

# ***Signal Acquisition and Conditioning With Low Supply Voltages***

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## **ABSTRACT**

This application report describes a pressure sensor circuit suitable for use in underwater equipment or in altitude measurement devices. The circuit operates from a 3-V supply and does the analog-to-digital conversions for pressure and temperature measurements.

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## **1 Introduction**

Measurement and control applications increasingly use digital systems to measure analog variables such as temperature, pressure, or light intensity. The analog sensor signals must be converted to a digital data format, and an interface element is needed to link the analog environment to the digital system.

This application report describes a pressure sensor circuit suitable for use in underwater equipment or in altitude measurement devices. The circuit operates from a 3-V supply and does the analog-to-digital (A/D) conversions for pressure and temperature measurements.

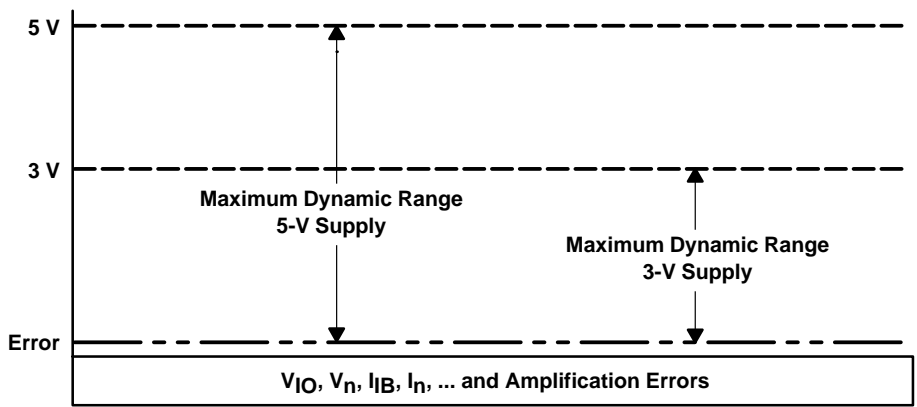
While the use of 3-V sensors in portable systems allows longer operation time, performance must match systems operating on higher supply voltages. This presents a challenge for 3-V sensor systems. The data acquisition system discussed in this report, using the TLV1543 10-bit analog-to-digital converter in conjunction with two microcomputers, attained a 10-bit resolution with 9-bit precision.

## 2 3-V Supply Signal Processing Limitations

Many electronic systems use a 5-V supply because of the widespread use of the SN74 family of logic devices. The demand for improvements in the characteristics and performance of portable electronic equipment, however, led to new families of devices that met the requirements for reduced power consumption and increased operating time in portable applications. Reducing the supply voltage to 3 V achieved the power savings without sacrificing performance.

The high noise immunity of digital signals (an important advantage over analog signals) ensures that the performance of digital circuits does not suffer significantly with a 3.3-V supply voltage. Components doing linear functions, such as operational amplifiers and analog-to-digital converters (ADC), are more sensitive to the effects of noise.

The dynamic range of an operational amplifier operated from a single supply voltage has an upper limit determined by the magnitude of the supply voltage, and a lower limit determined by the sum of all the errors present in the operational amplifier. A reduction in the supply voltage reduces the maximum dynamic range, and thus the overall performance. Figure 1 shows the relationship between supply voltage and dynamic range. Reducing the supply voltage from 5 V to 3 V reduces the dynamic range by 4 to 5 dB.



**Figure 1. The Effect of Supply Voltage on Dynamic Range**

Components that can be driven to the limits (rail-to-rail) of the supply voltage make maximum dynamic range available. Texas Instruments offers a number of such rail-to-rail operational amplifiers in advanced LinCMOS™ technology, for both 5- and 3-V systems.

Based on these requirements, this application uses the TLV2262 operational amplifier that operates rail-to-rail on a single 3-V supply. The TLV2262 is ideally suited for portable applications because it consumes only 200  $\mu$ A per channel.

In this application the operational amplifiers must not overload the pressure sensor. The TLV2262, like many other CMOS operational amplifiers, has PMOS transistors in the input stage, which ensures that the input resistance is extremely high.

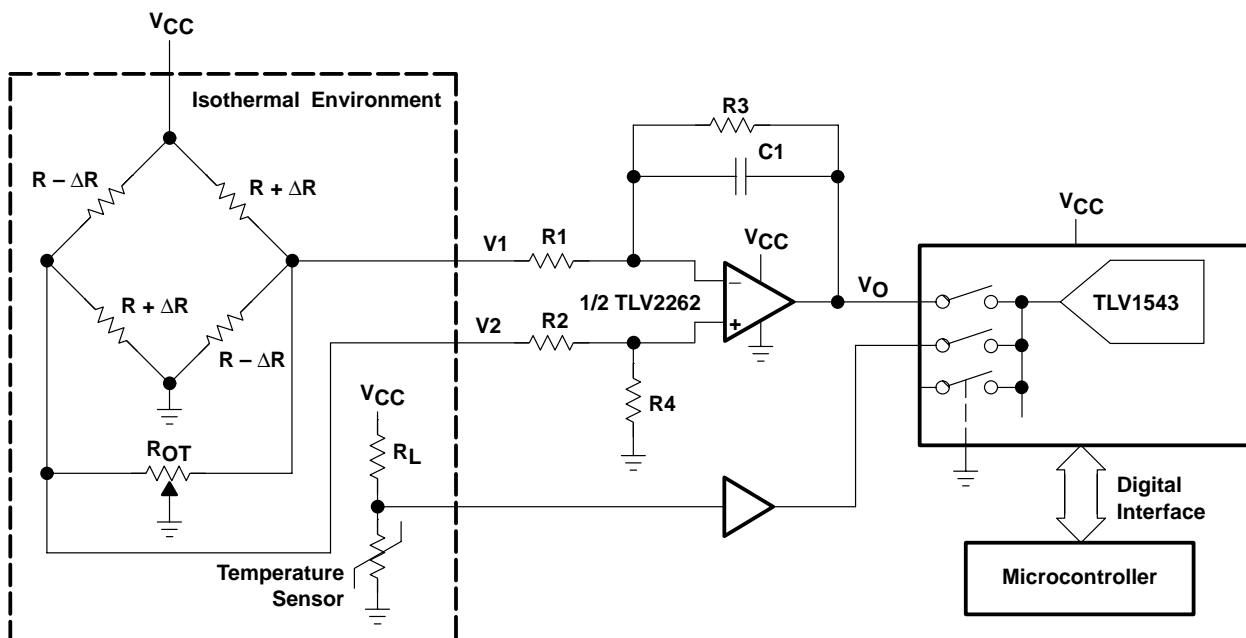
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An additional problem is that operational amplifiers of high dc precision (for example chopper operational amplifiers with input offset voltages,  $V_{IO}$ , of about  $1 \mu\text{V}$ ) are not available for operation with a single 3-V supply. Therefore, in order to achieve sufficient precision, the errors of all the components used are calibrated together. An explanation of this approach is given in Section 3.

The ADC (TLV1543) also operates from a single 3-V supply. The TLV1543 has 11 analog input channels. The integrated input changeover switch makes these ADCs particularly suitable for use in this sensor application. One ADC input channel monitors the amplified sensor signal, and another channel monitors the temperature signal. Section 6.2 gives a detailed description of the TLV1543.

### 3 Circuit Description

Figure 2 shows the pressure measurement circuit. The pressure sensor consists of four piezo-resistive resistors connected to form a Wheatstone bridge. The supply voltage is applied to one of the bridge diagonals, and a potential difference proportional to the applied pressure appears across the second bridge diagonal. This signal is applied to the input of a differential amplifier that consists of the TLV2262 operational amplifier and the resistance network that sets the amplification. Capacitor C1 acts as a low-pass filter to suppress high-frequency interference.



Pressure Sensor: Sensym SX05 or Similar  
 R1 = R2 = 470 kΩ  
 R3 = R4 = 470 kΩ  
 ROT = 500 kΩ (Offset Trimmer)  
 C1 = 50 pF  
 RL = Linerizing Resistor

$$V_O = (V_2 - V_1) \times \frac{R_3}{R_2}$$

for  $\frac{R_3}{R_1} = \frac{R_4}{R_2}$

Figure 2. Pressure Measurement Circuit Diagram

Because the operational amplifier operates from a single positive supply, it can only be driven positive. As a result of the polarity of the pressure sensor offset voltage, and because of the limited region into which the operational amplifier can be driven, the offset voltage of this pressure sensor must be shifted by means of the potentiometer ROT to ensure that the operational amplifier is not overloaded.

The output signal of the operational amplifier is applied to the 10-bit TLV1543 ADC. A microcontroller evaluates the result of the A/D conversion and controls the serial output of the ADC. In addition, a temperature sensor, which includes a series linearization resistor, measures the ambient temperature for each pressure measurement. The temperature signal is applied to a channel on the TLV1543. Section 5 describes the temperature measurement method.



The sensors and the operational amplifier operate as a closed black-box system, which allows the errors resulting from the sensors (for example, temperature coefficient of the offset and bridge resistors) and from the operational amplifiers (for example, the input offset voltage, the input offset current, and the temperature coefficients) to be grouped and treated as a single factor. As explained in Section 2.1, it is important to be able to drive the operational amplifier up to the supply voltage (rail-to-rail), so that the maximum dynamic range can be achieved. The pressure and thermal sensors must be subjected to the same temperature conditions. Figure 2 shows this isothermal part of the circuit enclosed in dotted lines.

Section 4 describes how to calibrate the system.

## 4 System Calibration

The system has two sources of potential errors that must be compensated for when a pressure measurement is taken. These temperature-dependent error sources are the system offset voltage and system amplification. To compensate for these errors, the behavior of the offset voltage and amplification as a function of temperature and pressure must be examined in more detail.

### 4.1 Characteristics of the System

Figure 3 shows that the circuit characteristics are linear at constant temperature.

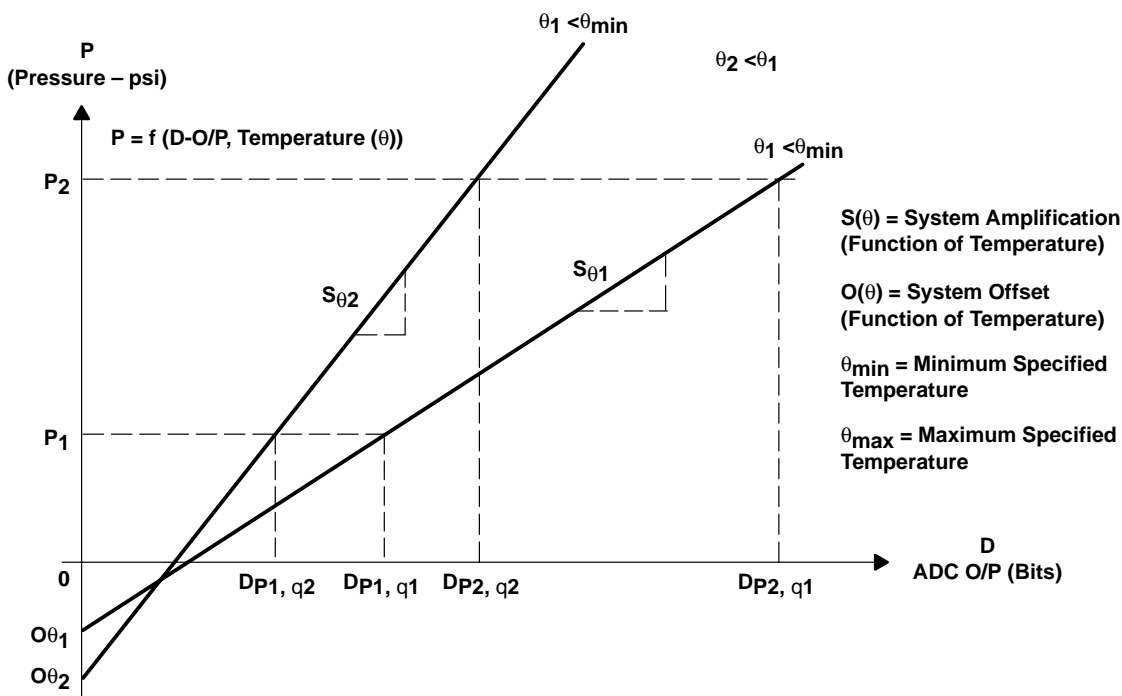


Figure 3. Characteristics of the System

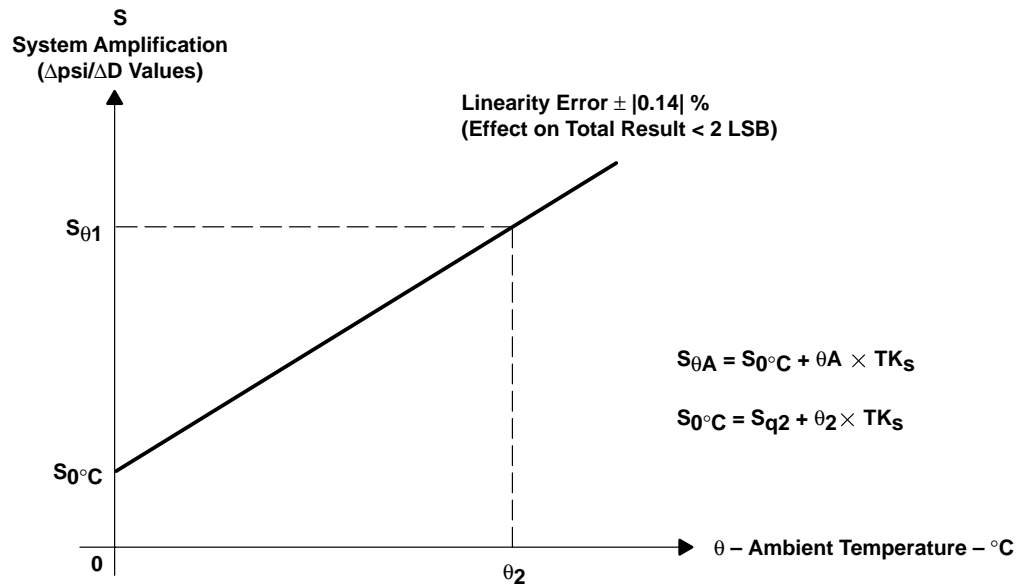
With a constant temperature,  $\theta$ , a linear characteristic having a system slope,  $S(\theta)$ , and an offset value,  $O(\theta)$ , (the intersection with the ordinate) results. These characteristics can be described mathematically as follows:

$$P = D \times S(\theta) + O(\theta)$$

The system slope,  $S(\theta)$ , and the offset value,  $O(\theta)$ , depend on the instantaneous ambient temperature, and it is necessary to deduce these dependencies.

### 4.2 Slope and Offset Behavior

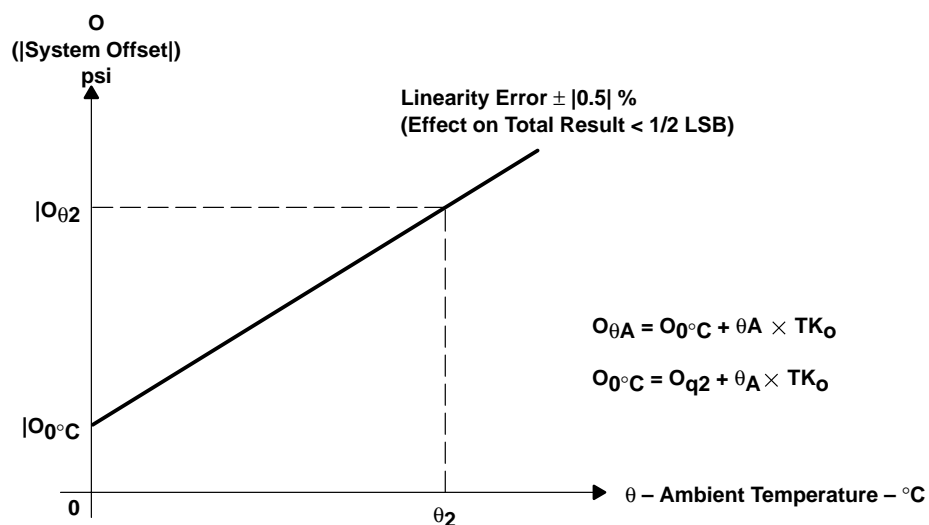
Several measurements used a precise and stable arrangement of the pressure and temperature measuring equipment to establish the temperature coefficients of the system slope and offset. Figure 4 shows the system slope (amplification) as a function of the ambient temperature.



These measurements show that the system amplification as a function of temperature characteristics is close to linear. The linearity error is  $\leq |0.14|\%$ . The effect of this error on the overall precision of the circuit is less than 2 LSB, which makes it possible to consider the system behavior linear, as shown in Figure 4.

The system offset, as a function of temperature, shows similar behavior. It has nearly linear characteristics, with a linearity error of  $\leq |0.5|\%$ ; the effect on overall performance in this case is less than 1/2 LSB. Again, linear behavior can be assumed for the system offset as a function of temperature.

Figure 5 shows the system offset as a function of temperature.



### 4.3 Derivation of the System Formula

The equations for system slope and system offset can be incorporated into an output equation to derive the valid system formula. The derivation of this system formula follows.

Equation for the linear characteristic:

$$P = D' S(q) + O(q) \quad (1)$$

System slope as a function of temperature:

$$S(q) = S_{0^\circ\text{C}} + q_A' TK_S \quad (2)$$

System offset as a function of temperature:

$$O(q) = O_{0^\circ\text{C}} + q_A' TK_O \quad (3)$$

Substituting equations (2) and (3) into the output equation (1) gives the applicable system formula (4):

$$P = D' (S_{0^\circ\text{C}} + q_A' TK_S) + O_{0^\circ\text{C}} + q_A' TK_O \quad (4)$$

Where:

- $P$  = Applied pressure
- $D$  = Digital value of ADC output
- $O_{0^\circ\text{C}}$  = System offset at  $0^\circ\text{C}$
- $O_\theta$  = System offset at temperature  $\theta$
- $S_{0^\circ\text{C}}$  = System slope at  $0^\circ\text{C}$
- $S_\theta$  = System slope at temperature  $\theta$
- $\theta_A$  = Ambient temperature
- $TK_O$  = System offset temperature coefficient
- $TK_S$  = System slope temperature coefficient

After reading the digital pressure and temperature values, the microcomputer uses the system formula to determine the actual pressure.

### 4.4 Calibration Formula

To calibrate the pressure measurement system, the parameters described in Section 4.3 must be determined. To calculate these parameters, four measurement points on two of the curves must be recorded as shown in Figure 3. With these four measurement points, the pressure measurement system can be calibrated using the calibration formulae given below.

#### 4.4.1 Calculation of the Slope Parameters

Slope  $S_{\theta_1}$  of the characteristic:

$$S_{\theta_1} = \frac{P_2 - P_1}{D_{P_2, \theta_1} - D_{P_1, \theta_1}} \quad (5)$$

Slope  $S_{\theta_2}$  of the characteristic:

$$S_{\theta_2} = \frac{P_2 - P_1}{D_{P_2, \theta_2} - D_{P_1, \theta_2}} \quad (6)$$

Temperature coefficient  $TK_S$  of the slope:

$$TK_S = \frac{S_{\theta_2} - S_{\theta_1}}{\theta_2 - \theta_1} \quad (7)$$

Slope  $S$  at  $0^\circ\text{C}$ :

$$S_{0^\circ\text{C}} = S_{\theta_2} - TK_S \quad (8)$$

#### 4.4.2 Calculation of the Offset Parameters

Offset  $O_{\theta_1}$  of the curve:

$$O_{\theta_1} = P_2 - D_{P_2, \theta_1} \times S_{\theta_1} \quad (9)$$

Offset of the curve:

$$O_{\theta_2} = P_2 - D_{P_2, \theta_2} \times S_{\theta_1} \quad (10)$$

Temperature coefficient  $TK_O$  of the offset:

$$TK_O = \frac{O_{\theta_2} - O_{\theta_1}}{\theta_2 - \theta_1} \quad (11)$$

Offset  $O$  at  $0^\circ\text{C}$ :

$$S_{0^\circ\text{C}} = S_{\theta_2} - TK_S \quad (12)$$

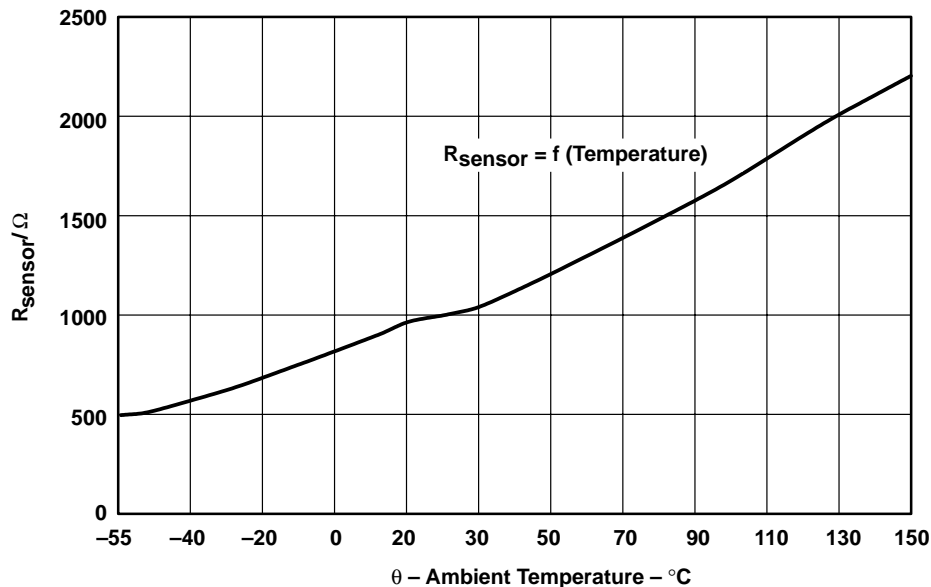
The microcomputer stores the calculated parameters and extracts them for each calculation.

## 5 Temperature Measurement

To compensate for the effects of temperature on the circuit, an ambient temperature measurement is necessary for every pressure measurement. In this application, the ambient temperature is measured with a silicon temperature sensor from Philips, type KTY81–150. The resistance of this sensor changes with temperature.

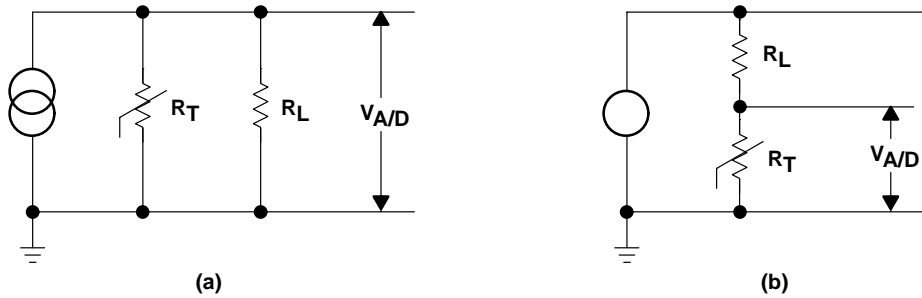
### 5.1 Linearization of the Sensor

Most temperature sensors have non-linear characteristics that must be linearized. Figure 6 shows the resistance characteristics of the temperature sensor used in this application as a function of temperature.



**Figure 6. Characteristics of the Temperature Sensor**

The characteristics of the temperature sensor can be linearized in two ways. If the circuit is fed from a constant current source, a linearization resistor can be connected in parallel with the sensor as shown in Figure 7(a). If the circuit is fed from a constant voltage source, a linearization resistor can be connected in series with the sensor as shown in Figure 7(b). The temperature sensor signal ( $V_{A/D}$ ) is buffered and applied to one of the free channels of the TLV1543 ADC as shown in Figure 2. The microcomputer can then evaluate the digitized value of the temperature.



**Figure 7. Temperature Sensor Linearization**

The value of the linearization resistor depends on the operating temperature range of the circuit. Equation (13) shows how to calculate the linearization resistor value.

$$R_L = \frac{R_M \times (R_1 + R_2) - 2 \times R_1 \times R_2}{R_1 + R_2 - 2 \times R_M} \tag{13}$$

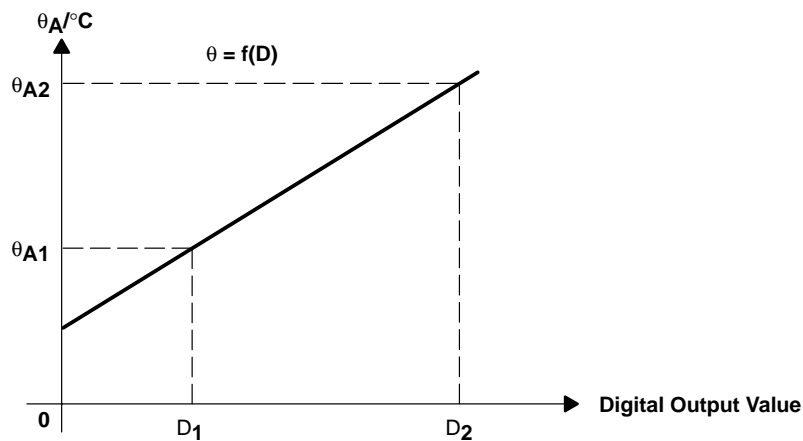
Where:

- $R_1$  = Sensor resistance at minimum temperature
- $R_2$  = Sensor resistance at maximum temperature
- $R_M$  = Sensor resistance at the average temperature

The linearization resistor reduces the linearity error to  $< \pm 0.15^\circ\text{C}$ . This represents an error of less than 1/2 LSB for the complete system.

## 5.2 Sensor Calibration

After linearization, the temperature sensor can be calibrated. A calibration formula for the microcomputer can be derived from the characteristics of the temperature sensor circuit. Figure 8 shows the characteristic of the circuit which represents the behavior of the digital value of the output as a function of the ambient temperature,  $\theta_A$ . Because it is a straight-line characteristic, two points on the characteristic curve determine the value of this linear expression.



**Figure 8. The Digital Value of the Output as a Function of the Temperature**

Equation (14) shows the linear expression for this characteristic.

$$\theta = D \times S_{\theta} + O_{\theta} \quad (14)$$

Where:

- $\theta$  = Correct temperature
- $D$  = A/D conversion value of the temperature measurement
- $S_{\theta}$  = Calibration parameter for the slope of the curve
- $O_{\theta}$  = Calibration parameter for the offset of the curve

Equations (15) and (16) are used to calculate the parameters  $S_{\theta}$  and  $O_{\theta}$ .

For calculating these parameters,  $\theta_{A_2}$  must be less than  $\theta_{A_1}$ .

$$S_{\theta} = \frac{\theta_{A_2} - \theta_{A_1}}{D_2 - D_1} \quad (15)$$

$$O_{\theta} = \theta_{A_2} - D_2 \times S_{\theta} \quad (16)$$

Where:

- $\theta_{A_1}$  = Ambient temperature 1
- $\theta_{A_2}$  = Ambient temperature 2
- $D_1$  = A/D conversion value of ambient temperature 1
- $D_2$  = A/D conversion value of ambient temperature 2

With these parameters and the linear expression (14), the microcomputer can calculate the exact value of the temperature using the results of the A/D conversion. This temperature value is needed in the system formula for calculating the actual pressure.



## 6 Interfaces

This section describes how to construct an interface between the TLV1543 and the TMS70C42 and MC68B11 microcomputers. The TMS70C42 microcomputer from Texas Instruments and the MC68B11 microcomputer from Motorola™ were chosen because they can operate from a 3.3-V supply.

### 6.1 TLV1543 ADC

The TLV1543 is a 10-bit ADC that operates from a single 3.3-V supply and has 11 analog input channels and a serial output channel. The TLV1543 uses successive-approximation conversion and capacitors in binary steps to achieve a maximum conversion time of 21  $\mu$ s. The serial interface to the microcomputer consists of five lines: I/O clock, chip select, address input, data output, and EOC (end of conversion).

Figure 9 shows the functional block diagram of the TLV1543. The converter contains a 14-channel analog multiplexer. Eleven of the fourteen channels are used for analog inputs, and three are used for a self-test. The self-test can be used later for tests on the complete system. A sample-and-hold stage follows the multiplexer. The voltage stored at this point is applied to a 10-bit converter. The converted data is read into a data register and converted from parallel to serial form. The input address register controls the multiplexer, and the control logic controls the functional blocks of the converter. After a conversion cycle, the converter outputs an EOC signal.

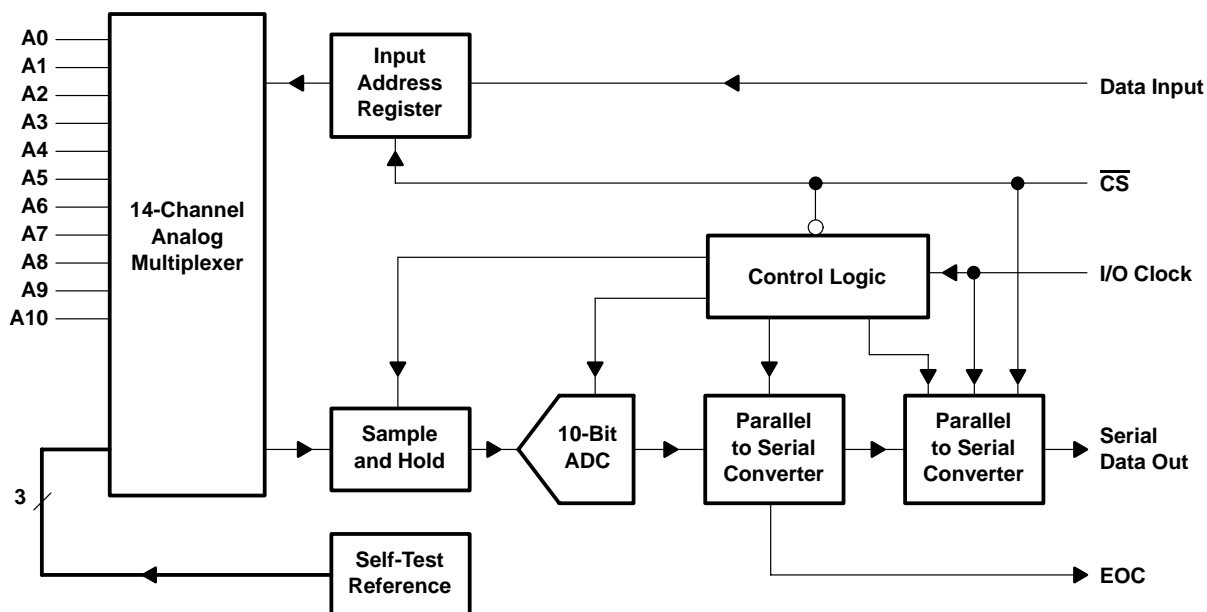


Figure 9. Functional Block Diagram of the TLV1543

### 6.2 TLV1543 Interface to TMS70C42

Figure 10 shows the connections between the TLV1543 and the TMS70C42 microcomputer. The interface consists of three port A inputs/outputs and one port B input. The internal port A direction register (ADDR) programs the direction of data flow from port A. Port B is an output-only port.

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The ADC positive reference (REF+) is connected to the supply voltage, and the negative reference (REF-) is connected to ground (GND).

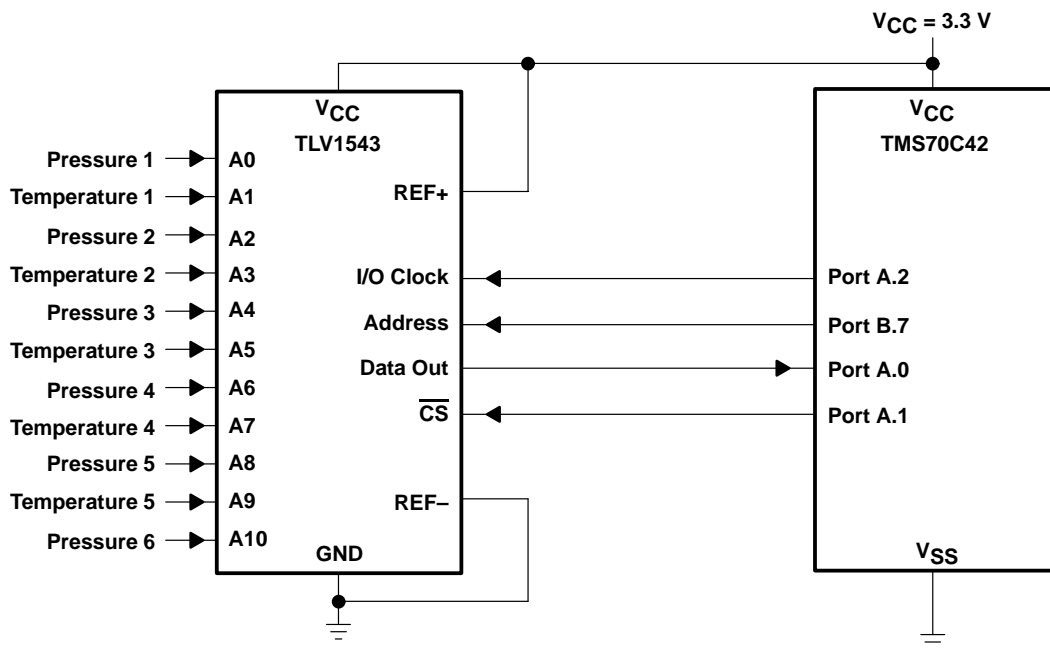


Figure 10. TMS70C42 Interface

### 6.2.1 Chip Select ( $\overline{CS}$ ) Signal

Because bit 1 from port A on the TMS70C42 controls the  $\overline{CS}$  signal, bidirectional port A.1 must be programmed as an output. The interface program must include an appropriate delay loop to maintain a high level on  $\overline{CS}$  for at least 21  $\mu$ s.

### 6.2.2 I/O Clock Signal

Bidirectional port A.2 on the TMS70C42 must also be programmed as an output to supply the I/O clock signal for the TLV1543. The interface program shown in Listing 1 generates the clock signal.

### 6.2.3 Address Data

Unidirectional port B.7 transmits the ADC address data for the channel to be converted.

### 6.2.4 Data Out

Because the ADC output is applied to port A, bit 0, the bidirectional port A.0 must be programmed as an input. The 10 data bits, controlled by two program loops, are read into registers R10 and R11 for further processing.

Figure 11 shows the pulse timing diagram for a 10-bit transfer making use of the  $\overline{CS}$  signal.

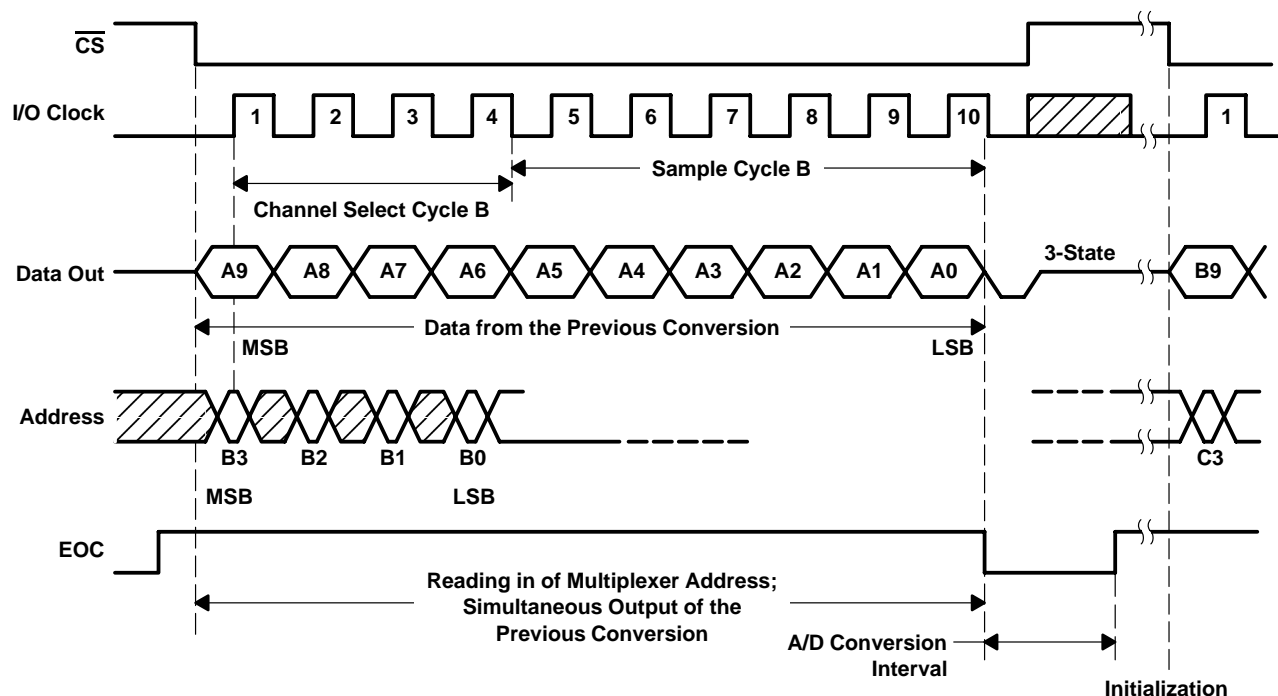


Figure 11. Timing Diagram of the TLV1543 and TMS70C42

### 6.2.5 Interface Program

Listing 1 is an example program for controlling the interface between the TLV1543 and the TMS70C42 (see Figure 10). This program shows how the TMS70C42 microcomputer controls the TLV1543 ADC and how the results of a conversion can be read out.

#### Listing 1. TMS70C42 Interface Program

```

0001 *****
0002 *                               TLV1543 - TMS70C42 Interface Program                               *
0003 *                                                                                                                                           *
0004 * This program shows an example of how the functions of                                     *
0005 * TLV1543 A/D Converter can be controlled via the Port A and*
0006 * Port B (A0, A1, A2 and B7)of the microcomputer, and how *
0007 * the conversion results can be read out. *
0008 *****
0009
0010 0000
0011 0004 APORT EQU P4 * * * * *
0012 0005 ADDR EQU P5 * Name of the register *
0013 0006 BPORT EQU P6 * * * * *
0014 F006 AORG >F006 Load start address of
0015 F006 52 INIT MOV %>60,B program 60h in B register
0016 F007
0017 F008 0D LDSP Load pointer to stack
0018 F009 72 MOV %>02,R4 Load control variable
0019 F00A 02
0019 F00B 04
0019 F00C A2 MOVP %>06,ADDR Data flow from Port A
0019 F00D 06
0019 F00E 05
    
```

```

0020 F00F 72 LOOP1 MOV    %>00,R10   R10 for converted data
      F010 00
      F011 0A
0021 F012 72      MOV    %>00, R11   R11 for converted data
      F013 00
      F014 0B
0022 F015 A2      MOVVP  %>20, BPORT Setting of the ADC channel
      F016 20
      F017 06
0023 F018 A4      ORP    %>02, APORT Set CS from Low to High
      F019 02
      F01A 04
0024 F01B A3      ANDP   %>FD, APORT Set CS from High to Low
      F01C FD
      F01D 04
0025 F01E 72      MOV    %>08, R2    Set control variable
      F01F 08
0026 F020 02
0027 F021 72      MOV    %>02, R3    Set control variable
      F022 02
      F023 03
0028 F024 91 LOOP2 MOVVP  APORT, B    PORT A (Bit A0 contains)
      F025 04
0029 F026 CD      RRC    B          Load data bit in CARRY FLAG
0030 F027 DF      RLC    R10         and thence into Register 10
      F028 0A
0031 F029 D2      DEC    R2          Decrement R2
      F02A 02
0032 F02B A4      ORP    %>04, APORT Clock from Low to High
      F02C 04
      F02D 04
0033 F02E A3      ANDP   %>FB, APORT Clock from High to Low
      F02F FB
      F030 04
0034 F031 91      MOVVP  BPORT, B    Channel address into
      F032 06                REGISTER B
0035 F033 CE      RL     B          Shift left
0036 F034 92      MOVVP  B, BPORT   Channel address to PORT B
      F035 06
0037 F036 76      BTJO   %>FF, R2, LOOP2 Query if R2=0
      F037 FF
      F038 02
      F039 EA
0038 F03A 91 LOOP3 MOVVP  APORT, B    PORT B to Register B
      F03B 04
0039 F03C CD      RRC    B          Load data bit into CARRY FLAG
0040 F03D DF      RLC    R11         and from there to Register 10
      F03E 0B
0041 F03F D2      DEC    R3          Decrement R3
      F040 03
0042 F041 A4      ORP    %>04, APORT Clock from Low to High
      F042 04
      F043 04
0043 F044 A3      ANDP   %>FB, APORT Clock from High to Low
      F045 FB
      F046 04
0044 F047 76      BTJO   %>FF, R3, LOOP3 Query if R3=0
      F048 FF
      F049 03
      F04A EF

```

```

0045 F04B A4      ORP    %>02, APORT PORT B to Register B
      F04C 02
      F04D 04
0046 F04E D2      DEC    R4
      F04F 04
0047 F050 76      BTJO   %>FF, R4, LOOP1 Query if R4=0
      F051 FF
      F052 04
      F053 BB
0048                                END

```

Table 1 shows which address must be loaded into the BPORT register to select the desired multiplexer input.

**Table 1. Channel Addresses**

ANALOG INPUT	HEX ADDRESS
A0	00
A1	10
A2	20
A3	30
A4	40
A5	50
A6	60
A7	70
A8	80
A9	90
A10	A0

Table 2 shows how the BPORT register must be loaded to address an ADC test function. In addition, the table gives the hexadecimal output value for each test function. In this case,  $V_{ref+}$  is the voltage which appears at the REF+ input of the ADC, and  $V_{ref-}$  is the voltage appearing at the ADC REF- input.

**Table 2. Test Input Addresses**

TEST INPUT	HEX ADDRESS	HEX OUTPUT VALUE
$\frac{V_{ref+} - V_{ref-}}{2}$	B0	200
$V_{ref+}$	C0	000
$V_{ref-}$	D0	3FF

### 6.3 TLV1543 Interface to MC68B11

A microcomputer equipped with a serial peripheral interface (SPI) is the most effective method for controlling the mode and data flow of the TLV1543. The MC68B11 used in this application has an SPI.

Figure 12 shows the SPI connections between the TLV1543 and the MC68B11. REF+ connects directly to  $V_{CC}$ , and REF- connects to GND. The four digital interface connections (SCK/PD4, MOSI/PD3, MISO/PD2, and SS/PD5) connect directly to the TLV1543. The following paragraphs describe this interface.

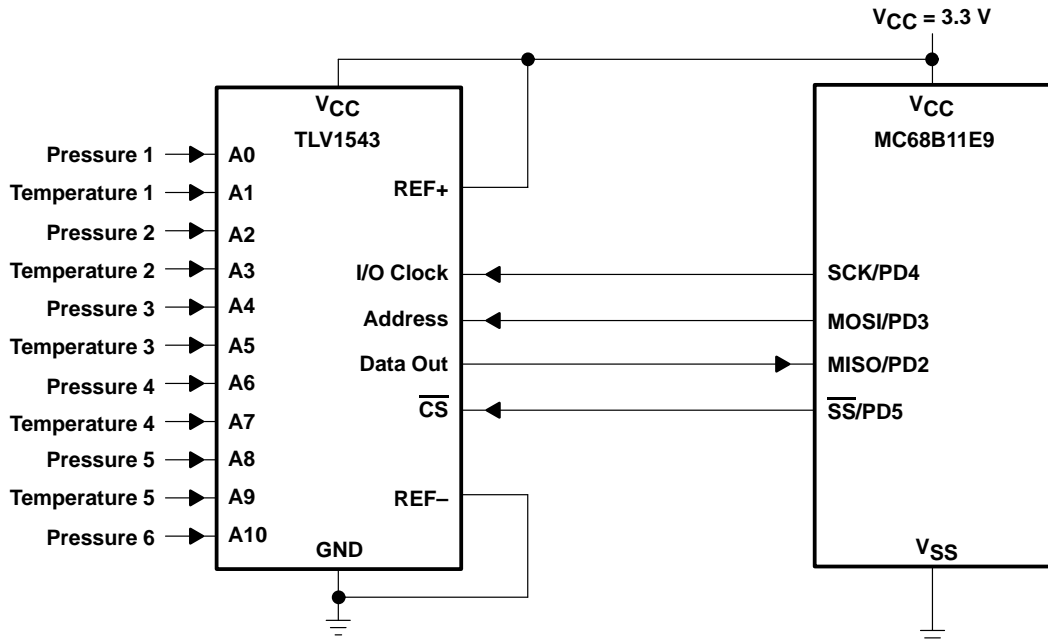


Figure 12. MC68B11 Interface

### 6.3.1 Serial Peripheral Interface (SPI)

The SPI (see Figure 13) consists of a serial 8-bit shift register, which is loaded with the data that needs to be sent to the ADC address input.

The SPI transfer begins simultaneously with the loading of this register. A microprogram controls the serial transfer of the data from the master-out-slave-in (MOSI) pin of the microcomputer to the ADC address input. At the same time the ADC transmits data from the previous conversion to the master-in-slave-out (MISO) pin of the microcomputer. This data is loaded into the shift register. At the end of a transmission cycle (8 bit), the contents of the shift register are loaded into the read data buffer, from where the program can read out the data.

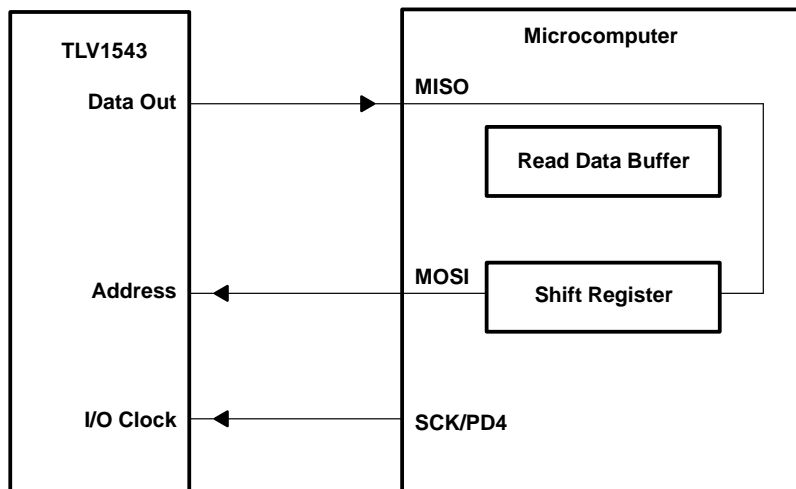


Figure 13. The Internal Structure and Data Flow of the SPI

The SPI provides the following features:

- Simultaneous data input and output
- Synchronous processing
- Shift clock pulse SPICLK with programmable frequency
- Internal flag to indicate the ending of a transmission cycle

The following SPI registers are essential for communication through the SPI:

- Serial peripheral control register (SPCR)
- Serial peripheral status register (SPSR)
- Serial peripheral data I/O register (SPDR)
- Data direction control register (DDRD)

#### **6.3.1.1 Serial Peripheral Control Register (SPCR)**

Bits 0 and 1 of this register program the SPI bit rates. These bits set the frequency of the SPICLK to 1/2, 1/4, 1/16, or 1/64 of the processor clock frequency.

Bit 2 sets the data transfer format; it must be set to 0 for correct operation with the TLV1543. Bit 4 must be set to 1 to make the microcomputer the master. A 1 in bit 6 switches on the SPI.

#### **6.3.1.2 Serial Peripheral Status Register (SPSR)**

A 1 in bit 7 (SPIF) of this register indicates that a data transfer has been completed between the microcomputer and the TLV1543. A loop in the program requests the status of the data transfer.

#### **6.3.1.3 Serial Peripheral Data I/O Register (SPDR)**

When the SPIF bit of register SPSR is set to 1, the SPDR register contains the information received from the ADC. The register can now be read out and processed as required.

#### **6.3.1.4 Data Direction Register (DDRD)**

Bits 5, 4, 3, and 2 of the DDRD register contain the SPI when it is active. The contents of this register control communication to the TLV1543. Bit 5 is an output register, so that pin SS/PD5 controls the chip select ( $\overline{CS}$ ) connection to the ADC. Bit 4 activates the SCK output (clock), and bits 3 and 2 define the microcomputer as master. This register must be loaded with the data word 58 hex.

### **6.3.2 Timing Relationship of the TLV1543 and SPI**

The SPI transmits 8 bits. Because the ADC in the TLV1543 has a resolution of 10 bits, the data transfer must be performed twice to get a complete conversion result. Figure 14 shows the pulse timing diagram for the transmission of a complete conversion result.

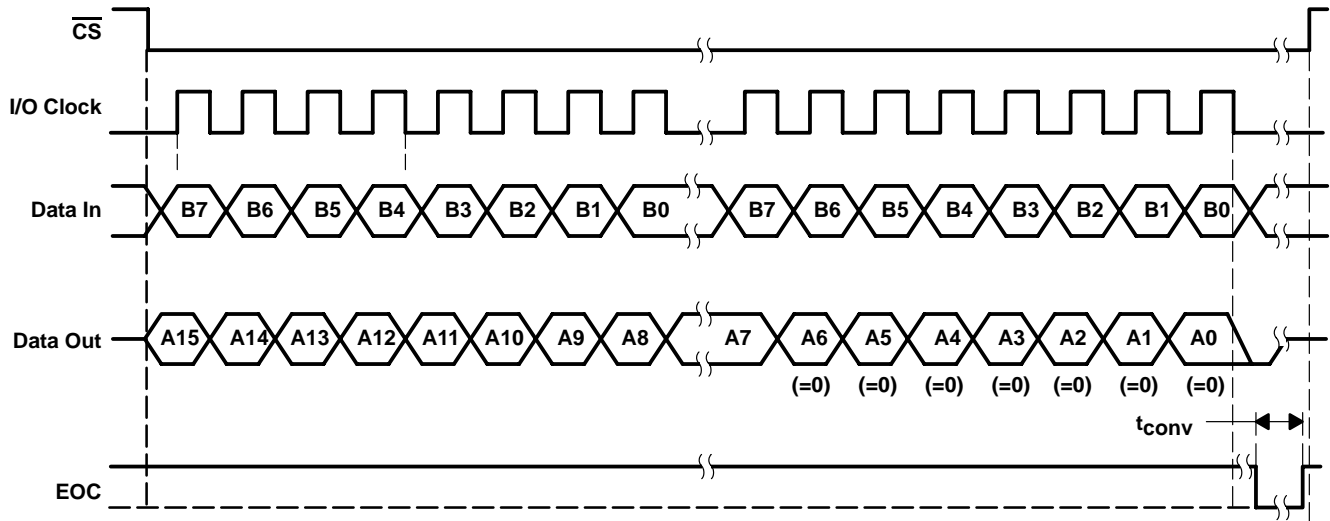


Figure 14. Pulse Timing Diagram for Data Transfer From TLV1543 To SPI

### 6.3.3 The MC68B11 Interface Program

Listing 2 is the program for interfacing the TLV1543 to the MC68B11. It shows how the ADC is controlled by the MC68B11 through the SPI, and how the conversion result is read out. In addition, it shows the configuration of the SPI.

The CHANNEL variable sets the channel number and the test mode. The addressing is done the same as with the TLV1543 interface to the TMS70C42, as shown in Tables 1 and 2.

#### Listing 2. MC68B11 Interface Program

```

0001      * * * * *
0002      *
0003      * This program shows an example of how the
0004      * function of the A/D Converter TLV1543 can be
0005      * controlled with the use of an SPI interface,
0006      * and how the conversion results can be
0007      * read out.
0008      *
0009      * * * * *
0010 1000  BASEADD EQU  $1000      Register Offset Address
0011 0008  PORTD   EQU  $08        Port D Data Register
0012 0009  DDRD   EQU  $09        PORT D Data Dir Register
0013 0028  SPCR   EQU  $28        SPI Control Register
0014 0029  SPSR   EQU  $29        SPI Status Register
0015 002a  SPDR   EQU  $2A        SPI Data Register
0016 01f0  MSBYTE EQU  $1F0       MSBYTE Address
0017 01f1  LSBYTE EQU  $1F1       LSBYTE Address
0018 01ff  MEMOL  EQU  $01FF      Memory Location Low Byte
0019 01fe  MEMOH  EQU  $01FE      Memory Location High Byte
0020 01f   COUNTER EQU  $1F2      Loop Counter
0021 01f3  CHANNEL EQU  $1F3      Channel Number
0022
0023 b600                ORG  $B600      Start Address
0024 b600 8e             LDS  #$0041     Set Pointer to Stack
      b601 00

```



```

    b602 41
0025 b603 ce          LDX  #BASEADD
    b604 10
    b605 00
0026 b606 86          LDAA #38          Load Accumulator with 38Hex
    b607 38
0027 b608 a7          STAA DDRD,X      Load DDRD with 38Hex
    b609 09
0028 b60a 86          LDAA #50          Load Accumulator with 50Hex
    b60b 50
0029 b60c a7          STAA SPCR,X      Set SPI as Master
    b60d 28
0032 b60e 86          LDAA #10         Channel Number under Variable
    b60f 10
0033 b610 b7          STAA CHANNEL    Store CHANNEL
    b611 01
    b612 f3
0034 b613 86          LDAA #01         Load COUNTER for program
    b614 01                                pass repeated twice
0035 b615 b7          STAA COUNTER
    b616 01
    b617 f2
0036 b618 bd  LOOP   JSR  TLV1543    Start conversion
    b619 b6
    b61a 27
0037 b61b bd          JSR  STORE      Store result
    b61c b6
    b61d 52
0038 b61e b6          LDAA COUNTER    Routine
    b61f 01
    b620 f2
0039 b621 4a          DECA          for a
0040 b622 b7          STAA COUNTER    program pass
    b623 01
    b624 f2
0041 b625 26          BNE  LOOP      repeated twice
    b626 f1
0043                  END
0044
0045 b627 86  TLV1543 BSET PORTD,X#$20 Set Chip Select to High
    b628 08
    b629 20
0047 b62a 86          LDAA #02         Chip Select = High
    b62b 02
0048 b62c 4a  CSHIGH DECA          for at least 21 us
0049 b62d 26          BNE  CSHIGH
    b62e fd
0050 b62f 1d          BCLR PORTD,X#$20 Switch Chip Select to Low
    b630 08
    b631 20
0051 b632 b6  MSB    LDAA CHANNEL    Load channel
    b633 01
    b634 f3
0052 b635 a7  STAA   SPDR,X      Send channel to ADC
    b636 2a
0053 b637 1f  LOOP1  BRCLR SPSR,X#$80 LOOP1    If SPIF=0, --> LOOP1
    b638 29
    b639 80
    b63a fc
0054 b63b a6          LDAA SPDR,X    Load received data in accumulator

```

```

    b63c 2a
0055 b63d b7          STAA MSBYTE  Store accumulator contents in MSBYTE
    b63e 01
    b63f f0
0056 b640 b6  LSB    LDAA CHANNEL    Load channel
    b641 01
    b642 f3
0057 b643 a7          STAA SPDR,X    Send channel to ADC
    b644 2a
0058 b645 1f  LOOP2  BRCLR SPSR,X#$80 LOOP2    If SPIF=0, --> LOOP2
    b646 29
    b647 80
    b648 fc
0059 b649 a6          LDAA SPDR,X    Store received data in accumulator
    b64a 2a
0060 b64b b7          STAA LSBYTE  Store contents of accumulator in LSBYTE
    b64c 01
    b64d f1
0063 b64e 39  RETURN  RTS
0064
0065 b64f b6  STORE   LDAA MSBYTE    Load Accumulator A with MSBYTE
    b650 01
    b651 f0
0066 b652 f6          LDAB LSBYTE    Load Accumulator B with LSBYTE
    b653 01
    b654 f1
0067 b655 04          LSRD
0068 b656 04          LSRD
0069 b657 04          LSRD
0070 b658 04          LSRD
0071 b659 04          LSRD
0072 b65a 04          LSRD
0073 b65b b7          STAA MEMOH    Store in MEMOH
    b65c 01
    b65d fe
0074 b65e f7          STAB MEMOL    Store in MEMOL
    b65f 01
    b660 ff
0075 b661 39  RETURN  RTS

```

## 7 Program Flow Diagram

Figure 15 shows the program structure for measuring pressure.

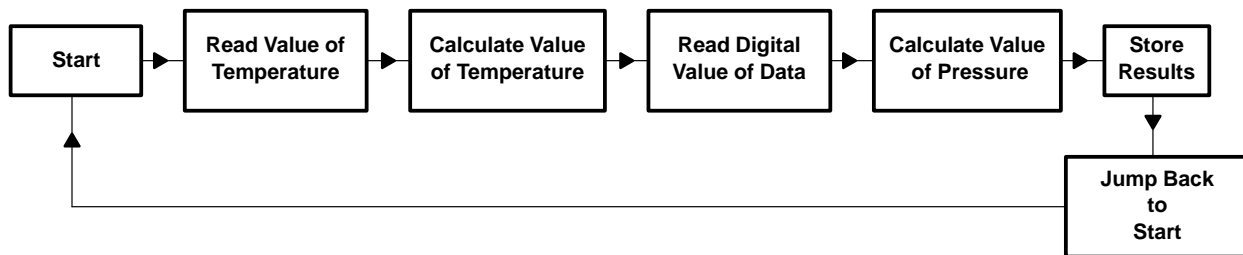


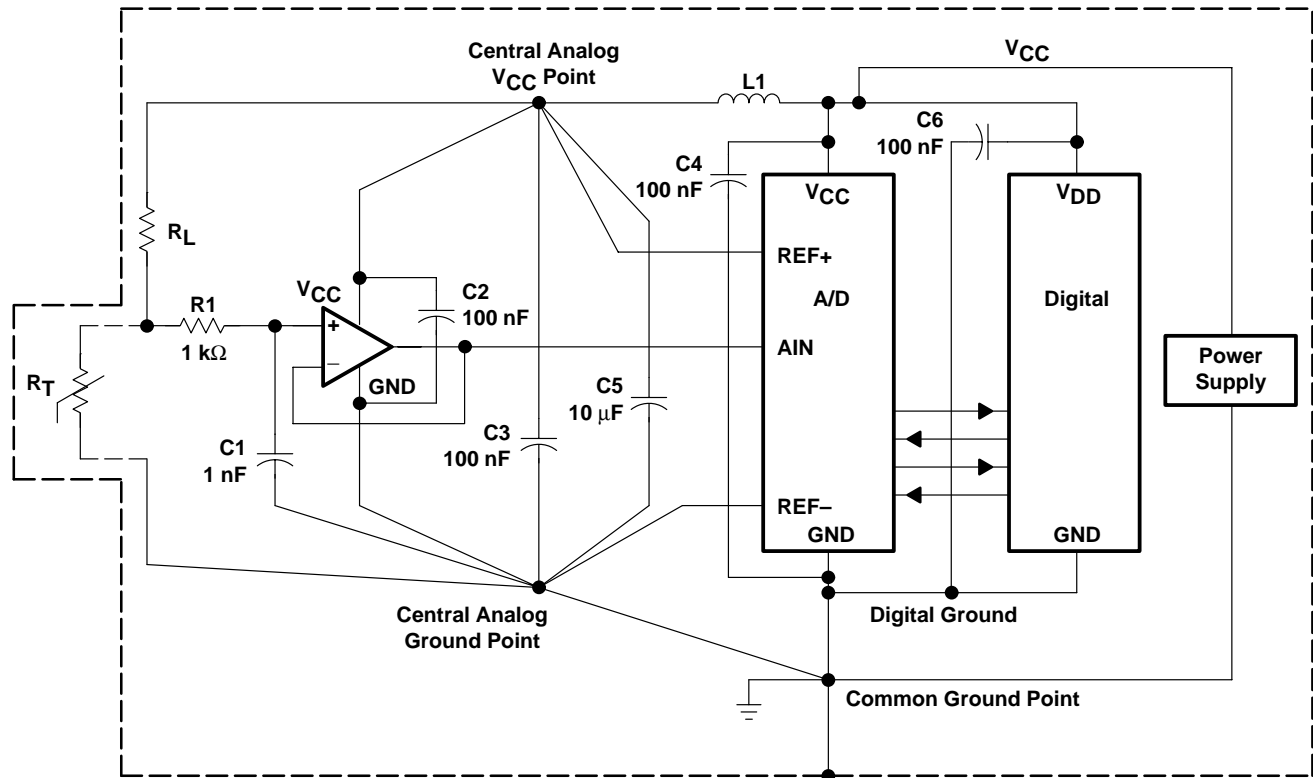
Figure 15. Program Flow Diagram

## 8 Circuit Construction

Printed circuit board (PCB) layout is critical for analog circuits. The analog circuit supply must be free of interference, such as hum and high-frequency voltage peaks. In contrast to digital circuits, where connections must be kept as short as possible to minimize inductance, it is customary to connect analog circuits in a star configuration around  $V_{CC}$  and ground connections. This prevents interference voltages from coupling to other parts of the circuit through common supply lines. Figure 16 shows a proposed layout for the temperature-measurement circuit.

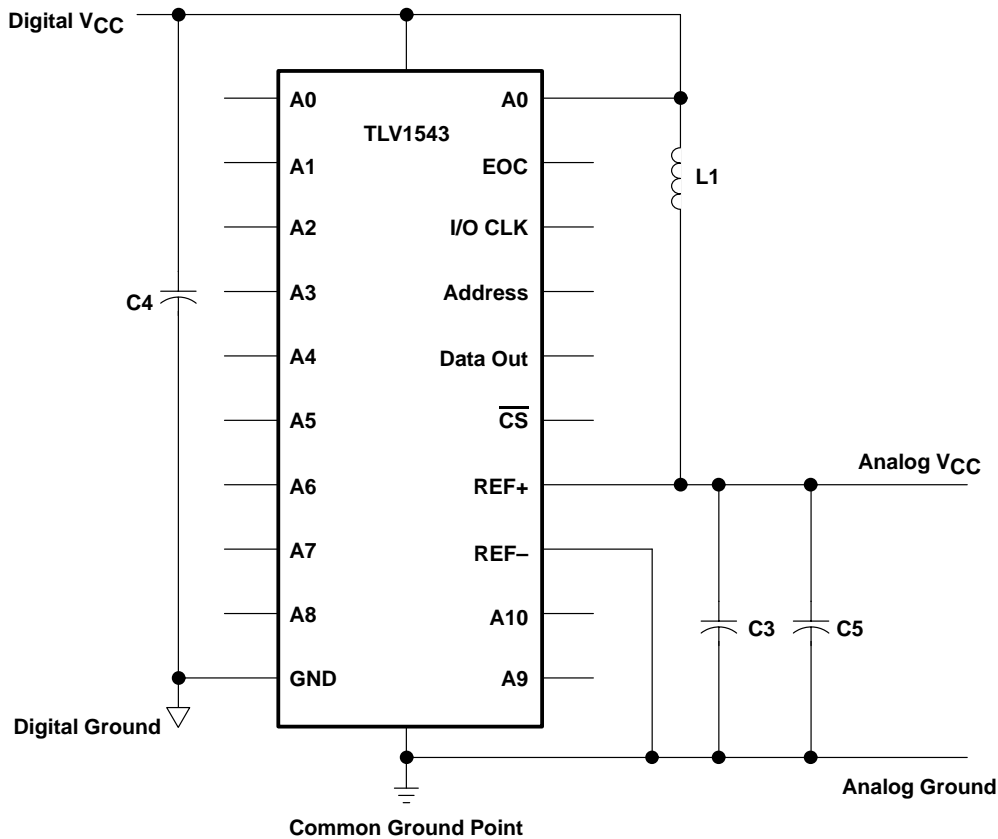
This circuit uses a single supply voltage for the digital and analog components. Inductor L1 and bypass capacitor C3 reduce high-frequency noise from digital-circuits. Electrolytic capacitor C5 suppresses low-frequency interference. The central analog grounding point is critical. The correct layout avoids undesirable coupling of measurement data signals. Such coupling causes errors in the measurement results. The reference voltage connections (REF+ and REF-) of the ADC are part of the analog circuit and are therefore connected directly to the central analog  $V_{CC}$  and ground points.

An RC network connected to the non-inverting input of the operational amplifier suppresses high-frequency interference coupled in through the sensor. Even when the frequency of the interference is beyond the operational amplifier range of operation, the danger exists that these voltages can be rectified by the non-linear characteristics of the semiconductors and be added to the measurement signal.



**Figure 16. Proposed Wiring Layout**

The TLV1543 ADC used in this application has a single common ground point (GND) for the internal analog and digital circuits. The analog and digital supply voltages are referenced to this common ground point. A large grounded area is recommended under the ADC. Figure 17 shows a proposed PCB layout for the TLV1543. The analog and digital grounds are tied to the common ground point, as shown in Figure 16. The screening and grounding connections, if available, are also tied to the common ground point.



**Figure 17. TLV1543 Proposed Layout**

Placement of the bypass capacitors relative to the active components is important when laying out the circuit board. Bypass capacitors provide a low-impedance path to shunt high frequencies to ground; this keeps high frequencies out of the supply voltage and avoids undesirable feedback and coupling paths. In addition, bypass capacitors provide the energy required for rapid load changes, a factor that applies particularly (but not exclusively) to digital circuits. To meet the high-frequency requirements, 100 nF ceramic bypass capacitors are used. Large (50  $\mu$ F) electrolytic bypass capacitors can be added to broaden the range of frequencies shunted to ground.

## 9 Summary

This application report has demonstrated that it is possible to construct an accurate and reliable signal acquisition and conditioning system using low supply voltages. Separate analog and digital ground planes reduce the impedance of the return lines and simplify the PCB layout.

## References

1. *TMS7000 Family Data Manual*, Texas Instruments Incorporated
2. *MC68HC11 Reference Manual*, Motorola
3. *TLV1543 Data Sheet*, Texas Instruments Incorporated
4. *Semiconductor Sensors Data Handbook*, Philips