AEAT-6600-T16

10 to16-Bit Programmable Angular Magnetic Encoder

Application Note 5501

Description

AEAT-6600-T16 is a CMOS magnetic sensor structure suitable for contactless 360° encoding based on the Hall Effect. It provides an angle output up to 16-bits of resolution and simultaneous incremental output of up to 1024 CPR. An integrated Hall structure at the core of the device uses a single dipole disc magnet to convert the magnetic field vector in the chip plane into an AC signal whose amplitude and phase correspond to the magnitude and direction of the field.

An internal digital signal processing unit then processes and conditions the raw AC signal from the sensor. The output signals are available in three different forms: Pulse Width Modulation (PWM), 16-bit absolute position through Serial Synchronous Interface (SSI), and incremental output with 10 bits of resolution. Several encoder features of the device can be programmed by configuring the internal registers in program mode.

More information about the product specification of AEAT-6600-T16 is available in the product datasheet.

1.0 Operation Mode

The AEAT-6600-T16 features four types of operational modes: normal operation mode, one-time programming (OTP) mode, alignment mode and power-down mode. Table 1 below shows the settings required to access the various modes.

Table 1. Operating Modes

Operating Modes	ALIGN	PROG	PWRDOWN
1. Normal Operation Mode	0	0	0
2. OTP Programming Mode	0	1	0
3. Alignment Mode	1	0	0
4. Power-down Mode	X	X	1

Note: X represents any condition of the pins

1.1 Normal Operation Mode (ALIGN = 0, PROG = 0)

The Normal mode is the normal operating mode of the chip. The absolute output (10, 12, 14 or 16-bit absolute position data) is available through SSI pins (DO, CLK and NCS pins). The output PWM is off by default, as are the incremental outputs, A/B/I and UVW. Output MAG_HI and MAG_LO are on to determine the presence and strength of the magnet.

1.2 OTP Programming Mode (ALIGN = 0, PROG = 1)

AEAT-6600-T16 is a One Time Programmable (OTP) ASIC. OTP registers are 0 by default. Programming is enabled in Programming Mode (ALIGN, PWRDOWN – Set Low, PROG – Set High) via the SPI/SSI pins (DO/CLK/NCS). During this mode, MAG_HI and MAG_LO perform the functionality of OTP_ERR and OPT_PROG_STAT respectively, recommended circuit diagram is shown in Figure 1 below. The First bit is set as 0 or 1 to Read or Write followed by 32-bit data and an even parity bit. VPP is connected to 6.5V. Programming of AEAT-6600-T16 can be performed with HEDS-8937, programming kit or any tester/programmer device per the guideline provided.

Write mode: Write 32-bit data plus even parity bit through DO (input) and CLK.

Read mode: Read 32-bit data plus even parity bit through DO (output) and CLK.

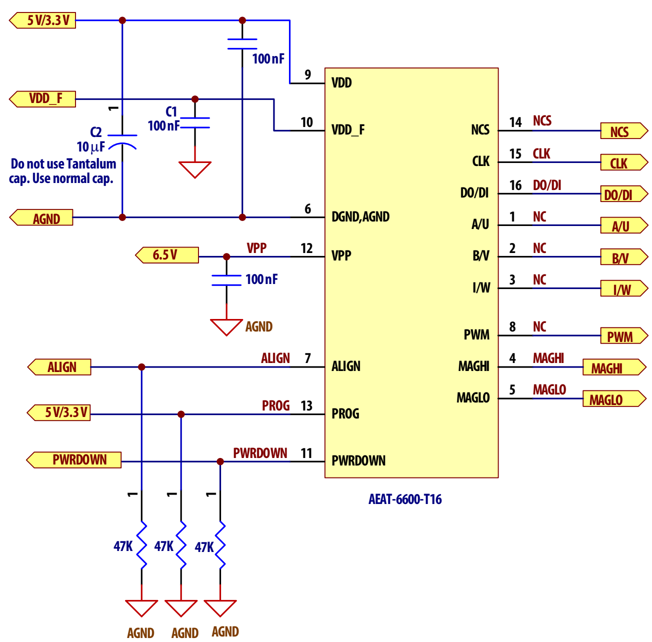

Figure 1. OTP Programming Mode Schematic

Note:

OTP_ERR is set when parity checks fail or OTP data ≠ User data; otherwise clear.

OTP _PROG_STAT is set when programming OTP after parity check valid; otherwise clear.

32-bit OTP Register Settings:

32-bits	31-24	23-16	15-8	7-0
OTP	Zero_Hi (OTP3)	Zero_Lo (OTP2)	Mode_Hi (OTP1)	Mode_Lo (OTP0)

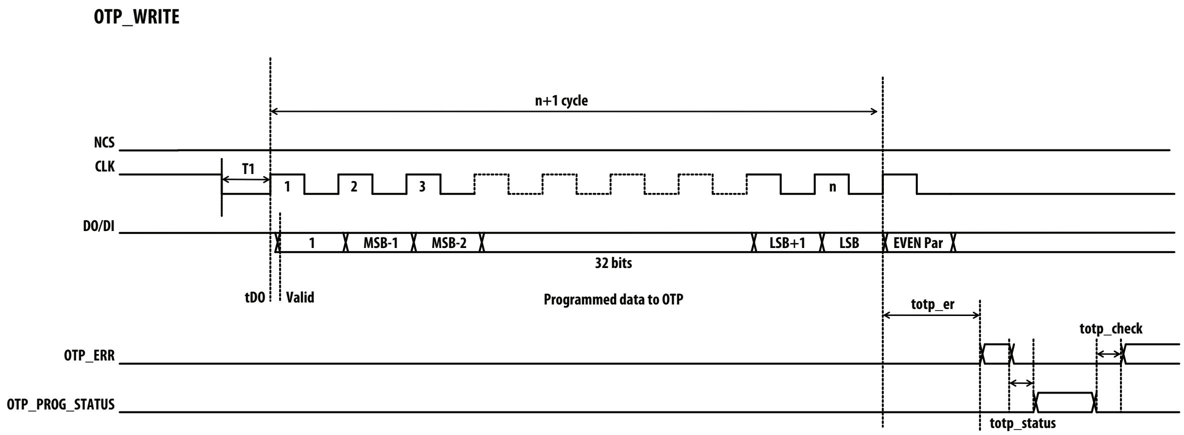

Figure 2. OTP Write Waveform

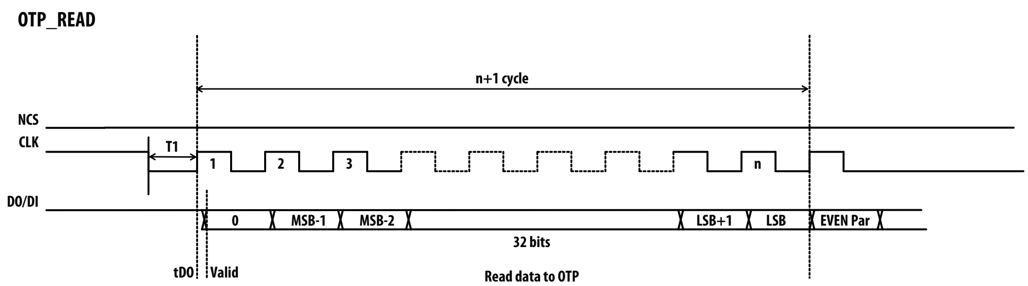

Figure 3. OTP Read Waveform

The AEAT-6600 can also be operated without programming. By default the absolute resolution is at 10 bit, zero position is not programmed, direction is counter-clock wise operation, incremental mode is disabled and speed mode is set at slow mode.

1.2.1 Absolute and Incremental Programming

The absolute resolution can be set to 10, 12, 14 or 16 bits. By default the resolution is set at 10 bits. For incremental selection, ABI or UVW can be selected. However, the incremental mode must be enabled first. The Pulse Width Modulation (PWM) output has to be enabled and the period can be enabled through this mode. The direction of rotation can also be selected here as well.

Absolute count has no hysteresis and always corresponds to the actual mechanical position in both positive and negative directions. Absolute count = 0 indicates mechanical zero position.

Mode_Lo Address: 0x03
Access: Read/Write Type: Binary Input

7	6	5	4	3	2	1	0
Index Output Level			Index Pulse [1]	Index Pulse [0]	Inc Resolution [2]	Inc Resolution [1]	Inc Resolution [0]

Bit(s)	Name	Reset	Description
7	Index Output Level	0	0: Active High. 1: Active Low
4:3	Index Pulse Width / UVW pole-pairs	00	Index 00: 90, 00: 180, 01: 270, 11: 360 / UVW 00: 1, 01: 2, 10: 4, 11: 8 pole pairs
2:1:0	Inc Resolution Bits	000	000: 8, 001: 16, 010: 32, 011: 64, 100: 128, 101: 256, 110: 512, 111: 1024 CPR

Mode_Hi Address: 0x04
Access: Read/Write Type: Binary Input

15	14	13	12	11	10	9	8
DIR	Speed Mode	PWM	PWM Period	Inc	Inc Select	ABS [1]	ABS [0]

Bit(s)	Name	Reset	Description
15	DIR	0	CCW = 1 – Angular values increases in counterclockwise direction CCW = 0 – Angular values increases in clockwise direction
14	Speed Mode	0	Averaging (0: Enable – Slow Mode, 1: Disable – Fast Mode)
13	PWM	0	0: Disable, 1: Enable
12	PWM Period Selection	0	0: 1 µs, 1: 2 µs
11	Incremental	0	0: Disable, 1: Enable
10	Incremental Select	0	0: ABI, 1: UVW
9:8	Absolute Resolution	00	00: 10 bits, 01: 12 bits, 10: 14 bits, 11: 16 bits

Note: PMW output is 2 bits lower in resolution with reference to the programmed absolute resolution

1.2.2 Zero Position Programming

Zero position programming is a feature in AEAT-6600-T16 which enables the user to set a zero position at any mechanical angle, without the need to mechanically adjust the magnet to zero position. To accomplish this, upon assembly of a system with the presence of a magnet, the user reads the 16-bit resolution position and inputs the binary value of the position into Zero_Lo and Zero_Hi, thereby setting the present position as the zero position.

Zero_Lo Address: 0x05

Access: Read/Write Type: Binary Input

23	22	21	20	19	18	17	16
X	X	X	X	X	X	X	X

Bit(s)	Name	Reset	Description
23-16	OTP1 data	00000000	Programmable Zero position

Zero_Hi Address: 0x06

Access: Read/Write Type: Binary Input

31	30	29	28	27	26	25	24
X	X	X	X	X	X	X	X

Bit(s)	Name	Reset	Description
31-24	OTP0 data	00000000	Programmable Zero position

The table below is the complete OTP bit assignment:

Table 2. OTP Bit Assignment Table

Parameter	OTP Register Bits	Value	Output Mode	Notes
Absolute Output				
Absolute Resolution Setting	OTP1[0]	0	10 bits	Default
		1	12 bits	
		2	14 bits	
		3	16 bits	
Incremental Output (Note: Please select 12 bits Absolute Resolution prior Incremental Mode Application)				
Incremental Mode	OTP1[2]	0	ABI Mode	Default
		1	UVW Mode	
Incremental Output Enable Selection	OTP1[3]	0	Disable	Default
		1	Enable	
Incremental Resolution Setting	OTP0[2:0]	0	8 CPR	Default
		1	16 CPR	
		2	32 CPR	
		3	64 CPR	
		4	128 CPR	
		5	256 CPR	
		6	512 CPR	
		7	1024 CPR	
Index Pulse Width Setting	OTP0[4:3]	0	90 edeg. (1 LSB)	Default
		1	180 edeg. (2 LSB)	
		2	270 edeg. (3 LSB)	
		3	360 edeg. (4 LSB)	
Index Output Level	OTP0[7]	0	Active high pulse	Default
		1	Active low pulse	
Pole Pair Setting	OTP0[4:3]	0	1 pole-pair	Default
		1	2 pole-pairs	
		2	4 pole-pairs	
		3	8 pole pairs	
PWM Output	OTP1[5]	0	Disable	Default
		1	Enable	
PWM Minimum Pulse Width Setting	OTP1[4]	0	1 µs	Default
		1	2 µs	
Speed mode	OTP1[6]	0	Slow	Default
		1	Fast	
Output Direction Invert	OTP1[7]	0	Direction of increasing count = CCW	Default
		1	Direction of increasing count = CW	
Zero Position Setting	OTP3[7:0]	0..255	High byte	Default = 0
	OTP2[7:0]	0..255	Low byte	Default = 0

Notes:
Incremental Output Setting, mandatory to select:
a) Absolute resolution -- 12 bits and above
b) Speed Mode -- Slow (Average On)
Absolute Output Setting, please select:
a) Speed Mode – Slow (Average On), recommended setting

1.3 Alignment Mode (ALIGN = 1, PROG = 0)

Alignment mode is used for monitoring the placement of the hall sensors to the center of the magnet rotation axis. In alignment mode, the SSI data bits are converted to an output value proportional to the magnetic field strength. Alignment error is detected by measuring the magnetic field strength variation as the magnet is rotated over one full revolution. A large misalignment offset will produce a large amplitude variation of the alignment value. To achieve an optimum setup of highest output accuracy, the difference between the highest and lowest alignment value over one full turn of the magnet should be minimized

The magnet is aligned to the hall sensor when the value of the peak to peak value and negative peak value at its lowest.

The alignment delta value plot against spatial is shown in firue 4.1, where the alignment delta value ranges from 150-500 (based on 110 mT magnet), with spatial displacement of +/- 500 µm.

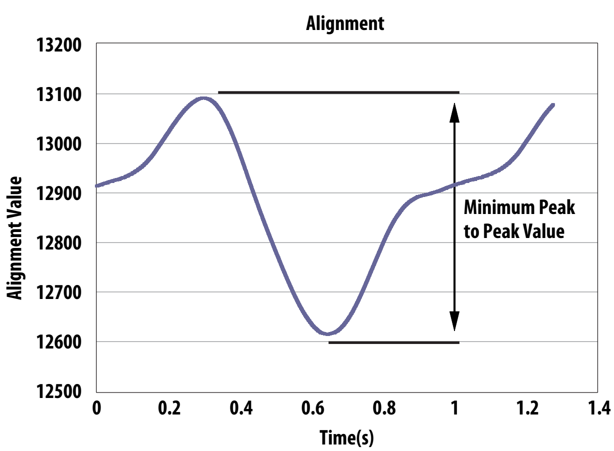

Figure 4a. Magnet Strength Indicator Data for Alignment

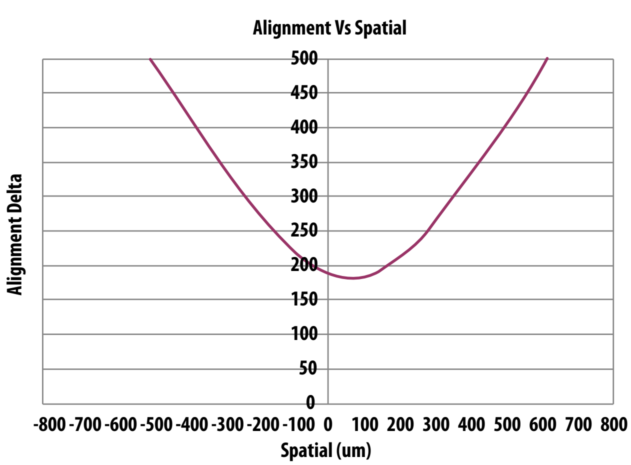

Figure 4b. Alignment Value against Spatial

To set alignment mode, the ALIGN pin is set to 1 and PROG pin is set to 0. The output is 16-bit magnet strength indicator data through SSI pins (DO/CLK/NCS).

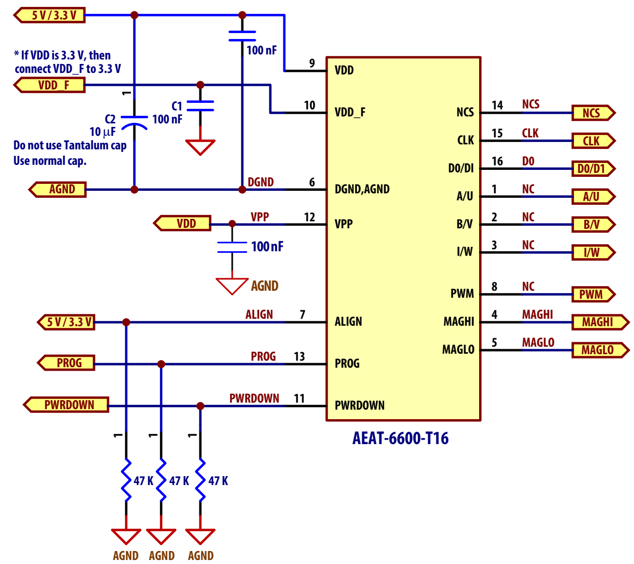

Figure 5. Schematic for Alignment Mode

1.4 Power-Down Mode (PWRDOWN = 1)

Power-down mode is a useful power saving feature. In this mode the entire set of output pins are switched to input state. When Power-down is switched from high to low (de-activated), the device will start operation after power-up time is completed. In Power-down mode, typical current consumption is 100 µA. To set Power-Down mode, the PWRDOWN pin is connected to VDD. Pull down resistor 47 kΩ is connected to ground to ensure Power-Down Mode is always set to 0, unless PWRDOWN pin is toggled to 1.

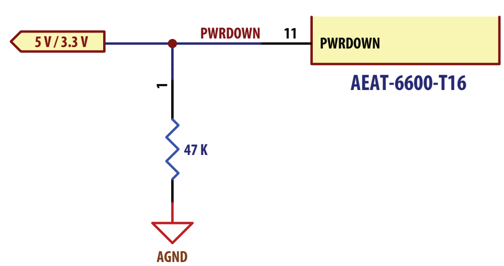

Figure 6. Pull down configuration for PWRDOWN

2.0 Speed Mode

The speed mode (register OTP1[6]) of AEAT-6600-T16 provides the user the option to enable the internal averaging function. If the slow mode is selected, a more precise positional reading is given, providing a higher accuracy measurement compared to the actual angular position. If the application requires faster operation, selecting the fast mode switches the internal averaging off. The reaction time for the slow mode with respect to the absolute resolution setting is as follows:

- 10-bit resolution 85 µs
- 12-bit resolution 340 µs
- 14-bit resolution 5440 µs
- 16 bit resolution 87040 µs

2.1 Effect of High Speed Operation

The AEAT-6600-T16 works at various speed configurations, however the rotational speed depends on several variables, including the output resolution and frequency, f, which is determined by:

$$f = \frac{\text{Resolution x Speed (RPM)}}{60}$$

Note: For example, for 10-bit resolution, 1024 positional data and a frequency (f) of 12 kHz, the maximum motor speed at which all the positional data can be obtained in one revolution is 703 rpm.

If the motor speed exceeds the calculated value, positional data may be missed because the detector was unable to keep up with the rotational speed, as shown in the Figure 4 below:

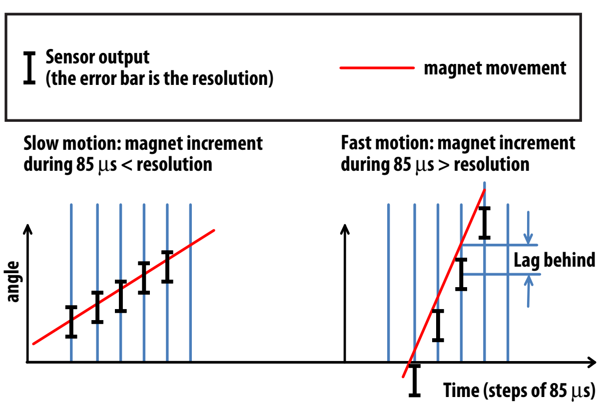

Figure 7. Sensor against magnet movement

The lag is calculated by,

$$\text{lag} = \frac{\omega\,\tau}{2}$$

Where ω is the magnet angular speed in deg/s and τ is the time increment (85 10^{-6} s).

Note: For example, 10 bit resolution, the maximum motor speed to obtain all the positional data in one revolution is 703 rpm and equivalent to 4218 deg/s. The lag with this magnet movement is 0.18 deg.

3.0 Accuracy

If we consider a set of angle measurements taken at different angular positions of the magnet, the accuracy is the maximum difference between the measurement and the best linear fit – this is sometimes called the "sensor linearity".

Note that this definition is valid for a sensor without a calibration curve. With calibration, the accuracy would be defined as the maximum difference between the measured value and the calibration value.

The errors that cause accuracy to deteriorate include:

- Errors caused by the sensor IC
- Errors caused by the system mounting (i.e., non-homogeneity of the magnet combined with the mechanical tolerances)

Therefore we define:

- Sensor accuracy – the accuracy obtained with the sensor placed in a perfectly homogeneous field
- Setup accuracy – the accuracy of a perfect sensor placed in the actual system setup (with the actual magnet and the worst case mechanical displacement given by the tolerances)
- Overall system accuracy – the accuracy obtained with the actual sensor and setup with the worst mechanical displacements given by the tolerances

3.1 Sensor Accuracy

The figure below is the absolute error plot of the AEAT-6600-T16 Hall sensor when paired with a perfect homogeneous magnetic field generated by an electro-magnet, at three different field strengths: 80 mT, 100 mT and 120 mT. At 120 mT the sensor accuracy is at ±0.11 deg.

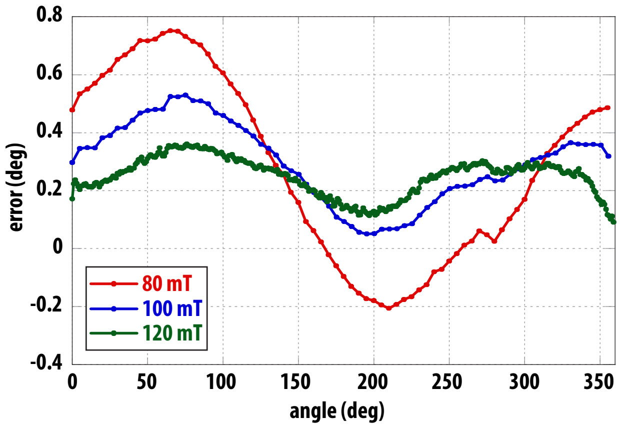

Figure 8. Sensor accuracy

3.2 Temperature Drift

The effect on accuracy over temperature drift is also important to consider. The drift measured for the AEAT-6600-T16 was 0.0005 deg/°C, which represents an error of 0.1deg when the temperature is increased from -40° C to +135° C. This performance is enabled by the internal temperature compensation circuit.

4.0 Recommended Magnet

The recommended magnet material for use with the AEAT-6600-T16 is Neodymium Iron Boron (NdFeB) alloy. This is the best candidate for reaching high field intensity at reasonable cost. The remnant field varies from 1.05 to 1.45T and the maximum working temperature ranges from 80° C to 200° C depending on the alloy quality grade. However, this material exhibits a relatively large temperature variation (0.7%/°C). The NdFeB alloy magnet, grade N35SH with a diameter of 9.0 mm and a thickness of 3.0 mm has been characterized with AEAT-6600-T16 and is recommended. Magnet radial field strength from center of thickness is 198 mT +/-5% (measured 1.3 mm away from magnet radial surface).

Figure 9 shows a plot of the simulation results for AEAT-6600-T16 B_plane (vertical plane magnetic strength) versus magnet size for different gap sizes. The optimum size magnet for a 1.3 mm gap is 9 x 3 mm. However, diff erent magnets sizes like 6 x 3 mm can also be used.

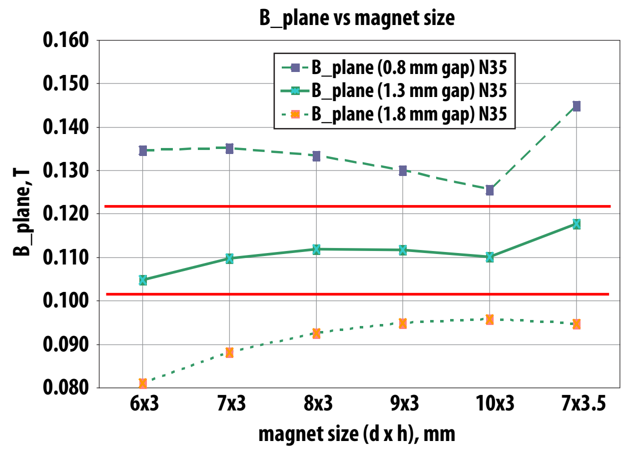

Figure 9. Magnetic strength vs. Magnet Size

5.0 3.3 V / 5 V Operation

AEAT-6600-T16 functions at two optional operating voltages: 3.3 V ±10% or 5 V ±10%. VDD_F is connected internally where VDD_F must shunt to GND with 100nF as shown in Figure 1.

6.0 Reference Design

A reference design, PCB level, for the AEAT-6600-T16 is shown in Figure 10. It is just an example of the application for use with one of the targeted modes of the application, as illustrated in the Table 3, which describes the different application modes and output pins. AEAT-6600-T16 must be programmed before setting the application modes. Connect only the output pins for respective application modes with 0 Ω and leave OPEN for the rest of the output pins. The capacitors present on the circuit serve as noise filters purposes.

Table 3. Application Modes of AEAT-6600-T16

Application Modes	Output Pins		
Absolute SSI (3-wire)	NCS	CLK	DO
Absolute SSI (2-wire)	PWRDOWN	CLK	DO
ABI Mode	A	B	I
UVW Mode	U	V	W
PWM Mode	PWM	MAGHI	MAGLO

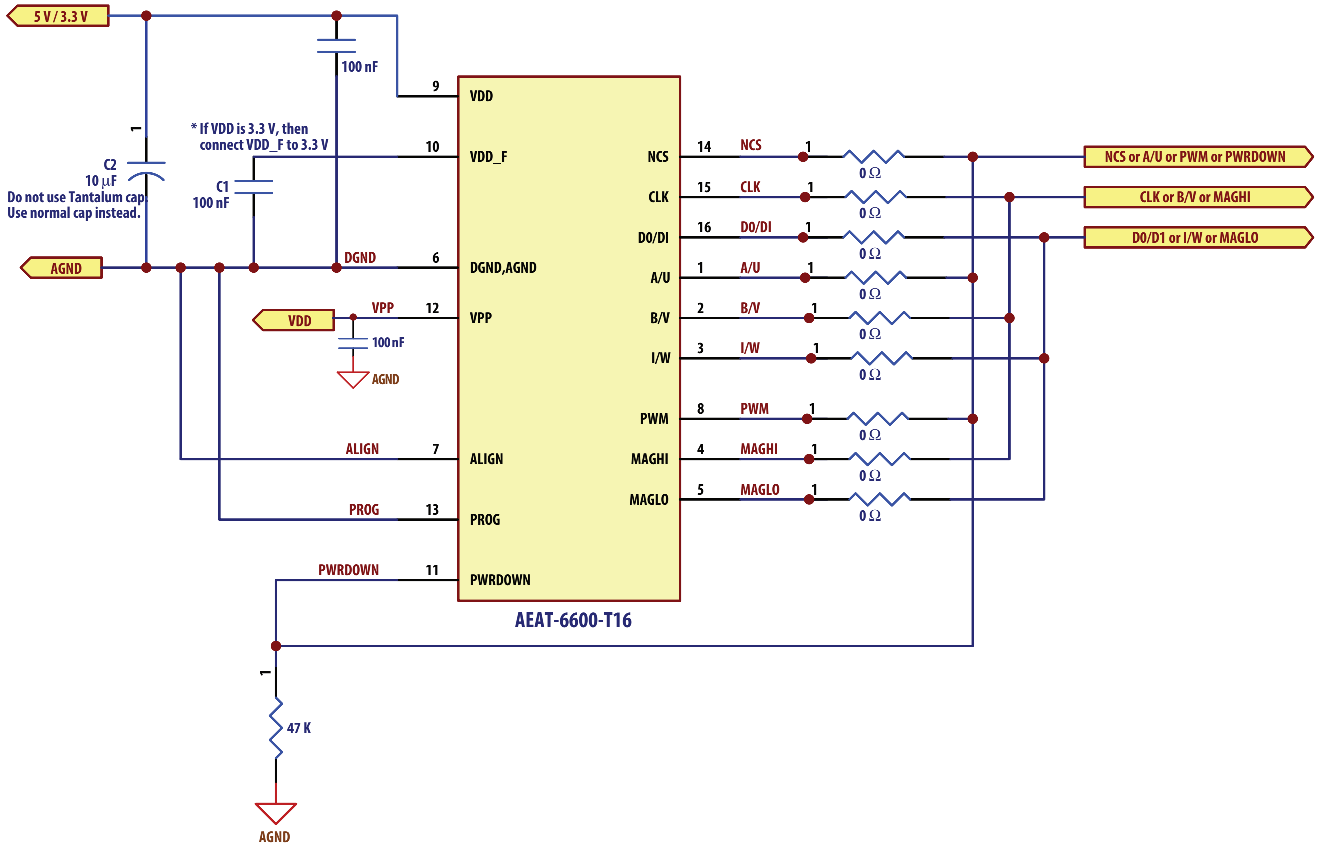

Figure 10. Application Schematic (PCB level) for AEAT-6600-T16

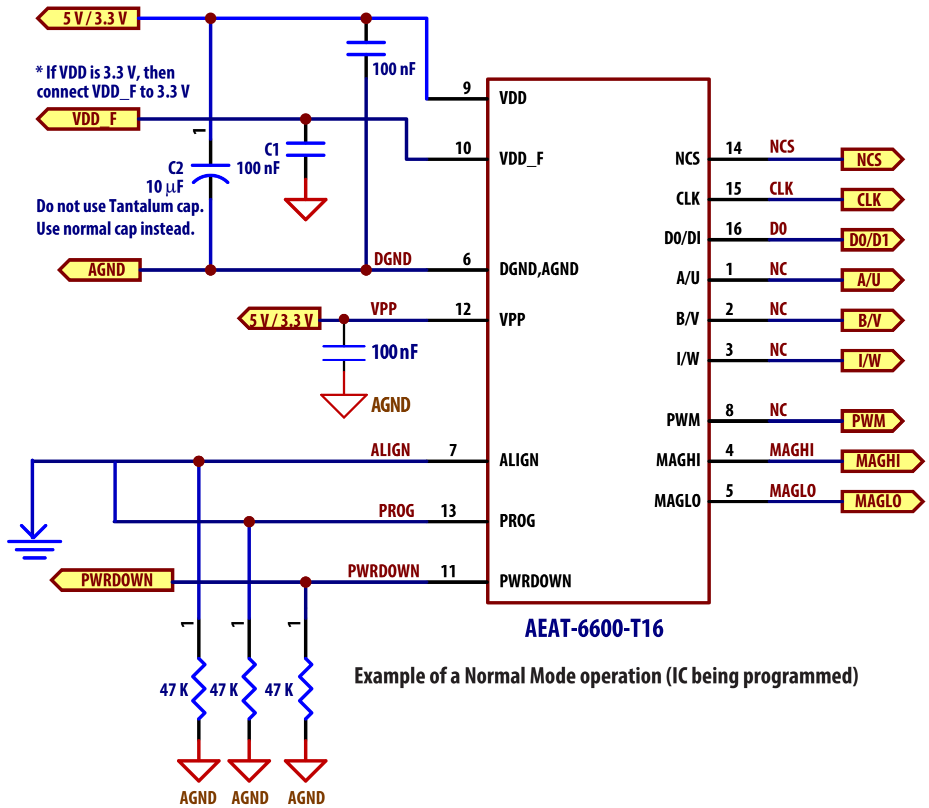

Figure 11. Normal Mode

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