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Abstract

The second quarter of the project was dedicated to convert the conceptual designs for the wireless tool and power generator into mechanical and electrical drawings as well as software code to create the new system.

The tasks accomplished during this report period were:

1. Basic mechanical design for the wireless communications system was created and the detailed drawings were started.
2. Basic design for the power generator system was created and the detailed machining drawings were started. The generator design was modified to provide a direct action between the wellbore fluid flow and the piezoelectric stack to generate energy. The new design eliminates the inefficiencies related to picking up outside the tubing wall the pressure fluctuations occurring inside the tubing walls.
3. The new piezoelectric acoustic generator design was created and ordered from the manufactured. The system will composed of 40 ceramic wafers electrically connected in parallel and compressed into a single generator assembly.
4. The acoustic two-way communications requirements were also defined and the software and hardware development were started.
5. The electrical hardware development required to transmit information to the surface and to receive commands from the surface was started.

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Introduction

The Downhole Power Generation and Wireless Communications for Intellligent Completions Application project progressed significantly during the January 03 - March 03 report period. The goals for this period were to develop the concepts for the acoustic communications system and downhole power generator into actual designs that could be manufactured. Basic mechanical design for the wireless communications system was created and the detailed drawings were started. The design for the power generator system was created and the detailed machining drawings were started. The generator design was modified to provide a direct action between the wellbore fluid flow and the piezoelectric stack to generate energy and to eliminate the inefficiencies of having the tubing between the flow stream and the piezo assembly. The acoustic two-way communications requirements were also defined and the software and hardware development were started. A new microprocessor will be used to receive data from the surface and pass that information to the main processor in the downhole tool. The electrical hardware development required to transmit information to the surface and to receive commands from the surface was started. An analog filter/amplifier was developed to receive and process the raw electrical signal converted from the acoustic information transmitted from the surface. A new power controller board was developed to minimize the amount of power consumed by the system to extend the system reliability and downhole operation when using batteries only for system power.

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Executive Summary

The highlights of the accomplishments for this report period are listed below.

1. Basic mechanical design for the wireless communications system was created and the detailed drawings were started. The new system has a 3.3 inches Internal Diameter and 6.75 inches Outside Diameter to provide the external pressure ratings required for burst and collapse in downhole applications. The tool will have 2 pressure sensors and 1 temperature sensor. The thread connections will be new Vamm normally used in deep well applications.
2. Basic design for the power generator system was created and the detailed machining drawings were started. The generator design was modified to provide a direct action between the wellbore fluid flow and the piezoelectric stack to generate energy. The new design eliminates the inefficiencies related to picking up outside the tubing wall the pressure fluctuations occurring inside the tubing walls. The piezoelectric assemblies are mounted on the inside of the tubing and the assemblies are exposed to the hydrostatic pressure in the well. A ceramic coating will be used to coat the assembly to prevent erosion as the hydrocarbons flow pass the piezo assembly. Multiple piezo stacks will be mounted on the tool ID.
3. Two new high temperature battery pack designs are being developed for use with the downhole wireless gauge. The 2 designs use different concepts although they both utilize the same battery chemistry. The first design is a doughnut shape approach were the battery pack slips onto the tubing OD. The second design uses 40 double AA battery cells connected in parallel and series to generate the 30 volts with an energy level of 30 Ampere – Hour.
4. The new piezoelectric acoustic generator design was created and ordered from the manufactured. The system will composed of 40 ceramic wafers electrically connected in parallel and compressed into a single generator assembly. The system will have a 4.588 inches ID and 5.138 inches OD with a length of 7.67 inches. The piezoelectric acoustic generator will have 2 brass pieces located at the end of the piezo stack to match the piezoelectric stack temperature coefficient of expansion to the tool material.
5. The acoustic two-way communications requirements were also defined and the software and hardware development were started. The tools software reached 94% of available program storage, therefore, an additional processor was added to handle high-priority tasks relating to the reception of packets. It was decided to use the hardware I2C bus on the two processors.
6. The electrical hardware development required to transmit information to the surface and to receive commands from the surface was started. An

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analog filter/amplifier was developed to receive and process the raw electrical signal converted from the acoustic information transmitted from the surface. A new power controller board was developed to minimize the amount of power consumed by the system to extend the system reliability and downhole operation when using batteries only for system power.

7. A new board based on the Intel 386 microprocessor was purchased to provide the data processing at the surface for the acoustic information transmitted from downhole. The board will be interfaced with an analog processing board, LCD display, and 4-20 milli Amperes output to create a complete surface system for data storage and display. The surface system will have a programmable 8 pole bandpass filter being developed now, and a variable gain amplifier that will be controlled from the PC also being developed now.
8. A new toroid based transformer design was created during this report period. The new design is more efficient and smaller than the previous doughnut shape transformer. The design will use a parallel toroid input and serial toroid output to provide the power conditioning for the piezo assembly.
9. A 3 Dimension software package was purchase for the mechanical design of the downhole tool. The AutoCad package called Inventor decreases the time required to design the system and will minimize the mechanical errors due to tolerances and fitting issues. The mechanical engineer took a class to become familiar with the software.

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Experimental

Experimental Apparatus –An experimental apparatus was created to determine the amount of power generated by a piezoelectric assembly. Multiple assemblies composed of a piezoelectric stack with various thickness of metal sheets were used to simulate the downhole tool assembly while water with approximately 30 psi of pressure were exerted onto the metal sheetsl Measurement of the power generated by the piezo assembly due to the vibration and movement of the metal sheets were recorded.

Experimental and Operating Data - The approximate current output at compressive force/movement were as following:

Test results of sample piezo cylinder using city water, a hose and metal plates.

	plate thickness	0.030	0.060		0.120		0.188		0.250		
test no.											
1	max	0.495	0.302		0.175		0.449		0.490		
	min		-0.252		-0.202		-0.430		-0.567		
	delta		0.554		0.377		0.879		1.057		
2	max	0.563	0.728		0.265		0.342		0.404		
	min				-0.238		-0.367		-0.405		
	delta				0.503		0.709		0.809		
3	max	0.793	0.098		0.176	***	0.315		0.595		
	min	-0.753	-0.110	*	-0.203		-0.283		-0.596		
	delta	1.546	0.208		0.379		0.598		1.191		
4	max	0.449	0.368		0.253		0.185		0.206	*	0.360
	min	-0.420	-0.236	**	-0.227				-0.215		
	delta	0.869	0.604		0.480				0.421		
5	max	0.053	0.025		0.022	0.021	0.056	0.048	0.053	0.066	
	min	-0.053	-0.008		-0.020	-0.020	-0.051	-0.048	-0.056	-0.069	
	delta	0.106	0.033		0.042	0.041	0.107	0.096	0.109	0.135	

current is in milliAmps

test 1 direct spray at 90° to the plate with full pressure
test 2 direct spray at 90° to the plate with full pressure
test 3 direct spray at 90° to the plate with full pressure
test 4 shallow angle spray on the plate with full pressure
test 5 direct spray at 90° to the plate with little pressure, a trickling stream.

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The results indicated that there was a significant amount of energy generated by the piezoelectric assembly with a very low pressure applied to the piezos. The results also indicated that a much larger power can be generated as the pressure applied to the piezoelectric assembly increases as in a downhole environment.

A significant amount of testing has been performed on the software required to provide a 2 way communications capability for the system. The assembly for software testing is composed of 2 Personal Computers, real time debug software, oscilloscope and multiple microprocessors and custom circuitry used to monitor in real time the activities of the software for data acquisition and processing as well as communications among the 3 processors used in the downhole tool via I2C communications bus. Multiple state machines have been developed to provide monitoring, control and processing of the data acquired downhole and for commands received from the surface.

Tests were also performed on the analog circuit for filtering and amplifying the analog signal converted from the acoustic transmission. The electronics for the circuit was connected via 26 gauge wires and the assembly attached to a frequency generator at the input of the circuit and to a oscilloscope at the output of the circuit. Multiple frequencies were placed on the input of the circuit and the output measured to determine if the filter was able to attenuate the frequencies that were not part of the transmission band while amplifying the frequencies of interest.

The new transformer design was created where small toroids are placed in series and parallel to create the voltages and currents required to drive the piezoelectric assembly to generate the acoustic signal that will travel through the

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production tubing to the surface. The transformer was tested in multiple toroid configurations including number of toroids in parallel and series and the voltage and current generated by the transformer were measured for a constant input voltage. The results indicated that 20 toroids will be combined to give the 1,000 volts required to drive the new piezo assembly.

The filter worked as designed. The band pass is 505Hz to 705Hz. The filter is a good candidate for the 2 way communication of the DOE project.
Results follow:

RC Clock Calc	INPUT	RESULT	COMMENTS
R	9.570E+03		51K-> 18.8K, 1K->957K Hz
C	4.70E-10		
Fclk		1.000E+05	

R	Fo
51	18.8
45	21.28
40	23.9
35	27.36
30	31.9
25	38.3
20	47.9
15.95	60.03
15	63.83
10	95.7
5	191.5
1	957

CLOCK RATIO	(TABLE 2)							
Fclk (KHz)	1.00E+05							
Desired Fo (KHz)	6.50E+02							
RATIO		153.846153						
Closest N	34							
TABLE RATIO	153.98		F5	F4		F3	F2	F1
Fo Calculated		6.49E+02	1	0	0	0	1	0
FREQ BITS 5-0								

MODE	1D

BP CALC		
Q	2.00E-00	
fH-fL		324.72
fH		831.78
Fo (KHz)		6.49E+02

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fL	507.06

fL	fo	fH	Vi	Vo
	650		5	5
505			5	4
		702	5	4
400			5	1.56
		1000	5	1.56

200	0		
400	1.56		
505	4		
650	5		
702	4		
1000	1.56		
1200	0		3dB point = 5 x .7071 = 4Vp-p

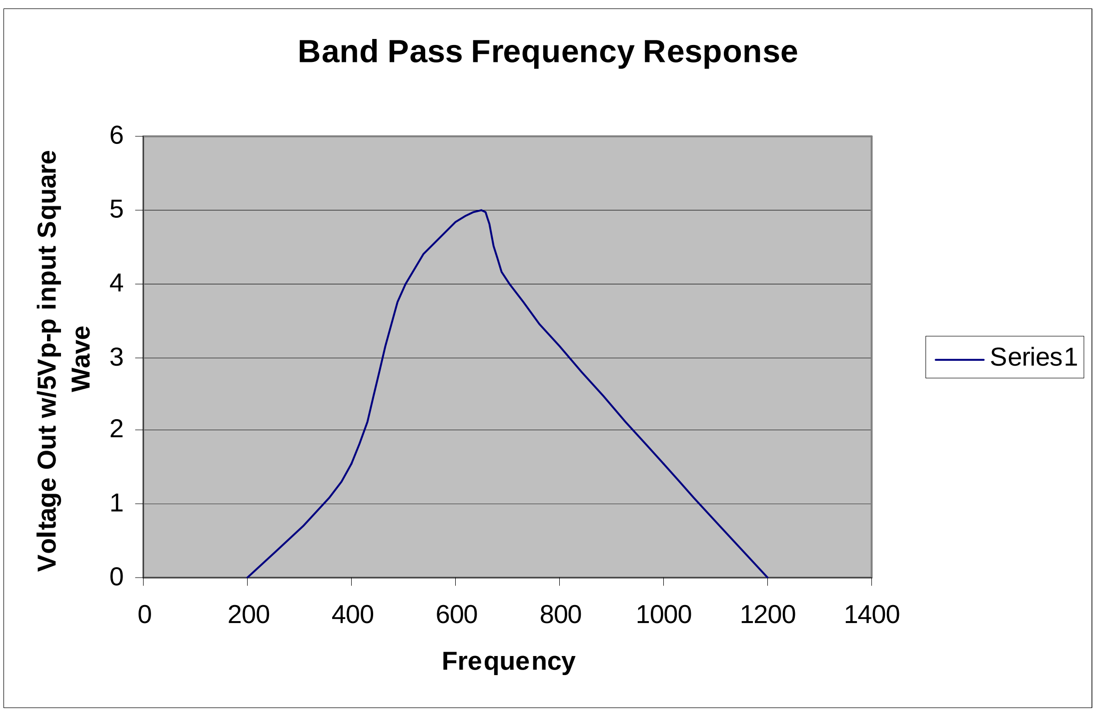

Figure 1. Bandpass Frequency Response of Bandpass Filter Assembly

Four different transformers were compared with the input voltage held at 30Vdc and was pulsed at 900 Hz (180uS) on pulse as specified by Northstar

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Transformer.(Figure.2) The results for both output voltage and current are listed in Table 1 as well as a calculated secondary current. An efficiency of 80% was also assumed with each unit.

The output wattages with a fixed load (i.e. a 12847-0 5.1x3.75" PIEZO Assembly) is compared in Figure 2.

A function generator was used and tuned to the precise frequency pattern seen in Figure 2 and the response parameters recorded.

Even with the New clamshell transformer and the Thru tubing transformer delivering a higher wattage, the Toroid transformers will deliver more usable power to the load with less overall loss making it the best choice to pursue. They are easier to build, cheaper, and have a much shorter lead time for delivery as well as being less massive. The only thing that will have to be changed is the number used in an assembly to double the delivered power. This is an easy task with this type of topology.

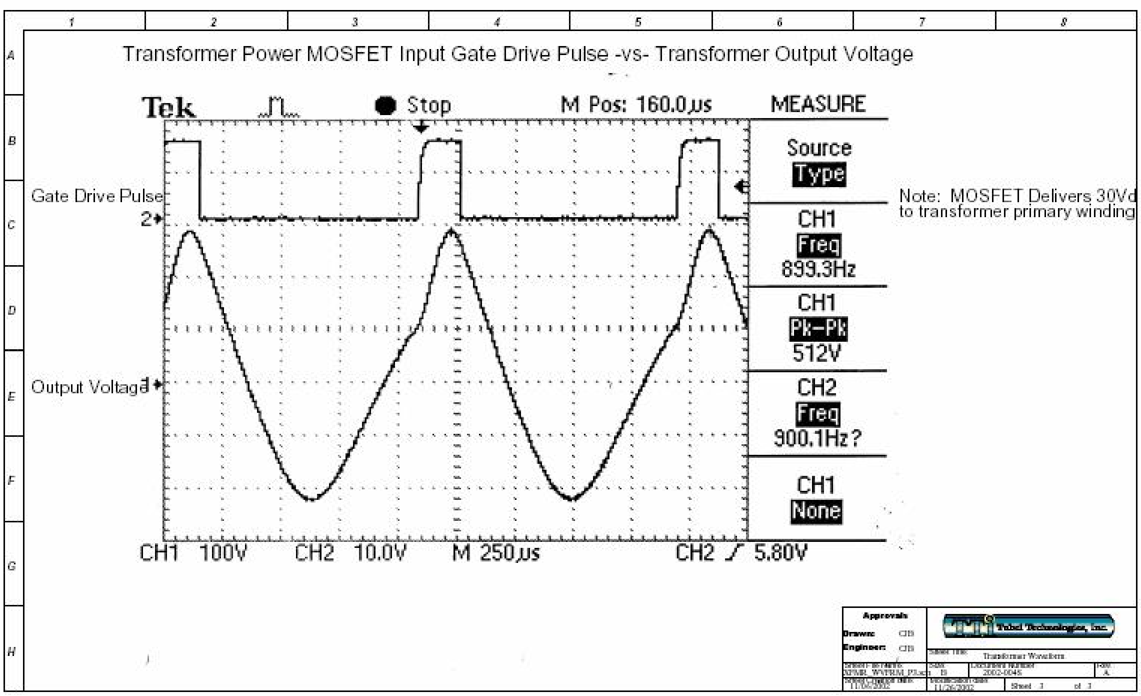

Figure 2: Transformer test pattern

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Transformer Comparison

3/15/2003

Description	Vin	Iin (mA)	Vop-p	Io(calc_mA)	Freq	Efficiency %	W in	W o	Condition
Old	30	113.8	1360	0.002510294	900	80	3.414	2.7312	No Load
	30	327	496	0.019778226	900		9.81	7.848	Loaded (PIEZO)
New	30	73.3	1160	0.00189569	900		2.199	1.7592	No Load
	30	585	612	0.028676471	900		17.55	14.04	Loaded (PIEZO)
Toroid Thru Tubing	30	160.6	2940	0.001638776	900		4.818	3.8544	No Load
	30	578	392	0.044234694	900		17.34	13.872	Loaded (PIEZO)
Toroid Corp	30	4	432	0.000277778	900		0.12	0.096	No Load (Parallel Pri)
	30	218	256	0.025546875	900		6.54	5.232	Loaded (PIEZO)
Toroid Corp	30	1.6	88	0.000545455	900		0.048	0.0384	No Load (Series Pri)
	30	13	56	0.006964286	900		0.39	0.312	Loaded (PIEZO)

	Vin	Vop-p	W o
Old	30	496	7.848
New	30	612	14.04
Toroid Thru Tubing	30	392	13.872
Toroid Corp(Series)	30	256	5.232
Toroid Corp(Parallel)	30	56	0.312

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Results and Discussion

The results indicate that the system can be manufactured to achieve the goals set for the project. The mechanical detailed drawings are going to be completed in April and it should take 6 weeks to receive all parts required to assemble the tool. The system will be manufactured using 4104 steel L80 material strength that can be used in pressures of up to 15,000 psi. A set of springs has been added to the piezoelectric mechanical housing to allow the compression or tension of the tubing while maintaining the piezo assembly compressional force constant.

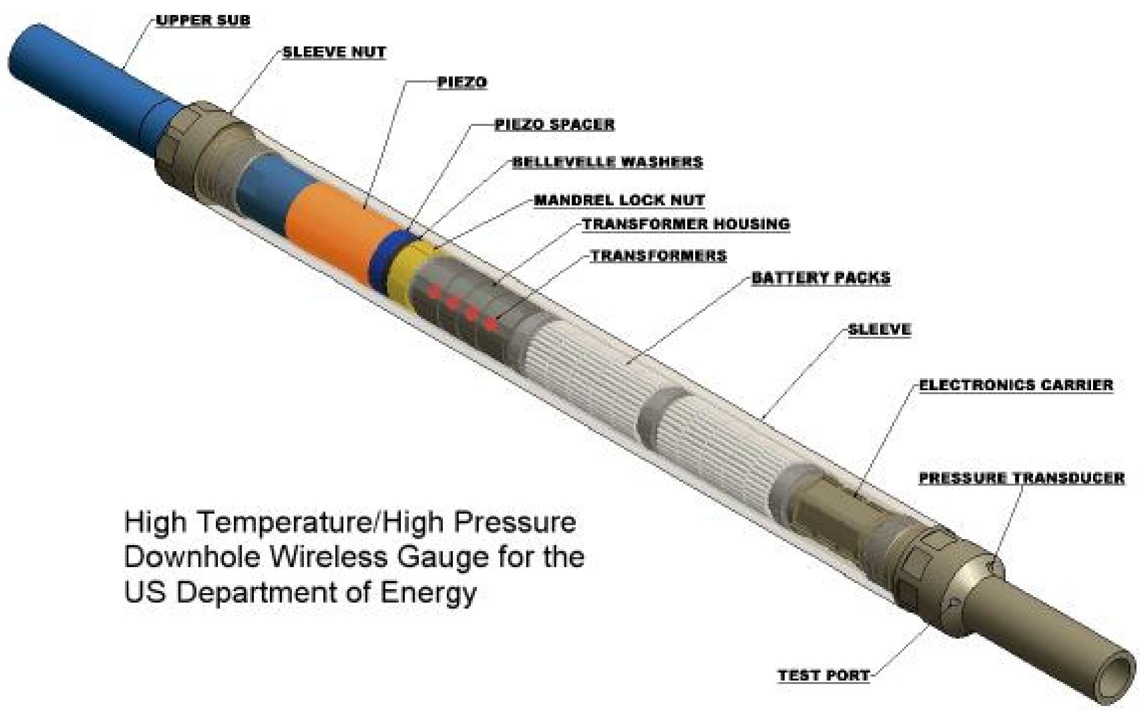

Figure 3. Wireless Communications based Downhole Gauge

The design of the power generator has been changed to reduce the inefficiencies related to having the piezo in the atmospheric chamber. Parts for the preliminary testing were received and tested. The testing indicated that the

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piezo stack is sensitive to water flowing by and spraying onto steel to which it was attached. The piezo also generated power when water was sprayed on adjacent and overlapping sheets of steel, not just the steel the piezo was directly attached to.The current conceptual design at the beginning of March used a rotating inner sleeve. Concern was raised about using a rotating part down hole. The concern was rather about scale or mud or debris build up preventing the rotation over the life of the tool. The preliminary concept was stopped. The secondary conceptual design was developed once the testing was completed. The testing indicated that rotation was not going to be needed. Rather that the vibration of fluid flowing by, if a turbulent environment is established, could be enough to cause the piezo to generate the needed power. The new concept was completed in a layout in 2-D, with preliminary conceptual part drawings for the generator and electrical mandrel sections. Coating of the generator section of the tool will need to be either a peek like coating, or a rubber like coating. Either process will help to seal the piezo's from bore fluids and are done at low enough temperature to allow the required wiring prior to coating.

The surface system and downhole receiver modules will utilize the same hardware design composed of a acoustic detector, analog bandpass filter and amplifier. The amplifier and filter will be computer controlled for the determination of the best parameters for the acoustic signal detected by the circuit. The filter is an 8 pole bandpass filter that will attenuate all frequencies except between 625 Hz and 675 Hz. Also, a low power controller circuit has been developed successfully to minimize the system power consumption inside the wellbore. The circuit is composed of a microprocessor that provides a timer function to wakeup the main system when time to acquire and transmit data to the surface. The microprocessor and support hardware operates at 90 micro Amperes at 32 Kilo Hertz frequency.

The new software will provide 2 way communications control and processing. Three processors will be used inside the tool to perform the functions in the downhole tool. The main processor software will collect data from the sensors,

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configure the information for transmission to the surface and create the frame for transmission of the data to the surface. The second processor software generates the timing required to wakeup the system and to tell the main processor what task to perform. The third processor receives the data from the surface and configures the data to transfer to the main processor for processing. All data transfer inside the tool is performed using I^2C serial bus. The software uses multiple, nested state machines to acquire and process the data. Also, mutiple levels of interrupts are used to provide the proper priority for the tasks to be performed.

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Conclusion

The conclusions for the first quarter for this project are as following:

- The mechanical drawings for the manufacturing of the wireless tool are being created using a 3D CAD package and should be completed during April.
- The power generation system was modified so that the piezoelectric assemblies are now located in the flow stream instead of inside the atmospheric chamber in the tool. The preliminary tests of the power generation capabilities of the piezo assemblies indicated that the power generator will meet the requirements for the operation of the downhole tool.
- The software for the transmission and reception of 2 way communications is being developed. The initial test results were very encouraging.
- The electrical hardware is also being developed with the key aspects of the development being tested successfully such as the analog data conditioner system.
- The new toroid based transformer has also been tested successfully and implemented on the design of the new wireless communications tool
- The piezoelectric assembly for the generation of the acoustic signal has been developed and it is being manufactured.

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References

There are no references related to this project and work performed over the past 3 months.

Bibliography

There is no bibliography related to the work being performed.

List of Acronyms and Abbreviations

There are no acronyms or abbreviations in this report.

Appendices

1. Half Duplex I2c Communication Protocol

Configuration Packets

Configuration data packets are I2C master transmit, slave receive handshakes. The R/#W bit is clear.

Frequency Table Packets

Frequency Table 0

Master Packet

0x5A, 0x30

ASCII equivalent: Slave address, ‘0’.

No slave response.

Frequency Table 2

Master Packet

0x5A, 0x32

ASCII equivalent: Slave address, ‘2’.

No slave response.

Surface Communication Packets

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Surface Data Request Packets

Surface data requests packets are I2c master receive, slave transmit handshakes. The R/#W bit is set.

Each type of data request is represented by one bit in the two bytes of data received.

The first byte received is byte 0, the second byte received is byte 1, etc.

Within each byte, the first bit received is bit 7, the second bit received is bit 6, etc.

The following table is the mapping between bit number and data request type.

Byte Number	Bit Number	Data Request
0	7	Unmapped
0	6	Unmapped
0	5	Unmapped
0	4	Unmapped
0	3	Unmapped
0	2	Unmapped
0	1	Unmapped
0	0	Unmapped
1	7	Unmapped
1	6	Unmapped

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1	5	Unmapped
1	4	Unmapped
1	3	Battery
1	2	Temperature
1	1	Pressure 2
1	0	Pressure 1

Master Packet Data

0x5A

ASCII equivalent: Slave address.

Slave Packet Data

0x00, 0b0000 Bit 3, Bit 2, Bit 1, Bit 0.

Individual bits are set according to the request from the surface.

Surface Data Request Example

Request for battery, temperature, pressure 2, and pressure 1.

0x5A, 0x00, 0x0F

2. Host PC Interface Control Document

Configuration Packets

Frequency Table Packets

Unidentified packets will be ignored.

Frequency Table 0

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Master Packet

0x46, 0x72, 0x65, 0x71, 0x3D, 0x30, 0x0D, 0x0A

ASCII equivalent: “Freq=0”

Slave Response

0x4F, 0x6B, 0x0D, 0x0A

ASCII equivalent: “0k”

Frequency Table 2

Master Packet

0x46, 0x72, 0x65, 0x71, 0x3D, 0x32, 0x0D, 0x0A

ASCII equivalent: “Freq=2”

Slave Response

0x4F, 0x6B, 0x0D, 0x0A

ASCII equivalent: “Ok”

Surface Communication Packets

The host PC is the master and the surface system is the slave.

All communication will be initiated by the host PC.

Unrecognized packets will be ignored.

For samples that have been taken autonomously by the tool, the host PC must poll for a list of sampled data.

Surface Data Request Packets

Sampled Data List

Master Polling Packet

0x44, 0x61, 0x74, 0x61, 0x0D, 0x0A

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ASCII equivalent: “Data”

Slave Response

The slave response is a concatenation of the individual sampled data strings, followed by 0x0D and 0x0A.

Pressure 1

0x50, 0x31

ASCII equivalent: “P1”

Pressure 2

0x50, 0x32

ASCII equivalent: “P2”

Temperature

0x54

ASCII equivalent: “T”

Battery Voltage

0x42

ASCII equivalent: “B”

Sampled Data List Handshake Example

Master Polling Packet

0x44, 0x61, 0x74, 0x61, 0x0D, 0x0A

ASCII equivalent: “Data”

Slave Response

0x50, 0x31, 0x50, 0x32, 0x54, 0x42, 0x0D, 0x0A

ASCII equivalent: “P1P2TB”

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Surface Pressure 1 Data Request

Master Polling Packet

0x50, 0x31, 0x0D, 0x0A

ASCII equivalent: “P1”

Slave Response

The slave response will be “P1 ” followed by four hex digits of data.

The first hex digit is the most significant.

0x50, 0x31, 0x20, most significant digit, digit, digit, least significant digit.

ASCII equivalent: “P1 Data Data Data Data”

Surface Pressure 2 Data Request

Master Polling Packet

0x50, 0x32, 0x0D, 0x0A

ASCII equivalent: “P2”

Slave Response

The slave response will be “P2 ” followed by four hex digits of data.

The first hex digit is the most significant.

0x50, 0x32, 0x20, most significant digit, digit, digit, least significant digit.

ASCII equivalent: “P2 Data Data Data Data”

Surface Temperature Data Request

Master Polling Packet

0x54, 0x0D, 0x0A

ASCII equivalent: “T”

Slave Response

The slave response will be “T ” followed by four hex digits of data.

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The first hex digit is the most significant.

0x54, 0x20, most significant digit, digit, digit, least significant digit.

ASCII equivalent: “T Data Data Data Data”

Surface Battery Voltage Data Request

Master Polling Packet

0x42, 0x0D, 0x0A

ASCII equivalent: “B”

Slave Response

The slave response will be “B ” followed by four hex digits of data.

The first hex digit is the most significant.

0x42, 0x20, most significant digit, digit, digit, least significant digit.

ASCII equivalent: “B Data Data Data Data”

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