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A SYSTEM FOR MEASURING THE QUADRATIC CONTENT OF TELEVISION SIGNALS

by

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A System for Measuring the Quadratic Content of Television Signals

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1.0 INTRODUCTION

The analysis of the performance of a real detection or recognition system is often a complicated procedure involving the inefficiencies and non-linearities of individual components of the sensor and the method of processing the sensor output. To obtain an indication of the overall performance of a real system it is useful to compare it to an optimum system which is limited only by the amount of information occurring in the input signal. Previous work at this laboratory has developed the theory which describes the performance of the optimum system.[1, 2, 3] The central result is that if the target is on a uniform background and the noise in the signal is Gaussian and white, then the statistical performance of the optimum system can be completely described from a knowledge of the noise properties of the signal and a property of the signal known as its quadratic content. The quadratic content of a signal is defined as[4]

$$\text{Quadratic content} = \int \Big[f(t) \Big]^2 dt \qquad (1)$$

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1. J. L. Harris, Scripps Inst. Oceanog. Ref. 58-56 (1958).
2. J. L. Harris, Scripps Inst. Oceanog. Ref. 59-65 (1959).
3. J. L. Harris, Resolving Power and Decision Theory, J. Opt. Soc. 54, 606 (1964).
4. S. Goldman, Information Theory (Prentice-Hall, Inc., New York, (1953) p. 80.

As applied here, f(t) is a noise-free signal referenced to the background of the target.

The Visibility Laboratory has been studying the application of television to detection and recognition systems under Bureau of Ships Contract NObs 84075, Assignment 3. One phase of this study was to determine the performance of a typical television system in a detection system. Thus the performance was to be weighted by the sensor's characteristics. However, no restriction was to be made on the method of processing the sensor output, i.e., the performance of the sensor was to be based upon optimum utilization of the sensor output. This was accomplished by measuring the quadratic content of the output signal of the sensor. From this quantity the performance assuming optimum processing could be calculated.

To implement these calculations the quadratic content per TV frame of a variety of complex targets illuminated under various lighting geometries and viewed by a television system at different resolutions was needed. Direct measurements from a television system and actual targets were desired. To obtain accurate measurements of quadratic content, the system was to be operated so as to maximize the signal-to-noise ratio. Then the results could be extended by simple calculation to other conditions such as reduced target contrast due to atmospheric scattering, increase of noise due to flux limitations or additional transmission links, and other factors. An instrument was developed to make these measurements. This report describes the operating principles, physical characteristics, and performance of this instrument.

2.0 REQUIREMENTS

From the definition of the quadratic content of a signal the steps necessary to measure it are well defined. First the signal must be squared point by point and then the squared signal must be integrated over the target. The target is referenced to its immediate background. Hence d.c. levels in the output of the television system are disregarded. The average value of the waveform on either side of the signal is considered to be the reference level and the signal is squared about this level. Both positive and negative excursions about this level must be squared.

Figure 1 shows a typical (except for absence of noise) oscillograph of a single TV scan across a target.

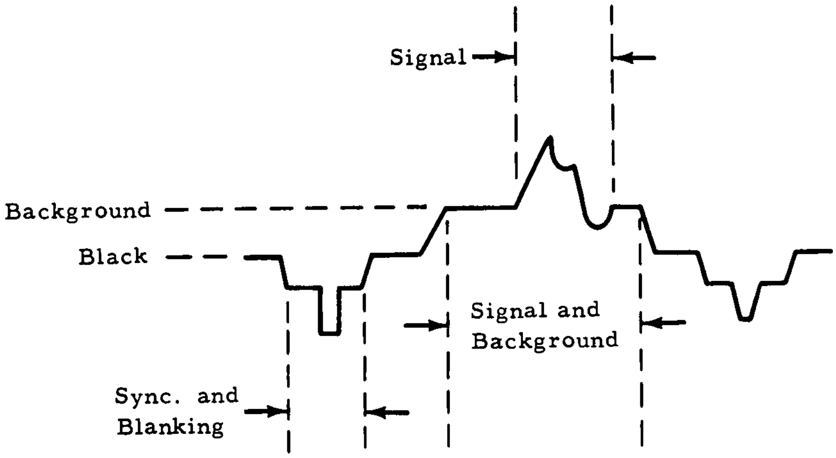
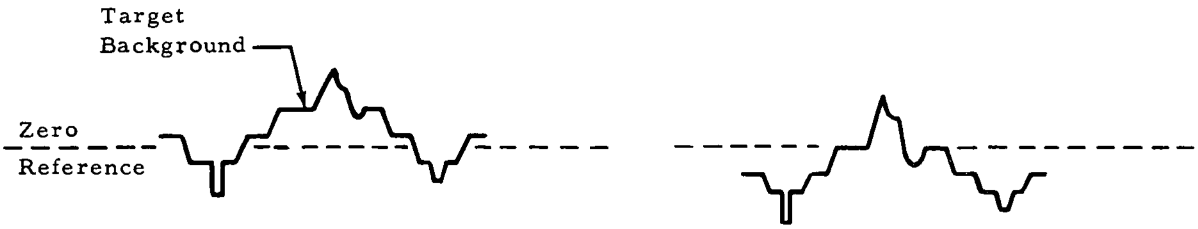


Fig. 1 Television video waveform for one horizontal scan line.

In addition to the signal of interest, the waveform contains synchronizing pulses, blanking pulses, and d. c. levels which must be eliminated. Figure 2 shows a sequence of operations demonstrating how this is accomplished.



Input Signal
(a)

D.C. Level Shifted
(b)

Video gated on only on target
(c)

Squared
(d)

Fig. 2 Processing of video waveform for squaring of signal

First the d. c. level of the waveform is shifted to put the background level at the zero reference. The signal is then gated on only during scanning of the target and its immediate background; at all other times the value of the waveform is zero. The waveform is then squared. Finally the gated and squared signal is integrated to give the quadratic content of the signal.

In practice the signal will be accompanied by noise which cannot be separated from the signal. For targets of sufficiently high contrast the effect of the noise can be ignored. In other cases the noise may be of significant amplitude compared to the target so that the quadratic content of the signal due to the target cannot be measured directly. However, if the noise can be measured in the absence of a target signal, then its contribution to the measurement of a target signal can be subtracted out. The method of doing this will be considered in a later section.

3.0 POSSIBLE METHODS

There are various ways in which the quadratic content measurement might be implemented. Several methods will be briefly discussed before a detailed description of the method used is given.

A method requiring a minimum of equipment is to take oscillograms of each TV line that crosses the target. The ordinates of the signal are read from the oscillograms and the squaring and integrating operations are performed by numerical methods. This method can be very tedious.

Various square-law devices such as diodes and resistor-thermocouple combinations exist which can be used to perform the quadratic-content measurement. These devices would have to be used with wide-band video and gating circuits. Design of these circuits is quite feasible. However, a much simpler method can be used in which the video signal is connected directly from the television system to an oscilloscope and the measurement is made from the oscilloscope display. This technique will be described.

4.0 OPTICAL MASK TECHNIQUE

The system devised employs an optical mask in conjunction with an oscilloscope to provide the squaring operation. Figure 3 shows the essential components of the system. A detailed block diagram of the system may be found in Fig. 7.

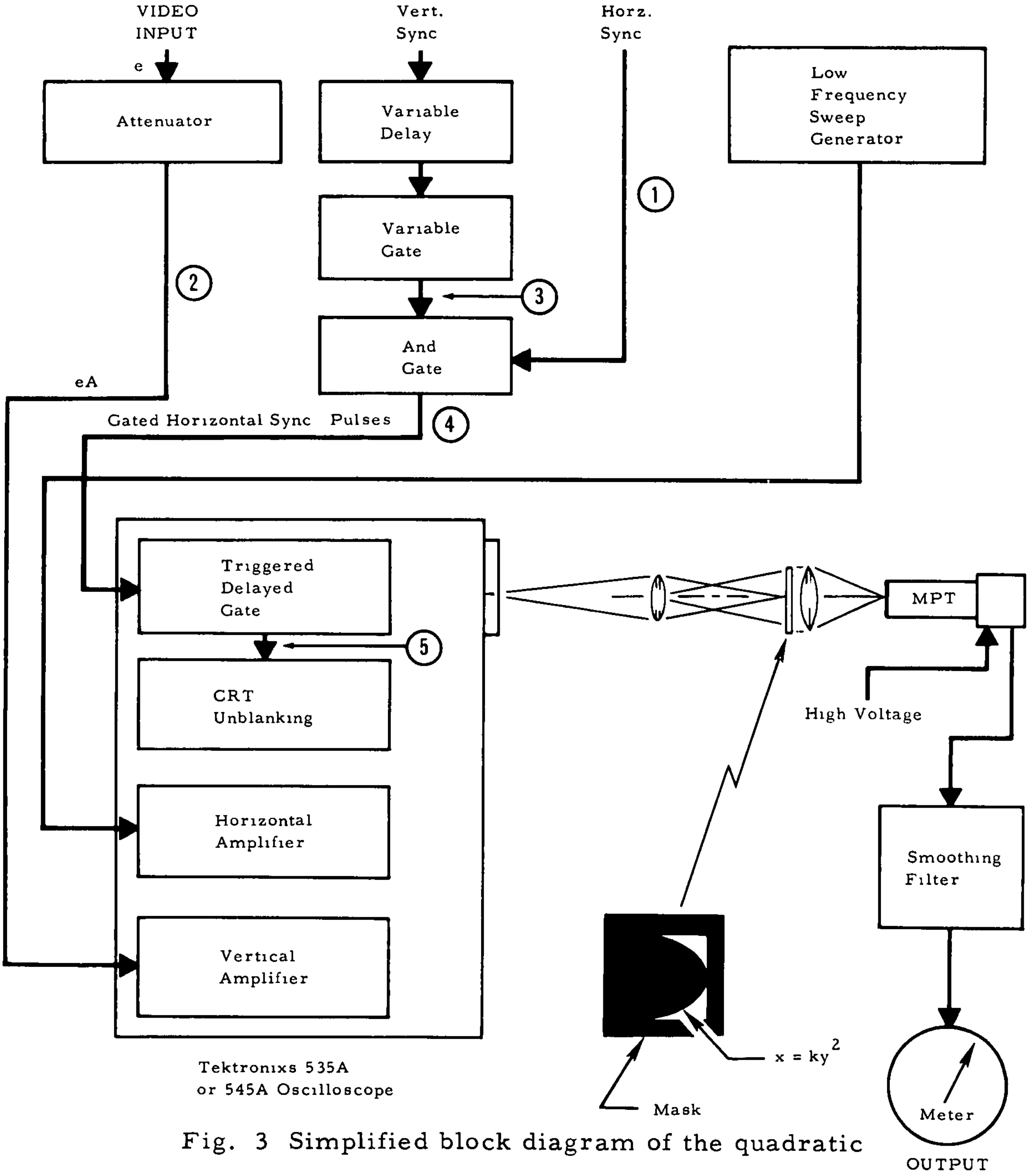


Fig. 3 Simplified block diagram of the quadratic content measurement system.

4.1 The Squaring and Integrating Operation

The squaring operation occurs in the following way. Consider a small increment of the video waveform representing the target. This increment is repeated at the frame rate of the TV system. Imagine that only this small increment is unblanked on the oscilloscope. Now if a slow horizontal sweep is applied to the oscilloscope the resulting display will be a series of dots across the CRT screen, each dot representing the increment during a TV field. Now let this display be imaged upon a mask as shown in Fig. 4.

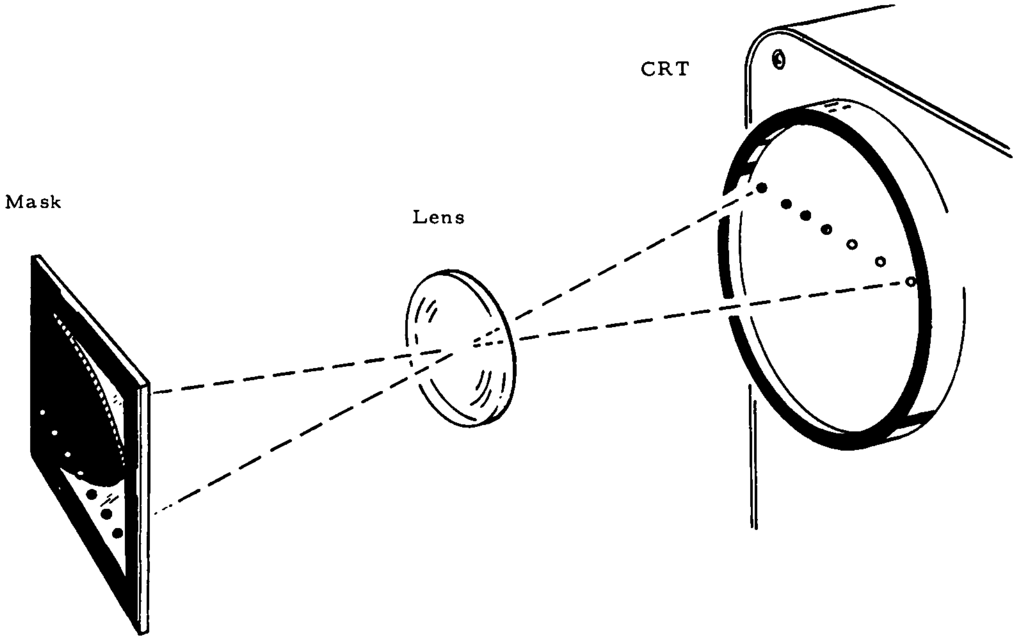


Fig. 4 Optical mask technique for squaring the video signal

The amount of flux passing through the opening in the mask will be dependent upon the vertical position of the dots upon the mask. Now assume the cutout in the mask is a parabola, $x=ky^2$, centered on the centerline of the CRT. The total flux, then, passing through the mask in one sweep due to an increment of the signal is proportional to the square of the vertical displacement of that increment from the center of the CRT. Actually, a small error is involved since the CRT pattern is a series of dots and not a continuous line. However, if the sweep is slow enough the dots will be closely spaced and the error will be small.

So far only the flux from a single increment of the target signal has been considered. The same reasoning used in the previous paragraph can be applied to each increment of the target signal. If the contribution from each target increment is considered, the flux coming through the mask in one horizontal sweep would be proportional to the sum of the squares of the vertical positions of all the increments of the signal. Since these increments are imaginary they may be considered to be infinitesimal and the sum becomes an integral. Hence the total flux passing through the mask in one sweep is

$$F_{total} = k_1 \int_0^{T_s} \left[e(t) \right]^2 dt \,, \qquad (2)$$

where T_s is the period of one sweep, k_1 is a constant of calibration of the system, and e(t) is the instantaneous value of the gated video waveform. The appearance of the display when all of the target signal is unblanked on the CRT would be a series of vertical lines, each line containing e(t) due to the target for a single TV field.

The instantaneous flux passing through the mask can be converted into an electrical current by means of a multiplier phototube. The total charge delivered at the anode (neglecting dark current) during a single sweep is directly proportional to the total flux received by the phototube during that time.

$$q_{total} = k_2 \int_0^{T_s} \left[e(t) \right]^2 dt \qquad (3)$$

The average current may be found by dividing the total charge delivered during T_s by T_s.

$$i_{ave} = \frac{k_2}{T_s} \int_0^{T_s} \left[e(t) \right]^2 dt = k_3 \int_0^{T_s} \left[e(t) \right]^2 dt \qquad (4)$$

The average current is measured by filtering the anode current with a low pass RC filter which passes only the d. c. or average value of the current. The voltage, E, developed across this filter is directly proportional to i_{ave}.

$$E = K \int_0^{T_s} \left[e(t)\right]^2 dt \qquad (5)$$

The average value of $e(t)^2$ has been found over a period of one slow sweep . Disregarding any errors due to noise, the average of $e(t)^2$ over the period of one TV frame would have the same value. Due to the gating of the CRT, the display is turned on only for a time τ. That is, the CRT beam is turned on only when the target and a small part of its immediate background is being scanned. Hence e(t) is effectively zero at all times outside of τ. Therefore Eq. (5) can be written as

$$E = K \int_0^{\tau} \left[e(t)\right]^2 dt \qquad (6)$$

Or

$$\int_0^{\tau} \left[e(t)\right]^2 dt = \frac{E}{K} \qquad (7)$$

Equation (7) expresses the quadratic content of the target signal in terms of a measurable quantity E and a constant K. K is easily evaluated by calibrating the system with a signal of known quadratic content.

4. 2 Correction for Noise and Dark Current

Equation (7) was derived neglecting video noise and phototube dark current. If the contribution of noise and dark current are considered, Eq. (6) becomes

$$E_{S+N+D} = K \int_0^{\tau} \left[e_S(t) + e_N(t)\right]^2 dt + E_D \ . \qquad (8)$$

The subscript notation is: S denotes signal, N denotes noise, and D denotes dark current. Expanding Eq. (8) yields

$$E_{S+N+D} = K \int_0^{\tau} \left\{ \left[e_S(t) \right]^2 + 2e_S(t)\, e_N(t) + \left[e_N(t) \right]^2 \right\} dt + E_D$$

$$= K \int_0^{\tau} \left[e_S(t) \right]^2 dt + 2K \int_0^{\tau} e_S(t)\, e_N(t)\, dt + K \int_0^{\tau} \left[e_N(t) \right]^2 dt + E_D. \tag{9}$$

Solving for the quadratic content of the signal gives

$$\int_0^{\tau} \left[e_S(t) \right]^2 dt = \frac{1}{K} \left[E_{S+N+D} - E_D - 2K \int_0^{\tau} e_S(t)\, e_N(t)\, dt - \int_0^{\tau} \left[e_N(t) \right]^2 dt \right]. \tag{10}$$

The first term in the brackets is the output of the anode filter circuit when measuring the unknown signal with its associated noise. The second term is the output of the anode filter when the phototube receives no flux from the CRT. The third term, involving the cross products of the signal and noise, is a random variable of zero mean. Since the output circuit passes only mean or d.c. values, the contribution of the third term is zero, assuming that the time constant of the anode circuit is long enough to smooth out the deviations from the mean. The fourth term is the quadratic content of the noise, which may be found by measurement in the absence of a target signal.

Thus all right hand members of (10) can be either measured or disregarded and the quadratic content of the target can be computed from these measurements. For some targets the contribution of the target to the output signal will be much greater than that due to noise and dark current. In such cases, Eq. (7) may be used directly.

4.3 Gating the Target

In making the measurement, only the video representing the target and its immediate background are to be unblanked on the CRT. Figure 5 shows the waveforms which demonstrate this gating operation. The numbers designating the waveforms are included in Fig. 3 to clarify the sources of the waveforms.

Line 1 shows the horizontal synchronizing pulses (H sync) generated by the TV system. Line 2 is a simplified representation of the TV video with a target extending over three lines. Line 3 shows a vertical gate generated to overlap the H sync pulses of the three lines containing the target. This gate is triggered by a delayed vertical sync pulse. Line 4 shows the output of an AND gate whose inputs are H sync (line 1) and the vertical gate (line 3). This output contains a horizontal sync pulse only for those lines containing the target. This signal is used as a trigger source for the delaying sweep channel of an oscilloscope such as the Tektronix 545A. The controls of the oscilloscope are set so that each gated H sync pulse generates a delayed pulse which slightly overlaps the target video, as shown on line 5. These pulses are used to unblank the CRT as shown on line 6. Line 7 represents the CRT display as the time scale is compressed. Finally, line 8 represents the oscilloscope display when the slow horizontal sweep is applied.

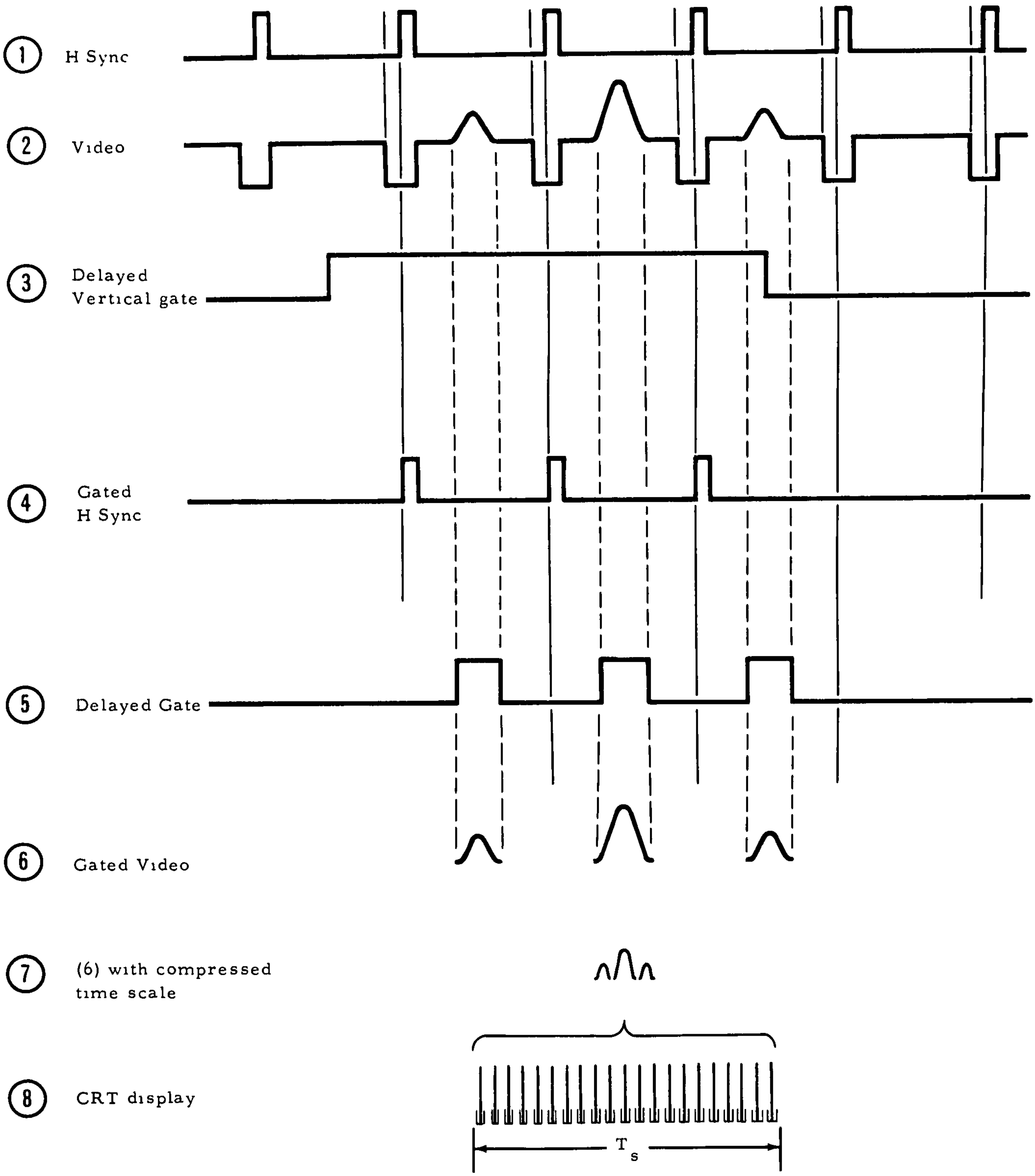


Fig. 5 Waveforms used in gating the target

5.0 THE SYSTEM

5.1 Description

Figure 6 shows the instrument and associated electronics developed by the Visibility Laboratory for the purpose of measuring the quadratic content of television signals. A detailed block diagram of the system is shown in Fig. 7.

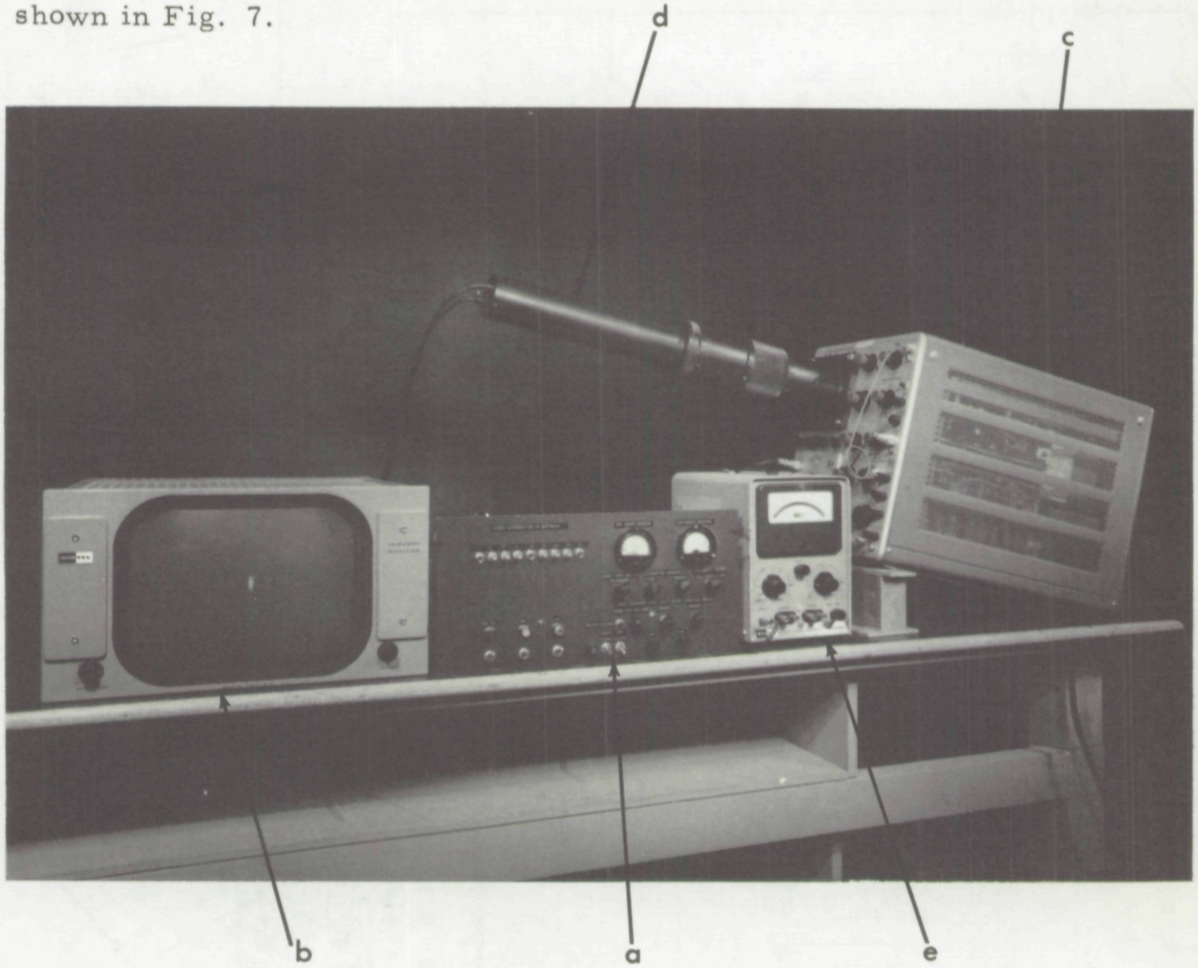


Fig. 6 The quadratic content measurement system.

The chassis labeled (a) contains a variety of circuits. The video from the television system is fed through this chassis via a calibrated video attenuator and selector switch to the oscilloscope. The attenuator is used

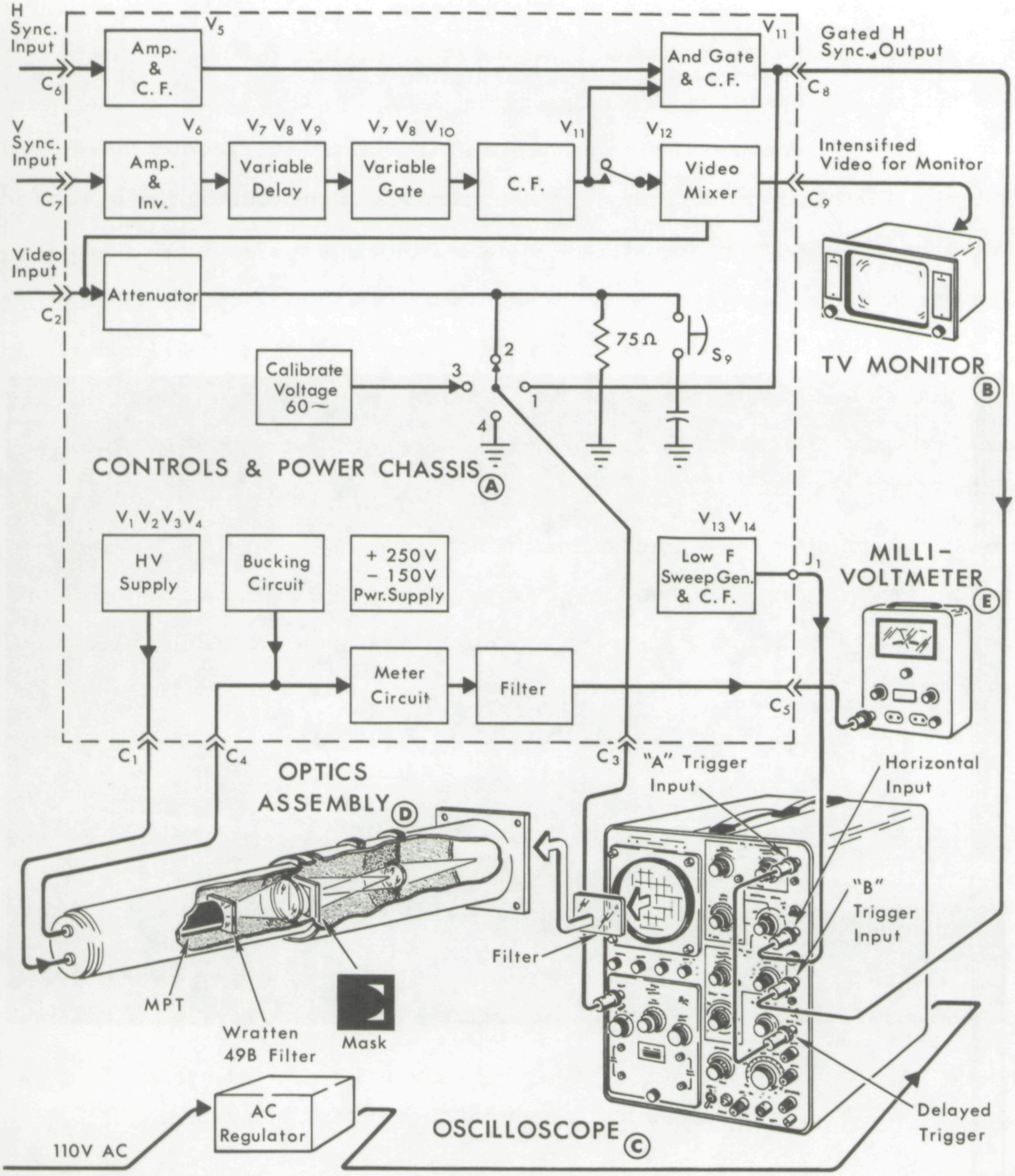


Fig. 7 Detailed block diagram of the system.

to set the video amplitude within the range of the square-law mask. The chassis contains the gating circuits needed to provide the gated H sync pulses for the oscilloscope, as shown on line 4, Fig. 5. A circuit is provided which mixes the video and the delayed vertical gate (line 3, Fig. 5) so that the portion of the TV picture being gated vertically can be observed on the television monitor (b). The chassis also contains a calibration source, the multiplier phototube high voltage supply, the phototube anode filter circuit, and the low frequency sweep generator for the oscilloscope.

The oscilloscope (c) is a Tektronix 545 A. A simple modification of the oscilloscope is necessary to allow the CRT to be unblanked in the "A delayed by B" mode while the horizontal selector switch is actually in the "external" position. Figure 12 in the appendix shows this modification.

The tube (d) attached to the oscilloscope contains the square law mask, associated lens and the multiplier phototube. The CRT display is imaged upon the mask by means of an objective lens. Immediately behind the mask is a lens which images the objective lens upon the phototube. This method eliminates scanning of the photocathode. Also within the tube is a mirror (not shown) which can be swung down in front of the phototube. Above the mirror is a small lamp which is turned on when the mirror is down. The optical system then projects the mask upon the face of the CRT. The operator can look at the CRT through a porthole and position the display with respect to the image of the mask.

Several other features of the optical system should be noted. A possible source of error in the instrument is the fact that the CRT spot has a halo of light around it. This halo results from light from the spot which is reflected at the face of the CRT back to the phosphor and then scattered. Thus the flux representing one of the increments of the signal is not imaged solely upon one vertical position of the mask. To reduce this effect, a neutral density filter is placed in optical contact with the CRT faceplate to increase the contrast. The image-forming rays from the spot pass through the filter once and are thus attenuated by a factor of T, the transmission of the filter. Rays from the spot which are reflected and scattered to form the halo pass through the filter at least three times and are attenuated by a factor of at least T^3. Addition of the filter thus increases the contrast of the spot by a factor of approximately $\frac{T}{T^3}$ or $\frac{1}{T^2}$.[5]

Another source of error involves phosphorescence of the CRT phosphor. If the CRT has been very bright prior to a measurement of a very small target, the phosphorescence of the previous display can add a significant amount of flux. This problem is circumvented by using a phosphor with a fast decay characteristic. Or, if a P2 phosphor which has a fast blue-green fluorescence and a slow green phosphorescence is used, the latter can be filtered out by placing a dark blue filter over the phototube.

The signal from the phototube is fed back to the chassis (a) where it is filtered. It is then measured by the d. c. VTVM (e). This reading is the output of the system, E_{S+N+D}, E_{N+D}, or E_D, depending on what is presented on the CRT.

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[5] For a description of this technique, see Zworken and Morton, "Television", Wiley and Sons, 1954.

5.2 Performance

The transfer function of the system is shown in Fig. 8. This curve was obtained by using a symmetrical square wave as the input to the system. The system output is proportional to the square of the input over a wide range of input amplitudes. The output near the edge of the mask falls off mainly due to a decrease of CRT intensity at the edge of the display. If this edge is avoided the output is within ±5% of the square of the input over a normalized input range of .05 to 1.

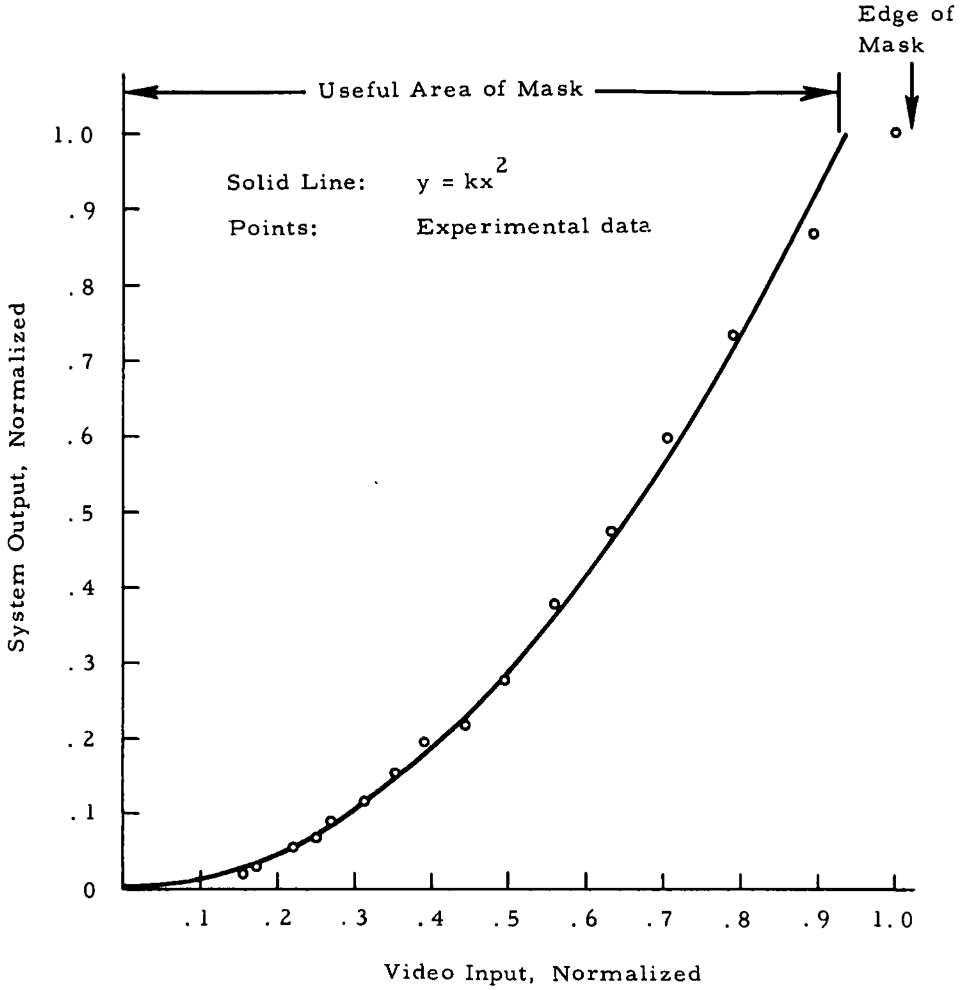


Fig. 8 Transfer characteristics of the quadratic content meter

The frequency response of the instrument is determined by several factors. One factor is the electrical bandwidth which is determined by the pass band of the interconnecting cables, video attenuator, and oscilloscope. Obtaining a pass band well beyond the frequency response of the television system (10 m.c.) is insured by using terminated 75 ohm coaxial cables, a precision high frequency attenuator, and a broad band (24 m.c.) plug-in unit in the oscilloscope. Another possible frequency-dependent factor is the CRT intensity. For some phosphors the intensity is non-linearly related to the writing speed of the beam. To see if this was an important factor, a sine wave input of constant amplitude at the CRT but of variable frequency was applied to the system. The output was found to deviate from the mean less than ± 3% over a range of 100 cps to 30 m.c.

The basic purpose of this instrument is to measure the quadratic content of television signals. Determining the accuracy of this type of measurement is difficult unless a comparison is made to a graphical analysis of a television signal. However, the accuracy can be checked by measuring the r.m.s. value of different waveforms since the r.m.s. value is simply related to quadratic content by

$$\text{r.m.s. value} = \left[1/T \text{ (Quadratic Content)}\right]^{1/2}$$

where T is the period of time over which the quadratic content is measured. In this system T is the total time during one television frame that the CRT beam is gated on. Measurements have been made on various waveforms of known r.m.s. values for various gating times. An internal 60 cps sine wave was used as the calibration source. The accuracy of the system has been found to be approximately ± 10% for quantities proportional to the square root of quadratic content and ± 20% for quantities directly proportional to quadratic content. Parameters such as output signal to noise used in analysis of systems are usually proportional to the square root of the quadratic content of the signal. Hence, in application, the accuracy of the system is approximately ± 10%. System inaccuracy is due to imperfect shape of the CRT beam gating pulse, resulting in a non-uniform CRT intensity during unblanking; deviations of the transfer function from the square law, and non-linearities of the slow CRT sweep.

5.3 Other Uses of the System

The system described here is not limited to the measurement of the quadratic content and r.m.s. values of a waveform. By changing the shape of the cutout in the mask many different transfer functions can be obtained. For example, a cutout of the form $x = ky$ would give a system output proportional to the integral of a full wave rectified input signal. If the is of the form $x = ky$ for $y \geq 0$ and $x = 0$ for $y \leq 0$, the system output would be proportional to the integral of a half wave rectified signal. Unusual transfer functions can be obtained by making the cutout in the mask of the appropriate form. It should be noted, however, that the system effectively full wave or half wave rectifies the input signal, because the phototube has no way of distinguishing between flux from positive signals and flux from negative signals. A non-rectifying system would require two phototube channels.

Nor is the system limited to the measurement of television waveforms. Any periodic or continuous (such as random noise) waveform can be measured. If only a portion of a periodic waveform is to be measured, then suitable synchronizing pulses must be available for gating the signal.

6.0 SUMMARY

A system has been devised for the measurement of the quadratic content of television signals. A unique feature of this system is that the video signal from the television system is connected directly to an oscilloscope and the measurement taken from the CRT using an optical mask technique. In addition to the measurement of quadratic content and r. m. s. values, the system can measure other properties of the signal if the appropriate mask is substituted for the square law mask.

The system is composed partly of commercially available instruments and requires the construction of only a few electronic circuits. The construction of the optical and mechanical components is simple and straightforward.

Accuracy of the system for quadratic content measurements is approximately ± 20%; for r. m. s. and signal-to-noise measurements, approximately ± 10%.

APPENDIX

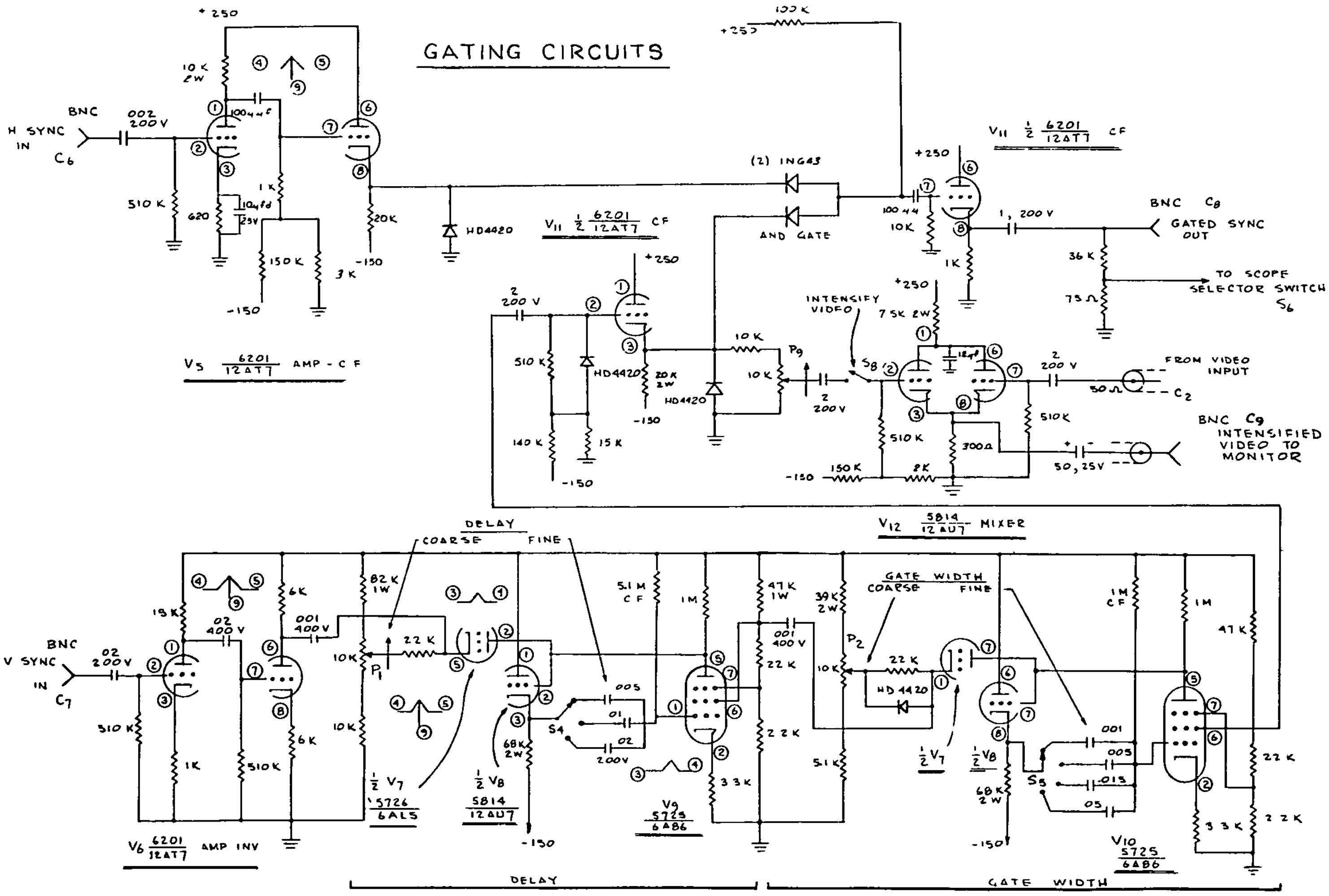


Fig. 9 Gating circuits.

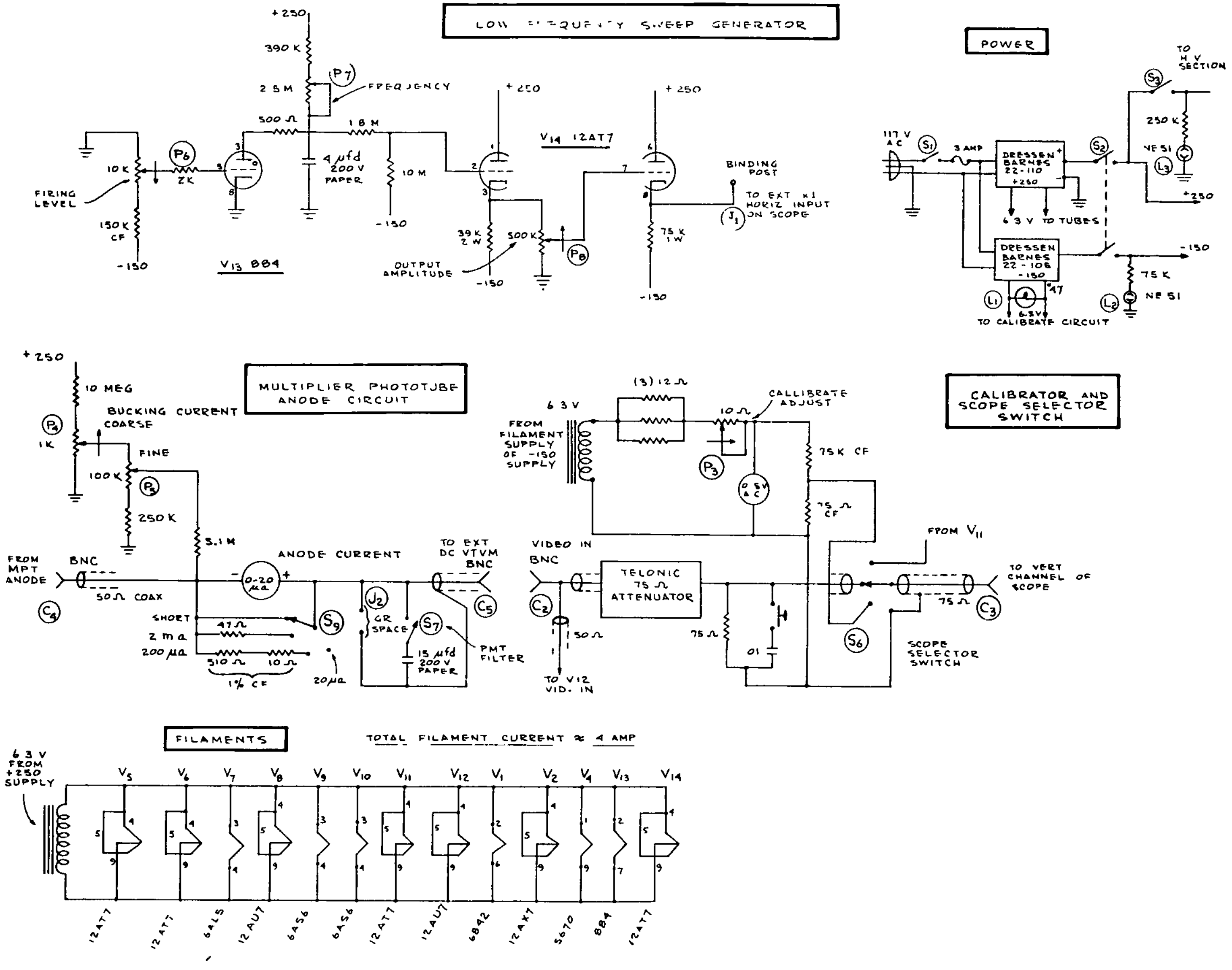
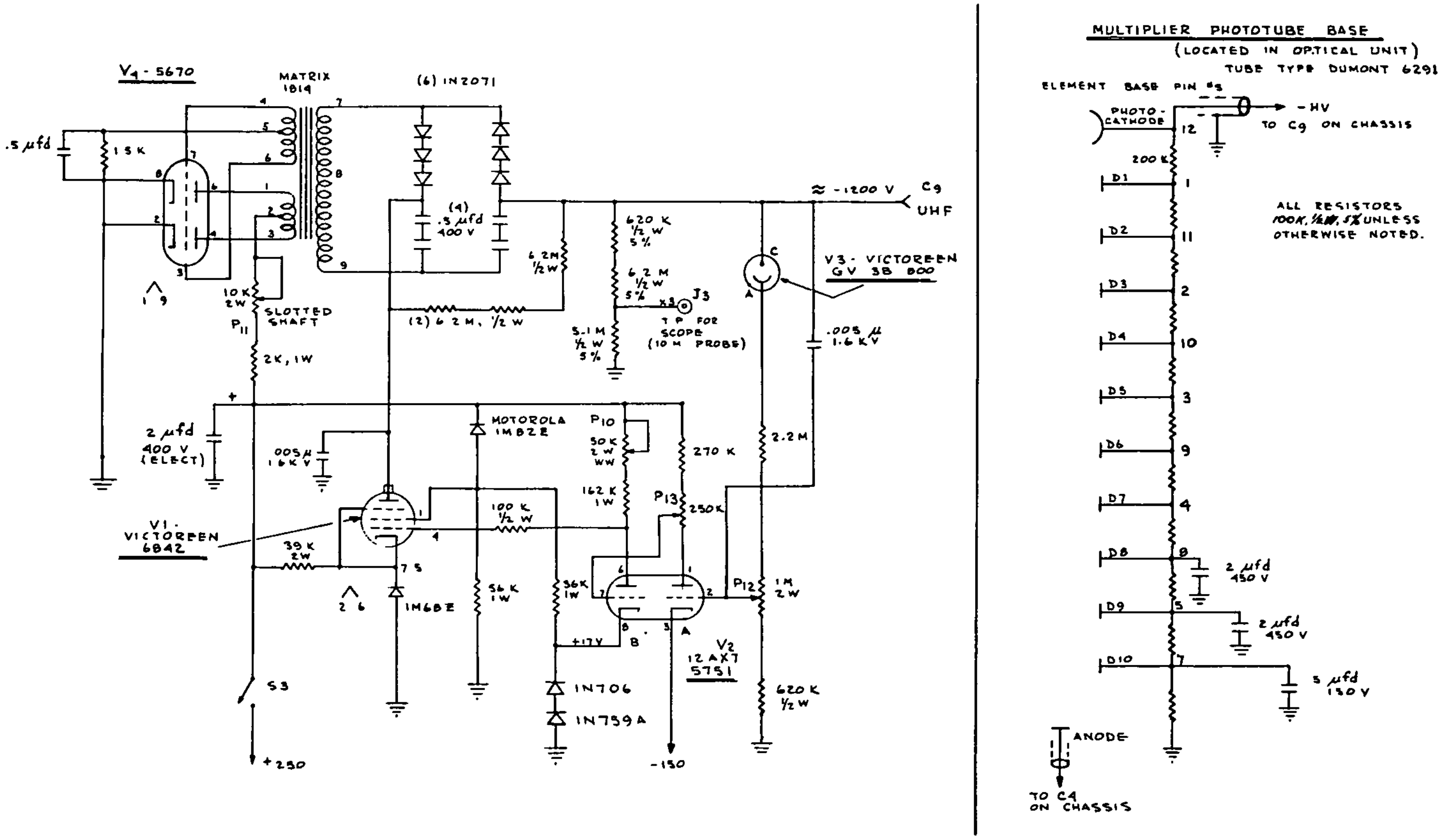
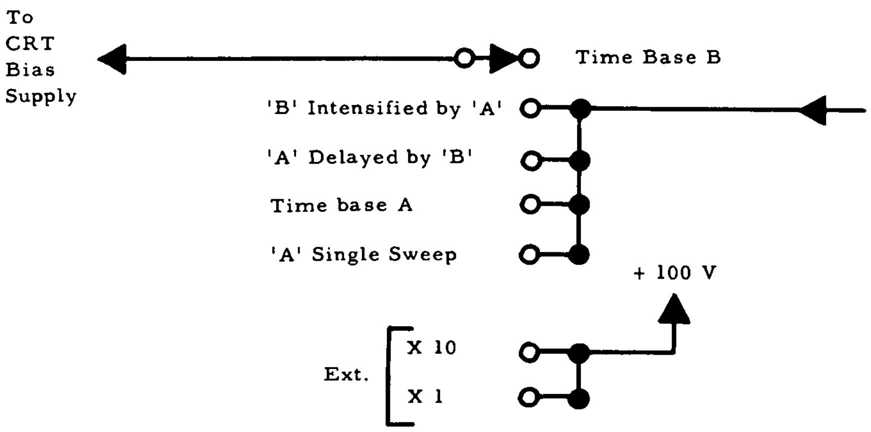


Fig. 10 Sweep generator, MPT anode, calibrator and power circuits.

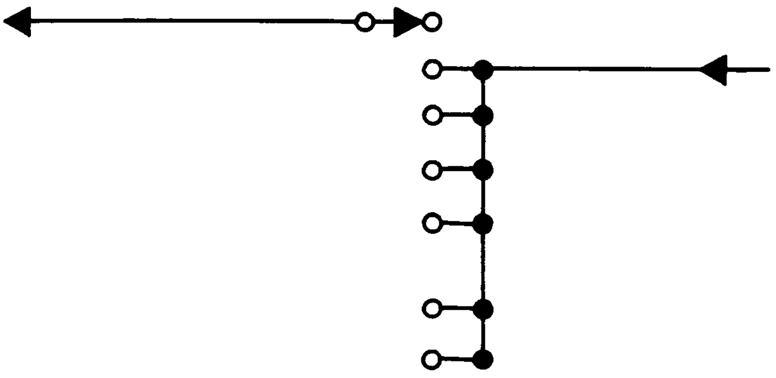


NOTE SET P_{10} & P_{13} FOR 9V BIAS ON V_{2a} & 180 ON PLATE OF V_1 WITH MAX. OUTPUT VOLTAGE & LOAD OF 1.35 MEGS.

Fig. 11 Multiplier phototube base and high voltage power supply.



BEFORE MODIFICATON



AFTER MODIFICATION

Fig. 12 Modification of Tektronix 545 or 535 horizontal display switch to allow CRT unblanking while in "Ext." position.