89BSD CALCULATION METHOD

APPLICATION NOTE

FUNCTIONAL DESCRIPTION

GENERAL

The 89BSD consists of a piezoresistive sensor and a sensor interface IC. The main function of the sensor interface IC is to convert the uncompensated analogue output voltage from the piezoresistive pressure sensor to a 24-bit digital value, as well as providing a 24-bit digital value for the temperature of the sensor.

FACTORY CALIBRATION

Every module is individually factory calibrated at seven points of various temperature and pressures. As a result, 10 coefficients necessary to compensate for process variations and temperature variations are calculated and stored in the 128-bit PROM of each module. These bits partitioned into 7 pressure coefficients (C0 to C6) and 3 temperature (A0 to A2) which must be read by the microcontroller software and used in the program converting D1 and D2 into compensated pressure and temperature values.

I^2C mode

The external microcontroller clocks in the data through the input SCLK (Serial Clock) and SDA (Serial Data). The sensor responds on the same pin SDA which is bidirectional for the I^2C bus interface. So this interface type uses only 2 signal lines and does not require a chip select, which can be favorable to reduce board space. In I^2C-Mode the complement of the pin CSB (Chip Select) represents the LSB of the I^2C address.

	Address (7 bits)
CSB PIN	0x77 (1110111 b)

Commands

The 89BSD has only five basic commands:

1. Reset
2. Read PROM (128 bit of calibration words)
3. D1 conversion
4. D2 conversion
5. Read ADC result (24 bit pressure / temperature)

Size of each command is 1 byte (8 bits) as described in the table below. After ADC read commands the device will return 24 bit result and after the PROM read 16bit result. The address of the PROM is embedded inside of the PROM read command using the a2, a1 and a0 bits.

	Command byte								hex value
Bit number	0	1	2	3	4	5	6	7	
Bit name	PRM	COV	-	Type	Ad2/Os2	Ad1/Os1	Ad0/Os0	Stop	
Command									
Reset	0	0	0	1	1	1	1	0	0x1E
Convert D1 (OSR=256)	0	1	0	0	0	0	0	0	0x40
Convert D1 (OSR=512)	0	1	0	0	0	0	1	0	0x42
Convert D1 (OSR=1024)	0	1	0	0	0	1	0	0	0x44
Convert D1 (OSR=2048)	0	1	0	0	0	1	1	0	0x46
Convert D1 (OSR=4096)	0	1	0	0	1	0	0	0	0x48
Convert D2 (OSR=256)	0	1	0	1	0	0	0	0	0x50
Convert D2 (OSR=512)	0	1	0	1	0	0	1	0	0x52
Convert D2 (OSR=1024)	0	1	0	1	0	1	0	0	0x54
Convert D2 (OSR=2048)	0	1	0	1	0	1	1	0	0x56
Convert D2 (OSR=4096)	0	1	0	1	1	0	0	0	0x58
ADC Read	0	0	0	0	0	0	0	0	0x00
PROM Read	1	0	1	0	Ad2	Ad1	Ad0	0	0xA0 to 0xAE

Figure 1: Command structure

CONVERSION SEQUENCE

The conversion command is used to initiate uncompensated pressure (D1) or uncompensated temperature (D2) conversion. The chip select can be disabled during this time to communicate with other devices.
After the conversion, using ADC read command the result is clocked out with the MSB first. If the conversion is not executed before the ADC read command, or the ADC read command is repeated, it will give 0 as the output result. If the ADC read command is sent during conversion the result will be 0, the conversion will not stop and the final result will be wrong. Conversion sequence sent during the already started conversion process will yield incorrect result as well.

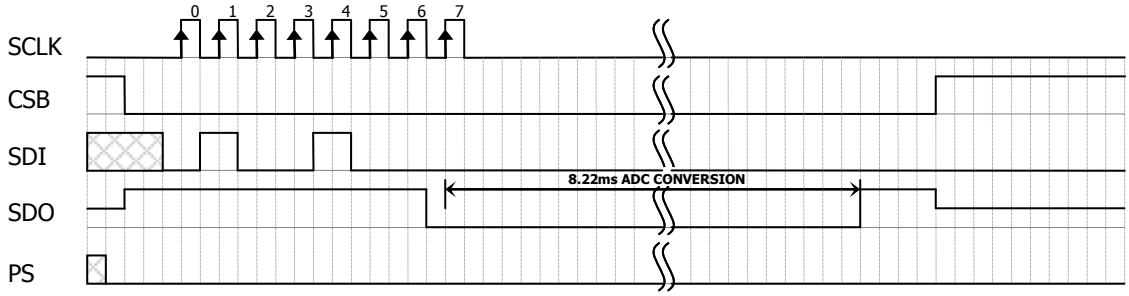

Figure 2: Conversion out sequence, Type=d1, OSR = 4096

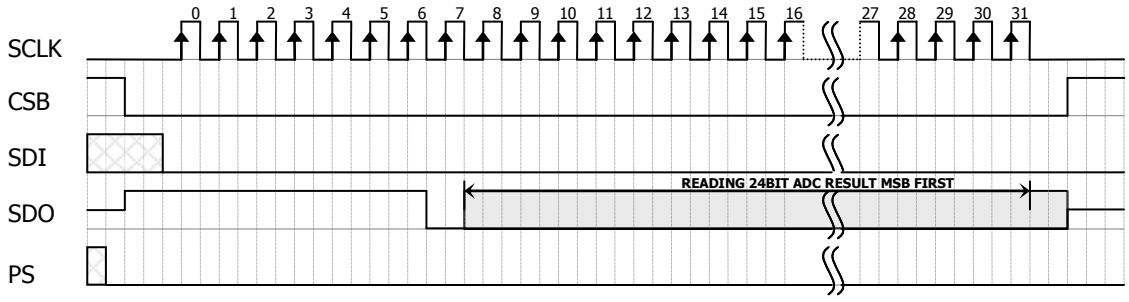

Figure 3: ADC Read sequence

PROM READ SEQUENCE

The read command for PROM shall be executed once after reset by the user to read the content of the calibration PROM and to calculate the calibration coefficients. There are in total 8 addresses resulting in a total memory of 128 bit. Address 0 contains factory data and the setup, addresses 1-6 calibration coefficients and address 7 contains the serial code and CRC. The command sequence is 8 bits long with a 16 bit result which is clocked with the MSB first.

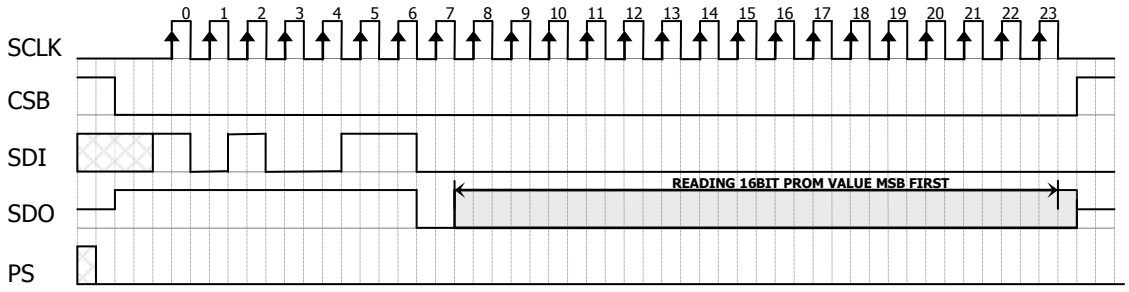

Figure 4: PROM Read sequence, address = 011 (Coefficient 3).

I2C INTERFACE

COMMANDS

Each I²C communication message starts with the start condition and it is ended with the stop condition. The 89BSD address is 111011Cx, where C is the complementary value of the pin CSB.

Reset sequence

The reset can be sent at any time. In the event that there is not a successful power on reset this may be caused by the SDA being blocked by the module in the acknowledge state. The only way to get the 89BSD to function is to send several SCLKs followed by a reset sequence or to repeat power on reset.

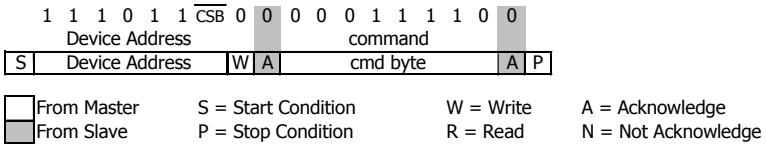

Figure 5: I²C Reset Command

Conversion sequence

A conversion can be started by sending the command to 89BSD. When command is sent to the system it stays busy until conversion is done. When conversion is finished the data can be accessed by sending a Read command, when an acknowledge appears from the 89BSD 24 SCLK cycles may be sent to receive all result bits. Every 8 bit the system waits for an acknowledge signal.

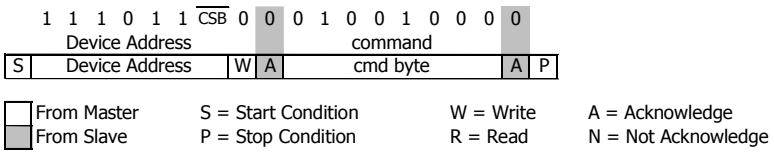

Figure 6: I²C Command to initiate a pressure conversion (OSR=4096, type=D1)

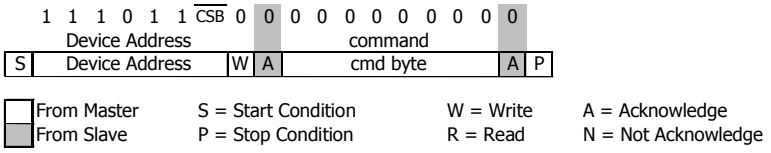

Figure 7: I²C ADC read sequence

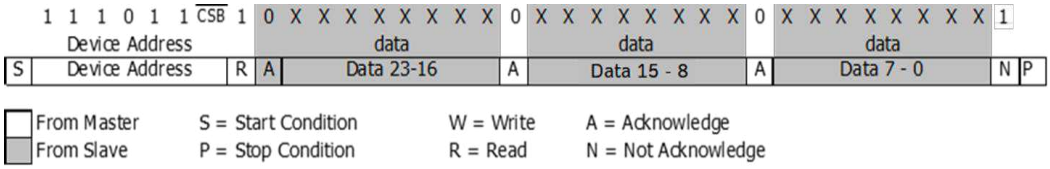

Figure 8: I²C pressure response (D1) on 24 bits from 89BSD

PROM Read Sequence

The PROM Read command consists of two parts. First command sets up the system into PROM read mode. The second part gets the data from the system.

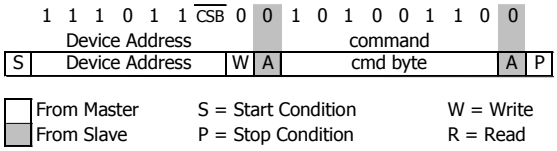

Figure 9: I²C Command to read memory address= 011 (Coefficient 3)

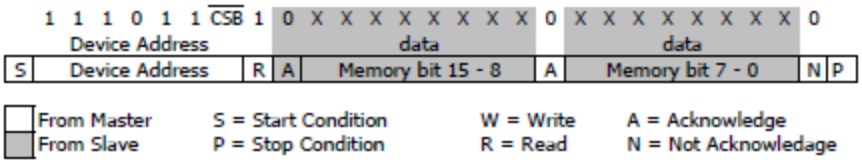

Figure 10: I²C answer from 89BSD

CYCLIC REDUNDANCY CHECK (CRC)

89BSD contains a PROM memory with 128-Bit. A 4-bit CRC has been implemented to check the data validity in memory. The application note AN520 describes in detail CRC-4 code used.

PRESSURE AND TEMPERATURE CALCULATION

Start
Maximum values for calculation results:
P_{MIN}= 0 barA, P_{MAX}=Product pressure
(e.g. for 89BSD-012BA, P_{MAX}=12barA)
T_{MIN} = -20°C T_{MAX} = 85°C

Read calibration data (factory calibrated) from PROM [2]

Variable	Description | Equation	Recommended Variable Type	Size [1] [Bit]	Value Min	Value Max	Example / Typical
C0	Bridge Offset	Signed int 16	14	-8192	8192	-5242
C1	Gain	Signed int 16	14	-8192	8192	4172
C2	Non-linearity 2nd order	Signed int 16	10	-512	512	80
C3	Temperature coefficient, Bridge offset 1st order	Signed int 16	10	-512	512	-77
C4	Temperature coefficient, Bridge offset 2nd order	Signed int 16	10	-512	512	67
C5	Temperature coefficient, Gain 1st order	Signed int 16	10	-512	512	-210
C6	Temperature coefficient, Gain 2nd order	Signed int 16	10	-512	512	222
A0	Temperature coefficient 1 of the temperature	Signed int 16	10	-512	512	-276
A1	Temperature coefficient 2 of the temperature	Signed int 16	10	-512	512	360
A2	Temperature coefficient 3 of the temperature	Signed int 16	10	-512	512	-190

Read digital pressure and temperature data

D1	Digital pressure value	Unsigned long	24	0	16777216	8128896
D2	Digital temperature value	Unsigned long	24	0	16777216	2865097

Calculate temperature

TEMP	Actual temperature (-20…85℃ with 0.01℃ resolution) $TEMP=A0/3+A1*2*D2/2^{24}+A2*2*(D2/2^{24})^2$	Double	32			19.87℃

Note: Earlier iterations of this product used formula TEMP = A0/5+A1...

Calculate temperature compensated pressure

Y	$Y=(D1+C0*2^{Q0}+C3*2^{Q3}*D2/2^{24}+C4*2^{Q4}*(D2/2^{24})^2)$ $/(C1*2^{Q1}+C5*2^{Q5}*D2/2^{24}+C6*2^{Q6}*(D2/2^{24})^2)$	Double	32			0.7673
P	$P=Y*(1-C2*2^{Q2}/2^{24}) + C2*2^{Q2}/2^{24}*Y^2$	Double	32			0.7669
Pressure	$Pressure= (P-0.1)/0.8*(P_{MAX}-P_{MIN}) + P_{MIN}$	Double	32			10.003

Display pressure and temperature value

Figure 11: Flow chart for pressure and temperature reading and software compensation.

MEMORY MAPPING [2]

Memory mapping

Address	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	$C0_{13}$	$C0_{12}$	$C0_{11}$	$C0_{10}$	$C0_{09}$	$C0_{08}$	$C0_{07}$	$C0_{06}$	$C0_{05}$	$C0_{04}$	$C0_{03}$	$C0_{02}$	$C0_{01}$	$C0_{00}$	$C1_{13}$	$C1_{12}$
2	$C1_{11}$	$C1_{10}$	$C1_{09}$	$C1_{08}$	$C1_{07}$	$C1_{06}$	$C1_{05}$	$C1_{04}$	$C1_{03}$	$C1_{02}$	$C1_{01}$	$C1_{00}$	$C2_{09}$	$C2_{08}$	$C2_{07}$	$C2_{06}$
3	$C2_{05}$	$C2_{04}$	$C2_{03}$	$C2_{02}$	$C2_{01}$	$C2_{00}$	$C3_{09}$	$C3_{08}$	$C3_{07}$	$C3_{06}$	$C3_{05}$	$C3_{04}$	$C3_{03}$	$C3_{02}$	$C3_{01}$	$C3_{00}$
4	$C4_{09}$	$C4_{08}$	$C4_{07}$	$C4_{06}$	$C4_{05}$	$C4_{04}$	$C4_{03}$	$C4_{02}$	$C4_{01}$	$C4_{00}$	$C5_{09}$	$C5_{08}$	$C5_{07}$	$C5_{06}$	$C5_{05}$	$C5_{04}$
5	$C5_{03}$	$C5_{02}$	$C5_{01}$	$C5_{00}$	$C6_{09}$	$C6_{08}$	$C6_{07}$	$C6_{06}$	$C6_{05}$	$C6_{04}$	$C6_{03}$	$C6_{02}$	$C6_{01}$	$C6_{00}$	$A0_{09}$	$A0_{08}$
6	$A0_{07}$	$A0_{06}$	$A0_{05}$	$A0_{04}$	$A0_{03}$	$A0_{02}$	$A0_{01}$	$A0_{00}$	$A1_{09}$	$A1_{08}$	$A1_{07}$	$A1_{06}$	$A1_{05}$	$A1_{04}$	$A1_{03}$	$A1_{02}$
7	$A1_{01}$	$A1_{00}$	$A2_{09}$	$A2_{08}$	$A2_{07}$	$A2_{06}$	$A2_{05}$	$A2_{04}$	$A2_{03}$	$A2_{02}$	$A2_{01}$	$A2_{00}$	CRC			

Figure 12: Memory mapping.

Q FACTOR

Q factor for temperature Compensated pressure calculation

Q0	9
Q1	11
Q2	9
Q3	15
Q4	15
Q5	16
Q6	16

Notes
[1] Maximal size of intermediate result during evaluation of variable
[2] All coefficients are 2's complement format

APPLICATION CIRCUIT

The 89BSD is a circuit that is to be used in conjunction with a microcontroller and a 3V DC supply.

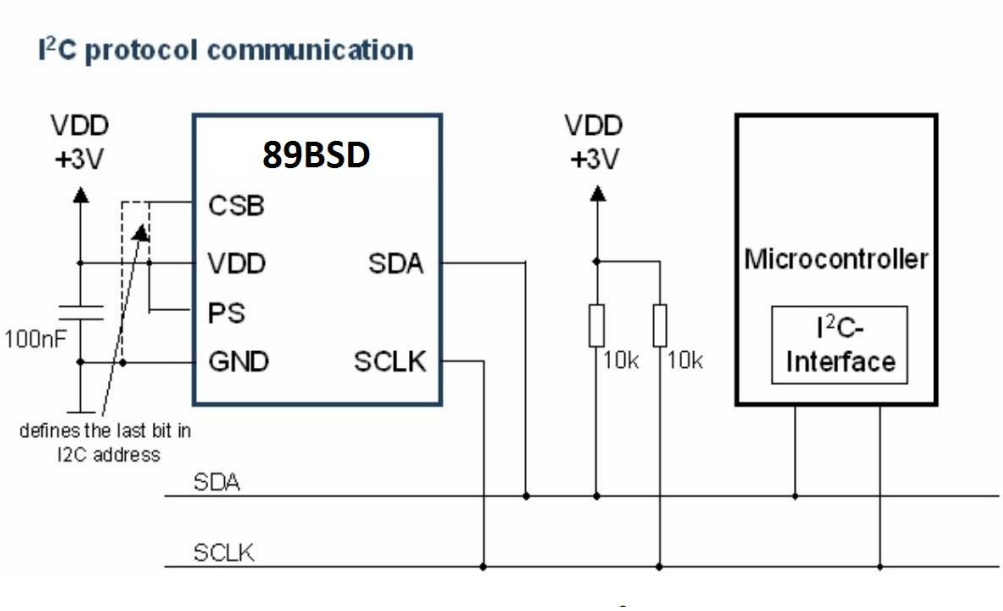

Figure 13: Typical application circuit for I²C protocol communication

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