3.1. Micro-Controller Basics : Introduction to Input and Output Interfacing

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Abstract – this brief gives an introduction to interfacing micro-controllers for motor drive applications.

I. Introduction

Micro-controllers are widely used in low-cost motor drives and often contain input/output interfaces such as pulse-width modulation (PWM) outputs, multiple analogue inputs and encoder interface capabilities. A simplified block diagram for a microcontroller is shown in Fig. 1.

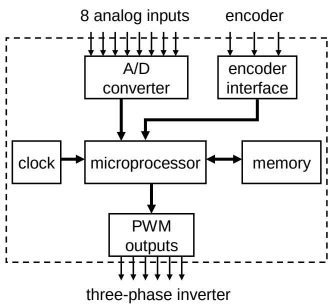

Fig. 1. Simplified block diagram of typical micro-controller designed for motor drive applications.

II. Digital Inputs and Outputs

Micro-controllers normally have a number of digital input/output (I/O) pins. Whether a particular I/O pin is acting as an input or output is set using a control register. For digital outputs, note that the output current capability is limited, for example the Microchip dsPIC30F series devices can sink about 8mA and source about 3mA [1].

A common task is to use a digital output to control an LED. As the digital outputs can sink more current than they can source, it is recommended to connect the LED between the +5V rail and the digital output. A current limiting resistor is essential. LEDs typically require about 5mA of current. Using a 5V rail, assuming a 1.7V drop across the LED and assuming the output has a voltage of say 0.5V when sinking 5mA, this gives a resistance value R of:

$$R = \frac{5 - 1.7 - 0.5}{5\text{mA}} = 560\Omega \qquad (1)$$

For digital inputs, micro-controllers offer a range of functionalities, including : generating an interrupt when the input changes (useful for Hall-effect position sensors); counting the number of rising edges of the input signal; and counting the number of clock cycles which occur when the input is high (useful for estimating the pulse width).

III. Pulse-Width Modulation Outputs

Micro-controllers usually have digital outputs which have a pulse-width modulation (PWM) capability. The state of these outputs are controlled by a counter (*count*) which is incremented at the *clock frequency* f_{CLOCK}. As shown in Fig. 2a, when *count* (dashed line) reaches the value given by the variable named *duty* the PWM output is set to zero. When *count* reaches a preset value *maxcount*, the PWM output is set to one and *count* is set to zero. This mode of operation results in a PWM switching frequency f_{PWM} given by (1) and an output duty-cycle d given by (2).

Micro-controllers for motor control normally have at least three PWM outputs, with independently controlled duty-cycles (e.g. *duty1*, *duty2* and *duty3* in Fig. 2b) but the same PWM switching frequency.

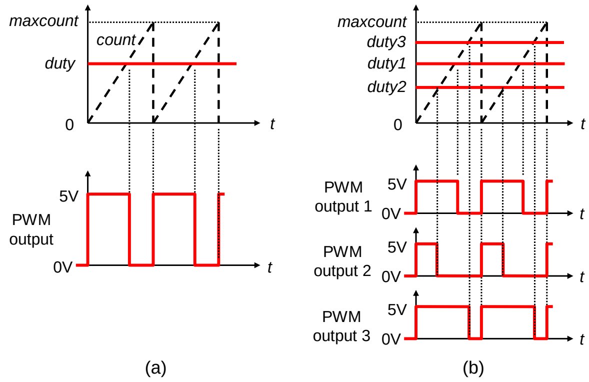

Fig. 2. (a) A PWM signal obtained by comparing a counter value with two reference levels, (b) a three-phase PWM output module.

$$f_{PWM} \approx \frac{f_{CLOCK}}{maxcount} \qquad (2)$$

$$d \approx \frac{duty}{maxcount} \qquad (3)$$

Example : the PWM counter is clocked at 8 MHz and *maxcount* = 256 and *duty* = 100. From (2), the PWM frequency = 8 MHz/256 = 31.3 kHz, and from (3) the duty-cycle = 100/256 = 39.1%. The duty-cycle resolution = 1/256 = 0.391%.

Caution : for the Microchip dsPIC30F series devices, due to the way the PWM operation is implemented, the duty-cycle is actually given by this formula,

$$d \approx \frac{1}{2}\frac{duty}{maxcount} \qquad (4)$$

Thus if *maxcount* = 100, then 100% duty cycle is achieved using a value of *duty* of 200.

IV. Analog Outputs

Most low-cost micro-controllers do not have analog outputs though if only a low bandwidth output is required, this can be synthesized by low-pass filtering a PWM output using a simple passive RC network.

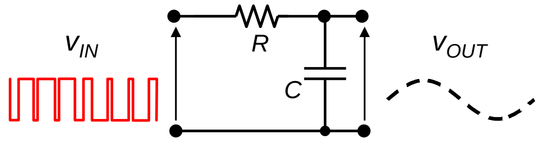

Fig. 3. Simulating an analog output by low-pass filtering a PWM output.

The low-pass filter reduces the amplitude of the PWM switching frequency component while allowing the lower frequency signal (fundamental) to pass through. With a resistance R and capacitance C, the filter will have an output

PWM switching frequency ripple component of peak-to-peak value Δv,

$$\frac{\Delta v}{V_S} \approx \frac{1}{4RCf_{PWM}} \tag{5}$$

where V_S is the peak value of the PWM output voltage (e.g. 5V) and f_{PWM} is the PWM switching frequency. In general, it is desirable to keep the ratio of the output ripple voltage to supply voltage the same as the duty-cycle resolution,

$$\frac{\Delta v}{V_S} \approx \frac{1}{maxcount} \tag{6}$$

combining (5), (6) and (2) gives,

$$RC \approx \frac{maxcount}{4\,f_{PWM}} = \frac{maxcount^2}{4\,f_{CLOCK}} \tag{7}$$

Example : It desired to produce an analog output for display on an oscilloscope. A clock frequency of 20MHz is being used. For an oscilloscope, the display resolution is limited and so a value of *maxcount* of a couple of hundred is reasonable. From (2) choosing *maxcount* = 200 gives a PWM switching frequency of 20MHz/200 = 100kHz. From (6) this gives $\Delta v/V_S = 1/200$ and from (5), gives $RC =$ 500µs, say $R = 4.7\text{k}\Omega$ and C = 100nF. Note the output cut-off frequency f_{LP} is given by,

$$f_{LP} = \frac{1}{2\pi RC} \tag{8}$$

which for this case is 320Hz.

It is also possible to produce an analog output for display on a multimeter. As the multimeter has a high display resolution, a value of *maxcount* in the thousands should be chosen. This results in a much lower output cut-off frequency but this is not an issue as the multimeter has a relatively slow update rate.

V. Analog Inputs

Micro-controllers often have a single analog-to-digital (A/D) converter with multiple inputs obtained by using a multiplexer (see Fig. 4). The A/D resolution is typically in the range from 8 to 14 bits and the conversion time is typically in the order of micro-seconds.

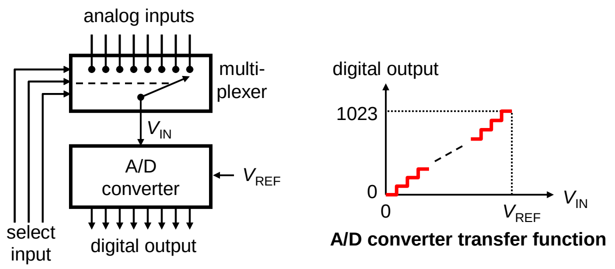

Fig. 4. Block diagram showing an A/D converter with an eight input multiplexer (left) and the transfer function for a 10-bit A/D converter (right).

The A/D converter has an allowable input range from 0 to the analogue reference voltage V_{REF}. A value of V_{REF} equal to the supply voltage is often chosen. For an n-bit A/D converter the digital output varies from 0 to ($2^n - 1$) where,

$$\text{A/D digital output} = \frac{V_{IN}}{V_{REF}}\;2^n - 1 \tag{9}$$

For example if V_{IN} = 2.3V, V_{REF} = 5V, n = 10 then the output value = 2.3V/5V x ($2^{10} - 1$) = 471. The input voltage resolution is V_{REF}/ ($2^{10} - 1$) = 4.89mV/bit.

In another example consider the above A/D converter used to measure the output of a Hall-effect current sensor which has an output of 1V/100A. As the A/D input range is 0 to 5V, this corresponds to a measured current range of 0 to 500A. Consider an input current of 435A, the current sensor output would be 4.35V, the A/D output is 4.35V/5V x ($2^{10} - 1$) = 890 and the input current resolution is 500A/1023 = 0.489A/bit.

Some Hall-effect current sensors are specially designed for use with micro-controllers and have an output voltage range of 0 to 5V where the output voltage is 2.5V with zero input current. This allows the micro-controller to measure both positive and negative currents.

VI. Optical Encoder Interface

To control a variable-speed motor drive, usually rotor position or speed information is required. This is often obtained by using either Hall-effect position sensors or an optical encoder. Hall-effect position sensors are generally used for low-cost permanent magnet (PM) motor drives while optical encoders are used for high performance PM or induction machine drives. Optical encoders are sometimes called incremental encoders or quadrature encoders.

The operating principle of an optical encoder is shown in Fig. 5. A disk with n holes is used to interrupt the light path between a light source and receiver and hence the receiver generates n pulses per revolution. Common encoders typically have between 100 to 2000 output pulses per revolution.

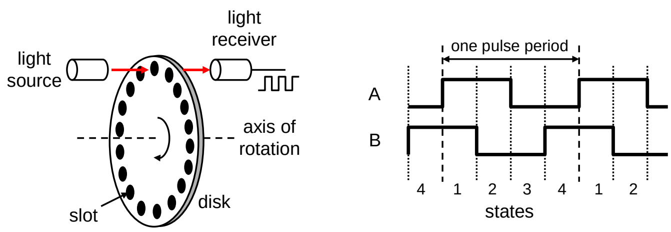

Fig. 5. Optical encoder : principle of operation (left) and example of two channel output signals showing four states per cycle (right).

Most encoders have two pairs of light sources/receivers which generate two sets of output pulses (two channels) which are phase shifted by 90°, that is, in quadrature (see Fig. 5). This has two benefits, firstly by comparing the two waveforms it is possible to distinguish four states per pulse period and hence the measurement resolution of the encoder is four times the number of pulses per revolution. For instance a 1000 pulse-per-revolution (PPR) encoder can distinguish 4000 angular positions per revolution. Secondly, from the order of the states it is possible to determine which direction the encoder is rotating and hence the position measurement will be correct even if the encoder changes direction.

Encoders generally have a third channel called the *index* which has a single pulse per revolution. This provides an absolute reference point for the encoder.

Micro-controllers generally have a hardware encoder interface which accepts the three encoder channel signals described above and "decodes" them to produce a count value which represents the angular position of the rotor. There are control registers associated with the encoder interface which allows configuration of the interface [2]. The instantaneous encoder position value can be read from the appropriate register.

VII. Conclusions

This brief has provided an overview of common micro-controller input/output interfaces used in motor drives. More detailed information can be obtained from the relevant micro-controller reference manuals.

VIII. References

[1] Microchip Corporation, "dsPIC30F3010-3011 Data Sheet," available at www.microchip.com, accessed May 2008.

[2] Microchip Corporation, "dsPIC30F Family Reference Manual," available at www.microchip.com, accessed May 2008.

A Word for Today

> *In the beginning God created the heavens and the earth. Now the earth was formless and empty, darkness was over the surface of the deep, and the Spirit of God was hovering over the waters. And God said, "Let there be light," and there was light.* Genesis 1:1-3 (NIV)