STM-1 Manual
Rev 1.3
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(for STM firmware version ACF2.0/ min HW rev B)

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1. Hardware

1.1 Specifications:

Sensor Inputs: 1
Sensor Frequency: 1.95MHZ - 10.05MHZ
Frequency Accuracy (Absolute): <2ppm
Frequency Stability (Relative Accuracy) Nominal: .03HZ
Measurement Period: 100ms (Ten measurements per second, regardless of frequency).

Thickness Resolution: .02 A

Rate (Raw) Resolution: .02 A/sec

Communication Electrical: RS232 or RS485 (dip-switch selectable), 9600 or 115200 BAUD (dip-switch selectable)
Communication Protocol: SMDP (Sycon Multi Drop Protocol)

1.2 Connections:

Electrical Connections at board (DB9 female connector):

Pin#	Description
1	Analog output ground. NOT ISOLATED.
2	RS232 TxD/RS485 inverting (-)
3	RS232 RxD/RS485 non-inverting (+)
4	No connection
5	Communication signal gnd.
6	Analog output, 0 to +10V, 12 bits, nominal. 30 mA current source.
7	No connection
8	No connection
9	Alternate power (+5V) input if J2 is not used, 500 mA supply required.

RS232 PC to STM1 communication cable:

DB9 male pin# (plug into STM1)	Connect to	DB9 FEMALE PIN# (plug into PC)
2 (STM1 TxD)		2 (PC RxD)
3 (STM1 RxD)		3 (PC TxD)
5 (STM1 GND)		5 (PC GND)

1.3 Dipswitch Settings:

On, or 1, is when the dipswitch is in the up position (top position when switch is viewed with switch labeled 1 on the left and switch 8 on the right). Off, or 0, is when the dipswitch is in the down position.

Switch number	Controls	Description
1	Nothing	Unused
2	Endian Selection (see note 1.1)	0 = little endian (LS first) 1 = big endian (MS first), Default
3	Communication Checksum (See note1.2)	0 = No checksum 1 = Checksum required, Default
4	Baud Rate	0 = 9600 Baud 1 = 115,200 Baud, Default

5-8	Communication Module Address and 232/485 selection	SW5…SW8 ASCII/hex/dec 0000 = RS232, address @/40/64, Default 0001 = RS485, address A/41/65 0010 = RS485, address B/42/66 0011 = RS485, address C/43/67 0100 = RS485, address D/44/68 0101 = RS485, address E/45/69 0110 = RS485, address F/46/70 0111 = RS485, address G/47/71 1000 = RS485, address H/48/72 1001 = RS485, address I/49/73 1010 = RS485, address J/4A/74 1011 = RS485, address K/4B/75 1100 = RS485, address L/4C/76 1101 = RS485, address M/4D/77 1110 = RS485, address N/4E/78 1111 = RS485, address O/4F/79

Note 1.1: Only meaningful if raw data query/updates are performed. ASCII mode query/updates are not affected by endian selection.

Note 1.2: See protocol specification for checksum/non checksum mode specifics.

1.4 Status/Communication LEDs

The STM1 board has two LEDs, status and communication. The status LED is closest to the circuit board, or on the bottom if viewed facing the STM1 unit with the power connection on the left and the sensor connector on the right. They work as follows:

Status LED: On power up, the STM1 blinks a 24-bit status word. A '1' is signaled with two quick blinks, and a '0' is signaled with a single blink. There is a one second delay in between bit codes, where the LED is off. The first eight bits are the dip switch settings, starting with switch 1. Then the next 16 bits are the firmware checksum, starting with D15 (most significant bit). After the 24 bits are communicated, there is a 4 second pause (where the LED is off) and then the status led goes into normal operation.

Status led normal operation (listed from highest priority to lowest priority):

1) Fast blink: In this mode, the led blinks very fast, too fast to count the blinks per second. This indicates that the measured frequency of the crystal (sensor head) is not within programmed range. This is the crystal bad indication.

2) Slow blink: In this mode, the led blinks once per second. This indicates that the measured frequency of the crystal (sensor head) is within programmed range, but the STM1 has not had it's power up reset flag acknowledged (a reset of the STM1 occurred and the host computer did not send the "reset power fail flag" command). See Sycon Multi Drop Protocol manual for details of this command.

3) Solid: In this mode, the LED does not blink, but stays on solid. This indicates that the measured frequency of the crystal (sensor head) is within programmed range and the host computer has acknowledged the power fail (reset) condition.

Communication LED: This LED blinks once on power up (as a lamp test). After that, the led lights up for one second every time a valid communication packet (correct address, checksum, etc) is received by the STM1 from the host computer. When this LED blinks, it means the STM1 has received a packet for it, and has parsed the packet and the packet is valid in structure. The STM1 will respond with a response packet in this case.

2. Communications

2.1 Protocol Structure:

The protocol used to interface with the STM-1 is a byte-packet protocol. A packet begins with ASCII STX (hex 02 or decimal 2) and ends with '\r' (carriage return). Each field in angle brackets (<>) is a byte, and is not optional. Fields in regular brackets ([]) are optional. Ellipses (…) mean one or more of the previous. The structure of the packet is below:

<STX><ADDR><CMD_RSP>[<DATA>…]<CKSUM1><CKSUM2><CR>

STX: Start of text character (hex 02). Multiple STX characters in a row are allowed.
Similarly, any data between STX characters is ignored. A single STX character syncs the receiver up to receive a new message, purging any data collected since the last STX character or carriage return received.

ADDR: Address field. This is a one-byte field. Valid ranges of a valid address are 10 hex to FE hex (16 to 254 decimal). Addresses less than 10 hex are not allowed as they may be mistaken for framing characters. An address of FF hex is reserved as it is used as an extension (to indicate another byte of address information follows) for products that have an address range higher than an address of FE hex. This is for future expansion and is not used at this time.

CMD_RSP: Command/Response field. When sending a packet to the STM-1, RSPF bit is zero and the RSP field (3 bits) is zero. When a packet is coming from the STM-1, CMD bits are the same as in the message that it was sent, but the RSP field will be non-zero (indicating actual unit response status). This allows the direction to be positively indicated, as well as the command preserved on the return reply.

Format of the CMD_RSP byte:

D7	D6	D5	D4	D3	D2	D1	D0
CMD3	CMD2	CMD1	CMD0	RSPF	RSP2	RSP1	RSP0

CMD: Command. These are the commands that can be issued to the STM-1.

CMD Dec/Hex	Mnemonic	Meaning
0/0	-----------	Cannot be used, byte could be mistaken for framing char.
1-2/1-2	Reserved	Reserved for future use in protocol stack.
3/3	Prod_id	Sycon product id, returned as decimal string.
4/4	Version	Request slave to return software version string.
5/5	Reset	Request slave to reset.
6/6	AckPF	Request slave to clear RSPF bit/flag.
7/7	PROTV	Request slave to return protocol stack version. Decimal string.
8/8	RndRead	Random query of database, data in raw format.
9/9	RndWrit	Random update of database, data in raw format
10/A	Lock	Lock database. Multiple locks not harmful but not nested
11/B	Unlock	Unlock database. Multiple unlocks not harmful but not nested.
12/C	AscRd	Random query of database, data in ASCII format.
13/D	AscWr	Update of database, data in ASCII format.

RSP: Once the packet is sent, the STM-1 receives and acknowledges the packet, and sends its response. In the CMD_RSP byte, the CMD bits are unchanged from the master, but the RSP bits are filled in according to the status of the slave. See table below.

RSP	Mnemonic	Meaning
0	------------	Response code must be non-zero, to indicate direction.
1	OK	Command understood and executed.
2	Err_inv_cmd	Illegal command (CMD code not valid).
3	Err_syntax	Syntax error. (Too many bytes in data field, not enough bytes, etc).
4	Err_range	Data range error.
5	Err_inhibited	Inhibited
6	Err_obso	Obsolete command. No action taken, but not really an error.
7		Reserved for future protocol stack use

Because there are multiple errors possible, but limited RSP codes, the following table describes the RSP code returned for database transaction errors:

Database transaction: Address to read/write is invalid.	Err_syntax
Database transaction: Attempt to write a read only record.	Err_syntax
Database Transaction: Attempt to write to the configuration parameters group while a commit or rollback operation is pending, or an attempt to query configuration parameters group while a rollback was pending.	Err_inhibited
Database transaction: An attempt to write to a semaphore register while flags still pending.	Err_inhibited
Database transaction: Number of bytes to write does not match record length.	Err_syntax
Database transaction: Update data value out of range	Err_range
Database transaction: Update data, ASCII mode, or data malformed.	Err_syntax

RSPF: This bit only has meaning when a packet is coming from the STM-1. If this bit is 1, then the slave has been reset since the last AckPF power fail acknowledgement was received.

DATA: The optional data. Interfacing with the STM-1 is done by querying and setting records in the database on the STM-1 card. Information about this database is provided in the Data Access section 2.2, and information on how the data field is formed in both outgoing and incoming packets is contained in section 2.3, Forming the Data Field.

Since this protocol is binary transparent, STX and carriage return characters are not allowed in the data field. To solve this problem, these characters must be escaped. To send a hex 02, send the protocol escape character (HEX 07) followed by '0' (hex 30). To send a hex 0D, send the protocol escape character (HEX 07) followed by '1' (hex 31). To send a hex 07, send the protocol escape character (HEX 07) followed by '2' (hex 32). Note that the protocol escape character (HEX 07) cannot be sent by itself, but can only be sent followed by a 0,1,or2. If the protocol escape character is sent by itself, or is not followed by a 0,1,or 2, then the packed is deemed invalid and ignored.

CKSUM1, 2: The checksum characters for the message. This is the mod-256 checksum of all packet bytes except the STX and carriage return **BEFORE ESCAPE CHARACTER BYTE STUFFING**. The data is encoded as follows:
Compute the mod 256 checksum of ADDR, CMD_RSP and DATA fields, before byte stuffing with escape characters.

CKSUM1 character is the upper (most significant) four bits of the checksum (read as a nibble, 0-15, or right justified) plus hex 30 (ASCII 0). This yields an ASCII character from '0' (hex 30) to '?' (hex 3f).

CKSUM2 character is the lower (least significant) four bits of the checksum plus hex 30 (ASCII 0). This yields an ASCII character from '0' (hex 30) to '?' (hex 3f).

Note 2.1: Invalid packets (bad checksum, too short, corrupt data, bad escape sequences) are ignored by the STM-1. That means there is no reply at all to an invalid packet.

2.2 Data Access:

The STM1 card is designed to act as a slave, connected to a master via RS-232/485.

Data flow to and from the STM1 is through a database resident on the STM1 card. This section will explain the database, all of the data items in it (records), and their properties.

The database is a collection of data objects. Each object has a record # (always one byte, from 0-255) and a data value. The record # is the key used to address a certain record. The combination of the record # and the data value is called a record. Writes to the database are called updates, and reads from the database are called queries. A query is when the master (device connected to the STM1 card via RS-232/485) reads a database record. An update is when the master writes to a database record on the STM1 card. Records are of variable length, depending on the data type.

The database is divided into 3 groups:

Configuration parameters: All members of this group are parameters that are used in the calculation of the Run Time Data. This group includes properties such as material density, etc, which are necessary to compute thickness.

Run Time Data: All members of this group are updated (by the STM1) every 100ms, based on sensor data and configuration parameters. This section of the database can be locked. When locked, all record queries are guaranteed to be from the same measurement cycle. This avoids temporal errors (rate and thickness not from the same measurement cycle, for example).

Utilities: This group provides utility functions, such as zeroing the thickness, setting the analog output voltage, etc.

2.2.1 Configuration Parameters Group:

All members of this group can be updated and queried.

Configuration parameter updates must be committed in order to take affect. See Note 2.2!

In each case: Uchar is an 8 bit unsigned value (0-255).
Uint is a 16 bit unsigned value (0-65535).
Ulong is a 32 bit unsigned value (0-4,294,967,295).
Double is a 64 bit floating point value, IEEE format; Sign/exponent in most significant bytes, mantissa in least significant byte.

Configuration Parameters:

Record# (dec/hex/ascii)	Name	Type	Description
65/41/A	SessId	Uchar	Session ID. Copied to Runtime data group CfgPrmSSID.
66/42/B	Fq	Double	Xtal start freq. (Hz)
67/43/C	Fm	Double	Xtal min freq. (Hz)
68/44/D	Density	Double	Material density (gm/cc).
69/45/E	Zratio	Double	Material Z ratio. Not scaled or unitized.
70/46/F	Tooling	Double	1.000 is 100 % tooling (unity).
71/47/G	RateReq	Double	Requested rate (A/S). For Q monitor only.
72/48/H	QlvlTrip	Uchar	Quality threshold, if non 0 and exceeded, xtal fail occurs.
73/49/I	SlvlTrip	Uchar	Stability threshold, if non 0 and exceeded, xtal fail occurs.
74/4A/J	Chmods	Xmods_class	Additional channel mode bits. See Xmods_class description below.

Configuration parameters, Min/Max/Default values:

Record# (dec/hex/ascii)	Name	Type	Minimum (dec)	Maximum (dec)	Default (dec)
65/41/A	SessId	Uchar	0	255	0
66/42/B	Fq	Double	1,950,000 (Hz)	10,050,000 (Hz)	6,050,000 (Hz)
67/43/C	Fm	Double	1,950,000 (Hz)	10,050,000 (Hz)	5,000,000 (Hz)
68/44/D	Density	Double	0.01 gm/cc	100 gm/cc	1 gm/cc
69/45/E	Zratio	Double	0.1	10	1
70/46/F	Tooling	Double	0.1	10	1
71/47/G	RateReq	Double	0 A/sec	1000 A/sec	1 A/sec
72/48/H	QlvlTrip	Uchar	0	9	0
73/49/I	SlvlTrip	Uchar	0	9	0
74/4A/J	Chmods	Xmods_class	0	255	0

Xmods_class description (single byte record):

Bit D7	Bit D6	Bit D5	Bit D4	D3	D2	D1	D0
X	X	X	X	X	X	HALT_ERROR	X

When HALT_ERROR = 1 and an error occurs (XtalStat is non-zero) then none of the run time data is computed, and ALL records in the run time data group (except CfgPrmSSID) remain unchanged until the error status is cleared (see XtalOP_class). This allows a view of the last measurement that caused an xtal fail. This is also useful if the master system does not want to see every measurement, but check the status of the system once in a while, and does not want to miss process glitches. When HALT_ERROR = 0, then XtalStat is cleared to no error at the beginning of each new measurement cycle, and the measurement cycle continues normally.

Note 2.2: Updates to this group are not "live", meaning updates to this table are not sent to the measurement engine logic until commanded to do so (committed), and therefore will have no effect on measurements until committed. Queries of these records return the last update value, not necessarily the value the measurement engine is using. Functions in the utilities section allows for commits of these parameters, and rollbacks (which fill these records with the data the measurement engine is using). All updates to all configuration parameter records performed between a commit command and a rollback command are lost. In summary: Commits send all configuration parameters to the measurement engine, and rollbacks take all the current data the measurement engine is using and overwrites all the configuration parameter records. Also, if both a commit and rollback are requested, rollbacks are done first, and therefore the effect of the commit is lost. Records cannot be queried or updated while a rollback is pending, and records cannot be updated while a commit is pending. See the description of CPY_CFG_OP_class and notes 2.10 and 2.11 in the Utilities Group for more info on the use of the CH1_CPY field.

Note 2.3: Changes to Tooling, Density, Z-Ratio, Fq, etc are NOT back-computed into XtalThick. Whenever these are changed, the measurement engine re-computes all internal constants and uses the last frequency value as a point. The next measurement therefore will have a correct point to determine rate, which is always accumulated into XtalThick.

Note 2.4: Although any numbers (between 2-10MHZ) can be used for Fq and Fm, the difference (Fq-Fm) should be less than Fq / 2. If the frequency shift (measured frequency, RawFreq – Fq) is greater than (Fq / 2), the thickness calculation formula will not work properly because of the nature of the Z-Ratio adjustment function. This would result in faulty thickness and rate numbers.

Note 2.5: Fq (crystal start frequency) is the frequency the crystal oscillates when uncoated. This is a property of the crystal.

2.2.2 Run Time Data Group:

All members of this group are query only.

Run Time Data:

Record# (dec/hex/ASCII)	Name	Type	Description
97/61/a	CfgPrmSSID	Uchar	Configuration parameter session ID used to compute data. See note 2.6
98/62/b	Srlno	Uint	Measurement serial number.
99/63/c	RawFreq	Double	Channel freq. (Hz)
100/64/d	GoodFreq	Double	Last used, good channel freq. (Hz). Used to compute rate and thickness.
101/65/e	RawThick	Double	Computed raw thickness, from frequency. (A)
102/66/f	XtalThick	Double	Computed material related thickness, can be zeroed. (A)
103/67/g	XtalThick_F	Double	Filtered computed material related thickness, can be zeroed. (A) See note 2.7.
104/68/h	XtalRate	Double	Rate, angstroms per second.
105/69/i	XtalRate_F	Double	Rate, angstroms per second, filtered. See note 2.8.
106/6A/j	XtalLife	Double	XtalLife (%). 0 if RawFreq = Fm, 100 if RawFreq = Fq, linear in between.
107/6B/k	XtalQual	Uchar	Quality level (0-9).
108/6C/l	XtalQualPeak	Uchar	Highest quality level seen (0-9).
109/6D/m	XtalStab	Uchar	Stability level (0-9).
110/6E/n	XtalStabPeak	Uchar	Highest stability level seen (0-9).
111/6F/o	XtalStat	XPROB_class	Channel status. See XPROB_class description below.
112/70/p	XtalLife_C	Uchar	XtalLife (%). 0 if RawFreq = Fm, 100 if RawFreq = Fq, linear in between.

XPROB_class description (single byte record):

Bit Weight	Description
0:XPROB_NONE	No Problems. The rest below are prioritized.
1:XPROB_FREQ	Frequency of xtal is > Fq or < Fm. Halts all other calculations. The only updated members are Srlno and RawFreq. Highest Priority**.**
2:XPROB_LOWLIFE	Frequency was bad (previous XtalStat was XPROB_FREQ) and frequency is now in range, but life is less than 3%. This is a hysteresis band. Updated members are Srlno, RawFreq, XtalLife and XtalLife_C.
3:XPROB_S_FAIL	Stability level XtalStab of xtal >= SlvlTrip. Updated members are Srlno, RawFreq, XtalLife XtalLife_C, XtalStab and XtalStabPeak.
4:XPROB_MATH	Unable to determine rate because of a computation error, most likely caused by a parameter (density, z-ratio, etc) having a zero or otherwise invalid (non numeric or infinity) value. Updated members are Srlno, RawFreq, XtalLife, XtalLife_C, XtalStab XtalStabPeak, and RawThick.
5:XPROB_Q_FAIL	XtalQual of xtal >= QlvlTrip. All members updated. Lowest Priority

Note 2.6: CfgPrmSSID: This record is a tag, used to identify what configuration parameters group session was used for the computation of data. When a configuration parameter group is committed, the SessId is copied from that group to this runtime data group. This allows a context to be known of what configuration parameters were used.

Note 2.7: XtalThick_F: Filtered thickness. This is the average thickness over 2 seconds (20 samples) minus the most recent 3 samples (.3 seconds). This is also useful when crystal fails, because this data member does not contain the last three samples before crystal failed, the thickness information reflected here will be most accurate.

Note 2.8: XtalRate_F: Filtered rate. This is the average rate over 2 seconds (20 samples) minus the most recent 3 samples (.3 seconds). This is also useful when crystal fails, because this data member does not contain the last three samples before crystal failed, the rate information reflected here will be most accurate.

Quality monitor: Monitors the quality of the deposition system by dividing the rate error (XtalRate_F-RateReq) by the requested rate and multiplying by 100, then taking the absolute value to determine a percent error: |(((XtalRate_F-RateReq)/RateReq)*100)|. The percent error is then broken up into ten categories:

Quality category (XtalQual)	% Error
0	0.0 – 4.9999
1	5.0 – 7.4999
2	7.5 – 9.9999
3	10.0 - 12.4999
4	12.5 - 14.9999
5	15.0 - 19.9999
6	20.0 - 24.9999
7	25.0 - 29.9999
8	30.0 - 39.9999
9	40.0 and up

Stability monitor: Monitors the frequency stability of the crystal. Single-measurement positive frequency hops are detected, and all positive frequency hops are accumulated. This data is then broken into ten categories:

Stability category (XtalStab)	Single measurement pos delta	Accumulated positive deltas
0	<25 Hz	<25Hz
1	25 Hz	25 Hz
2	50 Hz	100 Hz
3	100 Hz	101 Hz
4	100 Hz	200 Hz
5	200 Hz	201 Hz
6	400 Hz	400 Hz
7	600 Hz	600 Hz
8	1000 Hz	1000 Hz
9	1000 Hz	5000 Hz

2.2.3 Utilities Group:

Some members of this group can be updated and others are query only.

Record# (dec/hex/ASCII)	Name	Type	Description
48/30/0	Endiansel	Uchar	Query only. Endian select. See note 2.9.
49/31/1	Frmwrchsum	Uint	Query only. Firmware Checksum. (Build).
50/32/2	CH1_OPS	XtalOP_class	Semaphore record. See note 2.10.
51/33/3	CH1_CPY	CPY_CFG_OP_class	Semaphore record. See notes 2.10 and 2.11.
52/34/4	Serial Number	Ulong	Query only. STM1's factory programmed serial number
53/35/5	Build type	Uint	Query only. STM1's factory programmed build type.
54/36/6	Aout_wdog	Uchar	Analog output watchdog timeout, in seconds. (0-255)
55/37/7	Aout_value	Uint	Analog ouput value. 0-4095 is 0-10 V nominal.

XtalOP_class (single byte)

D7	D6	D5	D4	D3	D2	D1	D0
X	X	Clear serial number to Srlno = 0	Clear error to XtalStat = 0	Clear rate filter	Clear stability info XtalStab = 0 XtalStabPeak = 0	Clear quality info XtalQual = 0 XtalQualPeak = 0	Zero thickness XtalThick = 0

CPY_CFG_OP_class (single byte). See note 2.**Error! Bookmark not defined.** in Configuration Parameters section for details.

D7	D6	D5	D4	D3	D2	D1	D0
X	X	X	X	X	X	Rollback	Commit

Note 2.9: 0 = little endian (least significant byte first). 1 = big endian (most significant byte first). Applies to all records. This record is query only.

Note 2.10: Semaphore record description: Can only update this record if this record is all zeros. The bits in this record are cleared as the work pending is performed. Any attempt to update this record while any operation is pending (any bits non zero) will fail, causing an Err_inhibited response code. See specific protocol section for details on detection of this failure.

Note 2.11: Attempts to update configuration parameters are prohibited while a commit or rollback operation is pending. Also, queries are prohibited while a rollback is pending. See specific protocol section for detection of these failures.

2.2.4 Analog Output:

The STM1 comes with an analog output feature. The analog output is under the control of the host computer through the database. Writing to the Aout_value record causes that written value to be output to the analog connector almost instantly. The analog output digital to analog converter (DAC) is a 12-bit DAC, so the valid range is 0-FFF hex or 0-4095 decimal. Writing a value of 0 to the Aout_value register will result in an analog output voltage of near zero volts (which is also the power up condition). Writing a value of 4095 (FFF hex) results in an analog output of near 10 volts. The voltage output is proportional to the Aout_value record (linear 0-10V from 0-4095).

There is also a watchdog feature, which works as follows: If the Aout_wdog record value is non-zero, then the analog output watchdog is enabled. The record has a range of 0-255 (0 is disable). The 1-255 gives a watchdog timer period of 1-255 seconds. With the watchdog enabled, the host computer must write to the Aout_value record or Aout_wdog record at least once every n seconds, where n is the value in the Aout_wdog record. The watchdog timer will be satisfied with a write (update) operation to either of these registers, even if the value to write is the same or out of range. If the host computer does not update either of these records before the watchdog timer expires, the analog output will be forced to zero volts and the Aout_value record in the database will be set to zero.

2.2.5 Firmware Version

Firmware Version is a query only record.

Using the SMDP protocol command "version" (CMD opcode 4) the firmware version string can be obtained. This string is designed to produce all relevant information to the master in order to identify the STM1 and communicate properly. See below for the format:

1st Byte					6th Byte
Prefix	Family	Database covenant	Major version	Dot	Minor version
A=release Q=qualification T= test	C=STM1	A-Z @=Error	(0-9)	.	(0-9)

E.g.: ACF2.0 = STM1 release version 2.0 database covenant code E.
Prefix indicates STM1 major software class. (This document is for code A).
Family code indicates STM1 behavior family. (This document is for code C, standard STM1).
Database covenant indicates record locations and sizes. (This document is for code F).

Note 2.12: Database covenant of @ indicates a mismatched software/hardware platform. This is a fatal error, and the STM1 card will not take any measurements.
Major and minor version numbers increment with feature additions (bug fixes).

Note 2.13: This class is in ASCII, and the byte order does not change based on Endiansel.

2.3 Forming the Data Field:

Transactions: (Description of <DATA> field):
If the incoming command string <DATA> field does not follow any of the below formats, then the reply RSP portion of the CMD_RSP field will be Err_syntax and there will be no other data in the reply.

Locking the run time data group portion of the database (via the CmdOpcode_lock command) ensures all subsequent run time data queries are from the same measurement cycle. So a quick and easy way to check for new data is to send a lock database command, and check the byte in the reply. The user can then query any wanted records, and be certain that all of the data is from the same measurement. Just make sure to unlock the database after the queries of interest (if any) are performed. The database must be unlocked following a lock (and any queries, if any) in order for new data to post to the run time data group.

C: is data in <DATA> field in **command** packet sent **to** STM-1.
R: is data in <DATA> field in **reply** packet returned **from** STM-1.
<REC#> is the record number as described in section 2.
<PDAT> is the value that a record is being updated to, or the value a record is returning due to a query.

For opcode < **CmdOpcode_RndRead** >:
C: <REC#> : Do random read of database at <REC#>.
R: <REC#><PDAT>[<PDAT>…] : No Error occurred, PDAT is database record value.
or
R: <REC#> : If Error occurred, only record number echoed back.

For opcode <**CmdOpcode_RndWrit**>
C: <REC#><PDAT>[<PDAT>...] : Do random write of PDAT data to database at <REC#>.
R: <REC#> : Always echoes REC#, whether error occurred or not.

Note 2.14: for above, REC# and PDAT fields are in raw binary. Since there are less than 256 database records, REC# is a single byte binary. Also note that endian matters for database records whose data type is larger than one byte. The PDAT field must be expressed in the same endian setting as the dipswitch for updates, and it will be expressed as the dipswitch for queries.

For opcode <**CmdOpcode_Lock**>
C: : Data field must be empty for the execute lock database command.
R: <LOKSTAT> : No Error occurred. Return lock reply.
: '1' (ASCII 1, hex 31) = new data since last lock,
: '0' (ASCII 0, hex 30) = no new data since last lock.

For opcode <**CmdOpcode_Unlock**>
C: : Data field must be empty for the unlock database command.
R: : No reply in data field for this command.

For opcode <**CmdOpcode_AscRd**>
C: <REC#> : Do random read of database at <REC#>.
R: <REC#><PDAT>[<PDAT>...] : No Error occurred, PDAT is database record value.
or
R: <REC#> : If Error occurred, only record number echoed back.
Note 2.15: For reading double types, the ASCII reply is [-]d[d…].fff where d is the whole number portion and fff is the fractional information. In other words, there is always a decimal point and three digits past the decimal point. So a value of zero, type double, will echo back as 0.000

For opcode <**CmdOpcode_AscWr**>
C: <REC#><PDAT>[<PDAT>...] : Do random write of PDAT data to database at <REC#>.
R: <REC#> : Always echoes REC#, whether error occurred or not.

Note 2.16: for above, REC# fields is in raw binary, and is one byte. For convenience, the tables in this document that describe record address have an ASCII equivalent to the binary value, and can be placed in this field. The PDAT field is in ASCII form.

3. Calibration and Theory

3.1 Measurement Theory

The STM-1 uses the resonant frequency of an exposed quartz crystal to sense the mass of deposited films attached to its surface. There is a known relationship between the mass of such a film and the measured frequency of the sensor crystal. Knowing the frequency change due to accumulated mass, film thickness is determined by the following equation:

$$Af = \left[\frac{(Nq \bullet Dq)}{(\Pi \bullet Df \bullet Z \bullet Fc)} \right] \bullet ArcTan\left[Z \bullet Tan\left[\frac{\Pi \bullet (Fq - Fc)}{Fq} \right] \right]$$

Where the terms used in the equation are defined as:

Af Film Thickness, in Angstroms (1a=10^{-10} Meters)

Nq Frequency Constant for AT Cut Crystal, 1.668 X 10^{13} Hz/Å

Dq Density of Quartz 2.648 gm/cm^3

Π The Constant Pi, 3.14159265358979324

Df Density Of Film Material in gm/cm^3

Z Z-Factor of material, is the square root of the ratio [(Dq∗Uq)/(Df∗Uf)]. Dq and Df are the densities as above and Uq and Uf are the shear moduli of quartz and the film, respectively. These values are available in several materials handbooks.

Fq Frequency of sensor crystal prior to depositing film material on it. This value is a manufacturing controlled constant.

Fc Frequency Of Loaded Sensor Crystal.

3.2 Rate Computation

Rate computation is based on the rate of change of these thickness readings, updated ten times per second, and then filtered for display. Also available from the instrument is the raw measured frequency of the sensor crystal.

3.3 Thickness Reading Calibration

Instrument calibration is affected by three different parameters, material density, material Z-Factor, and tooling. Tooling is a deposition system geometry correction (location of sensor relative to substrates). Density and Z-Factor are material factors.

3.4 Density Determination

Use of the material bulk density value will normally provide sufficient film thickness accuracy. If additional accuracy is required, the following procedure may be used:

3.5 Density

Using a new sensor crystal (this eliminates Z-Factor errors) place a substrate adjacent to the sensor so that both sensor and substrate see the same evaporant stream. Set the instrument density to the bulk value of the material (see the Material Reference Table in Section 4.3). Set the Z-Factor to 1.000 and the Tooling Factor to 1.00. Deposit approximately 5000 Angstroms of material on the sensor and substrate. After deposition remove the substrate and measure the film thickness with a profilometer or multiple beam interferometer. The correct density value may be determined by the formula:
Correct Density = [Trial Value * Measured Thickness (from STM-1)] / (actual thickness (via profile))
After reprogramming with the new value, another run can be made to verify instrument reading against empirical results.

3.6 Z-Factor Determination

A list of Z-Factor values may be found in the Material Reference Table in Section 4.9. For other materials Z-Factor may be calculated by the following formula:

$$\text{Z - Factor} = \left[\frac{Dq \bullet Uq}{Df \bullet Uf} \right]^{1/2}$$

where:

D_q = Density Of Quartz
U_q = Shear Modulus Of Quartz
D_f = Density Of Film
U_f = Shear Modulus Of Film

The density and shear modulus values may be found in many material reference handbooks.

Z-Factor values are typically very close to bulk values. High stress materials seem to have values slightly lower than expected.

3.7 Tooling Determination

Place a substrate in the normal holder location and deposit a film of approximately 5000 Angstroms using either bulk or calibrated density and Z-Factor values. Make sure that when doing this calibration the tooling is set to 1.00. Measure the substrate film thickness as in the density calibration method and determine the correct Tooling Factor value by the following formula:

Tooling = (Substrate Thickness / Displayed Thickness)

3.8 Material Reference Table

Common Material
Bulk Density And Z-Factor Values

Material	Symbol	Bulk Density gm/CC	Z Factor
Aluminum	Al	2.73	1.080
Aluminum Oxide	Al2O3	3.97	--------
Antimony	Sb	6.62	0.768
Arsenic As	5.73	0.966	
Barium Ba	3.50	2.100	
Beryllium	Be	1.85	0.543
Bismuth Bi	9.80	0.790	
Bismuth Oxide	Bi2o3	8.90	--------
Boron B	2.54	0.389	
Cadmium	Cd	8.64	0.682
Cadmium Selenide	Cdse	5.81	--------
Cadmium Sulfide	Cds	4.83	1.020
Cadmium Telluride	Cdte	5.85	0.980
Calcium	Ca	1.55	2.620
Calcium Fluoride	CaF2	3.18	0.775
Carbon (Diamond)	C	3.52	0.220
Carbon (Graphite)	C	2.25	3.260
Cerium (III) Fluoride	CeF3	6.16	--------
Cerium (IV) Oxide	CeO2	7.13	--------
Chromium	Cr	7.20	0.305
Chromium (III) Oxide	Cr2O3	5.21	--------
Cobalt	Co	8.71	0.343
Copper	Cu	8.93	0.437
Copper (I) Sulfide (A)	Cu2S (A)	5.60	0.690
Copper (I) Sulfide (B)	Cu2S (B)	5.80	0.670
Copper (III) Sulfide	CuS	4.60	0.820
Dysprosium	Dy	8.54	0.600
Erbium	Er	9.05	0.740
Gadolinium	Gd	7.89	0.670
Gallium	Ga	5.93	0.593
Gallium Arsenide	GaAs	5.31	1.590
Germanium	Ge	5.35	0.516
Gold	Au	19.3	0.381
Hafnium	Hf	13.1	0.360
Hafnium Oxide	HfO2	9.63	--------
Holnium	Ho	8.80	0.580
Indium	In	7.30	1.650
Indium Intimonide	InSb	5.76	0.769
Indium Oxide	In2O3	7.18	--------
Iridium	Ir	22.4	0.129
Iron	Fe	7.86	0.349
Lanthanum	La	6.17	0.920
Lanthanum Fluoride	LaF3	5.94	--------
Lanthanum Oxide	LaO3	6.51	--------
Lead	Pb	11.3	1.130
Lead Sulfide	PbS	7.50	0.566
Lithium	Li	0.53	5.900
Lithium Fluoride	LiF	2.64	0.774
Magnesium	Mg	1.74	1.610
Magnesium Fluoride	MgF2	3.00	--------
Magnesium Oxide	MgO	3.58	0.411
Manganese	Mn	7.20	0.377
Manganese (II) Sulfide	MnS	3.99	0.940

Material	Symbol gm/CC	Bulk Density	Z Factor
Mercury	Hg	13.46	0.740
Molybdenum	Mo	10.2	0.257
Neodynium Fluoride	NdF3	6.506	--------
Neodynium Oxide	Nd2O3	7.24	--------
Nickel	Ni	8.91	0.331
Niobium	Nb	8.57	0.493
Niobium (V) Oxide	Nb2O5	4.47	--------
Palladium	Pd	12.0	0.357
Platinum	Pt	21.4	0.245
Potassium Chloride	KCl	1.98	2.050
Rhenium	Re	21.04	0.150
Rhodium	Rh	12.41	0.210
Rubidium	Rb	1.53	2.540
Samarium	Sm	7.54	0.890
Scandium	Sc	3.00	0.910
Selenium	Se	4.82	0.864
Silicon	Si	2.32	0.712
Silicon (II) Oxide	SiO	2.13	0.870
Silicon Dioxide	SiO2	2.20	1.070
Silver	Ag	10.5	0.529
Silver Bromide	AgBr	6.47	1.180
Silver Chloride	AgCl	5.56	1.320
Sodium	Na	0.97	4.800
Sodium Chloride	NaCl	2.17	1.570
Sulfur	S	2.07	2.290
Tantalum	Ta	16.6	0.262
Tantalum (IV) Oxide	Ta2O5	8.20	0.300
Tellurium	Te	6.25	0.900
Terbium	Tb	8.27	0.660
Thallium	Tl	11.85	1.550
Thorium (IV) Fluoride	ThF4	6.32	--------
Tin	Sn	7.30	0.724
Titanium	Ti	4.50	0.628
Titanium (IV) Oxide	TiO2	4.26	0.400
Titanium Oxide	TiO	4.90	--------
Tungsten	W	19.3	0.163
Tungsten Carbide	WC	15.6	0.151
Uranium	U	18.7	0.238
Vanadium	V	5.96	0.530
Ytterbium	Yb	6.98	1.130
Yttrium	Y	4.34	0.835
Yttrium Oxide	Y2O3	5.01	--------
Zinc	Zn	7.04	0.514
Zinc Oxide	ZnO	5.61	0.556
Zinc Selenide	ZnSe	5.26	0.722
Zinc Sulfide	ZnS	4.09	0.775
Zirconium	Zr	6.51	0.600
Zirconium Oxide	ZrO2	5.6	--------