

Knock Sensor Training

TPIC8101

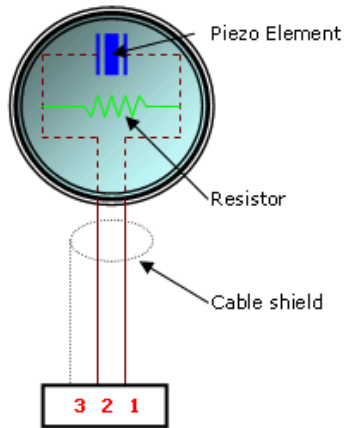
Updated: Nov. 2013

Knock Sensor Basics

Knock Sensor - Background

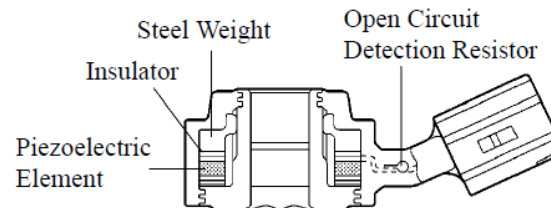
- Almost all cars have knock sensors to meet OBDII emissions control requirements.
- Engine knock can occur when the charge inside the cylinder detonates causing a pinging sound. This can be a result of:
 - Improper engine timing
 - Using the wrong octane gasoline
 - Worn or defective spark plugs
- Engine knock may damage the engine cylinder
- Cars/Trucks have knock sensors mounted on the engine block
- Knock sensors are piezo-electric elements
 - The vibrations of the engine are converted into electric signals
- Knocking is controlled using spark timing

Knock Sensor - Types



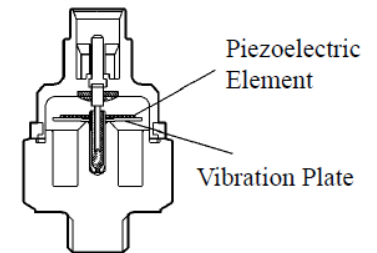
Knock sensor construction

- Piezo element to detect pressure wave.
- Resistor element to for open load detection
- Signal returns and cable shield.



**Flat Type Knock Sensor
(Non-Resonant Type)**

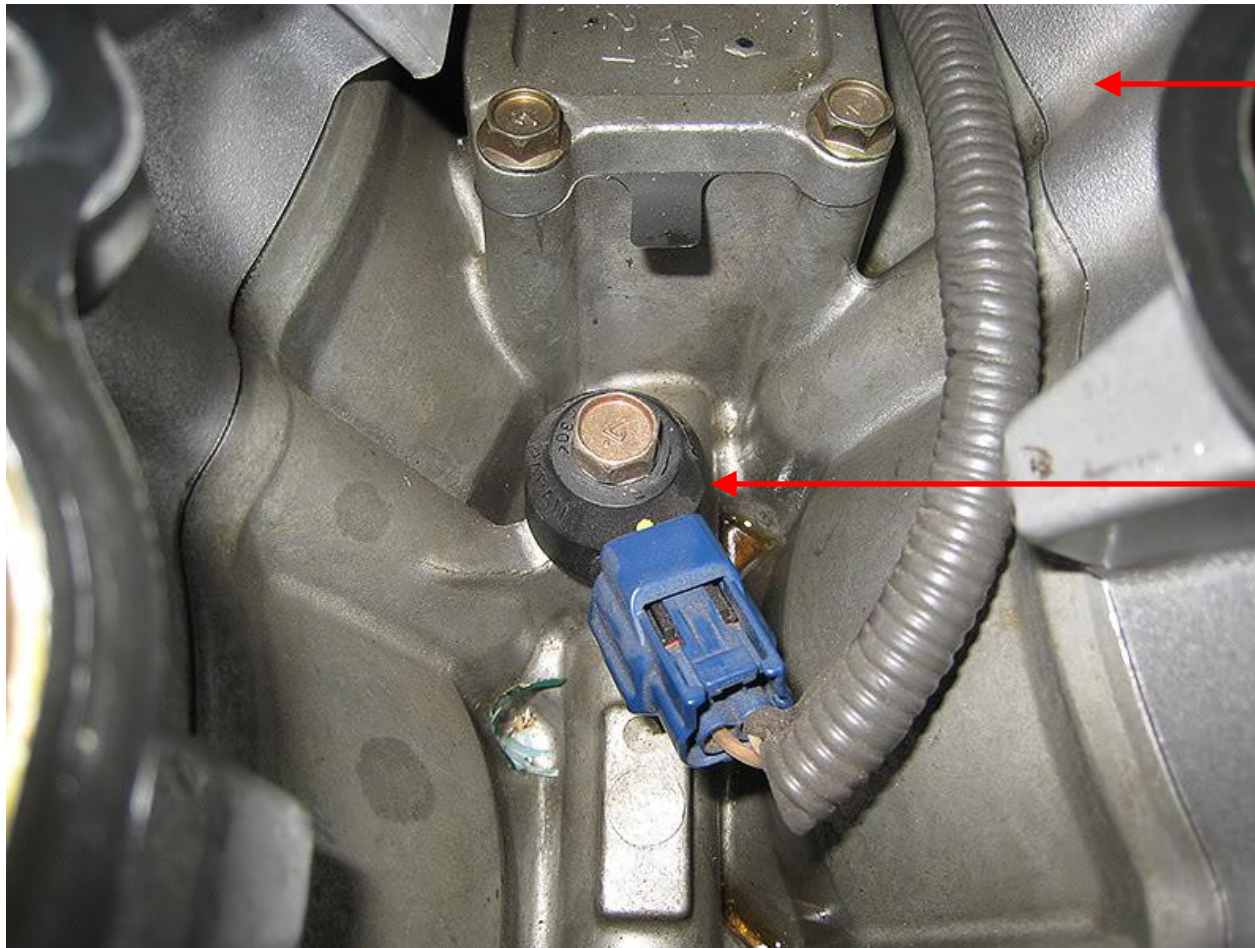
214CE01



**Conventional Type Knock Sensor
(Resonant Type)**

214CE02

Knock Sensor – Mounting Location

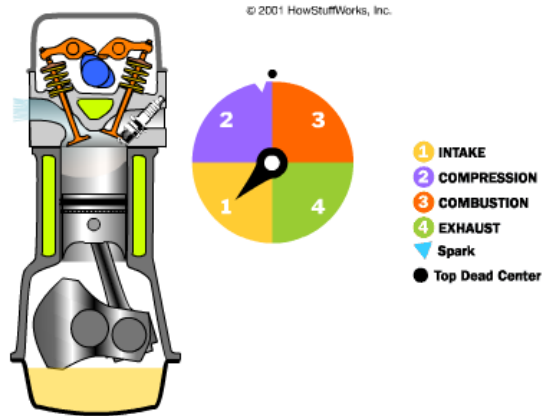


ENGINE

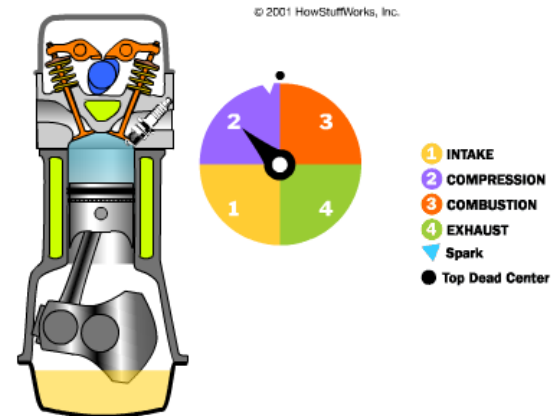
KNOCK
SENSOR

Most engines
have two knock
sensors

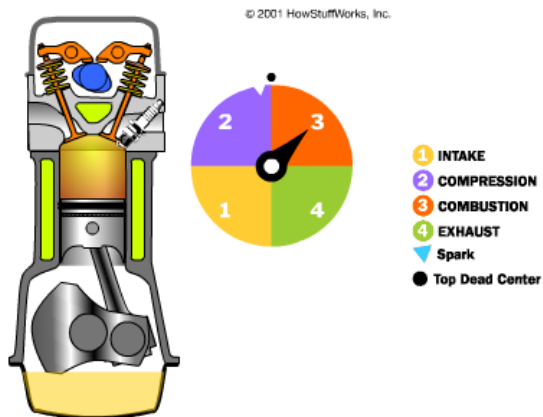
Ignition System Timing



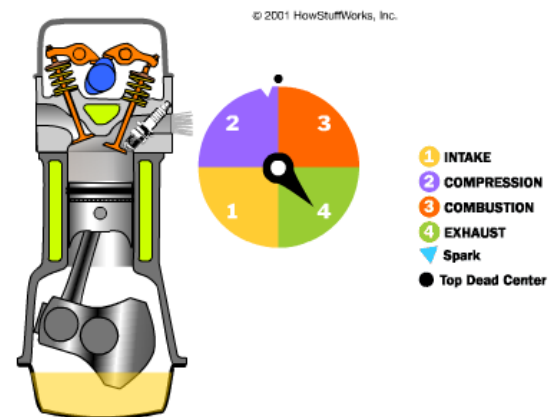
Intake Cycle



Compression Cycle

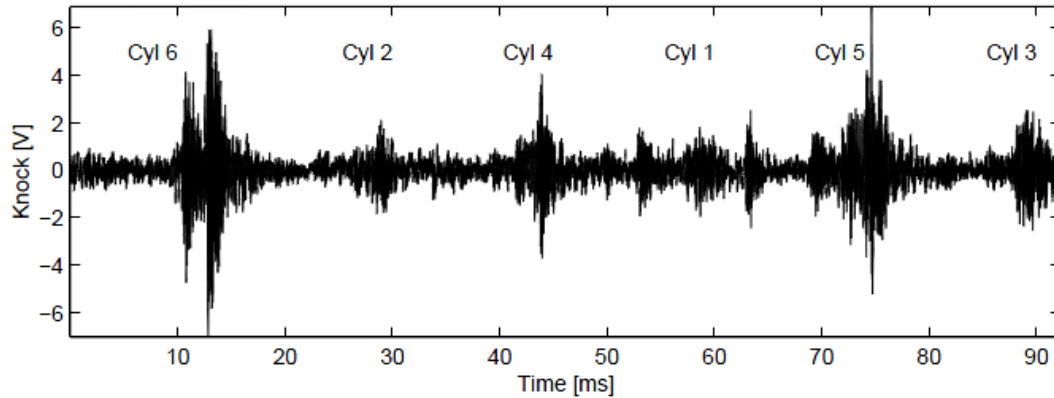


Combustion Cycle

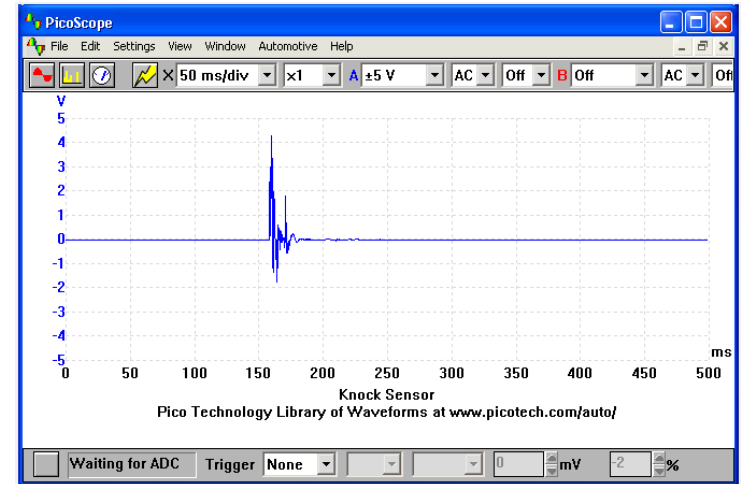


Exhaust Cycle

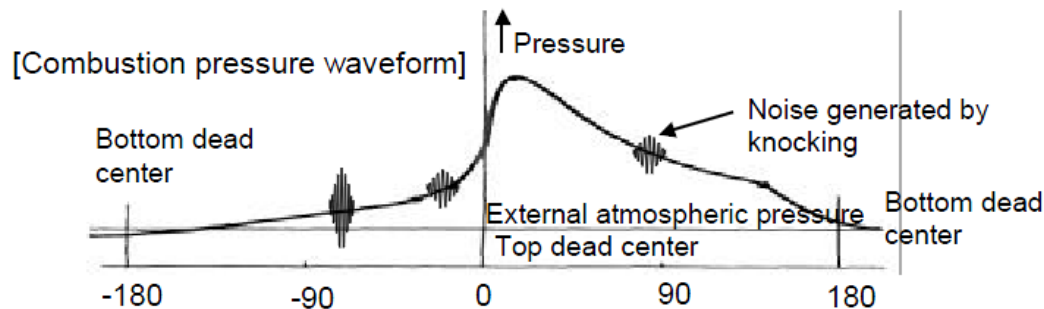
Knock Sensor - Waveforms



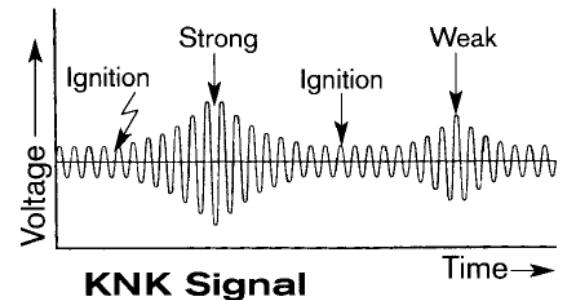
Typical noise content in a running engine.



Typical flat response type knock signal



Typical places where noise occurs in the ignition cycle.



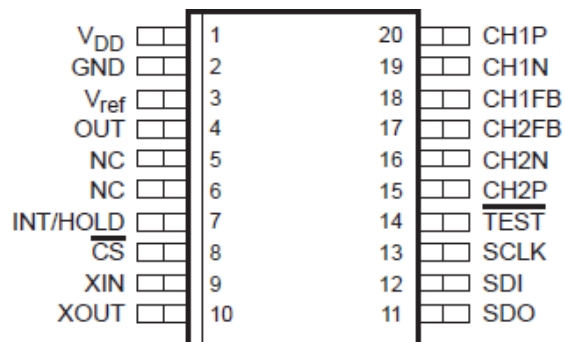
Typical resonant response type signal.

TPIC8101: Knock Sensor Interface

TPIC8101: Knock Sensor Interface

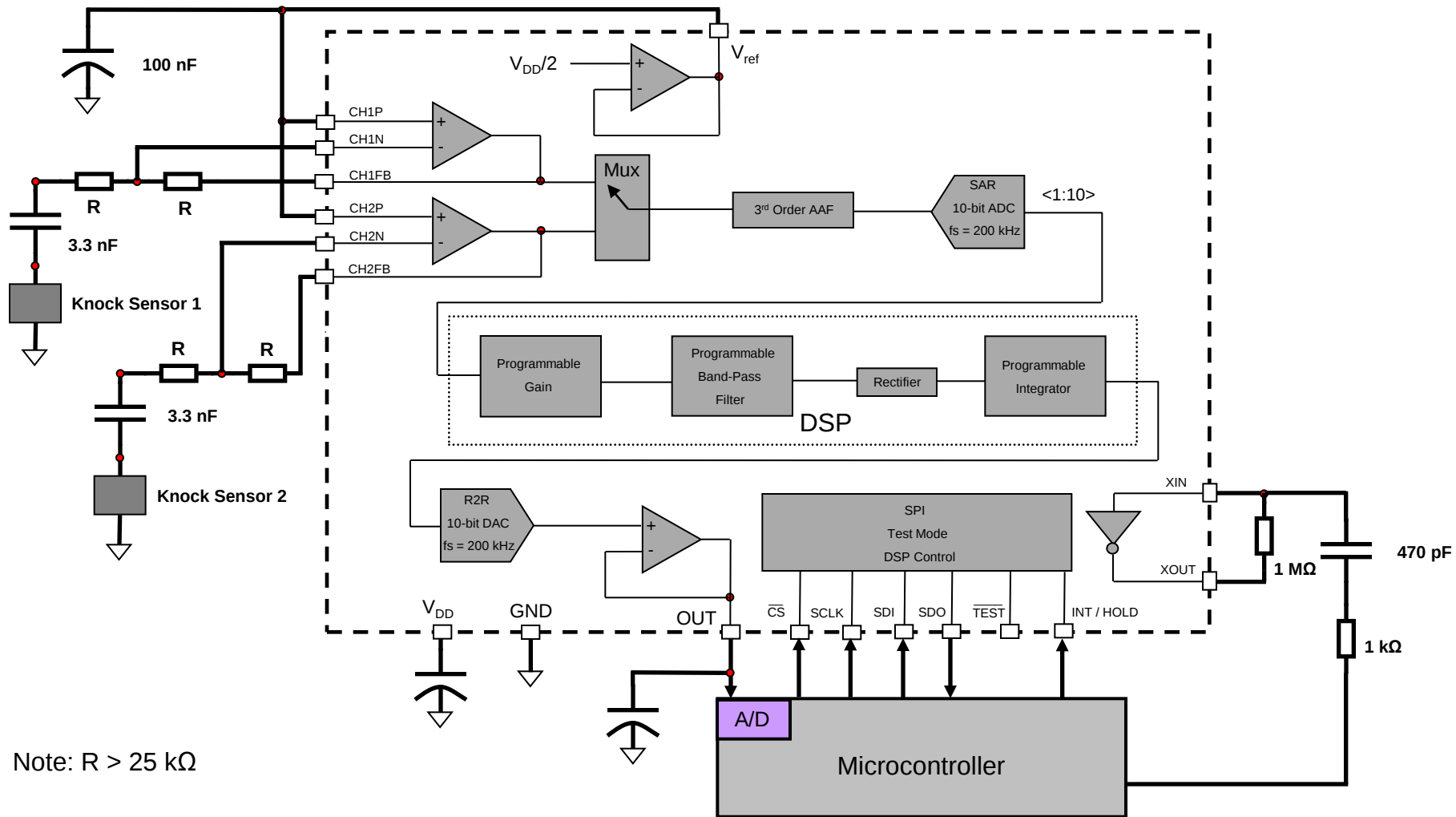
- Dual-channel Engine Knock Sensor Interface
- External Clock Frequencies up to 24 MHz
 - 4, 5, 6, 8, 10, 12, 16, 20, and 24 MHz
- SPI interface (for Microprocessor)
- Programmable Gain
- Programmable Band-Pass Filter Center Freq.
- Programmable Input Frequency Pre-scaler
- Operating Temp. Range: - 40°C to 125°C
- Engine Knock Detector Signal Processing
- Analog Signal Processing With Filter Characteristics
 - Piezoelectric sensing
 - Accelerometer sensing

Package: DW (20-pin, 1.27 mm pitch)



- Broad μ C selection via 9 selectable ext. clock frequencies
- Selectable input channels improve accuracy
- Choice of output signal profile: analog or digital
- Can use for general analog signal processing
- Advanced SPI mode capability available
- System-level diagnostics of device capable via Test Mode

Knock Sensor Applications Schematic



Engine Knock Sensor Key Parameters

Basic DC Quiescent Condition Parameters

- Quiescent current (I_{DDQ}): 7.5 mA (typ.)
- Max. Operating current ($I_{DD(OP)}$): 20 mA
- Hysteresis Voltage (Serial IF & Pre-scaler): 0.4 V (typ.)

Input Amplifier Parameters

- Cross-coupling attention: 40 dB (min.)
- Open-loop gain (A_v): 100 dB (typ.)
- Gain Bandwidth Product: 2.6 MHz (typ.)
- Offset Voltage @ Input: -10 mV to +10 mV
- CMRR range: 60 – 80 dB

Prescaler/Oscillator Parameters:

- Min. input peak amplitude: 150 mV
- Input Capacitance: 7 pF
- Leakage Current: -1 μ A to +1 μ A

Operating Temperature Range:

- -40°C to +125°C

Output (Buffer) Amplifier Parameters

- High-level output volt. (V_{OH}): VDD-0.15 (typ.)
- Low-level output volt. (V_{OL}): 175 mV (max.)
- Ripple voltage: 10 mV (max.)
- Settling time (t_s): 20 μ s (max.)

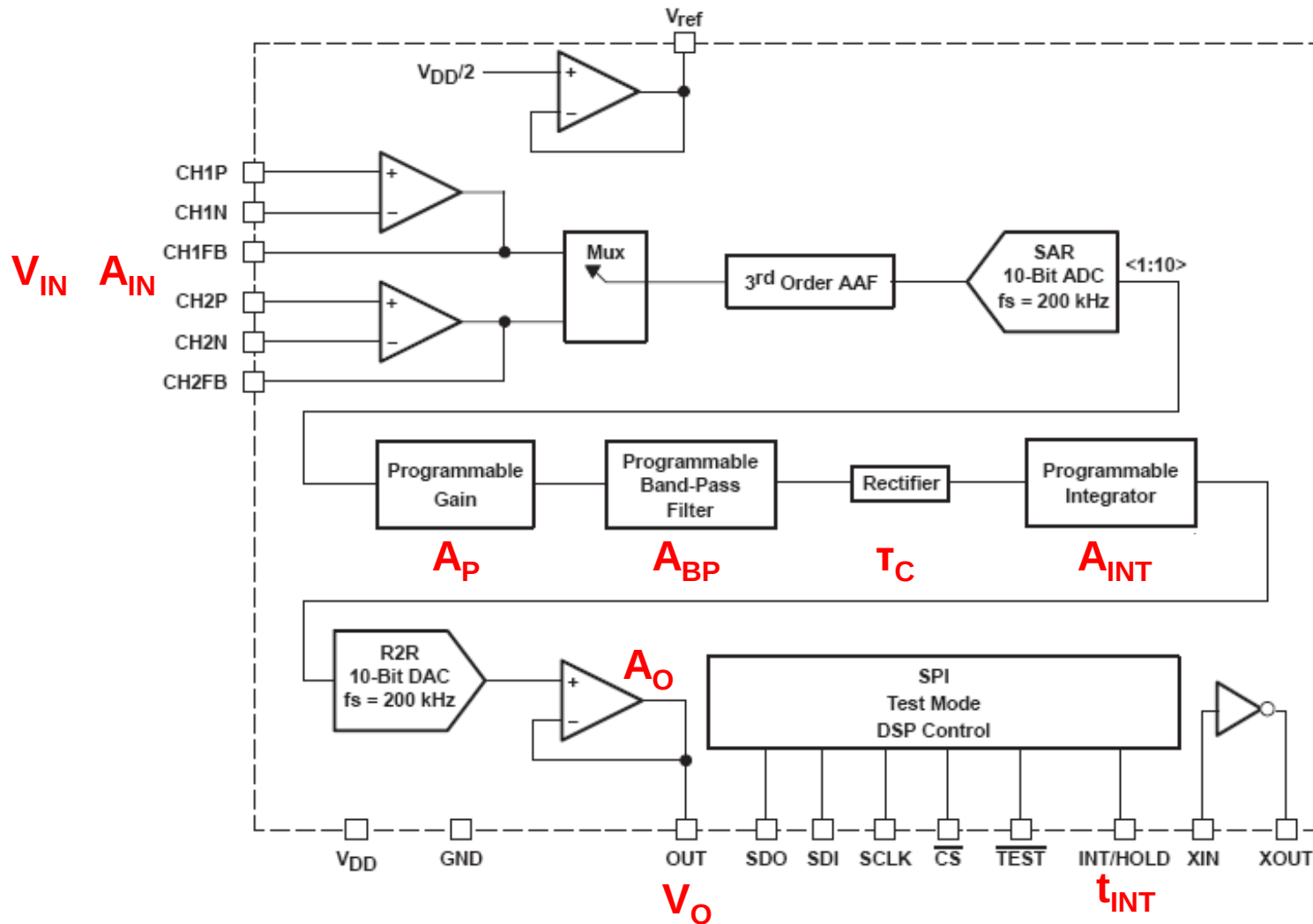
Anti-Aliasing Filter Parameters

- Frequency response (1 kHz to 20 kHz): ± 1 dB
- Attenuation @ 100 kHz: -15 dB to -10 dB
- -3 dB Frequency Range: 35 kHz to 55 kHz

Recommended Operation Conditions

- Regulated input voltage (VDD): -0.3 V to +5.5 V
- Output voltage range (buffer): -0.3 V to +5.5 V
- Input voltage range: 0.05 V to (VDD-0.05) V
- DC Input Current (I_{IN}): ± 1 μ A
> for CH1P, CH1N, CH2P, and CH2N pins
- DC Input Voltage (V_{DCIN}): $\frac{1}{2}$ VDD
> for CH1P, CH1N, CH2P, and CH2N pins
- Continuous Power Dissipation: 100 mW (max.)

TPIC8101 Knock Sensor Block Diagram



$$V_O = V_{IN} \times A_{IN} \times A_P \times A_{BP} \times A_{INT} \times \frac{t_{INT}}{\tau_C} \times A_O + V_{RESET} \quad (\text{System Transfer Function})$$

TPIC8101 Transfer Function

$$V_{OUT} = \int_0^{T_{INT}} V_{IN} \sin(\pi f_{BP} t) dt * A_{IN} * A_P * A_{BP} * A_{INT} * \frac{1}{t_C} * A_{OUT} + V_{RESET}$$

$$V_{OUT} = \frac{V_{IN}}{\pi f_{BP}} * (-\cos(\pi f_{BP} t)) \Big|_0^{T_{INT}} * A_{IN} * A_P * A_{BP} * A_{INT} * \frac{1}{t_C} * A_{OUT} + V_{RESET}$$

$$V_{OUT} = \frac{V_{IN}}{\pi f_{BP}} * (1 - \cos(\pi f_{BP} T_{INT})) * A_{IN} * A_P * A_{BP} * A_{INT} * \frac{1}{t_C} * A_{OUT} + V_{RESET}$$

$$V_{OUT} = \frac{V_{IN}}{\pi f_{BP}} * (1 - \cos(\pi f_{BP} T_{INT})) * A_{IN} * A_P * A_{BP} * A_{INT} * \frac{1}{t_C} * A_{OUT} + V_{RESET}$$

$$T_{INT} = \frac{N}{f}$$

$$V_{OUT} = \frac{V_{IN}}{\pi} * (1 - (-1)) * A_{IN} * A_P * A_{BP} * A_{INT} * \frac{T_{INT}}{t_C} * A_{OUT} + V_{RESET}$$

$$V_{OUT} = \frac{V_{IN}}{\pi} * 2 * A_{IN} * A_P * A_{BP} * A_{INT} * \frac{T_{INT}}{t_C} * A_{OUT} + V_{RESET}$$

TPIC8101 Transfer Function, continued

$$V_{OUT} = \frac{V_{IN}}{\pi} * 2 * A_{IN} * A_P * A_{BP} * A_{INT} * \frac{T_{INT}}{tc} * A_{OUT} + V_{RESET}$$

Assuming that

$A_{INT} = 2$ A_{BP} will vary with the input frequency

$A_{IN} = A_{OUT} = 1$

$V_{RESET} = 0.125$

$$V_{OUT} = V_{IN} * A_P * A_{BP} * \frac{4}{\pi} * \frac{T_{INT}}{tc} + 0.125$$

$$A_{BP} = \frac{2 * (\omega_c * \omega) / Q_{BP}}{\sqrt{(\omega_c^2 - \omega^2)^2 + (\omega_c * \omega / Q_{BP})^2}}$$

$$A_{BP} = \frac{2 * (\omega_c * \omega) / 2.3}{\sqrt{(\omega_c^2 - \omega^2)^2 + (\omega_c * \omega / 2.3)^2}}; \quad Q_{BP} = 2.3$$

$$V_{OUT} = V_{IN} * A_P * \frac{2 * (\omega_c * \omega) / 2.3}{\sqrt{(\omega_c^2 - \omega^2)^2 + (\omega_c * \omega / 2.3)^2}} * \frac{4}{\pi} * \frac{T_{INT}}{tc} + 0.125$$

for $f = f_c$

$$V_{OUT} = V_{IN} * A_P * 2 * \frac{4}{\pi} * \frac{T_{INT}}{tc} + 0.125$$

$$V_{OUT} = V_{IN} * A_P * \frac{8}{\pi} * \frac{T_{INT}}{tc} + 0.125$$

Simplified equation

V_{IN} is entered as a peak value.

V_{IN} = Input voltage peak (amplitude)

V_O = Output voltage

A_{IN} = Input amplifier gain setting

A_P = Programmable gain setting

A_{BP} = Gain of band-pass filter

A_{INT} = Gain of integrator

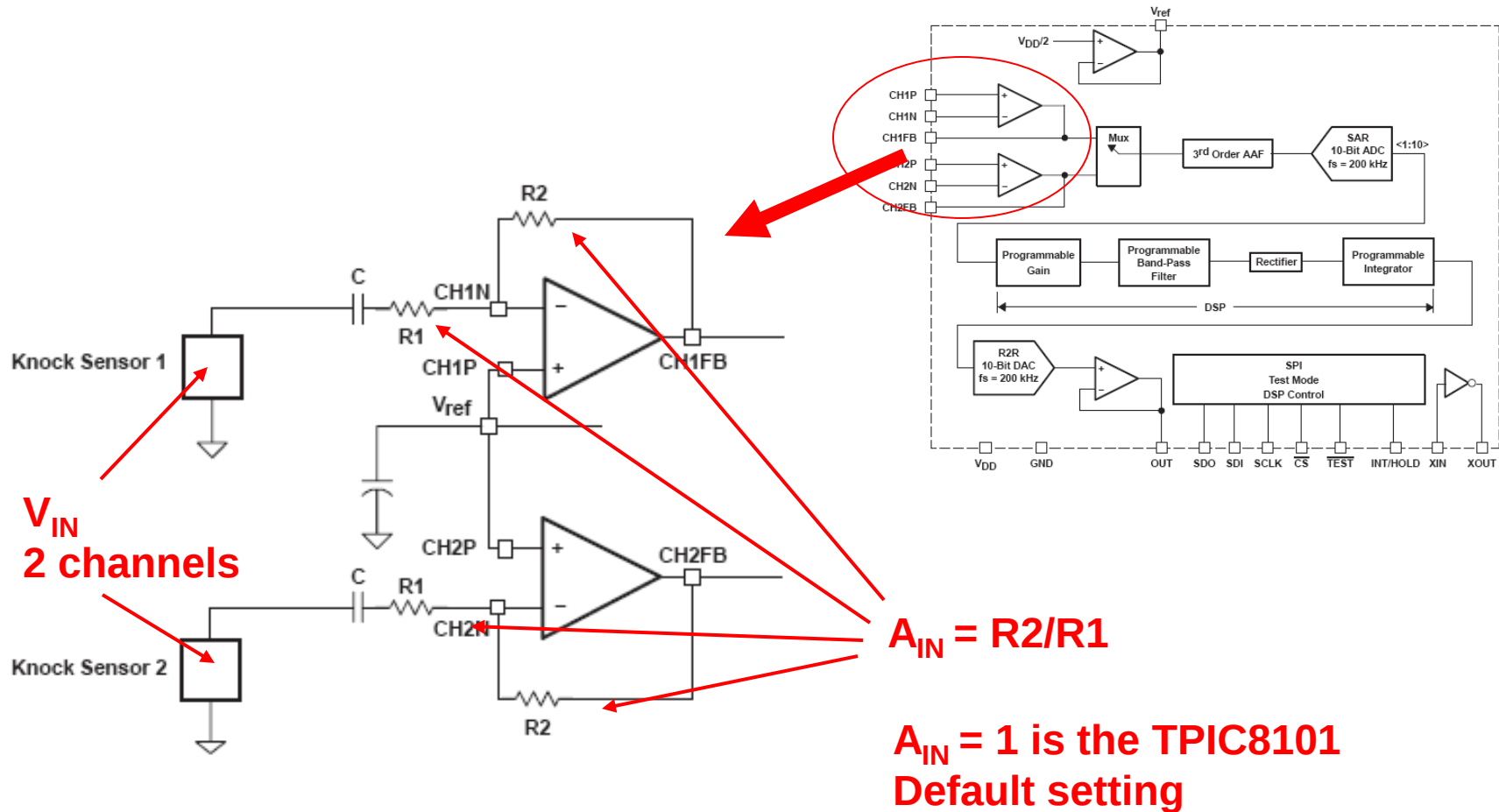
t_{INT} = Integration time from 0.5 ms to 10 ms

A_O = Output buffer gain

τ_C = Programmable integrator time constant

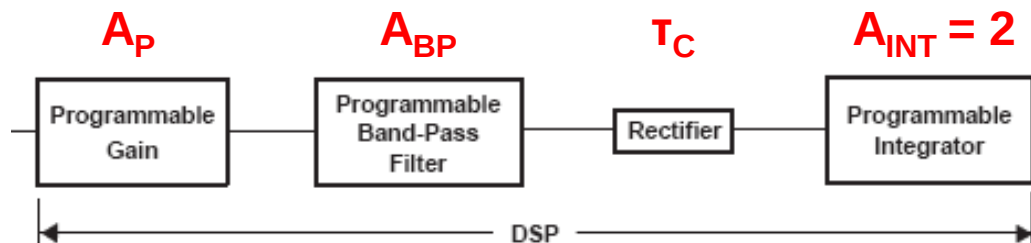
V_{RESET} = Reset voltage from which the integration operation starts

TPIC8101 Input Settings



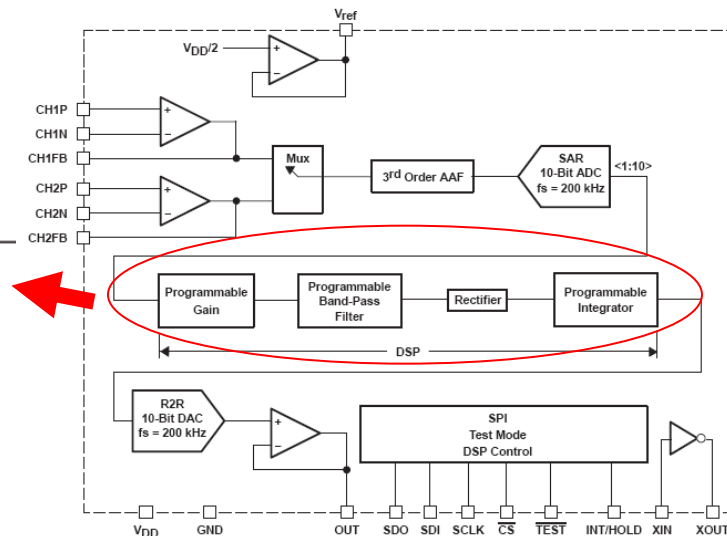
$$V_O = V_{IN} \times A_{IN} \times A_P \times A_{BP} \times A_{INT} \times \frac{t_{INT}}{\tau_C} \times A_O + V_{RESET}$$

TPIC8101 DSP Settings



$$V_{OUT} = V_{IN} * A_P * \frac{8}{\pi} * \frac{T_{INT}}{t_C} + 0.125$$

ABP = 2 at the center frequency.
Assumes that $A_{IN} = 1$.



Set to match sensor outputs

**Datasheet
page 10**

T_C		A_P		A_P		
DECIMAL VALUE (D4...D0)	INTEGRATOR TIME CONSTANT (μ SEC)	BAND-PASS FREQUENCY (kHz)	GAIN	DECIMAL VALUE (D5...D0)	BAND-PASS FREQUENCY (kHz)	GAIN
0	40	1.22	2	32	4.95	0.421
1	45	1.26	1.882	33	5.12	0.4
2	50	1.31	1.778	34	5.29	0.381
3	55	1.35	1.684	35	5.48	0.364
4	60	1.4	1.6	36	5.68	0.348

Integrator Programming

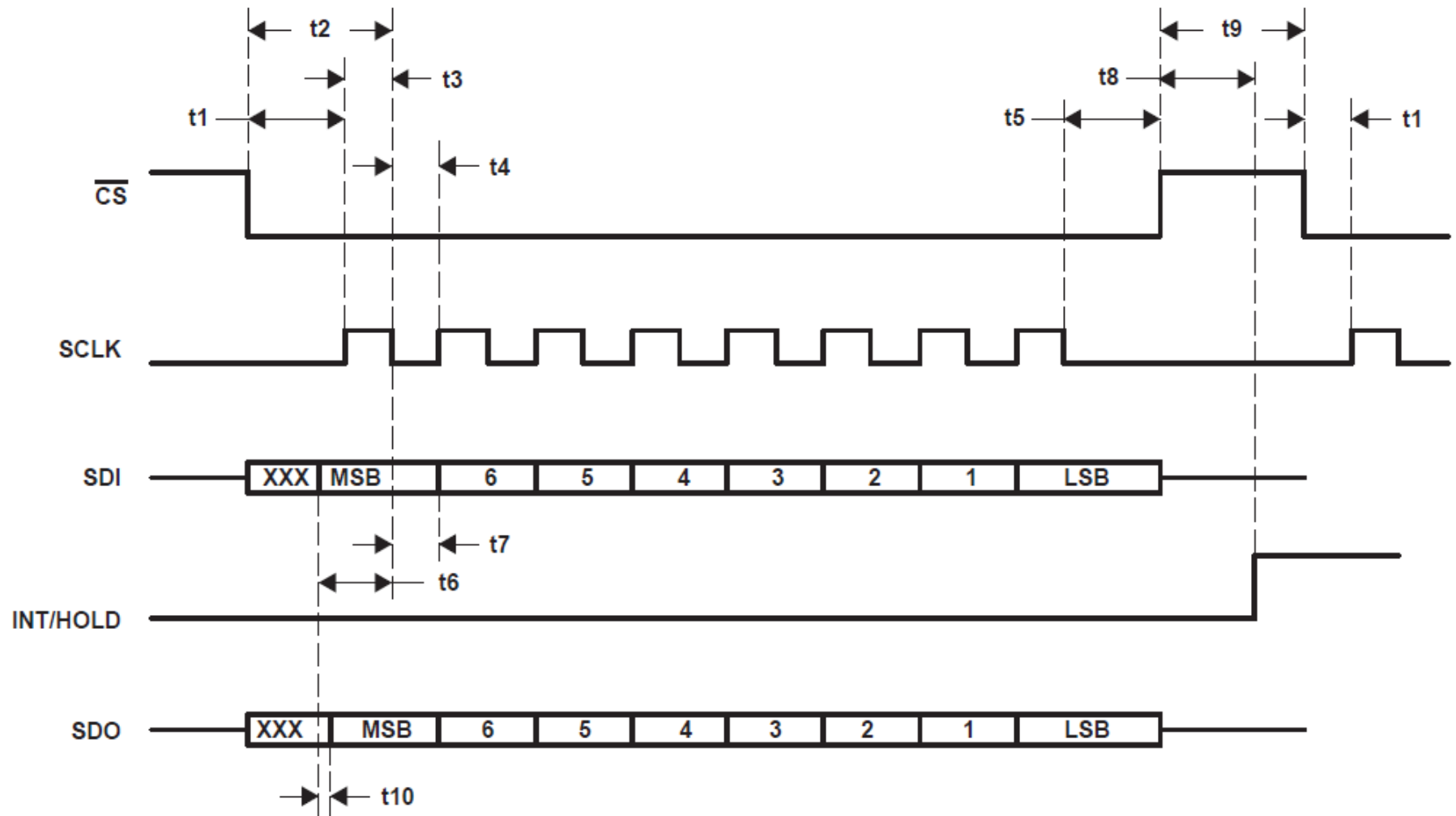
TPIC8101 Integrator Programming

DECIMAL VALUE (D4...D0)	INTEGRATOR TIME CONSTANT (μ SEC)	BAND-PASS FREQUENCY (kHz)	GAIN	DECIMAL VALUE (D5...D0)	BAND-PASS FREQUENCY (kHz)	GAIN
0	40	1.22	2	32	4.95	0.421
1	45	1.26	1.882	33	5.12	0.4
2	50	1.31	1.778	34	5.29	0.381
3	55	1.35	1.684	35	5.48	0.364
4	60	1.4	1.6	36	5.68	0.348
5	65	1.45	1.523	37	5.9	0.333
6	70	1.51	1.455	38	6.12	0.32
7	75	1.57	1.391	39	6.37	0.308
8	80	1.63	1.333	40	6.64	0.296
9	90	1.71	1.28	41	6.94	0.286
10	100	1.78	1.231	42	7.27	0.276
11	110	1.87	1.185	43	7.63	0.267
12	120	1.96	1.143	44	8.02	0.258
13	130	2.07	1.063	45	8.46	0.25
14	140	2.18	1	46	8.95	0.236
15	150	2.31	0.944	47	9.5	0.222
16	160	2.46	0.895	48	10.12	0.211
17	180	2.54	0.85	49	10.46	0.2
18	200	2.62	0.81	50	10.83	0.19
19	220	2.71	0.773	51	11.22	0.182
20	240	2.81	0.739	52	11.65	0.174
21	260	2.92	0.708	53	12.1	0.167
22	280	3.03	0.68	54	12.6	0.16
23	300	3.15	0.654	55	13.14	0.154

TPIC8101 Integrator Programming, continued

DECIMAL VALUE (D4...D0)	INTEGRATOR TIME CONSTANT (μ SEC)	BAND-PASS FREQUENCY (kHz)	GAIN	DECIMAL VALUE (D5...D0)	BAND-PASS FREQUENCY (kHz)	GAIN
24	320	3.28	0.63	56	13.72	0.148
25	360	3.43	0.607	57	14.36	0.143
26	400	3.59	0.586	58	15.07	0.138
27	440	3.76	0.567	59	15.84	0.133
28	480	3.95	0.548	60	16.71	0.129
29	520	4.16	0.5	61	17.67	0.125
30	560	4.39	0.471	62	18.76	0.118
31	600	4.66	0.444	63	19.98	0.111

TPIC8101 SPI Interface



TPIC8101 Default SPI Mode

NO.	CODE	COMMAND (t)	DATA	RESPONSE (t)
1	010 D[4:0]	Set the prescaler and SDO status	OSC _{IN} frequency D[4:1]=0000=> 4 MHz D[4:1]=0001=> 5 MHz D[4:1]=0010=> 6 MHz D[4:1]=0011=> 8 MHz D[4:1]=0100=> 10 MHz D[4:1]=0101=> 12 MHz D[4:1]=0110=> 16 MHz D[4:1]=0111=> 20 MHz D[4:1]=1000=> 24 MHz D[0]=0 => SDO active D[1]=1=> SDO high impedance	SDI (010 D[4:0])
2	1110 000 D[0]	Select the channel	D[0]=0 => Channel 1 selected D[1]=1=> Channel 2 selected	SDI (1110 000 D[0])
3	00 D[5:0]	Set the band-pass center frequency	D[5:0] (see Table 1)	SDI (00 D[5:0])
4	10 D[5:0]	Set the gain	D[5:0] (see Table 1)	SDI (10 D[5:0])
5	110 D[4:0]	Set the integration time constant	D[4:0] (see Table 1)	SDI (100 D[4:0])
6	0111 0001	Set SPI configuration to the advanced mode	None	SDI (0111 0001)

NOTE: Command #6 is to enter into the advanced mode.

TPIC8101 Advanced SPI Mode

NO.	CODE	COMMAND (t)	DATA	RESPONSE (t)
1	010 D[4:0]	Set the prescaler and SDO status	OSC _{IN} frequency D[4:1]=0000=> 4 MHz D[4:1]=0001=> 5 MHz D[4:1]=0010=> 6 MHz D[4:1]=0011=> 8 MHz D[4:1]=0100=> 10 MHz D[4:1]=0101=> 12 MHz D[4:1]=0110=> 16 MHz D[4:1]=0111=> 20 MHz D[4:1]=1000=> 24 MHz D[0]=0 => SDO active D[1]=1=> SDO high impedance	Byte 1 (D7 to D0) of the digital integrator output
2	1110 000 D[0]	Select the channel	D[0]=0 => Channel 1 selected D[1]=1=> Channel 2 selected	D9 to D8 of digital integrator output followed by six zeros
3	00 D[5:0]	Set the band-pass center frequency	D[5:0] (see Table 1)	Byte 1 (MSB) of the 00000001
4	10 D[5:0]	Set the gain	D[5:0] (see Table 1)	Byte 2 (LSB) 11100000
5	110 D[4:0]	Set the integration time constant	D[4:0] (see Table 1)	SPI configuration (MSB)01110001(LSB)
6	0111 0001	Set SPI configuration to the advanced mode	None	Inverted SPI configuration (MSB)10001110(LSB)

TPIC8101 Test Mode

NO.	TEST DESCRIPTION	SDI COMMAND MSB.....LSB	RESPONSE	NOTE
T1	AAF individual test	1111 0000	ADC clock	Deactivates the input and output op amps AAF input connected to CH1FB terminal AAF output connected to OUT terminal
T2	In-line test to AAF output	1111 0000	None	Deactivates the output op amp AAF output connected to OUT terminal
T3	Output buffer individual test	1111 0010	None	Opens the feedback loop of the output buffer and deactivates the input op amp and AAF CH1FB connected to positive input terminal of op amp CH2FB connected to negative input terminal of op amp
T4	ADC/DAC individual test (with the output buffer)	1111 0011	ADC data	Deactivates the input op amps and AAF INT/HOLD = ADC_Sync OSC _{IN} = ADC_SCLK DAC shifted in from SDI terminal
T5	ADC/DAC individual test (without the output buffer)	1111 0100	ADC data	Deactivates the input op amps, AAF, and output buffer INT/HOLD = ADC_Sync OSC _{IN} = ADC_SCLK DAC is shifted in from SDI terminal
T6	In-line test to ADC output	1111 0011	ADC data	INT/HOLD = ADC_Sync OSC _{IN} = ADC_SCLK DAC shifted in from SDI terminal
T7	Reading of digital clamp flag	1111 1000	Clamp flag D[2:0]	Implies command 6 (advanced SPI mode) D[0]: Gain stage clamp status D[1]: BPF stage clamp status D[2]: INT stage clamp status D=0 => No clamp activated D=1 => Clamp activated

TPIC8101: Application Example

Application Requirements

Requirements:

- $V_{IN} = 7.3\text{KHz}$, 300mVpp (Knock Sensor specification)
- Oscillator = 6MHz (Microprocessor clock specification)
- Knock window (T_{INT})= 3ms (system spec)
- $OUT = 4.5\text{V}$ (Microprocessor interface specification)

Need to set:

- Input amplifier gain (A_{IN})
- Programmable gain (A_P)
- Integration time constant (T_C)

Set $A_{IN} = 1$; $R1 = R2$

T_C is typically $T_{INT}/(2*\pi*V_{OUT}) \Rightarrow$

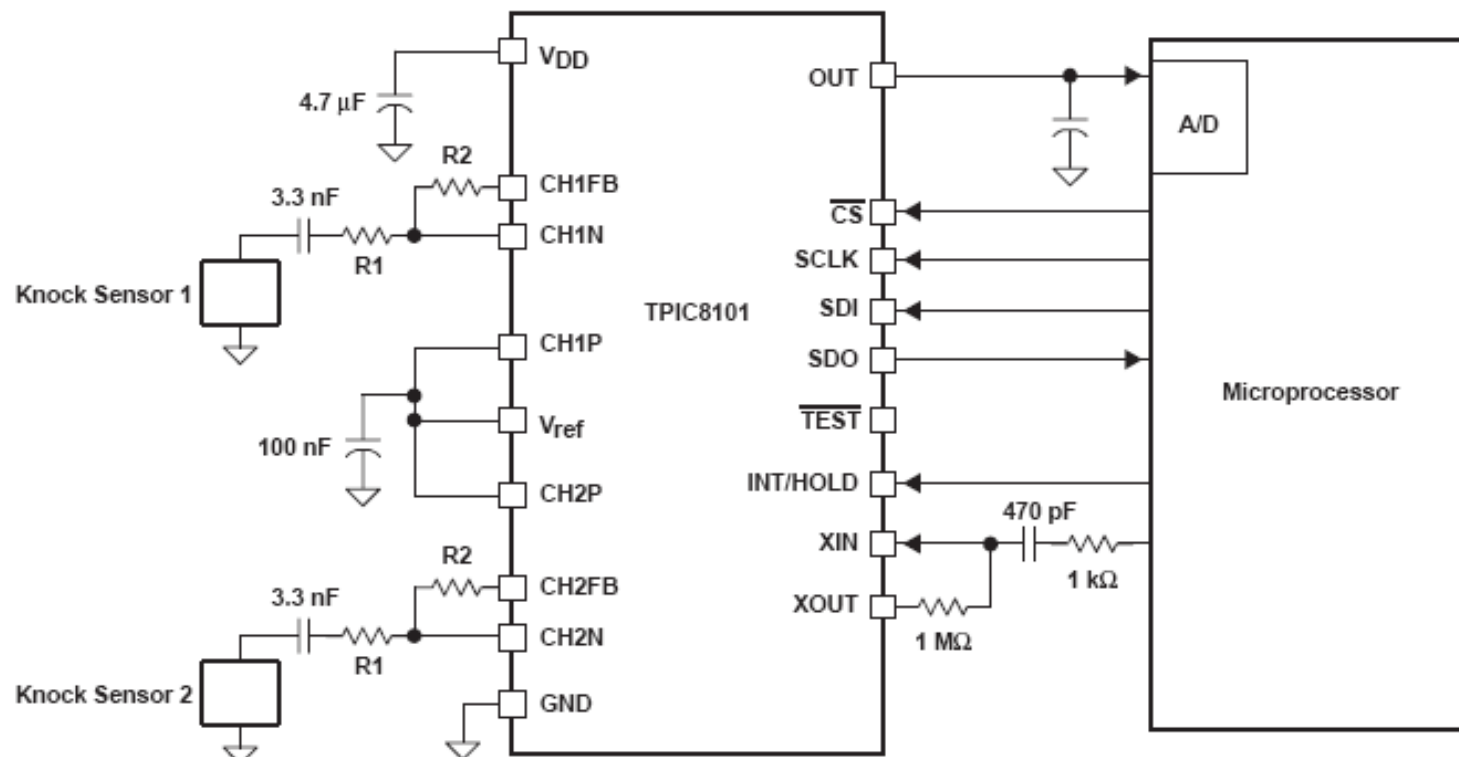
$$T_C = 3\text{ms} / (2*\pi*4.5) = 106\mu\text{s}$$

$$V_{OUT} = V_{IN} * A_P * \frac{8}{\pi} * \frac{T_{INT}}{t_C} + 0.125$$

$$4.5\text{V} = 0.15*A_P*2.55*3\text{ms}/100\mu\text{s} + 0.125 \Rightarrow$$

$$A_P = 0.38$$

TPIC8101 Application Schematic



NOTE: R1 is greater than 25 k Ω .

TPIC8101 SPI Settings

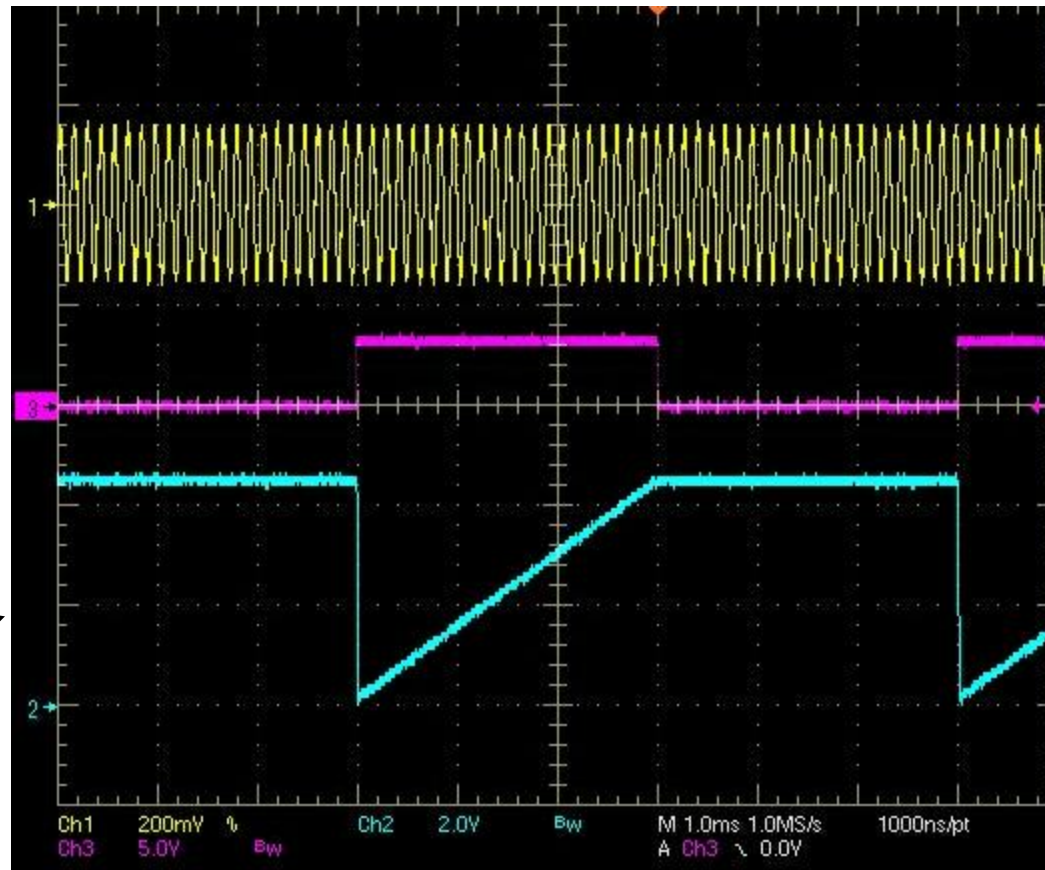
Parameter	Calculated Value	Programmed Value	Code DEC HEX		SPI
Oscillator	6MHz	6MHz			01000010
Channel	1	1			11100000
f_{C0}	7.3KHz	7.27KHz	42	2A	00101010
A_P	0.38	0.381	34	22	10100010
T_C	106 μ s	100 μ s	10	0A	10001010
T_{INT}	3ms				

TPIC8101 Waveforms

7270KHz,
300mVpp

INT,
3ms

Output



4.48V