Application Note
Analog voltage output with MLX90614

Scope

Analog output voltage is sometimes needed from sensors in a system. Current application note describes how to implement that with the MLX90614 IR thermometer.

The IR thermometer MLX90614 can be configured in EEPROM for any of the following 3 types of output:

PWM (push-pull or NMOS open drain)

SMBus (always a slave device on SMBus network)

Thermal relay (push-pull or NMOS open drain)

All these outputs provide measured temperature, linearized and ready to be used.

With the PWM option, the duty cycle of the continuous pulse train represents the measured temperature. Passing this pulse train through a low-pass filter will result in the average value that can be measured as an analog value. Some details of this option need to be taken into account in order to get relevant results.

Major drawbacks of PWM-to-voltage conversion are:

Accuracy & resolution: it would be very expensive to reach the resolution and accuracy the MLX90614 provides through the SMBus and PWM digital interface by means of an analog measurements. It is likely that both accuracy and resolution will be significantly degraded in most cases. The precise degree of that degradation is strongly application specific and can not be generally predefined for all cases.

EMC: analog lines are much more susceptible to noise than digital communications.

Dependence on environmental conditions such as temperature, power supply variations or humidity will be higher.

Therefore, conversion of MLX90614 measurements to an analog voltage output can hardly be recommended as an approach in applications where accuracy and resolution are important.

Related Melexis Products

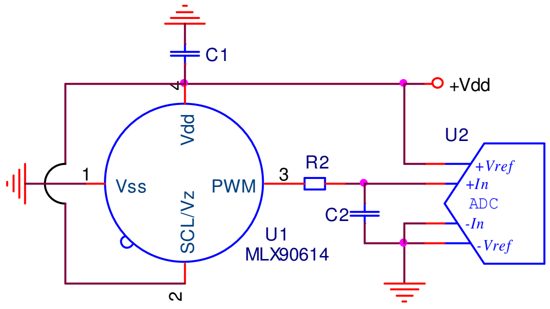
MLX90601 is the previous generation IR thermometers. MLX90614 is a replacement of that product and is recommended for new designs. EVB90614 is the Evaluation board which supports the MLX90614 devices.

Table of Contents

Other Components Needed

Passives used in the schematics within current application note include:
SMD ceramic capacitors 100nF 16V or higher.
Capacitors 1uF 16V or higher
Power supply bypass capacitors, like
Aluminum 470 uF 10V
Tantalum 10 uF 10V
Resistors 10 kOhm 5%.
Resistors 47 kOhm 5%
Resistors 470 kOhm 5%
Resistors 22 kOhm 5%
OpAmp AD8603 or equivalent
NPN BJT 2N5551 or equivalent

Typical Circuit



Explanation

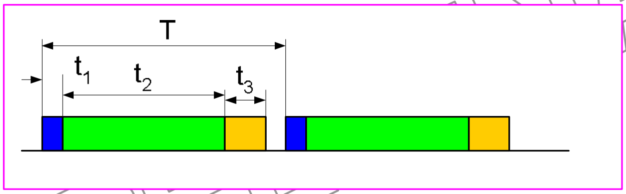
C1 is the local power supply bypass decoupling capacitor. The MLX90614 needs that for bypassing of the on-chip digital circuitry switching noise. The well known value 100nF (SMD ceramic type) is typically adequate for this component.

R2 and C2 form the LPF filter which restores the DC average value of the PWM output train. Their values will be discussed in detail below.

U2 is the voltage measurement unit. Shown is an ADC. Note that the reference voltage of that unit is taken from the MLX90614 power supply voltage (Vdd, pin 4). The averaged output voltage depends on the Vout,high of the MLX90614 (pin 3, PWM output). The PWM output of the MLX90614 is CMOS (configured as push-pull in this case), so the high output level is virtually equal to the Vdd in case of light loading. Therefore, a 5% tolerance of the Vdd will directly degrade the average voltage measured by 5%.

MLX90614 PWM output format

PWM output of MLX90614 can be configured in two modes – single data transmission and dual data transmission. For the average value to be useful the single PWM output format is required. It has the timings shown below:



Where T is the PWM period, t_1 is starting buffer (always high, with a duration which is always 12.5% of the period), t_2 is the data band, taking an additional 0…50% of the period. t_3 is the error signaling band (25% of the period). In normal operation the t_3 should be zero as well as the rest of the period.

The temperature reading can be calculated from the signal timing as:

$$Tout = \left[\frac{2t_2}{T} * (Tmax - Tmin)\right] + Tmin$$

where Tmin and Tmax are the corresponding rescale coefficients in EEPROM for the selected temperature output and T is the PWM period. Tout is T_{obj1}, T_{obj2} or T_a according to Config Register [5:4] settings. (*Refer to the MLX90614 Data sheet available on www.melexis.com for details.*)

Example:
Tobj1 => Config Reg[5:4] = 11'b
Tomin = 0°C => Tomin [EEPROM] = 100 * (tomin + 273.15) = 6AB3h
Tomax = +50°C => Tomax [EEPROM] = 100 * (tomax + 273.15) = 7E3Bh
Captured PWM high duration is 0.495*T => t2=(0.495 – 0.125)*T=0.370*T =>
measured object temperature = 2X0.370* (50°C -0°C)+0°C = +37.0°C.

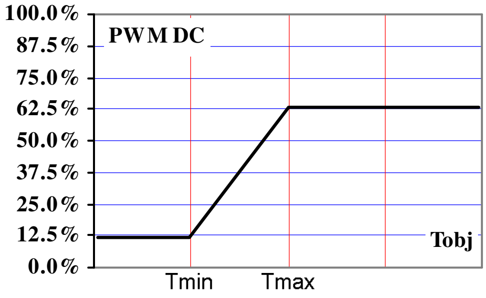
The data field transmitted via PWM is 10 bit. Tmin and Tmax are written in device's EEPROM, and then the output data swing (12.5 to 62.5% duty cycle) will represent temperatures within this range. This provides the "zoom in" option – 10 bits resolution over 50 degrees range, for example, would give 0.0488 degrees LSB. Outside this range the output will saturate (to 12.5% for T<Tmin and to 62.5% for T>Tmax).

PWM format in analog values

As shown, the temperature range of interest can be programmed in device EEPROM and then the measured temperature will give a 12.5 to 62.5% duty cycle. This will be the averaged value of the PWM output train (percents of the power supply voltage Vdd). The table below represents the averaged voltage values for T=Tmin, T=(Tmax+Tmin)/2 (midscale) and T=Tmax and several voltage supplies for both 5V and 3V MLX90614 versions.

	Version	MLX90614**A**Ax				
	DC\Vdd	Vdd,min=4.5V	Vdd,nom-5%=4.75V	Vdd,nom=5V	Vdd,nom+5%=5.25V	Vdd,max=5.5V
Tmin	12.5%	0.5625	0.59375	0.625	0.65625	0.6875
Tmid	37.5%	1.6875	1.78125	1.875	1.96875	2.0625
Tmax	62.5%	2.8125	2.96875	3.125	3.28125	3.4375
% of the Vdd,nom value		90%	95%	100%	105%	110%
	Version	MLX90614**B**Ax				
	DC\Vdd	Vdd,min=2.4V	Vdd,nom-5%=2.85V	Vdd,nom=3V	Vdd,nom+5%=3.15V	Vdd,max=3.6V
Tmin	12.5%	0.3	0.35625	0.375	0.39375	0.45
Tmid	37.5%	0.9	1.06875	1.125	1.18125	1.35
Tmax	62.5%	1.5	1.78125	1.875	1.96875	22.5
% of the Vdd,nom value		80%	95%	100%	105%	120%

The single data PWM output duty cycle is linearly dependent on the measured temperature:



Any of the temperatures measured is available for the PWM output. MLX90614 comes in single MLX90614xAx) or dual zone (MLX90614xBx) configuration. The single zone version differs with the following specifics:

no IR2 sensor is implemented

Tobj2 data is irrelevant

FOV is a symmetrical cone

A bit in EEPROM (CongifRegister1[05h], bit 6, 1 for dual zone) is set during factory calibration that identifies number of zones.

Herein, unless otherwise noted, a single zone with object temperature 1 transmitted via PWM is assumed. In most examples, 5V version is used. With extended PWM output format it would not be possible to use the average value, as it is composed of two independent data bands. Nevertheless it is possible to read the MLX90614xBx Tobj2 in the PWM-to-voltage conversion application (single PWM format, again).

It is possible to configure the output to swing in a human friendly format (like 3.00 V for 30.0 °C). As the duty cycle of the output PWM train swings in duration with a factor 1:5 (12.5% to 62.5%), the temperature range of the MLX90614 needs to be set accordingly. Note that this assumes that the ratiometric to the power supply voltage measurement option is unused. Therefore, if the output is 3.00V at 30.0°C and 5.00V power supply, with the specified operating voltage range of MLX90614AAA, 4.5…5.5V at 30.0°C the averaged value will vary as 2.70..3.30V. This is ±3°C error in a range of 25°C, or ±12% error.

Here are some examples of human friendly formats settings:

Example 1: Temperature range is 6.25…31.25°C. With 5.00V power supply the averaged voltage will be 625…3125mV, or 0.1V/°C. This case is possible for both ambient and object temperature. Hexadecimal values to be written in EEPROM for that range are:
For ambient temperature: one EEPROM address concatenates both Ta,min and Ta,max. This is Ta range, address 03h. Value to write is 6D45h.
For object temperature: there are two EEPROM addresses for To,min and To,max: To,min occupies EEPROM address 01h, and To,max – 00h. Values to write are:
To,min:To,max [01:00h]=6D24:76E8h.

Example 2: Temperature range is -37.5…+212.5°C. With 5.00V power supply the averaged voltage will be again 625…3125mV. 1 V needs to be subtracted from the output to get 10mV/°C scale with 0°C giving 1000 mV. This case is not an option for the ambient temperature range as the ambient calibration covers -40…+125°C only. To configure the To for that case, values to write in EEPROM are: To,min:To,max [01:00h]=5C0D:BDB5h.

Example 3: Temperature range is 62.5°F…312.5°F. Output is 10mV/°F. As in the previous example, ambient temperature range can not be configured in such a range. Values to write in EEPROM are To,min:To,max [01:00h]=7151:A7292h.

Kelvin temperature configuration is not an option, as even the wide object temperature (-70…+382.2°C) calibration range of the MLX90614 does not cover 1:5 ratio of Kelvin temperatures.

Configuration of MLX90614 for PWM-to-voltage conversion application

The MLX90614 Evaluation Kit, the EVB90614 accompanied by PC SW provides everything needed for configuration and customization of the device. With the Evaluation Board, included in the kit, small volumes of MLX90614 can be easily configured for use in applications that use voltage output.

The MLX90614 has on-chip EEPROM memory. Once configured as desired, it will power-up in the required configuration. (*PWMCTRL and ConfigRegister1, if altered, would require power-down and power-up in order for the changes to take effect*). EEPROM locations of interest for PWM-to-voltage conversion applications are:

To,max, address 00h : 16-bit value that represents the higher limit of the range to be transmited via PWM in case object temperature is transmitted.

To,min, address 01h : same as To,max, but the lower limit.

PWMCTRL, address 02h : PWM function configuration. Reviewed in details below, as well as in the MLX90614 datasheet.

Ta range, address 03h : 8+8 bit values of the higher (8 left bits) and lower (8 right bits) limits of the range to be transmitted via PWM in case ambient (package, or die) temperature is transmitted.

ConfigRegister1, address 05h : Contains selection of the data to be transmitted via PWM. Note that this register also consists of calibration settings, so adventurous writes of data in that register may cancel the factory calibration.

All ranges limits are valid for both zones in a dual zone MLX90614. For example, the upper and lower limits are set for both object temperatures Tobj1 and Tobj2.

Ranges limits are calculated as follows:

To,max[00h] = hex2dec [100*(to,max + 273.15)] , where to,max is the upper limit of the object temperature in degrees Celsius. For example, upper limit of +120℃ gives 9993h.

To,min[01h] = hex2dec [100*(to,min + 273.15)], where to,min is the lower limit of the object temperature in degrees Celsius. For example, lower limit of -20℃ gives 62E3h.

Ta range[03h] = Ta,H:Ta,L - each limit is coded in one half of the 16-bit number written. Bytes for Ta,H and Ta,L are calculated as follows:

Ta,L = hex2dec [100*(ta,min + 38.2)/64] , where ta,min is the lower limit of the ambient temperature in degrees Celsius. For example, lower limit of -20℃ gives 1Ch.

Ta,H = hex2dec [100*(ta,max + 38.2)/64] , where ta,max is the upper limit of the ambient temperature in degrees Celsius. For example, upper limit of +120℃ gives F7h. This way the example of Ta range -20…+120℃ gives EEPROM[03h]=F71Ch.

Note: all examples are calculated using round-to-nearest, not truncation conversion decimal-to-hexadecimal numbers.

PWMCTRL[02h]:

Bits [15:9] select the PWM period. For the PWM-to-voltage conversion applications highest possible frequency is desired as it results in best ripple rejection after LPF and average value restoration. The minimum period setting (1 ms) is 1 (b'0000001').

Bits [8:4] set the number of repetitions for each period. Valid for extended PWM format. Recommended value is 0 (b'00000').

Bit 3 when high enables thermal relay function of the MLX90614. Recommended value for PWM-to-voltage applications is 0.

Bit 2 when high configures the MLX90614 PWM output as push-pull ; Open drain NMOS when low. Most applications are likely to need push-pull (all examples and schematics reviewed herein are for push-pull output). Therefore the recommended value is 1.

Bit 1 when low enables SMBus. It is necessary to have this bit set for PWM output.

Bit 0 when low selects extended PWM format. Set this bit to 1 for PWM-to-voltage conversion applications.

ConfigRegister1[05h]:

Note that all bits except the discussed below are highly recommended not to be altered as this may cancel the factory calibration.

Bts [5:4] select the data to be transmitted via PWM. There are 3 possible options when averaging and LPF is used:

b'00' – Tamb

b'11' – Tobj1 (most likely to be the choice for these applications)

b'10' – Tobj2 (undefined on MLX90614xAx).

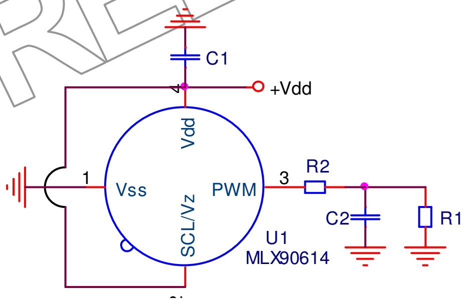
Considerations with analog output measurements

Input resistance

Any loading of the LPF network will inherently degrade the accuracy of the circuit operation. Without loading the averaged voltage will be

Vout = Vhigh*DC + Vlow*(DC-1)

,where Vhigh is the high level output voltage of the MLX90614, Vlow is the low level output voltage of the MLX90614, and the DC is the duty cycle of the PWM output train (0.125…0.625 in normal operation). For the estimation of the LPF loading assume R2 is high enough not to cause significant voltage drop over the output push-pull stage. That gives Vhigh=Vdd, Vlow=0. With loading of the LPF (to ground) the equivalent schematic will be:

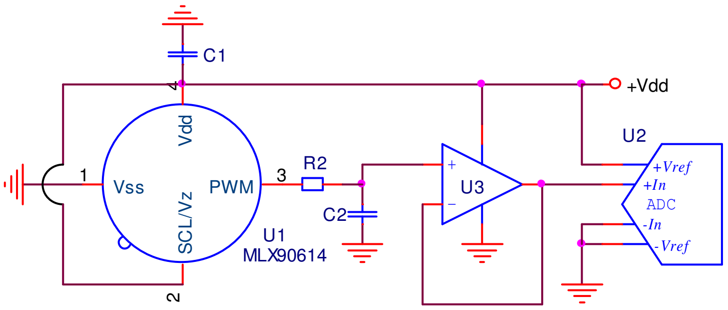


resulting in a passive resistive divider. In that case the output voltage will be

Vout' = [R1/(R1+R2)]*Vout

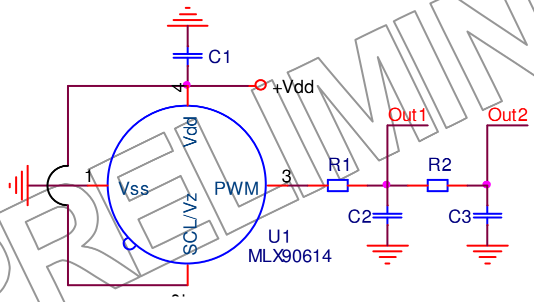
For an example, with R2 = 10 kOhm, and R1 = 1 MOhm, Vdd=5V and DC=0.2 instead of 1000mV the output voltage will be 990mV. In other words, R1:R2=100 introduces 1% error.

Some measurement units (for example, some ADCs and some handheld multimeters) can be demanding for the source resistance when accuracy is a must. In that case a buffer might significantly improve the accuracy, as on the schematic below. With the output voltage range 0.125Vdd...0.625Vdd demands on the input common mode voltage range are relaxed. As an example, AD8603 from www.analog.com would be an appropriate choice for this component.

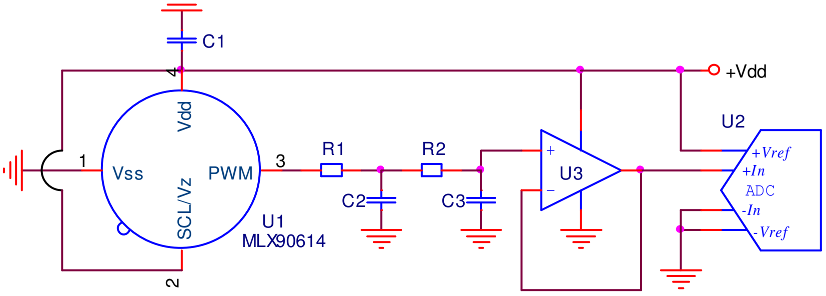


Ripple

The output of the LPF network R2C2 is never a perfect DC voltage. Some ripple is present after the filter network. The ripple amplitude depends on the duty cycle (within the 12.5…62.5% range the ripple would change by a factor of 2.3 with maximum at 50% duty cycle). With R1=R2=10kOhm, C2=C3=1uF, Vdd=5V, PWM frequency 1kHz and duty cycle 50% ripple is approximately 126mV peak-to-peak for Out1 and 1.6mV peak-to-peak for Out2.



If this amount of ripple is unacceptable, a more complicated schematic could be used, like



With R1=47k, R2=470k, C2=C2=1uF, the ripple (again at 5V, 50%, 1kHz) seen by the ADC will be less than 20 uV. Note that this ripple reduction comes with significantly increased settling time (3 seconds for this case). Certainly, a cost-effective approach might be to use a first order RC network between the MLX9614 and the ADC in conjunction with digital filtering of the ADC output.

Reference

Using the Vdd as an ADC reference voltage eliminates the Vdd influence on the Vhigh and therefore on the analog voltage output. For applications with low accuracy demands this influence might be acceptable, but it is recommended to check the error introduced. An alternative approach might be to also measure the Vdd, or power the MLX90614 from a voltage reference with tight tolerance. It is still not likely to expect easy and 100% successive cancellation of the Vdd influence compared to simply using the Vdd as reference voltage.

Maximum PWM frequency

In the “Configuration” section the setting for frequency recommended is the maximum MLX90614 output frequency of 1 kHz. Attenuation of the AC ripple improves with frequency (with constant RC time product). This way the maximum frequency will be filtered to least ripple.

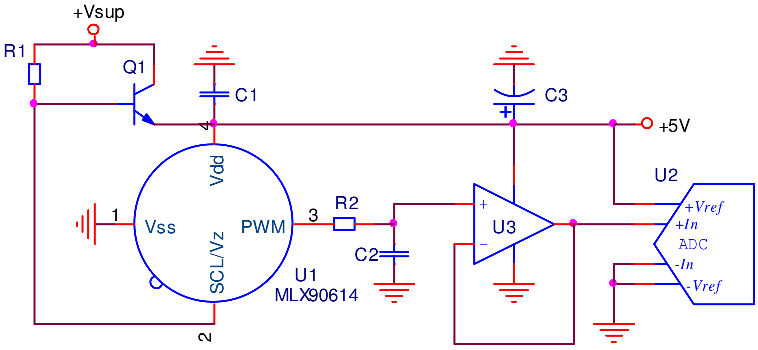
Output levels versus loading

The push-pull output stage of the MLX90614 is CMOS, with Rds,on 100 Ohm at 5V. This value is for design guidance only as this is not a controlled parameter. With 3V version Rds,on is likely to increase to about 200 Ohm. The NMOS and PMOS Rds,on values are pretty close, so it is not likely to expect degradation of the average value with the series resistor of the LPF network as far as this resistor value is high. Decreasing the series resistor value has additional disadvantages:

- Increased sink/source current via output stage resistors yields in voltage drops over the output stage transistors
- The PWM train results in a partial charging/discharging of the LPF capacitor. The alternating charge/discharge current is derived from the power supply. This means that the power drain will increase with decrease of the output series resistor.

General considerations

The MLX90614 is an integrated system in a metal can package. This results in good EMC performance of the device. However, power lines still need decoupling as with any mixed signal system. A 100nF SMD decoupling capacitor close to the package is typically good enough local bypass. Certainly, the entire power rail needs to be free of severe noise and ripple. In systems with strong EMI a careful EMC layout in conjunction with enhanced power supply filtering will be a must. It is obviously more simple and cheap to implement digital communication with the MLX90614 if EMC problems are expected.
With power supply voltages like 12V or 24V MLX90614Axx offers the extended flexibility for building voltage regulators. It integrates a synthesized zener diode that can be used to build 5V regulators as shown on the schematic below. Note that this zener diode is not provided as a reference voltage source (refer to the MLX90614 datasheet for electrical specifications).



As shown, this regulator can be used to power more than just a MLX90614Axx thermometer. However, the zener is not designed to sink large currents (refer to MLX90614 datasheet for specifications). Base current of the external NPN BJT Q1 multiplied by the current gain is the power drain of the circuitry, powered by this regulator. This base current can not exceed the bias from R1 with the minimum zener diode operating current subtracted. Note that the 3V version (MLX90614Bxx) does not provide the zener diode option.

Conclusion

Digital communications have inherent advantages that make them the prime choice for virtually any application. However, there is a way to use the purely digital communications embedded in the MLX90614 IR thermometer in analog applications on the price of only two passive components. With reasonable care about several design specifics many demands to such designs can be met. Visit www.melexis.com for most recent documents and tools.