A digital frequency discriminator for biofeedback research

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The design and construction of a digital frequency discriminator, useful in various research and clinical applications of biofeedback, is presented. The module may be constructed for approximately \$25 (excluding power supply and mounting hardware).

Biofeedback apparatus ranges in complexity from the R-C circuit to the digital computer. Apparatus of intermediary complexity, cost, and function typically have been constructed using analog processing techniques (Boudrot, 1972; Helmer, 1975; Pasquali, 1969; Rouse, 1975). The present paper describes an inexpensive device (approximately \$25) that precisely determines whether the period of a digital signal is within a criterion band of frequencies. When used with a Schmitt trigger for analog-to-digital conversion and an external signaling device such as a light or buzzer, the apparatus is well suited for biofeedback training and research.

STATEMENT OF THE PROBLEM

Line 1 of Figure 1 shows a prefiltered analog signal with the trigger level set at t_1 , and line 2 shows the analog-to-digital conversion produced by a Schmitt trigger. One could encode the input frequency by the duration of the digital signal, comparing the width of the trigger's output pulse to the periods of the cutoff frequencies (Paskewitz, 1971). However, a Schmitt trigger produces an ON signal for only one polarity of the input waveform. Since analog signals from human subjects are usually asymmetrical, the duration of the converted signal may not reliably express the input frequency.

The present approach uses only the leading edge of the trigger's output to define a response (R) (line 3). The time between responses, or interresponse times (IRT), will be equal to the period and inversely related to the dominant frequency of the input signal. The task of the discriminator described here is to determine at each occurrence of an R whether that IRT falls above, within, or below a criterion range of periods (a, b, and c, respectively). Thus, each IRT will initiate, maintain, or terminate the feedback signal, as shown in line 4.

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STATE NOTATION

The discrimination of IRTs is presented conceptually in Figure 2 as a state diagram. As shown, all responses start a clock that times the shortest acceptable period (State 1). Each response in State 1 reinitializes Timer 1 and switches off the feedback device (if it is on).

If no response occurs in State 1, Timer 1 times out and causes transition to State 2. In State 2, a second clock begins timing a period corresponding to the difference (ΔT) between the longest and the shortest periods to be discriminated (the low-frequency and high-frequency cutoffs, respectively). Thus, if a response occurs in State 2, the input signal is in the proper frequency range, the feedback device is switched on, and transition is made to State 1 so that the next IRT will be timed.

Figure 1. Conceptual diagram for the digital frequency discriminator.

$$T_1 = (\text{HIGH CUT-OFF FREQUENCY})^{-1}$$

$$T_2 = (\text{LOW CUT-OFF FREQUENCY})^{-1}$$

$$\Delta T = T_2 - T_1$$

Figure 2. State notation for digital frequency discriminator (feedback signal assumed to be tone).

Figure 3. Logic diagram for digital frequency discriminator.

If no response occurs while the second clock is timing, the IRT will be too long. Thus, when the second clock times out, the feedback device is switched off and the circuit enters State 3 to await the next response. A response in State 3 then returns the circuit to State 1 to begin timing the next IRT.

The state diagram can be translated into solid state circuitry employing digital logic devices readily available in many psychological laboratories (Figure 3). An inexpensive version that uses integrated circuits is presented in Figure 4, and a list of active components is presented in Table 1.

TTL IMPLEMENTATION

The R input to the system is via Pin 5 of IC1 and can be the output of any Schmitt trigger that is TTL compatible.

The Q output of the first one shot (OS1) is sent to AND (AG) Gates 1 (Pin 1, IC4) and 3 (Pin 13, IC4). The output of AG1 (Pin 3, IC4) is sent to OR (OG) Gate 1 (Pin 1, IC9), while the output of AG3 (Pin 11, IC4) sets Flip-Flop (FF) 3 (Pin 1, IC5).

Figure 4. Schematic diagram for digital frequency discriminator.

Table 1
List of Active Components

IC1, IC8, IC11, IC12 DM 74121 Monostable Multivibrator
IC2 LM555 Timer
IC3, IC5 DM74107 Dual JK Flip-Flop
IC4 DM7408 Quad Two-Input AND Gate
IC6, IC7 DM74122 Monostable Multivibrator (Retriggerable)
IC9 DM7432 Quad Two-Input OR Gate
IC10 4N28 Optical Coupler/Isolator (Motorola)
R1, R7, R8, R9, R10 10K
R4, R5, 20K Potentiometer
R2 1K
R3 200
R6 180
C1, C5, C6, C7 10-PicoF Ceramic
C2 .1-MicroF Electrolytic
C3, C4 4.7-MicroF electrolytic

Note—All resistors are in ohms (.5 W). Direct pin-to-pin TTL replacement devices of other manufactures may also be used.

The $\bar{Q}$ output of OS1 (Pin 1, IC1) is sent to AG2 (Pin 5, IC4) and to the second one shot, OS2 (Pin 5, IC8). The Q output of OS2 (Pin 6, IC8) sets FF1 (Pin 1, IC3), placing the system in State 1. The Q output of OS2 is also sent to OG2 (Pin 5, IC9).

The output of OG2 (Pin 6, IC9) resets FF2 (Pin 11, IC3). When FF1 is set (the Q output at Pin 3, IC11 goes high), one leg of AG1 (Pin 2, IC4) is enabled. Additionally, one leg of AG2 (Pin 5, IC4) is enabled by an R. The output of AG2 (Pin 6, IC4) initiates the timing sequence of the first multivibrator (MV1) through Pin 3 of IC6.

If no response occurs to cause retriggering of MV1, MV1 times out and its $\bar{Q}$ output (Pin 6, IC6) goes high. The $\bar{Q}$ output of MV1 is converted into a positive-going logic pulse by OS3 (input = Pin 5, IC11; output = Pin 6, IC11). The Q output of OS3 resets FF1 (Pin 4, IC3) and sets FF2 (Pin 8, IC3), thus placing the system in State 2. When the Q output of FF2 (Pin 5, IC3) is high, one leg of AG3 (Pin 12, IC4) is enabled, and MV2 (Pin 3, IC7) begins timing.

If no response occurs to cause retriggering of MV2, MV2 times out, placing the system in State 3. The $\bar{Q}$ output of MV2 (Pin 6, IC7) is conditioned by OS4 (Pin 5, IC12). The Q output of OS4 (Pin 6, IC12) is sent to OG1 (Pin 2, IC9) and to OG2 (Pin 4, IC9). The output of OG1 (Pin 3, IC9) resets FF3 (Pin 4, IC5).

When FF3 is set, the IRTs fall within the criterion range. The output of FF3 (Pin 3, IC5) is then fed into an appropriate interface module, or other suitable device, to operate the feedback signal. Figure 4 shows the output of FF3 being fed into an interface module (IC10) that has been described previously (Chiodo, 1977).

The Q output of IC2 (Pin 3) is used to supply the clock pulses necessary for JK flip-flop operation. In

Figure 3, IC2 is set to free run at a frequency of 10 kHz. The clock input of the flip-flops corresponds to Pins 9 and 12 of IC3 and IC5.

All the one shots (IC1, IC8, IC11, IC12) are designed to produce a fixed output of 70 nsec. This is accomplished by using 10-picoF capacitors (C1, C5, C6, C7) and 10K resistors (R1, R7, R9, R10). The typical gate-propagation time of regular TTL devices is 10 nsec.

The two multivibrators are constructed using SN74122 retriggerable monostable multivibrators and the four one shots are designed using SN74121 monostable multivibrators. The average propagation delay time of these ICs equals 35 nsec. With the appropriate timing components, the output pulse width of the multivibrators may be varied from 30 nsec to 40 sec. The circuit shown in Figure 4 is designed with C3 and C4 as 4.7-microF electrolytic capacitors and R4 and R5 as 20K potentiometers. These allow the pulse width of the retriggerable multivibrators to extend up to .97 sec beyond the last input.

The power requirement for this and all TTL integrated circuits is 5 V. Lancaster (1976, p. 19) describes a highly adequate TTL power supply.

Most TTL devices are sensitive to supply- and ground-line noise. TTL devices also tend to generate noise with state changes. These "glitches" may be prevented by placing one short-lead .1- to .01-microF (10-V) disc capacitor on the supply wires for every four IC chips. If there is unreliable triggering of IC1, a 270-ohm resistor can be used to reference the input (Pin 5) to the system ground (Chiodo, 1977).

The circuit described above has been extensively employed in our laboratories for both research (e.g., Glaros, Freedman, & Foureman, 1977) and clinical purposes. The device may be used for frequency discrimination of electroencephalographic activity, heart rate, respiration, or other semiperiodic events.

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