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ANALOG NYSTAGMUS ANALYZER

By

George W. Beeler, Jr., CPT, MSC

December 1967

U. S. ARMY AEROMEDICAL RESEARCH UNIT
Fort Rucker, Alabama

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Rapid to-and-fro movements of the eye are classified as nystagmus. This movement is usually the consequence of reflex exitation of the extra ocular muscles associated with stimulation of the semicircular canals. An analog nystagmus analyzer is described that can produce continuous information concerning the duration, amplitude and slow-phase velocity of each nystagmic beat during experiments involving the vestibular apparatus.

APPROVED: Robert W. Bailey
ROBERT W. BAILEY
LTC, MSC
Commanding

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INTRODUCTION

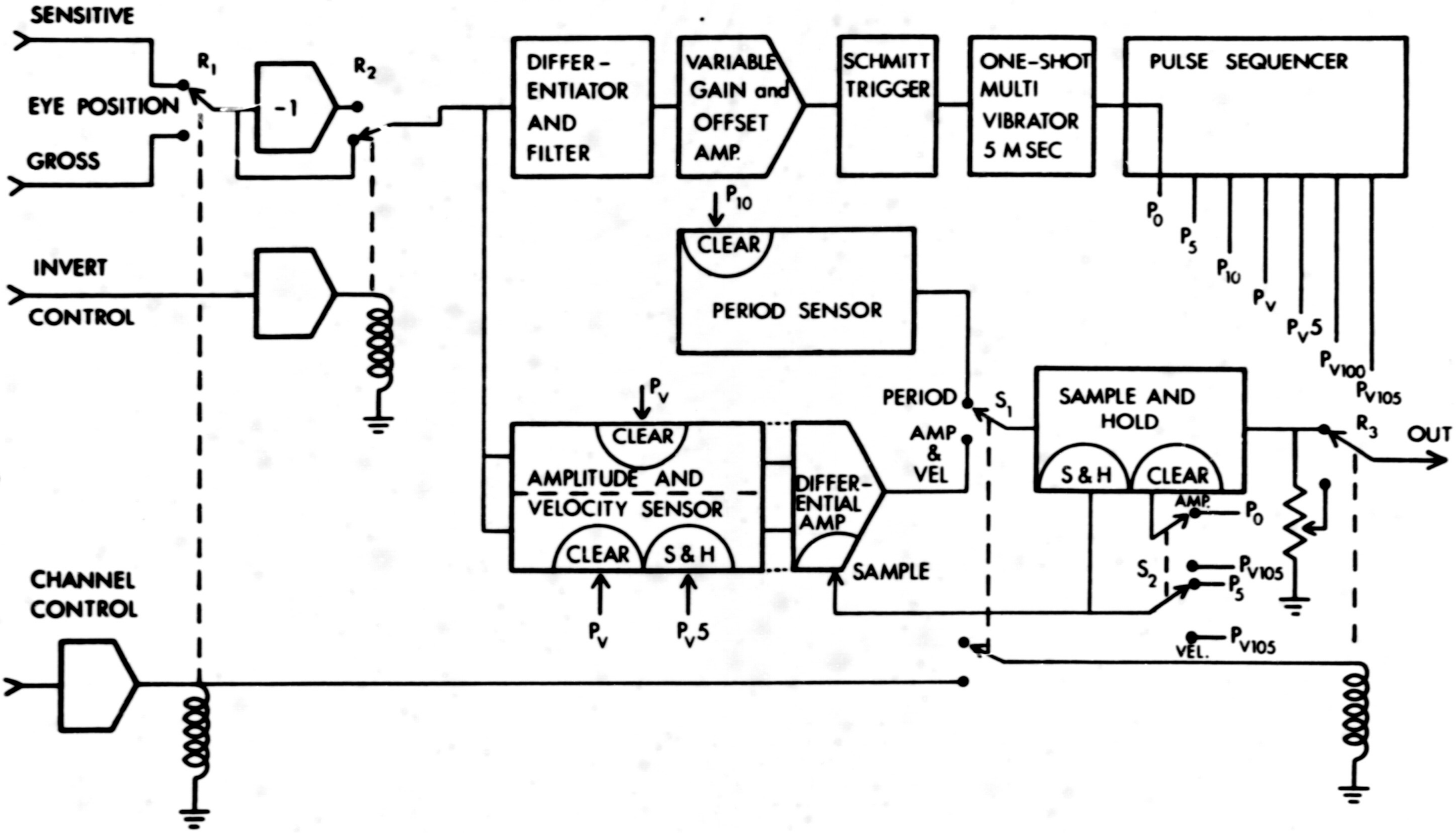
Throughout the world research is being performed on the characteristics of eye movements called nystagmus. Of primary interest to many research investigators, and of particular interest to military research, is the form of nystagmus arising from stimulation of the vestibular end organs. Research effort is frequently devoted to studying the eye movement characteristics which result from given profiles of accelerative input to the human head, because the characteristics of the vestibular nystagmus elicited thereby may be used as a measure of the response characteristics of the vestibular end organs.

Nystagmus can be simply characterized as a "saw-tooth" wave form. The eye movement consists of relatively slow movement in one direction followed by a rapid saccadic eye movement in the other direction. Research which has been done to date has pointed to the fact that the characteristics of interest within a nystagmus record are the amplitude, duration, and velocity of the so-called slow-phase eye movement. In the course of performing an experiment dealing with vestibular nystagmus, an analog nystagmus analyzer was designed and constructed to provide electrical measures of the various slow-phase characteristics in real time. This circuit, which is to be described below, can produce a continuous tract representing either the duration of each nystagmic beat, the overall amplitude of each nystagmic beat, or the slow-phase velocity of each nystagmic beat.

It is the author's opinion that for the majority of the experiments which one might wish to perform involving vestibular nystagmus, this form of analog processing would be beneficial and perhaps sufficient for the requirements of the experiment. The discussion which is to follow is broken down into two general sections. The first of these sections deals with the general design of the analyzer system, and the second section deals with the specific implementation of certain portions of that system.

ANALYZER BLOCK DIAGRAM

Figure 1 shows the block diagram of the analog nystagmus analyzer. Basically, this diagram can be divided into three separate sections. The left-hand side of the diagram shows the switching control which was built into the system to permit the operator to use a more versatile eye position measuring technique. This switching control is not essential to the operation of the analyzer and will be discussed at the end. The second block is the line across the top of the diagram, by which the timing sequence for the operation of the analyzer is determined. The third portion



ANALYZER BLOCK DIAGRAM

FIGURE 1

of this diagram is encompassed in the two-thirds of the diagram on the lower and right-hand sides. This is the heart of the system wherein the analog signals of interest are generated.

Analyzer Sequence Timer.

The primary timing of the nystagmus analyzer depends upon the ability of the electronics to detect the occurrence of the rapid saccadic eye movement which occurs between each of the slow-phase segments of the nystagmus wave form. The portion of the block diagram beginning with the "Differentiator and Filter", and continuing through the "Pulse Sequencer" accomplishes this task. This unit first differentiates the incoming eye position signal in order that the saccadic eye movements will stand out as pulses in the resulting wave form. Following the simple capacitor differentiator is a third-order, low-pass filter which cuts off at 40 Hz. This filter is included to minimize the effect of eye tremor and measuring system noise. The output of this differentiator-filter goes into an amplifier in which the experimenter can adjust both the gain and the offset in order to be assured of detecting only the saccadic eye movements. The output of this circuit then goes into a "Schmitt Trigger" where the peaks in the differentiated wave form are detected. The pulse output of the "Schmitt Trigger" is shaped by a 5 msec one-shot multivibrator. The resultant pulse is the first of a string of seven pulses which the "Pulse Sequencer" produces, and is known as P0.

The "Pulse Sequencer" consists of a series of one-shot multivibrators to produce six pulses subsequent to P0 at fixed positions in time. These pulses are all 5 msec wide, but the polarity of the various pulses differs as will be seen in the following discussion. The labeling of the pulses denotes their time of occurrence. In general, the pulse number gives the time in msec separating P0 and the pulse in question. Pv is a variable period of time after P0, and Pv5 is five msec after Pv. The variable time for Pv is set sufficiently long that the experimenter is assured that it will occur after the end of the saccadic eye movement. The resting level for pulses P0, P10, Pv, and Pv100 is + 6 volts, and they drop to -6 volts for the 5 msec duration of the pulse. Lines P5, Pv5, and Pv105 rest at -6 volts, and rise to +6 volts for 5 msec.

The insertion of these various pulses into the main body of the circuit is indicated by labeled lines on the block diagram. The descriptive function of these pulses is given in the block diagram, but it will remain for the circuit diagram discussion to follow later to explain the precise function of these pulses.

Analog Voltage Generation.

The generation of the various analog voltages to be used is performed by the three blocks labeled "Period Sensor", "Amplitude and Velocity Sensor", and "Sample and Hold". The selection of circuit function is made by two double-pole, double-throw switches. The first of these, S1, selects period measurements on one side and amplitude and velocity measurements on the other side. The Switch S2 selects between period and amplitude on the one hand and velocity on the other hand, and does so by switching timing pulses into both the sample and hold network and the amplitude and velocity sensor.

The "Period Sensor", which is shown switched into the system on the block diagram, consists of a simple capacitor which is continually being charged in a linear fashion. At the end of each nystagmic beat the following sequence of events takes place. First, P0 clears the sample and hold network; then P5 establishes a new sample in the sample and hold network based on the current value of the period sensor; and finally, P10 resets the capacitor which is being charged in the period sensor to zero so that the period of the next nystagmic beat may be timed. In this manner the output of the sample and hold network is always proportional to the period of the preceding nystagmic beat.

The amplitude and velocity sensor is a good deal more complex than the period sensor. In order to understand the operation of this unit, consider it first in the amplitude position. In this instance, Switch S1 is in the amplitude and velocity position, and S2 is in the period and amplitude position. Again, considering the chain of events which follows the occurrence of a saccadic eye movement, one finds that at P0 the sample and hold network is cleared. Secondly, at P5, a new sample is taken through the differential amplifier and held by the sample and hold network. Next, the two pulses Pv and Pv5 reset the amplitude sensor in order to measure the amplitude of the next slow-phase segment. The amplitude sensor consists of two independent channels, both working on the eye position. The upper channel, as shown in the block diagram, is a simple peak follower using a diode and capacitor. At Pv, the beginning of a slow-phase segment, this capacitor is cleared so that it will subsequently retain the maximum positive voltage which the eye position attains. The second half of the circuit is a sample and hold network which is cleared at Pv and sampled at Pv5. Thus the capacitor in this latter network holds the initial value of the slow-phase segment of the eye movement. The resulting difference between the upper and lower halves, then, is always proportional to the difference between the maximum value attained by the eye position and the value at the beginning of the slow-phase segment. Thus when the sample and hold network samples this difference at the next P5 it reads a close approximation to the amplitude of the preceding best.

The detection of slow-phase velocity is very similar to the measurement of nystagmus amplitude, but employs a fixed interval of time rather than measuring the total amplitude of the eye movement. Thus with Switch S2 in the velocity position, the sample and hold network is cleared and reset 100 msec after the two halves of the velocity sensor are reset. The measurement then corresponds to the amplitude over a 100 msec interval. If one assumes that the slow-phase velocity is relatively constant over a single nystagmic beat, then the output of this circuit is proportional to the slow-phase velocity of the nystagmic beat.

Switching System.

In order to maintain a greater degree of versatility with the system described immediately above, a series of relays was provided to give the experimenter automatic control over the input variable. Basically, there are two forms of control. The simplest of these is the inversion control, where, by activating the amplifier which drives relay R2, the signal being processed by the analyzer may automatically be inverted. The description given above cites a technique by which a nystagmus wave form may be analyzed, but this system works only if the nystagmus is recorded such that the slow-phase segments of the nystagmus are positive-going voltages, and the saccadic correction movements are negative-going. In the majority of experiments, the direction of nystagmus will reverse at some point and it will therefore be necessary to invert the wave form into the analyzer at this point in time. Accordingly, a control track can be used to drive the inversion relay at the appropriate times in order to provide for a positive-going slow-phase segment at all times.

The second half of the switching system permits the experimenter to use two different eye position sensors. Experience at this laboratory showed that nystagmic eye movements in the dark could readily be recorded by using the electroretinographic (ERG) technique. When the nystagmus was being measured in a lighted environment, however, the ERG technique was not sufficiently sensitive to detect the nystagmic eye movements. For this reason, many of the experiments involved two sets of sensors. One was the ERG system, to provide a gross measure of the eye movements, when the subject was in the dark, and the second system involved photo-electric tracking of the subject's iris. This latter system, while it is much more sensitive than the ERG system, will generally be saturated by the large eye movements which take place in the dark. Accordingly, provision was made to bring both of these eye position transducers into the analyzer, and select them using the channel control relays R1, and R3. R1 simply selects which channel is driving the total analyzer system. R3 is designed to scale the amplitude and velocity outputs such that the output record obtained from the whole system can be calibrated with a single number in terms of volts per degree. The potentiometer on the output of the sample and hold network is adjusted to represent the difference in sensitivity between the gross eye position system and the sensitive eye position measuring system. Note that when measuring the period of the wave form, no such attenuation of the output signal is desired, and therefore Switch S1 is included in the drive line to relay R3 in order to prevent the attenuation of the output signal during use of the period sensor.

INDIVIDUAL CIRCUIT DIAGRAMS

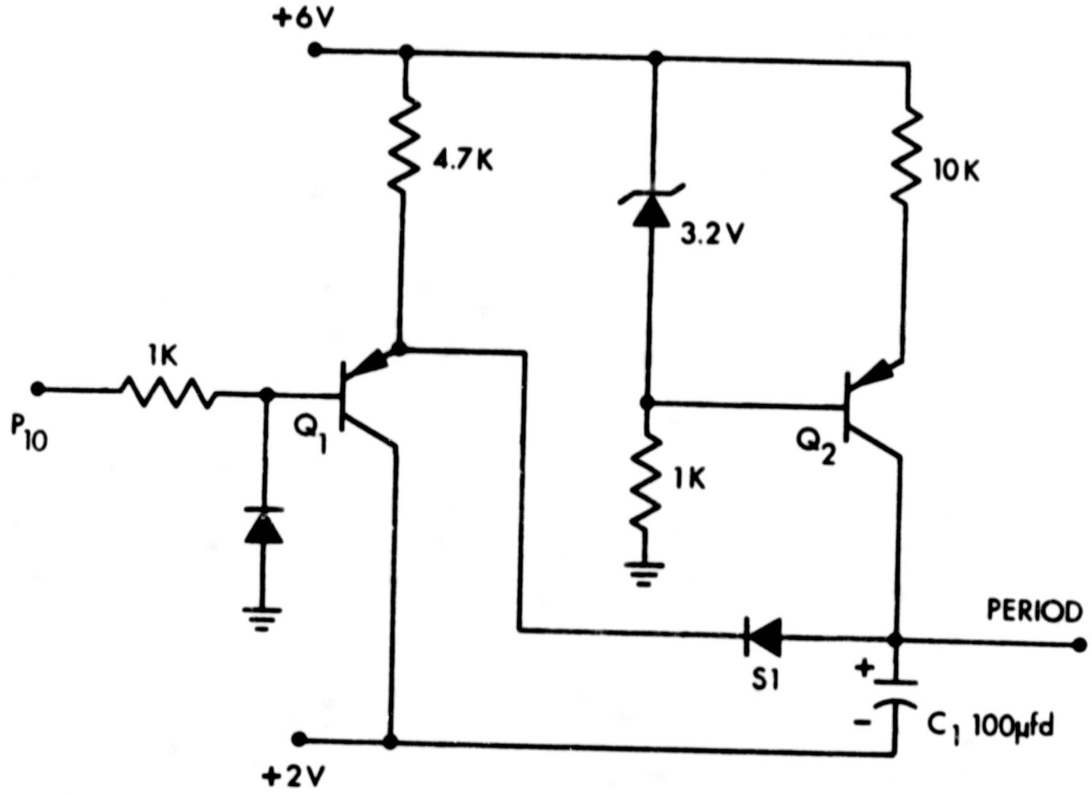
The majority of the circuits used within this system are standard designs, and these designs will not be discussed in any great detail. For instance, the whole of the pulse generation string is made up of simple amplifiers and digital circuits. The pulse sequencer itself is simply a string of one-shot multivibrators with inverters on the output where necessary to provide the proper polarity pulses. The circuits which are of interest, however, are those which involve the two sensors, and the sample and hold network. Although these circuits were made up entirely of discrete components, it is recommended that a re-design utilizing integrated circuits would provide better characteristics in terms of the decay time on the various capacitors which are holding the voltages of interest. Nevertheless, the circuit as described below has been tested and functions satisfactorily for a normal experimental regime.

Period Sensor.

Figure 2 shows the network which was used to measure the period of the nystagmic beats. The capacitor, C1, at the left of this diagram is continually charged by the constant current generator represented by Q2 and the Zener diode which drives that transistor. Everytime a saccadic eye movement is detected, the pulse P10 acts through transistor Q1 to discharge capacitor C1 back to a zero level. The line representing P10 normally rides at +6 volts, holding transistor Q1 off. However when the pulse arrives, P10 goes to -6 volts and the base of Q1 is clamped to ground by the diode. At this point, capacitor C1 is discharged through the silicon diode and transistor Q1 back to a zero volt level, preparatory to being recharged at a constant rate through Q2.

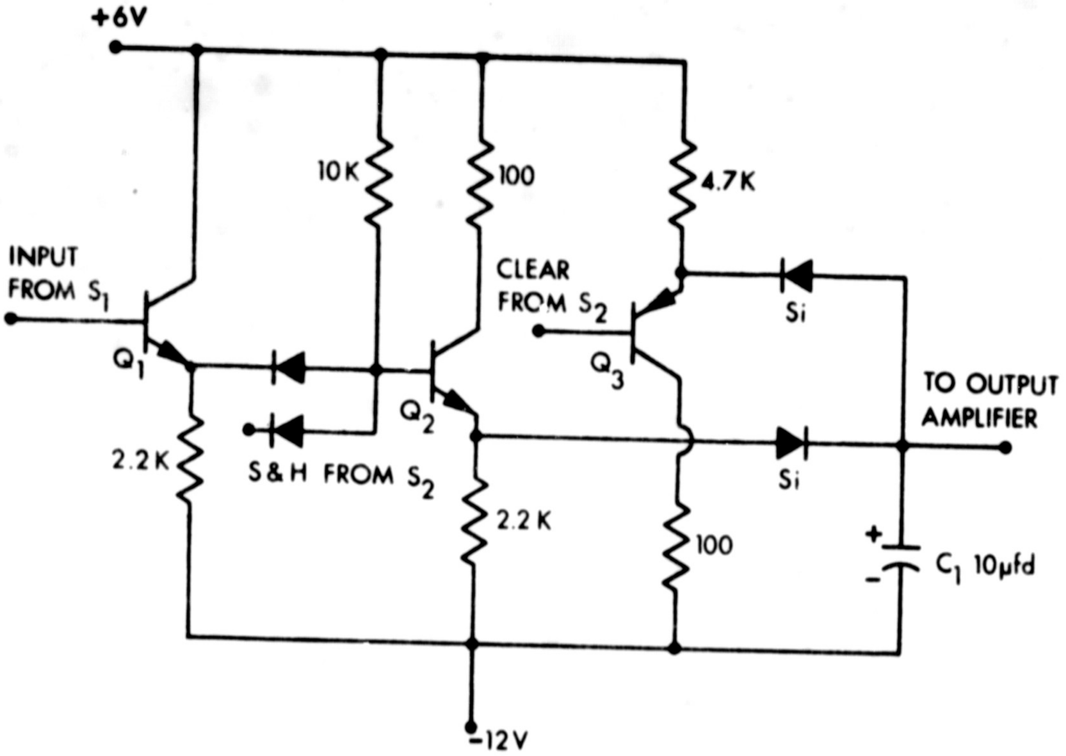
Sample and Hold Network.

Figure 3 shows the sample and hold network which is used in this apparatus. The input to this network comes from Switch S1 in the block diagram, and represents the present output level of the appropriate sensor. Capacitor C1 on the left of this diagram is the capacitor which holds the voltage of interest until the next sample is made. As was noted earlier, the timing of the clear, and sample-and-hold functions is determined by Switch S2. The clear line from Switch S2 normally rides at +6 volts,



PERIOD SENSOR

FIGURE 2



SAMPLE AND HOLD

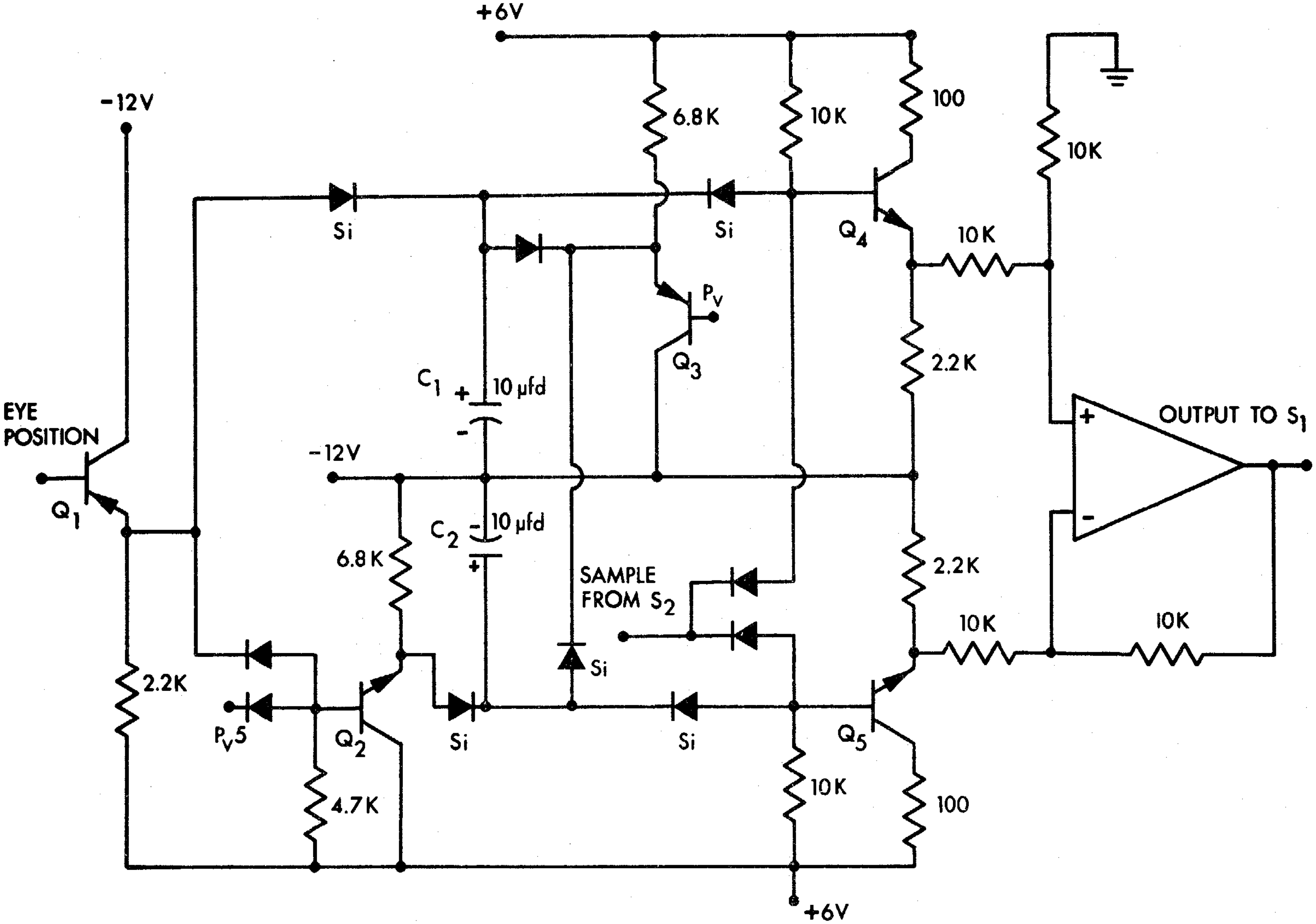
FIGURE 3

holding transistor Q3 off and therefore not affecting the voltage on capacitor C1. However when the clear pulse arrives, this line drops to -6 volts and capacitor C1 discharges through the silicon diode and transistor Q3. The sample and hold input to this circuit, which is connected via a diode to the base of Q2, normally rides at -6 volts. In this position, transistor Q2 is held off, and capacitor C1 is thereby effectively isolated from all other circuit components. However when the sample and hold pulse arrives, this input rises to +6 volts, and enables the transmission of the input signal through Q1 and Q2 to the sample and hold capacitor, allowing it to charge up to the current value of the input voltage.

Amplitude and Velocity Sensor.

As described above, the only difference between the detection of slow-phase amplitude, and slow-phase velocity is the timing of the sample pulses to the sample and hold network. Accordingly, the description which follows is independent of whether or not amplitude or velocity is being detected. Figure 4 shows the complete amplitude and velocity sensor. The input to this circuit is the eye position signal taken from relay R2. This voltage passes initially through a simple emitter follower represented by transistor Q1 in order to isolate the eye position transducers from the amplitude and velocity sensor. The location of the circuit elements on this circuit diagram correspond to the two halves of the sensor as shown in the block diagram of Figure 1. The upper segment is the peak follower which consists of a silicon diode charging capacitor C1. Pulse Pv normally rides at a +6 level, holding transistor Q3 off and therefore not affecting the capacitor C1. At the time of occurrence of the pulse Pv, this line goes to a -6 volts, thereby discharging capacitor C1 through Q3. When Pv is over, the circuit returns to its normal configuration and capacitor C1 tracks the most positive voltage input by the eye position transducers.

The lower half of the circuit diagram corresponds to another sample and hold network where the voltage being held is on capacitor C2. At time Pv, this capacitor is cleared in exactly the same manner that capacitor C1 is cleared. Pulse Pv5 normally rests at -6 volts, thereby holding transistor Q2 off and isolating capacitor C2. When the sample and hold signal appears at Pv5 however, this line rises to +6 volts permitting the eye position signal to be transmitted through transistors Q1 and Q2 to charge capacitor C2. In order to prevent the load of the output differential amplifier from discharging capacitors C1 and C2, it was necessary to provide another diode network to isolate these capacitors at all times when their value was not being sampled by the sample and hold network. The sample signal from Switch S2 accomplishes this purpose. This sample voltage is normally negative, thus holding the base of transistors Q4 and Q5 negative and isolating the two capacitors via the silicon diodes. At the appropriate sample pulse time this voltage rises to +6 volts permitting the emitter followers, Q4 and Q5, to read the capacitor voltages. The outputs of these



AMPLITUDE AND VELOCITY SENSOR

FIGURE 4