Innovate Serial Protocol 2 (ISP2) specification (preliminary)

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1. Serial Interface Settings

The LM-1 serial interface is set to

8 data bits
1 stop bit
no parity
19.2 kBaud.

2. Serial Protocol Format Version 2

This protocol supercedes Version 1 of the LM-1 serial protocol. It is designed to be backward compatible with protocol version 1. Devices that follow this protocol definition will be compatible with both.

The change to ISP2 allows to expand the data logging protocol to up to 32 or more channels. It also allows the user to add additional channels for logging and display at will.

The serial data consists of packets, (in normal operation every 81.92 msec).

The packets are organized as 16 bit words in big endian order.

The first 2 Bytes of a packet are the packet header. Both bytes of a packet header have their high bit set. The header also contains the total length of a packet, which may be modified by any data-source device in the chain.

Protocol Version 1 is distinguished from protocol version 2 by bits 13, 9 and 7. In Version 1 these bits are always 0. Version 1 consists of a LM-1 packet only.

Serial Protocol 2 Header

Header Word

Word	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 3	Bit 1	Bit 0
0	1	R	1	D/S	HF	X	1	B7	1	B6	B5	B4	B3	B2	B1	B0

The Header word can be distinguished from the start of a LM-1 packet by looking at Bit 13 and 9 and 7. In an LM-1 packet these bits are always 0.

Bit 15 of always set Header start marker

Bit 14 (R) is set if currently recording to Flash in LM-1 or other recorders .

Bit 13 is always 1

Bit 12 is 1 when the data is sensor data, it is 0 when the rest of the packet is response data to a programming command. In this case a display device will just ignore n data words, intermediate devices don’t add their sensor data. In a command response packet the next data word contains the bit 0..bit6 of the command in Bit 0.. Bit 6 of the word. Bit 7 of the word is 0, Bit 8 to Bit 14 of the word contains bit 7 to 13 of the command, Bit 15 of the word is 0. Following that is command response data.

Bit 11 is 1 if the originating device is capable of internal logging

Bit 10 reserved

Bit 9 always 1

Bit 8 High bit of the length word

Bit 6..0 Lower bits of length word

The length word specifies how many data words will follow this header (not including the header itself)

The header is followed by data sub-packets. Each device adds a sub-packet and modifies the header length word by the number of data words contained in its data packet (in normal data mode)

The first intermediate device that sees a LM-1 packet without a header adds the header in front.

If an LM-1 is involved, it will always be the first packet after the header.

LM-1 Sub-Packet format

Word	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 3	Bit 1	Bit 0
0	LM1	R	0	F2	F1	F0	0	AF7	0	AF6	AF5	AF4	AF3	AF2	AF1	AF0
1	0	0	L12	L11	L10	L9	L8	L7	0	L6	L5	L4	L3	L2	L1	L0
2	0	0	mb2	mb1	mb0	bv9	bv8	bv7	0	bv6	bv5	bv4	bv4	bv2	bv1	bv0
3	0	0	0	0	0	Ax19	Ax18	Ax17	0	Ax16	Ax15	Ax14	Ax13	Ax12	Ax11	Ax10
4	0	0	0	0	0	Ax29	Ax28	Ax27	0	Ax26	Ax25	Ax24	Ax23	Ax22	Ax21	Ax20
5	0	0	0	0	0	Ax39	Ax38	Ax37	0	Ax36	Ax35	Ax34	Ax33	Ax32	Ax31	Ax30
6	0	0	0	0	0	Ax49	Ax48	Ax47	0	Ax46	Ax45	Ax44	Ax43	Ax42	Ax41	Ax40
7	0	0	0	0	0	Ax59	Ax58	Ax57	0	Ax56	Ax55	Ax54	Ax53	Ax52	Ax51	Ax50

The first word of a packet contains function/status information.
The second word contains Lambda or status detail information.
The third word contains the battery voltage as seen by the LM-1.
The remaining words contain digitized auxiliary input data digitized to 10 bits.

2.1 Function/Status Word (Word 0)

Bit 15 always set

Bit 14 (R) is set if currently recording to Flash in LM-1.

Bit 13 Always 0

Bit 12..10 (Func2..0) are function/status bits indicating how interpret the next word (Lambda Word).

Func2..0

000	Lambda valid and Aux data valid, normal operation.
001	Lambda value contains O2 level in 1/10%
010	Free air Calib in progress, Lambda data not valid
011	Need Free air Calibration Request, Lambda data not valid
100	Warming up, Lambda value is temp in 1/10% of operating temp.
101	Heater Calibration, Lambda value contains calibration countdown.
110	Error code in Lambda value
111	Lambda Value is Flash level in 1/10%

Bit 8 contains high bit (bit 7) of AFR multiplier (AF7)

Bit 7 always 0

Bit 6..0 contain remaining 7 bits of AFR multiplier (AF6..AF0).

AFR multiplier is stoichiometric AFR value of current fuel setting in the LM-1 times 10. E.g. 147 for gasoline (14.7).
Air/Fuel Ratio = ((L12..L0) + 500)* (AF7..0) / 10000

2.2 Lambda Word (Word 1)

Lambda in 0.001 Lambda increments when F3..F0 is 0000, offset by 0.5 Lambda.

L = 0   -> 0.5 Lambda
L = 1022 -> 1.522 Lambda
L = 1023   Lambda = 1.523
L = 8191   Lambda = 8.691

2.3 Battery Voltage (Word 2)

Battery voltage digitized to 10 bit (bv9..bv0) and battery divider (mb2..mb0). Calculate battery voltage in Volt as
bv * 5 * mb / 1023.

2.4 Aux Input (Word 3..7)

Aux Inputs digitized to 10 bits. 0 = 0V, 1023 = 5V.

If RPM converter is used, Multiply WORD 3 value by 10 to get rpm.

LC-1 Sub-Packet format

This is a packet passed on by an LC-1 (Lambda cable). It consists of 2 Words.

Word	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 3	Bit 1	Bit 0
0	0	1	0	F2	F1	F0	1	AF7	0	AF6	AF5	AF4	AF3	AF2	AF1	AF0
1	0	0	L12	L11	L10	L9	L8	L7	0	L6	L5	L4	L3	L2	L1	L0

The first word of a packet contains function/status information.
The second word contains Lambda or status detail information.

2.1 Function/Status Word (Word 0)

Bit 15 of always 0

Bit 14 always 1

Bit 13 is always 0
Bit 12..10 (Func2..0) are function/status bits how interpret the next word (Lambda Word).

Func2..0

000	Lambda valid and Aux data valid, normal operation.
001	Lambda value contains O2 level in 1/10%
010	Free air Calib in progress, Lambda data not valid
011	Need Free air Calibration Request, Lambda data not valid
100	Warming up, Lambda value is temp in 1/10% of operating temp.
101	Heater Calibration, Lambda value contains calibration countdown.
110	Error code in Lambda value
111	reserved

Bit 9 always 1

Bit 8 contains high bit (bit 7) of AFR multiplier (AF7)

Bit 7 always 0

Bit 6..0 contain remaining 7 bits of AFR multiplier (AF6..AF0).

AFR multiplier is stochiometric AFR value of current fuel setting in the LC-1 times 10. E.g. 147 for gasoline (14.7).
Air/Fuel Ratio = ((L12..L0) + 500)* (AF7..0) / 10000

If an LM-1 is used, the AFR multiplier of the LM-1 packet should be applied to all further LC-1 packets independent of their AFR multiplier setting.
If no LM-1 but multiple LC-1's are used, the AFR multiplier of the first LC-1 packet be applied to all further LC-1 packets independent of their AFR multiplier setting.

2.2 Lambda Word (Word 1)

Lambda in 0.001 Lambda increments when F3..F0 is 0000, offset by 0.5 Lambda.

L = 0 -> 0.5 Lambda
L = 1022 -> 1.522 Lambda
L = 1023 Lambda = 1.523
L = 8191 Lambda = 8.691

Other data source sub-packets

Word	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 3	Bit 1	Bit 0
N	0	0	D12	D11	D10	D9	D8	D7	0	D6	D5	D3	D3	D2	D1	D0

Data devices like Aux-boxes add N channels of data of 10 to 13 bits each. Default is 10 bits.

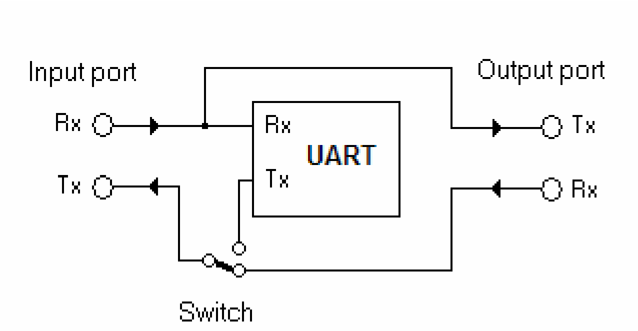
3. Serial Logging Physical Connections

Devices used with the ISP2 typically have 2 serial connections. One connection is called the input port, the other is called the output port. Physically the connections are implemented as 2.5 mm Stereo connectors. Only Tx, Rx and Gnd are used in the serial protocol.
The input and output designations are relative to the logging data stream. A device receives logging data on its input connection and sends data on its output connection.
Commands are received on the output connection and are transmitted on the input connection.
The devices are daisy-chained, so that the output port of one device is connected to the input port of the next device.
Devices that have only one serial port, but are data sources like the LM-1, must be used at the beginning of the chain. Data sources with 2 connections can be used in the middle or the beginning. Displays and data sink devices like recorders or laptops/PDAs are connected at the end of the chain.
Stand-alone data recorders are connected between data source and display devices. This way they can receive commands originating from the display devices.
The device at the beginning of the chain also acts as the timing source for the entire logging chain.
The device at the beginning of the chain sends a new data packet every 81.92 msec (8 MHz / 655360).
Each following device adds it's own data to the packet and modifies the header to reflect the new packet length. The resulting packet is then sent downstream to the next device. This can be done concurrently while receiving a packet, so the delay per device is only 2 byte times.

If the first device is an LM-1 running ISP1, the next device adds the header for ISP2 to the LM-1 packets, essentially converting the stream to ISP2.

Commands are send upstream in the chain. Commands typically consist of a single character command byte, followed by 0 or more command specific data bytes.

Display devices can use 1-1/2 serial ports. As display devices do not modify the logging data stream and typically aren't data sources, they can operate with a single UART. The following diagram shows how:



The switch (a electronic multiplexer in reality) is normally connected as shown. The display device switches this switch into the other state if it wants to send a command, but only for the time it takes to send the command.

To indicate which device is being programmed or is the first device in the chain, a special connector is installed in the input port. This connector just connects the Rx and Tx pins of the port together.

4. Serial Logging Commands

Normally each device in the chain ignores the commands sent and just passes them on to the next device. Exceptions are noted with each command.

The following commands are commonly understood by all devices:

4.1 Synchronize command

Command character: ‘H’
No additional data.
No response required.

Each device sends this character at boot-up out on it’s input port (upstream). It then listens immediately on its input port. If it sees this character, the device starts operation as data and timing source, sending a new data packet every 81.92 msec.
If a device receives this command from it’s output port, it will ignore it and NOT pass it on.

Display only devices do not need to send this command at boot time because they will never act as data sources.

4.2 Recording commands

4.2.1 Start Recording

Command character: ‘R’
No additional data.
No response required.

This command can only be received from the output port. If this command is received from the input port, it is ignored.

A device without logging memory will ignore this command and just pass it downstream if it is not the first device.

A device with logging memory will start recording log data and indicate this in the next header received or sent out. It will NOT pass this command downstream.

Note that a device with logging memory can only record data from it’s own data sources or upstream data devices.

4.2.2 End Recording

Command character: ‘r’
No additional data.
No response required.

This command can only be received from the output port. If this command is received from the input port, it is ignored.

A device without logging memory will ignore this command and just pass it downstream if it is not the first device.

A device with logging memory will stop recording log data and indicate this in the next header received or sent out. It will NOT pass this command upstream.

4.2.3 Erase Recording memory

Command character: ‘e’
No additional data.
No response required.

This command can only be received from the output port. If this command is received from the input port, it is ignored.

A device without logging memory will ignore this command and just pass it upstream if it is not the first device.

A device with logging memory will erase its log data. It will NOT pass this command upstream.

4.3 Calibration Command

Command character: ‘c’ (lower case c)
No additional data.
No response required.

This command is passed on upstream by all devices except the first device in the chain.
It initiates a free air calibration for all devices that have WB lambda sensors like LM-1 or LC-1s simultaneously. During the calibration these devices indicate that state in their data packets.
Devices without WB lambda sensors will ignore this command and just pass the command upstream.

4.4 Listen Command

Command character: 0xCC (Capital L with high bit set)
Followed by 8 characters of device name. If the device name is shorter, rest of 8 bytes is filled with 0.

All devices receiving this command on their output port pass this command on to the next device upstream, except for the the device that has that name. That device responds with a command response packet which contains the name.
If the device name is ‘LM-1’, the device that sits directly behind the LM-1 answers with the command response and then ignores all input data, but just passes any data on, downstream and upstream.

4.5 Unlisten Command

Command character: 0xEC (Lower case L with high bit set)
No Parameters

All devices seeing this command pass it on to the next device. All devices will resume normal operation. The device currently in listen mode, or the first device after an LM-1 if the LM-1 was put into listen, will respond with a command response containing the command.

4.6 Namelist Command and Response

Command character: 0xCE (Capital N with high bit set)
No additional data.

Any device receiving this command on the output port passes it on to the next device. If a device is the first in the chain, it responds with a command response that contains its name.
Any following device also adds its name to the command response.

If a device sits immediately behind an LM-1, doing Serial Protocol 1 to Serial Protocol 2 conversion, it responds with a command response containing first the name ‘LM-1’ and then its own name.

4.7 Typelist Command and Response

Command character: 0xF3 (Lower case s with high bit set)
No additional data.

Any device receiving this command on the output port passes it on to the next device. If a device is the first in the chain, it responds with a command response that contains the first 8 bytes of the device info data.
Any following device also adds its own first 8 bytes of device info data to the command response.

If a device sits immediately behind an LM-1, doing Serial Protocol 1 to Serial Protocol 2 conversion, it responds with a command response containing the following 16 bytes:
First the bytes:
0,0,’L’,’M’,’T’,’R’,0,0
And then the first 8 bytes of its own device info block.