UIC1001
Solid-State Optical Mouse Sensor with Quadrature Outputs

Functional Description

The UIC1001 is a reflective optical sensor that provides a non-mechanical tracking engine for implementing a standard mouse. It is based on optical navigation technology that measures changes in position by optically acquiring sequential surface images (frames) and mathematically determining the direction and magnitude of movement. The sensor is mounted in a plastic 18-pin optical DIP package and designed to be used with the special optical system and high efficiency red LED, providing a complete and compact tracking engine. This optical tracking engine has no moving parts and requires no precision assembly or optical alignment.

The UIC1001 provides a 2-dimensional quadrature output. Resolution is 500 dpi at rates of motion up to 1 linear meter per second.

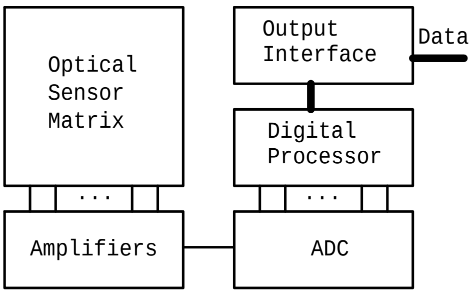

Fig.1. Block Diagram.

The UIC1001 is comprised of three major functional blocks (see fig.1): an Image Receiving System (IRS), Analog to Digit Converter (ADC), and Digital Signal Processor (DSP).

Image Receiving System includes the optical Sensor Matrix (16×16 elements) and 16 sampling amplifiers for reading output signals from full line of sensors. The size of the sensing Element is 50×50 μm. Sensor matrix converts the optical map of a desktop surface to an electrical signal. To reduce the influence of the transistor threshold voltage spread and the low frequency noise influence in amplifiers the double correlated sampling is used. The nominal frame frequency is equal to ~20KHz. With external 20MHz Quartz resonator the time of exposition equals 48 μs, and line-reading time is equal to 3.2 μs (including conversion in ADC).

Optical system gain is supposed to be 1:1. Under these conditions the size of a 1 pixel on the surface of a desktop is equal to 50um. It corresponds to 500 dpi resolution. If to use an optical system gain K:1 the resolution of the Mouse sensor increases as M · 500 dpi and maximum speed decreases as 1/M m/sec. In common case the resolution N[dpi] and maximum speed of motion S_{max}[inch/sec] are correlated by the following expression:

$$S_{max} \cdot N = F_{FR} ,$$

where – F_{FR} is a frame frequency (20000 sec^{-1}). This expression is true at any value of optical system gain.

Thanking to the original construction of CMOS optical receiving cell the dynamic range of optical sensors with amplifiers equals to 60 Db. The ADC has a pipe-lined structure. Its resolution is in accordance with dynamic range of previous part and is equal to 10 binary bits. Sampling frequency is equal to 10 MHz that corresponds to line conversion time 1.6 μs.

The accuracy required for appropriate operation of algorithm used for calculation of picture displacement is equal to 5÷6 bit. And 4÷5 bits is need to compensate the difference in reflective property of miscellaneous surfaces. Totally 10 bit of resolution is enough for normal operation. For this reason the LED used for surface illumination can be powered by dc current. However, for simplification of set-up of a system and dynamic range expansion the level of LED current is dynamically adjusted to adapt LED brightness for different types of surfaces (black or white). The dynamic range of current adjustment equals to 40Db.

Digital Signal Processor consists of a specialized processing unit and interfacing block. It receives series images of the surface from ADC. These images are further processed by the DSP to determine direction and distance of motion. The DSP generates a stream of ΔX and ΔY relative displacement values that are then communicated to the interfacing block. Interfacing block converts these values to quadrature format and gives 4 output signals – XA, XB, YA, YB.

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

Main IC parameters.

Chip parameters are submitted in the Table 1.

Table 1

N	Parameter	Unit	Value
General parameters			
1	Power supply voltage		
	Analogue Part - VDA	V	2.5
	Core	V	2.5
	I/O cells	V	3.3
2	Total consumption current (without LED)	mA	~(5÷6)*
3	Clock frequency	MHz	20
4	Operating temperature range	°C	0÷50
5	Tolerance temperature range at storage and haul	°C	-40÷85
Optical sensor			
6	Matrix dimension	-	16×16
7	Cell size	µm	50×50
8	Operating wave length	µm	0.64
9	Exposure time	µs	48
10	Line reading time	µs	3.2
11	Frame Frequency	kHz	20
Sample/hold amplifier buffer			
12	Number of cells	-	16
13	Input signal range	V	0.1÷2.0
13	Gain	-	1
14	Set time	µs	1.6
15	Dynamic range	dB	60
Analog-to-Digital Converter			
15	Resolution	bit	10
16	Conversion time	ns	100
Output for LED			
	Output current range	mA	0.2÷36
	Number of levels	-	16
	Current level ratio (for immediate levels)	-	1.41
Digital Signal Processor			
17	Memory volume for processed frame storage	Kbit	7.8
18	Processing time	µs	<35
Output Interface			
19	Output voltage in low level state	V	<0.2
20	Output voltage in high level state	V	>2.5

* Can be corrected after final IC measurements

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

Crystal structure and Package.

Internal structure of the IC is shown in Fig.2

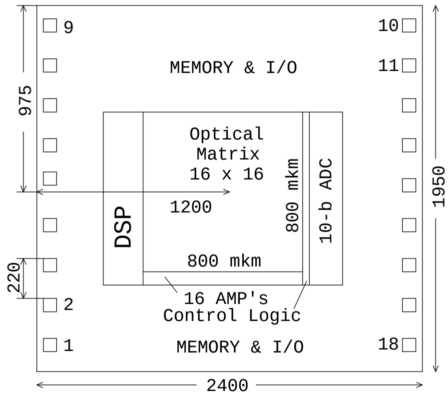

Fig.2. Internal IC structure

The Chip size is 2.4×1.95 mm^2 without scribe lines. It has 18 external PAD's. Some PAD's are used only for output testing. Chip is packaged in a 20 pin plastic DIP-package. It is arranged on an underside of the package. For this reason external Pads in Fig.2 are numbered clockwise.

DIP-package has an optical window on the bottom side (see Fig.13). The optical window should provide full passing of a luminous flux from a lens on an optical receiver. As the size of the Matrix is 0.8×0.8 mm, the window must be at least 1.2 mm in diameter.

Layout view of the chip is shown on the fig3.

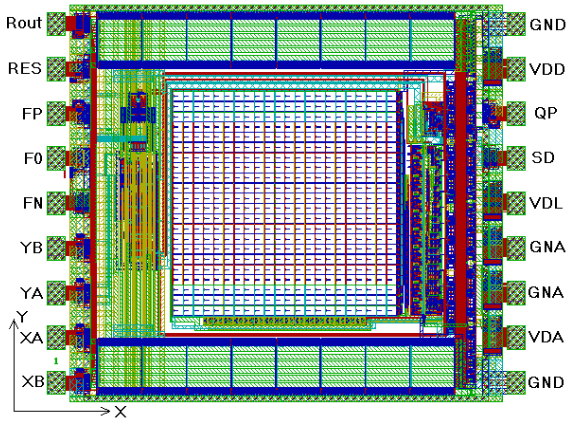

Fig.3. Layout view with PIN names.

The center of optical matrix is located exactly in the center of the chip. The chip is arranged on a framework of the package so that the optical matrix is placed precisely under an optical window. More detailed information on dimensional characteristics of the package see below (fig.12, 13, 14).

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

PIN description.

IC UIC1001 has 1operation mode. It provides two-channel quadrature output for direct interface to mouse microcontrollers. The Pin assignment is briefly submitted in the table 2.

IC UIC1001 has separate Power supply circuits for analog and digital parts.

GND (Num. 10, 18) is a Ground plane of digital part.

GNA (Num. 15, 16) is a Ground plane of analogue part.

VDA (Num. 17) is a Power supply +2.5V ±10% for analogue part.

VDL (Num. 14) is a Power supply +2.5V ±10% for digital part (control logic for optical Matrix and amplifiers, digital blocks of ADC, DSP and interface).

VDD (Num. 11) is a Power supply +3.3V ±10% for output cells.

F0 (Num. 6), **FN** (Num. 5) are used to generate 20 MHz clock. Normally they must be connected to 2-terminal 20 MHz ceramic resonator. In the case when external generator is used it must be connected to the terminal F0. FN in this case must be free.

FP (Num. 7) – control output from clock generator. The level of output voltage corresponds to 3.3V CMOS. It can be used for driving CLK-input of USB-controller chip.

RES (Num. 8) provides the power-up reset signal. Place a 0.22 μF capacitor from this pin to ground. An internal current source charges this capacitor during the reset interval to allow the oscillator and internal analogue nodes to stabilize.

R_out (Num. 9) – control output from reset-driver. The level of output voltage corresponds to 3.3V CMOS. It can be used for driving RESET input of USB-controller chip.

QP (Num. 12) - auxiliary standard CMOS logic output for adjustment of a LED current level. The level of output signal QP is updated at the end of each frame cycle depending of richness of most bright dot in the frame. If its level is not exceed maximum permissible value – Amax and simultaneously is greater, then $A_{max}/2$, output QP is set to low logic level. In opposite situation, when the level of surface illumination is too high or too low, the output QP is set to high logic level. The level of output voltage corresponds to 3.3V CMOS.

XB (Num. 1) – Quadrature output.

XA (Num. 2) – Quadrature output.

YA (Num. 3) – Quadrature output.

YB (Num. 4) – Quadrature output.

SD (Num. 13) – current generator output for LED. This current generator provides pull down current 0.2÷36 mA. The cathode of the LED is connected to the output SD, and the anode – to the external power source +2.5÷3.3V.

Pin description is summarised in table 2

.

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

Table 2

Pin number on chip	Name	Pin type	Description	Pin number in package
1	XB	Output	XA output for mouse microcontroller.	1
2	XA	Output	XB output for mouse microcontroller.	2
3	YA	Output	YA output for mouse microcontroller.	3
4	YB	Output	YB output for mouse microcontroller.	4
5	FN	Output	Are used to generate 20 MHz clock. Normally they must be connected to 2 terminal 20 MHz ceramic resonator.	5
6	F0	Input		6
7	FP	Output	Control output of generator 20MHz.	7
8	RES	Input	Provides the power-up reset signal. Place a 0.22 μF capacitor from this pin to ground.	8
9	R_out	Output	Control output of RESET circuit.	9
10	GND	PWR	Ground plane of digital part.	12
11	VDD	PWR	Power Supply +3.3V for output cells.	13
12	QP	Output	Auxiliary output for adjustment of a LED current level.	14
13	SD	Output	Current generator output for LED.	15
14	VDL	PWR	Power Supply +2.5 V for digital part of the IC.	16
15	GNA	PWR	Ground plane of analogue part of the IC.	17
16	GNA	PWR	Ground plane of analogue part of the IC.	18
17	VDA	PWR	Power Supply +2.5 V for analogue part of the IC.	19
18	GND	PWR	Ground plane of digital part.	20

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

Resolution and speed.

On the surface of matrix photo receiver is formed a picture of working surface with the aid of optical system. A single photo detector in matrix (pixel) has size 50×50mkm. If the picture is moving along the surface of matrix receiver, digital processor can calculate its displacement in each direction with resolution equal pixel size, that is 50mkm. If to use an optical system with gain K, resolution on the work surface equals to 50/K mkm. In other terms the resolution equals Ro=500·K dpi.

Displacement is computed by processor after receiving each frame. The algorithm of calculating assumes, that displacement in each direction does not exceed ±1 pixel. In opposite case system can't operate properly. This limits maximum speed along each axis by value Vmax=Fo/Ro inch/s, where Fo – frame frequency (Fo=20000). The product of Ro by Vmax is a constant value: Vmax · Ro=Fo. One can increase resolution by using an optical system with K>1, but this reduces maximum permissible speed of moving. With K=1 resolution equals to 500dpi and Vmax=1m/s.

Another view on this problem consist in limited productivity of processing block. If the shift is measured in pixels, maximum speed can be measured in pixels per second (pps). The UIC1001 provides maximum speed 20000 pps.

Clock generator.

IC UIC1001 is designed for operation with clock signal 20MHz. The value of clock frequency is not critical for correct IC operation. Maximum permissible frequency equals to 20MHz+20%. Minimum frequency value may be less then 100kHz. Frame frequency F_{FR} is tied with clock Fo by expression: F_{FR} = Fo/1024. Frequency lowering leads to photosensitivity increase. Consequently, one can to lower current consumption by LED. But at the same time the maximum permissible speed decreases. The UIC1001 has internal clock generator. Its simplified schematics diagram is shown on fig.4. It has 3 external pins: Fo, FN, FP.

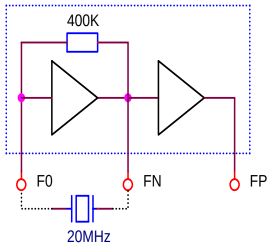

Fig.4. **Clock generator.**

Connect 2 terminal ceramic resonator between F0 and FN to generate clock. Control output FP is used for test purposes. It may be used as external clock for other IC, operating in pair with UIC1001. Output level on FP corresponds to 3.3V CMOS.

The UIC1001 may operate with external clock. It is applied to F0. The level of external clock mast be 2.5 or 3.3 V CMOS.

Quadrature outputs specification.

The UIC1001 emulates standard 2-coordinate quadrature encoder outputs for easy interface to existing mouse microcontrollers (e.g. PS/2, Serial, and USB mouse controller ICs). These outputs are called XA, XB, YA, YB. The output level of signals XA, XB, YA, YB corresponds to 3.3V CMOS.

The pair XA, XB – indicates the displacement in X-axis direction, and the pair YA, YB - indicates the displacement in Y-axis direction (see fig.3). The initial state of quadrature outputs may be arbitrary. The condition of quadrature outputs is renovated 1 time at the end of frame. While displacement in any direction equals 0, corresponding pair of quadrature outputs does not change. If in each frame displacement is equal to +1 pixel, quadrature outputs will change in accordance with timing diagram in fig.5.

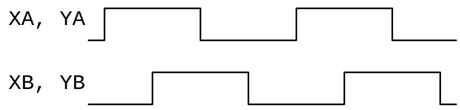

Fig.5. **Timing diagram for ΔX, ΔY=+1.**

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

When displacement is equal to -1 pixel, quadrature outputs will change in accordance with timing diagram in fig.6.

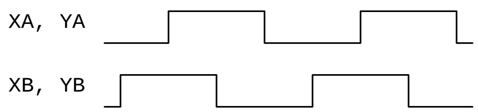

Fig.6. **Timing diagram for ΔX, ΔY=-1.**

As seen from fig.4, 5, pair XA, XB (YA, YB) do never change simultaneously. Minimum interval between change events for each pair equals to 50 mks.

Some microcontrollers have current sensitive quadrature inputs. This is made for optimum agreement with phototransistor output, which is commonly used in quadrature encoders. The UIC1001 has voltage-mode quadrature outputs. When UIC1001 is used in pair with current sensitive device, additional external resistors must be included in series between quadrature outputs XA, XB, YA, YB and current sensitive quadrature inputs (see Fig.9).

Brightness control.

The UIC1001 has a built-in brightness indicator with output QP. When the brightness of working surface less than ½ of maximum permissible one, QP equals to +3.3V. When the brightness of surface lies in interval from ½ to 1 of maximum permissible one, QP equals to 0. And when the brightness of surface exceeds 1, QP = +3.3V (see fig.7). The value of QP is renovated at the end of each frame cycle. So, QP=0 indicates optimum level of brightness. Output QP is not used in particular applications. It is used for test purposes. It also may be used at a stage of a LED current set-up. Optimum biasing current for LED depends on the clock frequency, LED efficiency and on optical system used.

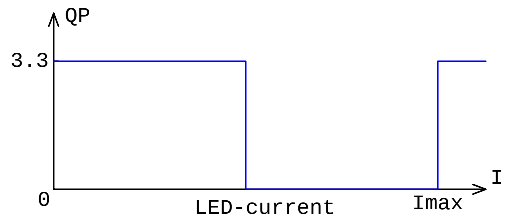

Fig.7. **Brightness control.**

Using QP-output one can measure maximum permissible LED current level (I_{MAX}) for particular system configuration. It corresponds to transition from QP=0V to QP=3.3V, while the LED biasing current increases. Optimum current equals ~80% from measured one.

Build-in DAC.

For automatic LED current adjustment the UIC1001 has a built-in current mode DAC with output SD. This DAC provides pull down current in range 0.2÷36 mA. The cathode of the LED is connected to the output SD, and the anode – to the external power source +2.5÷3.3V (see fig.11). The DAC provides 16 levels of output current and has exponential scale. The minimum current level equals to 0.2mA. Each following current level exceeds previous one in 1.41 times. Maximum current level equals to 36mA. Full dynamic range equals to 45 DB.

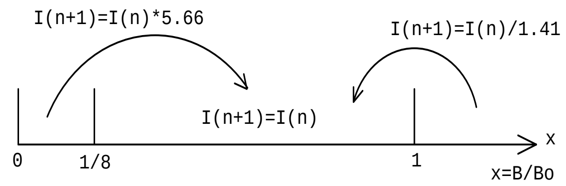

Fig.8. **Current adjustment algorithm.**

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

The level of output current is adjusted automatically. Algorithm of current adjustment is illustrated in fig8. X-axis in fig.8 shows the ratio of working surface brightness (B) to the maximum permissible one (Bo). When x lies in the range 1/8÷1, output current does not change. When x>1, output current decreases by the factor 1.41. When x<1/8, the output current increases by the factor 5.66. Any current changes are synchronised with the end of frame cycle. Each time, when the output current changes, digital processor ignores the current and the next frame.

LED-biasing.

Frame cycle in UIC1001 has no separation into an exposition and reading. The working surface must be lighted continuously. LED used for lighting must be powered by DC-current. The level of current depends on clock frequency, LED efficiency and on optical system used. For recommended 20MHz clock with HLMP-ED80 the biasing current equals to ~5mA.

There are two possible ways to bias the LED:

1. The LED is biased using build-in DAC. The cathode of the LED is connected to the output SD, and the anode – to the external power source +2.5÷3.3V (see fig.11). This method is convenient because it doesn't require additional external elements and tuning operations. But in this case current consumption does significantly depend on working surface brightness. When mouse manipulator operates on black surface, current consumption by the LED may increase in 10 times in comparison with consumption on a white surface.

2. The LED is biased from DC voltage source through series resistor (see fig.9, 10). Its nominal resistance may be optimised using QP output (see section "Brightness control"). For optimisation it is necessary to place an optical system and PCB-plate with UIC1001 and LED on a sheet of a white paper. This method in comparison with the previous one requires additional resistor and tuning operation. But in this case current consumption for the LED biasing is supported by a constant value as small as possible in existing configuration. The dynamic range of photo receiver and ADC is enough to suspend normal operation on different surface types.

Power requirements.

The UIC1001 has 3 power pins: VDD, VDL, VDA. It requires 2 power source: +3.3V and +2.5V. VDD is powered by +3.3V. Pins VDL and VDA may be integrated on PSB-plate in a single circuit and powered by +2.5V. Both power sources must have blocking ceramic capacitors not less then 0.1mkF in immediate proximity from power pins. For more reliability each power source must have additional blocking capacitor with nominal 4.7mkF.

Standard PC interfaces (PS/2, USB) have a power supply +5V. Therefore 2 DC-DC converters are need for powering UIC1001 (see fig.9). You may use the UIC1001 in pair with the USB controller UIC4001CP. The USB controller UIC4001CP has build-in DC-DC converter from +3.3V to +2.5V. In this case you need only 1 DC-DC converter (from +5V to +2.5V, see fig.10, 11).

Electronic Design Considerations.

Following are two application circuit diagrams for interfacing the UIC1001 using quadrature outputs – interface to PS/2 and USB mouse controllers (see fig.9, 10). When an external microcontroller is added, additional flexibility is added since plug and play codes and other manufacturer customizations are feasible.

Fig.11 shows typical application of an IC UIC1001 using dynamic LED biasing. Biasing current is automatically adjusted in range from 0,2mA up to 36mA depending on the surface brightness.

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

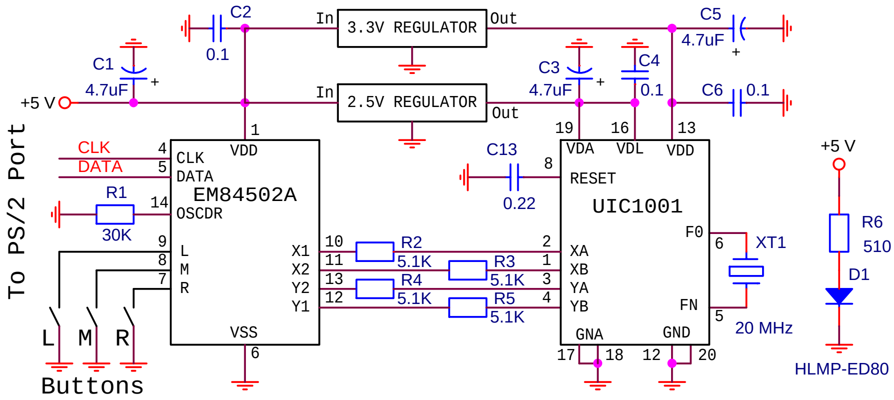

Fig.9. Typical Application using Quadrature Output Interfacing to PS/2 Mouse Controller.

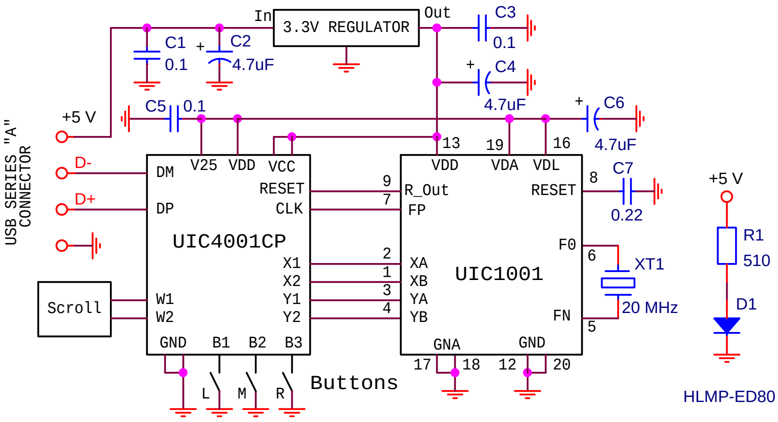

Fig.10. Typical Application using Quadrature Output Interfacing to USB Mouse Controller.

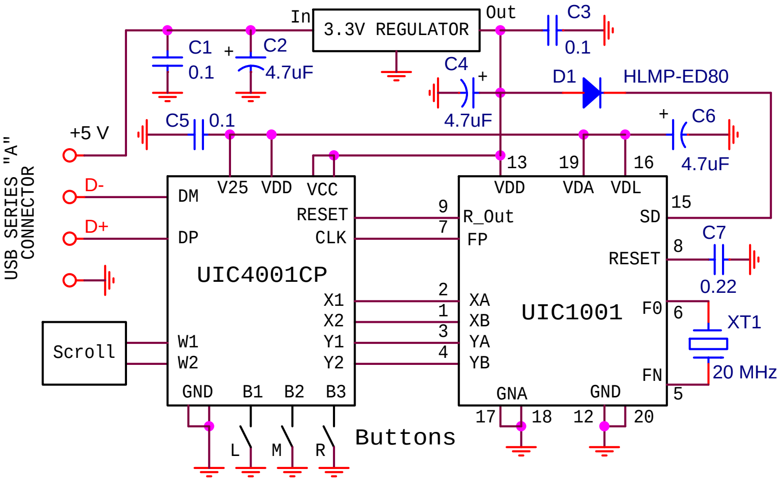

Fig.11. Application using Interfacing to USB Mouse Controller and dynamic LED biasing.

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

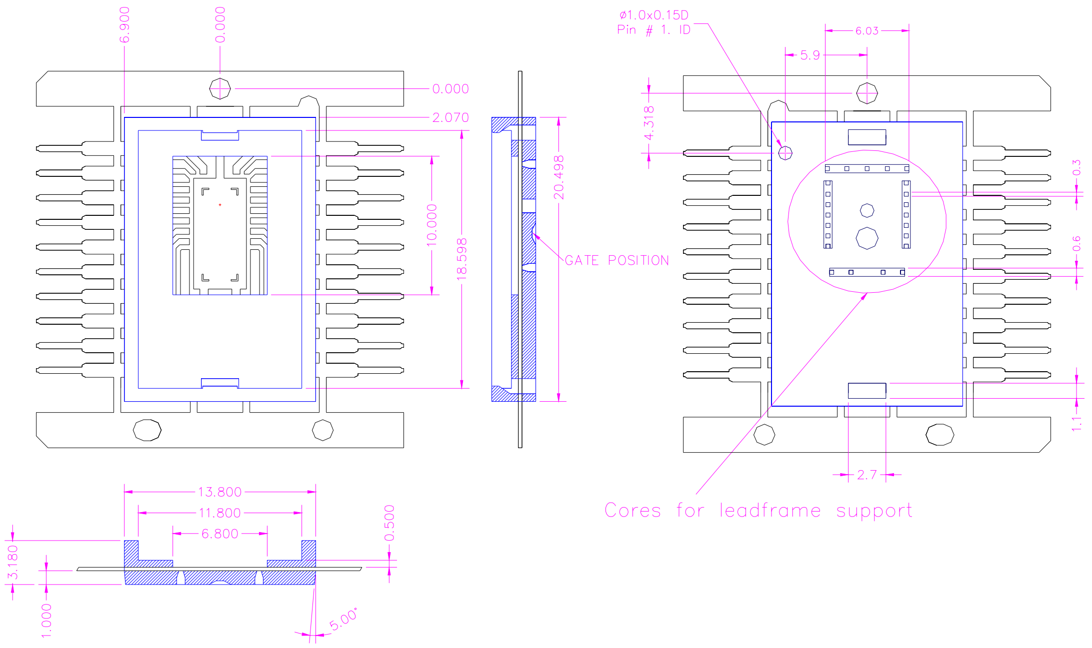

Fig.12. **Package drawing.**

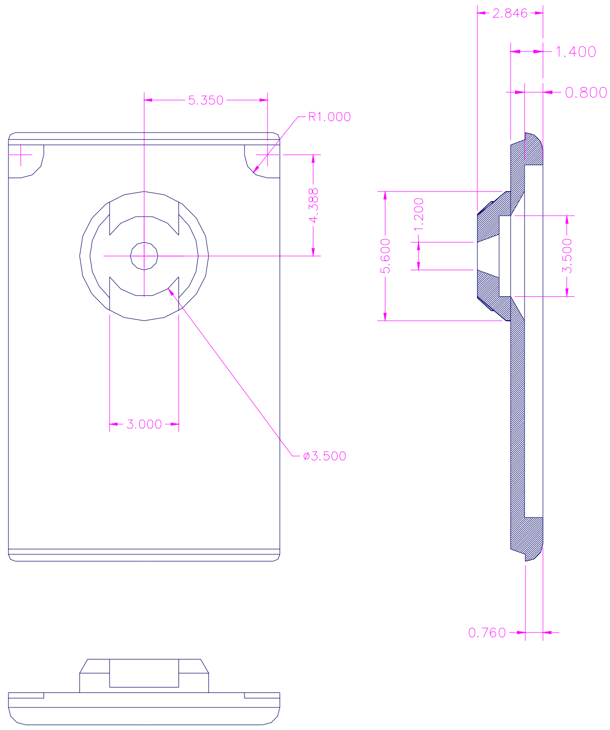

Fig.13. **Package Cower drawing.**

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com

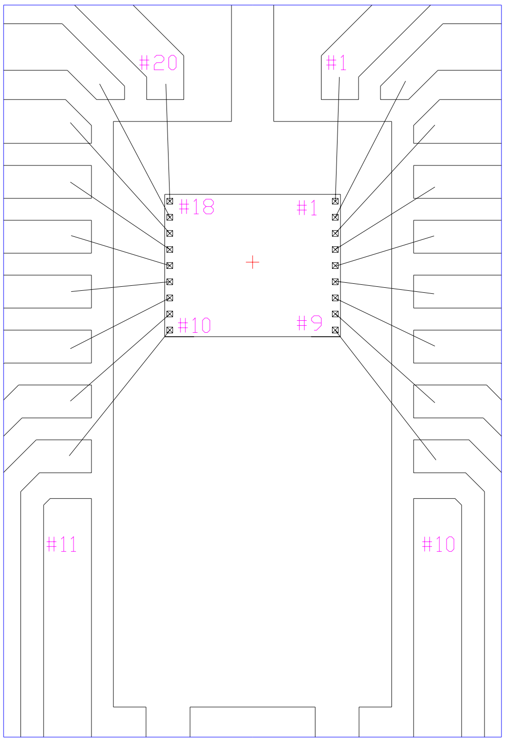

Fig.14. Packaging diagram.

Unique ICs, LLC
Building 20, House 5, Proezd 4806
Zelenograd, Moscow, 124498, Russia
Tel. +7 (095) 536 9939 Tel./Fax. +7(095) 530 7538
e-mail: mail@uniqueics.com
http://www.uniqueics.com