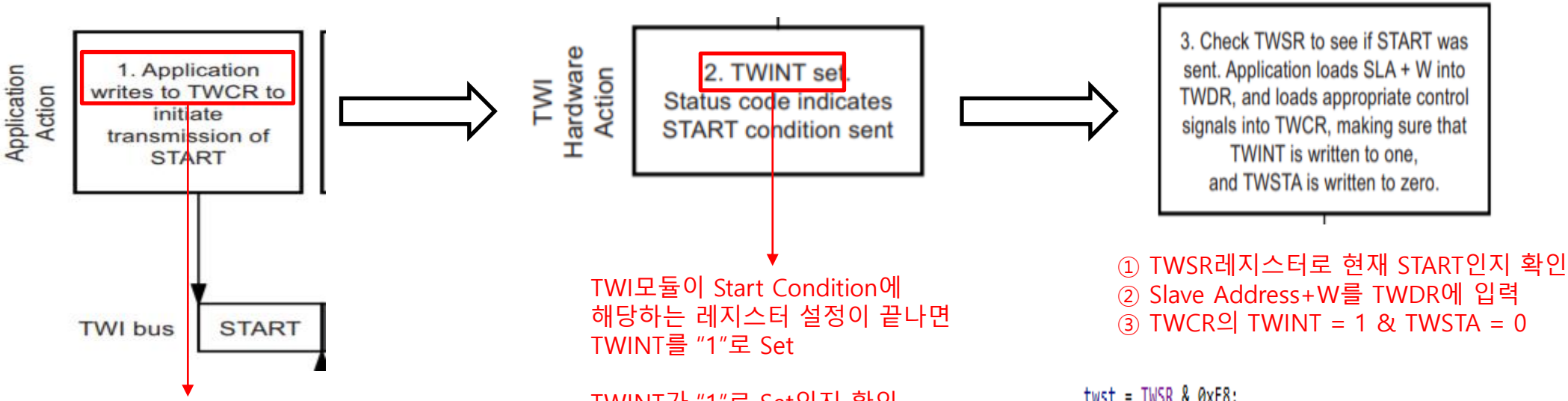
AVR - HW9

임베디드스쿨1기
Lv1과정
2020. 11. 06
손표훈

1. I2C통신-마스터 송신

(1) START Condition : Slave에 통신 시작을 알림.



Start Condition에 해당하는
TWCR레지스터 설정을 해야함

```
TWCR = (1<<TWINT) | (1<<TWSTA) | (1<<TWEN);
```

TWI모듈이 Start Condition에
해당하는 레지스터 설정이 끝나면
TWINT를 "1"로 Set

TWINT가 "1"로 Set인지 확인

```
while(!(TWCR & (1<<TWINT)));
```

① TWSR레지스터로 현재 START인지 확인
② Slave Address+W를 TWDR에 입력
③ TWCR의 TWINT = 1 & TWSTA = 0

```
twst = TWSR & 0xF8;
```

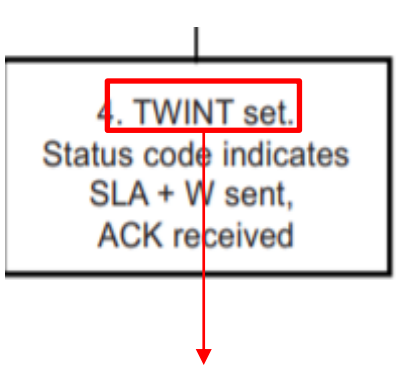
```
if((twst != TW_START) && (twst != TW_RESTART)) return 1;
```

0x08	A START condition has been transmitted

```
TWDR = address;
TWCR = (1<<TWINT) | (1<<TWEN);
```

1. I2C통신-마스터 송신

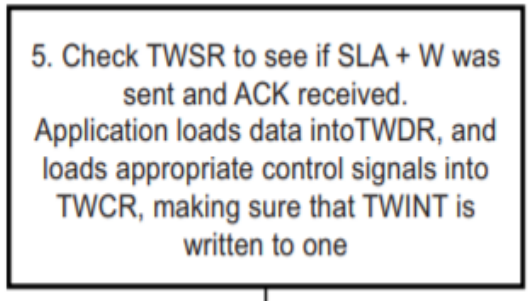
(1) START Condition : Slave에 통신 시작을 알림.



① Start Condition과 마찬가지로
Slave Address와 Write 명령이
송신이 되면 TWINT가 Set된다.

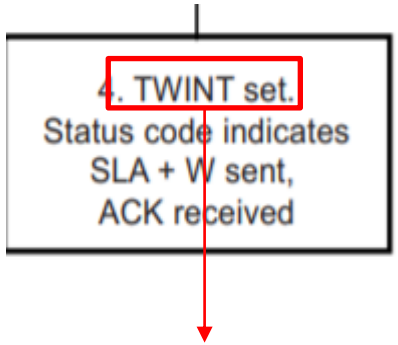
② Slave로 부터 ACK Bit를 수신한다.

```
while(!(TWCR & (1<<TWINT)));
```




```
twst = TWSR & 0xF8;
if((twst != TWI_MT_SLA_ACK) && (twst != TWI_MR_SLA_NACK)) return 1;
```

0x18	SLA+W has been transmitted; ACK has been received



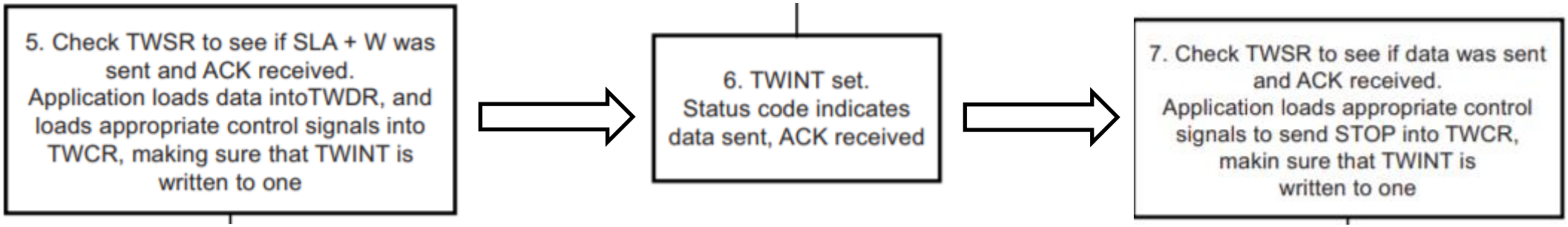
① Start Condition과 마찬가지로
Slave Address와 Write 명령이
송신이 되면 TWINT가 Set된다.

② Slave로 부터 ACK Bit를 수신한다.

```
while(!(TWCR & (1<<TWINT)));
```

1. I2C통신-마스터 송신

(1) Write Data: Slave에 Data를 송신한다.



① TWSR을 통해 Slave에서 송신한 ACK를 확인

② Slave에 송신할 Data를 TWDR에 입력한다.

① 전송이 완료되면 TWINT가 Set
② Slave에서 ACK Bit를 송신한다.

① TWSR을 통해 ACK Bit를 확인
② Slave로 부터 Data를 수신받거나 TWSR의 ACK를 확인한 후 STOP 또는 Restart를 통해 그 다음 Slave에 데이터를 보낼 준비를 한다.

```
twst = TWSR & 0xF8;
if((twst != TWI_MT_SLA_ACK) && (twst != TWI_MR_SLA_NACK)) return 1;
```

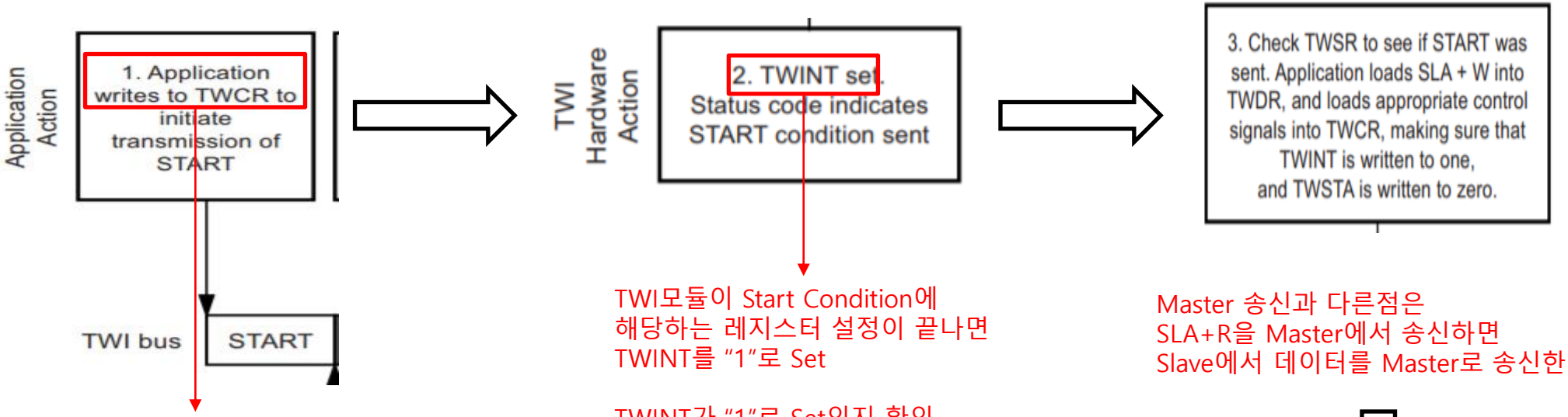
0x18	SLA+W has been transmitted; ACK has been received

0x28	Data byte has been transmitted; ACK has been received

```
TWDR = data;
TWCR = (1<<TWINT) | (1<<TWEN);
```

1. I2C통신-마스터 수신

(2) Read Data: Slave에서 Master로 데이터 송신.



Start Condition에 해당하는
TWCR레지스터 설정을 해야함

```
TWCR = (1<<TWINT) | (1<<TWEN) | (1<<TWEA);
```

TWI모듈이 Start Condition에
해당하는 레지스터 설정이 끝나면
TWINT를 "1"로 Set

TWINT가 "1"로 Set인지 확인

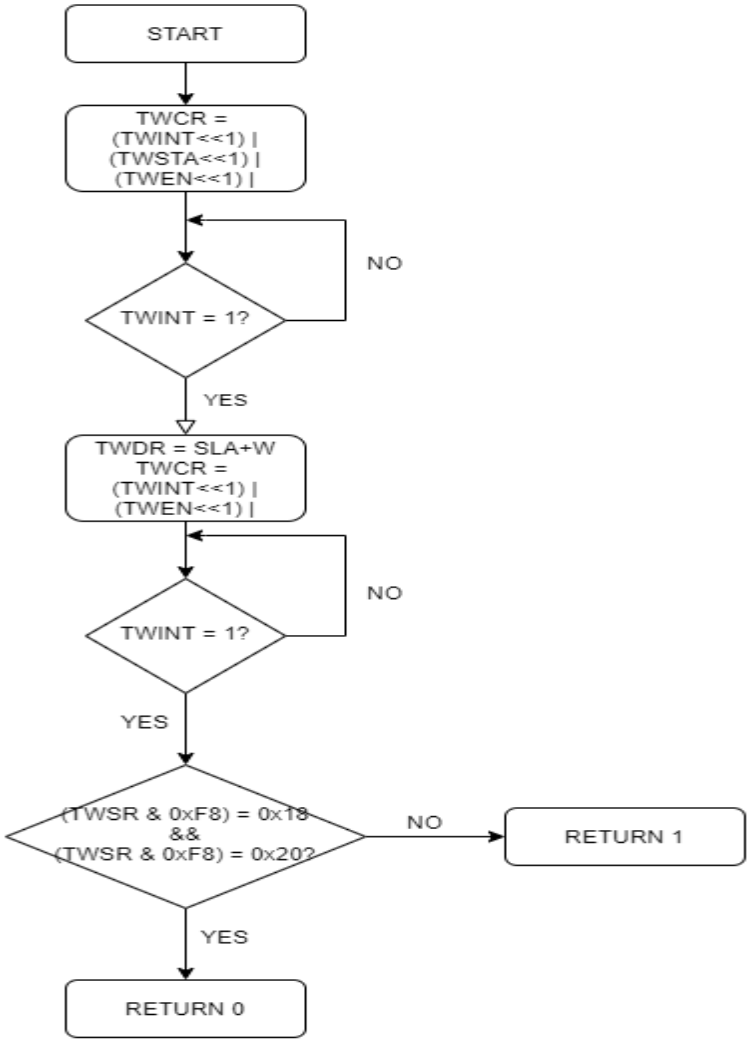
```
while(!(TWCR & (1<<TWINT)));
```

Master 송신과 다른점은
SLA+R을 Master에서 송신하면
Slave에서 데이터를 Master로 송신한다.

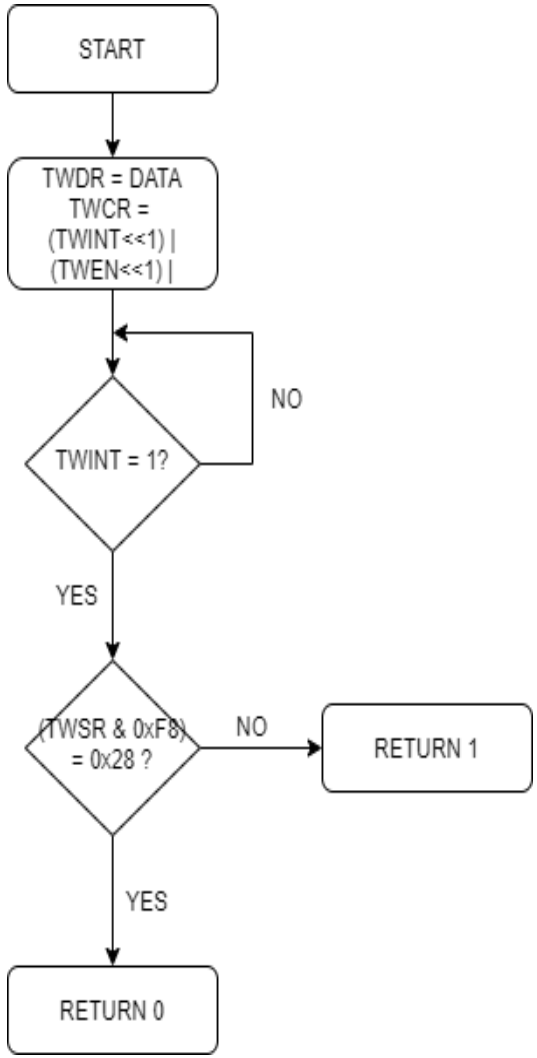
Master에서 TWDR의 Slave 데이터를 읽는다.

1. I2C통신-마스터 수신

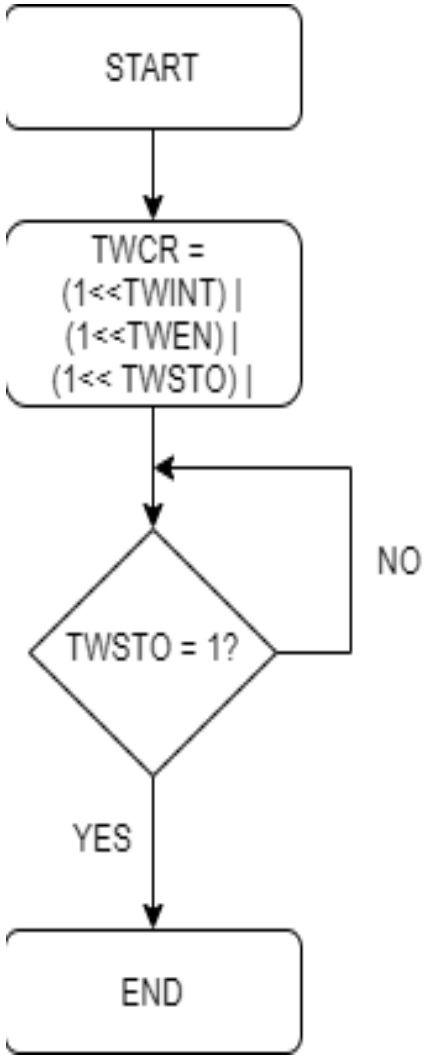
(3) I2C Flow Chart



I2C START Condition



I2C WRITE Condition



I2C Stop Condition

2. MS5611 기압센서

(1) MS5611? 기압센서로 내장된 온도센서와 압력센서를 통해 온도와 압력 값을 Analog to Digital 변환을 하여 I2C와 SPI 인터페이스를 가진 기압센서다.

측정가능 기압범위

Data 크기

분해능

오차범위

측정가능 온도범위

분해능

TECHNICAL DATA

Sensor Performances (V_{DD} = 3 V)				
Pressure	**Min**	**Typ**	**Max**	**Unit**
Range	10		1200	mbar
ADC		24		bit
Resolution (1)		0.065 / 0.042 / 0.027 / 0.018 / 0.012		mbar
Accuracy 25°C, 750 mbar	-1.5		+1.5	mbar
Error band, -20°C to +85°C, 450 to 1100 mbar (2)	-2.5		+2.5	mbar
Response time (1)		0.5 / 1.1 / 2.1 / 4.1 / 8.22		ms
Long term stability		±1		mbar/yr
Temperature	**Min**	**Typ**	**Max**	**Unit**
Range	-40		+85	°C
Resolution		<0.01		°C
Accuracy	-0.8		+0.8	°C
Notes: (1) Oversampling Ratio: 256 / 512 / 1024 / 2048 / 4096 (2) With autozero at one pressure point				

ELECTRICAL CHARACTERISTICS

Parameter	Symbol	Conditions	Min.	Typ.	Max	Unit
Operating Supply voltage	V_{DD}		1.8	3.0	3.6	V
Operating Temperature	T		-40	+25	+85	°C
Supply current (1 sample per sec.)	I_{DD}	OSR 4096		12.5		µA
		OSR 2048		6.3		
		OSR 1024		3.2		
		OSR 512		1.7		
		OSR 256		0.9		
Peak supply current		during conversion		1.4		mA
Standby supply current		at 25°C		0.02	0.14	µA
VDD Capacitor		From VDD to GND	100			nF

2. MS5611 기압센서

ANALOG DIGITAL CONVERTER (ADC)

Parameter	Symbol	Conditions	Min.	Typ.	Max	Unit
Output Word				24		bit
Conversion time	t_c	OSR 4096	7.40	8.22	9.04	ms
		2048	3.72	4.13	4.54	
		1024	1.88	2.08	2.28	
		512	0.95	1.06	1.17	
		256	0.48	0.54	0.60	

PRESSURE OUTPUT CHARACTERISTICS (V_{DD} = 3 V, T = 25°C UNLESS OTHERWISE NOTED)

Parameter	Conditions		Min.	Typ.	Max	Unit
Operating Pressure Range	P_{range}	Full Accuracy	450		1100	mbar
Extended Pressure Range	P_{ext}	Linear Range of ADC	10		1200	mbar
Total Error Band, no autozero	at 25°C, 700..1100 mbar at 0..50°C, 450..1100 mbar at -20..85°C, 450..1100 mbar at -40..85°C, 450..1100 mbar		-1.5 -2.0 -3.5 -6.0		+1.5 +2.0 +3.5 +6.0	mbar
Total Error Band, autozero at one pressure point	at 25°C, 700..1100 mbar at 10..50°C, 450..1100 mbar at -20..85°C, 450..1100 mbar at -40..85°C, 450..1100 mbar		-0.5 -1.0 -2.5 -5.0		+0.5 +1.0 +2.5 +5.0	mbar
Maximum error with supply voltage	V_{DD} = 1.8 V ... 3.6 V			±2.5		mbar
Long-term stability				±1		mbar/yr
Recovering time after reflow (1)				7		days
Resolution RMS	OSR	4096		0.012		mbar
		2048		0.018		
		1024		0.027		
		512		0.042		
		256		0.065		

(1) Time to recovering at least 66% of the reflow impact

0.012mbar/1LSB

TEMPERATURE OUTPUT CHARACTERISTICS (V_{DD} = 3 V, T = 25°C UNLESS OTHERWISE NOTED)

Parameter	Conditions		Min.	Typ.	Max	Unit
Absolute Accuracy	at 25°C -20..85°C -40..85°C		-0.8 -2.0 -4.0		+0.8 +2.0 +4.0	°C
Maximum error with supply voltage	V_{DD} = 1.8 V ... 3.6 V			±0.5		°C
Resolution RMS	OSR	4096		0.002		°C
		2048		0.003		
		1024		0.005		
		512		0.008		
		256		0.012		

0.002°C/1LSB

2. MS5611 기압센서

ANALOG DIGITAL CONVERTER (ADC)

Parameter	Symbol	Conditions	Min.	Typ.	Max	Unit
Output Word				24		bit
Conversion time	t_c	OSR 4096	7.40	8.22	9.04	ms
		2048	3.72	4.13	4.54	
		1024	1.88	2.08	2.28	
		512	0.95	1.06	1.17	
		256	0.48	0.54	0.60	

PRESSURE OUTPUT CHARACTERISTICS (V_{DD} = 3 V, T = 25°C UNLESS OTHERWISE NOTED)

Parameter	Conditions		Min.	Typ.	Max	Unit
Operating Pressure Range	P_{range}	Full Accuracy	450		1100	mbar
Extended Pressure Range	P_{ext}	Linear Range of ADC	10		1200	mbar
Total Error Band, no autozero	at 25°C, 700..1100 mbar at 0..50°C, 450..1100 mbar at -20..85°C, 450..1100 mbar at -40..85°C, 450..1100 mbar		-1.5 -2.0 -3.5 -6.0		+1.5 +2.0 +3.5 +6.0	mbar
Total Error Band, autozero at one pressure point	at 25°C, 700..1100 mbar at 10..50°C, 450..1100 mbar at -20..85°C, 450..1100 mbar at -40..85°C, 450..1100 mbar		-0.5 -1.0 -2.5 -5.0		+0.5 +1.0 +2.5 +5.0	mbar
Maximum error with supply voltage	V_{DD} = 1.8 V ... 3.6 V			±2.5		mbar
Long-term stability				±1		mbar/yr
Recovering time after reflow (1)				7		days
Resolution RMS	OSR	4096		0.012		mbar
		2048		0.018		
		1024		0.027		
		512		0.042		
		256		0.065		

(1) Time to recovering at least 66% of the reflow impact

0.012mbar/1LSB

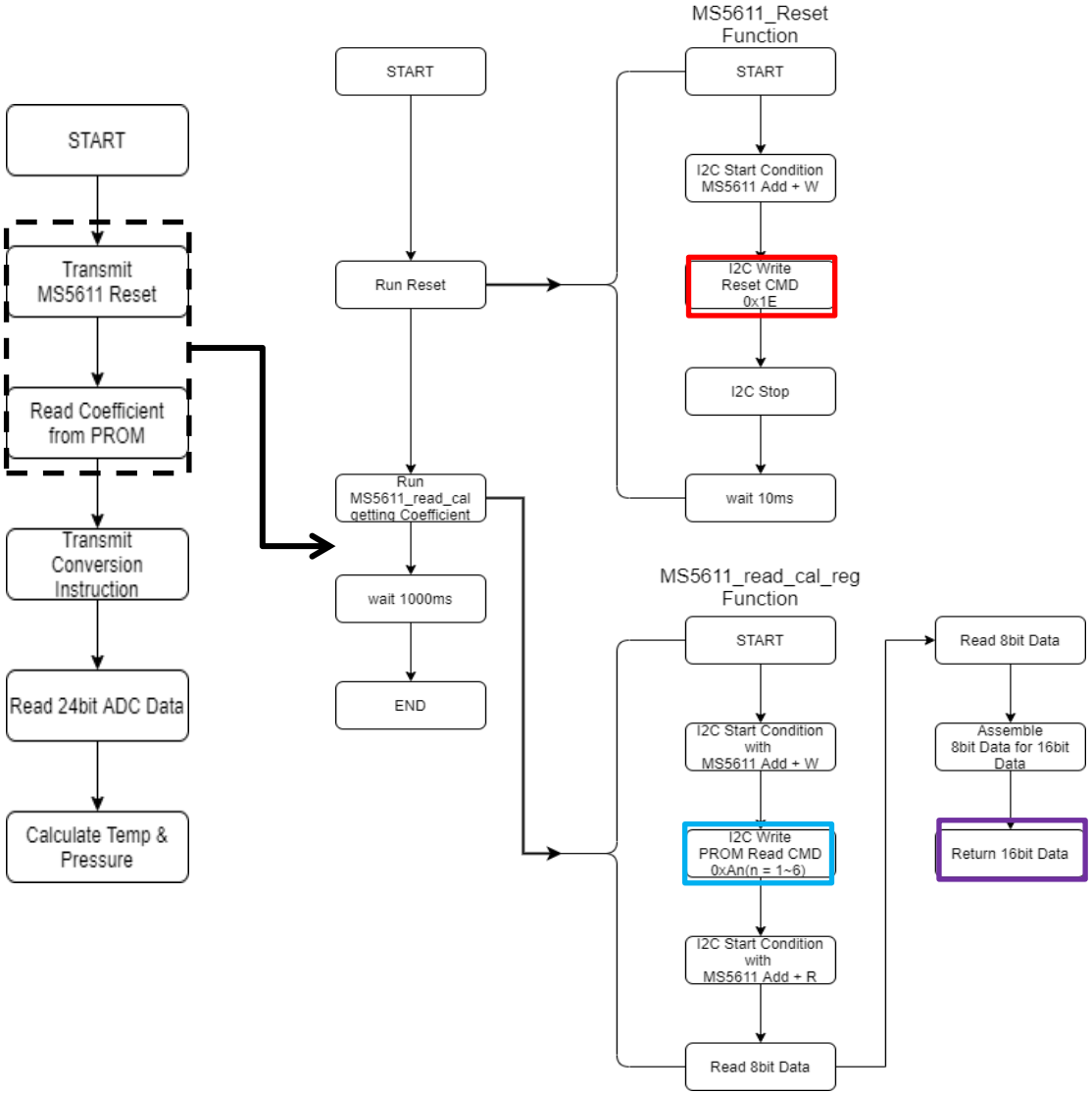
TEMPERATURE OUTPUT CHARACTERISTICS (V_{DD} = 3 V, T = 25°C UNLESS OTHERWISE NOTED)

Parameter	Conditions		Min.	Typ.	Max	Unit
Absolute Accuracy	at 25°C -20..85°C -40..85°C		-0.8 -2.0 -4.0		+0.8 +2.0 +4.0	°C
Maximum error with supply voltage	V_{DD} = 1.8 V ... 3.6 V			±0.5		°C
Resolution RMS	OSR	4096		0.002		°C
		2048		0.003		
		1024		0.005		
		512		0.008		
		256		0.012		

0.002°C/1LSB

2. MS5611 기압센서

(2) MS5611제어-Reset & Coefficient Data 수신



	Command byte								hex value
Bit number	0	1	2	3	4	5	6	7	
Bit name	PRM	COV	-	Typ	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

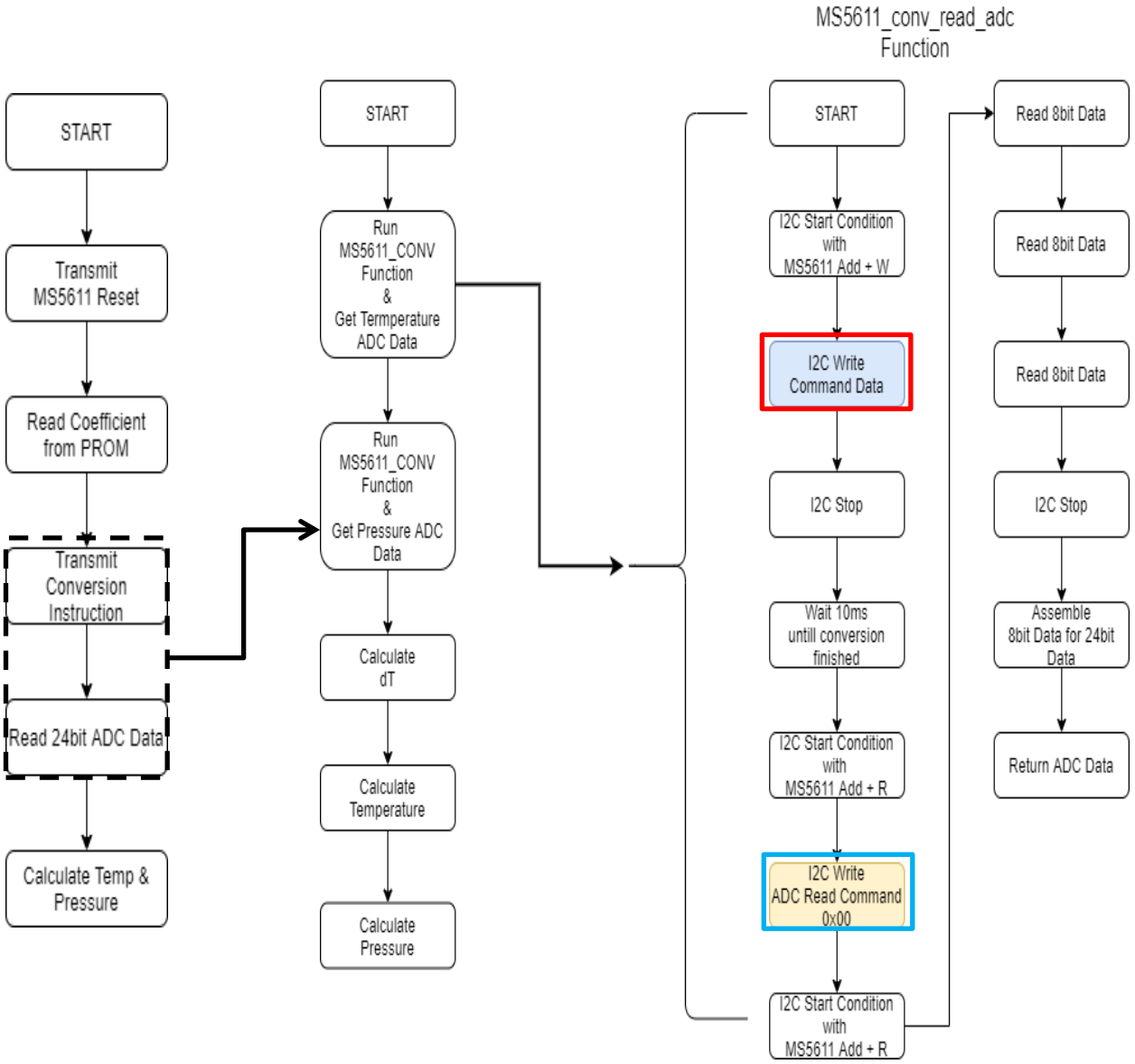
Figure 4: Command structure

Add	DB15	DB14	DB13	DB12	DB11	DB10	DB9	DB8	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	16 bit reserved for manufacturer															
1	Coefficient 1 (16 bit unsigned)															
2	Coefficient 2 (16 bit unsigned)															
3	Coefficient 3 (16 bit unsigned)															
4	Coefficient 4 (16 bit unsigned)															
5	Coefficient 5 (16 bit unsigned)															
6	Coefficient 6 (16 bit unsigned)															
7														CRC		

Figure 16: Memory PROM mapping

2. MS5611 기압센서

(2) MS5611제어-ADC데이터 및 온도&압력 값 계산



	Command byte								hex value
Bit number	0	1	2	3	4	5	6	7	
Bit name	PRM	COV	-	Typ	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 4: Command structure

2. MS5611 기압센서

(2) MS5611제어-온도&압력 값 계산

Read calibration data (factory calibrated) from PROM

Variable	Description | Equation	Recommended variable type	Size [1] [bit]	Value min	Value max	Example / Typical
C1	Pressure sensitivity | $SENS_{T1}$	unsigned int 16	16	0	65535	40127
C2	Pressure offset | OFF_{T1}	unsigned int 16	16	0	65535	36924
C3	Temperature coefficient of pressure sensitivity | TCS	unsigned int 16	16	0	65535	23317
C4	Temperature coefficient of pressure offset | TCO	unsigned int 16	16	0	65535	23282
C5	Reference temperature | T_{REF}	unsigned int 16	16	0	65535	33464
C6	Temperature coefficient of the temperature | TEMPSENS	unsigned int 16	16	0	65535	28312

Add	DB15	DB14	DB13	DB12	DB11	DB10	DB9	DB8	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	16 bit reserved for manufacturer															
1	Coefficient 1 (16 bit unsigned)															
2	Coefficient 2 (16 bit unsigned)															
3	Coefficient 3 (16 bit unsigned)															
4	Coefficient 4 (16 bit unsigned)															
5	Coefficient 5 (16 bit unsigned)															
6	Coefficient 6 (16 bit unsigned)															
7														CRC		

Figure 16: Memory PROM mapping

우선 MS5611에 내장된 PROM에 있는 계수들을 읽는다

Read digital pressure and temperature data

D1	Digital pressure value	unsigned int 32	24	0	16777216	9085466
D2	Digital temperature value	unsigned int 32	24	0	16777216	8569150

Calculate temperature

dT	Difference between actual and reference temperature [2] $dT = D2 - T_{REF} = D2 - C5 * 2^8$	signed int 32	25	-16776960	16777216	2366
TEMP	Actual temperature (-40…85°C with 0.01°C resolution) $TEMP = 20°C + dT * TEMPSENS = 2000 + dT * C6 / 2^{23}$	signed int 32	41	-4000	8500	2007 = 20.07 °C

Calculate temperature compensated pressure

OFF	Offset at actual temperature [3] $OFF = OFF_{T1} + TCO * dT = C2 * 2^{16} + (C4 * dT) / 2^7$	signed int 64	41	-8589672450	12884705280	2420281617
SENS	Sensitivity at actual temperature [4] $SENS = SENS_{T1} + TCS * dT = C1 * 2^{15} + (C3 * dT) / 2^8$	signed int 64	41	-4294836225	6442352640	1315097036
P	Temperature compensated pressure (10…1200mbar with 0.01mbar resolution) $P = D1 * SENS - OFF = (D1 * SENS / 2^{21} - OFF) / 2^{15}$	signed int 32	58	1000	120000	100009 = 1000.09 mbar

ADC데이터를 읽고 온도값을 계산한다음 압력 값을 계산한다.

2. MS5611 기압센서

(2) MS5611제어-온도&압력 값 계산

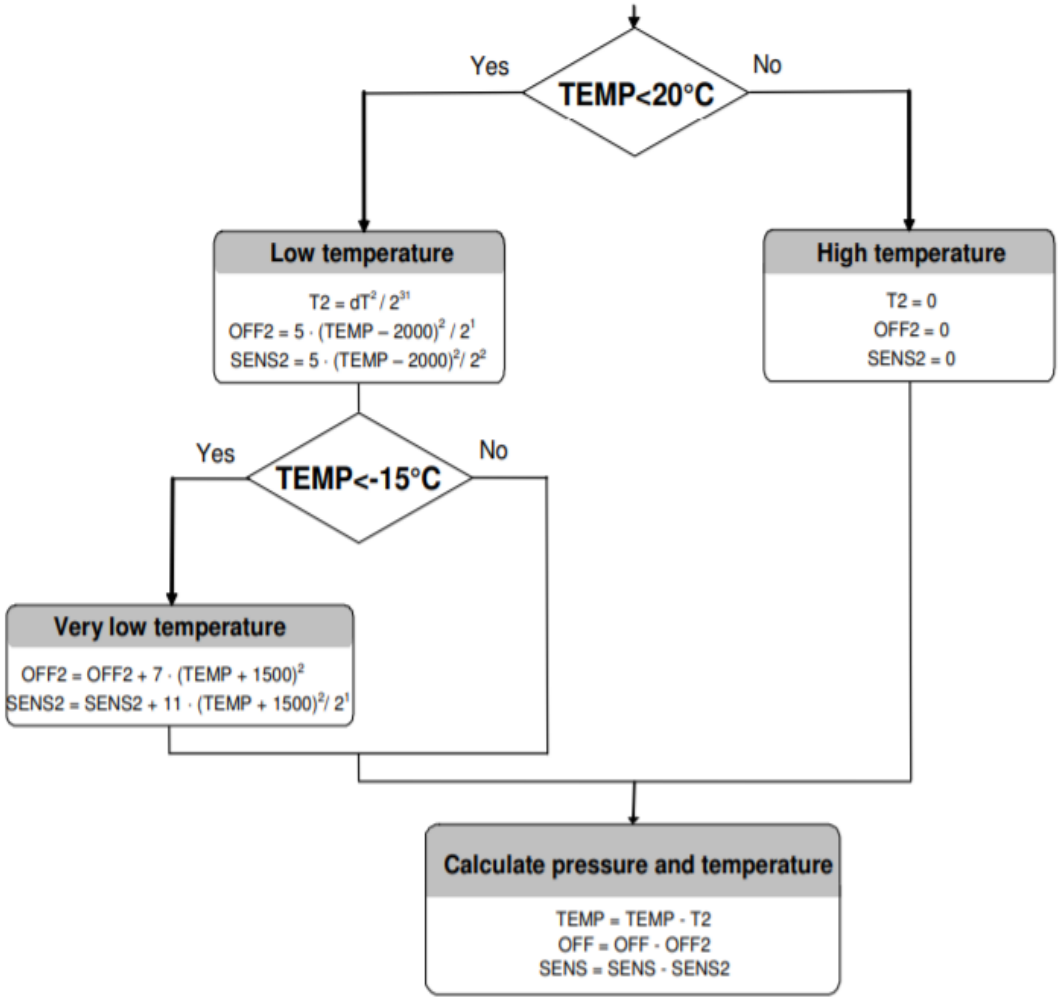


Figure 3: Flow chart for pressure and temperature to the optimum accuracy.

측정된 온도에 따라 OFFSET값과
계수값을 고려하여 계산!

2. MS5611 기압센서

(2) MS5611제어-고도 계산(표준 압력-고도 방정식을 이용)

Calculate temperature compensated pressure

OFF	Offset at actual temperature [3] $OFF = OFF_{T1} + TCO * dT = C2 * 2^{16} + (C4 * dT) / 2^{7}$	signed int 64	41	-8589672450	12884705280	2420281617
SENS	Sensitivity at actual temperature [4] $SENS = SENS_{T1} + TCS * dT = C1 * 2^{15} + (C3 * dT) / 2^{8}$	signed int 64	41	-4294836225	6442352640	1315097036
P	Temperature compensated pressure (10...1200mbar with 0.01mbar resolution) $P = D1 * SENS - OFF = (D1 * SENS / 2^{21} - OFF) / 2^{15}$	signed int 32	58	1000	120000	100009 = 1000.09 mbar

MS5611로부터 계산된 압력 값

$$\text{고도(ft)} = 145366.45 \left[1 - \left(\frac{\text{Station pressure in millibars}}{1013.25} \right)^{0.190284} \right].$$

해면 표준기압 1기압 값이며,
단위는 hpa
(해면기준으로 측정 시 Station Pressure = Barometric Pressure)