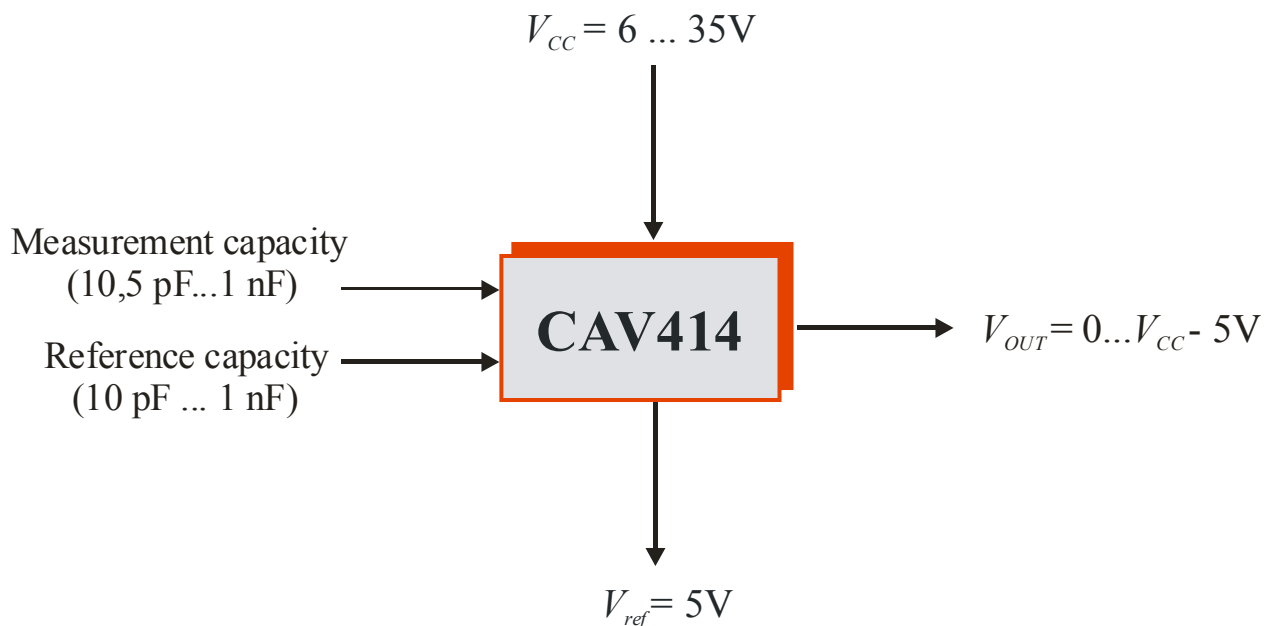


CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

PRINCIPLE FUNCTION

Measurement of a change in capacity in relation to a reference capacity. Conversion of the capacitive signal to an output voltage whose offset and full-scale signal can be adjusted externally across a wide range.



Typical applications

CAV414 is an integrated C/V transducer which can be used to build a capacitive linear encoder. The IC is suitable for all capacitive measurements which require a voltage output signal which is proportional to the change in the capacitance to be measured. It can be used for:

- Distance measurement
- Pressure sensing
- Humidity measurement
- Level sensing
- Load sensing
- Measurement of strength
- The IC can be used as a input circuit for microprocessors or as a stand-alone IC

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

Contents

FEATURES	3
GENERAL DESCRIPTION	3
BLOCK DIAGRAM	3
PRINCIPLE OF MEASUREMENT	4
HOW CAV414 WORKS	4
Oscillator function	5
Capacitive integrators	5
Signal conditioning	7
COMMENTS AND DEFINITIONS	9
EXTERNAL COMPONENTS	12
BOUNDARY CONDITIONS	12
THE DIMENSIONING PROCESS	13
EXAMPLE APPLICATIONS	14
Dimensioning the reference capacitance with a view to optimal linearity	14
Various example measurement capacitor configurations	15
Protective EMC circuitry	16
Shield circuit for cables with parasitic capacitances	17
BLOCK DIAGRAM AND PINOUT	18
DELIVERY	19
ADDITIONAL EQUIPMENT	19
FURTHER READING	19

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

FEATURES

- Adjustable full scale output voltage: 0...V_{cc}-5V
- Adjustable offset and gain
- High detection sensibility
- Wide capacitance measuring range: 5% – 100% relative to the reference capacitance, 10pF to 1nF
- Detection frequency of up to 2kHz
- Adjustable filter stages
- Wide supply voltage range of 6...35V
- Temperature range of -40°C...+85°C
- Internal 5V voltage reference
- Simple calibration (Excel program)
- Suitable for digital signal adjustment
- RoHS compliant

GENERAL DESCRIPTION

CAV414 is an integrated capacitance-to-voltage converter (C/V converter) which contains full signal conditioning and evaluation electronics for almost any source of capacitive signal. For a measurement capacitance of C_M CAV414 detects the relative change in capacitance $\Delta C_M = C_{M,max} - C_{M,min}$ in relation to that of a given, fixed reference capacitor C_R .

The IC can be used for reference capacitors of between 10pF and 1nF where the change in capacitance ΔC_M can be 5% to 100% of the reference capacitance C_R . This enables values $C_{M,min} = C_R$ and $C_{M,max} = 1.05 \cdot C_R$ to $2 \cdot C_R$ to be measured. The modular output stage enables output voltages to be adjusted using two external resistors within a voltage range of between 0 and V_{cc}-5V. Industrial values 0(5)...10V in particular can be easily set.

A short Excel program simplifies the dimensioning of CAV414 as stand alone IC.

BLOCK DIAGRAM

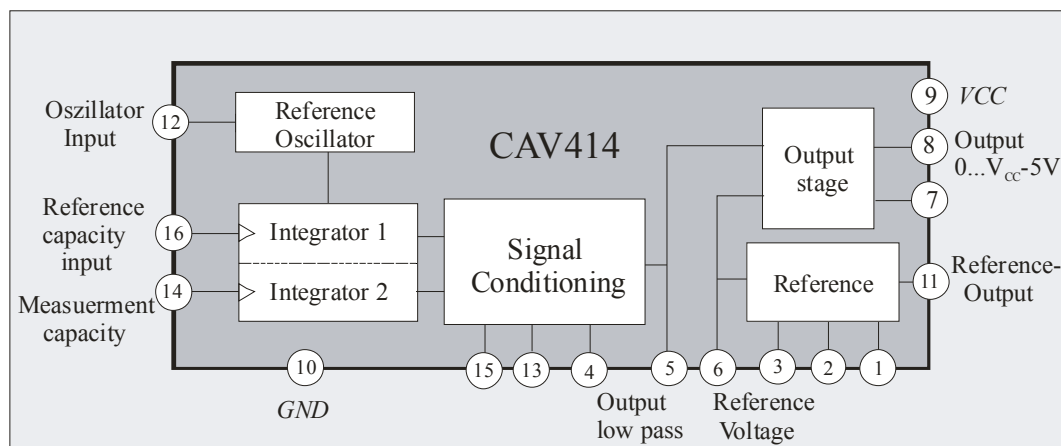


Figure 1: Block diagram of CAV414

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

PRINCIPLE OF MEASUREMENT

CAV414 is an integrated C/V converter which contains full signal conditioning and evaluation electronics for capacitive signal sources.

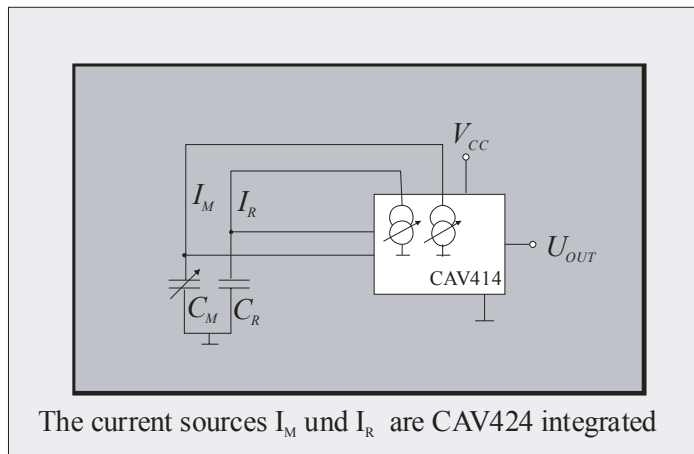


Figure 2: Principle of capacity measurement using CAV414

The principle of measurement behind CAV414 entails recording a change in capacitance in a sensor bridge comprising two adjustable constant current sources (integrated on CAV414) and two capacitors. The measurement capacitance (C_M) can be altered by the amount $\Delta C_M = C_{M,max} - C_{M,min}$. $C_{M,min}$ is the basic capacitance of C_M . The second capacitor is defined as a reference (C_R , see *Figure 2*). The change in measurement capacitance is compared to the fixed reference capacitance and the resulting signal converted into the output voltage.

HOW CAV414 WORKS

The CAV414 functions according to the following principle. An adjustable triangle voltage oscillator, the frequency of which is set using capacitor C_{OSC} , drives two identical integrators which are phase-locked and clock-synchronized (see *Figure 3*). The voltage amplitudes of the two driven integrators are determined by capacitors C_R and C_M . With high common-mode rejection and a high resolution, the difference between the two amplitudes produces a signal which corresponds to the difference in capacitance between C_R and C_M . This triangle difference signal is then filtered and smoothed in an ensuing active low pass. The resulting direct voltage signal passes on to an adjustable amplifier stage which sets the output signal to the required value.

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

If capacitors C_M and C_R are the same, following rectification and filtering (see *Figure 5*) a DC-voltage signal is generated with a value of 0. Should C_M change (measurement capacitor), a DC-voltage signal is produced which is proportional to ΔC_M .

If C_M and C_R are not the same, when $\Delta C_M = 0$ an offset would be generated at the output which is superimposed onto the actual direct voltage signal.

Oscillator function

The integrated oscillator charges up and then discharges the external oscillator capacitor C_{OSC} (see *Figure 3*).

Oscillator current I_{OSC} is determined by external resistor R_{OSC} and reference voltage V_M :

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

The oscillator frequency f_{OSC} is calculated as:

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

where ΔV_{OSC} is the difference between the thresholds of the internal oscillator ($V_{OSC,HIGH}$ and $V_{OSC,LOW}$). ΔV_{OSC} is defined via internal resistors in the IC and has a value of 2.1V which is independent of V_{CC} (see *Figure 3*). The oscillator frequency can thus be specified by the selection of R_{OSC} and C_{OSC} ; the relevant maximum and minimum values are given in *Table 1*.

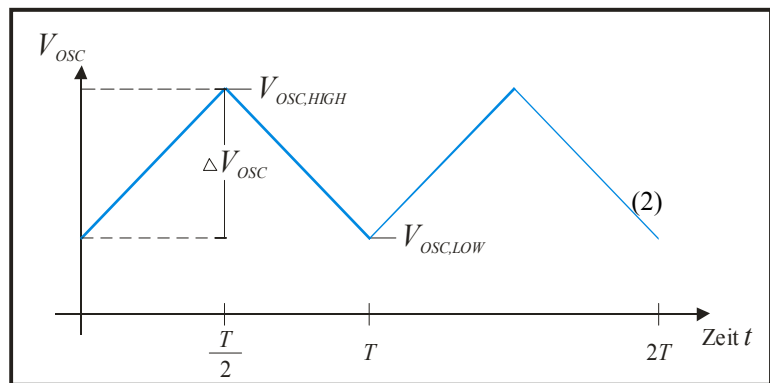


Figure 3: Oscillator voltage curve

Capacitive integrators

The built-in capacitive integrators function works in the same way as the mentioned oscillator. One difference lies in the discharge time, which here is half the length of the charge-up period.

Furthermore, the minimum oscillator voltage for the integrators is internally clamped to a value of $V_{CLAMP} = 1.2 \text{ V}$ (see *Figure 4*).

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

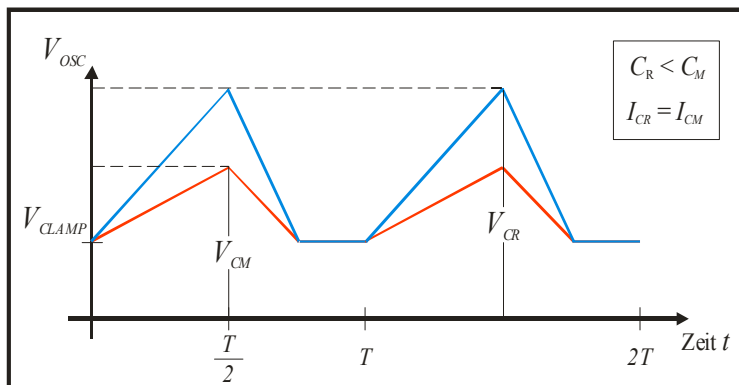


Figure 4: Integrator oscillator voltage

The capacitive integrator currents I_{CR} and I_{CM} are set by external resistors R_{CM} , R_{CR} and reference voltage V_M :

$$I_{CM} = \frac{V_M}{R_{CM}} \quad \text{and} \quad I_{CR} = \frac{V_M}{R_{CR}} \quad (3)^*, (4)^*$$

Capacitors C_M and C_R are charged up to a maximum voltage of V_{CM} and V_{CR} respectively and can be calculated as follows:

$$V_{CM} = \frac{I_{CM}}{2 \cdot f_{OSC} \cdot C_M} + V_{CLAMP} \quad (5)$$

$$V_{CR} = \frac{I_{CR}}{2 \cdot f_{OSC} \cdot C_R} + V_{CLAMP} \quad (6)$$

The two voltages V_{CM} and V_{CR} are subtracted from one another in the circuit's signal conditioning unit. Via this subtraction V_{CLAMP} is eliminated and a direct voltage of V_{TPAS} is produced as an output signal after filtering.

Should V_{CM} and V_{CR} be the same for $C_{M,min}$ (i.e. should the reference capacitance be the same as the basic value of the measurement capacitance), on subtraction and after smoothing a value of zero is obtained at the signal conditioning output (see *Figure 5*).

* The equations apply to $R_{CX} = 0$ (see *Figures 6 and 7*). Should $R_{CX} \neq 0$ for resistor R_{CX} due to better thermal coupling, the setup can be dimensioned using the Excel calibration spreadsheets *Kali1_cav414.xls* and *Kali2_cav414.xls*.

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

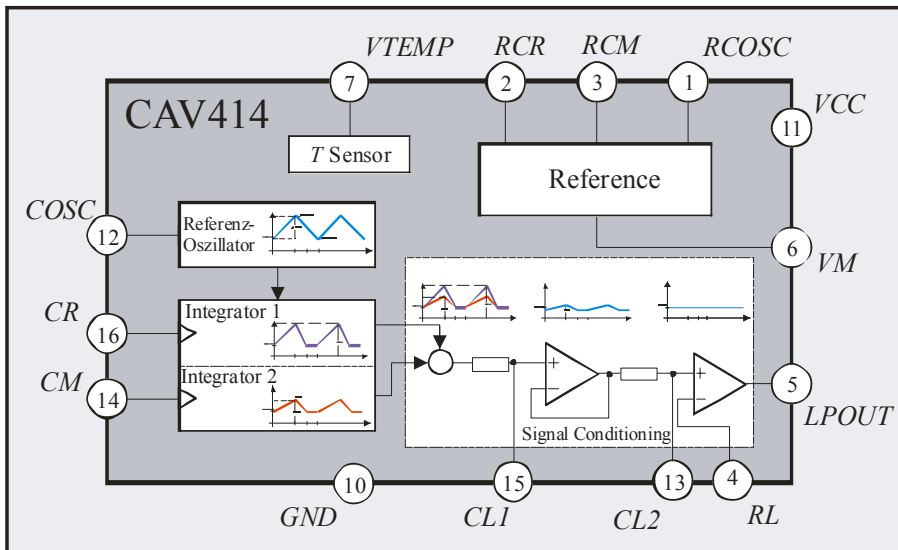


Figure 5: Block diagram and signal pattern

Signal conditioning

The filtered and smoothed direct voltage has a value of V_{TPAS} :

$$V_{TPAS} = \frac{3}{8} \cdot (V_{CM} - V_{CR}) \quad (7)$$

Signal V_{TPAS} can be boosted using the follow-on internal operational amplifier, with the degree of amplification G_{LP} being determined by resistors R_{L1} and R_{L2} . G_{LP} is calculated as:

$$G_{LP} = 1 + \frac{R_{L1}}{R_{L2}} \quad (8)$$

With (7), this results in:

$$V_{DIFF} = G_{LP} \cdot V_{TPAS} = G_{LP} \cdot \frac{3}{8} \cdot (V_{CM} - V_{CR})$$

According to *Figure 5* the following differential voltage is present between pins 5 and 6:

$$V_{DIFF} = V_{LPOUT} - V_{VM} \quad (9)$$

This voltage acts as an input voltage for the ensuing output stage which consists of an instrumentation and operational amplifier. The voltage is boosted by the internal instrumentation ampli-

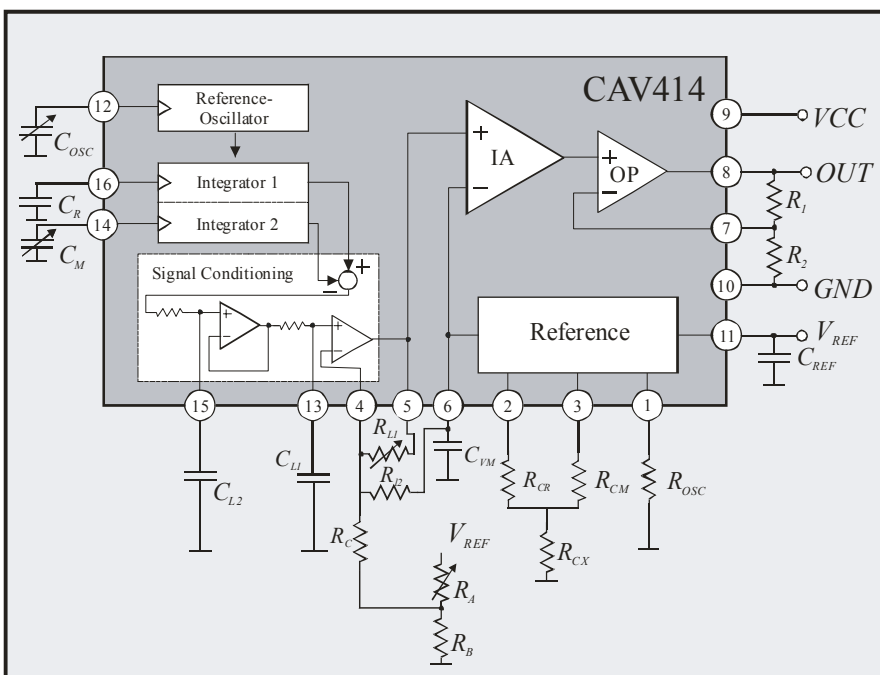
CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

fier (IA) with a fixed gain of $G_{IA} = 5$ and then by the operational amplifier (OP) with a gain of G_{OP} which can be adjusted using external resistors R_1 and R_2 .

The following transfer function is accrued:

$$V_{OUT} = G_{IA} \cdot G_{OP} \cdot V_{DIFF} = 5 \cdot \left(1 + \frac{R_1}{R_2} \right) \cdot V_{DIFF} \quad (10)$$

$V_{OUT} = f(C_M, (C_R), f_{osc}, I_{CM}, I_{CR})$, where the basic values of C_M and C_R must be placed in a fixed ratio. f_{osc} and I_{CM} or I_{CR} act as parameters.



If load currents I_{CM} and I_{CR} are selected as constants, the oscillator frequency dependent on $C_{M,min}$ can be adjusted electrically by changing the oscillator capacitance using a voltage-controlled capacitor, for example (Varicap diode).

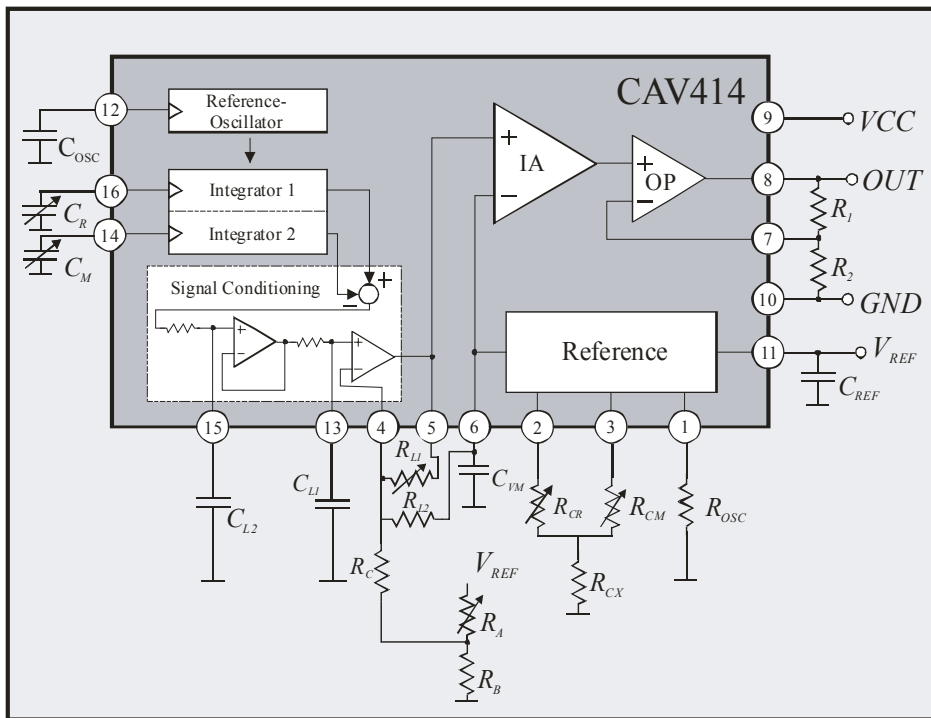
Figure 6: Functional diagram for CAV414 (with charging currents I_{CM} and I_{CR} constant)

Figure 6 assumes that the charging currents I_{CM} and I_{CR} are selected as constants. This means that with a change in the basic value of the measurement capacitance $C_{M,min}$ (as is the case when different objects are measured, for example) the oscillator frequency must be adjusted with each new measurement to an alternate $C_{M,min}$ value.

If oscillator frequency f_{osc} is to be set as a parameter, when $C_{M,min}$ is altered the two values I_{CM} and I_{CR} must also be adjusted. It is recommended that $I_{CM} = I_{CR}$.

Both procedures are equally effective; the choice thereof depends on the conditions stipulated by the application (see Figures 6 and 7).

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage



As a function of the measurement capacitance the output voltage is adjusted using resistors R_{CR} and R_{CM} .

If f_{OSC} is constant and $I_{CM}, I_{CR} = f(R_{CM}, R_{CR})$, the same equations apply (1 to 9) as for the case that I_{CM} and I_{CR} are constant and $f_{OSC} = f(C_M, C_R)$.

Figure 7: Functional diagram for CAV414 (with f_{osc} constant)

Comments and definitions

For dynamic measurements with periodically changeable measurement capacitances the various frequency ratios must be taken into account. Among other things the following applies: $f_{det} \ll f_{osc}$, where f_{det} is the detection frequency which gives the maximum change in measurement capacitance per unit of time. This is dependent on oscillator frequency f_{osc} itself. The following applies to the capacitance which determines the oscillator frequency:

$$C_{OSC} = 1.6 \cdot C_{M,min}$$

To achieve a high level of accuracy in the C/V conversion process it is necessary that resistors R_{CR} , R_{CM} and R_{OSC} have the same temperature coefficients and are placed as close together in the circuit as possible. The same applies to capacitors C_R , C_M and C_{OSC} .

I_{RCR}, I_{RCM} are the currents which must be set using resistors R_{CM} and R_{CR}

$I_C(CM), I_C(CR)$ are the load currents for capacitors C_M and C_R

$I_D(CM), I_D(CR)$ are the discharge currents for capacitors C_M and C_R

I_{OSC} is the load current of the reference oscillator (discharge current equal to load current here)

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

ELECTRICAL SPECIFICATIONS

$T_{amb} = 25^{\circ}\text{C}$, $V_{CC} = 24\text{V}$, $I_{REF} = 1\text{mA}$ (unless otherwise stated)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Supply						
Supply Voltage	V_{CC}		6		35	V
Quiescent Current	I_{CC}	$T_{amb} = -40 \dots 85^{\circ}\text{C}$, $I_{REF} = 0\text{mA}$		1.25	2.5	mA
Temperature Specifications						
Operating	T_{amb}		-40		85	$^{\circ}\text{C}$
Storage	T_{st}		-55		125	$^{\circ}\text{C}$
Junction	T_j				150	$^{\circ}\text{C}$
Thermal Resistance	Θ_{ja}	SO16 (n) plastic package		115		$^{\circ}\text{C}/\text{W}$
Oscillator						
Oscillator Capacitor Range	C_{OSC}	$C_{OSC} = 1.6 \cdot C_{M,min}$	14		1800	pF
Oscillator Frequency Range	f_{OSC}		1		130	kHz
Oscillator Current Ratio	I_{OSC}/I_C	$C_{OSC} = 1.6 \cdot C_{M,min}$		2		
Capacitive Integrators						
Reference Capacitor Range	C_R		10		1000	pF
Measurement Capacitor Range (min)	$C_{M,min}$	$C_{M,min} = C_R$	10		1000	pF
Measurement Capacitor Range (max)	$C_{M,max}$	$C_{M,max} = C_R + \Delta C_M$	10.5		2000	pF
Change in Capacitance C_M	$(\Delta C_M)/C_{M,min}$	$\Delta C_M = (C_{M,max} - C_{M,min})$	5		100	%
Adjustable Charge Current Source	I_{RCR} , I_{RCM}	$I_{RCM} = V_M/R_{CM}$ or $I_{RCR} = V_M/R_{CR}$	2		25	μA
Charge Current Ratio	$I_C(CM)/I_{RCM}$	$2\mu\text{A} \leq (I_{CX} = V_M/R_{CX}) < 5\mu\text{A}$	1.00	1.12	1.25	
	$I_C(CR)/I_{RCR}$	$5\mu\text{A} \leq (I_{CX} = V_M/R_{CX}) \leq 25\mu\text{A}$	0.95	1.05	1.15	
Discharge Current Ratio	$-I_D(CM)/I_{RCM}$	$2\mu\text{A} \leq (I_{CX} = V_M/R_{CX}) < 5\mu\text{A}$	1.85	2.10	2.25	
	$-I_D(CR)/I_{RCR}$	$5\mu\text{A} \leq (I_{CX} = V_M/R_{CX}) \leq 25\mu\text{A}$	1.80	1.95	2.10	
Detection Frequency	f_{DET}	$f_{DET} = f_{OSC}/65$	16		2000	Hz
Low Pass Stage						
Adjustable Gain	G_{LP}		1		10	
Output Voltage	V_{LPOUT}		$V_M - 0.4$		$V_M + 0.4$	V
Corner Frequency 1	f_{C1}	$R_{01} = 20\text{k}\Omega$, $C_{L1} = 1\text{nF}$			10	kHz
Corner Frequency 2	f_{C2}	$R_{02} = 20\text{k}\Omega$, $C_{L2} = 1\text{nF}$			10	kHz
Resistive Load at PIN LPOUT	R_{LOAD}		200			k Ω
Capacitive Load at PIN LPOUT	C_{LOAD}				50	pF
Temperature Coefficient V_{DIFF} (together with Input Stages)	dV_{DIFF}/dT	$T_{amb} = -40 \dots 85^{\circ}\text{C}$		± 100		ppm/ $^{\circ}\text{C}$
Internal Resistor 1 and 2	R_{01} , R_{02}			20		k Ω
Temperature Coefficient $R_{01,02}$	$dR_{01,02}/dT$	$T_{amb} = -40 \dots 85^{\circ}\text{C}$		1.9		$10^{-3}/^{\circ}\text{C}$
Power Supply Rejection Ratio (with the input stage)	PSSR	$I_{OUT} \leq 1\text{mA}$	80	90		dB
Voltage Reference V_{REF}						
Voltage	V_{REF}		4.75	5	5.25	V
V_{REF} vs. Temperature	dV_{REF}/dT	$T_{amb} = -40 \dots 85^{\circ}\text{C}$		± 90	± 140	ppm/ $^{\circ}\text{C}$

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Voltage Reference V_{REF} Part2						
Load Current	I_{REF}		0		9	mA
Load Capacitance	C_{REF}		1.9	2.2	5.0	μ F
Load Regulation	dV_{REF}/dI_{REF}			0.05	0.10	%/mA
Line Regulation	dV_{REF}/dI_{REF}	$I_{REF} = 4\text{mA}$		0.06	0.15	%/mA
	dV_{REF}/dV_{CC}	$V_{CC} = 6\text{V} \dots 35\text{V}$		30	80	ppm/V
	dV_{REF}/dV_{CC}	$V_{CC} = 6\text{V} \dots 35\text{V}, I_{REF} = 4\text{mA}$		60	150	ppm/V
Voltage Reference V_M						
Voltage	V_M		1.90	2	2.15	V
V_M vs. Temperature	dV_M/dT	$T_{amb} = -40 \dots +85^\circ\text{C}$		± 90		ppm/ $^\circ\text{C}$
Current	I_{VM}	Source			5	μ A
	I_{VM}	Sink			-5	μ A
Load Capacitance	C_{VM}		80	100	120	nF
Instrumentation Amplifier Input Stage						
Internal Gain	\tilde{G}_{IA}		4.9	5	5.1	
Differential Range	V_{IN}		0		500	mV
Common Mode Input Range	$CMIR$	$V_{CC} < 9\text{V}, I_{CV} < 2\text{mA}$	1.5		$V_{CC} - 3$	V
	$CMIR$	$V_{CC} \geq 9\text{V}, I_{CV} < 2\text{mA}$	1.5		6.0	V
Common Mode Rejection Ratio	$CMRR$		80	90		dB
Power Supply Rejection Ratio	$PSRR$			80		dB
Offset Voltage	V_{OS}			± 0.5	± 3.5	mV
V_{OS} vs. Temperature	dV_{OS}/dT				± 12	$\mu\text{V}/^\circ\text{C}$
Output Stage						
Adjustable Gain	G_{OP}		1			
Input Range	IR	$V_{CC} < 11\text{V}$	0		$V_{CC} - 5$	V
	IR	$V_{CC} \geq 11\text{V}$	0		6	V
Power Supply Rejection Ratio	$PSRR$	$I_{OUT} \leq 1\text{mA}$	80	90		dB
Offset Voltage	V_{OS}			± 0.5	± 2	mV
V_{OS} vs. Temperature	dV_{OS}/dT			± 3	± 7	$\mu\text{V}/^\circ\text{C}$
Input Bias Current	I_B			10	25	nA
I_B vs. Temperature	dI_B/dT			7	20	$\text{pA}/^\circ\text{C}$
Output Voltage Range	V_{OUT}	$V_{CC} < 19\text{V}$	0		$V_{CC} - 5$	V
	V_{OUT}	$V_{CC} \geq 19\text{V}$	0		14	V
Output Current Limitation	I_{LM}	$V_{CC} \geq 10\text{V}$	5	7	10	mA
Output Current	I_{OUT}		0		I_{LM}	mA
Load Resistance	R_L		2			k Ω
Load Capacitance	C_L				500	nF
Protection Functions						
Protection Against Reverse Polarity		Ground vs. V_{CC} vs. V_{OUT}			35	V

Table 1: Specifications for CAV414

Currents flowing into the IC are marked with a negative.

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

EXTERNAL COMPONENTS

External components which are independent of the measurement capacitance and remain unaltered during calibration are described as standard values:

Parameter	Symbol	Min.	Typ.	Max.	Unit
Low Pass Stage Resistors (1%)	R_{L2}, R_{L3}, R_B		100		k Ω
Output Stage Resistor (1%)	R_2		100		k Ω
Reference Voltage Capacity ($V_M = 2V$)	C_{VM}	80	100	120	nF
Reference Voltage Capacity ($V_{REF} = 5V$)	C_{REF}		2.2		μ F

Table 2: Standard values for fixed external components

For external components which are dependent on the measurement capacitance and contribute to the output signal (i.e. those which are adjusted during calibration), the following applies:

Parameter	Symbol	Min.	Typ.	Max.	Unit
Low Pass Stage Resistor (0.1%)	R_{L1}		22		k Ω
Low Pass Stage Resistor (0.1%)	R_A		200		k Ω
Output Stage Resistor (0.1%)	R_I	0	300		k Ω

Table 3: Standard values for variable external components

BOUNDARY CONDITIONS

The given boundary conditions must be kept to as such. They are taken into account in the dimensioning programs *Kali1_CAV414.xls* and *Kali2_CAV414.xls*.

Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Maximum Supply Voltage	V_{CCmax}				36	V
Oscillator Frequency Range	f_{OSC}		1		130	kHz
Reference Capacitive Integrator Current	I_{CR}		2		25	μ A
Measurement Capacitor Integrator Current	I_{CM}		2		25	μ A
Low Pass Stage Resistor Sum	$R_{L1} + R_{L2}$		90		200	k Ω
Output Stage Resistor Sum	$R_1 + R_2$		90		200	k Ω
V_{REF} Capacitance (5V Reference Voltage)	C_{REF}		1.9	2.2	5	μ F
V_M Capacitance (2V voltage used internally)	C_{VM}		80	100	120	nF
Low Pass Capacitance 1	C_{L1}		$100 \cdot C_R$	$200 \cdot C_R$		
Low Pass Capacitance 2	C_{L2}		$100 \cdot C_R$	$200 \cdot C_R$		
Oscillator Capacitance	C_{OSC}		$C_{OSC} = 1.55 \cdot C_R$	$C_{OSC} = 1.60 \cdot C_R$	$C_{OSC} = 1.65 \cdot C_R$	

Table 4: Boundary conditions

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

THE DIMENSIONING PROCESS

Programs *Kali1_cav414.xls* and *Kali2_cav414.xls* can be used for dimensioning purposes.

The dimensioning process takes the following scenarios into account:

- a) **Kali1_cav414.xls** – The integrator charging currents I_{CM} and I_{CR} are given and constant. Oscillator frequency f_{osc} must be adjusted to suit the minimum value of measurement capacitance $C_{M,min}$.
- b) **Kali2_cav414.xls** – Oscillator frequency f_{osc} is given and determined and integrator charging currents I_{CM} and I_{CR} must be adjusted to suit the minimum value of measurement capacitance $C_{M,min}$.

In a) the dimensioning process assumes that in addition to measurement capacitors C_M and C_R parasitic capacitances in both the IC and measurement circuit also influence the signal pattern. When dimensioning on the basis of the given equations a deviation from the theoretical value in the output characteristic must thus be reckoned with. For this reason a calibration algorithm has been developed (*Kali1_cav414.xls*) which at constant integrator charging currents (I_{CM} and I_{CR}) calculates a suitable oscillator frequency of f_{osz} depending on the minimum value of $C_{M,min}$ (basic capacitance). It then dimensions the resistors for the offset and signal span in such a way that the output signal adopts the required values.

Compensation of the sensor system is carried out in two stages. In *stage one* a calibration operating point is defined, during which process oscillator frequency f_{osc} is calculated depending on minimum measurement capacitance $C_{M,min}$. To this end the minimum and maximum values ($C_{M,min}$ and $C_{M,max}$) are entered in the Excel spreadsheet. The oscillator frequency, oscillator capacitance C_{OSC} and oscillator resistance R_{OSC} are then output. Gain resistor R_1 , which stipulates the final gain of the signal through the IA and OP, is also determined.

In addition low pass filter capacitances C_{L1} and C_{L2} are calculated which are dependent on the oscillator frequency. It is sufficient if these values are computed once for the largest expected value of minimum basic capacitance $C_{M,min}$ (for example during one production batch) and the relevant capacitors added to the circuit. The maximum signal frequency is also determined by which the measurement capacitance is permitted to change.

Taking the given, calculated external components and particularly predefined precision resistors $R_{L1(mess)}$ and $R_{L2(mess)}$, at the end of *stage one* we can calculate the output voltage $V_{LPOUT(mess)}$.

Important: $R_{L1(mess)}$ and $R_A(mess)$ must both be 100kOhm precision resistors with a tolerance of 0.1% maximum.

Output signal values $V_{LPOUT(mess)}$ are now entered in *stage two* of the calibration program. Using the measured values the algorithm now calculates the setpoint for the two calibration resistors R_{L1} and R_A which replace precision resistors $R_{L1(mess)}$ and $R_{L2(mess)}$ and must be individually mounted. Depending on the accuracy requirements of the setup their values should match those calculated as closely as possible.

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

Once the two calibration resistors R_{LI} and R_A have been replaced by precision resistors $R_{LI(mess)}$ and $R_{L2(mess)}$ the system is calibrated to the required output value – with all parasitic effects and tolerances taken into account.

In *stage one* of b), at a given fixed oscillator frequency of f_{osz} calibration spreadsheet *Kali2_cav414.xls* calculates the values of integration currents I_{CM} and I_{CR} which can be achieved by setting resistors R_{CM} and R_{CR} . Using these values and the other external elements output voltage $V_{LPOUT(mess)}$ is measured and the value entered into the calibration program. The rest of *stage two* is identical to the calibration procedure described in a).

EXAMPLE APPLICATIONS

Dimensioning the reference capacitance with a view to optimal linearity

When dimensioning the overall system it should be taken into account that there is a strong correlation between measurable variable $\Delta C_M = C_{M,max} - C_{M,min}$ and the non-linearity of the transfer characteristic. When $C_{M,max} = 2 \cdot C_{M,min}$, the change in signal capacitance is 100% with reference to $C_{M,min}$. This is the maximum permissible change in capacitance $C_{M,min}$. In this instance the non-linearity of the output voltage is greatest. Non-linearity of the characteristic curve is at its minimum when $C_{M,max} = 1,05 \cdot C_{M,min}$. In all cases $C_R = C_{M,min}$ applies to the reference capacitance.

If non-linearity NL is to be reduced for a given sensor, it is necessary to reduce the change in percent in $C_{M,max}$ with regard to $C_{M,min}$. This is possible if an additional capacitor C_{Par} is switched parallel to the circuit in addition to both C_M and C_R . This reduces the percentile change and thus the degree of non-linearity.

The following equation applies:

$$C_{Par} = \frac{C_{M,max} \cdot (-1 + NL)^2 - C_{M,min} \cdot (1 + NL)^2}{4 \cdot NL} \quad (11)$$

With the help of Equation (11) the necessary parallel capacitor C_{Par} can be determined dependent on $C_{M,max}$ and $C_{M,min}$ and the required degree of non-linearity NL . It must be taken into account that the capacitances which occur in the parallel circuitry are no greater than 2nF. This is the maximum permissible input capacitance. The oscillator frequency range (1kHz to 130kHz) and load current range (2µA to 25µA) may also not be exceeded. This can be verified by *Kali1_CAV414.xls* or *Kali2_CAV414.xls*.

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Various example measurement capacitor configurations

1) $C_{M,\min} = 10\text{pF}$, $C_{M,\max} = 20\text{pF}$, required linearity error **2%** $\rightarrow NL = 0.02$

According to (10), $C_{\text{Par}} = 110\text{pF}$

$\rightarrow C_{M,\min} // C_{\text{Par}} = 130\text{pF}$

$\rightarrow C_{M,\max} // C_{\text{Par}} = 120\text{pF}$

$\rightarrow C_{M,\max} / C_{M,\min} = 1.0833 \rightarrow (+8.33\%)$

2) $C_{M,\min} = 330\text{pF}$, $C_{M,\max} = 470\text{pF}$, required linearity error **4%** $\rightarrow NL = 0.04$

According to (10), $C_{\text{Par}} = 476.4\text{pF}$

$\rightarrow C_{M,\min} // C_{\text{Par}} = 806.4\text{pF}$

$\rightarrow C_{M,\max} // C_{\text{Par}} = 946.4\text{pF}$

$\rightarrow C_{M,\max} / C_{M,\min} = 1.1736 \rightarrow (+17.36\%)$

3) $C_{M,\min} = 100\text{pF}$, $C_{M,\max} = 160\text{pF}$, required linearity error **5%** $\rightarrow NL = 0.05$

According to (10), $C_{\text{Par}} = 170.75\text{pF}$

$\rightarrow C_{M,\min} // C_{\text{Par}} = 270.75\text{pF}$

$\rightarrow C_{M,\max} // C_{\text{Par}} = 330.75\text{pF}$

$\rightarrow C_{M,\max} / C_{M,\min} = 1.2216 \rightarrow (+22.16\%)$

4) $C_{M,\min} = 1000\text{pF}$, $C_{M,\max} = 1600\text{pF}$, required linearity error **7%** $\rightarrow NL = 0.07$

According to (10), $C_{\text{Par}} = 853.36\text{pF}$

$\rightarrow C_{M,\min} // C_{\text{Par}} = 2453.36\text{pF}$, **2nF exceeded!!**

$\rightarrow C_{M,\max} // C_{\text{Par}} = 1853.36\text{pF}$

$\rightarrow C_{M,\max} / C_{M,\min} = 1.3237 \rightarrow (+32.37\%)$

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Protective EMC circuitry

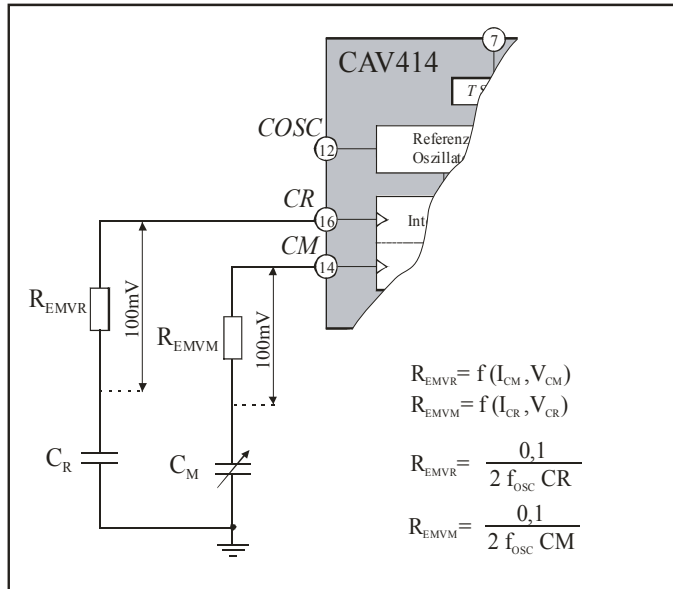


Figure 8: Protective EMC circuitry for CAV 414

When measuring capacitance the electrodes act like aerials for high-frequency disturbances. Measures must thus be taken to protect these high impedance inputs.

To protect against EMC resistors R_{EMVM} and R_{EMVR} are plugged into the supply lines servicing external capacitors C_M and C_R . Together with the parasitic and internal capacitances these act as low passes and thus suppress high-frequency disturbance factors.

The following applies:

$$R_{EMVM} = \frac{0.1V}{I_{CM}} \quad \text{and} \quad R_{EMVR} = \frac{0.1V}{I_{CR}}$$

Further protective EMC measures are not required for industrial applications.

As CAV414 has been manufactured using bipolar technology the IC is robust with regard to ESD.

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Shield circuit for cables with parasitic capacitances

With cables signal transmission can be disturbed by the presence of parasitic capacitances whose value is dependent on the capacitance per unit length and the length of the cable. It is thus advisable to install a shield circuit which can be realized using an additional operational amplifier.

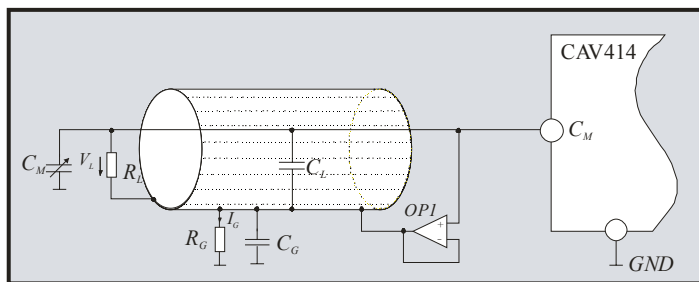


Figure 9: Shield circuitry

The components illustrated in Figure 9 are parasites of the cable alone. The only additional component required is the op amp which tracks the potential of the external lead to the internal wire ($v = 1$). Depending on the measurement setup the reference capacitor may also need a shield circuit. The same applies here as described for the measurement capacitor.

Operational amplifier requirements (OP)

The OP must have a sufficiently high slew rate in order to be able to recharge the external wire fast enough. The maximum load current must also be sufficient to recharge at maximum signal frequency. The necessary slew rate and load current are dependent on the signal frequency, the signal amplitude, the capacitance per unit length and the length of the cable. The OP must have unity gain.

The dual OP **AD8602** ($S_r = 5V/\mu s$, $I_{max} = 30mA$, unity gain) is recommended as a suitable operational amplifier. It is sufficient for most configurations and can shield both lines to signal capacitors C_M and C_R .

CAV414 – Capacity/voltage (C/V-) transducer IC with adjustable output voltage

BLOCK DIAGRAM AND PINOUT

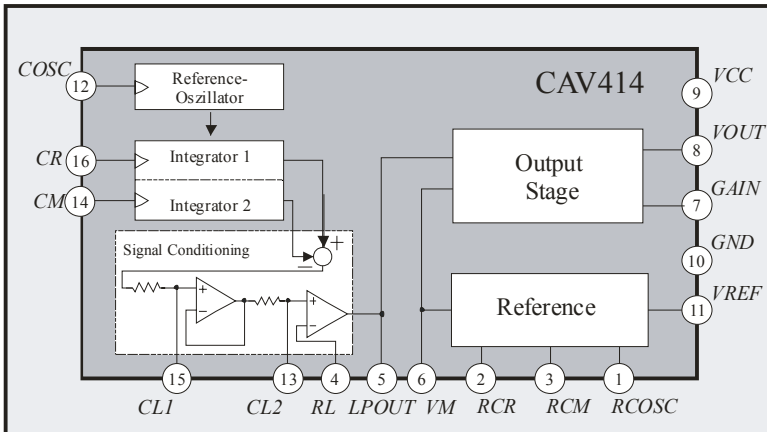


Figure 10: Block diagram of CAV414

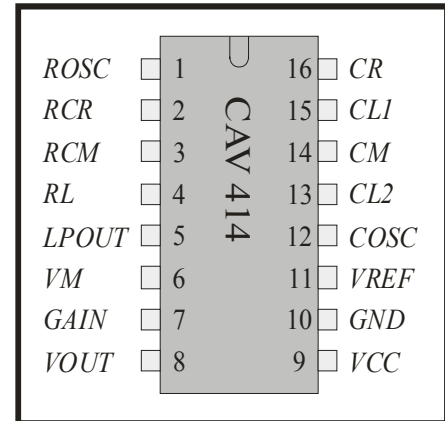


Figure 11: CAV414 pin out

PIN	NAME	DESCRIPTION
1	RCOSC	Oscillator current definition
2	RCR	Current setting for integrator C_R
3	RCM	Current setting for integrator C_M
4	RL	Gain setting
5	LPOUT	Low pass filter output
6	VM	Reference voltage 2.V
7	GAIN	Output stage gain setting
8	VOUT	Voltage output
9	VCC	Supply voltage
10	GND	IC ground
11	VREF	Reference voltage 5V
12	COSC	Reference oscillator capacitor
13	CL2	Low pass 2, capacitor for 3dB corner frequency
14	CM	Sensor measurement capacitor
15	CL1	Low pass 1, capacitor for 3dB corner frequency
16	CR	Sensor reference capacitor

Table 5: CAV414 Pin out

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DELIVERY

CAV414 is available as:

- An SO16 (n)
- Dice on 5" blue foil (on request)

Package dimensions: see <http://www.analogmicro.de/products/analogmicro.de.en.package.pdf>

ADDITIONAL EQUIPMENT

For design purposes, by way of support Analog Microelectronics GmbH can also supply a bread-board (**BBCAV414**) which has been assembled for a specific set of parameters but which can also be used for individual measurements.

FURTHER READING

Please see our website for further information (www.analogmicro.de):

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



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May 2008 - Rev 1.2 - Page 19/19