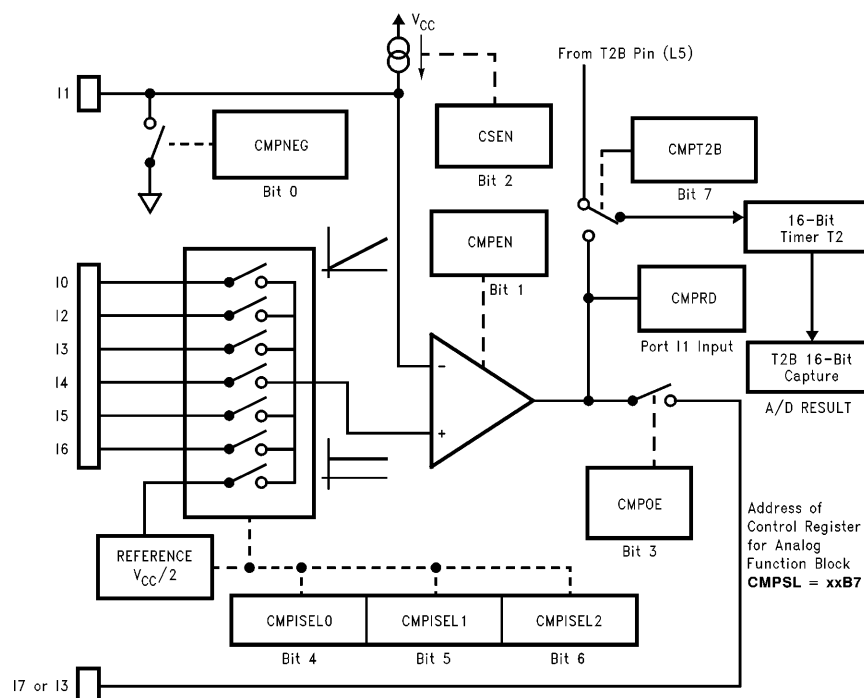


## Simple, Cost Effective A/D Conversion Using COP8888EK

## AN-983

- 256 bytes of on-board RAM
- Multi-Input Wakeup (8 pins) optionally usable as hardware interrupts with programmable transition
- Three 16-bit timers with two I/O pins assigned and two 16-bit autoreload/capture registers supporting:
  - Processor independent PWM mode
  - External Event counter mode
  - Input Capture mode
- Quiet design (low radiated emissions)
- WATCHDOG™/Clock monitor and Idle Timer
- Two power saving modes, HALT and IDLE
- Twelve multi-source vectored interrupts
- Software selectable I/O options
- Packages:
  - 28 SO or DIP with 23 I/O's each
  - 40 DIP with 35 I/O's
  - 44 PLCC with 39 I/O's

- Analog Function Block composed of a multiplexer with a total of 6 external analog inputs, a constant current source, an analog comparator, a software selectable  $V_{CC}/2$  reference and a dedicated 16-bit timer/16-bit capture register pair (see below).
- MICROWIRE/PLUS™ serial port with interrupt.
- 8 kbytes of on-board ROM



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## THE ANALOG FUNCTION BLOCK

The analog function block allows single slope (integration) type of A/D conversion on 6 analog multiplexed input pins. With this alternate function on the 8-bit I-port (which is an "input only" port in other devices) this derivative received a powerful enhancement.

Figure 1 illustrates the principles of the whole block. One of the six I-pins (I0, I2, . . . , I6) or an internally available  $V_{CC}/2$  reference can be multiplexed onto the positive terminal of an internal analog comparator. A ramp can be fed to the negative comparator terminal by simply applying a capacitor on pin I1 and initializing the on-chip constant current source. The 16-bit "T2B" capture register completes the analog function block and will be directly triggered from the output of the on-chip comparator. T2B is one of the two 16-bit autoreload/capture registers assigned to Timer 2.

## A/D CONSIDERATIONS

Single slope (integration) A/D converters have sources of inaccuracy affecting the quality of the digital result of the conversion. In addition, this serial approach is slower than successive approximation type A/D's and can not be applied in cases where fast conversion is required. The following considerations may help the user to judge if this technique is adequate for the particular A/D conversion task(s) the microcontroller has to perform.

A resolution of 11 bits can be established with a CKI frequency of 2 MHz and a 66 nF capacitor. The linearity of the ramp is dependent on the constant current source, the common mode range of the comparator and the type of capacitor. The optimum linearity can be obtained if the voltage level on the selected input channel does not exceed a maximum of  $V_{CC} - 1.5V$ . Therefore it may be necessary to attenuate the input levels as shown in Figure 2. In order to maximize the accuracy of the A/D conversion there are some guidelines the user should follow:

- An accurate reference is required. This can be a fixed reference (for example a reference diode) directly applied to one of the analog inputs. In many applications there is an EEPROM present which could hold a digital reference "burned in" during the manufacturing process. This can eliminate the need for an accurate and expensive crystal oscillator and a much cheaper RC clock can be used instead.
- The user should limit the levels at the analog inputs to values less than or equal to  $V_{CC} - 1.5V$ .
- Relating all measurements to the on-chip  $V_{CC}/2$  reference will help to compensate for temperature variations.
- Capacitors with values higher than 100 nF may not be useful because of decreasing linearity. For values higher than 33 nF, it is recommended to use styroflex capacitors or similar quality.

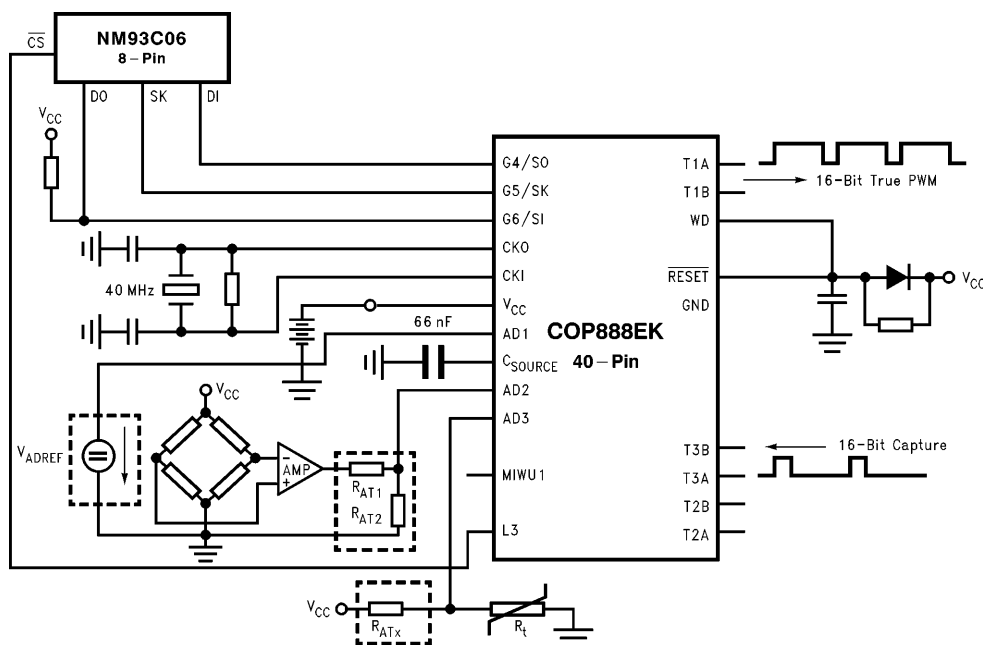


FIGURE 2. COP888EK with Strain Gauge Transducer

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The constant current delivered from the on-chip current source can vary in the range of 10  $\mu$ A–30  $\mu$ A. To calculate the minimum resolution, the following equation can be used:

$$X_{RES} = \frac{C \cdot dV}{I_{MAX} \cdot t_c}$$

with:

C = Value of capacitance in [nF]  
dV = Range of channel input voltage in [V]  
I<sub>MAX</sub> = Max. current delivered from current source [ $\mu$ A]  
t<sub>c</sub> = Instruction cycle rate of microcontroller [10/CKI]  
X<sub>RES</sub> = Resolution of Digital value (found in T2B).

#### APPLICATIONS EXAMPLES

Frequently used sensors in industrial and consumer applications are “NTC’s” and strain gauge transducers. *Figure 2* shows a configuration with both types connected. Using the above equation, the minimum resolution at 2 MHz CKI clock input and a 66 nF capacitor, is 10-bits with an input signal varying between 0V and 3V and a V<sub>CC</sub> voltage of 5V. The typical resolution with these parameters is more than 11-bit and the achievable accuracy is already better than the accuracy of an 8-bit successive approximation type of A/D converter. Doubling the CKI frequency will increase the resolution by 1-bit. A typical software initialization sequence for an A/D conversion (measuring the on-chip V<sub>CC</sub>/2 ref) looks as follows:

```

RESET:
    .
    .
    .

CONVERT:
    LD  CMPSL, #b'11110011  discharge Capacitor connected
                             to 'Csource' (I1); enable Comp.,
                             select timer 'T2B' input to be
                             driven from comparator output;
                             connect internal Vcc/2 ref. as a
                             positive input to the comparator;
                             disable constant current source.

    DELAY:
        NOP                  give time to discharge the
        NOP                  capacitor.
        .
        .

    LD  TMR2LO, #0FF         Preset Timer T2
    LD  TMR2HI, #0FF         with #0FFFF, initialize capture
    LD  T2CNTRL, #0E0        mode and start timer.

    LD  CMPSL, #b'11110110  enable constant current source
                             and start charging the capacitor
                             on I1.

    ADFIN:
        IFBIT 1, T2CNTRL     Testloop to check if T2B pending
        JP     DONE          flag is set. If this flag is set then
        JP     ADFIN         the A/D conversion is done. The
                             result can be picked up from the
                             T2B capture register.
    .
    .
    .

```

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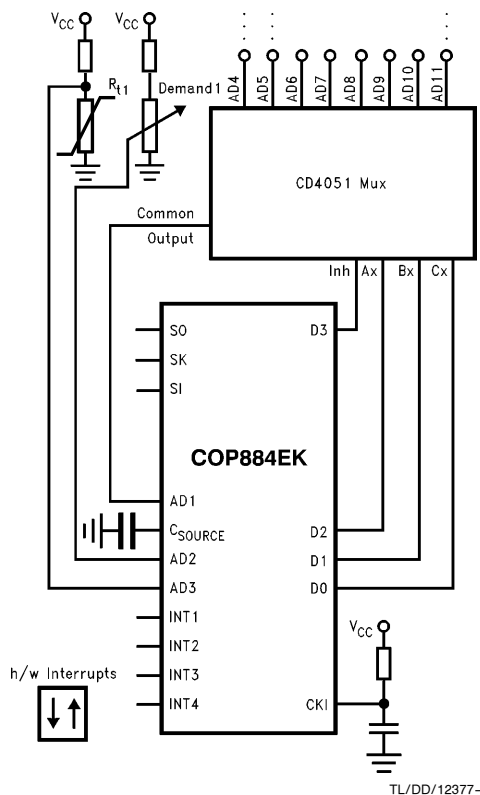
Similarly, the other (external) sources can be measured by appropriately setting bits 4, 5 and 6 in the **CMPSL** register, discharging the capacitor, setting the timer, and charging the capacitor.

#### A/D CONVERSION TIME

The minimum specified constant current fed into the capacitor connected to pin C<sub>SOURCE</sub> (I1) is 10  $\mu$ A and causes the longest possible conversion time. With the values given, the X<sub>RESmax</sub> = 3960 counts. A 2 MHz crystal will yield a t<sub>c</sub>-cycle of 5  $\mu$ s in a COP800 microcontroller. This means the conversion time to measure one channel is maximum:

$$T = 3960 \times 5 \mu s = 18.8 \text{ ms}$$

To ensure secure and stable measurements however it is recommended to do a minimum of 2 or 3 conversions on a particular input channel and compare subsequent results with each other. Taking the worst case with 3 A/D-cycles plus additional 3 cycles measuring the internal V<sub>CC</sub>/2 reference will result in a total conversion time of 6  $\times$  18.8 ms which gives 113 ms. The processing time to find the final digital value representing the analog level at the A/D channel will not contribute a significant period of time so that a total conversion time of 120 ms is a reasonable assumption for a worst case scenario. Likewise the total conversion time will be half with a CKI frequency of 4 MHz and a capacitance at pin C<sub>SOURCE</sub> equal to half the original value.



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FIGURE 3. Expansion of A/D Channels

## EXPANDING THE NUMBER OF A/D CHANNELS

Figure 3 shows an inexpensive way to establish additional A/D channels by using a CD4051 analog multiplexer. The COP884EK is a 28-pin version of the COP888EK and provides 3 analog inputs. One input must be used to connect the common output of the external mux which carries the channel selected via the pins (Ax, Bx, Cx). An additional control pin is required to enable the desired channel. The whole setup is capable of handling a total of 10 A/D channels. In many automotive and industrial applications, a controller has to scan temperature sensors, monitor fluid-levels and measure pots which hold "demand-values" for open- or closed-loop control systems. In these applications, timing is typically not a critical requirement. Also, the internal  $V_{CC}/2$  reference is most likely adequate to gain sufficient accuracy.

**TABLE I. Resolution and Accuracy vs dV and CKI**

	Ex1	Ex2	Ex3	Ex4	Ex5
$V_{CC}[V]$	5	5	5	5	3
$dV[V]$	3	3	3	3	1.8
$CKI[MHz]$	1	2	4	5	2
$t_c[\mu s]$	10	5	2.5	2	5
$X_{RESmin}$	8-bit	9-bit	11-bit	12-bit	9-bit
$X_{RES}typ$	> 9-bit	> 10-bit	> 12-bit	14-bit	> 10
Acc	6-bit	7-bit	8-bit	> 9-bit	7-bit
C[nF]	33	33	66	100	66

Table I shows some examples of achievable minimum resolution (row:  $X_{RESmin}$ ) and accuracy (row: Acc) dependent on the  $V_{CC}$  voltage, the CKI frequency and the capacitor value (connected to pin I1).

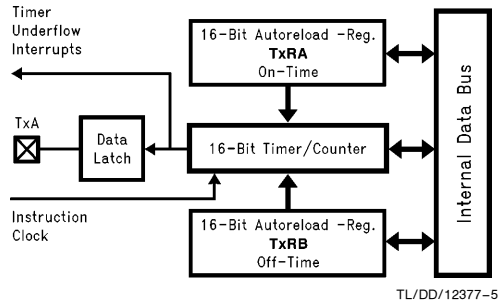
## OTHER FEATURES

### I. Timers

The COP888EK has three 16-bit timers with two I/O pins assigned and two autoreload/capture registers associated with each.

Figure 4 shows one of the timers configured for PWM mode. The contents of the 2 autoreload registers are copied alternately into the 16-bit timer (upon underflow) one holding the high time and the other holding the low time of the pulses presented to the Timer I/O pin TxA (with  $x = 1, 2$  or 3), thus being able to establish duty-cycles from 1/65535 to 65535/1.

In capture mode both I/O's assigned to a timer can be incorporated into time or frequency measurements. Inputs on TxA trigger measurements in capture register TxRA and inputs to pin TxB trigger measurements in capture register TxRB.



**FIGURE 4. Timer in PWM-Mode**

Thereby all possible combinations of transitions can be programmed.

There are many interrupt sources associated with all timer modes such as timer underflow, autoreloads on TxRA and TxRB and positive or negative transitions on the timer pins TxA and TxB thus allowing a very flexible use.

In addition, there is the free running 16-bit timer T0 that can be used for time base and to establish the low current idle-mode.

### II. Low EMI and Low Current Oscillator

Low radiated emissions are achieved by gradual turn-on output drivers and internal  $I_{CC}$  filters on the chip logic and crystal oscillator. All precautions taken lowered the radiated noise by about 20 dB compared to older COP888 family devices.

### III. Multi-Input Wakeup/Hardware Interrupts

The 8 pins of the 8-bit L-port can alternately be configured as wakeup inputs. The trigger condition can be either programmed on the "high to low" or "low to high" transition. The Multi-Input Wake-up can be used with the power saving Halt- (with Halt currents less than 10  $\mu A$ ) or Idle mode, to wakeup the device via one of the eight wakeup pins. Alternately these pins can serve as additional hardware interrupts with programmable transition polarity.

## CONCLUSIONS

- With the performance and the combination of functions provided (low EMI, multi-channel high resolution A/D, powerful timer structure ...) the COP888EK is ideally suited for many applications in automotive and industrial/consumer markets.
- The analog function block can be configured to perform integration type A/D conversions with resolutions of up to 14 bits and achievable accuracies significantly better than the 8-bit approximation type deliver.
- The strengths of the COP888EK can be supplemented from National's NeuFuz4™ development environment which supports the generation of intelligent control algorithms for open- and closed loop control systems delivering the final COP8 assembler code as a result.





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