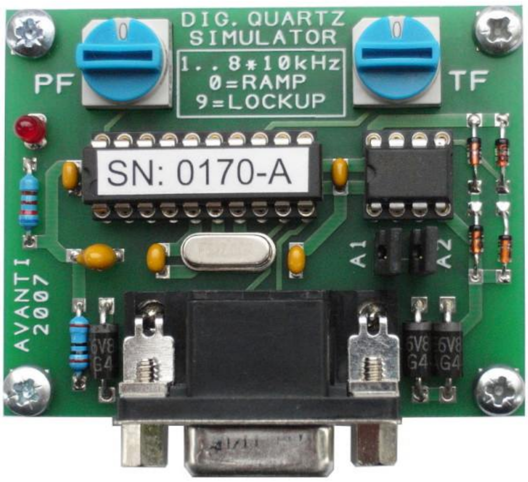
1. INTRODUCTION

The Avanti Digital Quartz Transducer Simulator substitutes a pressure/temperature transducer equipped with a two-wire serial I^{2}C interface. It was designed to be compatible with Quartzdyne's range of digital quartz pressure transducers and facilitates testing of data acquisition systems without the need for real transducers. The simulator also features a special error mode, which simulates erratic I^{2}C behaviour. This is useful for checking how well a data acquisition system recovers from a locked up I^{2}C bus and whether it can detect inconsistent data values.

In its latest implementation (model number AVA-02-A) the simulator supports the I^{2}C protocol enhancements introduced by Quartzdyne with ASIC V4.02 (and above). It is backward compatible with earlier versions.

2. HARDWARE DESCRIPTION

The simulator consists of a small standalone PCB (circa 50 x 60mm), containing a micro-controller and a serial EEPROM, which are both connected to the I^{2}C bus.
There are two rotary switches (labelled PF and TF) for setting pressure and temperature values and a LED, which flashes whenever the simulator has been polled successfully.
Two jumper links (labelled A1 and A2) are provided for setting the device address, allowing up to 4 devices on the same I^{2}C bus. The address lines are fitted with pull-up resistors and the jumpers make a connection to ground, i.e. a jumper inserted means the address line is low and a jumper removed means the address line is high. The address lines are also available externally via the 9-way D-type socket, so that alternatively the device address can be coded through ground connections on the host-board. The jumper links must be removed for this. The table below shows the pin-out of the D-type socket. The pin-out is also printed on the bottom side of the PCB. **Note that Quartzdyne transducer cables that are terminated with a D-type plug have a different pin-out.**



Pin-1	A1
Pin-2	SCL
Pin-3	GND
Pin-4	SDA
Pin-5	+VS (2.7V to 5.5V)
Pin-6	A2
Pin-7	GND
Pin-8	GND
Pin-9	GND

All external connections are over voltage and reverse voltage protected. However, in order to minimise the possibility of damage through ESD, unnecessary touching of component pins and PCB pads should be avoided.

3. I²C INTERFACE

With the introduction of their Digital ASIC in 2009 (V4.02), Quartzdyne made some enhancements to the I²C protocol. These include a checksum as a 5th byte when reading from the transducer, and the extension of the status/control register from a single byte to 4 bytes. These enhancements are backward compatible with earlier versions, i.e. a host system designed for an earlier transducer version will still work with the latest version.

Since 2010, the Avanti Transducer Simulator also supports the enhanced I²C protocol of V4.02 and later. Earlier simulators were based on Quartzdyne FPGA V3.02 and may be upgraded on request. Likewise, a new simulator may still be purchased with the older V3.02 firmware, should this be preferred (order as model AVA-02-F).

Old and new versions can be distinguished by their serial number. The old version serial number contains digits only (e.g. SN: 0123) while the new version is suffixed with an 'A' for ASIC (e.g. SN: 0123-A)

The Avanti Digital Quartz Transducer Simulator supports the following I²C commands. For details refer to the Quartzdyne Digital Transducer Programming Manual.

- Query the pressure counter. This returns a 32-bit pressure reading plus a check byte. Reading the check byte is optional. It may be used for validation of the pressure reading. In case a mismatch is found, the pressure value and the check byte can be read again, simply by continuing and reading 5 more bytes. When finished, the read access must be terminated by issuing an I²C STOP.

- Query the temperature counter. This returns a 32-bit temperature reading plus an optional check byte as above.

- Query the Version-ID. This returns a 32-bit version identifier plus an optional check byte as above.

- Query the status register. Up to 4 status bytes plus a check byte may be read as above, but in most applications only the information contained in the first status byte is of relevance (state of the pressure/temperature counters and the EEPROM write protection bit). The other 3 bytes are optional and have no function in the Avanti simulator, but must be included if the check byte is to be verified.

- Write to control register. Up to 4 control bytes may be written, but as above, only the first byte is of relevance in most applications. The first byte enables/disables the pressure and temperature counters and locks/unlocks the EEPROM write access. The other 3 bytes may be written, but are simply ignored by the Avanti simulator.

- Read/Write the serial EEPROM. The EEPROM is an independent device that shares the same I²C bus. The EEPROM is write protected by default and must be unlocked by writing to the control register, if its contents is to be changed. The EEPROM contains four redundant sets of coefficients at address locations 0...0xFF, 0x100...0x1FF, 0x200...0x2FF and 0x300...0x3FF.

The I²C bus was developed by Philips Semiconductors (now NXP) and its specification can be downloaded from their web-site. In its standard version the I²C bus allows a maximum clock/data frequency of 100kHz, i.e. minimum high and low times of clock and data lines must be observed by the master. The I²C protocol also specifies a mechanism called 'clock stretching', which allows slaves to slow down the bus to below 100kHz.

While in the actual Quartzdyne transducer the I²C interface is implemented in an FPGA or ASIC (i.e. entirely in hardware), the Avanti simulator employs a micro-controller with bit-level I²C support (i.e. a mixture of hardware and firmware). This means that the Avanti simulator is slightly less forgiving with respect to I²C timing issues. In particular 'clock stretching' must be recognised by the master if running at high speed. This happens automatically if the host-micro uses a dedicated I²C port. However, if the I²C interface in the host is 'bit-banged' using two ordinary port pins for SCL and SDA, the host firmware should check explicitly for 'clock stretching'. This is quite simple to implement: It only requires the host firmware to make sure the SCL line actually goes high whenever the SCL pin is set high and, if necessary, to wait for this to happen before proceeding.

4. VALUES RETURNED

Pressure and temperature values can be set independently by means of the two rotary switches. For positions 1...8 the returned value is the switch position multiplied by 10kHz, i.e. 10...80kHz. In switch position 0 a ramp is generated, which is repeated every 10 minutes. The pressure ramp starts at 30kHz and ramps upwards at a rate of 1Hz per second. The temperature ramp starts at 40kHz and ramps downwards at a rate of -1Hz per second. In switch position 9 the simulator runs in error mode, which generates regular I²C lockups and checksum errors (see paragraph 5 for details).

Switch Position	**PF**	**Raw-Pres returned**	**TF**	**Raw-Temp returned**
1	10000 Hz	0x005B05B1	10000 Hz	0x005B05B1
2	20000 Hz	0x00B60B61	20000 Hz	0x00B60B61
3	30000 Hz	0x01111111	30000 Hz	0x01111111
4	40000 Hz	0x016C16C1	40000 Hz	0x016C16C1
5	50000 Hz	0x01C71C72	50000 Hz	0x01C71C72
6	60000 Hz	0x02222222	60000 Hz	0x02222222
7	70000 Hz	0x027D27D4	70000 Hz	0x027D27D4
8	80000 Hz	0x02D82D84	80000 Hz	0x02D82D84
9	30000 Hz with regular I²C errors	0x01111111	40000 Hz with regular I²C errors	0x016C16C1
0	Ramp 30000...30600 Hz at 1Hz/sec => Sawtooth edge every 10 minutes	Ramp 0x01111111... 0x01168720	Ramp 40000...39400 Hz at -1Hz/sec => Sawtooth edge every 10 minutes	Ramp 0x016C16C1... 0x0166A0B1

The simulator is shipped with coefficients pre-loaded in the EEPROM. These coefficients were taken off a real transducer and therefore produce engineering values, which represent a typical Quartzdyne transducer. Only the serial number and the calibration date were modified to reflect the simulators serial number and date of manufacture. The following table shows the psi and °C values obtained with these coefficients:

PF TF	10kHz	20kHz	30kHz	40kHz	50kHz	60kHz	70kHz	80kHz
10kHz	-11421.63 psi 236.342 °C	-5648.515 psi 236.342 °C	-252.348 psi 236.342 °C	4842.551 psi 236.342 °C	9711.851 psi 236.342 °C	14431.22 psi 236.342 °C	19076.35 psi 236.342 °C	23722.88 psi 236.342 °C
20kHz	-8745.46 psi 194.991 °C	-3710.684 psi 194.991 °C	1101.552 psi 194.991 °C	5728.189 psi 194.991 °C	10206.17 psi 194.991 °C	14572.43 psi 194.991 °C	18863.92 psi 194.991 °C	23117.58 psi 194.991 °C
30kHz	-6871.39 psi 150.948 °C	-2371.768 psi 150.948 °C	2000.479 psi 150.948 °C	6262.484 psi 150.948 °C	10431.37 psi 150.948 °C	14524.28 psi 150.948 °C	18558.34 psi 150.948 °C	22550.67 psi 150.948 °C
40kHz	-5689.32 psi 98.854 °C	-1569.95 psi 98.854 °C	2476.813 psi 98.854 °C	6459.496 psi 98.854 °C	10386.63 psi 98.854 °C	14266.73 psi 98.854 °C	18108.34 psi 98.854 °C	21919.97 psi 98.854 °C
50kHz	-5089.159 psi 33.349 °C	-1243.407 psi 33.349 °C	2562.94 psi 33.349 °C	6333.302 psi 33.349 °C	10071.10 psi 33.349 °C	13779.75 psi 33.349 °C	17462.68 psi 33.349 °C	21123.30 psi 33.349 °C
60kHz	-4960.809 psi -50.927 °C	-1330.312 psi -50.927 °C	2291.249 psi -50.927 °C	5897.976 psi -50.927 °C	9483.968 psi -50.927 °C	13043.32 psi -50.927 °C	16570.13 psi -50.927 °C	20058.50 psi -50.927 °C
70kHz	-5194.183 psi -159.332 °C	-1768.852 psi -159.332 °C	1694.117 psi -159.332 °C	5167.578 psi -159.332 °C	8624.385 psi -159.332 °C	12037.38 psi -159.332 °C	15379.43 psi -159.332 °C	18623.38 psi -159.332 °C
80kHz	-5679.18 psi -297.226 °C	-2497.196 psi -297.226 °C	803.938 psi -297.226 °C	4156.19 psi -297.226 °C	7491.532 psi -297.226 °C	10741.93 psi -297.226 °C	13839.35 psi -297.226 °C	16715.77 psi -297.226 °C

When queried for the Version-ID, the simulator returns the value 0x0D090403, which reads as Quartzdyne Digital ASIC V4.03.

5. ERROR MODE

The Avanti simulator implements two error conditions when in error mode: I²C lockup and checksum error.

<u>a) I²C Lockup</u>

The Philips/NXP I²C specification doesn't include any timeout mechanism. It is the responsibility of the I²C master to recover from conditions, where the I²C sequence has gone out of synch. This may happen if electrical noise is coupled into the SDA/SCL lines, or if the I²C master is reset while an I²C transfer is in progress, e.g. by a watchdog timer. Also, some of the earlier Quartzdyne transducers didn't always power up in the correct I²C state. This can lead to a situation where the SDA line is stuck low, preventing the master from generating a START or STOP. The I²C bus appears to be locked.

The master can overcome this situation by issuing 9 clock pulses while SDA is released. After a maximum of 9 cycles the slave reaches the point where it reads the acknowledgement from SDA. Since SDA is released, the slave reads this as a NACK and terminates. The master should then finish with a STOP.

The operation of such a bus recovery procedure can be checked by setting the simulator into error mode. If the pressure switch is set to position 9, the simulator locks SDA low after every 10^{th} pressure query. Likewise, if the temperature switch is set to position 9, the simulator locks up after every 10^{th} temperature query.

The 10^{th} query itself is not affected and returns the correct result. However, the simulator ignores the NACK and the STOP at the end of the transfer and expects the master to clock out further data bits. The simulator is in a state as if it were interrupted during a read access, just after putting data bit-6 onto the bus. The data byte is assumed to be 0x0C (00001100), and therefore SDA is held low. A minimum of 7 clock pulses are required to clock out the remaining data bits and assert a NACK. Additional clock pulses after the NACK have no effect.

If both switches (pressure AND temperature) are in position 9, the simulator not only locks up after every 10^{th} pressure and every 10^{th} temperature query, but also powers up in a locked up state. Here the simulator assumes a data byte value of 0x0D (00001101) with SDA stuck at bit-5.

While SDA is stuck low, the simulator turns on the LED. If the I²C master in the host controller is implemented properly, it will be able to unlock a stuck I²C bus and no data loss or data corruption should occur.

b) Checksum Error

If the pressure switch and the temperature switch are both set to position 9, the simulator creates additional data errors every 30sec, which result in an invalid checksum. The data error may occur during a pressure query or a temperature query, whichever is the first after the 30sec error timer has elapsed.

In case of a data error, the MSByte of a pressure or temperature query is returned as 0x00 instead of 0x01. This shows up as a pressure frequency of 1875Hz instead of 30000Hz or a temperature frequency of 11875Hz instead of 40000Hz.

If the host controller reads and verifies the checksum it will detect a mismatch and read the data bytes again. On the second attempt the data is returned correctly and the checksum is valid.

Since earlier versions of digital Quartzdyne transducers (prior to V4.02) do not return a checksum, the host controller should first check the transducer's revision code by reading the identifier, and then take action accordingly.

6. ACKNOWLEDGEMENTS AND FURTHER INFORMATION

Quartzdyne is a trademark of Quartzdyne Inc.
Information on their range of digital pressure transducers can be downloaded from their web-site at http://www.quartzdyne.com
The following documents are of particular interest:
DigitalTransSpec.pdf - Digital Quartz Pressure Transducer Specifications
DigitalTransProg.pdf - Digital Transducer Programming Manual

I²C is a trademark of NXP Semiconductors (formerly Philips).
Specifications and application notes can be downloaded from their web-site at http://www.nxp.com
The following documents are of particular interest:
i2c.bus.specification.pdf - I²C Specification and User Manual Rev.03 / 2007
i2cbits.zip - Software Implemented I2C Drivers ('bit-banged')

Avanti Part Number: AVA-02-A Avanti Serial Number:

Tested: