AN004: Minimising CO_2 Sensor Power Consumption

ABSTRACT

All GSS sensors use a technique called non-dispersive infra-red (NDIR) sensing where light is injected into the optical measurement chamber, which contains the gas of interest. The light that passes through the optical cavity is detected by the photo diode. The signal from the photo-diode is digitised by the microcontroller and compared with a reference level stored in memory. The microcontroller can then calculate the level of CO_2 in the optical measurement chamber.

The power consumed by the CO_2 sensor depends on several interrelated factors.

The type and efficiency of the light source is the largest contributor to the power consumed by the sensor. In comparison to many other sensors that use incandescent light sources, GSS sensors use a highly efficient Light Emitting Diode (LED) to illuminate the CO_2 gas. LEDs can (but not always) be much more efficient in converting electrical power into light than conventional light sources.

The length of time the light source is active is also a major contributor to how much power is consumed by the sensor. The light source in a CO_2 sensor can be run continuously or pulsed to minimise overall power consumption.

Today's semiconductor devices consume much less power than their forebears due to lower supply voltages, effective power management and shrinking feature sizes. Nevertheless, improvements to signal processing strategies for filtering, data handling and communications can improve power savings.

This application note describes the fundamentals that underpin the low power design of GSS sensors and how to calculate the power consumption of each device.

Finally, strategies for reducing power consumption whilst optimising overall performance are presented, including the new CozIR®-Blink sensor.

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METHOD OF OPERATION

Gas Sensing Solutions' CO$_2$ sensors uses a solid state, ultra-low power LED light source. This type of light source has several advantages, particularly for low power applications. A CO$_2$ sensor module typically consists of four major functions, a mid-IR LED light source, a photo-diode detector, an optical light path measurement chamber and a microcontroller.
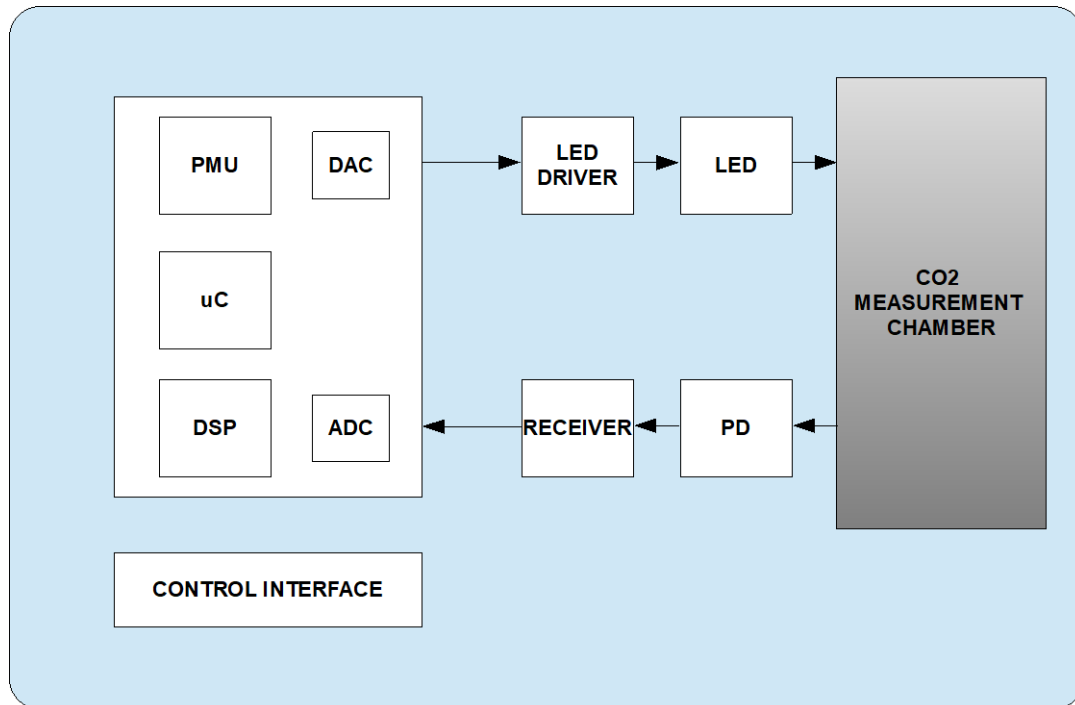
Figure 1: Block diagram of typical GSS solid-state LED NDIR sensor

Mid-IR 4.25μm light is strongly absorbed by CO$_2$ gas. Light from the LED is injected into the optical cavity, which contains the CO$_2$ gas that has been allowed to enter it through a membrane on the top surface. The light that passes through the optical cavity is detected by the photo diode. The signal from the photo diode is digitised by the microcontroller and compared with a reference level stored in memory. The microcontroller can then calculate the level of CO$_2$ in the optical cavity.

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LED EFFICIENCY ADVANTAGES

When the primary goal is to minimise power consumption of a sensor, choosing one with an LED light source is the optimum place to start. LEDs are semiconductor devices that emit light via the re-combination of electrons and holes within the active region of the device (a sequence of specially designed layers manufactured using a process called molecular beam epitaxy).

There are several metrics to describe the efficiency of converting electrons into photons, some of which are beyond the scope of this application note. The three most important ones to minimise power consumption of the sensor are the forward current used to drive the LED, the electro-optical efficiency of the LED and the effective bandwidth of the emitted light.

The forward current used to drive the LED is a balance of trade-offs. The LED needs to generate enough light at the photo-diode receiver to generate sufficient signal to be processed and converted into a CO$_2$ gas level measurement. Larger forward currents will generate bigger LED outputs (up to a point), which in turn will be easier to detect, resulting in lower noise measurements. This trade-off between LED forward drive current and LED illumination level is a design choice depending on the application and market requirements. Larger LED currents also can create heating effects that can cause issues with continuous emission.

Electro-optical efficiency, sometimes known as wall plug efficiency is a measure of how much of the electrical input power gets converted to optical power. Wall plug efficiency is a descriptor for several different parameters connected with how efficiently the LED converts electrons to photons. These factors are a facet of the LED design itself. GSS designs and manufactures its own LEDs, which have been optimised for high wall plug efficiency necessary for applications that are power sensitive.

LEDs generate photons with a relatively broad spectrum of light. All light that is generated outside of a narrow band around 4.25µm used for gas detection is wasted, consuming unnecessary power. GSS LEDs, which are manufactured in-house, have been specifically designed to be used in CO$_2$ gas sensors, with a centre wavelength of a nominal 4.25µm. This means little energy is consumed generating light of wavelengths that are unused. This is very different from a typical incandescent light source, which is intrinsically inefficient as it generates broadband light, most of which is wasted.

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CO_2 MEASUREMENT – PRINCIPLE OF OPERATION

GSS CO_2 sensors have been optimised for use in battery power applications where the short start-up time and low power consumption offer significant advantages over standard NDIR sensing technology. Regardless of the type of light source, measurement of the CO_2 level is determined using the Beer-Lambert law. Beer-Lambert's law states the loss of light intensity when it propagates in a medium is directly proportional to intensity and path length. CO_2 molecules absorb infrared radiation at a wavelength of around 4.25 microns.

All GSS sensors use an in-house designed ultra-efficient LED light source. Unlike an incandescent light source, which has a warmup time of sometimes several minutes, an LED can be used almost instantly to take measurements. In practice, the time needed before being able to take measurements can be as low as 100ms due to the requirements for downstream signal processing.

Due to the very rapid power-up and response time, for sensors targeted at power sensitive applications, GSS has chosen to 'pulse' the LED rather than run the LED at constant current. This strategy eliminates the effects of background IR and can reduce power consumption by over 95% compared to constantly powering the LED.

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POWER CONSUMPTION OF DIFFERENT OPERATING MODES

The behaviour of GSS sensors depends on the type of control and data interface (UART or I^{2}C) and product family. Common to almost all sensors are several different operating power states.

Outlined in this section is how the operating power consumption of the device can be calculated for each stage in the sensing cycle. The different sensing stages are sleep; wake-up; measurement (LED emission and detection); and data processing and transfer.

Sensor Type	UART Power States	I^{2}C Power States
CozIR®-Blink	All Off	All Off
	Wake-Up (from Power-on)	Wake-Up (from Power-On)
	Single measurement and data processing, data transfer on request	Single measurement and data processing, data transfer on request
	Sleep, no measurements (automatic mode)	Sleep, no measurements (automatic)
CozIR®-LP3	Standby (PWR-ON pin low)	Standby (PWR-ON pin low)
	Sleep (K0 mode), no measurements	Sleep mode, no measurements
	Wake-Up (from Power-On or Sleep state)	Wake-Up (from Power-On or Sleep)
	Continuous measurement, data processing and data transfer (K1 streaming mode)	
	Measurement and data processing, data transfer on request (K2 polling mode)	Measurement and data processing, data transfer on request (equivalent to K2 polling mode)
CozIR®-LP2	Sleep (K0 mode)	No Sleep state
	Wake-Up (from Power-On or Sleep state)	Wake-Up (from Power-On)
	Continuous measurement, data processing and data transfer (K1 streaming mode)	
	Measurement and data processing, data transfer on request (K2 polling mode)	Measurement and data processing, data transfer on request (equivalent to K2 polling mode)
All other GSS sensors	Sleep (K0 mode)	Not available
	Wake-Up	
	Continuous measurement, data processing and data transfer (K1 streaming mode)	
	Continuous measurement and data processing, data transfer on request (K2 polling mode)	

Table 1: List of available modes of operation for the GSS range of sensors

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SLEEP STATE

Except for the CozIR®-LP3 which has a standby function, for most GSS sensors, the lowest power state is when the sensor is in a Sleep state. The LED and sensors are not active, only the internal clock is being powered, whilst the controller awaits notification to wake-up, change sensor settings or take a reading. The measured average current consumption for a typical GSS sensor in this state is approximately 10 µA, equivalent to 33µW whilst operating in this quiescent state with a 3.3V supply.

GSS sensors must be manually put into the Sleep state by selecting the Command mode (K0), or by setting the appropriate register in I^{2}C interface mode for the CozIR®-LP3. All measurements are stopped but the sensor will respond to configuration changes.

The exception to this operating mode is the CozIR®-Blink. It is designed to be completely powered down by the user's system after a single CO$_2$ measurement cycle and does not therefore have a sleep state.

WAKE-UP

To wake up a GSS sensors when using the UART interface, the operating state must be changed from Command mode (K0) to either Polling mode (K2) or Streaming mode (K1). If the sensor is being controlled using the I^{2}C interface, after power-up, the sensor automatically wakes up and starts taking measurements.

A typical wake-up sequence of the CozIR®-LP3 is shown below.

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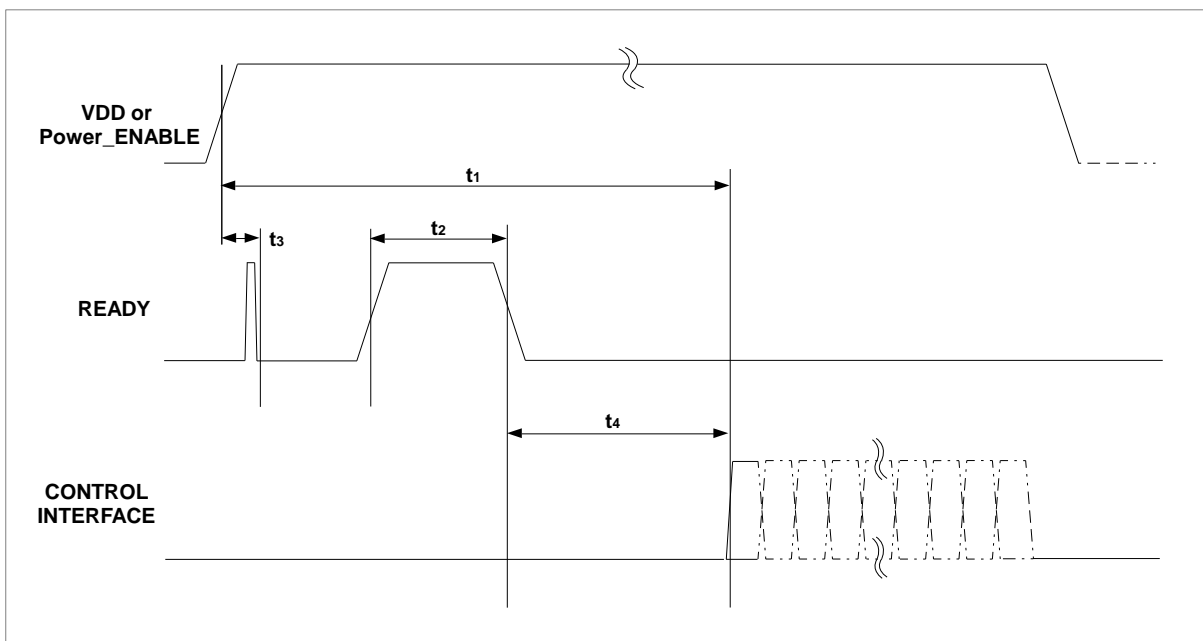
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PARAMETER	SYMBOL	MIN	TYP	MAX	UNIT
READY Data Valid from Power On	t_1	800			ms
READY High Pulse-Width	t_2		16.5		ms
READY Low from Power On	t_3			100	ms
Control Interface Setup Time	t_4	14			ms

Figure 2: CozIR®-LP3 wake-up timing sequence

In the case of the CozIR®-Blink, the sensor automatically starts taking measurements and goes into the Sleep state once it has calculated a single CO_2 reading. The sensor must be power cycled before it can start taking measurements again.

MEASUREMENT (LED EMISSION AND DETECTION)

Once the sensor has been triggered to wake-up, the on-board controller initialises charging of the LED capacitor bank for pulsed emission and subsequent detection of the transmitted light by the sensor. The LED is pulsed many times per CO_2 measurement. The pulse rate and measurement period are design specific and have been chosen to support the requirements for the GSS sensor application. The effect of pulsing the LED is a power consumption profile that changes in time.

The LED emission dominates the sensor's power consumption at this stage, with any power usage of the detector electronics assumed to be included in the power measurements. Prior to the formation of each pulse, a capacitor bank on-board the sensor is charged to allow stored energy to be released to power the LED. All GSS sensors have the necessary on-board storage capacitors, with no requirement for any additional components. Measurements of current consumption (over time) are made using specially designed high sided current measurement apparatus. As presented later in Figure 3, the current is seen to increase as the capacitor bank depletes during LED emission, requiring re-population of the charge and therefore increased current consumption as the LED emission phase progresses.

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SIGNAL PROCESSING AND DATA TRANSFER

The power consumed at this stage is dependent on how much data is recorded and transferred. The data transfer method depends on which interface method is chosen. The UART interface allows data to be streamed continuously or polled on request. If the sensor is operating in I^2C mode, the data can only be polled on request.

The typical power consumption during this phase of the sensor measurement cycle will depend on how much data is transferred across the interface. Measurements are based on a single data field (i.e. CO_2 concentration) being recorded and transferred once per measurement cycle. The amount of time this data transfer takes will depend on the interface, and the data interface transfer rate. In UART mode, a single field consists of 5 bytes being transferred at a rate of 9600 Baud, which equates to approximately 1 ms per character.

CALCULATING SENSOR POWER CONSUMPTION

The measurement of power consumption during the wake-up, measurement (LED emission and detection), data processing and transfer phases are all grouped into what is referred to as the active period, which is quoted for each device in the accompanying datasheet.

The current and therefore the power consumption varies over time. To calculate the average power consumption, it is necessary to measure current consumption over an appropriate time-period to ensure that all the functions that will be enumerated by the user. The table below shows the average power measured whilst each device is *active* or in *sleep* mode. Later in this section we describe the equations required to calculate the long-term power consumption for a system configured to be put to sleep between measurement cycles.

Sensor	Average Power - Sleep (mW@ 3.3V)	Average Power - Active (mW @ 3.3V)
CozIR®-LP2/LP3	0.03	3.5
CozIR®-LP	0.03	3.5
CozIR®-A	0.03	3.5
SprintIR®-R	0.03	70
SprintIR®-6S	0.03	30
SprintIR®-W	0.03	30
ExplorIR®-W	0.03	3.5
ExplorIR®-M	0.03	3.5

Table 2: Power consumption values for each device in the GSS sensor range whilst in active and sleep state.

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The exception to this approach is the CozIR®-Blink, where the sensor is designed to take a single CO$_2$ measurement per power cycle. After the CozIR®-Blink has completed one measurement, it automatically enters a sleep mode. The measurement is held in memory and all other functions are stopped. Once the measurement has been read by the host, CozIR®-Blink is designed to be powered-down.

Sensor	Average Power - Sleep (µW @ 3.3V)	Active Power (mW @ 3.3V)
CozIR®-Blink	3.3µW	<3.5 (for duration measurement cycle)

Table 3: CozIR®-Blink Power consumption

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SENSOR CURRENT PROFILES

As noted previously, the current consumption of the sensor varies over time. Below, in Figure 3, is a graph of the current consumption of a CozIR®-LP2 during one measurement cycle. As expected, the amount of current required by the sensor is dominated by demand during the LED pulses.

The current level increases as the capacitors are discharged between each pulse during the LED emission and sensing stage. This is due to the capacitors requiring re-charging, and therefore drawing more current as the LED pulse train progresses. Once into the data processing and transmission phases, the current usage drops consistently after LED emission has ended. Following this, the current gradually decays to near zero as it re-enters the quiescent state of the sensor in sleep mode.
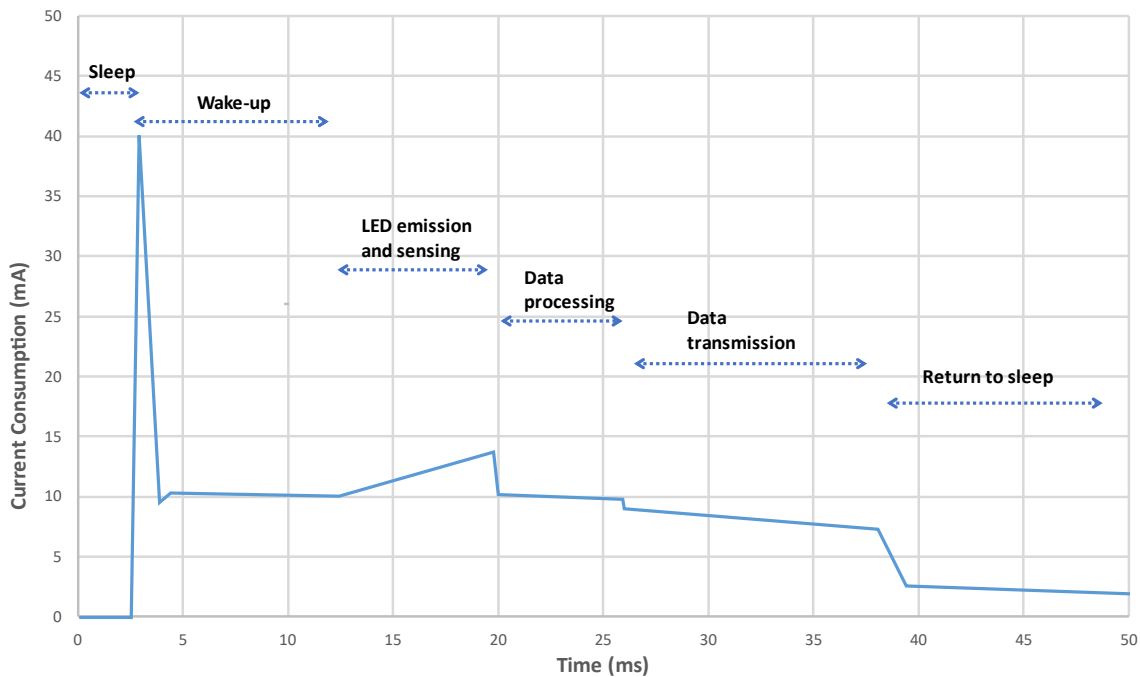
Figure 3: CozIR®-LP2 typical current consumption profile over 50ms

The CozIR®-LP2 takes a measurement every 500ms (2Hz), so the above graph shows only the 50ms where the device is not *asleep*. To calculate the average power consumption of a single measurement cycle, we can integrate the current consumed, as shown above, over a complete 500ms cycle. The energy consumed during each 500ms measurement is therefore given by:

$$Energy = Voltage \times \int_{0}^{500ms} Current\ consumed$$

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From Figure 3, the total integrated current consumption over a single 500ms measurement period is ~473µA. Together with a measured supply voltage of 3.3V, we can calculate the energy consumed by a CozIR®-LP2 device during a single measurement cycle as:

$$Energy(mJ) = 3.3V \times 473\mu A$$

From this we can calculate that each 500ms measurement cycle requires 1.56mJ of energy, which therefore equates to 3.12mW of average power whilst in the active measurement phase (K1). Figure 4 shows three consecutive measurement cycles, each consuming 1.56mJ, spaced 500ms apart.
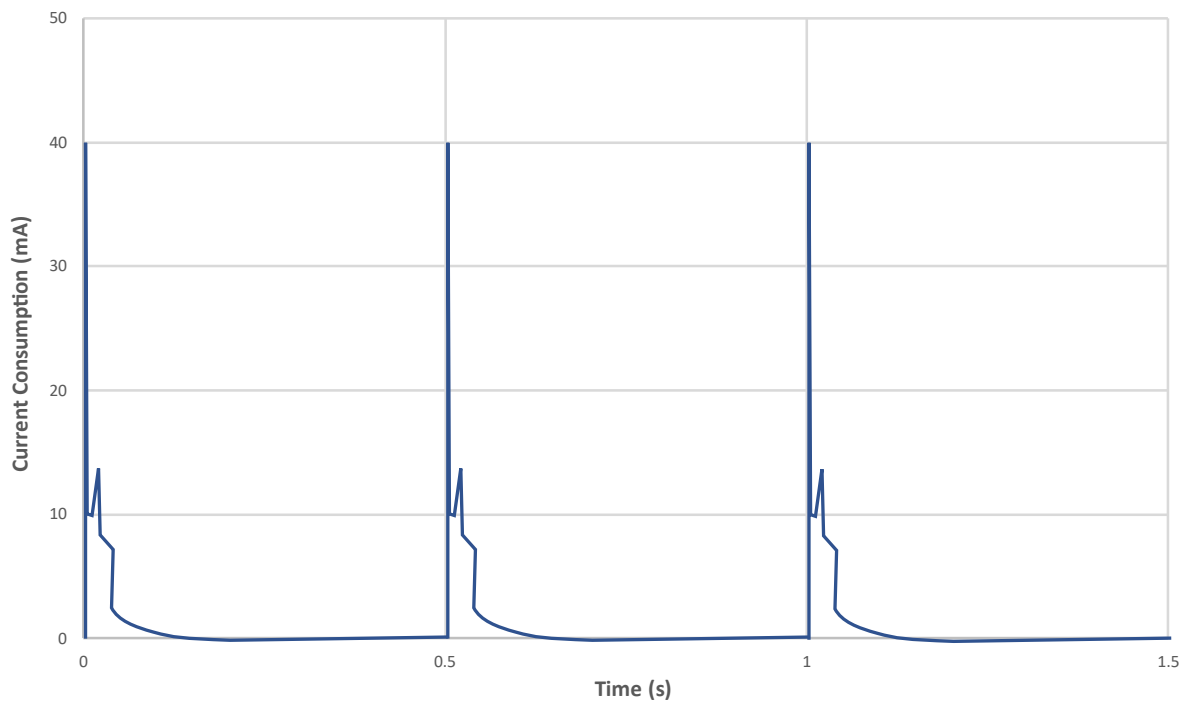
Figure 4: CozIR®-LP2 typical power consumption profile for 3 consecutive measurements at 500ms intervals

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All GSS sensors in UART interface mode are pre-configured to take measurements and read out data continuously when powered up. However, the user can configure their control system to put the sensor to sleep between measurements to conserve power. Therefore, with each device in the CozIR® range (excluding CozIR®-Blink) the average power based on the amount of time the device is actively taking measurements, compared with the duration it is asleep, can be expressed as:

$$P = \frac{E_{meas}N + P_{sleep}(t_{period} - t_{meas}N)}{t_{period}}$$

Where P is the average power consumption of the device in mW, E_{meas} is the energy consumed during a single measurement cycle as shown in Figure 3 in J, N is the number of measurements per cycle, P_{sleep} is the power consumed by the device in sleep mode in mW, t_{period} is the time between consecutive measurement cycles as dictated by the users system in *seconds*, t_{meas} is the time required for a single measurement (typically 0.5s) in *seconds.*

This calculation is standard for all GSS sensors, although it should be noted that the SprintIR® family of products take measurements at a higher frequency (shorter t_{meas}) for a faster sampling rate.

In the case of CozIR®-Blink, the number of measurement cycles for each reading is still programmable, but the sensor automatically enters the sleep mode state after taking a CO$_2$ reading.

The CozIR®-Blink is designed to be powered-down completely after the CO$_2$ concentration value is read out. The default number of measurements per reading for the CozIR®-Blink sensor is 16, but this can be fine-tuned for improved power consumption, down to a single measurement per CO$_2$ reading. The calculation of power consumption when using a CozIR®-Blink sensor can be found in the following section.

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COZIR®-BLINK POWER CONSUMPTION

As described previously, the CozIR®-Blink sensor is designed to be power cycled, where the whole device is powered down after a CO$_2$ reading has been made. Each CO$_2$ reading consists of a pre-programmed number of measurements that are averaged to create a single result. The number of measurements per reading can be set from 1 per reading to 32 per reading.

CozIR®-Blink sensors are specially adapted to halt sensing after a single averaged CO$_2$ reading has been taken. At which point, the data READY flag informs the user's system that data can now be extracted. Once the CO$_2$ reading has been transferred from memory to the host, the sensor can then be completely powered down by the user's control system. This is not the same as *sleep* mode as the device uses no power whilst powered down.

A typical measured current profile over time is shown below in Figure 5, illustrating 16 measurements that are averaged to give a single CO$_2$ reading. The number of measurements can be varied by the user up from 32 for best accuracy down to a minimum of 1 for best power consumption.
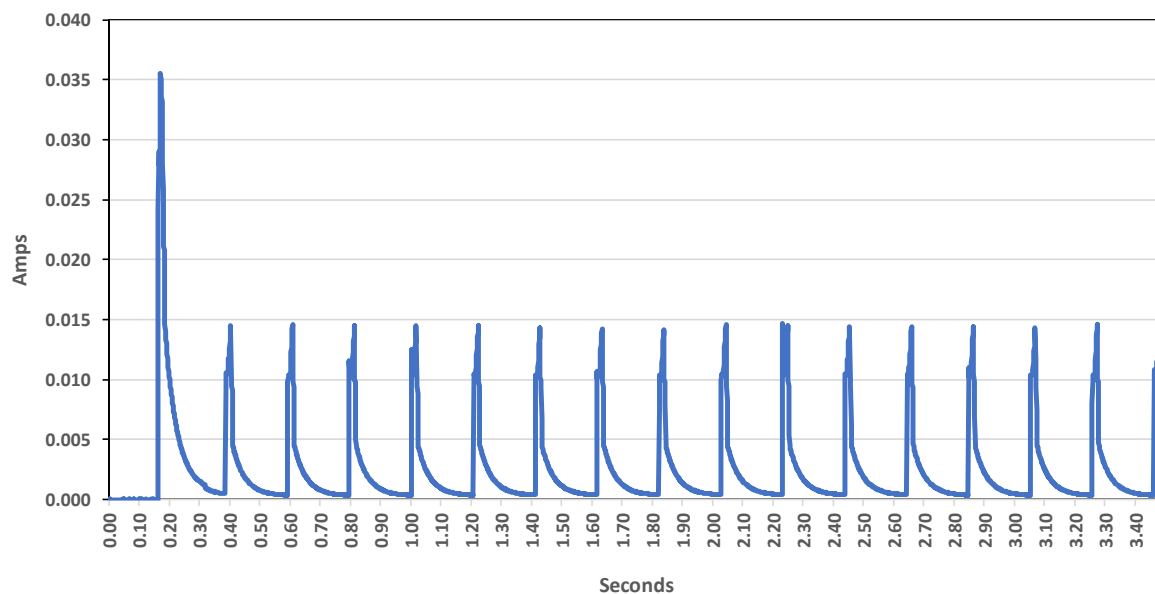
Figure 5: CozIR®-Blink current profile example showing 16 measurements to produce a single averaged CO$_2$ reading.

The power consumption mechanism for each measurement cycle (1 of 16 typically) is the same as described previously (Figure 3), except that the data processing and transfer phase is only done after completion of the final measurement cycle.

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The data processing and averaging is carried out fully automatically by the on-board electronics, and the user only has to setup extraction of the data to their system and powering up and down of the device.

Whilst the device is not taking measurements the device consumes negligible power, therefore the average power consumption of the CozIR®-Blink module can be described by the following simplified equation:

$$P = \frac{E_{meas} * N}{t_{period}}$$

Where P is the average power consumption of the device in mW, E_{meas} is the energy consumed during a single measurement cycle (1.5625mJ) as shown in Figure 3 in J, N is the number of measurements per reading as configured by the user, t_{period} is the time between consecutive readings in s as dictated by the user's system.

Depending on the required CO_2 measurement accuracy, if the sensor was configured to take a reading every minute, the power consumed per reading can be as low as **26µW**.

The number of measurements per reading can be selected to balance the power consumption and measurement accuracy. A single reading will be averaged over the selected number of measurements per reading, and therefore a higher number of pulses chosen will result in a more accurate reading. Conversely, a lower number of measurements per reading will reduce the power consumption of the device. Power consumption can be lowered even further by increasing the measurement interval. With careful selection of these parameters the user can achieve the lowest power consumption of any sensor in its class, still with industry leading performance.

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ADDITIONAL POWER CONSUMPTION REDUCTION STRATEGIES

GSS sensors operate in one of two different ways. When powered up, all GSS sensors automatically start making measurements. With exception of the CozIR®-Blink, all GSS sensors will continue to take measurements until instructed to stop by the user.

CONTINUOUS POWER, CONTINUOUS MEASUREMENT

Most GSS CO$_2$ sensors are designed for continuous power operation where the sensor is pre-programmed to take continuous measurements. There are several different methods for reading out the measurement data depending on the interface mode. Power consumption can be reduced by modifying the method used to read out the data.

If the UART interface mode is active, there are two methods of reading out the data, K1 mode where the data is continuously streamed from the device, and K2 polling mode where the measurement data is polled on request. In these modes, the sensor is constantly measuring. In streaming mode, all measurements are transmitted, and the power consumption is equal to the *active* value in Table 2. In polling mode, measurements are only transmitted when requested. As most of the power is consumed by the LED, the power saving here is modest as shown below in Table 3.

If the I^{2}C interface mode is active, measurement data is always polled on request. As with the UART interface, polling the measurement data reduces power consumption.

CONTINUOUS POWER, MEASUREMENT ON REQUEST

If the UART interface mode is active, the device can be programmed to take measurements when commanded. In K0 mode, the sensor is asleep, awaiting a command, and no measurements are being made. When measurement data is required, the sensor mode must be changed to either K1 streaming or K2 polling mode. This re-starts the measuring process. With careful management of the time spent in K0 (asleep) and K1/K2 (actively measuring) mode, the overall power consumption of the device can be optimised.

Interface Mode	Control Mode	Power Saving
UART	K1 Streaming	Reference mode, constant streaming of data
UART	K2 Polling	~500mW
UART	K0 Command	~3.3mW (depending on measurement period)
I^{2}C	-	~500mW

Table 4: Power savings with different control and interface modes

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SUMMARY

Strategies for reducing power consumption for measuring CO$_2$ fall into two categories. Solid state LED NDIR technology is intrinsically lower power than other competing alternatives and provides a fundamentally class leading foundation for all GSS sensors. In addition, clever use of the technology enhances its utility in real-world applications; only taking measurements when necessary; minimising current consumption with innovative control methods; and sophisticated power management. In combination, they enable GSS to offer some of the lowest power CO$_2$ sensors on the market today.

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IMPORTANT NOTICE

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REVISION HISTORY

DATE	RELEASE	DESCRIPTION OF CHANGES	PAGES
06/07/2020	1.0	First revision	All
29/03/2021	1.1	Added CozIR®-LP3	All