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Application of CO_2 NDIR gas sensors in air quality monitoring

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Abstract—**This paper explains the use of Non-Dispersive Infra-Red (NDIR) sensor that is built into the complex system for the air quality monitoring. It is known that CO_2 is an important indicator of the current state of the environment, especially in urban areas and indoor air quality. Latest CO2 NDIR sensors are low cost, low power consumption, miniature and have a long lifetime so that the increasingly built into new systems for measuring environmental parameters. By using commercially available detectors and advanced knowledge of the design of electronic circuits, measuring the concentration of CO2 is explained in detail in this paper.**

Keywords-CO_2 measuring; NDIR sensor; air quality monitoring;

I. INTRODUCTION

Emissions to the atmosphere of CO_2 from fossil-fuel combustion are of concern because of their growing magnitude, the resulting increase in atmospheric concentrations of CO_2 (Fig. 1), the concomitant changes in climate, and the direct impact of increased atmospheric CO_2 on ecosystems and energy demand [1].

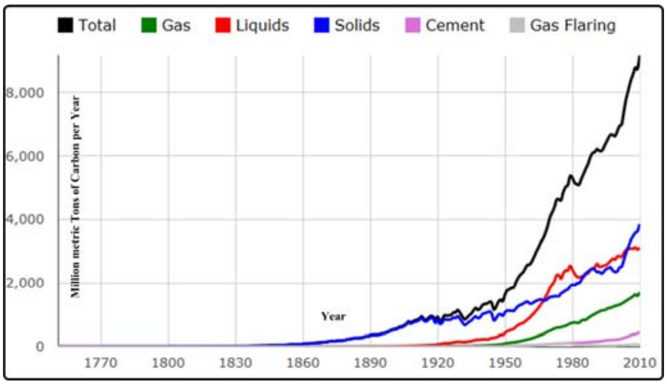

Figure 1. Annual global fossil-fuel CO_2 emissions, total and individual contributors

These ecosystem and climatic changes could adversely impact human society. Of the current 10 billion tons of carbon emitted annually as CO_2 into the atmosphere by human activities, only around 40% [2] remain in the atmosphere, while the rest is absorbed by the oceans and the land biota to about equal proportions. This airborne fraction of anthropogenic CO_2 is known to have stayed remarkably constant over the past five decades [2], but if it were to increase in a way predicted by models, this could add another 500 ppm of CO_2 to the atmosphere by 2100 [3], significantly more than the current total. By measuring the concentration of CO_2 in the longer period of time, it is possible to predict future changes, and based on them to develop a strategy for action.

In addition to the global influence of CO_2 on climate, it is important to consider the local impact on the environment, such as the impact on people living environment. The quality of air inside a building depends on the concentrations of contaminants, such as gases and particles, and how much fresh air is brought into the building through its ventilation system to dilute and remove these pollutants. It is essential to monitor indoor air quality to provide for occupant health, productivity and comfort [4]. Current ventilation guidelines recommend that indoor CO_2 levels not exceed the local outdoor concentration by more than about 650ppm. The performance of individuals in schools and offices with elevated CO_2 concentrations can be affected because occupants may become lethargic and drowsy. High concentrations of CO_2 are used for instance in the agriculture, refrigeration or beverage industry, whereby leakages can be dangerous for the living beings and require special safety measures. Typical CO_2 concentration guide can be represent as:

- ~ 40.000ppm – Exhaled human breath
- ~5.000ppm – Limit of CO_2 concentration at the workplace
- > 1.000ppm – Fatigue and reduced concentration
- ~1.000ppm – Recommended max. CO_2 level in indoor air
- ~400ppm – Outdoor air

Whether it's the atmosphere or indoor environment, measuring the concentration of CO_2 becomes increasingly important.

In this paper NDIR sensors are discussed, targeting only commercially available solutions for measuring CO_2 concentration. As a representative of NDIR sensors, Alphasense IRC-A1 sensor is selected. This sensor will be used as an example to explain the principles of operation of NDIR sensors. It will also be explained electronic circuit for processing signals from the sensor and the methods to calculate the final concentration of CO_2 from collected data. Finally, an example of measurement in field conditions with a detailed analysis is given.

II. PRINCIPLE OF OPERATION OF NDIR SENSORS

Infrared CO_2 detection sensor operates by transmitting an infrared beam through the sample, which absorbs the energy of the beam depending on the concentration of CO_2 present, and detecting how much of the infrared beam's energy is left after passing through the sample and converting that to a reading in actual concentration. On Fig. 2 is shown principle of operation of these sensors.

When light passes a gas stream containing CO_2, the gas absorbs energy from the light at specific wavelengths. The remaining light is filtered to a wavelength specific to carbon monoxide. The amount of light remaining at the specific wavelength is measured. The amount of light absorbed is directly proportional to the concentration of CO_2 present in the gas stream.

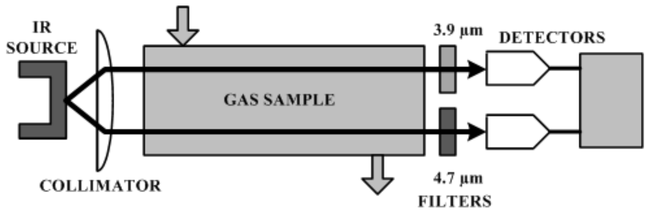

Figure 2. The conventional non-dispersive infrared detector - NDIR

NDIR sensors are simple spectroscopic devices often used for gas analysis. The key components of an NDIR sensor are an infrared source (lamp), a sample chamber or light tube, a wavelength filter, and an infrared detector. The gas is pumped or diffuses into the sample chamber and gas concentration is measured electro-optically by its absorption of a specific wavelength in the infrared (IR). The IR light is directed through the NDIR sample chamber towards the detector. The detector has an optical filter in front of it that eliminates all light except the wavelength that the selected gas molecules can absorb. Other gas molecules do not absorb light at this wavelength, and do not affect the amount of light reaching the detector. The IR signal from the source lamp is usually chopped or modulated so that thermal background signals can be offset from the desired signal. The conventional NDIR instrument operates by comparing the total amount of light transmitted at this filtered wavelength band as compared to that of another wavelength band, where no CO_2 absorbs. The difference in absorption between the two bands is used to determine the concentration of CO_2 present. This approach makes the simplistic assumption that all absorption in this 4260 nm band is from the target gas, CO_2. The intensity of 4260 nm light that reaches the detector is inversely related to the concentration of CO_2 in the sensing chamber. When the concentration of CO_2 in the chamber is zero, the detector will "see" the full light intensity. As the concentration of CO_2 increases, the intensity of light striking the detector decreases. The exact relationship between IR light intensity and CO_2 concentration is determined when the instrument is calibrated using pure nitrogen (0ppm CO_2) and a known concentration of CO_2 such as 1000 or 5000ppm.

III. ELECTRICAL CIRCUIT FOR SIGNAL PROCESSING OF NDIR SENSOR

Design of electronic circuits for signal processing of NDIR sensor will be explained in the case of a commercial sensor IRC-A1 that is produced by Alphasense. Alphasense IRC-A1 NDIR sensor consists of an infrared source, optical cavity, dual channel detector and internal thermistor. Typical block diagram is shown on Fig. 3.

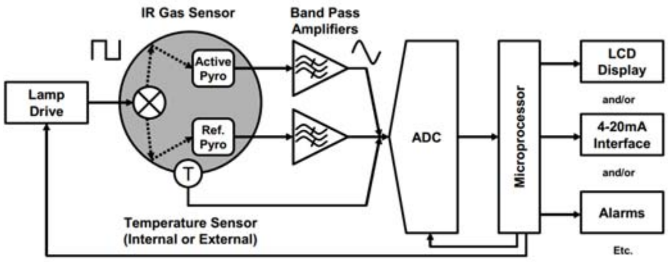

Figure 3. Typical block diagram of electronic circuit of NDIR IRC-A1 CO_2 sensor.

The infrared source should be switched at a low frequency with a 50% duty cycle. A switching frequency of 2 to 2.5Hz is recommended. The source should be driven from a constant voltage source and care should be taken to ensure the supply does not contain low frequency ripple that would otherwise modulate the output.

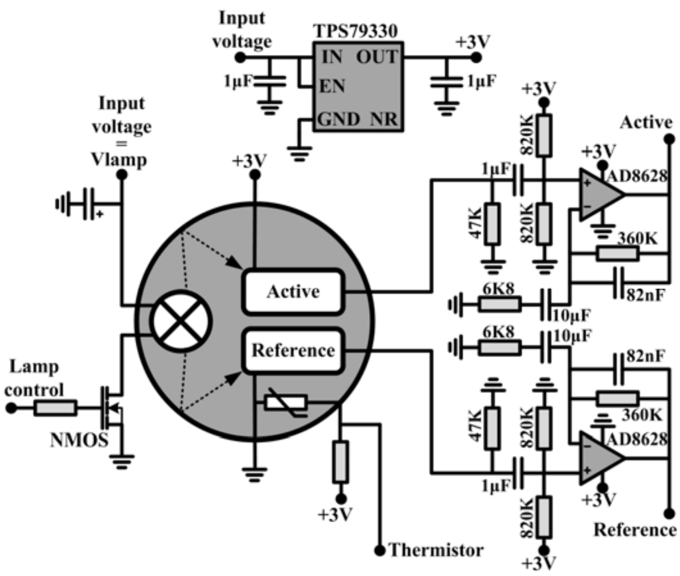

Figure 4. Detailed electronic circuit for NDIR signal processing

The circuit shown in Fig. 4 uses an n-channel MOSFET to switch the low side of the source with the high side connected to a stable supply, typically +5 VDC. The MOSFET should have a low RDS ON resistance to minimize its voltage drop. If the high side is driven and the low side is grounded, care must be taken to keep the detector ground separate from the source ground to avoid pickup due to the source current circulating in the detector ground. The source is galvanically isolated from the detectors and thermistor in the sensor.

Input voltage in our case is used for lamp drive, but for sensitive detectors and surrounding circuitry a stable low noise voltage from TPS79330 integrated circuit is used. Since minimum operating voltage of IRC-A1 sensor can be minimum at 2 VDC, stable supply of 3V is sufficient for proper operation. The raw active and reference signals are composed of a DC offset voltage (typically 0.7 V - 1.0 V) with a small (~20 - 50 mV peak-to-peak) superimposed response signal alternating in phase with the source drive voltage (Fig. 5). The alternating signal should be extracted and amplified in order to obtain a measure of the peak-to-peak amplitude of this oscillating component. This peak-to-peak amplitude can then be used to determine the gas concentration. Inside the sensor, the detector FET's are arranged as source followers. The load resistors (47K in Fig. 4) should be set to give approximately 30 µA bias current in the FET's. The nominal output voltage on the FET sources is between 0.6 and 1.2 V.

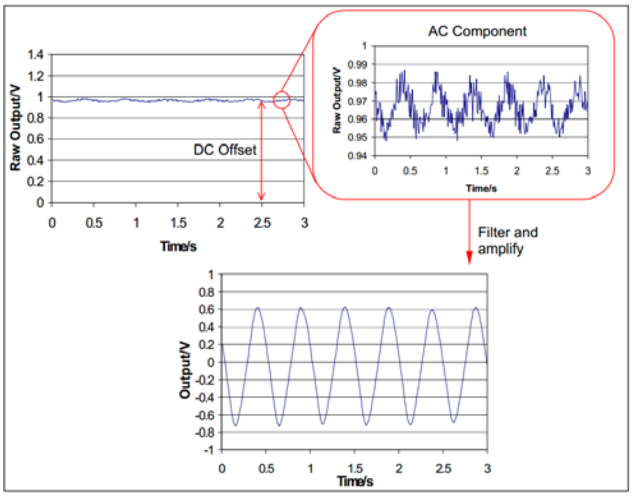

Figure 5. The appearance of the raw signal from IRC-A1 sensor followed by filtering and electronic processing

The source and detectors have a significant response time (hence the reason for the relatively low pulse frequency). The amplification stage should include a high pass response with a roll off of about four times the switching frequency to reduce high frequency noise, and a low pass (AC coupling) stage of approx. 0.1 Hz to remove the DC bias from the FET's. The frequencies need not be exact, but both detectors (reference and active) should have matching characteristics. The detectors will have a typical output of 45 mV peak-to-peak so the circuit should provide sufficient gain to give a reasonable input to any ADC used.

The sensor includes an integral thermistor to monitor the internal temperature. Internally, the thermistor is connected to same ground signal as detectors to minimize internal noise. The thermistor output should be connected in series with a known resistor and reference voltage. The potential at the junction between the resistors can then be used to determine the thermistor resistance and than using known table of resistance/temperature relation. IRC-A1 has internal NTC thermistor with resistance of 3000Ω at 25ºC.

Results from sensor are converted into digital form using analog to digital converter (ADC). In our case, internal ADC of microcontroller with 12 bits resolution is used. The appearance of a signal to be converted is shown in Fig. 6.

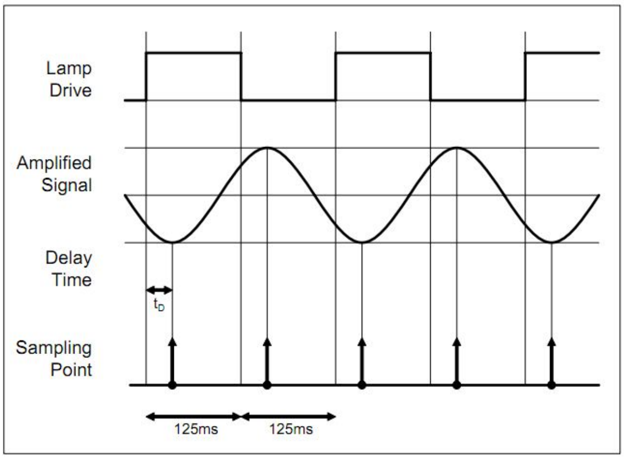

Figure 6. The proper way of taking the value from processed signal

It is important to take value at the right time. Since signal is AC type, we need to calculate peak-to-peak value, i.e. to take maximum and minimum value. There is a constant delay between the bulb switching point and the maximum or minimum of the signal response. This delay is typically around 25 ms but will depend on the model of gas sensor being used. In our example, MOSFET inverts the signal for lamp control, so that the program delay is set to be 220ms and this value is calculated using waveform from oscilloscope (Fig. 7.). Note that we first take maximum than minimum value, that's why our delay is much bigger, but result is same.

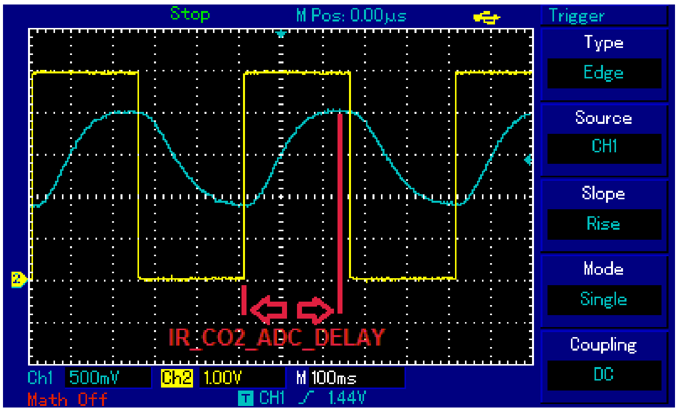

Figure 7. The appearance of the signal for controlling the lamp and the processed signal from the detector with the method of calculating proper delay for AD conversion

Fig. 8 shows the result of measuring the concentration of CO_2 during 24 hours in the city center. The value is not converted to the exact value of concentration, but represents raw data from the measuring station. Start of measurements was about 4:00 PM and values are taken every minute. It is clear that there are daily fluctuations in the values that are generally caused by traffic. It can be noticed that the signal is noisy, so the server application needs to do the processing such as signal averaging.

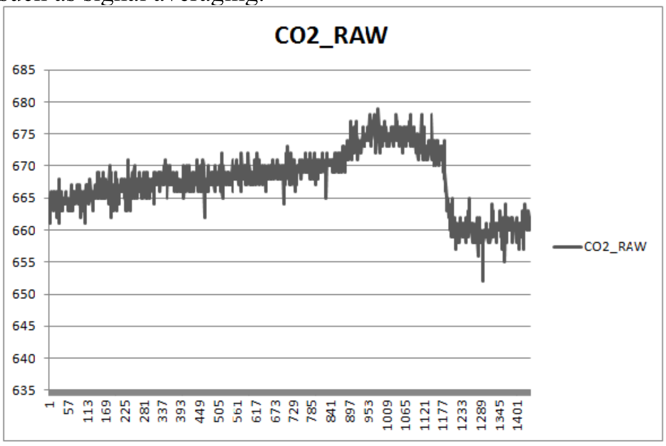

Figure 8. Change the value of the concentration of CO2 in the course of 24 hours of measurements in an urban environment.

IV. CALCULATING CO_2 CONCENTRATION

The IR intensity on the active detector will decrease according to a simple exponential relationship called the Beer-Lambert Law [5].

$$I = I_0 10^{-KLC} \tag{1}$$

Where I is the intensity in target gas, I_0 is the intensity in zero gas (for example nitrogen), K is a factor dependent on the gas absorption lines and the bandwidth of the filter, L is the optical path-length between lamp and detectors and C is the concentration of the gas. From (1) it is apparent that the gas concentration C can be determined. For the active detector output there is a corresponding output voltage change shown in (2).

$$\frac{V_0 - V}{V_0} = \frac{I_0 - I}{I_0} \tag{2}$$

Where V is the output in target gas and V_0 is the output in zero gas. Equation (2) is a measure of how well the 'set up' senses gas and is called the Fractional Absorbance (FA). For simplicity, the reference channel is excluded. Re-arranging equations (1) and (2) gives:

$$FA = 1 - 10^{-KLC} \tag{3}$$

If K and L are held constant, then FA may be plotted against C as shown for example in Fig. 9. The value of FA increases with C but eventually saturates at high gas concentration. This implies that for any fixed 'set up' the ability to resolve a change in gas level is better at low concentrations than at high. However since K, L and C are factors, then K and L can be adjusted to give the optimum absorbance for the required range of gas concentration.

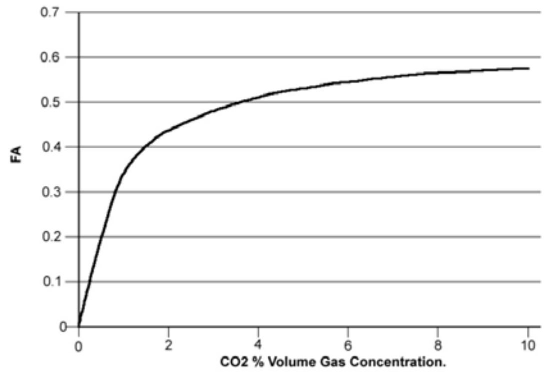

Figure 9. Typical fractional absorbance

In cases where the ambient pressure and temperature are changing, the ideal gas law must be used to calculate the exact gas concentration.

V. CONCLUSION

As part of designing a station for air quality monitoring, a subsystem that measure CO_2 concentration is also installed. This paper describes the working principle of NDIR sensors, electronic circuit design and calculation of concentration based on collected data. Designed monitoring station is mounted in urban environment and sends data to a remote server in the specified time period. For CO_2 sensor, a total of five values are sent of which there are two values, the maximum and minimum (Fig. 6), for the active and the reference channel respectively, and the voltage value of the thermistor. The data is then processed on the server, where the procedure described previously to obtain the final concentration is applied.

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