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dynamically programmable *Analog Signal Processing*

Application Note: Using the On-Chip Temperature Sensor on the AN231E04

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This application note contains multiple files, if you have only this pdf text document, go here

http://www.anadigm.com/sup_AppNoteLib.asp

to find the .AD2 file and example source code.

To successfully use the technique explained below you must have AnadigmDesigner2 and Anadigm AN231K04 Development board

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1 Purpose

The purpose of this document is to describe how to use the on-chip temperature sensor on the AN231E04. It describes how to:

- enable the sensor
- connect CAMs to the sensor in order to amplify its output
- control the amplification and offset of the temperature sensor output
- connect it to the ADC channel of the PIC on the AN231K04 development board
- read back the temperature sensor output via the USB or RS232 port

2 Using the Temperature Sensor

2.1 Create the Primary Circuit

The first thing to be done is to create the primary circuit, as shown in figure 1. The purpose of this circuit is to amplify the sensor output. The temperature sensor can be monitored directly without amplification on I4P (pin 24), in which case a blank circuit can be downloaded, or any other circuit provided that it does not use input 4.

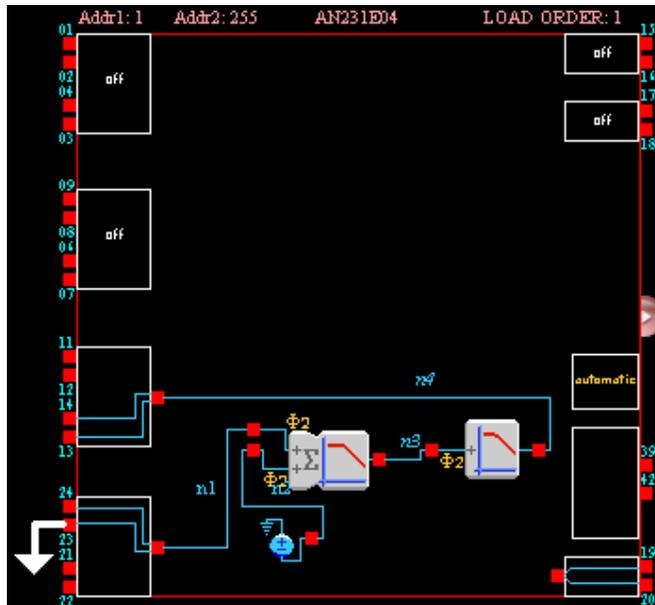


Figure 1: Primary circuit for amplifying sensor output

This circuit consists of a SumFilter CAM and a Bilinear Filter CAM which is set to low pass mode. It is very important that the input of the first CAM is connected to input 4 (as shown in figure 1) because the temperature sensor drives I4P. I4P does not need to be connected to anything externally so should be left open. I4N should be connected externally to VMR (+1.5V) as shown in figure 1. On the AN231K04 development board this can be done by shorting the header pin marked I4N to the adjacent VMR pin using a jumper, as shown in figure 2.

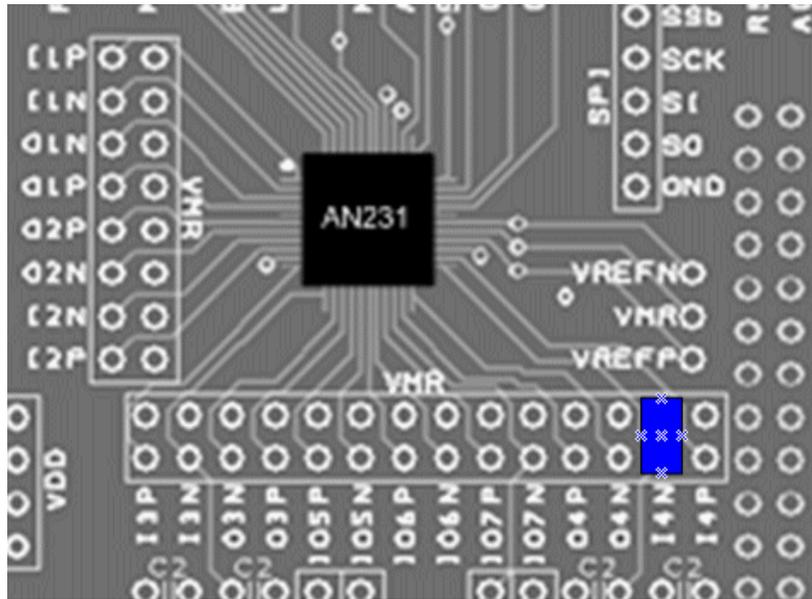


Figure 2: Jumper position for connecting VMR to I4N

The CAMs shown in figure 1 needs to be run with a slow clock (e.g. 1kHz) so as not to overload the temperature sensor (the slower the clock, the higher the input impedance of the CAM). Figures 3 and 4 show typical CAM settings for the SumFilter and low-pass FilterBilinear:

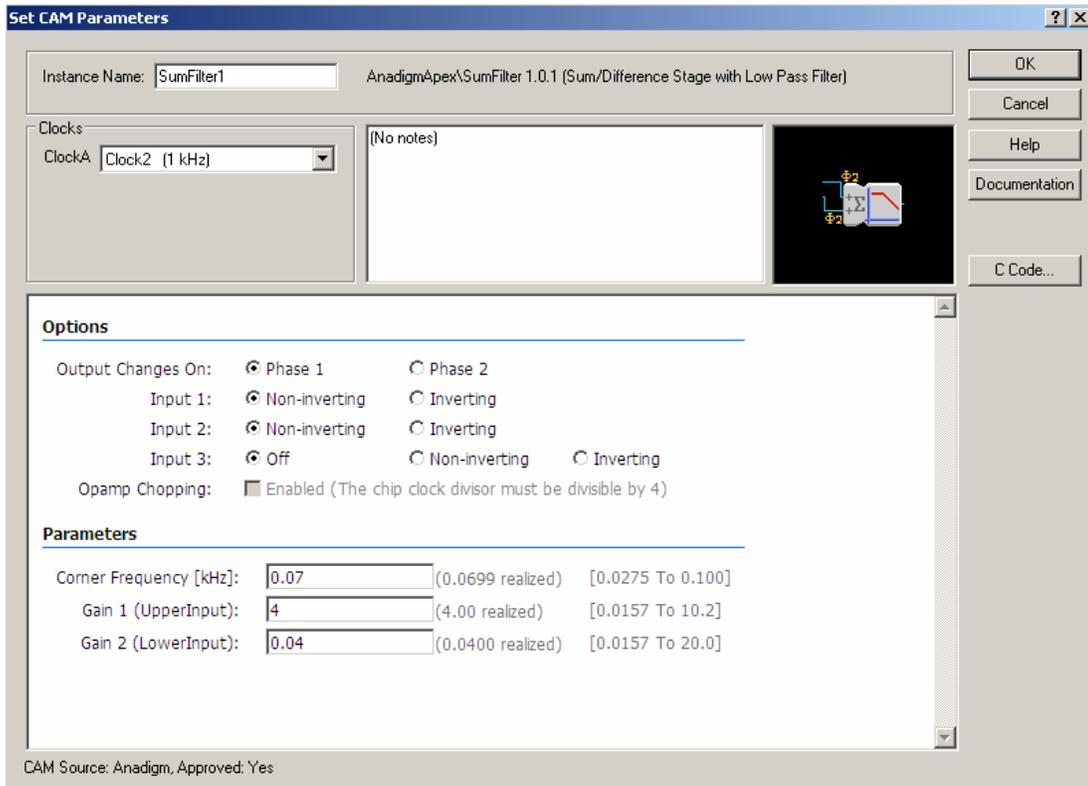


Figure 3: Typical CAM settings for the SumFilter CAM

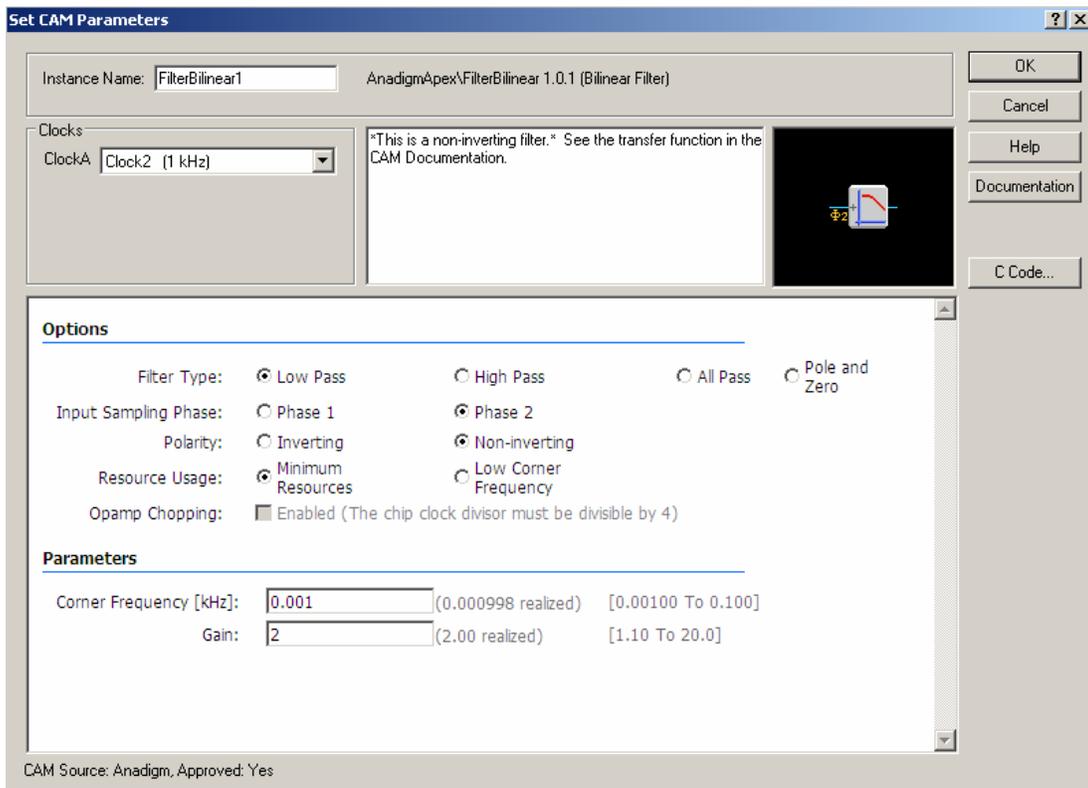


Figure 4: Typical CAM settings for the FilterBilinear CAM

NOTE: the circuit described above is for the purpose of amplifying the sensor output. The sensor output can be measured directly (un-amplified) on I4P (pin 24). In order to do this, it is still necessary to download a primary circuit before downloading the reconfiguration that enables the temperature sensor. In this case the primary circuit can be an empty circuit, or any other circuit that does not use I4P.

Before fine tuning of the CAM parameters can take place, the temperature sensor has to be enabled.

2.2 Enabling the Temperature Sensor

Having loaded the primary circuit, the temperature sensor must be enabled with the following reconfiguration data:

```
0xD5, 0x01, 0xC1, 0xD1, 0x00, 0x01, 0xF9, 0x2A, 0x89,
0x07, 0x01, 0x02, 0x2A, 0x00
```

NOTE: the last byte is a dummy byte (all reconfigurations should have a dummy byte at the end).

This data can be sent from AnadigmDesigner2 (AD2) in the following way: enter the data above into a text file without the "0x" prefixes and without the commas, and with the data in a vertical column as follows:

```
D5
01
C1 etc...
```

Now save the text file and then change the extension to AHF (Anadigm Hex Format). In AD2 click on the Configure menu and select "Write AHF File to Serial Port...". Browse to the .AHF file and click on Open. AD2 will then send the AHF data to the board.

After downloading the above reconfiguration, the temperature sensor will be enabled. The un-amplified sensor output should appear on O4P (pin 24) and the amplified output should appear on O3P (pin 14) if the primary circuit in figure 1 was used.

2.3 Setting the Reference Level

Now the reference level must be set by zeroing the DC offset at maximum gain by adjusting Gain 2 of the SumFilter (the gain of the input connected to the -2V DC source).

At room temperature, the sensor outputs a voltage of about +1.5V. The primary circuit shown in figure 1 amplifies the difference between the sensor voltage and VMR (also +1.5V) which was connected to I4N externally (with a jumper – figure 2). The amplified output will be seen on O3P and O3N as a differential output. The user can monitor O3P only, but it must be borne in mind that, since only half of the differential output is being measured, the total gain through the CAMs is effectively halved.

NOTE: if measuring only one side of the differential output, the gain inside the AN231E04 is effectively halved.

With the device at a measured reference temperature e.g. room temperature, first set the gain of the bilinear low-pass filter to x20 (maximum). Then adjust the SumFilter in the following way: keeping Gain 1 of the SumFilter at x4, adjust the gain of Gain 2 until the output on O3P (pin 14) reaches the zero reference level of +1.5V (mid rail). The temperature at which this is done should be measured.

It will be found that varying the temperature of the device by about 10 deg C in either direction will cause the output O3P to hit the rails i.e. if the reference temperature is 22 deg C, then a temperature of about 12 deg C will cause O3P to go to 0V and about 32 deg C will cause O3P to go to +3V. This is because:

The temperature coefficient of the sensor $T_c \sim 0.004 \text{ V / deg C}$

And maximum gain through the CAMs $G = x40$ (x4 in SumFilter, x20 in Bilinear, half total gain because only monitoring half of the differential output on O3P)

So $T_c \times G = 0.16 \text{ V / deg C}$ so a temperature change of 10 deg C will take the output O3P from VMR (+1.5V) to one of the rails.

The user can choose a different reference level and reference temperature if desired.

NOTE: the temperature sensor outputs a voltage of +1.5V at approximately room temperature. If the chosen reference temperature is room temperature, it may be found that achieving +1.5V on O3P is impossible by adjusting the offset (because there is no offset to compensate for). In this case the SumFilter CAM could be replaced by a FilterBilinear CAM with gain set to x4.

2.4 Calibrating the Sensor

In order to make a temperature measurement, it is necessary to calibrate the sensor. This should be done for every AN231E04 device separately because temperature coefficients will vary slightly from device to device. The graph in figure 5 shows how the sensor output voltage (un-amplified) typically varies with temperature. It can be seen that the response is linear and that the temperature coefficient for this device is 4 mV/deg C.

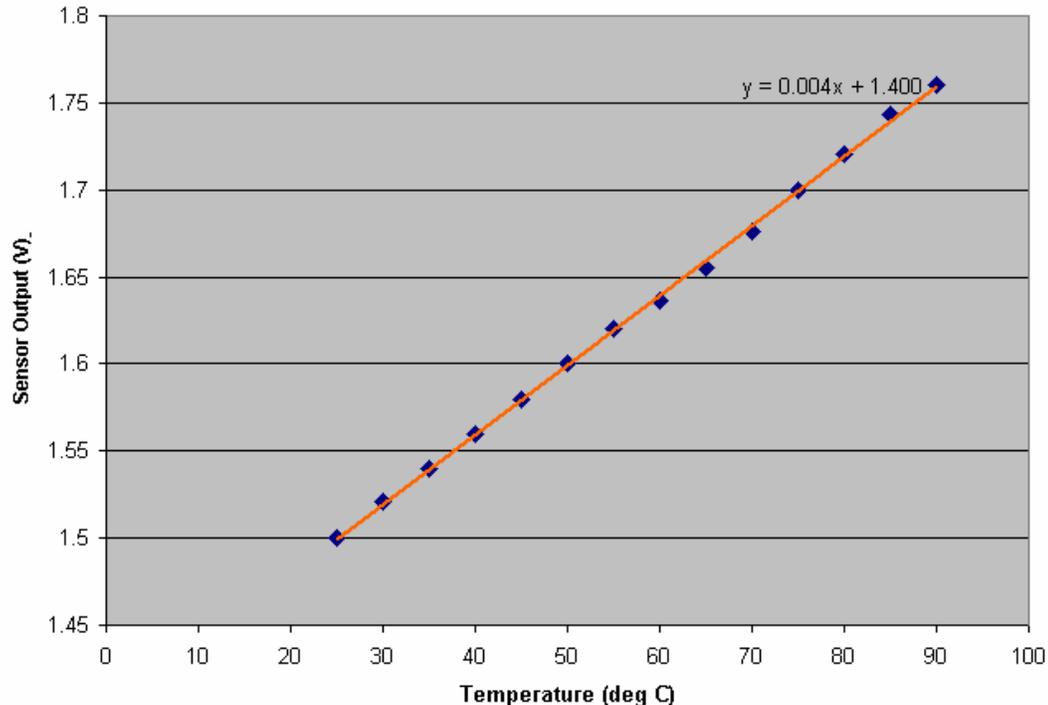


Figure 5: Typical sensor response

In order to make a temperature measurement, the temperature coefficient will have to be measured. Since the response is linear, this can be done using just 2 temperatures where one is the reference temperature, provided that these 2 calibration temperatures are sufficiently widely separated. The calibration could be carried out on the un-amplified sensor output, but it would be more accurate to set the gain in the FilterBilinear to x2 (keeping the gain in the SumFilter at x4). In this case, the sensor would hit the maximum level (+3V) at approximately 120 deg C, so making 2 calibration measurements at say 100 deg C and the reference temperature (room temperature) should provide an accurate measurement.

When measuring the temperature coefficient, take into account the total gain through the CAMs inside the AN231E04. Also remember that this total gain should be halved because only the positive side of the differential output (O3P) is monitored. The formula below gives the temperature coefficient (the halving of gain is taken into account by the factor of 2 in the equation).

$$Tc = 2 \times (V_{out} - 1.5) / (Gain \times (T - T_{ref}))$$

Where **Tc** is the temperature coefficient

V_{out} is the output voltage on O3P at the calibration temperature

Gain is the total gain setting in the CAMs (e.g. 4 x 2 = 8)

T is the calibration temperature

T_{ref} is the reference temperature

2.5 Measuring Temperature

Now that the temperature coefficient has been measured, a temperature measurement can be made. With the reference level set to 1.5V at say 22 deg C and the gain of the FilterBilinear low-pass filter set to x20, the measurement range will be approximately +/-10 deg C i.e. 12 deg C to 32 deg C. If it is required to make measurements outside this range then the gain of the FilterBilinear low-pass filter should be reduced accordingly. A gain of x1 in the FilterBilinear will give an effective measurement range of about +/-200 deg C which is more than enough to measure any practical temperature. Since the recommended operating temperature range is -40 deg C to +125 deg C, the gain of the FilterBilinear need not be set less than x2 for optimum accuracy.

NOTE: the AN231E04 should not exceed the recommended operating temperature range as quoted in the datasheet i.e. -40 deg C to +125 deg C.

The temperature will be given by the following formula:

$$T = T_{ref} + 2 \times (V_{out} - 1.5) / (T_c \times Gain)$$

Where

- T** is the temperature to be measured
- T_{ref}** is the reference temperature
- V_{out}** is the measured output voltage on O3P
- T_c** is the temperature coefficient
- Gain** is the total gain settings of the CAMs

NOTE: because only the positive side of the differential output is monitored, the gain settings of all the CAMs inside the AN231E04 is effectively halved. This is taken into account in the equation by the factor of 2.

2.6 Using the Development Board ADC

This section describes how to use the ADC of the PIC16F876A on the AN231K04 development board to read back the temperature sensor to a PC.

NOTE: this section describes commands that are sent to the development board and data that is received from it. This cannot be done from AnadigmDesigner2. It must be done from C-code written for the purpose.

The first thing that must be done is to connect the amplified sensor output O3P to an ADC channel. Figure 6 shows how to connect O3P to channel 0 of the ADC. This must be done by soldering on a flying lead. Any of the 3 ADC channels could be used.

In order to read the temperature sensor, the following set of commands must be sent to the board from the PC via the serial port (USB or RS232).

0x02 STX character
'V' the character V which tells the PIC to read its ADC
'0' this character represents the channel being read, in this case 0
0x03 ETX character

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The PIC will respond to this command by sending back a single byte representing the voltage read on ADC channel 0 (this byte will actually be returned before receiving the ETX character).

If the ADC reading is close to 0 or 255 then it is possible that the amplified sensor output is hitting the rails. In this case the gain of the FilterBilinear can be reduced in increments until a sensible ADC reading is returned. Alternatively, if the ADC value is close to 128, the gain of the FilterBilinear could be increased in order to improve accuracy of the measurement.

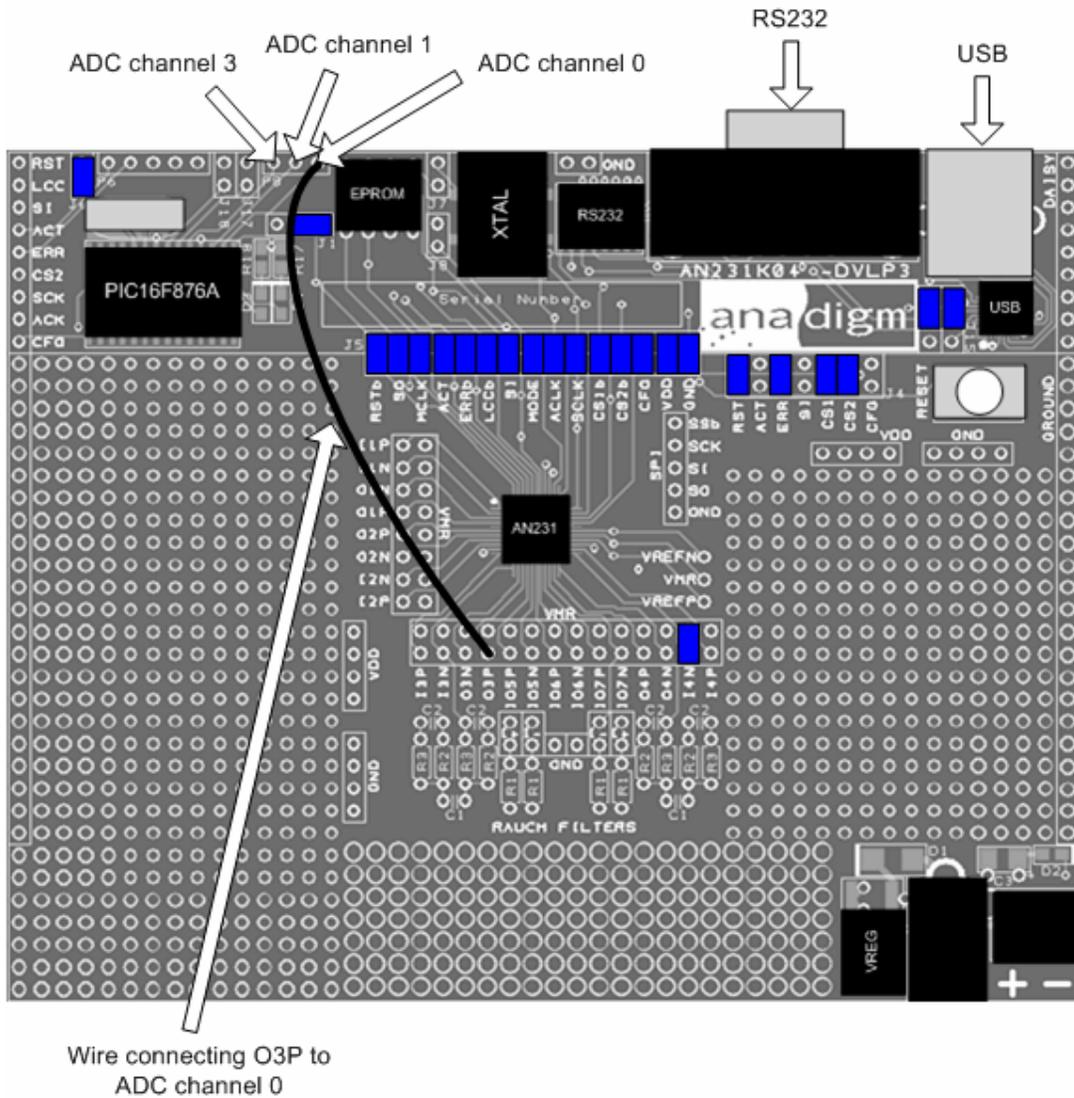


Figure 6: Connecting sensor to ADC

NOTE: Anadigm is happy to provide a simple C-code example of how to set up the serial port, send an ADC read command to the board, and read back data from the ADC. For details please contact Anadigm Support.