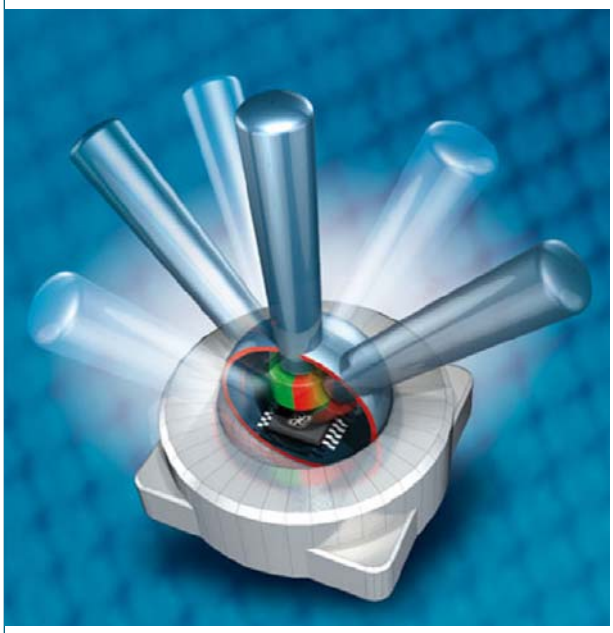
AN5046-10

Using the AS5046 Rotary Encoder in 3D Joystick Applications

APPLICATION NOTE



Abstract

Integrated Hall Effect Rotary Encoders can be used for accurate contactless angle measurements. However, by using an axially magnetized magnet instead of a diametrically magnetized a rotary encoder can be used to determine tilt direction as well as the tilt inclination. Additionally the distance between the magnet and the encoder can be estimated which allows to implement a push button functionality. The AS5046 allows easy determination of this information and thus provides an ideal basis for various contactless joystick-like applications.

1 Introduction

Hall Effect based Rotary Encoders like the austriamicrosystems' AS5046 enable a robust way to measure angular positions when used in combination with an diametrically magnetized magnet. The immunity against dust and the absence of mechanical parts make sensors built upon the AS5000 series ideal for use within harsh operating environments.

The application of these rotary encoders is not limited to angular measurements only. If the magnet is changed to an axially magnetized type the AS5046 can be used to measure the tilt direction and to estimate the tilt inclination. In addition to tilt direction and inclination a push button function can be implemented by using the so-called align mode of the rotary encoder.

This document introduces the background and details necessary to understand the joystick application. It is assumed that the reader of this document has knowledge of the operating principle of hall-based rotary encoders and the AS5046 data sheet.

2 Theory of Operation

The three degrees of movement of the joystick are illustrated in Figure 1. The degrees of movement are tilt direction α_{tilt}, tilt inclination relative to the z-axis φ_{tilt} and the distance of the magnet to the center of the hall element array *d*.

Note: The tilt angle's pivot point is located at the center of the hall element array.

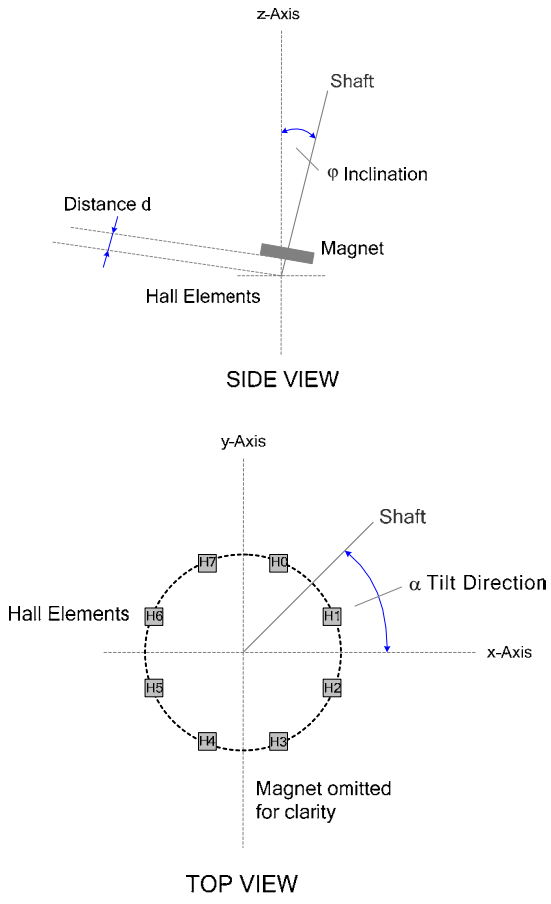
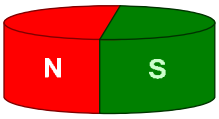
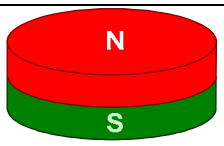


Figure 1: Illustration of the definitions

2.1 Determining Tilt Direction, Tilt Inclination and Magnet Distance

When tilting an axially magnetised magnet the Hall Elements will detect the inclined magnetic field lines.

For this reason a change of the magnet is all that is required to change a rotary encoder into a 3-D joystick. Table 1 states the changes in application of the AS5046 SIU register reading when using an axially instead of diametrically magnetized magnet.

Usage	Used Bomatec Magnet	Order #		SIU Position	SIU Magnitude	Alignment Mode
Rotary Encoder	6x2.5mm diametric	2694		Angular Position	Vertical Distance	Magnet Alignment
3-D Joystick	6x2.5mm axial magnetised	2991		Tilt Direction	Tilt Inclination	Vertical Distance of Magnet (important f. Push-Button)

With just one serial read command (reading the SIU register) tilt direction and tilt inclination is available.
When moving the magnet closer to the chip the absolute value of the flux density at the Hall Elements increases. For this reason the distance of the magnet can easily be read when using the Alignment-Mode of the AS5046 and reading the position related bytes of the SIU register.
The relation of the flux density and tilt direction is non-linear, depends on the diameter of the hall element array, the physical dimensions of the magnet, and the distance between the magnet and the hall element array. However, those properties are constant for a given magnet.

3 Implementing a 3D Joystick with an AS5046

The austriamicrosystems AS5046 magnetic rotary encoder features all components required to compute the tilt inclination and direction as well as the vertical distance (push button functionality).

3.1 Polar Coordinates Transformation

Some applications require the magnet's inclination data to be represented in a polar form. For example the emulation of behaviour of hat switches used in gaming pads. For this application the AS5046 SIU register (in conjunction with the OTP zero position and CCW bits) provides all data required. The direction of tilt equals the position available in the SIU register of the AS5046. The tilt inclination is proportional to the magnitude value of the SIU.

Example Code

The following code illustrates the basic operation of a hat switch emulation. It uses the two MSB of the position information to determine the tilt direction (north, east, south, west, etc.) and compares the magnitude value to a threshold (with hysteresis to avoid fast toggling of states when the magnet is held at a transition level) to decide whether the joystick is tilted far enough or still considered to be in a centred position.

```
// Variable f. Center Position Hysteresis
static int CtrMagThresh = LOW_MAG_THRESHOLD;

// read angle and magnitude information
readI2C(buffer,
        type_identifier = 0x05,
        internal_address = 0,
        num_bytes = 4);

// decide whether the joystick is centered
// from the magnitude information and threshold
if(buffer[2] < CtrMagThresh)
{
    state = CENTER;
    CtrMagThresh = HIGH_MAG_THRESHOLD
}else{
    // determine tilt direction by reading
    // the position information in SIU
    // three MSB will enable the detection of 8
positions
    switch(buffer[0] >> 5)
    {
        case 0: state = NORTH; break;
        case 1: state = NORTH_EAST; break;
        case 2: state = EAST; break;
        case 3: state = SOUTH_EAST; break;
        case 4: state = SOUTH; break;
        case 5: state = SOUTH_WEST; break;
        case 6: state = WEST; break;
        case 7: state = NORTH_WEST; break;
        default: state = UNDEFINED;
    }
    CtrMagThresh = LOW_MAG_THRESHOLD
}
```

3.2 Rectangular Application

In many applications the joystick data is required to be in rectangular representation. A typical example is the data from USB Human Interface Devices (HID) like mice, gamepads, and joysticks. With those applications the tilt direction and inclination has to be represented by a polar coordinates vector

$$\langle x,y\rangle^T = \langle \varphi_{tilt} \cdot \cos(\alpha_{tilt}), \varphi_{tilt} \cdot \sin(\alpha_{tilt})\rangle^T .$$

This information is immediately available in the AS5046 CORDIC register.

The x and y components are the input of the on-chip CORDIC (COordinate Rotation DIgital Computer) and can be directly read via the two wire serial interface of the chip. Any residual 22.5° position shift in relation to the chip axis caused by the Hall Element placement can be compensated either mechanically or by software.

Example Code

The following code snippet is part of an USB HID that enumerates as mouse and therefore allows the cursor on a PC screen to be moved by an AS5046 based joystick. The USB hardware used is a C8051F320 controller from Silicon Labs (see Figure 2). The firmware for the device is based on an example provided by Silicon Labs (AN249: www.silabs.com/public/documents/tpub_doc/anote/Microcontrollers/USB/en/AN249.pdf) and the only necessary code change to create an AS5046 based joystick – besides implementing the serial interface code – is shown below.

```
// read COS and SIN data
// see data sheet for details
readI2C(buffer,
        type_identifier = 0x04,
        internal_address = 0,
        num_bytes = 3);

// X_Axis (COS)
IN_PACKET[1] = (buffer[0]>>1);

// Y_Axis (SIN)
IN_PACKET[2] = (buffer[1]>>1);
```

The example code uses only the seven MSB of the 12 bit SIN and COS data of the AS5046 in order to create a hysteresis around the joystick's idle position.

3.3 Push Button Application

As mentioned in the theory part the push button functionality uses the mean value of the flux density. In order to measure the magnetic flux density (so to say the magnitude) the Alignment Mode of the AS5046 is used. During Align Mode all eight Hall Element values are summed up. Instead of the position information the field strength is now available in the SIU position register. The following example code illustrates the operation but uses only the eight MSB for simplicity.

```
// enable align mode of AS5046
CSn = 1;
PROG = 1;
CSn = 0;
PROG = 0;

// read flux density information
readI2C(buffer,
        type_identifier = 0x05,
        internal_address = 0,
        num_bytes = 4);

// decide whether the magnet is pushed or not
if(buffer[0] > FLUX_DENSITY_THRESHOLD)
{
    state = PUSHED;
}
```

It should be noted, when using the Alignment Mode to measure flux density for push button functionality the magnet has to be in centred position (Magnitude = 0). Summing all Hall Element field strength values in tilted position may lead to a maximum readout even if the magnet is not pushed.

4 Schematic

4.1 USB Interface Board

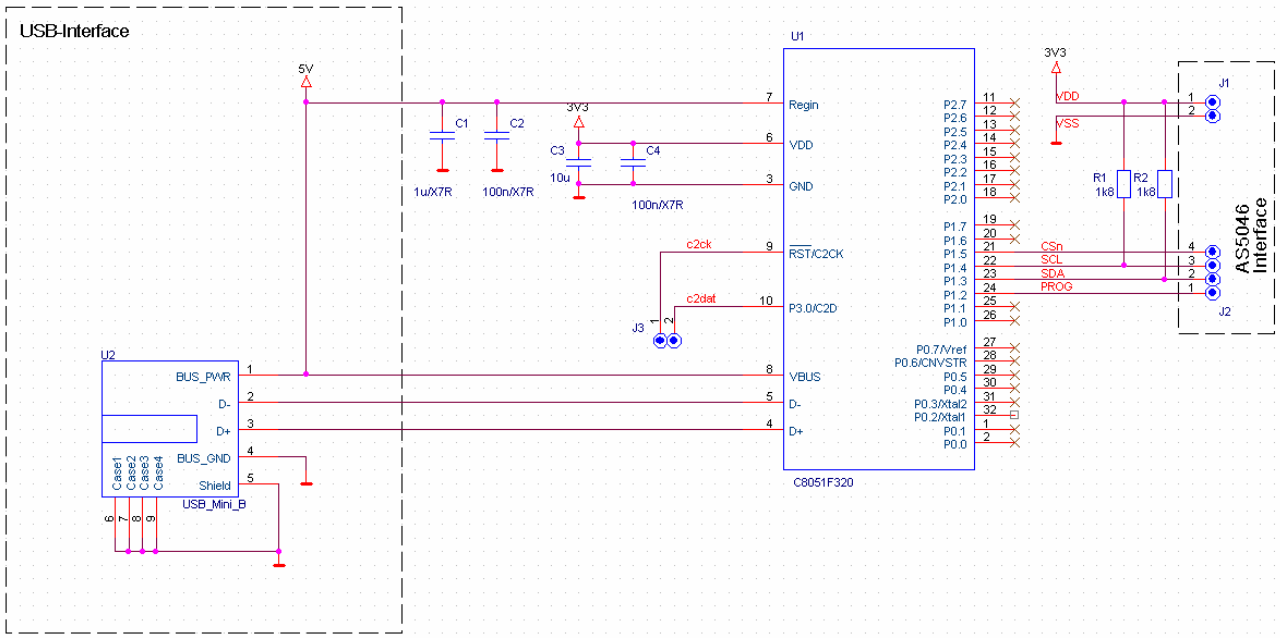


Figure 2: Schematic of USB Interface

4.2 AS5046 Interface Board (Joystick)

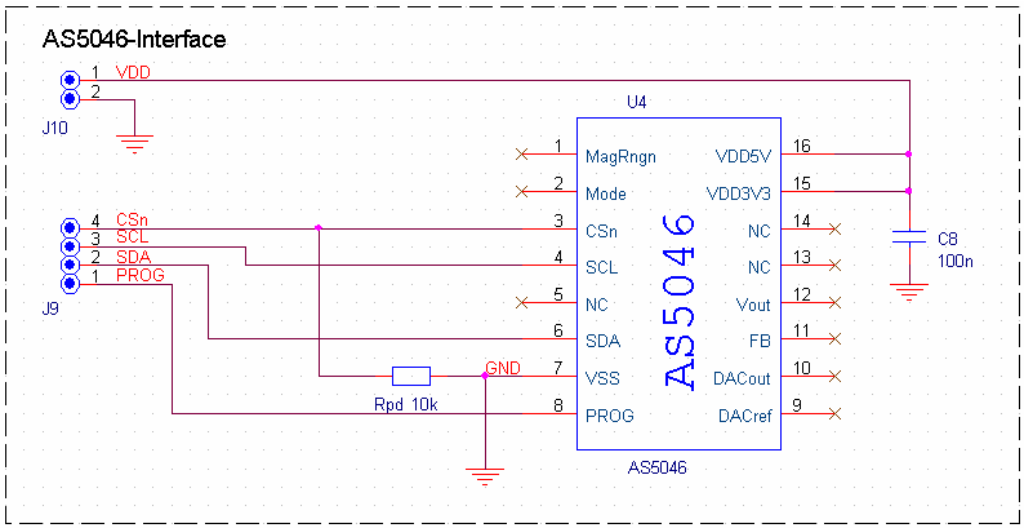


Figure 3: Schematic of AS5046 Interface Board

5 Contact

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