The variable stimulus arc: logic-driven light-emitting diodes for instantaneous stimulation of saccadic refixational eye movements*

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Abstract—*The mechanical features, electronics, and functional capabilities of the variable-stimulus arc are presented. The arc is a useful tool for studying saccadic refixational eye movements under a variety of experimental conditions.*

Keywords—*Visual stimulus arc; Saccadic eye movement stimulation, Saccadic latency, Saccadic duration, Step and pulse-step stimuli*

Introduction

SACCADES are rapid eye movements utilised to shift visual fixation from one object to another. Various aspects of saccadic refixations have been studied, including latency (SASLOW, 1967*b*; BARTZ, 1962), velocity–amplitude relationships (HYDE, 1959), accuracy (BECKER and FUCHS, 1969, and WEBER and DAROFF, 1972) and responses to pulse-step stimuli (WHEELESS *et al.*, 1966). Quantitative studies of saccadic eye movements require refixation stimuli with precise characteristics that can be varied by the experimenter. We have designed and constructed a variable-stimulus arc for the study of human saccadic eye movements. The arc provides exact target position, time of onset, duration, and time of extinction of the refixational stimuli. Physically it is equivalent to the 'illuminated perimeter', familiar to ophthalmologists and first described by MILES (1939). However, its utility as a research tool lies in its electronics which allow for programming of the time sequence and durations of target displays.

The ideal stimulus for eliciting a refixation saccade must present a step change in target position in zero time. More practically, this target repositioning should occur in an interval of time that is small compared with both the saccadic latency (200 ms) and the saccadic duration (10–120 ms). The electromechanical time constant of the driving equipment, which moves the light spot, must be made sufficiently small to meet the above criteria.

Another method of stimulating the refixation saccade involves the simultaneous extinction of one target and the illumination of another. Here, the limiting factors are the turnoff time of the first target, the turn-on time of the second, and the switching speed of the activating circuitry. Since this latter consideration is obviated with modern high-speed solid-state circuitry, the transient responses of the illumination sources are the critical factors. If the turn-on time is less than the turnoff time, there will be an interval during each transition when both sources will be illuminated. If, conversely, the turn-off time is less than the turn-on time, there will be an interval when neither target is visible. The effects of the above situations on saccadic latency have been reported by SASLOW (1967*a*). Our variable-stimulus arc resolves these difficulties by the use of light-emitting diodes (l.e.d.s), with transient times in the nanosecond range, and solid-state logic to provide the required switching speed and function-generation capabilities. The array of l.e.d.s around an arc minimises vergence changes which might accompany a refixation between targets on a plane surface.

Construction

Mechanical

The mechanical structure of the variable-stimulus arc is of rugged lightweight design and is constructed primarily of 6061–T6 aluminum. The arc cross-section configuration consists of an open box with a 13 mm aluminum base plate and 6 mm thick vertical supports and top plate (Fig. 1).

The viewing arc is a 1·6 mm thick aluminum sheet 140 mm in height, formed by the box frame into a 1120 mm radius front-surfaced arc. There are 29 1 mm diameter holes, positioned symmetrically about the datum centre line (central fixation point) formed by the centre hole which bisects the arc. They are located horizontally to within 0·013 mm and each is positioned to within ±45 s of arc. There are ten holes at 1° increments typically from the datum

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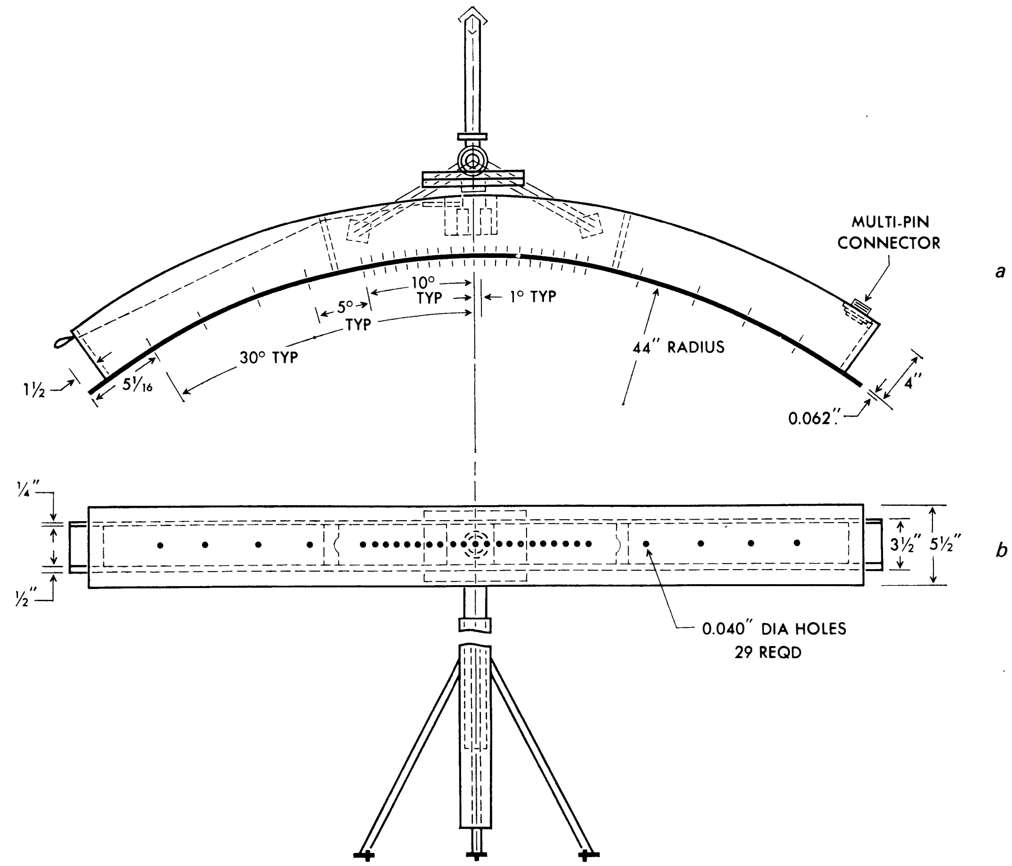


Fig. 1 Mechanical drawing showing construction of variable stimulus arc
a *top view* b *front view*

hole and additional holes are located typically on the same horizontal plane at 15°, 20°, 25° and 30°. The arc pivots on a 25mm i.d. dual-annular-race ball bearing and can be rotated from the horizontal to 30°, 45°, 60° and 90° by engaging a spring-loaded index pin.

Red l.e.d.s are used as the light stimulus and are assembled on a Z bracket permanently held by epoxy resin. Careful hand working all rivet heads ensures that no surface deviation exists in the light-stimulus area that could affect the eye movements. A tripod stand, fabricated from steel, supports the entire arc assembly and allows 460 mm of vertical adjustment. The tripod feet incorporate levelling screws. The entire arc assembly is sprayed with flat black paint to eliminate glare and visual cues.

Electronics

The circuitry for the stimulus arc control is provided by a specially designed 3-output programmable sequence generator. As shown in Fig. 2, the sequence generator consists of a 2 bit binary counter (FF_1 and FF_2), four decoding gates (A_1–A_4), three delay generators (D_1–D_3), and feedback logic (A_5, A_6, A_7, and 0_1). Provisions are made for resetting, stopping, and manually interrupting the sequence.

The operation of the sequence generator is as follows: initially, FF_1 and FF_2 are cleared, causing $\bar{Q}_1$ and $\bar{Q}_2$ outputs to be at logical 1 and A_1 output at logical 0.This condition starts delay generator D_1, which will produce a pulse at time t_1 later. This pulse will be passed by gates 0_1, A_5 and A_6 to the clock input of the binary counter advancing it to its next state. The next state causes the output of A_2 alone to go low, thereby starting delay generator D_2, which will fire at a time t_2 later. The pulse from D_2 will be passed by gates 0_1, A_5 and A_6 as before and it will advance the counter to its next state. This next state will cause one of two events depending upon the position of switch S_1. If the switch is set to the pulse-step position, the output of A_3 will start D_3 and the sequence will be advanced as before. This time, however, the output of A_4 alone will go low, causing A_7 to go to logical 1 and reset the binary counter. If, on the other hand, the switch is in the pulse position, the output of A_3 will cause A_7 to reset the binary counter and restart the sequence.

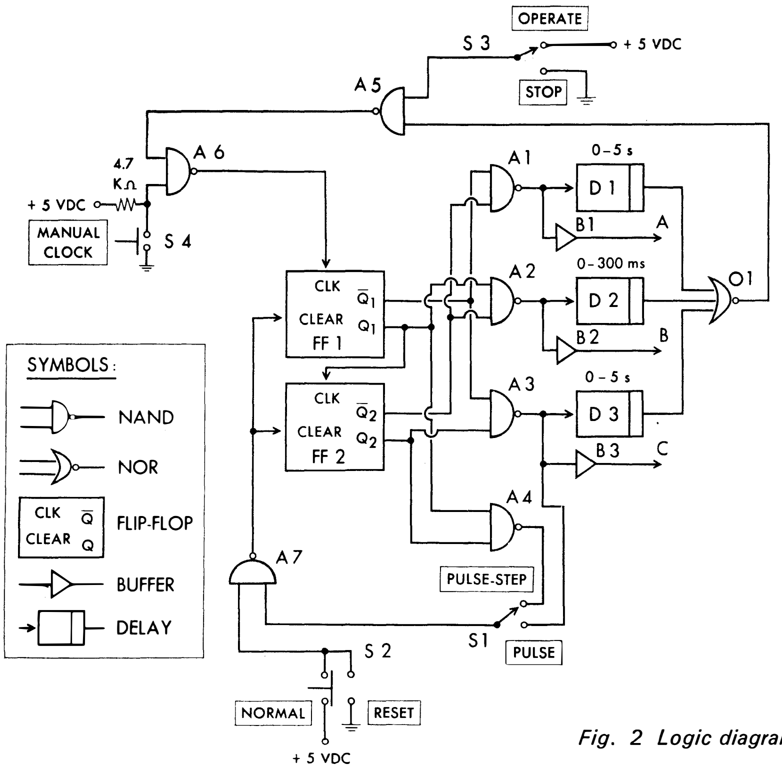


Fig. 2 Logic diagram of control electronics

The outputs of A_1, A_2 and A_3 are connected to buffers B_1, B_2 and B_3, respectively. The output A will be low for a time equal to the delay t_1 of D_1, the output B will be low for a period of time equal to t_2 and the output C will be low for t_3 for those modes when D_3 is used. The delay of each generator is controlled manually by the operator, as will be evident from the discussion of the delay circuitry.

To turn on any desired combination of l.e.d.s in the arc, a set of 6-position rotary switches, one for each of the l.e.d.s in the instrument, is provided (Fig. 3). Positions 1 and 6 turn the l.e.d. off, position 2 turns the l.e.d. on, positions 3, 4, and 5 connect the corresponding l.e.d. to outputs A, B, and C of the sequence generator, respectively. In this way, a large number of target stimuli can be obtained. Provision is made to monitor externally the transition instants by inclusion of the transformer and diode circuitry shown on the positive supply line to the l.e.d.s. The delay generator of Fig. 4 is the same type used in an on-line arrhythmia-monitoring system and was chosen for its accuracy and reliability (DELL'OSSO, 1973).

Transitor–transitor logic (t.t.l.) is used throughout except for one discrete NOR gate (01), which is constructed using 2N3707 transistors. Typical transition times for this type of logic are in the 15–20 ns range. This, coupled with similar turn-on and turnoff times for the l.e.d.s, provides for a complete lack in ambiguity of target positioning in time.

Functional capabilities

The logic circuitry that controls the l.e.d.s was designed to meet a variety of functional requirements and still have the flexibility for adding new functions or altering those contained in the original specifications. Listed below are descriptions of those target functions that will allow study of some of the more common ocular motor phenomena [i.e. latencies, nature of saccadic decision process, refixation errors (conjugate and disconjugate) and effects of distracting stimuli].

(*a*) *Step:* Targets instantaneously change from one position to another in either direction with no restrictions on initial or final target positions. The step change can be initiated manually or by the timing logic.

(*b*) *Pulse:* Targets change from any initial position to any second position and return to the initial position. The pulse width (time at the secondary position) is variable in the range 0–300 ms and can be preset in this range.

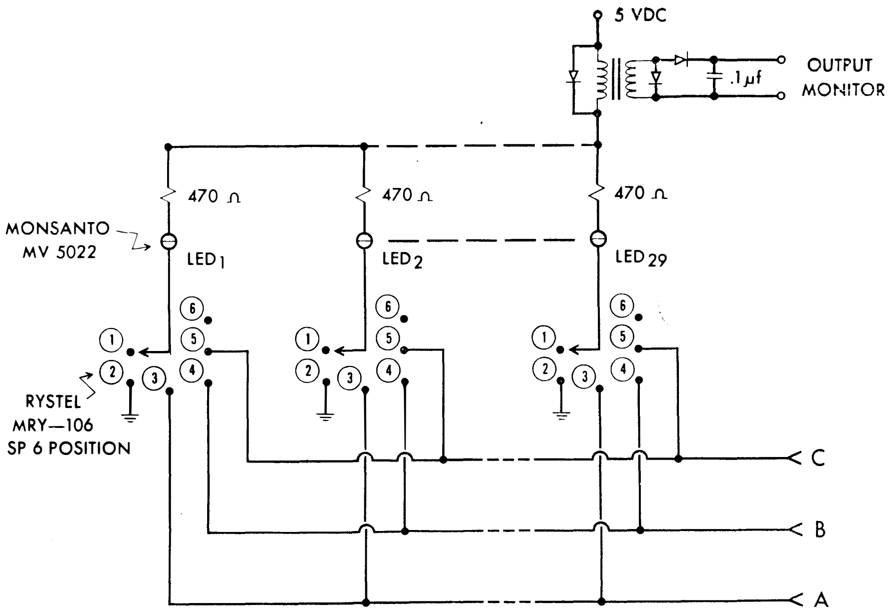
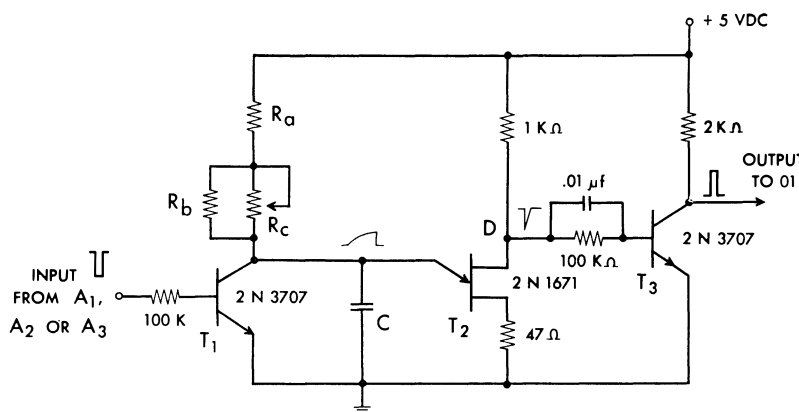


Fig. 3 Switch connections from electronics to various l.e.d.s. Provision for output monitoring is included



	R_a	R_b	R_c [POTENTIO-METER]	C
D 1 & D 3 0–5 sec	15 K	470 K	500 K	50 μf
D 2 0–300 ms	15 K	750 K	250 K	4.7 μf

Fig. 4 Delay circuit used with values shown for each of the three delay circuits necessary

(*c*) *Pulse step:* Targets change from initial to intermediate to final position with a variable time at each position. Again there are no restrictions on choice of positions or direction of each position shift.

(*d*) *Double pulse:* This is a modification of the pulse step where the time at the third position is made so short that the automatic return to initial position occurs before the eye has responded with its initial refixation saccade.

(*e*) *Step with pre-existing but disappearing extraneous target:* In addition to the step change in target position, an additional target is presented which disappears with the initial target position.

(*f*) *Step with fixed extraneous target:* As in function (*e*), but the extraneous target is always present.

With binocular recordings, the subject is positioned such that the central fixation point (the 0° target) is 1120 mm from and level with the centre of his 'cyclopean' eye. All gaze angles are measured from this datum. The exact gaze angle of either individual eye is easily calculated if needed by simple trigonometric relationships.

We have used the arc for studies of congenital nystagmus (DELL'OSSO, 1973; DELL'OSSO *et al.*, in press), latency studies (CARLOW, *et al.*, in preparation and studies of the velocity characteristics of saccades induced by different input stimuli (work in progress).

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