Low-Power and Turns-Count Sensing with the A1337 Angle Sensor IC

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Introduction

Numerous applications ranging from industrial automation and robotics to electronic power steering (EPS) and motor position sensing require monitoring the angle of a rotating target. The design of any successful angle measurement system for such applications needs to be based on the user's requirements. Application notes AN269115 and AN269121 cover the use of Allegro angle sensor ICs in on-axis and off-axis magnet configurations. This application note covers the use of the Allegro A1337 angle sensor IC for battery-powered applications (automotive or non-automotive) that require the sensor to operate in multiple mission modes.

Automotive Systems Requiring Sensor Operation Even in Key-Off Conditions

Certain automotive angle sensing applications require the ability to track angular position even in key-off conditions. In the key-off state, most voltage regulators in the vehicle are not operational. Therefore, sensors that must operate in the key-off state are often powered directly from the car battery (12 V). Examples of such applications include:

- Seat-belt passive safety systems
- EPS motor position

Often, these motor and seat-belt systems are geared down so that multiple angle sensor rotations need to be counted by the angle sensor IC. For this reason, the A1337 includes a circuit that counts the rotational turns of a magnet. When sensor ICs are connected to the car battery, they must also have low-power modes that enable efficient battery usage. Very often, a sensor IC must track the turns-count (TCs) of the magnet even when the vehicle is in the key-off state. The A1337 monitors and keeps track of TCs, even when set to Low Power Mode. This will ensure that the system can accurately and consistently track steering wheel position or seat-belt extension when using the A1337 in a key-on or key-off mode. Traditionally, this key-off requirement is achieved by a combination of relatively complex mechanical and electronic components. The A1337 can reduce system-level complexity and eliminate many system components by performing both the absolute angle measurement and the tracking of TCs, while maintaining low battery power consumption (85 µA) at vehicle key-off.
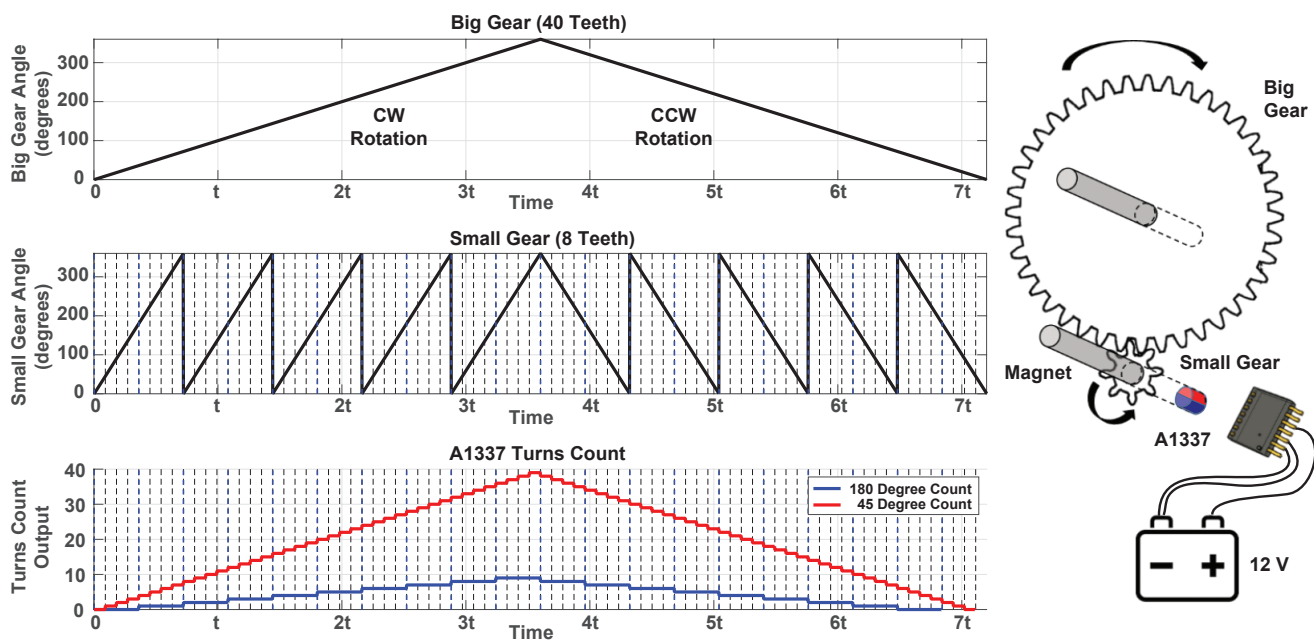

Figure 1

Overview of A1337

The A1337 is a 360° angle sensor IC that provides contactless high-resolution angular position information based on magnetic Circular Vertical Hall (CVH) technology. It has a system-on-chip (SoC) architecture that includes a CVH front-end, digital signal processing, and SPI, SENT, and PWM outputs. It also includes on-chip EEPROM technology for flexible end-of-line programming of calibration parameters. The A1337 is ideal for automotive applications requiring 0° to 360° angle measurements, such as electronic power steering (EPS), rotary shifters (PRNDLs), seat-belt tensioners, and throttle systems.

The A1337 angle sensor device is designed to support a wide variety of applications and has multiple operating modes, organized by output format or by power consumption.

By output format, the A1337 supports SPI, SENT, PWM, and Manchester interfaces. For each of these interfaces, the A1337 has the ability to report either the direct angle output (12-bit digital angle output reported over the selected output interface) or a Turns Count (TC) output, which is a quantized tracking count of the number of turns made by the magnetic target in either the clockwise or counter-clockwise direction.

By power consumption, the A1337 features a Normal Power Mode, a Low Power Mode, and an ultra-low power Transport Mode.

Normal Power Mode

In Normal Power Mode, the IC draws maximum current (nominally 8.25 mA—see Normal Mode Supply Current specification in the A1337 datasheet for more details) to operate its full feature set, and updates the angle output register at the fastest rate as selected by RPM mode and AVG settings (see the A1337 programming reference for more details).

Low Power Mode

Low Power Mode is useful for battery-powered applications where the task of tracking the target's rotation can be delineated into one of two mission modes. The first mission mode would be similar to an angle tracking mode, where the sensor tracks the output at full bandwidth and provides its measure of the angular output at full resolution. The second mission mode can be considered as a turns-tracking mode. In this mode, the sensor does not need to track the angle at full resolution—it is sufficient to track the Turns Count value of the target. The size of one turns-count unit can be preselected via EEPROM setting in the A1337 to be either 180 or 45 degrees. The A1337 tracks ±1280 turns in both directions. In Low Power Mode, the A1337 is mostly held in a lower quiescent current consumption state. The IC does not provide normal angle readings over the SPI, SENT, or PWM interfaces, but wakes up periodically to check for the occurrence of Turns Counts. The off-time of the Low Power Mode operation can be adjusted by the user based on the application, by programming on-chip EEPROM memory. Figure 2 shows Average I_{CC} in µA versus the programmable off-time t_{OFF}.

Transport Mode

Certain battery-powered applications require especially low power consumption from the IC during long-term storage and/or transportation (for example, when a new car is being transported from the assembly line to the dealer). To meet this need, the A1337 features an ultra-low power mode called Transport Mode. Transport Mode is used to put the A1337 into a deep-sleep state for ultra-low power consumption. When in this mode, the sensor IC does not track angle or turns counts. Typically, the IC consumes 30 µA of current per die when in Transport Mode.
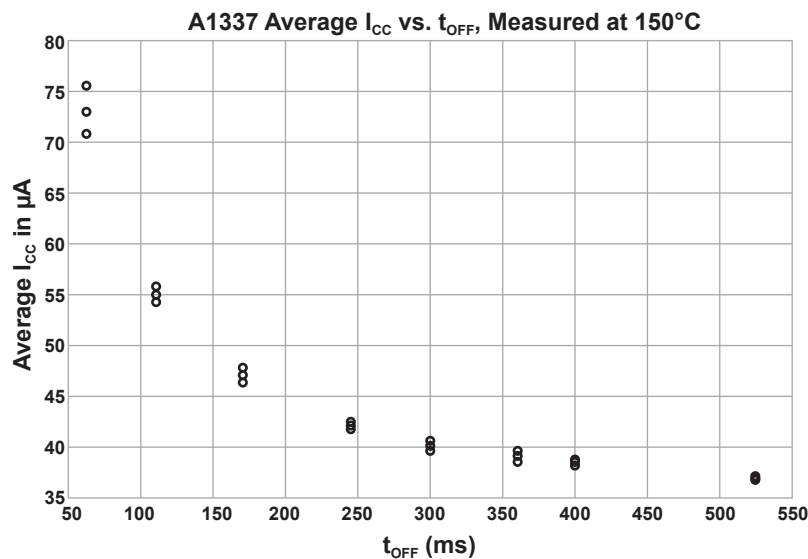

A1337 Average I_{CC} vs. t_{OFF}, Measured at 150°C

Figure 2

WAKE Pin

The A1337 also offers a WAKE input pin. This pin is intended to wake up the device from Low Power Mode, in special cases where the motor acceleration is too high, and the system cannot afford to wait for the entire Low Power Sleep time to expire, before the next periodic wakeup. When the voltage threshold on the WAKE pin exceeds $V_{WAKE(HITH)}$, the IC will wake up from Low Power Mode and begin to track Turns as it would in normal power mode. This pin is usually connected to a filtered version of the back-EMF voltage signal from the motor being used. This allows fast feedback from the motor to the Turns-Count circuit, in the case of high acceleration events. A symbolic waveform representation of the back EMF for a Star 3-phase motor, as well as a sample filtering circuit, are shown below.
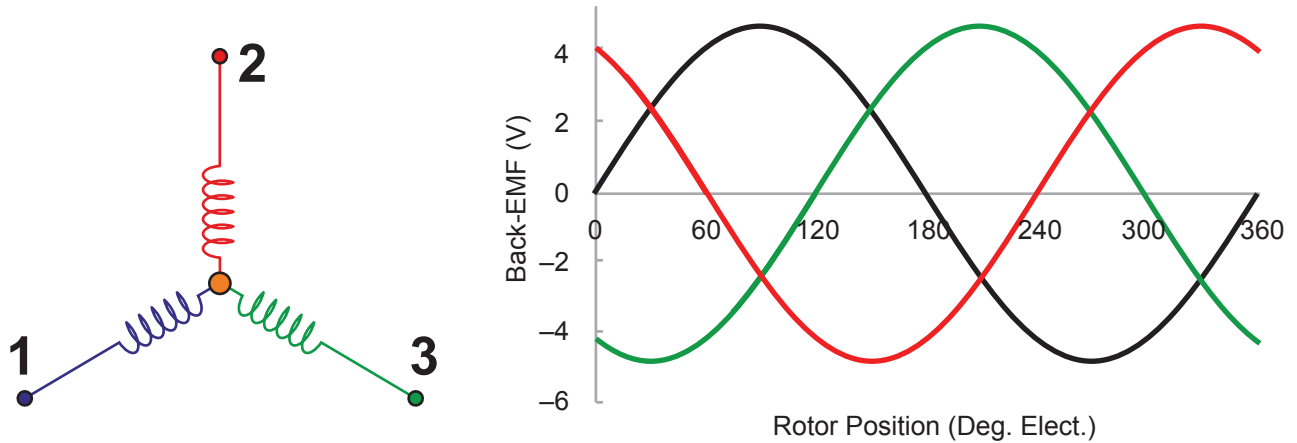
Back-EMF Frequency and Amplitude α motor RPM.
(Motor BEMF frequency and amplitude are both proportional to motor RPM.)

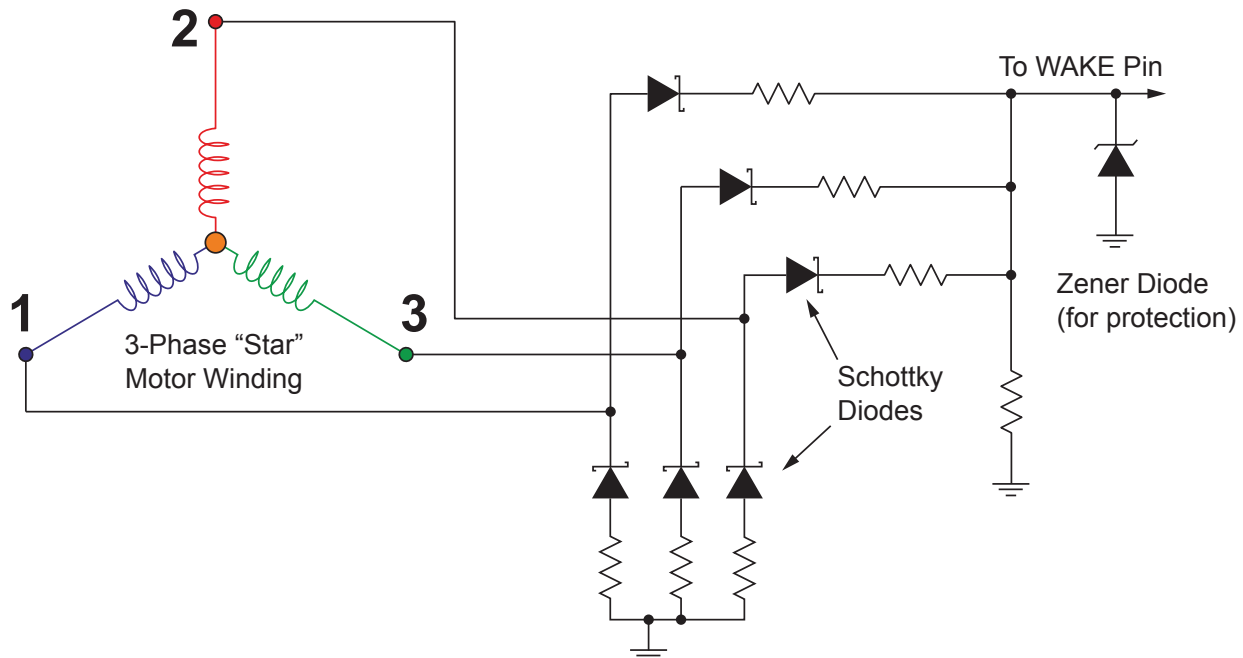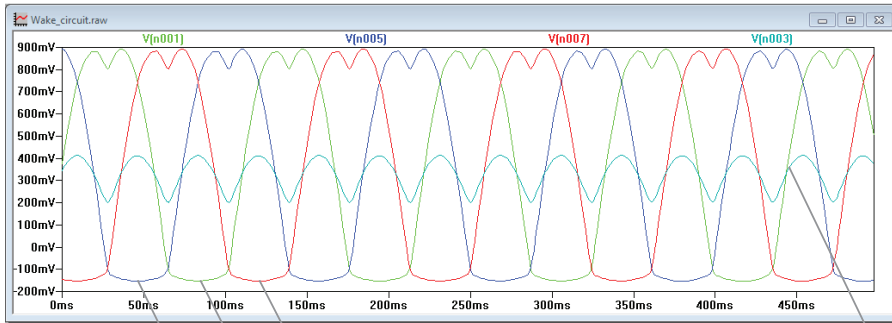**Figure 3: Back EMF of Star, 3-Phase Motor**

Figure 4: Sample Filtering Circuit

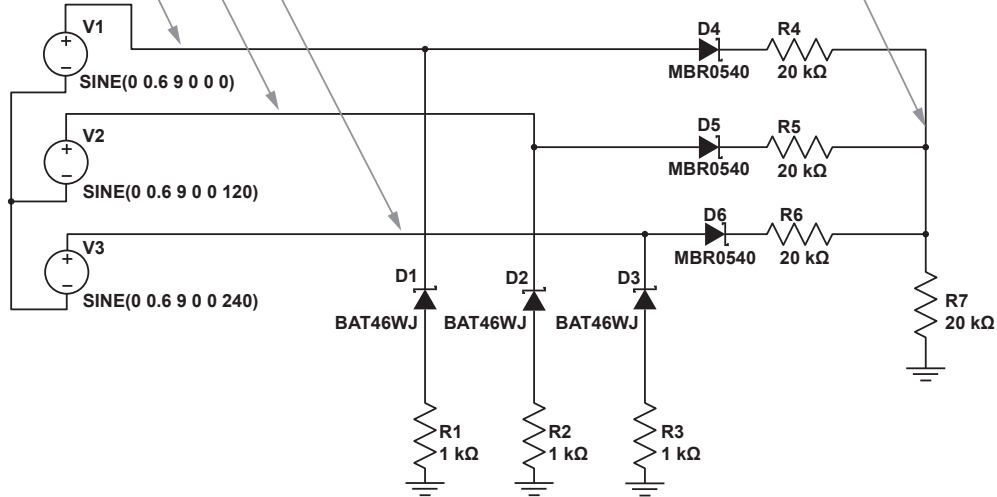This rectified voltage is based on simulating BEMF signals for a motor running at ~100 RPM.

Figure 5: SPICE Simulation Example for Filtered BEMF Signal

Transitioning Between Modes

The A1337 is designed so that it can transition between Normal Power Mode (NPM), Low Power Mode (LPM), and Transport Mode (TPM) based on either a command from the system microcontroller, by magnetic target rotation, or by exceeding the WAKE pin threshold, $V_{WAKE(HITH)}$. This dual scheme ensures that valuable TC information is not lost due to the target rotating too quickly while the sensor is in Low Power Mode.

To better understand this, consider a few scenarios based on the state diagram shown in Figure 6, as well as the information shown in Table 1. Assume that the sensor is powered up and in NPM. It would therefore be able to provide all the functionality as described under NPM in Table 1. Now, if the controller decided that to save power it should enter LPM, then it would have to satisfy all the conditions outlined in branch A of Figure

6 in order to enter LPM. In other words, the A1337 SPI lines would have to be held low for >50 µs, the WAKE pin voltage on the A1337 IC would have to be lower than the threshold $V_{WAKE(LOTH)}$, and the target RPM of the magnet would have to be lower than an average speed $S_{AWAKE(TH)}$. If all these conditions were met, then the IC would transition into LPM. While in LPM, the IC would be able to support the TC tracking functionality as described in Table 1.

If the system now needed to wake up from LPM and re-enter NPM, it would need to then satisfy any one of the conditions outlined in branch B of Figure 6—in other words, initiating activity on SPI pins, or rotating the target faster than $S_{AWAKE(TH)}$, or applying a voltage higher than $V_{WAKE(LOTH)}$ on the WAKE pin.

In a similar manner, the system can navigate between NPM, LPM, and TM, by meeting the appropriate conditions as specified by branches A, B, C or D of the state diagram.
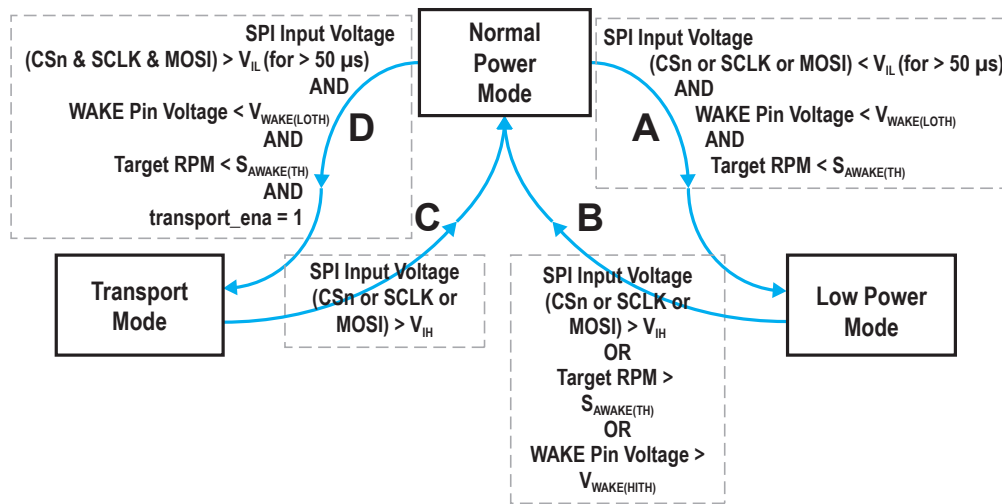

Figure 6: Operating Mode State Diagram

Table 1: Mode States

	Normal Power Mode (NPM)	Low Power Mode (LPM)	Transport Mode (TPM)
Angle Sensor Functionality	Available Communication Protocols: • **SPI 4-wire** • **PWM** • **SENT** • **Manchester Code**	Available Communication Protocols: • **Not Applicable**	Available Communication Protocols: • **Not Applicable**
	Available Angle Output Data: • **12-bit absolute angle value** • **Turns-Count (TC)**	Available Angle Output Data: • **Turns-Count (TC)*** *TC values are *tracked* in LPM, but available for read-only upon exiting LPM.	Available Angle Output Data: • **Not Applicable**
Current Consumption	8.5 mA nominal per die	85 µA nominal per die **100× power savings**	30 µA nominal per die **280× power savings**

User-Programmable Features for Low Power Mode and Turns Counting

The A1337 allows programmability of its LPM function. For instance, the IC provides the ability to select the size of its Turns-Count. Two choices are available: 180° or 45°. This feature is selectable via the TC1 bit in EEPROM address 0x15, Bit 18. In a similar manner, other functions of the LPM operation can also be programmed in EEPROM. Table 2 summarizes these features, with default values.

Table 2: User Programmable Features

Field	EEPROM Address	Size (bits)	Default[1] (Binary, Decimal)	Value	Function
TC1	0x15, Bit18	1	$(0)_2$	0	180 Degree Turns-Count
				1	45 Degree Turns-Count
LP_OFF_TIMER	0x15, (Bit17:10)	8	$(00110000)_2$, $(157)_{10}$	–	Sets LPM Off-time from ~2 ms to ~500 ms. In 2 ms steps.
NP_SPEED_TIMER	0x15, (Bit9:0)	9	$(0010011101)_2$, $(48)_{10}$	–	Sets the time interval over which the angular velocity of the target is measured. To ensure proper operation to datasheet specs, it is recommended to set this parameter to its default value.
NP_ANGLE_ THRESHOLD	0x16, (Bit22:12)	11	$(00000011010)_2$, $(26)_{10}$	–	Sets the maximum allowable angle displacement over the time set by NP_SPEED_TIMER. To ensure proper operation to datasheet specs, it is recommended to set this parameter to its default value.
LP_ANGLE_ THRESHOLD	0x16, (Bit10:0)	11	$(01010101010)_2$, $(682)_{10}$	–	Sets the maximum allowable angle displacement over the time set by LP_OFF_TIMER. To ensure proper operation to datasheet specs, it is recommended to set this parameter to its default value.

[1] Default values for LP_OFF_TIMER, NP_SPEED_TIMER, NP_ANGLE_THRESHOLD, and LP_ANGLE_THRESHOLD are for Angular Motion with Constant Acceleration (max acceleration 6000°/s^2) and t_{OFF} = 100 ms.

Conclusion

In addition to offering all of the standard benefits of non-contact magnetic angle sensing, the A1337 also offers the ability to operate in stringent, battery-powered (including automotive) systems that require low power consumption. Lastly, with its ability to track Turns Counts in both normal and low-power mode, the A1337 is ideally suited to simplify complex mechanical designs for tracking magnetic target position under key-off conditions without compromising the overall robustness and reliability of the system.

REVISION HISTORY

Number	Date	Description
–	March 11, 2016	Initial release
1	April 15, 2022	Updated document branding

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