TECHNICAL NOTE

INTEGRATED CIRCUIT PROBABILITY SELECTION DEVICE

An integrated circuit device, powered either by batteries or 28 v dc, was designed for use in probability learning or psychophysical detection experiments. This device opens one relay and closes a second relay with probability p , $0.01 \leq p \leq 0.99$. The use of Epoxy packaged J-K flip-flops and multiple NAND gates reduces the cost to less than \$40.

The principle of operation is as follows: assume that the trigger flip-flop (top left-hand corner of Fig. 1) is in the one state. T2 is therefore off and the timing capacitor C1 can charge toward 12 v through R4, D2, and a portion of R12. When the voltage across C1 reaches the peak voltage of the unijunction transistor, the capacitor discharges and a positive going pulse appears across inductor L1. After squaring, this pulse triggers the flip-flop to the zero state. T2 now turns on and T1 becomes nonconducting, allowing C1 to charge through R3, D1, and the other portion of R12. Again, when the peak voltage is reached, a positive going pulse is produced across L1 that, after squaring, triggers the flip-flop back to the one state. The cycle is then repeated.

The period of the square wave at test point D depends upon R3, R4, R12, and the capacitor C1. It is constant and equal to 1 ms for the values shown. However, the duty cycle, *i.e.*, the ratio $T1/(T1 + T2)$, can be changed by varying the setting on the potentiometer R12. With switch S2 in position 2, if switch S1 is depressed by a subject and then released, the contents of the trigger flip-flop at the time of release are transferred to the storage flip-flop that controls the two relays (shown in the lower half of Fig. 1). If S1 is released when the waveform at test point D is at +2 v (see Fig. 2), then relay 1 (associated with R11) will open while relay 2 (associated with R10) will close. If S1 is released when the waveform at D is near 0 v, then the reverse will happen. Thus, the probability p is determined by the ratio $p = T1/(T1 + T2)$ for relay 1 and $(1-p) = T2/(T1 + T2)$ for relay 2.

The probability is set by adjusting R12 while measuring T1 and $T1 + T2$ with an electronic counter or oscilloscope connected between test point D and ground. Another method is to measure the voltage between test point E and ground (VE) with an average reading meter, then substitute into the formula $p = (VE - 0.2)/(VB - 0.2)$ where VB is the actual value of the 12-v supply.

For automatic programming of an experiment where the probabilities will be changed frequently, the one 1M-ohm potentiometer (R12 in Fig. 1) should be replaced by two fixed resistors. Let RA and RB be the values of two resistors: then $p = (RA + R3)/(RA + RB + R3 + R4)$ where $RA + RB = 1M$ ohm. Different combinations of RA and RB can be mounted on a stepping switch to give different probabilities at specified times. The orientation of these two resistors is

such that when RA is placed between diode D1 and test point A, then $T1 > T2$ if $RA > RB$.

Switch S2 (Fig. 1) was introduced to make this device applicable to psychophysical detection thresholds (see Payne, 1967) as well as probability learning experiments. As mentioned previously, with S2 in position 2, depressing S1 to position 2 will not alter the relays; one will remain closed while the other remains open, depending upon their states in the previous operation. When S1 is released to position 1, one of the relays will open and the other will close with a certain probability depending upon the potentiometer setting. The operation is different with S2 in position 1. Here, when S1 is in position 2, both relays will close and will remain closed until S1 is released. Upon release, only one of the relays will open, depending upon the probability setting. The difference is that in the former case the relay outputs were complementary at all times; in the latter case they are complementary only with S1 in position 1. This mode of operation serves as a valuable disconnect function when obtaining visual detection thresholds; *i.e.*, it is possible to insure that the circuit powering the stimulus is broken whenever switch S1 is closed.

The device has been tested to insure proper operation. The results show that the probability depends only upon the setting of R12. The clock frequency does, however, vary by less than 1% over a temperature range from 0°C to 60°C. Varying the 12 v supply between 9 v and 15 v produces a frequency variation of less than 2%. These variations, however, do not affect the probability, since p depends on the ratio of on-time to the total period of the clock, which in turn depends on the sum of the on-time and the off-time. Because both of these are affected in the same proportion with any change in clock frequency, the probability remains constant.

From the principle of operation of this device it can readily be seen that the gating cycle (Clark and Hull, 1965) for this device is $(T1 + T2)$ or 1 ms long. The gate (corresponding to T1 for relay 1 and T2 for relay 2) is enabled each gating cycle or clock period and varies from 0.01 to 0.99 ms for $0.01 \leq p \leq 0.99$. This compares favorably with the apparatus described by Clark and Hull, for which the gate is enabled from 0.33 to 32.67 ms for the 3-kc/s clock and from 0.077 to 7.623 ms for the 13-kc/s clock. The smaller time during which the gate is enabled means that the device described here is not as subject to synchronization with an input as those described by Clark and Hull. In fact, the probability of any input producing an output will be independent of the result of the previous input, even for rapid and repetitive signals, so long as the times between successive releases of switch S1 vary randomly by more than 1 ms.

Two 6-v lantern batteries connected in series fur-

Fig. 1. Schematic of the digital probability selection device. Detailed specifications of parts are given in the text. Note that test point A is a high impedance part of the circuit and will be loaded even with a 1M-ohm probe, resulting in an apparent change in frequency.

Fig. 2. Critical voltages and waveforms at test points A through E (see Fig. 1) to be used in checking the circuit. Note that $p = T1/(T1 + T2) = 2/3$ is illustrated here.

nish all the power needed (6 v and 12 v), and the device draws less than 75 ma. To operate on +28 v, a 12-v zener diode can be connected between ground and the 28-v supply through an 820-ohm 0.5-watt resistor. The 12-v is obtained at the junction of the zener diode and the resistor. Similarly a 3.6-v zener diode connected between ground and the 28-v supply through a 330-ohm 2-w resistor gives 3.6 v. In this case, diode IN4370, shown in Fig. 1, is eliminated.

Circles with a flat spot on one side indicate an integrated circuit unit; pin numbers are labeled as in Fig. 1. The Epoxy package should be used since metal cases are much more expensive and are unnecessary for this application. Micrologic type (1) is the Fairchild RTL J-K flip-flop type μ L 923 in a TO-5 Epoxy case. Type (2) is the Fairchild RTL dual gate type μ L 914 in a TO-5 Epoxy case. Diode IN 4370, used to drop the voltage from 6 v to 3.6 v, is a 2.4-v zener diode. Resistors R3 and R4 and capacitor C1 must be of 1% tolerance and high stability. Capacitor C2 may be of 10% tolerance. Capacitors C4 and C3 must be electrolytic. All other components are of 10% tolerance. The 1M-ohm potentiometer, used to set p, should have a small temperature coefficient, and the switch S1 should be free of bounce.

The two relays must operate with a coil current of about 5 ma each. If the coil resistance of the relay is less than 640 ohms, then resistors R10 and R11 must be added so that $R(\text{coil}) + R10 = 640$ ohms, and $R(\text{coil}) + R11 = 640$ ohms. However, if the coil resistance is greater than 640 ohms, R10 and R11 are deleted from the circuit. For example, Sigma 48F-1000-G/SIL (Allied), drawing 3.2 ma with coil re-

istance of 1000 ohms, will work with no added resistance.

It is quite convenient to build the device on fiberglass matrix board using solder pins, which may be arranged octagonally to accommodate the integrated circuit modules. The entire device, including relays, can be mounted on a 5- by 8-in. matrix board and can be made very durable when enclosed in a cabinet.

The use of integrated circuits has reduced the total number of components in the device to 34, including the relays and switches. For this reason it should be

more reliable than other devices with more components. The simplicity also makes the device easy to service. All of the waveforms needed to insure proper operation of the device are shown in Fig. 2.

REFERENCES

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- Payne, W. H. Comparison of sensitivity of psychophysical and electrophysiological measures of scotopic thresholds in the vicinity of the blind spot. *Perception and Psychophysics*, 1967, 2, 128-130.

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