HCT Blood Glucose Meter Reference Design

D/N: WAS-199CEN

Introduction

An HCT (Hematocrit) blood glucose meter utilises an electrochemistry method to measure the DC current, AC impedance and phase angle generated by the reaction between blood and a reactive enzyme, and uses the measured values to calculate the exact blood glucose concentration. An HCT blood glucose meter is used together with an HCT blood glucose meter product assessment platform (AP). The AP can directly send commands to an MCU to implement a calibration and test, which support multiple measurement models. After the test is completed, the MCU will upload the measured data to the AP, in which the data will be converted, the impedance and phase angle will be calculated and displayed directly. This measured data can also be exported into an Excel chart. The phase angle measuring accuracy is about ±0.3° and the impedance measuring accuracy is about ±1%.

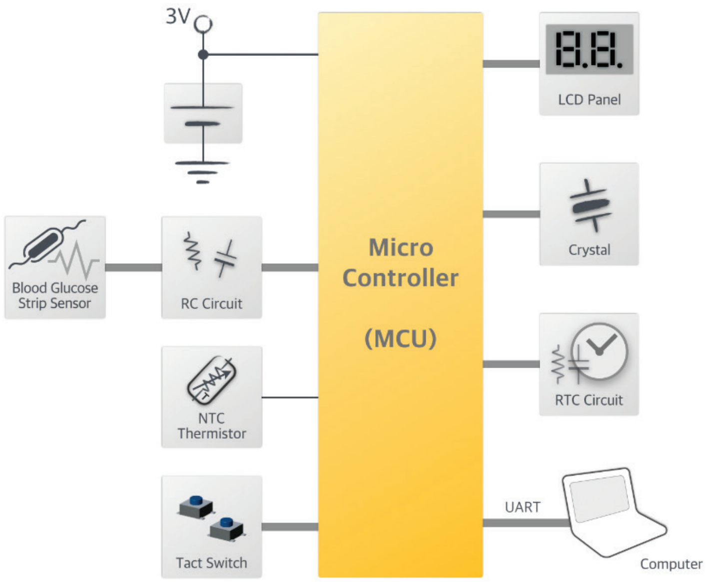

Figure 1. Application Block Diagram

Application Areas

HCT blood glucose meters, cholesterol testers, BIA (Bio-impedance Analysis) body composition analysers.

Solution Features

1. Integrated Blood Glucose AFE Circuit
   The integrated AFEs include a high-accuracy and low temperature drift stable voltage source, DAC, OPA, etc., only a few resistors and capacitors are required to implement DC current measurements.
2. Integrated HCT AFE Circuit
   Multi-frequency high-accuracy AC impedance and phase angle measurement can be implemented without the need for external components. The HCT can be calculated according to the measured values.

Functional Description

The HCT blood glucose meter solution can be divided into two parts, the HCT blood glucose meter development board with test strips and the BH67F2485 AC impedance & electrochemical measurement assessment platform (AP).

HCT Blood Glucose Meter Development Board with Test Strips

The HCT blood glucose meter development board performs continuous sampling and calculates the corresponding DC current, AC impedance and phase angle using an electrochemistry method. After measuring, these values are used to calculate the exact blood glucose concentration by using HCT compensation. The results are output via a UART communication interface.

- Master MCU: BH67F2485 - 80LQFP
- Operating voltage: 3V - Min: 2.2V, Max: 5.5V
- Impedance measuring range: 5kΩ~40kΩ – for major customer specifications, the reference resistance can be adjusted according to the measuring range
- Measuring accuracy: about ±0.3° for phase angle; about ±1% for impedance
- Output interface: UART - 38400, N, 8, 1

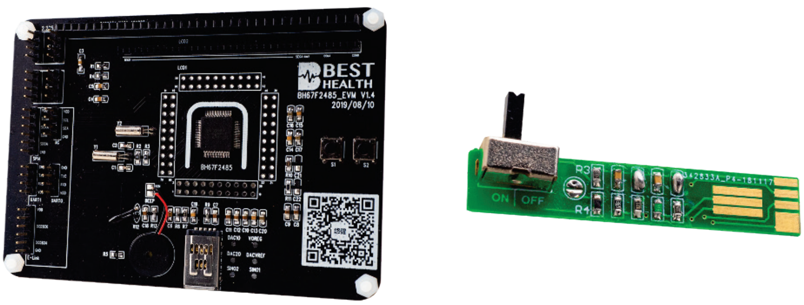

Figure 2. HCT Blood Glucose Meter Development Board with Test Strips

BH67F2485 AC Impedance & Electrochemical Measurement Assessment Platform (AP)

The BH67F2485 AC Impedance & Electrochemical Measurement Assessment Platform (AP) directly sends commands to the MCU which will adjust the internal reference voltage and the 12-bit D/A converter output voltage accordingly. This will obtain real-time data changes of DC current, AC impedance and phase angle, which after assessing the HCT and the blood glucose measuring accuracy specifications, the chemical physiological parameters can be obtained. The current measured data can also be exported into an Excel chart. The AP supports different measuring test strip models for which the interface is shown below.

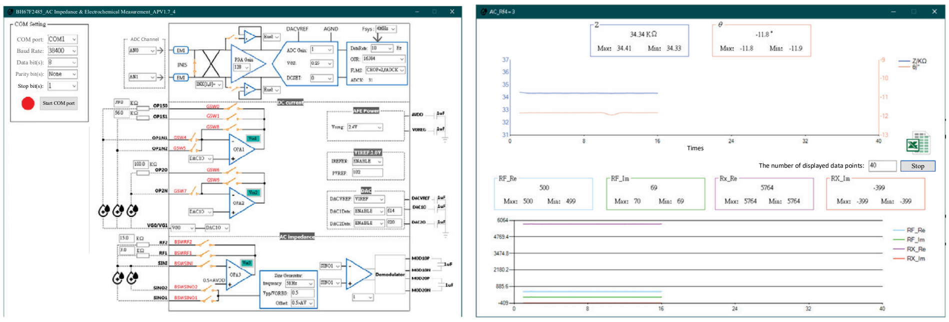

Figure 3. BH67F2485 AC Impedance & Electrochemical Measurement AP

- DACVREF Calibration

  The DACVREF voltage can be quickly adjusted to 2.0V by directly setting the D/A converter internal reference voltage data.

- DACO Calibration

  The DAC output voltage can be quickly adjusted to 0.3V and 0.4V by directly setting the D/A converter output voltage data.

- Vos Calibration

  The OPA input offset voltage calibration can be initiated by clicking on the V_{OS} buttons.

- DC Current Measurement

  Clicking on the corresponding blood glucose measurement icon in the DC current part will enter the measurement data display interface and start to measure. The MCU will upload the real-time measured data, allowing users to directly and conveniently monitor data changes.

- AC Impedance Measurement

  The excitation AC frequency and peak-to-peak voltage value V_{PP} can be setup directly. After the configuration is completed, click on the corresponding blood glucose measurement icon in the AC impedance part to enter the measurement data display interface after which measurements will start. The MCU will upload the real-time measurement data allowing users to directly and conveniently monitor data changes.

Data Output

The HCT blood glucose meter development board can connect to a PC via a serial port, the PC communicates with modules using serial ports.

- The sampled ADC values are output and calculated in the PC background to obtain the corresponding voltage, current value or impedance and phase angle, the data changes can be directly displayed in graphical form.
- The MCU will start operation after the PC sends a command for either calibration or test, the MCU will perform continuous measurements and upload the results to the AP in real-time.
- Default baud rate: 38400bps, data bit(s): 8, parity bit(s): None, stop bit(s): 1.
- The current tested data can be exported into an Excel chart for further data processing.

Operating Principles

The hematocrit (HCT) is the volume percentage of red blood cells in blood, which reflects the ratio of red blood cells to plasma. A blood glucose meter error is mainly caused by several conditions, such as the influence of interference substances and HCT in blood, a damp test strip, the existence of interference substances on a test strip, a circuit error, the influence of the ambient temperature to the chemical reaction, etc. This solution is suitable for HCT blood glucose meters, cholesterol testers and BIA body composition analysers.

The Holtek HCT blood glucose meter uses the BH67F2485 as the master MCU which is used together with an HCT blood glucose meter product assessment platform AP. Users can send commands through the AP to the MCU to implement calibration and measurements. The blood glucose meter utilises an electrochemical measurement principle, that is to calculate the glucose concentration in blood using the measured current generated by the reaction between blood and a reactive enzyme under a high-accuracy DC excitation voltage. It then calculates the HCT value using the AC impedance and phase angle of blood measured under different AC frequencies and peak-to-peak excitation voltages. HCT compensation is used to keep the blood glucose measuring accuracy within the full HCT range. A measurement temperature calibration is necessary as the degree of chemical reaction is closely related to temperature.

Hardware Description

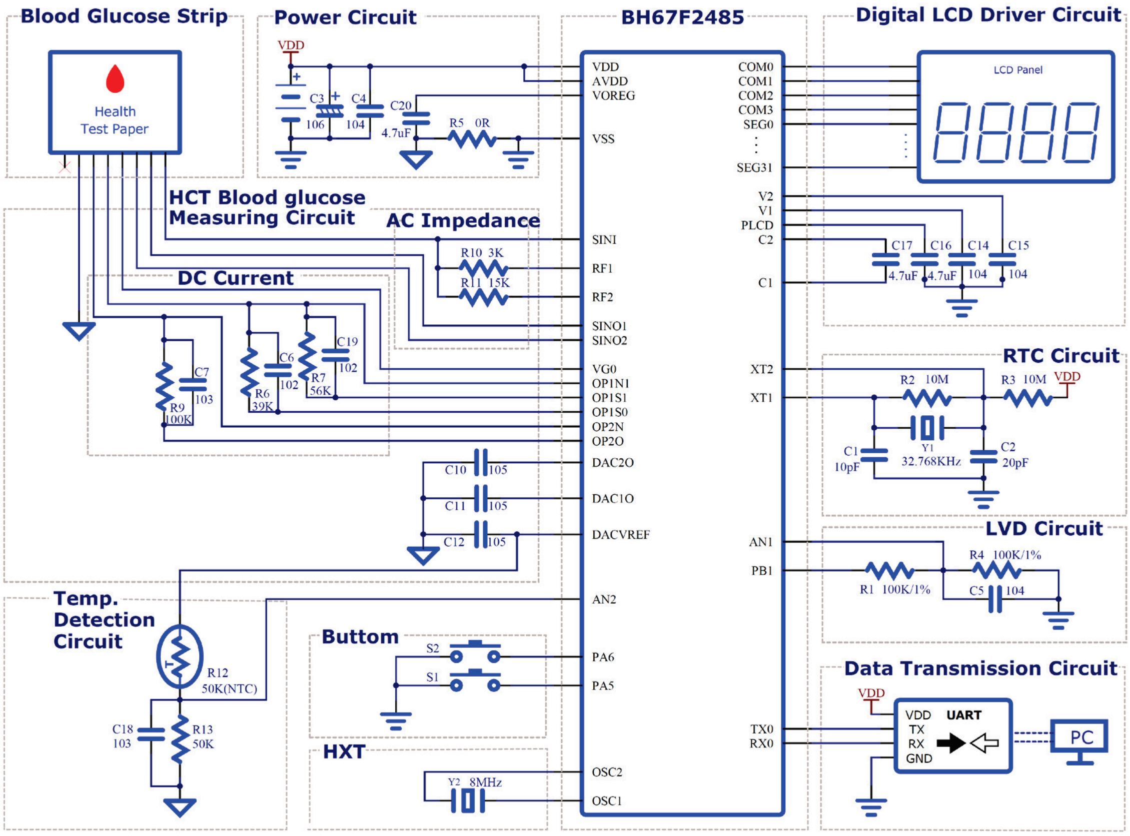

Figure 4. HCT Blood Glucose Meter Schematic Diagram

The HCT blood glucose meter schematic diagram includes a power circuit, HCT blood glucose measuring circuit which contains DC and AC measuring circuits, temperature calibration circuit, digital LCD driver circuit, RTC circuit, low voltage detection (LVD) circuit, data transmission circuit, external high-speed crystal (HXT) as well as various buttons.

Multiple ADC channels are used for sampling voltage ADC values. With these values, the AC impedance and phase angle generated by the reaction between blood and the reactive enzyme can be obtained.

One UART interface for communication.

Two ADC channels for the temperature detection calibration circuit and LVD circuit.

Three I/O pins for the LVD circuit and button circuits.

36 COMs or SEGs for the LCD display.

DC Current Measurement Principle

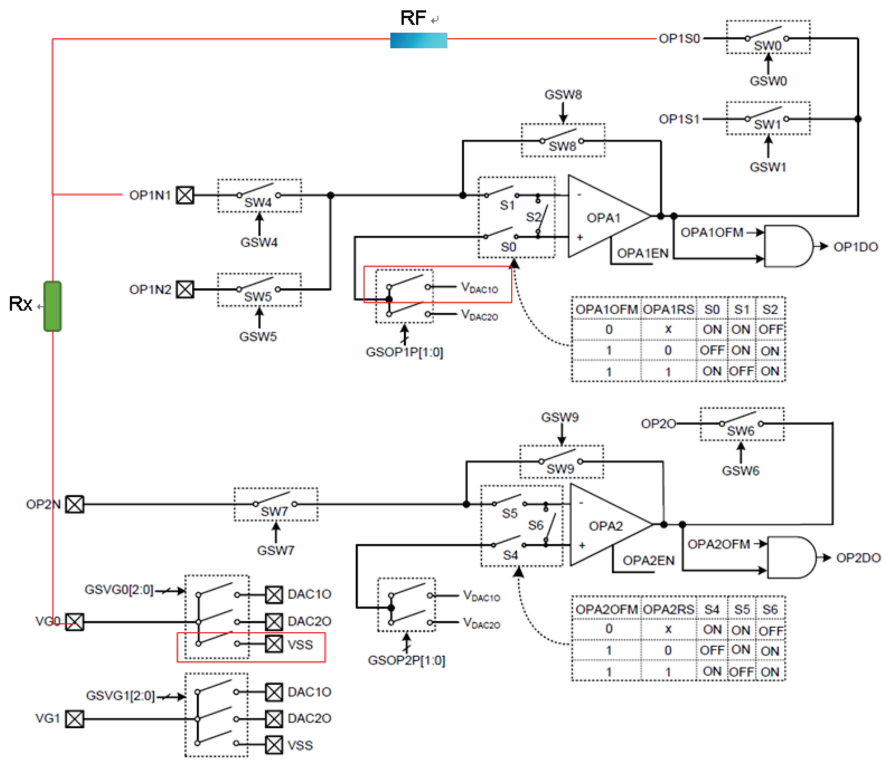

Figure 5. DC Current Measurement Circuit

According to the opamp virtual short theory, the voltage on the OPA1 positive end is V_{DAC1O}, which is set to 300mV. On the basis of constant current circuit, it can be seen that $I_{RX} = I_{RF}$, therefore $I_{RX} = U_{RF} / R_{RF}$, i.e. measuring the voltage across the RF resistor will obtain the current flowing through it, which is also the current flowing through RX.

After simplification of the A/D data conversion equation described in the BH67F2485 datasheet and the A/D converter configurations in the code, the final equation can be obtained as follows:

$U_{RF}(mV) = (U_{RF}\_ADC \times 1000) / 16384$, as a result, the $I_{RX}(\mu A) = (U_{RF}(mV)) / R_{RX}(k\Omega)$.

AC Impedance Measurement Principle

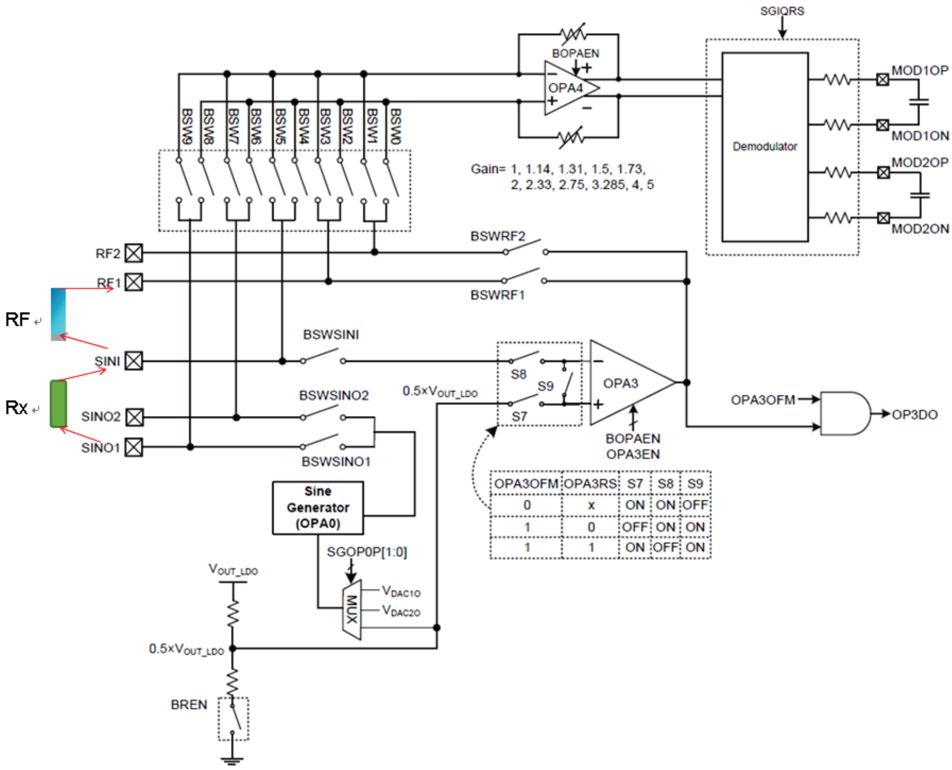

Figure 6. AC Impedance Phase Angle Measurement Circuit

The measurement circuit is shown above. Here the voltage on the OPA3 positive end is 0.5Voreg. According to the virtual short theory, the voltage on the OPA3 negative end is also 0.5Voreg. The sine wave output is fixed to provide a constant voltage. On the basis of the constant current circuit, a series of impedance calculation equation derivations are obtained as shown below:

$I_{RX} = I_{RF} \rightarrow V_{RX}/R_{RX} = V_{RF}/R_{RF} \rightarrow ADC_{RX}/R_{RX} = ADC_{RF}/R_{RF} \rightarrow R_{RX} = R_{RF} \times ADC_{RX}/ADC_{RF}$.

As a result, the $Z_{RF\_ADC} = (RF\_ADC\_Re^2 + RF\_ADC\_Im^2)^{0.5}$.

Therefore, $Z_{RX} = (RX\_ADC\_Re^2 + RX\_ADC\_Im^2)^{0.5} \times Z_{RF} \div Z_{RF\_ADC}$.

In this case, the angles can be calculated:

$\theta_{RF} = \text{atan2}\ (RF\_ADC\_Im, RF\_ADC\_Re) \div \pi \times 180$, note that if the result is less than 0, the final θ_{RF} value should add 360;

$\theta_{RX} = \text{atan2}\ (Rx\_ADC\_Im, Rx\_ADC\_Re) \div \pi \times 180 - \theta_{RF}/°$, note that if the result is greater than 180, the final θ_{RX} value should subtract 360;

Note: The units of Z_{RX} and Z_{RF} are kΩ, the units of θ_{RF} and θ_{RX} are degrees (°).

Hardware Considerations

The front view and back view of the HCT blood glucose meter layout are shown below. Special attention should be paid during PCB layout routing. The wiring in the BIA measurement circuit should be as short as possible and via should be small.

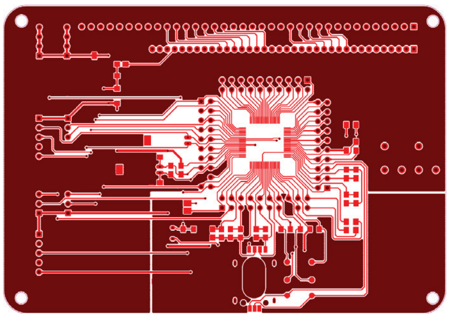

Figure 7. PCB Layout Front View

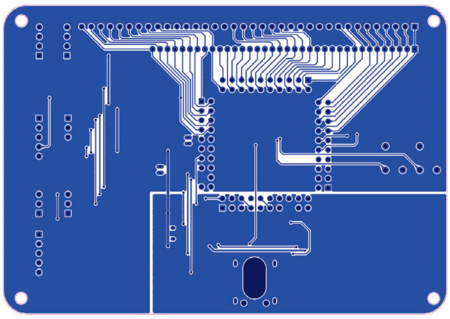

Figure 8. PCB Layout Back View

PCB BOM Table

Bill of Materials <Parameter Title not found>

Source Data From:	**SCH_HCTBGM.SchDoc**
Project:	**Free Documents**
Variant:	**None**
Creation Date:	2020/3/4 06:05:08 p.m
Print Date:	

Designator	Comment	LibRef	Footprint	Quantity
U1	BH67F2485	IC	LQFP_80	1
R1, R4	100K/1%	RESISTOR	R0805	2
R2, R3	10M	RESISTOR	R0805	2
R5	0R	RESISTOR	R0805	1
R6	39K	RESISTOR	R0805	1
R7	56K	RESISTOR	R0805	1
R9	100K	RESISTOR	R0805	1
R10	3K	RESISTOR	R0805	1
R11	15K	RESISTOR	R0805	1
R12	50K	RESISTOR	NTC	1
R13	50K	RESISTOR	R0805	1
C1	10pF	CAP(1)	C0805	1
C2	20pF	CAP(1)	C0805	1
C4, C5, C13, C14, C15	104	CAP(1)	C0805	5
C6, C19	102	CAP(1)	C0805	2
C7, C18	103	CAP(1)	C0805	2
C8, C9, C10, C11, C12	105	CAP(1)	C0805	5
C16, C17, C20	4.7uF	CAP(1)	C0805	3
C3	106	CAP(2)	CASE-A_3216	1
Y1	32.768KHz	Xtal(1)	Radial,2*6mm	1
Y2	8MHz	Xtal(1)	Radial,2*6mm	1
S1, S2	6*6	SW(2)	6*6mm	2
BZ1		BEEP		1
Y3		CONNECTOR	TEST_STRIP	1
				39

Approved	**Notes**

Table 1

AP Usage Process Description

Users can directly send commands through the AP to the MCU to initiate measurements. After the measurement is completed, the MCU will upload the measured data to the AP.

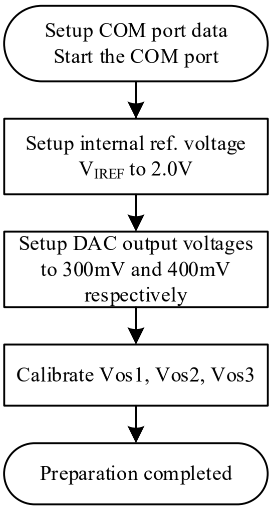

Figure 9. HCT Blood Glucose Meter AP Preparation Flowchart

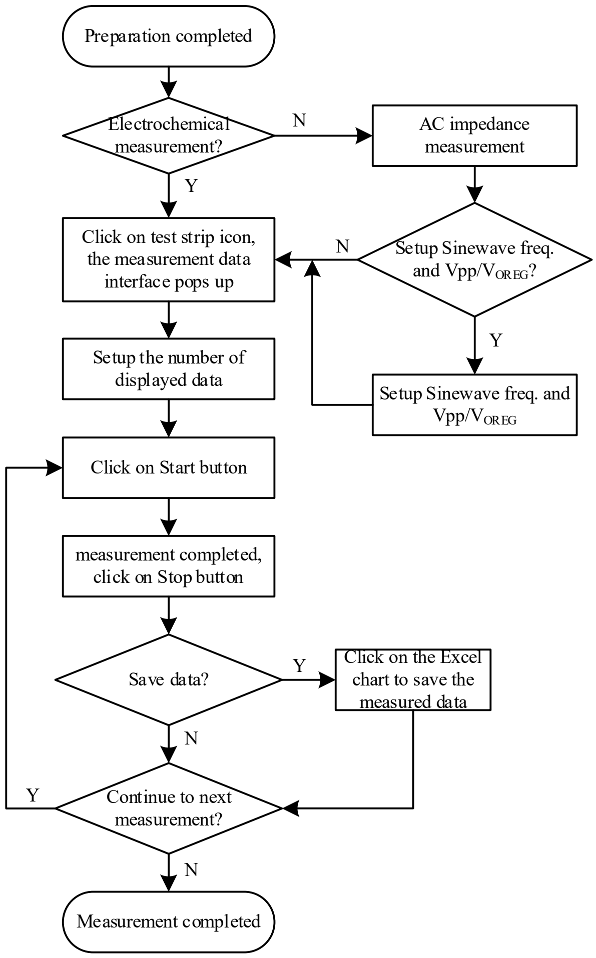

Figure 10. HCT Blood Glucose Meter AP Test Process

Preparation

The HCT blood glucose meter performs an internal reference voltage adjustments described above after connecting to the PC. This procedure can be ignored if the voltages have been adjusted already.

Test Process

After the preparation is completed, click on the blood glucose test icon, if the AC impedance test is utilised, the peak-to-peak voltage value (V_{PP}) ratio and sinewave frequency should also be configured. This procedure can be ignored if the values used are the default values. Click on the Start button to start the measurement after the number of displayed data has been setup.

Considerations

The HCT blood glucose meter operating voltage is 3.0V, it can be powered by battery or through a USB interface. After the code programming, the blood glucose meter can start to operate by inserting a serial port tool and connecting to the PC. If the message box shown below pops up when saving data, indicating that the current "Microsoft .NET Framework" version is too old, users should install the patch "Microsoft .NET Framework 4.5".

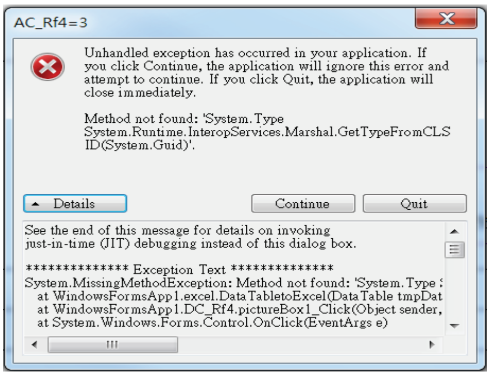

Figure 11. HCT Blood Glucose Meter AP Error Message

AP Operation Description

Platform Home Page Diagram

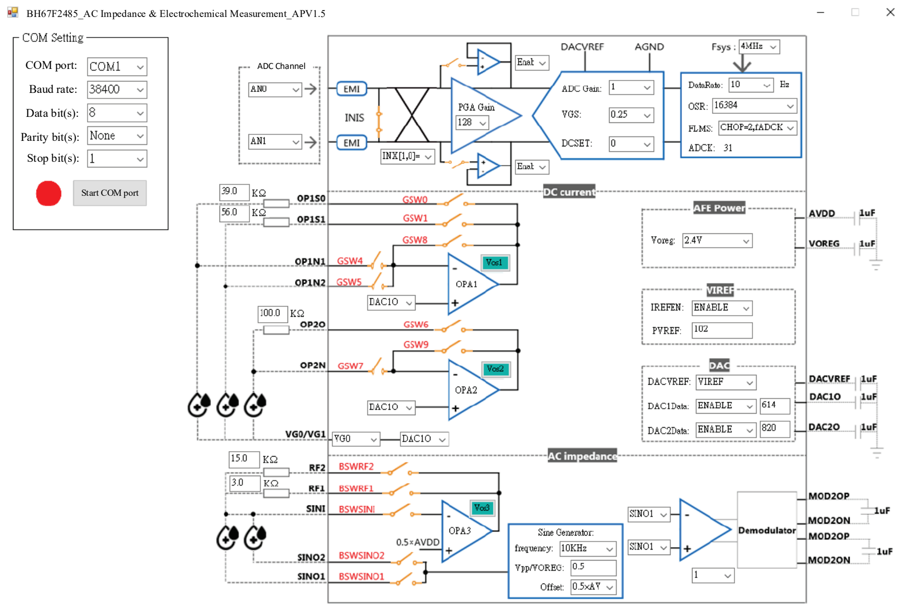

Figure 12. BH67F2485 Platform Home Page

Preparation

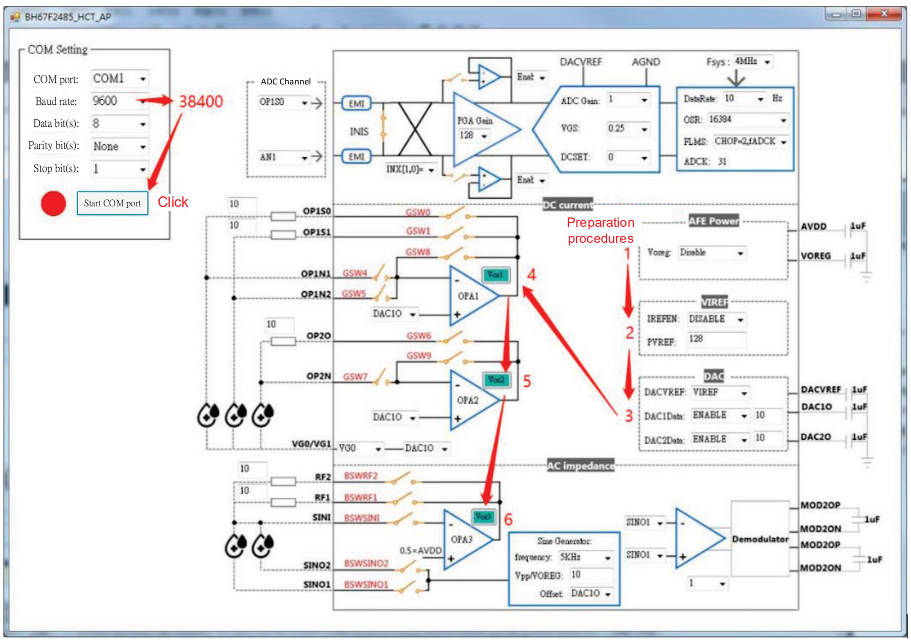

Figure 13. Preparation Procedure Diagram

1. Setup the COM port: baud rate: 38400; data bit(s): 8; parity bit(s): None; stop bit(s):1, then start the COM port.
2. Set the AFE power to 2.4V. The analog power, with the exception of the ADC, is sourced from Voreg, therefore this voltage source must be turned on if any of these analog functions are used.

3. Calibrate the VIREF to 2.0V.
   ① IREFEN: Enable;
   ② DACVREF: VIREF;
   ③ PVREF: the data filled in is a decimal number, adjust this value until the DACVREF equals 2.0V.
4. Setup DACO voltage.
   ① DAC1Data: Enable, the data filled in is a decimal number, adjust this value until the DAC1O voltage equals 300mV.
   ② DAC2Data: Enable, the data filled in is a decimal number, adjust this value until the DAC2O voltage equals 400mV.
5. Click on Vos1, Vos2 and Vos3 in order as shown in the above diagram to calibrate the OPAs.

DC Current Measurement

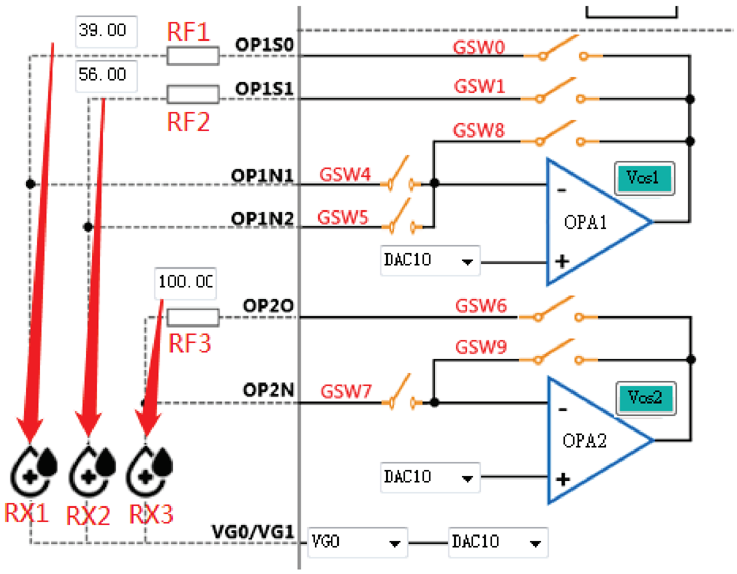

Figure 14. DC Measurement Procedure Diagram

Figure 15. DC Data Display Window Diagram

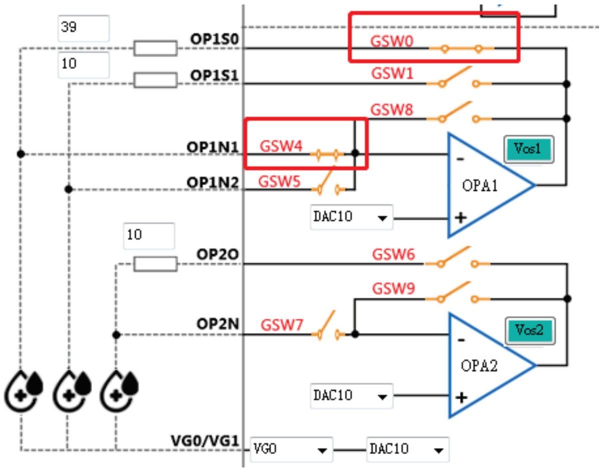

Figure 16. DC Test Switch Diagram

Fill in the corresponding reference resistance and then click on the corresponding blood glucose icon, the blood glucose measurement data window will pop up, as shown in Figure 15. Click on Start to initiate the measurement, during which time the internal circuit switch condition is shown in Figure 16.

DC test items:

① RX1: the reference resistance is about 39, two decimal fractions can be reserved depending on the actual measurement values. Insert a test strip, turn the switch to ON and click on the RX1 blood glucose icon. The measurement data window will pop up as shown in Figure 15, then click on Start to initiate the measurement.

② RX2: the reference resistance is about 56, for other procedures refer to ①.

③ RX3: the reference resistance is about 100, turn the switch to OFF, for other procedures refer to ①.

Note: The reference resistance is referenced according to actual measurement values, the test strip switch condition is referenced according to the actual measurement circuit.

AC Impedance Measurement

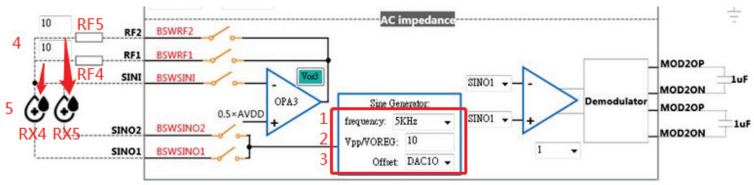

Figure 17. AC Measurement Procedure Diagram

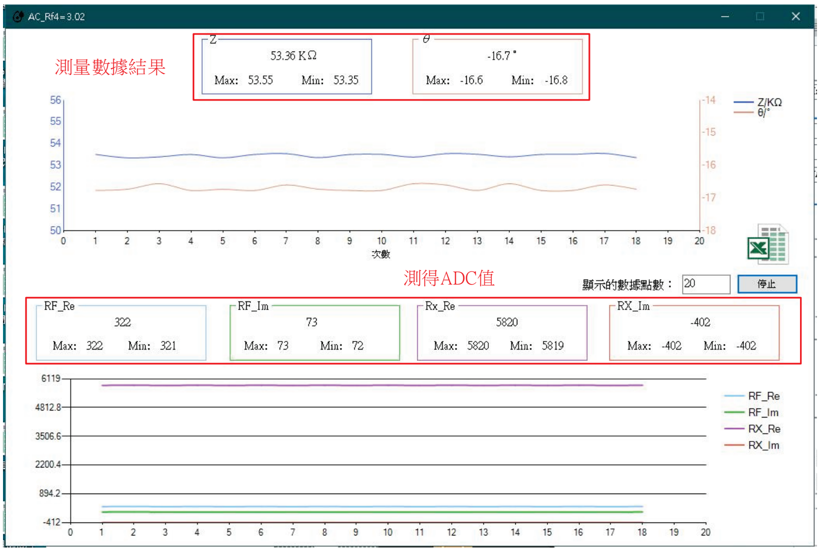

Figure 18. AC Data Display Window Diagram

1. Setup the measurement frequency.
2. Setup the V_{PP} value, the V_{PP} value is the ratio of V_{PP} to V_{OREG}, if V_{PP}/V_{OREG}=0.1, the input value is 10.
3. Setup the Sinewave Offset to $0.5AV_{DD}$.
4. Fill in the reference resistance, click on the corresponding blood glucose icon, the measurement data window will pop up as shown in Figure 18. Click on Start to initiate the measurement.

Transport Protocols

1. When Vos1, Vos2 and Vos3 are clicked, or the DACVREF, DAC1O, DAC2O, Frequency and Scales are configured:

AP→MCU: AP will send data to the MCU to initiate calibration or test:

Byte Serial Number	Type	Value	Description
0	Command	0xA1	Write register command
1~2	Data address	0x00A0~0x00FF	MSB first
3~4	Data	0x0000~0xFFFF	MSB first
5	Parity bit	0x00-0xFF	The sum of the bytes from the command to the previous bit of the parity bits

MCU receives data and returns to AP:

Byte Serial Number	Type	Value	Description
0	Command	0xA1	Write register command
1~2	Data address	0x00A0~0x00FF	MSB first
3~4	Data	0x0000~0xFFFF	MSB first
5	Parity bit	0x00-0xFF	The sum of the bytes from the command to the previous bit of the parity bits

Address description:

Test Items	Address	Data Description
Vos1	0x00A0	0x0000
Vos2	0x00A1	0x0000
Vos3	0x00A2	0x0000
DACVREF	0x00A3	0x0000~0x00FF
DAC1O	0x00A4	0x0000~0x0FFF
DAC2O	0x00A5	0x0000~0x0FFF
Sine Wave	0x00A6	0x0000~0xFFFF, the higher half-byte is Frequency while the lower half-byte is Scales: Frequency data is listed as follows: 0x01 5kHz 0x02 10kHz 0x03 20kHz 0x04 25kHz 0x05 50kHz 0x06 100kHz 0x07 200kHz 0x08 250kHz 0x09 500kHz 0x0A 1MHz

2. Click on the test strip button to turn on the ADC for measurement:

AP→MCU: AP sends a data to MCU to initiate calibration or test:

Byte Serial Number	Type	Value	Description
0	Command	0xA2	Read register command
1~2	Data address	0x00A0~0x00FF	MSB first
3~4	Data	0x0000	MSB first
5	Parity bit	0x00-0xFF	The sum of the bytes from the command to the previous bit of the parity bits

MCU→AP: complete the measurement and upload data to AP:

Byte Serial Number	Type	Value	Description
0	Command	0xA2	Read register command
1~2	Data address	0x00A0~0x00FF	MSB first
3~4	ADC Data1	0x0000~0xFFFF	MSB first, ADC Data is RF_Re (effective when the address is 0xAA/ 0xAB)
5~6	ADC Data2	0x0000~0xFFFF	MSB first, ADC Data is RF_Im (effective when the address is 0xAA/ 0xAB)
7~8	ADC Data3	0x0000~0xFFFF	MSB first, ADC Data is RX_Re (effective when the address is 0xAA/ 0xAB)
9~10	ADC Data4	0x0000~0xFFFF	MSB first, ADC Data is RX_Im
11	Parity bit	0x00-0xFF	The sum of the bytes from the command to the previous bit of the parity bits

Address description:

Test Items	Address	Data Description
RX1	0x00A7	Byte3~Byte8=0x00, Byte9 and Byte10 are valid data
RX2	0x00A8	Byte3~Byte8=0x00, Byte9 and Byte10 are valid data
RX3	0x00A9	Byte3~Byte8=0x00, Byte9 and Byte10 are valid data
RX4	0x00AA	Byte3~Byte10 are valid data
RX5	0x00AB	Byte3~Byte10 are valid data

Data Examples

	A	B	C	D	E	F	G	H
1	Freq./KHz	V_{P-P}/VOREG	Z/KΩ	θ/°	RF_Re_ADC	RF_Im_ADC	RX_Re_ADC	RX_Im_ADC
2	5	0.5	43.24	-0.4	401	-25	5777	-396
3	5	0.5	43.14	-0.2	402	-26	5779	-396
4	5	0.5	43.04	-0.2	403	-26	5780	-396
5	5	0.5	43.03	-0.2	403	-26	5779	-396
6	5	0.5	43.04	-0.2	403	-26	5780	-396
7	5	0.5	43.15	-0.2	402	-26	5780	-396
8	5	0.5	43.15	-0.2	402	-26	5780	-396
9	5	0.5	43.04	-0.2	403	-26	5780	-396
10	5	0.5	43.15	-0.2	402	-26	5780	-396
11	5	0.5	43.04	-0.2	403	-26	5780	-396
12	5	0.5	43.15	-0.2	402	-26	5780	-396
13	5	0.5	43.15	-0.2	402	-26	5781	-396
14	5	0.5	43.15	-0.2	402	-26	5781	-396
15	5	0.5	43.05	-0.2	403	-26	5781	-396
16	5	0.5	43.04	-0.2	403	-26	5780	-396

Figure 19. AC Impedance Test Data Examples

Conclusion

This application note has introduced how to use the HCT blood glucose meter and the HCT blood glucose meter product assessment platform. The HCT blood glucose meter utilises an electrochemistry method to calculate the current, AC impedance and phase angle generated by the reaction between blood and a reactive enzyme. It uses the measured value to obtain the exact blood glucose concentration. Using a low frequency, the impedance accuracy is about ±1% and the phase angle accuracy is about ±0.3°. The HCT blood glucose meter product assessment platform sends commands to the MCU directly to initiate calibration and test, which support multiple measurement models. After the test is completed, the MCU will upload the measured data to the AP, in which the data can be converted and used to calculate the impedance and phase angle. These results will be directly displayed while the measured data can be exported into an Excel chart. These features will help users to rapidly complete development of their blood glucose meter products.

Reference File

Reference file: BH67F2485 Datasheet.

For more information, consult the Holtek website www.holtek.com .

Version and Revision

Date	Author	Issue
2020.04.02	程素英	V1.00

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