Signal Acquisition and Conditioning With Low Supply Voltages

SLAA018
August 1997

TEXAS INSTRUMENTS

IMPORTANT NOTICE

Texas Instruments (TI) reserves the right to make changes to its products or to discontinue any semiconductor product or service without notice, and advises its customers to obtain the latest version of relevant information to verify, before placing orders, that the information being relied on is current.

TI warrants performance of its semiconductor products and related software to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

Certain applications using semiconductor products may involve potential risks of death, personal injury, or severe property or environmental damage ("Critical Applications").

TI SEMICONDUCTOR PRODUCTS ARE NOT DESIGNED, INTENDED, AUTHORIZED, OR WARRANTED TO BE SUITABLE FOR USE IN LIFE-SUPPORT APPLICATIONS, DEVICES OR SYSTEMS OR OTHER CRITICAL APPLICATIONS.

Inclusion of TI products in such applications is understood to be fully at the risk of the customer. Use of TI products in such applications requires the written approval of an appropriate TI officer. Questions concerning potential risk applications should be directed to TI through a local SC sales office.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards should be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein. Nor does TI warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used.

Copyright © 1997, Texas Instruments Incorporated

Contents

List of Figures

Signal Acquisition and Conditioning With Low Supply Voltages

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.

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.

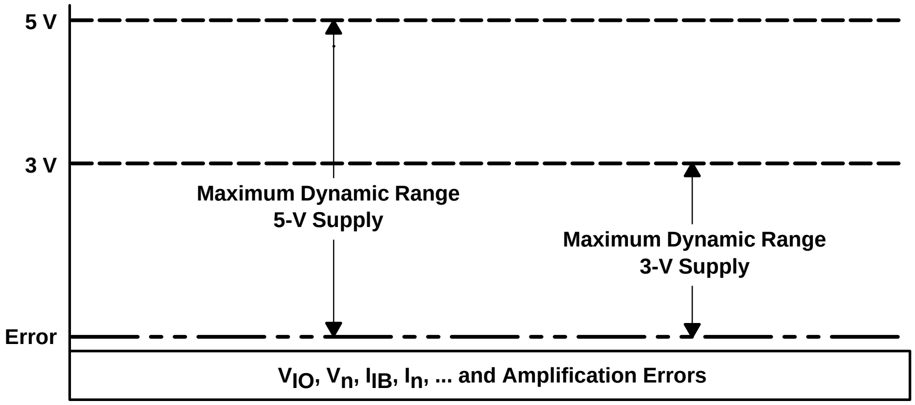


Figure 1. The Effect of Supply Voltage on Dynamic Range

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 µA 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.

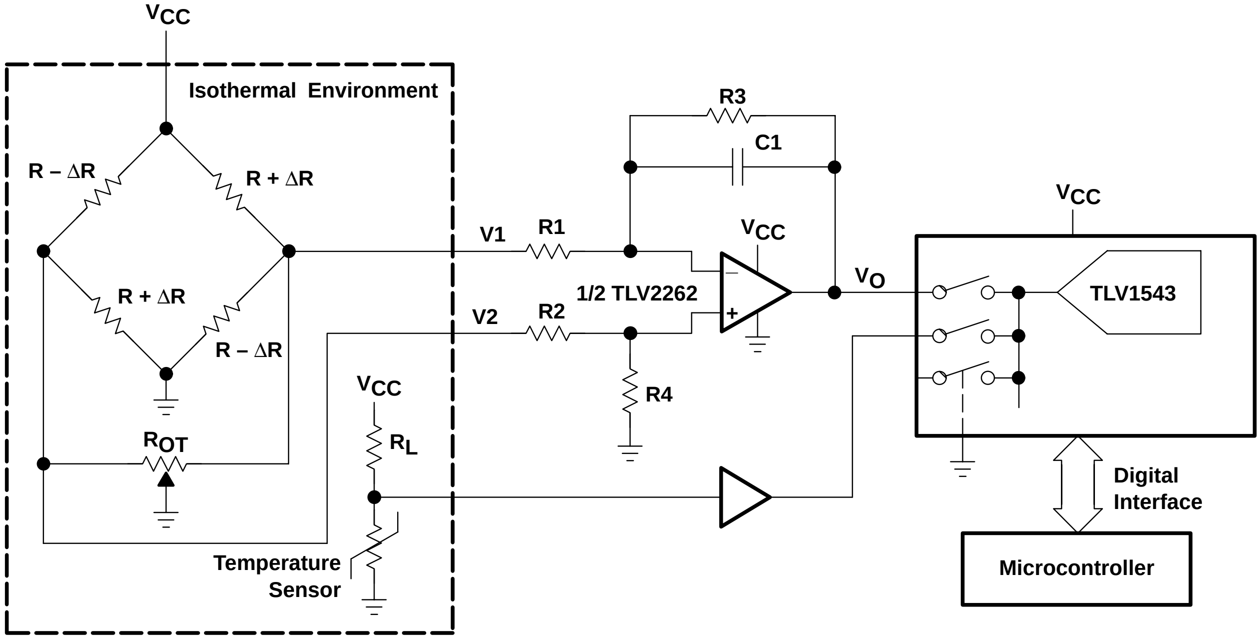
LinCMOS is a trademark of Texas Instruments Incorporated.

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 µV) 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
$R1 = R2 = 470\ k\Omega$
$R3 = R4 = 470\ k\Omega$
$R_{OT} = 500\ k\Omega$ (Offset Trimmer)
$C1 = 50\ pF$
R_L = Linerizing Resistor

$$V_O = (V_2 - V_1) \times \frac{R3}{R2}$$

$$\text{for } \frac{R3}{R1} = \frac{R4}{R2}$$

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 R_{OT} 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.

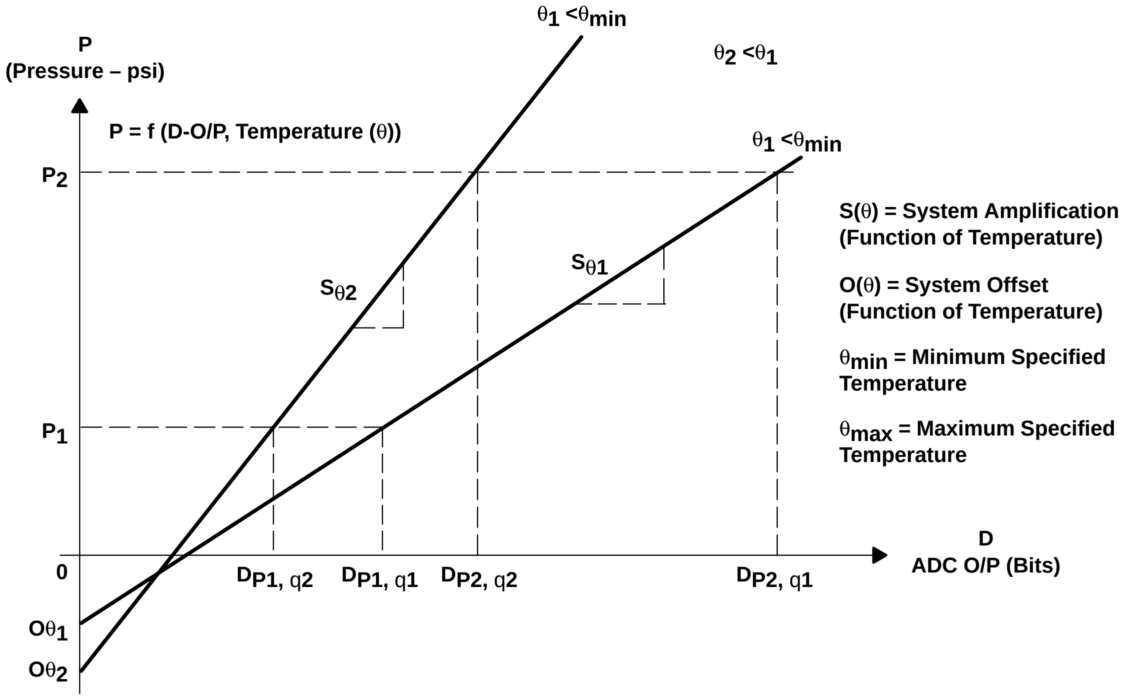


Figure 3. Characteristics of the System

With a constant temperature, θ, a linear characteristic having a system slope, *S(θ),* and an offset value, *O(θ),* (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(θ),* and the offset value, *O(θ),* 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.

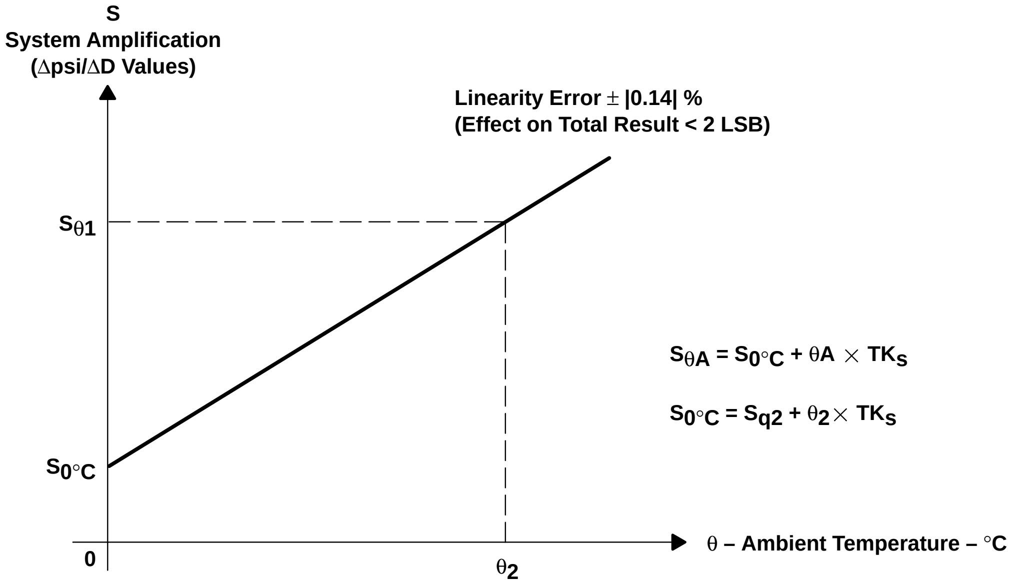


Figure 4. System Slope as a Function of Temperature

These measurements show that the system amplification as a function of temperature characteristics is close to linear. The linearity error is ≤ |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 ≤ |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.

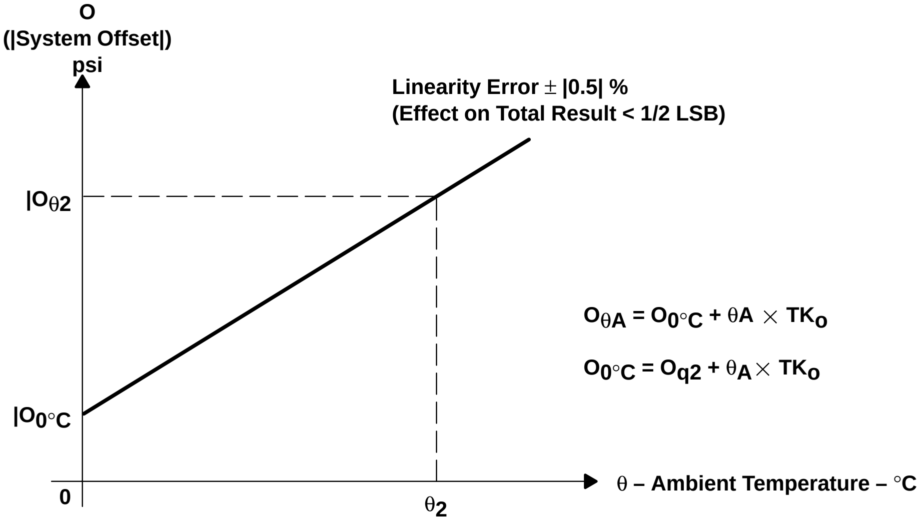


Figure 5. System Offset as a Function of Temperature

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:

$$P = D \text{ ’ } S(q) + O(q) \tag{1}$$

System slope as a function of temperature:

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

System offset as a function of temperature:

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

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

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

Where:

P = Applied pressure
D = Digital value of ADC output
$O_{0^\circ C}$ = System offset at 0°C
O_θ = System offset at temperature θ
$S_{0^\circ C}$ = System slope at 0°C
S_θ = System slope at temperature θ
θ_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_{θ_1} of the characteristic:

$$S_{\theta_1} = \frac{P_2 - P_1}{D_{P_2,\theta_1} - D_{P_1,\theta_1}} \tag{5}$$

Slope S_{θ_2} of the characteristic:

$$S_{\theta_2} = \frac{P_2 - P_1}{D_{P_2,\theta_2} - D_{P_1,\theta_2}} \tag{6}$$

Temperature coefficient TK_S of the slope:

$$TK_S = \frac{S_{\theta_2} - S_{\theta_1}}{\theta_2 - \theta_1} \tag{7}$$

Slope S at 0°C:

$$S_{0°C} = S_{\theta_2} - TK_S \tag{8}$$

4.4.2 Calculation of the Offset Parameters

Offset O_{θ_1} of the curve:

$$O_{\theta_1} = P_2 - D_{P_2,\theta_1} \times S_{\theta_1} \tag{9}$$

Offset of the curve:

$$O_{\theta_2} = P_2 - D_{P_2,\theta_2} \times S_{\theta_1} \tag{10}$$

Temperature coefficient TK_O of the offset:

$$TK_O = \frac{O_{\theta_2} - O_{\theta_1}}{\theta_2 - \theta_1} \tag{11}$$

Offset O at 0°C:

$$S_{0°C} = S_{\theta_2} - TK_S \tag{12}$$

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.

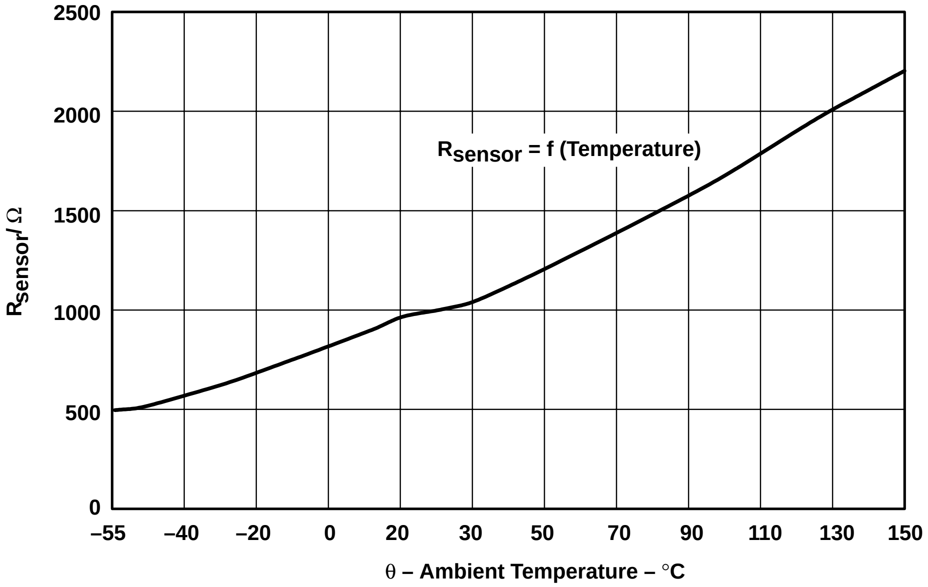


Figure 6. Characteristics of the Temperature Sensor

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.

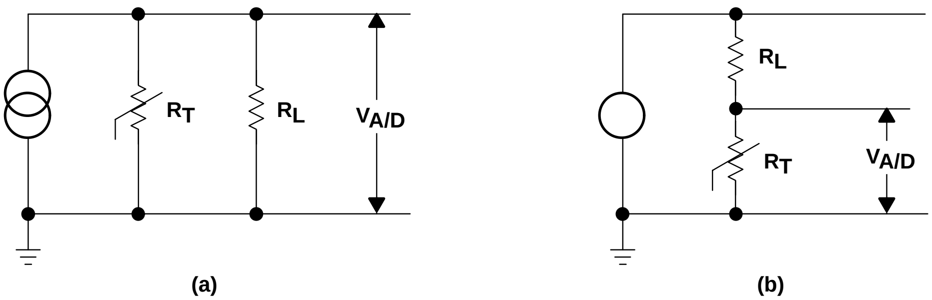


Figure 7. Temperature Sensor Linearization

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 < ± 0.15°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, θ_A. Because it is a straight-line characteristic, two points on the characteristic curve determine the value of this linear expression.

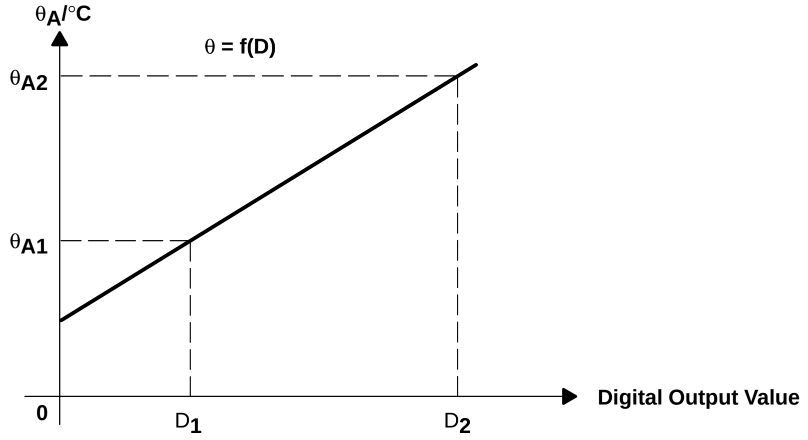


Figure 8. The Digital Value of the Output as a Function of the Temperature

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

$$\theta = D \times S_{\theta} + O_{\theta} \tag{14}$$

Where:

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

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

For calculating these parameters, θ_{A_2} must be less than θ_{A_1}.

$$S_{\theta} = \frac{\theta_{A_2} - \theta_{A_1}}{D_2 - D_1} \tag{15}$$

$$O_{\theta} = \theta_{A_2} - D_2 \times S_{\theta} \tag{16}$$

Where:

θ_{A_1} = Ambient temperature 1
θ_{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 µs. 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.

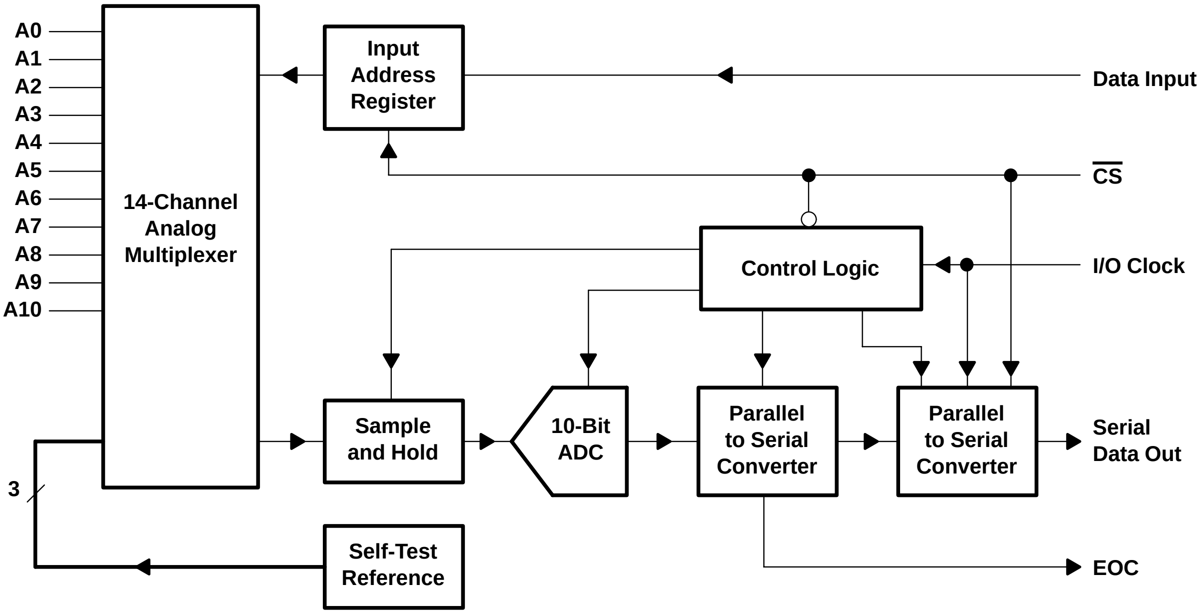


Figure 9. Functional Block Diagram of the TLV1543

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.

Motorola is a trademark of Motorola Incorporated.

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

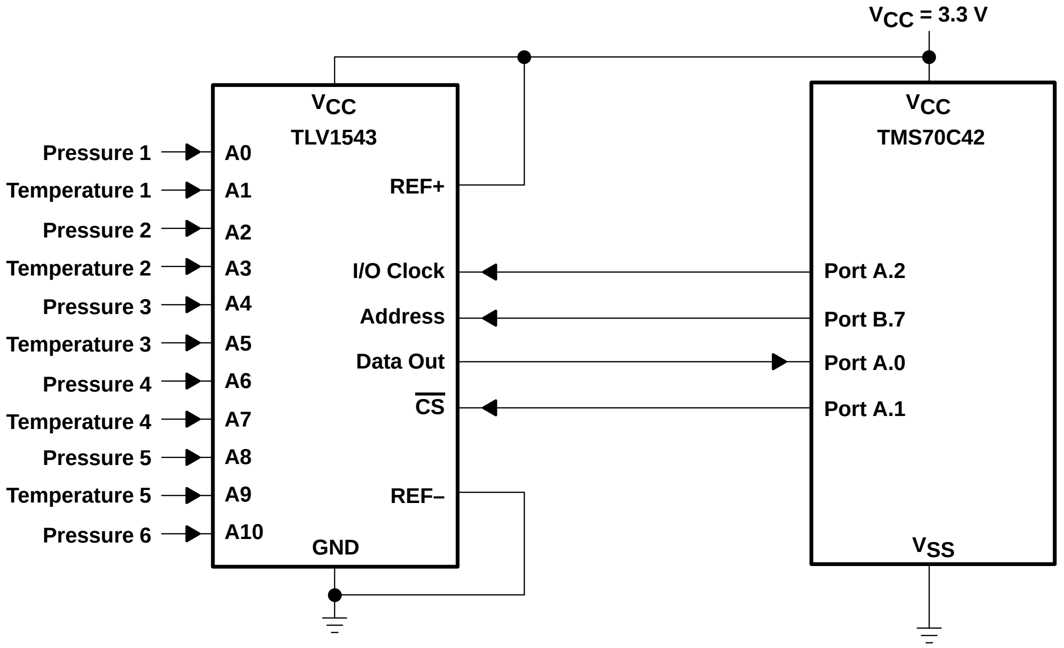


Figure 10. TMS70C42 Interface

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 µs.

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.

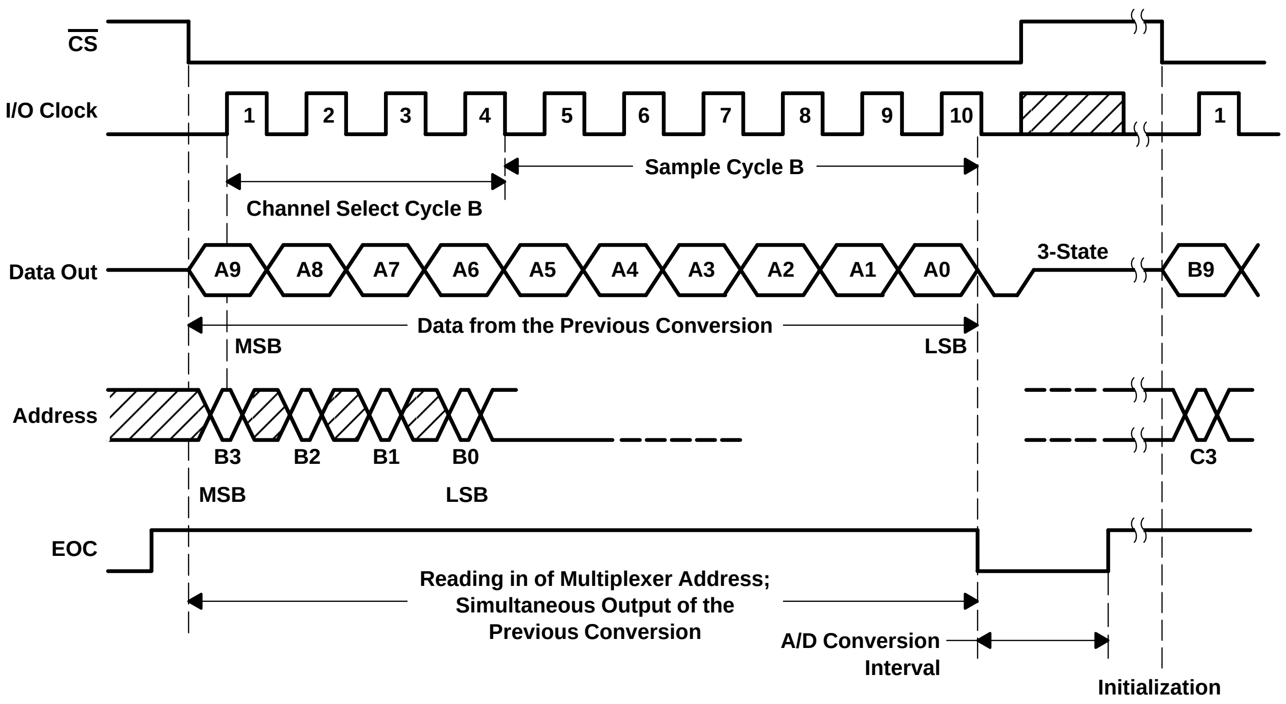


Figure 11. Timing Diagram of the TLV1543 and TMS70C42

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

```
 *************************************************************
 *               TLV1543 – TMS70C42 Interface Program        *
 *                                                           *
 * This program shows an example of how the functions of     *
 * TLV1543 A/D Converter can be controlled via the Port A and*
 * Port B (A0, A1, A2 and B7)of the microcomputer, and how   *
 * the conversion results can be read out.                   *
 *************************************************************

0000
0004  APORT     EQU    P4          * * * * * * * * * * * * * *
0005  ADDR      EQU    P5          * Name of the register    *
0006  BPORT     EQU    P6          * * * * * * * * * * * * * *
F006  AORG      >F006              Load start address of
F006  52 INIT   MOV    %>60,B      program 60h in B register
F007
F008  0D        LDSP               Load pointer to stack
F009  72        MOV    %>02,R4     Load control variable
F00A  02
F00B  04
F00C  A2        MOVP   %>06,ADDR   Data flow from Port A
F00D  06
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       MOVP   %>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  MOVP   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        MOVP   BPORT, B    Channel address into
     F032  06                          REGISTER B
0035 F033  CE        RL     B          Shift left
0036 F034  92        MOVP   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  MOVP   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.

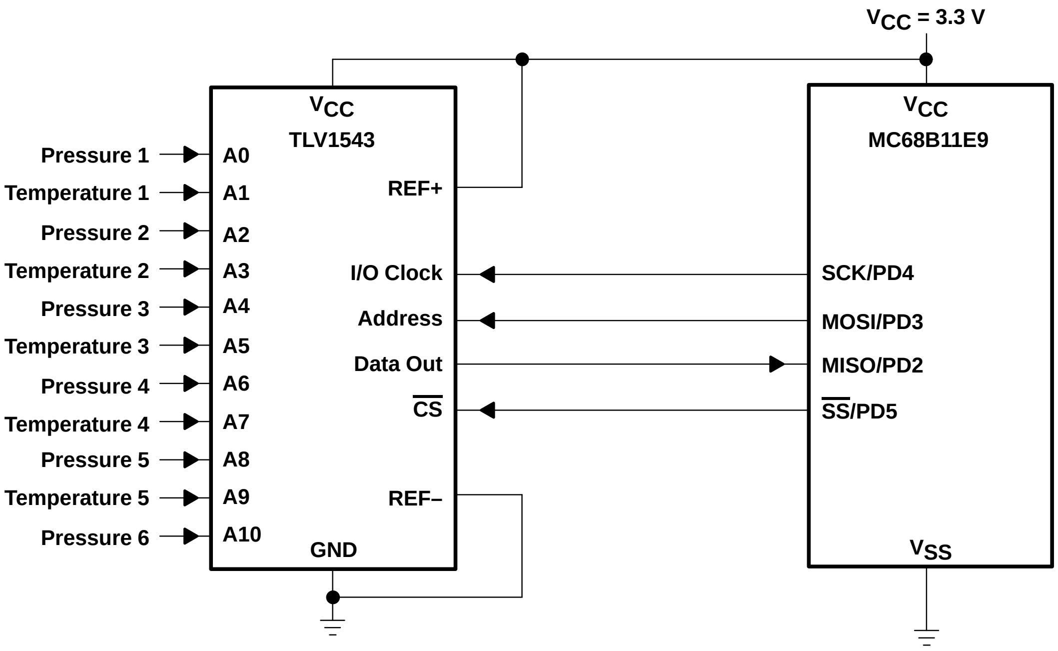


Figure 12. MC68B11 Interface

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.

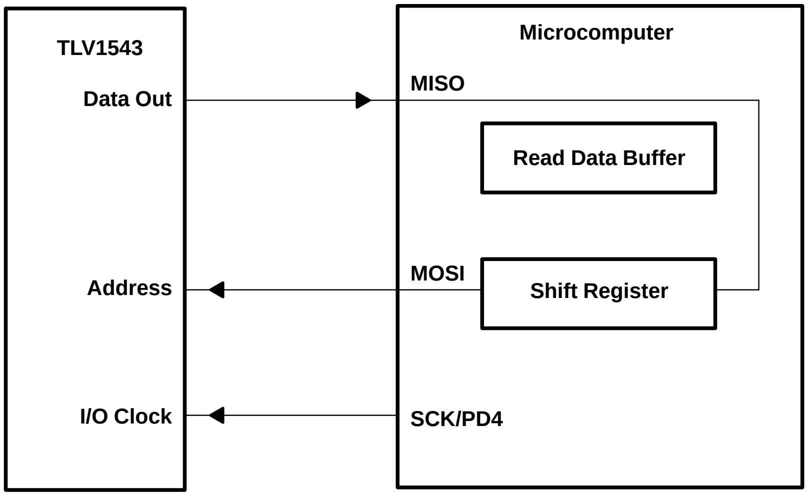


Figure 13. The Internal Structure and Data Flow of the SPI

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 ($\overline{\text{CS}}$) 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.

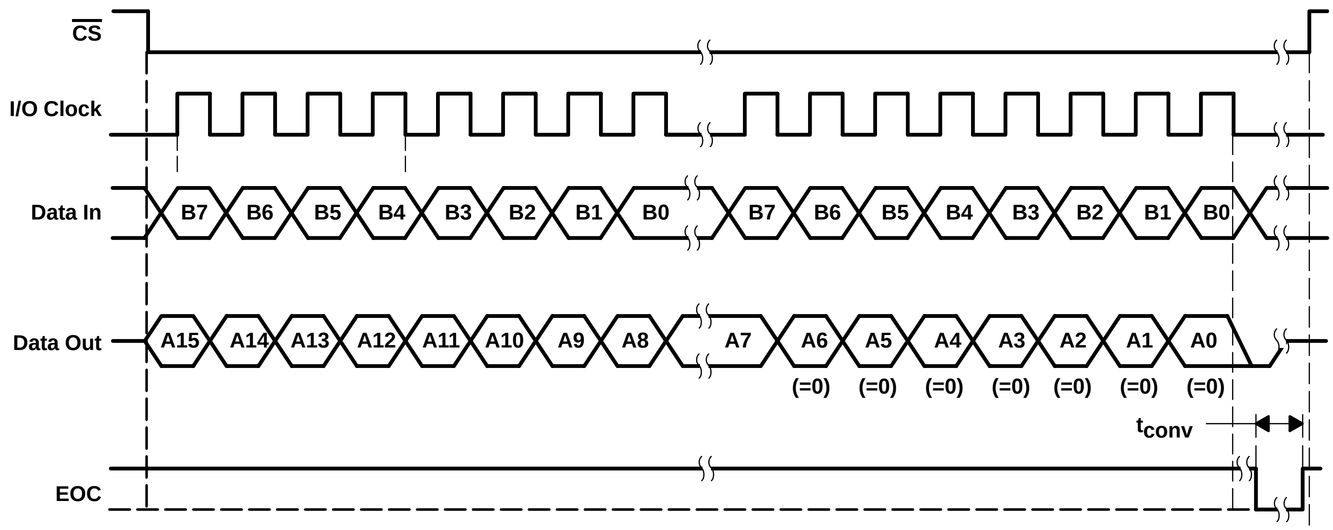


Figure 14. Pulse Timing Diagram for Data Transfer From TLV1543 To SPI

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

```
      * * * * * * * * * * * * * * * * * * * * * * * * *
      *                                               *
      * This program shows an example of how the      *
      * function of the A/D Converter TLV1543 can be  *
      * controlled with the use of an SPI interface,  *
      * and how the conversion results can be be      *
      * read out.                                     *
      *                                               *
      * * * * * * * * * * * * * * * * * * * * * * * * *
1000  BASEADD EQU  $1000          Register Offset Address
0008  PORTD   EQU  $08            Port D Data Register
0009  DDRD    EQU  $09            PORT D Data Dir Register
0028  SPCR    EQU  $28            SPI Control Register
0029  SPSR    EQU  $29            SPI Status Register
002a  SPDR    EQU  $2A            SPI Data Register
01f0  MSBYTE  EQU  $1F0           MSBYTE Address
01f1  LSBYTE  EQU  $1F1           LSBYTE Address
01ff  MEMOL   EQU  $01FF          Memory Location Low Byte
01fe  MEMOH   EQU  $01FE          Memory Location High Byte
01f   COUNTER EQU  $1F2           Loop Counter
01f3  CHANNEL EQU  $1F3           Channel Number

b600             ORG  $B600       Start Address
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              Formatting of the converted
0068 b656 04          LSRD              ADC value
0069 b657 04          LSRD
0070 b658 04          LSRD              A15 A14 A13 ... A7 A6 A5
0071 b659 04          LSRD              MSB                   LSB
0072 b65a 04          LSRD              A4, A4, A3, A2, A1 and A0=0
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.

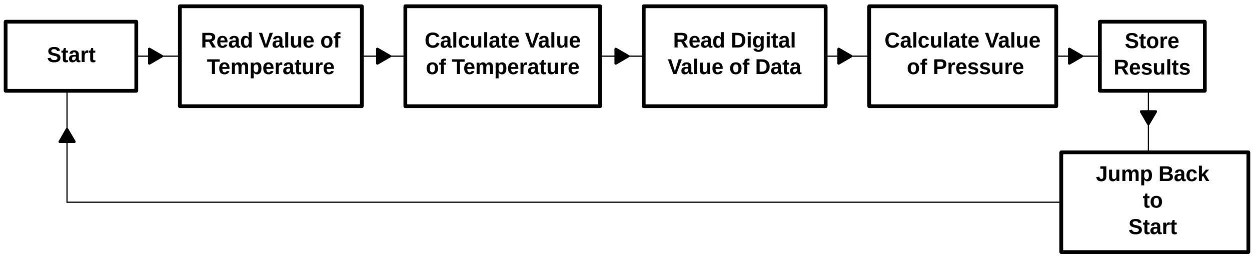


Figure 15. Program Flow Diagram

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.

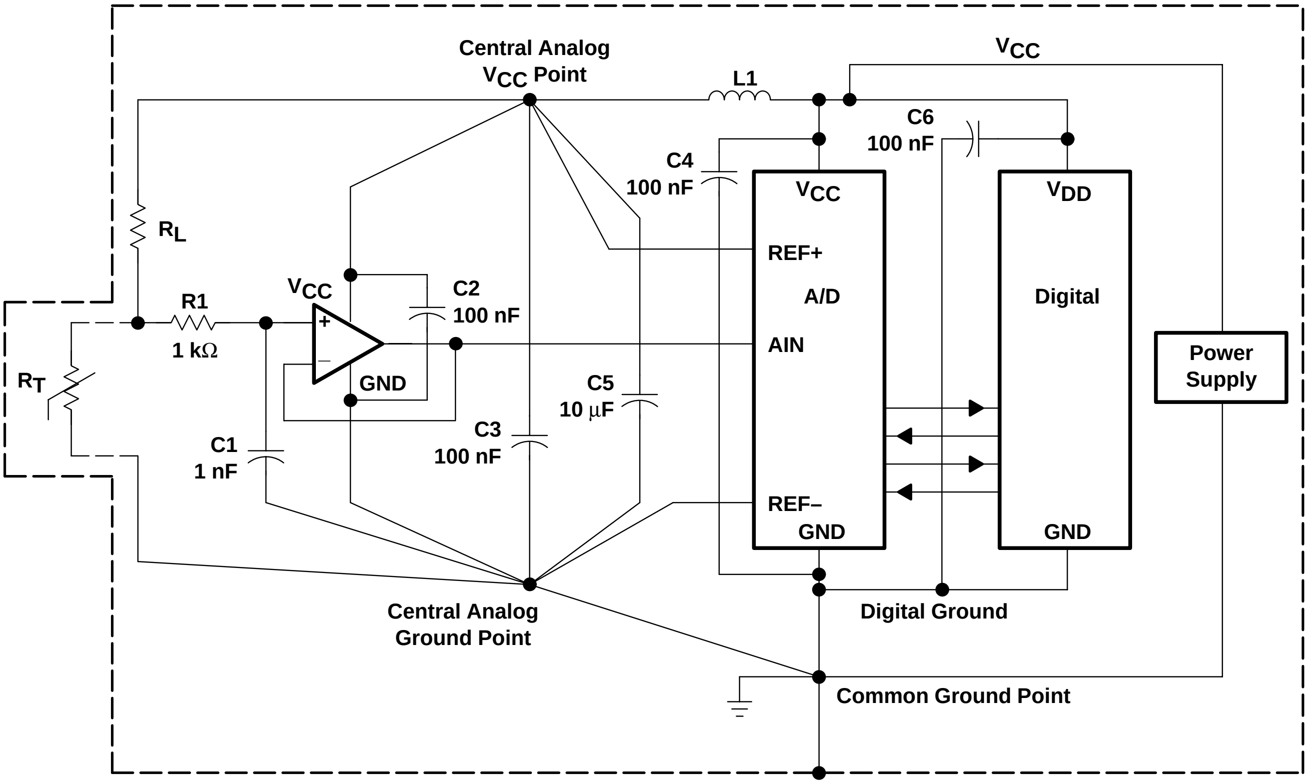


Figure 16. Proposed Wiring Layout

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.

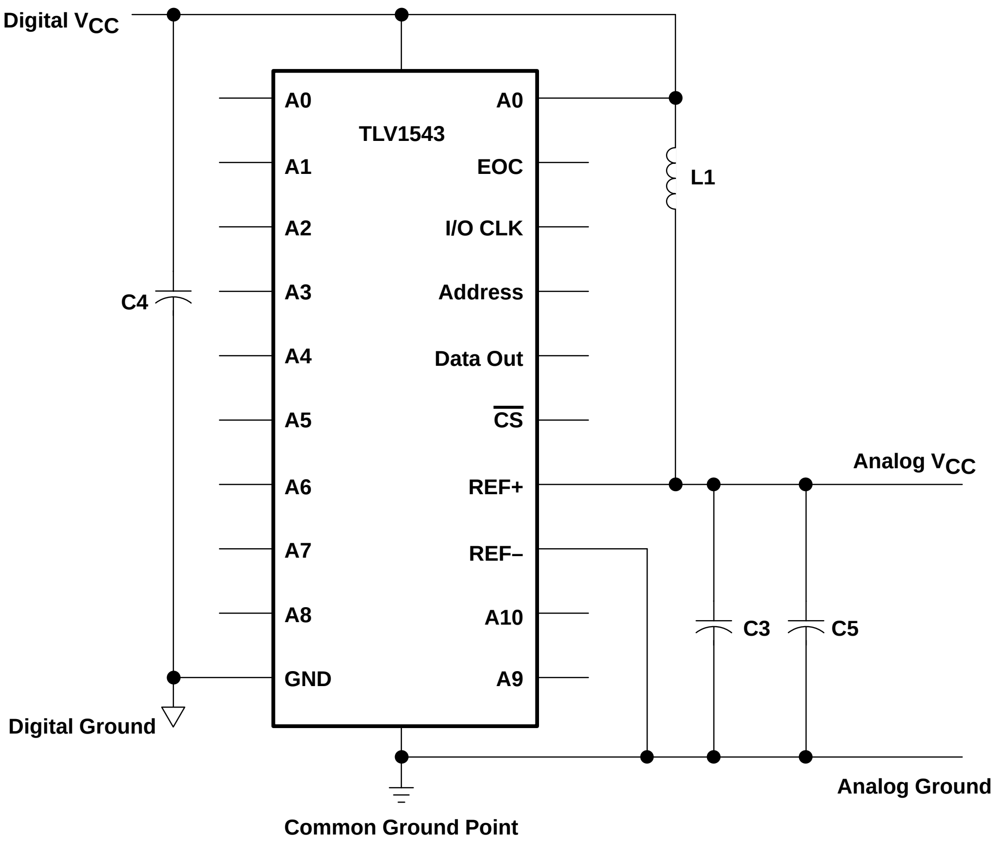


Figure 17. TLV1543 Proposed Layout

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 µF) 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