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A fish activity-monitoring device using a low-power infrared photobeam

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An activity-monitor system for fish or other aquatic animals has been developed that uses a single low-level infrared (IRED) photobeam. The IRED source emits with a peak wavelength of 960 nm and requires only 70-mW average power input for an operating range of greater than 50 cm in sea water. This represents an order of magnitude reduction in power and more than a doubling of range over other reported designs. The cost for a single-beam channel is approximately $30.

Devices to monitor the activity of aquatic animals, particularly fish, both marine and fresh water, have taken many forms, including (1) tethering the animal to an electromechanical position sensor, (2) electromechanical systems that require the animal to physically displace a door, flap, or other obstacle in order to pass from one compartment to another (Davis, 1963; Spoore, 1941), (3) ultrasonic or doppler-shift movement detection (Byrne, 1971; Cummings, 1963; Meffert, 1968), (4) magnetic field or inductive movement detection (Schuyf & de Groot, 1971), (5) time-lapse cinematography (Bainbridge, 1958; Webb, 1970), (6) closed-circuit TV/computer analysis (Uter, 1977), (7) detection of the changes in thermal absorption characteristics at a solid-liquid interface as affected by movement (Northmore & Muntz, 1974), (8) detection of distortion or interruption of a photobeam (Cripe, Cripe, & Livingston, 1975; Hafeez & Baber, 1976; Kleerekoper, Timms, Westlake, Davy, Malar, & Anderson, 1970; Parker, 1975), and (9) using photocells to monitor shadows cast against a screen by the moving animal (Hudson & Bussell, 1972).

To study the diurnal characteristics of the marine fish *Oxyijulius californica* (Senorita fish) under the effects of various experimental alterations, the following requirements for an activity monitor were established: (1) no training of the animal; (2) no mechanical or package attachments to the animal; (3) not affected by changes in ambient light level; (4) two or more monitors must operate in the same aquarium, which has been divided into multiple compartments with each compartment containing one fish; (5) must not alter the "normal" behavior of the fish; (6) inexpensive to construct; (7) operate over a distance of at least 40 cm in sea water; (8) be compact so that 10 experimental aquaria plus detectors can fit into an existing relatively small space; and (9) be capable of driving an event recorder directly.

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In matching up the list of requirements with the advantages and disadvantages of the existing techniques, it became apparent that the method of photobeam interruption had the most likelihood of satisfying all needs. Furthermore, based on the work of Chaston (1968) and Northmore and Muntz (1974), there was good evidence to support a choice of an infrared detector system.

METHOD

Following the work of Cripe et al. (1975), we decided to employ an IRED photodiode source and phototransistor detector operating in the 960-nm wavelength region. However, the Cripe et al. design proved unsatisfactory for our use, owing to its limited 20-cm range.

To produce the needed 40-cm range, a synchronous source-detector design was chosen (Sahm, 1976). This technique has several inherent advantages over the more common continuous wave (CW) approaches. One such advantage is that the IRED source can be pulsed at 5 to 10 times the CW power levels, while maintaining the average power at much lower levels. In the Cripe et al. design, each IRED source must dissipate about 600-mW average power. In our design, the source dissipates only 60-mW average power. Second, operating at higher instantaneous photoemission levels extends the distance the photobeam travels before being attenuated to undetectable levels. A third advantage is that the system inherently averages over time and thus, short-term perturbances in the IRED source output are ignored. Finally, being synchronous, the detector is relatively insensitive to ambient light levels, particularly if these levels are produced by fluorescent lamps that are continuously turning on and off at 120 Hz, since the synchronous oscillator can easily be set at a frequency that will cause the 120-Hz light source to average to zero in its effect on the system. On the other hand, incandescent or filament light sources produce a large amount of "dc" IRED radiation. Since the source is nearly constant in intensity, the monitor should not "see" this dc light source, as the monitor is an ac coupled amplifier. In practice, however, it is possible for a dc light source to drive the IRED detector phototransistor out of its correct bias conditions, thereby limiting its amplification properties. Although the peak response of the selected

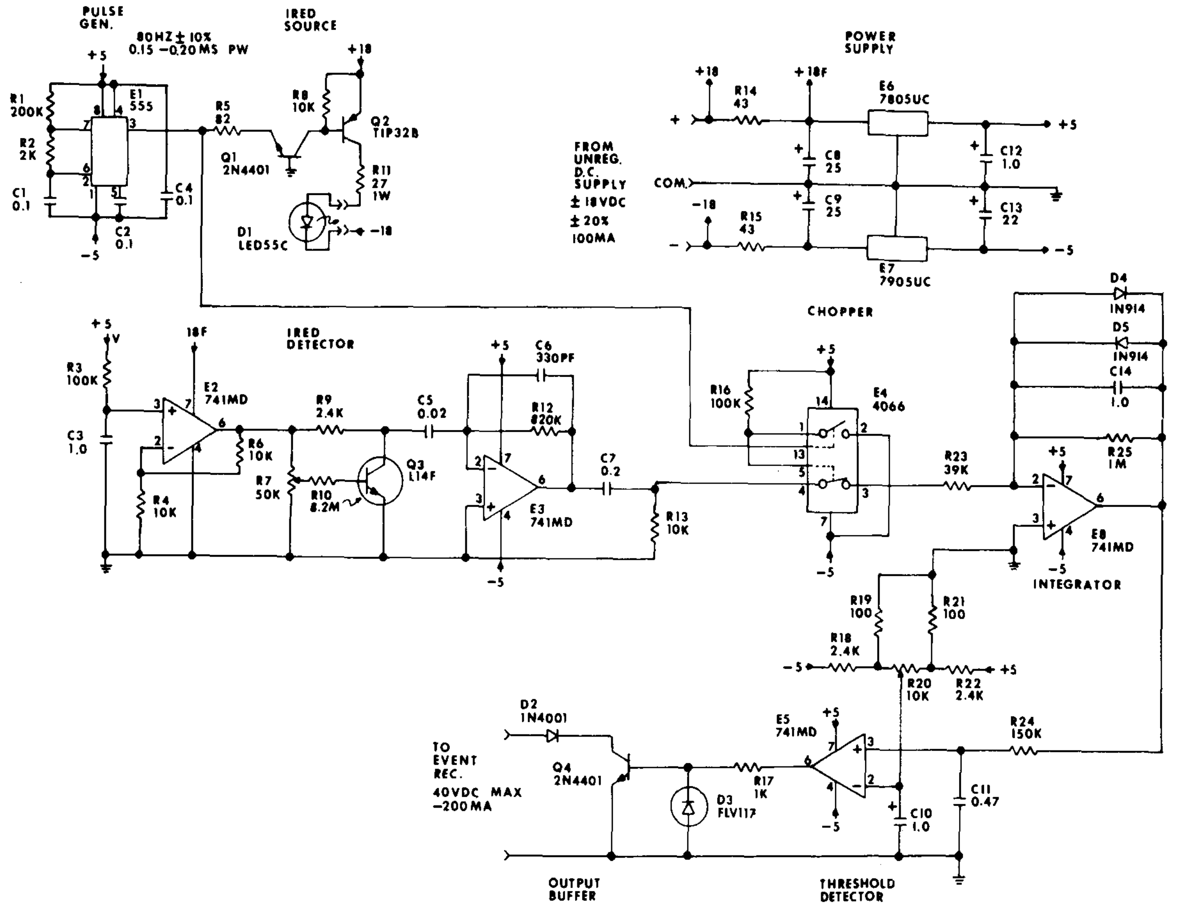

Figure 1. Schematic of complete fish activity monitor. Unless otherwise noted, all resistors are 1/4 W, 5%, and all capacitor values are in microfarads. Q3 and D1 are General Electric devices. D3 is a Fairchild device. All other devices should be available from several manufacturers. R7 is a single-turn trimmer, and R20 is a 10-turn panel mount. D3 and R20 should be mounted for easy access during system installation.

phototransistor is in the 960-nm range, it will respond to shorter wavelength visible light. To reduce the effects of ambient light on the detector, two techniques were used. The first was to shroud the detector so that only photons traveling parallel to the axis of the detector were allowed to reach its face. Concurrently, all ambient light sources were placed so that the principal beam of photons was at 90 deg to the detector's axis. A second preventive measure was to use a Wratten 92 red filter in front of the detector.

CIRCUIT DESCRIPTION

Figure 1 shows the complete IRED source-detector circuit except for the unregulated 18-V dc supply. E1 is a source of clock pulses that drive both the IRED source D1 and the synchronous chopper E4. The pulse width is .2 msec and the repetition rate is about 80 Hz. The duty cycle is therefore .16.

On each transition of the pulse generator from a high to low state, common base-connected Q1 is turned on. The emitter, and thus collector current, is determined by R5 and the –5-V dc level of the clock pulse. Q1 is simply a voltage translator acting to buffer the clock signal from the 18-V dc supply at the emitter of Q2. Current in the collector of Q1 comes through the emitter base junction of Q2 and is sufficient to put Q2 into saturation, so that there is 36 V dc across the R11/D1 combination, and D1 is forward biased at 1.2 A. Thus, D1 emits. When the clock pulse returns to its high state, Q1 and thus Q2 and D1 are turned off and D1 does not emit.

Q3 is a photoDarlington amplifier. It is biased into its active region by R7 and R10. E2 provides a source of filtered and regulated 10 V dc for Q3. E3 is connected as an ac current-to-voltage amplifier, and acting through C5, presents a nearly zero ac impedance to the collector of Q3, thus maximizing the switching speed of Q3. The output of E3 is ac coupled via C7 to eliminate dc offset voltage effects and is synchronously chopped by switch E4, acting as a SPST switch and logic inverter, and integrated by E8.

The output of integrator E8 is low-pass filtered by R24 and C11 and then fed to the noninverting input of E5, acting as a threshold detector, where it is compared to a dc level between +200 and –200 mV dc, as determined by R20. The output of E5 will be high or low depending on the relative magnitudes of its two inputs. When the photobeam is uninterrupted, the output is low, and the LED indicator D3 will be on. Q4 will be off and no current will flow through D2. When the photobeam is interrupted, the output will be high, and Q4 will be on, thus allowing current to flow in D2, which completes the event-recorder circuit.

CONSTRUCTION

To facilitate construction of 12 independent monitors, a printed circuit board was designed. Although crude (the art work was done using standard terminal pads interconnected by hand-drawn lines), it was relatively fast to develop and straightforward to manufacture. Prior to laying out the art work, several hand-wired prototypes were constructed.

If the user desires to hand wire an instrument, he should be aware that the IRED detector, Q3 in combination with E3, is a very high-gain current-to-voltage amplifier. Therefore, precautions should be taken to keep it well isolated from the IRED source circuitry. The design of the power supply and the decoupling capacitor C4 associated with E1 electrically isolate the IRED detector. Keeping all leads associated with the IRED source separated by a minimum of 1 cm from those of the IRED detector decreases the possibility of cross talk between the two circuits.

Since our system is required to "see" from one side of an aquarium to the other, D1 is mounted at the end of a two-conductor shielded cable of suitable length (the shield is grounded). Because of the very low power dissipated within the IRED source, no heat sinking is required. The remainder of the instrument is mounted in an aluminum box that serves as an E-field shield and light shroud.

A plastic bracket holds the IRED source in place on the aquarium side opposite the receiver box. The IRED beam is admitted to the receiver box through a small hole in the box cover covered by a Wratten 92 red filter. The filter minimizes the effects of ambient background-light levels as explained earlier.

Both R20 and D3 are mounted on the top of the receiver box to facilitate set-up. Terminals for connecting to a remotely located event recorder are also provided. A long length of two-conductor shielded cable is hardwired to the receiver box to bring in power from the unregulated dc supply. To minimize corrosion, the aluminum receiver box is sealed in a plastic bag. Adjustment of R20 is made with the bag in place.

ADJUSTMENTS

At initial start-up, R7 is adjusted so that the collector voltage of Q3 is between 4.5 and 5.5 V dc. This adjustment is carried out with Q3 exposed to the ambient-light operating conditions, but not to the IRED source. In our application, the ambient light is a 24-h light-dark cycle. R7 was adjusted under dark ambient, then checked for differences in the operation of the system in light ambient. No differences were found.

R20 sets the event threshold; it is set empirically in combination with the physical alignment of the IRED source and detector. For initial checkout, holding the beam axis of the IRED source at right angles to the axis of the detector transistor with a separation distance of 15 cm simulates normal operating conditions without requiring the use of a sea water tank. R20 is adjusted one rotation (in the direction of keeping D3 on) past the point where D3 just lights with no object interrupting the photobeam. During installation, R20 is further trimmed to provide suitable system operation using an opaque object to interrupt the photobeam. Finally, a fish is introduced into the tank.

MODIFICATIONS

Only a single photobeam has been implemented in this design. Addition of more beams can be accomplished without increasing power supply requirements, since additional IRED sources may be placed in series with the existing IRED source, and R11 reduced. One must, of course, add additional detectors. The outputs of each detector may be "wired OR'd" at the collector of Q4, or summed and integrated by E8. In the latter case, the interruption of any one beam would be sufficient to lower the integrated output below the required threshold.

PERFORMANCE

Tests show that objects as small as a standard pencil (6-mm diam) interrupt the photobeam at either side of a 50-cm-wide aquarium filled with sea water. Because the particular fish being studied are relatively large and slow moving, circuit time constants require that the photobeam be interrupted for 2 sec before the leading edge of an event is recorded. The beam must be reestablished for 1 sec for the trailing edge of the event to be recorded.

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