Application Note

Low Power Design Using Hall-Effect Sensors

TEXAS INSTRUMENTS

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ABSTRACT

Gaming controllers and virtual reality controllers have various controls that can be actualized through Hall-effect sensors. As controllers are compact and battery powered, efficiency is paramount. This document explores the various ways to optimize Hall-effect sensor power usage while not compromising on the user experience of controllers.

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1 Introduction

Gaming controllers are a standard user interface that is often paired with gaming consoles like the Xbox, PlayStation, etc. These gaming controllers are rife with many different controls that include triggers, thumb sticks, buttons, and d-pads that all require sensors for converting the user's mechanical input into an electrical stimulus. As these are ergonomically designed to fit in your hands, be portable, and remain powered on for extended periods of time, it is important to incorporate the most compact, power efficient sensing solutions as possible. This document will explore a variety of use cases for different low power modes pertaining to the sensors used in the gaming controllers.

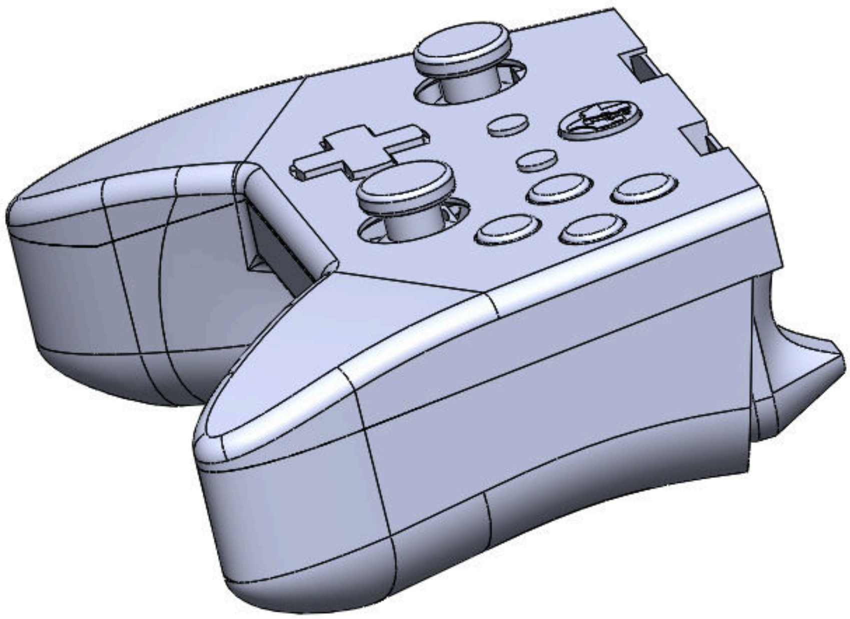

Figure 1-1. Typical Gaming Controller With User Interfaces like Triggers, Thumb Sticks, and Buttons

2 Low Power Modes

Typically, linear Hall sensors are used in triggers or thumb-sticks to detect precise position. These sensors have either an analog output or a digital output interface such as SPI or I^2C. To be power efficient, the sensors with analog output can be power cycled by the microcontroller and the sensors with digital output can be placed in trigger mode or self duty cycled modes. In the following sections, we show these implementations in detail.

2.1 Power Cycling

Linear Hall sensors such as DRV5055 and TMAG5253 with an analog output are simple to use and are typically used for analog triggers and thumb-sticks in gaming controllers.

These sensors could be powered directly from a battery or from a regulated supply voltage such as 1.8 V or 3.3 V. To power cycle the sensor, the sensor's supply voltage could be turned off and on by the microcontroller, but in many cases it is not possible since that supply voltage might be also powering up other components in the board. In those cases a load switch could be used to power cycle the sensor. To eliminate additional components such as load switches and achieve the desired power efficiency, linear Hall sensors such as TMAG5253 are available with an EN pin, that is used for power cycling. The linear Hall sensors such as TMAG5253 also feature a very fast power on time (< 25 µs) that allows an external ADC to not only sample the signal faster, but also allows it to shutdown quickly to lower the system power consumption. Figure 2-1 below shows a typical diagram where the sensor's EN pin is being controlled by the microcontroller. The EN pin can be controlled using a Pulse Width Modulated (PWM) signal, enabling the microcontroller to trade off the sampling frequency and power as needed in the system.

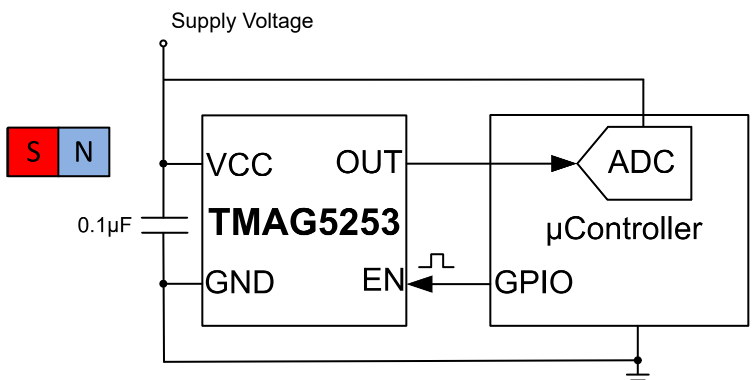

Figure 2-1. Typical Application Diagram Showing the Ability to Power Cycle the Sensor Using the EN pin

Figure 2-2 shows the timing diagram where the sensor is power cycled using the EN pin. The sensor is turned on for active time, t_{active}, where the sensor provides an output that is proportional to the external magnetic field and turned off for the time, t_{shdn} to conserve power. Equation 1 shows the average current consumption of the device, where $I_{CC,ACTIVE}$ refers to the active current during operation and the $I_{CC,SHDN}$ refers to the shutdown current.

$$I_{CC,\ AVG} = \left(\frac{I_{CC,\,ACTIVE} \times t_{ACTIVE} + I_{CC,\,SHDN} \times t_{SHDN}}{t_{ACTIVE} + t_{SHDN}}\right) \tag{1}$$

As an example, TMAG5253 has an active current of 2.1 mA during active mode and less than 10 nA during shutdown mode. If the sensor is power cycled with active time of 50 us and shutdown for 100ms, then this results in an average current consumption of 1.06 µA.

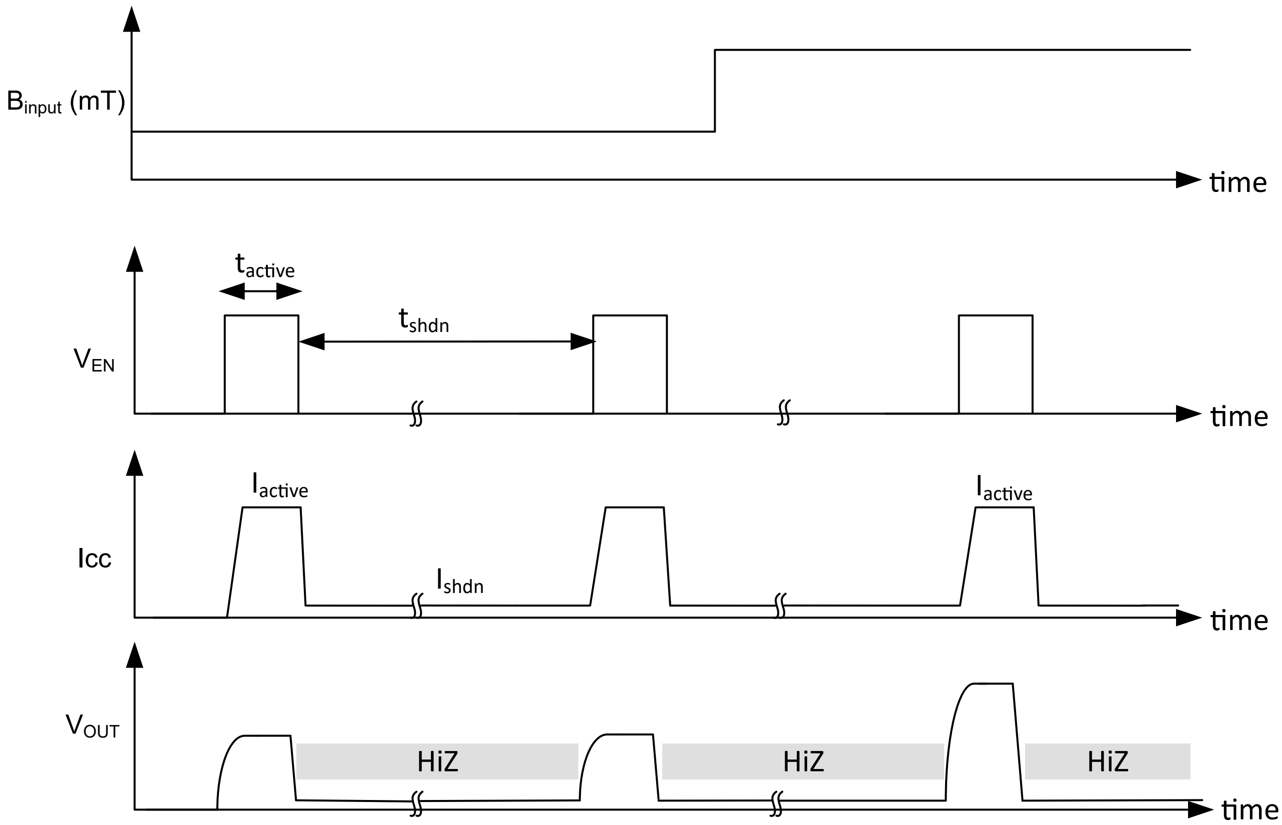

Figure 2-2. Timing Diagram Showing Device Current Consumption When Power-Cycled by the Microcontroller

2.1.1 Self Duty Cycled Low Power Operation

In cases, where the burden on microcontroller needs to be reduced , digital 3D Hall sensors like the TMAG3001, TMAG5273 and TMAG5170 provide multiple power modes with different current levels to reduce the system power consumption. Table 2-1 outlines the different power modes available for TMAG5273

and TMAG3001.

Table 2-1. Different Power Modes for TMAG5273 and TMAG3001

Operating Mode	Device function	Current consumption for TMAG5273	Current consumption for TMAG3001
Continuous measure mode ($I_{CC, ACTIVE}$)	Active state where the device is continuously measuring x, y, z axis data	2.3 mA	2.1 mA
Stand-by Mode ($I_{STANDBY}$)	Device is ready to start active conversion when triggered	0.45 mA	0.45 mA
Wake-up and Sleep Mode (I_{CC_DCM})	Wakes up at a configured time interval to measure the x, y, z, and temp axis data at 1000Hz	240 µA	230 µA
Sleep Mode (I_{SLEEP})	Ultra low power state	1 µA	40 nA

Based on the system level power constraints and the required output data rate, TMAG5273 can be placed in any one of the power modes. When placed in the wake-up and sleep mode, the sensor is self duty cycled, based on the user configured sleep interval. For applications such as thumb sticks, where angle measurements are needed to determine the direction and magnitude, the users can configure the TMAG5273 to measure more than one axis data, every time the device wakes up. To calculate the average current consumption, the conversion time, $t_{measure}$ for 1, 2 or 3 channels and the sleep time, t_{sleep} is needed. The average current consumption , $I_{cc\_average}$ can be then calculated for TMAG5273 using Equation 2.

$$I_{CC\_DCM} = \frac{I_{cc,active} * T_{measure} + I_{standby} * T_{start\_sleep} + I_{sleep} * T_{sleep}}{T_{measure} + T_{sleep} + T_{start\_sleep}} \tag{2}$$

where,

- $I_{cc,active}$ is the active current consumed during conversion typically about 2.3 mA
- $T_{measure}$ is the time taken to convert the selected channels typically about 50 us for 1channel, 75us for 2 channels and 100 us for 3 channels
- I_{DCM_sleep} refers to the current consumed during wake-up and sleep mode (also known as the Duty Cycle Mode)
- T_{sleep} is the time that the sensor remains in the sleep portion of the Wake up and Sleep mode
- $I_{standby}$ refers to the current consumed during standby mode
- T_{start_sleep} is the time the device takes to transition from the sleep portion of the duty cycle mode to the standby state. The typical value is 50 µs.
- $T_{start\_measure}$ is the time the device takes to transition from the standby state to the active conversion mode

Table 2-2 shows the average power consumption during wake-up and sleep mode with an interval of 1-ms and 20-s.

Table 2-2. Average Current Consumption of TMAG5273 in Self Duty Cycle Mode with Different Sleep Times

Sleep mode duration (ms)	Average current (uA) with three magnetic channels enabled (VCC=1.8 V)	Average current (uA) with two magnetic channels enabled (VCC=1.8 V)	Average current (uA) with one magnetic channel enabled (VCC=1.8 V)
1	220.4	174.2	125.9
5	50	39.0	27.9
10	25.9	20.3	14.6
15	17.7	14	10.1
20	13.5	10.7	7.8
30	9.3	7.4	5.5
50	6.0	4.9	3.7
100	3.5	3	2.4
500	1.5	1.4	1.3
1000	1.3	1.2	1.1
2000	1.1	1.1	1.1
5000	1.1	1.0	1.0
20000	1.0	1.0	1.0

2.2 Conversion on Demand

To maintain better control over the sampling instants and maintain low power consumption, digital linear Hall sensors such as TMAG5273, or TMAG3001 for space-constrained designs, allow the microcontroller to trigger conversions only when necessary. The TMAG5273 can be placed in a low power standby mode, where the microcontroller can trigger conversions using an INT pin or through the I^{2}C command and have the sensor synchronized with the system needs. Figure 2-3, shows a typical application diagram for a 3D Hall effect sensor connected to a microcontroller. Figure 2-4 shows the timing diagram where the conversions are triggered by the microcontroller.

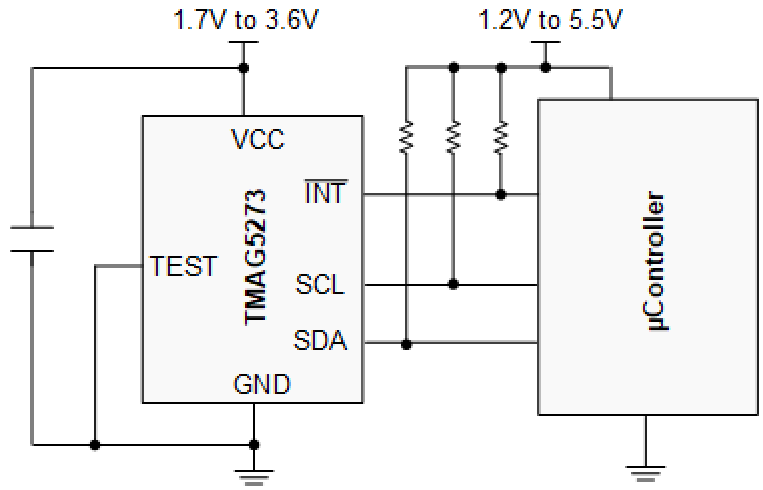

Figure 2-3. Typical Application Diagram of the TMAG5273 Showcasing the Ability to Trigger Conversions Using the INT Pin

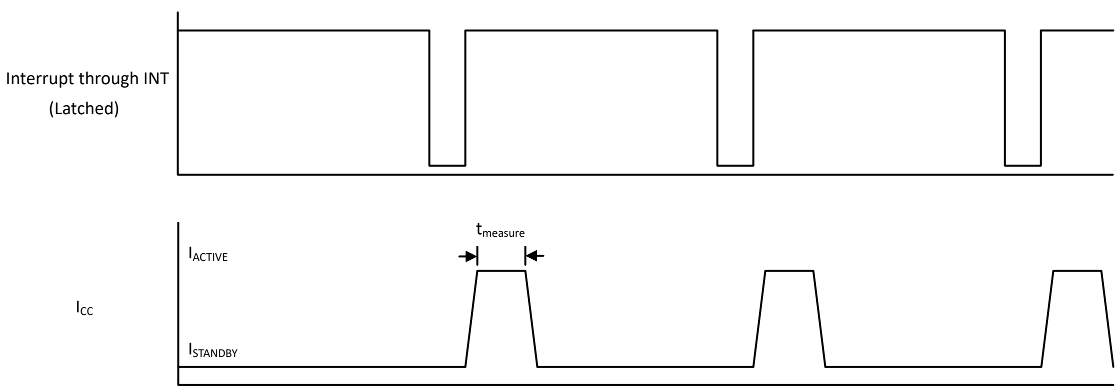

Figure 2-4. Timing Diagram for Conversion on Demand

2.3 Wake on Detection

Additionally, in wake up and sleep mode, digital 3D Hall sensors similar to the TMAG5273 can be configured to generate an interrupt once a certain threshold is crossed. This process is particularly useful in cases, where the user interfaces like buttons or triggers are used to wake up the system. A device like TMAG5273 can be placed in wake up and sleep mode, where the sensor wakes up after a preconfigured sleep time interval, takes a measurement and goes back to sleep. If the measurement crosses a set threshold, the interrupt condition is met. The device can proceed to exit wake and sleep (W&S) mode and can go to stand-by mode as shown in Figure 2-5.

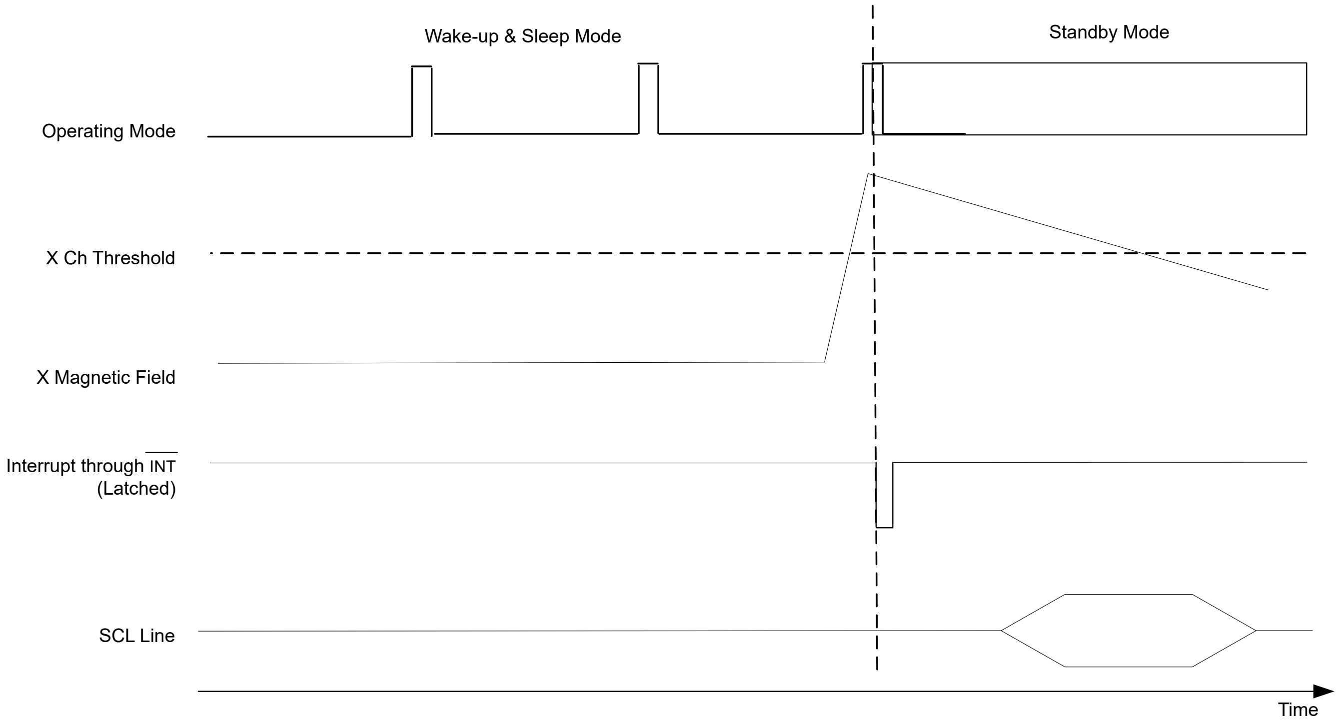

Figure 2-5. TMAG5273 in Wake and Sleep Mode, Responding to a Threshold Crossing

2.4 Wake on Change

In wake on change mode, the TMAG3001 monitors either one of the magnetic axes or the angle output for a change and wakes up the system by providing an interrupt response. When user interfaces such as scroll wheels are used to wake up the system, this feature is incredibly advantageous. This device can be configured to provide a wake on change response in standby, active or the wake and sleep mode, where when an interrupt response is obtained, the new sensor measurement is used as the reference threshold for the successive measurements. Figure 2-6 shows the device response where the device is responsive to the X magnetic field and Figure 2-7 shows the device response where the device is responsive to the angle measurements.

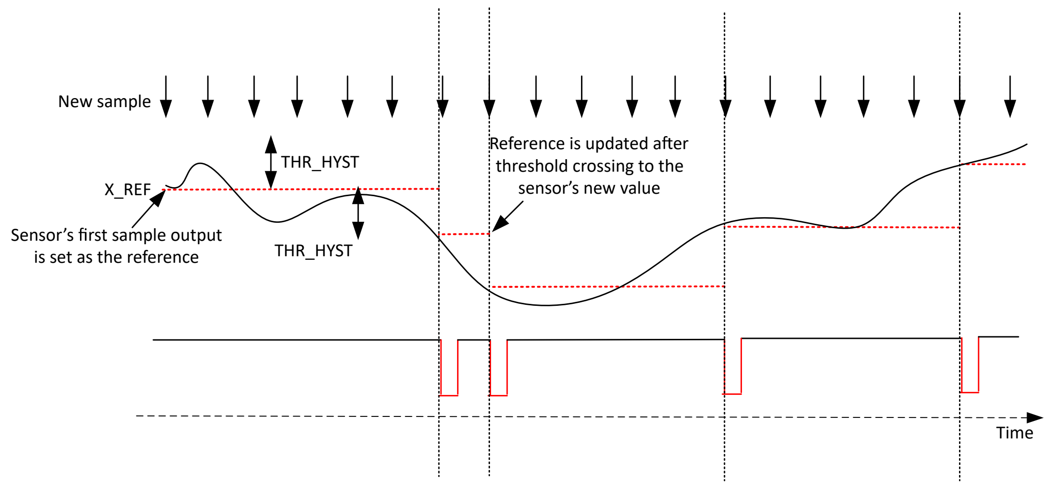

Figure 2-6. TMAG3001 Wake on Change with Magnetic Axes Measurements

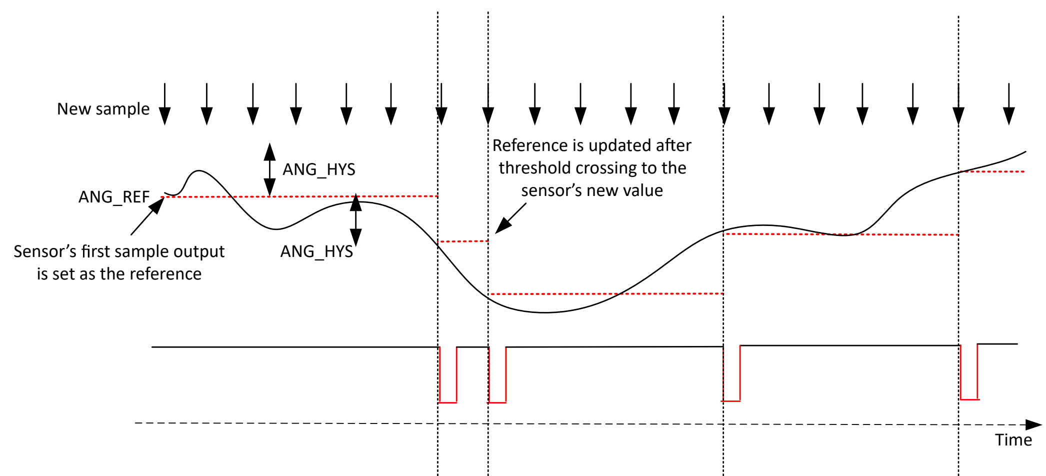

Figure 2-7. TMAG3001 Wake on Change with Angle Measurements

3 Low Power Modes with Multiple Sensors

Consider the left and right linear triggers in a gaming controller that use two different position sensors to measure the respective trigger positions. Instead of using multiple ADCs to digitize each of the sensors, it is possible to reduce the system power by reducing the number of ADC's by multiplexing the sensor outputs using the EN pin, as shown in *Figure 3-1*. During shutdown, TMAG5253 places the outputs in a high impedance state that enables multiple devices to be connected together to the same ADC, eliminating the need for additional multiplexers in the system.

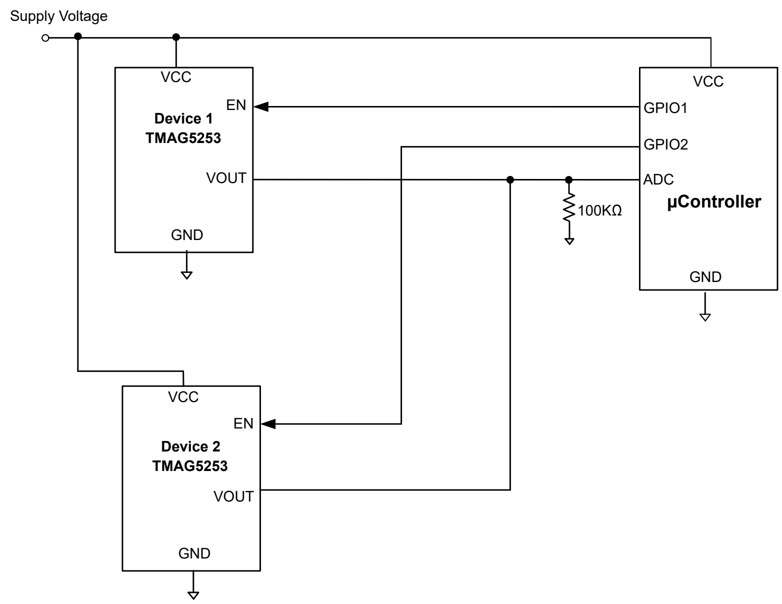

Figure 3-1. Multiple Sensors Connected Together in Same Bus

Figure 3-2 shows the timing diagram on the GPIO's of the microcontroller o multiplex the outputs from the two sensors. B_1 and B_2 correspond to the magnetic fields seen by Device 1 and Device 2 respectively. When the GPIO1 goes high, the Device 1 is enabled and drives the output line to the voltage corresponding to the field B_1. During this time, GPIO2 is driven low and the Device 2 is placed in shutdown mode. To avoid both the devices to be turned on simultaneously, a dead time, t_{mux} has to be programmed when switching between the devices. It is also important to note that these devices have to have a fast power on time, t_{on} , so that they can be sampled quickly before they are turned off to save power.

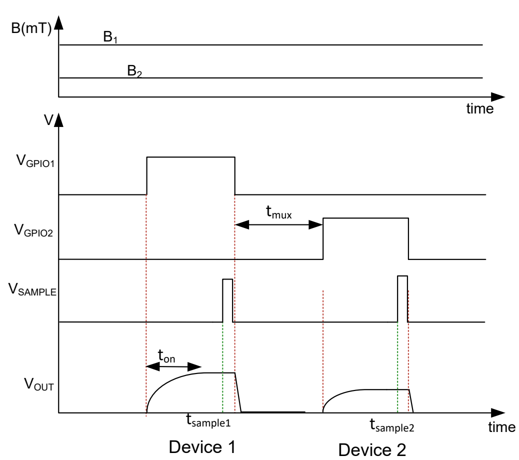

Figure 3-2. Timing Diagram Showing the Signals When Multiple TMAG5253 Devices are Connected Together

4 Low Power Mode Design Examples

In a wireless gaming or a VR controller, multiple user interfaces such as triggers, thumb sticks, and buttons need to be constantly monitored. In this example, consider a couple of scenarios that can enable to reduce the system power consumption based on the different methods discussed previously.

4.1 Design Example Scenario 2

In this scenario, take a look at the power savings just from the triggers and thumb sticks, for a 2-hour gaming session. The interactions in a gaming controller are fairly slow in nature, even with expert gamers reaching only up to 10 to 15 clicks per second. For a smooth response, the sensor signals could be sampled at a 10 times higher rate, at up to 100 Hz. Table 4-1 shows the comparison in power savings between two cases, one with power savings enabled using duty cycling, where the sensors are turned on once every 10 ms and the other case without any power savings where the sensors are just turned on continuously. From the analysis, it is seen that by power cycling the sensors at around 100 Hz or every 10 ms, the total system power can be easily reduced by around 100 times.

Table 4-1. Power Savings in System Level for Scenario 1

Scenario 1	No Power savings	Power Savings
Duration in Active mode	120 minutes	0.6 minutes
Duration disabled or in sleep mode	0 minutes	119.4 minutes
Average current consumption per thumb stick using 1 TMAG5273 (if 2 magnetic channels are enabled)	2.3 mA	20 μA
Average current consumption per trigger using 1 TMAG5253	2.1 mA	10 μA (with tactive = 50 μs)
Total current consumption of the system with 2 Triggers and 2 Thumb sticks (mWh)	8.8 mA	60 μA

4.2 Design Example Scenario 2

For the second scenario, consider the case in which a wireless gaming controller is turned on and left unused (idle) for more than 2 hours. In this case, the user interfaces if left unused can be put in sleep mode by the microcontroller, to further save power. By placing the TMAG5273 in sleep mode, the current consumption per thumb stick can be reduced to 5 nA. And with a shutdown current of less than 10 nA for TMAG5253, the current consumed by triggers can also be reduced. Table 4-2 shows the analysis to understand the savings in power consumption just from the triggers and thumb sticks, for a 2-hour idle mode. In Table 4-2, assume that in active mode, the sensors are turned on for 50 μs once every 10 ms. Compare this scenario to the mode where the sensors are shutdown to save power. As shown in the power savings that we can achieve by just power cycling the devices during run time is more than 1000 times compared to the case where the sensors are power cycled.

Table 4-2. Power Savings in System for Scenario 2

Scenario 2	No Power savings	Power Savings
Duration in Active mode	0.6 minutes	0 minutes
Duration disabled or in sleep mode	119.4 minutes	120 minutes
Supply voltage	1.8 V	1.8 V
Average current consumption per thumb stick using 1 TMAG5273 (if 2 magnetic channels are enabled)	20 μA at 100 Hz	5 nA
Average current consumption per trigger using 1 TMAG5253	10 μA at 100 Hz	20 nA
Power consumption of the system with 2 Triggers and 2 Thumb sticks (mWh)	60 μA at 100 Hz	50 nA

5 Summary

Magnetic position sensors are a viable low power design for designing controls like thumb sticks and triggers found in gaming controllers and VR controllers. Features like enable pins not only help increase efficiency, but reduce device count, free up board space, and allow a single ADC to monitor multiple devices. Diverse operating modes for devices like the TMAG5273 and TMAG3001 provide the user with multiple methods of reducing device power consumption while providing flexibility for different signal chain setups.

6 References

1. Texas Instruments, *Reduce Bridge Measurement Offset and Drift Using the AC Excitation Mode in the ADS1235 and ADS1261*, application brief.

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (May 2023) to Revision A (December 2023)	Page
• Added TMAG3001 throughout the document and 'Wake on Change' section	1