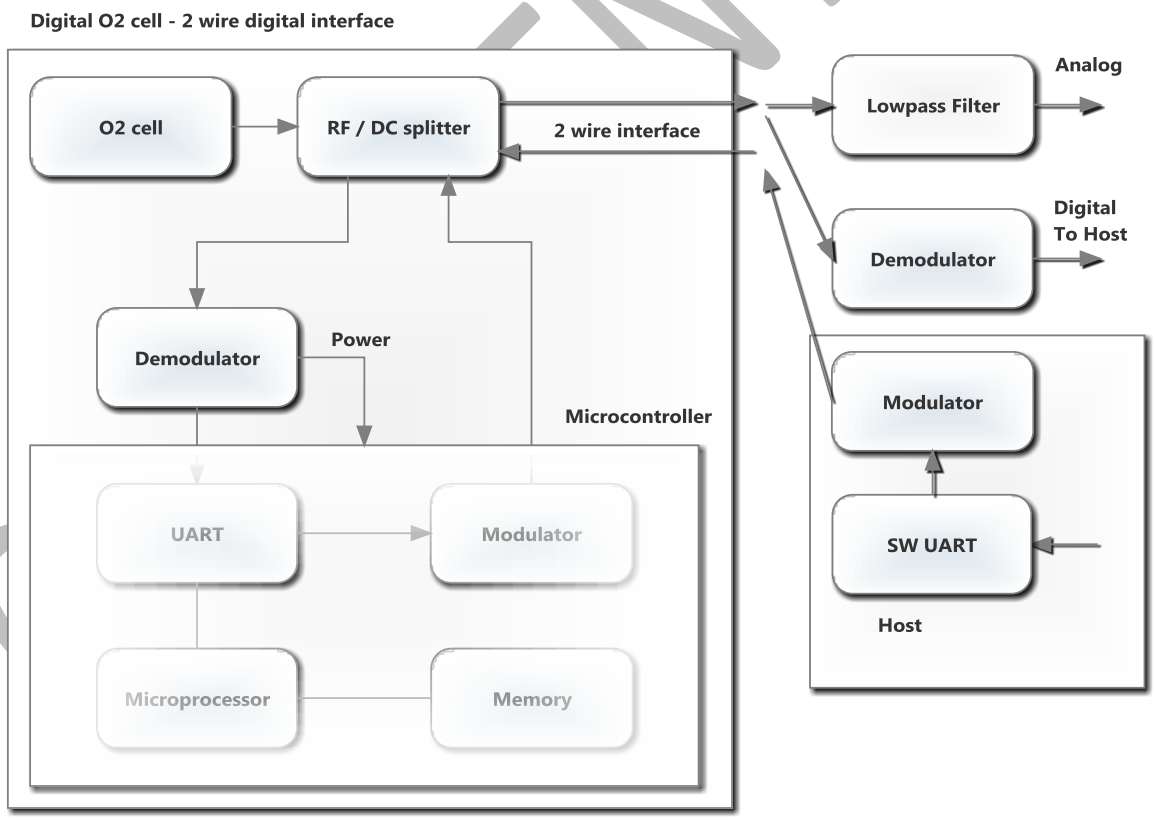
1.0 PURPOSE

This document describes the physical, transport, and protocol layers of Shearwater Research Inc.'s 2-wire digital link.

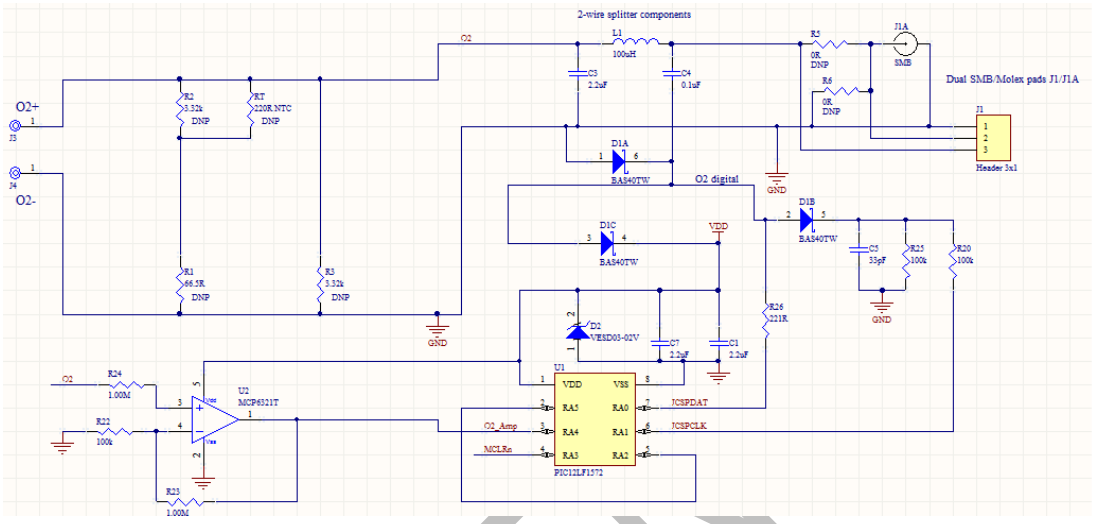
This protocol is designed for use with a digital O2 sensor board, but also may be used for other types of sensors or peripheral devices. The digital link is a host/peripheral arrangement, where the host supplies power and initiates all communications on one signal wire along with a return ground wire. The peripheral responds to commands from the host, and is not required to have any power supply of its own.

2.0 BLOCK DIAGRAM

A block diagram of the implementation of the 2-Wire interface on a Digital O2 cell in a host system is shown below.



3.0 PROTOTYPE CIRCUIT BOARD



The digital O2 board circuit shown above is an implementation of this specification. Several circuit sections are of note:

- R1-R3 and RT are the analog temperature compensation network for the O2 cell.
- D1A/C direct power input on the digital line to charge storage in C1 and C7. D1B with C5, R25, R20, and an internal comparator in U1 form the demodulator function to convert the modulated high frequency waveform to NRZ serial UART signals.
- U1 is the microcontroller that receives commands, measures inputs or recalls recorded data, and responds to the commands via a single digital line. This microcontroller contains the serial data UART and high frequency modulator.
- U2 is an op amp to condition the low signal from the O2 sensor to a voltage readable by the ADC of U1.
- L1-C3 is a lowpass filter to isolate the high frequency signal from the O2 cell. C6 resonates with L1 at 1MHz to select the operating frequency. C4 couples the high frequency to the digital logic but isolates the DC voltage of the O2 cell from the logic. Together these components form the RF/DC splitter function.

3.1 Analog and Digital Interface Compatibility

The Digital O2 signal will work over existing 2-wire connections to analog cells. It is expected existing analog interfaces will be used for reading the analog cells. The digital features are for diver information and assistance, not for controlling the rebreather loop. The analog amplifier circuits will need sufficient filtering to prevent perturbation of the analog signals by the digital messages.

Recommended low-pass filter attenuation = 80dB minimum at 1MHz

This filter specification may be met by a single RC low-pass circuit

- Minimum 10k + 0.22uF
- Recommended 100k + 0.1uF for reduced digital signal loading

Note that it is recommended to minimize capacitive loading directly on the analog/digital O2 wiring pair, as it will reduce the digital signal level. Twisted pair or shielded wiring, and keeping wire lengths as short as practical is also recommended to reduce outside signal susceptibility of the digital O2 interface. Typically this is already in the analog configuration without any changes.

4.0 PHYSICAL LAYER

The 2-Wire interface uses a single signal wire plus ground for bi-directional communications from host to peripheral, supplying both power and messaging to the peripheral unit (sensor).

Signals from host to peripheral and return are 1MHz square wave carrier, On-Off Keyed (OOK). 1 bit defined as signal, 0 bit as no signal.

2-Wire Link Operation Sequence

Charge	Sync	Charge	Command	Command execute	Response
111111111111…	000…	1111…	3/4 byte	111111111111111…	High_impedance

The 2-wire link operates in several phases, controlled by the host (main board) unit:

1. Charge: 1MHz square wave drive for power transfer to peripheral.
2. Sync: no signal.
3. Charge: 1MHz square wave re-power and data preamble.
4. Send command: Serial UART 31.25kbps, 1start, 8 data, 2 stop bits modulated on 1MHz square wave carrier (high = modulation ON) 3 or 4 byte command transfer to peripheral.
5. Command execute: 1MHz square wave for power transfer during peripheral command execution.
6. Response: Host signal off, high impedance listen mode for peripheral response.

Peripheral unit sequence

1. Main charge storage during power transfer stage, start-up and self-check. Low power operation must be maintained to allow charge build-up.
2. Synchronization pulse initiates receiver.
3. Command reception, perform commanded task.
4. Transmission of response back to host using stored energy in a capacitor.

Host-Generated Phase Timing

Parameter	Minimum	Maximum	Units
Phase 1 charge	7		ms
Phase 2 sync	0.9	1.1	ms
Phase 3 preamble	1.8	2.2	ms
Phase 4 command	1.0	1.5	ms
Phase 5 execute	3.5	4.5 (v15) 10 (v16+)	ms
Phase 6 command wait time	2		ms
Command turn-around time phase 6 complete to next phase 1 start (carrier off)	2		ms
Carrier frequency	0.90	1.10	MHz
Carrier duty cycle	45	60	%
Carrier amplitude (1 bit)	2.7	3.6	Vpp
Serial Bit Rate	30.75	31.75	Kbps
Maximum capacitive line load		100	pF

- Recommended Phase 5 time = 6ms (requires firmware v18 and later)

5.0 LINK FORMAT

3 byte command structure, host to peripheral

Command 0x00 – 0x7F	Payload LSB byte	Checksum

Checksum = sum of command and data bytes MOD 8, then 1's complement

4 byte command structure, host to peripheral

Command 0x80 – 0xFF	Payload MSB byte	Payload LSB byte	Checksum

Checksum = sum of command and data bytes MOD 8, then 1's complement

3 Byte peripheral to host response structure

Response MSB	Response LSB	Checksum

Checksum = sum of MSB and LSB response bytes MOD 8, then 1's complement

6.0 COMMANDS

Unrecognized commands or errors result in no response.

Unused command payload bytes can be any value, but 0xAA, 0xF0 recommended.

Checksum = sum of command and data bytes MOD 8, then 1's complement

0x00 - 0x3F Reserved

0x00 – 0x3F	Reserved	Checksum

Response:

None.

0x40 Configuration (and Flash memory size)

0x40	0xAA (unused)	Checksum

Response:

1 byte (MSB) configuration bits + upper bit of Flash memory size (in lower bit)

1 byte (LSB) Flash memory size in words (total 9 bits size when combined with MSb)

0x41 Firmware version (and device type)

0x41	0xAA (unused)	Checksum

Response:

1 byte firmware version (hexadecimal after v25) value MSB

1 byte peripheral type LSB

Peripheral type table:

Type byte	Name	Description	Protocol version
00	Reserved		
01	Digital O2 Sensor	Digital-enhanced O2 sensor cell	A, B+
02	CO2 Sensor	Solid state CO2 sensor	B+
03	CO2 Temperature Stick	CO2 Scrubber temperature sensor array	B+
04-FF	Reserved		

0x42 Reference voltage

0x42	0xAA (unused)	Checksum

Response:

The reference voltage check returns 2 bytes (12 bits unsigned ADC reading: MSB, LSB), reading a 2.048V reference voltage. The result will vary with supply voltage, so the supply voltage may be calculated (this formula is valid for firmware v18 and later):

Supply_Voltage (charge level) = 1024 * (4096 / ADC_Reading) (mV)

This result will be accurate only if the ADC reading is less than 4095.

0x43 Temperature

0x43	0xAA (unused)	Checksum

Response:

This command returns a 2 byte temperature sample (12 bits unsigned ADC reading: MSB, LSB). This reading is two diode drops below the positive supply voltage (recommended to read supply voltage before reading temperature value).

Temperature (C * 100) = Ref_Temp + (ADC_Reading – ADC_Ref) * Supply_Voltage / (Temp_Scale)

Where:

Ref_Temp is calibration reference temperature (in degree C * 100 or degree C if < 100)

ADC_Ref is the ADC_Reading at calibration reference temperature

Supply_Voltage is calculated using the reference voltage command (in mV * 100)

Temp_Scale is nominal 7800, may be calibrated with a two-point temperature calibration

0x44 O2 voltage

0x44	0xAA (unused)	Checksum

Response:

This command returns a 2 byte O2 voltage sample (lower 12 bits ADC reading: MSB, LSB).

O2_Voltage = (100 * ADC_Reading) / (11 * 2) + OpAmp_Offset (mV * 100)

Where:

OpAmp_Offset is the OpAmp compensation offset in mV * 100 (signed value)

0x45 Reserved

0x45	Reserved	Checksum

Response:

None.

0x46-47 Find free flash WORD starting at WORD address

0x46 – 47	WORD address	Checksum

Response:

This command returns 2 byte address of unprogrammed flash: MSB, LSB

The address range is memory size (no response if outside this range). Starting address is 9 bit, 0x00-0xFF addressed by command 0x46, 0x100-0x1FF by 0x47.

0x48-49 Read flash WORD at WORD address

0x48 - 49	WORD address	Checksum

Response:

This command returns 2 bytes: MSB, LSB (only lower 14 bits valid).

The address range is memory size (no response if outside this range). Word address is 9 bit, 0x00-0xFF addressed by command 0x48, 0x100-0x1FF by 0x49.

0x4A-4B Erase flash PAGE at WORD address

0x4A – 4B	WORD address	Checksum

Response:

None

The address range is memory size (no response if outside this range). Word address is 9 bit, 0x00-0xFF addressed by command 0x4A, 0x100-0x1FF by 0x4B. Erases FULL PAGE (16 WORDS) containing word address. No verify is performed – read command may be used for erase verify.

CAUTION: DO NOT ERASE manufacturing information area (words 0x00 – 0x1F).

0x4C-7F Reserved

0x4C – 0x7F	Reserved	Checksum

Response:

None.

0x80-FF Write flash WORD at WORD address

0x80 – 0xFF	Data to write MSB	Data to write LSB	Checksum

Writes (MSB, LSB in payload bytes, lower 14 bits valid) at WORD address 00 to 7F. WORD address is calculated from the lower 7 bits of the command byte. Write address is extended by the upper 2 bits of data MSB, total address size 9 bits (512 words). The write only occurs if the memory location is blank (WRITE-ONCE). These are 4-byte commands. Read the flash size from command 0x40.

Response:

None.

Use a read flash command to verify the written data.

7.0 FLASH MEMORY MAPS

7.1 Digital O2 Flash MAP

Map size = 240 x 14 bit words (was 128 words in firmware v15)

Address	**Content**
00 – 0F	Manufacturer ID
10 – 1F	Factory calibration
20 – DF	96 Field calibrations, 2 words each
E0 – EF	Reserved

Manufacturer ID area 16 words

Index	WORD address	Name	Format	Size, words
0	0x00	Model	14 char (7 bit)	7
1	0x07	MFG ID	6 char (7 bit)	3
2	0x0A	Manufacture date/time	28 bit m/Y/M/D/H	2
3	0x0C	Expiry date/time	28 bit m/Y/M/D/H	2
4	0x0E	Memory map version number (version 6 bits, type 8 bits)	14 bit uint	1
5	0x0F	Reserved		1

- Time format unused:1 bit/minutes:6/year:7/month:4/day:5/hour:5 bits (24 hour time)

Factory calibration data area 16 words

Index	WORD address	Name	Format	Size, words
0	0x10	Serial number	12 char (alphanumeric)	6
1	0x16	Temp_Scale	14 bit uint	1
2	0x17	Ref_Temp, degree C*100	14 bit uint	1
3	0x18	ADC_Ref, counts at calibration	14 bit unit	1
4	0x19	OpAmp_Offset mV * 100	14 bit unit	1
5	0x1A	Manufacturing PPO2 calibration data	3 cal x 2 x 14 bit uint	6

Field calibration record 2 words (at each location, 96 locations)

Index	Name	Format	Size, words
0	Calibrate date/time – hours from manufacture * 3 (5.6 year limit)	14 bit uint	1
1	Gain value 1024 * PPO2_Full_Scale	14 bit uint	1

Calibration timestamp calculation:

- Convert current time and manufacture time each to time_t, where time_t is ‘seconds from epoch’
- Subtract manufacture time from current time (if negative, clock setting error)
- Calibration record is difference value / (3 * 3600)

7.2 CO2 Sensor Flash MAP (*Preliminary)

Map size = 240 x 14 bit words

Address	**Content**
00 – 0F	Manufacturer ID
10 – 1F	Factory calibration
20 – DF	96 Field calibrations, 2 words each
E0 – EF	Reserved

Manufacturer ID area 16 words

Index	WORD address	Name	Format	Size, words
0	0x00	Model	14 char (7 bit)	7
1	0x07	MFG ID	6 char (7 bit)	3
2	0x0A	Manufacture date/time	28 bit m/Y/M/D/H	2
3	0x0C	Expiry date/time	28 bit m/Y/M/D/H	2
4	0x0E	Reserved		2

Factory calibration data area 16 words

Index	WORD address	Name	Format	Size, words
0	0x10	Serial number	12 char (alphanumeric)	6
1	0x16	Temp_scale	14 bit uint	1
2	0x17	Ref_Temp, degree C*100	14 bit uint	1
3	0x18	ADC_Ref, counts at calibration	14 bit unit	1
4	0x19	R, G, B calibration offset	3 x 14 bit unit	3
5	0x1C	R, G, B calibration gain	3 x 14 bit uint	3
6	0x1F	Reserved		1

Field calibration record 2 words

Index	Name	Format	Size, words
0	Calibrate date/time – hours from manufacture * 6 (11.2 year limit)	14 bit uint	1
1	CO2 reading at 400ppm (outdoor)	14 bit uint	1

8.0 REVISION HISTORY

Revision	Description	Date (yyyy-mm-dd)	Author
A	Initial released revision, based on draft 0.3	2014-12-05	MB
B	Updated for 2-wire modulated protocol, major edits for clarity (tables, diagrams)	2015-07-03	MB
C	Updated timing table, and O2 calibration values	2015-07-14	MB
D	Added commands 0x46/47 and 0x4A/4B	2017-09-22	MB
E	Error corrections, expanded description	2017-11-17	MB