

Economic Measurement Techniques With the Comparator_A Module

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ABSTRACT

This report describes the methods for comparing input signals, and measuring voltage, current, capacitance, and resistance using the Comparator_A module of the MSP430 family. Two measurement principles (charge and discharge) are explained, and schematics and equations are given for different measurement principles.

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1 The Comparator_A

Comparator_A is a module contained in some members of the MSP430x1xx family. It is designed for precise analog measurements. Figure 1 shows the versatile hardware of the module.

1.1 Comparator_A Attributes and Functions

Some of the most important attributes of the Comparator_A module are:

- Very low input current at the comparator inputs CA0 and CA1
- It can be switched off to minimize current consumption (control bit CAON)
- It is controlled by three memory-mapped control bytes (see Section 1.2)
- Stability with slow-changing input voltages (control bit CAF) can be provided by switching of an analog filter to the comparator output.
- Interrupt capability for the leading and trailing edges of the output signal CAOUT. Use without interrupt is also possible.

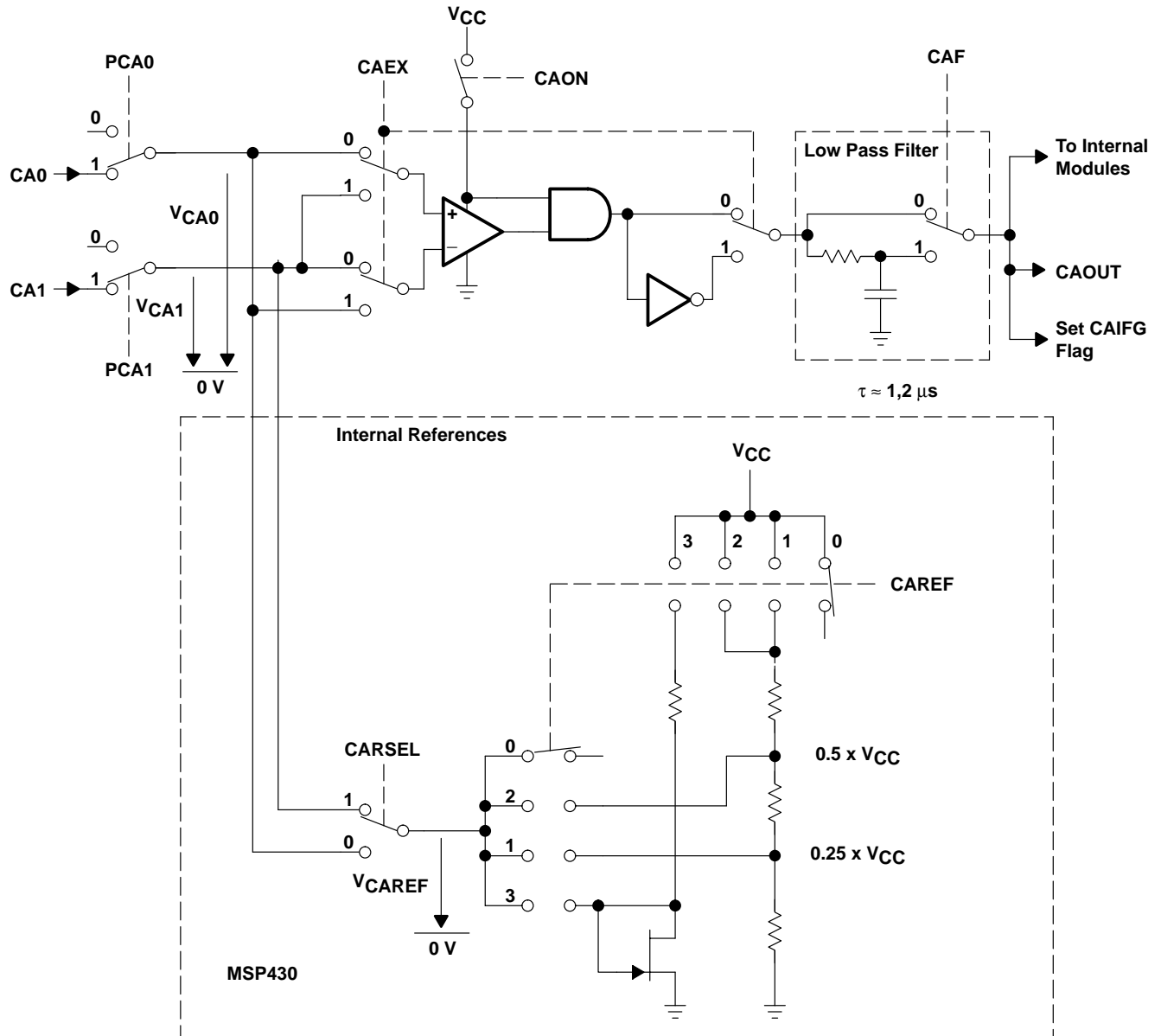


Figure 1. Comparator_A Hardware

Bit CAOUT contains the result of the comparison. The following are the comparison combinations allowed by the hardware:

- Comparison of two external inputs
- Comparison of each external input with $0.25 \times V_{CC}$, or $0.5 \times V_{CC}$
- Comparison of each external input with an internal-reference voltage

Additional functions performed by Comparator_A are:

- The internal reference voltages can be output to comparator input pins CA0 and CA1 for use by external hardware (see Section 2.8.2).
- A register allows switching off the port 2 input buffers, which are used for analog purposes. This removes current into the input buffers caused by input voltages that differ from V_{CC} or V_{SS} .

- The input change-over switch CAEX allows offset-free measurements. The same software can be used for both states of CAEX due to the inversion of the comparator output signal.

The above attributes allow simple voltage, current, resistor, and capacity measurements.

The main function of Comparator_A is to indicate which one of the two voltages, V_{CA0} or V_{CA1} , is higher. The output CAOUT is set accordingly:

$$\text{If } V_{CA0} > V_{CA1} \text{ then: } CAOUT = 1 \text{ else: } CAOUT = 0$$

The two voltages V_{CA0} and V_{CA1} can be external or internal reference voltages. Any combination is possible (see Figure 1).

1.2 The Control Registers

The two control registers, CACTL1 and CACTL2, contain all the control bits necessary to use Comparator_A. See Figure 1 for the function of the control bits.

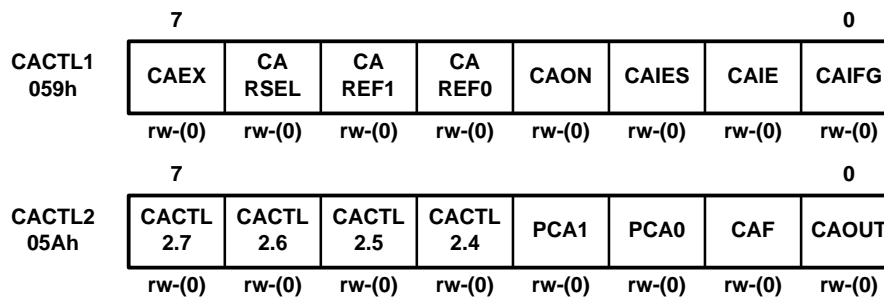


Figure 2. Comparator_A Control Registers

The functions of the Comparator_A control bits, not shown in Figure 1, are:

CAIFG	Interrupt flag	0: No interrupt pending 1: Interrupt pending
CAIE	Interrupt enable flag	0: Interrupt disabled 1: Interrupt enabled
CAIES	Interrupt edge select bit	0: Leading edge of CAOUT sets CAIFG 1: Trailing edge of CAOUT sets CAIFG
CACTL2.x:		Bits are implemented but do not control any hardware. They can be used for flags.

2 Applications

The following sections present some Comparator_A applications. In addition, the Comparator_A hardware allows all applications presented in the *MSP430 Application Report Book* to be used with the Universal Timer/Port. One of the 16-bit capture/compare registers of Timer_A is used in place of the two 8-bit counters of the Universal Timer/Port.

NOTE: The hardware and Timer_A configuration of the MSP430F1121 are used in the application examples. Other MSP430 family members may have slightly-different hardware (ports and Timer_A).

2.1 Comparison of Two Voltages

The simplest Comparator_A application is the comparison of two external voltages. Neither internal reference voltage nor Timer_A are necessary. Figure 3 shows the comparison of a divided input voltage V_{IN0} with the output voltage V_{IN1} of an op amp (amplifier, Schmitt trigger, comparator, and sensor bridge amplifier). It is not necessary to change the comparator setting during the measurement since internal reference voltages are not used. The value of the signal CAOUT at the comparator output is:

$$\text{If } V_{IN0} \times \frac{R2}{R1 + R2} > V_{IN1} \text{ then: CAOUT} = 1; \text{ else CAOUT} = 0$$

Because the output filter is switched on (CAF = 1), any change in the comparator output is delayed by approximately 1.2 μs .

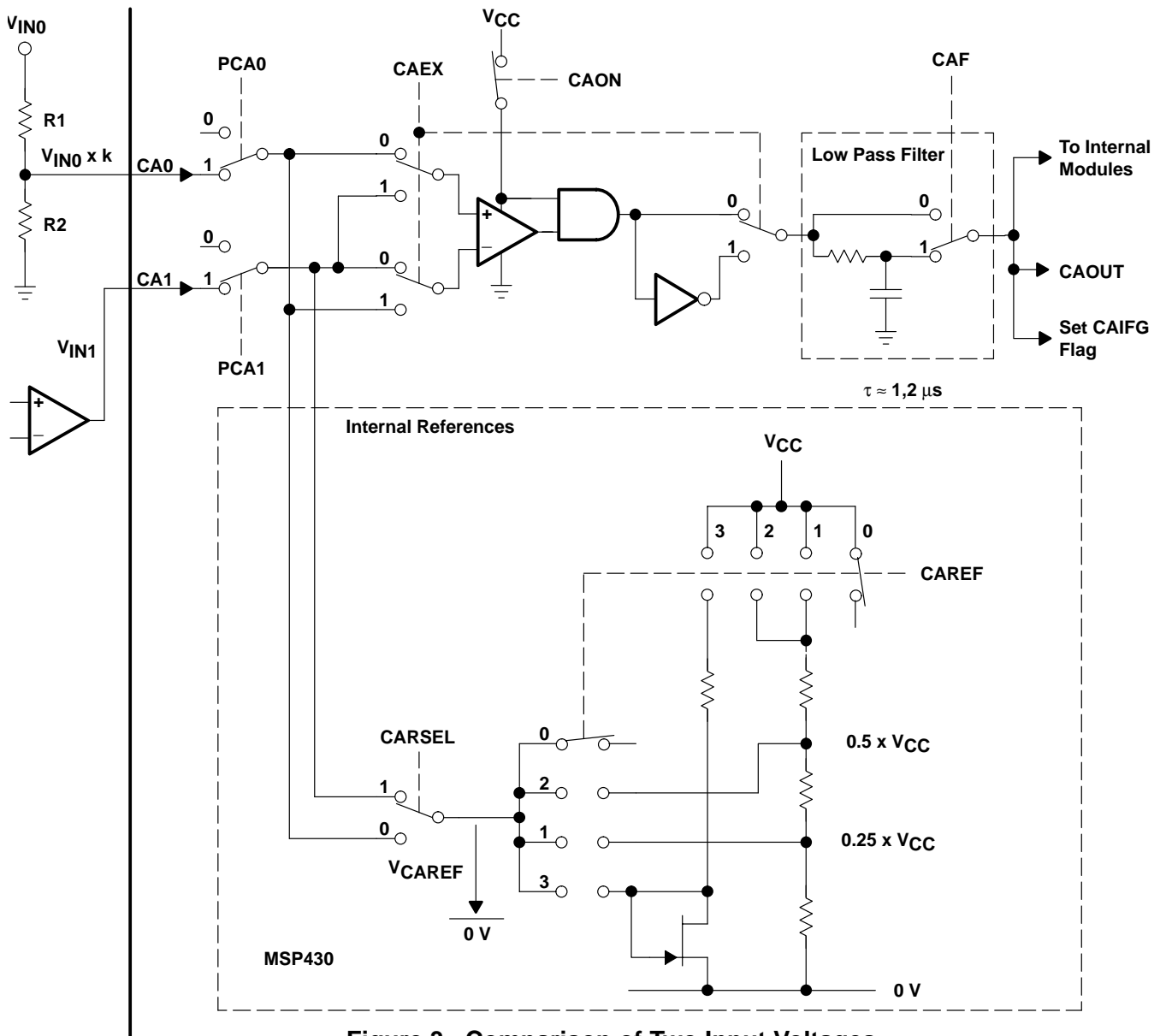


Figure 3. Comparison of Two Input Voltages

The following software example shows initialization and a test of comparator input voltages to determine which is higher. Figure 3 shows the hardware.

```

; Initialize Comparator_A for the input voltage test
;
    MOV.B #CAON,&CACTL1          ; Define Comp_A mode
    MOV.B #PCA1+PCA0+CAF,&CACTL2 ; Connect CA0 and CA1
    ...                          ; Proceed with initialization
;
; Compare the two input voltages VIN0*k and VIN1. k=R2/(R1+R2)
;
    BIT.B #CAOUT,&CACTL2        ; VIN0*k > VIN1?
    JNZ   V0GTV1                ; Yes
    ...                          ; No, VIN0*k < VIN1

```

Figure 4 shows other possibilities for the two input voltages. Four input voltages V_{IN00} to V_{IN03} , selected by an analog multiplexer, are compared with an external programmable-reference voltage. The reference voltage can be switched off for lower current consumption using port P1.2. The output signal at CAOUT is:

$$\text{If } V_{IN0x} > V_{TLV431} \times \frac{R3 + R4}{R4} \text{ then: } CAOUT = 1; \text{ else } CAOUT = 0$$

Where V_{IN0x} is the particular input voltage selected from the range V_{IN00} to V_{IN03} .

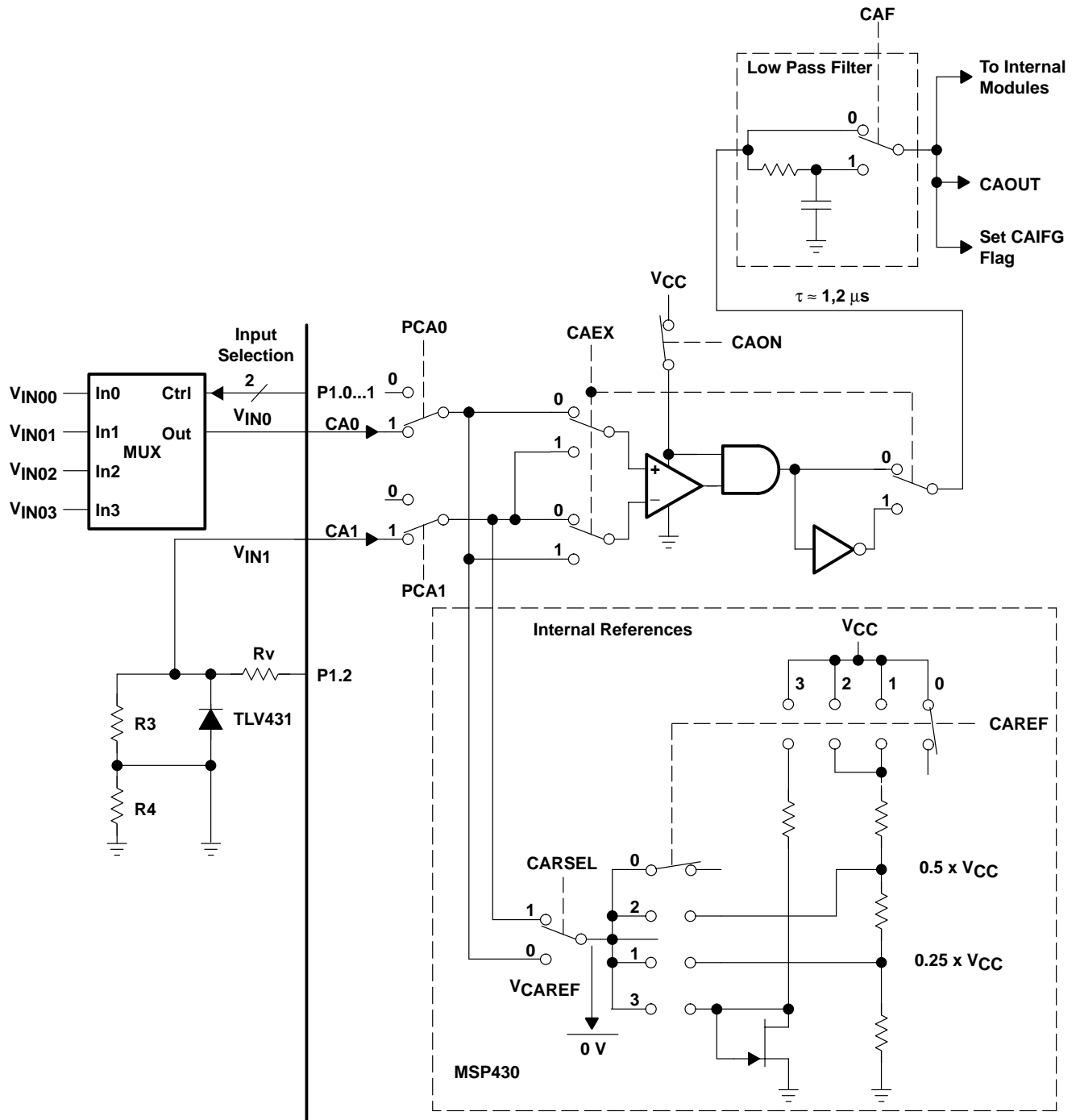


Figure 4. Variation for the Comparison of Two External Voltages

The following software example includes initialization and a test to determine which of the voltages V_{IN02} or reference voltage V_{IN1} is higher. Figure 4 shows the hardware.

```

; Initialize Comparator_A for the input voltage test
;
MOV.B #CAON,&CACTL1           ; Define Comp_A mode
MOV.B #PCAL+PCA0,&CACTL2      ; Connect CA0 and CA1
BIS.B #7,&P1DIR                ; P1.0...2: outputs
...                            ; Proceed with initialization
;
; Compare input voltage VIN02 with the ext. reference voltage
;
BIC.B #7,&P1OUT                ; Select VIN02
BIS.B #6,&P1OUT                ; Switch on VIN1
...                            ; Wait for settling of VIN1
BIT.B #CAOUT,&CACTL2          ; VIN02 > VIN1?
JNZ   V0GTV1                  ; Yes
...                            ; No, VIN02 < VIN1

```

2.2 Fast Comparator Input Sampling

Very fast sampling of sequential input values is often necessary. The following measurement sequence is the fastest way to accomplish this using Comparator_A inputs. After n input checks, a majority test, or its equivalent, can be performed to reach a conclusion. Figure 5 shows the hardware used for this example. The software samples the voltage generated by the current I_{MEAS} over resistor R_m —a voltage drop higher than $0.25 \times V_{CC}$ sets CAOUT, a lower voltage drop resets CAOUT. After n samples, the number of sampled 1s is checked. Any other input combination can also be used.

Any of the indirect instructions which read byte CACTL2 used only two CPU cycles. The contents of control register CACTL2 does not change during the n samples, so the number of 1s can be easily found by subtraction of $n \times$ (initialized register contents).

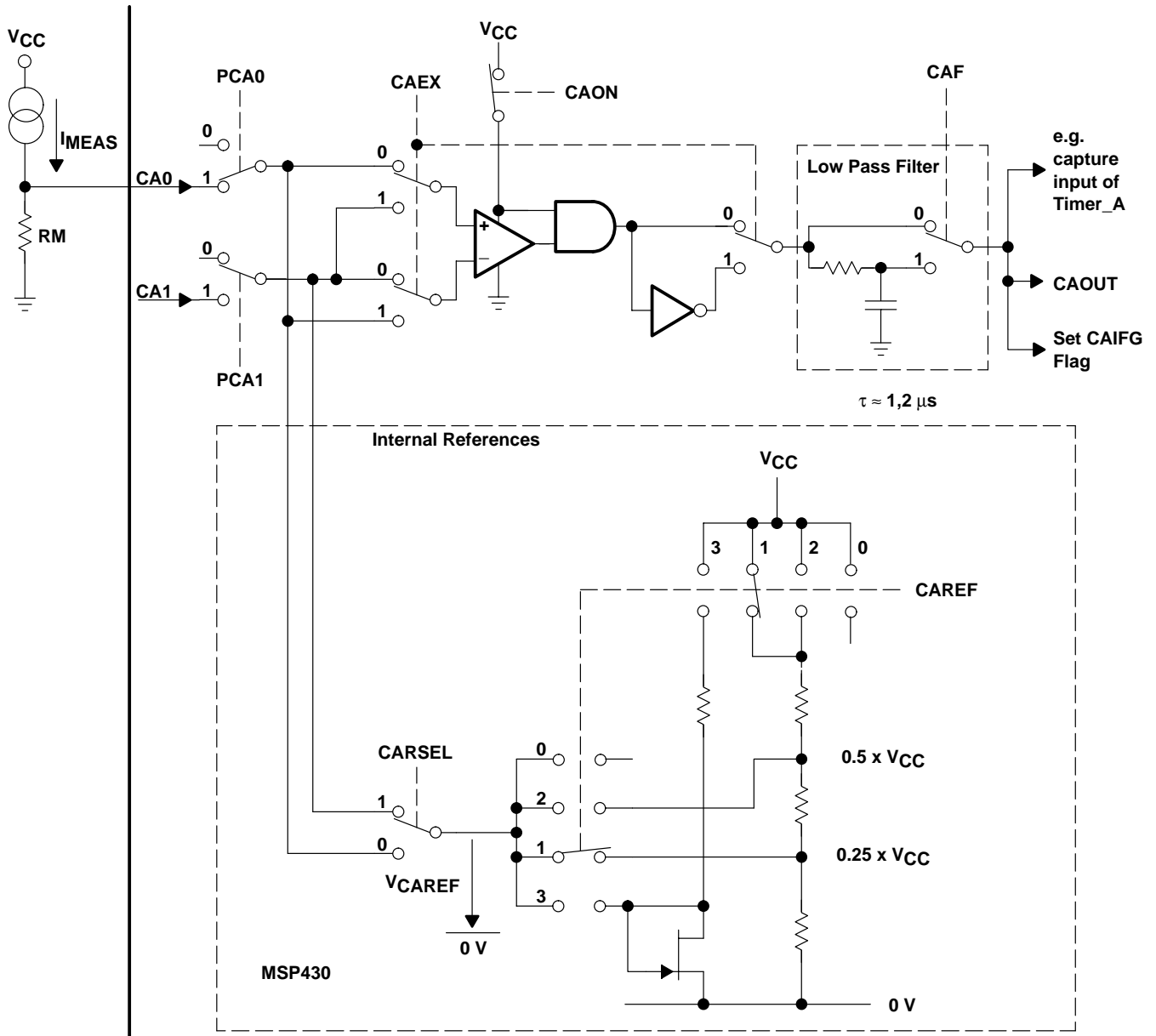


Figure 5. Circuit for Fast Comparator Input Sampling

```

; Fast test for the state of the Comparator_A input CA0
;
MOV.B #CARSEL+CAREF0+CAON,&CACTL1 ; Define Comp_A mode
MOV.B #PCA0,&CACTL2 ; Connect CA0 to noninv. input
MOV #CACTL2,R15 ; Prepare pointer to reg. CACTL2
...
MOV.B @R15,R5 ; Sample CAOUT (CAOUT = CACTL2.0)
ADD.B @R15,R5 ; Add next sample
... ; Add following samples
ADD.B @R15,R5 ; Add sample n
;
; Test if CAOUT showed more than n/2 times a positive result
;
SUB #n*PCA0,R5 ; Correct result
CMP.B #(n/2+1),R5 ; R5 - (n/2+1)
JGE POS ; More "1" samples
... ; More "0" samples

```

or, for an even faster decision:

```

; Test if CAOUT showed more than n/2 times a positive result
;
CMP.B #n*PCA0+(n/2+1),R5 ; R5-(n*PCA0+(n/2+1))
JHS POS ; More samples are 1
... ; More samples are 0

```

This method allows 10 samples within 5 μ s ($1/4$ MHz \times 2 cycles \times 10 samples = 5 μ s) for an MCLK frequency of 4 MHz.

The input CA1 can be used as an external reference voltage instead of the internal reference voltages.

2.3 Resistance Measurement

Figure 6 shows the minimum hardware configuration for the measurement of a resistive sensor: the sensor R_{sens} itself, the reference resistor R_{ref} , and the capacitor C_m .

Capacitor C_m is charged to the voltage V_{CC} before each measurement. At the start of capacitor discharge, the contents of timer register TAR (which always counts upwards in continuous mode) is stored. When capacitor C_m voltage reaches the value $0.25 \times V_{CC}$, the negative edge of CAOUT causes the actual TAR value to be captured in register CCR1. The differences between the values in CCR1 and the start values represent the discharge time intervals t_{sens} and t_{ref} , respectively.

Comparator_A is not changed during the measurements, but the outputs of Port 1 perform the switching of the resistors to be measured.

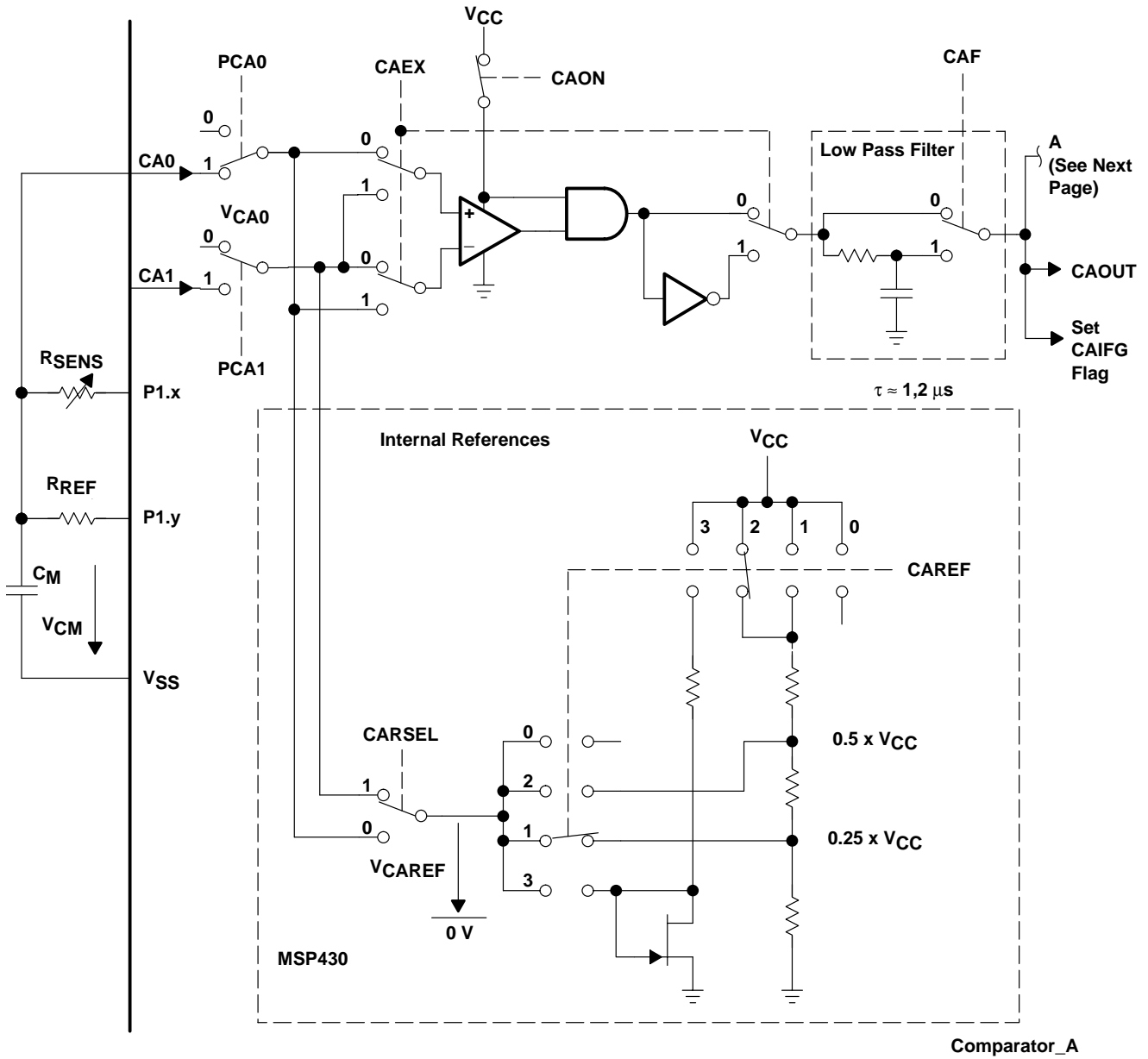


Figure 6. Measurement of Resistors

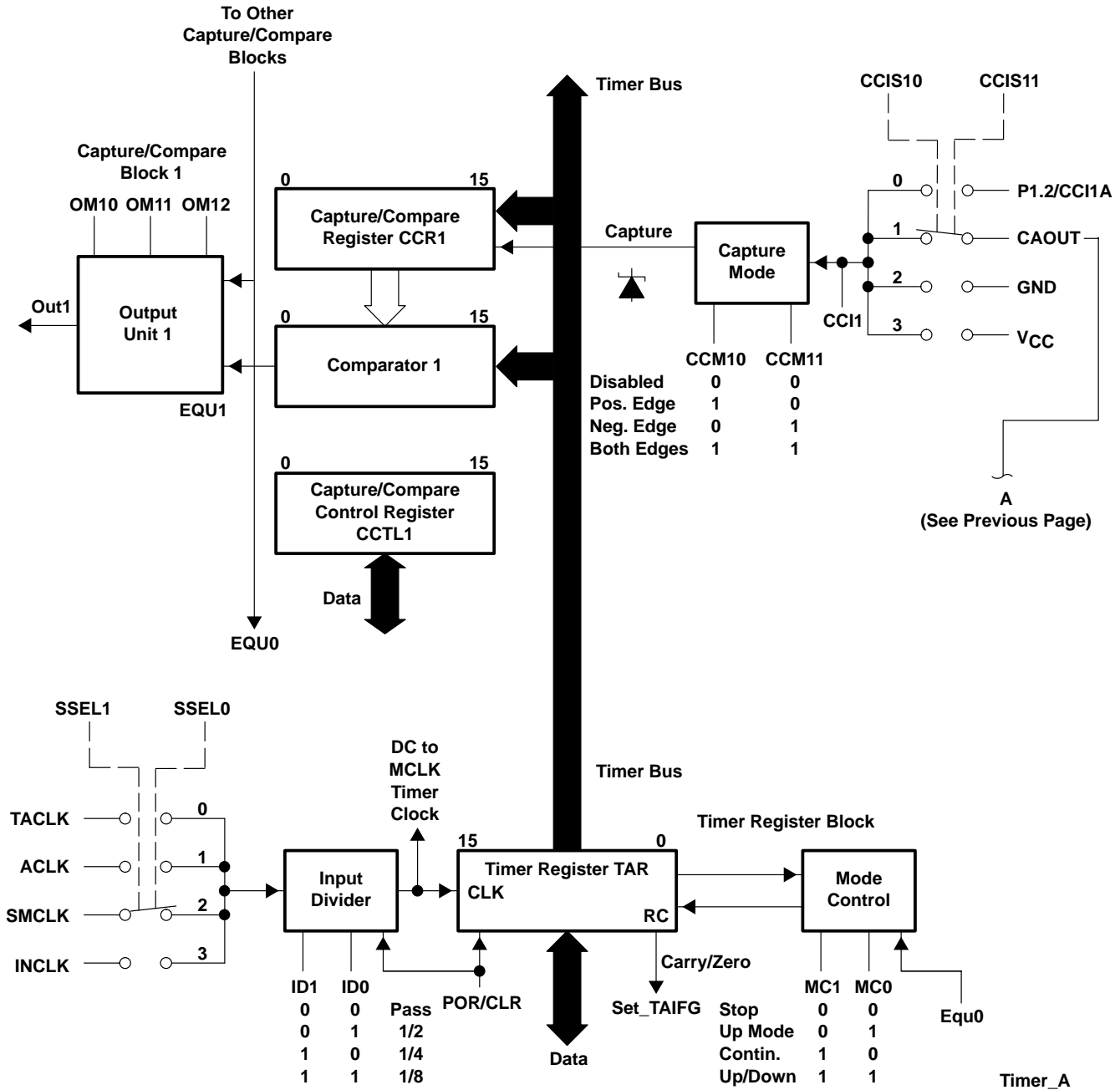


Figure 6. Measurement of Resistors (Continued)

Figure 7 shows the voltage V_{cm} across capacitor C_m during the two measurements. The charge time t_c must be between 5τ (for 1%) and 7τ (for 0.1%), depending on the accuracy required, where $\tau = R_{ref} \times C_m$.

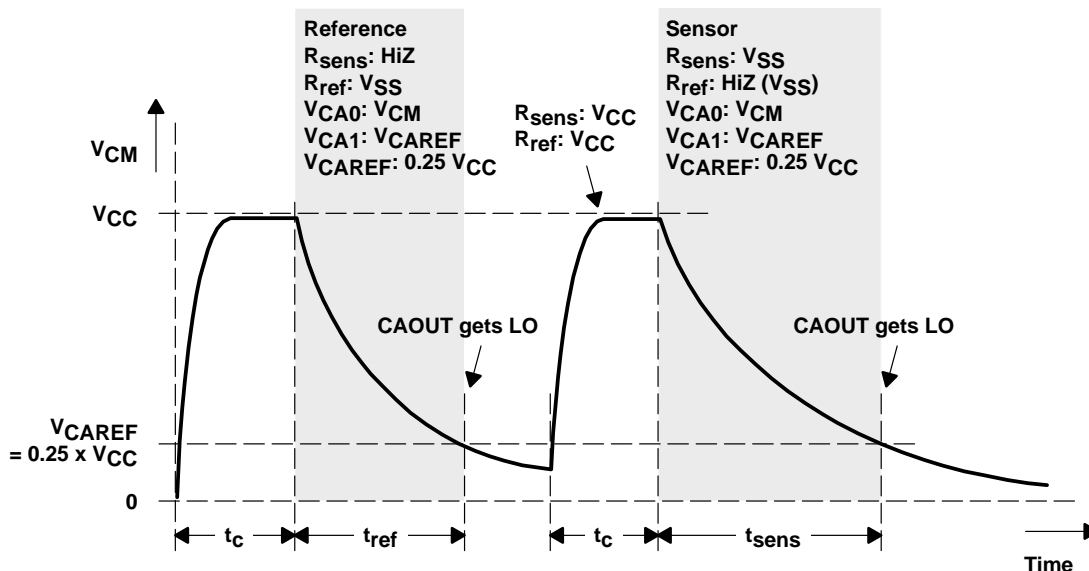


Figure 7. Voltage at Cm During Resistance Measurement

Solution of the two exponential equations describing the capacitor discharge for reference resistor R_{ref} and sensor R_{sens} leads to a simple equation for the calculation of R_{sens} :

$$\frac{R_{sens}}{R_{ref}} = \frac{t_{sens}}{C_m \times \ln \frac{V_{CAREF}}{V_{CC}}} \times \frac{C_m \times \ln \frac{V_{CAREF}}{V_{CC}}}{t_{ref}} \rightarrow R_{sens} = R_{ref} \times \frac{t_{sens}}{t_{ref}}$$

For highly nonlinear sensors (such as NTC sensors), reference resistor R_{ref} is chosen to be the optimum linearization resistor. It is connected in parallel with the sensor R_{sens} during sensor measurement. The formula then becomes:

$$R_{sens} = R_{ref} \times \frac{t_{sens}}{t_{ref} - t_{sens}}$$

The previous calculation formula (written for floating-point package FPP4) is contained in the *MSP430 Application Report Book* (see Section 2, *Temperature Calculation Example*).

It is also possible to connect more than one sensor (switched by ports) and two reference resistors, one for the beginning and one for the end of the measurement range. The calculation formulas are contained in Section 2.1 of the *MSP430 Application Report Book*.

2.4 Voltage Measurement

Figure 8 shows how to measure an external voltage V_{IN0} . The supply voltage V_{CC} is used as a reference. The split configuration of resistor divider and discharge circuit has the advantage of not using input voltage V_{IN0} to charge capacitor C_m (normally with large time constants). Instead, the input voltage always has the correct value at input pin CA0. Figure 8 shows the position of the comparator switches during the reference measurement.

NOTE: The complex formulas developed ahead can always be reduced to relatively simple equations with constant values:

$$V = A \times e^{x \times B}, \text{ and } V = A \times (1 - e^{x \times B})$$

The logarithmic functions used are contained in floating-point package FPP4. See Section 5.6 of the *MSP430 Application Report Book*.

If integers are used in the calculation, the exponential function can be emulated by a hyperbola. Then only one division is necessary:

$$V = \frac{D}{x + C} + E$$

See Section 5.5 of the *MSP430 Application Report Book*.

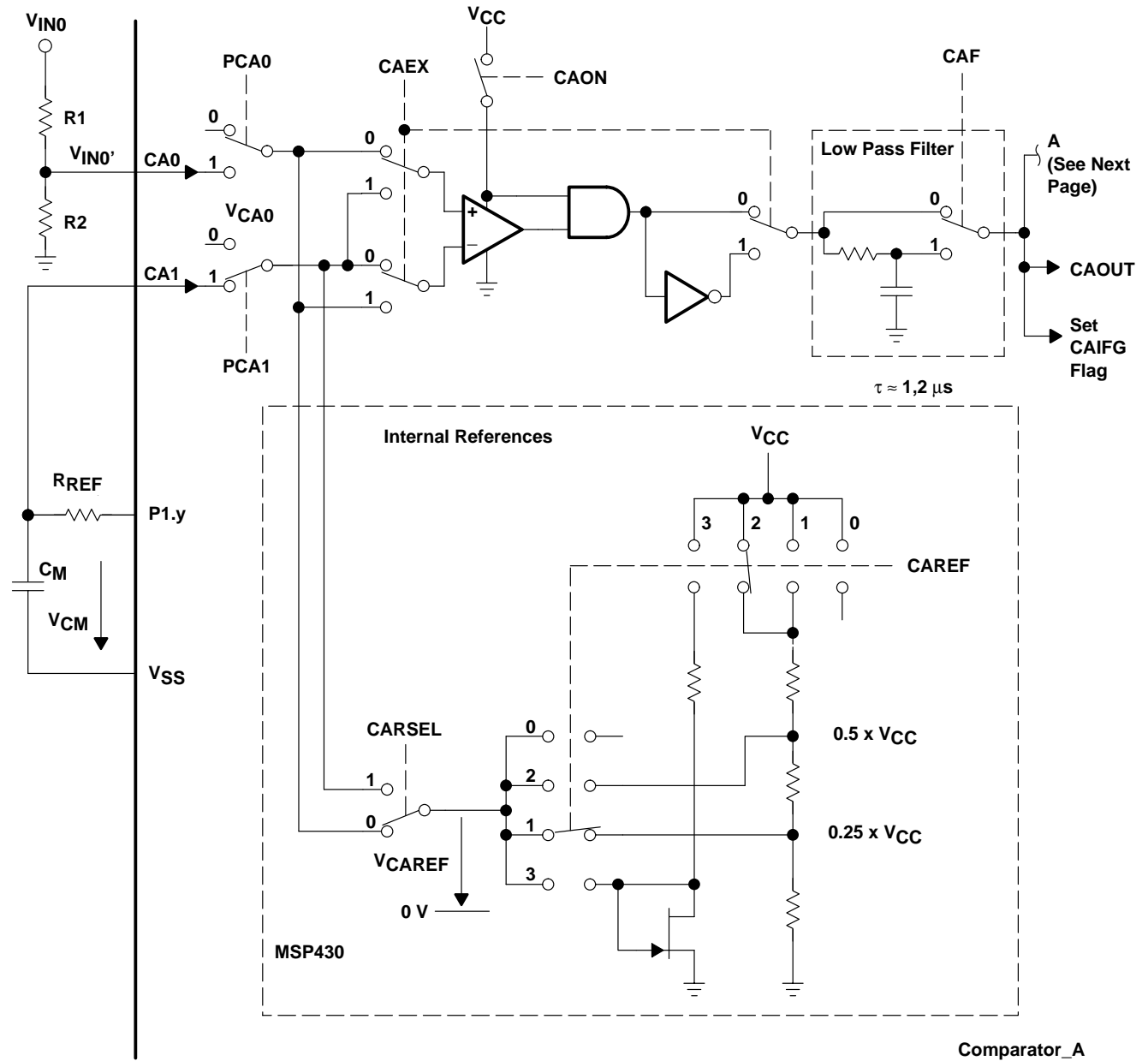


Figure 8. Voltage Measurement

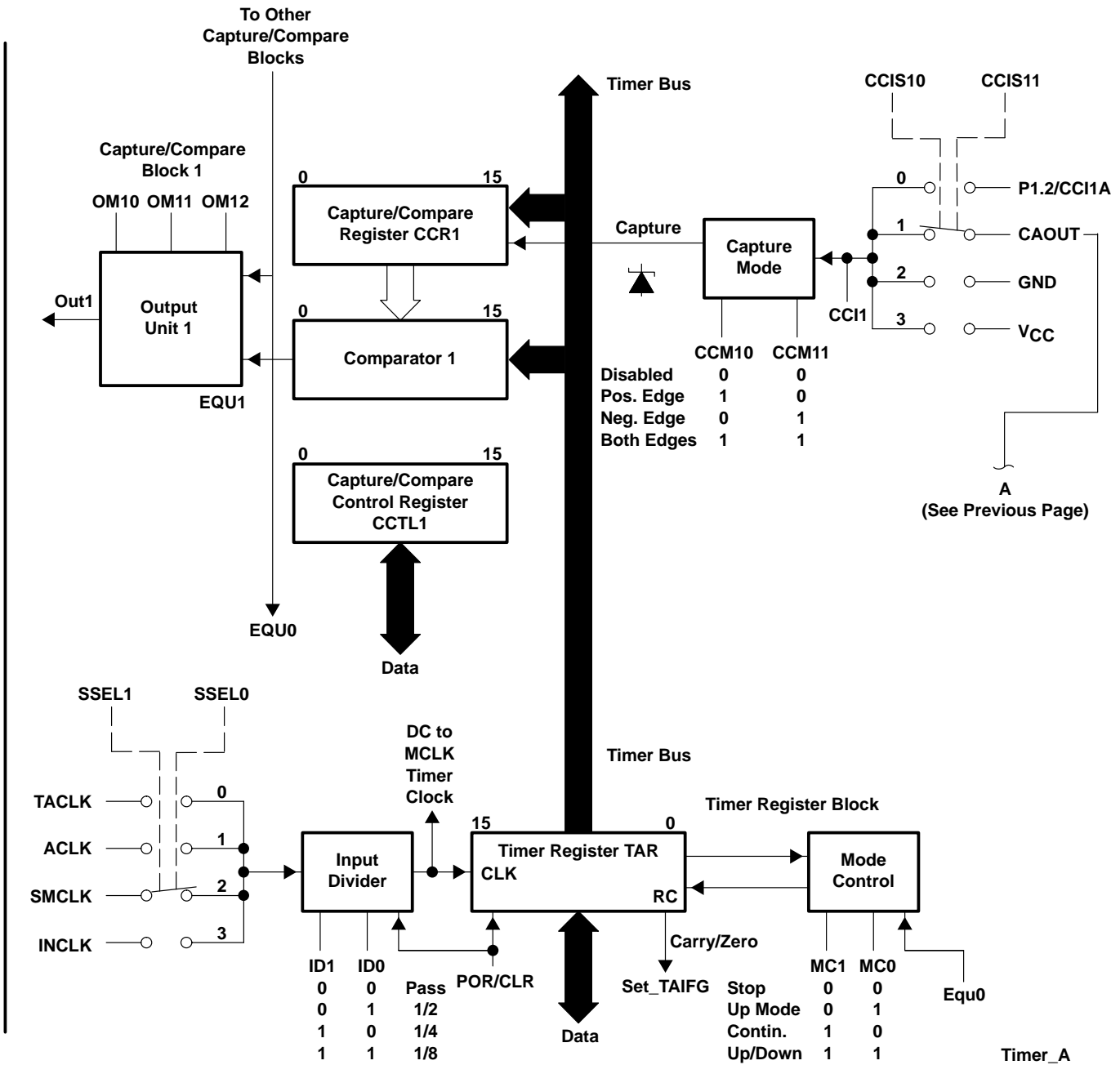


Figure 8. Voltage Measurement (Continued)

The voltage range of V_{CA0} (seen at the comparator input CA0) that can be measured with the previous discharge circuit is limited to the following nominal range:

$$V_{CAREF} < V_{CA0} \leq V_{CM(MAX)} \quad (\text{Refer to device data sheet})$$

This implies that for a supply voltage $V_{CC} = 3.3 \text{ V}$, voltages at the inputs (V_{CA0} and V_{CA1}) between 0.825 V ($0.25 \times 3.3 \text{ V}$) and V_{CM} can be measured.

With a resistor divider consisting of resistors R1 and R2, the nominal input voltage range for V_{IN0} becomes:

$$V_{CAREF} \times \frac{R1 + R2}{R2} < V_{IN0} \leq V_{CC} \times \frac{R1 + R2}{R2}$$

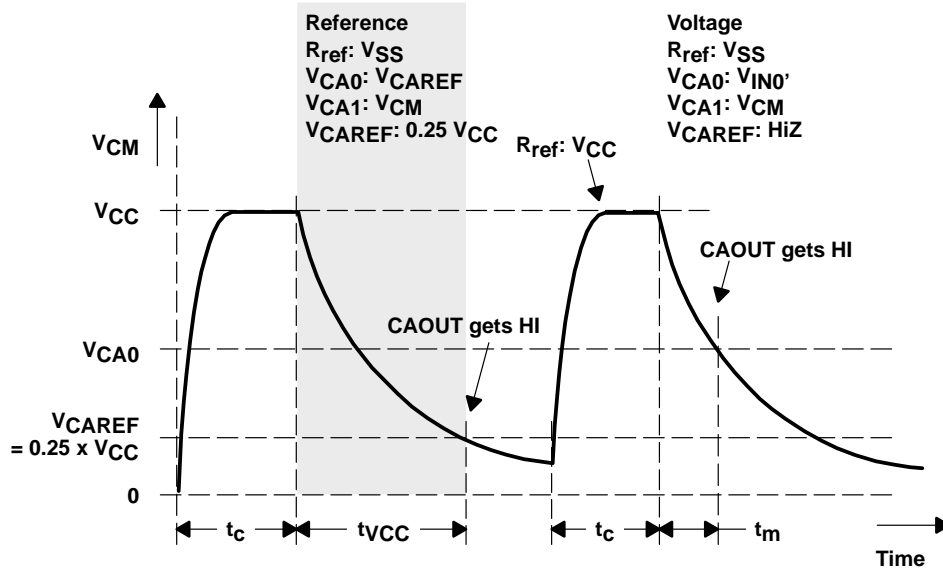


Figure 9. Voltage Measurement With the Discharge Method

As shown in Figure 9, capacitor C_m (previously charged to V_{CC}) is discharged through resistor R_{ref} . The time interval t_{vcc} (from the start of discharge until V_{CAREF} is reached) is measured with `Timer_A`, as shown before for the resistance measurement.

Next, switch `PCA0` is set to 1 (the divided voltage V_{IN0} is switched to the noninverting input), the internal reference voltage is switched off with `CAREF` = 0, and the discharge of the charged capacitor C_m is repeated. When V_{cm} reaches the voltage V_{CA0} , the comparator output `CAOUT` is switched high and the accurate time is captured in register `CCR1` of `Timer_A`.

The charge time t_c required depends on the measurement accuracy required: 5τ for 1%, 7τ for 0.1% ($\tau = R_{ref} \times C_m$).

The voltage V_{IN0} is calculated from the two measured time intervals t_m and t_{vcc} using the following formula (discharge method):

$$V_{IN0} = V_{CC} \times \frac{R1 + R2}{R2} \times e^{\frac{t_m}{t_{vcc}} \times \ln \frac{V_{CAREF}}{V_{CC}}}$$

Because $V_{CAREF} = 0,25 \times V_{CC}$ here, the logarithm of the above formula can be replaced by $\ln 0.25 = -1.3862944$.

The voltage V_{IN0} can also be proportional to a current I_{IN0} . This also allows to perform current measurement.

The charge method must be used when it is necessary to measure voltages or currents down to a value of zero. The reference voltage in this case is $V_{CAREF} = 0.5 \times V_{CC}$. The measurements are taken with capacitor C_m completely discharged. It is then charged until the voltages V_{CAREF} and V_{CA0} , respectively, are reached. (See also Section 2.5, *Digital Motor Control*, where the charge method is used). Using the two measured time intervals tm and $tvcc$, the input voltage V_{IN0} can be calculated:

$$V_{IN0} = \frac{R1 + R2}{R2} \times V_{CC} \left[1 - e^{\frac{tm}{tvcc} \times \ln \left(1 - \frac{V_{CAREF}}{V_{CC}} \right)} \right]$$

Because $V_{CAREF} = 0.5 \times V_{CC}$ here, the logarithm of the above formula can be replaced by $\ln 0.5 = -0.6931471$.

2.5 Digital Motor Control (DMC)

Figure 10 shows an integrated motor control with an MSP430F1121 and an L293. This L293 chip contains two H-bridges in a single package. The direction of rotation is defined by the static output P1.1, and the speed of the motor is determined by the PWM output TA1 of Timer_A. Motor current and temperature can be measured with simple circuitry at the Comparator_A inputs. Only the charge method can be used because the motor current, which is always positive, must be measured down to a zero value.

Capacitor C_m is discharged to 0 V before each measurement, and the time interval until it reaches the voltage V_{CAREF} relative to V_{SHUNT} is measured. Using the measured time intervals $tvcc$ and ti , the absolute value of the motor current $|Imotor|$ can be calculated. The equation for the motor current $|Imotor|$ is:

$$|Imotor| = \frac{1}{R_{shunt}} \times V_{CC} \left[1 - e^{\frac{ti}{tvcc} \times \ln \left(1 - \frac{V_{CAREF}}{V_{CC}} \right)} \right]$$

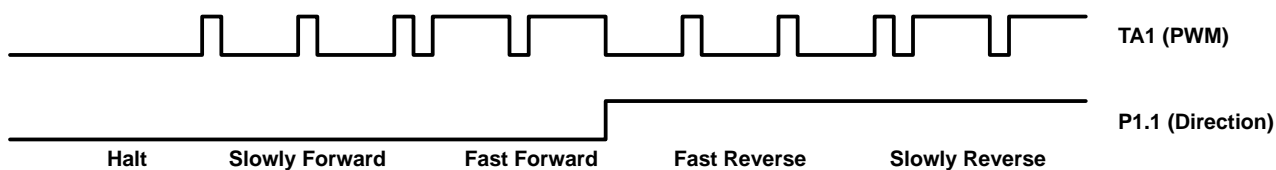
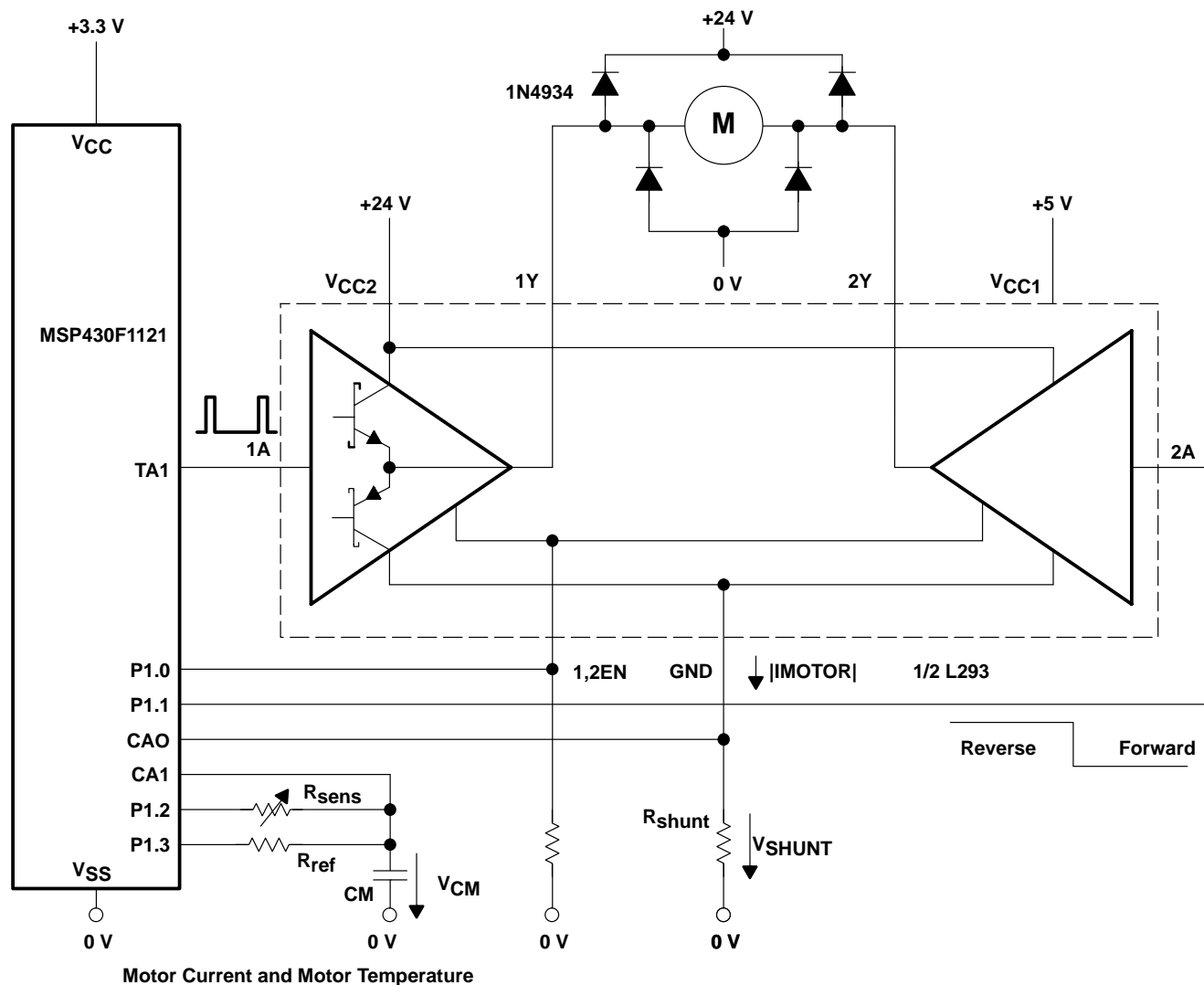


Figure 10. Current and Temperature Measurement for a PWM Motor Control

The temperature of the motor is measured using temperature sensor R_{sens} . To allow the use of the reference measurement for the current measurement (which delivers the value tv_{cc}) as well as for the temperature measurement, the sensor R_{sens} is also measured using the charge method. The formula for calculation of the sensor resistance using the two values tv_{cc} and $tsens$ is:

$$R_{sens} = R_{ref} \times \frac{tsens}{tv_{cc}}$$

Figure 11 shows the voltage V_{CM} at capacitor C_m for the current and temperature measurements. The discharge time t_d required depends on the measurement accuracy desired, namely 5τ for 1% and 7τ for 0.1% (where $\tau = R_{ref} \times C_m$).

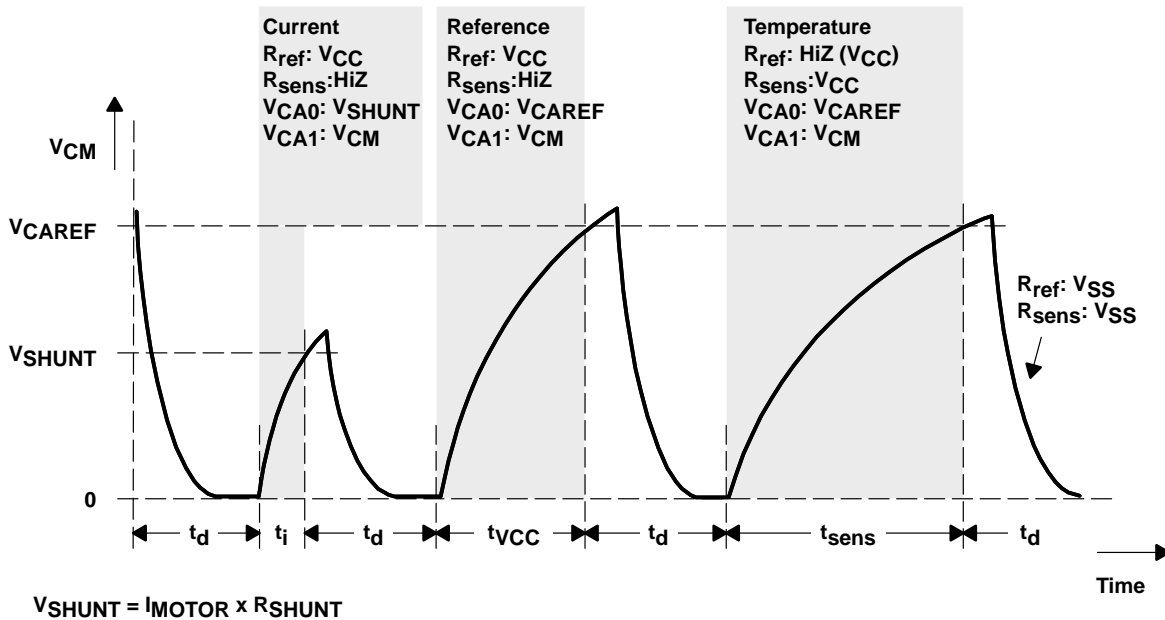


Figure 11. Current and Temperature Measurement (Charge Method)

It is possible to take frequent measurements because the capacitor C_m is not charged up to the voltage V_{SHUNT} with a high resistance. The frequency of the measurements depends only on the time constant $\tau = C_m \times R_{ref}$.

The current of triac-controlled motors can also be measured using Comparator_A. However, the method previously shown only allows measurement of the positive half wave of the motor current.

2.6 Connection of Sensor Bridges

It is also possible to measure sensor bridges connected to Comparator_A. There is a difference between applications with and without amplification. Both possibilities are shown.

2.6.1 Measurement Without Amplification

The circuitry of Figure 12 can be used when no amplification is required. The two capacitors C_{m0} and C_{m1} are charged up to the voltages V_m and V_p of the two midpoints of the bridge legs. Then they are discharged to reference voltage $0.25 \times V_{CC}$ while taking two adjacent measurements. The time intervals measured, $tm0$ and $tm1$, are used on the calculation of voltages V_p and V_m . The references are represented by time intervals $tvcc0$ and $tvcc1$ for the capacitors to discharge from the supply voltage V_{CC} down to $0.25 \times V_{CC}$. The equations for the two bridge voltages V_p and V_m are:

$$V_p = V_{CC} \times e^{\frac{tvcc1 - tm1}{tvcc1} \times \ln \frac{V_{CAREF}}{V_{CC}}} \quad V_m = V_{CC} \times e^{\frac{tvcc0 - tm0}{tvcc0} \times \ln \frac{V_{CAREF}}{V_{CC}}}$$

The value of most interest $\Delta R_b/R_b$ (the relative change of the bridge resistor R_b with pressure) can be calculated using the former two equations:

$$\frac{\Delta R_b}{R_b} = \frac{\Delta(V_p - V_m)}{V_{CC}}$$

A complete measurement cycle consists of four voltage measurements: V_m , V_p , $2 \times V_{CC}$. Figure 12 shows the switch positions of the comparator for the measurement of voltage V_p . Switches PCA0, PCA1, CARSEL, and CAEX are toggled to measure V_m . This ensures that both voltages are measured with the same comparator offset.

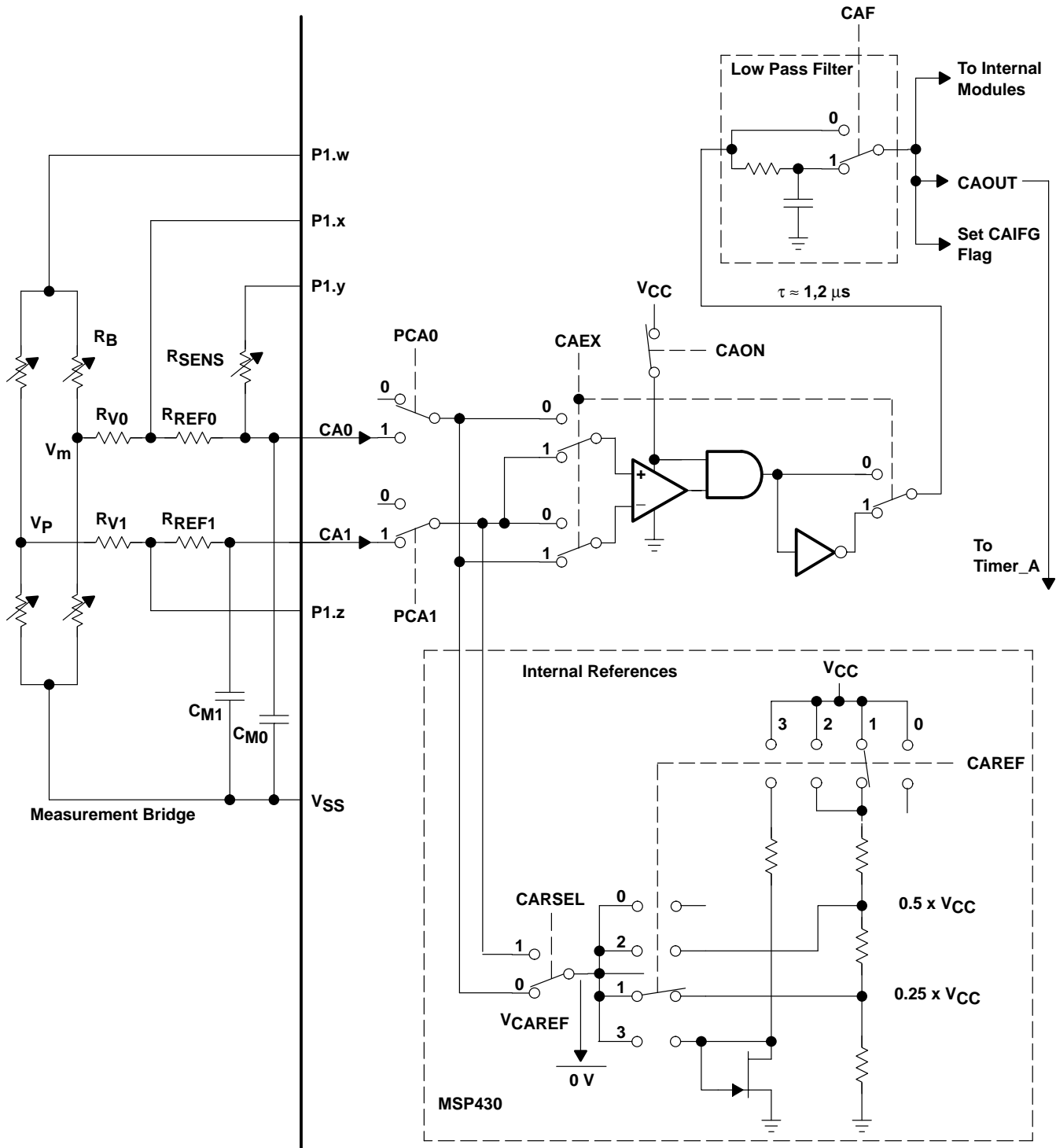


Figure 12. Connection of a Measurement Bridge to Comparator_A

Figure 13 shows the voltage curve for the bridge leg connected to comparator input CA0; this input measures the voltage V_m and the temperature.

The charge time t_c required depends on the measurement accuracy desired—namely, 5τ for 1%, 7τ for 0.1%, where $\tau_c = R_{ref0} \times C_{m0}$. The same is valid for time interval t_{ce} , where the time constant is $\tau_{ce} = (R_{ref0} + R_{v0} + R_b/2) \times C_{m0}$.

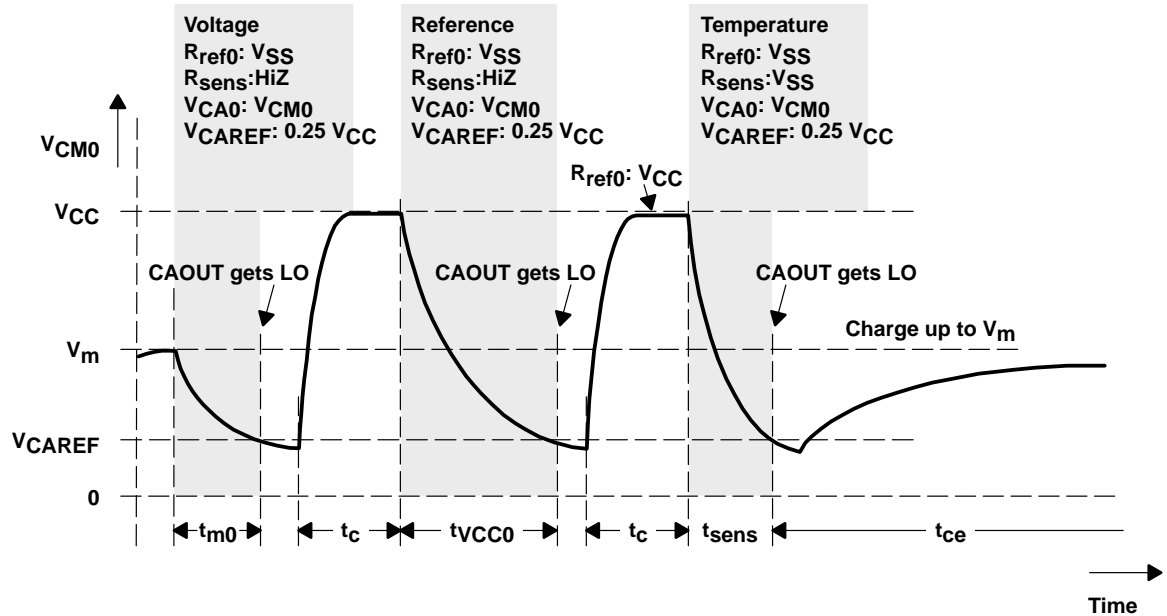


Figure 13. Voltage V_{cm0} During Bridge Measurement (V_m and Temperature)

The temperature of the bridge can also be measured as shown in Figure 12. The temperature is necessary for the compensation of the bridge. The value R_{sens} of a temperature sensor is measured the normal way. Resistor R_{ref0} must be selected so it can also be used for linearization of the temperature sensor. This is necessary because resistor R_{ref0} cannot be switched off completely. The equation for the sensor resistance R_{sens} is:

$$R_{sens} = R_{ref0} \times \frac{t_{sens}}{t_{vcc0} - t_{sens}}$$

Calculation of the components

The following steps are used to calculate the components shown in Figure 12. Components R_{ref1} , C_{m1} , and R_{v1} have the same values as components R_{ref0} , C_{m0} and R_{v0} calculated below.

1. $R_{sens} = f(T)$ is given → This defines the optimum linearization resistor R_{lin}
2. R_{lin} equals R_{ref0}
3. The time constant τ is chosen to reach a given minimum resolution n for a given $\Delta R_b/R_b$

$$\tau = R_{ref0} \times C_{m0} > \frac{n}{f_{meas} \times \left(\ln\left(0.5\left(1 + \frac{\Delta R_b}{R_b}\right)\right) - \ln\left(0.5\left(1 - \frac{\Delta R_b}{R_b}\right)\right) \right)}$$

4. With τ , the capacitor C_m is: $C_{m0} > \frac{\tau}{R_{ref0}}$
5. Resistor R_{v0} should impose minimum load to the bridge: $R_b \ll R_{v0} \geq R_{ref0}$

Where:

n	Minimum resolution for a given $\Delta R_b/R_b$	
R _{lin}	Optimum linearization resistor for the temperature sensor	[Ω]
f _{meas}	Measurement frequency	[Hz]

EXAMPLE: a bridge system needs to be designed using the following data:

R_{lin} = 10 k Ω , n = 500 for $\Delta R_b/R_b = 30\Omega/1$ k Ω , R_b = 1 k Ω , f_{meas} = 3 MHz

1. R_{lin} defines R_{ref0}: $R_{ref0} = 10$ k Ω

2. Time constant τ :

$$\tau = > \frac{500}{3 \text{ MHz} \times \left(\ln\left(0.5\left(1 + \frac{30}{1000}\right)\right) - \ln\left(0.5\left(1 - \frac{30}{1000}\right)\right) \right)} = \frac{500}{3 \text{ MHz} \times 0.06}$$

$$= 2.78 \times 10^{-3} \text{ s}$$

3. Capacitor C_{m0}: $C_{m0} > \frac{2.78 \times 10^{-3} \text{ s}}{10 \text{ k}\Omega} = 278 \text{ nF} \rightarrow C_{m0} = 330 \text{ nF}$

4. Resistor R_{v0}: $1 \text{ k}\Omega \ll R_{v0} \geq 10 \text{ k}\Omega \rightarrow R_{v0} = 20 \text{ k}\Omega$

This results in a resolution n for $\Delta R_b/R_b = 30 \Omega/1$ k Ω :

$$n = \tau \times f_{meas} \times \left(\ln\left(0.5\left(1 + \frac{30}{1000}\right)\right) - \ln\left(0.5\left(1 - \frac{30}{1000}\right)\right) \right)$$

$$n = 330 \text{ nF} \times 10 \text{ k}\Omega \times 3 \text{ MHz} \times 0.06 = 594$$

2.6.2 Measurement With Amplification

An op amp must be used if the resolution of the circuitry of Figure 12 is not sufficient. This op amp amplifies the voltage difference of the two bridge legs. It is connected to Comparator_A as shown in Figure 14. The measurement method and the equations are identical to those shown in the *Voltage Measurement* section. The value of interest, $\Delta R_b/R_b$ (assuming R_b \ll R₂) is now:

$$\frac{\Delta RB}{RB} = \frac{\Delta V_{BR}}{v \times V_{CC}} = \frac{R_2}{R_1} \times \frac{\Delta V_{BR}}{V_{CC}}$$

A complete measurement cycle consists of two voltage measurements:

- One measurement with the bridge unloaded (that is, without pressure)
- One measurement with the bridge loaded

The difference voltage ΔV_{BR} resulting from the two measurements is calculated. If a temperature measurement is necessary, it is done as described in the *Resistance Measurement* section.

under

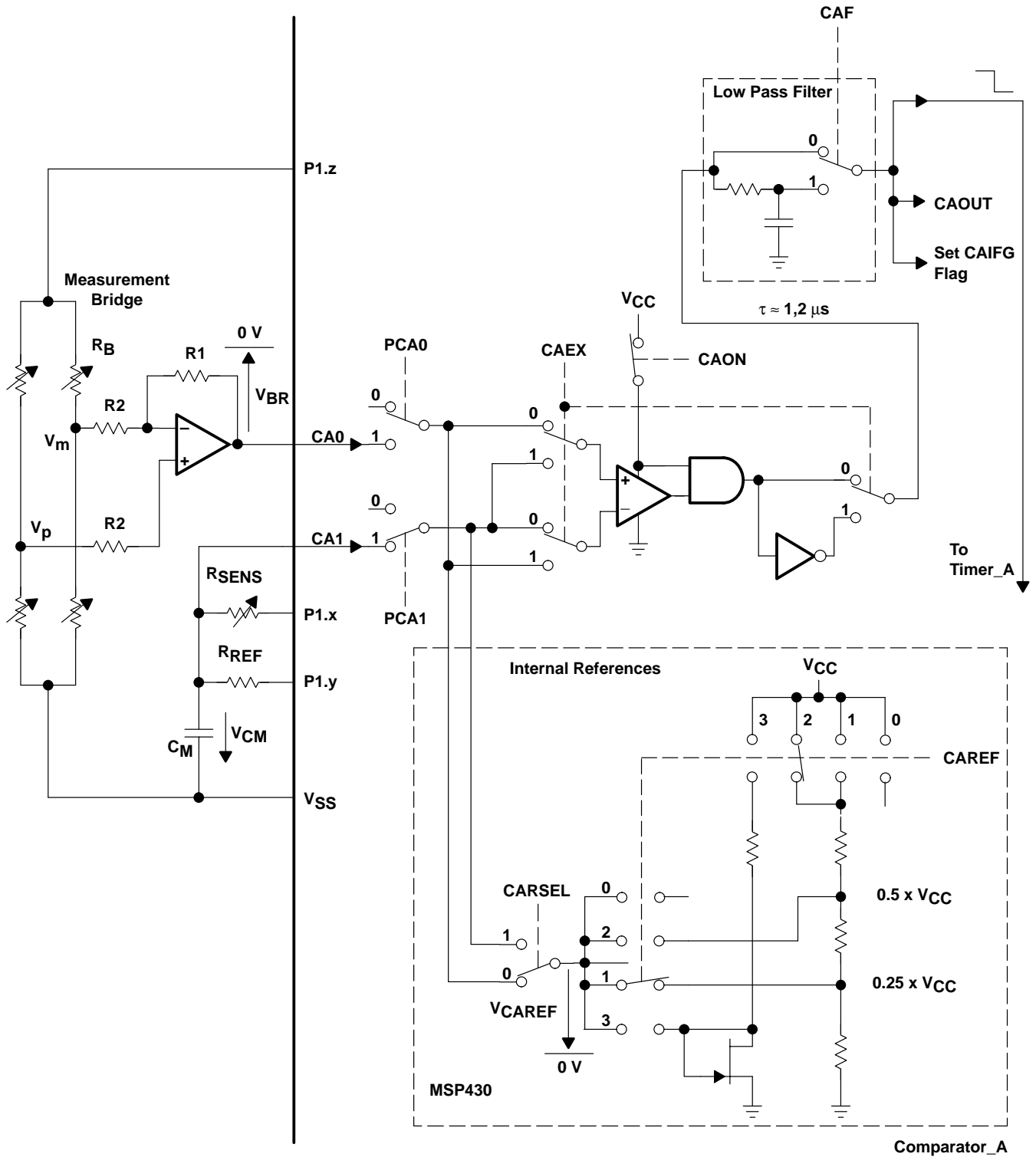


Figure 14. Connection of a Bridge With Amplification

2.7 Capacitance Measurement

Figure 15 shows the circuit used to measure a capacitor C_x using a reference capacitor C_{ref} . Output P1.y connects capacitor C_{ref} to V_{SS} during the reference measurement, and output P1.z connects the unknown capacitor C_x to V_{SS} during the capacitance measurement. Both ports are otherwise switched to high impedance. C_s represents the stray capacitance of the measurement circuit.

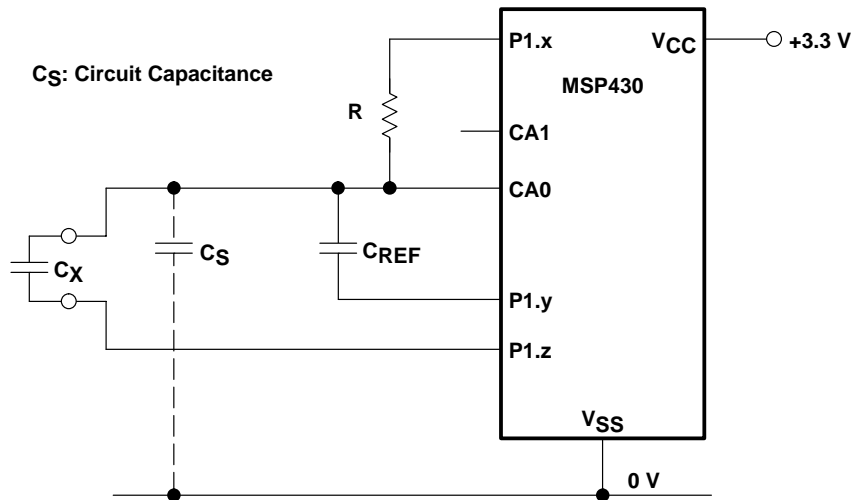


Figure 15. Measurement of an Unknown Capacity C_x

The voltage curve for the two measurements is the same as that shown in Figure 7 (resistance measurement). The equation for C_x is:

$$C_x = \frac{t_x}{t_{ref}} \times (C_{ref} + C_s) - C_s$$

Where t_x and t_{ref} represent the measured discharge intervals for C_x and C_{ref} . Capacitor C_m can be used for reference purposes in the existing circuitry for resistance and voltage measurement. Comparator input CA1 can also be used for other purposes. See the following sections.

2.8 Other Applications

Two of many possible applications of the Comparator_A module are described below.

2.8.1 Two Independent Measurement Circuits

It is possible to connect two completely independent measurement circuits to the Comparator_A inputs CA0 and CA1. It is only necessary that both circuits use the internal reference voltages. This allows, for example, measuring voltage with one channel and checking a threshold on the other one. Figure 16 shows the connection of two independent measurement circuits for resistance measurement and fast sampling of an input signal (see also Sections 2.2 and 2.3). The positions of the internal switches are shown for resistance measurement. To measure the circuit at input CA0, all switches, with the exception of filter switch CAF, must be toggled.

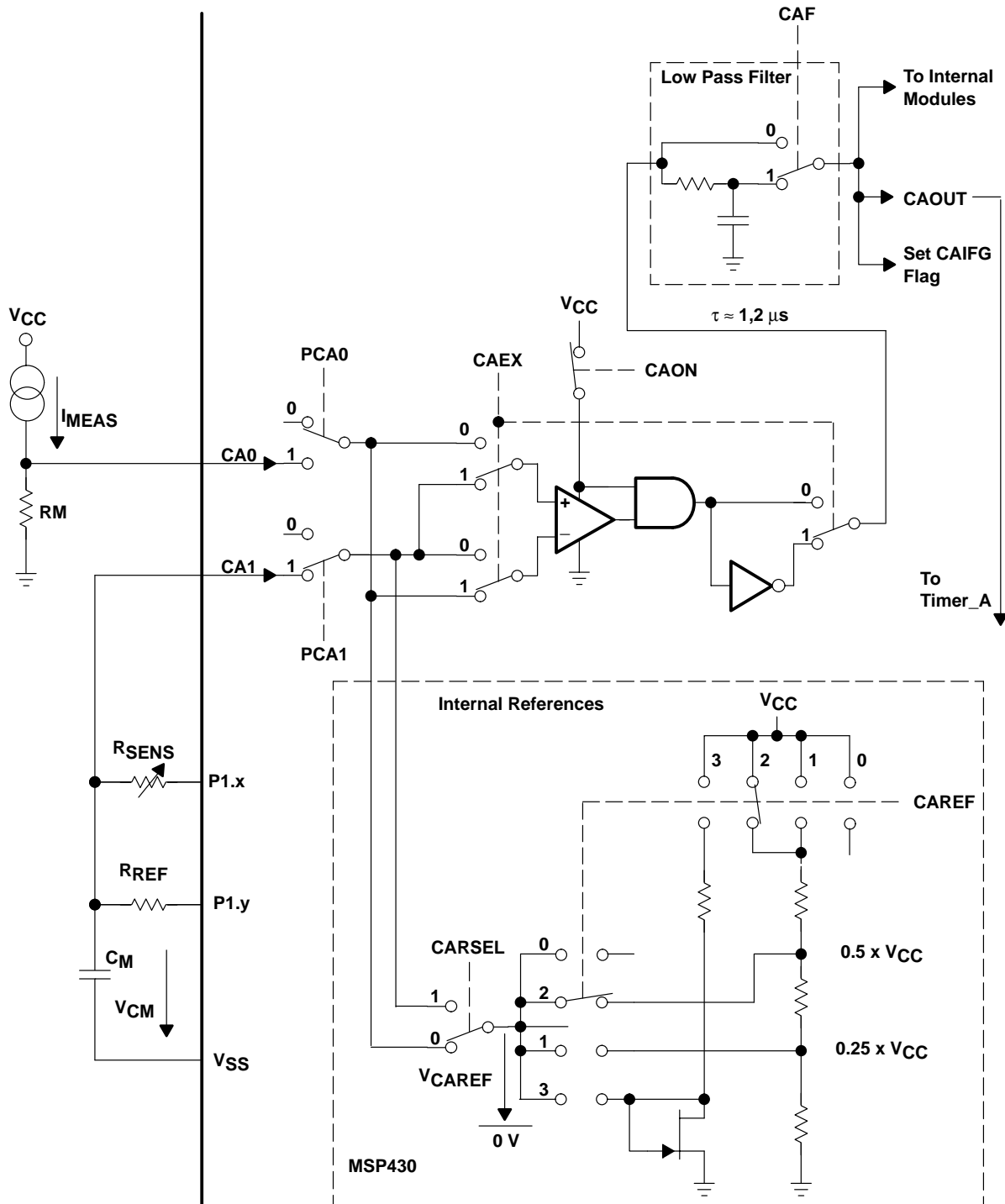


Figure 16. Independent Use of the Two Comparator_A Inputs

2.8.2 External Use of the Internal Reference Voltage

Sometimes it can be convenient to have access to the internal reference voltage in Comparator_A that is used for the comparison. This allows the use of the exact reference value in the external circuitry. Figure 17 shows the switch positions required to make the internal reference diode voltage available at the input CA1 and at the inverting comparator input.

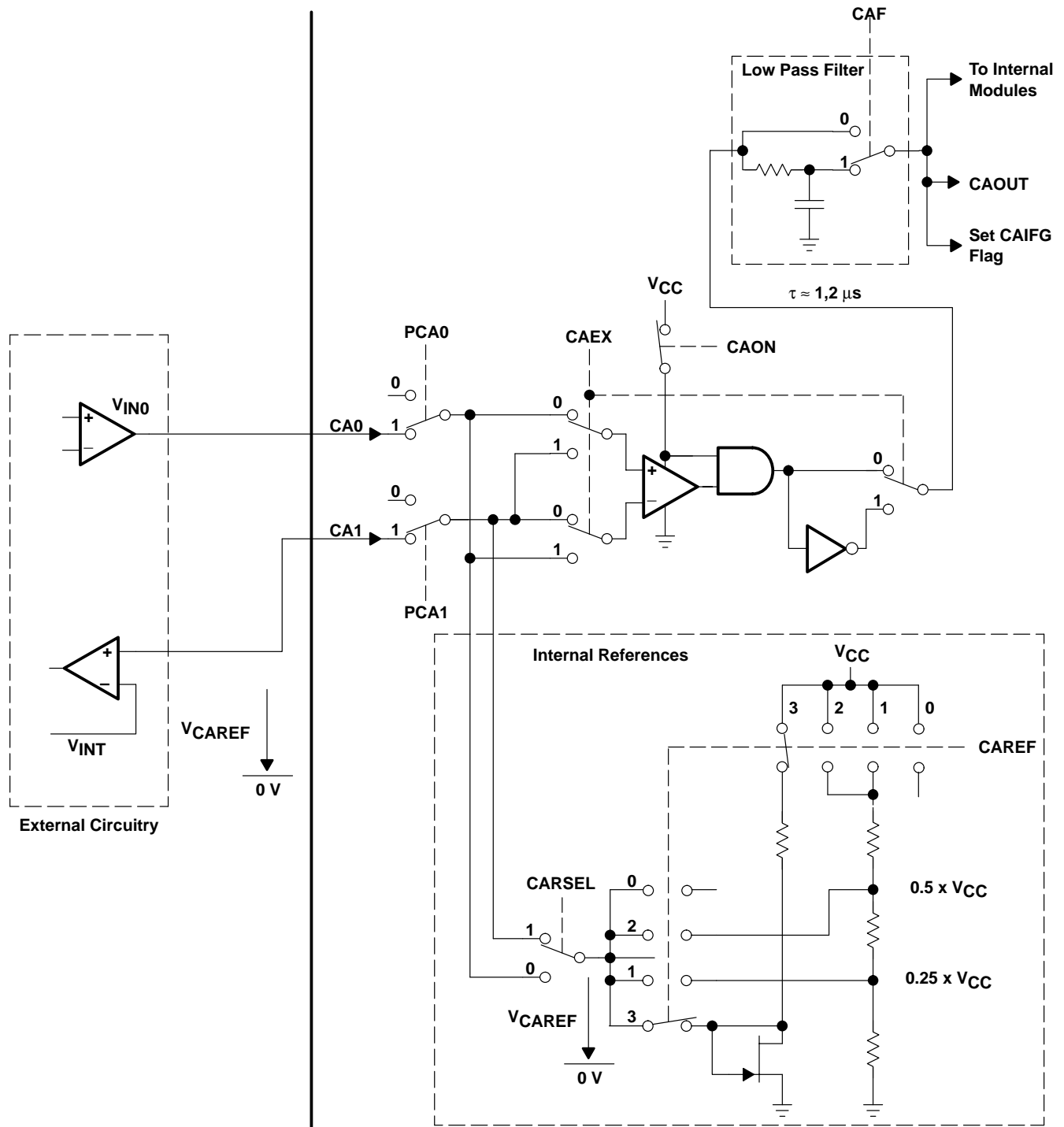


Figure 17. Use of the Internal Reference Voltage in the External Circuitry

3 References

1. *MSP430x1xx Family User's Guide* SLAU049
2. *MSP430x4xx Family User's Guide* SLAU056
3. *MSP430 Application Report Book* SLAA024
4. *MSP430F1121A Data Sheet* SLAS241
5. *MSP430 14-Bit Analog-to-Digital Converter Application Reports*
..... SLAA045, SLAA046, SLAA047, SLAA048, SLAA050

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