Universal Frequency-to-Digital Converter (UFDC-1)

Specification and Application Note

International Frequency Sensor Association (IFSA)
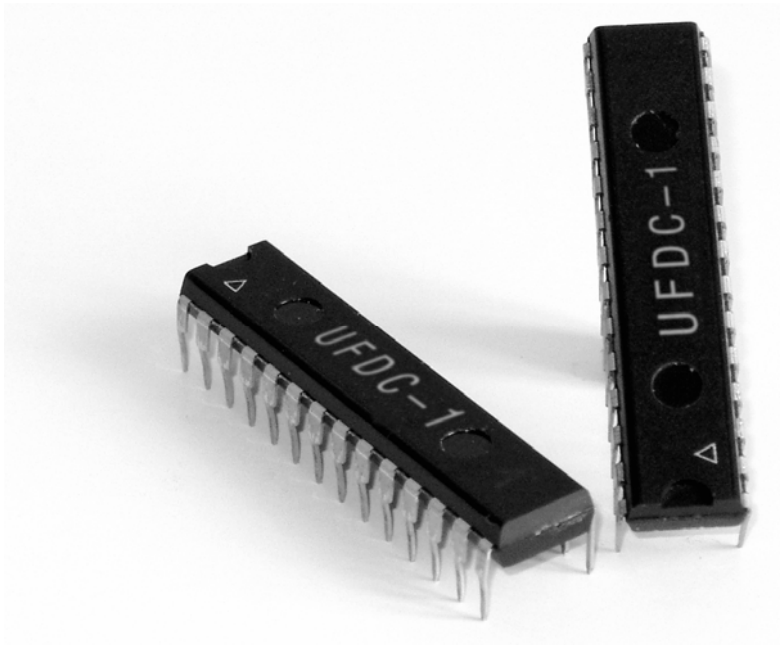
Contents

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1. Introduction

The **U**niversal **F**requency-to-**D**igital **C**onverter (UFDC-1) 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 UFDC-1 covers all specified converted range of frequencies and accuracy for modern frequency-time domain sensors.

2. Features

- 16 measuring modes
- Provides interfacing for many types of frequency-time domain sensors and transducers
- Frequency range from 0.05 Hz up to 7.5 MHz (at 40 ÷ 50 % duty-cycle for f_{xmax}) without prescaling and 120 MHz with prescaling
- Programmable accuracy (relative error) for frequency (period) conversion from 1 % up to 0.001 % for rectangular waveform input pulse signals
- Relative quantization error is constant in all specified frequency range
- Non-redundant conversion time
- Internal reference clock 500 kHz, 16 MHz @ 16MHz quartz oscillator
- Quartz-accurate automated calibration
- Simple 3-wire serial interface (SPI compatible)
- 2-wire interface (I^2C compatible)
- Two direction RS232/485 serial interface
- Master and slave communication modes for RS232/485
- Frequency generator mode $f_{osc}/2$ = 16 MHz / 2 = 8 MHz with quartz crystal stability
- Single power supply 4.5 – 5.5 V
- Current consumption at 16 MHz, 5V, 25 ^{0}C below 20 mA
- Operating temperature range (- 40 ^{0}C to + 85 ^{0}C)
- Package Type: 28-lead Plastic Dual Inline Package (PDIP), compact 32-lead small Thin Profile Plastic Quad Flat Package (TQFP) and 32-pad Micro Lead Frame Package (MLF)

3. General Description

The **U**niversal **F**requency-to-**D**igital **C**onverter (UFDC-1) 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.
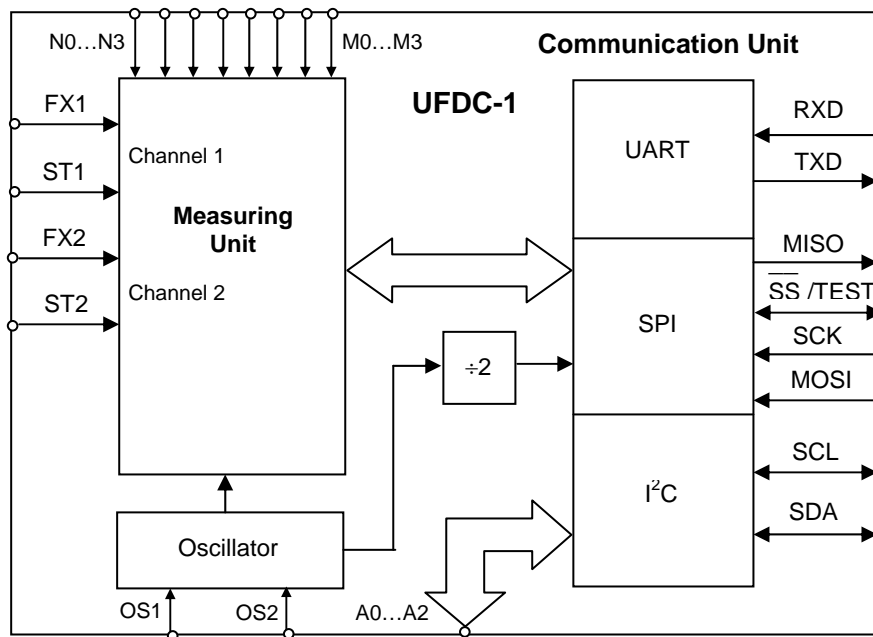

Figure 1. The UFDC-1 Block Diagram.

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The UTDC-1 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.
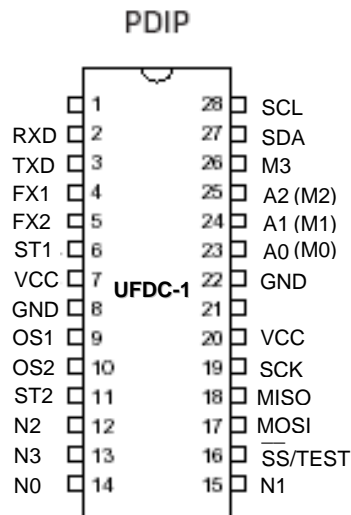
The IC converts frequency-time domain signals into digital domain and provides interface to microcontroller, DAQ or sensor system to read these digital results.

The UFDC-1 can measure the following frequency-time parameters of signals:

- Frequency, f_{x1} 0.05 Hz – 7.5 MHz directly and up to 120 MHz with prescaling
- Period, T_{x1} 150 ns – 20 s
- Phase shift, φ_x 0 - 360^0 at f_{xmax} = 500 kHz at 50 % duty-cycle
- Time interval between start – and stop-pulse, τ_x 2 μs – 250 s
- Duty-cycle, D.C. 0 – 1 at $f_{xmax} \leq$ 500 kHz
- Duty-off factor, Q 10^{-8} – $8 \cdot 10^6$ at $f_{xmax} \leq$ 500 kHz
- Frequency difference, $f_{x1} - f_{x2}$ with sign recognition, 0 – 7.5 MHz
- Period difference, $T_{x1} - T_{x2}$ with sign recognition, 0 – 20 s
- Frequency ratio, f_{x1}/f_{x2} 7 $\cdot 10^{-9}$ – 1.4 $\cdot 10^8$
- Period ratio, T_{x1}/T_{x2} 7.5 $\cdot 10^{-9}$ – 1.33 $\cdot 10^8$
- Rotation speed, $n_x = (f_x \cdot 60)/Z$, where Z is the number of encoder teeth
- Pulse width, t_p 2μs – 250 s
- Space interval, t_s 2μs – 250 s
- Pulse number (events) counting, N_x 0 – 4$\cdot 10^9$

4. Pin-out and Housing

The UFDC-1 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). Figure 2a and 2b shows the pin configuration of PDIP and TQFP/MLF accordingly. The function of the pins is listed in Table 1.

PDIP

	1	28	SCL
RXD	2	27	SDA
TXD	3	26	M3
FX1	4	25	A2 (M2)
FX2	5	24	A1 (M1)
ST1	6	23	A0 (M0)
VCC	7 UFDC-1	22	GND
GND	8	21	
OS1	9	20	VCC
OS2	10	19	SCK
ST2	11	18	MISO
N2	12	17	MOSI
N3	13	16	$\overline{SS}$/TEST
N0	14	15	N1

a)

Pin Number	Function	Pin Number	Function
1	FX2	17	SCK
2	ST1	18	VCC
3	GND	19	-
4	VCC	20	-
5	GND	21	GND
6	VCC	22	-
7	OS1	23	A0 (M0)
8	OS2	24	A1 (M1)
9	ST2	25	A2 (M2)
10	N2	26	M3
11	N3	27	SDA
12	N0	28	SCL
13	N1	29	-
14	SS/TEST	30	RXD
15	MOSI	31	TDX
16	MISO	32	FX1

TQFP/MLF Top View
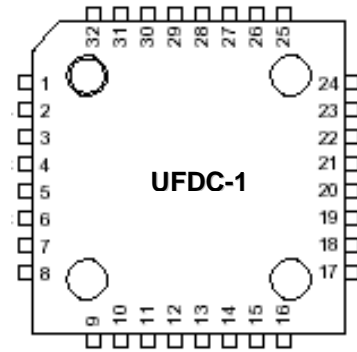
b)

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
V_{DD}	Supply voltage
GND	Ground
FX1, ST1	Input channel 1
FX2, ST2	Input channel 2
OS1, OS2	Oscillator
M0…M3	Mode selection (see table 2)
N0…N3	Accuracy selection (see table 3)
A0…A2	Addresses (for I^{2}C 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^{2}C compatible) Serial Bus Clock Line
SDA	Two-wire (I^{2}C compatible) Serial Bus Data Input/Output Line
RXD	UART Input Pin
TXD	UART Output Pin

5. Functionality

5.1 Accuracy

As described in sections 2-3, the UFDC-1 has 16 measuring and one generating modes. The measuring mode can be hardware-selected by using four selection pins M0-M3 and the relative error by using four selection pins N0-N3. The mode and accuracy can be also selected by using any of three possible interfaces. A communication interface type (RS232, SPI or I^{2}C) can be automatically selected according to the circuit connection.

For frequency-time output sensors or sensing elements, the UFDC 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 UFDC-1 should be 0.001 % or at least, 0.002 %. In this

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case the conversion error can be neglected. The UFDC-1 has non-redundant conversion time. The higher conversion accuracy needs longer conversion time. However, it is non-redundant for any chosen 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 modes.

Table 2. Modes of the UFDC-1.

M3	M2	M1	M0	Mode	Name	Mode No.
0	0	0	0	Frequency (channel 1), f_{x1}	FX1	0
0	0	0	1	Period (channel 1), T_{x1}	TX1	1
0	0	1	0	Phase-shift, φ_x	Fi	2
0	0	1	1	Time interval between start- and stop-impulse, τ_x	T	3
0	1	0	0	Duty-Cycle, *D.C.*	D.C.	4
0	1	0	1	Duty-Off Factor, *Q*	Q	5
0	1	1	0	Frequency difference with sign determination f_{x1}-f_{x2}	FD	6
0	1	1	1	Period difference with sign determination T_{x1}-T_{x2}	TD	7
1	0	0	0	Frequency ratio, f_{x1}/f_{x2}	FR	8
1	0	0	1	Period ratio, T_{x1}/T_{x2}	TR	9
1	0	1	0	Rotation speed (rpm), n_x	n	10
1	0	1	1	Pulse width, t_p	tp	11
1	1	0	0	Space interval, t_s	ts	12
1	1	0	1	Pulse number (events) count, N_x	N	13
1	1	1	0	Frequency (channel 2), f_{x2}	FX2	14
1	1	1	1	Period (channel 2), T_{x2}	TX2	15

Table 3. Programmable Accuracy of the UFDC-1.

N3	N2	N1	N0	Relative Error, δ_x %	Note
0	0	0	0	1	-
0	0	0	1	0.5	-
0	0	1	0	0.25	-
0	0	1	1	0.1	-
0	1	0	0	0.05	-
0	1	0	1	0.025	-
0	1	1	0	0.01	-
0	1	1	1	0.005	-
1	0	0	0	0.0025	-
1	0	0	1	0.001	-
1	0	1	0	1	With prescaler, f_{x1max}, f_{x2max} = 120 MHz
1	0	1	1	0.25	With prescaler, f_{x1max}, f_{x2max} = 120 MHz
1	1	0	0	0.05	With prescaler, f_{x1max}, f_{x2max} = 120 MHz
1	1	0	1	0.01	With prescaler, f_{x1max}, f_{x2max} = 120 MHz
1	1	1	0	0.0025	With prescaler, f_{x1max}, f_{x2max} = 120 MHz
1	1	1	1	0.001	With prescaler, f_{x1max}, f_{x2max} = 120 MHz

In modes 2, 4-5, 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 strictly depends on the converted values and does not depend on value programmed using selection pins N0_N3 or accuracy selection commands (A0-AF). This error can be calculated according to the following equation:

$$\delta_q = \frac{1}{16 \cdot 10^6 \cdot t_x} \cdot 100 \quad \% , \tag{1}$$

where t_x is 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 mode 13.

The UFDC-1 can work as an independent measuring unit (master mode), controlled by any external microcontroller, or embeded into sensor or DAQ board (slave mode). In the master mode, the conversion accuracy and measurement mode should be selected by external switches. In this mode the UFDC-1 works 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 UFDC-1 as a simple peripheral circuit for a microcontroller. A bidirectional data exchange is possible with any of three interfaces RS232, SPI or I^2C. The UFDC-1 works as a standard element in different systems with I^2C 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

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 UFDC-1 has not received any command through the RS232, the converter reads the external switches and is placed in 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 – A0 (1 %). The data transfer rate can be chosen from the following range: 300, 600, 1 200, 2 400, 4 800, 9 600, 19 200 and 38 400 (for slave mode).

The brief communication command set description for RS232 interface, appropriate modes and programmed accuracies are adduced in Table 4. 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).
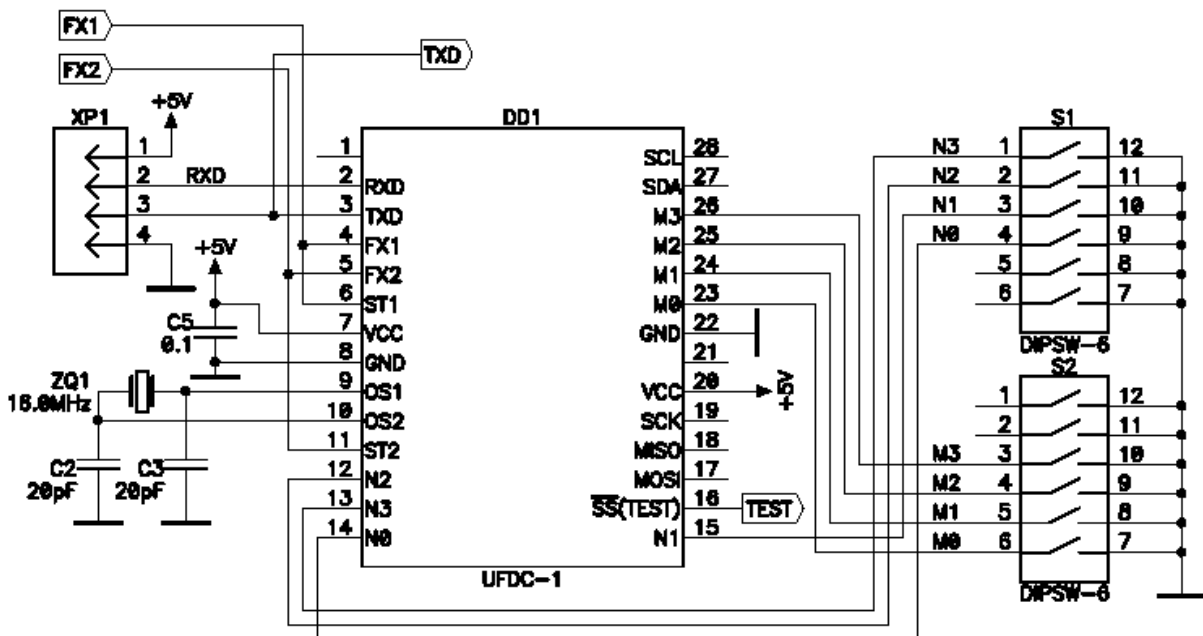

Figure 3. Circuit Diagram for the UFDC-1 Working in Autonomous (Master) Mode, RS232 Interface.
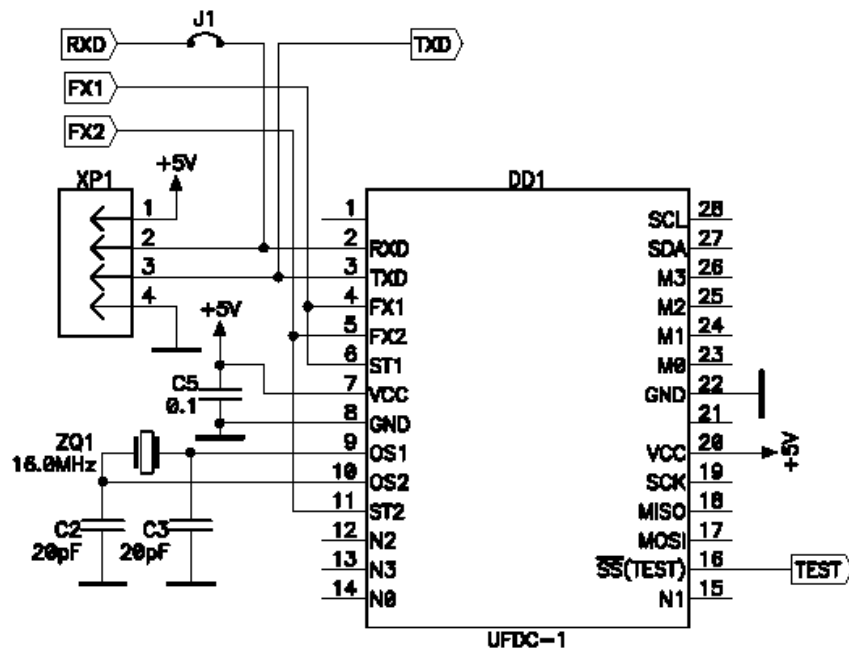
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Figure 4. Circuit Diagram for the UFDC-1 Working Embedded in a Sensor or DAQ Board (Slave Mode).

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 UFDC-1 to PC through the RS232 interface the additional circuit (Figure 5) for interfacing function is recommended.
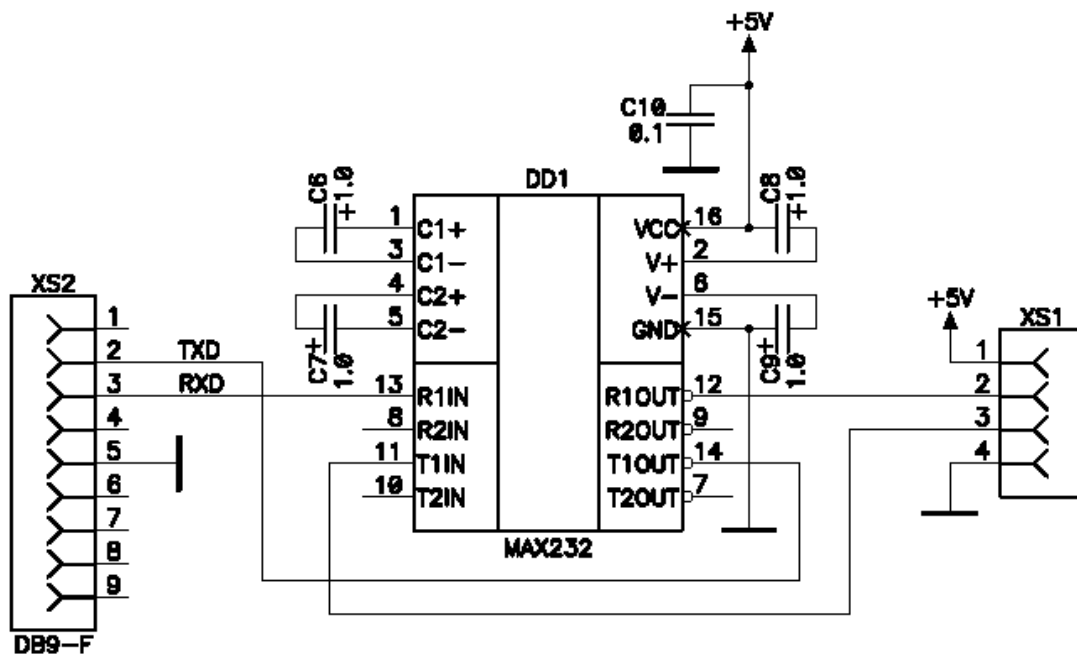

Figure 5. Interfacing Circuit for Connection the UFDC-1 to PC.

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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 5. 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. Maximum frequency of SPI data-rate should be chosen from 100 kHz to 500 kHz to guarantee a reliable operation.

5.2.3 2-wire Interface (I^{2}C Compatible)

The brief communication command set description for I^{2}C interface, appropriate measuring modes and programmed converted accuracies are adduced in Table 6. The UFDC-1 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 I^{2}C 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. Maximum possible communication speed in this mode is 100 kHz.

5. 3 Quartz-Accurate Automated Calibration

The 16 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 16 MHz, 30 ppm quartz crystal can have a real frequency of 16 001 400 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 UFDC-1 must be calibrated in order to take into account the quartz crystal systematic error.

The UFDC-1 provides so-called in-circuit quartz-accurate automated calibration. The calibration is made by means of the communication interface RS232. The UFDC-1 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 UFDC-1 is the following.

1) The test command "T" toggles the UFDC-1 to the calibration mode. A sequence of rectangular pulses with frequency $f_{oso}/2$ 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) The fractional part of the measurement result is rejected and the number 8 000 000 (Hz) should be subtracted from the integer part.
4) The received correction factor Δ need to be converted into a hexadecimal number. Use the command "F $\pm \Delta$" taking into account the result sign to put the correction value into the UFDC-1. The command "F" without parameters indicates the internal value of the correction factor 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 UFDC-1, which holds this value after power-off.

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Table 4. Communication Command Set for RS232 Interface

Interface RS232	Description	Parameter
A	Get current accuracy number	–
An	Set accuracy number 'n' ($0 \leq n \leq 9$) without an external divider; ($A \leq n \leq F$) – with an external divider by 16	0 – 1 % 1 – 0.5 % 2 – 0.25 % 3 – 0.1 % 4 – 0.05% 5 – 0.025% 6 – 0.01% 7 – 0.005% 8 – 0.0025% 9 – 0.001% A – 1 % B– 0.25 % C – 0.05% D – 0.01% E – 0.0025% F – 0.001%
B	Get current baud rate number	–
Bn	Set com port baud rate number 'n' ($0 \leq n \leq 7$)	0 – 300 1 – 600 2 – 1 200 3 – 2 400 4 – 4 800 5 – 9 600 6 – 19 200 7 – 38 400
C	Check the measurement status. Returns "r" if result is ready and "b" if measurement is in progress	–
F	Get current calibration constant	–
Fsnnn	Set calibration constant. "s" is the sign ('+' or '-') "nnn" - three hex digits ($000 \leq nnn \leq FFF$)	Integer hex digit from 000 up to FFF
M	Get current measuring mode number	–
Mn	Set measurement mode number 'n' ($0 \leq n \leq F$)	0 – frequency, FX1 1 – period, TX1 2 - phase shift, Fi 3 - time interval T 4 - duty cycle D.C. 5 - duty-off factor Q 6 - frequencies difference FD 7 - periods difference TD 8 - frequencies ratio FR 9 - periods ratio TR A - rotation speed n B - pulse interval tp C - space interval ts D - pulse counter N E - frequency 2 FX2 F - period 2 TX2
R	The same as R0	–
Rn	Get measurement result in format number 'n' ($0 \leq n \leq 3$)	0 - Decimal 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.	–
Z	Get current number of modulation rotor gradations	–
Znn	Set the number "nn" ($01 \leq nn \leq FF$) of modulation rotor gradations for rotation speed measurement mode ("nn" - hex digits)	1–255

Table 5. 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 'n' (00 ≤ nn ≤ 09) without an external divider; 0A ≤ nn ≤ 0F– 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 – 1 % 0B– 0.25 % 0C – 0.05% 0D – 0.01% 0E – 0.0025% 0F – 0.001%
<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 measuring mode number	–
<06><nn>	Mn	Set measurement mode number 'n' (00 ≤ nn ≤ 0F)	00 – frequency, FX1 01 – period, TX1 02 - phase shift, Fi 03 - time interval T 04 - duty cycle D.C. 05 - duty-off factor Q 06 - frequencies difference FD 07 - periods difference TD 08 - frequencies ratio FR 09 - periods ratio TR 0A - rotation speed n 0B - pulse interval tp 0C - space interval ts 0D - pulse counter N 0E - frequency 2 FX2 0F - period 2 TX2
<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 gradations	–
<0C><nn>	Znn	Set number of modulation rotor gradations "nn" = (01...FF) - set number "nn" of modulation rotor gradations	1–255

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

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Table 6. 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 'n' (00 ≤ nn ≤ 09) without an external divider; 0A ≤ nn ≤ 0F– 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 – 1 % 0B– 0.25 % 0C – 0.05% 0D – 0.01% 0E – 0.0025% 0F – 0.001%
<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 'n' (00 ≤ nn ≤ 0F)	00 – frequency, FX1 01 – period, TX1 02 - phase shift, Fi 03 - time interval T 04 - duty cycle D.C. 05 - duty-off factor Q 06 - frequencies difference FD 07 - periods difference TD 08 - frequencies ratio FR 09 - periods ratio TR 0A - rotation speed n 0B - pulse interval tp 0C - space interval ts 0D - pulse counter N 0E - frequency 2 FX2 0F - period 2 TX2
<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 gradations	–
<0C><nn>	Znn	Set number of modulation rotor gradations "nn" = (01...FF) - set number "nn" of modulation rotor gradations	1–255

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
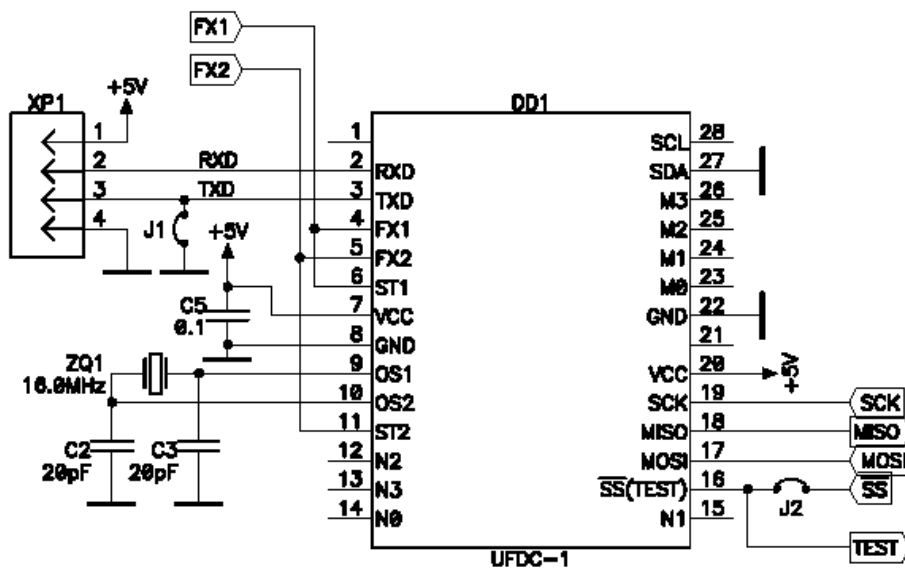<Fn> - byte n of fractional part of result

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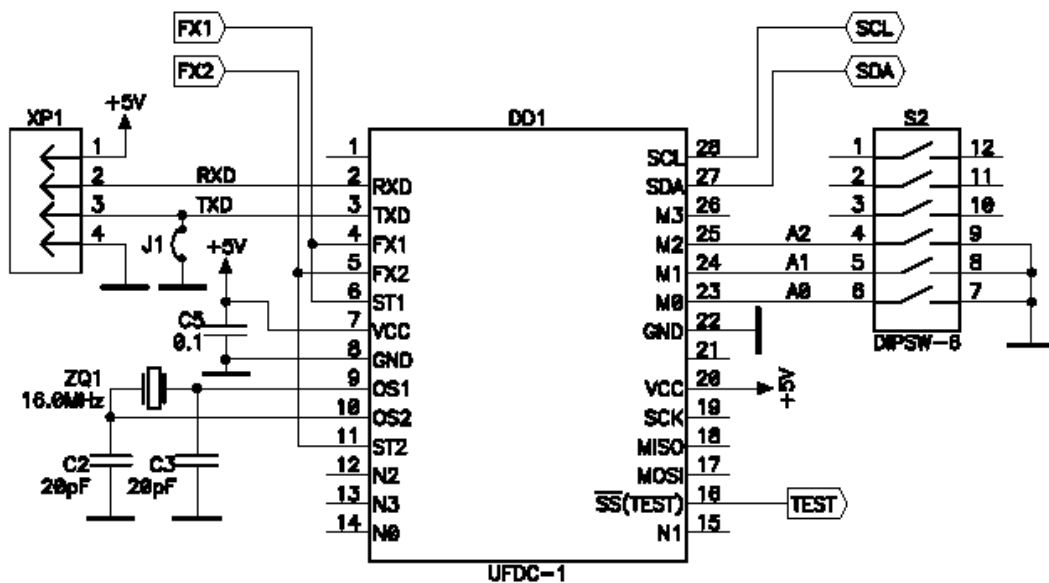**Figure 6**. The UFDC-1 Circuit Diagram for the 3-wire Serial Interface (SPI).

Figure 7. The UFDC-1 Circuit Diagram for the 2-wire I^2C Interface.

Example:

Toggle the UFDC-1 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 8 000 694.257865 Hz, for example. We reject a fractional part and received integer number is 8 000 694 Hz. Then we calculate the correction factor 8 000 694 - 8 000 000 = 694 Hz and convert the result into the hexadecimal number $(694)_{10} = (2B6)_{16}$. Finally we send the correction command with taking into account the correction factor's sign:

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>F+2B6

Then to check programmed value we send the command

>F
2B6

The returned result 2B6 testifies about the properly stored value of correction factor for the given quartz crystal. After that the UFDC-1 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 UFDC-1 usage, such periodical calibration will also reduced the quartz crystal error due to the crystal aging.

6. Measuring Modes

In this section, we specify the UFDC-1 properties for all measuring modes. Names of these modes are the same as used in Table 2.

6.1 Mode 0. FX1: Frequency, channel I, 0.05 Hz – 7.5 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 7.5 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-N3. By this way the frequency range will be expanded up to 120 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.

6.2 Mode 1. TX1: Period, channel I, 150 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. Fi: Phase-Shift, 0- 360^0, f_{xmax} = 500 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, 2 μs - 250 s

Start- and stop-pulse are connected to FX1, ST1 and FX2, ST2 inputs accordingly. The UFDC-1 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: 0 – 1 at $f_{xmax} \leq$ 500 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 $\leq$ 500 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}, 0-7.5 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}, $7 \cdot 10^{-9}$ – $1.4 \cdot 10^{8}$

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}, $7.5 \cdot 10^{-9}$ – $1.33 \cdot 10^{8}$

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 UFDC-1 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 system the UFDC-1 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:

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

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

_____

6.12 Mode 11. tp: Pulse Width, t_p 2 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-N3 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. ts: Space Interval, t_p 2 μs – 250 s

This mode of measurement is similar to the Mode 11.

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

The UFDC-1 can count the pulse number (events) on FX1, ST1 inputs. Each reinitialization of the mode resets the counter to zero.

6.15 Mode 14. FX2: Frequency, channel II, 0.05 Hz – 7.5 MHz without prescaling

In this mode a frequency signal f_{x2} (should be TTL rectangular pulses) must be connected in parallel to inputs FX1 and ST1. 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 7.5 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-N3. By this way the frequency range will be expanded up to 120 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. TX2: Period, channel II, 150 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.

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 UFDC-1 and a personal computer. A 16 MHz crystal completes the on-chip oscillator of the UFDC-1. 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 UFDC-1 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 UFDC-1. 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 8.

7.2 Software

There are many ways to display the measurement results. Any terminal software for Windows can be used with the UFDC-1 development board using the serial port of a PC. The configuration of the Terminal is: 2400 baud, 8 data bit, 1 stop bit and No parity error check. Following the RS232 communication commands from Table 4 it is easy to manage the development boards and display measuring results. There are four possible data format in the Terminal: BCD ASCII, BCD Hex, BIN Hex and BIN. One of the possible choices is Terminal V1.9b (http:// http://www.sensorsportal.com/DOWNLOADS/Terminal.exe) free software. Its screen is shown in Figure 9. Here is a calibration procedure example and conversion result.

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.

Commands must be printed in Transmit window, the results will be shown in Receive window.

Example:

>A9
>S
>R
12000.089992800575

- These commands set up the accuracy 0.001%, start measurement (S), ask for BCD ASCII format (R) and return the result of measurement in Hz.

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 4) in order to check if the result is ready. In opposite side it is a risk to get a result of previous measurement.

8. Applications

The UFDC-1 has many applications. Some typical applications are following:

- Any physical, chemical or biosensor systems
- Any frequency, period, duty-cycle, time interval, phase-shift, pulse number output sensors in order to produce a digital output
- Digital sensors design
- Smart (self-adaptive) sensors due to programmable accuracy and non-redundant conversion time - adaptive possibilities of UFDC-1 automatically choice the conversion time depending on the given error of measurement and opposite
- Multifunctional and multiparamters sensors for simultaneous detection various parameters proportional to frequency and duty-cycle carrying the information provided by sensing elements.
- Data acquisition (DAQ) boars and systems for frequency-time parameters
- 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 different measuring and communication applications.
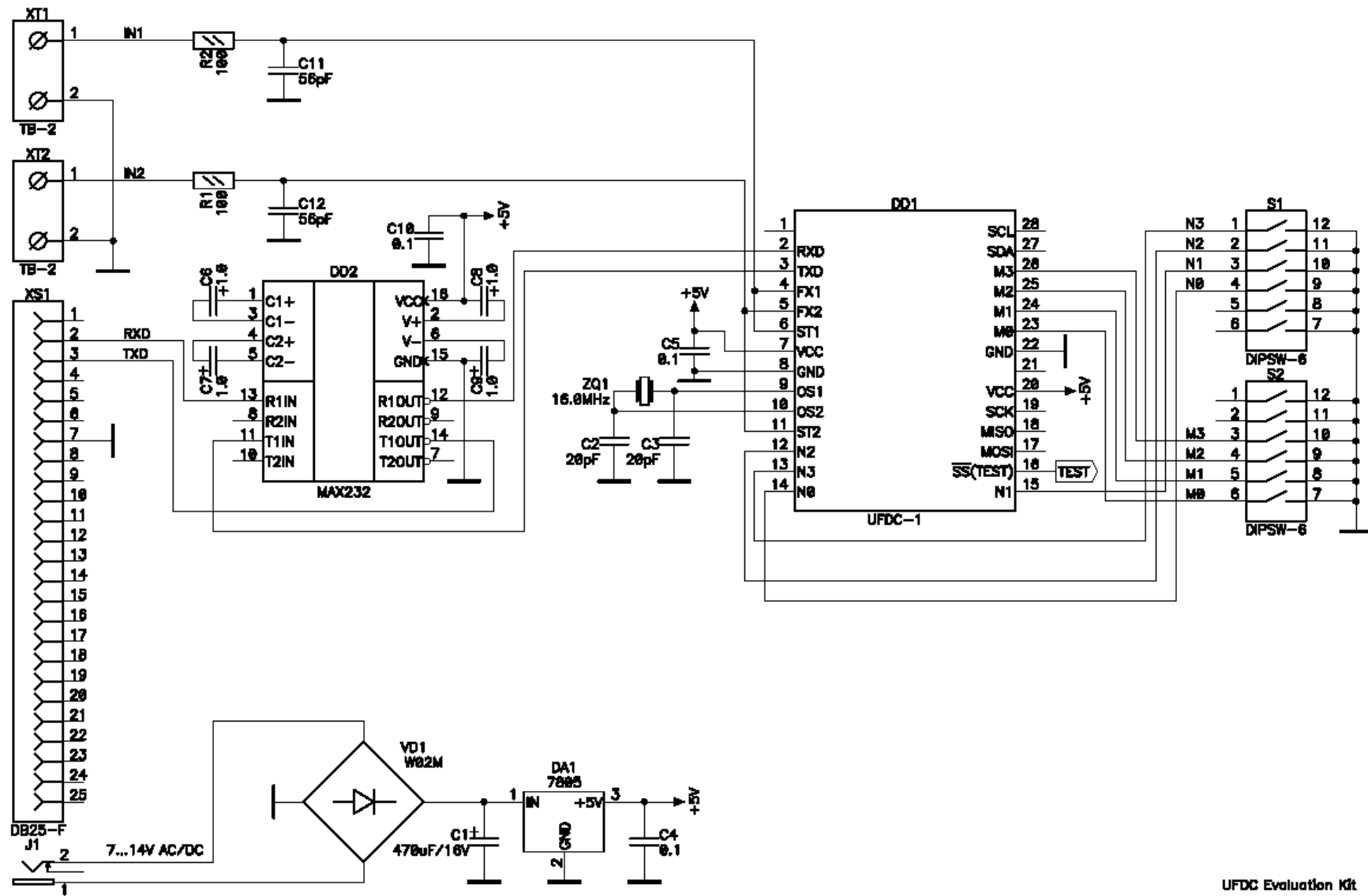
Figure 8. The UFDC-1 Development Board Circuit Diagram.

The UFDC-1 can also work with 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.
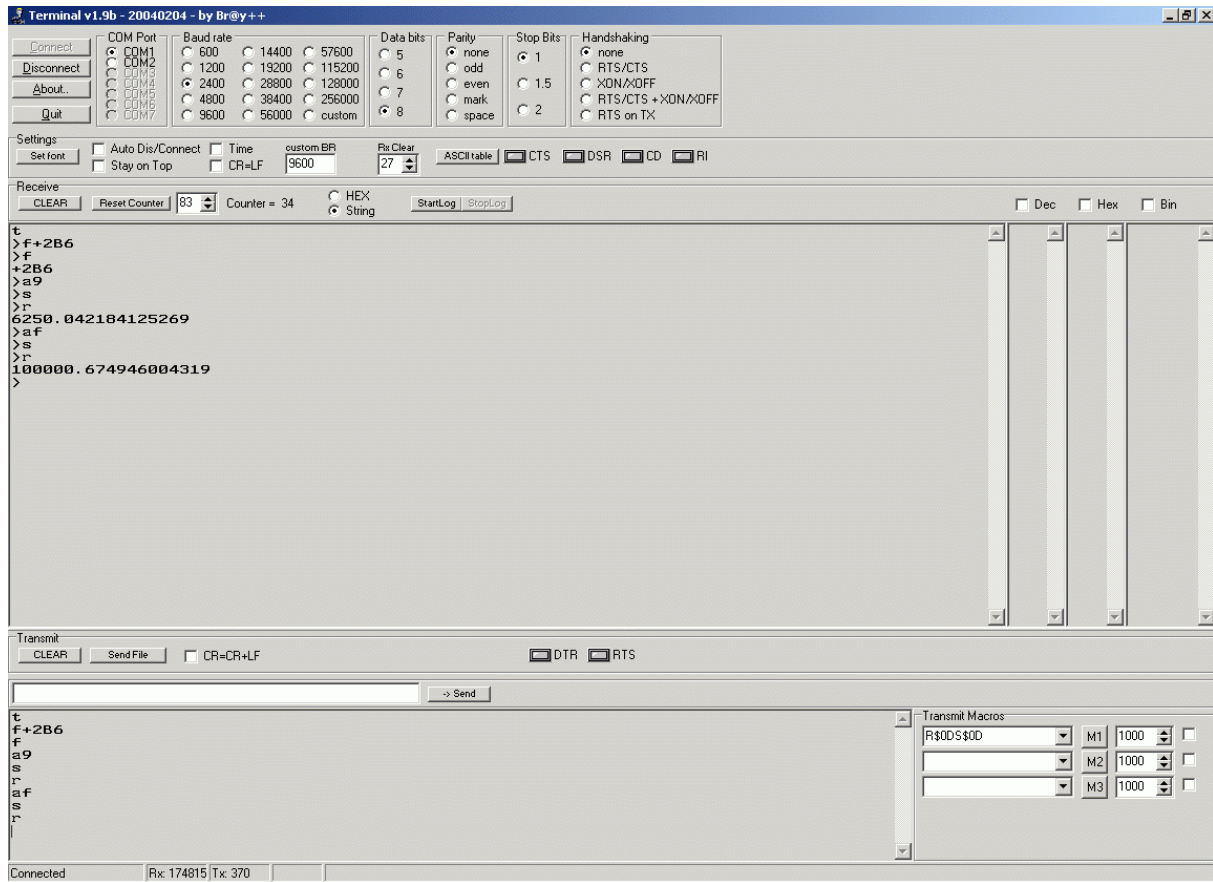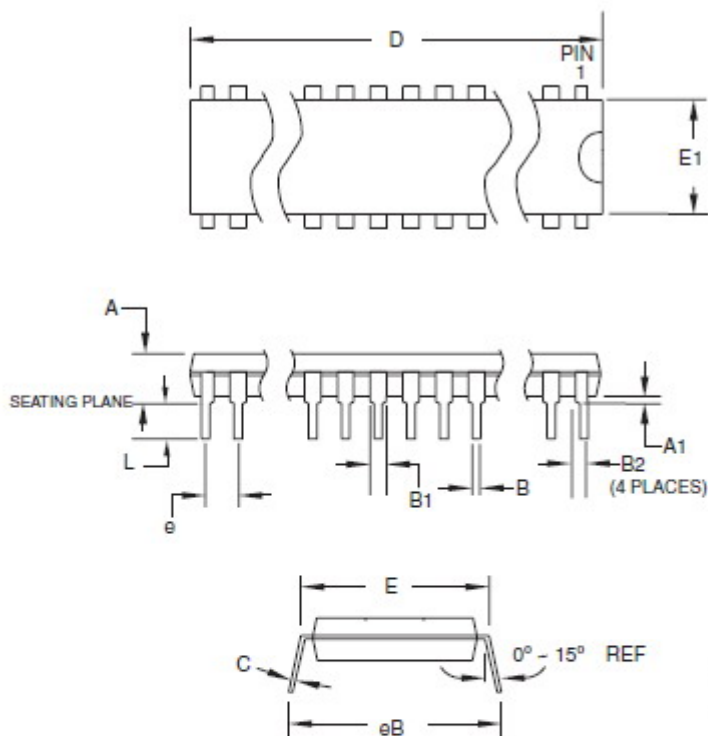

Figure 9. Terminal V1.9b Window.

Note: This device can also be supplied in wafer form. Please contact SWP sales office for detailed ordering information and minimum quantities.

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9. Packaging Information

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

COMMON DIMENSIONS
(Unit of Measure = mm)

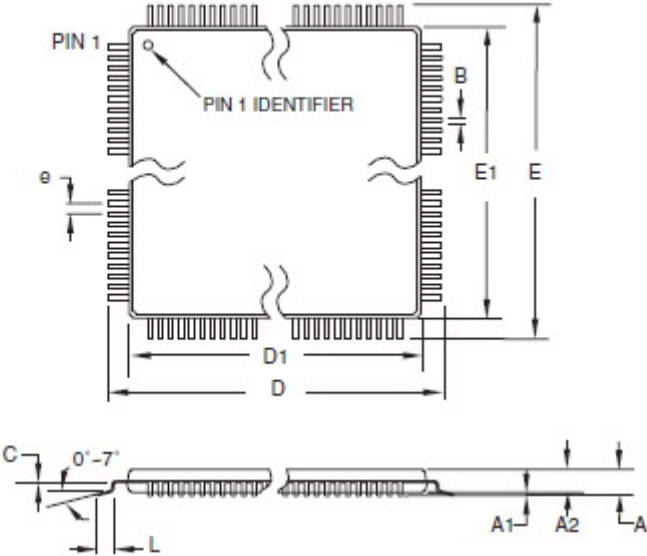| SYMBOL	MIN	NOM	MAX	NOTE
A	–	–	4.5724	
A1	0.508	–	–	
D	34.544	–	34.798	Note 1
E	7.620	–	8.255	
E1	7.112	–	7.493	Note 1
B	0.381	–	0.533	
B1	1.143	–	1.397	
B2	0.762	–	1.143	
L	3.175	–	3.429	
C	0.203	–	0.356	
eB	–	–	10.160	
e		2.540 TYP		

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

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.

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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).
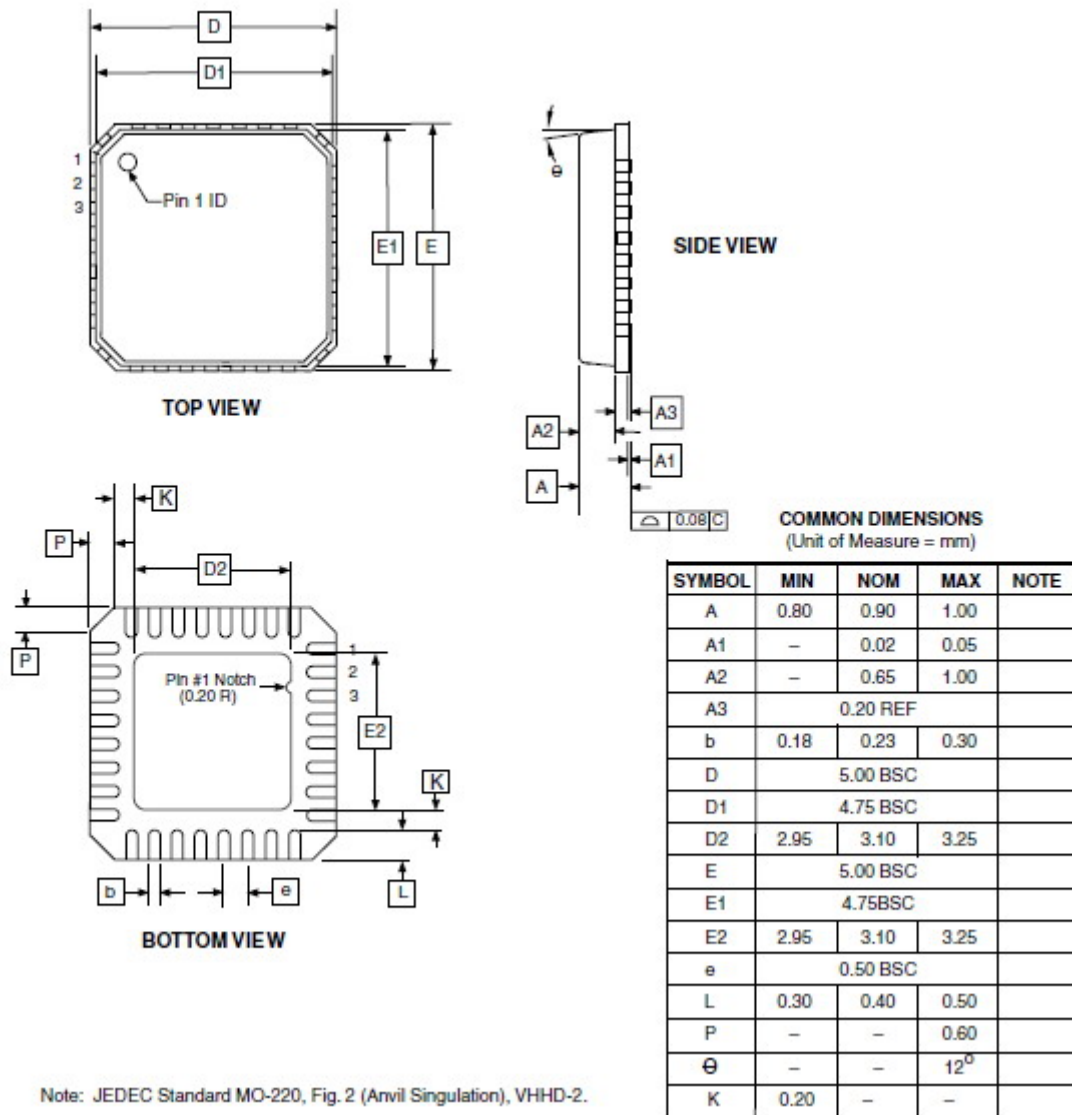

COMMON DIMENSIONS
(Unit of Measure = mm)

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		

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.

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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	–	–	

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International Frequency Sensor Association (IFSA)