the first converter which operated the grid at an intermediate potential. This distortion took the form of a rotation of the very bright portions of the image relative to the less intense regions. The power required to generate the larger shutter pulse is four times greater, but the improvement in image quality justifies this.

To provide sufficiently fast rise and fall times for the shutter pulse at 0.1-μsec duration requires a load resistance for the power amplifier of 200 ohms. The 6-kv pulse is produced by drawing 30 amp through the load resistance. At the longer exposure times the plate current may be reduced by using larger load resistances, resulting in an increase in rise time. The point of doing this is to allow the pulse amplifier to operate at higher pulse repetition rates without exceeding the power dissipation rating of the circuit. The screen voltage on the power amplifier is reduced as the load resistance is increased to reduce screen dissipation. The anode supply voltage must also be adjusted to produce exactly a 6-kv pulse to give a correctly focused image. The grid drive can be left the same under these conditions, which simplifies the driving circuitry. The pulse generating circuitry has the capability of generating groups of six 0.1-μsec shutter pulses at a group repetition rate of 5000/sec.

The sweep waveforms for this system are shown in Fig. 3 and produce the image sequence shown. The basic waveforms are generated by three Eccles-Jordan flip-flops triggered by the shutter pulses. The logic between the flip-flops produces the required waveforms which are amplified by EFP60's and fed to 715 tetrodes which drive the deflection coils.

The y-axis deflection coils are connected to a switch which places them in parallel for the high repetition rate and switches them to series for the slower rates. This arrangement is used to get the highest possible self-resonant frequency in the coils since this limits the speed with which the current can be changed from one value to another.

The deflection coils for this camera were wound on the legs of a rectangular ferrite core built up of ferrite slabs. This coil is vastly easier to build than the distributed winding coil used on the first converter and produces deflections with apparently negligible image distortion.

Initial image positioning is obtained by a set of offset coils wound on a similar rectangular coil form whose core is made of soft iron. The coils are driven by two low-voltage rectifiers. Undistorted deflection of the image can be obtained to any part of the screen.

The linear sweep circuit for this converter is required to generate sweeps of 2–400-μsec duration in approximately logarithmic sequence. Various attempts to do this with capacitors discharging through a thyratron directly into the deflection coil were unsuccessful. Therefore an amplified sweep was tried and successfully developed.

The linear sweep generator is shown in Fig. 4. The starting trigger sets the main flip-flop which cuts off the gate tube, allowing the voltage to build up on the sweep capacitor.

The exponential voltage rise is fed through the cathode follower to the sweep power amplifier — the same tubes used on the y-axis in the sequential mode. The waveform shows a step at the beginning of the sweep. This is produced by the resistor in series with the sweep capacitor and is used to bring the 715 tubes from cutoff into the region having appreciable transconductance. This avoids serious nonlinearities at the beginning of the sweep. Further linearization of the sweep is achieved by using the exponential shape of the voltage rise to counterbalance the plate current vs. grid voltage curve of the 715's which increases in slope as the grid voltage approaches zero. The amount of curvature required in the voltage waveforms can be controlled by choice of the charging voltage in relation to the grid swing on the tubes. In this circuit we have used about one third of the total rise.

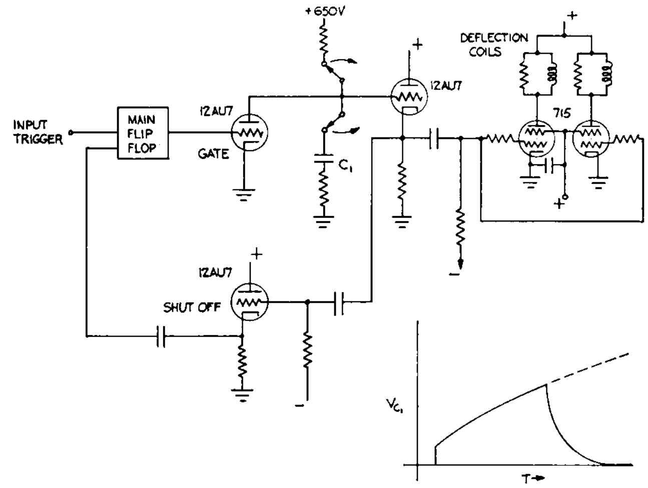

Fig. 4. Linear sweep generator for 2–400-μsec duration.

The triode in the lower left section of Fig. 4 labeled "shut off" is biased with the same voltage that appears on the 715 grids. When the sweep waveform drives it up into conduction, the output across the cathode resistor is used to shut off the main flip-flop and terminate the sweep. Thus all sweeps from 2 μsec to 400 μsec have the same length on the IC tube screen.

Latest Image-Converter Camera

The third and latest camera design is similar to the second, having exposures of 0.1, 0.3, 1.0, 3.0 and 10.0 μsec and corresponding exposure rates from 2 $\times$ 10^6 to 2

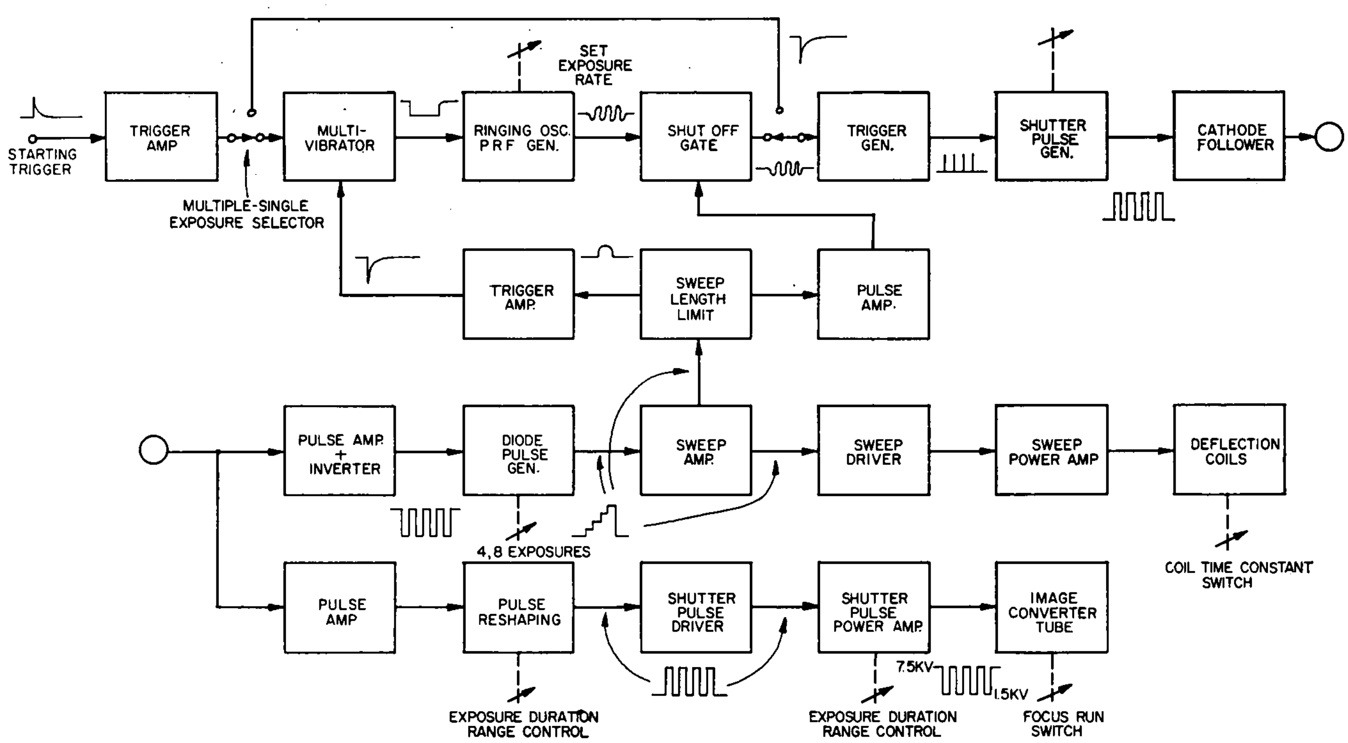

Fig. 5. Block diagram of latest image-converter camera showing waveforms at each step.

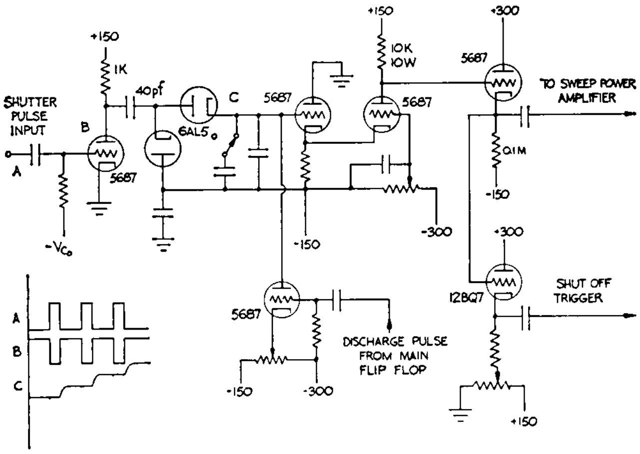

Fig. 6. Sweep generator circuit using diode-pump counting.

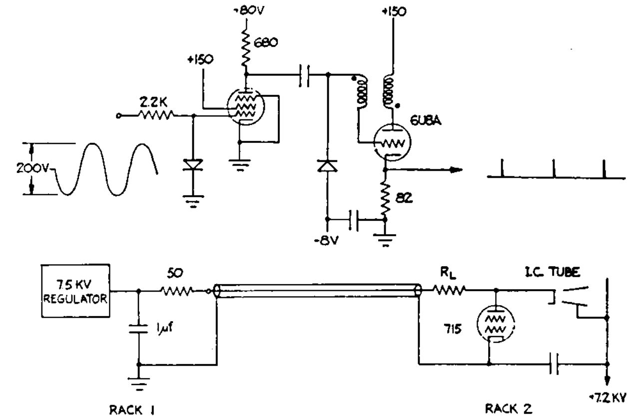

Fig. 7. Above: trigger generator; below: power supply coupling.

× 10^4 exposures/sec. The sequence of pulse and shutter pulse is very similar. The sweep, however, is on only one axis and therefore is similar in appearance to that of the first camera described. The mechanism of sweep generation is different, however, since a high exposure group repetition rate is required. The block diagram of this system is shown in Fig. 5. The sweep generator circuit is shown in Fig. 6.

The shutter pulses at low level are taken from the EFP60 generator and are put into a diode-pump counting circuit. The shutter pulse charges the input capacitor and the trailing edge dumps the charge into the accumulating capacitor where it produces a step rise in voltage. A cathode-driven sweep amplifier feeds a cathode follower driving the sweep power amplifier tubes and deflection coil, which are the same as in the second camera described above. A biased triode connected to the amplifier sweep voltage wave generates a pulse on the final step of the sweep and shuts off the sequence pulse generator, thus ending the cycle. This pulse also discharges the accumulating capacitor in the sweep generator. The number of exposures made on a single frame may readily be varied by changing the size of the accumulating capacitor. Any selected number of exposures will fill the same area of the screen, as determined by the bias on the shut-off diode.

The diode-pump circuit produces the output voltage staircase waveform independent of the shutter pulse width since the input capacitor can be readily charged by the 0.1-μsec pulse. Since the charge is always dumped on the trailing edge of the shutter pulse, relative timing of the sweep motion and exposure is correctly maintained for all pulse durations.

Several circuit features common to the second and third cameras are of some interest. The first to be described allows one to separate the power supplies from the converter tube chassis without requiring very large voltage capacitors for energy storage in the camera chassis. Figure 7 shows the power supply coupling and the trigger generator.

The anode supply for the shutter pulse power amplifier is connected to the amplifier load resistance through a 50-ohm coaxial cable. The cable is terminated at the power supply by a 50-ohm noninductive resistor in series with the storage or filter capacitor. The power amplifier looking back into the cable to the power supply sees a 50-ohm resistance source which can be put in series with the anode load resistance of the power amplifier and form a part of it. Thus no storage or by-pass capacitor on the anode supply is required in the camera box in spite of the 30-amp pulsed load current.

The trigger generator circuit converts the sine-wave output of the ringing oscillator into sharp triggers to be used to start the EFP60 pulse generator over a frequency range of 100 : 1. The sine wave at a frequency between 20 kc/sec and 2 Mc/sec is fed into a pentode. The series resistors and shunt diode provide sharp clipping of the positive half of the input. Cutoff of the plate current provides negative clipping. The small plate load resistor and low plate voltage limits the plate voltage swing to about 10 v.

The plate is capacitively coupled to the grid circuit of a blocking oscillator, which produces pulses of 0.1-μsec duration. The negative swing at the input causes a rise in plate voltage which triggers the blocking oscillator. After one pulse the oscillator remains cut off by the −8-v bias. The diode in the grid of the 6U8A removes the charge on the coupling capacitor accumulated during the pulse and makes the circuit immediately available for retriggering.

By limiting the amplitude of the pentode plate voltage swing to just slightly more than the triggering voltage required by the blocking oscillator, we ensure that only one output pulse is produced for each input excursion. The blocking oscillator output is taken across an 82-ohm resistor in the cathode circuit where it is reasonably isolated from the rest of the circuit.

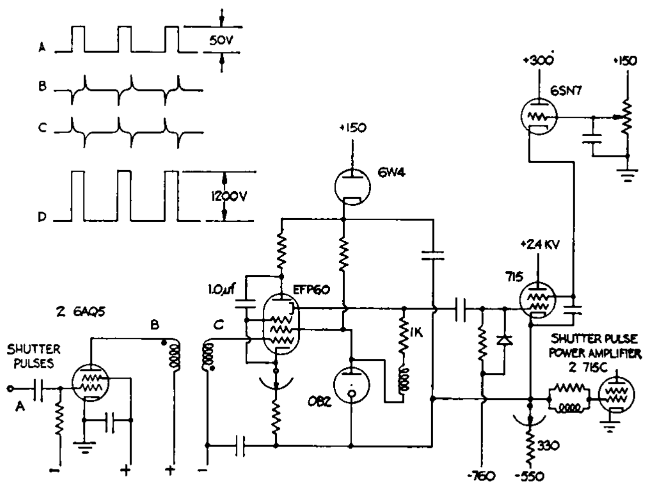

Fig. 8. Bootstrap pulse amplifier.

The final circuit to be described is a bootstrap pulse amplifier and driver for the shutter pulse power amplifier. This circuit, shown in Fig. 8, accepts input pulses of the correct duration at about 50-v amplitude and provides output pulses to the power amplifier grids at 1200 v and 1 amp of grid current. It does this over a pulse width range of 4000 : 1 with a minimum of switching.

The input pulses (*A*) are fed to a current drive with a pulse transformer in the plate circuit. The pulses are differentiated, inverted and coupled to the grid of an EFP60. The first trigger is positive and turns on the EFP60. Feedback on the EFP60 immediately causes it to saturate itself and generate an output. The second trigger is negative and shuts off the EFP60, thus terminating the output pulse. The feedback constants are designed to provide an inherent pulse width always greater than the input. At the same time the EFP60 must be nearly ready to shut off or the negative trigger may fail to stop it. This conflict accounts for the switching of cathode resistors required to cover the total range of pulse widths from 0.1 to 400 μsec. By providing sufficiently large input triggers, the switching requirements are reduced. With the circuit shown, five values of cathode resistance were provided for reliability, although the circuit would work with three values. The output pulse is coupled by a 715 tetrode connected as a cathode output amplifier to avoid inverting the signal. The entire EFP60 circuit is connected to the 715 cathode so that it rises and falls with the output pulses.

The functions of the pulse transformer now are clear. It must isolate the circuit from ground while coupling in the trigger, and it must differentiate and invert input current pulse. This is much more easily accomplished than designing a pulse transformer to cover a 4000 : 1 pulse width range.

The plate supply voltage for the EFP60 is supplied through the 6W4 diode and stored in the 20-μf capacitor. When the circuit rises during a pulse the 6W4 cuts off and isolates it from the power supply.

A similar problem exists in the screen circuit of the 715 which is tied to the cathode by the capacitor. Here a 6SN7 was used to provide the switching action and simultaneously to provide cathode follower low-impedance output to recharge the screen capacitor rapidly at the end of the pulse. It also provides a convenient means of adjusting the screen voltage with a small variable resistor in the grid circuit.

Fig. 9. Sequential pictures taken by Improved Framing Camera.

The load resistance in the cathode of the 715 driver is also switched to economize on plate current during the longer pulses, thus reducing the power dissipation per pulse and allowing a higher power repetition frequency.

Figure 9 shows test pictures taken, by light reflected from the test chart, with the Improved Framing Camera. The illumination was by a Sylvania R4330 lamp. The exposures were 3 μsec and the interval 12 μsec. The first lens was a Cooke 2 in., *f*/2 operated at an object distance of 52 in. so that the charts read directly in lines per millimeter resolution at the cathode. A Leica camera with a 50 mm *f*/2.8 lens was used to record the fluorescent screen image. The lamp intensity was not sufficient to allow adequate printing of the 0.1 μsec pictures.