MAS1641

Capacitance Change Detection with Piezo Alarm

- **Adjustable Capacitance Sensing Range and Alarm Threshold**
- **Very Low Power Consumption**
- **3x Charge Pump**
- **Self-Drive Type Piezo Driver**
- **Up to 18Vpp Output Piezo Drive from 3V Supply**
- **High Efficiency**
- **Solution without Inductors**

DESCRIPTION

MAS1641 is a single chip system for capacitance change detection with piezo alarm function. It is an ideal solution for capacitive infusion and other liquid level change detection and alarm systems. Either capacitance decrease or increase is detected depending on change direction selection input (DSEL). DSEL=GND chooses the capacitance decrease detection and DSEL=VIN chooses the capacitance increase detection.

The system is configurable with three external resistors. The R_{CLK} resistor sets system clock frequency which runs the control unit events and their timing. R_{COM} and R_{INC} (only in increase detection) or R_{DEC} (only in decrease detection) resistors adjust oscillator frequency in reference and monitoring measurements of capacitance. The reference measurement is done only once but the monitoring measurements are run periodically. Together the R_{COM} and the R_{INC} or R_{DEC} resistor values define range of sensed capacitance and amount of capacitance decrease (DSEL=GND) or increase (DSEL=VIN) which is needed to trigger the alarm.

The MAS1641 is turned on just by connecting the supply voltage. An internal undervoltage-lockout (UVLO) circuit allows the device to turn on only if the supply voltage exceeds 2.1V typ. Also the UVLO circuit turns off the device if the supply voltage drops below 2.0V typ after the power up.

After power up the device gives a beep signal to the piezo to indicate it has been turned on. After 4.2s delay there is done reference capacitance measurement. This is done by counting pulses from the measurement oscillator which frequency is defined by resistors connected to path from RREF pin to GND. Next there is started a loop where monitored capacitance is measured periodically using the oscillator which frequency is defined by resistors connected to path from MON pin to GND. Monitoring measurements are run nominally once in two seconds to minimize the current consumption. Alarm is triggered when the monitoring measurement count value crosses the reference measurement count value.

In the alarm the charge pump turned on and an intermittent (0.2s ON, 1.8s OFF) alarm sound signal is driven to the piezo. The alarm can be turned off only by switching off the supplies.

The piezo driver is suitable for driving self-drive type piezoelectric sounder or diaphragm. It has two outputs (VOB, VOS) and one feedback input (FEED) to drive 3-terminal self-drive type piezo in bridge tied load (BTL) configuration. The piezo driver can drive outputs up to 18Vpp from 3V supply since it is supplied from an internal 3x charge pump that generates boosted 9V supply voltage.

The charge pump switches at 1MHz, allowing to using as small as 100nF external flying and output capacitors.

The MAS1641 is available in a small 3x3x0.75 mm size QFN-16 package.

FEATURES

- Thin 3x3x0.75 mm QFN-16 package
- Adjustable Sensing Range and Alarm Threshold
- Very Low Power consumption
- 3x Charge Pump with 1MHz Switching Frequency
- Self-Drive Type Piezo Driver
- High Efficiency
- Inductorless Low EMI Solution

APPLICATIONS

- Infusion liquid level drop detection and alarm
- Capacitive water leakage detection and alarm
- Capacitance change detection and alarm

BLOCK AND APPLICATION DIAGRAM

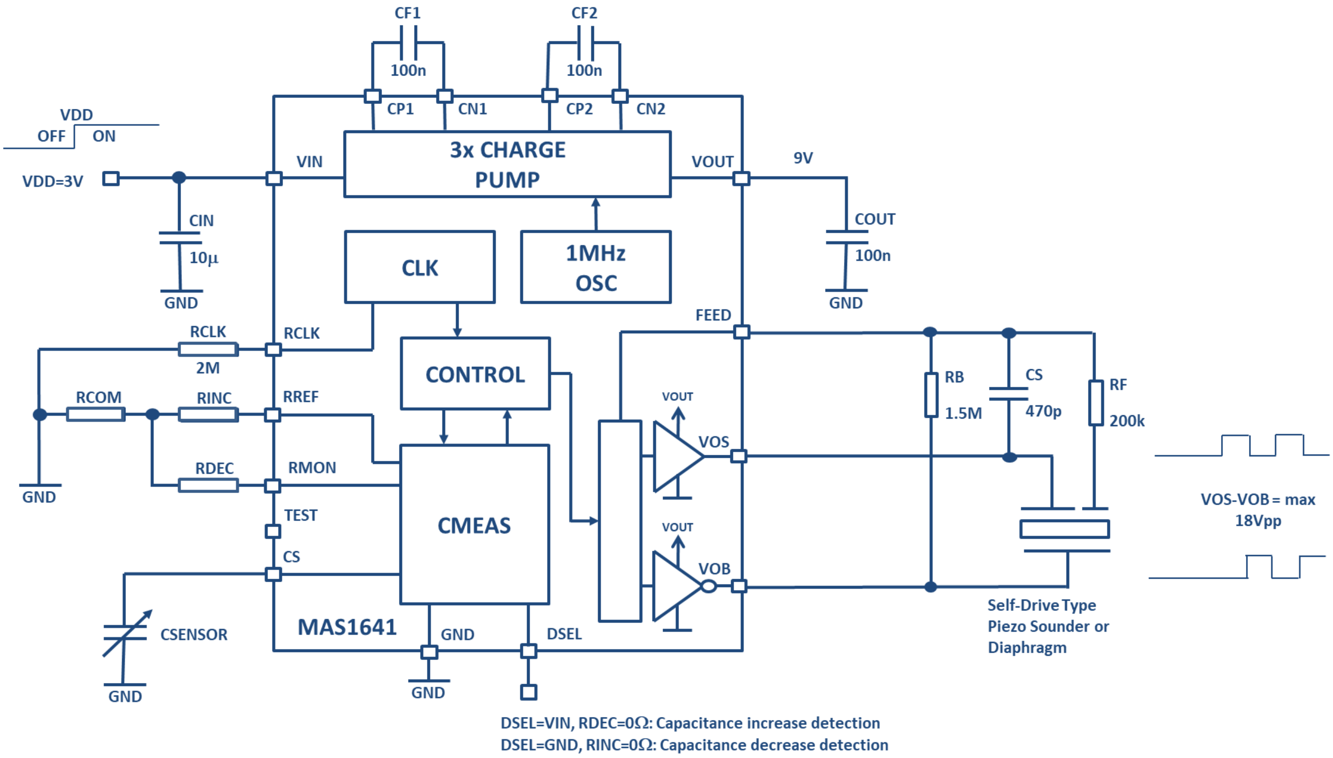


Figure 1. Typical application circuit (max 18Vpp signal for piezo from 3V supply voltage)

Note: In capacitance decrease detection (DSEL=GND) the RINC resistor is not needed and it is replaced by a short circuit (0Ω). Similarly, in capacitance increase detection (DSEL=VIN) the RDEC resistor is not needed and it is replaced by a short circuit (0Ω).

ABSOLUTE MAXIMUM RATINGS

All voltages with respect to ground.

Parameter	Symbol	Conditions	Min	Max	Unit
Supply Voltage	VIN	Charge pump OFF Charge pump ON		5.5 4.5	V
Output and Flying Capacitor Pin Voltages	VOUT, CP1, CP2, VOS, VOB		-0.3	15	V
	CN2		-0.3	13	V
	CN1		-0.3	VIN + 0.3	V
Input Pin Voltages	FEED		-20	30	V
	DSEL		-0.3	VIN + 0.3	V
Storage Temperature			-55	+150	°C
Operating Junction Temperature	T_J		-40	+125	°C
ESD Rating	V_{HBM}	Human Body Model (HBM) (1)		±2000	V
	V_{CDM}	Charged Device Model (CDM) (2)		±500	V

Note: Stresses beyond the values listed may cause a permanent damage to the device. The device may not operate under these conditions, but it will not be destroyed.
Note 1: JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.
Note 2: JEDEC document JEP157 states that 250V CDM allows safe manufacturing with a standard ESD control process.

RECOMMENDED OPERATING CONDITIONS

All voltages with respect to ground.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Operating Ambient Temperature	T_A		0	+27	+70	°C
Operating Supply Voltage	V_{IN}		2.25	3.0	3.6	V
Measurement Oscillator Frequency	F_{MEAS}	Adjusted by R_{COM} and R_{MON} resistors	50	100	150	kHz
Piezo Resonance Frequency	F_{PIEZO}		2	3.4	5	kHz
Percentage Change of Sensed Capacitance	$\Delta C/C_{REF}$		5	10	100	%

ELECTRICAL CHARACTERISTICS

T_A = -40°C to +85°C, typical values at T_A = 27°C, V_{IN} = 3.0 V, C_{IN} = 10 µF, C_{F1} = C_{F2} = C_{OUT} = 100 nF, C_{piezo} = 15 nF, FEED=3.4kHz; unless otherwise specified

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output Voltage	VOUT	VIN = 3.0 V	7.2		9	V
Average Current Consumption	I_{DD}	Normal mode (no alarm)		36	60	µA
		Alarm state and piezo driving C_{piezo} = 15 nF, f= 3.4 kHz		0.45		mA
Peak Current Consumption	I_{DD_PEAK}	Alarm state, no load		3.9		mA
		Alarm state and piezo driving C_{piezo} = 15 nF, f= 3.4 kHz		6.8		mA
Internal System Clock Frequency	F_{CLK}	Set by external R_{CLK} resistor RCLK=2MΩ	8	10	13.3	Hz
Charge Pump Switching Frequency	F_{OSC}		0.6	1	1.8	MHz
Undervoltage-lockout Threshold Levels	$UVLO_{RISE}$ $UVLO_{FALL}$	Turn on level at VDD rising Turn off level at VDD falling		2.1 2.0		V
DSEL Control Input Threshold	VIH	High-level input voltage	80		100	%VIN
	VIL	Low-level input voltage	0		20	%VIN

FLOW GRAPH OF OPERATION

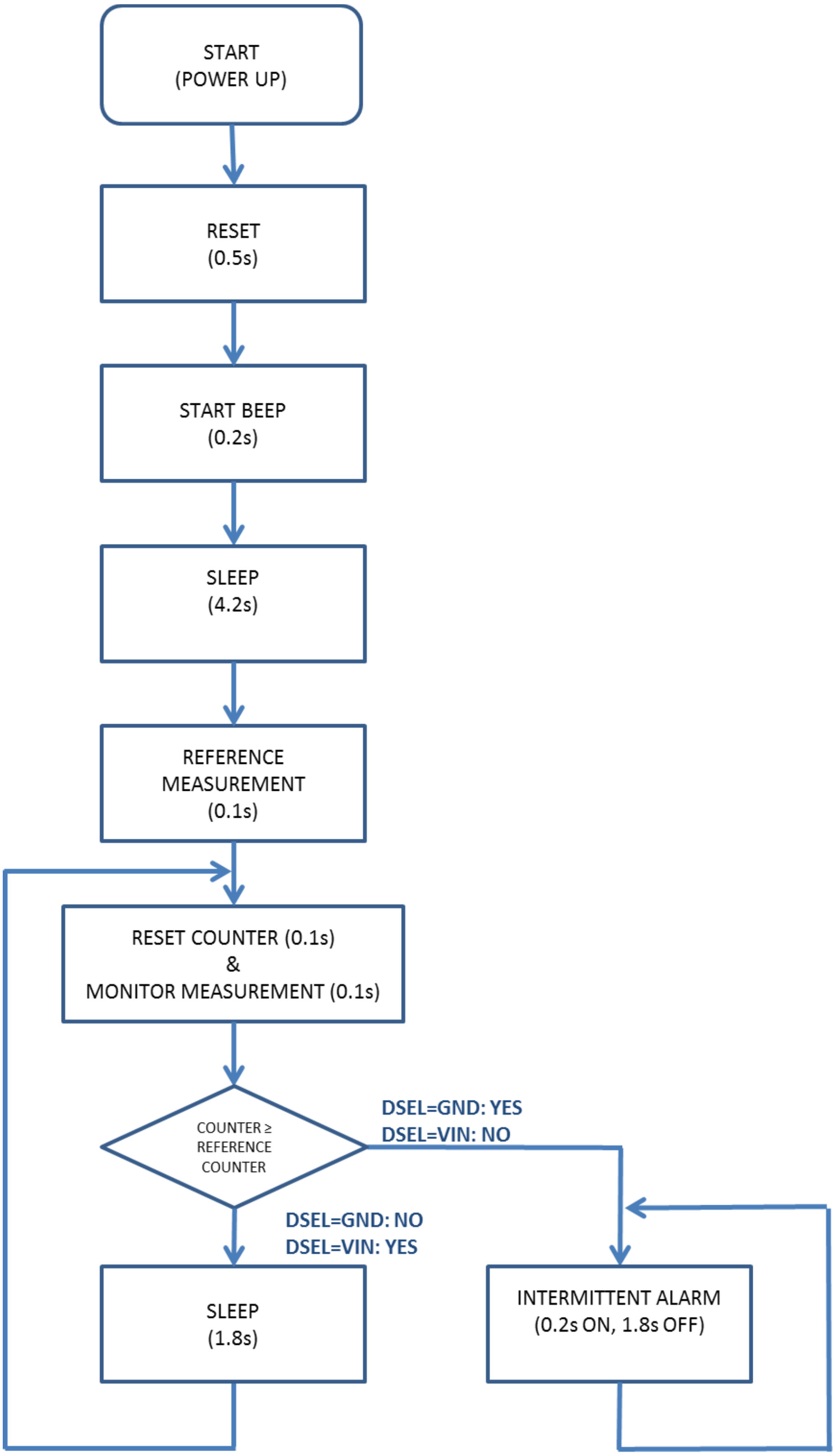


Figure 2. Flow graph of MAS1641 operation

Figure 2 presents flow graph of the MAS1641 operation. In parentheses there is shown typical duration of each event when using nominal system clock frequency f_{CLK}=10Hz (R_{CLK}=2MΩ).

APPLICATION INFORMATION

System clock resistor (R_{CLK}) value

The external R_{CLK} resistor adjusts internal system clock frequency (f_{CLK}) which defines rate at which measurements are looped and intermittent alarm sound is repeated. Nominal frequency for the internal system clock frequency is f_{CLK}=10Hz which corresponds to operation flow chart timing presented in the figure 2.

Suitable R_{CLK} resistor value is calculated using equation 1.

$$R_{CLK} = \frac{1}{8192 \cdot 6.1pF \cdot f_{CLK}}$$ **Equation 1.**

With nominal system clock frequency f_{CLK}=10Hz we get R_{CLK}=1/(8192*6.1pF*10Hz)≈2.0MΩ.

Measurement oscillator resistor (R_{COM}, R_{INC}, R_{DEC}) values

The external R_{COM} and R_{INC} or R_{DEC} resistor values adjust measurement oscillator frequencies used in reference and monitoring capacitance measurements. Nominal oscillator frequency in reference measurement should be as close to f_{REF} = 100kHz when using nominal internal system clock 10Hz. Thus the frequency ratio f_{REF}/f_{CLK} should be nominally close to 10000.

See figure 1 for resistor circuit configuration. Note that in capacitance decrease detection (DSEL=GND) the R_{INC} resistor is not needed and it is replaced by a short circuit (0Ω). Analogously in capacitance increase detection (DSEL=VIN) the R_{DEC} resistor is not needed and it is replaced by a short circuit (0Ω).

The resistance R_{REF} seen from RREF pin to ground defines measurement oscillator frequency (f_{REF}) during reference measurement (the first measurement after power up). See equation 2.

$$R_{REF} = R_{INC} + R_{COM} = \frac{1}{2 \cdot f_{REF} \cdot C_{REF}}$$ **Equation 2.**

Similarly, resistance R_{MON} seen from RMON pin to ground defines measurement oscillator frequency (f_{MON}) during monitoring measurements (repeated measurements after the reference measurement). See equation 3.

$$R_{MON} = R_{DEC} + R_{COM} = \frac{1}{2 \cdot f_{MON} \cdot C_{MON}}$$ **Equation 3.**

Resistor values R_{COM}, R_{INC} and R_{DEC} are chosen to set f_{REF} = 100kHz and capacitance threshold for alarm (C_{ALARM}) to optimal point. Optimal value for the alarm threshold is mid value between reference capacitance (C_{REF}) and changed monitoring capacitance ($C_{MON} = C_{REF} + \Delta C$) since this maximizes margin to both false and missing alarms. See equation 4.

$$C_{ALARM} = \frac{C_{REF} + C_{MON}}{2} = C_{REF} + \frac{\Delta C}{2}$$ **Equation 4.**

Mid valued capacitance threshold for alarm is illustrated in figure 3 for increasing and decreasing capacitance cases.

APPLICATION INFORMATION (continued)

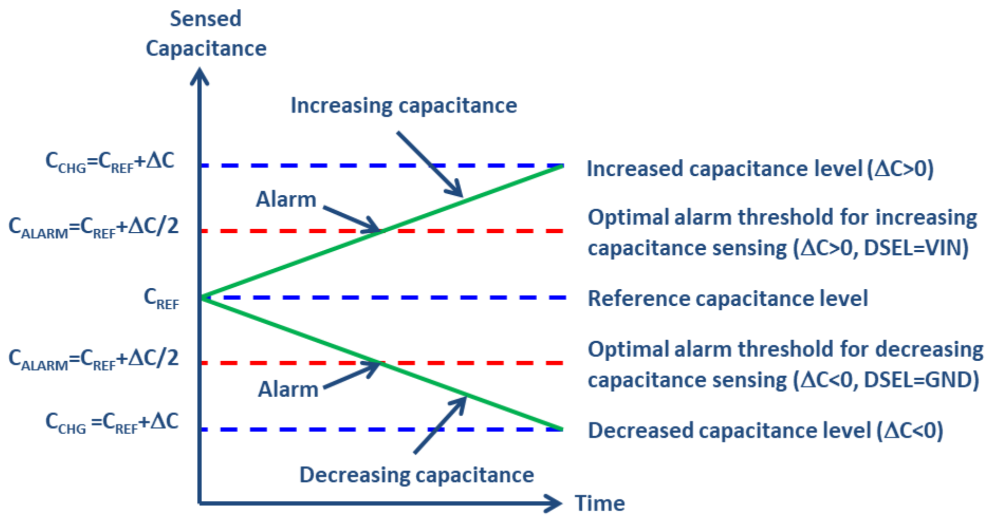


Figure 3. Illustration of optimal alarm threshold in increasing or decreasing capacitance sensing

At alarm threshold following applies.

$$C_{MON} = C_{ALARM}$$ **Equation 5.**

$$f_{MON} = f_{REF}$$ **Equation 6.**

For external resistor value (R_{CLK}, R_{COM}, R_{DEC} and R_{INC}) calculations one can derive following equations shown in the table 1. Resistor values are calculated differently whether capacitance decrease or increase is sensed.

Table 1. Equations for calculating resistor values

Resistor	Capacitance decrease sensing (DSEL=GND)	Capacitance increase sensing (DSEL=VIN)
C_{ALARM}	$\mathbf{C_{ALARM} = \frac{C_{REF}+C_{MON}}{2} = C_{REF} + \frac{\Delta C}{2} = = \frac{C_{REF}}{\left(\frac{R_{DEC}}{R_{COM}}+1\right)}}$	$\mathbf{C_{ALARM} = \frac{C_{REF}+C_{MON}}{2} = C_{REF} + \frac{\Delta C}{2} = = C_{REF}\cdot\left(\frac{R_{INC}}{R_{COM}}+1\right)}$
R_{CLK}	$\mathbf{R_{CLK} = \frac{1}{8192 \cdot 6.1pF \cdot 10Hz} \approx 2M\Omega}$	$\mathbf{R_{CLK} = \frac{1}{8192 \cdot 6.1pF \cdot 10Hz} \approx 2M\Omega}$
R_{COM}	$\mathbf{R_{COM} = \frac{1}{2 \cdot f_{REF} \cdot C_{REF}}}$	$\mathbf{R_{COM} = \frac{1}{2 \cdot f_{REF} \cdot C_{ALARM}}}$
R_{DEC}	$\mathbf{R_{DEC} = R_{COM} \cdot \left(\frac{C_{REF}}{C_{ALARM}} - 1\right)}$	0Ω (shorted)
R_{INC}	0Ω (shorted)	$\mathbf{R_{INC} = \frac{1}{2 \cdot f_{REF} \cdot C_{REF}} - R_{COM}}$

EXAMPLE 1: Capacitance decrease sensing

f_{CLK} = 10Hz, f_{REF} = 100kHz, C_{REF} = 3.2pF, C_{MON} = 2.7pF i.e. ΔC=C_{MON} - C_{REF} = 2.7pF - 3.2pF = -0.5pF
C_{ALARM} = (3.2pF+2.7pF)/2=2.95pF
R_{CLK} = 1/(8192*6.1pF*10Hz)/2=2MΩ
R_{COM} = 1/(2*100kHz*3.2pF)=1.5625MΩ
R_{DEC} = 1.5625MΩ*(3.2pF/2.95pF-1)=132.4kΩ
R_{INC} = 0Ω (shorted)
Important note: In above R_{COM} and R_{DEC} calculations there must be used non-rounded calculated resistor values. The resistor value rounding to standard series values can be done only in the next step.
R_{COM} (E24 5% series) = 1.5625MΩ ≈ 1.6MΩ (E24 5% series)
R_{DEC} (E24 5% series) = 132.4kΩ ≈ 130kΩ (E24 5% series)
Alarm threshold check: C_{ALARM}=3.2pF/(130kΩ/1.6MΩ+1)=2.96pF **OK!** (very close to target 2.95pF)

APPLICATION INFORMATION (continued)

EXAMPLE 2: Capacitance increase sensing
f_{CLK} = 10Hz, f_{REF} = 100kHz, C_{REF} = 3.2pF, C_{MON} = 3.7pF i.e. $\Delta C = C_{MON} - C_{REF}$ = 3.7pF - 3.2pF = +0.5pF
C_{ALARM} = (3.2pF+3.7pF)/2=3.45pF
R_{CLK} = 1/(8192*6.1pF*10Hz)/2=2MΩ
R_{COM} = 1/(2*100kHz*3.45pF)=1.4493MΩ
R_{DEC} = 0Ω (shorted)
R_{INC} = 1/(2*100kHz*3.2pF)-1.4493MΩ=113.22kΩ
Important note: In the above R_{COM} and R_{INC} calculations there must be used non-rounded calculated resistor values. The resistor value rounding to standard series values can be done only in the next step.
R_{COM} (E24 5% series) = 1.4493MΩ ≈ 1.5MΩ
R_{INC} (E24 5% series) = 113.22kΩ ≈ 110kΩ
Alarm threshold check: C_{ALARM}=3.2pF*(110kΩ/1.5MΩ+1)=3.43pF **OK!** (very close to target 3.45pF)

Capacitor andta resistor values for charge pump and piezo driver

The external CIN, CF1, CF2 and COUT capacitors must be low loss (low ESR) ceramic capacitors. Recommended resistor and capacitor values are shown in the table 2.

Table 2. Recommended capacitor and resistor values

Capacitor	Nominal value	Voltage rating
CIN	10µF (min 1µF)	min 6.3V
CF1, CF2	100nF	min 6.3V
COUT	100nF	min 16V
CS	470pF	min 16V
RB	1.5MΩ	
RF	200kΩ	

Note: Some capacitor dielectric materials such as Y5V have strong voltage dependence. The actual capacitance value may reduce remarkably when operating near rated voltage. In such case the nominal capacitor value should be chosen larger to compensate the voltage dependence.

The input (CIN), flying (CF1, CF2) and output (COUT) capacitor value selections have influence on output (VOUT) ripple and disturbances at supply voltage input (VIN). Table 3 shows alternative capacitor value selections in different applications. In battery operated applications it is recommended to use CIN=10µF which keeps the start-up inrush current low.

Table 3. Capacitor value selections in different applications

CIN	CF1-2	COUT	Application
1µF	100nF	100nF	Minimum size layout
10µF	100nF	100nF	Low input disturbances
10µF	100nF	1µF	Low input disturbances and low output ripple

Note: the voltage ripple at VOUT output is approximately proportional to ratio of piezo load capacitance (C_{PIEZO}) and charge pump output capacitor (COUT). Then the output ripple can be reduced by choosing output capacitor value which is much larger relative to piezo capacitance value. However, note that large output capacitor also lengthens output voltage rise time and increases inrush current during start-up.

APPLICATION INFORMATION (continued)

TEST output for determining sensed input capacitance value

MAS1641 has open drain output TEST pin. By connecting 4.7kΩ pull-up resistor from TEST output to VIN it is possible to determine measured input capacitance by analyzing the TEST output signal using an oscilloscope (see figure 3 for measurement configuration). This is useful feature when not knowing exact values of the sensed input capacitances.

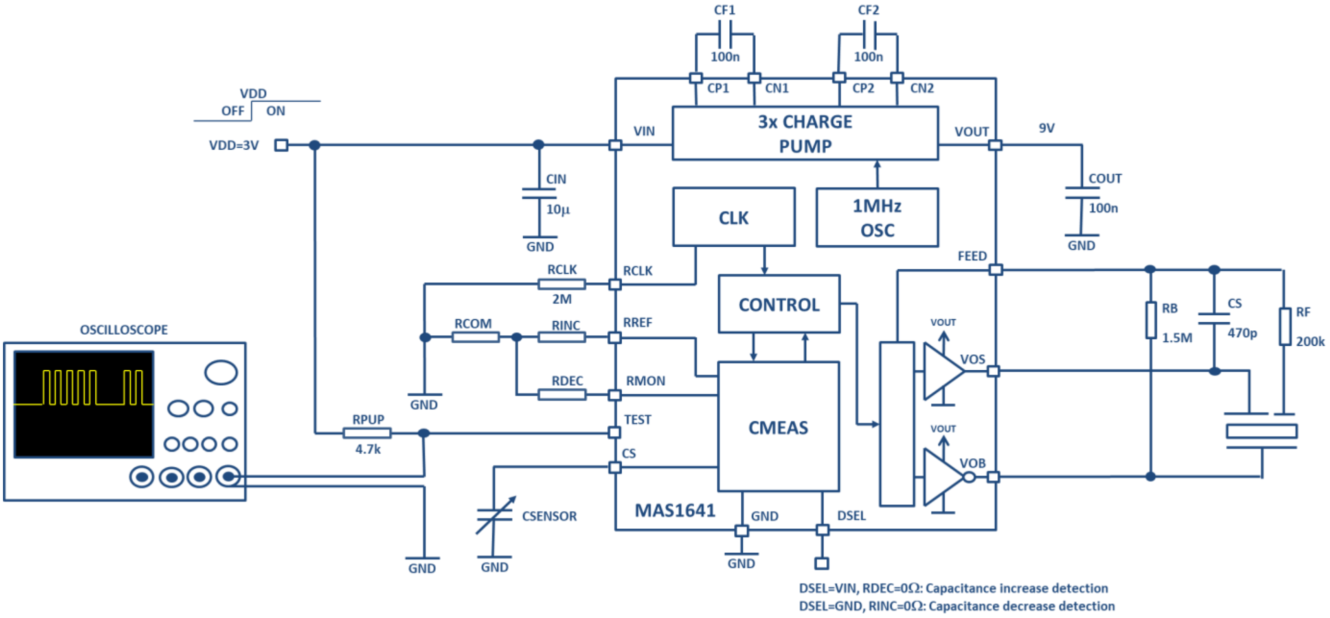


Figure 3. TEST output monitoring circuit for determining sensed input capacitance value

After power up (VIN rise above $UVLO_{RISE}$ voltage) and after typical (0.5+0.2+4.2)s=4.9s time MAS1641 starts the reference measurement which lasts typically 0.1s. Counter reset period lasts 0.1s and which is followed by 0.1s monitoring measurement. After this the counter reset and monitoring measurement are repeated in 2s period. See flow graph in the figure 2.

During reference and every monitoring measurement the measurement oscillator signal is transmitted to the TEST output. Thus after power up there is seen first 0.1s long burst of reference measurement oscillator pulses and after 0.1s delay another 0.1s burst of monitoring measurement oscillator pulses. Figure 4 presents measured TEST pin signal after power up. It shows the reference and the first monitoring measurement signal bursts.

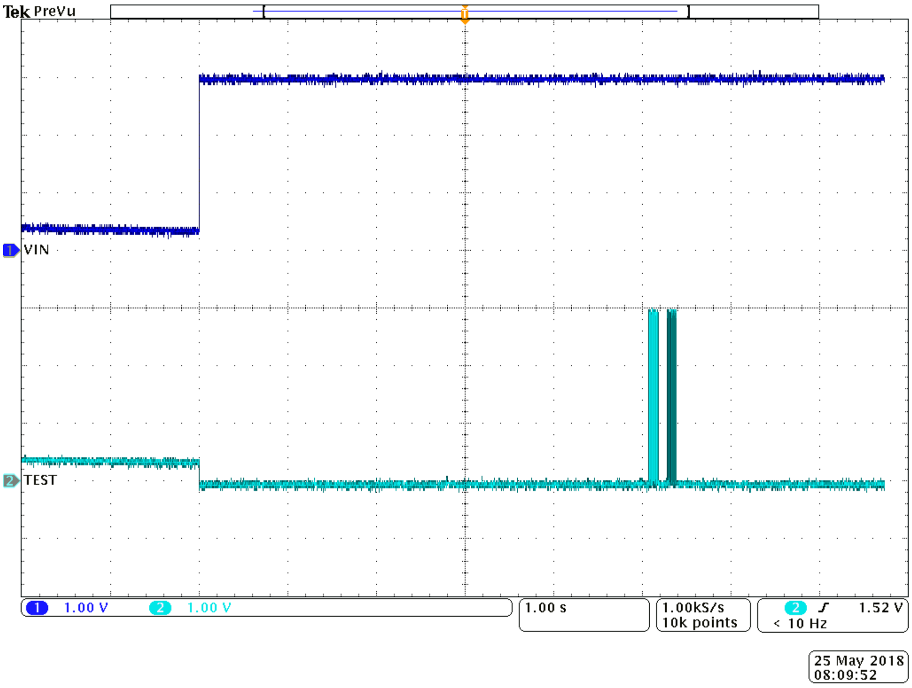


Figure 4. TEST pin signal of reference and first monitoring measurement bursts after 4.9s(typ) from power up (VIN)

The frequencies of reference (f_{REF}) and monitoring (f_{MON}) measurement signal bursts have following dependency on external R_{COM} and R_{MON} resistors and sensed capacitance (C_{SENSOR}).

$$f_{REF} = \frac{1}{2 \cdot (RCOM + RINC) \cdot C_{SENSOR}}$$ **Equation 6.**

$$f_{MON} = \frac{1}{2 \cdot (RCOM + RDEC) \cdot C_{SENSOR}}$$ **Equation 7.**

Either from equation 6 or 7 we can solve the sensor capacitance value C_{SENSOR} as follows.

$$C_{SENSOR} = \frac{1}{2 \cdot (RCOM + RINC) \cdot f_{REF}}$$ **Equation 8.**

$$C_{SENSOR} = \frac{1}{2 \cdot (RCOM + RDEC) \cdot f_{MON}}$$ **Equation 9.**

For example if in capacitance decrease sensing (DSEL=GND, R_{INC}=0Ω) we measure the reference measurement signal frequency as f_{REF}= 97.66kHz and have R_{COM}=1.60MΩ then C_{SENSOR}=1/[2*1.60MΩ*97.66kHz]≈3.2pF.
If instead we measure the monitoring measurement signal frequency as f_{MON}= 90.32kHz and have R_{COM}=1.60MΩ and R_{INC}=130kΩ then C_{SENSOR}=1/[2*(1.60MΩ+130kΩ)*90.32kHz]≈3.2pF. Thus the sensed input capacitance C_{SENSOR} can be defined either from reference or any monitoring measurement burst frequency.

Hint: When using oscilloscope it is better to measure period of at minimum ten or more oscillator signal pulses (N pcs) to get better time resolution i.e. better clock frequency (f_{OSC}) measurement accuracy. The oscillator signal frequency can be calculated from equation 10 when T_{NOSC} period of N pulses is measured.

$$f_{OSC} = \frac{N}{T_{NOSC}}$$ **Equation 10.**

APPLICATION INFORMATION (continued)

Figures 5 and 6 show examples of reference measurement clock signal in capacitance decrease sensing (DSEL=GND, R_{COM}=1.5MΩ, R_{INC}=0Ω) when clock period is calculated either using ten or twenty clock pulses respectively.

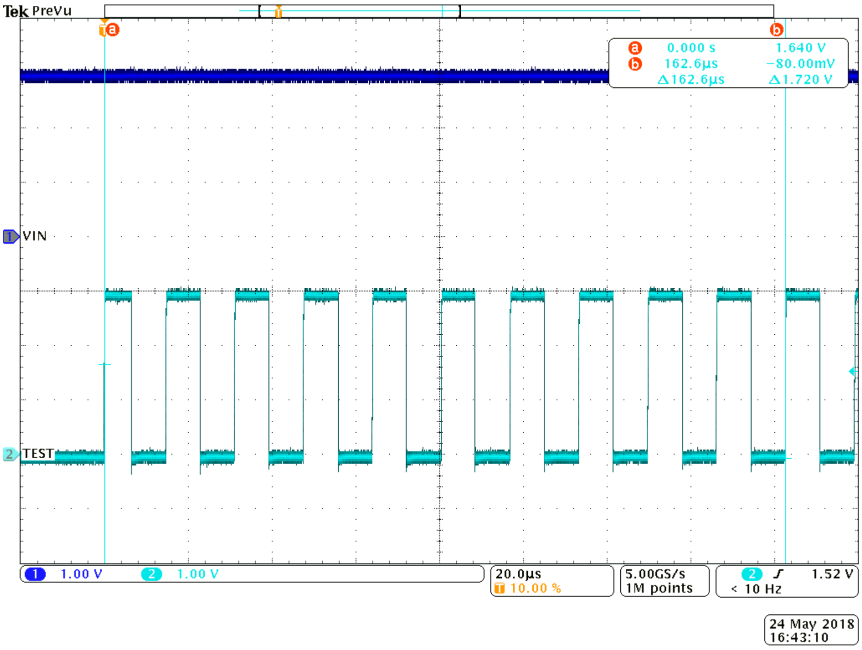


Figure 5. TEST pin signal closer look for measuring period of ten pulses of reference measurement burst

Measured reference measurement period of ten clock pulses (N=10) is $T_{NOSC(REF)}$=162.6µs. Using equations 10 and 8 we can calculate clock frequency and corresponding sensor capacitance.

f_{REF}=10/162.6µs =61.5kHz, C_{SENSOR}=1/[2*(1.5M+0)*61.5kHz]=5.42pF.

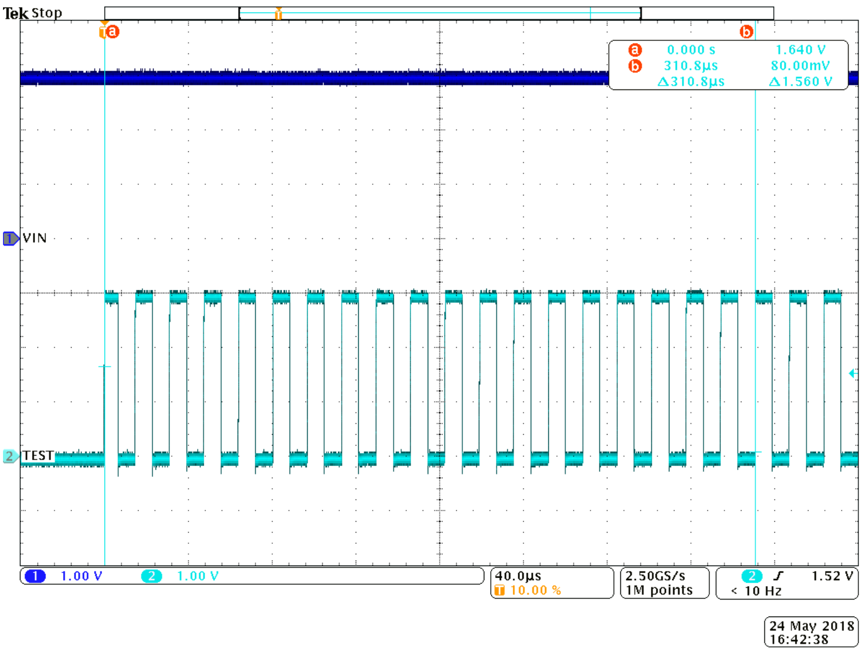
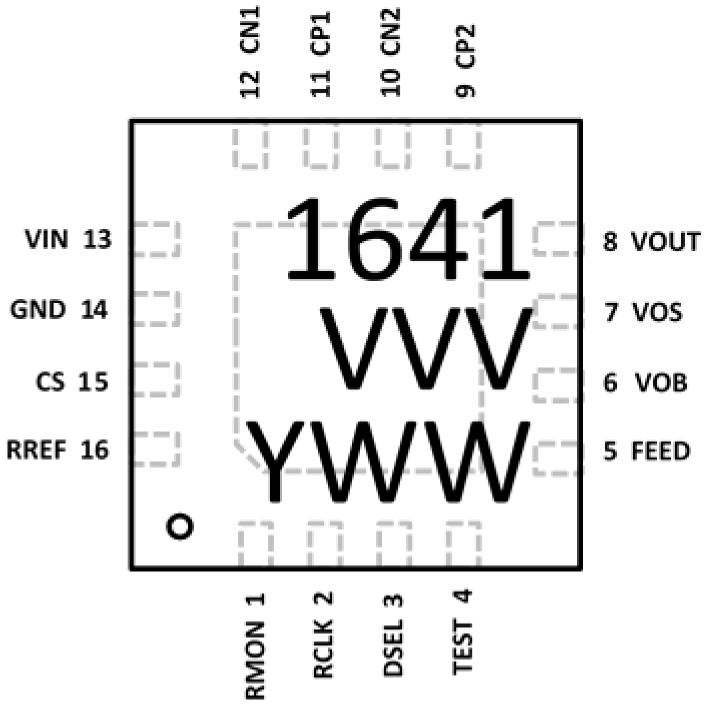


Figure 6. TEST pin signal closer look for measuring period of twenty pulses of reference measurement burst

Measured reference measurement period of twenty clock pulses (N=20) is $T_{NOSC(REF)}$=310.8µs. Now we get little more precise clock frequency and sensor capacitance value.

f_{REF}=20/310.8µs =64.35kHz, C_{SENSOR}=1/[2*(1.5M+0)*64.35kHz]=5.18pF.

DEVICE OUTLINE CONFIGURATION



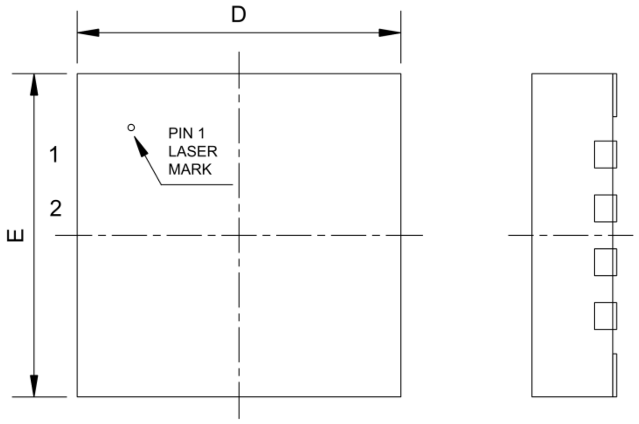
Top Marking Information:
1641 = Product Number
VVV = Version Number
YWW = Year Week

QFN-16 3.0x3.0x0.75 PIN DESCRIPTION

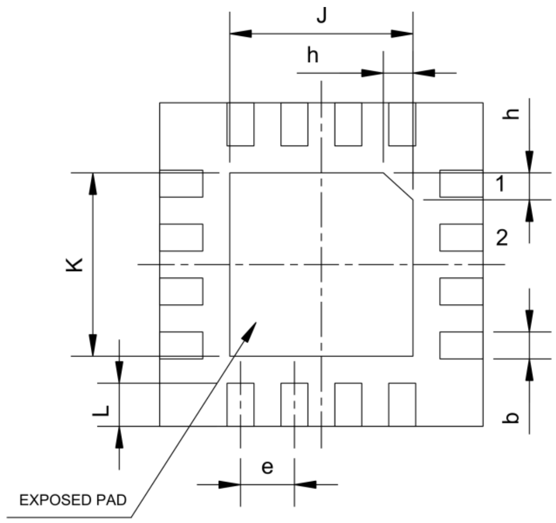
Pin Name	Pin	Type	Function	Note
RMON	1	AO	Monitoring oscillator adjustment resistor	
RCLK	2	AO	System clock adjustment resistor	
DSEL	3	DI	Capacitance change direction selection input DSEL=VIN: Capacitance increase detection DSEL=GND: Capacitance decrease detection	
TEST	4	DO	Open drain test output of measurement oscillator	
FEED	5	AI	Input for piezo sounder feedback terminal	
VOB	6	DO	Output for piezo sounder brass (ground) terminal	
VOS	7	DO	Output for piezo sounder silver terminal	
VOUT	8	AO	Charge pump output	
CP2	9	AI/O	Flying capacitor 2 positive terminal	
CN2	10	AI/O	Flying capacitor 2 negative terminal	
CP1	11	AI/O	Flying capacitor 1 positive terminal	
CN1	12	AI/O	Flying capacitor 1 negative terminal	
VIN	13	P	Power supply	
GND	14	G	Supply ground	2
CS	15	AIO	Capacitive sensor sensing terminal	2
RREF	16	AO	Reference oscillator adjustment resistor	
EXP_PAD	-	G	Exposed pad	1

G = Ground, P = Power, D = Digital, A = Analog, I = Input, O = Output, NC = Not Connected
Note 1: On PCB the exposed pad must be connected to GND.
Note 2: Capacitive sensor is connected between CS and GND pins. Parasitic capacitances between these signals and surroundings should be minimized when routing and wiring these signals to the sensor.

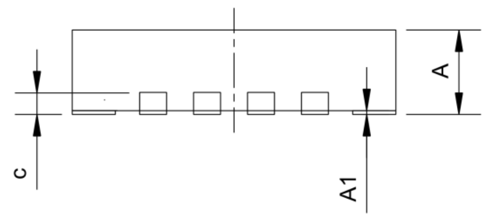
PACKAGE (QFN-16 3X3x0.75) OUTLINE



TOP VIEW



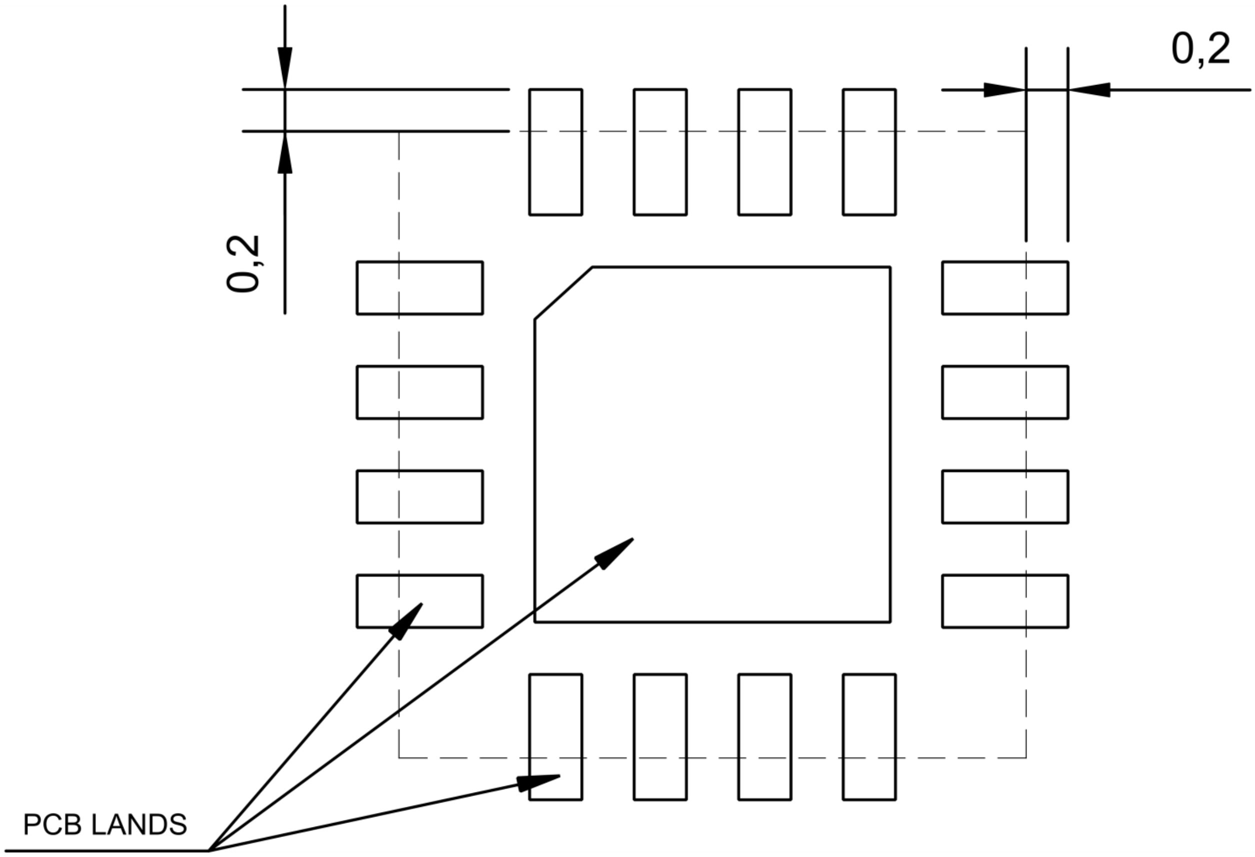
BOTTOM VIEW



Symbol	Min	Nom	Max	Unit
PACKAGE DIMENSIONS				
A	0.7	0.75	0.8	mm
A1	---	0.035	0.05	mm
b	0.2	0.25	0.3	mm
c		0.203 REF		mm
D		3 BSC		mm
E		3 BSC		mm
e		0.5 BSC		mm
J (Exposed.pad)	1.6	1.7	1.8	mm
K (Exposed.pad)	1.6	1.7	1.8	mm
L	0.35	0.4	0.45	mm
h	0.2	0.25	0.3	mm

Dimensions do not include mold or interlead flash, protrusions or gate burrs.

QFN-16 3X3x0.75 PCB LAND PATTERN



Notes

- I/O lands should be 0.2mm longer than QFN pads and extend the same 0.2mm outside package outline
- exposed pad land size should be the same as QFN exposed pad size
- solder resist opening should be 120μm…150μm larger than the land size resulting in 60μm…75μm clearance between copper land and solder resist

ORDERING INFORMATION

Product Code	Product	Package	Comments
MAS1641CA1Q1306	Capacitance Change Detection with Piezo Alarm	QFN-16 3x3x0.75, Pb Free, RoHS Compliant	Tape and Reel 3000 pcs / r
MAS1641CA1WAD00	Capacitance Change Detection with Piezo Alarm	EWS Tested 8” wafers, thickness 370 µm	
MAS1641CA1WAD05	Capacitance Change Detection with Piezo Alarm	370 µm thick dies in waffle pack	

Contact Micro Analog Systems Oy for other wafer thickness options.

LOCAL DISTRIBUTOR

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