

## SHORT COMMUNICATION

# A SIMPLE, SENSITIVE AND VERSATILE SOLID-STATE PRESSURE TRANSDUCER

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Sensitive and accurate pressure transducers are useful in many areas of biology. Two common applications are the measurement of pressure changes within the respiratory system of an animal, and quantification of the small pressure fluctuations that accompany the humidification and warming of inspired air in whole-body closed-system or open-system flow-through plethysmography (see Malan, 1973; Bucher, 1981). The design of such transducers is often complicated by the requirement to measure very small pressure fluctuations in the presence of a substantial pressure offset. Moreover, such pressure offsets often vary slowly with time. Frequent adjustments are then required to keep the output of the pressure transducer from saturating in either direction.

Various transducers have been used to detect small pressure changes. Most commonly, a flexible diaphragm attached *via* a lever system to a strain gauge has been employed (see, for example, Bucher, 1981). Unfortunately, such transducers yield a low and sometimes non-linear output, require extensive supporting circuitry, drift with temperature, and have to be frequently recalibrated. In response to this problem, I have designed a simple, inexpensive, general-purpose pressure transducer that is based on a commercially available, solid-state sensor. The sensor response is linear over the differential pressure range  $\pm 1243$  Pa and consists of a pressure-sensitive integrated circuit in the form of a small diaphragm. Two gas ports connect to opposite sides of a diaphragm, permitting differential measurements. The diaphragm is housed in a compact plastic package, complete with electronics that provide a temperature-compensated, calibrated output of  $497.3 \text{ Pa V}^{-1}$  (typical accuracy  $\pm 1\%$ ), ranging from 1.0 V ( $-1243$  Pa) through 3.5 V (0 Pa) to 6.0 V ( $+1243$  Pa). The complete sensor is available from Omega Engineering Inc., PO Box 4047, Stamford, CT 06907-0047, USA (part number PX164 005 BD 5V). Part number PX164 010 D 5V can be substituted for measurement of differential pressures from 0 to 2486 Pa. The addition of a simple circuit (Fig. 1), based on inexpensive and readily available components, allows the user to specify gain (1–50 $\times$ ) and offset, over the entire pressure range of the sensor. A description of the circuit follows.

**Key words:** pressure, transducer, plethysmography.

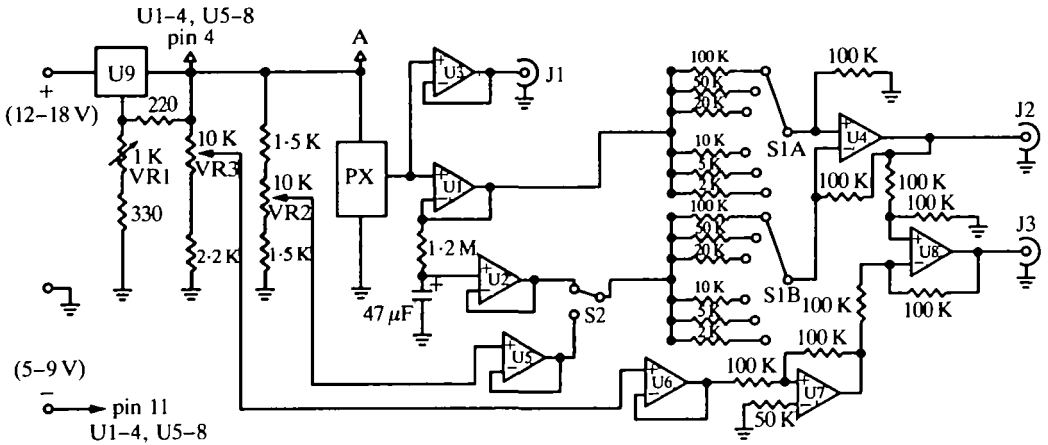


Fig. 1. Circuit diagram of the pressure transducer. PX is the pressure sensor (see text). U1–U8 are two LM324 or equivalent quad operational amplifiers (dual or single op-amps, e.g. LM741, can be substituted). U9 is an LM317 adjustable voltage regulator. VR1 and VR3 are 10-turn preset potentiometers. VR2 is a panel-mounted 10-turn potentiometer; it can be replaced by a series combination of a 10 K (coarse adjustment) and a 1 K (fine adjustment) potentiometer. J1–J3 are panel-mounted connectors. All fixed resistors should be 1% or preferably 0.1% precision, metal film or wire-wound. The 47  $\mu$ F capacitor is tantalum. See text for circuit description and testing procedures.

A voltage regulator reduces the positive power supply voltage (12–18 V) to a well-regulated 8.00 V required by the sensor electronics. The output of the pressure sensor is buffered by U1, and fed into an RC integrator that has a time constant of about 60 s (see below, this paragraph), the output of which is buffered by U2. A further buffer (U3) provides a front-panel source of the unprocessed sensor output *via* connector J1. The output of U1 is connected to the non-inverting input of a variable-gain differential amplifier built around U4. Gain is controlled by the double-ganged wafer switch S1 over the range 1–50 $\times$ . The inverting input of the differential amplifier is switch-selectable (S2), and allows the user to select either a continuously variable offset (10-turn potentiometer VR2 and buffer U5) or a 'floating' offset derived from the RC integrator, that is close to the mean of the applied pressure over the last 60 s. The latter setting is useful for measuring small, rapid fluctuations (e.g. avian respiration) superimposed on a large, slowly drifting pressure offset. The output of U4 is available on the front panel at J2. Because operation in floating offset mode produces an output from U4 that is symmetrical about 0 V, a summing circuit (U6–U8) adds a voltage adjustable by VR3 to the output of U4. This is necessary to prevent the input of negative voltages to the single polarity A/D converters often used in computerized data acquisition. The summed voltage is available on the front panel at J3. Circuit layout is not critical, but good wiring practice should be followed, such as the use of a single-point ground node.

The circuit is simple to set up. The only instrument required is an accurate digital voltmeter. After applying the supply voltage, the voltage at point A is adjusted by

VR1 to  $8.00 \pm 0.01$  V. The voltage at J1 should now be  $3.50 \pm 0.05$  V if no gas connections have been made to the sensor ( $1.00 \pm 0.05$  V in the case of sensor type PX164 010 D 5V). Set switch S1 to  $1\times$  gain, and switch S2 to fixed offset. The voltage at J2 should be adjustable to zero by the offset control VR2. The sensitivity of adjustment should increase markedly with increasing gain (the gains can be checked, if desired, by dividing the output voltage at J2 by the difference between the voltages at the inverting and non-inverting inputs of the differential amplifier). Set switch S2

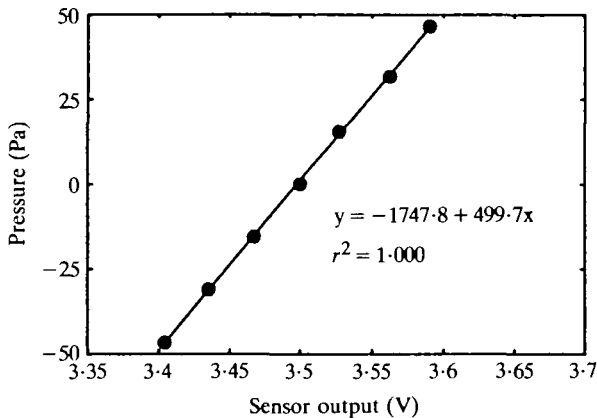


Fig. 2. The voltage output of an Omega PX 165 005 BD 5V pressure sensor regressed against input pressure measured by an accurate manometer. The relationship between pressure and voltage output is extremely linear, and the slope of  $499.7 \text{ Pa V}^{-1}$  is close to its expected value of  $497.3 \text{ Pa V}^{-1}$ . Each transducer will have a unique slope value, which should be carefully measured for optimal accuracy.

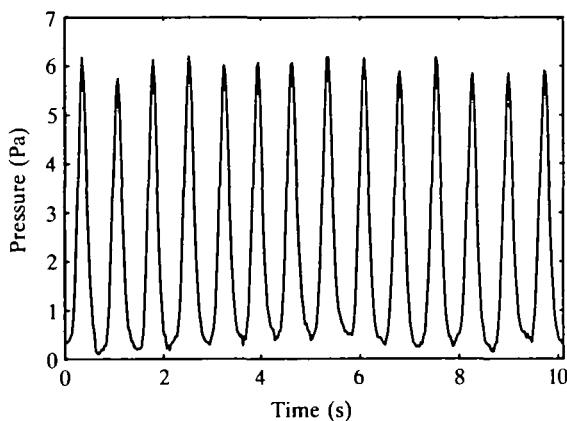


Fig. 3. Pressure fluctuations caused by the humidification and warming of inspired air by a sleeping lesser double collared sunbird, *Nectarinia chalybdea* (mass  $6.89 \text{ g}$ ), in a flow-through plethysmographic respirometer at  $10^\circ\text{C}$  (J. R. B. Lighton & B. Leon, unpublished results). The constant pressure offset was approx.  $1200 \text{ Pa}$ . Mean respiration period was  $0.72 \text{ s}$  ( $1.39 \text{ Hz}$ ), mean amplitude  $5.73 \text{ Pa}$ .

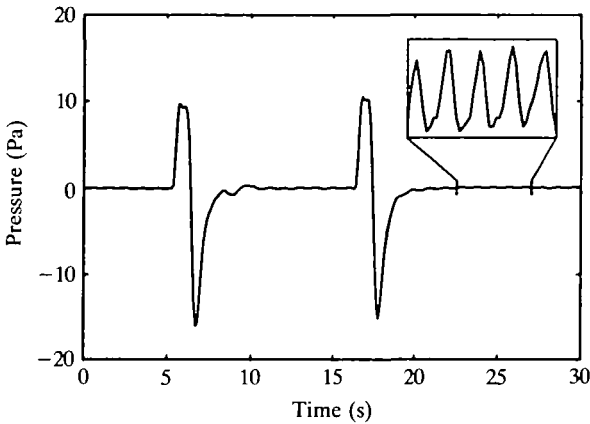


Fig. 4. Pressure fluctuations beneath the cannulated elytra of a *Psammodes striatus* tenebrionid beetle (mass 3.08 g). The large excursions correspond to ventilatory pumping of the abdomen. The much smaller excursions (magnified insert; peak to peak amplitude 0.18 Pa) correspond to the beetle's dorsal vessel pulsations (J. R. B. Lighton, unpublished results).

to floating offset; the voltage at J2 should fluctuate about 0 V with pressure changes. Measure the voltage at J3, and with the gain on 1 $\times$ , adjust VR3 to give a suitable reading corresponding to no pressure differential (e.g. 1.250 V for an A/D converter or chart recorder with an input range of 0–2.500 V). Adjustment is now complete.

In critical applications the pressure sensor should be calibrated against a good manometer, and the slope of sensor output voltage plotted against differential pressure should be recorded (Fig. 2). Because the transducer is primarily employed to measure differences in pressure, offset pressures are first nulled by VR2, and the output voltage of the transducer corresponding to pressure changes is then divided by the gain set by S1 and multiplied by the pressure/voltage slope to yield pressure changes in Pa. If calibrated in this way, and if precision resistors are used for gain determination, the absolute accuracy of the transducer as a whole should be better than 1% over the entire pressure range. Resolution should in any event be better than 0.1 Pa.

Several transducers of this type have been made, and they have proved to be reliable, sensitive and accurate. Figs 3 and 4 show typical results in two very different applications. Both were plotted directly from data captured by a computerized data acquisition and analysis system (Lighton, 1985).

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