A low-cost integrated circuit comparator system*

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This paper describes a circuit that allows multiple-unit neural activity to be converted to standardized pulses for computer data acquisition. Positive or negative spikes can be converted at any voltage level from positive 25 V to negative 25 V with visual identification of exactly where on the amplified spike potential conversion occurs. This circuit provides active output voltages compatible with TTL logic.

The electronic circuit described here was designed to transform neural discharges into discrete digital events. Up to 12 of these circuits are used in conjunction with programs operating on a PDP-12 computer. The PDP-12 is equipped with 12 external sense lines and an instruction set designed to permit differential branching as a function of input voltage levels on any sense line.

We have found it more efficient to use the comparators to preprocess unit data to indicate unit activity as strictly digital events. This circuitry permits the quantization of unit activity as a function of amplitude. Thus, all unit activity greater than a selected voltage (pickoff level) will be indicated by a pulse out of the circuit. Consequently, by connecting in parallel several comparators set incrementally to different pickoff levels, one can obtain, in digital form, an indication of the unit activity that exceeds each successive threshold. The use of the computer to determine the actual amplitude window in which a specific unit discharge falls is then facilitated. Without preprocessing, the computer would have to determine if a unit discharge was present at a specific electrode and then determine the amplitude of the discharge prior to classifying it into one of several possible amplitude categories or windows. This is readily done, but at the expense of adequate frequency following. That is, such a program effectively follows discharge frequencies to about 900 Hz on each of, say, five electrodes. A similar five-electrode, two-amplitude configuration, using the comparators for preprocessing, permits acquisition at data rates of up to 7,000 Hz (both large and small amplitudes combined) at all five electrodes.

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THEORY OF OPERATION

The following discussion of circuit operation will be in terms of Channel A (see Fig. 1): S1 provides ac and dc input options, while S2 allows either direct input or 5:1 attenuation of the input signal through the voltage divider formed by R1 and R2. IC-1 can be operated safely only with input voltages limited to ± 5 V. Therefore, S2 allows an attenuator circuit to be switched into the input path, allowing a maximum voltage at J2 of ± 25 V. R1 is adjusted so that a 5.0 V input (with S1 closed) provides exactly 1.0 V across R2. The RC network, formed by dc Blocking Capacitor C1 and the sum of R1 (adjusted as described above) and R2, is a high-pass filter that is flat above 70 Hz.

R3 provides a continuously variable pickoff level from inputs slightly above -5.0 V to slightly below $+5.0$ V. When looking at multiple-unit activity, it is desirable to have output pulse onset coincident with the intersection of the leading edge of the input waveform and the pickoff level. Since the leading edge can be of positive or negative slope, depending on whether a positive or a negative waveform is considered, it is necessary to provide a means for choosing either slope. S3 performs this function, which Fig. 2 shows graphically.

IC-1 acts as a comparator and has a low (-5 V) output at Pin 13, until the input voltage exceeds the pickoff level voltage. When this happens, the output at Pin 13 goes high ($+5$ V) for as long as the input remains above the pickoff level. The positive-going transition is coupled to the monostable multivibrator (IC-2) by D1. The transition initiates complimentary output pulses from IC-2. The pulse width (PW) of the output is controlled by Resistors R5, R6, and Capacitor C5, according to the equation:

$$PW = 0.32 C_5 (R_5 + R_6) \left(1 + \frac{0.7}{R_5 + R_6} \right)$$

R in K ohms, C in picofarads, PW in nanoseconds.

There are no restrictions on the size of C5; however, consult the spec sheet for IC-2 (Texas Instruments Bulletin No. DL-S 7011367)¹ before changing values of R5 and R6 or using an electrolytic capacitor for C5. R5 allows continuous PW adjustment over a limited range. The two output pulses have amplitudes of about 4.5 V—the positive pulse going from 0 V to approximately $+4.5$ V, and the complimentary output going from approximately $+4.5$ V to 0 V. The zero volts in this case is an active “pull down” to a maximum of 0.4 V dc.

Power may be supplied by two batteries or any dual, regulated power supply capable of delivering 100 mA or more. If the latter is used, the amount of regulation

Fig. 1. Circuit schematic.

necessary will be determined by the precision required of amplitude discrimination. Any ripple found on the supply voltage will be seen on the pickoff level voltage also, and will dictate the amount of error in picking off an input. For example, if there is a 50-mV ripple on the supply voltage, there can be as much as 50 mV error (worst case) in detecting the peak of an input signal.

If batteries are used, any of the readily available 6-V variety are satisfactory. When using batteries, however, it is necessary to add two 1N4001 diodes to the circuit. The diodes should be connected so that the cathode (the end with the circumscribed stripe) of one goes to the +5-V input connection of the circuit, and the anode of the other goes to the -5-V input of the circuit. The positive terminal of one battery is connected to the anode of the first diode, and the negative terminal is connected to ground. The negative terminal of the second battery is connected to the cathode of the other diode, and the positive terminal of the battery is connected to ground. The diodes serve two purposes: They drop the battery voltages down to about 5.5 V at the circuit inputs, which is within the tolerance range of the components, and they "idiot proof" the circuit so that hooking up the batteries backwards will not blow out the integrated circuits.

Operation is quite simple, using a dual-trace oscilloscope. Both scope channels should be set to the same voltage range and the inputs temporarily grounded so that the vertical position controls can be adjusted to superimpose the two traces. (For proper operation, it is necessary for this adjustment to be made carefully and for both scope channels to be calibrated identically.) The *pickoff level monitor* jack (J1) is connected to one channel of the scope, and the multiple-unit data is fed into the *input* jack (J2) through a "T," which allows it also to be fed to the second scope channel. The scope inputs are then switched to dc, and the pickoff level trace will accurately indicate the point above (or below, if negative) which all activity will be converted to standard pulses. This level is continuously variable (R3)

over the input range.

Figure 3 shows examples of actual multiple-unit activity being converted to standard pulses for computer acquisition. In this case, the pickoff voltage is set for about 300 mV, which corresponds to 34 microV at the electrode tip.

While this circuit was designed to interface to a computer, it is not limited to computer applications. Any instrumentation which has a high input impedance may be used to collect the standardized output pulses. For example, after standardizing multiple-unit neural activity with the circuit, the output could be fed into an integrator circuit to obtain a measure of relative neural

Fig. 2. (A-D) One-kilohertz input sine wave, pickoff voltage, and corresponding 150-microsec output pulses as a function of the slope of the input waveform as controlled by Polarity Switch S3 (Channel A). Photographs were made by using a multitrace scope amplifier (Tektronix Type 3A74) at 0.2 msec/cm sweep speed. Amplitude calibration is 0.2 V/cm in the upper two traces and 5.0 V/cm in the lower trace of each part. A and B show, respectively, positive and negative slope selection at the same pickoff voltage; C shows pickoff voltage at 0 V with negative slope selection; and D shows negative pickoff voltage and negative slope selection.

Table 1
Parts List

R1, R5, R7, R11	25,000-ohm trimmer
R2, R8	4,700-ohm ½ W 10%
R3, R9	10,000-ohm linear-taper 10-turn potentiometer
R4, R10	1,000-ohm ½ W 10%
R6, R12	6,800-ohm ½ W 10%
C1, C6	0.33 μ F
C2, C7	1.0 μ F (not electrolytic)
C3, C4	100 μ F 15-V dc electrolytic
C5, C8	see text
J1 through J10	BNC panel connectors
D1, D2	1N3064 Silicon switching diodes
IC-1	Fairchild U6A7739393 dual low-noise operational amplifier
IC-2	Texas Instrument SN74123 dual retriggerable monostable multivibrator
S1, S4	spst toggle switch
S2, S5	spdt toggle switch
S3, S6	dpdt toggle switch

activity levels. Alternatively, if exact activity counts are desired over a precise time period, the circuit could be connected to a frequency counter. The exact procedure will depend on the type of counter used, but the following might apply. If only the time period of collection is important, the output of one comparator channel would be fed into the counter, and the count period would be determined by the counter frequency control. If, however, it is important for counting to begin at a specific time (e.g., CS onset, or synchronized with a pulse from a magnetic tape playback), one channel could be used to standardize the multiple-unit activity while the other gated the counter. For example, C5 and C8 could be chosen for output pulse widths of 100 microsec and 250 msec, respectively. Multiple-unit activity would then be fed into Channel A and the resultant 100-microsec output pulses fed into the counter input. A pulse identifying the start of the period to be counted would be fed into Channel B, whose 250-msec output pulse would be used to gate the counter on for that period. The result would be the exact total number of spikes which occurred during the 250-msec counting period.

The output of the circuit can source or sink only 10 mA safely. Consequently, to drive most relays or other low input impedance devices, one would need a current amplifier (a single transistor, in most cases) at the output of the oneshot.

At the time of this writing, the components on the parts list (see Table 1) cost \$28.59 from our suppliers. In addition to these parts, some form of packaging will be necessary, the nature of which will be determined by individual applications of the circuit. A small chassis box, power switch (DPDT toggle), mounting board, IC sockets (these are highly recommended to avoid possible heat damage to the ICs during soldering, and also to allow easy troubleshooting if it should become necessary) and miscellaneous hardware should not cost more than about \$7. Total cost of the circuit then is about \$36, or \$18 per channel. It should be noted, however, that prices vary widely, depending on locale, manufacturer, and supplier.

Fig. 3. Four examples of raw multiple-unit data being converted to standardized 150-microsec pulses for acquisition by the computer. The pickoff level (a) is fully adjustable and is the level above which all unit activity (b) is converted to standard pulses (c). The total sweep durations are 5 msec (A) and 10 msec (B). The dotted appearance of the multiple-unit trace is a result of the fast sweep speeds while the oscilloscope was in the chopped mode for three-trace operations. (The faster sweep speed in A has unfortunately caused portions of the multiple-unit trace to appear rather dim.) In these pictures, the pickoff level corresponds to 34 microV at the electrode tip.

CONCLUSION

The major advantages of the circuitry described here are its low construction cost and relative flexibility of application. Since the output pulse widths can be specified over a wide range (by appropriate selection of C5), they may be applied to a number of neural and behavioral data collection requirements where digital preprocessing or logic system control is necessary.

NOTE

1. Individual specification sheets for the μ A 739 and SN 74123 integrated circuits may usually be obtained without charge by writing to the manufacturers at the following addresses, respectively: Fairchild Semiconductor, 313 Fairchild Drive, Mountain View, California 94040; and Texas Instruments, P.O. Box 5012, Dallas, Texas 75222.

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