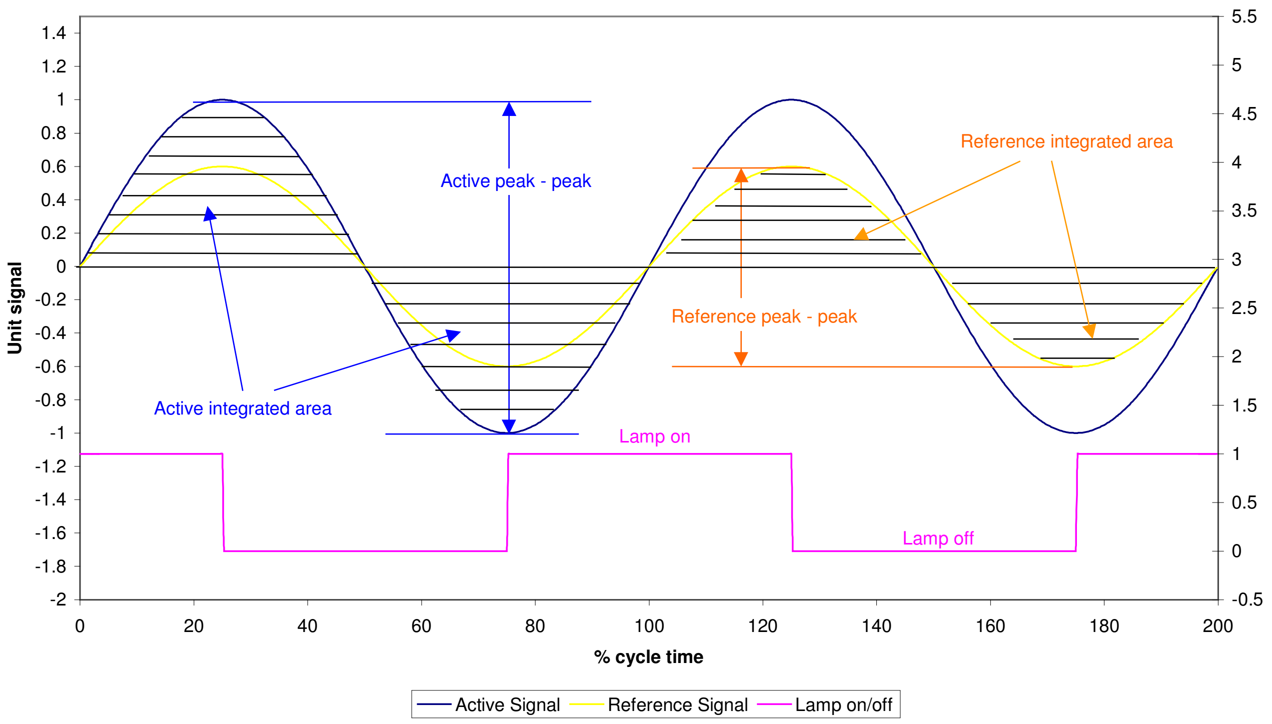
# Application Note DESA2: Signal extraction

This application note discusses the means to extract the target gas concentration from the output signals of an infrared sensor preamplifier. The mathematics is discussed along with means to compensate for temperature and cross-referencing. The expressions to extract the concentration are given along with a programming guide.

## 1) Signal waveforms and entry values:

The signals resulting from amplification as discussed in application note DESA1 should appear as an approximate sine wave, one signal for the active and one signal for the reference. The meaningful signal is related to the integrated charge generated by the detector for each channel during each on-off cycle of the lamp. So we need to extract firstly a measure we can use. This measure can simply be the peak-to-peak measurement or it can be the integrated area within the waveform or it can be the RMS equivalent of the waveform. Whichever method is used results in a value for the active signal strength and a value for the reference signal strength. This measure should be taken every on-off cycle of the lamp.  Figure 1 shows typical sample waveforms, the relationship between the waveforms and the lamp cycle plus the peak to peak and integrated area measures as examples.

**Figure 1: Sample waveforms**



For each cycle a new measure of the active and reference signal strengths should be taken. This measure can be the new peak to peak value, the new integrated area value or the new RMS value, whichever method is chosen depends on the software approach being taken.

In the presence of target gas the active signal strength will reduce and this is the basic detection means. The reference signal strength is used to compensate for changes in incident radiation, changes in optical transmission and any changes in responsivity of the detectors due to temperature. It is the ratio of active signal strength to the reference signal strength that is used to extract the gas concentration in the mathematics routines.

2) Basic equations to extract gas concentration:

The Beer-Lambert law describes the absorbance of radiation as a function of the gas concentration and is expressed as A=εcl where A is absorbance (dimensionless), **ε** is the extinction coefficient for the wavelength being absorbed, c is the gas concentration and l is the pathlength. The absorbance, A, is related to the intensity of radiation by A = -log( $I/I_0$), where I is the intensity of radiation in the presence of target gas and $I_0$ is the intensity in the absence of target gas. This law holds for a single wavelength since the extinction coefficient changes with wavelength in accordance with the spectrum of the target gas.

The detectors consist of an active channel and a reference channel. Each channel has a passband infrared filter in order that the channel only responds to wavelengths of radiation that pass through the filters. Therefore the detectors see a band of wavelengths, each wavelength having its own extinction coefficient from the target gas and its own transmission through the passband filter. Consequently this distorts the Beer-Lambert law relationship between intensity and gas concentration, modifying it in general terms from I/I0 = exp{ - εcl } to:

$$1 - I/I_0 = s * (1 – \exp\{ - a * [c]^b \} )$$

where s represents a span value, a is an exponential constant for a given target gas and range related to εl, c remains as the gas concentration and b is a power term. The span value represents the maximum reduction in intensity expected for a given target gas while the exponential and power term constants are derived empirically from measurements of the intensity as a function of gas concentration.

The ratio of active to reference signal should be normalised in order to get a value for $I/I_0$ which is within the range 0 to 1. In order to do this, measures of the active and reference signals are taken in the absence of target gas and the ratio of these signals is then stored as a zero value. So zero = $I_{active}$/ $I_{reference}$ in the absence of target gas where $I_{active}$ is the active signal value and $I_{reference}$ is the reference signal. The normalised value of $I/I_0$ is then obtained for each lamp cycle from:

$$I/I_0 = I_{active}/(zero * I_{reference})$$

The resulting modified form of the relationship is then given by:

$$1 - I_{active}/(zero * I_{reference}) = span * (1 – \exp\{ - a * [concentration]^b \} )$$

Rearranging the expression allows us to extract the gas concentration from:

$$[concentration] = ( - \ln \{1 – [(1 - I_{active}/(zero * I_{reference})) / span] \} / a ) ^ (1/b)$$

If we denote absorbance as being equal to (1 - $I_{active}$/(zero * $I_{reference}$)) then:

$$[concentration] = ( - \ln \{1 - (absorbance / span)\} / a ) ^ (1/b)$$

For each cycle of the lamp a new reading of $I_{active}$ and $I_{reference}$ is used to update the calculation. The parameters required in addition to the active and reference signal sizes are the zero (found from calibration), the span (also found from calibration), the exponential constant a and the power term constant b.

The value for span can be found by measuring the active and reference signals when the sensor is exposed to a known target gas concentration, calculating the absorbance and then using the rearranged form:

$$Span = absorbance / (1 – \exp\{ - a * [concentration]^b\} )$$

3) Temperature compensation:

Temperature can make several possible contributions to the signals. The responsivity of the detectors changes with temperature and this is approximately compensated by the inverse temperature characteristic of the on-chip FETs within the detector. In addition, the effect of temperature on capacitance values within the preamplifier can change the frequency response and the subsequent gain. The suggested circuit in DESA1 is balanced to give a plateau response in the frequency range of interest so this effect should be minimal. However, if other circuit arrangements are used then care should be taken to ensure the gain is not affected significantly by temperature. Finally, the ideal gas law has an absolute effect on the relationship between the gas concentration and temperature, as given by the ideal gas law relationship:

$$PV = nRT$$

Where P = pressure, V = volume of the sensor, n = number of moles of gas inside the sensor, R = Ideal gas law constant and T = absolute temperature.

The sensor effectively monitors the number of moles of gas within the optical path and therefore this is affected by both pressure and temperature, where we assume the volume of the sensor remains constant. This ideal gas law effect is normally compensated in software by applying ideal gas law correction, at least for temperature.

Temperature correction is typically applied to both the zero and to the span. Note that ideal gas law correction can be incorporated in the span temperature compensation if desired, otherwise it is applied to the final concentration value. The general expression for zero temperature compensation is:

$$Z_{corr} = Z_{cal} * (1 + \alpha * (T - T_{cal}))$$

Where $Z_{corr}$ is the temperature compensated zero result, $Z_{cal}$ is the zero value when calibrated, α is the temperature compensation factor, T is the absolute temperature inside the sensor and $T_{cal}$ is the absolute temperature inside the sensor when the zero was calibrated. It is advisable to have 2 temperature compensation factors, one for temperatures greater than the calibration temperature and one for temperatures less than the calibration temperature.

A similar expression is used for the span temperature compensation:

$$S_{corr} = S_{cal} * (1 + \beta * (T - T_{cal}))$$

Where $S_{corr}$ is the temperature compensated span result, $S_{cal}$ is the soan value when calibrated, β is the temperature compensation factor, T is the absolute temperature inside the sensor and $T_{cal}$ is the absolute temperature inside the sensor when the span was calibrated. Again, it is advisable to have 2 temperature compensation factors, one for temperatures greater than the calibration temperature and one for temperatures less than the calibration temperature.

Finally, the ideal gas law correction for temperature can be applied to the final calculated concentration according to:

$$[\text{concentration}]_{corr} = [\text{concentration}] * T / T_{cal}$$

where [concentration] is the calculated resulting gas concentration, T is the absolute temperature in Kelvin, $T_{cal}$ is the absolute temperature in Kelvin when the span was calibrated and $[\text{concentration}]_{corr}$ is the ideal gas law corrected concentration value.

The above expressions and means of compensation are summarised below in the form of a typical software algorithm.

## 4) Example concentration calculation software routine:

```
//----------------------------------------------------------------------------
//  FUNCTION NAME: float GetConcentration(void)
//
//  DESCRIPTION:
//  Calculates the gas concentration from measured active, reference and temperature values measured during one full lamp on – lamp off cycle
//  using the expression:  Concentration = ( -ln(1-Absorbance/span)/exponent )^(1/powerterm)
//----------------------------------------------------------------------------
//
//  Entry requirements:
//          Active_Cycle:               Value of the active signal (float)
//          Reference_Cycle:            Value of the reference signal (float)
//          Temperature_Reading:        Value of the current temperature in Kelvin (float)
//          Zero_Value:                 Value of the zero determined during calibration (float)
//          Span_Value:                 Value of the span determined during calibration (float)
//          Zero_Temperature:           Temperature in Kelvin when zero calibrated (float)
//          Span_Temperature:           Temperature in Kelvin when span calibrated (float)
//          Positive_Zero_Tempcomp:     Value of the temperature correction factor for zero if temperature > when calibrated (float)
//          Negative_Zero_Tempcomp:     Value of the temperature correction factor for zero if temperature < when calibrated (float)
//          Positive_Span_Tempcomp:     Value of the temperature correction factor for span if temperature > when calibrated (float)
//          Negative_Span_Tempcomp:     Value of the temperature correction factor for span if temperature < when calibrated (float)
//          Exponent:                   Linearity exponent constant (float)
//          Powerterm:                  Linearity power term constant (float)
//          IdealGasLaw:                Switch for applying ideal gas law temperature correction (integer)
//
//  Exit result:        Concentration (float)
//  Side effects:       none
//----------------------------------------------------------------------------

float GetConcentration(void)
{
// local variables:
        float temp_comp_ratio = 0;
        float absorbance = 0;
        float temp_comp_span = 0;
        float value = 0;
        float Concentration = 0;

// Calculate the absorbance from the temperature compensated normalized_ratio:

        temp_comp_ratio = Active_Cycle / ( Reference_Cycle * Zero_Value ); Get normalised ratio

        if (Temperature_Reading > Zero_Temperature)
                {
                temp_comp_ratio = temp_comp_ratio * (1 + Positive_Zero_Tempcomp * (Temperature_Reading - Zero_Temperature ));
                }

        else if (Temperature_Reading < Zero_Temperature)
                {
                temp_comp_ratio = temp_comp_ratio * (1 + Negative_Zero_Tempcomp * (Temperature_Reading - Zero_Temperature ));
                }

//Get absorbance value:

        absorbance = (1 - temp_comp_ratio);

// Calculate SpanCorrection:

        temp_comp_span = Span_Value ;

        if (Temperature_Reading > Span_Temperature)
                {
                temp_comp_span = temp_comp_span * (1 + Positive_Span_Tempcomp * (Temperature_Reading - Span_Temperature));
                }

        else if (Temperature_Reading < Span_Temperature)
                {
                temp_comp_span = temp_comp_span * (1 + Negative_Span_Tempcomp * (Temperature_Reading - Span_Temperature));
                }
// Calculate the value for conversion:

        if (temp_comp_span != 0)
                {
                value =  absorbance / temp_comp_span;
                }

        else
                {
                value = 0;
                }

        if(value > 0)
                {
                    sign = POSITIVE;
                }
        else if (value < 0)
                {
                    sign = NEGATIVE;
                    value = fabs(value);
                }
        else
                {
                // If here then value = 0 so return result = 0:
                Concentration = 0;
                return(Concentration);
                }


// Calculate the concentration using the expression Concentration = ( -ln(1-Absorbance/span)/exponent )^(1/powerterm):

        value = - log(1 - value);

        value = pow((value / Exponent), (1 / Powerterm));

        if(sign == NEGATIVE)
                {
                value = -value;
                }

// Apply ideal gas law temperature correction if required:

        if(IdealGasLaw == TRUE)
                {
                Concentration = value * ( Temperature_Reading / Span_Temperature )
                }
        else
                {
                Concentration = value;
                }

//Return new concentration result:

        return(Concentration);
}

//------------------------------------------------------------------------------
//
//          End of routine
//
//------------------------------------------------------------------------------
```