Universal Sensors and Transducers Interface (USTI)

Specification and Application Note

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Technology Assistance BCNA 2010, S.L. (Excelea)

Contents

1. Introduction

The Universal Sensors and Transducers Interface (USTI) is a universal 2-channel high precision multifunctional converter based on novel frequency-time conversion methods. It is perfectly suited to any applications where frequency-time parameters but also sensors output signal, have to be measured with highest resolution and programmable accuracy during the non-redundant conversion time and self-adaptive possibilities. The USTI covers all specified converted range of frequencies and accuracy for modern frequency-time domain sensors. In addition, the USTI provides interfacing for resistive (including platinum resistors and thermistors), capacitive sensors and resistive bridges.

2. Features

- 29 measuring modes and one generating mode
- 2 identical channels
- Provides interfacing for many types of frequency-time domain sensors and transducers
- Provides interfacing for resistive (including platinum (Pt), cuprum (Cu) resistors and thermistors Ni)), capacitive sensors and resistive bridges
- Frequency range from 0.05 Hz up to 9 MHz (at $40 \div 50$ % duty-cycle for f_{xmax}) without prescaling and 144 MHz with prescaling
- Programmable accuracy (relative error) for frequency (period) conversion from 1 % to 0.0005% for rectangular waveform input pulse signals
- Relative quantization error is constant in all specified frequency range
- Non-redundant conversion time
- Scalable resolution
- Internal reference clock 625 kHz, 20 MHz @ 20MHz quartz oscillator
- Quartz-accurate automated calibration
- Slave communication mode for 3-wire serial interface (SPI compatible)
- Slave communication mode for 2-wire interface (I^2C compatible)
- Slave communication mode for RS232/485 serial interface
- Master communication mode for RS232/485
- Frequency generator mode $f_{osc}/2$ = 20 MHz/2 = 10 MHz with quartz crystal stability
- Single power supply 4.5 – 5.5 V
- Active supply current at 20 MHz, 4.5V, 25ºC below 9.5 mA
- Operating temperature range (- 40ºC to + 85ºC)
- Package Type: 28-lead Plastic Dual Inline Package (PDIP); compact 32-lead Thin Profile Plastic Quad Flat Package (TQFP); and 32-pad Micro Lead Frame Package (MLF).

3. General Description

The Universal Sensors and Transducers Interface (USTI) is a complex fully digital CMOS integrated circuit based on novel patented methods for frequency, period, its ratio, duty-cycle and phase-shift measurements (Figure 1). By using this IC it is possible to build a wide variety of digital, smart sensors and intelligent sensor systems. The device represents a high-resolution conversion for data acquisition systems designed to support all range of frequency-time domain and digital sensor applications. It offers high performance with flexibility and requires minimum possible number of external components.
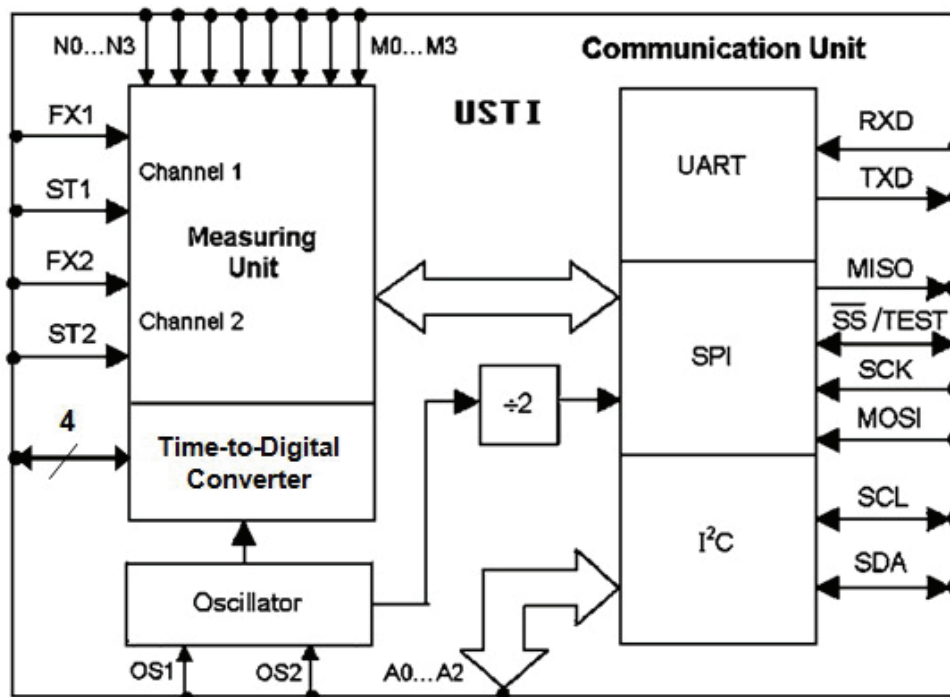

Figure 1. The USTI Block Diagram.

The USTI can be easy included into digital environment, controlled by an external microcontroller or work independently as a separate measuring unit without an external control. The function selection can be configured in both software and hardware.

The IC converts frequency-time domain signals, resistance and capacitance of sensing elements and resistance of sensor bridges into digital domain and provides digital, bus interface to microcontroller, DAQ or sensor system to read these digital results. Sensing elements can be directly connected to the USTI without the need for extra electronics. Only a single reference element, of the same kind as the sensor, is required.

The USTI can measure the following frequency-time parameters of electrical signals and sensing elements:

- Frequency, f_{X1} 0.05 Hz – 9 MHz directly and up to 144 MHz with prescaling
- Frequency, f_{X2} 0.05 Hz – 9 MHz directly and up to 144 MHz with prescaling
- Period, T_{X1} 110 ns – 20 s
- Period, T_{X2} 110 ns – 20 s
- Phase shift, φ_X 0 - 360° at f_{xmax} = 625 kHz at 50% duty-cycle
- Time interval between start – and stop-pulse, τ_X 1.5 µs – 250 s
- Duty-cycle, DC_1 0 – 1 at $f_{xmax} \leq$ 625 kHz
- Duty-cycle, DC_2 0 – 1 at $f_{xmax} \leq$ 625 kHz
- Duty-off factor, Q_1 10^{-8} – $8 \cdot 10^6$ at $f_{xmax} \leq$ 625 kHz
- Duty-off factor, $Q2$ 10^{-8} – $8 \cdot 10^6$ at $f_{xmax} \leq$ 625 kHz
- Frequency difference, $f_{X2} - f_{X2}$ with sign recognition, 0 – 9 MHz
- Period difference, $T_{X1} - T_{X2}$ with sign recognition, 0 – 20 s
- Frequency ratio, f_{X1}/f_{X2} $5.5 \cdot 10^{-9}$ – $1.8 \cdot 10^8$
- Period ratio, T_{X1}/T_{X2} $4.0 \cdot 10^{-9}$ – $2 \cdot 10^8$
- Rotation speed, n_{X1} = $(f_X \cdot 60)/Z$, where Z is the number of encoder teeth
- Rotation speed, n_{X2} = $(f_X \cdot 60)/Z$, where Z is the number of encoder teeth
- Pulse width, t_{P1} 1.5 µs – 250 s
- Pulse width, t_{P2} 1.5 µs – 250 s
- Space interval, t_{S1} 1.5 µs – 250 s
- Space interval, t_{S2} 1.5 µs – 250 s
- Pulse number (events) counting, N_{X1} 0 – $4 \cdot 10^9$
- Pulse number (events) counting, N_{X2} 0 – $4 \cdot 10^9$
- Frequency deviation absolute $D_{A1,}$ 0-9 MHz
- Frequency deviation relative $D_{R1,}$ 0-100 %
- Frequency deviation absolute $D_{A2,,}$ 0-9 MHz
- Frequency deviation relative $D_{R2,}$ 0-100 %
- Resistance, R_x 10 Ω to 10 MΩ with average relative error $\pm$ 0.47 % and $\pm$ 0.01 % at splitting of the range into sub ranges
- Capacitance, C_x 50 pF to 100 µF with average relative error $\pm$ 0.036 % and 0.7 % the worst case relative error
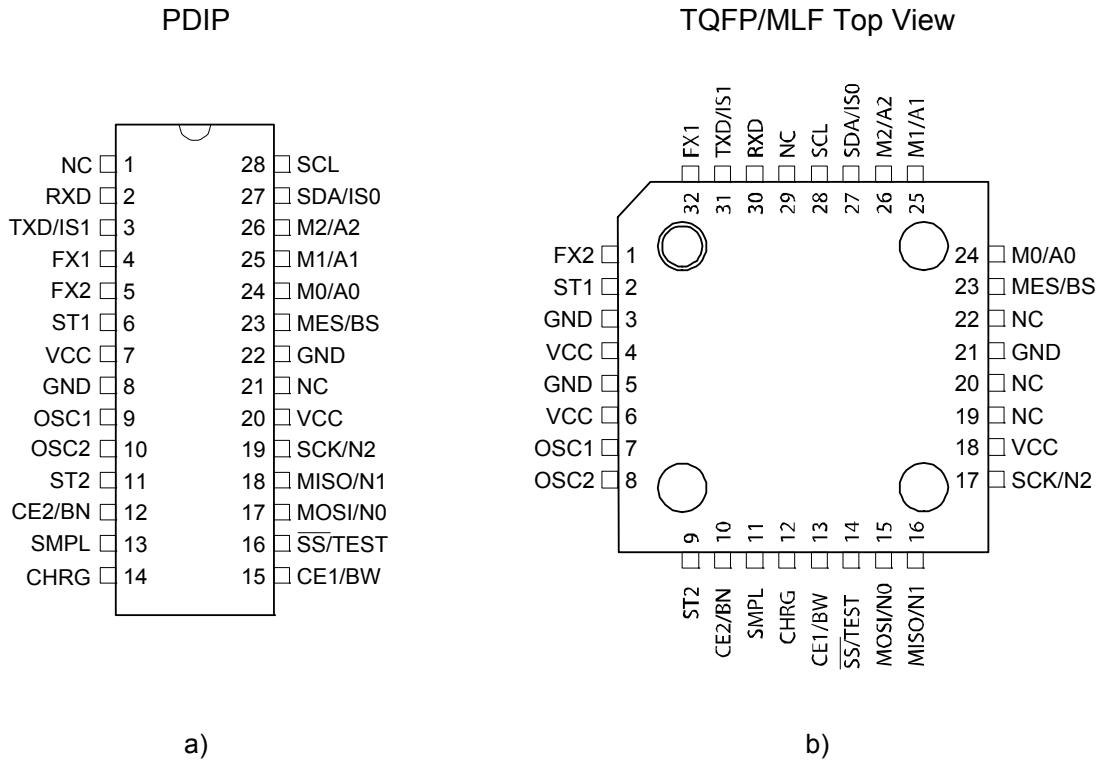- Resistive bridges, B_x must not include any internal components other than 4 arms forming a bridge

4. Pin-out and Housing

The USTI is available in a 28-lead Plastic Dual Inline Package (PDIP), 32-lead small Thin Profile Plastic Quad Flat Package (TQFP) and 32-pad Micro Lead Frame Package (MLF) package. Figure 2a and 2b show the pin configurations of PDIP and TQFP/MLF accordingly. The function of the pins is listed in Table 1.

5. Functionality

5.1 Accuracy

As described in sections 2-3, the USTI has 29 measuring and one generating modes. The measuring mode can be hardware-selected by using three selection pins M0-M2 and the relative error by using four selection pins N0-N2 (RS232 master communication mode). The mode and accuracy can be also selected by using any of three possible interfaces (slave communication mode). A communication interface type (RS232, SPI or I^2C) can be automatically selected according to the circuit connection.

PDIP

NC	1	28	SCL
RXD	2	27	SDA/IS0
TXD/IS1	3	26	M2/A2
FX1	4	25	M1/A1
FX2	5	24	M0/A0
ST1	6	23	MES/BS
VCC	7	22	GND
GND	8	21	NC
OSC1	9	20	VCC
OSC2	10	19	SCK/N2
ST2	11	18	MISO/N1
CE2/BN	12	17	MOSI/N0
SMPL	13	16	$\overline{SS}$/TEST
CHRG	14	15	CE1/BW

TQFP/MLF Top View

a)   b)

Figure 2. Pin Configuration and Housing (Not to Scale). NOTE: Bottom Pad for MLF Package Should be Soldered to Ground.

Table 1. Pin Description.

Name	Pin Descriptions
VCC	Supply voltage
GND	Ground
FX1, ST1	Input channel 1
FX2, ST2	Input channel 2
OSC1, OSC2	Oscillator
M0, M1, M2	Mode selection (see table)
N0, N1, N2	Accuracy selection (see table)
A0, A1, A2	Address of I^2C slave (for I^2C bus communication)
TEST	Calibration signal
SCK	SPI Bus Master clock Input
MISO	SPI Bus Master Input/Slave Output
MOSI	SPI Bus Master Output/Slave Input
SS	SPI Bus Master Slave select
SCL	Two-wire (I^2C compatible) Serial Bus Clock Line
SDA	Two-wire (I^2C compatible) Serial Bus Data Input/Output Line
RXD	UART Input
TXD	UART Output
IS0,IS1	Interface mode selection
BN	North port of bridge
BW	West port of bridge
BS	South port of bridge
CE1	Calibration element 1
CE2	Calibration element 2
CHRG, MES, SMPL	R_x and C_x measurement pins

For frequency-time output sensors and transducers, the USTI relative error should be selected small enough. If the sensor error is, for example, 0.01 %, the conversion error should be ten times (or at least, five times), smaller, i.e. accuracy of USTI should be 0.001 % or at least, 0.002 %. In this case the conversion error can be neglected. The USTI has non-redundant conversion time. The higher conversion accuracy needs longer conversion time. However, it is non-redundant for any selected accuracy and frequency. The quantization error is constant and does not depend on the measures frequencies in all frequency range for 0, 1, 6 -10, 14 -15, 19, 22 and 26 modes.

Table 2. Measurement Mode Number, Accuracy Number and Charge Time Number
to Ternary Jumpers State Conversion.

Dec	Hex	Measurement Mode	Accuracy	Time	J2	J1	J0
0	00	Frequency 1	1	100 μs	O	O	O
1	01	Period 1	0.5	200 μs	O	O	L
2	02	Phase Shift	0.25	300 μs	O	O	H
3	03	Time Interval	0.1	400 μs	O	L	O
4	04	Duty Cycle 1	0.05	500 μs	O	L	L
5	05	Duty Off 1	0.025	600 μs	O	L	H
6	06	Frequency Difference	0.01	700 μs	O	H	O
7	07	Period Difference	0.005	800 μs	O	H	L
8	08	Frequency Ratio	0.0025	900 μs	O	H	H
9	09	Period Ratio	0.001	1 ms	L	O	O
10	0A	Rotation Speed 1	0.0005	2 ms	L	O	L
11	0B	Pulse Interval 1	1 Presc.	3 ms	L	O	H
12	0C	Space Interval 1	0.5 Presc.	4 ms	L	L	O
13	0D	Pulse Counter 1	0.25 Presc.	5 ms	L	L	L
14	0E	Frequency 2	0.1 Presc.	6 ms	L	L	H
15	0F	Period 2	0.05 Presc.	7 ms	L	H	O
16	10	Resistance	0.025 Presc.	8 ms	L	H	L
17	11	Capacitance	0.01 Presc.	9 ms	L	H	H
18	12	Bridge	0.005 Presc.	10 ms	H	O	O
19	13	Frequency Deviation 1*	0.0025 Presc.	20 ms	H	O	L
20	14	Duty Cycle 2	0.001 Presc.	30 ms	H	O	H
21	15	Duty Off 2	0.0005 Presc.	40 ms	H	L	O
22	16	Rotation Speed 2	N/A	50 ms	H	L	L
23	17	Pulse Interval 2	N/A	60 ms	H	L	H
24	18	Space Interval 2	N/A	70 ms	H	H	O
25	19	Pulse Counter 2	N/A	80 ms	H	H	L
26	1A	Frequency Deviation 2*	N/A	90 ms	H	H	H

* Measurement mode not available in master RS232 interface configuration.

In modes 2, 4-5, 20-21 the accuracy does not depend on the period of pulse sequence. The programmable accuracy influences only the conversion error of period. Measurement results in these modes only depend on the pulse width. The conversion error for modes 3, 11-12, 23-24 strictly depends on the converted values and does not depend on value programmed using selection pins N0-N2 or accuracy selection commands (A00-A0F). This error can be calculated according to the following equation:

$$\delta_q = \frac{1}{20 \cdot 10^6 \cdot t_x} \times 100\%, \qquad (1)$$

where t_x is the appropriate measuring value of t_p, t_s or τ_x depending on the mode. Programmed converted accuracy also does not influence on a conversion result in the mode 13.

The USTI can work as an independent measuring unit (master mode), controlled by any external microcontroller, or embedded into sensor, DAQ board or PC (slave mode). In the master mode, the conversion accuracy and measurement mode should be selected by external switches. In this mode the USTI works only through the RS232 interface in a unidirectional mode. In the slave mode (with an external microcontroller), all measuring modes and programmed accuracy can be set up by a data bus or through communication I/O ports of master microcontroller. This allows us use the USTI as a simple peripheral circuit for a microcontroller. A bidirectional data exchange is possible with any of three interfaces RS232, SPI or I^{2}C. The USTI works as a standard element in different systems with I^{2}C bus architecture, or can be controlled through the RS232 or SPI interfaces. The choice of interface can be performed automatically depend on the circuit connections.

5.2 Communication Interfaces

The selection of communication interface is performed automatically based on the state of IS0 and IS1 inputs at the power switch on:

IS1	IS0	Communication Interface
0	0	SPI slave
0	1	I2C slave
1	0	RS232 master
1	1	RS232 slave

5.2.1 RS232 Interface

The converter can work in an autonomous operating mode (master mode, unidirectional data transfer) as well as in systems (slave operating mode, bidirectional data transfer). If during five seconds after being powered-on the USTI has not received any command through the RS232, the converter reads the external switches and is placed into the unidirectional mode of data transfer through the RS232 in BCD ASCII format. By default, the transmission speed is 2400, mode - 0 (frequency measurement in the first channel), accuracy – A00 (1 %). The data transfer rate can be chosen from the following range: 300, 600, 1200, 2400, 4800, 9600, 14400, 19200, 28800 and 38400 (for slave mode).

The brief communication command set description for RS232 interface, appropriate modes and programmed accuracies are adduced in Table 3. Circuit diagrams for master mode and slave mode are shown in Figure 3 and 4 accordingly. Pin numbers in all circuit diagrams correspond to the converter in 28-lead Plastic Dual Inline Package (PDIP).

The connector XP1 is intended for in-circuit automated calibration. In the working mode jumper J1 must be in ON position and in the calibration mode it must be in OFF position.

For connection the USTI to PC through the RS232 interface the additional circuit (Figure 5) for interfacing function is recommended.

5.2.2 3-wire Serial Interface (SPI Compatible)

The brief description of communication command set for SPI interface, appropriate modes and programmed converted accuracies are adduced in Table 4. The circuit diagram for the 3-wire Serial Interface communication mode is shown in Figure 6. The connector XP1 is intended for in-circuit automated calibration. Jumpers J1 and J2 must be in the ON position in the working mode and in the OFF position in the calibration mode.

Table 3. Communication Command Set for RS232 Interface.

Command	Description	Parameter
A	Get current accuracy number	–
Ann	Set accuracy number "nn" "nn" – two hex digits (00 ≤ nn ≤ 15) (00 ≤ nn ≤ 0A) – without an external divider (0B ≤ nn ≤ 15) – with an external divider by 16	00 – 1 % 01 – 0.5 % 02 – 0.25 % 03 – 0.1 % 04 – 0.05 % 05 – 0.025 % 06 – 0.01 % 07 – 0.005 % 08 – 0.0025 % 09 – 0.001 % 0A – 0.0005 % 0B – 1 % 0C – 0.5 % 0D – 0.25 % 0E – 0.1 % 0F – 0.05 % 10 – 0.025 11 – 0.01 % 12 – 0.005% 13 – 0.0025 14 – 0.001 % 15 – 0.0005 %
B	Get current baud rate number	–
Bn	Set com port baud rate number "n" (0 ≤ n ≤ 9)	0 – 300 1 – 600 2 – 1200 3 – 2400 4 – 4800 5 – 9600 6 – 19200 7 – 38400 8 – 14400 9 – 28800
C	Check the measurement status Returns "r" if result is ready and "b" if measurement is in progress	–
E	Get current reference value	–
Ei.f	Set reference value	"i.f" – fixed point decimal number "I" – integer part (1 to 12 decimal digits) "." – decimal point "f" – fractional part (0 to 12 decimal digits)
F	Get current calibration constant	–
Fi.f	Set calibration constant	"i.f" – fixed point decimal number "I" – integer part (1 to 12 decimal digits) "." – decimal point "f" – fractional part (0 to 12 decimal digits)
M	Get current measurement mode number	–
Mnn	Set measurement mode number "nn" (00 ≤ nn ≤ 1A)	00 – Frequency 1, $F_x 1$ 01 – Period 1, $T_x 1$ 02 – Phase Shift, φ 03 – Time Interval, T 04 – Duty Cycle 1, DC1 05 – Duty-Off Factor 1, Q1 06 – Frequencies Difference, FD 07 – Periods Difference, TD

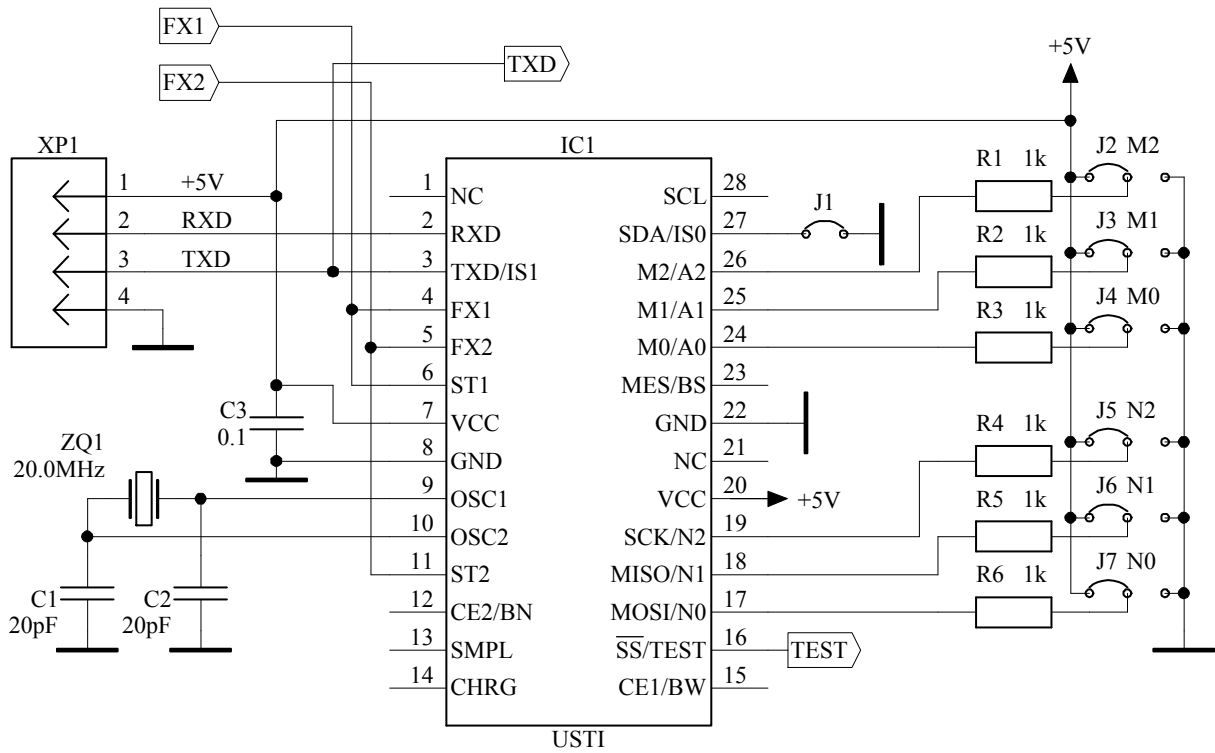|			
			08 – Frequencies Ratio, FR
			09 – Periods Ratio, TR
			0A – Rotation Speed 1, V1
			0B – Pulse Interval 1, T_p1
			0C – Space Interval 1, T_s1
			0D – Pulse Counter 1, N1
			0E – Frequency 2, F_x2
			0F – Period 2, T_x2
			10 – Resistance, R_x
			11 – Capacitance, C_x
			12 – Bridge, B_x
			13 – Frequency Deviation 1, D1
			14 – Duty Cycle 2, DC2
			15 – Duty-Off 2, Q2
			16 – Rotation Speed 2, V2
			17 – Pulse Interval 2, T_p2
			18 – Space Interval 2, T_s2
			19 – Pulse Counter 2, N2
			1A – Frequency Deviation 2, D2
R	The same as R0		–
Rn	Get measurement result in format number 'n' ($0 \leq n \leq 3$)		0 – BCD ASCII 1 – BCD HEX 2 – BIN HEX 3 – BIN
S	Start measurement		–
T	Test mode. After this command signal $f_{osc}/2$ is generated on pin 16.		–
W	Get current charging time constant		–
Wnn	Set charging time constant number ($00 < n < 1B$)		00 – 100 μs 01 – 200 μs 02 – 300 μs 03 – 400 μs 04 – 500 μs 05 – 600 μs 06 – 700 μs 07 – 800 μs 08 – 900 μs 09 – 1 ms 0A – 2 ms 0B – 3 ms 0C – 4 ms 0D – 5 ms 0E – 6 ms 0F – 7 ms 10 – 8 ms 11 – 9 ms 12 – 10 ms 13 – 20 ms 14 – 30 ms 15 – 40 ms 16 – 50 ms 17 – 60 ms 18 – 70 ms 19 – 80 ms 1A – 90 ms 1B – 100 ms
Z	Get current number of modulation rotor teeth number		–
Znn	Set the number "nn" of modulation rotor teeth number for rotation speed measurement mode ($01 \leq nn \leq FF$)		1–255

Figure 3. Circuit Diagram for the USTI Working in Autonomous (Master) Mode, RS232 Interface.
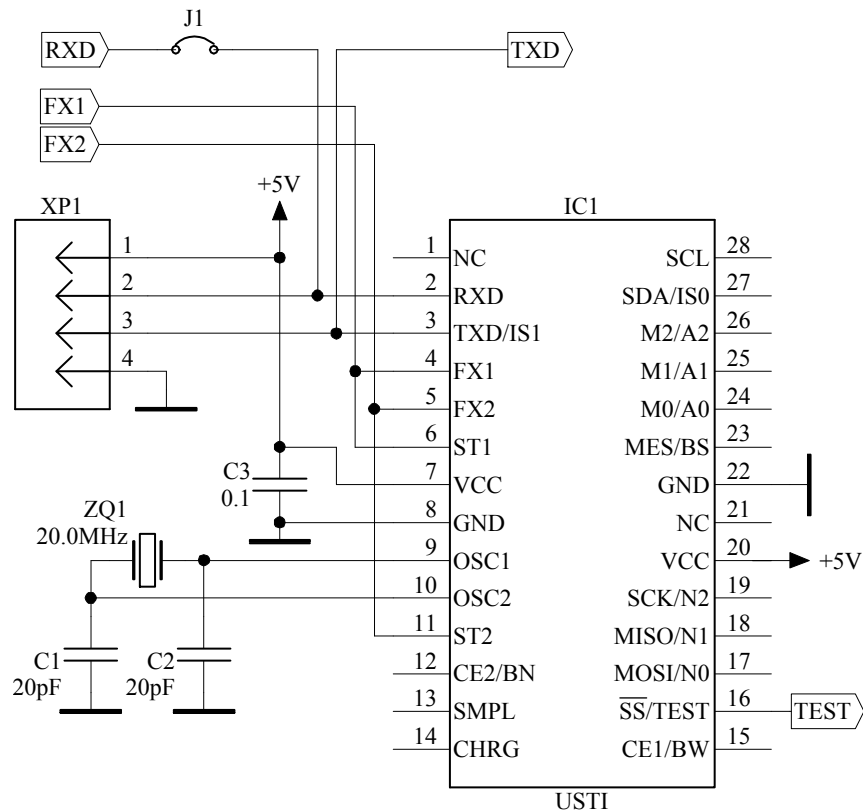

Figure 4. Circuit Diagram for the USTI Working Embedded in a Sensor or DAQ Board (Slave Mode).

Table 4. Communication Command Set for SPI Interface.

Interface		Description	Parameter
SPI	RS232 command analog		
<01><FF>	A	Get current accuracy number	–
<02><nn>	An	Set accuracy number "nn" (00 ≤ nn ≤ 0A) – without an external divider (0B ≤ nn ≤ 15) – with an external divider by 16	00 – 1 % 01 – 0.5 % 02 – 0.25 % 03 – 0.1 % 04 – 0.05 % 05 – 0.025 % 06 – 0.01 % 07 – 0.005 % 08 – 0.0025 % 09 – 0.001 % 0A – 0.0005 % 0B – 1 % 0C – 0.5 % 0D – 0.25 % 0E – 0.1 % 0F – 0.05 % 10 – 0.025 11 – 0.01 % 12 – 0.005% 13 – 0.0025 14 – 0.001 % 15 – 0.0005 %
<03><FF>	C	Check measurement status Returns 0 if result is ready and not 0 if measurement is in progress	–
<05><FF>	M	Get current measurement mode number	–
<06><nn>	Mnn	Set measurement mode number "nn" (00 ≤ nn ≤ 1A)	00 – Frequency 1, F_x1 01 – Period 1, T_x1 02 – Phase Shift, φ 03 – Time Interval, T 04 – Duty Cycle 1, DC1 05 – Duty-Off Factor 1, Q1 06 – Frequencies Difference, FD 07 – Periods Difference, TD 08 – Frequencies Ratio, FR 09 – Periods Ratio, TR 0A – Rotation Speed 1, V1 0B – Pulse Interval 1, T_p1 0C – Space Interval 1, T_s1 0D – Pulse Counter 1, N1 0E – Frequency 2, F_x2 0F – Period 2, T_x2 10 – Resistance, R_x 11 – Capacitance, C_x 12 – Bridge, B_x 13 – Frequency Deviation 1, D1 14 – Duty Cycle 2, DC2 15 – Duty-Off 2, Q2 16 – Rotation Speed 2, V2 17 – Pulse Interval 2, T_p2 18 – Space Interval 2, T_s2 19 – Pulse Counter 2, N2 1A – Frequency Deviation 2, D2

<07><FF>	R1	Get measurement result in BCD format Returns sign byte and 12 bytes of result in BCD code: <Sign><I5><I4><I3><I2><I1><I0> <F0><F1> <F2><F3><F4><F5>	–
<08><FF>	R2	Get measurement result in BINARY format Returns 12 bytes of result in binary complementary code: <I5><I4><I3><I2><I1><I0> <F0><F1><F2><F3><F4><F5>	–
<09>	S	Start measurement	–
<0B><FF>	Z	Get current number of modulation rotor teeth number	–
<0C><nn>	Znn	Set the number "nn" of modulation rotor teeth number for rotation speed measurement mode (01 ≤ nn ≤ FF)	1–255
<0D><FF>	E	Get current reference value	
<0E><i><f>	Ei.f	Set reference value <I5><I4><I3><I2><I1><I0> <F0><F1><F2><F3><F4><F5>	<I5>…<I0> integer part of BCD number <F0>…<F5> fractional part of BCD number
<0F><FF>	W	Get current charging time constant	–
<10><nn>	Wnn	Set charging time constant number (00 < n < 1B)	00 – 100 µs 01 – 200 µs 02 – 300 µs 03 – 400 µs 04 – 500 µs 05 – 600 µs 06 – 700 µs 07 – 800 µs 08 – 900 µs 09 – 1 ms 0A – 2 ms 0B – 3 ms 0C – 4 ms 0D – 5 ms 0E – 6 ms 0F – 7 ms 10 – 8 ms 11 – 9 ms 12 – 10 ms 13 – 20 ms 14 – 30 ms 15 – 40 ms 16 – 50 ms 17 – 60 ms 18 – 70 ms 19 – 80 ms 1A – 90 ms 1B – 100 ms

Legend:

<sign>   – sign of result
         0x20 (space char) for positive result
         0x2D (minus char) for negative result

<In>   – byte n of integer part of result

<Fn>   – byte n of fractional part of result

<FF>   – dummy byte

Figure 5. Interfacing Circuit for Connection the USTI to PC.

Figure 6. The USTI Circuit Diagram for the 3-wire Serial Interface (SPI).

5.2.3 2-wire Interface (I²C Compatible)

The brief communication command set description for I²C interface, appropriate measuring modes and programmed converted accuracies are adduced in Table 5. The USTI can have one of 8 possible addresses that can be setup by A0-A2 pins. The absolute address of a device has the following format 1110<A2><A1><A0>.

The circuit diagram for the 2-wire I²C interface is shown in Figure 7. The connector XP1 is used for in-circuit automated calibration. In the working mode the jumper J1 must be set in the ON position and in the calibration mode it should be switched to the OFF position.

Table 5. Communication Command Set for I²C Interface.

Interface		Description	Parameter
I²C	RS232 command analog		
<01>	A	Get current accuracy number	–
<02><nn>	An	Set accuracy number "nn" (00 ≤ nn ≤ 0A) – without an external divider (0B ≤ nn ≤ 15) – with an external divider by 16	00 – 1 % 01 – 0.5 % 02 – 0.25 % 03 – 0.1 % 04 – 0.05 % 05 – 0.025 % 06 – 0.01 % 07 – 0.005 % 08 – 0.0025 % 09 – 0.001 % 0A – 0.0005 % 0B – 1 % 0C – 0.5 % 0D – 0.25 % 0E – 0.1 % 0F – 0.05 % 10 – 0.025 11 – 0.01 % 12 – 0.005% 13 – 0.0025 14 – 0.001 % 15 – 0.0005 %
<03>	C	Check measurement status Returns 0 if result is ready and not 0 if measurement is in progress	–
<05>	M	Get current measuring mode number	–
<06><nn>	Mn	Set measurement mode number "nn" (00 ≤ nn ≤ 1A)	00 – Frequency 1, F_x1 01 – Period 1, T_x1 02 – Phase Shift, φ 03 – Time Interval, T 04 – Duty Cycle 1, DC1 05 – Duty-Off Factor 1, Q1 06 – Frequencies Difference, FD 07 – Periods Difference, TD 08 – Frequencies Ratio, FR 09 – Periods Ratio, TR 0A – Rotation Speed 1, V1 0B – Pulse Interval 1, T_p1 0C – Space Interval 1, T_s1 0D – Pulse Counter 1, N1 0E – Frequency 2, F_x2 0F – Period 2, T_x2 10 – Resistance, R_x 11 – Capacitance, C_x 12 – Bridge, B_x 13 – Frequency Deviation 1, D1 14 – Duty Cycle 2, DC2 15 – Duty-Off 2, Q2 16 – Rotation Speed 2, V2 17 – Pulse Interval 2, T_p2 18 – Space Interval 2, T_s2 19 – Pulse Counter 2, N2 1A – Frequency Deviation 2, D2
<07>	R1	Get measurement result in BCD format Returns sign byte and 12 bytes of result in BCD code: <Sign><I5><I4><I3><I2><I1><I0> <F0><F1> <F2><F3><F4><F5>	–

<08>	R2	Get measurement result in BINARY format Returns 12 bytes of result in binary complementary code: <I5><I4><I3><I2><I1><I0> <F0><F1><F2><F3><F4><F5>	–
<09>	S	Start measurement	–
<0B>	Z	Get current number of modulation rotor teeth number	–
<0C><nn>	Znn	Set the number "nn" of modulation rotor teeth number for rotation speed measurement mode (01 ≤ nn ≤ FF)	1–255
<0D>	E	Get current reference value	
<0E><i><f>	Ei.f	Set reference value <I5><I4><I3><I2><I1><I0> <F0><F1><F2><F3><F4><F5>	<I5>…<I0> integer part of BCD number <F0>…<F5> fractional part of BCD number
<0F>	W	Get current charging time constant	–
<10><nn>	Wnn	Set charging time constant number (00 < n < 1B)	00 – 100 μs 01 – 200 μs 02 – 300 μs 03 – 400 μs 04 – 500 μs 05 – 600 μs 06 – 700 μs 07 – 800 μs 08 – 900 μs 09 – 1 ms 0A – 2 ms 0B – 3 ms 0C – 4 ms 0D – 5 ms 0E – 6 ms 0F – 7 ms 10 – 8 ms 11 – 9 ms 12 – 10 ms 13 – 20 ms 14 – 30 ms 15 – 40 ms 16 – 50 ms 17 – 60 ms 18 – 70 ms 19 – 80 ms 1A – 90 ms 1B – 100 ms

Legend:

<sign>   – sign of result
         0x20 (space char) for positive result
         0x2D (minus char) for negative result

<In>   – byte n of integer part of result

<Fn>   – byte n of fractional part of result

Figure 7. The USTI Circuit Diagram for the 2-wire I^{2}C Interface.

5. 3 Quartz-Accurate Automated Calibration

The 20 MHz quartz crystal is a reference in the converter. Very often, low-cost quartz crystals have a low accuracy (> 30 ppm) because of systematic errors due to crystal manufacturing. For example, a low cost 20 MHz, 30 ppm quartz crystal can have a real frequency of 20001400 Hz that corresponds approximately to 90 ppm. Therefore, if the user is going to work with an error not better than 0.01 %, no any calibration is necessary. If the relative error must be better than 0.01 %, the USTI must be calibrated in order to take into account the quartz crystal systematic error.

The USTI provides so-called in-circuit quartz-accurate automated calibration. The calibration is made by means of the communication interface RS232. The USTI is connected to a PC by connector XP1 (Figures 3-4, 6-7). In the calibration mode all jumpers in Figures 4, 6, 7 must be in the OFF position.

The calibration sequence for the USTI is the following.

1) The test command "T" toggles the USTI to the calibration mode. A sequence of rectangular pulses with frequency $f_{osc}/2$ is generated at the TEST output.
2) The frequency of this pulse sequence should be measured with the help of an external frequency counter with accuracy not worse than 0.0001 % or at least 0.0002 %.
3) Use the command "Fi.f" to put the clock constant value into the USTI. The command "F" without parameters indicates the internal value of the clock constant and can be used for checking the number loaded.

The calibration is performed only once. The correction factor Δ is stored in the nonvolatile memory of the USTI, which holds this value after power-off.

Example:

Toggle the USTI in the calibration mode by "T" command entered in any terminal software, working under Windows operation systems:

>T

Let the measured frequency on the TEST output is 10000694.257865 Hz, for example. So we send the clock constant command:

>F10000694.257865

17

Then to check programmed value we send the command

>F

10000694.257865

The returned result 10000694.257865 testifies about the properly stored value of correction factor for the given quartz crystal. After that the USTI is ready for conversion in the frame of accuracy ranges specified in this document.

The similar calibration also is useful at work of the converter outside normal conditions (for example, at the increased or decreased ambient temperature) with the purpose of correction of an additional temperature error. After a long term USTI usage, such periodical calibration will also reduce the quartz crystal error due to the crystal aging.

6. Measuring Modes

In this section, we specify the USTI properties for all measuring modes. Names of these modes are the same as used in Table 2.

6.1 Mode 0. F_{X1}: Frequency, channel 1, 0.05 Hz – 9 MHz without prescaling

In this mode a frequency signal f_{x1} (should be TTL rectangular pulses) must be connected in parallel to inputs FX1 and ST1. If the pulse shape differs from square wave, the usage of an external input shaper (Schmitt-trigger signal conditioner) is recommended. At low and infralow frequency measurements it is recommended to use a low-pass filter.

If the maximum converted frequency exceeds 9 MHz, it is necessary to use an external prescaler (external divider by 16) and to choose the appropriate mode and accuracy by means of commands or external switches N0-N2. By this way the frequency range will be extended up to 144 MHz.

The conversion error in this mode is constant and does not exceed the programmed in all frequency range. The conversion result is represented in Hz. All conversion accuracies specified in the Table 2 are available in this mode.

6.2 Mode 1. T_{X1}: Period, channel 1, 110 ns – 20 s

This mode of measurement is similar to the Mode 1. The conversion result is represented in microseconds. All conversion accuracies specified in Table 2 are available in this mode. The mode with prescaling (external divider by 16) is also possible.

6.3 Mode 2. φ: Phase-Shift, 0 - 360º, fxmax = 625 kHz at 50 % duty-cycle

The pulse sequences with the same frequency, a phase-shift between which need to be converted into a digital are connected to inputs FX1, ST1 and FX2, ST2 accordingly. Units for conversion result are degrees. The programmed accuracy influences on the period conversion. The conversion error of phase-shift does not depend on the pulse sequences period, but depends on the pulse width.

6.4 Mode 3. T: Time Interval Between Start- and Stop-Impulse, 1.5 µs - 250 s

Start- and stop-pulse are connected to FX1, ST1 and FX2, ST2 inputs accordingly. The USTI converts the time interval between these pulses into digital. In this mode the conversion error does not depend on the value on inputs N0-N3 or given in a command mode through one of possible interfaces and can be calculated according to the equation (1) for each value of converted time interval. Units of measurements for conversion result are microseconds.

6.5 Mode 4. D.C.: Duty-Cycle 1: 0 – 1 at $f_{xmax} \leq 625$ kHz for 40-60 % D.C.

The pulse signal is coming on inputs FX1, ST1. The programmed accuracy influences on the period conversion. The conversion error does not depend on the period of pulse signal, but depends on the pulse width.

6.6 Mode 5. Q: Duty-Off Factor (1/D.C), $10^{-8} – 8 \cdot 10^6$, at ≤ 625 kHz for 40-60 % D.C.

Similarly to the Mode 4, the pulse sequence is coming on FX1, ST1 inputs. The programmed accuracy influences on the period conversion. The conversion result depends on the pulse width.

6.7 Mode 6. FD: Frequency Difference with Sign Determination f_{x1} - f_{x2}, 0-9 MHz.

The frequency signal f_{x1} is coming on FX1, ST1 inputs and signal f_{x2} - on FX2, ST2 inputs. The sign "minus" before the result of measurement testifies that $f_{x1} < f_{x2}$. All conversion accuracies specified in Table 2 are available in this mode. The mode with prescaling (external divider by 16) is also possible.

6.8 Mode 7. PD: Period Difference with Sign Determination T_{x1} - T_{x2}, 0 – 20 s

The pulse signal with period T_{x1} is coming on FX1, ST1 inputs and signal with period T_{x2} - on FX2, ST2 inputs. The sign "minus" before the result of measurement testifies that $T_{x1} < T_{x2}$. All conversion accuracies specified in Table 2 are available in this mode. The mode with prescaling (external divider by 16) is also possible.

6.9 Mode 8. FR: Frequency Ratio, f_{x1}/f_{x2}, $5.5 \cdot 10^{-9} – 1.8 \cdot 10^8$

The frequency signal f_{x1} is coming on FX1, ST1 inputs and signal f_{x2} - on FX2, ST2 inputs. All conversion accuracies specified in Table 2 are available in this mode. The mode with prescaling (external divider by 16) is also possible.

6.10 Mode 9. PR: Period Ratio, T_{x1}/T_{x2}, $4 \cdot 10^{-9} – 2 \cdot 10^8$

The pulse sequence with period T_{x1} is coming on FX1, ST1 inputs, and pulse sequence with period T_{x2} – on FX2, ST2 inputs. All conversion accuracies specified in Table 2 are available in this mode. The mode with prescaling (external divider by 16) is possible.

6.11 Mode 10. n: Rotation Speed (rpm), n_x

The USTI can measure a rotation speed and present the results in rpm units. The number of encoder's teeth Z (1…255) must be set up in advance. In the Master Mode (interface RS232, unidirectional mode), by default Z=1.

In a sensor system the USTI can also measure rotation acceleration. An external microcontroller or PC calculates acceleration of rotation based on two measurements n_1 and n_2 of rotation speed and time interval for the second measurement t_2:

$$\varepsilon = \frac{n_1 - n_2}{t_2}, \text{ r/min}^2 \tag{2}$$

The sign "-" indicates deceleration of rotation, and "+" indicates acceleration of rotation.

6.12 Mode 11. t_p: Pulse Width, t_p 1.5 µs – 250 s

Pulse signal is coming on FX1, ST1 inputs. In this mode the conversion error does not depend on the value on N0-N2 inputs or given through one of possible interfaces and can be calculated according to the formula (1) for each value of converted pulse width. Units of measurements for result are microseconds.

6.13 Mode 12. t_s: Space Interval, t_s 1.5 µs – 250 s

This mode of measurement is similar to the Mode 11. Pulse signal is coming on FX1, ST1 inputs. In this mode the conversion error does not depend on the value on N0-N2 inputs or given through one of possible interfaces and can be calculated according to the formula (1) for each value of converted pulse width. Units of measurements for result are microseconds.

6.14 Mode 13. N: Pulse Number (Events) Count, N_X 0 – $4 \cdot 10^9$

The USTI can count the pulse number (events) on FX1, ST1 inputs. Each reinitialization of the mode resets the counter to zero.

6.15 Mode 14. F_x2: Frequency, channel 2, 0.05 Hz – 9 MHz without prescaling

In this mode a frequency signal f_{x2} (should be TTL rectangular pulses) must be connected in parallel to inputs FX2 and ST2. If the pulse shape differs from rectangular, the usage of an external input shaper is recommended. At low and infralow frequency measurements it is recommended to use the low-pass filter.

If the maximum converted frequency exceeds 9 MHz, it is necessary to use an external prescaler (external divider by 16) and to choose the appropriate mode and accuracy by means of commands or external switches N0-N2. By this way the frequency range will be expanded up to 144 MHz.

The conversion error in this mode is constant and does not exceed the programmed in all frequency range. The conversion result is represented in Hz. All conversion accuracies specified in Table 2 are available in this mode.

6.16 Mode 15. T_x2: Period, channel 2, 110 ns – 20 s

This mode of measurement is similar to the Mode 14. The conversion result is represented in microseconds. All conversion accuracies specified in Table 2 are available in this mode. The mode with prescaling (external divider by 16) is also possible.
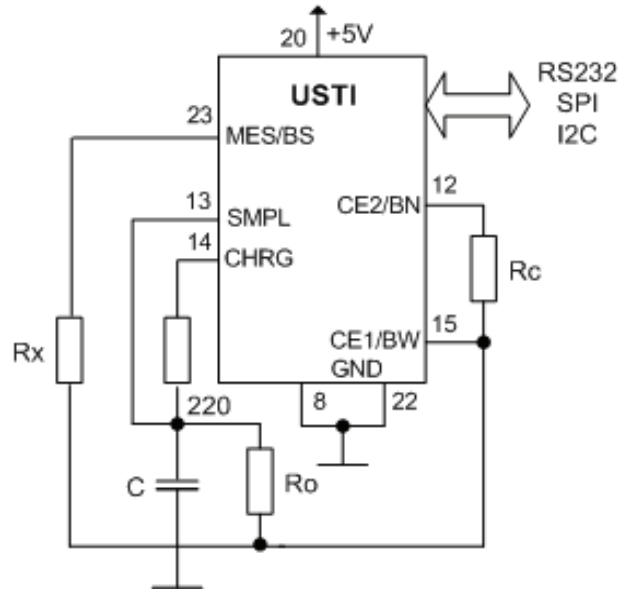
6.17 Mode 16. Resistance, R_x, 10 Ω to 10 MΩ

In this mode unknown resistor R_x (or sensing elements as platinum resistor or thermistor), reference resistor R_c, calibrating capacitor C and limiting resistor R_o must be connected to the USTI as it is show in Figure 8.

The capacitance (in Farads) of calibrating capacitor should be calculated according to the following equation:

$$C \geq \frac{0.002}{R_c}, \tag{3}$$

and $R_c \leq R_x$. The limiting resistor must be $R_0 \approx 300 \dots 600 \, \Omega$.

Figure 8. The USTI Circuit Diagram for Resistance Measurement.

The value of reference resistor R_c must be set up with the help of "Ei.f" command (see Table 2), where "i.f" is the fixed point decimal number: "I" is the integer part (1 to 12 decimal digits) and "f" is the fractional part (0 to 12 decimal digits).

The charging time (in seconds) should be calculated as

$$T = 2200 \times C ,$$ (4)

The charging time can be set up with the help of USTI's command "Wnn". All possible values for "Wnn" command are shown in Table 2. It is not necessary to set up accuracy in this mode.

In the master communication mode the charging time should be set up with the help of external switches N0, N1, N2 (see Table 2). In this mode the result at the converter's output will be presented as R_x/R_c. In order to get the actual capacitance, such result must be multiplied by R_c.

The USTI has the average relative error ±0.47 % in a wide measuring range from 10 Ω to 10 MΩ. A conditional splitting of the range of measurement into sub ranges with a choice of appropriate values and types of R_c and C has allowed to receive also the relative error ± 0.01 % or better by using of precision external electronic components.

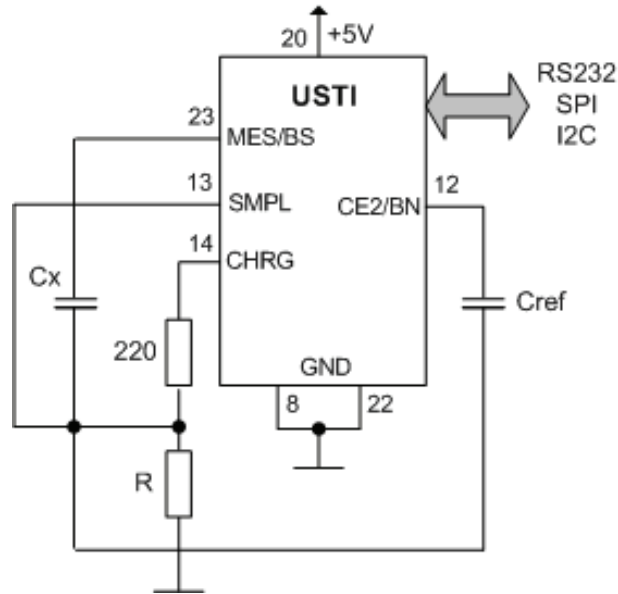### 6.18 Mode 17. Capacitance, C$_x$, 50 pF to 100 μF

In this mode unknown capacitor C_x (or sensing element), reference capacitor C_{ref} and limiting resistor R must be connected to the USTI as it is show in Figure 9.

The resistance (in Ohm) should be calculated according to the following equation:

$$R \geq \frac{0.002}{C_{ref}}$$ (5)

The charging time (in seconds) should be calculated according to equation (4) and set up with the same command "Wnn". The value of C_{ref} should be set up with the help of appropriate USTI's command Ei.f, where "i.f" is the fixed point decimal number: "I" is the integer part (1 to 12 decimal digits) and "f" is the fractional part (0 to 12 decimal digits).

In the master communication mode the charging time should be set up with the help of external switches N0, N1, N2 (see Table 2). In this mode the result at the converter's output will be presented as C_x/C_{ref} . In order to get the actual capacitance, such result must be multiplied by C_{ref}.
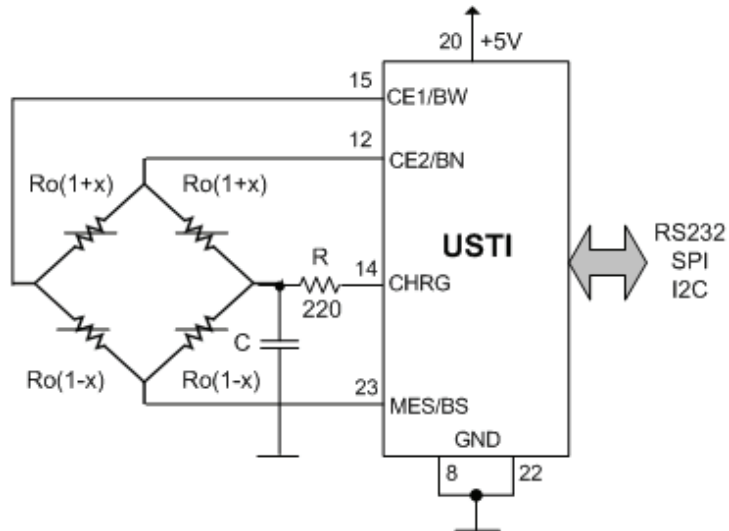
Figure 9. The USTI Circuit Diagram for Capacitance Measurement.

The average relative error in this mode is ± 0.036 % over all wide measuring range and does not exceed 0.7 % the worst case. It can be reduced by the using of precision external components.

6.19 Mode 18. Resistive bridge

In this mode a passive resistive bridge, a limiting resistor R and capacitor C must be connected to the USTI as in shown in Figure 10.

Figure 10. The USTI Circuit Diagram for Resistive Bridge Measurement.

The capacitance (in Farads) of capacitor C should be calculated according to the following equation:

$$C \geq \frac{0.002}{R_a}, \qquad (6)$$

where R_a is the resistance of a bridge arm. The charging time (in seconds) should be calculated according to equation (4). It must be set up with the help of command "Wnn". In the master communication mode the charging time should be set up with the help of external switches N_0, N_1, $N_{2;}$

6.20 Mode 19. Frequency Deviation 1, D_{A1}, 0-9 MHz

In this mode an absolute (in Hz) or relative (%) frequency deviation from the value, which is set-up with the help of "Ei.f" command (see Table 2) will be measured. The absolute or relative frequency deviation mode is selected by "Ann" command (see Table 2): at A00 and A0B (a mode with prescaller) the absolute deviation will be measured; at other parameters – the relative deviation will be measured. Accuracy in this mode(s) does not depend on parameters of "Ann" command and is selected maximal possible (0.0005 % relative error).

6.21 Mode 20. D.C.2: Duty-Cycle 2: 0 – 1 at $f_{xmax} \leq 625$ kHz for 40-60 % D.C.

This mode is the same as the Mode 4 (see section 6.5) but measurements will be made in the 2nd channel of USTI.

6.22 Mode 21. Q2: Duty-Off Factor 2: (1/D.C), $10^{-8} – 8 \cdot 10^6$, at ≤ 625 kHz for 40-60 % D.C.

This mode is the same as the Mode 5 (see section 6.6) but measurements will be made in the 2nd channel of USTI.

6.23 Mode 22. n_2: Rotation Speed 2 (rpm), n_x

This mode is the same as the Mode 10 (see section 6.11) but measurements will be made in the 2nd channel of USTI.

6.24 Mode 23. t_p2: Pulse Width 2, t_p 1.5 µs – 250 s

This mode is the same as the Mode 11 (see section 6.12) but measurements will be made in the 2nd channel of USTI.

6.25 Mode 24. t_s2: Space Interval 2, t_s 1.5 µs – 250 s

This mode is the same as the Mode 12 (see section 6.13) but measurements will be made in the 2nd channel of USTI.

6.26 Mode 25. N2: Pulse Number (Events) Count 2, N_X 0 – $4 \cdot 10^9$

This mode is the same as the Mode 13 (see section 6.14) but measurements will be made in the 2nd channel of USTI.

6.27 Mode 26. Frequency Deviation 2, D_{A2}, 0-9 MHz

This mode is the same as the Mode 19 (see section 6.20) but measurements will be made in the 2nd channel of USTI.

7. Development Kit

7. 1 Development Board

For actual development purposes and non-in-circuit calibration a development kit is recommended. The development board is equipped with an RS232 interfacing chip offering a serial communication between the USTI and a personal computer. A 20 MHz crystal completes the on-chip oscillator of the USTI. A voltage regulator (7805) supplies a DC power supply of 5 V for the converter and the RS232 interface. The external power supply required for the development board amounts to 7…14 V DC or AC.

Connection to the USTI development board is implemented with appropriate connectors/connecting pads. XT1 and XT2 are used to connect the external frequency-time domain signal.

The development board can be used for all functions of the USTI. The setting of the operating modes and accuracy is respectively performed by external switches S1 and S2, or by appropriate commands through the RS232 interface.

The development board full circuit diagram is shown in Figure 11. The silkscreen of development board is shown in Figure 12, and sensing elements connection diagrams are shown in Figure 13.

The Schmidt trigger 74HC14D is optional and can be use in separate cases to improve an input signal shape.

7.2 Software

There are many ways to display the measurement results. For this purpose the LabView or custom designed software can be used. Any terminal software for Windows also can be used with the USTI development board using the serial port of a PC. One of the possible choices is Terminal V1.9b (http://www.sensorsportal.com/DOWNLOADS/Terminal.exe) free software.

In order to have correct measurement results the following options must be selected in the main terminal window: an appropriate COM port; baud rate 2400; data bits – 8; parity – non; stop bits – 1; handshaking – non.

Following the RS232 communication commands from the Table 3 it is easy to manage the development board and display measuring results. There are four possible data format in the Terminal: BCD ASCII, BCD Hex, BIN Hex and BIN.

Its screen is shown in Figure 14. Commands must be printed in Transmit window, the results will be shown in Receive window.

Example:

>M00   Select a frequency measurement mode in the 1st channel.

>A09   These commands set up the accuracy 0.001%, start

>S   measurement (S), ask for BCD ASCII format (R) and

>R   return the result of measurement in Hz.

12000.089992800575

NOTE: For low and infralow frequencies, low rotation speed measurements as well as for long time intervals, periods, pulse widths and spaces measurements it is strongly recommended to use the command "C" between "S" and "R" commands (see Table 3) in order to check if the result is ready. In opposite side it is a risk to get a result of previous measurement.
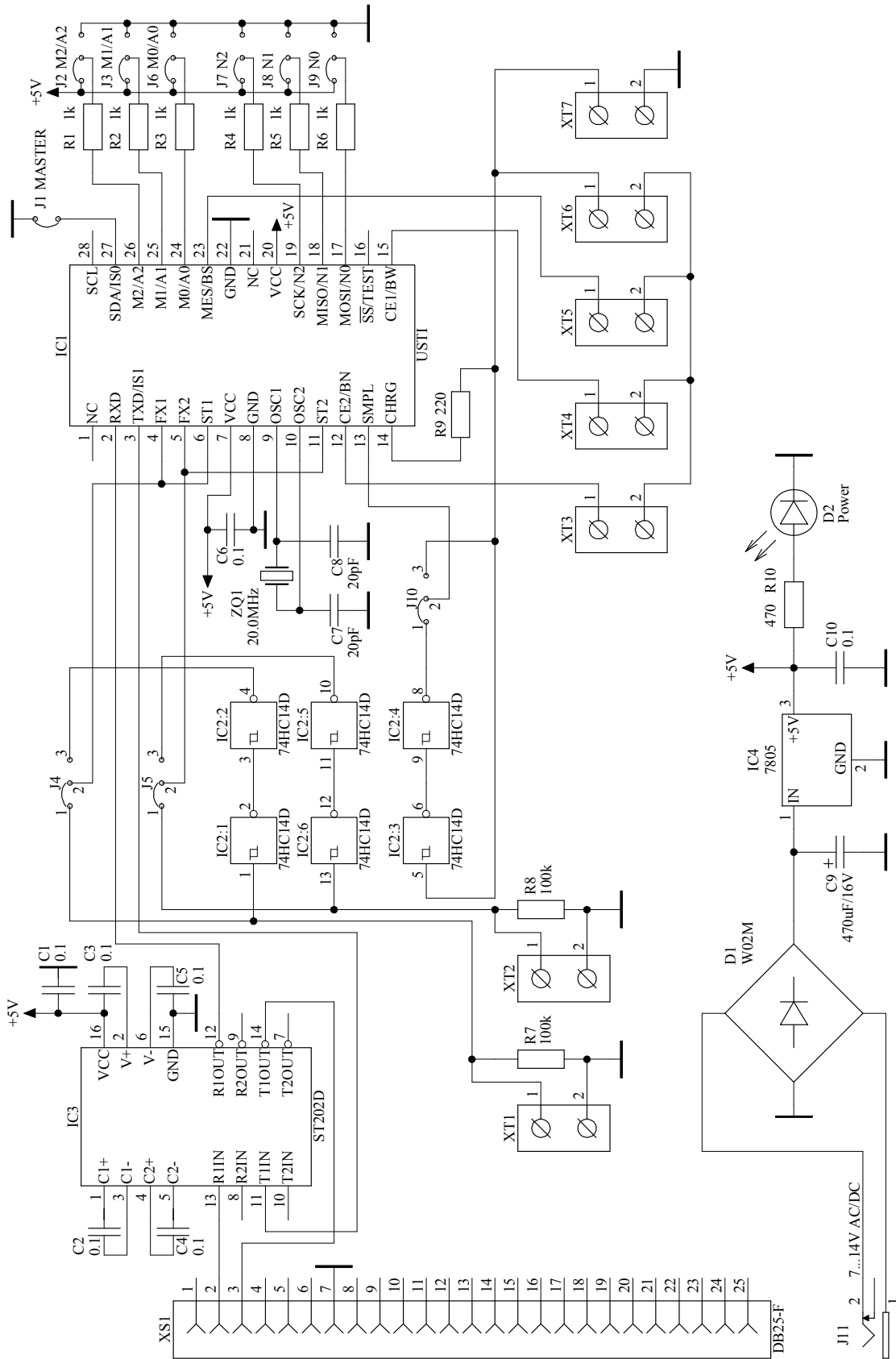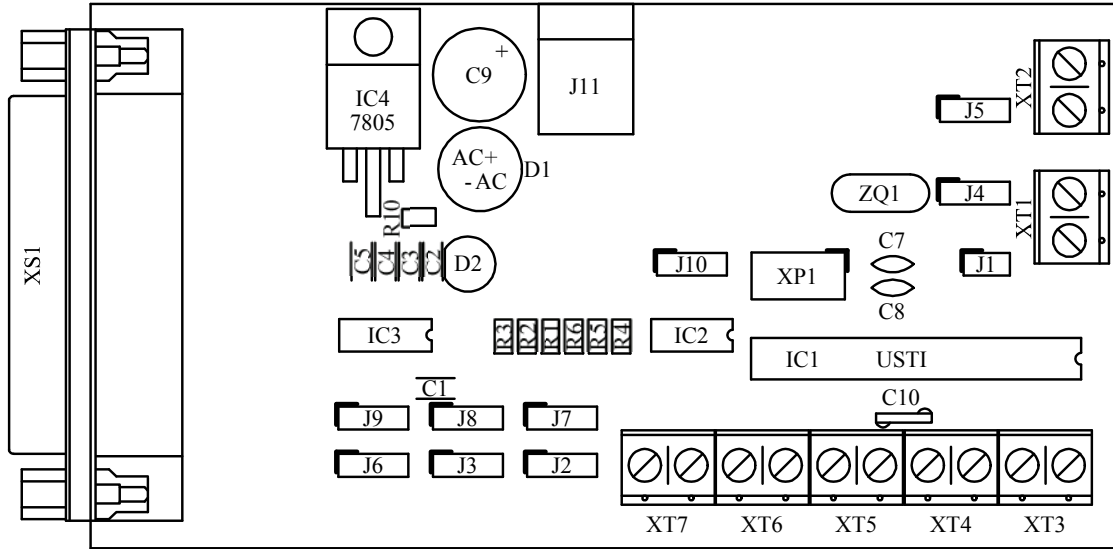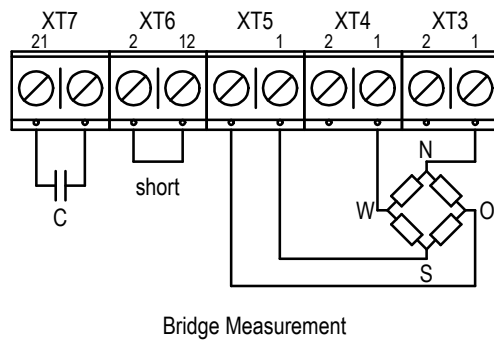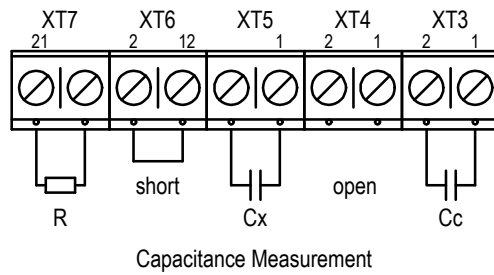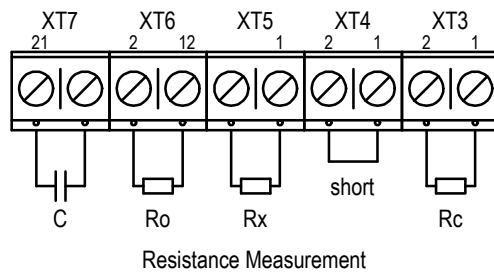
Figure 11. The USTI Development Board Circuit Diagram.

Figure 12. The USTI Development Board Silkscreen (Not to Scale).

Resistance Measurement

Capacitance Measurement

Bridge Measurement

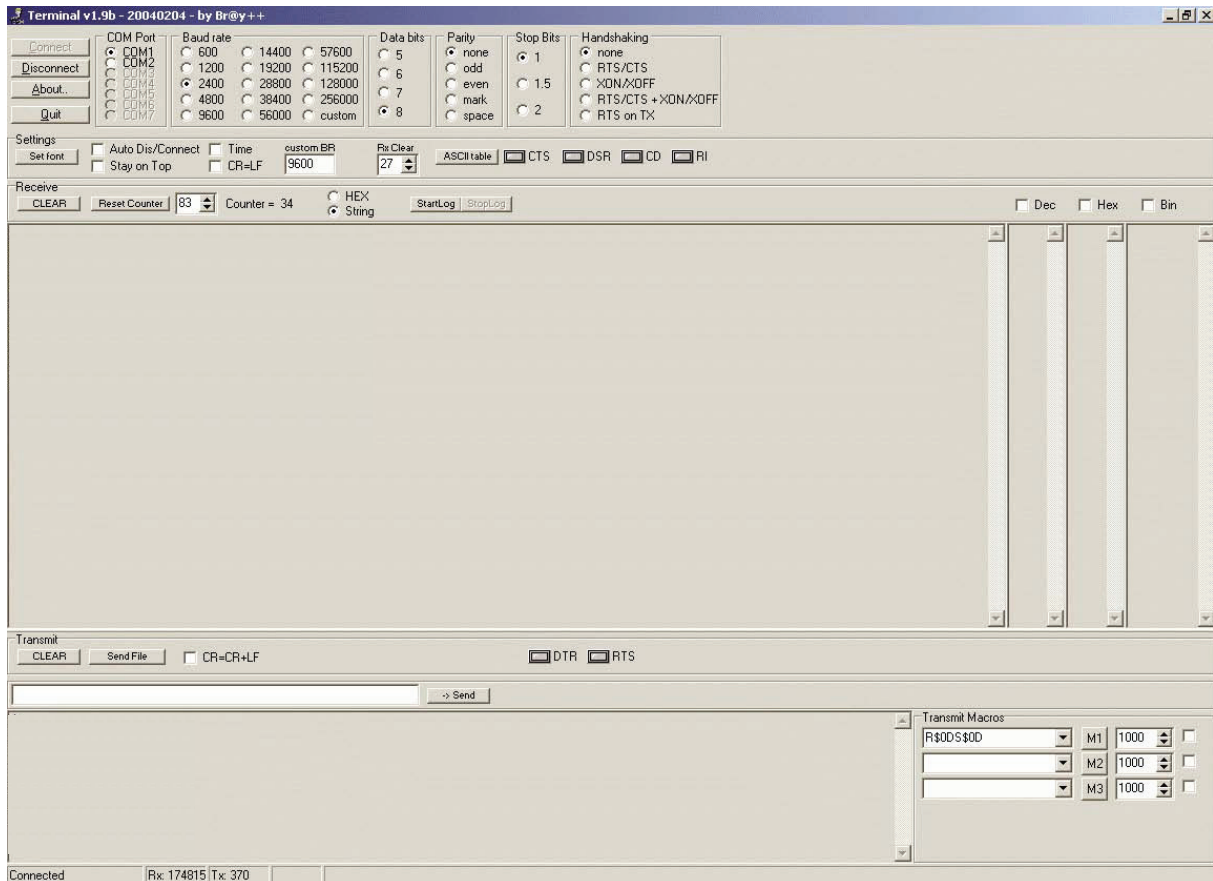**Figure 13.** Sensing Elements Connection Diagrams.

Figure 14. Terminal V1.9b Window.
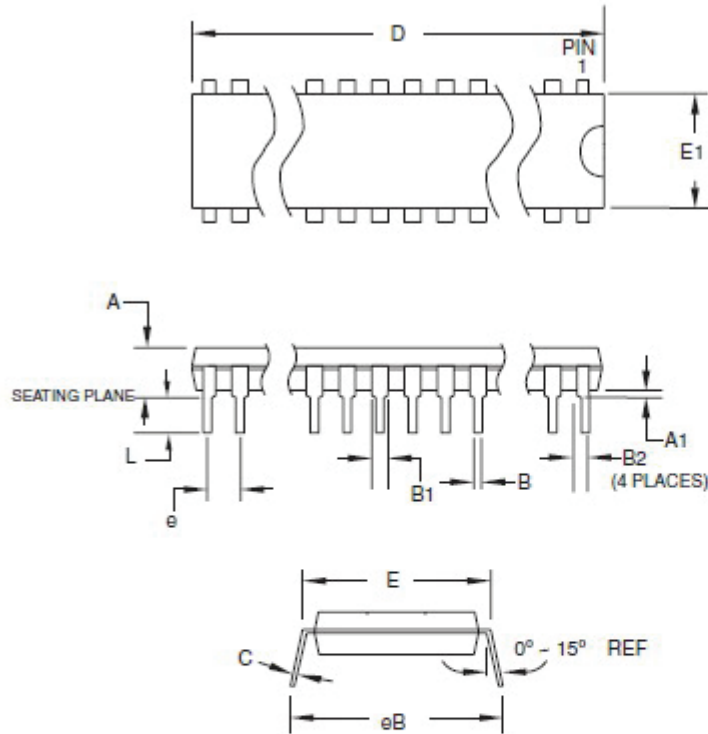
8. Applications

The USTI has many applications. Some typical applications are the following:

- Sensor systems with any frequency, period, duty-cycle, time interval, phase-shift, pulse number output sensors and transducers;
- Physical, chemical, bio- and immunosensors; quartz crystal microbalance (QCM) based sensors, BioMEMS, Lab-on-Chip;
- Digital sensors design, SoC, SiP;
- ADCs based on intermediate voltage-to-frequency conversion;
- Smart, intelligent (self-adaptive) sensors and sensor systems due to programmable accuracy and non-redundant conversion time - adaptive possibilities of USTI automatically choice the conversion time depending on the given error of measurement and opposite;
- Multifunctional and multiparameters sensors for simultaneous detection various parameters proportional to frequency and duty-cycle carrying the information provided by sensing elements;
- Data acquisition (DAQ) boars and measuring systems for frequency-time parameters of electric signal;
- Virtual instruments;
- Desktop multifunctional frequency counters;
- Tachometers and tachometric systems;
- Handheld multimeters for frequency-time parameters of electric signals;
- High-end, mid- and low-range ABS;
- High accuracy programmable frequency-time parameters – to – digital converters for various measuring and communication applications.

NOTE: The USTI can also work with any voltage and current output sensors. It this case, any voltage–to-frequency converter (VFC) can be used. The accuracy of such system will be determined by sensor accuracy as well as by VFC accuracy.

9. Packaging Information

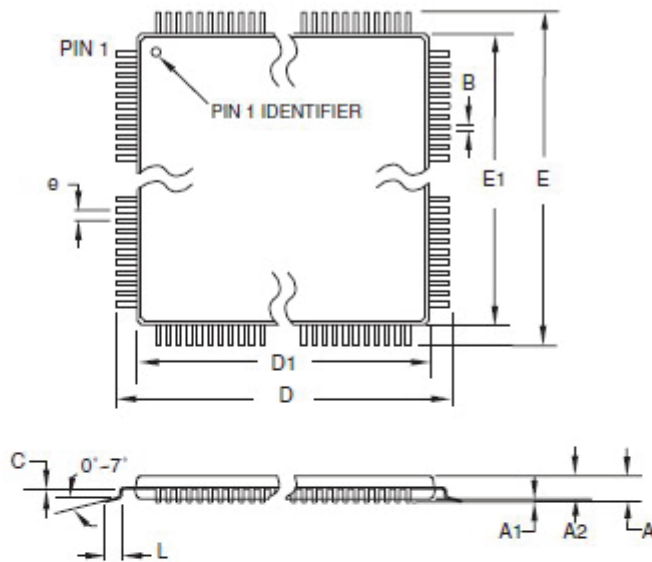## 9.1 28-lead (0.300"/7.62 mm Wide) Plastic Dual Inline Package (PDIP)

Note: 1. Dimensions D and E1 do not include mold Flash or Protrusion.
Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.5724	
A1	0.508	–	–	
D	34.544	–	34.798	Note 1
E	7.620	–	8.255	
E1	7.112	–	7.493	Note 1
B	0.381	–	0.533	
B1	1.143	–	1.397	
B2	0.762	–	1.143	
L	3.175	–	3.429	
C	0.203	–	0.356	
eB	–	–	10.160	
e	2.540 TYP			

Note: This device can also be supplied in wafer form. Please contact Technology Assistance BCNA 2010 S. L. sales office for detailed ordering information and minimum quantities.

9.2 32-lead, 7 x 7 mm Body Size, 1.0 mm Body Thickness, 0.8 mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP).
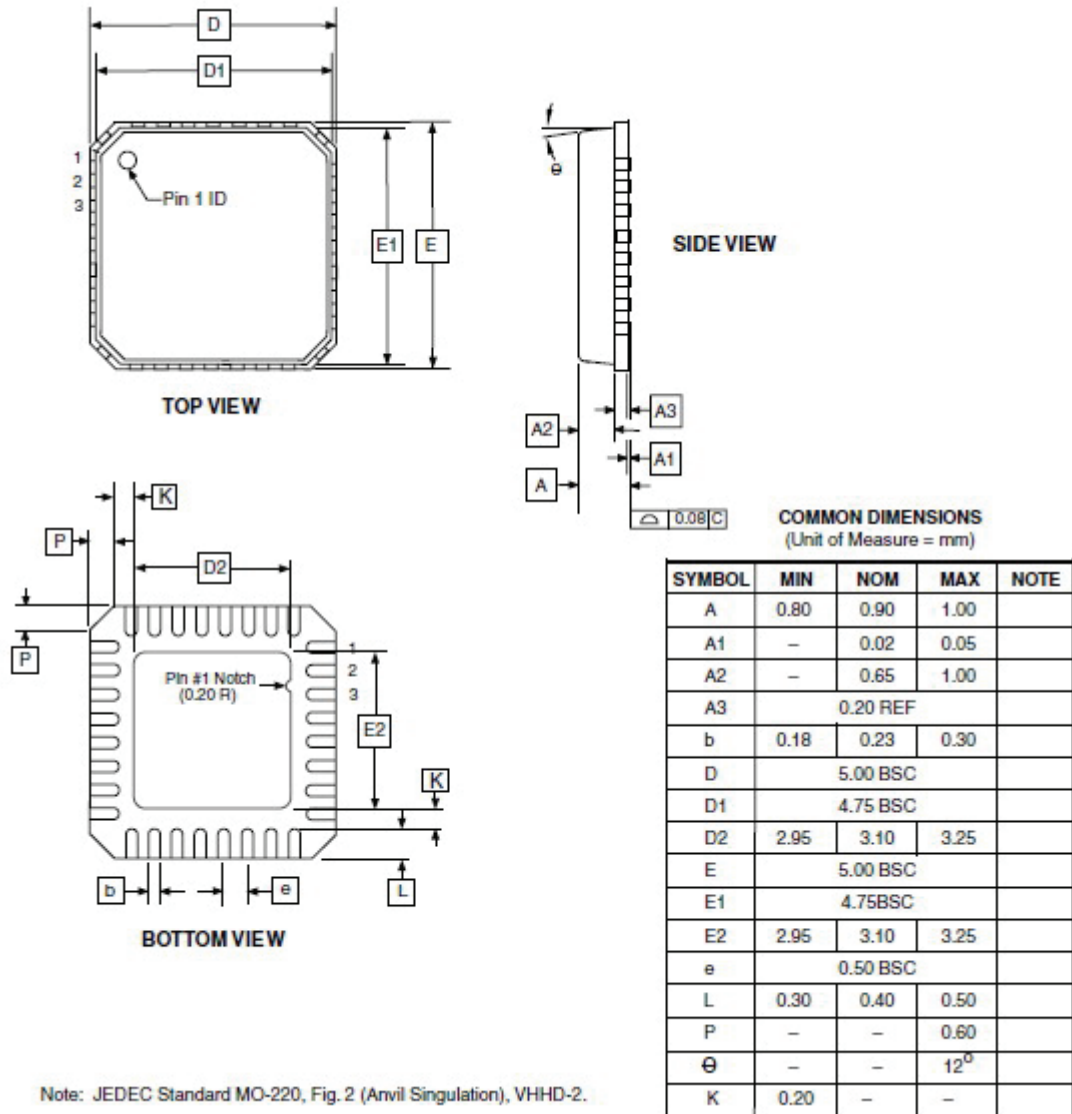

Notes:
1. This package conforms to JEDEC reference MS-026, Variation ABA.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25 mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10 mm maximum.

COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	1.20	
A1	0.05	–	0.15	
A2	0.95	1.00	1.05	
D	8.75	9.00	9.25	
D1	6.90	7.00	7.10	Note 2
E	8.75	9.00	9.25	
E1	6.90	7.00	7.10	Note 2
B	0.30	–	0.45	
C	0.09	–	0.20	
L	0.45	–	0.75	
e	0.80 TYP			

9.3 32-pad, 5 x 5 x 1.0 mm Body, Lead Pitch 0.50 mm 3.10 mm Exposed Pad, Micro Lead Frame Package (MLF)

TOP VIEW

SIDE VIEW

BOTTOM VIEW

Note: JEDEC Standard MO-220, Fig. 2 (Anvil Singulation), VHHD-2.

COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	0.80	0.90	1.00	
A1	–	0.02	0.05	
A2	–	0.65	1.00	
A3		0.20 REF		
b	0.18	0.23	0.30	
D		5.00 BSC		
D1		4.75 BSC		
D2	2.95	3.10	3.25	
E		5.00 BSC		
E1		4.75BSC		
E2	2.95	3.10	3.25	
e		0.50 BSC		
L	0.30	0.40	0.50	
P	–	–	0.60	
Θ	–	–	12°	
K	0.20	–	–	

For addition information and orders, please contact:

Technology Assistance BCNA 2010, S. L. (Excelera)
Parc UPC-PMT, Edifici RDIT-K2M,
c/ Esteve Terradas, 1, 08860 Castelldefels, Barcelona, Spain
E-mail: info@excelera.io
Web: http://www. excelera.io

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