



Description

This note is a quick-start guide for developing around the ecFlex electrochemical sensor platform. The document is meant for developers seeking to integrate the ecFlex platform with their own readout applications.

Introduction

The ecFlex (Figure 1, Figure 2) is a stamp-sized, flexible electronics platform that supports the readout of electrochemical sensors wirelessly^{1,2}. The small size and weight (22x25x1 mm, 21 g) makes it field-deployable in most applications, including medical, environmental, and even as a payload for drones, whereas its flexibility allows for fixation to curved or moving surfaces, like sewage pipes or the human body. It is primarily meant for reporting continuous, steady-state signals vs. time, such as chronoamperometry and open-circuit chronopotentiometry, but can be adapted to do more dynamic techniques like square-wave voltammetry. The ecFlex has so far been used to monitor, but by no means limited to, glucose, lactate, potassium, pH, sodium and TAS (total antioxidants) status in human and animal bodily fluids, as well as the hotness of chili sauces. Please refer to the datasheet for technical specifications.

The ecFlex is not meant to constitute an end-product, but rather a rapid prototype platform to accelerate market traction and provide the ability

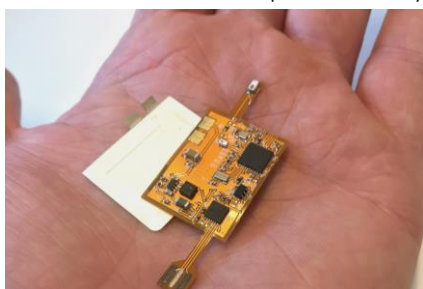


Figure 1. ecFlex and flexible battery inside human hand.

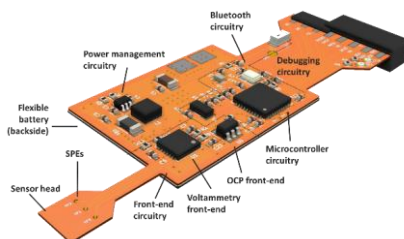


Figure 2. Diagram of ecFlex and its main functional blocks.

to demonstrate proof-of-concept in the actual field, rather than on the lab bench. Zimmer & Peacock often refers to the lab-to-field barrier as the main hurdle in productization, commercialisation or readying a product for clinical trials, as illustrated in Figure 3. Bringing an electrochemical laboratory setup with a tangle of wires to the field is a possibility (blue trace). However, it might be impractical, and carries the increased risk of compromising the setup. It also tends to be less impressive to potential investors. A second path to follow is to develop bespoke instrumentation for field integration (orange trace). This is not an effort-free endeavour and can seem daunting in the shadow of the 40+ years and billions of funds that have gone into the home monitoring of glucose for diabetes treatment (and we are still not happy with the state-of-art). The ecFlex seeks to lower the barrier (green trace) by providing a generic platform onto which the developers can, with less

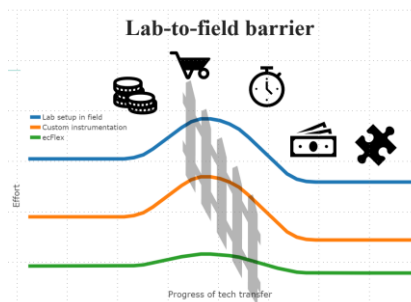


Figure 3. Lab-to-field illustration.



effort than the alternatives, transfer the assay and quickly meet the challenges of the field.

Precautions

While the ecFlex is built on a flexible carrier, its flexibility will be limited by its rigid components. Avoid extraneous and repeated bending (> 20 deg).

While electrostatic discharge protection may not be practical in all situations, it is recommended when possible. In situations where it is impractical it is recommended to avoid excessively touching the components.

Exposed pads, like the battery pads, will oxidize over time, and may need a gentle wipe with isopropanol.

If the antenna trace is covered with oils from the skin or other matter, it will impede on the transmission power, and may lead to an unreliable connection. Clean with isopropanol.

Readout software

A standard readout user interface for PC (Win10 and newer) can be downloaded from the website. The application provides graphical visualization of the sensory data, data export functionality and manual potentiostat control.

Communications protocol

Most customers wish to develop their own applications to go with the ecFlex. Common use cases are iPhone, Android smartphone and smartwatch applications, or web-based hosting. This section outlines the wireless and wired protocols available for transferring sensory data.

The BLE stack utilizes the generic attribute protocol (GAP). The ecFlex acts as server, whereas the user device will be the client. The quickest way to assess the relevant parameters is to scan through their descriptions using a packet sniffer, like "Bluetooth LE Explorer" (Windows). The device is recognized by the manufacturer name "ecFlex". Each device has its own unique MAC address. For communications, Copyright 2020. All rights reserved. Zimmer and Peacock AS

either note down the MAC address of the specific device, or write a Bluetooth scanner algorithm filtering for the manufacturer name "ecFlex", and obtain the MAC address thusly. All the relevant characteristics are found under Service 3 – Name: "11661".

Pulling sensor data

The live data is pulled by subscribing to "Handle 17 – Sensor command". The data has the following

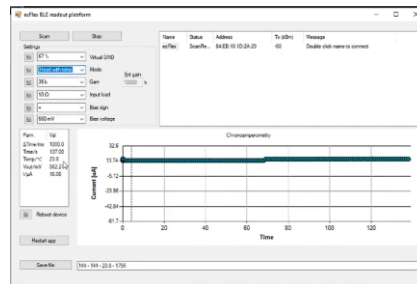
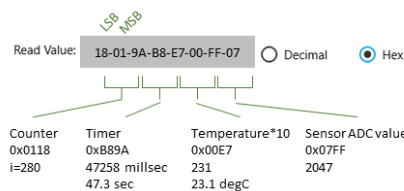


Figure 4. ecFlex readout software for windows.

Commented [AF1]: Add the link!!!

(hex) form:



To decompose from an eight-element byte array, the application code could look something like this:

```
ecFlex_idx = ((uint16)((data[1] << 8) + data[0])); // Sample counter
ecFlex_timer = ((uint16)((data[3] << 8) + data[2])); // Timer in milliseconds
ecFlex_temp = ((uint16)((data[5] << 8) + data[4])); // Temperature * 10
ecFlex_adc = ((uint16)((data[7] << 8) + data[6])); // ADC value
```

For serial interface, the format is the same as above, except the ecFlex acts as a serial peripheral interface (SPI) slave.

Timer (byte bytes 3-4)



Since the timer is limited to two bytes, it will overflow if the sampling rate is fast or the measurement goes on for an extended period. A robust way of tracking the time client-side is to utilize the timer to get the interval between two adjacent sample, and use the counter (**bytes 1-2**) to iterate the software timer. A code example as follows:

```
deltaT = ((data[1] << 8) + data[2]) - ecFlex_timer; // milliseconds
timeVal = ((double)deltaT * (double)ecFlex_idx) / 1000; // seconds
```

Temperature readout (bytes 5-6)

The temperature is simply divided by 10 for presenting as degrees Celsius.

Sensor readout (bytes 7-8)

The ADC value needs to be converted to a user-friendly number. Often this is an electrochemical current, potential or chemical concentration. The most robust way of getting the conversion parameters is reading them off the characteristics in Service 3 and converting through the following formula:

$$V_o = \frac{N_0}{D_0} \times ADC - \frac{X_0}{100} \quad (1)$$

$$I = -100 \frac{N_1}{D_1} V_o \quad (2)$$

$$C = I / N_2 \quad (3)$$

Var.	Description	Handle
V_o	Voltage readout	
N_0	ADC reference voltage * 100	24
D_0	ADC resolution * 100	21
ADC	Analog to digital conversion	
X_0	Virtual ground level*100	27
I	Current or voltage	
N_1	Scale factor for current *100 for converting to mA, μ A, mV etc.	97
D_1	Current-to-voltage amplification * 100	30
C	Chemical concentration	

N_2 Scale-factor for non-offset linear conversion

The electrical parameter I that will be proportional with the chemical quantity C will be either a current or voltage, depending on whether an amperometric or potentiometric technique is used. This can be further converted to C either through (3) or (4), depending on whether the sensor is pre-calibrated with the device, or if calibration constants are different from sensor-to-sensor or lot-to-lot. The latter is the most common case. The calibration constants should therefore be adjustable through the end application in case they change.

$$C = c_1 I + c_0 \quad (4)$$

c_1, c_0 Sensor or lot specific linear calibration coefficients

The code might look like below:

```
double Vout = (ADC / D0) * N0 - X0 / 100; // Volts
double Iout = -100 * (Vout * N1 / D1);
double C = c1 * Iout + c0;
//double val = Iout / D2;
```

Writing to the ecFlex

Writing to the ecFlex is possible. This is mainly for potentiostat control. Note that for circuits shipped with the factory setting "Low power mode", or are programmed set up for potentiometric readings, the write functionality is limited only to soft reset of the device. All writeable characteristics are listed in the below tables.



Attribute handle 78 in service 11661 Potentiostat operational mode		
Bit	Value	Function
7	0	Short RE and WE: OFF
	1	Short RE and WE: ON
6:3	N/A	N/A
2:0	000	Sleep
	010	Maintain cell voltage
	011	Normal operation without temperature
	110	Temperature only
	111	Normal operation

Attribute handle 81 in service 11661 Current-voltage conversion resistor values		
Bit	Value	R value / kOhm
7:5	N/A	N/A
4:2 Current to voltage conversion amplification resistance	000	External resistor (C6)
	001	2.75
	010	3.5
	011	7
	100	14
	101	35
	110	120
	111	350
0:1 Input resistor to I-V converter	00	10
	01	33
	10	50
	11	100

Attribute handle 87 in service 11661 Voltage settings		
Bit	Value	Function
7	0	Default
	1	N/A
6:5 Allocation of dynamic range for positive current	00	100 %
	01	
	10	
	11	
4	0	Negative cell voltage
	1	Positive cell voltage
3:0 Cell voltage magnitude. The sign is determined by bit 4	0000	0 mV
	0001	30 mV
	0010	60 mV
	0011	120 mV
	0100	180 mV
	0101	240 mV
	0110	300 mV
	0111	360 mV
	1000	420 mV
	1001	480 mV
	1010	540 mV
	1011	600 mV
1100	660 mV	
1101	720 mV	

Attribute handle 108 in service 11661 System reset		
Bit	Value	Function
7:0	Anything	Reboot device



Troubleshooting

Fault	Action / solution
Connection lost	<ol style="list-style-type: none">1. Reboot ecFlex2. Clean battery terminals and reset ecFlex (power off and back on) disconnection the positive terminal of the battery.3. Make sure there is a proper connection between the battery terminals and the cooper patches on the ecFlex (solder them in position if necessary). The LiPO batteries can handle low-temp soldering4. Clean antenna trace. Check if there is any damping material (e.g. clothing) affecting your wireless transmission.5. Reduce distance between transmitter and receiver.6. Change battery
Signal low or indistinguishable	<ol style="list-style-type: none">1. Check sensor with lab potentiostat.2. Check that sensor is properly inserted in the connector.3. If signal is maxed out, please check for liquid in the connector.4. Increase voltage5. Increase amplification.6. An external gain resistor can be added for nanoAmp resolution