LabSmith uDevice Electrical Interface

Overview

LabSmith has developed a family of devices (uDevices) comprising active devices, including syringe pumps and valves, and sensors for modular microfluidics and miniature lab automation applications. These devices are designed to facilitate low-time-resolution device-function sequencing via external control, e.g., via a computer that is issuing commands to and polling for data from the devices. Such commands reach the uDevices via a two-line I2C interface (SCL and SDA). This I2C interface conforms to the physical-layer standards set by the Philips Corporation for 100 kb/s data transfer.

Electrical interface

Figure 1 shows a diagram of the connector pinout on the uDevice side and the 3M part number (151220-7422-TB) used on the uDevice. Power for uDevices must be supplied externally, including 5V (up to 1 A) and 12 V (up to 2A). A typical uDevice draws far less than the rated power. E.g., a syringe pump draws a maximum of ~200 mA from the 12 V supply and < 50 mA from the 5 V supply. The 5 V supply should not droop below 4 V or rise above 5.5 V. The 12 V supply should not droop below 10 V or rise above 13.6 V. The common current return line or ground is labeled “GND.” For reduced analog sensing noise, a separate analog ground line (AGND) that draws little current is used. In the driving circuitry, this line should be connected to ground (0 V) in a way that current drawn on the GND lines do not couple offset voltages to the AGND line.

The electrical interface between uDevices is designed to support enhanced time resolution sequencing and controller-less sequencing via an array of eight shared digital signaling lines (D0—D7). These digital lines may be used for handshaking, signaling, or timing. In addition, a signal line “INT” has the ability to generate an interrupt for event-driven functions. A signal line “SYNC” can provide for high-accuracy time synchronization (better than ~1%) of all uDevices. If used by the uDevice firmware, this pin may be driven by a 32.768 kHz TTL oscillator. Current standard uDevice firmware versions do not use this synchronization line, however it is anticipated that future firmware versions will.

Four lines (D0, D1, D2, and D3) can be configured in firmware as analog sensing lines over the range 0 to 5 V. These lines are intended to be used in an application specific manner, such as to control the flow rate of a syringe pump uDevice via the analog output of a uDevice pressure sensor or external potentiometer, etc.

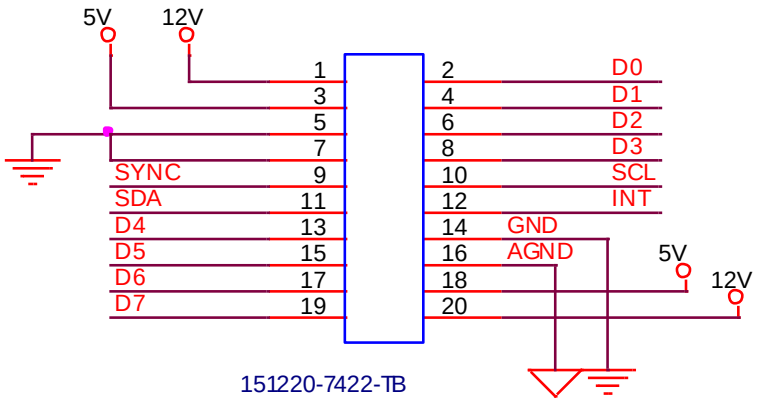


Figure 1 uDevice-side interface connector pinout.

The uDevices employ 18F-series PIC microcontrollers from Microchip. The uDevice firmware supports firmware updates over the I2C bus. The microcontrollers contain ~512 bytes of unused RAM, ~4k of unused instructions, and ~128 bytes of unused EEPROM space to support application-specific code.

Multi-byte integer format

Multiple-byte integers are always transmitted with the least-significant byte first.

I2C packet protocol

Each uDevice has a 7-bit address between 0x01 and 0x6F. These are saved in EEPROM and can be changed by commands issued over the I2C bus.

There are "Write" packets, in which a block of data or command is transmitted to a uDevice, and "Read" packets, in which a block of data is transmitted from a uDevice. A uDevice loads an internal buffer with the response to a "Write packet." The data in this buffer is transmitted from the uDevice during a "Read" packet. For this reason, a "Write packet" should always precede a "Read" packet. It is not necessary to issue a "Read" packet after every "Write" packet, however the response data from the previous "Write" will be overwritten and lost. It is good practice always to read the response to "Write" packets, since the response may indicate an error.

Write Packets

To issue a packet to a device, begin with an idle I2C bus (SDA high, SCL high, all devices unaddressed). You may ensure this state exists by executing a "Stop" or `P` sequence according to the I2C spec. Begin the packet with an I2C "Start" sequence (`S`). The first transmitted byte is the I2C address, comprising the device address bit shifted to the left with a zero inserted in the LSB position. In accordance with the I2C spec, this initiates a write to a slave, in this case the uDevice. Next the master transmits the number of bytes (`Cnt`) that follow in the packet. Next the master transmits a one-byte command (`Cmd`). If the

command calls for data, the master transmits the data, finally the master transmits a Chksum and ends the packet with a stop sequence (P):

Write packet sequence:

S / Addr<<1 | 0 <Ack>/ Cnt <Ack> / Cmd <Ack> /{optional data block $Data_1$/<Ack>…$Data_N$<Ack>}/Chksum<Ack>/ P

The <Ack>s are conditions where the uDevice holds the SDA line low during a 9th SCL pulse that follows the transmission of a byte. If a uDevice does not issue an <Ack> the packet should be aborted by issuing a P and retry-ed from the start. Under normal operation, the only time an <Ack> will not appear is when no device matches the address byte.

The uDevices employ clock stretching according to the I2C spec, in which they hold the SCL line low following an <Ack> until the received byte is processed. The master must wait for clock stretches following an <Ack> before attempting to transmit the next byte. The logic may look like this:

```
Release SCL (allow it to be pulled up by resistor)

While (SCL is low) wait

…
```

The checksum is calculated by subtracting all the previous bytes in the packet from zero and truncating the result to 8 bits, e.g., in the following function:

```
void FormatCommand(unsigned char Addr, unsigned char*& pPkt, const unsigned
char* pData, unsigned int dataLength)
{
	unsigned char Chksum = 0;
	Chksum -= *(pPkt++) = Addr<<1;
	Chksum -= *(pPkt++) = (BYTE)(dataLength + 1);//Cnt
	unsigned* end = pPkt+dataLength;
	while (pPkt < end)
		Chksum -= *(pPkt++) = *(pData++);

	*(pPkt++) = Chksum;
}
```

Read Packets

Begin with the bus idle. Master perform a start sequence, followed by transmitting the slave (uDevice) address bit shifted to the left with a '1' inserted into the LSB. Addressed device shall <Ack> on 9th clock pulse.

Next the master transmits SCL pulses and shifts the SDA state in on the rising edge of the clock pulse according to the I2C spec. The uDevice controls the SDA line for the first 8 clock pulses. The master device holds SDA low during the 9th clock pulse, in other words, the master generates the

acknowledgement <MAck>. The first byte is a byte-sized status token (Tok) having one of two valid values: 0xAA means command executed; 0xEE means command not executed. A command not executed usually indicates a checksum or other command packet error.

The master continues by a repeated process of transmitting SCL pulses and shifting bits in from the slave for 8 pulses and producing a <MAck> on the following pulse to read the balance of the packet. The next byte is the count (RCnt) of bytes that follow, including the checksum. If RCnt is zero, then the packet contains no checksum or data, only the status symbol (0xAA or 0xEE) and the packet is complete. If RCnt is greater than zero, the master should repeat shifting RCnt bytes. The last byte is a checksum such that the sum of the received bytes following (not including) the status token is zero. The master terminates the packet by issuing a stop sequence (P).

Read packet sequence:

S / Addr<<1 | 1 <Ack>/ Tok <MAck> / RCnt <MAck> /{data block $Data_1$/<MAck>…$Data_N$<MAck>}/Chksum<MAck>/ P

If RCnt > 0, then N, the number of response data bytes is RCnt – 1.

Commands

As of the current firmware version, the commands are

Command	Cmd value	Target	Args	Returned data (blank means ack or nak only)
CB_GETDATABLOCK	0x00	uDevice	None	Device dependent
CB_PING	0x01	uDevice	None	
CB_SETDEVADDR	0x02	uDevice	1-byte new address	
CB_GETVERSION	0x03	uDevice	None	2-byte firmware version 2-byte bootloader version 2-byte hardware version
RESERVED	0x04	SPS01		
CB_RESET	0x05	uDevice	None	
CB_STOP	0x06	uDevice	None	
CS_SETPERIOD	0x07	SPS01	3-byte period	
CV_SETVALVES	0x07	4VM01	Packed target position data. See format below	
CP_SETCHANNEL	0x07	4PM01	Channel, regulation mode and target. See format below	
CS_MOVETOPOS	0x08	SPS01	2-byte position	
CS_GETMODE	0x09	SPS01	None	
CB_SETNAME	0x0A	uDevice	16 char uDevice “name”	

CB_GETNAME	0x0B	uDevice	None	16 char uDevice "name"
RESERVED	0x0C	SPS01		
CS_SETPOWER	0x0D	SPS01	1-byte power setting between 0x60 and 0xC0	
RESERVED	0x0E	uDevice		
RESERVED	0x0F	SPS01		
RESERVED	0x10	SPS01		
RESERVED	0x11	SPS01		
CB_SETCAL	0x12	uDevice	Device dependent	
CB_AUTOCAL	0x13	uDevice	None	
CB_GETCAL	0x14	uDevice	None	Device dependent
CS_SETDIAMETER	0x15	SPS01	2-byte unsigned integer	
CS_GETDIAMETER	0x16	SPS01	None	2-byte unsigned integer
RESERVED	0x17	SPS01		
CS_GETFACTORYCAL	0x18	SPS01		2-byte unsigned integer
CB_GETSERIALNUMBER	0x19	uDevice		2-byte "length" followed by "length" bytes
CB_GETSTATUS	0x1A	uDevice	None	Device dependent real-time status block. See formats below.
CS_MOVEPERCHANNEL	0x1C	SPS01	One byte: with chA: 0x1 with chB: 0x2 with chC: 0x3 with chD: 0x4 opp. chA: 0x11 opp. chB: 0x12 opp. chC: 0x13 opp. chD: 0x14 off/unchg: 0x00	
CV_MOVEPERCHANNEL	0x1C	4VM01, 4VM02	Two bytes: Set3<<4 | Set4 Set1<<4 | Set2 Where SetX is the setting for valve X: with chA: 0x8 with chB: 0x9 with chC: 0xA with chD: 0xB opp. chA: 0xC opp. chB: 0xD opp. chC: 0xE opp. chD: 0xF unchanged: 0	
CB_GETRAMBLOCK	0x1E	uDevice	1-byte RAM address 1-byte block count (16-bytes maximum)	Requested block of RAM

CB_SETRAMBLOCK	0x1F	uDevice	1-byte RAM address 1-byte block "cnt" (<=16 bytes) "cnt" bytes of data	
RESERVED	0xB5	uDevice		

Data block for SPS01 "Set Period" command CS_SETPERIOD:

The data block for the SetPeriod command is a 24-bit number proportional to the time delay between microsteps. The example below shows how to convert specify a volumetric flow rate.

```
#define CS_SETPERIOD 0x07
#define CS_ACTUATION_DIST 0.02 //mm/step
#define CS_CLOCK_FREQ     41943040/16*44.59 //counts/second

4 ul syringe: m_dDiameter = 0.729;//mm
8 ul syringe: m_dDiameter = 1.031;//mm
20 ul syringe: m_dDiameter = 1.458;//mm
40 ul syringe: m_dDiameter = 2.304;//mm
80 ul syringe: m_dDiameter = 3.256;//mm


bool CSyringe::CmdSetFlowRate(double dRate) //dRate is flow rate in ul/min
{
	if (m_dDiameter <= 0.0) return false;
	if (!m_pInterface) return false;

	const double cSpeed = (CS_ACTUATION_DIST * CS_CLOCK_FREQ * 0.04908738521234);
	int nPeriod = (int)(cSpeed * m_dDiameter * m_dDiameter / dRate + 0.5);

	int maxper = 0xFFFFFF;

	if (nPeriod < CS_MIN_PERIOD ) nPeriod = CS_MIN_PERIOD;
	else if ( nPeriod > maxper) nPeriod = maxper ;

	BYTE command[12];
	BYTE* pc = &command[0];
	*(pc++) = BYTE(CS_SETPERIOD);
	*(pc++) = nPeriod&0xFF;
	*(pc++) = (nPeriod>>8)&0xFF;
	*(pc++) = (nPeriod>>16)&0xFF;

	CCommand* pCommand = new CCommand(m_nAddress,command, 4, "Setting speed...");
	bool retval = m_pInterface->DoCommand(pCommand);
	delete pCommand;

	return retval;
}
```

Data block for 4VM01 and 4VM02 "Set Valves" command CV_SETVALVES:

Bit7 (MSB) and Bit6 = V1 setting
Bit5 and Bit4 = V2 setting
Bit3 and Bit2 = V3 setting
Bit1 and Bit0 (LSB) = V4 setting

V<X> setting is

0	No change
1	Move to position A
2	Move to closed position
3	Move to position B

Thus the binary code for the argument to move valve 1 to the A position and leave the other channels where they are 01000000 (0x40).

Data Block for 4VM01 and 4VM02 "Move Per Channel" command CV_MOVEPERCHANNEL:

Arguments are two bytes.

Byte 1 Bit7-4 is V3 configuration, Bit3-0 is V4 configuration
Byte 2 Bit 7-4 is V1 configuration, Bit 3-0 is V2 configuration.

VX configuration is

0	No change
1–7	Reserved
8	Move with Channel A
9	Move with Channel B
10	Move with Channel C
11	Move with Channel D
12	Move opposite Channel A
13	Move opposite Channel B
14	Move opposite Channel C
15	Move opposite Channel D

Data block for the 4PM01 "Set Channel" command CP_SETCHANNEL:

The command data block comprises:

1 byte: channel: 0 = channel 1, 1 = channel 2, 2 = channel 3, 3 = channel 4

1 byte: one of the following regulation modes:

```
PM_REG_OFF          0
PM_REG_VOLTAGE      1
```

```
PM_REG_CURRENT      2
PM_REG_POWER        3
PM_REG_PER_CHA      4
PM_REG_PER_CHB      5
PM_REG_PER_CHC      6
PM_REG_PER_CHD      7
```

```
2 bytes: a 16-bit target value (LSB first)
```

This value depends on the regulation mode. For example, to regulate to a voltage, set the regulation mode to PM_REG_VOLTAGE and convert your target voltage to device units and send the 16-bit integer result. To regulate per a channel, set the regulation mode to PM_REG_PER_CH<X> , where <X> is A, B, C, or D and set the initial voltage slew-rate sensitivity (V/s) in the target value. See functions below for how to convert between real and device units.

```
int C4PM::ConvertVoltsPerSecondToDeviceUnits(double dVps) { return (int)(dVps*(32768 *
256) / (5.*460.0) + 0.5); }
int C4PM::ConvertAmpsToDeviceUnits(double dI) { return (int)(dI / 4.0 * 0x6000 + 0.5); }
int C4PM::ConvertResistanceToDeviceUnits(double dR) { return (int)(dR * 0x10000 + 0.5); }
int C4PM::ConvertWattsToDeviceUnits(double dP) { return (int)(dP / 20.0 * 0x6000 + 0.5);}
```

Returned data block format for "Get Calibration" command CB_GETCALIBRATION:

This format depends on the device type.

SPS01:

Currently, only the SPS01 sends a response that is useful for calculations. The response block comprises two two-byte numbers: first the position reading when the plunger is fully out (0 volume in the syringe) and second the position reading when the plunger is full in (syringe full). See GetStatus, SPS01 to see how to use and interpret these numbers

Returned data block format for "Get Status" command CB_GETSTATUS:

The data block returned byte the "GetStatus" command depends on uDevice type.

SPS01:

```
The data block comprises a 1-byte motion status flag, a 2-byte (16-bit)
measured position, and a 2-byte motor micropulse count.

The motion status flag is an an or-ed combination of:

      SPS_MOVING_IN           0x01
      SPS_MOVING_OUT          0x02
      SPS_RUNNING             0x04
      SPS_STALLED             0x08
```

```
SPS_FULLSPEED           0x10
SPS_STARTING_MOTION     0x40
```

To convert the 16 bit position value (pos) to volume of liquid in the syringe:

```
double CSyringe::GetVolumeFromPos(int pos)const
{
	const double coeff = 0.7853975/GetEncoderRange();
	return coeff * m_dDiameter*m_dDiameter * m_dPositionScale * (pos-m_nOutStop);

//m_nOutStop is the first 16-bit number returned by the SPS01 in response to the
//GetCalibration() command, corresponding to the position measurement when the plunger
//is at the end of the syringe (0 volume)
}

const double CSyringe::m_dPositionScale = 13.0; //mm of stroke length

int CSyringe::GetEncoderRange()const { return 65536; }
```

The micropulse count may be less useful than the position reading for inferring the volume, because it does not account for backlash, but it has no measurement noise.

4AM01:

You retrieve the data from the 4AM via sending the CM_GETSTATUS command. The 4AM returns one status byte followed by four sets of 3-byte integers that contain the readings, followed by four bytes that describe the regulation status of each sensor. The 4AM can sample a variety of different sensors, each having its own scale factor between 4AM-reported readings and standard units. Here is sample code for polling the status and interpreting the answer:

```
bool C4AM::CmdGetStatus()
{
	if (!IsOnline()) return false;
	//this is an efficient state poll.
	BYTE   command[12];
	BYTE   *pc = &command[0];

	*pc = BYTE(CB_GETSTATUS);

	CCommand* pCommand = m_pInterface->LockCommand();
	pCommand->Create(m_nAddress, command, 1, _T("Reading 4AM Status..."));
	pCommand->SetTimeout(500);
	bool retval = m_pInterface->DoCommand();

	if (retval)
	{
		unsigned char* pdata = &pCommand->m_pResponse[2];
		m_Status = *(pdata++);
		m_bIdle = ((m_Status&0x80) == 0);
		if (m_pS1)
```

```
                m_pS1->SetRawStatus(pdata);
            pdata += 3;
            if (m_pS2)
                m_pS2->SetRawStatus(pdata);
            pdata += 3;
            if (m_pS3)
                m_pS3->SetRawStatus(pdata);
            pdata += 3;
            if (m_pS4)
                m_pS4->SetRawStatus(pdata);
            pdata += 3;
            bool bDone = true;
            //next come 4 bytes of reg status
            BYTE bStatus = *(pdata++);
            if (m_pS1)
            {
                m_pS1->SetRegStatus(bStatus);
            }
            bStatus = *(pdata++);
            if (m_pS2)
            {
                m_pS2->SetRegStatus(bStatus);
            }
            bStatus = *(pdata++);
            if (m_pS3)
            {
                m_pS3->SetRegStatus(bStatus);
            }
            bStatus = *(pdata++);
            if (m_pS4)
            {
                m_pS4->SetRegStatus(bStatus);
            }
        }

        m_pInterface->UnlockCommand();
        return retval;
}

void CSensor::SetRegStatus(BYTE bStatus)
{
        ...

}

The regulation status byte (bStatus) comprises:
        REG_STATUS_INRANGE          0x1    //reading is currently within specified range
        REG_STATUS_OVERTARGET       0x2    //reading is currently over the target value
        REG_STATUS_REACHEDRANGE     0x8    //reading has passed into specified range
                    //since the last change in regulation setting. Cleared by sending
                    // a new regulation setting command.


void CSensor::SetRawStatus(unsigned char* pdata)
```

```
{
	int i = 0;
	i |= *(pdata++);
	i |= *(pdata++)<<8;
	char t = *(pdata++);
	i |= t<<16;
	if (t &0x80)//convert from 24-bit signed int to 32-bit signed int
		i |= 0xFF000000;
	double dStdValue = ConvertDeviceUnitsToStdReading(i);
	double dStdValue = p*m_dGainScale;
	//dStdValue is in kPa.  From here convert to desired units

}

// For the UTS temperature sensor:
virtual double CUTS::ConvertDeviceUnitsToStdReading(int r)const
{
	double rat = double(r);
	rat *= s_iscale;
	rat *= (GetTemperatureMax_C()-GetTemperatureMin_C());
// e.g., = (500.0 – (-50.0)) C
	rat += GetTemperatureMin_C();// e.g., +=(-50.0) C
	return rat;
}

// For the UPS pressure sensor:
virtual double ConvertDeviceUnitsToStdReading(int r)const
{
	double rat = double(r);
	rat *= s_iscale;
	rat *= GetPressureRange_kPa();//returns full-scale pressure in kPa,
	//     e.g., 250kPa sensor returns 250.0;

	return rat;
}

// etc.
```

4VM01/4VM02:

Two byte packed status, 4 bits per valve. Lower nibble of first data byte is valve 4 status, upper nibble is valve 3 status. Lower nibble of second data byte is valve 2 status, upper nibble is valve 1 status. The status is:

```
4VM_STATE_UNKNOWN    0 //   e.g. in motion
4VM_STATE_A          1
4VM_STATE_CLOSED     2
4VM_STATE_B          3
```

4PM01:

4 sets of 7-byte status values. First 7-byte block is for channel 1, second is for channel 2, etc. Each block comprises:

1 byte regulation status:

2 byte power measurement

2 byte current measurement

2 byte voltage measurement.

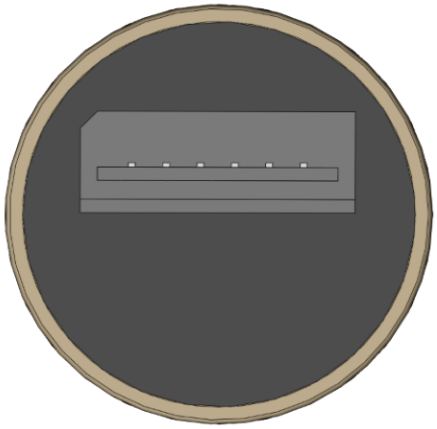
Here is sample code to convert the measurements to W/A/V units:

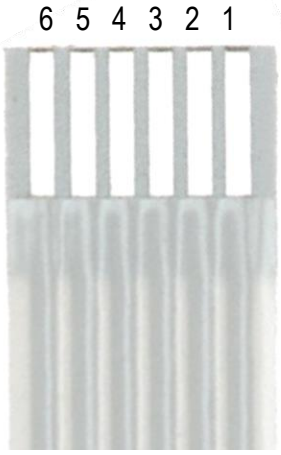
```
void C4PMChDat::SetStatus(const BYTE*& ps)
{
	m_RegStatus = *(ps++);
	int i = *(ps++);
	i |= ((char)(*ps++)) << 8;
	m_dMeasP = C4PM::ConvertDeviceUnitsToWatts(i);//
	i = *(ps++);
	i |= ((char)(*ps++)) << 8;
	m_dMeasI = C4PM::ConvertDeviceUnitsToAmps(i);//
	i = *(ps++);
	i |= ((char)(*ps++)) << 8;
	m_dMeasV = C4PM::ConvertDeviceUnitsToVolts(i);//
}
double C4PM::ConvertDeviceUnitsToWatts(int i) { return (20.0*i) / 0x6000; }
double C4PM::ConvertDeviceUnitsToAmps(int i) { return (4.0*i) / 0x6000; }
double C4PM::ConvertDeviceUnitsToVolts(int i) { return (5.*i) / 0x6000; }
```

The regulation status byte (m_RegStatus) comprises:

```
	REG_STATUS_INRANGE		0x1	//reading is currently within specified range
	REG_STATUS_OVERTARGET		0x2	//reading is currently over the target value
	REG_STATUS_REACHEDRANGE		0x8	//reading has passed into specified range
				//since the last change in regulation setting. Cleared by sending
				// a new regulation setting command.
```

uPS Pressure Sensor Pinout





Pin	uPS Pressure Sensor
1	Digital Data (reserved)
2	Sensor PWR (3.3-5 V, low noise recommended)
3	Pressure out positive (positive leg of sensing bridge)
4	Pressure out negative (negative leg of sensing bridge)
5	Thermistor sense (ground referenced temperature-indicating, nonlinear signal)
6	Analog GND

The Pressure out negative and positive lie approximately at half the Sensor PWR voltage. The negative voltage decreases with increasing pressure. The positive voltage increases with increasing pressure. We recommend using differential amplification and A/D conversion. Temperature compensation is imperative where accuracy is important.

Additional Information

Could you give me more information on the serial commands (RS-232) to interface to the EIB100/EIB200?

The only difference in the packet that goes over the serial and the i2c is the serial package starts with a "%" sign and you don't need to poll the devices for a response. The EIB100 automatically read the device and forwards the response back over the serial port.

I2C Example:

S / Addr<<1 | 1 <Ack>/ Tok <MAck> / RCnt <MAck> /{data block Data1/<MAck>.DataN<MAck>}/Chksum<MAck>/ P

RS232 Example (computer to device):

'%' / Addr<<1 | 1 / Tok / RCnt /{data block Data1/.DataN}/Chksum

RS232 Example Response:

0xAA / 0x00

I'm not getting the pic to relay my commands. What serial port configuration is correct? I'm using 57600, 8, n, 1, no flow control. COM light on the EIB flashes, but I get no corresponding sda/scl toggles going out to the pump when I send a "%".

Make sure the packet is sent as a single block (i.e., use one serial port block write to send a packet). There is a timeout in the packet receive routine in the EIB100 to help prevent hangs and permanent alignment errors. You have some inter-byte time, but you will not be able to step through byte writes will debugging, etc.

The problem may be that you included the token '%' in your calculation of the checksum. You should be receiving a Nak 0xEE 0x00 back from the EIB over the com port because the checksum is bad.

The correct checksum should be 256 - 2 (destination = device 1) - 26 (command is GETSTATUS) = 228.

I hope this helps. Internally, here is the routine we use to format our outgoing packets. The calling function sets up the data payload at pdata and the length of the data payload in length and provides a buffer pd for the outgoing data (in this implementation, the function

advances the buffer, but that's not important. What's important is the calculation of the checksum etc.

```
void CCommand::FormatCommand(BYTE dest, BYTE*& pd, int& i, const BYTE*
pData, DWORD length) {
      BYTE checksum = 0;
      BYTE* pStart = pd;

      *(pd++) = '%'; //first byte is the header token.  Note that the
header is not included in the checksum.
                              //this is only used as a
packet-alignment indication for the EIB and is stripped from the
                              //packet before the EIB forwards it over
the I2C bus.
      checksum -= *(pd++) = dest<<1; //next byte is the destination
address * 2
      checksum -= *(pd++) = (BYTE)(length + 1); //next byte is the
length of bytes to follow (+1 for checksum)
      BYTE* end = pd+length;
      while (pd < end)
//memcpy with checksum update
            checksum -= *(pd++) = *(pData++);

      *(pd++) = checksum;
//now add the checksum.
      i = pd - pStart;  //count of bytes in formatted packet
      //Now you should write the packet of i bytes starting at pStart
to the serial port.
}
```

How would I specify/query the flow rate and position for the SPS01?

The conversions from volume and flow-rate to counts are usually done in the SDK. I included a few critical functions below. Note that the implementation details are subject to change. Note that the CCommand(...) constructor calls the FormatCommand function I sent you previously. The second arg is the data payload and the third arg is the length of the data payload.

```
#define USYR_ENCODER_SIZE 65536
const double CSyringe::m_dPositionScale = 13.0; //mm of fictitious full
stroke.
            //can get alternatively read this from SPS01
#define CS_MAX_PERIOD         655350//Clock cycles between microsteps
#define CS_MIN_PERIOD         108
#define CS_CLOCK_FREQ         41943040/32*44.59 //counts/second

bool CSyringe::CmdMoveToVolume(double dVolume)//dVolume is in ul {
      if (m_dDiameter == 0.0) return false;

      const double coeff = 1.27324062 * USYR_ENCODER_SIZE;
      int nPos = (int)(coeff * dVolume
/(m_dDiameter*m_dDiameter*m_dPositionScale) + 0.5);
      return CmdMoveToPosition ( nPos + m_nOutStop ); }
```

```
double CSyringe::GetVolumeFromPos(int pos)const {
	const double coeff = 0.7853975/USYR_ENCODER_SIZE;
	return coeff * m_dDiameter*m_dDiameter * m_dPositionScale * (pos-
m_nOutStop); }

#define CB_GETCAL		0x14
bool CSyringe::CmdGetCal()//need to call this to get m_nOutStop.
Usually only once during // initialization {
	BYTE  command[12] ;
	BYTE  *pc = &command[0] ;

	if(!m_pInterface) return false;

	*(pc++) = BYTE( CB_GETCAL ) ;

	CCommand* pCommand = new CCommand( m_nAddress, command, 1,
"Reading Syringe End Points..." ) ;
	bool retval = m_pInterface->DoCommand( pCommand ) ;

	if( retval )
	{
		short int nOutStop,nInStop;
		BYTE* pd = &pCommand->m_pResponse[2] ;
		nOutStop = *(pd++) ;
		nOutStop |= *(pd++)<<8 ;
		nInStop = *(pd++) ;
		nInStop |= *(pd++)<<8 ;

		m_nInStop = nInStop; //copy over atomically to prevent
multithreading issues
		m_nOutStop = nOutStop;

	}
	else
	{
		//don't change the previous cal values
	}

	delete( pCommand ) ;

	return retval;
}

#define CS_SETPERIOD 0x07
bool CSyringe::CmdSetSpeed(double dSpeed) //dSpeed is flow rate in
ul/min {
	if (m_dDiameter <= 0.0) return false;
	if (!m_pInterface) return false;


	const double cSpeed = (CS_ACTUATION_DIST * CS_CLOCK_FREQ *
0.04908738521234);
	int nPeriod = (int)(cSpeed * m_dDiameter * m_dDiameter / dSpeed
+ 0.5);

	int maxper = 0xFFFFFF;
```

```
        if (nPeriod < CS_MIN_PERIOD ) nPeriod = CS_MIN_PERIOD;
        else if ( nPeriod > maxper) nPeriod = maxper ;

        BYTE command[12];
        BYTE* pc = &command[0];
        *(pc++) = BYTE(CS_SETPERIOD);
        *(pc++) = nPeriod&0xFF;
        *(pc++) = (nPeriod>>8)&0xFF;
        *(pc++) = (nPeriod>>16)&0xFF;

        CCommand* pCommand = new CCommand(m_nAddress,command, 4, "Setting
    speed...");
        bool retval = m_pInterface->DoCommand(pCommand);
        delete pCommand;

        return retval;
    }
```

What is CS_ACTUATION_DIST?

```
    #define CS_ACTUATION_DIST     0.02 //mm/step
```

What are the standard syringe sizes for the SPS01?

```
        m_dStdDia[0] = 0.729;//mm
        m_dStdVol[0] = 4.0;
        m_csName[0]= _T("4 ul");

        m_dStdDia[1] = 1.031;//mm
        m_dStdVol[1] = 8.0;
        m_csName[1] = _T("8 ul");

        m_dStdDia[2] = 1.458;//mm
        m_dStdVol[2] = 20.0;
        m_csName[2] = _T("20 ul");

        m_dStdDia[3] = 2.304;//mm
        m_dStdVol[3] = 40.0;
        m_csName[3] = _T("40 ul");

        m_dStdDia[4] = 3.256;//mm
        m_dStdVol[4] = 80.0;
        m_csName[4] = _T("80 ul");
```

How do I read/interpret sensor measurements from the 4AM?

You retrieve the data from the 4AM via sending the CM_GETSTATUS command. The 4AM returns one status byte followed by four sets of 3-byte integers that contain the readings, followed by four bytes that describe the regulation

status of each sensor. The 4AM can sample a variety of different sensors, each having its own scale factor between 4AM-reported readings and standard units. Here is sample code for polling the status and interpreting the answer:

```
bool C4AM::CmdGetStatus()
{
	if (!IsOnline()) return false;
	//this is an efficient state poll.
	BYTE  command[12];
	BYTE  *pc = &command[0];

	*pc = BYTE(CB_GETSTATUS);

	CCommand* pCommand = m_pInterface->LockCommand();
	pCommand->Create(m_nAddress, command, 1, _T("Reading 4AM Status..."));
	pCommand->SetTimeout(500);
	bool retval = m_pInterface->DoCommand();

	if (retval)
	{
		unsigned char* pdata = &pCommand->m_pResponse[2];
		m_Status = *(pdata++);
		m_bIdle = ((m_Status&0x80) == 0);
		if (m_pS1)
			m_pS1->SetRawStatus(pdata);
		pdata += 3;
		if (m_pS2)
			m_pS2->SetRawStatus(pdata);
		pdata += 3;
		if (m_pS3)
			m_pS3->SetRawStatus(pdata);
		pdata += 3;
		if (m_pS4)
			m_pS4->SetRawStatus(pdata);
		pdata += 3;


		bool bDone = true;
		//next come 4 bytes of reg status
		BYTE bStatus = *(pdata++);
		if (m_pS1)
		{
			m_pS1->SetRegStatus(bStatus);
		}

		bStatus = *(pdata++);
		if (m_pS2)
		{
			m_pS2->SetRegStatus(bStatus);
		}

		bStatus = *(pdata++);
		if (m_pS3)
		{
			m_pS3->SetRegStatus(bStatus);
```

```
            }

            bStatus = *(pdata++);
            if (m_pS4)
            {
                  m_pS4->SetRegStatus(bStatus);
            }
      }

      m_pInterface->UnlockCommand();

      return retval;
}

void CSensor::SetRawStatus(unsigned char* pdata)
{
      int i = 0;
      i |= *(pdata++);
      i |= *(pdata++)<<8;
      char t = *(pdata++);
      i |= t<<16;
      if (t &0x80)//convert from 24-bit signed int to 32-bit signed int
            i |= 0xFF000000;
      double dStdValue = ConvertDeviceUnitsToStdReading(i);
      double dStdValue = p*m_dGainScale;
      //dStdValue is in kPa.  From here convert to desired units

}

double CSensor::ConvertDeviceUnitsToStdReading(int r)const
{

      const double igscale = 1.0/(256.0*256.0*128.0);

      double rat = double(r);
      rat *= igscale;
      rat *= GetPressureRange_kPa();//returns full-scale pressure in kPa,
      //    e.g., 250kPa sensor returns 250.0;
      return rat;
}
```