

This invention relates to a sensor arrangement for a sensor having a differential output. The arrangement is particularly although not exclusively useful for pressure sensors.

Pressure sensor elements are known to suffer from two major variations namely device to device variations and temperature effects.

Device variations take the form of an offset, which is the voltage output of the sensor for zero applied pressure, which offset differs for different devices, and a variation in the full scale output of the device.

Temperature variations influence both the offset and the full scale of pressure sensors. In respect of the offset the entire output voltage versus pressure characteristic is shifted whilst the effect of temperature changes on the full scale is to change the slope of the characteristic.

It is usual to use an operational amplifier to increase the amplitude of the pressure sensor signal. Such amplifiers themselves introduce errors such as input voltage and current offsets and an input bias current which develop an output voltage offset.

In order to compensate for these amplifier voltage offsets for absolute value and temperature variations it is necessary to utilise precision dedicated operational amplifiers with an extensive calibration procedure, which must be carried out for each sensor-amplifier unit. This procedure can be the most expensive part of the manufacturing process.

This invention seeks to provide an improved sensor arrangement in which the above mentioned problem is mitigated.

According to one aspect of the invention there is provided a sensor arrangement comprising a sensor having first and second outputs; first and second amplifier means; switching means for switching coupling of the first and second sensor outputs between the first and second amplifier means to provide two pairs of amplifier output signals;

control means for controlling switching of the switching means; storage means for storing signals representative of
5 the two pairs of amplifier output signals and combining means for combining the stored signals substantially to cancel amplifier offset voltages.

In a preferred embodiment the sensor is a pressure sensor.

10 The first and second amplifier means are typically operational amplifiers.

The arrangement may further include analogue to digital conversion means for converting the two pairs of amplifier output signals to digital signals to provide said
15 representative signals.

The storage means may conveniently comprise digital storage register means.

In a preferred embodiment the storage means and the combining means are formed by a microcomputer operative to
20 store and combine digital signals derived from said two pairs of amplifier output signals.

The microcomputer may also comprise said control means and has a control output coupled to control the switching of the switching means.

25 According to a second aspect of the invention there is provided a method of processing sensor signals including the steps of switching first and second signals provided by the sensor between first and second amplifier means to provide two pairs of amplifier output signals, storing signals
30 representative of the two pairs of amplifier output signals and combining the stored signals substantially to cancel amplifier offset voltages.

In a preferred embodiment the stored signals of each pair are subtracted from one another within their pairs and
35 the results of the subtractions are combined.

An exemplary embodiment of the invention will now be described with reference to the drawings in which:

Figure 1 shows a sensor arrangement in accordance with the invention; and

Figures 2-3 are explanatory graphs; and

Figure 4 shows part of an alternative embodiment of
5 the sensor arrangement of the invention;

Referring to Figure 1 a pressure sensor 10 which is typically a Motorola MPX 2100AP unit has inputs 1 and 3 which are coupled respectively to supply lines 5 and 6 and has differential outputs 2 and 4.

10 The outputs 2 and 4 of the sensor 10 are coupled to two switches 21 and 22. The switch 21 has inputs 23 and 25 which are respectively coupled to the sensor outputs 2 and 4 whilst the switch 22 has inputs 24 and 26 which are similarly coupled to the sensor outputs 2 and 4.

15 The switch 21 has an output 27 which is coupled to one input 31 of an operational amplifier 30. The switch 22 has an output 28 which is coupled to one input 41 of an operational amplifier 40. The operational amplifiers 30 and 40 are advantageously formed as a single integrated circuit,
20 such as a Motorola MC33078, having supply inputs 32 and 42 respectively coupled to the supply lines 5 and 6.

The operational amplifiers 30 and 40 have outputs 33 and 43 which are coupled to respective input channels 51 and 52 of a microcomputer unit 50. The amplifiers 30 and 40 have
25 second inputs 34 and 44 respectively which are coupled to respective outputs 33 and 43 via respective feedback resistors 35 and 45. A gain control resistor 36 is connected between the second inputs 34 and 44 of the amplifiers 30 and 40.

30 Finally the microcomputer (MCU) 50 has a control output 53 which is coupled to control inputs 20 and 29 of the switches 21 and 22.

In operation the control output 53 of the MCU 50 controls the switches 21 and 22 via control inputs 20 and 29
35 so that the sensor output 2 is coupled via the switch 22 to the operational amplifier 30 and the sensor output 4 is coupled to the operational amplifier 40.

The amplifier 30 provides an output voltage V1 which is coupled to the input 51 of the MCU 50 and the amplifier

40 provides an output voltage V2 which is fed to the input 52 of the MCU 50.

5 The voltages V1 and V2 are converted to digital values by analogue to digital converter means in the MCU 50 and the digital values are stored in the registers R1 and R2.

 The MCU 50 via its control output 53 changes over the switches 21 and 22 so that their inputs are reversed and the
10 sensor output 2 is coupled via the switch 22 to the amplifier 40 whilst the output 4 is connected via the switch 21 to the amplifier 30.

 The amplifier 30 provides an output voltage V1C which is stored in digital form in a register R1C in the MCU 50
15 whilst the amplifier 40 provides an output voltage V2C which is stored in digital form in a register R2C.

 The first transfer function of the arrangement is obtained by combining the contents of the four registers in the following way:

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$$(R1-R2) + (R2C-R1C)$$

 The actual value stored in the MCU is given in counts or bits as:

$$\text{count} = \{(V1-V2) + (V2C-V1C)\} \times \frac{2^n - 1}{VRH-VRL}$$

25 where n is the number of bits of analogue to digital conversion and VRH and VRL are the values of the supply voltages coupled to the lines 5 and 6 respectively.

 Assuming that $V1-V2 = VPS \times AV$ where VPS is the pressure sensor output voltage and AV is the gain of the
30 operational amplifiers, then for 8 bit A to D conversion and a 5 volt supply

$$\text{count} = 2 \times VPS \times AV \cdot \frac{255}{5}$$

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 The MPX 2100AP pressure sensor has a VPS of 20 mV at
35 voltage supply Vs of 5V and a maximum pressure of 100 kPa. With a gain AV of 113 chosen to maximise the number of counts available in the MCU register and the excursion of the output voltage of the amplifier:

$$\text{count} = 0.020 \times 113 \times 102 = 230$$

 The resolution is thus 0.43 kPa per count or bit.

Considering now the above calculation in more detail with respect to the signals involved, the output signals S2 and S4 are provided by the sensor outputs 2 and 4 and we have, with outputs 2 and 4 respectively coupled to amplifiers 30 and 40

$$S2 = a(p) + of2$$

$$S4 = b(p) + of4$$

where a(p) and b(p) are functions of pressure and of2 and of4 are pressure sensor offsets.

$$\text{Thus } V1 = G1(S2+OF1)$$

$$V2 = G2(S4+OF2)$$

where G1 and G2 are the gains of the amplifiers 30 and 40 and OF1 and OF2 are the voltage offsets of those amplifiers.

Reversing the switches 21 and 22 gives

$$V1C = G1(S4+OF1)$$

$$V2C = G2(S2+OF2)$$

$$V1-V2 = G1(S2+OF1)-G2(S4+OF2)$$

$$V2C-V1C = G2(S2+OF2)-G1(S4+OF1)$$

$$\begin{aligned}(V1-V2)+(V2C-V1C) &= G1.S2+G2.S2-G1.S4 \\ &\quad - G2.S4+G1.OF1-G2.OF2 \\ &\quad - G1.OF1+G2.OF2\end{aligned}$$

$$\begin{aligned}&= S2(G1+G2)-S4(G1+G2) \\ &= (G1+G2).(S2-S4)\end{aligned}$$

Thus the offset voltages OF1 and OF2 of the amplifiers 30 and 40 together with temperature variations are completely cancelled.

The final result is

$$\begin{aligned}V_{out} &= G.2.(S2-S4) = G_T[(a(p)+of2)-(b(p)+of4)] \\ &= GT[V(P)+V \text{ offset}]\end{aligned}$$

where GT is the overall gain of the transfer function of the arrangement.

The advantages of the sensor arrangement of the invention are illustrated in the graphical figures 2 and 3.

Figure 2 shows the direct output of the pressure sensor 10. As can be seen the full scale and the offset have a positive TC. The variation of the full scale output with temperature, may be compensated by the use of resistors, namely the resistors 35, 36 and 45 used to fix the gain of the amplifiers.

The overall transfer characteristic of the sensor arrangement of the invention is shown in Figure 3 and has an excellent common mode rejection ratio and minimises the number of external passive components required to set the gain of the amplifiers. The resolution and sensitivity of the digitally converted signal is improved and expensive calibration steps are avoided.

Referring to Figure 4 there is shown part of an alternative embodiment of sensor arrangement in accordance with the invention. Like parts to those in Figure 1 have the same reference numbers.

This embodiment is the same as that of Figure 1 except that the outputs 33 and 34 of the amplifiers 30 and 40 are now fed in turn to a single input port 54 of the microcomputer unit 50 via a switch 60 which is controlled by the MCU 50 by means of a control output 55 coupled to a control input 61 of switch 60. The MCU controls the switch 60 to couple firstly the output of the amplifier 30 followed by the output of the amplifier 40 to its input port 54. As before the voltage outputs of the two amplifiers 30 and 40 are stored, after analogue to digital conversion, in registers R1 and R2.

On commutation of the switches 21 and 22 the process is repeated with the voltage outputs of the amplifiers 30 and 40 being fed in turn to be stored as digital values in registers R1C and R2C. The MCU 50 then performs the calculations as described above with reference to Figure 1.

The invention has been described by way of example and modifications may be made without affecting the scope of the invention. In particular although the invention is particularly useful for pressure sensor applications it may be used with any sensor having a differential output.

Claims

- 5 1. A sensor arrangement comprising a sensor having first and second outputs; first and second amplifier means; switching means for switching coupling of the first and second sensor outputs between the first and second amplifier means to provide two pairs of amplifier output signals;
- 10 control means for controlling switching of the switching means; storage means for storing signals representative of the two pairs of amplifier output signals and combining means for combining the stored signals substantially to cancel amplifier offset voltages.
- 15 2. The arrangement of claim 1 wherein the sensor is a pressure sensor.
3. The invention of claim 1 or 2 wherein the first and second amplifier ^{means} are operational amplifiers.
- 20 4. The arrangement of any preceding claim and further comprising analogue to digital conversion means for converting the two pairs of amplifier output signals to digital signals to provide said representative signals.
- 25 5. The arrangement of any preceding claim wherein the storage means comprises digital storage register means.
- 30 6. The arrangement of claim 1 wherein the storage means and the combining means are formed by a microcomputer operative to store and combine digital signals derived from said two pairs of amplifier output signals.
- 35 7. The arrangement of claim 6 wherein the microcomputer comprises said control means and has a control output coupled to control the switching of the switching means.



8. The arrangement of claim 6 or 7 wherein the microcomputer has first and second inputs coupled to
5 respective ones of the first and second amplifier means.

9. The arrangement of claim 6 or 7 wherein the microcomputer has an input coupled to the first and second amplifier means by second switching means, and a control
10 output coupled to control switching of the second switching means.

10. A method of processing sensor signals including the steps of switching first and second signals provided by the
15 sensor between first and second amplifier means to provide two pairs of amplifier output signals, storing signals representative of the two pairs of amplifier output signals and combining the stored signals substantially to cancel amplifier offset voltages.

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11. The method of claim 8 wherein the stored signals of each pair are subtracted from one another within their pairs and the results of the subtractions are combined.

25 12. A sensor arrangement substantially as herein described with reference to and as shown in the drawings.

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