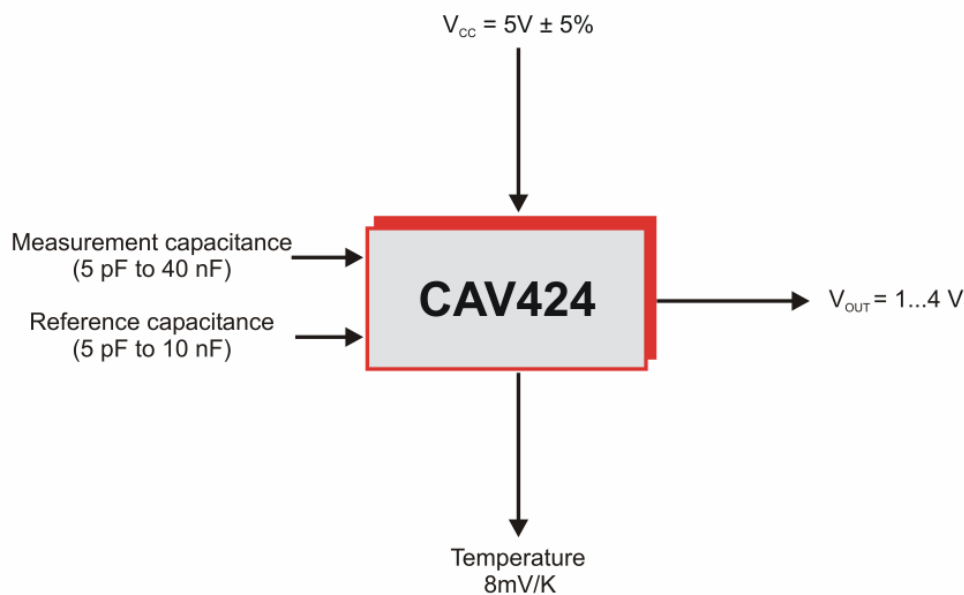


# CAV424

## C/V-converter for single and differential capacitive input signals

### Principle Function

Capacitance/Voltage-converter IC with adjustable voltage output and integrated temperature sensor



### Function

CAV424 is an integrated capacitance-to-voltage converter. The IC measures the capacitance of a connected capacitive measurement head against a reference capacitance and converts the difference into a DC output voltage.

CAV424 can be used as analog front end for a micro processor or as stand-alone IC.

### Typical Applications

- Humidity measurement
- Distance measurement
- Suitable for capacitive pressure sensors
- Level sensing
- Material identification
- Object detection

# CAV424

## C/V-converter for single and differential capacitive input signals

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# CAV424

## C/V-converter for single and differential capacitive input signals

### FEATURES

- large measurement capacitance range: 5 pF up to 40 nF
- suitable for single and differential capacitive sensor heads
- high detection sensitivity
- ratiometric voltage output
- adjustable offset and gain
- fast response time
- integrated temperature sensor
- supply voltage  $5V \pm 5\%$
- large temperature range:  $-40^{\circ}\text{C} \dots +105^{\circ}\text{C}$
- easy-to-use calibration procedure (Excel-sheet)
- available in SO16 or as Die
- RoHS conform

### GENERAL DESCRIPTION

CAV424 is an integrated C/V-converter suitable for the capacitance measurement in single or differential capacitive sensor systems. Its output voltage is a linear function of the reciprocal measurement capacitance and it is ratiometric to the supply voltage.

The IC is completely analog leading to a fast response time and a resolution only limited by the signal to noise ratio.

CAV424 provides the complete electronics needed for the conversion of single or differential capacitive input signals into voltage output signals, which can be an amplified and offset adjusted using external trimming resistors.

The IC can be used as stand-alone analog signal-processing IC or as front-end for a micro processor for electronically calibratable sensor systems.

An Excel-sheet simplifies the external component's dimensioning as well as the trimming of complete sensor systems.

### BLOCK DIAGRAM

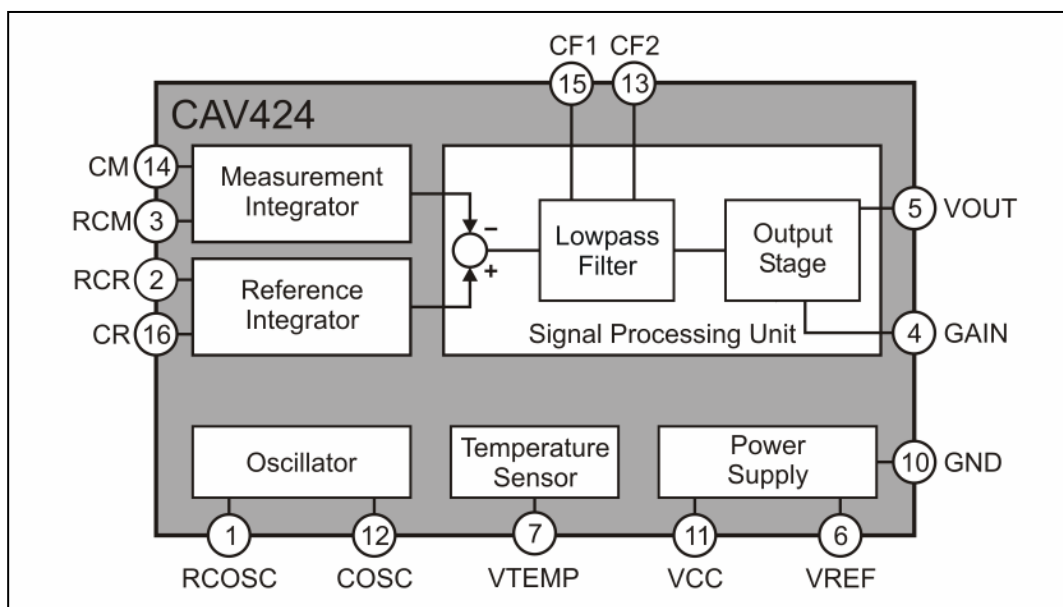


Figure 1: CAV424's block diagram

# CAV424

## C/V-converter for single and differential capacitive input signals

### SPECIFICATIONS

#### 1. Electric Specifications

$T_{amb} = 25^{\circ}\text{C}$ ,  $V_{CC} = 5\text{V}$ ,  $I_{OSC} = 20\mu\text{A}$ ,  $I_{CR} = I_{CM} = 2.5\mu\text{A}$  (unless otherwise noted)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
<b>System</b>						
Operating Temperature	$T_{amb}$		-40		105	$^{\circ}\text{C}$
Supply Voltage	$V_{CC}$	<i>ratiometric range</i>	4.75	5.00	5.25	V
Current consumption	$I_{CC}$	$T_{amb} = 25^{\circ}\text{C}$ , $G = 1$ $T_{amb} = -40 \dots 105^{\circ}\text{C}$ , $I_{CR} = I_{CM} = 25\mu\text{A}$			1.3 1.7	mA
Measurement Capacitance <sup>1), 2)</sup>	$C_M$		5		40000	pF
Reference Capacitance Range <sup>2)</sup>	$C_R$		5		10000	pF
Output Voltage <sup>3)</sup>	$V_{OUT}$		1.0		4.0	V
Differential Output Voltage	$V_{DIFF}$	$V_{DIFF} = V_{OUT} - V_{REF}$	-1.5		1.5	V
Temperature Coefficient $V_{OUT}$ <sup>4)</sup>	$TC_{V_{OUT}}$	$dV_{OUT}/(dT \cdot V_{SPAN})$ @ $T_{amb} = -40 \dots 85^{\circ}\text{C}$			$\pm 200$	ppm/ $^{\circ}\text{C}$
Maximum Input Signal Frequency <sup>5)</sup>	$f_{sig,max}$	@ $f_{OSC} = 230\text{ kHz}$ , $C_{F1} = C_{F2} = 2\text{ nF}$		3.5		kHz
Minimal Response Time <sup>6)</sup>	$t_{RES,min}$	@ $f_{OSC} = 230\text{ kHz}$ , $C_{F1} = C_{F2} = 2\text{ nF}$		0.4		ms
<b>Oscillator</b>						
Oscillator Capacitor Range <sup>2)</sup>	$C_{OSC}$		20		11000	pF
Oscillator Frequency Range	$f_{OSC}$	$f_{OSC} = V_{REF} / (2 \cdot \Delta V_{OSC} \cdot R_{OSC} \cdot C_{OSC})$	1		240	kHz
Oscillator Voltage Amplitude	$\Delta V_{OSC}$		2.1	2.15	2.2	V
Oscillator Current Resistor	$R_{OSC}$		50		125	k $\Omega$
Oscillator Charge Current	$I_{OSC}$	$I_{OSC} = V_{REF} / R_{OSC}$	20		50	$\mu\text{A}$
Charge Current Spread	$I_{OSC,var}$	@ $R_{OSC} = 125\text{k}\Omega$	19	20	21	$\mu\text{A}$
<b>Reference Integrator (for <math>C_R</math>)</b>						
Min. Ref. Integrator Voltage	$V_{CR,min}$	@ Pin 16	1.15	1.2	1.25	V
Max. Ref. Integrator Voltage	$V_{CR,max}$	@ Pin 16		4.1		V
Ref. Integrator Current Resistor	$R_{CR}$		100		1250	k $\Omega$
Ref. Integrator Charge Current	$I_{CR}$	$I_{CR} = V_{REF} / R_{CR}$	2		25	$\mu\text{A}$
Charge Current Spread	$I_{CR,var}$	@ $R_{CR} = 1000\text{k}\Omega$	2.4	2.5	2.6	$\mu\text{A}$
<b>Measurement Integrator (for <math>C_M</math>)</b>						
Min. Meas. Integrator Voltage	$V_{CM,min}$	@ Pin 14	1.15	1.2	1.25	V
Max. Meas. Integrator Voltage	$V_{CM,max}$	@ Pin 14		4.1		V
Meas. Integrator Current Resistor	$R_{CM}$		100		1250	k $\Omega$
Meas. Integrator Charge Current	$I_{CM}$	$I_{CM} = V_{REF} / R_{CM}$	2		25	$\mu\text{A}$
Charge Current Spread	$I_{CM,var}$	@ $R_{CM} = 1000\text{ k}\Omega$	2.4	2.5	2.6	$\mu\text{A}$
<b>Lowpass Stage</b>						
Internal Resistor 1 and 2	$R_{01}, R_{02}$			20		k $\Omega$
Low Pass Filter Capacitors <sup>7)</sup>	$C_{F1}, C_{F2}$		2		500	nF
Corner Frequency	$f_c$	$R_{01} = R_{02} = 20\text{k}\Omega$ , $C_{F1} = C_{F2} = 2\text{ nF}$			4	kHz
LP-Stage Voltage Input	$V_{LP,in}$		0.8		4.2	V
Offset Voltage	$V_{LP,ofs}$	between Pin 15 and 13, $V_{LP,in} = V_{REF}$	-2		2	mV

# CAV424

## C/V-converter for single and differential capacitive input signals

Output Stage						
Adjustable Gain	$G$		1			
Output Current	$I_{OUT}$	Source, Sink <sup>8)</sup>	-100		100	$\mu\text{A}$
Resistive Load at Pin $V_{OUT}$	$R_L$		40			$\text{k}\Omega$
Capacitive Load at Pin $V_{OUT}$	$C_L$				100	$\text{pF}$
Input Offset Voltage	$V_{OFS}$	$R_L = 100 \text{ M}\Omega$	-2		2	$\text{mV}$
Reference $V_{REF}$						
Reference Voltage	$V_{REF}$	$V_{REF} = V_{CC} / 2$	2.49	2.5	2.51	$\text{V}$
Temperature Coefficient	$\text{TC}_{VREF}$	$dV_{REF} / (dT \cdot V_{REF})$ , $T_{amb} = -40 \dots +105^\circ\text{C}$			$\pm 50$	$\text{ppm}/^\circ\text{C}$
Current	$I_{VREF}$	Source, Sink <sup>8)</sup>	-100		100	$\mu\text{A}$
Load Capacitance	$C_{VREF}$		80	100	120	$\text{nF}$
Temperature Sensor $V_{TEMP}$						
Output Voltage	$V_{TEMP}$	$R_{TEMP} \geq 50 \text{ M}\Omega$	2.20	2.32	2.45	$\text{V}$
Sensitivity	$S$	$S = dV_{TEMP} / dT$ , $R_{TEMP} \geq 50 \text{ M}\Omega$		8		$\text{mV}/^\circ\text{C}$
Resistive Load	$R_{TEMP}$		10			$\text{M}\Omega$
Thermal Nonlinearity	$NL_{TEMP}$	$R_{TEMP} \geq 50 \text{ M}\Omega$ , end point meth.		0.5		$\%$

**Table 1: CAV424's electric specifications**

### Notes:

- 1) If a small deviation ( $< 1\%$ ) from equation (8) (or (11) resp.) is needed, a maximum measurement capacitance  $C_{M,max}$  not larger than ten times the particular minimum measurement capacitance  $C_{M,min}$  should be used.
- 2) The specified value doesn't include parasitic IC capacitance (typ. 5 pF for SO16(n) package at pin 12, 14 and 16).
- 3) If  $V_{CC} \neq 5 \text{ V}$ , the maximum of  $V_{OUT}$  is given by  $0.8 \cdot V_{CC}$ .
- 4) The temperature coefficient is normalized with  $V_{Span} = V_{OUT}(C_{M,max}) - V_{OUT}(C_{M,min})$ .
- 5) The maximum input signal frequency  $f_{SIG,max}$  is defined as the measurement capacitance's change rate, at which the low pass filter reduces the output voltage by 6 dB.
- 6) The response time is defined as the time until  $V_{OUT}$  reaches 99.99% of its final value after a 100 % input step.
- 7) The typical dimensioning of the low pass capacitors  $C_{F1}$  and  $C_{F2}$  is based on the requirement that a ripple of less than 1‰ remains on the output voltage at the oscillator frequency. Smaller capacitances can be chosen to decrease the response time but lead to a higher ripple.
- 8) Currents flowing into the IC have a negative sign.

## 2. Absolute Maximum Values

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Maximum Supply Voltage	$V_{CCmax}$		6			$\text{V}$
Maximum Oscillator Charge Current	$I_{OSCmax}$		50			$\mu\text{A}$
Max. Meas. Oscillator Charge Current	$I_{CMmax}$		25			$\mu\text{A}$
Max. Ref. Oscillator Charge Current	$I_{CRmax}$		25			$\mu\text{A}$
Storage Temperature	$T_{Store}$		-55		125	$^\circ\text{C}$
ESD Susceptibility	$V_{ESD}$	HBM		2		$\text{kV}$

**Table 2: Absolute Maximum Values**

### Notes:

- 1) ESD Protection on all pins except pin 12, pin 14 and pin 16.

# CAV424

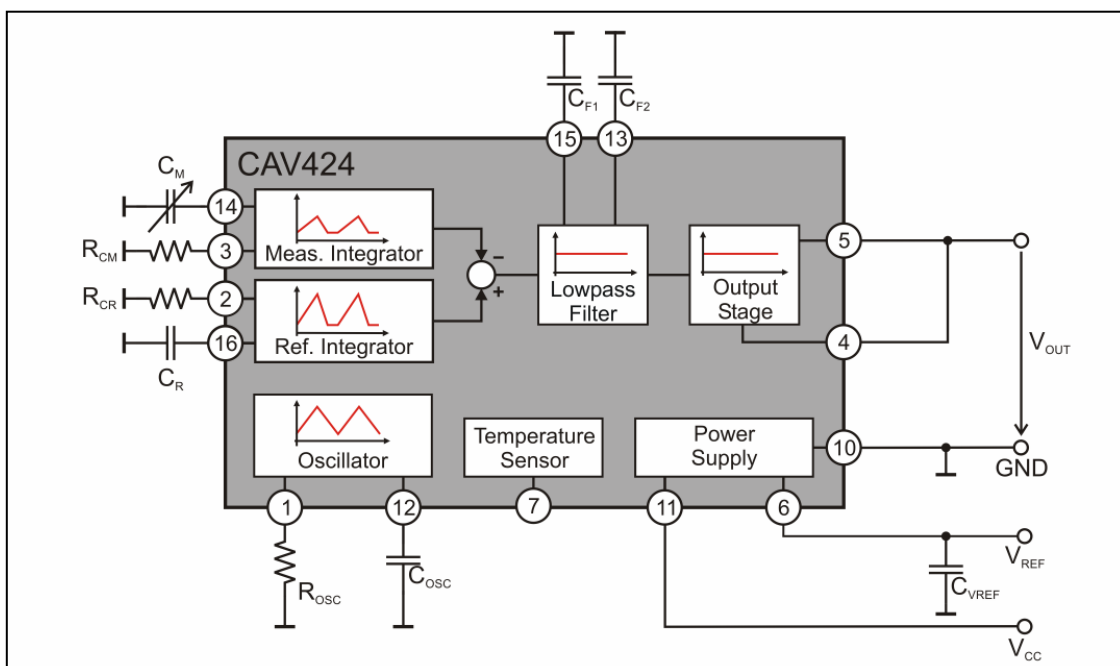
## C/V-converter for single and differential capacitive input signals

### FUNCTIONAL PRINCIPLE

CAV424's functional principle is described using *Figure 2*, where the functional blocks of the IC, the signal patterns inside the IC and a basic external circuit with necessary passive components are illustrated.

The IC consists of seven functional blocks: the oscillator, the measurement integrator, the reference integrator, the low pass filter, the output stage, the temperature sensor and the power supply. The power supply block drives all the other blocks and also generates a reference voltage of 2.5 V. The temperature sensor block provides an output voltage  $V_{TEMP}$  proportional to the IC's temperature. The capacitance measurement path consists of the remaining five blocks and is described below.

CAV424 uses a differential measurement principle to evaluate the measurement capacitance  $C_M$ . Using two symmetric integrator blocks  $C_M$  is measured against a reference capacitance  $C_R$ . Both capacitances are charged and discharged synchronously with constant current by their separate integrator blocks. The charge currents for  $C_M$  and  $C_R$  can be adjusted using  $R_{CM}$  and  $R_{CR}$  respectively. The time constant for the charge and discharge process is given by the oscillator block, whose frequency can be adjusted using  $C_{OSC}$  and  $R_{OSC}$ . The measurement and the reference integrator both generate a sawtooth output voltage with an amplitude proportional to  $1/C_M$  and  $1/C_R$  respectively. At the low pass stage the difference of these sawtooth output voltages is converted into a DC voltage. The output voltage  $V_{OUT}$  at pin 5 is ratiometric to the supply voltage and is a linear function of  $1/C_M$ . It can be referenced to GND or to pin 6 to obtain the differential output voltage  $V_{DIFF} = V_{OUT} - V_{REF}$ . Using the circuit in *Figure 6* the output signal's offset and gain can be adjusted too.



**Figure 2: CAV424 with signal path and a basic circuit**

# CAV424

## C/V-converter for single and differential capacitive input signals

### FUNCTIONAL DESCRIPTION

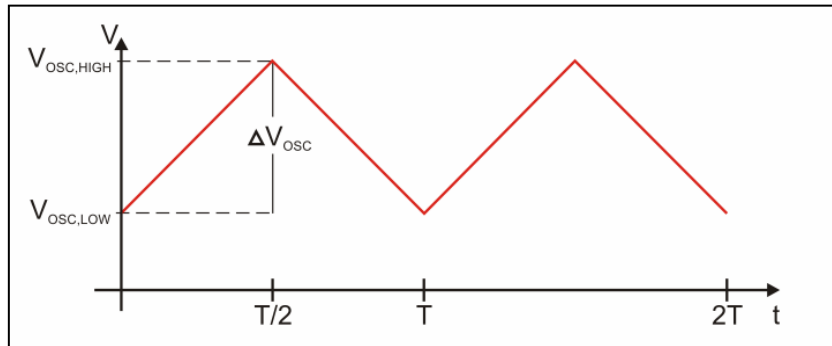
#### 1. Oscillator

To generate a clock for the integrator blocks, the oscillator block charges and discharges the external oscillator capacitance  $C_{OSC}$  periodically with a constant current given by:

$$I_{OSC} = \frac{V_{REF}}{R_{OSC}} \quad (1)$$

where  $V_{REF}$  is the reference voltage and  $R_{OSC}$  is the oscillator current resistor.

The time dependent voltage at the oscillator capacitance is illustrated in *Figure 3*.  $C_{OSC}$  is charged with  $I_{OSC}$  beginning at the oscillator's lower threshold  $V_{OSC,LOW}$  until the upper threshold  $V_{OSC,HIGH}$  is reached. Then the current's direction is reversed and  $C_{OSC}$  is discharged until the lower threshold is reached again.



**Figure 3: Oscillator voltage signal over time**

This leads to a triangular voltage signal at  $C_{OSC}$  with the frequency  $f_{OSC}$ :

$$f_{OSC} = \frac{I_{OSC}}{2 \cdot \Delta V_{OSC} \cdot C_{OSC}} = \frac{2.5}{4.2 \cdot R_{OSC} \cdot C_{OSC}} \quad (2)$$

with  $\Delta V_{OSC} = 2.1 \text{ V}$  and  $V_{REF} = 2.5 \text{ V}$  (@  $V_{CC} = 5 \text{ V}$ ).

#### 2. Measurement and Reference Integrators

The measurement and reference integrator blocks are the core part of the measurement path. At these symmetrically built integrators the connected capacitances' values are converted into a voltage signal. Both integrators are driven by the oscillator block and charge and discharge the connected capacitances with constant current.

As illustrated in *Figure 4*, for half a period the measurement capacitance  $C_M$  is charged with  $I_{CM}$  and the reference capacitance  $C_R$  is charged with  $I_{CR}$ , which are given by

$$I_{CM} = \frac{V_{REF}}{R_{CM}} \quad \text{and} \quad I_{CR} = \frac{V_{REF}}{R_{CR}} \quad (3)$$

where  $R_{CM}$  and  $R_{CR}$  are the measurement and reference integrator current resistors. The capacitances  $C_M$  and  $C_R$  are charged to a maximum voltage of  $V_{CM}$  and  $V_{CR}$  respectively, which can be calculated as follows:

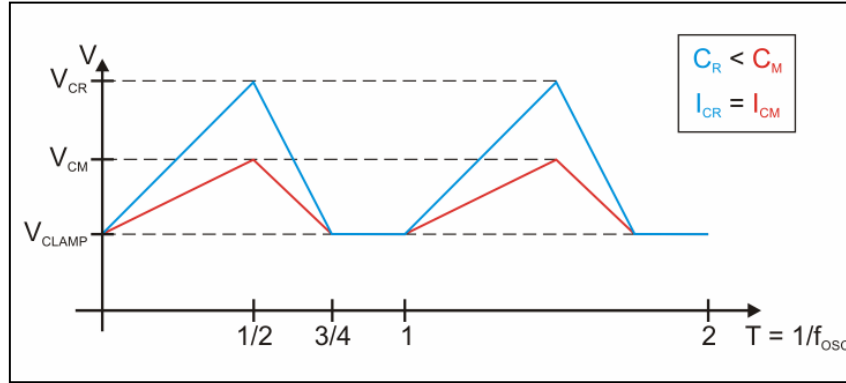
$$V_{CM} = \frac{I_{CM}}{2 \cdot f_{OSC} \cdot C_M} + V_{CLAMP} \quad \text{and} \quad V_{CR} = \frac{I_{CR}}{2 \cdot f_{OSC} \cdot C_R} + V_{CLAMP} \quad (4)$$

with  $V_{CLAMP} = 1.2 \text{ V}$ , which is the minimum integrator voltage.

# CAV424

## C/V-converter for single and differential capacitive input signals

Then for the next quarter of a period the capacitances  $C_M$  and  $C_R$  are discharged with twice the charge current ( $2 \cdot I_{CM}$  and  $2 \cdot I_{CR}$ ) until  $V_{CLAMP}$  is reached.  $V_{CLAMP}$  is held for the last quarter of the period. Afterwards this cycle starts again.



**Figure 4: Measurement and reference integrator voltage signals over time**

### 3. Signal Processing Unit (Low Pass Filter and Output Stage)

To generate a single voltage from the measurement and reference integrator voltage signals,  $V_{CM}$  and  $V_{CR}$  are subtracted from each other and  $V_{REF}$  is added. The resulting maximum voltage at the low pass stage's input is given by:

$$V_{LP.in}^{max} = (V_{CR} - V_{CM}) + V_{REF} = \frac{V_{REF}}{2 \cdot f_{OSC}} \left( \frac{1}{R_{CR} \cdot C_R} - \frac{1}{R_{CM} \cdot C_M} \right) + V_{REF} \quad (5)$$

This voltage is integrated and averaged by the low pass filter block, which consists of two passive first order low pass RC-networks decoupled by an operational amplifier. The filter resistors  $R_{01} = R_{02} = 20 \text{ k}\Omega$  are implemented in CAV424 and the filter capacitors  $C_{F1}$  and  $C_{F2}$ , which are external components, define the corner frequency  $f_c$ :

$$f_c = \frac{1}{2\pi \cdot 20\text{k}\Omega \cdot C_{Filter}} \quad \text{with} \quad C_{Filter} = C_{F1} \text{ or } C_{F2}. \quad (6)$$

Typically the filter capacitors are chosen in such a way that  $C_{F1} = C_{F2}$  and  $f_c = 10 \cdot f_{OSC}$ , leading to a ripple smaller than 1 % of the output signal. The DC voltage at low pass filter's output is given by:

$$V_{LP}^{DC} = \frac{3}{8} \cdot (V_{CR} - V_{CM}) + V_{REF} = \frac{3}{8} \cdot R_{OSC} \cdot C_{OSC} \cdot \Delta V_{OSC} \cdot \left( \frac{1}{R_{CR} \cdot C_R} - \frac{1}{R_{CM} \cdot C_M} \right) + V_{REF} \quad (7)$$

Using the circuit in *Figure 2* this DC voltage is impedance transformed by the output stage. For this case the output voltage  $V_{OUT}$  at pin 5 is given by equation (8).

The DC voltage can be amplified and offset adjusted using the circuit in *Figure 6*. For that case the output voltage  $V_{OUT}$  at pin 5 is given by equation (11).



# CAV424

## C/V-converter for single and differential capacitive input signals

### APPLICATION INFORMATION

#### 1. Transfer Function

For the capacitive sensor system shown in *Figure 2* the output voltage  $V_{OUT}$  at pin 5, which is referenced to GND, is given by:

$$V_{OUT}(C_M) = \left( \frac{3}{8} \cdot \Delta V_{OSC} \cdot C_{OSC} \cdot R_{OSC} \right) \cdot \left( \frac{1}{R_{CR} \cdot C_R} - \frac{1}{R_{CM} \cdot C_M} \right) + V_{REF} \quad (8)$$

with

$C_M$  = variable measurement capacitance

$C_R$  = reference capacitance

$C_{OSC}$  = oscillator capacitance

$R_{CM}$  = measurement integrator current resistor

$R_{CR}$  = reference integrator current resistor

$R_{OSC}$  = oscillator current resistor

$\Delta V_{OSC}$  = voltage amplitude at the oscillator (with  $\Delta V_{OSC} = 2.15 \text{ V} @ V_{CC} = 5 \text{ V}$ )

$V_{REF}$  = reference voltage ( $V_{REF} = 2.5 \text{ V} @ V_{CC} = 5 \text{ V}$ )

Using equation (8) it is easy to see that the output voltage is a linear function of the reciprocal measurement capacitance  $1/C_M$ . The following relationships can be used to reduce the number of parameters and to ensure that CAV424 works properly:<sup>1</sup>

$$R_{CR} \cdot C_R = R_{CM} \cdot C_{M,min} \quad \text{and} \quad C_{OSC} = 0.55 \cdot \frac{R_{CM}}{R_{OSC}} \cdot C_{M,min} \quad (9)$$

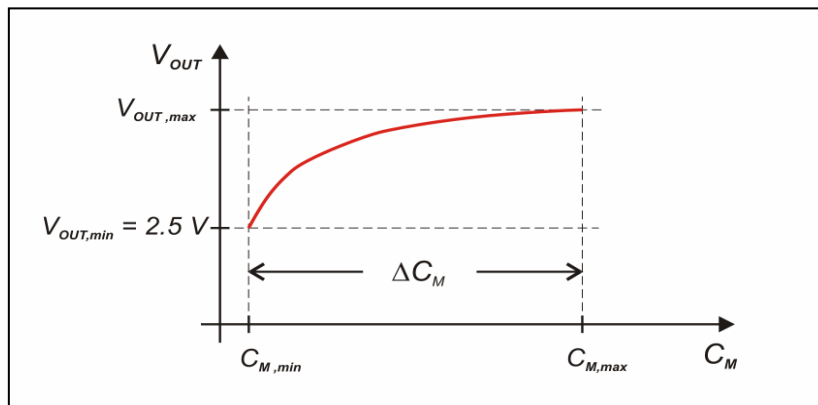
wherein  $C_{M,min}$  is the specific minimum measurement capacitance of the measurement setup.

Inserting (9) into (8) leads to the following easy transfer function,

$$V_{OUT}(C_M) = 0.44 \cdot \left( 1 - \frac{C_{M,min}}{C_M} \right) + V_{REF} \quad (10)$$

wherein  $V_{OUT}$  only depends on  $C_{M,min}$  and  $C_M$ .

Equation (10) is illustrated in *Figure 5* for the measurement range  $\Delta C_M = C_{M,max} - C_{M,min}$ , wherein  $C_{M,max}$  is the specific maximum measurement capacitance of the measurement setup. For  $C_M = C_{M,min}$  equation (10) leads to  $V_{OUT}(C_{M,min}) = V_{REF}$ .



**Figure 5: Output signal  $V_{OUT}$  as a function of the measurement capacitance  $C_M$**

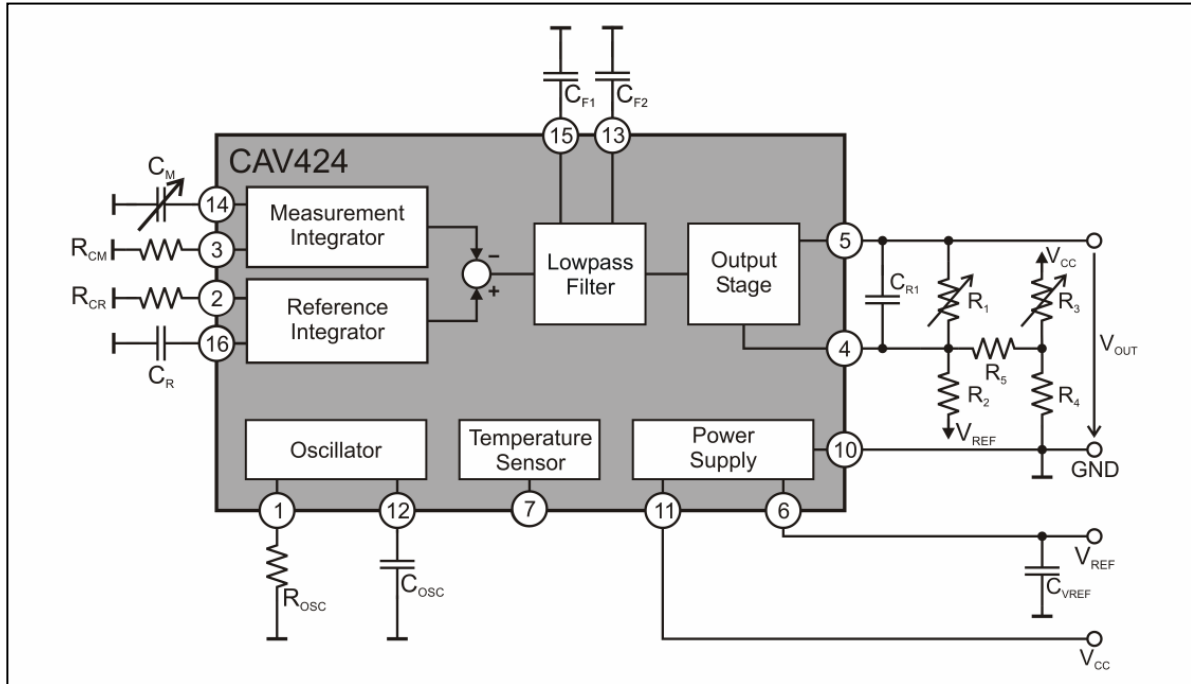
<sup>1</sup> For an optimal and easy dimensioning of the external passive components Analog Microelectronics has developed the Excel-sheet, Kali\_CAV424 (see section "Further Literature").

# CAV424

## C/V-converter for single and differential capacitive input signals

### 2. CAV424 used as C/V-converter with adjustable gain and offset

For the adjustment of the output signal's offset and gain five resistors  $R_1 \dots R_5$  have to be added to the network in Figure 2. The complete measurement circuit with CAV424 is illustrated in Figure 6.



**Figure 6: CAV444 used as C/V-converter with adjustable gain and offset**

For the capacitive measurement system in Figure 6 the output voltage  $V_{OUT}$  at pin 5 (referenced to GND) is given by:

$$V_{OUT} = G \cdot \left( \frac{3}{8} \cdot \Delta V_{OSC} \cdot C_{OSC} \cdot R_{OSC} \right) \cdot \left( \frac{1}{R_{CR} \cdot C_R} - \frac{1}{R_{CM} \cdot C_M} \right) + B \cdot V_{REF} \quad (11)$$

with

$$G = 1 + \frac{R_1}{R_2} + \frac{R_1}{R_5} \cdot \frac{R_3 R_5 + R_4 R_5}{R_3 R_4 + R_4 R_5 + R_3 R_5} \quad \text{and} \quad B = 1 + \frac{R_1}{R_5} \cdot \frac{R_3 R_5 - R_4 R_5}{R_3 R_4 + R_4 R_5 + R_3 R_5} \quad (12)$$

wherein  $R_2$ ,  $R_4$  and  $R_5$  are fixed resistors,

$R_1$  is the trimming resistor for the adjustment of gain and

$R_3$  is the trimming resistor for the adjustment of offset.

Using the equations (11) and (12) it is easy to see that the output voltage is again a linear function of the reciprocal measurement capacitance  $1/C_M$ .

Inserting (9) into (11) leads to the following easy transfer function,

$$V_{OUT}(C_M) = 0.44 \cdot G \cdot \left( 1 - \frac{C_{M,min}}{C_M} \right) + B \cdot V_{REF} \quad (13)$$

wherein  $V_{OUT}$  only depends on  $C_{M,min}$  and  $C_M$ .

# CAV424

## C/V-converter for single and differential capacitive input signals

### 3. Standard Dimensioning

A basic dimensioning of the passive external components in *Figure 6* with a measurement capacitance not larger than 1 nF is given in the table below. For the application specific capacitance ranges or if  $C_R$  is given by the measurement setup an optimal dimensioning can be calculated using the Excel-sheet Kali\_CAV424.

Parameter	Symbol	Min.	Typ.	Max.	Unit
Reference Capacitor	$C_R$		$C_{M,min}$		pF
Oscillator Capacitor	$C_{OSC}$		$4.4 * C_{M,min}$		pF
Measurement Integrator Current Resistor	$R_{CM}$		1000		k $\Omega$
Reference Integrator Current Resistor	$R_{CR}$		1000		k $\Omega$
Oscillator Current Resistor	$R_{OSC}$		125		k $\Omega$
Low Pass Filter Capacitors <sup>1)</sup>	$C_{F1}, C_{F2}$		500		nF
Output Stage Resistor (1%)	$R_2, R_4, R_5$		100		k $\Omega$
Full-Scale Resistor (0.1%) Calibration Meas. Value <sup>2)</sup>	$R_{1(start)}$		100		k $\Omega$
Offset Resistor (0.1%) Calibration Meas. Value <sup>2)</sup>	$R_{3(start)}$		100		k $\Omega$
Reference Voltage Capacitor ( $V_{REF} = 2.5V$ ) <sup>3)</sup>	$C_{VREF}$	80	100	120	nF

**Table 3: Standard dimensioning at  $I_{CM} = I_{CR} = 2.5 \mu A$ ,  $I_{OSC} = 20 \mu A$ ,  $C_{M,max} < 1 nF$ ,  $C_R = C_{M,min}$**

#### Notes:

- 1) The optimal value of  $C_{F1}$  and  $C_{F2}$  depends on the oscillator frequency. The given value can be used for  $C_{M,min}$  from 5 pF to 1000 pF, but leads to a slow response time.
- 2)  $R_1 = R_3 = 100 k\Omega$  are used to measure the output voltages at  $C_{M,min}$  and  $C_{M,max}$  at the start of the trimming process. During the trimming process  $R_1$  and  $R_3$  will be set to individual values (calculated by the Excel-sheet Kali\_CAV424).
- 3) For best performance a high grade ceramic capacitor has to be used for  $C_{VREF}$ .
- 4) Usually it is sufficient to use standard components with low temperature coefficients ( $\leq 100$  ppm). For  $R_{CM}$ ,  $R_{CR}$ ,  $R_{OSC}$ ,  $C_{VREF}$  and  $C_{F1/F2}$  a variance of 5% of the given values is acceptable without a decrease in performance. For components, which have to have lower variances, the tolerances are given in round brackets in *Table 3*.

### 4. Calibration Procedure

During the design of capacitive sensor systems it always has to be taken into account that there are parasitic capacitances beside the connected measurement capacitance, which influence the output signal and the calibration process. To simplify the consideration of these effects during the calibration of sensor systems, Analog Microelectronics developed a calibration strategy, implemented in the Excel-sheet Kali\_CAV424. This Excel-sheet, based on the circuit in *Figure 6*, is available free of charge at [www.analogmicro.de](http://www.analogmicro.de).

Using this strategy the calibration of sensor systems with CAV424 is done in two steps, a dimensioning and a trimming step. At first a dimensioning of the external components is calculated for the specific type of sensor implemented with CAV424. This dimensioning is mostly dependent on the capacitive measurement range of the sensor. Based on a few input values characterizing the capacitive sensor system the program calculates a suitable dimensioning of the remaining external components.

After the specific sensor systems have been built with the calculated dimensioning a trimming of offset and gain (using the trimming resistors  $R_1$  and  $R_3$ ) of the individual sensor systems has to be done. Therefore the output voltage has to be measured at the minimum and the maximum measurement capacitance. Based on these values the Excel-sheet calculates the final trimming resistor values for  $R_1$  and  $R_3$ . After trimming  $R_1$  and  $R_3$  to the calculated values the sensor is ready for operation and all parasitic capacitances as well as the tolerances of the used components are taken into account.

# CAV424

## C/V-converter for single and differential capacitive input signals

### 5. Operation Instructions

For first investigations Analog Microelectronics offers the BBCAV424, a pre-assembled breadboard (see section “Accessories”) with easily adaptable measurement capacitance ranges, which can be used to study the behavior of capacitance sensor heads as well.

Capacitive measurement heads with a single capacitive output signal have to be connected to pin 14 (CM). In this case the reference capacitance is typically chosen as a ceramic capacitor with  $C_R = C_{M,min}$ , where  $C_{M,min}$  is the specific minimum measurement capacitance.

If a differential capacitive measurement head with a measurement and an integrated reference capacitance is used, a differential measurement can be made by connecting the measurement capacitance to pin 14 (CM) and the reference capacitance to pin 16 (CR).

For both cases it is recommended to do the external component's dimensioning using the Excel-sheet Kali\_CAV424. To consider possible production variances in the capacitive measurement heads it is recommended to do the dimensioning using the specific minimal value of  $C_{M,min}$  and the maximal value of  $C_{M,max}$ . If a reference capacitance is integrated in the measurement head, the minimal reference capacitance value should be used for  $C_R$  as well.

To realize the dimensioning, calculated by the Excel-sheet, networks of not more than two resistors or capacitors should be used. In many applications it is sufficient to use standard components, like e-series capacitors, which fit to the calculated values within 5% (see section “Standard Dimensioning”).

For the PCB layout it is recommended to keep conducting lines from the IC to its external passive components short, leading to small parasitic capacitances. Furthermore the conducting lines for  $C_M$  and  $C_R$  should be routed symmetrically.

The parasitic capacitances in the sensor setup enlarge the used capacitances, especially the measurement, the reference and the oscillator capacitance and influence the capacitance measurement directly. It is important to keep the parasitic capacitances as small and stable as possible. If flexible wiring has to be used, then only shielded wires should be used for  $C_M$  and  $C_R$  and the wires should be kept as short as possible.

The parasitic capacitances inside the IC have to be considered as well if small capacitances have to be measured. Typically a parasitic capacitance of 5 pF is added to the connected capacitance at pin 12, 14 and 16, when the SO16(n) package is used.

CAV424's differential measurement principle can be used to reduce the susceptibility against electromagnetic disturbances. To use the benefits of this measurement principle  $C_M$  and  $C_R$  should be placed close to each other and their wiring should be kept symmetrical.

In real sensor applications the temperature behavior is mainly influenced by  $C_M$ 's,  $C_R$ 's and  $C_{OSC}$ 's and further external component's temperature coefficients (TCs). In general an optimal temperature behavior can be achieved by using  $C_{OSC}$  with a low TC and  $C_M$  and  $C_R$ , which have equal TCs.

In general ESD precautions are necessary during assembly and handling of the device. It is essential to ground machines and personnel properly.

Take care that the absolute maximum values in *Table 2* are not exceeded, when the device is put into operation.

Notes:

1. If the voltage signal at pin 12, 14 or 16 is measured using an oscilloscope, the probe's capacitance is added to the capacitance at the specific pin, which changes the output voltage signal. To check the frequency and the differential signal amplitude without influencing the output signal it is possible to remove the low pass filter capacitor  $C_{F1}$  and measure at pin 15.
2. For level sensing applications it is important to isolate the measurement electrode from a conductive medium. Otherwise the output voltage is affected by the medium's conductivity.

# CAV424

## C/V-converter for single and differential capacitive input signals

### PACKAGE AND PINOUT

The CAV424's standard packaging is a SO16 (n) package (for dimensions please see the packaging catalog <http://www.analogmicro.de/products/analogmicro.de.en.package.pdf>).

PIN	NAME	BESCHREIBUNG
1	<i>RCOSC</i>	Oscillator current adjustment
2	<i>RCR</i>	Integrator current adjustment for $C_R$
3	<i>RCM</i>	Integrator current adjustment for $C_M$
4	<i>GAIN</i>	Gain adjustment
5	<i>VOUT</i>	Output voltage
6	<i>VREF</i>	Reference voltage ca. 2.5V
7	<i>VTEMP</i>	Temperature sensor voltage output
8	<i>N.C.</i>	Not connected
9	<i>N.C.</i>	Not connected
10	<i>GND</i>	IC ground
11	<i>VCC</i>	Supply voltage
12	<i>COSC</i>	Oscillator capacitor
13	<i>CF2</i>	2 <sup>nd</sup> order lowpass capacitor
14	<i>CM</i>	Measurement capacitance
15	<i>CF1</i>	1 <sup>st</sup> order lowpass capacitor
16	<i>CR</i>	Reference capacitor

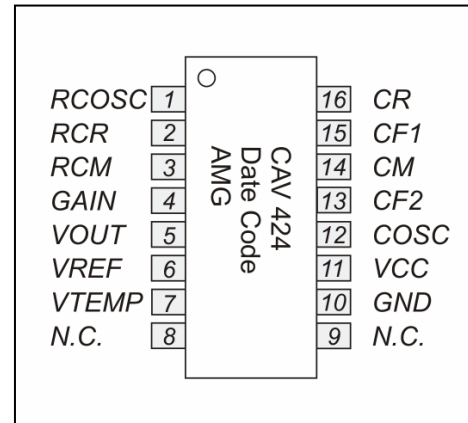


Figure 7: Pinout CAV424 SO16

Table 4: Pin assignment CAV424 SO16 Package

### DELIVERY FORMS

CAV424 is available as:

ORDER NUMBER	DELIVERY FORM
CAV424-0-SO16	CAV424 in an SO16(n) package
CAV424-WAF	Sawn wafer on 8" blue foil
CAV424-Adapt	CAV424 soldered to an SO16-DIL16 adapter

### ACCESSORIES

To support developments using CAV424 Analog Microelectronics GmbH offers the Breadboard BBCAV424.

ORDER NUMBER	DELIVERY FORM
BBCAV424	BBCAV424 – BreadBoard (PCB with CAV424)

# CAV424

## C/V-converter for single and differential capacitive input signals

### FURTHER LITERATURE

All documents below are available on the website: [www.analogmicro.de](http://www.analogmicro.de)

1. Excel-sheet Kali\_CAV424
2. Application Notes on CAV424
3. Package catalog (<http://www.analogmicro.de/products/analogmicro.de.en.package.pdf>)
4. CAV424 – Die Size and Padout (on request)

### NOTES

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Analog Microelectronics GmbH reserves the right to amend any dimensions, technical data or other information contained herein without prior notification.