Functional Description

The functional description gives the necessary formulas to calculate the CAV414 with the sensing element (capacitor of a capacitive sensor). The formulas are a good approximation of the reality.

Reference Oscillator:

The reference oscillator works by charging and discharging the external oscillator capacitor C_{OSC}, the internal parasitic capacitor $C_{OSC,PAR,INT}$ of the IC and the external parasitic capacitor $C_{OSC,PAR,EXT}$ (e.g. of the circuit board). The external oscillator capacitor C_{OSC} has to be

$$C_{OSC} = 1.6 \cdot C_{X1} \qquad (1)$$

where C_{X1} is the fixed capacitor of a capacitive sensor.

The reference oscillator current I_{OSC} is determined by the external resistor R_{OSC} (see *Data Sheet*) and the reference voltage V_M (see *Data Sheet*):

$$I_{OSC} = \frac{V_M}{R_{OSC}} \qquad (2)$$

The frequency of the reference oscillator f_{OSC} is given by

$$f_{OSC} = \frac{I_{OSC}}{2 \cdot \Delta V_{OSC} \cdot \left(C_{OSC} + C_{OSC,PAR,INT} + C_{OSC,PAR,EXT}\right)} \qquad (3)$$

whereby ΔV_{OSC} is the difference of the internal threshold voltages ($V_{OSC,HIGH}$ and $V_{OSC,LOW}$) of the reference oscillator. ΔV_{OSC} is defined by internal resistors and has 2.1V ± 5%. The oscillator voltage is shown in *Figure 1*.

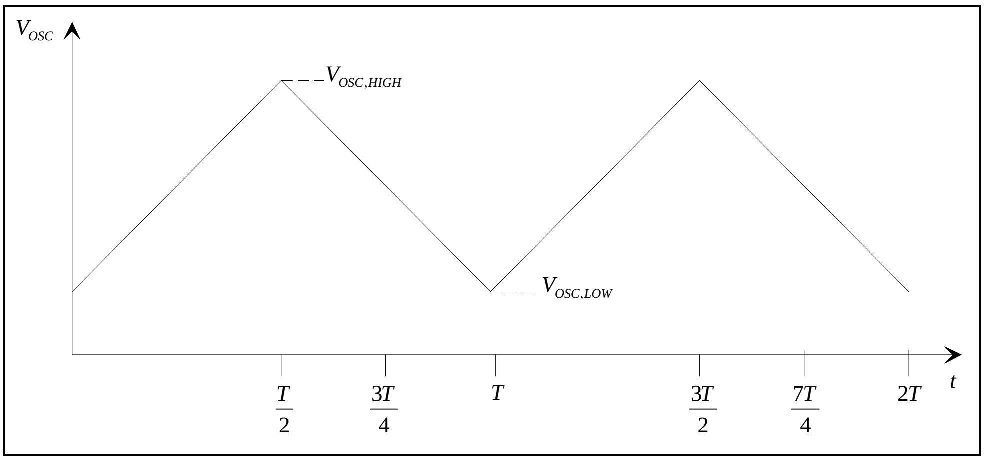

Figure 1

Capacitive Integrators:

The principle of operation is basically the same as the behaviour of the reference oscillator. The difference is the time of discharging the capacitors which is twice the time of charging and is clamped at an internal fixed voltage V_{CLAMP} . In *Figure 2*, the signal voltage over the capacitors C_{X1} and C_{X2} is shown.

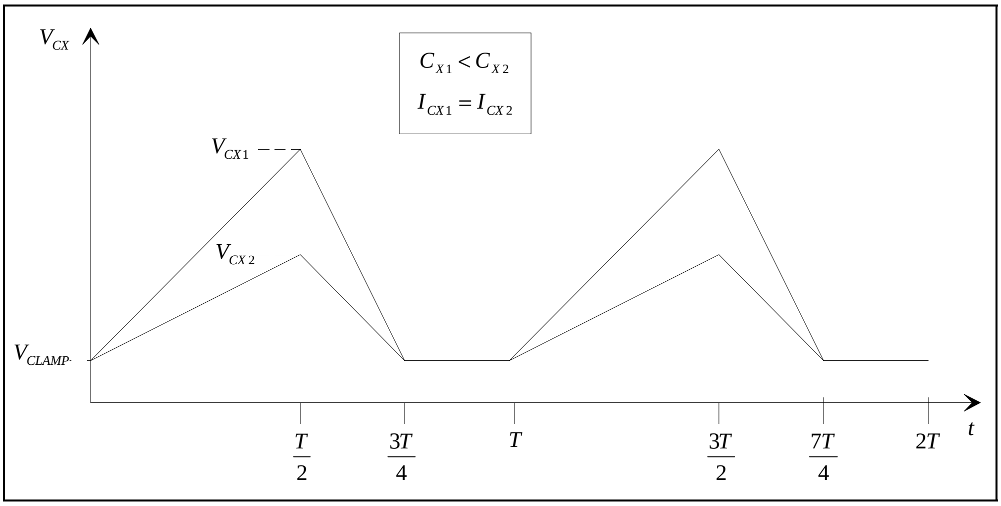

Figure 2

The capacitive integrator current I_{CX} is determined by the external resistor R_{CX} (see *Data Sheet*) and the reference voltage V_M (see *Data Sheet*):

$$I_{CX} = \frac{V_M}{R_{CX}} \tag{4}$$

The capacitor C_X is charged up to the maximum voltage V_{CX} (see *Figure 2*) and can be calculated as follows

$$V_{CX} = \frac{I_{CX}}{2 \cdot f_{OSC} \cdot (C_X + C_{X,PAR,INT} + C_{X,PAR,EXT})} + V_{CLAMP} \tag{5}$$

The two voltages over the capacitors C_{X1} and C_{X2} are subtracted and the resulting differential voltage referred to the reference voltage V_M is given by

$$V_{CX,DIFF} = (V_{CX1} - V_{CX2}) + V_M \tag{6}$$

The differential voltage $V_{CX,DIFF}$ goes directly into the 2nd-order lowpass. The 3dB-corner frequencies f_{C1} and f_{C2} of the two stages are adjusted with the external capacitors (C_{L1}, C_{L2}) and the internal resistors (R_{01}, R_{02}; typ. 20kΩ). The 3dB-corner frequencies have to be chosen depending on the reference oscillator frequency f_{OSC} (see *Equation 3*) and the desired detection frequency f_{DET} of the entire sensor system. The following relation for the different types of frequencies has to be fulfilled in all cases:

$$f_{DET} < f_C << f_{OSC} \tag{7}$$

The external capacitors for a desired corner frequency are calculated as follows

$$C_L = \frac{1}{2\pi \cdot R_0 \cdot f_C} \quad (8)$$

The output signal of the lowpass with the ideal waveform becomes

$$V_{LPOUT} = V_{DIFF,0} + V_M \quad (9)$$

with

$$V_{DIFF,0} = \frac{3}{8} \cdot (V_{CX1} - V_{CX2}) \quad (10)$$

If the differential output voltage $V_{DIFF,0}$ is too small, it can be amplified with the external resistors R_{L1} and R_{L2} while using the internal non-inverting amplifier of the lowpass.

The maximum amplification of the differential output voltage $V_{DIFF,0}$ is limited to the maximum allowed input voltage range of the following instrumentation amplifier ($V_{IA,IN,max}$ = 400mV).

The gain of the stage is

$$G_{LP} = 1 + \frac{R_{L1}}{R_{L2}} \quad (11)$$

Hence follows the output signal of the lowpass stage

$$V_{LPOUT} = V_{DIFF} + V_M \quad (12)$$

with

$$V_{DIFF} = G_{LP} \cdot V_{DIFF,0} = G_{LP} \cdot \frac{3}{8} \cdot (V_{CX1} - V_{CX2}) \quad (13)$$

With the instrumentation amplifier and the output stage, the output signal becomes

$$V_{OUT} = G_{IA} \cdot G_{OP} \cdot V_{DIFF} \quad (14)$$

with the fixed gain G_{IA} = 5 and the adjustable gain

$$G_{OP} = 1 + \frac{R_1}{R_2} \quad (15)$$

Example

The *Example* describes the calculation of a typical application for the output voltage 0 ... 10V.

The following values are given:

- voltage source V_{CC} = 24V
- fixed capacitance C_{X1} = 50pF
- minimum capacitance $C_{X2,min}$ = 48pF, maximum capacitance $C_{X2,max}$ = 93pF

Adjustment:

The zero-adjustment is made by the resistors R_{CX1} or R_{CX2} for the case that the varying capacitance has nearly the same (and its smallest) value as the fixed capacitance (C_{X1} = 50pF, C_{X2} = 48pF). Therefore, one of this resistors is varied until the output voltage

$$V_{DIFF} = V_{LPOUT} - V_M \tag{16}$$

is zero:

$$V_{DIFF} = 0 \tag{17}$$

Calculation:

With the equations of the functional description, the following values for the devices can be calculated:

C_{OSC}: 80pF [with *equation 1*]

f_{OSC}: 26.46kHz (with $C_{OSC,PAR}$ = 10pF) [with *equation 3*]

$V_{DIFF,0}$: 246.6mV (with $C_{X,PAR}$ = 10pF) [with *equation 10*]

To achieve a good performance of the entire sensor system, the differential voltage $V_{DIFF,0}$ is amplified to its maximal allowed value of 400mV. Hence follows the gain:

$G_{LP} \approx 1.62$

With the chosen resistors:

R_{L1} = 100kΩ, R_{L2} = 56kΩ [with *equation 11*]

The gain of the output stage (for the output voltage 0 ... 10V) has to be G_{OP} = 5.04 so that the resistors become

R_1 = 100kΩ, R_2 = 24.75kΩ [with *equation 15*]

The capacitors of the lowpass filter are set for the given oscillator frequency f_{OSC} = 26.46kHz to:

C_{L1}, C_{L2}: 10nF ($\rightarrow f_{C1}$ =796Hz) [with *equation 8*]

By increasing the value of the capacitors, the ripple of the filtered output signal but also the detection frequency will be reduced.

Circuit:

The resulting circuit is shown in *Figure 3*.

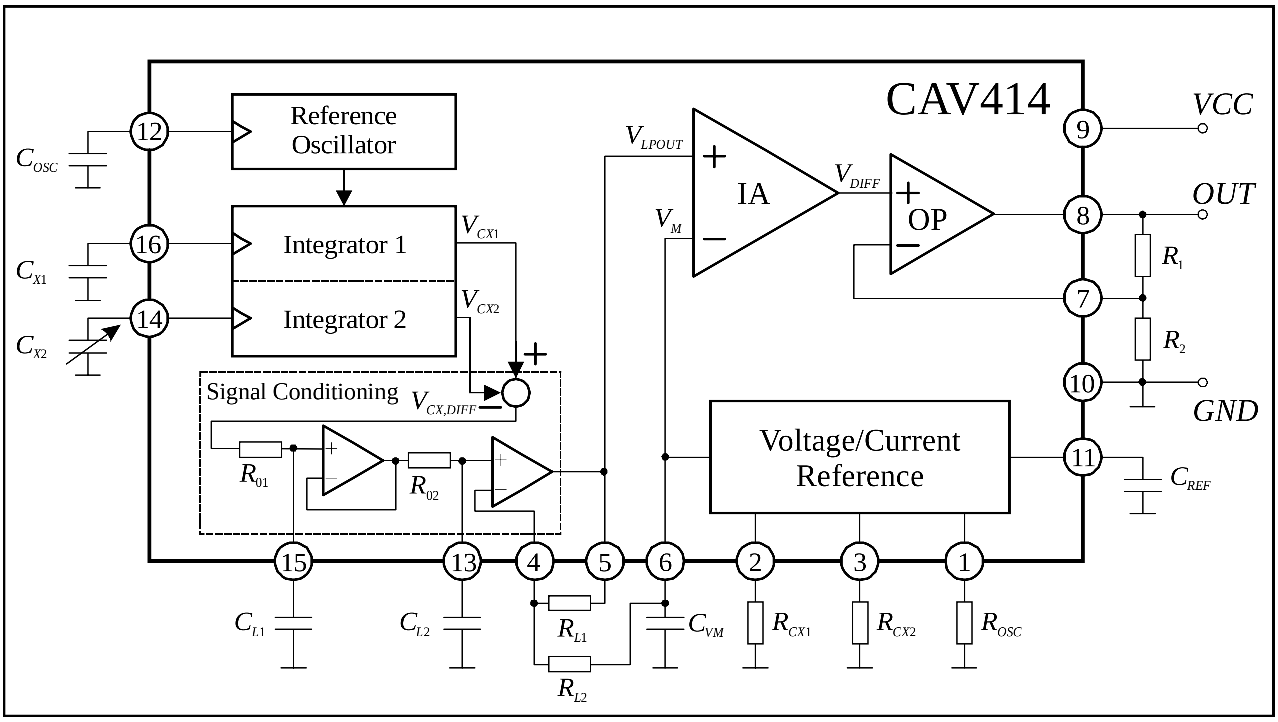

Figure 3

Component List:

Component	Symbol	Typ. Value	Notes
V_M Capacitor	C_{VM}	100nF	Ceramic
V_{REF} Capacitor	C_{REF}	2.2µF	Ceramic
Lowpass Capacitor 1	C_{L1}	10nF	Ceramic, X7R
Lowpass Capacitor 2	C_{L2}	10nF	Ceramic, X7R
Oscillator Capacitor	C_{OSC}	100pF	Ceramic, CGO (NP0), very small temperature coefficient
Set Resistor 1	R_{CX1}	400kΩ	adjustable, very small temperature coefficient
Set Resistor 2	R_{CX2}	400kΩ	adjustable, very small temperature coefficient
Set Resistor 3	R_{OSC}	200kΩ	very small temperature coefficient
Gain (*LP*) Resistor 1	R_{L1}	100kΩ	
Gain (*LP*) Resistor 2	R_{L2}	56kΩ	
Gain (*OUT*) Resistor 1	R_1	100kΩ	
Gain (*OUT*) Resistor 1	R_2	24.75kΩ	

For the performance of the entire sensor system, it is important that all *Set Resistors* have to have a small temperature coefficient. An offset compensation over temperature can only be achieved by choosing the resistors R_{CX1}, R_{CX2} and R_{COSC} with the same temperature coefficient and a very close placement of them in the entire circuit.

Breadboard

Analog Microelectronics developed a *breadboard* that allows tests of the CAV414 in different configurations, e.g. with different capacitive sensors. To cover the great variety of applications, the breadboard contains all of the components needed.

Breadboard Circuit:

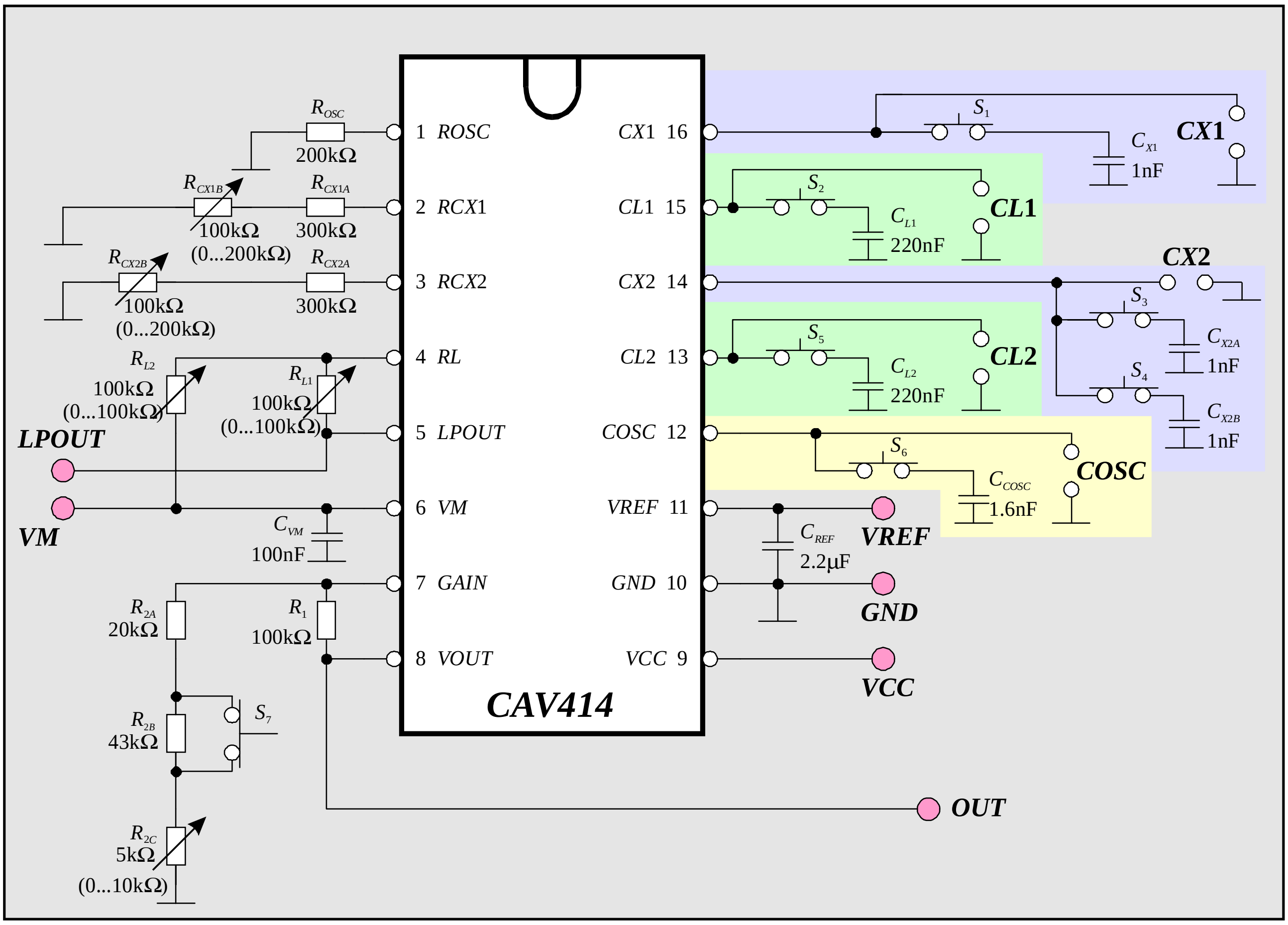

Figure 4

Breadboard Description:

The capacitive input signal can be led to the circuitry by an external capacitive sensor or by discrete capacitors. Since the two capacitive inputs *CX*1 and *CX*2 are available, it is also possible to connect a differential sensor. Without adding extra components, the principle function of the system can be proofed which is achieved by the built-in capacitors C_{X1}, C_{X2A} and C_{X2B} at the input. By closing the jumpers S_1 and S_3, a capacitive change of $\Delta C_X = 0\%$ is achieved that can be increased to $\Delta C_X = 100\%$ by closing the additional jumper S_4. When testing other configurations, the three jumpers S_1, S_3 and S_4 have to be open.

The desired output voltage (0 ... 5/10V) is adjusted by R_{2C}. If the 0 ... 10V output is used, the jumper S_7 is closed.

When the jumpers S_2 and S_5 are open, the 3dB-corner frequency can be set by external capacitors ($CL1$ and $CL2$).

The reference voltage V_{REF} of the CAV414 with the maximum output current of $I_{REF,max}$ = 9mA can be used to supply additional circuits.

Breadboard Adjustment:

Each of the resistors R_{CX1} and R_{CX2} offers an adjustment of the input capacitances of ±25% so that an overall adjustment of ±50% can be made. The output gain G_{OP} (typ.: 5) can be varied by ±20% by the resistor R_{2C}.

Before putting the circuit into operation, an adjustment of the entire system has to be made.

1. The first step when using the breadboard is to calculate the oscillator capacitance C_{OSC} :

   $$C_{OSC} = 1.6 \cdot C_{X1}$$

   and the two lowpass capacitances C_{L1} and C_{L2} which have the same value

   $$C_L = 200 \cdot C_{X1}$$

2. The zero-adjustment is made by the resistors R_{CX1} or R_{CX2} for the case that the varying capacitance C_{X2} has nearly the same (and its smallest) value as the fixed capacitance C_{X1} (reference capacitance), e.g. in the case of a displacement sensor without any target in front of it. For the adjustment, one of the resistors is varied until the differential voltage

   $$V_{DIFF,\min} = V_{LPOUT,\min} - V_M$$

   is zero:

   $$V_{DIFF,\min} = 0$$

3. The span-adjustment is made by the resistors R_{L1} or R_{L2} for the case that the varying capacitance C_{X2} has its greatest value, e.g. in the case of a displacement sensor with a target directly in front of it. One of the two resistors, (depending on the maximum capacitive change of C_{X2}) is varied until the differential voltage is

   $$V_{DIFF,\max} = 400\text{mV}$$

The output voltage V_{OUT} is adjusted to its maximum value of 10V by the resistor R_{2C}.

Breadboard Component List:

Part Symbol	Value	Notes
CAV414	–	standard IC from Analog Microelectronics GmbH
R_{OSC}	200kΩ	metal film, ±50ppm/°C
R_{CX1A}	300kΩ	metal film, ±50ppm/°C
R_{CX2A}	300kΩ	metal film, ±50ppm/°C
R_{CX1B}	200kΩ	trimmer, ±100ppm/°C, 25 turns
R_{CX2B}	200kΩ	trimmer, ±100ppm/°C, 25 turns
R_{L1}	100kΩ	trimmer, ±100ppm/°C, 25 turns
R_{L2}	100kΩ	trimmer, ±100ppm/°C, 25 turns
R_1	100kΩ	metal film, ±50ppm/°C
R_{2A}	20kΩ	metal film, ±50ppm/°C
R_{2B}	43kΩ	metal film, ±50ppm/°C
R_{2C}	10kΩ	trimmer, ±100ppm/°C, 25 turns
C_{REF}	2.2µF	ceramic, Z5U
C_{VM}	100nF	ceramic, X7R
C_{L1}	220nF	ceramic, X7R
C_{L2}	220nF	ceramic, X7R
C_{OSCA}	1.5nF	ceramic, COG, ± 30ppm/°C
C_{OSCB}	100pF	ceramic, COG, ± 30ppm/°C
C_{X1}	1nF	ceramic, COG, ± 30ppm/°C
C_{X2A}	1nF	ceramic, COG, ± 30ppm/°C
C_{X2B}	1nF	ceramic, COG, ± 30ppm/°C
S_1 ... S_7	–	jumper

Breadboard Component Side:

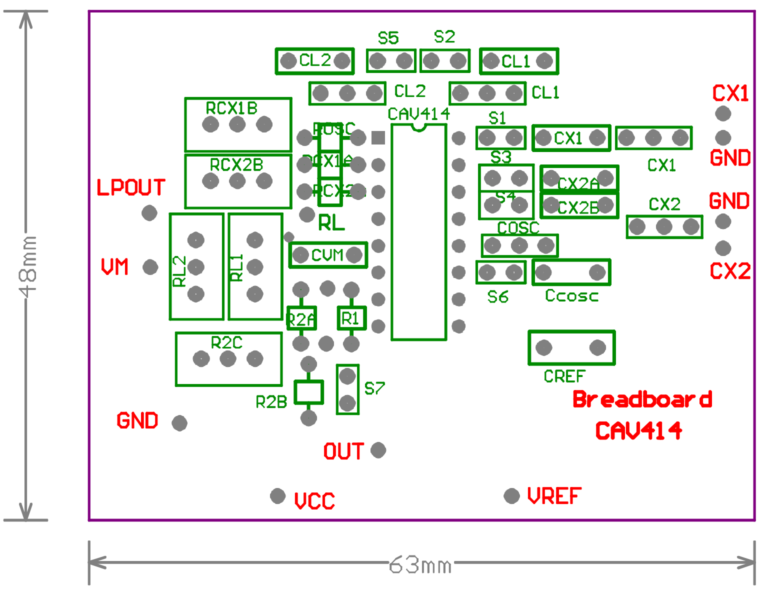

Figure 5