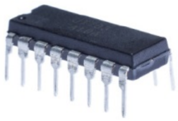
Datasheet

Smartec Universal Transducer Interface UTI and Applications

Features：



- Provides interfacing for:
    - **Capacitors**
    - **Platinum resistors**
    - **Thermistors**
    - **Resistive bridges**
    - **Potentiometers**
    - **Combinations of above sensors**

- Measurement of multiple sensor elements
- Single 2.9V - 5.5V power supply, current consumption below 2.5mA
- Resolution and linearity up to 14 bits and 13 bits
- Continuous auto-calibration of offset and transfer coefficient
- Microcontroller-compatible output signal
- Tri-state output
- 2/3/4-wire measurement available for almost all measurements
- AC excitation voltage signal for all sensor elements
- Two measurement speeds: typical measurement times 12ms or 100ms
- Sleep mode
- Suppression of 50/60 Hz interference
- Operating temperature range for DIL and SOIC -40ºC to 85ºC
- Operating temperature range for bare die -40°C to 180ºC

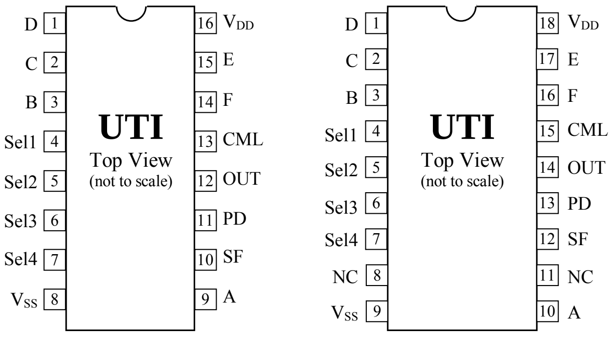
Applications

Automotive, industrial and medical applications, including:

- Capacitive level sensing
- Position sensing
- Angle sensing
- Accurate temperature measurement (Platinum, NTC)
- Resistive-bridge sensors for pressures, forces, etc.

Pin configurations

UTI is available in a 16-pin plastic dual-in-line package (DIL) and an 18-lead small outline package (SOIC), see *Fig. 1*.



16-pins DIL 18-pins SOIC

Fig. 1：UTI Pin configurations for DIL-16 and SOIC-18.

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Contents

1. General description

The Universal Transducer Interface (UTI) is a complete analogue front end for low-frequency measurement applications, based on a period-modulated oscillator. Sensing elements can be directly connected to the UTI without the need for extra electronics. Only a single reference element, of the same kind as the sensor, is required. The UTI outputs a microcontroller-compatible period-modulated signal. The UTI can provide interfacing for:

- Capacitive sensors 0pF to 2pF, or 0pF to12pF, and a variable range up to 300pF
- Platinum resistors Pt100, Pt1000
- Thermistors 1kΩ to 25kΩ
- Resistive bridges 250Ω to 10kΩ, with maximum imbalance of ± 4% or ± 0.25%
- Potentiometers 1kΩ to 50kΩ
- Combinations of above sensors

UTI is ideal for use in smart microcontroller-based systems. All data is presented at a single-wire microcontroller-compatible output, which reduces the number of connecting wires and reduces the number of couplers required in insulated systems. For information about insulated UTI applications, please see the relevant **application notes** in the website: http://www.smartec-sensors.com/cms/. Continuous auto-calibration of offset and transfer coefficient of the complete system is performed by using the three-signal technique. The effect of low-frequency interference is reduced by an advanced chopping technique. For different applications, 16 operating modes are available.

A functional block diagram of UTI is shown in *Fig. 2*. The functions of the pins are listed in Table 1.

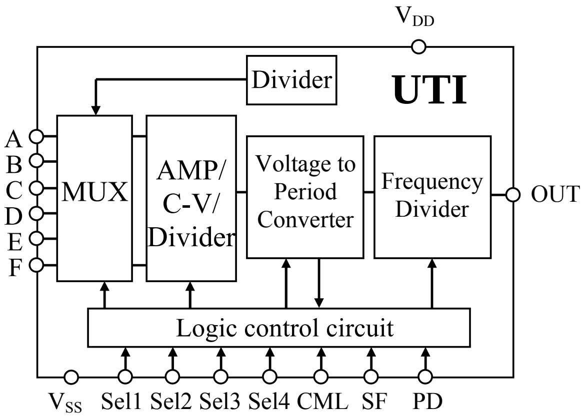


Fig. 2：A functional block diagram of UTI.

Table 1： Pin Configuration of UTI.

Pin name	Pin function
V_{DD},V_{SS}	Power supply
A to F	Sensor connection
Sel1 to Sel4	Mode selection
OUT	Output
SF	Measurement speed selection
CML	CMUX02/CMUX12 mode selection
PD	Power Down (tri-state)

2. Absolute maximum ratings

Specified at T_A=25°C, unless otherwise noted.

Table 2：Absolute maximum ratings of UTI.

Parameters	Value
Power supply voltage	-0.3V to 7V
Supply voltage (sensor current not included）	3mA at 5V
Power dissipation	21mW
Power dissipation at power down (PD=0) mode	7µW
Output voltage	-0.3V to V_{DD}+0.3V
Output driving current	8mA
Output impedance	60Ω
Input voltage referred to V_{SS}	-0.3V to V_{DD}+0.3V
Input current on each pin	±2µA
ESD rating	> 4000V
Storage temperature range	-65°C to 150°C
Operating temperature range	-40°C to 85°C
Lead temperature (soldering, 10s)	300°C

3. Control lines of UTI

3.1. Mode selections

Pins Sel1 to Sel4 are used to select the measurement mode. In total there are 16 measurement modes, as shown in Table 3:

Table 3: Measurement modes of UTI.

Mode pins				Name	Number of phases	Measurement
Sel1	**Sel2**	**Sel3**	**Sel4**			
Capacitive Measurements, see Section 6						
0	0	0	0	**C25**	5	5 Capacitors 0pF to 2pF
0	0	0	1	**C23**	3	3 Capacitors 0pF to 2pF
0	0	1	0	**C12**	5	5 Capacitors 0pF to12pF
0	0	1	1	**CMUX**	-	Multi- cap with external Mux, 0pF to 2pF/0pF to 12pF
0	1	0	0	**C300**	3	3 Capacitors up to 300pF
Resistive Measurements, see Section 7						
0	1	0	1	**Pt**	4	Platinum resistor Pt100/Pt1000
0	1	1	0	**Ther**	4	Thermistor 1kΩ to 25kΩ
0	1	1	1	**Pt2**	5	2 or 3 Pt100/Pt1000
1	0	0	0	**Ther2**	5	2 or 3 Thermistors 1kΩ to 25kΩ
Bridge Measurements, see Section 8						
1	0	0	1	**Ub2**	3	Resistive-bridge, V-excitation, imbalance range ±4%
1	0	1	0	**Ub1**	3	Resistive-bridge, V-excitation, imbalance range ±0.25%
1	0	1	1	**Ib2**	3	Resistive-bridge， I-excitation, imbalance range ±4%
1	1	0	0	**Ib1**	3	Resistive-bridge， I-excitation, imbalance range ±0.25%
1	1	0	1	**Brg1**	5	R-bridge +2 resistors, V-excitation, imbalance range ±4%
1	1	1	0	**Brg1**	5	R-bridge +2 resistors, V-excitation, imbalance range ±0.25%
1	1	1	1	**Potm**	5	3 Potentiometers 1kΩ to 50kΩ

3.2. Other control lines

In Tables 3 and 4, logic '1' and '0' corresponds to connection to V_{DD} and to GND, respectively. Besides the 4 selection pins **Sel1** to **Sel4**, UTI has also other control lines for two other measurement options: measurement speed selection and power-down. These modes are set by **SF** and **PD**, respectively. Pin **CML** is always connected to GND except for mode CMUX. Table 4 lists the other control lines of UTI

Table 4: Other control lines of UTI.

Control lines	Operating modes
SF=0	Speed 1, typical measurement time 80ms to 150ms
SF=1	Speed 2, typical measurement time 10ms to 18ms
PD=1	Normal measurement mode
PD=0	Sleep mode, Output with high impedance
CML=0	CMUX mode， range 0pF to 2pF
CML=1	CMUX mode， range 0pF to 12pF

!! The best measurement resolution can be obtained by setting the measurement speed to speed 1 (SF=0). Then the typical measurement time is around 100ms. By selecting speed 2 (SF=1) typical measurement time is around 12.5ms.

Attention: All control line must be set to the state (HIGH or LOW); floating is not allowed !!!

4. General specifications

4.1. Output

The UTI output (pin OUT) is a microcontroller-compatible period-modulated signal. Table 5 shows some output specifications of UTI. Because all UTI data is present on one single digital output, only three wires would be needed to make a versatile insulated front end. For information about insulated use of UTI please go to the relevant **application notes,** on the website: *http://www.smartec-sensors.com/cms/.*

Table 5：Output specifications of UTI.

Parameter	Value	Unit	Conditions
Output Low V_{ol}	0.4	V	
Output High V_{oh}	V_{DD}-0.6	V	
Output impedance R_{out}	60	Ω	
Maximum I_{out}	8	mA	V_{DD}=5V
Output impedance at pin B-F	800	Ω	Used as output in capacitive modes
Maximum I_{out} at E and F	20	mA	For resistive and bridge modes
Rise time	14	ns	
Fall time	13	ns	
propagation delay from control lines to OUT (Speed 1)	30	ms	(3.75ms in Speed 2)

4.2. Excitation signals

Pins A to F are not only used for connection with sensing elements, they are also used to provide the excitation signals for sensing elements. The specifications are listed in Table 6:

Table 6：The driving specifications of UTI.

Parameter	Value	Unit	Conditions
Output impedance at pin B to F	800	Ω	Used as voltage source in capacitive modes
Maximum I_{out} at E and F	20	mA	For resistive and resistive-bridge modes

4.3. Analog input

Various sensing elements can directly be connected to the inputs of the UTI. The connections of the sensing elements with UTI for various modes are described in section 6 to section 8. *Table 7* shows some input specifications of UTI.

Table 7：Some input specifications of UTI，at V_{DD}=5V, T_A=25ºC.

Parameters	Values	Unit	Conditions
Input capacitance	20	pF	
Cross capacitance leakage between (A) and (B to F)	30×10^{-3}	pF	DIL package
Suppression of 50Hz/60Hz	>60	dB	

5. The measurement principles applied in UTI

5.1. Auto-calibration by three-signal measurement

The three-signal technique is a technique to eliminate the effects of an unknown offset and an unknown transfer coefficient in a linear system. In order to apply this technique, in addition to the measurement of the sensor signal, two reference signals are required to be measured in an identical way. Suppose a system has a linear transfer function of:：

$$F_i = kE_i + F_{off}$$

where F_i is the output signal, E_i represents the input signal, k is the transfer coefficient, M_{off} is the offset. The system measures three different inputs values: E_0=0, E_1=E_{ref}, and E_2=E_x, there are three output values respectively：

$$F_1 = F_{off}$$

$$F_2 = F_{ref} = kE_{ref} + F_{off}$$

$$F_3 = F_x = kE_x + F_{off}$$

Then the measurement result M is found from the equation:

$$M = \frac{F_3 - F_1}{F_2 - F_1} = \frac{F_x - F_1}{F_{ref} - F_1} = \frac{E_x}{E_{ref}}$$

For a linear system, the transfer coefficient k and offset F_{off} are cancelled out. Knowing the reference signal E_{ref} and the ratio M, the unknown signal E_x can be derived accurately. Such measurement technique is called three-signal technique (or three-signal method). The transfer coefficient k and offset F_{off} may vary with time and temperature, but they wouldn’t affect the measurement accuracy provided that the whole system is linear. Therefore, the three-signal technique can be considered as a special way of auto-calibration.

The implementation of the three-signal technique requires a microcontroller, which is used to digitize the period-modulated output signals of UTI and to perform data storage and calculations. Such a system, which includes a sensing element (sensor), a signal-processing circuit, such as UTI, and a microcontroller, is called a microcontroller-based smart sensor system. The auto-calibration properties of UTI renders such a system to be insensitive to the effects of environmental drift.

5.2. Measuring the sensor element

The output of UTI is a period-modulated signal. For example, *Fig. 3* shows two complete cycles of the output signal of UTI, each cycle consists of three phases, represented by the three time intervals T_{phase1}, T_{phase2}, and T_{phase3}, respectively：

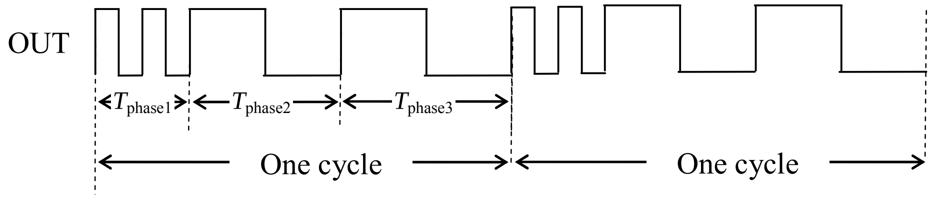


Fig. 3： The output signal of UTI in three-phase mode

As explained in section 5.1, in order to realize the three-signal measurement UTI has to be switched to three or more elements. During the first phase the internal offset of the linear system is measured (normally there are no external component connected to the corresponding pins). During the second phase the UTI measures the value of a reference element, by switching to the corresponding connecting pins. During the following phase (s) the UTI is measuring the value (s) of one or more sensor elements. The output signal depicted in ***Error! Reference source not found.*** applies for a situation where only a single unknown sensor element is being measured. The switching between phases is completely controlled by UTI.

During the first phase, the offset of the overall linear system is measured ($T_{\mathrm{phase1}} = T_{\mathrm{off}}$). During the second phase, the reference signal is measured and during the last phase, the actual sensor signal is measured. The duration of each phase is proportional to the signal which is measured during that phase, in three time intervals, which equal：

Capacitive measurement	Resistive measurement
$T_{\mathrm{phase1}} = T_{\mathrm{off}}$	$T_{\mathrm{phase1}} = T_{\mathrm{off}}$
$T_{\mathrm{phase2}} = T_{\mathrm{off}} + Nk_1C_{\mathrm{ref}}$	$T_{\mathrm{phase2}} = T_{\mathrm{off}} + Nk_2R_{\mathrm{ref}}$
$T_{\mathrm{phase3}} = T_{\mathrm{off}} + Nk_1C_{\mathrm{x}}$	$T_{\mathrm{phase3}} = T_{\mathrm{off}} + Nk_2R_{\mathrm{ref}}$

where C_{x} or R_{x} is the sensor signal to be measured, C_{ref} or R_{ref} the reference signal, and k_1 or k_2 the transfer coefficient. The factor N represents the number of internal oscillator periods in one phase. In Speed 1, N=1024 and in Speed 2 N=128. The output signal of the UTI can be digitized by counting the number of microcontroller clock cycles fitting in each phase. This results in the numbers N_{phase1}, N_{phase2} and N_{phase3}. The ratio $C_{\mathrm{x}}/C_{\mathrm{ref}}$ or $R_{\mathrm{x}}/R_{\mathrm{ref}}$ can now be calculated by the microcontroller:

$$M = \frac{N_{\mathrm{phase3}} - N_{\mathrm{phase1}}}{N_{\mathrm{phase2}} - N_{\mathrm{phase1}}} = \frac{C_{\mathrm{x}}}{C_{\mathrm{ref}}}\, or\, \frac{R_{\mathrm{x}}}{R_{\mathrm{ref}}} \tag{1}$$

As explained in section 5.1, the unknown sensor signal C_{x} or R_{x} can be derived from the ratio M and the accurate value of C_{ref} or R_{ref}. The ratio calculation removes the effects of the offset and the transfer coefficient of the system.

The three phases are time-multiplexed, as depicted in *Fig. 3*. The offset phase consists of two short periods (for this phase, the output frequency is doubled with respect to the other phases). Because of this, the microcontroller can identify the respective phase and make the correct calculation, according to equation (1). Because the offset phase is always the shortest, this fact can also be used for identifying the phases. The number of phases in a complete cycle varies between 3 and 5, depending on the measurement mode of UTI. Each specific mode has a fixed number of periods. There is always one offset measurement, one reference measurement and one or more measurements of unknown value(s).

6. Measurement of capacitors (modes 0000 to 0100)

6.1. Mode 0000, C25: 5 Capacitors 0pF to 2pF

In this mode, 3 unknown capacitors can be measured in combination with 2 reference capacitors (in general one of them is 0pF, while the other one has a value equal to the full range value). The measurement principle has been explain in section **5.5**. The connection of the capacitors is depicted in *Fig. 4*. All capacitors have a common receiver electrode, connected to node A, which is virtual ground at a level of $V_{DD}/2$. The excitation signal at the transmitting electrodes (B to F) is a square-wave voltage with peak-to-peak value V_{DD}. When a capacitor is not measured, the node corresponding to this capacitor is internally grounded. For instance, during phase 2, C_{CA} is measured, thus nodes B, D, E and F are internally grounded. In this **C25** mode, one measurement cycle consists of 5 measurement phases, as depicted in Table 8.

Suppose that the first two phases correspond to the offset and reference measurement respectively (C_{BA}=0pF and $C_{CA}=C_{ref}$), N_{phase1} to N_{phase5} correspond to the digitized time intervals of 5 periods respectively, see Table 8. The capacitances of the three unknown capacitors can be calculated by:

$$C_{DA}=\frac{N_{phase3}-N_{phase1}}{N_{phase2}-N_{phase1}}\cdot C_{ref}\ ;\quad C_{EA}=\frac{N_{phase4}-N_{phase1}}{N_{phase2}-N_{phase1}}\cdot C_{ref}\ ;\quad C_{FA}=\frac{N_{phase5}-N_{phase1}}{N_{phase2}-N_{phase1}}\cdot C_{ref}$$

The capacitance of the reference capacitor C_{ref} should accurately be known.

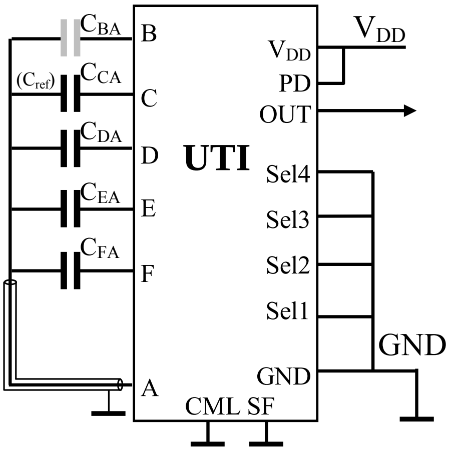


Fig. 4: Connection of capacitors to UTI.

(set SF=1 for speed 2)

Table 8: Measured capacitors in each phase

Phase	Capacitor	Digitized number
1	$C_{BA}+C_0$	N_{phase1}
2	$C_{CA}+C_0$	N_{phase2}
3	$C_{DA}+C_0$	N_{phase3}
4	$C_{EA}+C_0$	N_{phase4}
5	$C_{FA}+C_0$	N_{phase5}

*Table 9: Specifications for the **C25/C23** mode.*

Parameter	Typical value
Max cap value (C_{DA} to C_{FA})	2pF
Linearity	13bits
Resolution (Speed 1, SF=0)	14bits
System offset	$<15\times10^{-3}$pF

In phase 1 the input capacitor $C_{BA}+C_0$ is measured. In this phase the output frequency is doubled, resulting in two short periods. This enables synchronization of the microcontroller. In straight-forward applications, no capacitor is connected between B and A, as explained in section 5.2.

The specifications for the mode **C25** (0000) and **C23** (0001) are listed in Table 9.

The remaining measurement error (system offset) is caused by the parasitic capacitances between bonding wires, bonding pads and IC pins, which may vary from pad to pad. When this error is too large, one should use mode CMUX. In this case, an external multiplexer is used and the measurement error can be as low as 20×10^{-6}pF.

Note:

Please be aware that any parasitic capacitance between node A and other nodes (B to F) will cause extra measurement errors. For this reason it is recommended to use a coax cable to connect node A of UTI to the capacitive sensors to be measured, see *Fig. 4*. This applies to all capacitive measurement modes (0000 to 0100).

6.2. Mode 0001, C23: 3 Capacitors 0pF to 2pF

The setup in this mode is similar to that of mode 0000, the difference is that there are three capacitors being measured, so that the measurement can be faster. The connection and the time intervals during the three phases are indicated in *Fig. 5* and table 10, respectively. The specifications of UTI are the same as in mode 0000, see table 9.

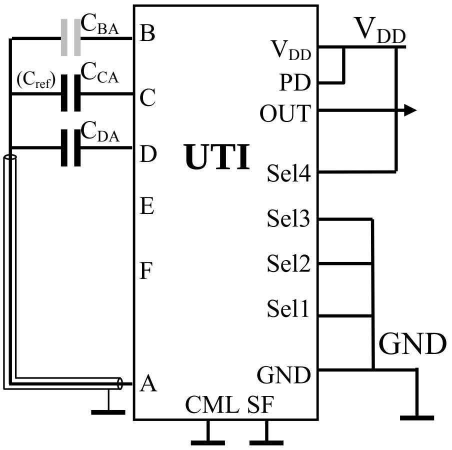


Table 10：Measured capacitors in each phase.

Phase	Capacitor	Digitized number
1	$C_{BA}+C_0$	N_{phase1}
2	$C_{CA}+C_0$	N_{phase2}
3	$C_{DA}+C_0$	N_{phase3}

$$C_{DA} = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot C_{ref} \quad （C_{BA}=0pF\ 和\ C_{CA}=C_{ref}）$$

Fig. 5：Connection of capacitors to UTI for ***C23*** *mode (set SF=1 for speed 2).*

6.3. Mode 0010, C12: 5 Capacitors 0pF to 12pF

The setup in this mode is similar to that of mode 0000, the difference is that the measurement range is 0pF to 12pF. The connection are shown in *Fig. 6*. The time intervals of five periods are listed in table 8. The specifications of UTI is shown in table 11.

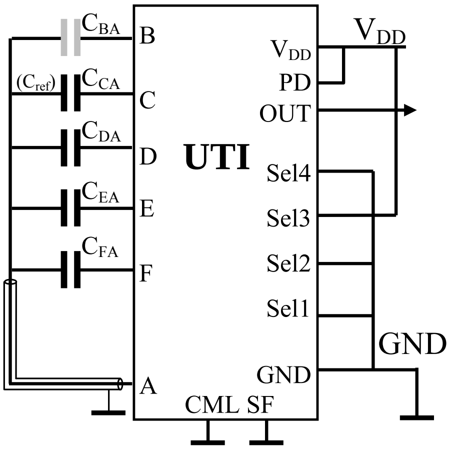


Table 11：UTI specifications for the ***C12*** *mode.*

Parameter	Typical value
Max capacitance (C_{iA})	12pF
linearity	13bits
Resolution (Speed 1, SF=0)	14bits
System offset	$<15\times10^{-3}$pF

Fig. 6：Connection of capacitors to UTI for ***C12*** *mode (set SF=1 for speed 2).*

When：C_{BA}=0pF and $C_{CA}=C_{ref}$，the capacitances C_{DA}, C_{EA} and C_{FA} of the three unknown capacitors can be calculated from the equations:

$$C_{DA} = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot C_{ref}\ ;\quad C_{EA} = \frac{N_{phase4} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot C_{ref}\ ;\quad C_{FA} = \frac{N_{phase5} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot C_{ref}$$

6.4. Mode 0011, CMUX: X Capacitors 0pF to 2pF or 0pF to 12pF

In this mode, UTI can be used to measure any number of capacitors in the range of 0pF to 2pF (CML = 0) or 0pF to 12pF (CML=1). In this mode UTI works as a free-running oscillator. The oscillator period depends on the capacitance connected at input A. In this mode, UTI doesn't perform the phase selection, because this is performed with an external multiplexer. Optionally, this can be performed with a special multiplexer MUX which has been developed by Smartec. This special multiplexer is implemented with nine outputs and four inputs. The typical connection is shown in *Fig. 7*. By coupling a number of MUX devices in series, the number of capacitors that can be measured can be extended without limit. Detailed specifications of MUX are available in the data sheet on the website: http://www.smartec-sensors.com/cms/. The specifications of UTI in **CMUX** mode are shown in Table 12.

*Table 12：UTI specifications for the **CMUX** mode.*

Parameter	Typical value (CML=0)	Typical value (CML=1)
Max capacitance (C_{iA})	2pF	12pF
linearity	13 bits	13 bits
Resolution (Speed 1, SF=0)	14 bits	14 bits
System offset	$< 2\times10^{-5}$pF	$< 2\times10^{-5}$pF

As shown in *Fig. 7*, an external multiplexer is controlled by the microcontroller (μC), it multiplexes the excitation signal that has a frequency f_{osc}, from node B to one or more selected capacitors. Up to nine capacitors can be measured with one multiplexer. The UTI output appears on the node "output". Nominal frequencies of the output signal during an offset measurement (none of the capacitors are selected) are $f_{osc}/8 \approx 6$kHz (SF=1) and $f_{osc}/1024 \approx 50$Hz (SF=0). More multiplexers can be used in parallel to measure more capacitors, as described in the data sheet.

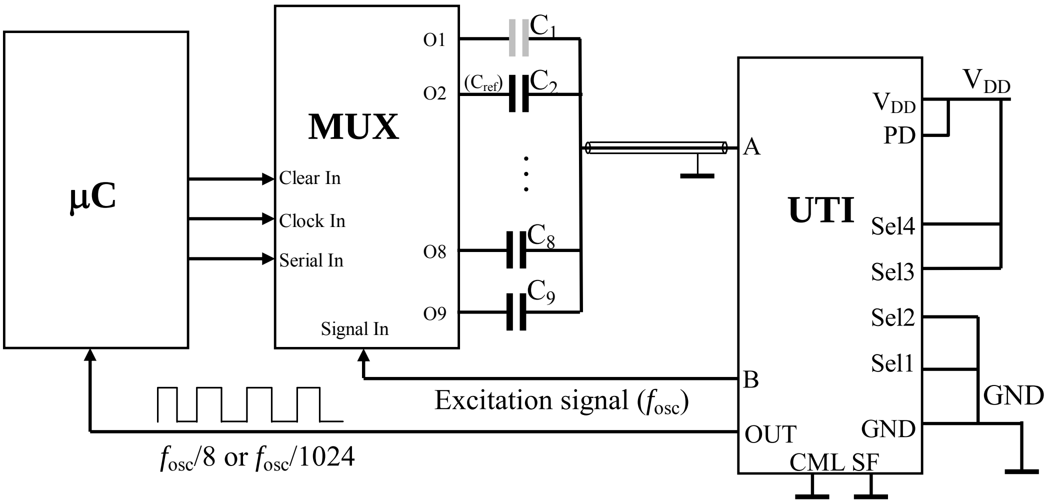


*Fig. 7：A possible measurement setup in **CMUX** mode to measure multi-capacitors.*

6.5. Mode 0100, C300: 3 Capacitors, range up to 300pF

In this mode, 3 capacitors in a variable range up to 300pF can be measured. The connection of sensors and external resistors is depicted in *Fig. 8*. Since relatively large capacitors are measured, the excitation voltage should be smaller than in the other modes in order to keep the transferred charge to C-AMP in the similar range as in modes 0000 to 0011 (see Appendix A1.3 and *Fig. 23*(b)). The excitation signal is derived from the power supply with an external voltage divider R_1, R_2 and R_3. From the DC voltage V_{EF}, a square-wave excitation signal is derived with a peak-to-peak value that equals V_{EF}, which is delivered to one of the selected capacitor connected to the pins B, C or D.

The total capacitance at node A must be limited to 500pF in order to keep the nonlinearity below 10^{-3}. The tolerances of the three resistors R_1, R_2 and R_3 are not critical, while R_1 or R_3 may be zero. The DC voltage V_{EF} should satisfy the following condition: $V_{EF}<K_V/C_{max}$, where the constant $K_V=60\text{V}\cdot\text{pF}$, and C_{max} is the maximum value of C_{BA}, C_{CA} and C_{DA} expressed in pF. The total time constant of all resistors and capacitors should be less than 500ns. This sets the values of the resistors.

For example: When C_{CA}=300pF, C_{DA}=200pF, C_{BA}=0pF and V_{DD}=5V, practical values of the resistors are R_1=25kΩ, R_2=1kΩ and R_3=0Ω. In this case the peak-to-peak value of the excitation signal amounts to V_{EF}=0.2V.

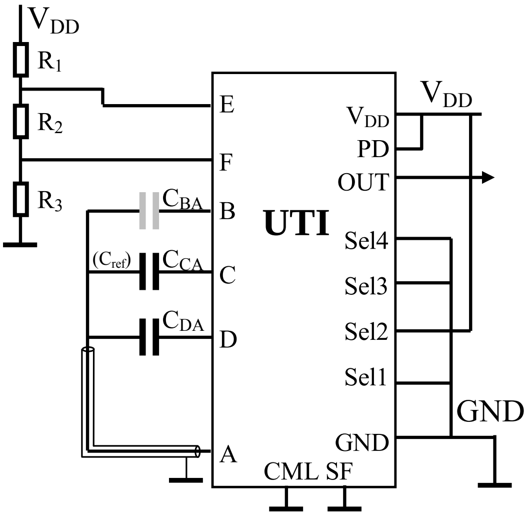


Fig. 8：Connection of capacitors and resistors with UTI in ***C300*** *mode (set SF=1 for speed 2).*

The system contains two time constants: $C_{tot}\cdot(R_3//(R_1+R_2))$ and $C_{tot}\cdot(R_1//(R_2+R_3))$, where $C_{tot}=C_{BA}+C_{CA}+C_{DA}+C_p$. Both time constants must be smaller than 500ns. The nonlinearity and resolution in Speed 1 are depicted in Table 13. Here, the value of C_{DA}=0pF, C_p=30pF and V_{EF} has the maximum value K_V/C_{max}, as described before. The measured capacitors during each phase are listed in Table 14.

Table 13：Non-linearity and resolution for different capacitances.

Capacitance	Non-linearity	Resolution（pF）
$C_{BA}=C_{CA}$=33pF	1.4×10^{-4}	1.2×10^{-3}
$C_{BA}=C_{CA}$=150pF	1.9×10^{-4}	6.6×10^{-3}
$C_{BA}=C_{CA}$=270pF	9.0×10^{-4}	17×10^{-3}
$C_{BA}=C_{CA}$=330pF	2.6×10^{-3}	20×10^{-3}
$C_{BA}=C_{CA}$=560pF	6.3×10^{-3}	46×10^{-3}

Table 14：Measured capacitors in each phase.

Phase	Capacitor	Digitized number
1	$C_{BA}+C_0$	N_{phase1}
2	$C_{CA}+C_0$	N_{phase2}
3	$C_{DA}+C_0$	N_{phase3}

With C_{BA}=0pF, $C_{CA}=C_{ref}$, the capacitance of the unknown capacitor (C_{DA}) is calculated by:

$$C_{DA}=\frac{N_{phase3}-N_{phase1}}{N_{phase2}-N_{phase1}}\cdot C_{ref}$$

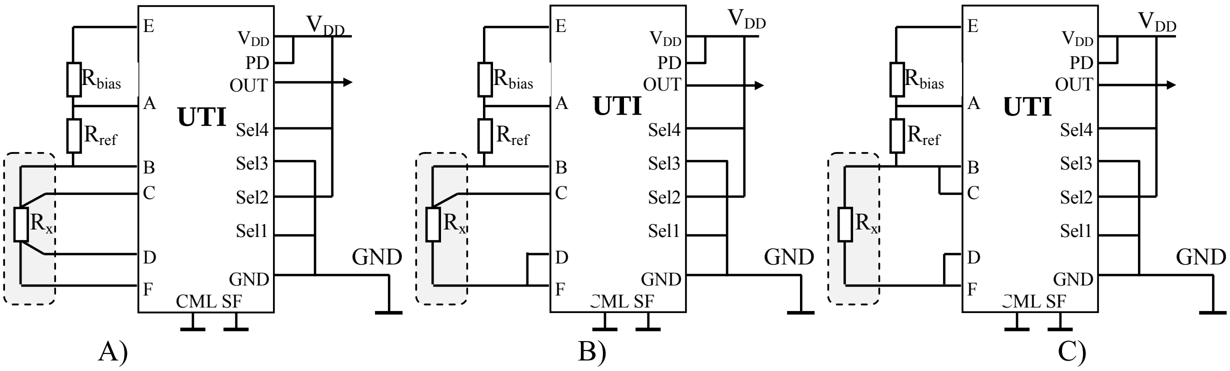
7. Measurement of resistors (mode 0101-1000)

7.1. Mode 0101, Pt: Platinum resistor[1] Pt100/Pt1000

In this mode, one sensor resistor can be measured in combination with an offset resistor and a reference resistor. The connection of the resistors to UTI is depicted in *Fig. 9*. Because of the use of force/sense wires, both resistors R_x and R_{ref} are measured in a 4-wire setup, thereby the effects of lead resistances are completely eliminated. The excitation voltage V_{EF} is a square-wave signal with an amplitude of V_{DD} and a frequency which is 1/4 of the internal oscillator frequency. The resistor R_{BIAS} is used to set the current through the resistor chain. For measurement of a Pt100, the residual measurement inaccuracy is less than ±40mΩ. This 40mΩ can be considered as a systematic error caused by the internal design of the chip.
One measurement cycle consists of 4 phases. These phases contain the information for a 2-, 3- or 4-wire measurement, as shown in Table 15：

Table 15：Measured voltages in each phase.

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$V_{CD}+V_0$	N_{phase3}
4	$V_{BC}+V_0$	N_{phase4}



A) B) C)

(set SF=1 for speed 2)

Fig. 9：Connection of Pt100 with UTI，A) 4-wire，B) 3-wire，C) 2-wire.

The resistance of Pt100 can be calculated from the following equations:

2-wire or 4-wire：

$$R_x = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

3-wire：

$$R_x = \frac{N_{phase3} - N_{phase4}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

The linearity is better than 13bits provided that the amplitude of the voltages V_{AB} and V_{CD} are below 0.7V for V_{DD}=5V, and 0.4V for V_{DD}=3.3V, respectively. This limits the current through the platinum resistor.
Current limitation is also required to limit the error due to self-heating. For instance, for a thermal resistance of 200K/W (still air) at V_{CD} = 0.7V and 0ºC, the self-heating effect of a Pt100 causes an error of 1K. If this self-heating error is too large, R_{BIAS} should be increased to reduce the current through the Pt100. For V_{CD}=0.2V, the temperature error due to self-heating amounts to 80mK, which is two times less than the initial inaccuracy of a class A Pt100. In this case, the current through the Pt100 amounts to 2mA which requires R_{BIAS}=2.2kΩ.

[1]: **Platinum resistors can also be measured using mode 1011**.

The relative sensitivity of a Pt100 is about 3.9×10^{-3}/K. When the current through the Pt100 is 2mA, this sensitivity corresponds to 780µV/K. In mode 0101 and speed 1, the UTI resolution, as limited by to noise effects, is 7µV, corresponding to 9mK resolution in temperature. The specifications of UTI in Pt mode are listed in Table 16.

Table 16：UTI specifications for the ***Pt*** *mode.*

Parameter	Typical value
R_{bias} (Pt100, self-heating error=80mK for thermal resistance of 200K/W)	2.2kΩ (5%) I=2mA
R_{bias}(Pt1000, self-heating error=80mK for thermal resistance of 200K/W)	6.2kΩ (5%) I=600µA
Maximum excitation current from E and F	20mA
System offset	10µV
Linearity	13bits
Resolution (Speed 1, SF=0) (Pt100, 2mA)	14bits (9mK）

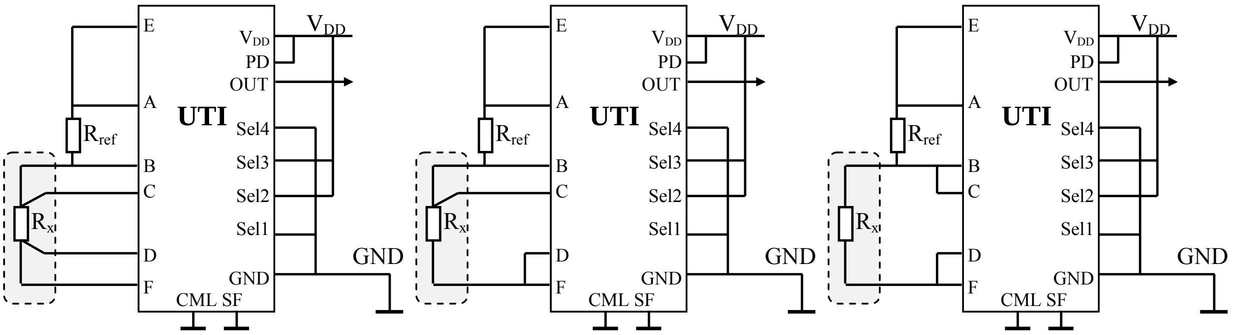
Amplitudes of V_{CD} and V_{AB} up to 2.5V peak-to-peak are allowed (very good resolutions can be obtained), but self-heating effects and nonlinearity are deteriorated. Linearity is decreased to 8 bits for peak-to-peak amplitudes in the range of 0.7V-2.5V.

Excitation of the measurement chain is done with an AC voltage. The cable capacitance has influence on the measurement accuracy. For applications with extra-long (shielded) cable a special interface circuit in combination with UTI has been developed. For more information, the reader is referred to the relevant application notes on the website (*http://www.smartec-sensors.com/cms/*). There it can be found, that for sensor cable with lengths up to 200 meter still a good measurement accuracy can be achieved. Smartec recommends this solution for all resistive applications, where the sensing element is located far from UTI.

7.2. Mode 0110, Ther: Thermistor

In this mode, one thermistor can be measured in combination with an offset and a reference resistor. The connections for the thermistor and the reference resistor are shown in *Fig. 10*, for 4-wire, 3-wire and 2-wire measurements, respectively.

The excitation voltage V_{EF} is a chopped voltage with an amplitude of $V_{DD}/12.5$ (0.4V at V_{DD}=5V) and a common mode level of $V_{DD}/2$.



(a) (b) (c)

(set SF=1 for speed 2)

Fig. 10：Connection of the Thermistor with UTI，(a) 4-wire，(b) 3-wire，(c) 2-wire.

Table 17：Measured voltages in each phase.

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$V_{CD}+V_0$	N_{phase3}
4	$V_{BC}+V_0$	N_{phase4}

The signals that are measured during the various phases are listed in Table 17. The voltage V_{AB} is not constant, it reduces with increasing R_x, which linearizes the sensor characteristic. The ratio between the thermistor and the reference resistor is also given by:

2-wire and 4-wire：

$$R_x = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

3-wire：

$$R_x = \frac{N_{phase3} - N_{phase4}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

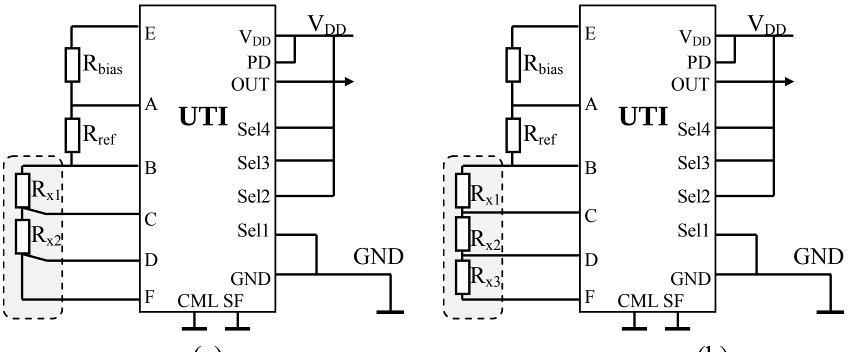
UTI specifications and the limitations for R_x and R_{ref} in **Ther** mode are listed in Table 18. For very large and very small values of R_x (10 times or 0.1 times R_{ref}), the resolution, in voltage, is still the same, but the resolution in temperature is decreased. This is due to the linearization method.

*Table 18：UTI specifications for the **Ther** mode.*

Parameter	Typical value
$R_{ref}//R_X$	<5kΩ
$R_{ref}+R_X$	>1kΩ
System offset	10μV
Linearity	13bits
Resolution (Speed 1, SF=0)	7μV (1mK)

7.3. Mode 0111, Pt2: 2 or 3 Platinum resistors

In this mode, 2 or 3 platinum resistors can be measured in combination with an offset resistance (not shown in the figures) and a reference resistor. The connection of the resistors to UTI is depicted in *Fig. 11*.



(set SF=1 for speed 2)

(a) (b)

Fig. 11: *Connection of Platinum resistors with UTI (set SF=1 for speed 2), (a) 2 Pt resistors, (b) 3 Pt resistors.*

The same restrictions for the current through the resistors in Pt mode apply here as well. The specifications are listed in Table 16. Note that only R_{x2} can be measured with a 4-wire setup. Resistor R_{x1} is measured in series with the resistance of the upper lead that connects R_{x1} with R_{ref}. Phase 5 can be used to measure just one lead resistance or to measure R_{x3}. The main difference with the Pt mode is that one measurement cycle takes 5 phases, as listed in Table 19.

Table 19: *Measured voltages in each phase in* ***Pt2*** *mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$V_{CD}+V_0$	N_{phase3}
4	$V_{BC}+V_0$	N_{phase4}
5	$V_{DF}+V_0$	N_{phase5}

The resistances of Pt100 resistors can be calculated as follows:

2 Pt100 resistors (*Fig. 11* (a)):
$$R_{x1} = \frac{N_{phase4} - N_{phase5}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

$$R_{x2} = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

3 Pt100 resistors (*Fig. 11* (b)):
$$R_{x1} = \frac{N_{phase4} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

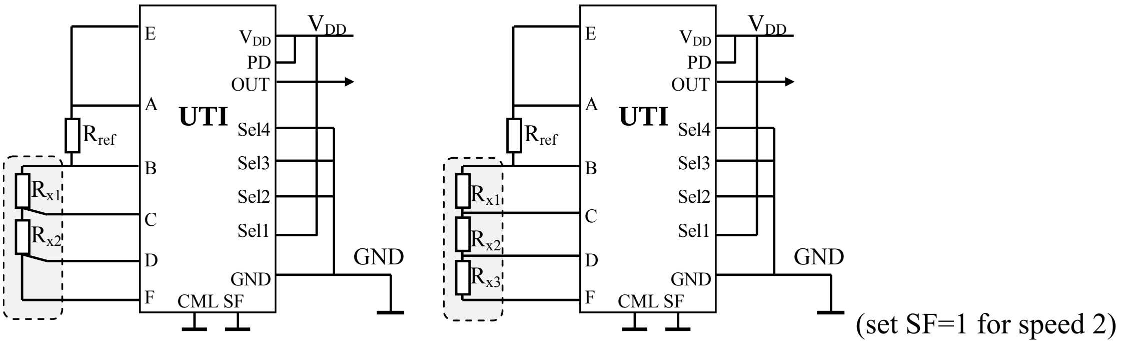
$$R_{x2} = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

$$R_{x3} = \frac{N_{phase5} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

With the connection shown in *Fig. 11* (b), the effect of lead resistances cannot be eliminated, there will be extra error in R_{x1} and R_{x3}. In this case, the internal connection wires of the UTI will cause an error of about 0.9Ω for the Pt100 and 3Ω for the Pt1000 for the measurement of R_{x3}, respectively. This measurement error may vary with supply current and temperature, but is stable and systematic.

7.4. Mode 1000, Ther2: 2 or 3 Thermistors

In this mode, 2 or 3 thermistors can be measured in combination with an offset resistance (not shown in the figures) and a reference resistor. The connection of the resistors to UTI is depicted in *Fig. 12*.



(a) (b)

Fig. 12：Connection of thermistors with UTI，(a) 2 thermistors，(b) 3 thermistors.

With the connection shown in *Fig. 12* (b), the effect of lead resistances cannot be eliminated, there will be extra error in R_{x1} and R_{x3}. In this case, the internal connection wires of the UTI will cause an error in the value of R_{x3}. For instance, when all resistors are with the same resistances, the measurement error of R_{x3} is between 11Ω and 14Ω, for the resistance of R_{x3} between 1kΩ and 10kΩ. This measurement error depends on the supply current and temperature, but is stable and systematic.

The five phases and the corresponding voltages are listed in Table 20.

Table 20：Measured voltages in each phase in ***Ther2*** *mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$V_{CD}+V_0$	N_{phase3}
4	$V_{BC}+V_0$	N_{phase4}
5	$V_{DF}+V_0$	N_{phase5}

The resistances of each unknown resistors can be calculated by:

2 resistors(*Fig. 12* a)：

$$R_{x1} = \frac{N_{\text{phase4}} - N_{\text{phase5}}}{N_{\text{phase2}} - N_{\text{phase1}}} \cdot R_{\text{ref}}$$

$$R_{x2} = \frac{N_{\text{phase3}} - N_{\text{phase1}}}{N_{\text{phase2}} - N_{\text{phase1}}} \cdot R_{\text{ref}}$$

3 resistors (*Fig. 12* b)：

$$R_{x1} = \frac{N_{\text{phase4}} - N_{\text{phase1}}}{N_{\text{phase2}} - N_{\text{phase1}}} \cdot R_{\text{ref}}$$

$$R_{x2} = \frac{N_{\text{phase3}} - N_{\text{phase1}}}{N_{\text{phase2}} - N_{\text{phase1}}} \cdot R_{\text{ref}}$$

$$R_{x3} = \frac{N_{\text{phase5}} - N_{\text{phase1}}}{N_{\text{phase2}} - N_{\text{phase1}}} \cdot R_{\text{ref}}$$

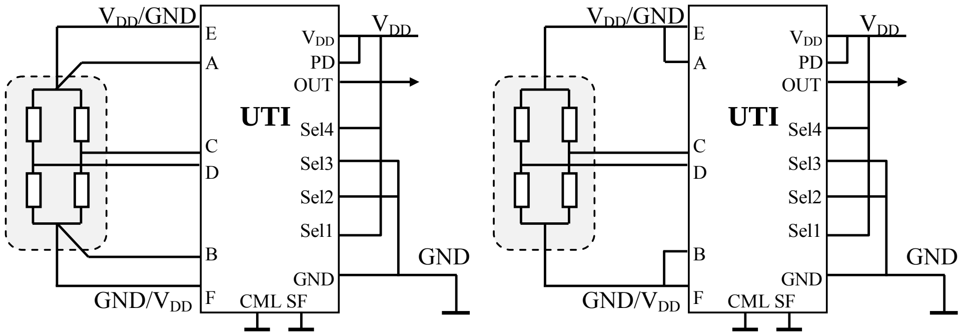
8. Measurement of resistive-bridges (mode 1001-1111)

8.1. Mode 1001，Ub2: Resistive-bridge，V-excitation, Imbalance range ±4%

In this mode the imbalance of a resistive bridge can be measured. The ratio between the imbalance voltage V_{CD} and the excitation voltage V_{AB} represent accurately the bridge imbalance.

In this mode the measurement range of a bridge imbalance is ±4%, corresponding to a voltage $V_{CD} = \pm 0.2V$ at 5V excitation voltage.

The connection of the bridge with UTI is shown in *Fig. 13*. The excitation signal across the bridge is a voltage that is chopped between V_{DD} and GND, where the frequency is ¼ of the internal oscillator frequency f_{osc}. The use of separate force and sense wires (*Fig. 13*, (a)) makes it a 4-wire measurement, thus the effect of lead resistance can be eliminated. The 2-wire connection shown in *Fig. 13* (b) can be applied for cases that the sensor bridge is close to UTI.



(a) (b)

(set SF=1 for speed 2)

Fig. 13： The connection of the resistive bridge with UTI in (a) 4-wire and (b) 2-wire ways.

*Table 21： Measured voltages in each phase in **Ub2** mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}/32+V_0$	N_{phase2}
3	$V_{CD}+V_0$	N_{phase3}

For all phases, the measured signals are listed in Table 21. During phase 2, the voltage across the bridge V_{AB} is measured. A very accurate on-chip voltage divider divides this voltage with a factor of 32. This divider does not need calibration. After division, V_{AB} is further processed in the same way as V_{CD}.

The bridge imbalance M can be calculated as：

$$M = \frac{1}{32}\frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} = \frac{V_{CD}}{V_{AB}}$$

Other UTI specifications are listed in Table 22.

*Table 22： UTI specifications for the **Ub2** mode.*

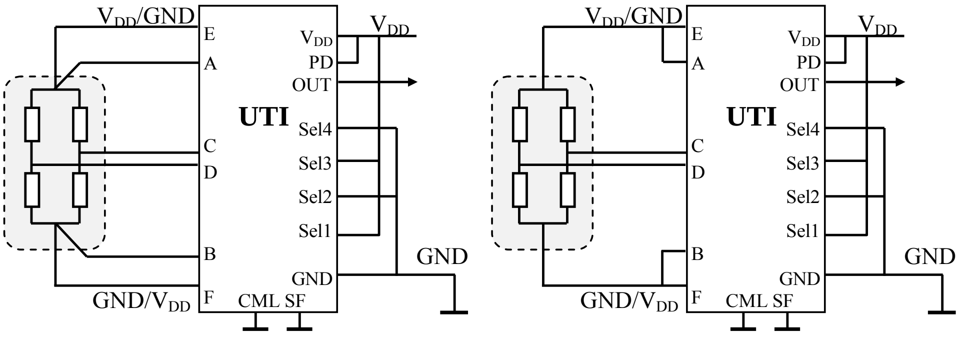
Parameter	Typical value
Excitation signal	AC V_{DD}
Max excitation current	20mA
Bridge resistance	250Ω to 10kΩ
Bridge output voltage	<±0.2V
Accuracy	11 bits
System offset	<10μV
Resolution (Speed 1, SF=0)	7μV

8.2. Mode 1010，Ub1: Resistive-bridge，V-excitation, Imbalance range ±0.25%

In this mode the imbalance of a resistive bridge can be measured. The ratio between the imbalance voltage V_{CD} and the excitation voltage V_{AB} represent accurately the bridge imbalance.

In this mode the measurement range of a bridge imbalance is ±0.25%, corresponding to a voltage of ±12.5mV at 5V excitation voltage.

The connection of the bridge with UTI is shown in *Fig. 14*. The excitation signal across the bridge is a square-wave voltage with amplitude of V_{DD}, and the frequency is ¼ of the internal oscillator frequency f_{osc}. The use of separate force and sense wires (*Fig. 14* (a)), (a)) makes it a 4-wire measurement, thus the effect of lead resistance can be eliminated. The 2-wire connection in *Fig. 14* (b) can be applied for the cases when the sensor is connected with short wires to UTI.



(set SF=1 for speed 2)

(a) (b)

Fig. 14:The connection of the resistive bridge with UTI in (a) 4-wire and (b) 2-wire ways.

For all phases, the measured signals are listed in Table 23. During phase 2, the voltage across the bridge V_{AB} is measured. A very accurate on-chip voltage divider divides this voltage with a factor of 32. This divider does not need calibration. After division, V_{AB} is further processed. During phase 3, the bridge imbalance voltage V_{AB} is measured. An accurate on-chip voltage amplifier amplifies this voltage with a factor of 15. This amplifier does not need calibration. After amplification, V_{CD} is further processed.

*Table 23：Measured voltages in each phase in **Ub1** mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}/32+V_0$	N_{phase2}
3	$15V_{CD}+V_0$	N_{phase3}

The bridge imbalance *M* can be calculated as：

$$M = \frac{1}{480}\frac{N_{phase3}-N_{phase1}}{N_{phase2}-N_{phase1}} = \frac{V_{CD}}{V_{AB}}$$

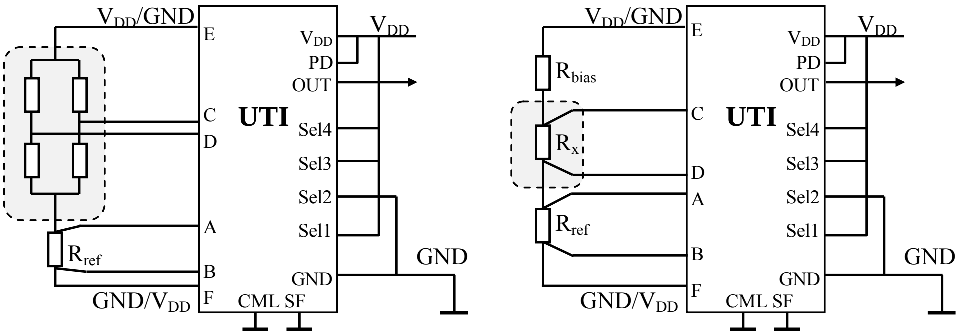
Other UTI specifications are listed in Table 24.

*Table 24：UTI specifications for the **Ub1** mode.*

Parameter	Typical value
Excitation signal	AC ~V_{DD}
Max excitation current	20mA
Bridge resistance	250Ω-10kΩ
Bridge output voltage	<±0.2V
Accuracy	11 bits
System offset	<10μV
Resolution (Speed 1, SF=0)	0.7μV

8.3. Mode 1011，Ib2: Resistive-bridge，I-excitation，Imbalance range ±4%

In this mode the imbalance of a resistive bridge can be measured for maximum values up to 4%. In contrast with the modes described in sections 8.1 and 8.2, in this mode the bridge is supplied with a current I_{ex}. With resistor R_{ref}, this current I_{ex} is converted into a reference voltage V_{AB}. The connections of the bridge and the reference element are shown in *Fig. 15*. **The value of R_{ref} should be chosen so that V_{AB} is between 0.1V and 0.2V.** This mode can also be used to measure a platinum resistor in a 4-wire setup (*Fig. 15* (b)). The advantage in comparison with Pt mode is that now only three phases have to be measured, see Table 24.



(a) (b)

Fig. 15：(a) The connection of the resistive bridge and reference resistor with UTI, (b) the connection for platinum resistor measurement (set SF=1 for speed 2).

*Table 25：Measured voltages in each phase in **Ib2** mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$V_{CD}+V_0$	N_{phase3}

The bridge imbalance M can be calculated as：

$$M = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} = \frac{V_{CD}}{V_{AB}} = \frac{V_{CD}}{I_{ex} R_{ref}}$$

When a platinum resistor is measured, the resistance is calculated as：

$$R_x = \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} \cdot R_{ref}$$

Other UTI specifications are listed in Table 26:

*Table 26：UTI specifications for the **Ib2** mode.*

Parameter	Typical value
Excitation signal	AC ~V_{DD}
Max excitation current	20mA
Bridge resistance	250Ω-10kΩ
Bridge output voltage	<±0.2V
Accuracy	11 bits
System offset	<10µV
Resolution (Speed 1, SF=0)	7µV

8.4. Mode 1100，Ib1: Resistive-bridge，I-excitation，Imbalance range ±0.25%

This mode is similar to mode 11, the difference is that the bridge-imbalance range is ±0.25%. **The value of R_{ref} should be chosen so that V_{AB} is between 0.1V and 0.2V.** The connections of the bridge and the reference resistor are shown in *Fig. 16*.

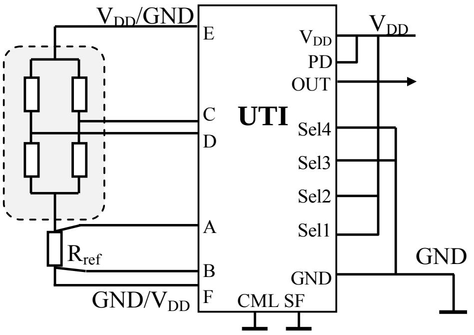


Fig. 16：The connection of the resistive bridge and reference resistor with UTI (set SF=1 for speed 2).

During phase 3, the bridge imbalance voltage V_{CD} is measured. An accurate on-chip voltage amplifier amplifies this voltage with a factor of 15. This amplifier does not need calibration. After amplification, V_{CD} is further processed. Table 27 shows the periods in each phase.

Table 27：Measured voltages in each phase in ***Ib1*** *mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$15V_{CD}+V_0$	N_{phase3}

The ratio between the imbalance voltage and the reference voltage is then calculated as：

$$M = \frac{1}{15}\frac{N_{phase3}-N_{phase1}}{N_{phase2}-N_{phase1}} = \frac{V_{CD}}{V_{AB}} = \frac{V_{CD}}{I_{ex}R_{ref}}$$

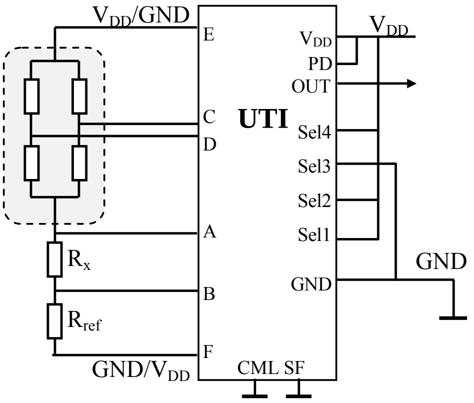
Other UTI specifications are listed in Table 28:

Table 28：UTI specifications in ***Ib1*** *mode*

Parameter	Typical value
Excitation signal	AC ~V_{DD}
Max excitation current	20mA
Bridge resistance	250Ω-10kΩ
Bridge output voltage	<±12.5mV
Accuracy	10 bits
System offset	<10μV
Resolution (Speed 1, SF=0)	700nV

8.5. Mode 1101，Brg2: Resistive-bridge and 2 resistors, V-excitation, Imbalance range ±4%

In this mode a resistive bridge and 2 resistors can be measured. The imbalance of the resistive bridge should be less than +/- 4%. One of the resistors can be temperature sensitive, so the bridge imbalance can be digitally compensated for temperature variation. **The values of R_{ref} and R_x should be chosen so that V_{BF} and V_{AB} are between 0.1V and 0.2V.** Both, the voltage across the bridge and the current through the bridge are measured. The connection of the elements to the UTI is shown in *Fig. 17*.



(set SF=1 for speed 2)

*Fig. 17：The connection of the resistive bridge and resistors with UTI in **Brg2** mode .*

During phase 5, when the bridge voltage V_{EA} is measured, a very accurate on-chip voltage divider divides this voltage with a factor of 32. This divider does not need calibration. After division, V_{EA} is further processed. Table 29 shows in which phases the various voltages are measured.

*Table 29：Measured voltages per phase in the **Brg2** mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$V_{CD}+V_0$	N_{phase3}
4	$V_{BF}+V_0$	N_{phase4}
5	$V_{EA}/32+V_0$	N_{phase5}

The bridge imbalance M is calculated as:

$$M = \frac{1}{32}\frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} = \frac{V_{CD}}{V_{EA}}$$

The resistance R_x is calculated as:

$$R_x = \frac{N_{phase2} - N_{phase1}}{N_{phase4} - N_{phase1}} \cdot R_{ref}$$

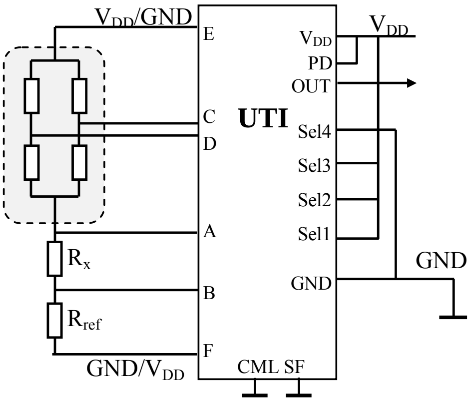
Other UTI specifications are listed in Table 30:

*Table 30：UTI specifications for the **Brg2** mode.*

Parameter	Typical value
Excitation signal	AC ~V_{DD}
Max excitation current	20mA
Bridge resistance	250Ω-10kΩ
Bridge output voltage	<±0.2V
Accuracy	11 bits
Linearity	12 bits
System offset	<10μV
Resolution (Speed 1, SF=0)	7μV

8.6. Mode 1110，Brg1: Resistive-bridge and 2 resistors, V-excitation, Imbalance range ±0.25%

This mode is similar to mode 1101, but now the maximum bridge imbalance amounts to ±0.25%. **The values of R_{ref} and R_x should be chosen so that V_{BF} and V_{AB} are between 0.1V and 0.2V.** The connections of the elements to the UTI are shown in *Fig. 18*.



(set SF=1 for speed 2)

*Fig. 18：The connections of the resistive bridge and resistors with UTI in **Brg1** mode.*

During phase 5, when the bridge supply voltage V_{EA} is measured, a very accurate on-chip voltage divider divides this voltage with a factor of 32. After division, V_{EA} is further processed. During phase 3, when the bridge imbalance voltage V_{CD} is measured, an accurate on-chip voltage amplifier amplifies this voltage with a factor of 15. After amplification, V_{CD} is further processed. Both the divider and the amplifier do not need calibration. Table 31 shows the periods and the corresponding voltage signals.

*Table 31：Measured voltage in each phase in **Brg1** mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{AB}+V_0$	N_{phase2}
3	$15V_{CD}+V_0$	N_{phase3}
4	$V_{BF}+V_0$	N_{phase4}
5	$V_{EA}/32+V_0$	N_{phase5}

The bridge imbalance M is calculated as:

$$M = \frac{1}{480} \frac{N_{phase3} - N_{phase1}}{N_{phase2} - N_{phase1}} = \frac{V_{CD}}{V_{EA}}$$

The resistance R_x is calculated as:

$$R_x = \frac{N_{phase2} - N_{phase1}}{N_{phase4} - N_{phase1}} \cdot R_{ref}$$

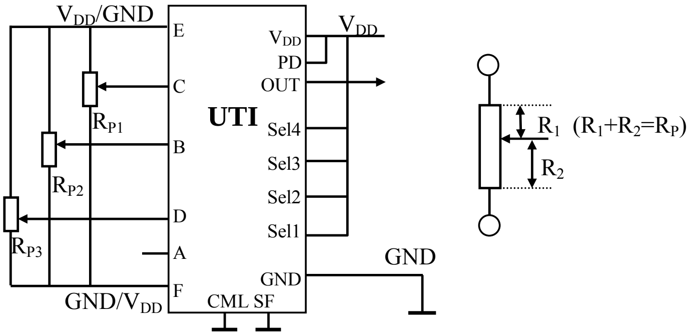
Other UTI specifications are listed in Table 32:

*Table 32：UTI specifications for the **Brg1** mode.*

Parameter	Typical value
Excitation signal	AC ~V_{DD}
Max excitation current	20mA
Bridge resistance	250Ω-10kΩ
Bridge output voltage	<±12.5mV
Accuracy	10 bits
Linearity	12 bits
System offset on V_{CD}	<10μV
System offset on V_{AB}	<10μV
Resolution (Speed 1, SF=0)	7μV

8.7. Mode 1111，Potm: 3 Potentiometers, 1kΩ-50kΩ

In this mode, up to 3 potentiometers in the range of 1kΩ to 50kΩ can be measured. The connection of potentiometers is depicted in *Fig. 19*. When only a single potentiometer is measured with its slide connected to, for instance, node B, nodes C and D should be connected to F. The voltage across the potentiometers is a square-wave voltage with amplitude V_{DD} and frequency ¼ of the internal oscillator frequency f_{osc}.



(set SF=1 for speed 2)

Fig. 19： The connection of potentiometers with UTI in ***Potm*** *mode.*

Table 33：Measured voltage in each phase in ***Potm*** *mode.*

Phase	Voltages	Digitized number
1	V_0	N_{phase1}
2	$V_{EF}+V_0$	N_{phase2}
3	$V_{CF}+V_0$	N_{phase3}
4	$V_{BF}+V_0$	N_{phase4}
5	$V_{DF}+V_0$	N_{phase5}

In this mode, it is not possible to compensate the effect of lead resistances. Therefore, the use of low-ohmic potentiometers should be avoided. The measured voltages during each phase are indicated in Table 33. The relative position M for each potentiometer equals:

$$M_{1,2,3} = \frac{N_{\mathrm{phase3,4,5}} - N_{\mathrm{phase1}}}{N_{\mathrm{phase2}} - N_{\mathrm{phase1}}} = \left(\frac{R_2}{R_1 + R_2}\right)_{1,2,3}$$

Other UTI specifications are listed in Table 34:

Table 34：UTI specifications for the ***Potm*** *mode.*

Parameter	Typical value
Excitation signal	AC V_{DD}
Potentiometer resistance	1kΩ-50kΩ
Resolution (Speed 1, SF=0)	14 bits

9. Encapsulations of UTI

Fig. 20 shows the pad configuration of the UTI die and the SOIC encapsulation. The size of the UTI die is 3.1mmx2.1mm.

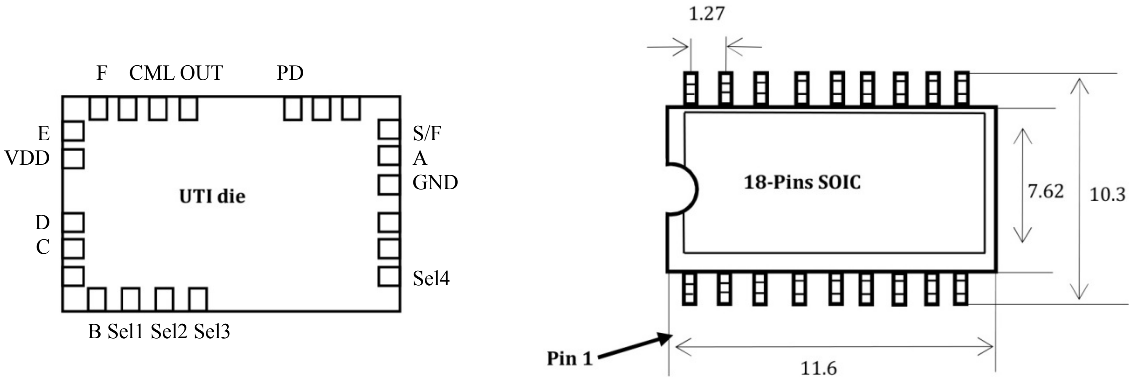


Fig. 20：The pad configuration of the UTI die and sizes of the SOIC package.

All sizes in mm

10. UTI order code

UTIDIL:	UTI in DIL-16 package
UTISOIC:	UTI in SOIC-18 package
UTI die:	UTI die
UTI wafer:	UTI wafer
TOOLKIT USB mini:	UTI Evaluation board，with USB mini connector.

For more information please visit our website: http://www.smartec-sensors.com/cms/.

Appendix 1 Important measurement principles applied in UTI

A1.1 Resolution

The output signal of UTI is digitized by a microcontroller, using sampling with a timer. This sampling introduces quantization noise, which affects the measurement resolution. The quantization noise for any phase-time interval T_{phase}, as given by the relative standard deviation σ_{q}, amounts to:

$$\sigma_q = \frac{1}{\sqrt{6}} \frac{t_s}{T_{phase}}$$

where t_{s} is the period of the sampling clock signal. When, for example, with $t_{\mathrm{s}}=1\mu\mathrm{s}$, and $T_{\mathrm{phase}}=20\mathrm{ms}$ for the offset phase, then the standard deviation of the offset phase amounts to 1/49000, which results in a standard deviation corresponding to about 15.5bits.

Further improvement of the resolution can be obtained by averaging over several values of *M*. When *P* values T_1 … T_{P} are used to calculate the average value of T_{phase}, and because there is no correlation between the values of the phase times, the value of σ_{q} decreases with a factor of $\sqrt{P}$.

Besides quantization noise, another limitation of the resolution is due to the thermal noise of the oscillator itself and the possible effect of a parasitic (cable) capacitance C_{p} (see paragraph 5.5). For the **CMUX** mode (see section 6.4), the resolution as a function of the parasitic capacitance C_{p} is shown in *Fig. 21*.

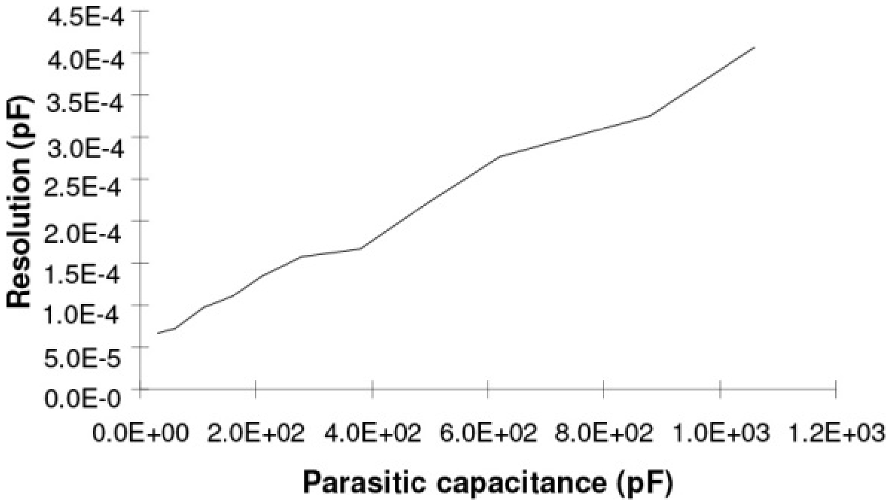


*Fig. 21： The resolution versus the parasitic capacitance C_p (**CMUX** mode).*

A1.2 Linearity

Typically, the linearity of the UTI has values between 11bits and14 bits, depending on the mode. For the CMUX mode, the nonlinearity as a function of the parasitic capacitance C_{p} is shown in *Fig. 22*. For the nonlinearity test, the parasitic capacitance has been connected as C_{p2} in *Fig. 23*(b).

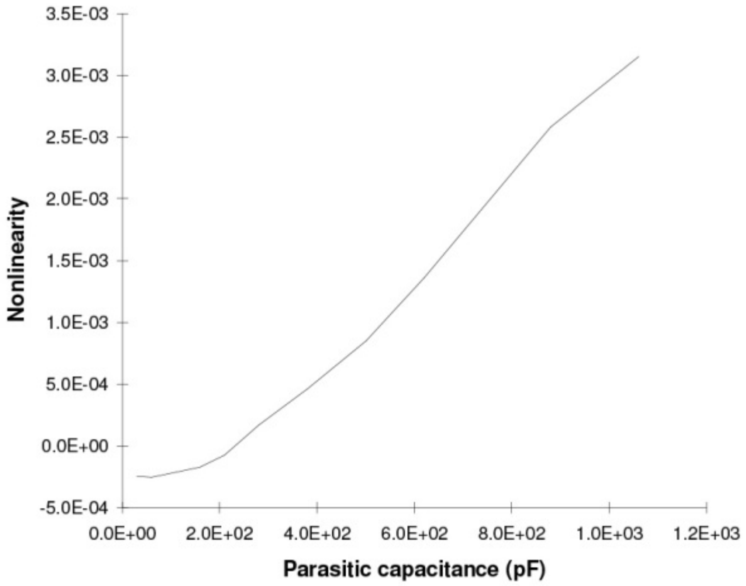
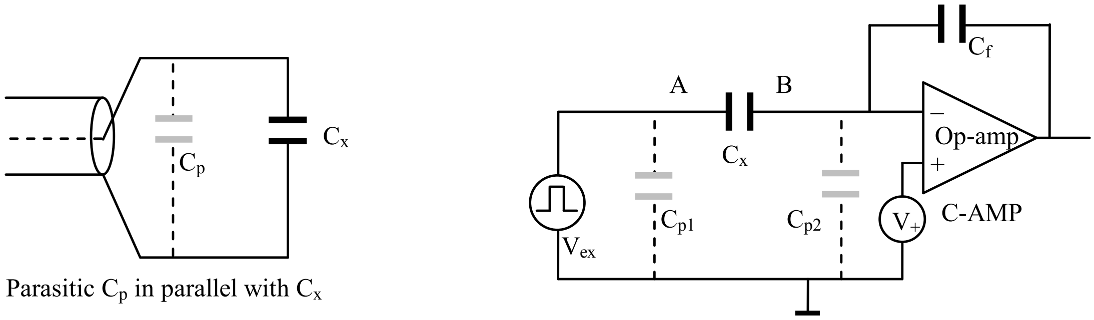


Fig. 22：The linearity versus the parasitic capacitance C_p (CMUX mode).

A1.3 Capacitive measurement with UTI

The UTI can accurately measure capacitances that are connected via a cable with the UTI, while the cable capacitance C_p is much larger than the sensor capacitance. When this would be performed in the way shown in Fig. 8(a), the parasitic capacitance C_p would cause a large error. Therefore, in the UTI the so-called two-port method is used (*Fig. 23*(b), in which the both sides of the sensor capacitance are connected with separated cables to the UTI excitation source V_{ex} and the UTI front-end amplifier C-AMP, respectively.



(a) (b)

Fig. 23： (a) Classical way of C-measurement, (b) UTI way of C-measurement.

In this case, the cable capacitance C_{p1} is connected in parallel with the voltage source V_{ex} and will not affect the measurement. Amplifier C-AMP is implemented as a charge amplifier, which has a very low input impedance. In fact the input terminal of this amplifier is at “virtual-ground” level. This causes that the current through C_{p2} is very small (negligible), so that all current through sensor capacitor C_x is transferred to the charge amplifier, so that C_{p2} will not affect the measurement error. With this two-port measurement technique it is possible to measure capacitances as small as a few atto-Farads (aF) while the cable capacitances might have values which are thousands (or more) times as large.
In *Fig. 22* the relation between accuracy and parasitic cable capacitance C_p is depicted. From the graph it can be seen that even in case of a cable capacitance of about 500pF the linearity is still 10^{-3}.

When multiple capacitances are measured, each node (say B, C, D, E, F) is activated for a certain time and after that UTI switches to the next node. The inactive nodes are connected to ground and become parasitic and have therefore no influence on the measurement. Node selection is automatically controlled by UTI. In CMUX mode the number of capacitors is unlimited. All the capacitors can be connected to a different voltage source and are all wired together to the receiver input of the charge amplifier (node A), which enables the measurement of the sum of several capacitors or the difference of some capacitors. Further CMUX applications are given in the CMUX specifications. For more information about measuring capacitors with UTI please look into relevant **application notes** which can be found on a separate website: http://www.smartec-sensors.com/cms/.

Note:
In most capacitive applications the input which is measured during the first phase (offset phase) is left unconnected. Under those circumstances only the internal capacitance of UTI is measured (on-chip capacitance and the parasitic capacitances of the bonding wires and leads). During the second phase the reference capacitor is measured. This is the most straightforward way to apply the three-signal methods and to eliminate the effects of the offset and the transfer coefficient. As a result, in the **5-capacitor** mode (mode 0 or mode 2), **three unknown capacitors can be measured,** while in **3-capacitor** mode (mode 1 or mode 4) only **one unknown capacitor can be measured**.
However, under certain circumstances, it may be desirable to connect an external offset component (C_0). When the value of this offset component is known with the same accuracy as the value of the reference component, the three signal method can still be applied.

Appendix 2 UTI toolkit

In order to enable the user to get to know and use UTI in a fast way, an evaluation board has been developed and is available for order. This board can directly be connected with different types of sensors. The board can communicate with a PC via a USB mini cable (*Fig. 25*). To control the board and display the measurement results in real time, LabVIEW software is available for the user. For the various types of sensors, different modes are used. All measurement modes (except for CMUX) and the measurement speed as well can be set by the microcontroller. For application notes please visit our website: http://www.smartec-sensors.com/cms/.

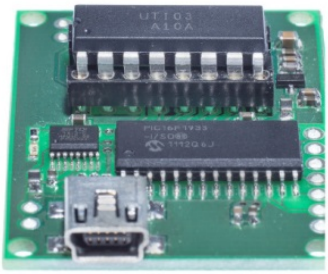


Fig. 24: UTI evaluation board.

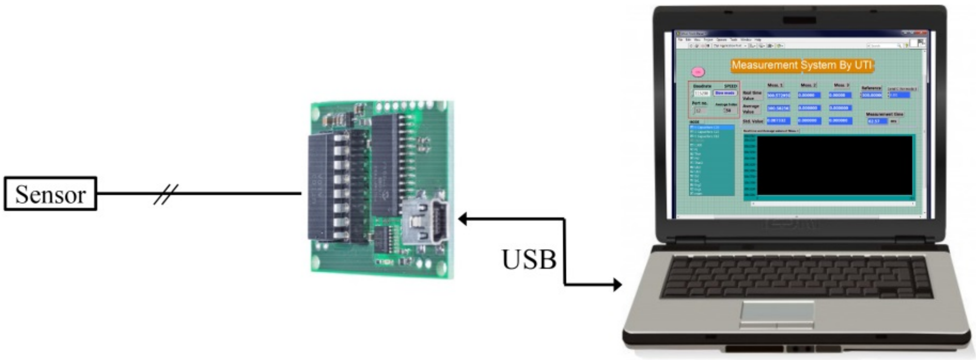


Fig. 25：UTI-based measurement set up.