

Measuring Speed and Position with the QEI Module

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INTRODUCTION

This document provides an overview of the Quadrature Encoder Interface (QEI) module present on the motor control family of dsPIC30F Digital Signal Controllers. Code examples are also provided for a typical motor control application, where speed and position measurements of the rotor are required.

QEI MODULE

Quadrature encoders (also known as incremental encoders or optical encoders) are used for position and speed detection of rotating motion systems. Quadrature encoders enable closed loop control of many motor control applications.

The QEI module provides a simple interface to incremental optical encoders, which allows you to obtain signed velocity and relative rotor position information from the motor or mechanical system. The QEI module accepts the A, B and index connections from the incremental encoder and stores the accumulated count pulses in a dedicated 16-bit time base. Velocity and position information can be measured at X2 or X4 resolution.

The two channels, Phase A (QEA) and Phase B (QEB), have a unique relationship. If Phase A leads Phase B, then the direction of the motor is deemed positive or forward. If Phase A lags Phase B then the direction of the motor is deemed negative or reverse. A third channel, termed Index pulse, occurs once per revolution and is used as a reference to establish an absolute position. The index signal may not be present on all encoders and is not required for proper operation of the QEI. See Figure 1 for a relative timing diagram of these three signals.

The QEI consists of quadrature decoder logic to interpret the Phase A, Phase B and Index signals and an up/down counter to accumulate the count. Digital glitch filters on the inputs condition the input signal. Figure 2 depicts a simplified block diagram of the QEI Module.

The QEI module includes these features:

- Three input pins for two phase signals and index pulse
- Programmable digital noise filters on inputs
- Quadrature decoder (provides counter pulses and count direction)
- 16-bit up/down position counter
- Count direction status
- X2 and X4 count resolution
- Two modes of position counter reset
- General purpose 16-bit Timer/Counter mode
- Interrupts generated by QEI or counter events

FIGURE 1: QUADRATURE ENCODER INTERFACE SIGNALS

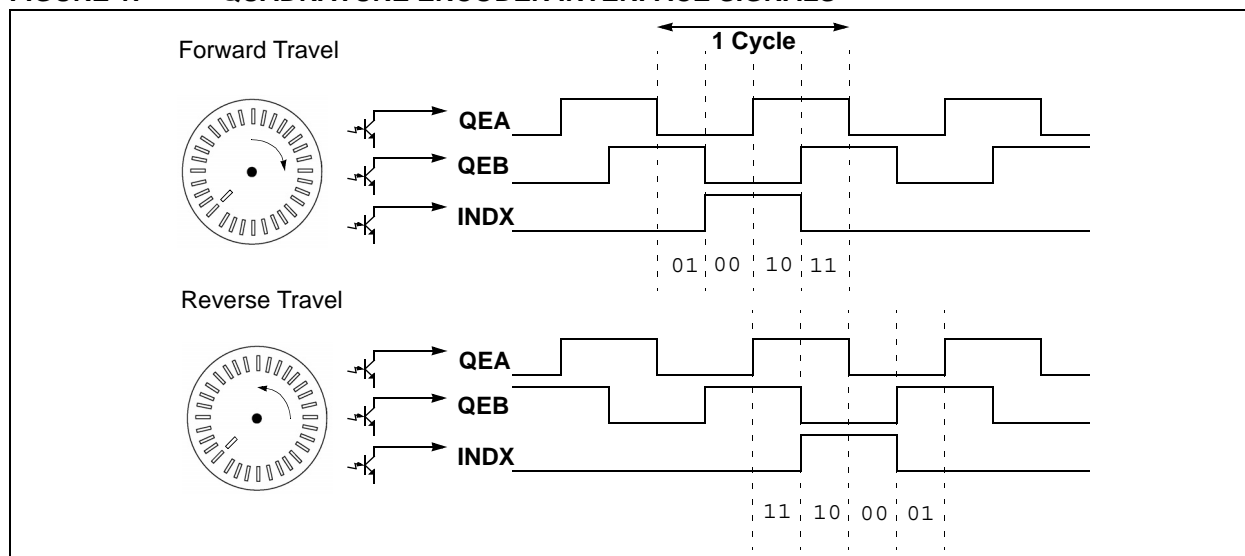
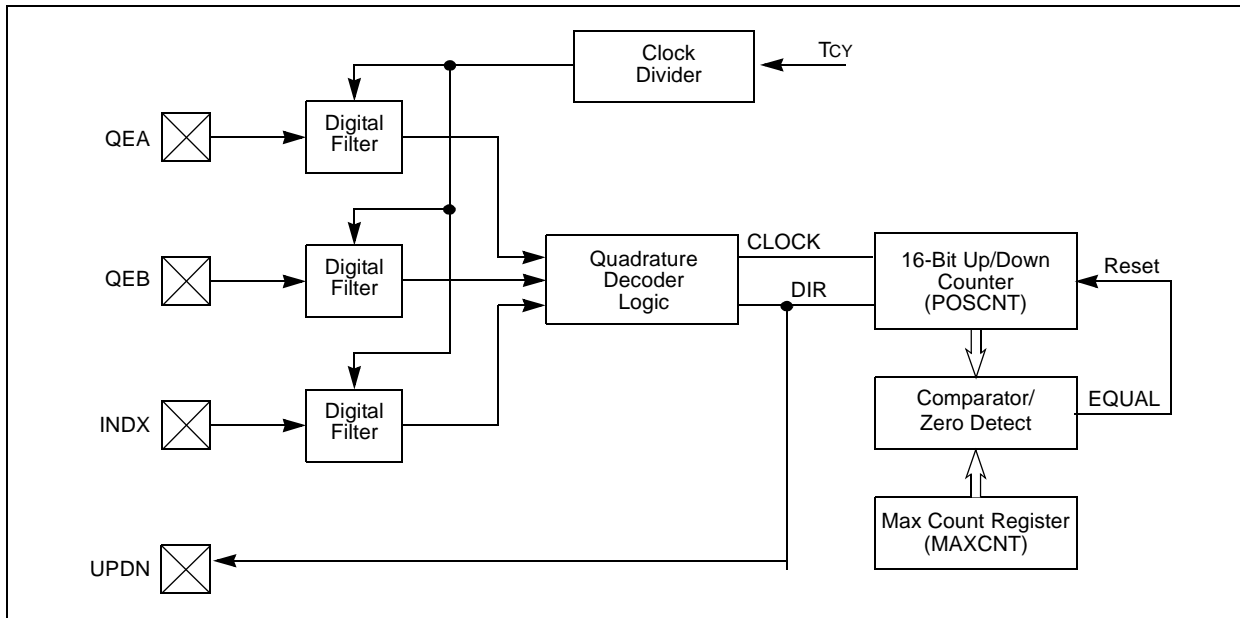


FIGURE 2: QUADRATURE ENCODER INTERFACE MODULE SIMPLIFIED BLOCK DIAGRAM

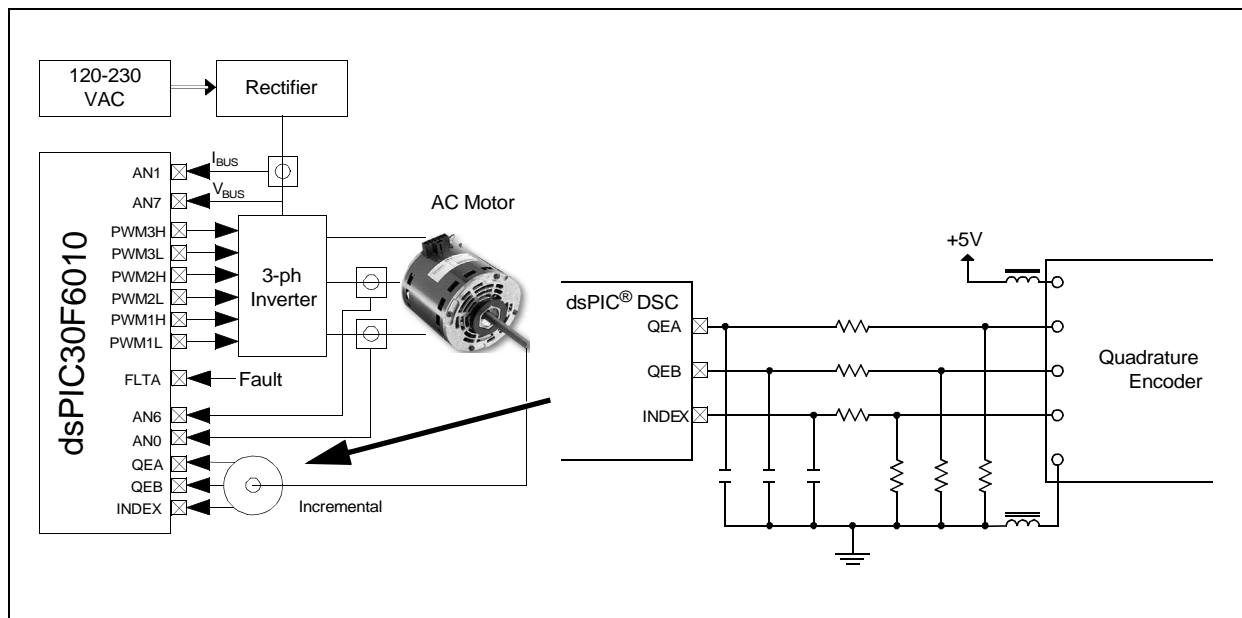


For more information on the CPU, peripherals, register descriptions and general device functionality, refer to the “dsPIC30F Family Reference Manual” (DS70046).

APPLICATION EXAMPLE

Figure 3 illustrates a typical application using the QEI module, where an AC Induction Motor (ACIM) is controlled by using a quadrature encoder for feedback information.

FIGURE 3: TYPICAL APPLICATION WITH SIMPLIFIED SCHEMATIC



The requirements of the application example are:

1. **Measure rotor angular position from 0° to 360°.** The number of lines of the incremental encoder must be known in order to set the proper scaling factors. A 16-bit unsigned variable is used for this requirement.
2. **Measure signed angular speed.** Motor maximum speed is to be known for proper conversion. A signed 16-bit variable is used, where the sign represents forward (+) or reverse (-) direction of rotation.

For these requirements, you need information about the incremental encoder that is used and the speed ranges of the motor.

The following motor and encoder combination was used to develop this application example:

Motor	Leeson Cat# 102684 Rated speed 3450 RPM.
Encoder	U.S. Digital model E3-500-500-IHT. 500 lines of resolution

Note: The Leeson motor can be obtained from an electric motor distributor, or you can order it from Microchip. The encoder can be ordered from the U.S. Digital web site, www.usdigital.com. Any other similar encoder with 500 lines of resolution may be used instead of the U.S. Digital device, if desired.

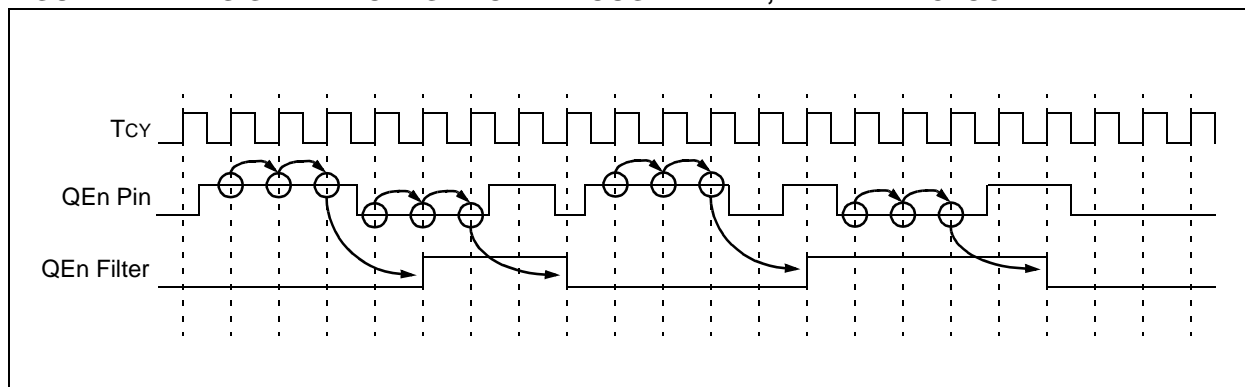
INITIALIZING THE QEI MODULE

Based on the incremental encoder used in this example, the module is configured as follows:

Enable Digital Filters

Enabling the digital filters is desirable to filter any possible glitches on the incremental encoder signals. For the configuration used in this example, the timing diagram of Figure 4 shows how the input signals are filtered.

FIGURE 4: SIGNAL PROPAGATION THROUGH FILTER, 1:1 FILTER CLOCK DIVIDE



A rule of thumb to calculate the filter is based on the minimum pulse width of the encoder, which is determined by the maximum motor speed. In this example, the minimum pulse width is determined by Equation 1:

EQUATION 1: MINIMUM PULSE WIDTH

$$\text{MIN_PULSE} = \frac{30}{\text{MAX_RPM} \times \text{ENCODER_PULSES}} = \frac{30}{4000 \times 500} = 15 \mu\text{sec}$$

So configuring the filter to reject any signal lower than 15 μs will be fine for the application. In this example, we are running at 14.75 MIPS, so the closest filter configuration to achieve our requirement is calculated as shown in Equation 2:

EQUATION 2: FILTER DIVIDER

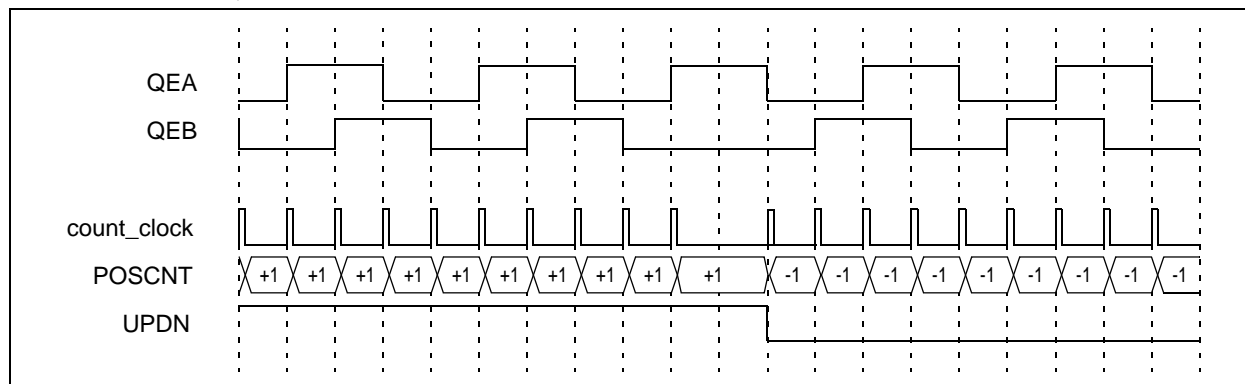
$$\text{FILTER_DIV} = \frac{\text{MIPS} \times \text{FILTERED_PULSE}}{3} = \frac{14.75 \text{ MIPS} \times 15 \mu\text{sec}}{3} = 73.7 \Rightarrow 64$$

With the available options on the QEI module, a divider of 64 is selected, so pulses below 13 μsec will be filtered.

Increment Pulse Counter

Increment pulse counter on each QEn pins transition. In order to get as much resolution as possible, the QE1 is configured for X4. The X4 Counting mode increments or decrements the POSCNT register on every QEA and QEB signal edge. Figure 5 shows a timing diagram for the X4 configuration.

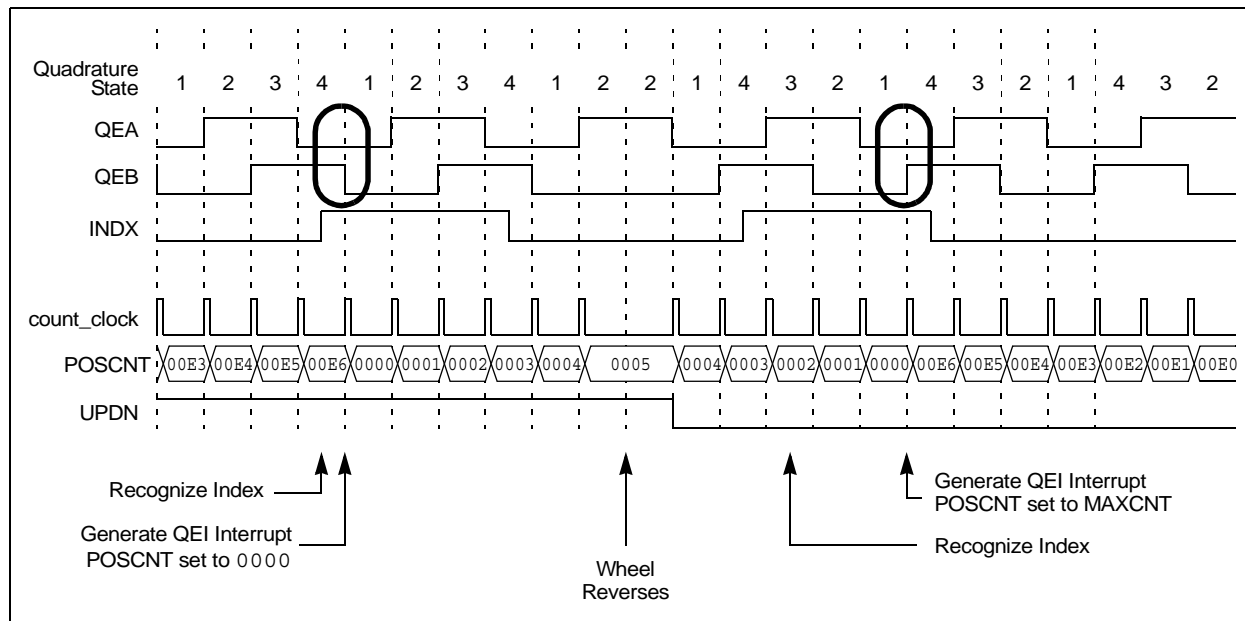
FIGURE 5: QUADRATURE ENCODER SIGNALS IN X4 MODES



Reset Pulse Counter

The pulse counter is reset by the index pin. Some incremental encoders don't have this output to generate an absolute reference position. However, the one used in this example has this output, and we will take advantage of it. See Figure 6 for a timing diagram when the index pulse resets the counter.

FIGURE 6: RESET BY INDEX MODE



Code Example

The following code example initializes the QEI module based on the requirements of this application example:

EXAMPLE 1: INITIALIZING THE QEI MODULE

```
void InitQEI(void)
{
    ADPCFG |= 0x0038;           // Configure QEI pins as digital inputs
    QEICONbits.QEIM = 0;        // Disable QEI Module
    QEICONbits.CNTERR = 0;       // Clear any count errors
    QEICONbits.QEISIDL = 0;      // Continue operation during sleep
    QEICONbits.SWPAB = 0;        // QEA and QEB not swapped
    QEICONbits.PCDOUT = 0;       // Normal I/O pin operation
    QEICONbits.POSRES = 1;       // Index pulse resets position counter
    DFLTCONbits.CEID = 1;        // Count error interrupts disabled
    DFLTCONbits.QEOUT = 1;       // Digital filters output enabled for QEn pins
    DFLTCONbits.QECK = 5;        // 1:64 clock divide for digital filter for QEn
    DFLTCONbits.INDOUT = 1;      // Digital filter output enabled for Index pin
    DFLTCONbits.INDCK = 5;       // 1:64 clock divide for digital filter for Index
    POSCNT = 0;                 // Reset position counter
    QEICONbits.QEIM = 6;        // X4 mode with position counter reset by Index
    return;
}
```

CALCULATING ANGULAR POSITION WITH QEI

To prepare the variable for fractional operations performed by control algorithms, you need to convert the position counter result into a signed fractional number. Equation 3 shows the calculation for maximum count per revolution, based on the information of the incremental encoder and the QEI module configuration.

EQUATION 3: MAXIMUM COUNT PER REVOLUTION

$$\text{MAX_COUNT_PER_REV} = \text{PULSES_PER_REV} \times \text{COUNT_INC_PER_REV} - 1 = 500 \times 4 - 1 = 1999$$

Where the resolution would be:

$$\text{RESOLUTION} = \frac{360^\circ}{2000} = 0.18^\circ$$

With this resolution, the position count variable needs to be converted from 0 to 1999 to a signed fractional 16-bit value of 0 to 32767. The following formula shows the scaling factor.

$$\text{AngPos}[0] = \frac{\text{POSCNT} \times 2048}{125}$$

Code Example

The following code example shows how to implement this simple subroutine in C:

EXAMPLE 2: CALCULATING ANGULAR POSITION WITH QEI

```
int AngPos[2] = {0,0};           // Two variables are used for Speed Calculation
int POSCNTcopy = 0;
void PositionCalculation(void)
{
    POSCNTcopy = (int)POSCNT;
    if (POSCNTcopy < 0)
        POSCNTcopy = -POSCNTcopy;
    AngPos[1] = AngPos[0];
    AngPos[0] = (unsigned int)((unsigned long)POSCNTcopy * 2048)/125);
                                // 0 <= POSCNT <= 1999 to 0 <= AngPos <= 32752
    return;
}
```

Note: POSCNT is automatically reset by the Index pulse as configured.

CALCULATING ANGULAR VELOCITY WITH QEI

The velocity calculation is performed in a periodic interrupt, since the angular velocity is the number of increments in a fixed period of time. This interrupt interval

must be less than the minimum time required for a ½ revolution at maximum speed. The motor's rated speed is 3450 RPM, so 4000 RPM is used in this example to avoid any velocity calculation overflow. The formula shown in Equation 4 is used to calculate time interval.

EQUATION 4: INTERRUPT PERIOD CALCULATION

$$\text{INTERRUPT_PERIOD} = \frac{60}{2 \times \text{MAX_SPEED_RPM}} = \frac{60}{2 \times 4000} = 0.0075 \text{ seconds}$$

Example 3 shows the initialization of Timer1 used to generate this periodic interrupt with the dsPIC DSC running at 14.75 MIPS:

EXAMPLE 3: TIMER1 INITIALIZATION TO GENERATE 0.0075 SEC PERIODIC ISRS

```
void InitTMR1(void)
{
    TMR1 = 0;                // Reset timer counter
    T1CONbits.TON = 0;       // Turn off timer 1
    T1CONbits.TSIDL = 0;     // Continue operation during sleep
    T1CONbits.TGATE = 0;     // Gated timer accumulation disabled
    T1CONbits.TCS = 0;       // use Tcy as source clock
    T1CONbits.TCKPS = 2;     // Tcy / 64 as input clock
    PR1 = 1728;              // Interrupt period = 0.0075 sec with a 64 prescaler
    IFS0bits.T1IF = 0;       // Clear timer 1 interrupt flag
    IEC0bits.T1IE = 1;       // Enable timer 1 interrupts
    T1CONbits.TON = 1;       // Turn on timer 1
    return;
}
```

Example 4 shows how the Speed variable is calculated in the periodic ISR:

EXAMPLE 4: ANGULAR SPEED CALCULATION EXAMPLE

```
#define MAX_CNT_PER_REV (500 * 4 - 1)
#define MAXSPEED (unsigned int)((unsigned long)MAX_CNT_PER_REV*2048)/125)
#define HALFMXSPEED (MAXSPEED>>1)
int Speed;
void __attribute__((__interrupt__)) _T1Interrupt (void)
{
    IFS0bits.T1IF = 0;    // Clear timer 1 interrupt flag
    PositionCalculation();
    Speed = AngPos[0] - AngPos[1];
    if (Speed >= 0)
    {
        if (Speed >= (HALFMXSPEED))
            Speed = Speed - MAXSPEED;
    }
    else
    {
        if (Speed < -(HALFMXSPEED))
            Speed = Speed + MAXSPEED;
    }
    Speed *= 2;
    return;
}
```


CONCLUSION

From the code examples in this document, the following values are obtained:

TABLE 1: SUMMARY OF VARIABLE VALUES AND RESOLUTION

Variable	Angular Values	Integer Values	Fractional Values	Resolution
AngPos[n]	0° to 359.82°	0 to 32752	0.0 to 0.99951	0.18°
Speed	-4000 to 4000 RPM	-32752 to 32752	-0.99951 to 0.99951	8.19 RPM

If the application requires more resolution in the Speed or Angular position measurements, you can use the following guidelines:

- Accumulate counts in a longer period of time. You must be careful to avoid overflow conditions of the pulse counter register POSCNT, so accumulations of the POSCNT register are recommended in this case.
- Use input capture channels to measure the period between transitions instead of counts per revolution.
- Select an Incremental Encoder with more pulses per revolution.

Note: The code examples were tested on a dsPIC30F6010 device and developed using Microchip MPLAB® IDE 7.11 and the Microchip MPLAB® C30 Compiler v1.31.

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