DigiPile® Family TPS 01T

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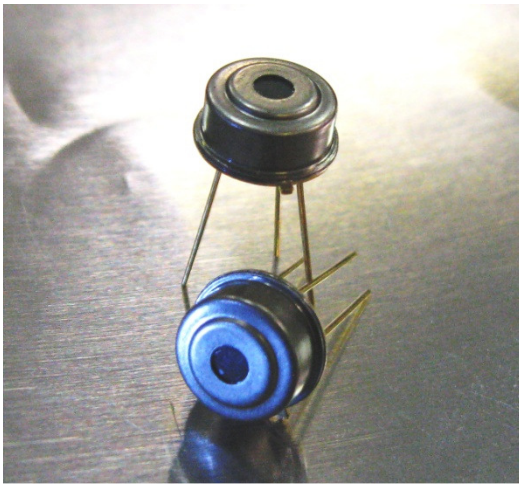
How to use Single Element DigiPile®
Basics – Application – Advantages

SENSOR SOLUTIONS

APPLICATION NOTE



Introduction

The EXCELITAS thermopile sensors are used for remote temperature sensing by the measurement of infrared (IR) radiation. They consist of a silicon (Si) based thermopile chip in a metal housing with IR transmissive filter. The Si-chip carries a series of thermo-elements, forming a sensitive area covered by an IR absorbing material.

The thermopile sensing principle allows for broadband IR measurements. EXCELITAS thermopile sensors are equipped with a MEMS state-of-the art sensing element and an optical filter that defines the sensitive spectral range of the sensor and at the same time serves as device window.

Until today, all available detectors were analogue, i.e. they provide an analogue signal output. EXCELITAS now introduces the first thermopile detector series that, unlike previous generations, offers a digital signal output.

Features and Benefits

- Digital output sensor
- 17 Bit Tobj Output “Direct Link”
- 14 Bit Tamb Output “Direct Link”
- 3-pin TO-5 Housing
- Thermopile sensor with large absorber area
- High signal to noise ratio
- 5.5 µm cut on IR filter
- Operating voltage down to 2.4V
- Low current consumption

Applications

- High precision temperature sensing
- Ear thermometer
- Infrared Pyrometry

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EXCELITAS TECHNOLOGIES

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1 Definitions

Element: This is a sensing surface with a defined size. As all units work with optics, this element and the optics will determine the performance.
Detector / Sensor: A detector gives a pure output signal; the sensor has a processed signal output.
***Direct link* interface:** The *direct link* is the interface between DigiPile® and any micro controller. It is a bidirectional single wire connection specially designed for this kind of application.
Data Rate: The refresh time of data (availability of new data block).
Resolution: The analogue value of one bit.
Clock Time: This refers to the n x (1 / internal clock frequency (the frequency of internal command processing)).

2 Electrical Configuration

The DigiPile® consists of a single element thermopile chip that is connected to a special integrated circuit. It contains the analogue -to-digital converters that are generating 17-bit Tobj and 14 bit Tamb signals, a second-order digital low-pass filter, an on-chip low-power oscillator, and a serial interface. The functional block diagram is shown below.

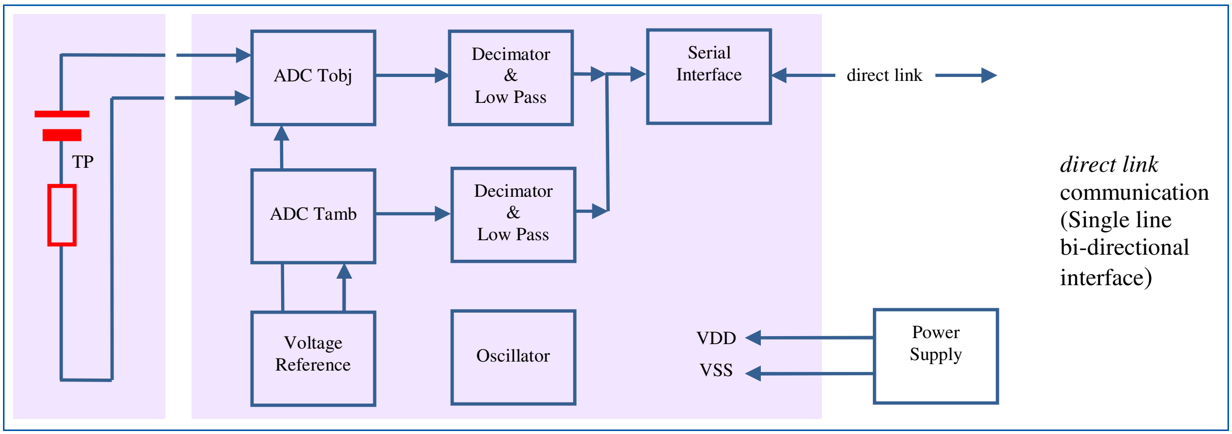


Figure 1 Block diagram of DigiPile®

2.1 From Analogue to Digital

The DigiPile® is a Thermopile Sensor that displays information in "bit" as compared to mV signals of analogue detectors. For engineers traditionally laying out systems in respect to analogue signals, the following rough comparison may be helpful:

- Resolution: 1 count ≙ 0.8 µV
- Range: 0 to 130000 count ≙ ± 52.0 mV
- DC offset 64500 counts ≙ 0V typical
- Noise: ≈ 10 counts ≙ 8 µV (with low-pass)

2.2 The Digital Zero Signal Line

Due to the principle of thermopile temperature measurement, the thermopile voltage can be positive or negative depending on if the object temperature is higher or lower than the ambient temperature. In order to allow signal processing of negative voltages with a single supply system, the thermopile signal needs an electrical offset to process the signals. The internal voltage reference provides this offset. To the user, this offset appears as a digital zero line ranging at a value of 64500 (decimal) and may differ in series from one part to the next. To recognize the zero line of the individual detector, the user may use either a digital band-pass or subtract the measured offset from the signal. To do so, the detector must be covered from incidental radiation and protected from possible air drafts and indirect radiations. The detector output is then monitored. The resulting signal represents the individual zero line. Once the reading is stabilized, this value can be taken and stored in the user's µProcessor as the detector's zero line.

2.3 Data Communication

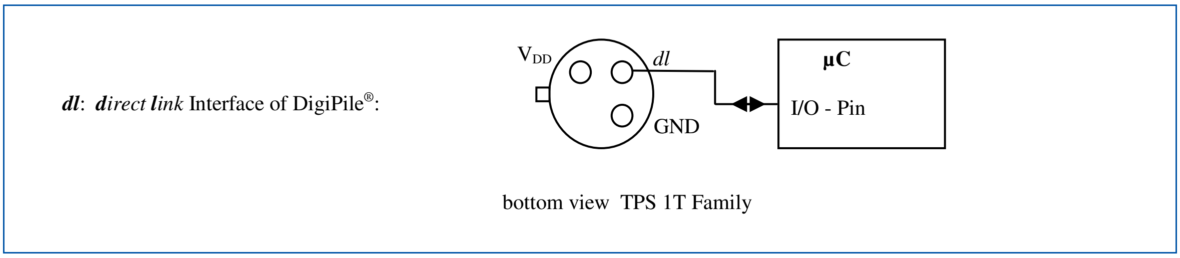


Figure 2 DigiPile® connections

The serial interface has a 31-bit binary output format. The leading 17-bit represent the thermopiles (Tobj) output signal. The subsequent 14-bit represent the integrated ambient temperature (Tamb) output signal. The *direct link* pin is used as bi-directional data output and clock input.

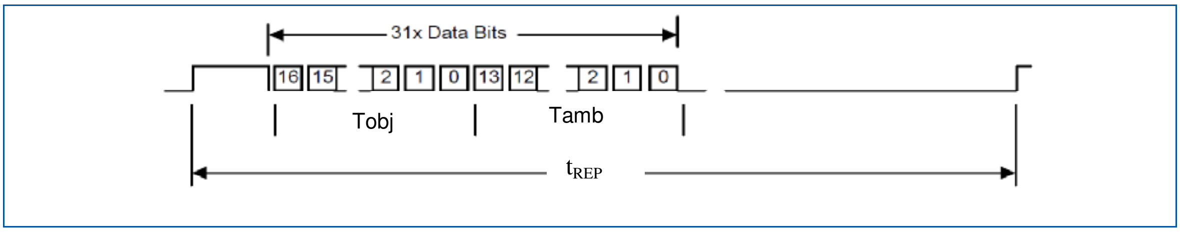


Figure 3 DigiPile® Data representation

The data output update rate is controlled by the host and can be up to 3ms (≈330Hz). To initiate a read out the host has to drive the direct link pin to High for min. 90µs.

The following diagram shows the mode communication signal flow:

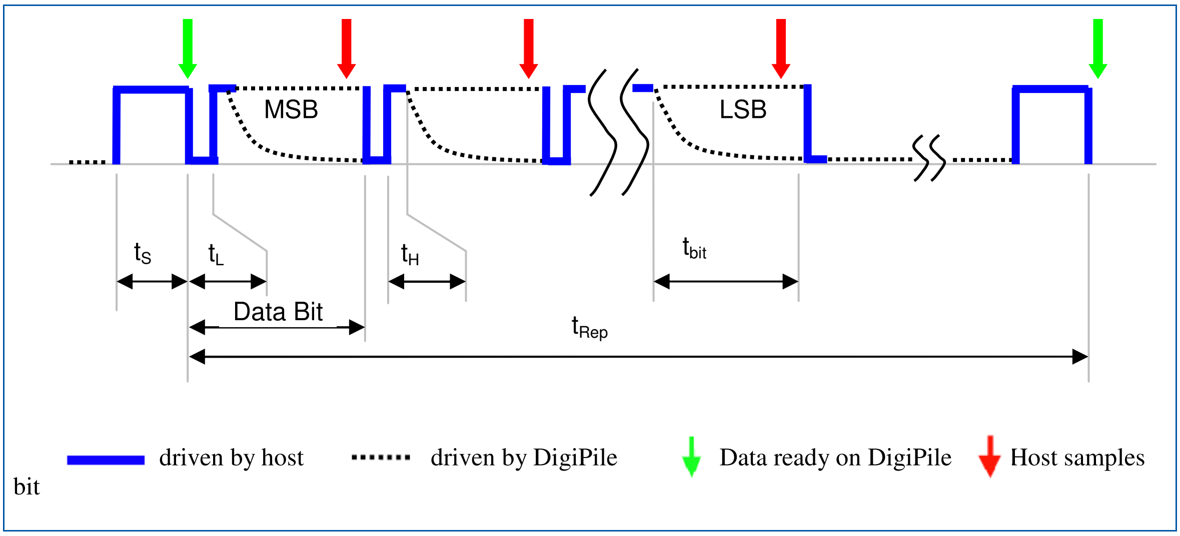


Figure 4 ADC and data transmission diagram

After the setup time (t_s) has passed, the DigiPile® expects a LOW to HIGH transition (t_L, t_H) on the *direct link* pin and will subsequently output the data bit state. After the data bit setup time (t_{bit}), the DigiPile® waits for the next LOW to HIGH transition and the sequence is repeated until all 31 bits have been shifted out. After the output of the last bit (bit 0) and the corresponding data bit setup time (t_{bit}), the host controller forces the *direct link* pin to LOW and subsequently releases the *direct link*. The DigiPile® remains with the *direct link* pin at LOW level low until the next signal sample read out is forced by the host or will change to HIGH level if read out rate (t_{REP}) becomes slower than15ms.

The data bit setup time t_{bit} specified under electrical data is a minimum time. For the LOW level, it can vary depending on the capacitive load of the *direct link* pin. It is recommended to start host interface implementation with a longer data bit settling time t_{bit} to ensure proper LOW level settling, reducing t_{bit} empirically to optimize reliable data transmission at maximum transmission speed. To avoid communication issues do not exceed the direct link Low time.

If data transmission is interrupted during data clock low time (t_L), the serial interface is updated with a new value, provided t_L lasts longer than the serial interface update time (t_{REP}), which can cause a false reading if the data transmission is continued. Therefore data transmission should preferable be interrupted during data clock high time (t_H). If interruption lasts longer than the serial interface update time (t_{REP}), the serial interface will not be updated with new values.

If a host reads the serial interface output faster than the maximum update rate of the serial interface (t_{REP}), the data bits are all read LOW.

2.4 Pull up/down current

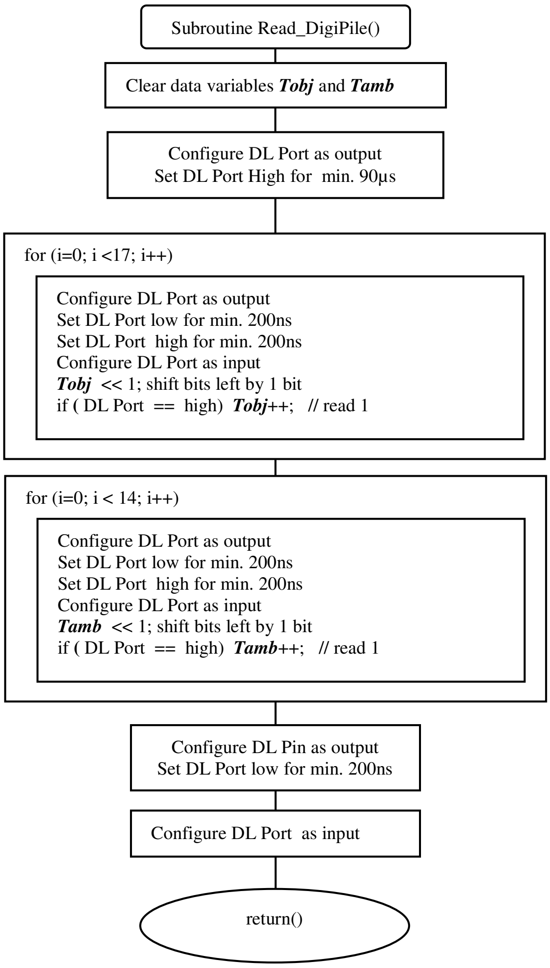
Despite the fact that the *direct link* interface is designed is to be operated as input and as output, physically it is only an output with limited current drive capabilities. This allows the host to overwrite the output by driving and sinking the appropriate pull up and pull down currents.

When the *data link* pin drives HIGH level and the host forces low level, e.g. during data clock low time (t_L) in order to start readout sequence of the next bit, the host must be capable to sink the pull up current as specified, without exceeding the maximum LOW level voltage.

When the *data link* pin drives LOW level and the host forces HIGH level, e.g. during data clock high time (t_H), the host must be capable to source the pull up current as specified, without falling below the minimum HIGH level voltage.

Although the Pull up and Pull down currents exceed the maximum supply current considerably it becomes not perceptible for the supply current, since it appears only during a very short time period while the host generates the data clock. Therefore it is recommended to keep *data clock low time* (t_L) and *data clock high time* (t_H) as short as possible in order to avoid unnecessary power consumption.

2.5 Direct Link interface Read Out



Note: Make sure this routine is executed only once within 3 ms. Faster read out will cause false readings

Figure 5 DigiPile® read-out flow chart

To transfer the above read-out flow chart into a software code, the following program code in C-language can be applied. (Program code example for Microchip PIC 16 / PIC 18 family - as I/O- pin port B0 is used, CCS C Compiler)

```
// DL: Direct Link Interface of the DigiPile®. A bidirectional single wire interface,
// directly connectable to most µC's I/O- pins.

#TYPE LONG=32

#if defined(__PCM__)                              // if PIC 16 family is used
#include <16F886.h>                               // <=== type in the appropriate MC type here

#byte TrisReg_B=0x086                             // <=== Look at datasheet for this value
#fuses INTRC_IO, NOWDT, NOPROTECT, NOLVP, NOBROWNOUT
#use delay(clock=8000000)                         // <=== type in the appropriate clock rate in Hz
#use rs232(baud=57600, xmit=PIN_C6, rcv=PIN_C7, stream=serial)

// ------ include files -------- ----------------------------------------------------------------------------------------------------

#include <stdlib.h>
#include <stdio.h>
#include <string.h>
```

```
// ------ I/O port definitions ------------------------------------------------------------------------------------------------

#define DPDL            PIN_B0
#define DPDL_BIT        0                                   // Bit position of PortB0 in TrisReg_B

// ------ Variable definitions ------------------------------------------------------------------------------------------------

long Tobj, Tamb;

//-----------------------------------------------------------------------------------------------------------------------------------
// This leaves the Direct Link line in a state where the sensor can generate an interrupt
//-----------------------------------------------------------------------------------------------------------------------------------
void clear_DPDL_interrupt(void)
{
        #use fast_io(B)                                     // do I/O without programming of
                                                            // direction register
        output_low(DPDL);                                   // Clear DPDL pin
        bit_clear(TrisReg_B,DPDL_BIT);                      // Clear direction bit for output
        delay_cycles(5);
        bit_set(TrisReg_B,DPDL_BIT);                        // Set direction bit for floating/input
        #use standard_io(B)                                 // make  I/O pin either input or output every
                                                            // time I/O pin is used

}

//-----------------------------------------------------------------------------------------------------------------------------------
// Read from DigiPile Direct Link interface
//-----------------------------------------------------------------------------------------------------------------------------------
void read_DigiPile(void)
{
 int i;
#use fast_io(B)
 Tobj=0;
 Tamb=0;

        output_high(DPDL);                                  // Set DPDL pin
        bit_clear(TrisReg_B,DPDL_BIT);                      // Clear direction bit for output
        delay_us(90);                                       // wait 90 µsec (tS)
        output_low(DPDL);                                   // Clear DPDL pin

        for(i=0;i<17;i++)   // There are 17 bits of data from the Tobj signal of the sensor
        {
                output_low(DPDL);                           // Clear DPDL pin
                bit_clear(TrisReg_B,DPDL_BIT);              // Clear direction bit for output
                output_high(DPDL);                          // Set DPDL pin

                bit_set(TrisReg_B,DPDL_BIT);                // Set direction bit for input
                Tobj<<=1;                                   // Make room for next bit
                // for long LOW level settling a delay of a few microseconds might be needed here
                // but make sure max. tbit time is not exceeded
                if (input(DPDL)==1)
                        Tobj++;
        }

         for(i=0;i<14;i++)   // There are 14 bits of data from the Tamb signal of the sensor
        {
                output_low(DPDL);                           // Clear DPDL pin
                bit_clear(TrisReg_B,DPDL_BIT);              // Clear direction bit for output
                output_high(DPDL);                          // Set DPDL pin
                bit_set(TrisReg_B,DPDL_BIT);                // Set direction bit for input
                Tamb<<=1;                                   // Make room for next bit
                // for long LOW level settling a delay of a few microseconds might be needed here
                // but make sure max. tbit time is not exceeded
                if(input(DPDL)==1)
                        Tamb++;
        }

        clear_DPDL_interrupt();
        #use standard_io(B)
}

#int_timer1
//==========================================================================
void t1_service routine (void)
{
        read_DigiPile ();                                   // read out sensor data
        set_timer1(53036);                                  // 50ms
        printf("%lu\t%lu\r",Tobj, Tamb);                    // print  sensor output data
}
```

```
//==========================================================================
void main(void)
{
        setup_timer_1(T1_INTERNAL | T1_DIV_BY_8);     // Setup timer 1
        enable_interrupts(INT_TIMER1);
        enable_interrupts(GLOBAL);
        port_b_pullups(FALSE);                         // disable Port B0 pull up resistor
        clear_DPDL_interrupt();

        while(1);                                      // loop forever

}
```

Figure 6 DigiPile® read-out program example

2.6 Electrical Data

Below is all required data to operate the detector. Unless specified differently, all data refers to 25°C environmental temperature.

Parameter	Symbol	Min	Typ	Max	Unit	Remarks
Operating Voltage	V_{DD}	2.4	3.3	3.6	V	
Supply Current	I_{DD}		11	15	µA	V_{DD} = 3.3 V
Input Low Voltage	V_{IL}			$0.2V_{DD}$	V	
Input High Voltage	V_{IH}	$0.8\ V_{DD}$			V	
Pull Up Current			130		µA	*direct link* pin to V_{ss}
Pull Down Current			200		µA	*direct link* pin to V_{DD}
Input Capacitance			5		pF	
Data Setup Time	t_s	90			µs	
Data Clock Low Time	t_L	200			ns	
Data Clock High Time	t_H	200			ns	
Data Bit Settling Time	t_{bit}	1			µs	C_{LOAD} = 10 pF
direct link Low time	$t_{bit}+t_L$			25	µs	1)
Serial Interface Refresh Time	t_{REP}			3.0	ms	
ADC Resolution Tobj			17		Bits	Max Count = 131071
ADC Resolution Tamb			14		Bits	Max Count = 16383
ADC Sensitivity		0.7	0.8	0.9	µV/count	
ADC Offset Tobj			64500		counts	
RMS output noise refereed to input			0.5		$\mu V{*}Hz^{-0.5}$	@1Hz
Sensitivity of Tamb			90		counts/K	Linear for Tamb from 0°C to 90°C
Count @ Tamb = 25°C			7900		counts	
LPF Cut-Off Frequency			8		Hz	
Operating Temperature	T_o	-20		70	°C	The electrical parameters may vary from specified values in accordance with their temperature dependence.
Storage Temperature	T_s	-40		100	°C	Avoid storage under high humid environment.

Note 1): Exceeding *direct link* Low time can result in false readings

Table 1 DigiPile® electrical data

3 Software Filter Recommendation

The most unique feature of DigiPile® is the direct communication with the hosting microcontroller without requiring any hardware filtering. Thus, it is recommended that software filters be implemented within the host.
Various websites give recommendations for software designed filters. You may also check at:

http://www-users.cs.york.ac.uk/~fisher/mkfilter/
http://www.atmel.com/dyn/resources/prod_documents/doc2527.pdf

Please note: The links above are to external websites and beyond EXCELITAS's control or responsibility. For that reason, EXCELITAS does not guarantee the accuracy of the content or any functions provided by these links.

4 Typical Application Circuit

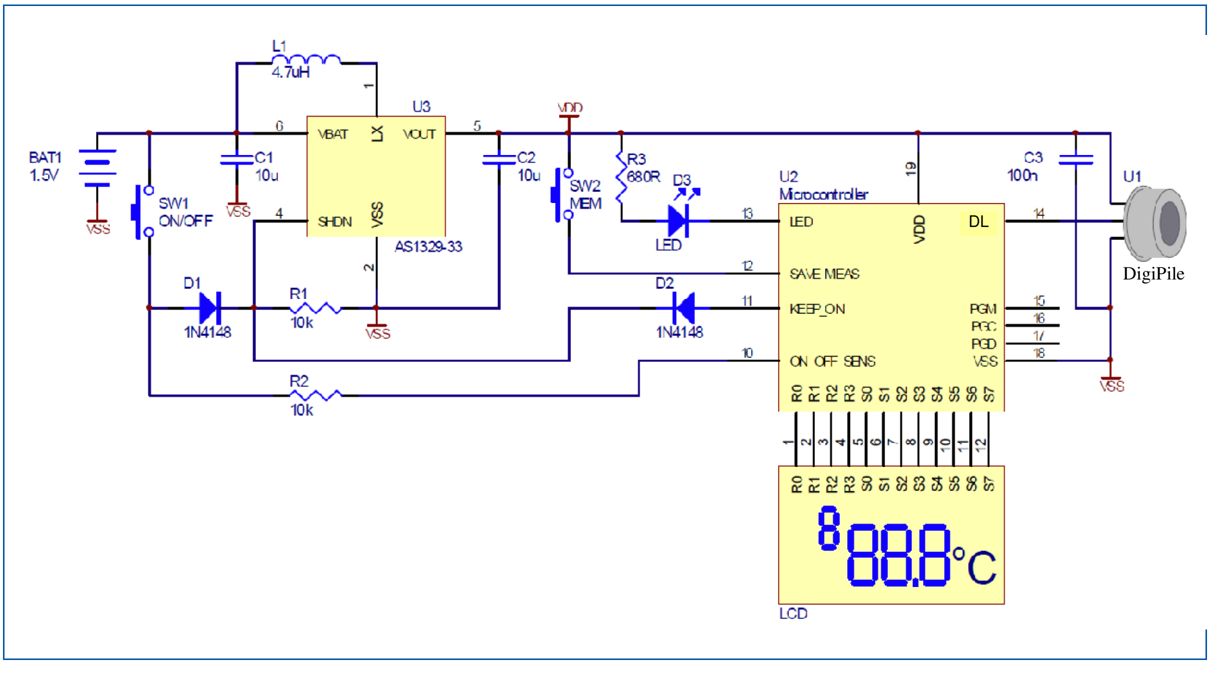


Figure 7 Typical application circuit

The above circuit shows a possible application for DigiPile® as a compact ear thermometer with LC-Display.

5 Ambient Temperature Compensation

The thermopile sensor converts the temperature radiation of an object surface to an electrical signal by means of thermocouples (Seebeck effect). The sensor output voltage is caused by the temperature difference between radiation heated (hot) junctions and cold junctions with a good thermal contact to the housing.

In order to deliver an output signal which is only dependent on the object temperature, any change of housing (ambient) temperature has to lead to an appropriate output signal correction, by adding the Tobj – and the Tamb-temperature reference signals.

6 Operating and Handling

6.1 Handling

Stresses above the absolute maximum ratings may cause damages to the device. Handle the detectors as ESD sensitive devices and protect them from electrostatic discharges. Working areas should be conductive and grounded. When handling detectors, operators must be grounded. Avoid mechanical stress on the housing and especially on the leads. Be careful when cutting or bending leads to avoid damage. Do not bend leads less then 5 mm from their base. Do not drop detectors on the floor. Do not expose the sensor to aggressive detergents such as Freon, Trichloroethylene, etc. Avoid touching the detector window. To clean windows when necessary, use only ethyl alcohol with a cotton swab.

6.2 Soldering Conditions

For soldering the detectors within PCBs, the typically applied and recommended process is hand or wave soldering. Hand soldering and wave soldering may be applied by a maximum temperature of 260°C for a dwell time less than 10 s. Avoid heat exposure to the top and the window of the detector. Reflow soldering is not recommended.

6.3 Product Safety & RoHS

Modern high-tech materials are applied in the production of our Thermopile sensors. Some of these materials are sensitive to high temperature exposure or to specific forms of stress. Our parts are compliant with environmental regulations that may be reviewed on the EXCELITAS website. We recommend always checking your local regulations. Disposal should only be carried out in accordance with the latest legislation and directives. In Europe, WEEE directives must be followed. The Sensor fully complies with the European RoHS environmental directives against the use of hazardous materials in electrical and electronic equipment.

6.4 Performance Advice

Before taking a reading during testing, and/or operation, the unit must become thermally stable due to its nature as a thermal detector and the high sensitivity of the device.
All data are specified at room temperature. When operating at other temperatures within the specified operating range, parameters may vary. The detector might operate outside the quoted range, but may exhibit degraded performance.

7 Frequently Asked Questions

1. **What is the data frame rate?**
   330Hz max.
2. **Is the Thermopile output signal linear ?**
   No: The thermopile voltage shows a non-linear output characteristic versus the object temperature.
3. **What is the Thermopile signal range?**
   Theoretically 0 to 131071. In the application it depends on the sensing range and the optical system.
4. **Why do I have 64500 digits output with no radiation?**
   Digital offset / working point allows to measure below and above room temperature (25°C)
5. **How often will the Master need to request a signal package? Is a 10 Hz sampling rate suitable?**
   The Master may repetitive request up to 330 times/s - one request = 1 package.
   10 Hz may be sufficient with respect to the time constant and the LPF of the sensor. Higher data rates in combination with averaging or low pass filtering may be of advantage for noise reduction.
6. **Will I need signal filtering?**
   Filtering is not mandatory but may be of advantage for noise reduction.
7. **Does the DigiPile® offer any cost saving advantages?**
   Yes, less component requirements, PCB space, and assembly work will result in lower system costs.
8. **What is power supply requirement?**
   Minimum voltage requirement is 2.7 Volts, maximum supply current is 15 µA. As for any digital device, the sensor may cause current peaks. Thus, a buffering capacitor of 100nF is recommended.
9. **What are the advantages of DigiPile® compared to analogue version?**
   Thermopiles provide only very low voltage signals in the range of micro- to some milli-volts and have a high output impedance. This makes them susceptible e.g. to RF disturbance. The DigiPile® output signal is much more immune against RF. The signal does not need amplification and can be directly processed, resulting in higher reliability for the complete system.
10. **After power is applied how long before accurate readings can be obtained from the device?**
    a) The internal A/D- converter needs t_{REP} = 3 ms to convert a value.
    b) The detector has to reach thermal equilibrium with the environment. This can take a few seconds to achieve accurate readings, which is typical for all thermal sensors.
11. **What is the sampling rate?**
    Sampling rate is determined by the hosting µC and can be up to the specified refresh time of 3ms (≈ 1/330 Hz).
12. **What is the content of a data package?**
    A data package consists of a 'read data word' signal (= high) initiated by the host. The microcontroller then reads 17+14 bits. Data arrives with MSB first. The reading procedure is defined in chapter 2.3 data communication.
13. **How do I handle interrupts in data read out, without corrupting data?**
    The sensor only updates the data in the direct link interface, while it is at low level. There is no update if *direct link* line is kept at high level.
    If the controller has to serve an Interrupt, set the *direct link* line "high" for the duration of the interrupt. When coming out of the interrupt routine, release it and read the value/bit. Continue reading as normal.
14. **Output of the sensor: Is there a need for pull-up or may the sensor directly be hooked to the computer pin?**
    The DigiPile® can be hooked directly to a digital I/O- pin of a microcontroller. But the µC must be able to drive the pin to High and Low. With some µC's it might be necessary to have a pull-up resistor in the 25 kΩ range, if the µC has problems to push the pin to High (the DigiPile® input current is typ. 130 µA).
15. **How to read the data output of TPS 1T Family by using a µC I/O port?**
    It should not be a problem to use an I/O- pin directly. The typical push/pull- current of the DigiPile® is in the range of 130 … 200 µA. This is enough for µC- input- impedance higher than 15kOhms. Please check the output voltage with an oscilloscope. Does the voltage drop to Low too? If the DigiPile® cannot produce a High, a pull- up- resistor in the 15kOhm- range will help. But most likely it is a communication problem/timing problem rather than a problem with the voltage levels.
16. **Summary: The procedure to read the data from the DigiPile®**
    1. Drive the Direct Link interface high.
    2. Then wait for 90 µs.

3. Drive the line low for at least t_L = 200 ns then pull it high for at least t_H = 200 ns, then release it to read (high impedance).
4. Then the detector will give the first bit (MSB) to the output.
5. Depending on your input capacitance, you have to wait with reading until there is a saturation of the output (otherwise you will read a high)
6. Wait for at least t_{bit} =1µs (for 10 pF on your input line, for higher C wait longer) to allow the line to discharge your input capacitor.
7. Read the bit.
8. Repeat this (step 3 to 8) until all 17+14 data bits are read.
9. Then drive it low for at least t_L = 200 ns, then release it (high impedance).
10. Wait minimum 2ms before reading the next value by repeating this procedure (steps 1 to 9) from the start.

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