THEORY OF OPERATION

The KT-EX9-2 is an autonomous sensor system that starts when it has a valid power supply. After running through its initialization process, it begins sampling, processing, and loading calibrated sensor data into the output registers, which are accessible using the SPI port. The SPI port typically connects to a compatible port on an ARM, using the connections as shown in Figure 23.

The four SPI signals facilitate synchronous, serial data communication. Connect the reset line (RST) to VDD or do not connect it to anything for normal operation. The factory default configuration provides users with a data ready signal on the DIO2 pin, which pulses high when new data is available in the output data registers.

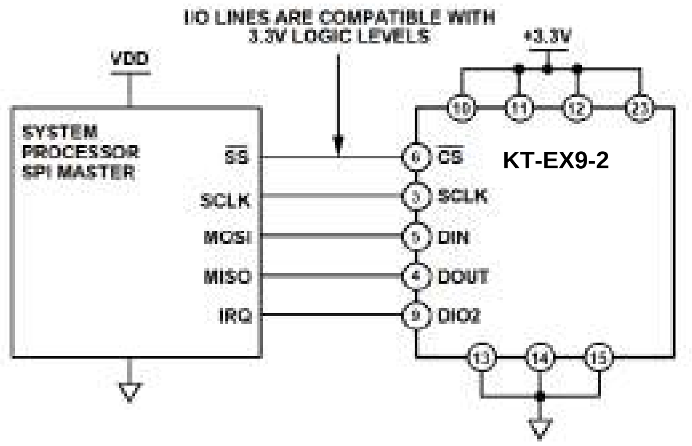

Figure 23. Electrical Connection Diagram

Table 7. Generic Master Processor Pin Names and Functions

Mnemonic	Function
SS	Slave select
IRQ	Interrupt request
MOSI	Master output, slave input
MISO	Master input, slave output
SCLK	Serial clock

Embedded processors typically use control registers to configure their serial ports for communicating with SPI slave devices, such as the KT-EX9-2. Table 8 provides a list of settings describing the SPI protocol of the KT-EX9-2. The initialization routine of the master processor typically establishes these settings using firmware commands to write them into its serial control registers.

Table 8. Generic Master Processor SPI Settings

Processor Setting	Description
Master	The KT-EX9-2 operates as a slave
SCLK ≤ 16 MHz	Maximum serial clock rate
SPI Mode 3	CPOL = 1 (polarity), and CPHA = 1 (phase)
MSB-First Mode	Bit sequence
16-Bit Mode	Shift register/data length

REGISTER STRUCTURE

The register structure and SPI port provide a bridge between the sensor processing system and an external, master processor. It contains both output data and control registers. The output data registers include the latest sensor data, a real-time clock, error flags, alarm flags, and identification data. The control registers include sample rate, filtering, input/output, alarms, calibration, and diagnostic configuration options. All communication between the KT-EX9-2 and an external processor involves either reading or writing to one of the user registers.

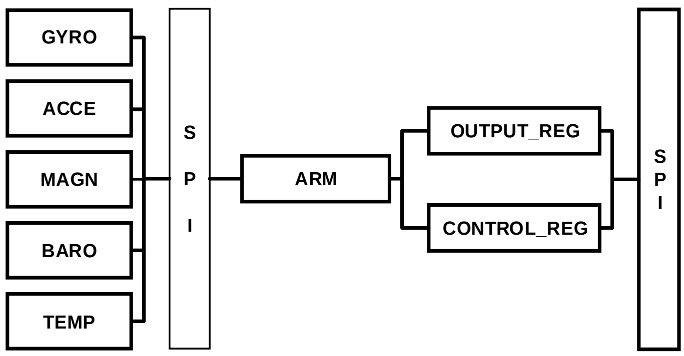

Figure 24. Basic Operation

The register structure uses a paged addressing scheme that is composed of 13 pages, with each page containing 64 register locations. Each register is 16 bits wide, with each byte having its own unique address within the memory map of that page. The SPI port has access to one page at a time, using the bit sequence shown in Figure 25.

Select the page to activate for SPI access by writing its code to the PAGE_ID register. Read the PAGE_ID register to determine which page is currently active. Table 9 displays the PAGE_ID contents for each page, together with their basic functions. The PAGE_ID register is located at Address 0x00 on every page.

Table 9. User Register Page Assignments

Page	PAGE_ID	Function
0	0x00	Output data, clock, identification
3	0x03	Control: sample rate, filtering, input/output, alarms
4	0x04	Serial number
5~12	0x05~0x0C	Filter

SPI COMMUNICATION

If the previous command was a read request, the SPI port supports full duplex communication, which enables external processors to write to DIN while reading DOUT (see Figure 25). Figure 25 provides a guideline for the bit coding on both DIN and DOUT.

Figure 25. SPI Communication Bit Sequence

DEVICE CONFIGURATION

The SPI provides write access to the control registers, one byte at a time, using the bit assignments shown in Figure 25. Each register has 16 bits, where Bits[7:0] represent the lower address (listed in Table 10) and Bits[15:8] represent the upper address. Write to the lower byte of a register first, followed by a write to its upper byte (the only register that changes with a single write to its lower byte is the PAGE_ID register).

For a write command, the first bit in the DIN sequence is set to 1. Address Bits[A6:A0] represent the target address, and Data Command Bits[DC7:DC0] represent the data being written to the location. Figure 26 provides an example of writing 0x03 to Address 0x00 (PAGE_ID [7:0]) using DIN = 0x8003. This write command activates the control page for SPI access.

Figure 26. SPI Sequence for Activating the Control Page

FLASH MEMORY

For a flash memory update, ensure that the power supply is within specification for the entire processing time (see Table 1).

READING SENSOR DATA

The KT-EX9-2 automatically starts up and activates Page 0 for data register access. Write 0x00 to the PAGE_ID register (DIN = 0x8000) to activate Page 0 for data access after accessing any other page.

A single register read requires two 16-bit SPI cycles. The first cycle requests the contents of a register using the bit assignments in Figure 25, and then the register contents follow DOUT during the second sequence.

The first bit in a DIN command is zero, followed by either the upper or lower address for the register. The last eight bits are don’t care, but the SPI requires the full set of 16 SCLKs to receive the request.

Figure 27 includes two register reads in succession, which starts with DIN = 0x1A00, to request the contents of the Z_GYRO_OUT register, and follows with 0x1800, to request the contents of the Z_GYRO_LOW register.

Figure 27. SPI Read Example

Figure 28 provides an example of the four SPI signals when reading PROD_ID in a repeating pattern. This is an effective pattern to use for troubleshooting the SPI interface setup and communications because the contents of PROD_ID are predefined and stable.

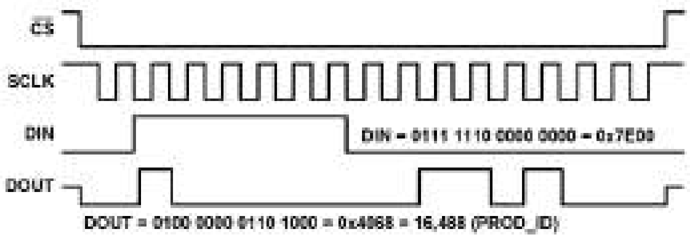

Figure 28. SPI Read Example, Second 16-Bit Sequence

USER REGISTERS

Table 10. User Register Memory Map (N/A = Not Applicable)

Name	R/W[1]	Flash	PAGE_ID	Address	Default	Register Description	Format
PAGE_ID	R/W	No	0x00	0x00	0x00	Page identifier	N/A
ALM_STS	R	No	0x00	0x0C	0x0000	Output, alarm error flags	Table 48
TEMP_OUT	R	No	0x00	0x0E	N/A	Output, temperature	Table 46
X_GYRO_LOW	R	No	0x00	0x10	N/A	Output, x-axis gyroscope, low word	Table 15
X_GYRO_OUT	R	No	0x00	0x12	N/A	Output, x-axis gyroscope, high word	Table 11
Y_GYRO_LOW	R	No	0x00	0x14	N/A	Output, y-axis gyroscope, low word	Table 16
Y_GYRO_OUT	R	No	0x00	0x16	N/A	Output, y-axis gyroscope, high word	Table 12
Z_GYRO_LOW	R	No	0x00	0x18	N/A	Output, z-axis gyroscope, low word	Table 17
Z_GYRO_OUT	R	No	0x00	0x1A	N/A	Output, z-axis gyroscope, high word	Table 13
X_ACCL_LOW	R	No	0x00	0x1C	N/A	Output, x-axis accelerometer, low word	Table 22
X_ACCL_OUT	R	No	0x00	0x1E	N/A	Output, x-axis accelerometer, high word	Table 18
Y_ACCL_LOW	R	No	0x00	0x20	N/A	Output, y-axis accelerometer, low word	Table 23
Y_ACCL_OUT	R	No	0x00	0x22	N/A	Output, y-axis accelerometer, high word	Table 19
Z_ACCL_LOW	R	No	0x00	0x24	N/A	Output, z-axis accelerometer, low word	Table 24
Z_ACCL_OUT	R	No	0x00	0x26	N/A	Output, z-axis accelerometer, high word	Table 20
X_MAGN_OUT	R	No	0x00	0x28	N/A	Output, x-axis magnetometer, high word	Table 39
Y_MAGN_OUT	R	No	0x00	0x2A	N/A	Output, y-axis magnetometer, high word	Table 40
Z_MAGN_OUT	R	No	0x00	0x2C	N/A	Output, z-axis magnetometer, high word	Table 41
BAROM_LOW	R	No	0x00	0x2E	N/A	Output, barometer, low word	Table 45
BAROM_OUT	R	No	0x00	0x30	N/A	Output, barometer, high word	Table 43
X_DELTANG_LOW	R	No	0x00	0x40	N/A	Output, x-axis delta angle, low word	Table 29
X_DELTANG_OUT	R	No	0x00	0x42	N/A	Output, x-axis delta angle, high word	Table 25
Y_DELTANG_LOW	R	No	0x00	0x44	N/A	Output, y-axis delta angle, low word	Table 30
Y_DELTANG_OUT	R	No	0x00	0x46	N/A	Output, y-axis delta angle, high word	Table 26
Z_DELTANG_LOW	R	No	0x00	0x48	N/A	Output, z-axis delta angle, low word	Table 31
Z_DELTANG_OUT	R	No	0x00	0x4A	N/A	Output, z-axis delta angle, high word	Table 27
X_DELTVEL_LOW	R	No	0x00	0x4C	N/A	Output, x-axis delta velocity, low word	Table 36
X_DELTVEL_OUT	R	No	0x00	0x4E	N/A	Output, x-axis delta velocity, high word	Table 32
Y_DELTVEL_LOW	R	No	0x00	0x50	N/A	Output, y-axis delta velocity, low word	Table 37
Y_DELTVEL_OUT	R	No	0x00	0x52	N/A	Output, y-axis delta velocity, high word	Table 33
Z_DELTVEL_LOW	R	No	0x00	0x54	N/A	Output, z-axis delta velocity, low word	Table 38
Z_DELTVEL_OUT	R	No	0x00	0x56	N/A	Output, z-axis delta velocity, high word	Table 34
PROD_ID	R	Yes	0x00	0x7E	0x4068	Output, product identification (16,488)	Table 49
PAGE_ID	R/W	No	0x03	0x00	0x0000	Page identifier	N/A
FNCTIO_CTRL	R/W	Yes	0x03	0x06	0x000D	Control, input/output pins, functional definitions	Table 67
DEC_RATE	R/W	Yes	0x03	0x0C	0x0000	Control, output sample rate decimation	Table 50
FILTR_BNK_0	R/W	Yes	0x03	0x16	0x0000	Filter selection	Table 51
FILTR_BNK_1	R/W	Yes	0x03	0x18	0x0000	Filter selection	Table 52
ALM_CNFG_0	R/W	Yes	0x03	0x20	0x0000	Alarm configuration	Table 64

Name	R/W[1]	Flash	PAGE_ID	Address	Default	Register Description	Format
ALM_CNFG_1	R/W	Yes	0x03	0x22	0x0000	Alarm configuration	Table 65
XG_ALM_MAGN	R/W	Yes	0x03	0x28	0x0000	Alarm, x-axis gyroscope threshold setting	Table 58
YG_ALM_MAGN	R/W	Yes	0x03	0x2A	0x0000	Alarm, y-axis gyroscope threshold setting	Table 59
ZG_ALM_MAGN	R/W	Yes	0x03	0x2C	0x0000	Alarm, z-axis gyroscope threshold setting	Table 60
XA_ALM_MAGN	R/W	Yes	0x03	0x2E	0x0000	Alarm, x-axis accelerometer threshold	Table 61
YA_ALM_MAGN	R/W	Yes	0x03	0x30	0x0000	Alarm, y-axis accelerometer threshold	Table 62
ZA_ALM_MAGN	R/W	Yes	0x03	0x32	0x0000	Alarm, z-axis accelerometer threshold	Table 63
PAGE_ID	R/W	No	0x05	0x00	0x0000	Page identifier	N/A
FIR_COEF_Axxx	R/W	Yes	0x05	0x02 to 0x7E	N/A	FIR Filter Bank A, Coefficient 0 through Coefficient 59	Table 53
PAGE_ID	R/W	No	0x06	0x00	0x0000	Page identifier	N/A
FIR_COEF_Axxx	R/W	Yes	0x06	0x02 to 0x7E	N/A	FIR Filter Bank A, Coefficient 60 through Coefficient 119	Table 53
PAGE_ID	R/W	No	0x07	0x00	0x0000	Page identifier	N/A
FIR_COEF_Bxxx	R/W	Yes	0x07	0x02 to 0x7E	N/A	FIR Filter Bank B, Coefficient 0 through Coefficient 59	Table 54
PAGE_ID	R/W	No	0x08	0x00	0x0000	Page identifier	N/A
FIR_COEF_Bxxx	R/W	Yes	0x08	0x02 to 0x7E	N/A	FIR Filter Bank B, Coefficient 60 through Coefficient 119	Table 54
PAGE_ID	R/W	No	0x09	0x00	0x0000	Page identifier	N/A
FIR_COEF_Cxxx	R/W	Yes	0x09	0x02 to 0x7E	N/A	FIR Filter Bank C, Coefficient 0 through Coefficient 59	Table 55
PAGE_ID	R/W	No	0x0A	0x00	0x0000	Page identifier	N/A
FIR_COEF_Cxxx	R/W	Yes	0x0A	0x02 to 0x7E	N/A	FIR Filter Bank C, Coefficient 60 through Coefficient 119	Table 55
PAGE_ID	R/W	No	0x0B	0x00	0x0000	Page identifier	N/A
FIR_COEF_Dxxx	R/W	Yes	0x0B	0x02 to 0x7E	N/A	FIR Filter Bank D, Coefficient 0 through Coefficient 59	Table 56
PAGE_ID	R/W	No	0x0C	0x00	0x0000	Page identifier	N/A
FIR_COEF_Dxxx	R/W	Yes	0x0C	002 to 0x7E	N/A	FIR Filter Bank D, Coefficient 60 through Coefficient 119	Table 56

[1] R is read only, W is write only, R/W is read and write, and N/A means not applicable.

OUTPUT DATA REGISTERS

After the KT-EX9-2 completes its start-up process, the PAGE_ID register contains 0x0000, which sets Page 0 as the active page for SPI access. Page 0 contains the output data, real- time clock, status, and product identification registers.

INERTIAL SENSOR DATA FORMAT

The gyroscope, accelerometer, delta angle, delta velocity, and barometer output data registers use a 32-bit, twos complement format. Each output uses two registers to support this resolution. Figure 18 provides an example of how each register contributes to each inertial measurement. In this case, X_GYRO_OUT is the most significant word (upper 16 bits), and X_GYRO_LOW is the least significant word (lower 16 bits). In many cases, using the most significant word registers alone provides sufficient resolution for preserving key performance metrics.

Figure 29. Gyroscope Output Format Example, DEC_RATE > 0

The arrows in Figure 30 represent the direction of the motion, which produces a positive output response in the output register of each sensor. The accelerometers respond to both dynamic and static forces associated with acceleration, including gravity. When lying perfectly flat, as shown in Figure 19, the z-axis accelerometer output is 1 g, and the x and y accelerometers are 0 g.

ROTATION RATE (GYROSCOPE)

The registers that use the x_GYRO_OUT format are the primary registers for the gyroscope measurements (see Table 11,Table 12 ,Table 13). When processing data from these registers, use a 16-bit, twos complement data format. Table 14 provides x_GYRO_OUT digital coding examples.

Table 11. X_GYRO_OUT (Page 0, Base Address = 0x12)

Bits	Description
[15:0]	X-axis gyroscope data; twos complement, ±450°/sec range, 0°/sec = 0x0000, 1 LSB = 0.02°/sec

Table 12. Y_GYRO_OUT (Page 0, Base Address = 0x16)

Bits	Description
[15:0]	Y-axis gyroscope data; twos complement, ±450°/sec range, 0°/sec = 0x0000, 1 LSB = 0.02°/sec

Table 13. Z_GYRO_OUT (Page 0, Base Address = 0x1A)

Bits	Description
[15:0]	Z-axis gyroscope data; twos complement, ±450°/sec range, 0°/sec = 0x00 00, 1 LSB = 0.02°/sec

Table 14.x_GYRO_OUT Data Format Examples

Rotation Rate	Decimal	Hex	Binary
+450°/sec	+22,500	0x57E4	0101 0111 1110 0100
+0.04/sec	+2	0x0002	0000 0000 0000 0010
+0.02°/sec	+1	0x0001	0000 0000 0000 0001
0°/se c	0	0x0000	0000 0000 0000 0000
−0.02°/sec	−1	0xFFFF	1111 1111 1111 1111
−0.04°/sec	−2	0xFFFE	1111 1111 1111 1110
−450°/sec	−22,500	0xA81C	1010 1000 0001 1100

The registers that use the x_GYRO_LOW naming format provide additional resolution for the gyroscope measurements (see Table 15,Table 16,Table 17). The MSB has a weight of 0.01°/sec, and each subsequent bit has ½ the weight of the previous one.

Table 15. X_GYRO_LOW (Page 0, Base Address = 0x10)

Bits	Description
[15:0]	X-axis gyroscope data; additional resolution bits

Table 16. Y_GYRO_LOW (Page 0, Base Address = 0x14)

Bits	Description
[15:0]	Y-axis gyroscope data; additional resolution bits

Table 17. Z_GYRO_LOW (Page 0, Base Address = 0x18)

Bits	Description
[15:0]	Z-axis gyroscope data; additional resolution bits

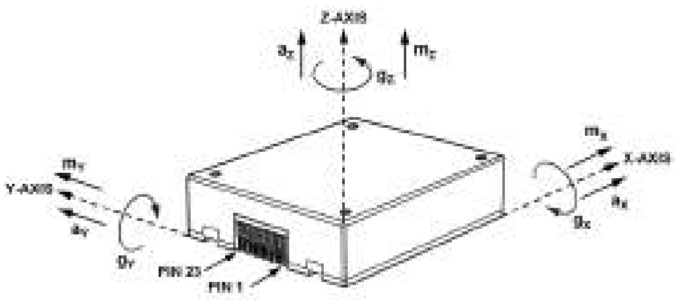

Figure 30. Inertial Sensor Direction Reference Diagram

ACCELERATION

The registers that use the x_ACCL_OUT format are the primary registers for the accelerometer measurements (see Table 18,Table 19,Table 20). When processing data from these registers, use a 16-bit, twos complement data format. Table 21 provides x_ACCL_OUT digital coding examples.

Table 18. X_ACCL_OUT (Page 0, Base Address = 0x1E)

Bits	Description
[15:0]	X-axis accelerometer data; twos complement, ±18 g range, 0 g = 0x0000, 1 LSB = 0.8 mg

Table 19. Y_ACCL_OUT (Page 0, Base Address = 0x22)

Bits	Description
[15:0]	Y-axis accelerometer data; twos complement, ±18 g range, 0 g = 0x0000, 1 LSB = 0.8 mg

Table 20. Z_ACCL_OUT (Page 0, Base Address = 0x26)

Bits	Description
[15:0]	Z-axis accelerometer data; twos complement, ±18 g range, 0 g = 0x0000, 1 LSB = 0.8 mg

Table 21. x_ACCL_OUT Data Format Examples

Acceleration	Decimal	Hex	Binary
+18 g	+22,500	0x57E4	0101 0111 1110 0100
+1.6 mg	+2	0x0002	0000 0000 0000 0010
+0.8 mg	+1	0x0001	0000 0000 0000 0001
0 mg	0	0x0000	0000 0000 0000 0000
−0.8 mg	−1	0xFFFF	1111 1111 1111 1111
−1.6 mg	−2	0xFFFE	1111 1111 1111 1110
−18 g	−22,500	0xA81C	1010 1000 0001 1100

The registers that use the x_ACCL_LOW naming format provide additional resolution for the accelerometer measurements (see Table 22,Table 23,Table 24). The MSB has a weight of 0.4 mg, and each subsequent bit has ½ the weight of the previous one.

Table 22. X_ACCL_LOW (Page 0, Base Address = 0x1C)

Bits	Description
[15:0]	X-axis accelerometer data; additional resolution bits

Table 23. Y_ACCL_LOW (Page 0, Base Address = 0x20)

Bits	Description
[15:0]	Y-axis accelerometer data; additional resolution bits

Table 24. Z_ACCL_LOW (Page 0, Base Address = 0x24)

Bits	Description
[15:0]	Z-axis accelerometer data; additional resolution bits

DELTA ANGLES

The x_DELTANG_OUT registers are the primary output registers for the delta angle calculations. When processing data from these registers, use a 16-bit, twos complement data format (see Table 25,Table 26,Table 27). Table 28 provides x_DELTANG_OUT digital coding examples.

The delta angle outputs represent an integration of the gyroscope measurements and use the following formula for all three axes (x-axis displayed):

$$\Delta\theta_{x,nD} = \frac{1}{2f_S} \times \sum_{d=0}^{D-1}\left(\omega_{x,nD+d} + \omega_{x,nD+d-1}\right)$$

where：

D is the decimation rate = DEC_RATE + 1.

f_s is the sample rate.

d is the incremental variable in the summation formula.

ω_x is the x-axis rate of rotation (gyroscope).

n is the sample time, prior to the decimation filter.

When using the internal sample clock, f_s is equal to 2460 SPS. When using the external clock option, f_s is equal to the frequency of the external clock, which is limited to a minimum of 2 kHz, to prevent overflow in the x_DELTANG_xxx registers at high rotation rates. See Table 50 and Figure 31 for more information on the DEC_RATE register (decimation filter).

The x_DELTANG_LOW registers (see Table 29,Table 30,Table 31) provide additional resolution bits for the delta angle and combine with the x_DELTANG_OUT registers to provide a 32-bit, twos complement number. The MSB in the x_DELTANG_LOW registers have a weight of ~0.011° (720°/216), and each subsequent bit carries a weight of ½ of the previous one.

Table 25. X_DELTANG_OUT (Page 0, Base Address = 0x42)

Bits	Description
[15:0]	X-axis delta angle data; twos complement, ±720° range, 0° = 0x0000, 1 LSB = 720°/2 15 = ~0.022°

Table 26. Y_DELTANG_OUT (Page 0, Base Address = 0x46)

Bits	Description
[15:0]	Y-axis delta angle data; twos complement, ±720° range, 0° = 0x0000, 1 LSB = 720°/2 15 = ~0.022°

Table 27. Z_DELTANG_OUT (Page 0, Base Address = 0x4A)

Bits	Description
[15:0]	Z-axis delta angle data; twos complement, ±720° range, 0° = 0x0000, 1 LSB = 720°/2 15 = ~0.022°

Table 28. x_DELTANG_OUT Data Format Examples

Angle (°)	Decimal	Hex	Binary
+720 × (215 − 1)/215	+32,767	0x7FFF	0111 1111 1110 1111
+1440/215	+2	0x0002	0000 0000 0000 0010
+720/215	+1	0x0001	0000 0000 0000 0001

0	0	0x0000	0000 0000 0000 0000
−720/215	−1	0xFFFF	1111 1111 1111 1111
−1440/215	−2	0xFFFE	1111 1111 1111 1110
−720	−32,768	0x8000	1000 0000 0000 0000

Table 29. X_DELTANG_LOW (Page 0, Base Address = 0x40)

Bits	Description
[15:0]	X-axis delta angle data; additional resolution bits

Table 30. Y_DELTANG_LOW (Page 0, Base Address = 0x44)

Bits	Description
[15:0]	Y-axis delta angle data; additional resolution bits

Table 31. Z_DELTANG_LOW (Page 0, Base Address = 0x48)

Bits	Description
[15:0]	Z-axis delta angle data; additional resolution bits

DELTA VELOCITY

The registers that use the x_DELTVEL_OUT format are the primary registers for the delta velocity calculations. When processing data from these registers, use a 16-bit, twos complement data format (see Table 32,Table 33,Table 34). Table 35 provides x_DELTVEL_OUT digital coding examples. The delta velocity outputs represent an integration of the accelerometer measurements and use the following formula for all three axes (x-axis displayed):

$$\Delta V_{x,nD} = \frac{1}{2f_x} \times \sum_{d=0}^{D-1} \left(a_{x,nD+d} + a_{x,nD+d-1} \right)$$

where:

- **D is the decimation rate = DEC_RATE + 1.**
- **f_s is the sample rate.**
- **d is the incremental variable in the summation formula.**
- **a_x is the x-axis linear acceleration.**
- **n is the sample time, prior to the decimation filter.**

When using the internal sample clock, f_s is equal to 2460 SPS. When using the external clock option, f_s is equal to the frequency of the external clock, which is limited to a minimum of 2 kHz, to prevent overflow in the x_DELTVEL_xxx registers at high rotation rates. See Table 50 and Figure 31 for more information on the DEC_RATE register (decimation filter).

Table 32. X_DELTVEL_OUT (Page 0, Base Address = 0x4E)

Bits	Description
[15:0]	X-axis delta velocity data; twos complement, ±200 m/sec range, 0 m/sec = 0x0000 1 LSB = 200 m/sec ÷215 = ~6.104 mm/sec

Table 33. Y_DELTVEL_OUT (Page 0, Base Address = 0x52)

Bits	Description
[15:0]	Y-axis delta velocity data; twos complement, ±200 m/sec range, 0 m/sec = 0x0000 1 LSB = 200 m/sec ÷215 = ~6.104 mm/sec

Table 34. Z_DELTVEL_OUT (Page 0, Base Address = 0x56)

Bits	Description
[15:0]	Z-axis delta velocity data; twos complement, ±200 m/sec range, 0 m/sec = 0x0000 1 LSB = 200 m/sec ÷215 = ~6.104 mm/sec

Table 35. x_DELTVEL_OUT, Data Format Examples

Velocity (m/sec)	Decimal	Hex	Binary
+200 × (215 −1)/215	+32,767	0x7FFF	0111 1111 1111 1111
+400/215	+2	0x0002	0000 0000 0000 0010
+200/215	+1	0x0001	0000 0000 0000 0001
0	0	0x0000	0000 0000 0000 0000
−200/215	−1	0xFFFF	1111 1111 1111 1111
−400/215	−2	0xFFFE	1111 1111 1111 1110
−200	−32,768	0x8000	1000 0000 0000 0000

The x_DELTVEL_LOW registers (see Table 36,Table 37,Table 38) provide additional resolution bits for the delta velocity and combine with the x_DELTVEL_OUT registers to provide a 32-bit, twos complement number. The MSB in the x_DELTVEL_LOW registers have a weight of ~3.052 mm/sec (200 m/sec ÷216), and each subsequent bit carries a weight of ½ of the previous one.

Table 36. X_DELTVEL_LOW (Page 0, Base Address = 0x4C)

Bits	Description
[15:0]	X-axis delta velocity data; additional resolution bits

Table 37. Y_DELTVEL_LOW (Page 0, Base Address = 0x50)

Bits	Description
[15:0]	Y-axis delta velocity data; additional resolution bits

Table 38. Z_DELTVEL_LOW (Page 0, Base Address = 0x54)

Bits	Description
[15:0]	Z-axis delta velocity data; additional resolution bits

MAGNETOMETERS

The registers that use the x_MAGN_OUT format are the primary registers for the magnetometer measurements. When processing data from these registers, use a 16-bit, twos complement data format. Table 39,Table 40,Table 41 provide the numerical format for each register, and Table 42 provides x_MAGN_OUT digital coding examples.

Table 39. X_MAGN_OUT (Page 0, Base Address = 0x28)

Bits	Description
[15:0]	X-axis magnetometer data; twos complement, ±3.2767 gauss range, 0 gauss = 0x0000, 1 LSB = 0.1 mgauss

Table 40. Y_MAGN_OUT (Page 0, Base Address = 0x2A)

Bits	Description
[15:0]	Y-axis magnetometer data; twos complement, ±3.2767 gauss range, 0 gauss = 0x0000, 1 LSB = 0.1 mgauss

Table 41. Z_MAGN_OUT (Page 0, Base Address = 0x2C)

Bits	Description
[15:0]	Z-axis magnetometer data; twos complement, ±3.2767 gauss range, 0 gauss = 0x0000, 1 LSB = 0.1 mgauss

Table 42. x_MAGN_OUT Data Format Examples

Magnetic Field	Decimal	Hex	Binary
+3.2767 gauss	+32,767	0x7FFF	0111 1111 1111 1111
+0.2 mgauss	+2	0x0002	0000 0000 0000 0010
+0.1 mgauss	+1	0x0001	0000 0000 0000 0001
0 gauss	0	0x0000	0000 0000 0000 0000
−0.1 mgauss	−1	0xFFFF	1111 1111 1111 1111
−0.2 mgauss	−2	0xFFFE	1111 1111 1111 1110
−3.2768 gauss	−32,768	0x8000	1000 0000 0000 0000

BAROMETER

The BAROM_OUT register (see Table 43) and BAROM_LOW register (see Table 45) provide access to the barometric pressure data. These two registers combine to provide a 32-bit, twos complement format. Some applications can use BAROM_OUT by itself. For cases where the finer resolution available from BAROM_LOW is valuable, combine them in the same manner as the gyroscopes (see Figure 29). Table 43 provides the numerical format for BAROM_ OUT, and Table 44 provides digital coding examples.

Table 43. BAROM_OUT (Page 0, Base Address = 0x30)

Bits	Description
[15:0]	Barometric pressure; twos complement, ±1.31 bar range, 0 bar = 0x0000, 40 µbar/LSB

Table 44. BAROM_OUT Data Format Examples

Pressure (Bar)	Decimal	Hex	Binary
+0.00004 × (215 −1)	+32,767	0x7FFF	0111 1111 1110 1111
+0.00008	+2	0x0002	0000 0000 0000 0010
+0.00004	+1	0x0001	0000 0000 0000 0001
0	0	0x0000	0000 0000 0000 0000
−0.00004	−1	0xFFFF	1111 1111 1111 1111
−0.00008	−2	0xFFFE	1111 1111 1111 1110
−0.00004 × 215	−32,768	0x8000	1000 0000 0000 0000

The BAROM_LOW register provides additional resolution for the barometric pressure measurement. The MSB has a weight of 20 µbar, and each subsequent bit carries a weight of ½ of the previous one.

Table 45. BAROM_LOW (Page 0, Base Address = 0x2E)

Bits	Description
[15:0]	Barometric pressure; additional resolution bits

INTERNAL TEMPERATURE

The TEMP_OUT register provides an internal temperature measurement for observing relative temperature changes inside the KT-EX9-2 (see Table 46). Table 47 provides TEMP_OUT digital coding examples. Note that this temperature reflects a higher temperature than that of ambient temperature, due to self heating.

Table 46. TEMP_OUT (Page 0, Base Address = 0x0E)

Bits	Description
[15:0]	Temperature data; twos complement, 0.00565℃ per LSB, 25℃ = 0x0000

Table 47. TEMP_OUT Data Format Examples

Temperature (℃)	Decimal	Hex	Binary
+85	+10,619	0x297B	0010 1001 0111 1011
+25 + 0.0113	+2	0x0002	0000 0000 0000 0010
+25 + 0.00565	+1	0x0001	0000 0000 0000 0001
+25	0	0x0000	0000 0000 0000 0000
+25 − 0.00565	−1	0xFFFF	1111 1111 1111 1111
+25 − 0.0113	−2	0xFFFE	1111 1111 1111 1110

The ALM_STS register in Table 48provides the alarm bits for the programmable alarm levels of each sensor. Note that reading the ALM_STS register causes all of its bits to restore to 0. The bits only return to 1 if the error condition persists.

Table 48. ALM_STS (Page 0, Base Address = 0x0C)

Bits	Description (Default = 0x0000)
5	Z-axis accelerometer alarm flag (1 = alarm is active)
4	Y-axis accelerometer alarm flag (1 = alarm is active)
3	X-axis accelerometer alarm flag (1 = alarm is active)
2	Z-axis gyroscope alarm flag (1 = alarm is active)
1	Y-axis gyroscope alarm flag (1 = alarm is active)
0	X-axis gyroscope alarm flag (1 = alarm is active)

PRODUCT IDENTIFICATION

The PROD_ID register (see Table 49) contains the binary equivalent of the device number (16,488 = 0x4068).

Table 49. PROD_ID (Page 0, Base Address = 0x7E)

Bits	Description (Default = 0x4068)
[15:0]	Product identification = 0x4068

DIGITAL SIGNAL PROCESSING

GYROSCOPES/ACCELEROMETERS

Figure 31 provides a signal flow diagram for all of the components and settings that influence the frequency response for the accelerometers and gyroscopes. The sample rate for each accelerometer and gyroscope is 2.46 kHz. Each sensor has its own averaging/decimation filter stage. When using the external clock option (FNCTIO_CTRL[7:4], see Table 67), the input clock drives a sample rate of 2.46 kSPS.

AVERAGING/DECIMATION FILTER

The DEC_RATE register (see Table 50) provides user control for the final filter stage (see Figure 31), which averages and decimates the accelerometers, gyroscopes, delta angle, and delta velocity data. The output sample rate is equal to 2460/(DEC_RATE + 1).
When using the external clock option (FNCTIO_CTRL[7:4], see Table 67)), replace the 2460 number in this relationship with the input clock frequency. For example, turn to Page 3 (DIN = 0x8003), and set DEC_RATE = 0x18 (DIN = 0x8C18, then DIN = 0x8D00) to reduce the output sample rate to 98.4 SPS (2460 ÷25).

Table 50. DEC_RATE (Page 3, Base Address = 0x0C)

Bits	Description (Default = 0x0000)
[15:11]	Don't care
[10:0]	Decimation rate, binary format, maximum = 2047, see Figure 20 for impact on sample rate

MAGNETOMETER/BAROMETER

The update rates for the magnetometer and barometers do not change with the DEC_RATE register settings.
The magnetometer and barometer sampling frequency is 50Hz. It is not configurable via the SEQ_CNT register.

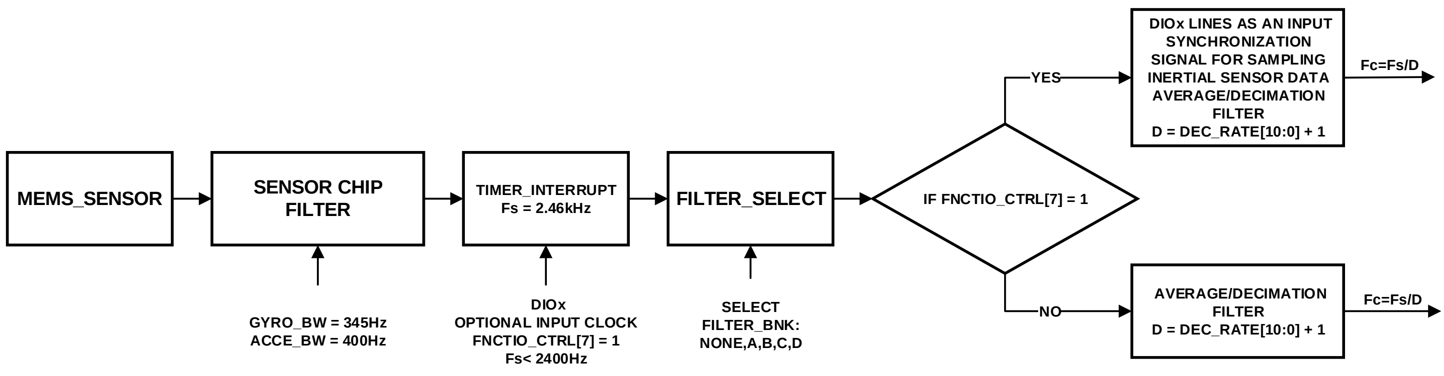

Figure 31. Sampling and Frequency Response Signal Flow

FIR FILTER BANKS

The KT-EX9-2 provides four configurable, 120-tap FIR filter banks. Each coefficient is 16 bits wide and occupies its own register location for each page. When designing a FIR filter for these banks, use a sample rate of 2.46 kHz and scale the coefficients so that their sum equals 32,768. For filter designs that have less than 120 taps, load the coefficients into the lower portion of the filter and start with Coefficient 1. To prevent adding phase delay to the response, ensure that all unused taps are equal to zero.

The FILTR_BNK_x registers provide three bits per sensor, which configure the filter bank (A, B, C, D) and turn filtering on and off. For example, turn to Page 3 (DIN = 0x8003), then write 0x0057 to FILTR_BNK_0 (DIN = 0x9657, DIN = 0x9700) to set the x-axis gyroscope to use the FIR filter in Bank D, to set the y-axis gyroscope to use the FIR filter in Bank B, and to enable these FIR filters in both x- and y-axis gyroscopes. Note that the filter settings update after writing to the upper byte; therefore, always configure the lower byte first. In cases that require configuration to only the lower byte of either FILTR_BNK_0 or FILTR_BNK_1, complete the process by writing 0x00 to the upper byte.

Table 51. FILTR_BNK_0 (Page 3, Base Address = 0x16)

Bits	Description (Default = 0x0000)
15	Don't care
14	Y-axis accelerometer filter enable (1 = enabled)
[13:12]	Y-axis accelerometer filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D
11	X-axis accelerometer filter enable (1 = enabled)
[10:9]	X-axis accelerometer filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D
8	Z-axis gyroscope filter enable (1 = enabled)
[7:6]	Z-axis gyroscope filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D
5	Y-axis gyroscope filter enable (1 = enabled)
[4:3]	Y-axis gyroscope filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D
2	X-axis gyroscope filter enable (1 = enabled)
[1:0]	X-axis gyroscope filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D

Table 52. FILTR_BNK_1 (Page 3, Base Address = 0x18)

Bits	Description (Default = 0x0000)
[15:12]	Don't care
11	Z-axis magnetometer filter enable (1 = enabled)
[10:9]	Z-axis magnetometer filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D
8	Y-axis magnetometer filter enable (1 = enabled)
[7:6]	Y-axis magnetometer filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D
5	X-axis magnetometer filter enable (1 = enabled)
[4:3]	X-axis magnetometer filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D
2	Z-axis accelerometer filter enable (1 = enabled)
[1:0]	Z-axis accelerometer filter bank selection: 00 = Bank A, 01 = Bank B, 10 = Bank C, 11 = Bank D

FILTER MEMORY ORGANIZATION

Each filter bank uses two pages of the user register structure. See Table 53,Table 54,Table 55 and Table 56 for the register addresses in each filter bank.

Table 53. Filter Bank A Memory Map

Page	PAGE_ID	Address	Register
5	0x05	0x00	PAGE_ID
5	0x05	0x02 to 0x07	Not used
5	0x05	0x08	FIR_COEF_A000
5	0x05	0x0A	FIR_COEF_A001
5	0x05	0x0C to 0x7C	FIR_COEF_A002 to FIR_COEF_A058
5	0x05	0x7E	FIR_COEF_A059
6	0x06	0x00	PAGE_ID
6	0x06	0x02 to 0x07	Not used

6	0x06	0x08	FIR_COEF_A060
6	0x06	0x0A	FIR_COEF_A061
6	0x06	0x0C to 0x7C	FIR_COEF_A062 to FIR_COEF_A118
6	0x06	0x7E	FIR_COEF_D119

Table 54. Filter Bank B Memory Map

Page	PAGE_ID	Address	Register
7	0x07	0x00	PAGE_ID
7	0x07	0x02 to 0x07	Not used
7	0x07	0x08	FIR_COEF_B000
7	0x07	0x0A	FIR_COEF_B001
7	0x07	0x0C to 0x7C	FIR_COEF_B002 to FIR_COEF_B058
7	0x07	0x7E	FIR_COEF_B059
8	0x08	0x00	PAGE_ID
8	0x08	0x02 to 0x07	Not used
8	0x08	0x08	FIR_COEF_B060
8	0x08	0x0A	FIR_COEF_B061
8	0x08	0x0C to 0x7C	FIR_COEF_B062 to FIR_COEF_B118
8	0x08	0x7E	FIR_COEF_B119

Table 55. Filter Bank C Memory Map

Page	PAGE_ID	Address	Register
9	0x09	0x00	PAGE_ID
9	0x09	0x02 to 0x07	Not used
9	0x09	0x08	FIR_COEF_C000
9	0x09	0x0A	FIR_COEF_C001
9	0x09	0x0C to 0x7C	FIR_COEF_C002 to FIR_COEF_C058
9	0x09	0x7E	FIR_COEF_C059
10	0x0A	0x00	PAGE_ID
10	0x0A	0x02 to 0x07	Not used
10	0x0A	0x08	FIR_COEF_C060
10	0x0A	0x0A	FIR_COEF_C061
10	0x0A	0x0C to 0x7C	FIR_COEF_C062 to FIR_COEF_C118
10	0x0A	0x7E	FIR_COEF_C119

Table 56. Filter Bank D Memory Map

Page	PAGE_ID	Address	Register
11	0x0B	0x00	PAGE_ID
11	0x0B	0x02 to 0x07	Not used
11	0x0B	0x08	FIR_COEF_D000
11	0x0B	0x0A	FIR_COEF_D001
11	0x0B	0x0C to 0x7C	FIR_COEF_D002 to FIR_COEF_D058
11	0x0B	0x7E	FIR_COEF_D059
12	0x0C	0x00	PAGE_ID
12	0x0C	0x02 to 0x07	Not used
12	0x0C	0x08	FIR_COEF_D060
12	0x0C	0x0A	FIR_COEF_D061
12	0x0C	0x0C to 0x7C	FIR_COEF_D062 to FIR_COEF_D118
12	0x0C	0x7E	FIR_COEF_D119

DEFAULT FILTER PERFORMANCE

The FIR filter banks have factory-programmed filter designs. They are all low-pass filters that have unity dc gain. Table 57 provides a summary of each filter design, and Figure 32 shows the frequency response characteristics. The phase delay is equal to ½ of the total number of taps.

Table 57. FIR Filter Descriptions, Default Configuration

FIR Filter Bank	Taps	−3 dB Frequency (Hz)
A	120	310
B	120	55
C	32	275
D	32	63

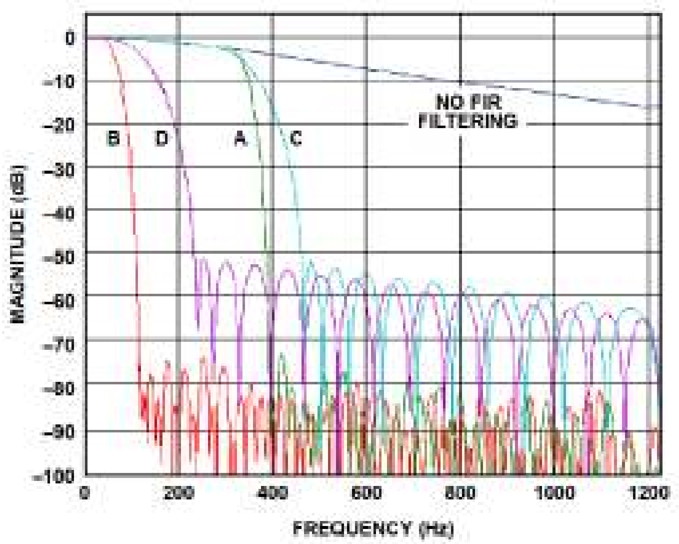

Figure 32. FIR Filter Frequency Response Curves

ALARMS

Each sensor has an independent alarm function that provides register (see Table 48) contains the alarm output flags and the FNCTIO_CTRL register (see Table 67) provides an option for configuring one of the digital input/output lines as an alarm indicator.

ALARM USE

The dynamic alarm setting provides the option to compare the change in the output of each sensor over a period of 48.7 ms with that sensor's xx_ALM_MAGN register.

Table 58. XG_ALM_MAGN (Page 3, Base Address = 0x28)

Bits	Description (Default = 0x0000)
[15:0]	X-axis gyroscope alarm threshold settings, twos complement, 0°/sec = 0x0000, 1 LSB = 0.02°/sec

Table 59. YG_ALM_MAGN (Page 3, Base Address = 0x2A)

Bits	Description (Default = 0x0000)
[15:0]	Y-axis gyroscope alarm threshold settings, twos complement, 0°/sec = 0x0000, 1 LSB = 0.02°/sec

Table 60. ZG_ALM_MAGN (Page 3, Base Address = 0x2C)

Bits	Description (Default = 0x0000)
[15:0]	Z-axis gyroscope alarm threshold settings, twos complement, 0°/sec = 0x0000, 1 LSB = 0.02°/sec

Table 61. XA_ALM_MAGN (Page 3, Base Address = 0x2E)

Bits	Description (Default = 0x0000)
[15:0]	X-axis accelerometer alarm threshold settings, twos complement, 0 g = 0x0000, 1 LSB = 0.8 mg

Table 62. YA_ALM_MAGN (Page 3, Base Address = 0x30)

Bits	Description (Default = 0x0000)
[15:0]	Y-axis accelerometer alarm threshold settings, twos complement, 0 g = 0x0000, 1 LSB = 0.8 mg

Table 63. ZA_ALM_MAGN (Page 3, Base Address = 0x32)

Bits	Description (Default = 0x0000)
[15:0]	Z-axis accelerometer alarm threshold settings, twos complement, 0 g = 0x0000, 1 LSB = 0.8 mg

ALARM REG CONFIG

To use the alarm function, you need to configure the alarm setting bit [11:8] in the FNCTIO_CTRL register, then set the value of the xx_ALM_MAGN register as the alarm threshold, and finally set the enable bit of the relevant alarm in the ALM_CFGN_x register

Table 64. ALM_CNFG_0 (Page 3, Base Address = 0x20)

Bits	Description (Default = 0x0000)
15	X-axis accelerometer alarm (1 = enabled)
14	Not used
13	X-axis accelerometer alarm polarity (1 = greater than)
12	X-axis accelerometer dynamic enable (1 = enabled)
11	Z-axis gyroscope alarm (1 = enabled)
10	Not used
9	Z-axis gyroscope alarm polarity (1 = greater than)
8	Z-axis gyroscope dynamic enable (1 = enabled)
7	Y-axis gyroscope alarm (1 = enabled)
6	Not used
5	Y-axis gyroscope alarm polarity (1 = greater than)
4	Y-axis gyroscope dynamic enable (1 = enabled)
3	X-axis gyroscope alarm (1 = enabled)
2	Not used
1	X-axis gyroscope alarm polarity (1 = greater than)
0	X-axis gyroscope dynamic enable (1 = enabled)

Table 65. ALM_CNFG_1 (Page 3, Base Address = 0x22)

Bits	Description (Default = 0x0000)
15	Not used
14	Not used
13	Not used
12	Not used
11	Not used
10	Not used
9	Not used
8	Not used
7	Z-axis accelerometer alarm (1 = enabled)
6	Not used
5	Z-axis accelerometer alarm polarity (1 = greater than)
4	Z-axis accelerometer dynamic enable (1 = enabled)
3	Y-axis accelerometer alarm (1 = enabled)
2	Not used
1	Y-axis accelerometer alarm polarity (1 = greater than)
0	Y-axis accelerometer dynamic enable (1 = enabled)

ALARM EXAMPLE

Table 66 offers an alarm configuration example, which sets the z-axis gyroscope alarm to trip when Z_GYRO_OUT > 131.1°/sec (0x199B).

Table 66. Alarm Configuration Example

DIN	Description
0xAC9B	Set ZG_ALM_MAGN[7:0] = 0x9B
0xAD19	Set ZG_ALM_MAGN[15:8] = 0x19
0xA000	Set ALM_CNFG_0[7:0] = 0x00
0xA103	Set ALM_CNFG_0[15:8] = 0x08

SYSTEM CONTROLS

GENERAL-PURPOSE INPUT/OUTPUT

There are four general-purpose input/output pins: DIO1, DIO2, DIO3, and DIO4. The FNCTIO_CTRL register controls the basic function of each input/output pin, which provides a number of useful functions. Each input/output pin only supports one function at a time. In cases where a single pin has two different assignments, the enable bit for the lower priority function automatically resets to zero and is disabled. The priority is (1) data ready, (2) sync clock input, (3) alarm indicator, and (4) general purpose, where 1 identifies the highest priority and 4 indicates the lowest priority.

Table 67. FNCTIO_CTRL (Page 3, Base Address = 0x06)

Bits	Description (Default = 0x000D)
[15:12]	Not used
11	Alarm indicator: 1 = enabled, 0 = disabled
10	Alarm indicator polarity: 1 = positive, 0 = negative
[9:8]	Alarm indicator line selection: 00 = DIO1, 01 = DIO2, 10 = DIO3, 11 = DIO4
7	Sync clock input enable: 1 = enabled, 0 = disabled
6	Sync clock input polarity: 1 = rising edge, 0 = falling edge
[5:4]	Sync clock input line selection: 00 = DIO1, 01 = DIO2, 10 = DIO3, 11 = DIO4
3	Data-ready enable: 1 = enabled, 0 = disabled
2	Data ready polarity: 1 = positive, 0 = negative
[1:0]	Data ready line selection: 00 = DIO1, 01 = DIO2, 10 = DIO3, 11 = DIO4

DATA-READY INDICATOR

FNCTIO_CTRL[3:0] provide some configuration options for using one of the DIOx lines as a data ready indicator signal, which can drive the interrupt control line of a processor. The factory default assigns DIO2 as a positive polarity, data ready signal. Use the following sequence to change this assignment to DIO1 with a negative polarity: turn to Page 3 (DIN = 0x8003) and set FNCTIO_CTRL[3:0] = 1000 (DIN = 0x8608, then DIN = 0x8700). The timing jitter on the data ready signal is ±1.4 µs.

INPUT SYNC/CLOCK CONTROL

FNCTIO_CTRL[7:4] provide some configuration options for using one of the DIOx lines as an input synchronization signal for sampling inertial sensor data. For example, use the following sequence to establish DIO4 as a positive polarity, input clock pin and keep the factory default setting for the data ready function: turn to Page 3 (DIN = 0x8003) and set FNCTIO_CTRL[7:0] = 0xFD (DIN = 0x86FD, then DIN = 0x8700). Note that this command also disables the internal sampling clock, and no data sampling occurs without the input clock signal. When selecting a clock input frequency, consider the 330 Hz sensor bandwidth because undersampling the sensors can degrade noise and stability performance.

APPLICATIONS INFORMATION

MOUNTING BEST PRACTICES

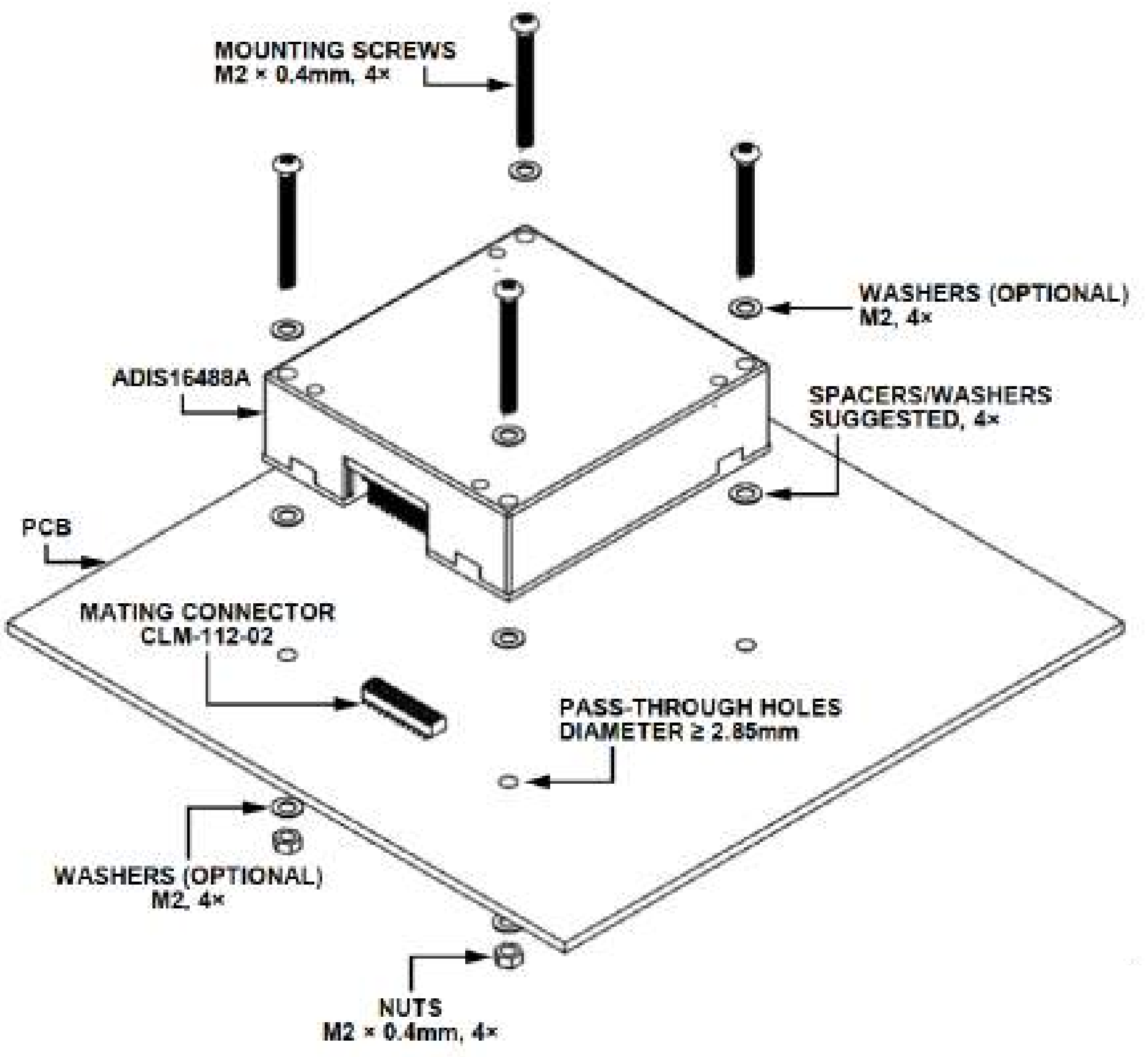

Figure 33. Mounting Example

For best performance, follow these simple rules when installing the KT-EX9-2 into a system:

1. **Eliminate opportunity for translational force (x- and y-axis direction, per figure 6) application on the electrical connector.**
2. **Isolate mounting force to the four corners, on the portion of the package surface that surrounds the mounting holes.**
3. **Use uniform mounting forces on all four corners. The suggested torque setting is 40 inch-ounces (0.285 N-m).**

These three rules help prevent irregular force profiles, which can warp the package and introduce bias errors in the sensors. Figure 33 provides an example that leverages washers to set the package off the mounting surface and uses 2.85 mm pass-through holes and backside washers/nuts for attachment. Figure 34 and Figure 35 provide some details for mounting hole and connector

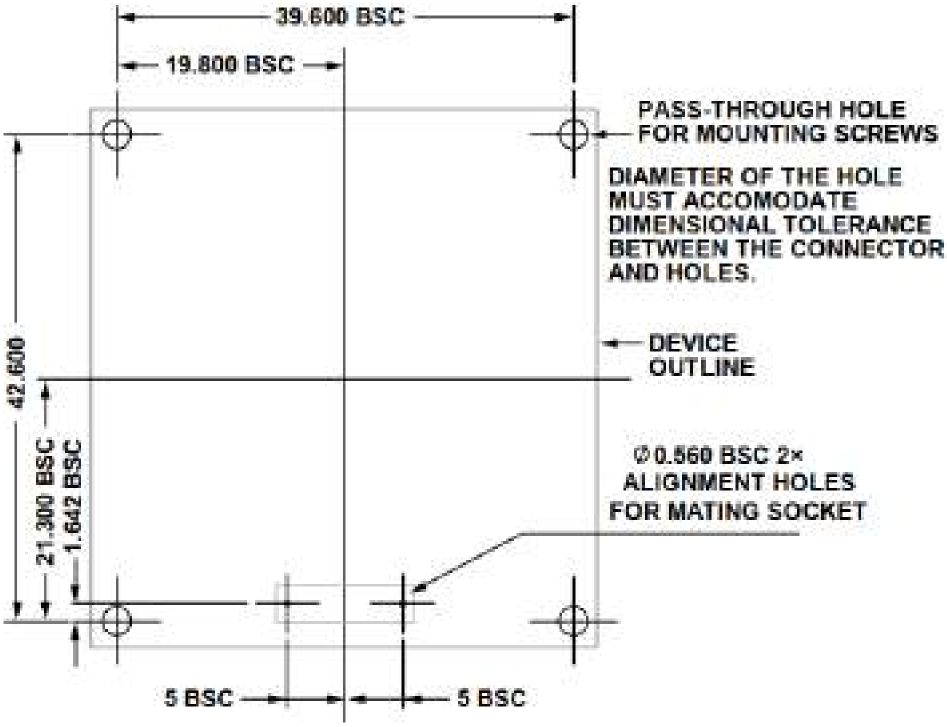

Figure 34. Suggested PCB Layout Pattern, Connector Down

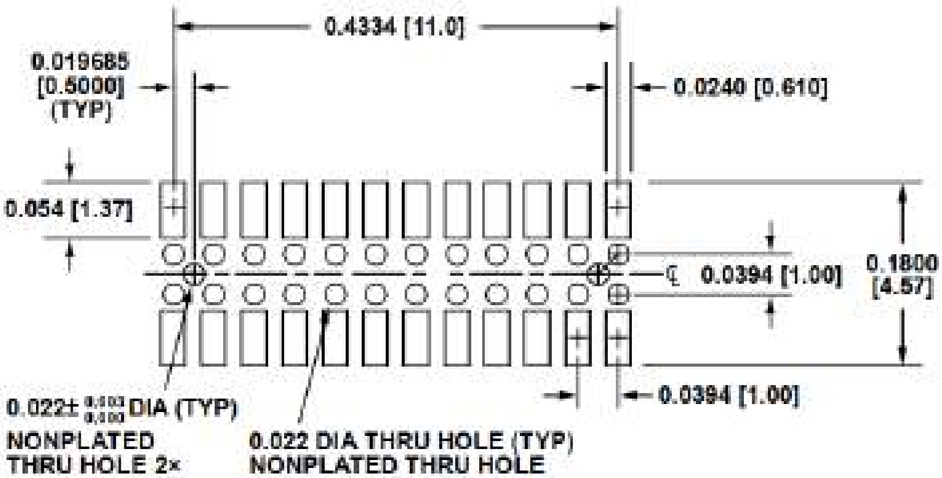

Figure 35. Suggested Layout and Mechanical Design When Using for the Mating Connector

POWER SUPPLY CONSIDERATIONS

The KT-EX9-2 has approximately 30 μF of capacitance across the VDD and GND pins. Whereas this capacitor bank provides a large amount of localized filtering, it also presents an opportunity for excessive charging current when the VDD voltage ramps quickly.

Test with a 3.3V DC regulated power supply, and under 500mA current limiting, Figure 36 offers the spikes current in power on process, Figure 37 provides more detail on the input voltage and current behavior during the whole power on process. According the two figures, in the power on process, the max spikes current is 800mA, 200us, and the power on time is about 10ms. To ensure a reliable power on process, we recommend a guaranteed power supply capacity of at least 200mA.

Figure 36. Transient Current Demand, Start Up

Figure 37. Transient Current Demand, Peak Demand

X-RAY SENSITIVITY

Exposure to high dose rate X-rays, such as those in production systems that inspect solder joints in electronic assemblies, can affect accelerometer bias errors. For optimal performance, avoid exposing the KT-EX9-2 to this type of inspection.

ACOUSTIC NOISE SENSITIVITY

An inertial sensor can be placed in a chamber with a loud speaker to see whether the performance of the sensor is affected by the acoustic environment that might be encountered in a missile, helicopter, or other such mission. The shape of the chamber could be such that the sound from the loud speaker is focused onto the test article.

The product adopts a technical solution of internal shock absorption design in a closed chamber, and the inertial sensors are packaged in a vacuum ceramic tube shell. These measures greatly improve the product's noise resistance performance. After an acoustic noise test with a total sound pressure of 150dB, frequency from 50Hz to 10000Hz, it has been proven that the product is immune to the acoustic noise.

OUTLINE DIMENSIONS

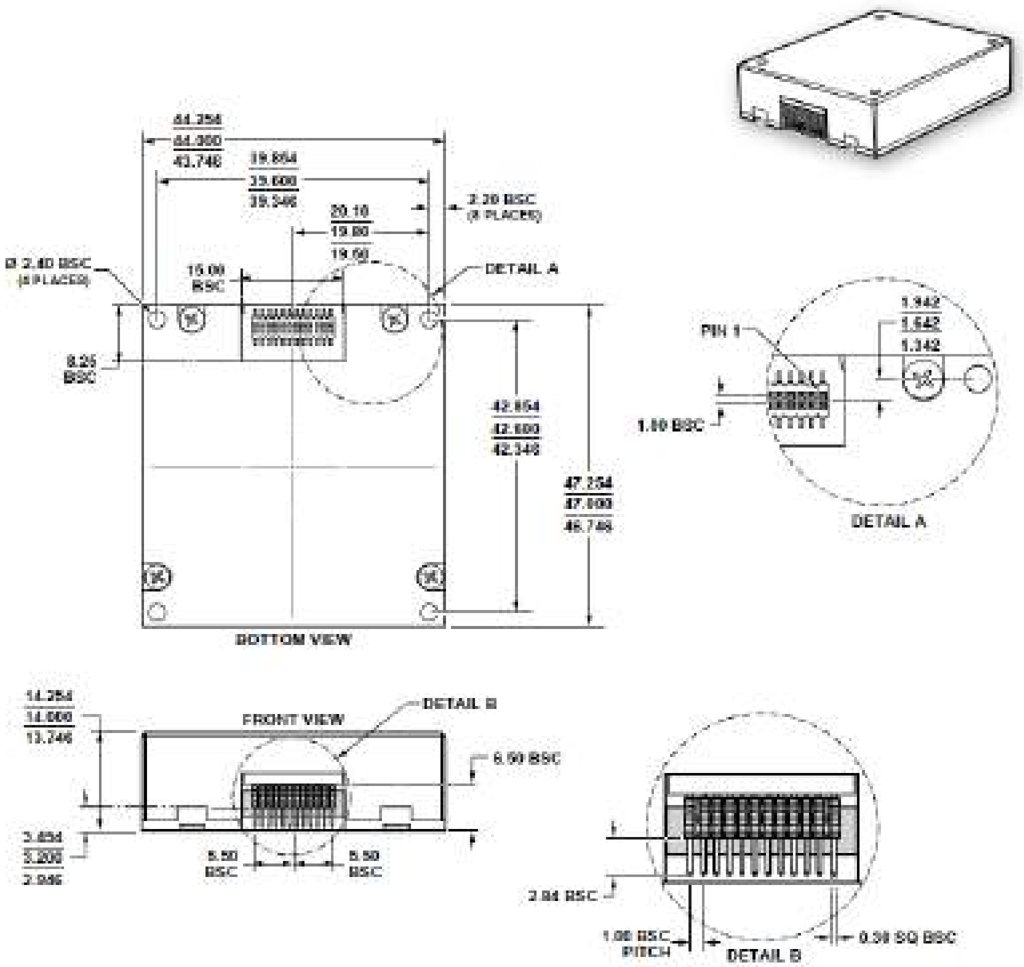

Figure 38. 24-Lead Module with Connector Interface Dimensions shown in millimeters