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Electronic gating

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by

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PREFACE

This work was undertaken at the United States Naval Postgraduate School during the writer's third year at that Institution and as a result of his interest in the various types of gating used in Radars and other electronic devices.

The writer extends his appreciation to the engineers of the Special Weapons Department, Glenn L. Martin Company, for their assistance given and the literature made available while working on gating circuits at the Glenn L. Martin Company.

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TABLE OF SYMBOLS AND ABBREVIATIONS

A - Amplitude of sine wave reference voltage in volts

AC - Alternating current

α - Offset angle of conical scan in degrees

B - Voltage range representing gate width

β - Beam width of antenna in degrees

C - Capacity in farads

cps - Cycles per second

CRT - Cathode ray tube

δ - Gate width

DC - Direct current

E - DC value of voltage

e - Instantaneous value of AC voltage

E_{bb} - DC voltage supply for vacuum tubes

E_{sc} - DC voltage supply for screen grid of vacuum tubes

f - Frequency in cycles per second

θ - Azimuth angle in degrees

i - Instantaneous value of AC current

IF - Intermediate frequency

K - Slope of triangular wave in volts/degree

μ - Amplification factor of vacuum tubes

R - Resistance in ohms

r_p - Plate resistance of vacuum tubes in ohms

T - Time in seconds of one complete cycle

V - Vacuum tube

CHAPTER I

TYPES OF ELECTRONIC GATES

1. Introduction.

The complexity of modern radar systems and electronic devices has made it necessary to develop many types of electronic gates. A modern radar system may be required to present several types of information to a number of remote indicators simultaneously. The desired presentation at each indicator can be displayed properly because electronic gating circuits allow only the information which is necessary for that type of presentation to be passed from the system to the indicator.

No attempt will be made to describe or analyze all the electronic gating circuits in use today. However, it is believed that the circuits named below are sufficiently representative of the types in use today. A brief description of their use and operation along with a more complete analysis of an azimuth gating circuit will be given in this paper.

2. Types.

An electronic gate is usually a square-voltage wave which switches a circuit on or off electronically, usually by application to a grid or cathode. The most common method of producing an electronic gate is by the use of a multivibrator.

Three types of gates which are used quite extensively today in radars and electronic devices are:

(a) Azimuth and/or Elevation gates.

Azimuth gates are commonly employed in radar systems where it is desired to display only part of the sector being scanned by the antenna. The method of producing the gate depends, to a large extent, upon the type of scanning system being used by the radar. The azimuth gate is usually applied to the cathode of the CRT, in which case the tube is intensified during the time that the antenna is in the sector to be displayed. A complete chapter will be devoted to a particular azimuth gating circuit later.

(b) Range gates.

Range gates have many variations and several types of range gates may be used within one radar system.

(1) Fixed (intensifier gate).

The fixed or intensifier gate is normally used on all radar sets and is nothing more than the blanking and unblanking used on oscilloscopes. It is obtained from the sweep multivibrator which gives a square wave of the same duration as the range sweep.

(2) Fixed length, variable in position.

A range gate which is fixed in length and variable in position is used on some fire control radars to acquire and track a target. The position of the gate may be varied either manually or at a fixed rate automatically while acquiring the target. After the target is acquired the system can be switched to automatic tracking and then the gate will continue to bracket the target automatically.

(3) Sensitivity time control gate.

This type of gate is commonly employed on surface search radars to overcome the effects of sea return. The basic circuit shown in Fig. 1 illustrates a method of producing and using a gate of this type. The initial amplitude of the gate is determined by the ratio of $\frac{R_1}{R_1 + R_2}$ while the time required to reach maximum sensitivity is determined by the time constant $(R_1 + R_2)C$. With this type of gate, the gain control on the radar can be set to the desired level for long range search and targets can still be seen at short range because the gain is reduced at the start of the sweep, thus preventing saturation due to sea return.

(c) Electronic switch.

An electronic switch is a device whereby two or more waveforms can be applied to a single gun cathode ray oscilliscope simultaneously. A simple electronic switch is shown in Fig. 2 that will permit two waveforms to be presented simultaneously upon the face of a single gun

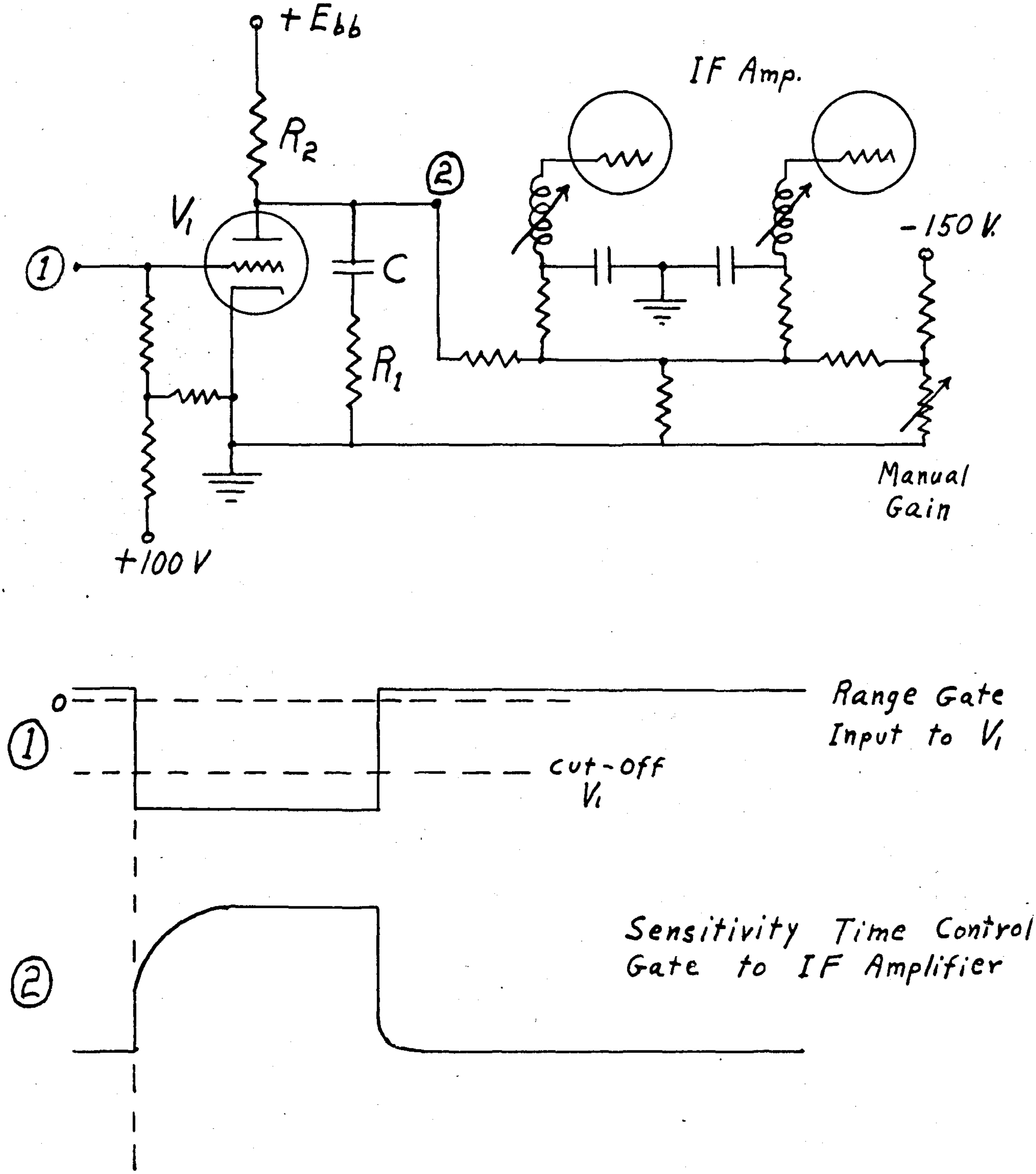


Fig. 1
Sensitivity time control gating circuit

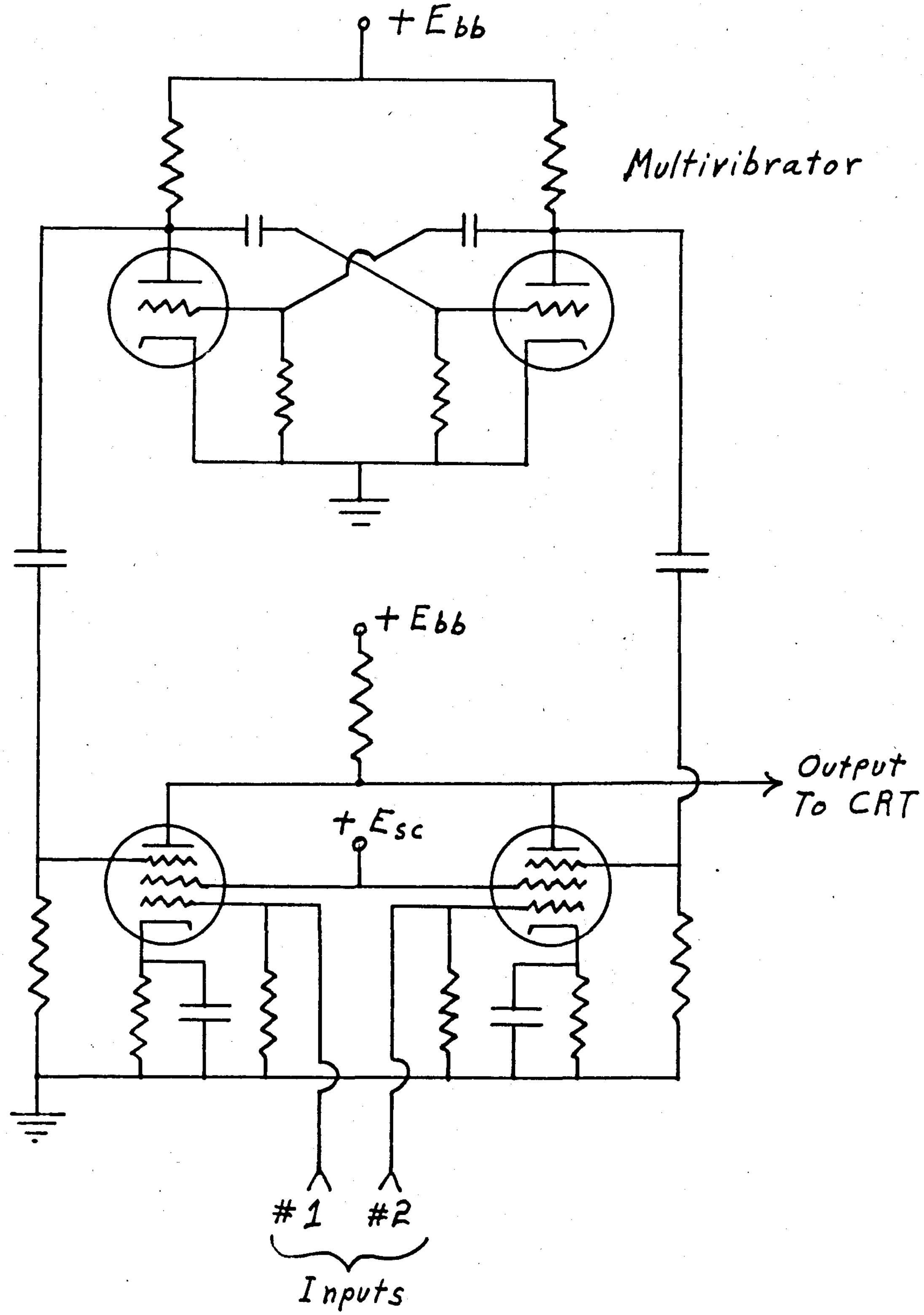


Fig. 2
Electronic switch

cathode ray oscilloscope. One requirement of an electronic switch being used in this manner is that the sampling rate be high in comparison to the frequency of either of the waveforms being presented.

Recent developments in multi-gun cathode ray tubes have made it possible to present several waveforms upon the face of the tube simultaneously without the use of an electronic switch. Multi-gun cathode ray tubes have many advantages over single gun tubes in some respects, such as better efficiency in the display of more than one waveform simultaneously and the fact that no electronic switch is necessary. However, multi-gun tubes also have disadvantages such as higher cost, variations in gun to gun deflection sensitivity, interaction of the beams, parallax, etc. In view of the above, it is believed that single gun cathode ray tubes employing electronic switching will have a place in the display of multiple waveforms for many years to come.

CHAPTER II

THE ANALYSIS OF A TYPICAL AZIMUTH GATING CIRCUIT

1. General.

The azimuth gating circuit shown in Fig. 3 will be analyzed in this chapter. The circuit is used to provide gated video to one gun of a multi-gun CRT. The arm of R_{24} is ganged to the antenna thus giving a triangular waveform at the grid of V_5. The output of the cathode follower, V_5, is mixed with a DC level from R_{20}, and applied to the grid of V_2. V_1 and V_2 comprise a cathode coupled phase inverter stage known as the gating amplifier. V_3 and V_4 comprise the azimuth gating tube which applies an azimuth gate to the suppressor grid of the video amplifier tube V_7.

It will be noted that direct coupling is used all the way from the antenna potentiometer R_{24} to the suppressor grid of V_7. This is necessary because the frequency of the triangular waveform generated at R_{24} is 0.4 cps and the duration of the azimuth gate may be several thousand microseconds.

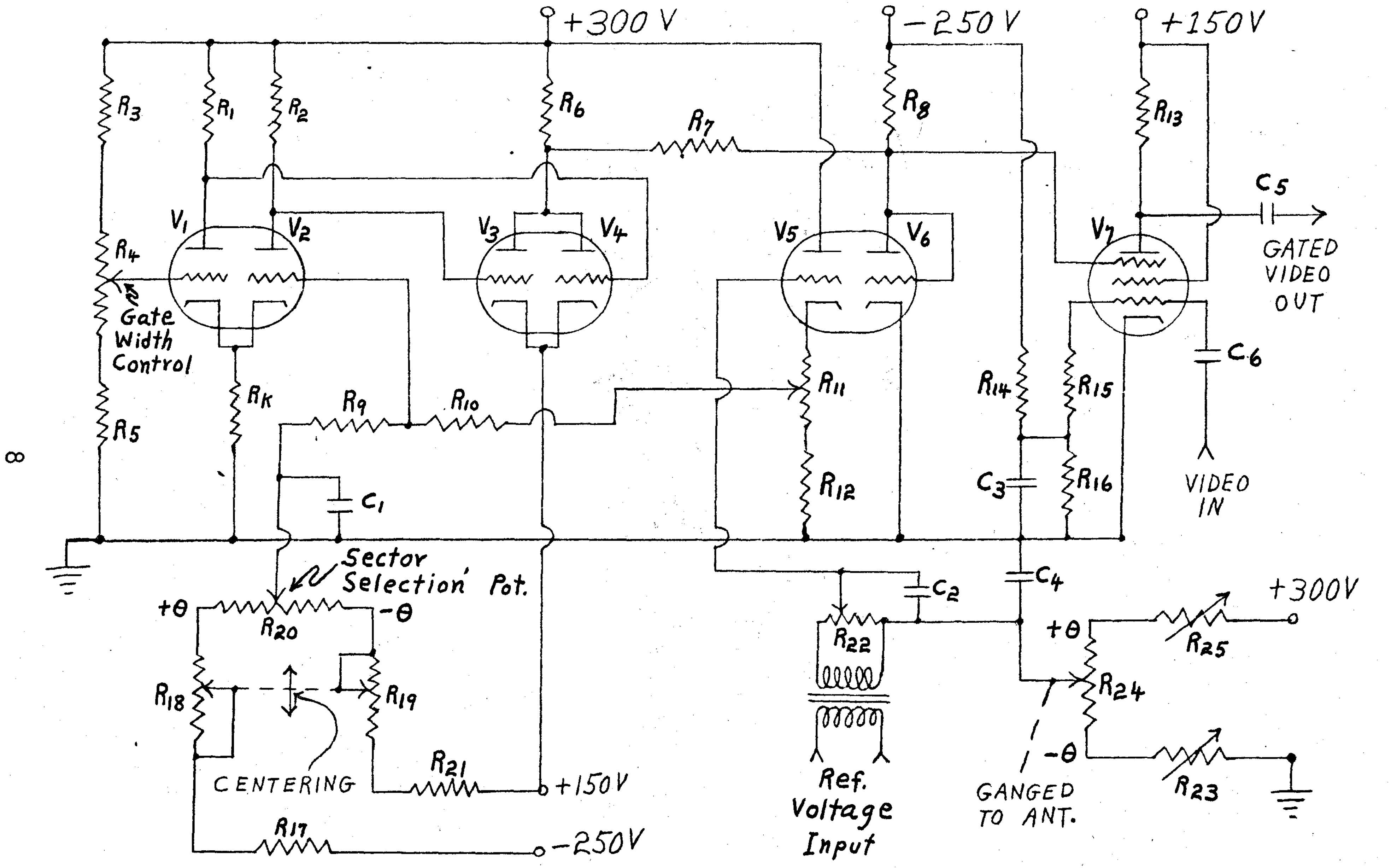


Fig. 3

Typical azimuth gating circuit

2. An analytical study of the gating amplifier.

The circuit of the gating amplifier is shown in Fig. 4. This is a cathode coupled phase inverter with the signal input e applied to the grid of V_2. We get push-pull output e_1 and e_2 because of the common cathode resister R_k.

The equivalent circuit of the gating amplifier is shown in Fig. 5. The arrows in the circuit indicate positive directions of current or voltage. In other words, if we assume the input signal e to be positive, and then find that e_2 is a negative quantity, this means that the plate voltage e_2 is 180° out of phase with the input signal to the grid which is what we would expect in a resistance loaded vacuum tube amplifier, if we neglect lead inductance and stray capacity. We are neglecting all lead inductance, stray and interelectrode capacities, in the analysis of this circuit because of the very low frequencies involved.

The voltages and currents indicated in the analysis of this circuit are only the AC components of the total instantaneous values. It will be pointed out later in this chapter that the DC levels about which these AC components operate are very important in the overall operation of the azimuth gating circuit.

The circuit will be solved by assuming that we have a pure resistance load and that we are operating with small signals within the linear portion of the tube's characteristics.

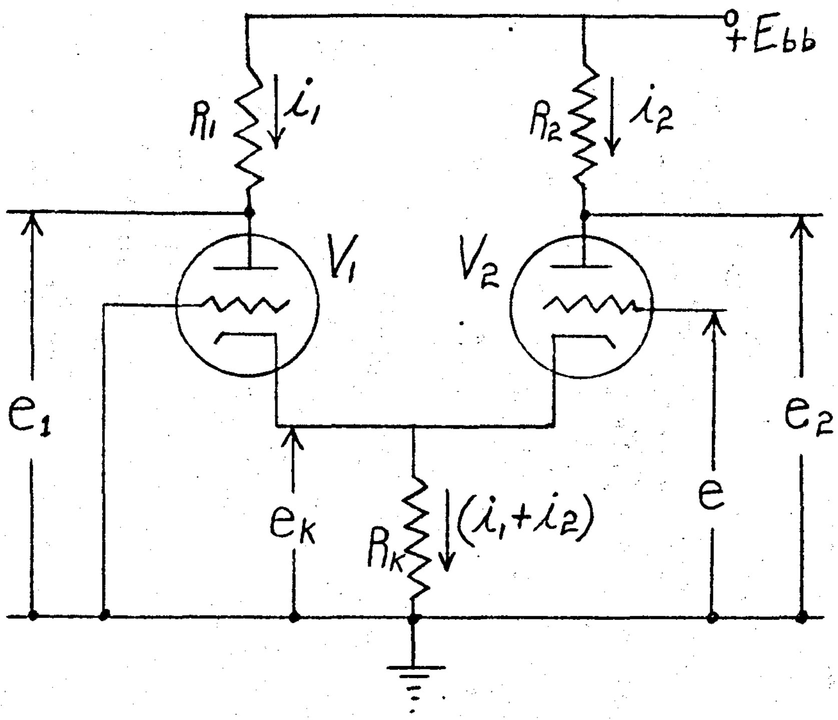


Fig. 4

Gating amplifier circuit

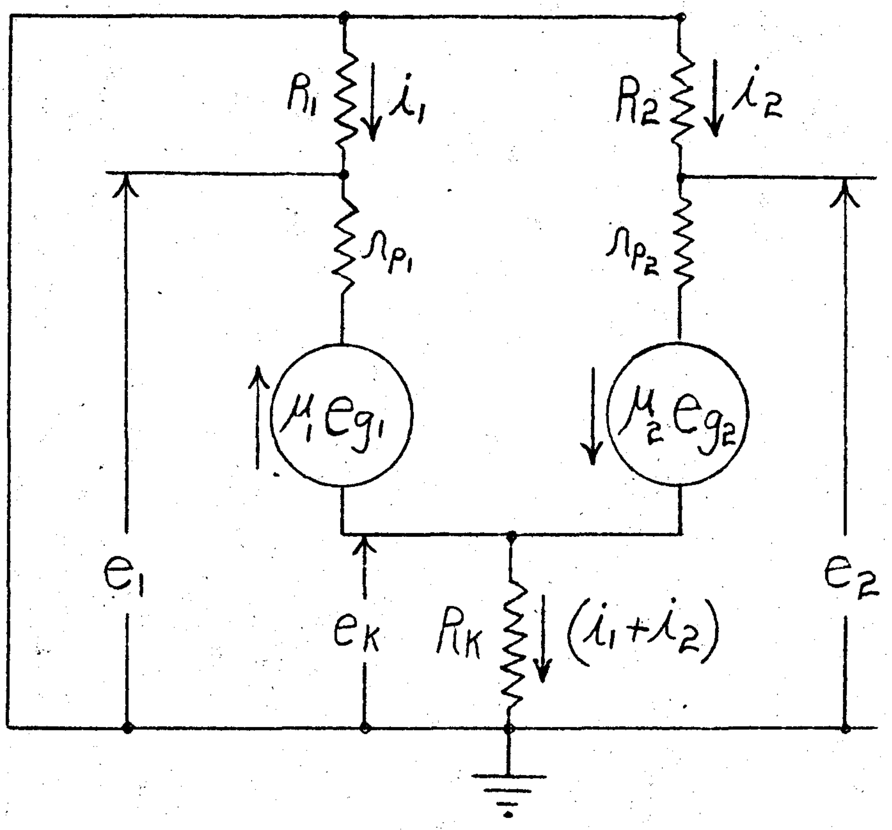


Fig. 5

Gating amplifier equivalent circuit

$$e_{g2} = e - e_K = e - (i_1 + i_2)R_K \qquad (1)$$

$$e_{g1} = -e_K = -(i_1 + i_2)R_K \qquad (2)$$

Now writing the loop equations of the equivalent circuit we get:

$$(i_1+i_2)R_K - \mu_2\left[e-(i_1+i_2)R_K\right] + i_2(R_2 + r_{p2}) = 0 \qquad (3)$$

$$(i_1+i_2)R_K + \mu_1(i_1+i_2)R_K + i_1(R_1 + r_{p1}) = 0 \qquad (4)$$

Rearranging equation (3) we get:

$$i_1 = \frac{-i_2\left[(\mu_2+1)R_K + (R_2 + r_{p2})\right] + \mu_2 e}{(\mu_2+1)R_K} \qquad (5)$$

Rearranging equation (4) we get:

$$i_2 = \frac{-i_1\left[(\mu_1+1)R_K + (R_1 + r_{p1})\right]}{(\mu_1+1)R_K} \qquad (6)$$

Substituting i_1 from eq.(5) into eq.(6) gives:

$$i_2 = \frac{\mu_2 e\left[(\mu_1+1)R_K + (R_1 + r_{p1})\right]}{(\mu_2+1)(R_1+r_{p1})R_K + (\mu_1+1)(R_2+r_{p2})R_K + (R_2+r_{p2})(R_1+r_{p1})} \qquad (7)$$

$$e_2 = -i_2 R_2 \qquad (8)$$

$$e_2 = \frac{-\mu_2 e R_2\left[(\mu_1+1)R_K + (R_1 + r_{p1})\right]}{R_K\left[(\mu_2+1)(R_1+r_{p1}) + (\mu_1+1)(R_2+r_{p2})\right] + (R_2+r_{p2})(R_1+r_{p1})} \qquad (9)$$

Define the gain of V_2 as,

$$N_2 = \left|\frac{e_2}{e}\right| \qquad (10)$$

$$N_2 = \frac{\mu_2 R_2\left[(\mu_1+1)R_K + (R_1 + r_{p1})\right]}{R_K\left[(\mu_2+1)(R_1+r_{p1}) + (\mu_1+1)(R_2+r_{p2})\right] + (R_2+r_{p2})(R_1+r_{p1})} \qquad (11)$$

Now if: $(\mu_1 = \mu_2 = \mu)$ & $(r_{p1} = r_{p2} = r_p)$ & $(R_1 = R_2 = R)$,

$$N_2 = \frac{\mu R\left[(\mu+1)R_K + (R+r_p)\right]}{2(R+r_p)\left[(\mu+1)R_K + \frac{(R+r_p)}{2}\right]} \qquad (11\text{-}1)$$

and further if $\mu R_K \gg (R+r_p)$,

$$N_2 \approx \frac{\mu R}{2(R+r_p)} \qquad (11\text{-}2)$$

Substituting i_2 from eq.(6) into eq.(5) gives:

$$i_1 = \frac{-\mu_2 e R_K(\mu_1+1)}{R_K\left[(\mu_2+1)(R_1+r_{p1})+(\mu_1+1)(R_2+r_{p2})\right]+(R_2+r_{p2})(R_1+r_{p1})} \tag{12}$$

$$e_1 = -i_1 R_1 \tag{13}$$

$$e_1 = \frac{\mu_2 e R_K R_1(\mu_1+1)}{R_K\left[(\mu_2+1)(R_1+r_{p1})+(\mu_1+1)(R_2+r_{p2})\right]+(R_2+r_{p2})(R_1+r_{p1})} \tag{14}$$

Now dividing eq.(14) by eq.(9) we get the amount of unbalance in the output.

$$\left|\frac{e_1}{e_2}\right| = \frac{R_1 R_K(\mu_1+1)}{R_2\left[(\mu_1+1)R_K+(R_1+r_{p1})\right]} \tag{15}$$

and if $R_1 = R_2$,

$$\left|\frac{e_1}{e_2}\right| = \frac{1}{1+\frac{(R_1+r_{p1})}{(\mu_1+1)R_K}} \tag{15.1}$$

3. The gate width control.

Before we discuss the operation of the gate width control R_4, a general understanding of how the gating circuit operates should be known. The waveforms given in Fig. 6 are those of the gating amplifier with the antenna moving back and forth at a linear rate between the limits of $+\theta$ and $-\theta$.

In order for the circuit to operate at all, the bias of the gating amplifier and the azimuth gating tube must be adjusted such that when the grid voltage of V_1 is equal to the grid voltage of V_2, the grids of V_3 and V_4 are below cutoff. If the grid of V_2 rises, the grid of V_3 goes farther into cut-off causing no effect but the grid of V_4 will rise and when it reaches cut-off the plate will fall, causing the gate to close. Now if we go back to the initial condition and assume the grid of V_2 falls, the grid of V_4 goes farther into cut-off but the grid of V_3 will rise above cut-off, thus causing the gate to close.

The waveforms of Fig. 6 illustrate what happens when the gate width control is changed. E_1 represents a DC voltage level set by the gate width control. The waveforms shown in Fig. 6 are those we would get with the sector selection potentiometer set in the center and with the centering control properly adjusted. E represents the cut-off value of the azimuth gating tube and the gate is open when both e_1 and e_2 are below E. With the gate width control set at E_1 we get a gate width δ. If we raise the

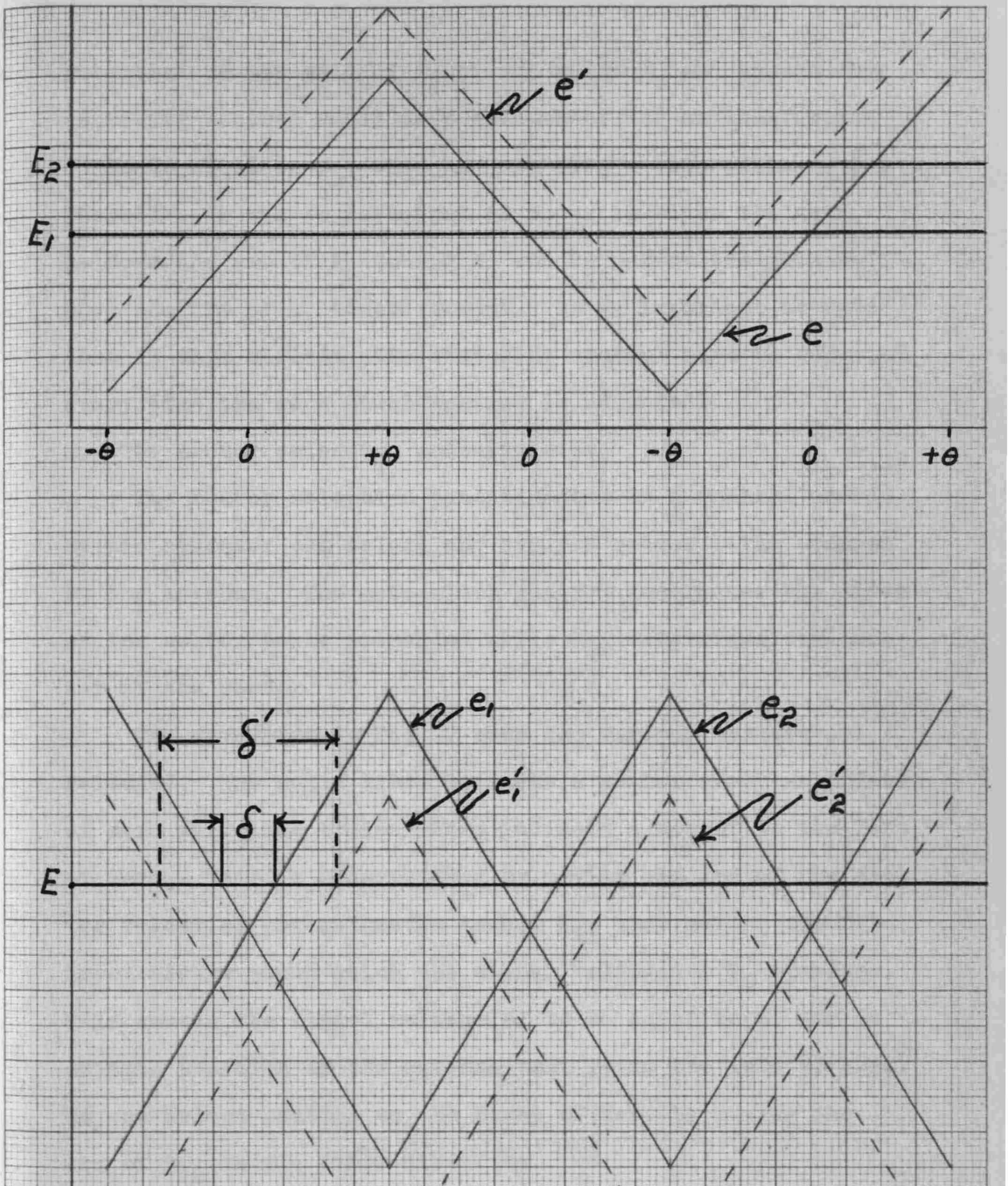


Fig. 6

Effect of gate width control on waveforms potential of the grid of V_1 to the value E_2 and adjust the centering control until zero azimuth of the antenna causes e' to be equal to E_2, then we will have a gate width of δ'. Therefore it can be seen that in order to widen the gate, we move the arm of R_4 toward R_3 and to narrow the gate we move the arm of R_4 toward ground. It is important to note that in this circuit, the centering control must be adjusted every time the gate width control is adjusted.

4. The sector selection potentiometer.

The sector selection potentiometer is a control whereby the operator can select any desired sector being scanned by the antenna. The gate width control determines the width of the sector to be presented while R_{20} determines the center of the sector.

The waveforms in Fig. 7 show how various sectors are selected. The solid lines indicate a sector about an azimuth of zero while the broken lines indicate a sector to the left of zero. This is accomplished by moving the arm of the sector selection potentiometer toward R_{19} thus making the DC level higher about which the signal voltage to V_2 operates. This causes the signal voltage e' to be equal to E_1 for an azimuth position of the antenna that is to the left of zero. We can select sectors to the right of zero by moving the arm of R_{20} in the other direction.

5. The use of a more complex antenna scanning system.

The circuit shown in Fig. 3 will also accommodate a more complex scanning system than the one represented in

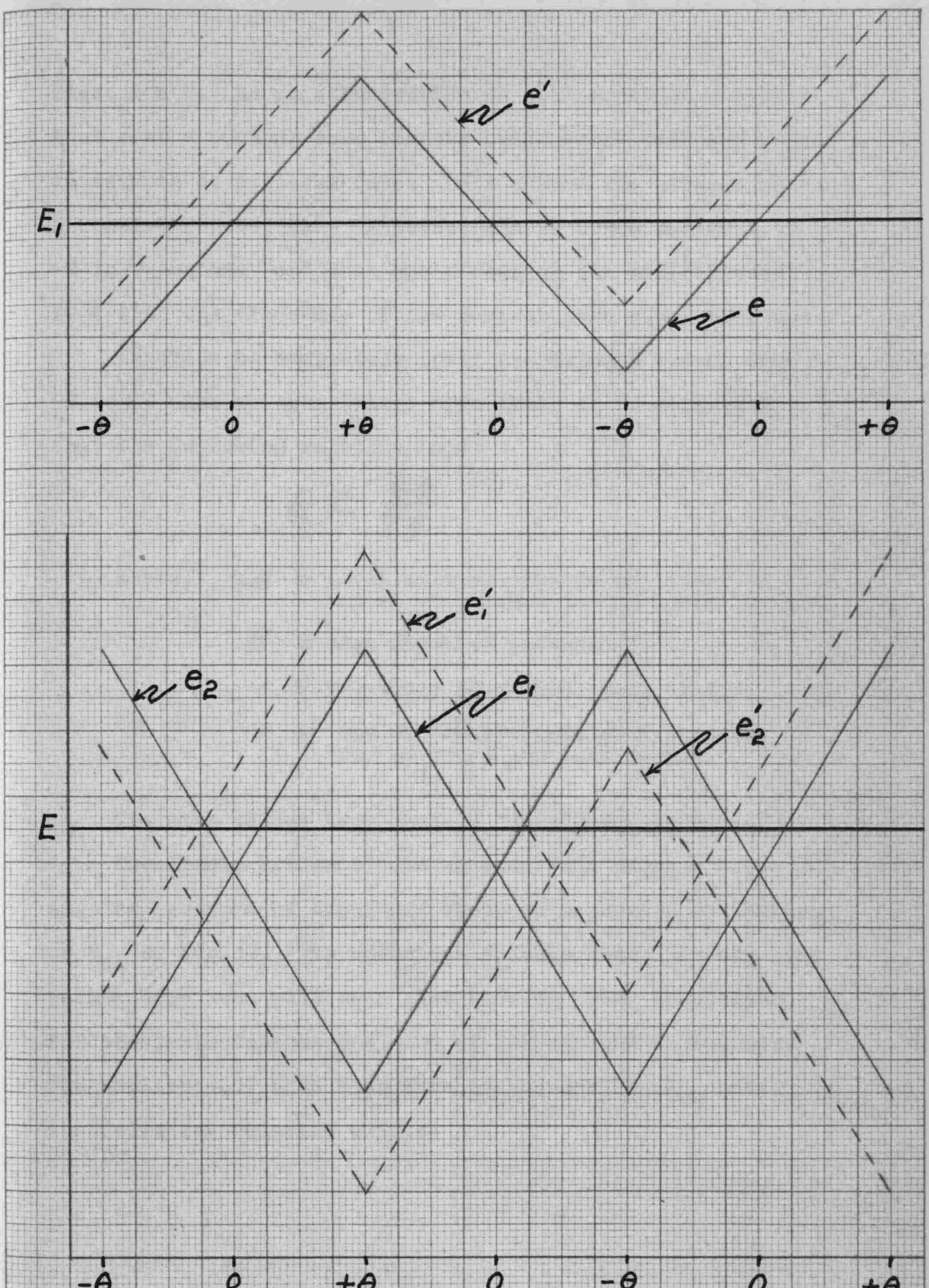


Fig. 7

Effect of centering control on waveforms

Figs. 6 & 7. As an illustration we will consider a system that uses a conical scan that is being swept back and forth in azimuth at a linear rate. Lets assume the antenna makes a complete cycle, that is moves from $-\theta$ to $+\theta$ and back to $-\theta$ in T seconds, and that the offset of the conical scan is α with the frequency of the conical scan equal to f cps.

In order to completely cover the azimuth sector from $-\theta$ to $+\theta$ with an open palmer type scan, it is necessary that the following relation hold:

$$\beta \geq \frac{4\theta}{Tf}$$

where: 4θ = total azimuth covered by linear motion of antenna in one cycle

β = beam width of antenna

f = frequency of conical scan in cps

T = time of complete cycle of antenna from $-\theta$ to $+\theta$ and back to $-\theta$.

The open palmer type scan is illustrated in Fig. 8.

The linear motion of the antenna will cause a triangular waveform of amplitude $K\theta$ to be generated at the arm of R_{24} of Fig. 3. The reference voltage input for the open palmer type scan will be a sine wave in order to correct for the instantaneous position of the antenna in azimuth. The amplitude of this sine wave is adjusted by R_{22} until the following relation exists:

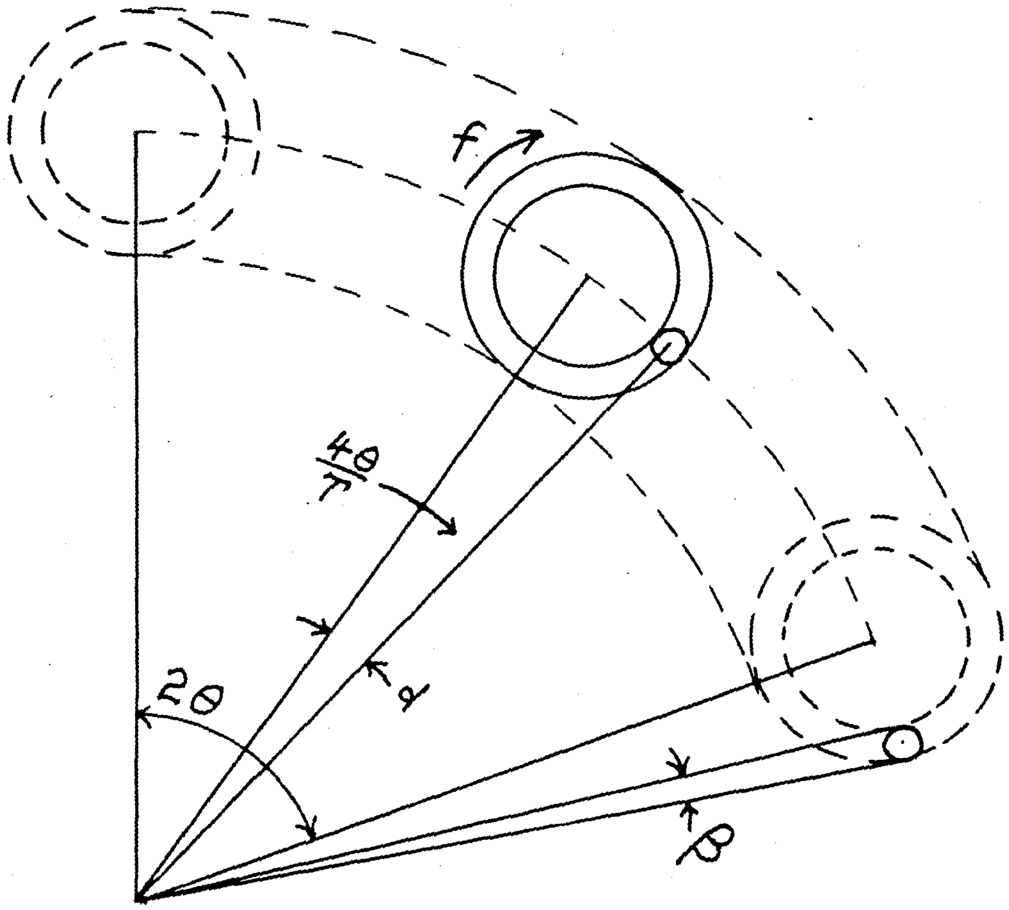


Fig. 8
Open palmer type scan

where: A = amplitude of sine wave reference voltage.

α = number of degrees offset of conical scan.

K = slope of triangular wave in volts/degree.

The input to V_2 is a sine wave superimposed upon a triangular wave when using this type of antenna scanning. Fig. 9 shows a portion of the waveform applied to the grid of V_2 with the resultant azimuth gates to V_7 shown below. The gate width control is set such that B is the voltage range of the grid of V_2 that will allow both grids of the azimuth gating tube V_3 and V_4 to be below cut-off thereby giving open gates during the time that the input to V_2 is within the voltage range represented by B.

It can be seen that the azimuth gates vary in length during any one scan of the antenna. This is because the actual azimuthal position of the antenna varies at a sinusodial rate plus a constant. Fig. 10 represents the longest and the shortest azimuth gate produced with this type scanning system for a particular gate width setting B. The following equations can be used to calculate the maximum and minimum length of gates produced by the circuit:

$$\delta_{max} \approx 2\left[\cos^{-1}\left(\frac{A-B}{A}\right)\right]\frac{1}{360f} \qquad \text{for } A \geq B$$

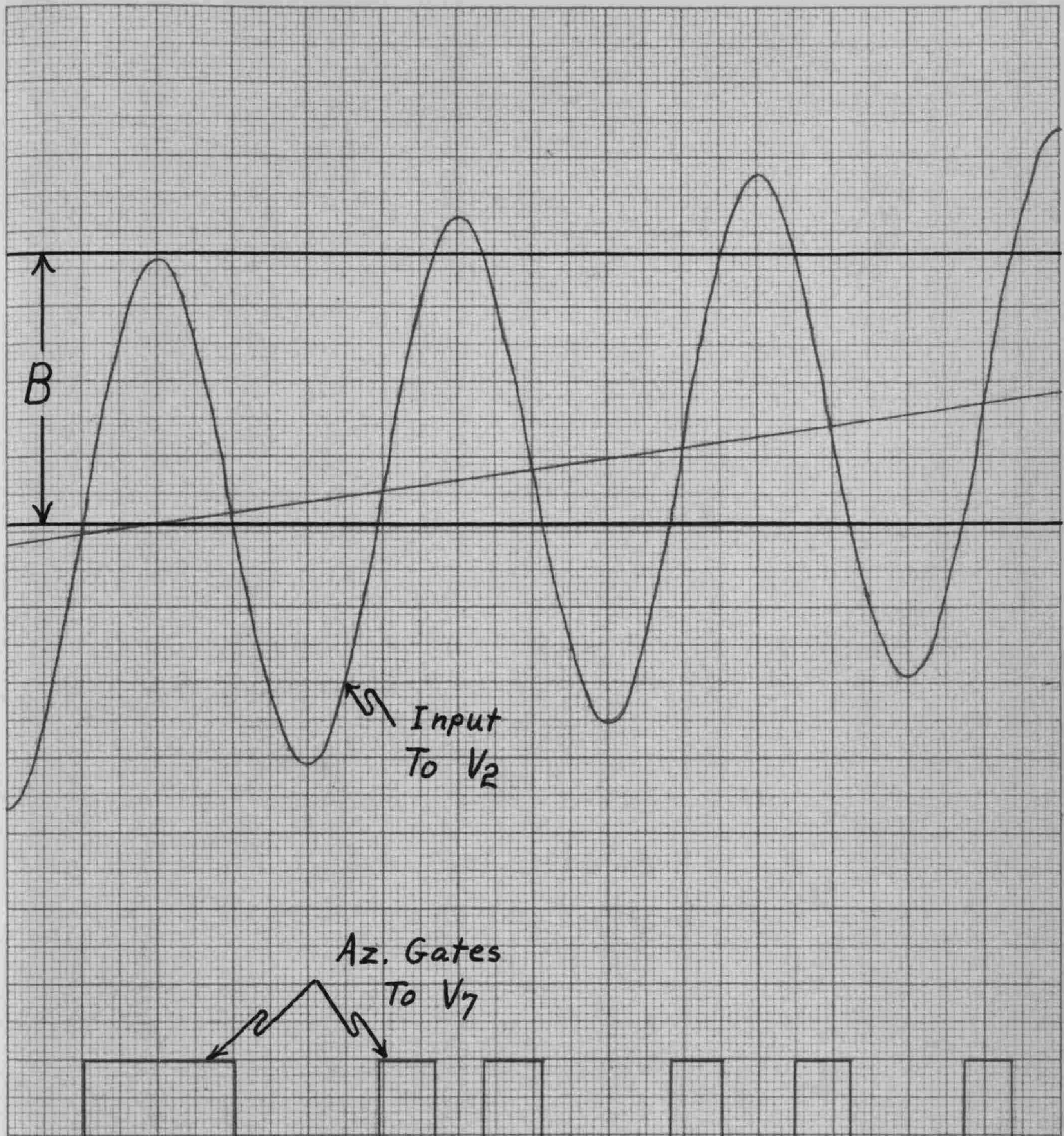
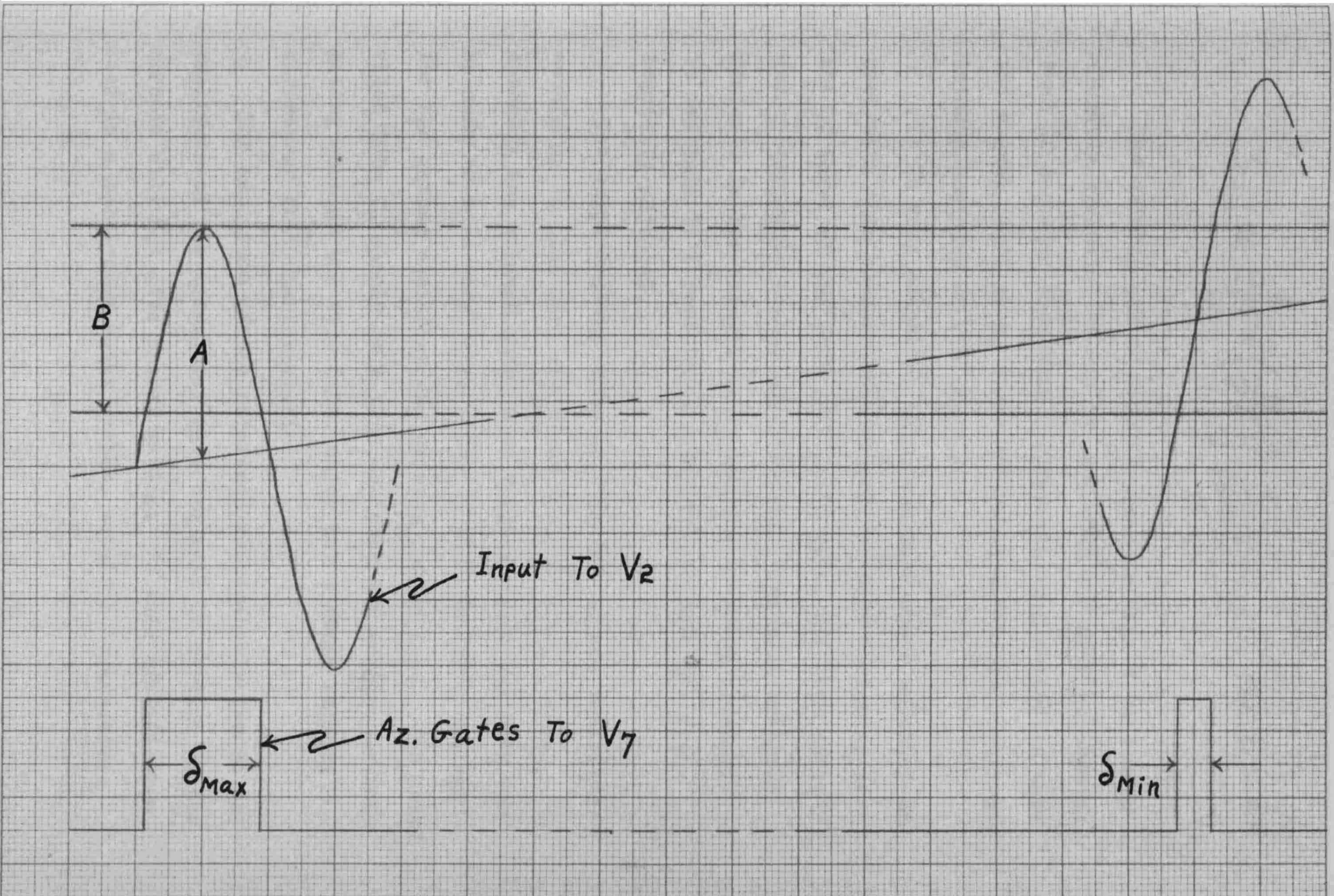


Fig. 9

Typical input waveforms and resultant azimuth gates



Longest and shortest azimuth gates produced

Fig. 10

$$\delta_{Min} \approx 2\left[\sin^{-1}\left(\frac{B}{2A}\right)\right]\frac{1}{360f} \qquad \text{for } B < 2A$$

The azimuth gating circuit shown in Fig. 3 is a very flexible circuit. It can be used with any type of antenna scan if a proper reference voltage can be provided so that the signal input to V_2 is proportional to the instantaneous azimuth position of the antenna.

It is very essential that regulated power supplies be used with this circuit because only a small variation of the DC level at the grid of V_1 will cause the gate width and centering to change considerably. The most critical resistor in the circuit is R_k insofar as being required to maintain it's resistance after the circuit has been initially adjusted.

The azimuth gates drawn in Fig. 9 & 10 are idealized waveforms in that they are shown with vertical sides. Actually the azimuth gates have sloping sides but they can be made to have very steep sides if high mu tubes are used for the gating amplifier and azimuth gating tube. The gated video tube V_7 should be a type designed for suppressor grid gating such as the type 6AS6, which has a sharp cut-off suppressor grid characteristic.

The amplitude of the reference voltage relative to the amplitude of the triangular waveform must be correct or the circuit will not give proper gating. If this circuit were used in a particular radar system, sepcific instructions could be given for initial adjustment of the circuit, however no attempt will be given in this paper.

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