A biphasic 60-Hz synchronizer circuit for the recording of visually evoked responses in high-noise environments

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A simple synchronizer clock circuit is described that aids in the rejection of 60-Hz noise from evoked potential measurements.

Evoked potential measurements are routinely made in electrically shielded environments through the use of signal averaging techniques (Goff, 1974; Perry & Childers, 1969; Regan, 1972). Shielding is desirable since the extraneous non-time-locked signals are reduced merely as the reciprocal of the square root of the number of individual responses which make up the average.

We decided to make these measurements from patients who had suffered closed-head trauma. These patients were usually in a hospital ward on a respirator, were often receiving hyperalimentation, and were heavily instrumented for continuous monitoring of vital signs. We found it impossible to routinely obtain high-quality evoked potential measurements because of the 60-Hz fields associated with these life-support instruments. The use of high common mode rejection amplifiers significantly reduced the 60-Hz interference. However, even after averaging 100 individual responses, substantial 60-Hz contamination remained in the signal. The device described here has provided remarkable improvement in the signal-to-noise quality of our evoked response measurements. Although our application involved patient recordings, the technique should be useful in

experimental research where evoked potentials must be measured in "noisy" environments.

APPARATUS

Reduction of 60-Hz noise by signal averaging can only occur if the synchronizing clock pulses used to trigger the averaging computer are independent of the 60-Hz line. Commercial timers that count cycles from the 60-Hz power line produce sync-pulses time locked to the 60-Hz line, with the result that 60-Hz interference does not average out. If the synchronizing clock generates successive triggering pulses that are (with respect to the 60-Hz line signal) 180 deg out of phase with the preceding triggering pulse, constant-amplitude 60-Hz noise averages to zero in two sweeps. We therefore constructed the two-phase clock circuit shown in Figure 1.

The output from a 6.3-V transformer is full-wave rectified to produce positive-going clock waveforms at 120 Hz. The clock pulses are voltage regulated and smoothed using an RC network and a 4.7-V Zener diode following the full-wave rectifier. The output from this network reliably triggers the Schmitt trigger input of a 74121 monostable multivibrator (IC1) to produce 120-Hz 10-microsec-duration clock pulses at its output. These clock pulses trigger the clock input of a JK Master-Slave flip-flop (IC2a), causing the Q and $\bar{Q}$ outputs to alternately go high for half of each cycle (Φ_1 or Φ_2) of the incoming 60-Hz sine wave, resulting in a 60-Hz biphasic clock. The synchronous input is from an external stimulator that provides the basic repetition rate for the evoked responses, usually on the order of 1 pulse/sec. For the purpose of this circuit, we assumed that the synchronous input was a TTL-compatible pulse. This pulse, which triggers the clock input of the 7473 (IC2b) JK Master-Slave flip-flop on the

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Figure 1. Logic (a) and timing (b) diagrams for biphasic 60-Hz synchronizer. IC1, IC4, IC5-74121 (monostable multivibrator), IC2-7473 (dual JK Master-Slave FF), IC3-7474 (dual D-type edge triggered FF), IC6-7402 (quad two-input pos NOR).

negative-going transition, causes the Q and $\bar{Q}$ outputs to toggle with respect to the incoming synchronizing pulses. The Q and $\bar{Q}$ outputs are fed into the D inputs of two 7474 D-type edged trigger flip-flops (IC3a and IC3b). When one of the D inputs goes high, it allows the next clock pulse to cause the Q output to go high. As IC3a can trigger only at Phase 1 and IC3b only at Phase 2, successive positive transitions of the Q outputs of the D flip-flops (IC3a and b) must be alternately at Phase 1 or Phase 2 of the 60-Hz clock. (The Q output of each D flip-flop will go low at the next same-phase clock pulse after the D input goes low.)

The Q outputs of the D flip-flops (IC3a and b) are each connected to the input of a 74121 monostable multivibrator (IC4 and IC5), sensitive to positive-going transitions. The 74121s convert each long positive-going output pulse from the IC3 into a relatively brief (10 microsec) pulse. The outputs from the two 74121 monostable multivibrators are fed into the inputs of a two-input NOR gate (IC6a). The IC6a output is inverted by another available two-input NOR gate (IC6b) to produce a single brief (approximately 10 microsec) positive sync-out pulse for each sync-in pulse. The leading edge of this sync-out pulse is used to drive the Schmitt trigger synchronizing input of the computer and also the synchronizing circuit of the oscilloscope.

Simply stated, the entire circuit allows synchronous output pulses to occur that are always time locked to the 60-Hz power line, in such a manner that every other synchronous output is 180 deg out of phase with respect to the preceding pulse.

RESULTS

The advantages of this circuit are shown in Figure 2, which provides the appropriate performance data. Trace A shows the visually exposed response obtained from one of the authors (J. L. R.) The response was produced by a Grass Instrument Company PS22 photostimulator at maximum intensity, with a constant background illumination of 7 fc at the level of the subject's eyes. Responses were obtained by recording differentially between electrodes placed at theinion and approximately 5 cm directly above theinion on the mid-line. The voltages were referred to an earlobe ground electrode. For Trace A, the measurements were made in a very low 60-Hz environment using the two-phase clock circuit described in this communication. Trace B shows a similar evoked potential, using a clock driven by a 10-kHz crystal oscillator in no way related to the 60-Hz line. Each of the traces (A and B) is the average of 100 individual responses. In the low-noise environment, the evoked potentials obtained using the two different clocks are virtually identical. This means that the clock circuit produced no appreciable unwanted alteration of physiologically important components. Trace C, also an average of 100 responses, shows a similar evoked potential obtained with the use of the two-phase clock when a constant 60-Hz field equivalent to a signal of 80 microV peak to peak after common mode rejection was presented at the amplifier input. Again, the evoked response is very similar to the preceding traces made in the low-noise environment. Trace D shows the evoked response obtained in a similar 60-Hz field when using the crystal oscillator clock without two-phase 60-Hz rejection capability. Even after the average of 100 individual responses,

Figure 2. Performance data for biphasic 60-Hz synchronizer. Each trace (A, B, C, D) is average of 100 individual responses. Trace A = biphasic 60-Hz synchronizer in low-noise environment, Trace B = uncorrelated crystal clock in low-noise environment, Trace C = biphasic 60-Hz synchronizer in high-noise environment, and Trace D = uncorrelated crystal clock in high-noise environment (high noise = 80 microV peak-to-peak input noise).

the 60-Hz noise is appreciable, obscuring all but the major components of the visually evoked response. We obtained evoked responses as clean as is seen in Trace C in the presence of constant 60-Hz fields equivalent to a 500-microV differential signal after common mode rejection. It is desirable that an even number of evoked responses are averaged; otherwise the last sweep adds its full 60-Hz component to the composite signal.

DISCUSSION

The results presented are for the ideal circumstance, where the 60-Hz fields are constant in amplitude. It should also be noted that a 120-Hz component in the interfering field is accentuated by the two-phase synchronizing clock. This 120-Hz component can be eliminated by using either a four-phase clock built along similar lines or by an analog filter. It is intuitively obvious that an averaging circuit, alternately triggered 180 deg out of phase with respect to the constant-amplitude 60 Hz, would reduce the amplitude of 60-Hz noise to near zero in two sweeps. However, in real recording situations, the 60-Hz fields are rarely constant in amplitude from one sweep to another. Even under the circumstance of sweep-to-sweep amplitude variation, the use of our circuit significantly reduced the amplitude of the 60-Hz noise component. Seven patients were measured before and five after the construction of our circuit. For comparisons we used the ratio of the peak-to-peak amplitude of the 60-Hz component of the 100-event average to that of a typical single sweep. All five patients measured with our circuit had between one-

third and one-tenth of the 60-Hz noise found for the best patient measured with a conventional clock circuit. It is therefore routinely possible to record low-noise visually evoked responses in high-60-Hz noise environments.

REFERENCES

GOFF, W. R. Human average evoked potentials. In R. F. Thompson & M. M. Patterson (Eds.), *Bioelectric recording*

techniques. Part B: Electroencephalography and human brain potentials. New York: Academic Press, 1974.
PERRY, N. W., & CHILDERS, D. G. *The human visual evoked response.* Springfield: Charles C Thomas, 1969.
REGAN, D. *Evoked potentials in psychology, sensory physiology and clinical medicine.* London: Chapman and Hall, 1972.

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