SGX SENSORTECH

Infrared Sensor Application Note 5
Determining Coefficients for Linearisation and Temperature Compensation

INTRODUCTION

This application note can be used to assist with the methods of determining the linearisation and temperature compensation coefficients used during the target gas concentration calculations for infrared gas sensors. Differences in circuit designs (i.e. lamp supply) could cause small variations in these coefficients and may therefore require new coefficients based upon the circuit design in to which the sensors will be installed. Four coefficients (see Table 1) are required for each sensor type in order to obtain a linearised output over temperature. This information should be read in conjunction with Infrared Sensor Application Note 2.

Coefficient	Purpose
a	Linearisation
n	Linearisation
α	“Zero” variations over temperature
β	“Span” variations over temperature

Table 1 – Linearisation and Temperature Coefficients

The use of an appropriate curve fitting program is recommended to calculate the “a” and “n” coefficients. Although values for each of the coefficients are shown in Infrared Sensor Application Note 2, they are based upon the performance of the sensors in circuits designed by SGX Sensortech technologies.

DETERMINING “a” AND “n” COEFFICIENTS

The following equation is used to determine the “a” and “n” coefficients and has been derived by rearranging the equation used for the calculation of the span stated in Infrared Sensor Application Note 2:

$$1 - (\text{Act} / [\text{Zero} \times \text{Ref}]) = \text{Span} \times [1 - \exp(-aC^n)]$$

Where:

Act = the peak-to-peak output of the Active Detector in volts in the calibration test gas.
Ref = the peak-to-peak output of the Reference Detector in volts in the calibration test gas.
Zero = the “Zero” value (Act/Ref in 0% vol. Test gas).
Span = the value calculated as part of the calibration process.
Note: This value is not required when determining “a” and “n” as it will be automatically determined by the curve fitting program.
a = fixed linearisation coefficient (to be derived using the curve fitting program).
C = the concentration of the applied calibration test gas in % volume (i.e. 5 for 5% vol.)
n = fixed linearisation coefficient (to be derived using the curve fitting program).

To determine the coefficients, it is recommended that calculations of the Normalised Absorbance (1 - [Act / (Zero x Ref)]) are used at ten different concentrations evenly spaced over the full concentration range on at least five sensors. An average of these readings is then used to determine the “a” and “n” coefficients. Table 2 shows typical data obtained from the IR12BD.

Applied Concentration (% vol.)	Average Normalised Absorbance
0.0	0.000
0.5	0.031
1.0	0.050
1.5	0.064
2.0	0.076
2.5	0.086
3.0	0.095
3.5	0.103
4.0	0.110
4.5	0.117
5.0	0.123

Table 2 – Typical Normalised Absorbance Measurements for the IR12BD

Once this information has been obtained, the following equation can be used in a curve fitting program to determine “a” and “n”:

y = s*(1 - exp[-a*(x^n)])

Where:
y = Average Normalised Absorbance at each concentration.
x = Methane Concentrations.

A curve fitting program can then be run to determine “a” and “n” (“s” can be ignored).

DETERMINING TEMPERATURE COEFFICIENTS

In order to compensate for temperature changes, two levels of compensation are recommended. Firstly, the Alpha compensation to compensate for the apparent changes in the Zero reading and, secondly, the Beta compensation to compensate for the apparent changes in the Span reading. This information should be read in conjunction with the Temperature Compensation section of Infrared Sensor Application Note 2.

The principle behind determining Alpha and Beta is to convert the following equations, used during the calculations to obtain a temperature compensated concentration, into the form “y = mx + c”, so that “m” (gradient) is equivalent to the Alpha or Beta coefficient.

Alpha Compensation (Equation 1)

$$\text{Normalised Transmittance}_{(comp)} = \text{Normalised Transmittance} \times (1 + \alpha\,(T - T_{cal})$$

Where,
Normalised Transmittance = Act / (Zero x Ref), or
Normalised Transmittance = 1 – Normalised Absorbance
Act = the peak-to-peak output of the Active Detector in volts (in zero gas).
Zero = the “Zero” value calculated during the calibration routine.
Ref = the peak-to-peak output of the Reference Detector in volts (in zero gas).
α = the Alpha coefficient.
T = the actual temperature measured at the sensor in kelvin.
T_{cal} = the temperature (stored in non-volatile memory) measured during the calibration routine (see below) in kelvin.

Beta Compensation (Equation 2)

$$\text{Span}_{(comp)} = \text{Span} + [\ \beta \times ((T - T_{cal}) / T_{cal})]$$

Where:
Span = the “Span” value calculated during the calibration routine.
β = the Beta coefficient.
T = the actual temperature measured at the sensor in kelvin.
T_{cal} = the temperature measured during the calibration routine in kelvin.

DETERMINING ALPHA (α) TEMPERATURE COEFFICIENT

To change the Alpha coefficient equation to a “y = m x + c” format from which “m” (gradient) will be the “α” coefficient, Equation 1 is rearranged to give the following:

$$(\text{Normalised Transmittance}_{(comp)} / \text{Normalised Transmittance}) = \alpha\,(T - T_{cal}) + 1$$

As the Alpha coefficient effectively temperature compensates the zero reading, the target value for the Normalised Transmittance $_{(comp)}$ calculation should be equal to 1 as this is equivalent to 0% vol. concentration.

Therefore:

$$(1 / \text{Normalised Transmittance}) = \alpha\,(T - T_{cal}) + 1$$

Where:
y = (1 / Normalised Transmittance)
m = α
x = $(T - T_{cal})$
c = 1

To determine the Alpha coefficient, values for y and x are required. It is recommended that calculations of the Normalised Transmittance (Act / (Zero x Ref)) when exposed to 0% vol. are used for at least two different ambient temperatures (ideally incorporating one of the extreme temperatures and normal ambient temperature of 21 °C or more) on at least five sensors. Complete these calculations and then take an average of these values. Table 3 shows typical data obtained from the IR12BD.

Temperature (°C)	Average Normalised Transmittance (to 0% vol. Target Gas)
60	0.978
40	0.989
20	1.000
0	1.011
-20	1.022

Table 3 – Typical Normalised Transmittance Measurements for the IR12BD at Various Temperatures

A graph of "**T - T$_{cal}$**" (x-axis) V's "**1/(Normalised Transmittance)**" (y-axis) should now be plotted from which Alpha (gradient of slope) can be determined as shown in Figure 1. The value of Alpha shown below is 0.000549.

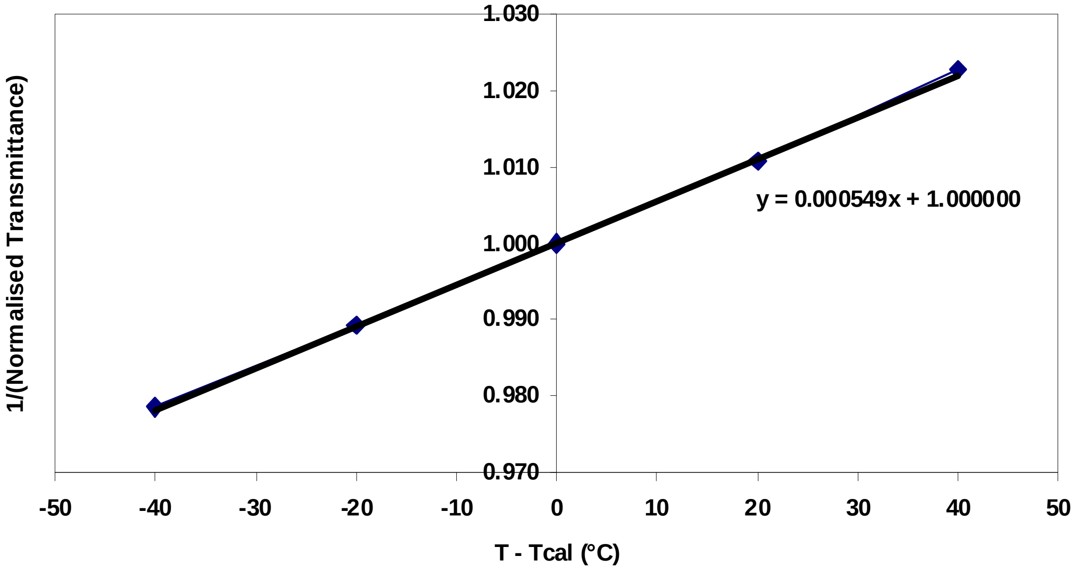

Figure 1 – Graph to Determine Alpha

DETERMINING BETA (β) TEMPERATURE COEFFICIENT

To change the Beta coefficient equation to a "y = mx + c" format from which "m" (gradient) will be the "β" coefficient, Equation 2 is rearranged to give the following:

$\text{Span}_{(comp)} = \beta \times [(T - T_{cal}) / T_{cal}] + \text{Span}$

Where:
y = $\text{Span}_{(comp)}$
m = β
x = $[(T - T_{cal}) / T_{cal}]$
c = Span

To determine the Beta coefficient, values for y and x are required. It is recommended that calculations of the Span when exposed to the calibration gas, for at least two different ambient temperatures (ideally incorporating one of the extreme temperatures and normal ambient temperature of 21 °C or more) on at least five sensors. Complete these calculations and then take an average of these values. Table 4 shows typical data obtained from the IR12BD.

Note: Span = (1 – Normalised Transmittance) / (1 – exp(-aC^n))

Temperature (°C)	Average Normalised Transmittance (to 5% vol. Methane)	$\text{Span}_{(comp)}$
60	0.873	0.186
40	0.877	0.199
20	0.880	0.212
0	0.883	0.227
-20	0.885	0.243

Table 4 – Typical Normalised Transmittance Measurements for the IR12BD at Various Temperatures

A graph of "$\mathbf{(T - T_{cal}) / T_{cal}}$" (x-axis) V's "$\mathbf{Span_{(comp)}}$" (y-axis) should now be plotted, from which Beta (gradient of slope) can be determined as shown in Figure 2. The value of Beta shown below is –0.2097.

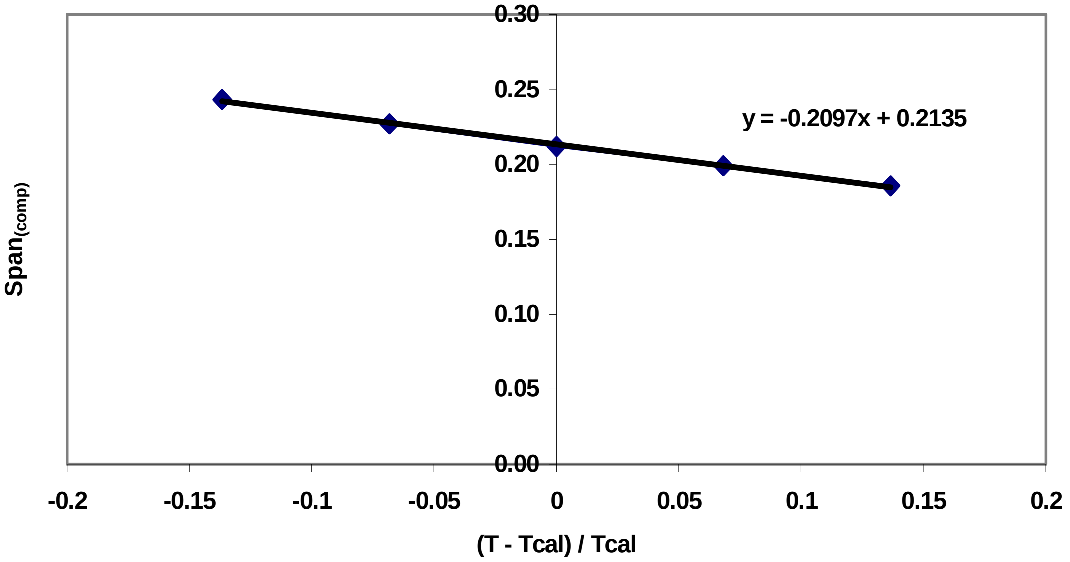

Figure 2 – Graph to Determine Beta