Hall Effect Magnetic Position Sensor
On Board Training

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### Si72xx Hall Effect Magnetic Sensor Applications

**Metering**
- **Si72xx replaces reed switches in gas and water meters**

Benefits:
- Highest sensitivity enables smaller, lower cost magnets
- Low power for reed switch replacement
- Tamper detection
- SMT compatible
- High reliability
- Highly configurable

**Security and Automation**
- **Si72xx replaces reed switches in window sensors**

Benefits:
- Highest sensitivity: Smaller magnets and/or longer range
- Low power for reed switch replacement
- Tamper detection
- Temperature sensing
- SMT compatible
- High reliability
- Highly configurable

**Consumer Products**
- **Si72xx enables smaller form factors**

Benefits:
- Highest sensitivity enables smaller, lower cost magnets
- SMT compatible
- Coming soon: 1.4x1.6mm DFN package for smallest PCB area
- High reliability
- Highly configurable

**Industrial and Automotive**
- **Si72xx delivers higher performance position sensing**

Benefits:
- Highest sensitivity: enables smaller, lower cost magnets and/or longer range
- Replace expensive rare-earth magnets with ceramics
- Built-in self-test capability
- Highly configurable
- AEC Q100 (Grade 1)

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**Key Message:** The Si72xx has industry leading sensitivity, low power and flexibility
Si72xx 3 Base Part Numbers + Documentation

- **Si720x : Switch or Latch Digital Output**
  - Si7201/2 Low voltage switch/latch
  - Si7203/4 Low voltage dual switch/latch (SOT23-5)
  - Si7205/6 High voltage switch/latch (current or voltage out)
  - Packages: TO92, SOT23-3, SOT23-5
    - Added pin on SOT23-5 is usually used for tamper indication

- **Si7210 : I2C Programmable Position Sensor with Digital Alert Pin**
  - Orderable with 4 I2C address options + integrated temperature sensor
  - Packages: SOT23-5, DFN-8

- **Si721x : Analog or PWM or SENT Outputs**
  - Si7211/12/13 Analog/PWM/SENT out
  - SI7214/15 High voltage PWM/SENT out
  - Packages: TO92 (3pin), SOT23 (3 or 5pin), DFN (8pin)

- **For full OPN list, see Ordering Guide** ([link](#))
  - Additional part options will be created based on market demand
Hall Effect Basics

- Discovered by Edwin Herbert Hall in 1879
- Coordinate setup:
  - Current flowing in Y direction, $I_y$
  - Magnetic field is applied in Z direction, $B_z$
  - Result: Voltage is produced across X dimension, $V_x$
- Why?
  - Lorentz Force Law applies to charges moving in a magnetic field
  - Lorentz Force (magnetic component):
    - Proportional to the magnetic field
    - Proportional to the velocity of the charges
    - At right angle to both the magnetic field and velocity (right hand rule)
  - Force causes carriers to move towards one side of the conductor – until that creates an Electric field sufficient to create an equal opposing force

\[ V_x = -w v_y B_z = -\frac{I_y B_z}{n q t} \]
Magnetic Field: B-field

- Magnetic Field: B-field
  - Aka magnetic flux($\Phi_B$) density: Wb/m$^2$
- Magnetic field lines have a strength and direction
- For international system of units, B-field is measured in Teslas (symbol: T)
- For Gaussian-cgs units, B-field is measured in gauss (symbol: G)
  - $1 \text{T} = 10,000 \text{G}$
  - $1 \text{mT} = 10 \text{G}$

Magnetic field lines for a cylindrical magnet

Magnetic field strength from a magnet drops off with distance
Permanent Magnets

- Objects which produce their own persistent magnetic fields
  - Magnetized with a North and South pole
- Made from “hard” ferromagnetic materials
  - E.g. Iron, cobalt, and nickel
- Magnets are generally graded by their Maximum Energy Product ($BH_{\text{max}}$)
  - $BH_{\text{max}}$ comes from the magnet’s hysteresis curve (aka BH Curve)
  - Measured in units of Mega Gauss Oersted (MGOe)
- Rare earth magnets: stronger & more expensive
  - Neodymium magnets
    - Varying levels of strength: Graded from N35 (weak) to N52 (stronger)
    - Neodymium is a member of the "rare earth" elements on periodic table
- Ceramic magnets: weaker & cheaper
  - Earth’s magnetic field: 30uT to 60uT (0.3 to 0.6 G)

<table>
<thead>
<tr>
<th>Magnet Type</th>
<th>Max Energy Product (MGOe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neodymium</td>
<td>35-52</td>
</tr>
<tr>
<td>SmCo 26</td>
<td>26</td>
</tr>
<tr>
<td>Alnico 5/8</td>
<td>5.4</td>
</tr>
<tr>
<td>Ceramic</td>
<td>3.4</td>
</tr>
<tr>
<td>Flexible</td>
<td>0.6-1.2</td>
</tr>
</tbody>
</table>

For more info on magnets, go to K&J Magnetics, Inc. website (link)
Si72xx Common Design-in Challenges

- **Distance:** Trade-offs between Rare-Earth and Ceramic magnets
  - Ceramic Magnets: Cheaper but weaker, magnet could need to be bigger
  - Rare-earth Magnets: More expensive and stronger, allows for a smaller magnet in volume
  - Solution: Si72xx’s High sensitivity + low-offset allows for high performance with ceramic magnets

- **Ferromagnetic materials located within the system affect the magnetic field lines of the magnet**
  - The shell of coin cell batteries are magnetic and will bend the magnetic field lines
    - 2mm to 6mm away from the coin cell battery’s edge, the field will be reduces due to the bending effect
    - Directly under the coin cell battery, the field will be amplified

- **Operating in hot temperatures**
  - Si72xx sensors’ offset, gain accuracy will vary causing $B_{OP}/B_{RP}$ thresholds to change
  - The strength of a magnet becomes weaker as temperature is elevated from room temp
  - Magnets can become irreversibly demagnetize above 80°C losing some of their strength even when brought back down to room temp
  - Above the temperature where the magnet material was sintered, the magnet will become permanently demagnetized

For further info, please go to K&J Magnets’ webpage on Magnets & Temperature (link)
Si72xx Hall Effect Sensor: Key Differentiators

- These parts are offered in 3 industry standard packages
  - SOT23 (3-pin & 5-pin)
  - Thin DFN (8-pin)
  - TO92 (3-pin)

- 1 dimensional: Only sensitive to 1 axis of magnetic field
  - SOT23 & DFN: Perpendicular to the PCB
  - TO92: Parallel to the PCB

- While we can cross reference many parts, we offer the advantages of:
  - Lower power
  - Higher Sensitivity & Low Noise
  - The option of tamper indication
  - Better linearity, offset and gain accuracy
  - Very configurable (factory programmed) for special applications
  - I2C parts with users programmable interrupt thresholds

- We can quickly create a new configuration for customers with higher volume applications
  - Contact Marketing
Si720x Hall Effect Sensor: Switches

- Used for detecting the presence of a magnet
  - Typical application: Window sensor for security

- Unipolar Switch
  - Factory programmable operate and release points
  - Add hysteresis to avoid jitter at the decision point

- Omni-polar switch
  - Decision based on magnetic field magnitude $|B|$ 

- We can customize the sampling rate, switching thresholds and several other parameters at factory test
  - See ordering guide for full details
What is tamper indication?
- Drives OUT back to the zero-field state when an overly strong field is detected

Why tamper feature?
- In a window sensor, external magnet could fool sensor into thinking the window is closed
- Tamper would create an alarm condition like door or window open which is also zero field

- Tamper can be output on separate pin or multiplexed on OUT
  - 5-pin Switches can have Tamper on separate pin
  - 3-pin Switches can multiplex Tamper on OUT

- Tamper threshold is factory programmed
- See ordering guide for tamper thresholds
Si720x Hall Effect Sensor: Latches

- Latch: Used for detecting the polarity of the magnet
  - Low hysteresis, highly sensitive
  - Typical Application: Revolution counting
  - Wider hysteresis, used for wide range of motion and revolution counting
Si721x Hall Effect Sensors: Analog, PWM, SENT

- All of these parts sample the magnetic field periodically then output a signal that represents the field.
- The part must be active at 0.4mA to keep the output pin active.
- DIS pin: Puts parts into sleep mode (100nA)
  - DIS (disable) pin only available on 5-pin parts.
- BISTb will turn on a on chip coil that increases or decreases the magnetic field.
  - Only available on 5-pin parts.
- $I_{DD}$ depends on sample rate + samples averaged.

Analog Out

\[ V_{DD} \rightarrow V_{OUT} \]

PWM

\[ t \rightarrow \text{OUT} \]

SENT (Single Edge Nibble Transmission)

\[ t \rightarrow \text{OUT} \]
Si7210 I²C Hall-Effect Sensors

- Read field strength with 12-bit resolution
- I²C programmable output field thresholds (Set B_{OP} & B_{RP})
- Integrated temperature sensor (1°C accuracy)
- Factory configuration options include I²C address, sleep mode sample rate and tamper threshold
  - See ordering guide for complete details
  - I²C Address
  - Sleep mode time
  - Tamper threshold
- With $I_{dd}(\text{avg})$ of 0.4μA, Si7210 can monitor magnetic field 5 times a second and generate a programmable interrupt
  - Then wake and read field data
  - Or use sleep mode at 0.1μA and poll for data periodically for very low power
Si720x: Replacing Reed Switches

- Solid state sensors have many advantages over reed switches
  - Smaller
  - More sensitive
  - More reliable
  - More accurate
  - Capable of outputting the field value – not a simple magnet present/absent
  - Much better tamper detection
  - Can be much faster acting
- Still you will get questions
  - The main issue is the type of magnet needs to change

No need to change magnet shape, only change the way it is magnetized
Si7210: Position Sensing

- 2x Si7210 Sensors for detecting 360° of rotation
  - Competitors have similar solutions with 2 or more integrated sensors. Generally they are more expensive and power hungry. Typically require on chip look up tables and calculations
  - 2x Si7210 sensors required due to 2D position

- It is possible to do angle position sensing with resolution <1 degree and position sensing with resolution in the range of 1um
  - Absolute accuracy in this range will depend on mechanical design

- Code for demo is available in Simplicity Studio

Example from App Note AN1018, Section 9. Position Measurement “Wheel Demo”
Si72xx-WD-Kit: Wheel Demo EVB Training

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Demo summary

- See UG288 for demo details
- Demo is pre-programmed on a EFM32 Happy Gecko starter kit
  - Code is also available through Simplicity Studio
- Demo includes wheel angle calculation and rotation counting on the Si72xx-EXP expansion board
- 6 different types of sensors are included
  - Switch, Latch, I²C, analog, PWM, SENT
Hall Effect Sensor: Demo

- After plugging the boards together apply power with the switch close to the battery
- Choose the demo option using PB0 and PB1
Two 1/8” by 1/16” N42 magnets are placed at 180° from wheel center

One magnet faces up and the other magnet faces down

Two Si7210 parts are placed at 90° offset from the wheel center

Same bus, two different I²C addresses

As the wheel is turned the magnetic field varies approximately as a sinusoid

Parts sleep at 100nA between readings

Position measurement at 1 Hz, 
\[ I_{AVE} = 0.3 \, \mu A \]

150 nC x2 devices = 300 nC
Hall Effect Sensor: Wheel Demo

- Shows the high sensitivity and low noise Si72xx Hall effect sensors
- Display shows the magnetic field at U1 & U2 plus the angle of the wheel
- Wheel position determined by a look up table
  - With interpolation, resolution is better than 1 degree
  - Without calibration accuracy is about 5 degrees
  - A calibration mode can be entered by pushing PB0 and PB1 together to get accuracy to 1 degree
- The Si7210 parts can monitor for a change in wheel position and interrupt the MCU when a change is noted (e.g. more than 20% variation in field)
  - This enables very low power operation when the wheel is not turning
Hall Effect Sensor: Revolution Counter Demo

- The I2C sensor operate and release points are programmed so that the parts act as sensitive “latches” where outputs vary in “quadrature”

- On entering this mode, whole revolutions are counted
- This uses the very low energy pulse counter available in most EFM32 parts
- Pressing PB1 allows the display of the wheel quadrant
This demo requires an Si7210 postage stamp

The magnetic field sensed by an I2C sensor is displayed

This has been useful to several customers already basically allowing evaluation of the magnetic field data from different magnets at different positions

Pressing PB1 allows switching from 20mT full scale to 200mT full scale
Simple display of output pin high or low

Will work for 3 pin switch or latch parts

Cannot detect the type of board connected so we do not attempt to interpret the data to translate in magnet present or absent

If an Si7210 is detected then “tamper” events are displayed (output pin going back low in the presence of a strong magnetic field)
If and Si7210 I2C part is detected we can also display the temperature data available from I2C parts.

This offers customers making remote sensor nodes the possibility of getting both “open/closed” and temperature data from one sensor.
The sensor is assumed to be an Si7211 which has an analog output going from 0 to Vdd as the magnetic field varies from -20mT to +20mT.

- \( V_{out} \)/Vdd as well as the calculated magnetic field strength is displayed.
- If the postage stamp plugged in is incorrect, the magnetic field data will be incorrect.
The sensor is assumed to be an Si7212 which has a PWM output going from 0 to 100% duty cycle as the magnetic field varies from -20mT to +20mT.

- Duty cycle as well as the calculated magnetic field strength is displayed.
- If the postage stamp plugged in is incorrect the magnetic field data will be incorrect.
SENT Output Postage Stamp

- The sensor is assumed to be an Si7213 which has a 12 bit SENT output going from 0 to 4096 as the magnetic field varies from -20mT to +20mT
- SENT = Single Edge Nibble Transmission
  - 4 bit nibbles are encoded as 12 to 27 clock “ticks” (1 tick = 5 usec) from falling edge to falling edge
  - SENT data is broadcast continuously
- The decoded SENT word as well as the calculated magnetic field strength is displayed
- If the postage stamp plugged in is incorrect the magnetic field data will be incorrect
Thank you
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ADDITIONAL SLIDES ATTACHED
Si72xx Hall-Effect Magnetic Sensor: Key Specifications

- Si7210 I²C programmable linear sensors
  - 4x orderable I²C address options
- Low power consumption 400 nA @ 5 samples/second
- Tamper indication feature
- High 12-bit resolution and ±0.1% output linearity
- Industry-leading <0.9 mT sensitivity (B_{OP} max)
- Very low offset (±0.25 mT) and noise (0.03 mT RMS)
- Integrated 1.0°C temperature sensor
- High accuracy over temperature
- Two V_{DD} range options: 1.7V — 5.5V or 3.3V — 26.5V
- Extended temp. -40°C to +125°C, AEC-Q100 (Grade 1)
- Integrated coil provides built-in self-test (BIST) capability

![Si72xx Hall-Effect Magnetic Sensor Diagram]
## Si720x Switches and Latches Comparison Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Silicon Labs Si720x</th>
<th>AKM EW-6672</th>
<th>AKM AK8788A</th>
<th>Allegro A3211/12</th>
<th>Honeywell SM351LT</th>
<th>Melexis MLX90248</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>1.7 – 26.5V</td>
<td>2.4 – 3.3V</td>
<td>1.6 – 5.5V</td>
<td>2.5 – 3.5V</td>
<td>1.65 – 5.5V</td>
<td>1.5 – 3.6V</td>
</tr>
<tr>
<td>Supply Current</td>
<td>0.4 µA</td>
<td>5 µA</td>
<td>7.5 µA</td>
<td>6.7 µA</td>
<td>0.4 µA</td>
<td>6.5 µA</td>
</tr>
<tr>
<td>Minimum Field</td>
<td>0.9 mT</td>
<td>2.9 mT</td>
<td>4.1 mT</td>
<td>5.5 mT</td>
<td>1.1 mT</td>
<td>6 mT</td>
</tr>
<tr>
<td>Release Point and Hysteresis</td>
<td>Selectable or Programmable</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
</tr>
<tr>
<td>Sample Rate</td>
<td>Selectable or Programmable</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
</tr>
<tr>
<td>Output Type</td>
<td>Open-drain, digital high/low, I²C, 2-wire</td>
<td>Digital high/low</td>
<td>Digital high/low</td>
<td>Open-drain</td>
<td>Digital high/low</td>
<td>Open-drain</td>
</tr>
<tr>
<td>Tamper Detect</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Parameter</td>
<td>Silicon Labs Si721x</td>
<td>AKM EQ-430L</td>
<td>Allegro A1395</td>
<td>Melexis MLX90288</td>
<td></td>
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<td>---------------------------------</td>
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<td></td>
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</tr>
<tr>
<td>Supply Voltage</td>
<td>1.7 – 26.5V</td>
<td>3.0 – 5.5V</td>
<td>2.5 – 3.5V</td>
<td>4.5 – 5.5V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply Current (Continuous mode)</td>
<td>3mA</td>
<td>9 mA</td>
<td>3.2 mA</td>
<td>8.8 mA</td>
<td></td>
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<tr>
<td>Supply Current (Pulsed mode)</td>
<td>0.4 µA</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linearity</td>
<td>0.1 %FS</td>
<td>0.5 %FS</td>
<td>0.5 %FS</td>
<td>0.1 %FS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Type</td>
<td>Ratiometric voltage, PWM, I^2C</td>
<td>Ratiometric voltage</td>
<td>Ratiometric voltage</td>
<td>Ratiometric voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Monitoring / Threshold</td>
<td>Yes (I^2C)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Si720x Hall-Effect Sensor switches and Latches

- Industry standard 3-pin SOT23 and TO-92 footprint
  - Si7201 1.7 to 5.5V switches
  - Si7202 1.7 to 5.5V latches
  - Si7205 3.3 to 26.5V switches
  - Si7206 3.3 to 26.5V latches
- Three pins: \( V_{DD}, \text{OUT}, \text{GND} \)
  - OUT goes high/low at pre-programmed magnetic field level
  - \( V_{DD} \) current signaling option
    - \( I_{DD} \) increases/decreases as thresholds are passed
  - Tamper protection optionally available on OUT pin
    - Reverts to zero field level when tamper threshold passed
- Average \( I_{DD} \) depends on sample rate
  - As low as 0.4\( \mu \text{A} \) sampling at 5 times per second
Si72xx Hall-Effect Sensor Ordering Options

- Sample rate
  - 5 Hz to ~1 kHz with 100 nA sleep current between samples
  - 5 Hz to ~50 kHz with 360 µA idle current between samples
  - 113.6 kHz continuous

- Decision points \( B_{\text{op}} \) (operate) and \( B_{\text{rp}} \) (release)

- Type of output (open drain, push-pull, analog)

- Output polarity (high or low for strong field)

- Field polarity (into or out of package or “omnipolar”)

- Filtering
  - Burst of N samples (FIR) (1, 2, 4, 8 up to 2048 samples)
  - IIR averaging (1, 2, 4, 8 up to 32,768 samples)

* 1 mT = 10 Gauss
Si72xx Hall-Effect Sensor Ordering Options

- Temperature compensation
  - Compensate for a magnets field strength variation with temperature
  - Standard compensation for Neodymium (-0.12%/°C) or Ceramic (-0.2%/°C)

- Tamper feature
  - Drives OUT back to the zero field state in strong field (3-pin)
  - Separate TAMPER pin (5-pin)

- Magnetic field measurement range
  - Standard ranges are 20 mT and 200 mT (200 Gauss and 2000 Gauss)*
  - On 20 mT range single sample RMS noise is 30 μT RMS, this can be reduced by filtering

- I²C address (4 available)
Solid state sensors have many advantages over reed switches
- Smaller
- More sensitive
- More reliable
- More accurate
- Capable of outputting the field value – not a simple magnet present/absent
- Much better tamper detection
- Can be much faster acting

Still you will get questions
- The main issue is the type of magnet needs to change
Position sensing

- Several solutions are available from competitors that have 2 or more integrated sensors which are used for calculating the absolute position or angle of a magnet
  - These are generally expensive and power hungry devices with on chip electronics to go from a calibration look up table to a calculated position or angle

- Our I²C devices are perfect for this kind of application
  - Can save cost and power by doing the calculations on the host
  - Can add tamper indication to the algorithms to support tamper detection with no added cost

- The “wheel demo” shows one example of this
  - See AN1018 for details
  - Code is available in Simplicity studio September STK release

- It is possible to do angle position sensing with resolution <1 degree and position sensing with resolution in the range of 1um
  - Absolute accuracy in this range will depend on mechanical design
  - Please contact applications support if your customer has a position sensing requirement and needs further assistance
Low Cost EVB Solution

- A lower cost demo
- "postage stamps" only (no wheel demo)
- A USB to I2C adapter
- A PC GUI
  - To allow data graphing a logging and more detailed control of the Si7210 I²C registers