

VECTOR 2X and 2XG ELECTRONIC COMPASS MODULES

Complete App. Notes

Vector modules are low-cost, 2-axis compass and magnetic sensor modules suitable for OEM applications. Using Precision Navigation's patented magneto-inductive magnetometer technology (United States Patent #4,851,775), the Vector modules deliver high accuracy, low power, and low cost in small packages.

VECTOR 2X MODULE FEATURES

- Accuracy = 2°
- Small size and weight: 1.50" x 1.30" x 0.39"; 0.3oz.
- Low power requirement: single-sided 5-volt (regulated) supply
- Low resolution output is 5 Hz; high resolution output is 2.5Hz
- Input voltage on all I/O ports: -0.3 to $V_{DD} + 0.3$ volts
- Output voltage on all I/O ports: -0.3 to $V_{DD} + 0.3$ volts
- Output ports can source or sink 5 mA
- 3-wire serial output format (Motorola SPI- and National Microwire-compatible) makes for easy installation into OEM systems
- Hard iron calibration
- Raw uncalibrated output option
- Pin-selectable Binary-Coded Decimal (BCD) or Binary output format
- Polled or continuous mode options
- Master or slave capability for data clock generation
- Operating temperature range: -20°C to 70°C
- Storage temperature range: -30°C to 90°C

VECTOR 2XG offers the above features, plus:

- Dynamic tilt range of $\pm 15^\circ$
- Small size: 1.50" x 1.30" x 1.025"

POSSIBLE APPLICATIONS

- GPS system backup azimuth data
- Remote terrestrial antenna direction indicators
- Auto and industrial navigation systems
- Consumer and hobbyist markets
- Survey instruments
- Laboratory equipment
- Robotics systems
- Azimuth indicators
- Vehicle detection
- Detection of magnetic fields or materials

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INTRODUCTION TO THE VECTOR SERIES OF MODULES

PNI makes two modules in the Vector series: the Vector 2X ("V2X") and the Vector 2XG. Other than the gimbal feature of the Vector 2XG, operation of the V2X and the V2XG is the same. Therefore, these Application Notes are for both the V2X and the V2XG. The term "Vector" is used when the statement applies to either module. **Before using a Vector module, please review these Notes carefully to understand the features and limitations.** Besides these Application Notes, PNI does *not* provide any other information (such as sample software for controlling a microprocessor) for applications of the Vector modules.

DIFFERENCE BETWEEN THE V2X AND THE V2XG

The V2X

The V2X is a 2-axis magnetometer that measures the magnetic field in a single plane. This plane is the plane created by its two sensors, which are perpendicular to each other on the board. To calculate heading accurately, a compass must measure the Earth's field in the plane which is level. "Level" means the plane parallel to the surface of a glass of water --- even though the glass tilts, the water's surface will remain "level."

If the V2X is not level, the calculated heading will have errors related to the tilt of the board from level. Tilt is the pitch and/or roll of the board. The amount of error varies depending on where you are on the Earth. For example, in Mountain View, CA, for each 1° of tilt, there would be about 3° of heading error. In Greenland, for 1° of tilt, there can be about 10° of heading error. The U.S. Geological Survey in Menlo park, CA, publishes maps which relate the error values for various parts of the world. Therefore, try to mount the V2X as level as possible within the host system. For systems that do not require precise heading information when the compass is tilted, the V2X is a cost-effective solution.

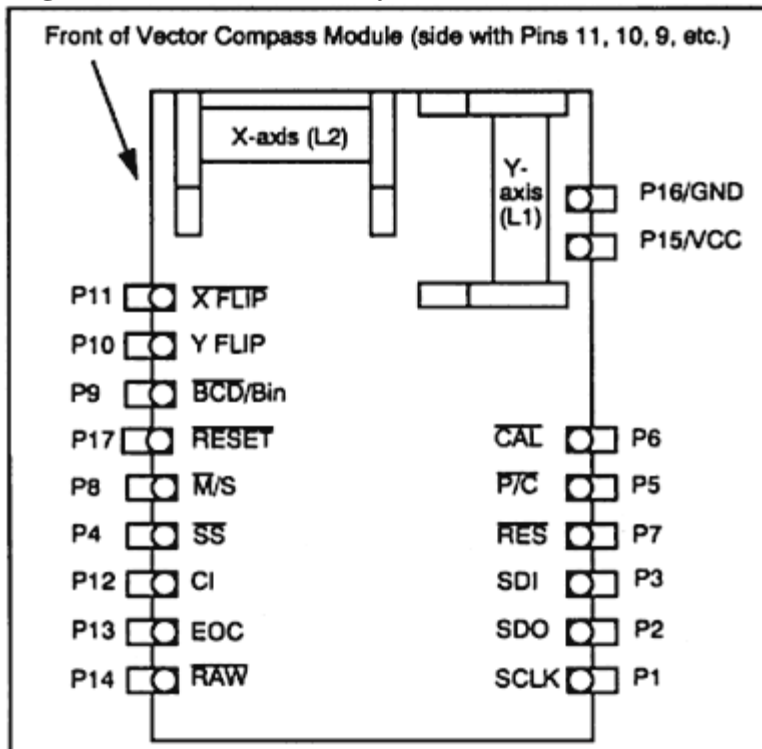
The V2XG

The V2XG uses mechanical gimbals to minimize the effect of tilt in compass applications. The V2XG has gimbals on its two sensors so that when its board is tilted up to 15° from level, its sensors swing back to level, which allows the V2XG to maintain its compass heading accuracy over that tilt range. Therefore, the V2XG is more suitable as a compass than a 2-axis magnetometer.

FEATURES AND SPECIFICATIONS

A board layout of the Vector is shown in Figure 1 below. The pin programmability allows users to set up the compass for their specific needs. The Vector uses a synchronous serial port for communication to the host device (compatible with Motorola SPI, QSPI, and National Microwire). The output data format is pin-selectable between BCD and binary mode, and the serial data output (SDO) is tri-stated when the unit is not selected in Slave mode.

Figure 1: Vector Board Layout



Front of Vector

When the Vector is used as a compass, heading is calculated with respect to the front of the Vector. The direction the front faces is the heading.

These Notes define the "front" of the Vector as the side of the Vector with nine pins, which are all right next to each other (these pins are XFLIP, YFLIP, BCD/Bin, RESET, M/S, SS, CI, EOC, and RAW). This also assumes that the Vector is mounted with the "pins down," which means that the pins (Pin 1 through 17) would stick in the ground if you set the Vector down on the ground. The V2XG can only be mounted with the pins down so its sensors will swing on the gimbals properly.

To make a different side of the Vector the "front," you need to determine whether XFLIP or YFLIP should be low or high. To mount the V2X with the "pins up" --- the sensor coils would hit the ground if you put it on the ground with the pins up --- you need to determine whether XFLIP or YFLIP should be low or high.

Basic Outputs

The Vector can output either **heading** (also called yaw or azimuth) of the compass module or the **raw outputs** of the two sensors on the board --- these outputs are related to the magnetic field.

- The heading is output in degrees in either binary coded decimal (BCD) or binary output format.
- There are two raw outputs related to the magnetic field. We call one raw output the "X" axis and the other raw output the "Y" axis of the magnetic field. The X-axis reading and the Y-axis reading from the two sensors (the coils) on the Vector are unitless.

PROTECTION AGAINST THE ELEMENTS

Coatings, RTV

The Vector does not have a conformal coating. You can apply one (any standard conformal coating should be fine) to protect the Vector from moisture. However, because the V2XG has mechanical gimbals, any coating should not be put on the gimbals. Also, dust or other particles may get into the moving parts and compromise performance. Therefore, the V2XG should be mounted in a sealed housing for maximum performance. Note that RTV and similar "potting" substances applied to the crystal or the sensors themselves should not hurt the Vector. Adding conformal coating or potting material will only void the warranty (if any applies) if the coating or potting material interferes with repair or otherwise damages the Vector.

Housings

Our customers choose a variety of materials for housings. The housing material should not have a magnetic field and should not shield the module from magnetic fields from the host system or the Earth. Plastic and aluminum are examples of suitable housing materials; note also that screws and other parts of the housing should also be non-ferrous. We do not recommend or offer any particular housing because our customers have very different requirements.

Compass Calibration

When used as a compass, the Vector can calibrate for constant magnetic fields in the host system. However, the Vector cannot calibrate for magnetic fields which are not constantly in the same place with respect to the Vector. For example, in a car, the Vector can subtract the car's magnetic field from the total magnetic field to calculate the Earth's magnetic field (and therefore, heading). However, it cannot correct for a truck driving by. See the description of the "CAL" pin for how to calibrate the Vector.

NOTE: The Vector does not have non-volatile memory (such as EEPROM), so when the power is turned off, it loses its calibration settings. To maintain the calibration settings, the Vector can be kept in "sleep mode" (with a power of 2.5 volts) or the host system can calculate calibration values and headings.

POWER CONSIDERATIONS

POWER SUPPLY. The minimum and maximum supply voltages are standard TTL: 5 V \pm 0.25 V (or 4.75 V to 5.25 V). The minimum and maximum voltages (for input and output pins) are also standard TTL (4.75 V to 5.25 V). The voltage for the change of state (from "0" to "1") of input and output pins is standard CMOS: less than 1.35 V is a zero, and greater than 3.15 V is a one.

MASTER MODE. When running in master mode, the Vector draws about 6.0 mA; when idle the Vector draws about 300 μ A; and with power of 2.5 V, the Vector draws about 100 μ A.

SLAVE OR RAW MODE. When running in slave or RAW mode, the Vector draws about 4 mA at the 5 Hz poll rate; when idle the Vector draws about 100 μ A; and with power of 2.5 V, the Vector draws about 30 μ A.

SLEEP MODE. The Vector is in "sleep mode" when P/C, EOC, and SS are all high because the Vector is inactive. You can lower the power from 5 V to 2.5 V to maintain the calibration information in the Vector; if the power is lower than 2.5 V, the Vector loses the calibration information.

POWER CONSERVATION. If the Vector must be turned off entirely to conserve power in a certain application, you have two options if calibration is needed. Either (1) calibrate the Vector each time it is powered up (which is undesirable in most applications) or (2) have the host system calculate the calibration values and store them in the host's own non-volatile memory. If the host calculates the calibration settings, the host system must also do the heading calculations because the calibration values cannot be fed back into the Vector.

MAGNETIC FIELDS

The Vector calibrates for constant magnetic fields in the host system as long as they do not saturate the sensors. An example of a "host system" is a vehicle where the Vector is mounted on the dashboard.

Static (unchanging) fields create "hard-iron" distortion. These fields can be mathematically modeled as a constant offset when they are always in the same place with respect to the Vector. This means the Vector can compensate for hard iron in the host system because the Vector is mounted within the host system. Note that the farther the Vector is from a source of a magnetic field, the better.

Magnetic fields from sources which are not part of the host system will interfere with the calculation of compass heading. Thus, the Vector can calibrate for its host, but it cannot compensate for some other vehicle driving by or for a steel bridge. For example, the calculated heading can be thrown off a few degrees by a small car that drives about 10 feet away from the Vector.

The Vector cannot be calibrated for magnetic fields that are not static (such as an A/C motor). Its simple calibration routine also cannot compensate for "soft-iron" distortion, which is created by ferrous metals. Soft-

iron materials distort the magnetic field in different ways when they point in different directions in the Earth's field. If a compass is strapped to a piece of soft-iron and the compass/soft-iron combination is pointed in different directions, the compass measures different offsets from the soft-iron. With hard-iron, the compass measures a constant offset. The effect of soft-iron cannot be modeled as a constant. Therefore, the Vector needs to be as far away from sources of soft-iron distortion as possible --- even a few centimeters of separation can be helpful, as the strength of the field is inversely proportional to the square of the distance.

VIBRATION

Vibration may cause the V2X to tilt because the V2X has no moving parts. We do not have test data on the effects of vibration (that is, we know that some amount of shaking will harm the board, but we do not have test data to show exactly what that amount is). The V2XG also has not been tested in vibration. The mechanically damped gimbal is designed to minimize the effects of vibration.

TEMPERATURE

The temperature range for operation of the Vector (-20°C to 70°C is based on the specifications of the components of the module. The temperature range for storage is -30°C to 90°C.

OUTPUT FORMATS

The Vector has a synchronous serial port for communication with a host system. This port is compatible with Motorola SPI, QSPI and National Microwire. The output can be (1) BCD (binary coded decimal), (2) Binary, or (3) Raw Output. For BCD, the first six bits are zeroes; for Binary, the first seven bits are zeroes. After these zeroes, the first bit out of the Vector is the most significant bit (MSB), and the last bit out is the least significant bit (LSB). The following are examples of BCD and Binary outputs for 359 degrees:

OOOUTPUT EXAMPLES:

BCD bits 000000 1 1 0 1 0 1 1 0 0 1

where the BCD bits represent the following values:

200	100	80	40	20	10	8	4	2	1
MSB									LSB

and $200 + 100 + 40 + 10 + 8 + 1 = 359$ degrees.

Binary bits 0000000 1 0 1 1 0 0 1 1 1

where the binary bits represent the following values:

256	128	64	32	16	8	4	2	1
MSB								LSB

and $256 + 64 + 32 + 4 + 2 + 1 = 359$ degrees.

RAW OUTPUTS

Form of Raw Output

The "raw" outputs are the measurements of magnetic field from the Vector's two sensors. One is called the "X" axis and the other is the "Y" axis. The serial data output from SDO is 32 bits. The first 16 bits are X, and the last 16 are Y. The first bit of each of X and Y indicates the sign (+ or -) of the number. X and Y are signed binary numbers from -32,000 to +32,000.

Uses for Raw Outputs

1) Compass heading: From the X and Y magnetic sensor measurements, heading is derived as follows: X divided by Y is the tangent of the heading angle (with respect to north), so the heading angle equals the arctangent (X/Y).

2) Calibrated magnetometers: To relate the raw magnetic sensor X and Y outputs from the V2X to μ Tesla (or Gauss or another unit), you have to calculate the relationship between magnetic field (e.g., in μ Tesla or Gauss) and the output from a particular sensor. Each sensor must be calibrated separately; you cannot assume the output from the X-axis sensor in a certain field will be exactly the same as the output from the Y-sensor. The sensors are linear over their operating range, so the formula for magnetic field from a sensor is of the form:

$$X \text{ in magnetic field units} = A1 * (X \text{ from sensor}) + B1$$

To find the constants A1 and B1, place the X-axis sensor in a known magnetic field (e.g., 50 μ Tesla) so that the long axis of the X sensor is parallel to the field. This value from the X sensor is S1. Then do the same thing in another known magnetic field (e.g., 70 μ Tesla) to get X2. Use these two known fields and the two measured values from the sensor (X1 and X2) to solve for A1 and B1 using the following two equations:

$$50 \mu\text{T} = A1 * X1 + B1$$

$$70 \mu\text{T} = A1 * X2 + B1$$

For the Y sensor, there is a similar equation:

$$Y \mu\text{Tesla} = A2 * (Y \text{ from sensor}) + B2$$

Perform similar measurements with the Y sensor in two known magnetic fields to calculate A2 and B2.

NOTE: when the sensors are used in this configuration, the V2X can measure magnetic fields in the range of $\pm 200 \mu\text{T}$.

OTHER THINGS TO KEEP IN MIND

- All four of $\overline{\text{P/C}}$, $\overline{\text{SS}}$, $\overline{\text{CAL}}$ and $\overline{\text{RESET}}$ must be *high* during power-up. If any of these is low during power-up, the Vector will not operate properly --- it will "hang."
- You can toggle $\overline{\text{RESET}}$ after power-up to start the Vector operating properly, but when you reset it, $\overline{\text{P/C}}$, $\overline{\text{SS}}$ and $\overline{\text{CAL}}$ must be high.
- $\overline{\text{RESET}}$, $\overline{\text{SS}}$, $\overline{\text{SCLK}}$ and $\overline{\text{P/C}}$ must be connected to bi-directional I/Os set to inputs.

- For sleep mode (to draw the least power), \overline{SS} and $\overline{P/C}$ must be high.
- $\overline{P/C}$, \overline{SS} , \overline{CAL} , \overline{RESET} , \overline{RES} , $\overline{M/S}$, $\overline{BCD/BIN}$, \overline{YFLIP} , and \overline{XFLIP} are internally pulled up with 100 kohm resistors. All I/O pins have 15mF capacitors. The voltage for the change of state (from "0" to "1") of input and output pins is standard CMOS: less than 1.35 V is a zero and greater than 3.15 V is a one.

OPERATING MODES

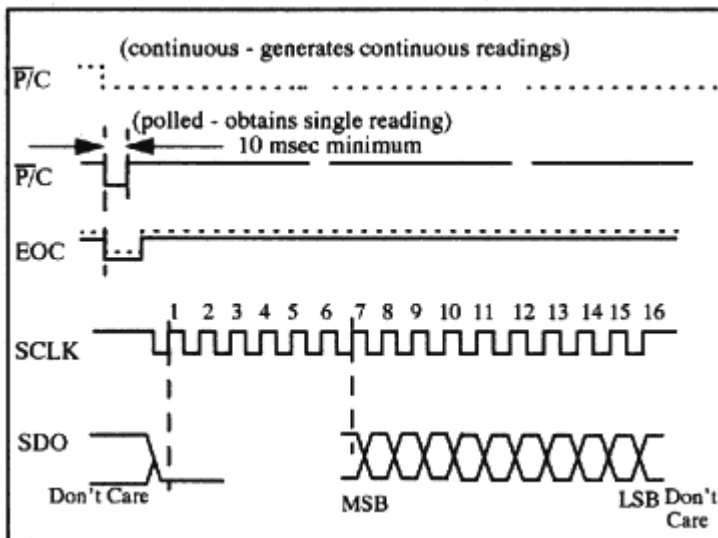
The Vector can operate in three different modes:

- Master Mode
- Slave Mode
- RAW Mode (Slave Mode with RAW outputs)

MASTER MODE

In Master Mode, the Vector generates its own clock (SCLK), which can be an output to clock the host system. You can use master mode to load data into devices such as serial-to-parallel shift registers without a host processor. The serial data output (SCO) is never tri-stated in Master Mode. The V2X can be either polled once or sampled continuously. See Figure 2 below for the timing diagram for master mode --- the dotted line is for continuous outputs; the solid line is for polling the Vector once.

**Figure2: Data Clock Timing Diagram
(Master Mode 16-bit Data Format)**



To put the vector into Master mode:

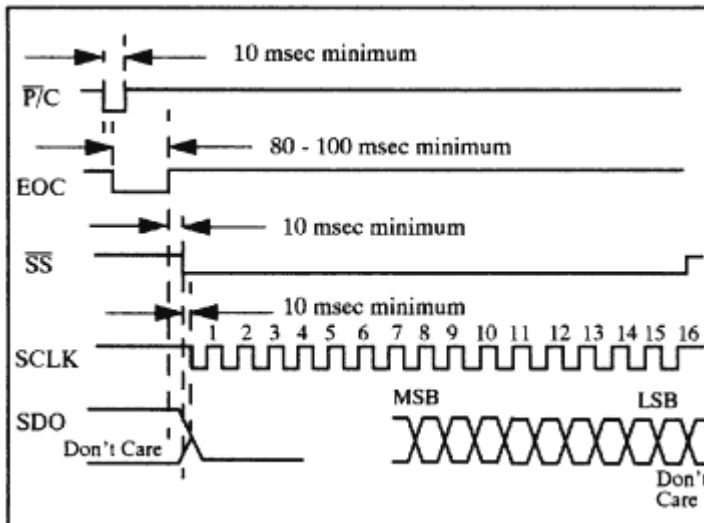
1. Tie the $\overline{M/S}$ pin low. \overline{RAW} should be high (or not connected).
2. \overline{SS} should be high or not connected.
3. $\overline{BCD/Bin}$ should be low for BCD, take it high for Binary output format.
4. For resolution, see the \overline{RES} pin description below.
5. To ask the Vector for output:

- Pulse $\overline{P/C}$ low (for at least 10 msec) to poll (ask) the Vector for one reading.
 - Hold $\overline{P/C}$ low continuously to have the Vector output data continuously.
6. The Vector calculates the output:
 - For a single output request (when $\overline{P/C}$ is pulsed for at least 10 msec), after $\overline{P/C}$ drops low, the Vector drops EOC low, and then the Vector calculates the output and then EOC goes high.
 - For continuous output (when $\overline{P/C}$ is always low), the Vector drops EOC low, and then the Vector calculates the output and then EOC goes high.
 7. After the Vector calculates the heading *and while EOC is high*, SCLK is an output of 16 clock pulses at a rate of 4 KHz.
 8. After the Vector calculates the heading and while EOC is high, SDO is the heading output; see "Outputs" above.
 9. After providing the output:
 - If $\overline{P/C}$ was pulsed for one reading, after the Vector gives one output (in BCD or Binary), it goes back into sleep mode until the next time it is polled.
 - If $\overline{P/C}$ is low continuously, the Vector automatically will start the cycle over again.

SLAVE MODE

In Slave Mode, the host must clock the data out of the Vector, so the host must provide the clock (SCLK) as an input. The host clock *should not go faster than 1 MHz* (i.e., the maximum rate for clocking out data is 1 Mhz). The timing diagram is shown below.

Figure 3: Data Clock Timing Diagram (Slave Mode 16-bit Data Format)



To put the Vector in Slave Mode:

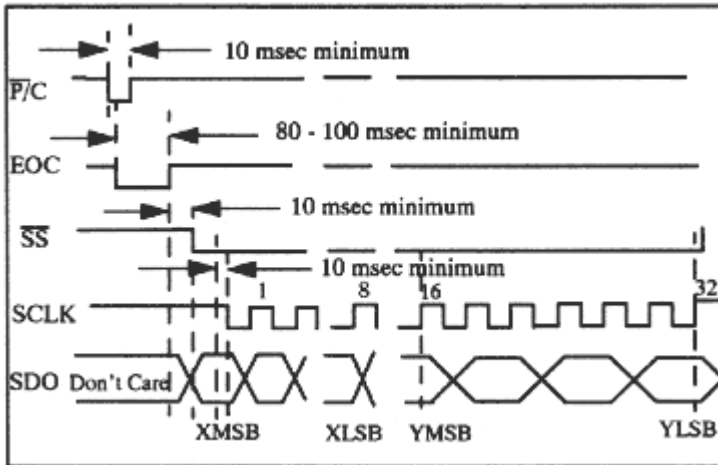
1. Tie the $\overline{M/S}$ pin high. \overline{RAW} should also be tied high (or not connected).
2. BCD/Bin should be tied low for BCD and high for Binary output.
3. For resolution, see the RES pin description below.
4. Request a reading:
 - If $\overline{P/C}$ and \overline{SS} are not tied together, pulse $\overline{P/C}$ low (for at least 10 msec) to poll the Vector for one reading. There is no maximum time for holding $\overline{P/C}$ low, but $\overline{P/C}$ must be raised again before \overline{SS} is dropped low (for clocking out data). NOTE: \overline{SS} must be high before $\overline{P/C}$ is dropped

- low (until at least 10 msec after EOC goes high).
- If $\overline{P/C}$ and \overline{SS} are tied together, pulse $\overline{P/C}$ (and \overline{SS}) low until the last bit of data is clocked out from SDO.
5. The Vector calculates heading while EOC is low (when EOC later goes high, the data will be ready to be output).
 - After $\overline{P/C}$ is dropped low, the Vector drops EOC low.
 - After the Vector completes its calculation of the output, the Vector takes EOC high. NOTE: $\overline{P/C}$ must be high before EOC will go high.
 6. After EOC goes high, wait *at least* 10 msec, and then take \overline{SS} low. \overline{SS} must be low while the data is clocked out.
 7. SCLK has to receive 16 complete clocks (NOTE: *SCLK should not be more than 1 Mhz*) to clock out the data. The process goes like this:
 - Before taking SCLK low, \overline{SS} must be low for a period of time, which depends on your system (e.g., this time was 5 msec in one application. You may have to change this time in your system), then ...
 - Take SCLK low, then ...
 - Take SCLK high, and *then* read the first bit from SDO.
 - Take SCLK through 7 more complete cycles (SCLK goes low, SCLK goes high, read SDO), then ...
 - If your system requires, it may need to wait a period of time, which depends on the system (e.g., this time was 5 msec in one application. You may have to change this time in your system), then ...
 - Take SCLK through 8 more complete cycles (SCLK goes low, SCLK goes high, read SDO). Therefore, when SCLK goes high for the 16th time, the last bit is read from SDO, and SCLK will stay high until the next heading is ready to be clocked out.
 - NOTE: Data is read out which SCLK is *high* (data is valid on the rising edge of SCLK), and there must be 16 rising and 16 falling edges or the Vector will hang.
 8. The last bit must be clocked out of the V2X within 20 μ sec of SCLK being raised for the last time. The first 15 bits can be clocked out at any time; there can be any delay between bits.
 9. After the data is clocked out, take \overline{SS} high again. The Vector goes back into sleep mode.

RAW MODE

The RAW Mode is actually the slave mode with raw outputs. The timing is the same as for the slave mode, but SCLK needs 32 clocks (instead of the 16 clocks of slave mode). The timing diagram is shown below.

**Figure 4: RAW Data Mode Format
(Slave Mode only, 16-bit Data Format)**



To put the Vector in RAW mode:

1. Tie $\overline{\text{RAW}}$ low, and tie the $\overline{\text{M/S}}$ pin high (or do not connect $\overline{\text{M/S}}$) for slave mode with raw output. BCD/Bin should not be high or not connected.
2. $\overline{\text{P/C}}$, $\overline{\text{SS}}$ and SCLK work the same as in slave mode, except that SCLK requires 32 clocks (instead of 16 clocks).
 - o Before each byte (8 bits) is read out, your system may need to wait a period of time, which depends on your system (e.g., this time was 5 msec in one application; you may have to change this time in your system).
 - o NOTE: Data is read out while SCLK is *high* (data is valid on the rising edge of SCLK). NOTE ALSO: SCLK should not be more than 1 MHz. The first 31 bits can be read at any time. The last bit must be read within 20 μsec of SCLK being raised.
3. The output is in binary as four bytes (for a total of 32 bits). The output is two signed 16-bit integers.
 - o The first 16-bit integer is the binary number of the X-axis field. The first bit out is the sign bit, and then comes the most significant bit of this integer. The sixteenth bit out is the least significant bit of this integer.
 - o The second 16-bit integer is the binary number of the Y-axis field. The seventeenth bit out is the sign and the eighteenth bit is the most significant bit of this integer. The thirty-second bit out is the least significant bit of this integer.
 - o These two binary numbers do not have *units* (that is, they are unitless). They are each from -32,000 to +32,000. These numbers do not require units (such as tesla) in the calculation of heading because one is divided into the other, so the units are irrelevant.

PINS

The pins of the Vector have the following functions:

Vector Pins	Function
P1	SCLK
P2	SDO
P3	SDI (never connected)
P4	$\overline{\text{Slave Select}}$
P5	$\overline{\text{Poll/Cont}}$
P6	$\overline{\text{CAL}}$
P7*	$\overline{\text{Resolution}}$
P8	$\overline{\text{Master/Slave}}$
P9	$\overline{\text{BCD/BIN}}$
P10	Y FLIP
P11	$\overline{\text{XFLIP}}$
P12	Cal Indicator
P13	EOC
P14	$\overline{\text{RAW}}$
P15	Power (+5 volts)
P16	Ground
P17	$\overline{\text{RESET}}$

*The pinout in Figure 1 is the correct pinout of the board. On some Vector boards, Pin 7 ($\overline{\text{RES}}$) is mislabeled as an additional "P4" (Pin 4 is also labeled as "P4" on these boards). The $\overline{\text{RES}}$ pin is the pin between $\overline{\text{P/C}}$ and SDI.

PIN DESCRIPTIONS

Following are descriptions of the pins' functions, states and related pins (in alphabetical order by function):

$\overline{\text{BCD/BIN}}$. The $\overline{\text{BCD/BIN}}$ pin chooses between binary coded decimal and output formats.

$\overline{\text{BCD/BIN}}$ pin should be low for binary coded decimal (BCD) output format.

$\overline{\text{BCD/BIN}}$ pin should be high for binary output format.

$\overline{\text{RAW}}$ must be high for either BCD or binary output in master or slave mode.

For raw outputs, $\overline{\text{RAW}}$ is low, and $\overline{\text{BCD/BIN}}$ must be high or not connected.

$\overline{\text{CAL}}$. The Calibration pin is used to calibrate the Vector.

$\overline{\text{P/C}}$ must be high during calibration.

$\overline{\text{CAL}}$ is high while the Vector is operating (and is not being calibrated).

To calibrate the Vector, (1) point the host system (with the Vector mounted in it) in any direction; (2) take $\overline{\text{CAL}}$ low for at least 10msec; (3) take $\overline{\text{CAL}}$ back high; (4) rotate the host system (with the Vector mounted in it) 180° (so it is facing the opposite direction and is again level); (5) take $\overline{\text{CAL}}$ low for at least 10 msec again; and (6) take $\overline{\text{CAL}}$ back high to complete calibration.

TO ABORT calibration or to clear a previous calibration, pulse the $\overline{\text{CAL}}$ pin low (for at least 10 msec) twice *without* moving the Vector.

CI. The Calibrate Indicator pin indicates when the Vector is in calibration mode. The CI pin goes high after CAL is pulsed low (for at least 10 msec) the first time. After CAL is pulsed again, CI goes low again to indicate the Vector is no longer in calibration mode.

EOC. The EOC pin works as follows:

In master mode, EOC drops low after the Vector is polled by dropping P/C low (EOC drops low about 4-5 msec after P/C is dropped). After the Vector calculates the heading, EOC goes high and then the clock (SCLK) is an output (16 clock pulses at a rate of 4 Hz) and SDO is also an output.

In slave mode or RAW mode, the end of convert pin indicates that the Vector has completed all calculations. EOC drops low after the Vector is polled by dropping P/C low (EOC drops low about 4-5 msec after P/C is dropped low). When EOC goes high again (after about 80-100 msec), the data is ready to be retrieved.

In slave or RAW mode, after EOC goes high to indicate the end of conversion, wait at least 10 msec before dropping SS low.

GRD. The Ground pin must be tied to ground.

M/S. The Master/Slave pin selects between master and slave mode.

For master mode, M/S is low, and SS should not be connected.

For slave mode, M/S is high.

For RAW mode, M/S is high and RAW is tied low.

P/C. The Poll/Continuous pin asks the Vector for data when it is pulled low.

P/C must be low for at least 10 msec to poll the Vector for one reading.

P/C must be high during power-up, calibration (CAL) and RESET.

In master mode, keep P/C low for the Vector to continuously output data.

In slave or RAW mode, P/C must be high before SS goes low for clocking out the data (if P/C and SS are not tied together).

POWER. The Power pin must be tied high to +5 Volts (± 0.25 Volts) for operation. To maintain calibration settings in sleep mode, power must be greater than 2.5 V. A low battery may cause the output to drift.

RAW. The RAW pin selects raw outputs of the X and Y magnetometer readings. The RAW mode is a slave mode with raw outputs.

For RAW mode, RAW must be tied low.

M/S must be high (or not connected) for raw outputs.

BCD/Bin must be high (or not connected) for raw outputs.

Data is only available in binary output format in RAW mode; see the description of raw outputs above.

RES. The Resolution pin determines how much resolution the Vector gets in its calculations of heading.

To sample the Vector faster, RES is grounded for low resolution --- the Vector is usually set for low resolution so that it can be sampled faster.

choose high resolution (RES high) for areas with weak magnetic field strength.

RES can be low or high in Master, Slave or RAW mode.

The actual sample rate of the Vector depends on the magnetic field (whether RES is high or low). The Vector will operate more slowly in strong magnetic fields. From experiments, the slowest sample rate in low resolution mode is 5 Hz, and it can go up to about 10 Hz. The slowest rate in high resolution mode is 2.5 Hz, and it can go up to about 5 Hz.

The accuracy specification for the Vector is for the high resolution mode.

RESET. The $\overline{\text{RESET}}$ pin resets the Vector. Use $\overline{\text{RESET}}$ when the Vector enters an unknown state or hangs; e.g., if the outputs are outside of the expected range (such as 0° to 359°), the Vector should be reset.

During normal operation, $\overline{\text{RESET}}$ is high.

To reset the Vector, take $\overline{\text{RESET}}$ low for *at least* 10 msec (and then take $\overline{\text{RESET}}$ high again). The $\overline{\text{P/C}}$, $\overline{\text{SS}}$ and $\overline{\text{CAL}}$ pins *must be high during* the reset pulse.

If the $\overline{\text{P/C}}$, $\overline{\text{SS}}$, $\overline{\text{CAL}}$ and $\overline{\text{RESET}}$ pins are not all *high* at power-up, toggle $\overline{\text{RESET}}$ after power-up to start the Vector operating properly.

After $\overline{\text{RESET}}$ is pulsed low, wait *at least* 500 msec before taking $\overline{\text{P/C}}$ low to poll the Vector.

Resetting the Vector will clear any calibration data stored by the Vector. After reset, a new calibration should be done.

SCLK. The Serial Clock pin is either an input or an output.

In master mode, SCLK is an output; the rate is 4 KHz.

In slave mode, SCLK is an input, and data must be read from the Vector *when SCLK is high* (data is valid on the rising edge of SCLK). The maximum rate for clocking out data is 1 Mhz. There is no minimum time that the data is valid, so you can wait as long as you want before clocking out a bit of data.

In slave mode, the Vector must receive 16 falling and 16 rising edges of the clock (32 of each in RAW mode) to clock out the data before it is polled again (unless it is RESET before the next time it is polled again).

SDO. The Serial Data Out pin is the output pin. See the description of the Outputs above.

In slave mode or RAW mode, data must be read from SDO *when SCLK is high* (data is valid on the rising edge of SCLK).

SDI. The Serial Data In pin is no used, so it does not need to be connected.

SS. The Slave Select pin is not connected in master mode. $\overline{\text{SS}}$ can be tied to $\overline{\text{P/C}}$ in slave mode, but this ties up the serial port for the entire time that $\overline{\text{SS}}$ is low. Assuming $\overline{\text{SS}}$ and $\overline{\text{P/C}}$ are *not* tied together in slave mode: $\overline{\text{SS}}$ cannot be low before $\overline{\text{P/C}}$ is dropped low to poll the Vector (otherwise the Vector will hang).

$\overline{\text{SS}}$ must be high which the Vector is doing calculations (while $\overline{\text{P/C}}$ is low and while EOC is low).

$\overline{\text{P/C}}$ must be high before $\overline{\text{SS}}$ is dropped low. That is, pulse $\overline{\text{P/C}}$ for at least 10 msec to poll the Vector, but make sure you take $\overline{\text{P/C}}$ high before dropping $\overline{\text{SS}}$ low to clock out data.

After EOC goes high, wait at least 10 msec before dropping $\overline{\text{SS}}$ low so data can be clocked out.

After $\overline{\text{SS}}$ is taken low, you may need to wait a short time (e.g., 5 msec) before dropping SCLK low to clock the data out (SDO).

XFLIP. The XFLIP pin flips the X axis. For operation of the Vector with its pins down (see the discussion of the "front of Vector" above) for outputs from 0° to 360° going from North (0°) to East (90°) to South (180°) to West (270°), XFLIP should be high.

Use XFLIP and YFLIP to choose the "front" of the board. See discussion of the "front" above for more detail.

YFLIP. The Y FLIP pin flips the Y axis. For operation of the Vector with its pins down for outputs from 0° to 360° going from North (0°) to East (90°) to South (180°) to West (270°), YFLIP should be low.

COMMON PROBLEMS

PROBLEM 1:

The X-component or Y-component of the RAW output is always zero or is always -1; or in slave mode, the output is constant.

Common Cause #1: $\overline{P/C}$ is not high before \overline{SS} is taken low.

Common Cause #2: The host system does not have the correct timing for reading the output. Most often, the Vector is not receiving 16 (32 in RAW mode) complete clock cycles to output the data.

Common Cause #3: A sensor coil is broken and needs to be replaced. Call the company you purchased the product from for instructions on returning the unit for repair. *Do not return any product to PNI before calling PNI.*

PROBLEM 2:

When the Vector is stationary, the output drifts more than 2 or 3 degrees. You should not see more than 2 or 3 degrees of drift while the Vector is stationary.

Common Cause #1: A low battery may cause the output to drift. Make sure the power is a regulated +5 V.

Common Cause #2: The host system does not have the correct timing for reading the output. Most often, the Vector is not receiving 16 (32 in RAW mode) complete clock cycles to output the data.

APPLICATIONS FOR THE VECTOR

Typical compass applications for the Vector are described below; they demonstrate how to connect the Vector to various types of circuits and *are not intended to be finished designs*. For magnetometer applications, the V2X should be in Slave Mode.

NOTE: For the schematics shown in Figures A1 to A3 of Appendix A, the battery is used to maintain RAM data, so hard iron calibration is not lost during powerdown of circuit. Regulated +5 V is still required for operation of the Vector.

Serial-to-Parallel Conversion

Vector Connected to a Motorola Processor

Vector Connected to an Intel-type Processor

SERIAL-TO-PARALLEL CONVERSION

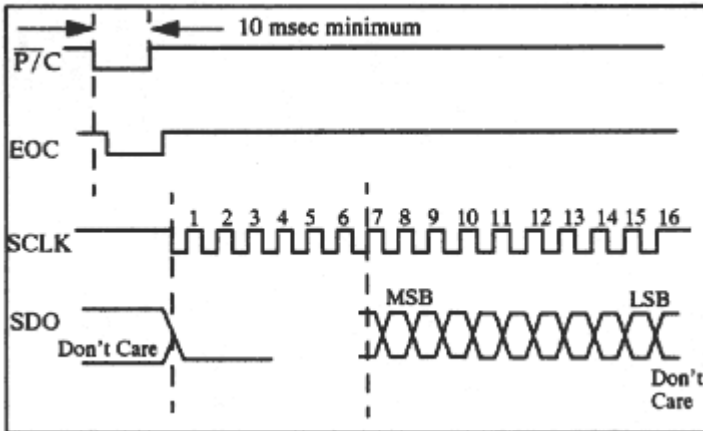
The circuit described here is a Vector with serial-to-parallel shift registers and an LED display. The schematic for this application is shown as Figure A1 in Appendix A.

The Vector is used in the following configuration:

Inputs: $\overline{M/S} = 0$ Master Mode operation
 $\overline{BCD/Bin} = 0$ BCD output format
 $\overline{RES} = 0$ Low resolution
 $\overline{XFLIP} = \text{open}$ X normal
 $\overline{Y FLIP} = 0$ Y normal
 $\overline{RAW} = \text{open}$ Not RAW magnetometer output mode

Figure 5 illustrates the timing diagram for this arrangement.

Figure 5: Timing Diagram for Connecting Vector with Serial-to-Parallel Shift Registers



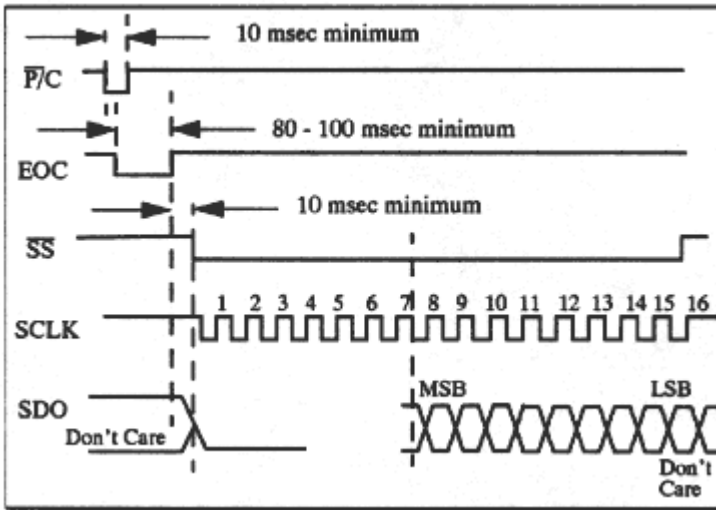
In this configuration, the Vector is ready to output data to the shift registers when the $\overline{P/C}$ pin is grounded. If $\overline{P/C}$ is held low continuously, the heading data should be ready out entirely before the Vector outputs the next reading. SDO of the Vector is connected to the serial input of the shift registers, which converts the serial data stream to a parallel format. The data from the Vector is clocked with the SCLK signal, and the format is most significant bit (MSB) first. Ten bits are required to indicate 0 to 359 degrees (BCD), and the first six bits are always sent as zeroes. The parallel outputs of the shift registers are connected to two 8-bit latches. When $\overline{P/C} = 0$, the Vector acquires heading information and outputs the data when the calculations are complete. The data at the output of the latches is BCD-formatted data which can be connected to an LCD or LED through the appropriate display driver ICs. The Vector acquires and outputs heading data for as long as the $\overline{P/C}$ pin is pulled low; when the $\overline{P/C}$ pin is pulled high, the Vector finishes the last heading, outputs the data and then returns to sleep mode.

VECTOR CONNECTED TO A MOTOROLA PROCESSOR

The Vector can be connected to a Motorola 68HC705C8 processor, or similar Intel-type processor, with a synchronous serial bus. A good discussion on SPI can be found in any Motorola Microprocessor, Microcontroller and Peripheral Data handbook. Some SPI read code can be found In Appendix B; its corresponding schematic is shown in Figure B1. PNI does not provide any other sample code.

Figure 6 shows the timing diagram for this connection; the schematic is presented in Figure A2 of Appendix A.

Figure 6: Timing Diagram for Connecting Vector to a Motorola or Intel-Type Processor



As shown in Figure A2, the Vector shares the serial bus with a MC14489P display driver. The SCLK line from the processor is connected to both the display driver and the Vector; SDO is connected to PD2/MISO (master in, slave out) and SDI is not connected. The processor requests heading data from the Vector, retrieves the data, reformats the data into BCD format suitable for the display driver, then outputs the data to the display driver (the output from the Vector in this case is set to Binary output mode, but it can also be set to BCD format if so desired).

The Vector is used in the following configuration:

Inputs: $\overline{M/S}$ = open	Slave Mode operation
$\overline{BCD/Bin}$ = open or closed	Either format
\overline{RES} = 0 or 1	Depending on application
\overline{XFLIP} = open	X normal
\overline{YFLIP} = 0	Y normal
\overline{RAW} = open	Not RAW magnetometer output mode

These settings set the Vector to Slave Mode. X-axis and Y-axis are in the normal positions, and the input to the RES pin determines resolution.

The Motorola processor was set to acquire data from the Vector at a rate of 0.5 second per data request. The processor updates the display and goes into a wait mode until 0.5 second elapses, then it repeats the cycle. The P/C pin is used to tell the Vector how to acquire new heading data. The SS pin and the P/C pin are connected to different ports of the processor, which allows the processor to talk to other devices on the bus while the Vector calculates heading.

The Vector wakes up from sleep mode on the falling edge of $\overline{P/C}$. The EOC pin drops when the Vector starts to acquire data; the rising edge on the EOC pin indicates heading data has been acquired, and the Vector returns to sleep mode. P/C must be high before SS goes low. At this point the data is available at the serial port (SDO) of the Vector; the processor must now drop SS low to retrieve the data and provide 16 complete clocks (16 falling and 16 rising edges) to retrieve the data. In slave mode, SCLK must be supplied by the processor to output the data.

The data is valid on each rising edge of the 16 clock pulses of SCLK. The processor must supply the SCLK pin with the serial data clock; 16 complete clocks (16 falling and 16 rising edges) are required to transfer all of the data from the Vector. After the 16th clock elapses, the processor must raise \overline{SS} , which allows the Vector to return to sleep mode and prepare for the next cycle of $\overline{P/C}$ readings.

VECTOR CONNECTED TO AN INTEL-TYPE PROCESSOR

Some applications may employ the Vector to control a stepper motor to keep the orientation of the directional component of the system constant with the direction of the compass. In this configuration, the Vector is connected to a non-SPI processor (see Figure A3 of Appendix A). To start the Vector, the host drops $\overline{P/C}$ for 10 msec and raises it again, which initiates the compass data acquisition process. The EOC line drops soon after the falling edge of $\overline{P/C}$ and returns to a high state when the heading calculation is complete; at this time, the data is ready and can be retrieved from the Vector by dropping \overline{SS} and providing 16 complete clocks to SCLK.

The data is valid on each rising edge of the 16 clock pulses of SCLK. The processor must supply the SCLK pin with the serial data clock (see Figure 6 for timing diagram). The data from the Vector appears at SDO and must be logically ORed with the accumulator, then shifted right eight times for each byte.

An alternate method for connecting the Vector to a host processor is illustrated in Figure A4 of Appendix A; this configuration can be used if there are no other serial devices to be connected.

The $\overline{P/C}$ pin and the \overline{SS} pin are connected together to reduce the number of I/O pins required. The EOC pin can be connected to the processor to signal the processor that the data is ready to be clocked out using SCLK. This application ties up the serial port for the entire time the Vector is calculating the heading. The $\overline{P/C}$ pin is kept low until the data is retrieved only because it is tied together to the \overline{SS} pin. Toggling $\overline{P/C}$ before the data is completely output causes the Vector to overwrite the old data, even if there is untransmitted data from the previous conversion.

CALIBRATION COMPUTATIONS

The Vector does not have non-volatile memory (such as EEPROM). Therefore, when the power is turned off, it loses its calibration settings. To save the calibration settings so that it does not have to be calibrated each time it is powered up, your host system can calculate the calibration values and store them in its non-volatile memory. This means that your host system will also do the heading calculations during normal operation of the compass.

To calibrate the Vector:

1. Set the Vector to operate in RAW mode with raw outputs, and place the Vector in the host system (where it will operate). The Vector should be as level as possible during calibration and operation (e.g., place it on the dashboard of a car).
2. Point the host system (e.g., the car) in any direction (e.g., 50°) and take a reading of the raw X and Y values. Point the host system in the opposite direction (e.g., 230°) and take another reading of the raw X and Y values. These two directions should be different by 180° for the best calibration (i.e., you have just taken two readings in directions that are 180° apart, so you have two X and Y values from

the sensors).

o Assume (X_1, Y_1) and (X_2, Y_2) are the two readings of magnetic field that you took.

3. In operating the compass, as you move the Vector so its heading changes, you will use the readings of raw X and Y to calculate heading.

o Assume (X_n, Y_n) is the actual output from the Vector for a particular direction.

4. The actual reading of (X_n, Y_n) is made up of the Earth's magnetic field (X_e, Y_e) and a constant offset (X_0, Y_0) :

$$(A) X_n = X_e + X_0 \quad Y_n = Y_e + Y_0$$

where:

(X_e, Y_e) is the Earth's magnetic field. These are the values, which are used to calculate heading. (X_0, Y_0) is the constant offset which results from the local magnetic field of the system in which the Vector is mounted.

5. Solve for the Earth's magnetic field by subtracting the constant offset values from both sides:

$$(B) X_e = X_n - X_0 \quad Y_e = Y_n - Y_0$$

6. The hard-iron offsets (X_0, Y_0) are the same at both (X_1, Y_1) and (X_2, Y_2) . The Earth's magnetic field at (X_1, Y_1) is opposite the Earth's magnetic field at (X_2, Y_2) --- because they are 180° apart --- so adding (X_1, Y_1) and (X_2, Y_2) gives:

$$(C) X_1 + X_2 = 2X_0 \quad Y_1 + Y_2 = 2Y_0$$

7. Solve equation (C) for the constant offset values, X_0 and Y_0 , which you store in the host's nonvolatile memory:

$$(D) X_0 = (X_1 + X_2)/2 \quad Y_0 = (Y_1 + Y_2)/2$$

8. For each reading (X_n, Y_n) from the Vector, your system calculates the heading (angle A_e) with (X_e, Y_e) :

$$A_e = \text{ARCTANGENT}(X_e/Y_e) = \tan^{-1}(X_e/Y_e)$$

where:

$$X_e = X_n - X_0 \quad Y_e = Y_n - Y_0$$

(NOTE: This equation for A_e assumes the arctangent function goes from 0° to 359°.)

WARRANTY

LIMITED WARRANTY - UNITED STATES CUSTOMERS

Precision Navigation, Inc. ("PNI") warrants each Vector 2X or Vector 2XG module purchased by a person or entity ("Buyer") in the United States directly from PNI ("Product") against defects in materials and workmanship for a period of NINETY (90) DAYS from the date of original purchase of the Product by Buyer.

This warranty does not apply if the damage was caused by accident, abuse, misuse or misapplication of the Product or by service or alteration of the Product by anyone (including but not limited to the Buyer) other than PNI; if the Product has been modified (including but not limited to application of solder to any part of the Product), serviced or altered by anyone without the written permission of PNI; or if the Buyer cannot

provide proof of original purchase from PNI.

PNI's liability is limited (at PNI's sole election) to (1) refund of Buyer's purchase price for the Product (without interest), (2) repair of the Product, or (3) replacement of the Product, provided, however, that for any such refund, repair, or replacement first the Buyer must contact PNI for a return material authorization number ("RMA") which will be issued in PNI's sole discretion, and then the Product must be returned to PNI during the warranty period, transportation, shipping, and insurance charges prepaid, with (a) its RMA, (b) acceptable documentation of purchase from PNI, and (c) a complete description of the defect.

THE WARRANTY AND REMEDIES SET FORTH ABOVE ARE EXCLUSIVE AND IN LIEU OF ALL OTHERS, AND PNI MAKES NO OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, AND WITHOUT LIMITING THE FOREGOING, PNI SPECIFICALLY DISCLAIMS ANY AND ALL IMPLIED WARRANTIES, INCLUDING WITHOUT LIMITATION WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. No PNI distributor, agent or employee (or any other person or entity) is authorized to make any modification, extension or addition to this warranty.

PNI SHALL NOT BE LIABLE OR RESPONSIBLE FOR ANY INDIRECT, INCIDENTAL, CONSEQUENTIAL, OR SPECIAL DAMAGES OF ANY KIND, INCLUDING WITHOUT LIMITATION LOSS OF PROFIT, PROMOTIONAL OR MANUFACTURING EXPENSES, OVERHEAD, BUSINESS INTERRUPTION OR LOSS OF GOODWILL, RESULTING FROM ANY BREACH OF WARRANTY OR UNDER ANY OTHER LEGAL THEORY. Some states do not allow the exclusion or limitation of incidental or consequential damages or exclusion of limited warranties, so the above exclusions or limitations may not apply to you. This warranty gives you specific legal rights, and you may also have other rights that vary from state to state.

APPENDIX A

SCHEMATICS FOR APPLICATIONS FOR THE VECTOR

Figure A1: Schematic for Connecting Vector 2X with Serial-to-Parallel Shift Registers

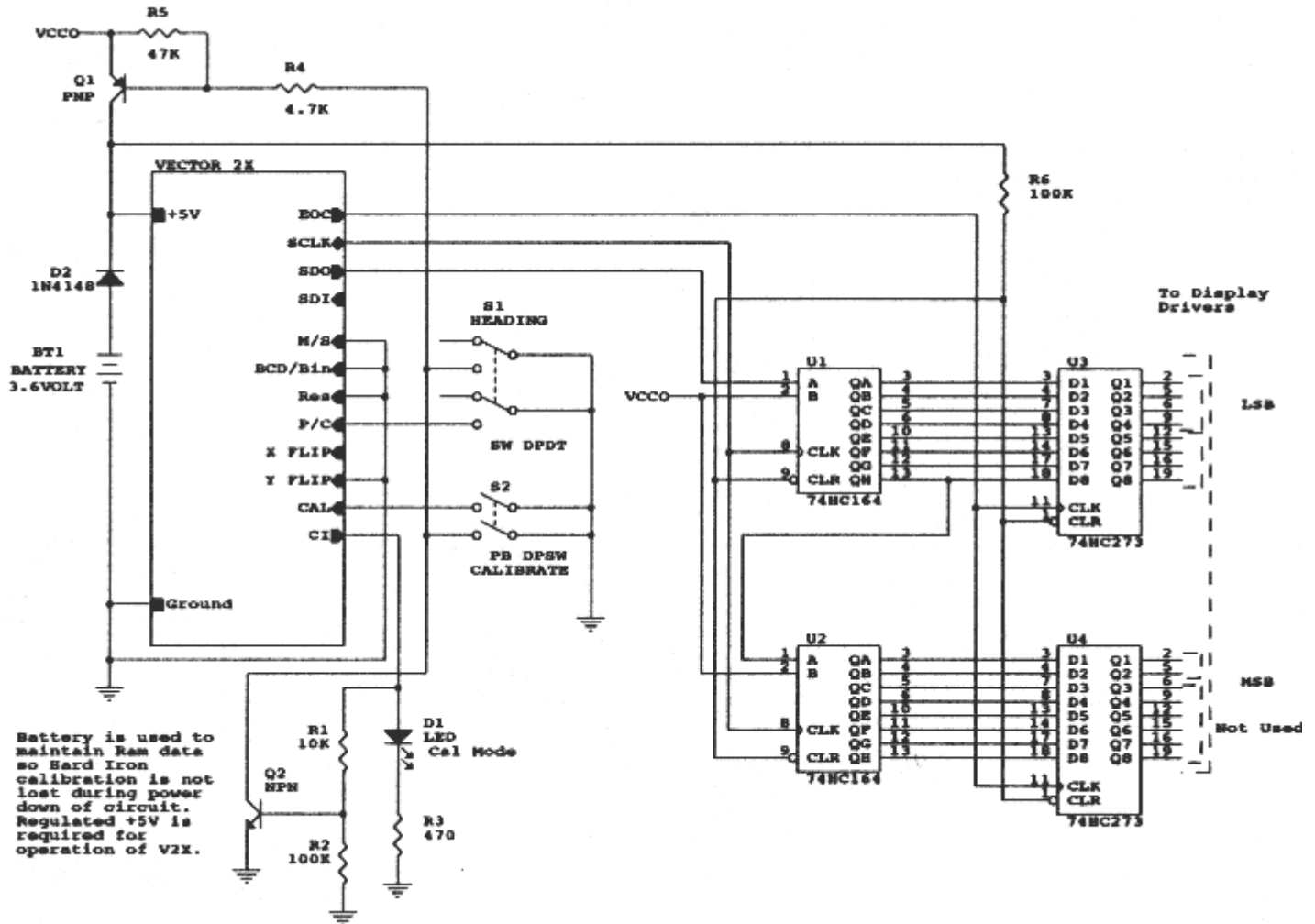


Figure A2: Schematic for Connecting Vector 2X to a Motorola Processor

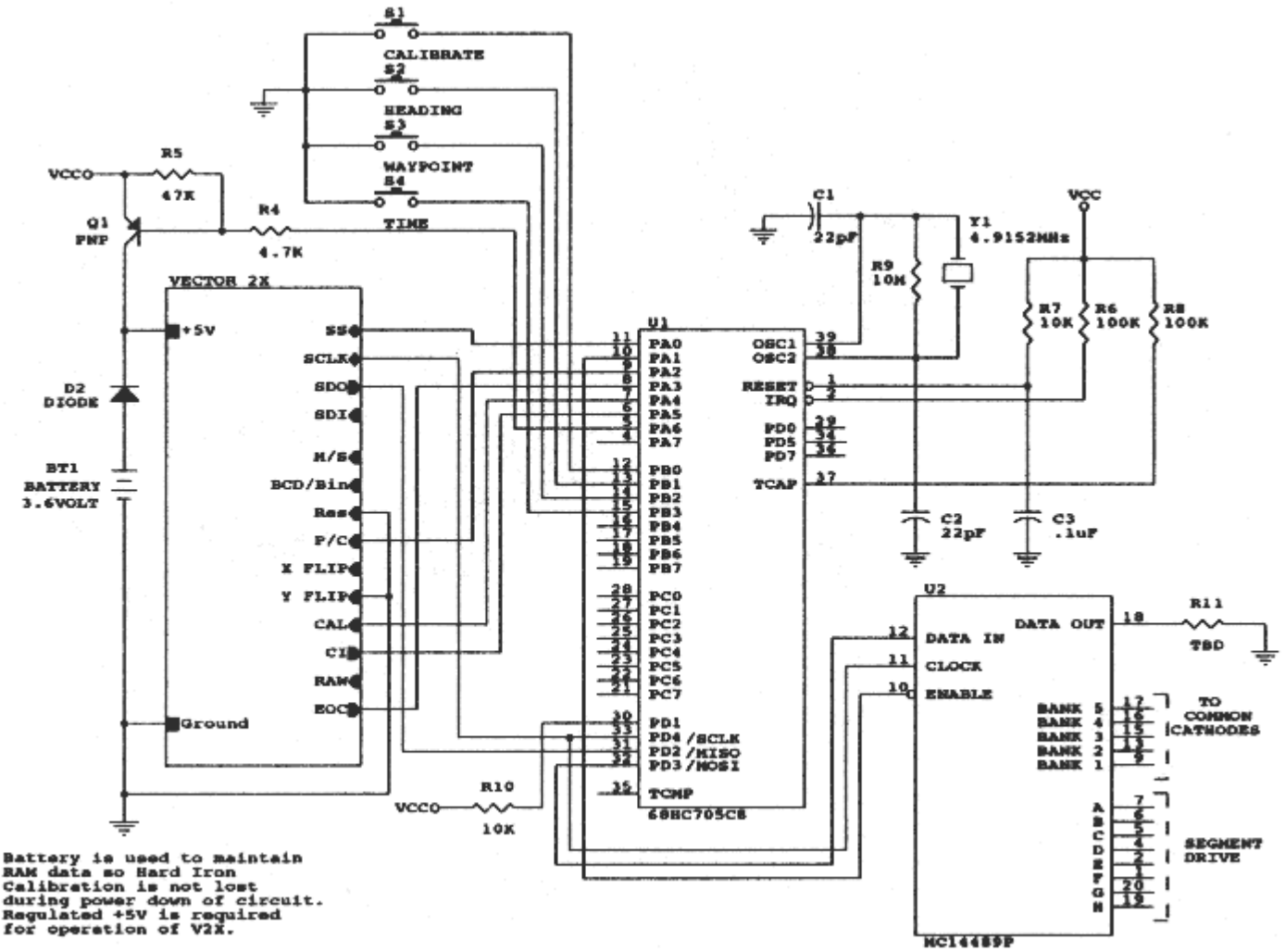


Figure A3: Schematic for Connecting Vector 2X to an Intel-Type Processor

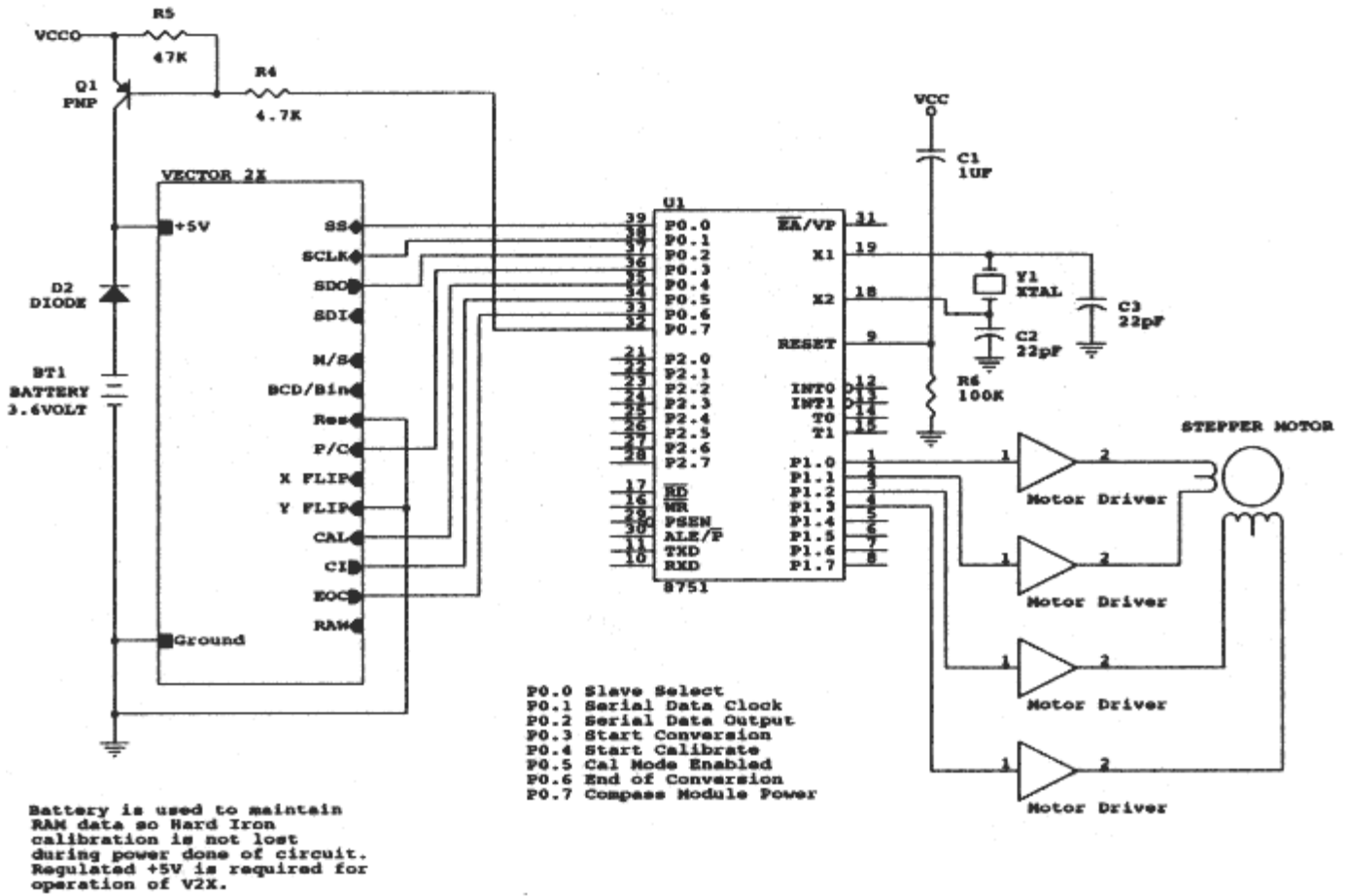
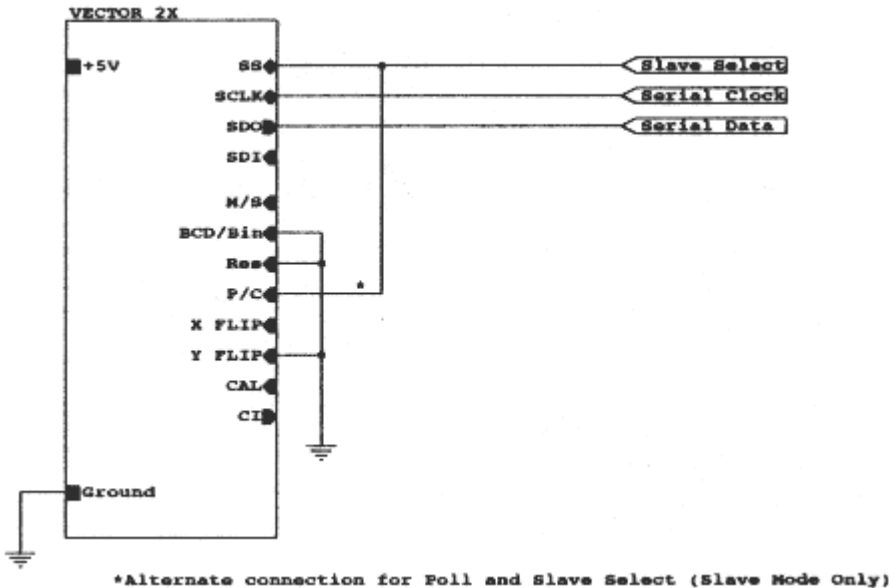


Figure A4: Schematic for Alternate Method of Connecting Vector 2X to an Intel-Type Processor



APPENDIX B

SAMPLE SPI-READ CODE

```
*Sample SPI read code for Motorola 68HC705 family
*
* processor
* Note: Not executable with schematics shown in
* the Application Notes appendix!
*****
* SPI - Master mode (68HC705)
* Port A: Input
* A0: EOC from V2X (End of Conversion)
* A7: RES relect (Resolution Select)
*
* Port C1: Slave select bar to V2X
* C0: SS (Slave Select [bar]) to V2X
* C7: P/C (Poll/Continuous [bar])
*****
* Equates
  EOC equ 0 ;EOC input to processor
  RES equ 7 ;Resolution select
  SS equ 0 ;Slave select from processor
  POLL equ 1 ;Poll/Continuous control
*****
*RAM Location
  org $050 ;ORG RAM

BYTE1 rmb 1 ;high order byte temp storage
BYTE2 rmb 1 ;low order byte temp storage
*****
*ROM Location
  org $200 ;ORG ROM
* slave_read - read teh 2 bytes of data from the V2X
  over the SPI port
* data is returned in bytel, byte2
*****
slave_read:
*Start V2X to acquire heading
  bclr poll,portc ;drop POLL line to compass
  jsr delay10msec ;wait awhile ~10 msec
  bset poll,portc ;raise POLL line after 10 msec

*Wait for V2X to complete conversion for heading data
  jsr waiteoc ;not wait for EOC to go high

*Retrieve data from V2X
  bclr 1,portc ;lower SS line to enable xfer
  tst SPSR ;see if SPI is clear
  sta SPDR ;write to SPDR to start SPI xfer

*Wait for data transfer to complete
rspiflpl:
  brclr 7,spsr,rspiflpl ;keep looping till SPI
  ;xfer done

*Get the first data byte
  lda SPDR ;
  sta BYTE1 ;put in BYTE1 ref
  jsr delayinterb ;delay between bytes
  clra ;set a = 0

*Start transfer of second byte
  sta SPDR ;write to SPI

*Wait for data transfer to complete
rspiflp2:
  brclr 7,spsr,rspiflp2 ;keep looping till done

*Get the second data byte
  lda SPDR ;get second byte
  sta byte2 ;

*****
* Waiteoc: after the poll has been strobed, wait
  for the eoc to go high to mark end of measurements
  and computations
*****
```



```

waiteoc:
  brclr  EOC,Porta,waiteEOC  ;branch if EOC bit is
                               ;clear; keep looping
                               ;till EOC returns high

  rts

*****
*   Delay 10msec - delay 10 milliseconds
*   uses a & x registers for delay countdown
*****

delay 10 msec:
  ldx  #!20  ;20 passes of olp: delay loop
  bra  olp

olp:
  lda  #!156 ;156 x 3 usec delay

ilp:
  deca
  bne  ilp
  decx
  bne  olp
  rts

*****
*   delayinterb - delay about 160µ between bytes read
*   in order to give time to SPI to lead second byte.
*****

delayinterb:
  lda  #!50  ;50 x 3 usec delay
  bra  olp

dilp:
  deca
  bne  dilp
  rts

```

Figure B1: Schematic for SPI read Code Example

