ELM404
Rotary Decoder - 3 wire 2x Interface

Description

The ELM404 is an 8 pin integrated circuit that is used to convert the output from a rotary encoder into three signals (chip select, clock and up/down) that can be used to control various devices. The low power CMOS technology used ensures that only a very small current is required over the entire 2.0 to 5.5 volt operating range.

There is no need for external filtering or debounce circuits with the ELM404, as this is all performed within the integrated circuit. After debouncing the encoder signals, the ELM404 determines the direction of shaft rotation, and then generates the appropriate outputs. The polarity of the clock output can be changed at any time to accommodate different needs.

The ELM404 provides 2x decoding of a rotary encoder signal. If your application requires 4x decoding, please see the ELM405 (it is identical to the ELM404 in every respect, except that it provides 4x decoding).

Applications

• Digital audio potentiometer controls
• Variable voltage or temperature circuits
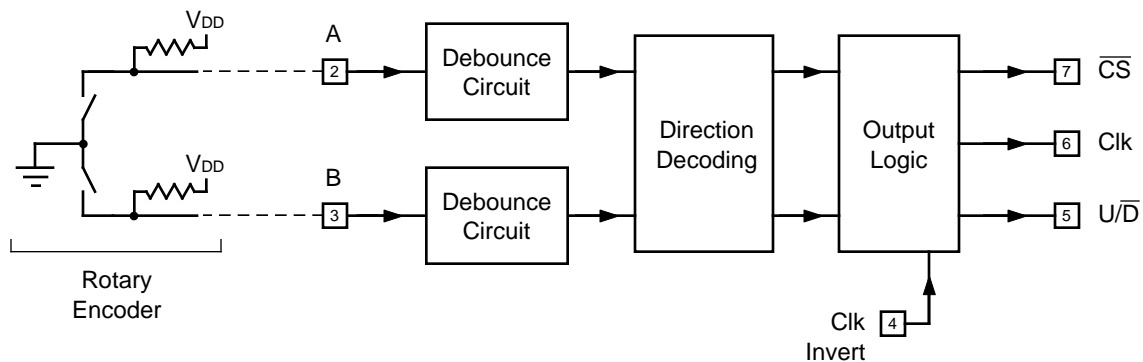• Positioning controls
• Tuning circuits

Features

• Low power CMOS design
• Wide supply range – 2.0 to 5.5 volts
• Complete debouncing of the encoder inputs
• No external filtering needed
• 2x decoding
• Startup delay timer
• High current drive outputs

Connection Diagram
PDIP and SOIC
(top view)
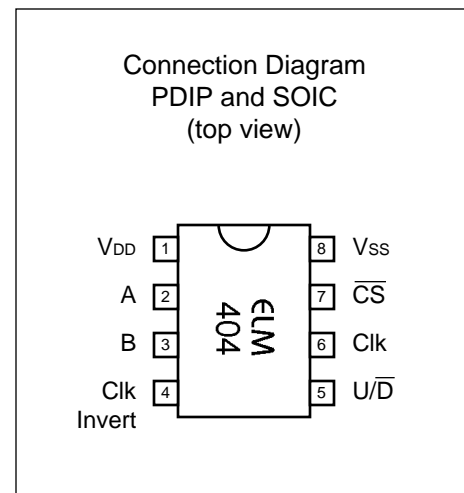
Block Diagram

Pin Descriptions

V_{DD} (pin 1)

This pin is the positive supply pin, and should always be the most positive point in the circuit. Internal circuitry connected to this pin is used to provide power on reset of the internal logic, so an external reset signal is not required. Refer to the Electrical Characteristics section for more information.

A (pin 2)

This input should be connected to what is normally known as the 'A' signal from a rotary (quadrature) encoder. The signal at this pin should lead (ie change state before) the signal at pin 3 when the device is being moved in a clockwise or up direction.

An external pullup resistor is required for the encoder (a typical value is 10 K), but no external capacitors are needed (as the internal debounce circuitry provides the filtering).

B (pin 3)

This input should be connected to what is normally known as the 'B' signal from a rotary (quadrature) encoder. The signal at this pin should lag behind (ie change state after) the signal at pin 2 when the device is being moved in a clockwise or up direction.

An external pullup resistor is required for the encoder (a typical value is 10 K), but no external capacitors are needed (as the internal debounce circuitry provides the filtering).

Clk Invert (pin 4)

This input controls the polarity of the pulse at pin 6. If pin 4 is at a low level, the Clk output will maintain a low quiescent level, with the pulses going to the V_{DD} level. If pin 4 is at a high level, then pin 6 will normally be at a high level, with pulses going low (to Vss). This input can be changed at any time.

U/$\overline{\text{D}}$ (pin 5)

This 'Up/Down' output changes with the direction of encoder rotation. For a clockwise movement (the A input appears first, followed by the B), this output will be set high before the $\overline{\text{CS}}$ output (pin 7) is switched low. For counter-clockwise movement, the output will be set low prior to the Chip Select going low. The U/$\overline{\text{D}}$ output does not change state when the $\overline{\text{CS}}$ and Clk pulsing is complete - it remains at the level it was just prior to the $\overline{\text{CS}}$ going low.

Clk (pin 6)

A 'Clock' pulse will be output at this pin 200 µsec after the Chip Select (pin 7) has gone low. The pulse is 200 µsec wide, and is typically used to cause the controlled device to change state based on the level at the U/$\overline{\text{D}}$ pin. The polarity of this output can be changed at any time by changing the logic level at pin 4.

$\overline{\text{CS}}$ (pin 7)

This output provides a 'Chip Select', or enable function. As the shaft rotates, a series of clock pulses are generated at pin 6. Just prior to these pulses appearing, the CS output will go low, and stay at that level until 200 µsec after the Clk pulse is complete. See the Output Waveforms section (on page 7) for more information.

V_{SS} (pin 8)

Circuit common is connected to this pin. This is the most negative point in the circuit.

Ordering Information

These integrated circuits are only available in either a 300 mil plastic DIP format, or in a 150 mil SOIC surface mount type of package. To order, add the appropriate suffix to the part number:

300 mil Plastic DIP.............................. ELM404P   150 mil SOIC.................................... ELM404SM

Outline Diagrams

The diagrams at the right show the two package styles that the ELM404 is available in. The first shows our ELM404P product, which is an ELM404 in a 300 mil DIP package. This is a standard through hole type dual inline package. The ELM404SM is our surface mount version of the ELM404. The device package has a 3.90 mm wide body, and is commonly called a 150 mil SOIC package.

The drawings shown here provide the basic dimensions for these ICs only. Please refer to the following Microchip Technology Inc. documentation for more detailed information:

• *Microchip Packaging Specification*, document name en012702.pdf (7.5MB). At the www.microchip.com home page, click on Packaging Specifications, or go to www.microchip.com/packaging

• *PIC12F508/509/16F505 Data Sheet*, document 41236E.pdf (1.5 MB). At the www.microchip.com home page, click on Data Sheets, then search for 12F508.

ELM404P

2.54
6.35
9.27
max
10.92

ELM404SM

1.27
3.90
4.90
6.00
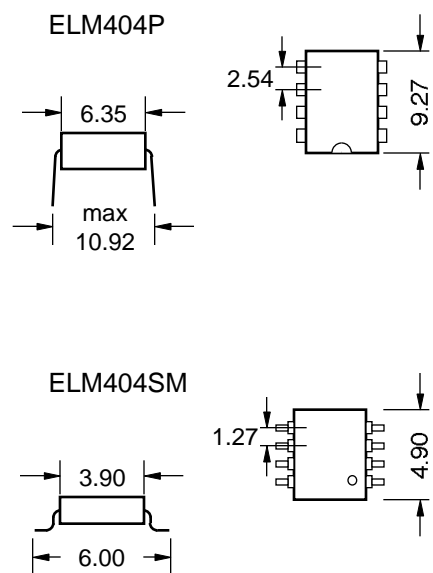
Note: all dimensions shown are in mm.

Absolute Maximum Ratings

Storage Temperature....................... -65°C to +150°C

Ambient Temperature with
Voltage Applied..................................-40°C to +85°C

Voltage on V$_{DD}$ with respect to V$_{SS}$............ 0 to +6.5V

Voltage on any other pin with
respect to V$_{SS}$........................... -0.3V to (V$_{DD}$ + 0.3V)

Note:

Stresses beyond those listed here will likely damage this device. These values are given as a design guideline only. The ability to operate to these levels is neither inferred nor recommended.

Electrical Characteristics

All values are for operation at 25°C and a 5V supply, unless otherwise noted. For further information, refer to note 1 below.

Characteristic		Minimum	Typical	Maximum	Units	Conditions
Supply voltage, V$_{DD}$		2.0	5.0	5.5	V	
V$_{DD}$ rate of rise		0.05			V/msec	see note 2
Power on reset time		9	18	30	msec	see note 3
Average supply current, I$_{DD}$			0.6	1.1	mA	V$_{DD}$ = 5.0V
			0.2	0.3	mA	V$_{DD}$ = 2.0V
Output low current (sink)	V$_{DD}$ = 5.0V		10		mA	V$_{OL}$ = 0.25V
	V$_{DD}$ = 3.0V		5.0		mA	V$_{OL}$ = 0.25V
Output high current (source)	V$_{DD}$ = 5.0V		2.5		mA	V$_{OH}$ = 4.75V
	V$_{DD}$ = 3.0V		1.7		mA	V$_{OH}$ = 2.75V
Debounce period			5.5		msec	see note 4
Startup time delay			50		msec	
Internal timing variation			1	4	%	see note 5

Notes:

1. This integrated circuit is based on a Microchip Technology Inc. PIC12F5XX device. For more detailed specifications, please refer to the Microchip documentation (www.microchip.com).

2. This spec must be met in order to ensure that a correct power on reset occurs. It is quite easily achieved using most common types of supplies, but may be violated if one uses a slowly varying supply voltage, as may be obtained through direct connection to solar cells, or some charge pump circuits.

3. The internal reset circuitry stops the ELM404 from doing anything during this period, so that the power supplies and oscillators have time to stabilize. During this time, all pins behave like inputs.

4. Typical only - the actual period varies with the amount of noise present in the input signal.

5. All filtering, delay, and output timing is based on an internal master oscillator. The frequency of this oscillator will vary with voltage and temperature. Values shown are typical maximums for 2.0V V$_{DD}$ 5.5V, and temperatures of -40°C to +85°C

Rotary Encoders

A rotary encoder (sometimes referred to as a quadrature encoder) is a device that produces digital (on/off) outputs in response to rotary, or circular, motion. It is often constructed such that it looks very much like a potentiometer, or audio volume control (see the picture of a typical device, at the right).

As the encoder shaft is turned, internal contacts open and close, creating two waveforms that are ideally separated in phase by 90 degrees (ie 'in quadrature'). Actually, you need to provide external 'pullup' resistors and a power supply to create these waveforms, as the contacts themselves can not do this. An ideal waveform from a rotary encoder would look like this:
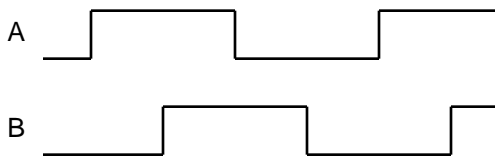

A typical rotary encoder

Figure 1. Quadrature Waveforms

Due to the 90 degree phase difference, when one waveform changes, the other is always stable. By noting the direction of the change and the level of the other input at that time, you can determine the direction of motion of the shaft.

Rotary encoders are not ideal, however. Due to their construction, and variations in shaft speed, the waveforms are not perfectly square with the 50% duty cycles shown. Figure 2 shows a captured trace from a real rotary encoder that is more representative of what you will typically find. Note that the two 'scope channels (1 and 2) represent the encoder outputs A and B, respectively. The ch 1 (A) waveform leads the ch 2 (B) waveform, which usually means that the shaft is turning in a clockwise direction.

The first rising edge of the channel 2 waveform shows another problem that occurs with moving mechanical contacts - multiple pulses due to bounce. When two contacts meet, the moving one will tend to bounce, like a ball does when it is dropped on the floor. Each bounce results in an electrical connection being made, then broken, which will look like multiple inputs to a fast electronic circuit. Various mechanical means are used to reduce the amount of bounce, but it can never really be eliminated. The following section discusses how the ELM404 uses electronic means to remove the bounce.
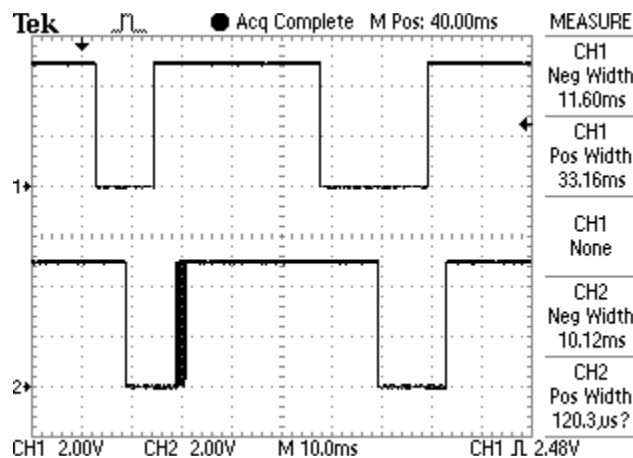

Figure 2. Actual Rotary Encoder waveform

Debouncing Circuits

Any time that two metal surfaces meet, as they do inside a rotary encoder, there will be a tendency for the moving one to bounce, which causes the electrical connection to make and break. The duration of this bouncing action may be very short, but it is usually fast enough to cause multiple counts to be recorded by connected electronic circuits. As the number of bounces can not be predicted, a means of removing them is necessary. Circuits that remove the bounce are usually called 'debouncing' circuits.

Many debouncing circuits employ a simple timer to determine if an input is stable. This generally works well if the two contacts meet and then remain still. With a rotary encoder however, one of the contacts meets the other then usually continues sliding over the surface of the stationary contact. This will produce noise while the contact is sliding, occasionally enough to make it look like there are more inputs.

The ELM404 employs a two stage system to remove the bounce and the sliding noise from the input signal. A block diagram of the stages are shown in figure 3. The first stage is a digital filter circuit that is used to determine the average value of the waveform over a time. If a long enough time is chosen, short duration pulses will have little effect on the overall average. If the time chosen is too long, however, the

circuit will be slow to respond, and may in fact average out some legitimate inputs. Choosing the time period (or time constant of the circuit) is thus very important in determining how effective the filtering function will be. We have found that with typical rotary encoder specifications (usually 3.0 msec of bounce or noise, maximum), the ELM404 debounce circuit works quite well.

After the signal has been filtered, it is compared to some reference levels, and the output of these comparators are used to control a simple timer. The timer is used to ensure that the output of the filter is stable, and not just a momentary transient, while the use of two comparator levels provides hysteresis, so that some variation in the filter output can be tolerated.

Once the signals from the rotary encoder have been debounced, they may be used by the direction logic circuitry. The following section shows what the ELM404 is able to produce from these signals.
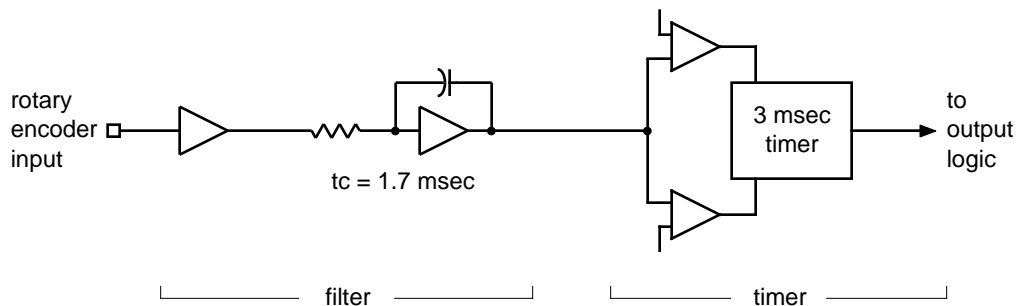

rotary encoder input

tc = 1.7 msec

3 msec timer

to output logic

filter   timer

Figure 3. Internal Debouncing Logic

Output Waveforms

Once the ELM404 has some bounce-free signals to work with, it can generate outputs based on them.

The logic to decode the motion of an encoder shaft is not as simple as it would first appear. Some authorities recommend simply monitoring an input and when it changes, provide an output based on the level of the other input. This does not always work, as the encoder can output multiple signals from only the 'A' or or only the 'B' contact if the shaft is moved ever so slightly when at the detent or at the mid-point position (between detents). Simply seeing one input change is not sufficient to say that there is any significant shaft rotation.

The ELM404 monitors both 'A' and 'B' transitions, and determines the outputs based on the sequence in which the transitions have occurred. This is a better way to guarantee that the output signals are generated properly. The internal logic also performs some self-checking, and monitors for problems such as an output pulse being initiated before the previous one had completed, which might occur for some very fast inputs (the second one will be ignored in this case).

The output of the ELM404 is a series of pulses, as shown in Figure 4 (representative pulses are enlarged and shown in Figures 5 and 6). When the encoder is moving in a clockwise direction, the pulses will be generated with the U/$\overline{\text{D}}$ output at a high level, while a counter-clockwise rotation of the shaft results in pulses

generated with the U/$\overline{\text{D}}$ output at a low level. The direction assumes that the encoder is a standard one, where the 'A' signal leads the 'B' for a clockwise rotation. Note that an Up output is always a result of a change in A followed by a change in B, while the Down output is from a change in B followed by a change in A. Figure 4 also shows what happens when the rotary encoder shaft is 'wiggled', generating pulses on only the A or only the B input - the logic detects this and ignores them. In order for an output to be generated, the ELM404 must see a change on one of the rotary encoder inputs followed by a change on the other input.

Note that the ELM404 uses what is known as 2x decoding of the signals. This means that for each motion of the shaft between the detents, when the 'A' and 'B' outputs go through one complete cycle, there will be two output signals. The other type of decoder that is very common is the 4x decoder, as used by the ELM405. We do not currently offer a product for 1x decoding - if you require that, you will need to use the ELM401 and decode the signal with your own logic.
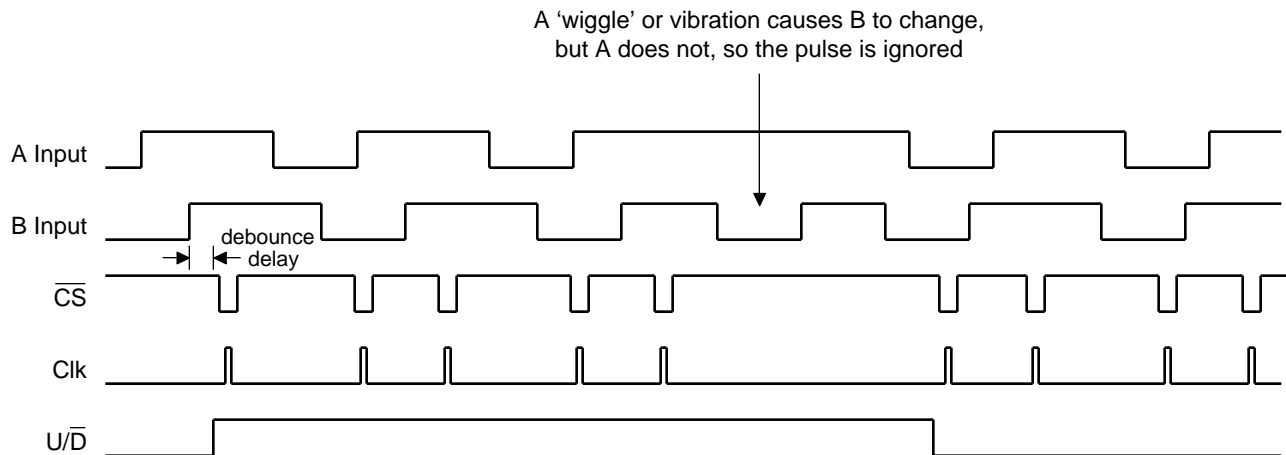

A 'wiggle' or vibration causes B to change, but A does not, so the pulse is ignored

Figure 4. Output signals (pin 4 = 0V)
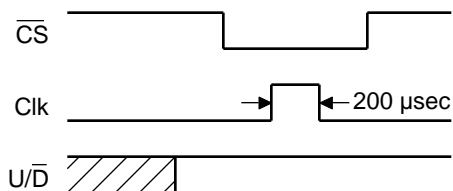
Output Waveforms (continued)
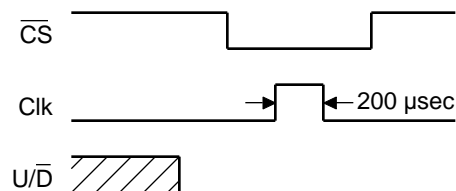

Figure 5. Up or Clockwise Output

Figure 6. Down or Counter-clockwise Output

Design Considerations

There are a few details to consider when using the ELM404 to interface to a rotary encoder. The first is the fact that the signals available from the encoder are usually only dry contacts closing and opening. You will need to provide pullup resistors for these signals in order to use them in a circuit.

The size of the pullup resistor is chosen based on the encoder specifications. The main concern is the maximum current carrying capacity, which sets a lower limit for the pullup resistance. An upper limit for the resistance is set by the minimum current required for contact wetting. If you do not provide enough current through mechanical contacts when they are closed, they will tend to go open with time. A maximum current specification is usually in the range of 1 to 10 mA, while the minimum wetting current would be in the range of 1 mA. This means that with a 5V supply, a pullup resistor of 5 to 10 KΩ is typically required.

The second concern is the use of capacitors on the 'A' and 'B' signal lines. Many encoder circuits show these as a way to provide some pre-filtering of the signal. That is fine, as long as you realize that the ELM404 inputs are CMOS and do not have Schmitt trigger waveshaping. This means that you should keep the rate of change of the input signal as high as possible to avoid problems (we usually try to maintain at least 1V/µsec). Typically, with a 5V supply, a 10 KΩ pullup, and TTL thresholds, this means capacitor values of no more than about 330 pF, while with a 2.0V supply, the limit would be about 100 pF.

One other issue to consider is that during the initial circuit startup, there is a period (of about 20 msec) when the ELM404 is being held in a reset state, and the outputs are in a tristate condition. During this time, the outputs will sit at the level they were at before power up (0V) due to stray capacitance having discharged through the protection diodes. Since the $\overline{CS}$ (Chip Select) is an active low output, this may cause a problem, if your controlled circuit is ready too fast. If you require that pin 7 (and possibly pin 6) go high as quickly as possible, you may want to install a pullup resistor (of about 10 KΩ) on the output(s) to ensure that the voltage rises quickly to V$_{DD}$.

After the initial 20 msec period, the ELM404 sets all pins to their quiescent levels, but does not change any outputs for an additional 50 msec. This ensures that the external circuits have had adequate time to initialize, before being presented with signals to process.

Example Application

Figure 7 below shows how the ELM404 might be used with a digital potentiometer (in this case, an AD5220 from Analog Devices).

Pullup resistors of 10 K are used with the rotary encoder to provide voltages for the A and B inputs. Power for the ELM404 and the AD5220 has been supplied from a common source (it must be between 2.7V and 5.5V for the AD5220), and a small capacitor has been added to ensure that the supply is filtered. Note that the output lines are directly connected to the AD5220 inputs, but we have added a 10 k pullup resistor on the $\overline{CS}$ line, to ensure that it rises rapidly to the V_{DD} level as quickly as possible after power up. This may not be absolutely necessary in this case (as

the AD5220 setting only changes on the falling edge of the clock signal), but it does not hurt to add it.

That's about all there is to using the ELM404. Connect pullup resistors to your rotary encoder, connect the encoder signals to the ELM404, then connect the ELM404 to the controlled circuit. Use a common supply for all the devices, and add a small bypass capacitor across the supply line. The controlled devices can be digital pots, microprocessors, or almost any circuit that will accept CMOS signals. Enjoy!

Figure 7. Connecting the ELM404 to an AD5220