**SOME ELECTRONIC CONTROL UNITS FOR OPERANT BEHAVIOR STUDIES:
III. A TIMER AND COUNTER WITH PRINT-OUT¹**

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The present apparatus supplements devices in our laboratory described earlier (Schoenfeld *et al.*, 1960a and 1960b), and serves as a general timing and counting unit with varied applications, among them the measurement of response durations and inter-response times, the counting of response or other events in specified time segments, and the printing out of these data sequentially.

In serving as a counter of responses or reinforcements (or other class of events), a period may be set over which a count is taken. At the end of each set counting period the total number of events is printed out by a Hewlett-Packard 560A Digital Recorder. The shortest inter-event time which can be resolved is 10 microseconds. The length of the counting period may be set as low as about 50 ms., with unlimited maximum.

As a timer, the apparatus can measure response durations as short as one ms. provided the responses are separated by not less than 25 ms. Inter-response time may be measured either (a) from response onset to onset of the next response, or, (b) from response offset to onset of the next response, the latter being called here "corrected inter-response time" (CIRT in Fig. 2). Both inter-response times may be measured down to a value of 25 ms. with an accuracy of 1.0 ms.

Figure 1 is the schematic flow chart for the entire system. When timing is desired, the subject's response is fed to the coding circuit together with a tone pair of either 10 kc.-1 kc. or 1 kc.-100 cps. generated by a Hewlett-Packard oscillator Model 100D. The coding circuit gates the given tone pair so as to produce wave trains of the higher frequency of lengths equal to the intervals being measured. The choice of frequency depends on the accuracy desired, the 10 kc. tone permitting measurement to the nearest 0.1 ms., the one kc. tone to

Figure 1. Flow chart for the system, including possible additions of external inputs and an external timer. Switch S permits introduction of tape recording, or direct use of the decoder, as desired.

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Figure 2. The coding circuit. In the boxed switching legend, IRT means inter-response time, and "intra-response" (A) refers to response duration.

Index for Figure 2

C ₁ —.1 mf., 200 v.	R ₅ —1.1 megohms, 1/2 watt
C ₂ —.001 mf., 200 v.	R ₆ —470 K ohms, 1/2 watt
C ₃ —.001 mf., 200 v.	R ₇ —100 K ohms, 1/2 watt
C ₄ —.001 mf., 200 v.	R ₈ —5.6 K ohms, 1/2 watt
C ₅ —.05 mf., 200 v.	R ₉ —33 K ohms, 1/2 watt
C ₆ —.001 mf., 200 v.	R ₁₀ —1.5 megohms, 1/2 watt
C ₇ —.001 mf., 200 v.	R ₁₁ —39 K ohms, 1/2 watt
C ₈ —.3 mf., 200 v.	R ₁₂ —470 K ohms, 1/2 watt
C ₉ —.037 mf., 200 v.	R ₁₃ —5.6 K ohms, 1/2 watt
C ₁₀ —.001 mf., 200 v.	R ₁₄ —10 megohms, 1/2 watt
C ₁₁ —.001 mf., 200 v.	R ₁₅ —47 K ohms, 1/2 watt
C ₁₂ —.1 mf., 200 v.	R ₁₆ —1 megohm, 1/2 watt
C ₁₃ —.001 mf., 200 v.	R ₁₇ —1 megohm, 1/2 watt
C ₁₄ —300 mmf., 200 v.	R ₁₈ —1 megohm, 1/2 watt
C ₁₅ —.001 mf., 200 v.	R ₁₉ —5 megohms, 1/2 watt
C ₁₆ —.025 mf., 200 v.	R ₂₀ —270 K ohms, 1/2 watt
C ₁₇ —.2 mf., 200 v.	R ₂₁ —75 K ohms, 1/2 watt
C ₁₈ —.5 mf., 200 v.	R ₂₂ —22 K ohms, 1/2 watt
C ₁₉ —.25 mf., 200 v.	R ₂₃ —100 K potentiometer
C ₂₀ —.001 mf., 200 v.	RY ₁ —Mercury-wetted-contact relay ^d
C ₂₁ —.001 mf., 200 v.	RY ₂ —10 K ohm plate relay
B+ —200 v. DC ^a	RY ₃ —General purpose relay
D ₁ ^b —Sperry diode No. SD20	RC ₁ —Relay 1 contacts
D ₂ —Sperry diode No. SD20	RC ₂ —Relay 2 contacts
E ₁ ^c —EECO Z-90001, Squaring circuit	RC ₃ —Relay 3 contacts
E ₂ —EECO Z-8327, Pulse gate	S ₁ —3P DT toggle switch
E ₃ —EECO Z-8327, Pulse gate	S ₂ —3P DT toggle switch
E ₄ —EECO Z-8489, Pulse amplifier	S ₃ —2P DT toggle switch
E ₅ —EECO Z-8771, Phantastron	S ₄ —2P DT toggle switch
E ₆ —EECO Z-8489, Pulse amplifier	S ₅ —2P DT toggle switch
E ₇ —EECO Z-8342, Flip-flop	S ₆ —2P DT toggle switch
E ₈ —EECO Z-8489, Pulse amplifier	S ₇ —1P ST toggle switch
E ₉ —EECO Z-8489, Pulse amplifier	S ₈ —4P DT switch
E ₁₀ —EECO Z-8771, Phantastron	T ₁ —One-half 5963 tube
E ₁₁ —EECO Z-8489, Pulse amplifier	T ₂ —One-half 5963 tube
E ₁₂ —EECO Z-8327, Pulse gate	T ₃ —One-half 6AL5 diode
E ₁₃ —EECO Z-8348, One-shot	T ₄ —One-half 5963 tube
E ₁₄ —EECO Z-8327, Pulse gate	T ₅ —One-half 5963 tube
N ₁ —Ne51 neon bulb	T ₆ —One-half 6AL5 diode
R ₁ —47 K ohms, 1/2 watt	T ₇ —One-half 6AL5 diode
R ₂ —47 K ohms, 1/2 watt	T ₈ —One-half 12AT7 tube
R ₃ —47 K ohms, 1/2 watt	o —Output to Sodeco counter
R ₄ —3 megohms, 1/2 watt	p —Output to tape recorder or decoder

*All tube filaments are used with 6.3 volts. The power supply for the complete systems of Figures 2 and 3 should provide well-filtered and regulated B+ at 200 ma. (of which about 30 ma. is in excess of marginal requirement).

^bAn acceptable substitute is a 6AL5 vacuum tube, or other diode of similar characteristics.

^cAll EECO plug-in circuits are manufactured and sold by the Engineered Electronics Co., Santa Ana, California.

^dSimilar to HG1042 made by C. P. Clare Co.

the nearest millisecond. The second tone of the pair is used to record any special event (such as reinforcement), its onset resulting in the print-out of a special symbol. Furthermore, the coding circuit totals, on the mechanical (Sodeco) "error counter," the number of responses which occur within 25 ms. of a preceding response (and which, for that reason, are not otherwise measured). The coding circuit output is switched to the tape recorder when the 10 kc.-1 kc. frequency pair is used, or to the decoder when the other pair is used. As stated, use of the tape recorder reduces the "dead" print-out time by a factor of eight since the wave trains have a minimum of 25 ms. between them guaranteed by the coding circuit. The reduction is afforded by recording at 15 inches per second and playing back the tape at $1\frac{7}{8}$ inches per second, thus expanding the time between wave trains to match the print-out cycle (200 ms.) of the printer. Where 200 ms. is an expected inter-response time minimum, the two lower frequencies may be used without tape recording and fed directly to the decoding and print command circuit. From the latter, the higher frequency wave train of the tone pair being used is fed to the electronic counters. At the end of each wave train, the decoding circuit commands print-out of the electronic counter totals and resets these counters to zero. For special events, signaled by a low frequency wave train, these counters remain blank and a row of zeros is printed.

When counting events in a specified time segment, rather than measuring inter-response times or response durations, the event pulses may be fed directly to the electronic counters. The interval between prints is determined by an external timer which triggers the printing circuit.

Figure 2 details the coding circuit of the foregoing flow chart. Subject's response is converted at E_1 to a squared wave the duration of which is equal to response duration. Tubes T_1 and T_2 produce negative pulses, T_1 at response onset and T_2 at response offset. The three subsequent subcircuits are concerned with gating the measures of (a) response duration, (b) inter-response time, and, (c) inter-response time minus response duration ("corrected" inter-response time). To ease the reading of each subcircuit, a position of switches $S1-S7$ should be assumed. For example, if it is sought to measure inter-response times, $S2$ must be thrown in the appropriate direction (arrow pointing upward to IR), and $S1$ thrown down (arrow pointing downward to R), and similarly for the other switches. Switch $S8$ (parts A,B,C,D working together) determines whether tape operation or direct operation is obtained. The gates E_2 , E_3 , E_{12} , and E_{14} pass pulses or not, depending on what voltage (as generated by E_5 , E_7 , E_{13}) is controlling them. Lacking input to E_5 and E_{13} , their respective gates pass pulses. The positive gating pulses generated by E_5 and E_{13} are 25 ms. and 24 ms., or 200 ms. and 198 ms., long, respectively, the shorter pair of output pulses being used with the tape operation. A pulse from E_6 puts E_7 into position to allow gate E_{14} to pass pulses, and similarly for E_8 positioning E_7 with regard to gate E_{12} . Furthermore, the output of E_5 (pin 6) is differentiated at the input of E_2 (pin 4), the latter being under the control of E_{13} ; only the negative pulse resulting from the differentiation of E_5 's output will pass E_2 if E_{13} is not fired simultaneously, while if E_{13} is firing no pulse passes E_2 . Pin numbers are shown on EECO units (E_1 , E_2 , E_3 , E_5 , E_{12} , E_{14}) where unusual connections are employed, or where possible ambiguity exists as to direction of pulse flow (this is also done in Figure 3 below). E_{10} delays the negative pulse from E_9 by approximately 100 microseconds. When E_{14} is open, E_{12} is closed, and vice versa.

As an example of the operation of the coding circuit in Figure 2, consider the switching mode for measuring IRT's. For this, the switches are in the position shown in the figure with

the difference that S7 is to be taken as closed. Assume, further, that a 10 kc. tone is passing through E_{14} to p . The negative pulse generated by T_1 at response onset passes through S1, S2, S3, S6, and S5, but is finally blocked at E_{12} . The same pulse also goes through E_3 and then triggers E_5 . The 25 ms. positive pulse from E_5 blocks E_3 and also is differentiated by C_{10} ; the positive spike derived from the differentiation is inverted by T_5 , and then is delayed 100 microseconds by E_{10} . The output of E_{10} switches E_7 , closing E_{14} and opening E_{12} . It is this delay which prevents the pulse from T_1 from passing E_{12} , as stated above. Twenty-five milliseconds later, the negative-going side of E_5 's output passes through E_2 , S1, and T_6 , to switch E_7 back to its original state, returning the 10 kc. tone to output point p . If another response (negative pulse from T_1) had occurred during the 25 ms. operation of E_5 , it would have passed through E_{12} , driving E_{13} and generating a 24 ms. pulse which, in turn, would have closed relay 2 (registering a unit on the Sodeco counter connected at o), and would have blocked E_2 (preventing E_7 from being switched by the negative-going trailing edge of E_5 's output). Another response must occur after E_5 has finished its cycle before the circuit will recommence the timing train. Should another response, in fact, occur during the operation of E_5 , normal operation would be resumed at the occurrence of the next response coming after the completion of the 25 ms. operation of E_5 . With the arrangement described here, only one response occurring within E_5 's operation time will register on the counter; the counting of all responses within that time, should more than one be made, may be accomplished by inserting an electronic counter at the output of E_{12} . The operation of the coding circuit in the other two modes is to be traced in analogous fashion.

Figure 3 details the operation of the decoding circuit. Wave trains of the selected tone pair are fed (from either the tape recorder or directly from the coding circuit) into this circuit through transformer TR₁. T_1 and T_2 are buffer amplifiers. The output of T_2 is filtered to remove the higher frequency tone; the lower frequency is converted at E_1 to a train of square waves of uniform amplitude which are then differentiated by C_3 and R_7 , rectified by T_3 , and then filtered by the network composed of R_8 , R_9 , R_{10} , and C_4 . The time constant of the network at the grid of T_4 is chosen large enough to allow sufficient time for the printer to complete any cycle going on at the time the low frequency wave train starts. The negative bias on T_4 , whenever the low frequency tone is present, makes the plate of T_4 sufficiently positive to change the state of E_2 . The change-over pulse from pin 6 of E_2 resets the counters to zero, if necessary; the pulse from pin 7 triggers the phantastron E_5 . The 150 ms. positive pulse from E_5 closes the gates on the two Hewlett-Packard electronic counters and initiates the print cycle. The output of T_1 is filtered to remove the low frequency tone, and the remaining high frequency tone is treated in a manner analogous to that described above for the low frequency tone, with the exceptions, first, that the number of cycles in the wave train produced at E_3 is counted by the electronic counters, and, second, that phantastron E_5 is triggered only at the end of the high frequency wave train. The two Hewlett-Packard 520AR electronic decade counters have four decades each. The two counters are used in series (the last decade of one being joined to the first of the other through E_6) to produce effectively eight decades.

For use of the circuit as an event counter, switch S1 in the decoding circuit (Fig. 3) is thrown to connect E_5 to relay RY₁. In this position, activation of RY₁ by an external timer (or other means) will initiate the print cycle and reset the electronic counters to zero at the end of the cycle. During the print cycle, events are not counted; at the end of the cycle, events are again counted until the next subsequent print signal. Events to be counted are fed

Figure 3. The decoding circuit. V13 refers to Hewlett-Packard's tube number in the 520AR electronic counter.

Index for Figure 3

C ₁ —.25 mf., 200 v.	R ₁₃ —100 K ohms, 1/2 watt
C ₂ —.1 mf., 200 v.	R ₁₄ —390 K ohms, 1/2 watt
C ₃ —.1 mf., 200 v.	R ₁₅ —100 K ohms, 1/2 watt
C ₄ —17.0 mf., 200 v.	R ₁₆ —100 K ohms, 1/2 watt
C ₅ —.01 mf., 200 v.	R ₁₇ —68 K ohms, 1/2 watt
C ₆ —.1 mf., 200 v.	R ₁₈ —50 K ohms, 1/2 watt
C ₇ —.001 mf., 200 v.	R ₁₉ —150 K ohms, 1/2 watt
C ₈ —1.0 mf., 200 v.	R ₂₀ —150 K ohms, 1/2 watt
C ₉ —.001 mf., 200 v.	R ₂₁ —5 K ohms, 1/2 watt
C ₁₀ —.001 mf., 200 v.	R ₂₂ —270 K ohms, 1/2 watt
C ₁₁ —300 mmf., 200 v.	R ₂₃ —20 K ohm potentiometer
C ₁₂ —.001 mf., 200 v.	R ₂₄ —180 K ohms, 1/2 watt
C ₁₃ —.001 mf., 200 v.	R ₂₅ —1.0 megohm, 1/2 watt
C ₁₄ —.05 mf., 200 v.	R ₂₆ —1.0 megohm, 1/2 watt
C ₁₅ —.16 mf., 200 v.	R ₂₇ —980 ohms, 1/2 watt
C ₁₆ —.02 mf., 200 v.	R ₂₈ —100 K ohm potentiometer
C ₁₇ —.1 mf., 200 v.	R ₂₉ —330 K ohms, 1/2 watt
C ₁₈ —2.0 mf., 200 v.	R ₃₀ —200 K ohms, 1/2 watt
C ₁₉ —.001 mf., 200 v.	R ₃₁ —200 K ohms, 1/2 watt
C ₂₀ —.103 mf., 200 v.	R ₃₂ —150 K ohms, 1/2 watt
C ₂₁ —.005 mf., 200 v.	R ₃₃ —47 K ohms, 1/2 watt
C ₂₂ —.005 mf., 200 v.	R ₃₄ —47 K ohms, 1/2 watt
C ₂₃ —.05 mf., 200 v.	R ₃₅ —47 K ohms, 1/2 watt
C ₂₄ —.05 mf., 200 v.	R ₃₆ —1.0 megohm, 1/2 watt
C ₂₅ —.0015 mf., 200 v.	R ₃₇ —8 megohm potentiometer
C ₂₆ —50 mmf., 200 v.	R ₃₈ —3.0 megohms, 1/2 watt
B ⁺ —200 v. DC ^a	R ₃₉ —39 K ohms, 1/2 watt
D ₁ ^a —Sperry diode No. SD20	R ₄₀ —47 K ohms, 1/2 watt
D ₂ —Sperry diode No. SD20	R ₄₁ —47 K ohms, 1/2 watt
D ₃ —Sperry diode No. SD20	R ₄₂ —470 K ohms, 1/2 watt
D ₄ —Sperry diode No. SD20	R ₄₃ —220 K ohms, 1/2 watt
E ₁ ^a —EECO Z-90001, Squaring circuit	R ₄₄ —24 K ohms, 1/2 watt
E ₂ —EECO Z-90001, Squaring circuit	RY ₁ —Mercury-wetted-contact relay ^a
E ₃ —EECO Z-90001, Squaring circuit	RC ₁ —Relay 1 contacts
E ₄ —EECO Z-90001, Squaring circuit	S ₁ —SP DT toggle switch
E ₅ —EECO Z-8771, Phantatron	T ₁ —One-half 5963 tube
E ₆ —EECO Z-8348, One-shot	T ₂ —One-half 5963 tube
R ₁ —100 K ohms, 1/2 watt	T ₃ —One-half 6AL5 diode
R ₂ —100 K ohms, 1/2 watt	T ₄ —One-half 5963 tube
R ₃ —200 K ohms, 1/2 watt	T ₅ —One-half 5963 tube
R ₄ —47 K ohms, 1/2 watt	T ₆ —One-half 5963 tube
R ₅ —100 K ohm potentiometer	T ₇ —One-half 6AL5 diode
R ₆ —68 K ohms, 1/2 watt	T ₈ —One-half 5963 tube
R ₇ —1.0 megohm, 1/2 watt	T ₉ —One-half 6AL5 diode
R ₈ —1.1 megohm, 1/2 watt	T ₁₀ —One-half 5963 tube
R ₉ —1.0 megohm, 1/2 watt	T ₁₁ —One-half 6AL5 diode
R ₁₀ —150 K ohms, 1/2 watt	T ₁₂ —One-half 5963 tube
R ₁₁ —150 K ohms, 1/2 watt	TR ₁ —Audio transformer, 3 ohm input
R ₁₂ —1.0 megohm, 1/2 watt	and 10 K ohm output

^aThe footnotes of Figure 2 index apply equally here to the tube filaments and power supply, diodes, EECO units, and mercury-wetted-contact relay.

directly into the electronic counter in the form of pulses which must conform to the manufacturer's minimum specifications (for the Hewlett-Packard 520AR, pulses must be at least 0.2 volts). In the present case, we have found it convenient to use the two electronic counters separately, one for counting responses while the other simultaneously records reinforcements.

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