VT5376

Ultra-low power laser motion sensor for optical mouse applications

Preliminary Data

Features

- Ultra-low power performance and high speed/high accuracy motion detection (1 m/s, 20 g)
- Optional on-chip power management scheme (RUN/IDLE1/IDLE2/SLEEP)
- On-chip boost-converter controller enables a complete autonomous single AA/AAA-type battery supply application
- Very low quiescent and operating current mode for battery life saving
- I2C interface, with fast polling rate capability for high end applications (report rate up to 1 per ms)
- Internal oscillator
- CPI programmable up to 3,200 CPI
- On-chip ADC for battery level reporting
- Laser drive circuitry, fault detection scheme and safety features
- Versatile usage: the sensor is designed to operate with a companion microcontroller, and can be used for any optical mouse system although it is optimized for wireless applications (27 MHz/2.4 GHz/BT).

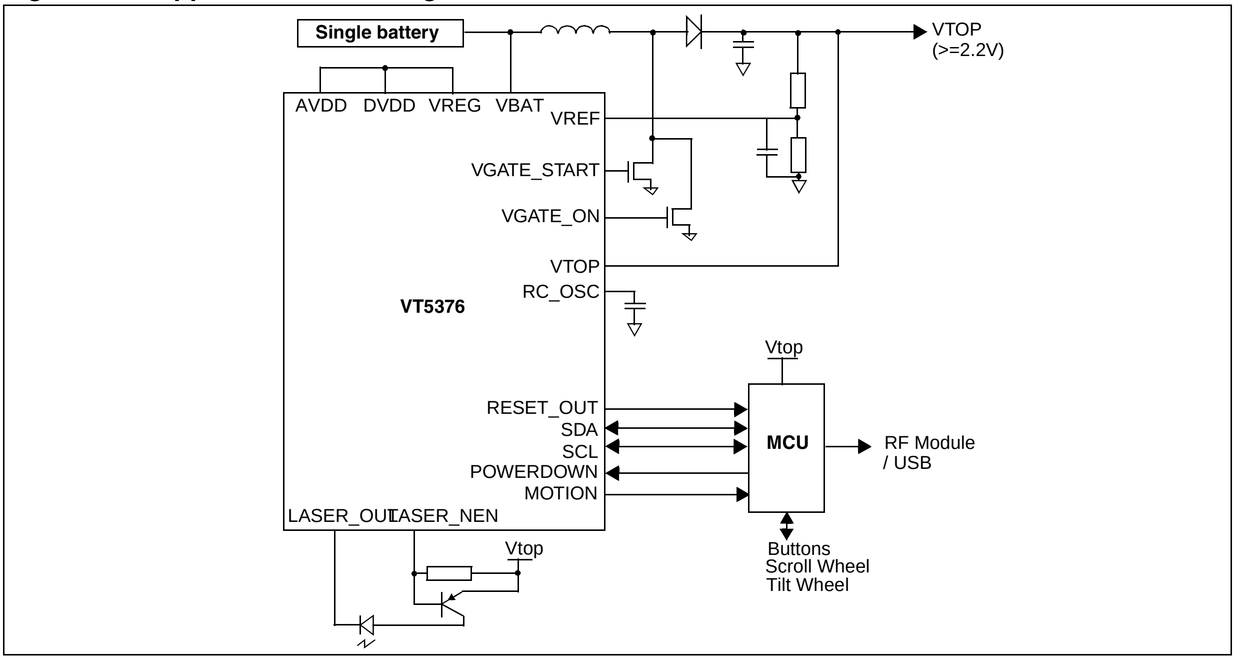
Applications

- Ultra-low power wireless optical mouse - 27 MHz, 2.4 GHz and Bluetooth
- Also suitable for laser USB mouse applications

Description

This device is intended to fit into any 2-chip applications (companion MCU) and offers the best compromise between application cost, power and performance.

Figure 1. Application block diagram



Contents

1 Motion performance

The sensor can operate with an **LED** or **VCSEL**, and when bundled with the appropriate optics subsystem is able to track motion on a wide range of surfaces up to speeds of **1 m/s (40 ips)**, and to detect acceleration of up to **20 g**. The sensor achieves this top speed with very low drift and high accuracy.

Note: *Although this device features an UltraLowPower motion detection machine, the power saving has not been achieved by compromising tracking accuracy.*

1.1 Technical specifications

Table 1. Technical specifications

Parameter	Description
Resolution	Programmable up to 3200 CPI
Pixel size	30.4µm
Array size	20*20 pixels
Frame rate	up to 4000 fps
Tracking performances	**LED** or **Laser**: 1m/s Very low drift.
Supply voltage	1 V to 1.6 V (1)
Operating temperature	0°C to 60°C
Package type	7 mm x 7 mm x 1.4 mm 32 lead LOQFP (Low profile Optical Quad Flat Pack)

1. Using internal boost converter controller. Otherwise, voltage supply ranges from 1.6V to 3.2V

1.2 Battery life management

The battery life management (in no motion state) can be done manually where the external MCU is the master and controls the sensor state via its POWERDOWN pin.

Alternatively, the sensor can manage its own power states. In no motion, it will cycle through IDLE and SLEEP modes automatically without any intervention from the MCU.

Therefore by using the sensor's automatic power management, the MCU can be fully switched OFF in the case of no motion allowing for extra power savings, and resulting in a very simple driver firmware design.

1.2.1 Manual power management via POWERDOWN pin

In this mode the chip is woken-up by de-asserting the POWERDOWN pin. When doing so both the analog and DCDC engines are woken up in a programmed sequence. The POWERDOWN pin can be de-asserted straight away as the sensor undergoes just a single frame sequence.

1.2.2 Automatic power management via internal timer

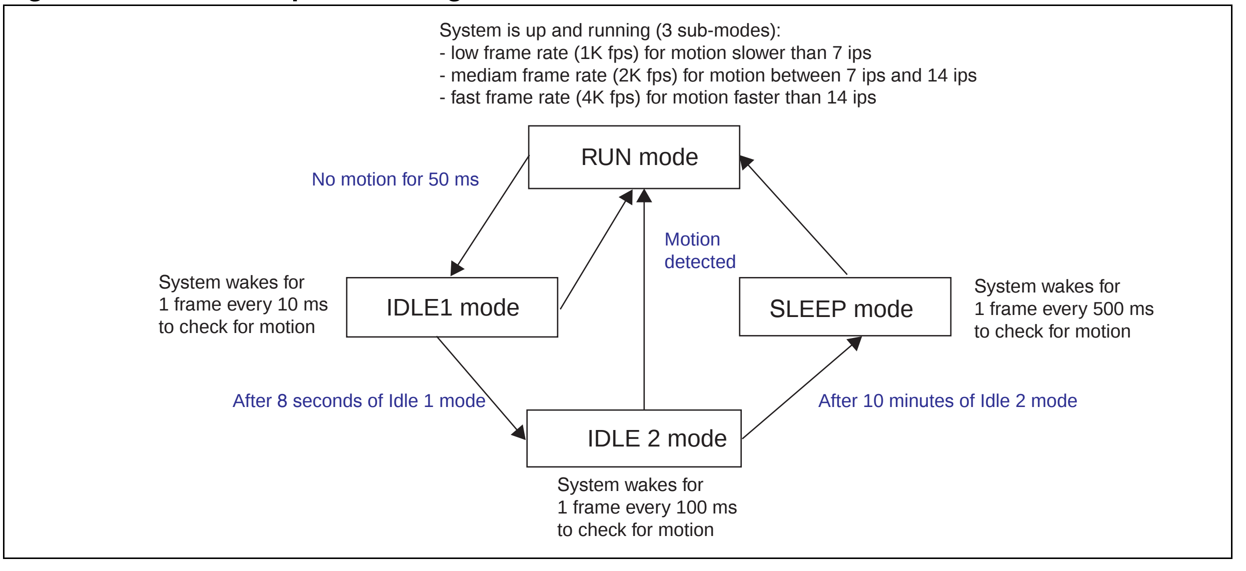
In this mode, after having written the initialization I2C command, the POWERDOWN pin must be left high at all times.

In running mode the motion engine operation is basically the same as above, however, in the case no motion (after a set time) the chip now has the ability to put itself to sleep for a determined period of time. This mode features the usual modes: RUNNING, IDLE1, IDLE2 and SLEEP, with on-chip preprogramming time constants (firmware).

In no motion it will in turn cycle to IDLE1/IDLE2 then SLEEP. In each of these modes, the behavior is a single frame operation, the RC timer is programmed to wake up for next period then the sensor goes to sleep.
The MOTION pin will go up if motion is ready for polling, here the sensor will remain in RUNNING mode until the host has polled ALL motion data.

In this automatic power management mode the external MCU can set itself to STDBY and just wait for the MOTION pin to come up, hence saving power in the no motion condition. This enables application MCU firmware to be simplified as much as possible.

Figure 2. Automatic power management



The VT5376 automatic power management has a 4 state power scheme - RUN, IDLE1, IDLE2 and SLEEP.

RUN mode is the mode where the whole system is up and running. This mode has 3 sub-modes, dependant on the mouse velocity: 1K fps (for motion slower than 7 ips), 2K fps (for motion between 7 ips and 14 ips) and 4K fps (for motion faster than 14 ips).
As long as there is motion the mouse will remain in this state.

After 5*0 ms* of mouse inactivity the mouse goes into the IDLE 1 mode. In this mode the system wakes up every *10 ms* for 1 frame and checks for motion; if the mouse has not moved the system automatically goes back to its low power state otherwise the system will go into RUN mode.

After 8 secs of IDLE 1 mode, the system then goes into IDLE 2 mode where it wakes up for 1 frame every 100 ms. After 10 mins of no activity the system then falls into SLEEP mode, which is exactly the same as the IDLE modes except that the system wakes up only every *500 ms* to check motion activity.

2 Power supply options and power consumption

The sensor includes a DCDC controller to supply the laser or the LED. This allows the overall sensor system to operate from a single AA or AAA battery supply voltage (from 1.6V down to 1V), allowing for a simple and low power / low cost system design. Two power supply schemes can be used.

2.1 Low cost application

The internal DCDC controller and voltage regulators are used so that the overall application can be supplied from a single AA/AAA battery cell, without the need of an extra DCDC chip. This approach is extremely economical.

Table 2. Power supply and power consumption

	Run			**IDLE1**[1]	**IDLE2**[2]	**SLEEP**[3]
	4,000fps	**2,000fps**	**1,000fps**			
Conditions	speed>14ips	7ips < speed < 14ips	7ips >speed	wake up latency 10ms	wake up latency 100ms	wake up latency 500ms
Total @Vtop chip + LED/laser	5.3mA	3mA	1.9mA	0.22mA	0.1mA	0.08mA
Total chip @Vbat	0.04mA	0.04mA	0.04mA	0.04mA	0.04mA	0.04mA

1. No motion for 50 ms
2. No motion for 8 seconds
3. No motion for 10 minutes

Note: 1 *DCDC efficiency from single battery cell to Vtop (typical 2.2V) is around 70%.*

2 *DCDC output maximum drive is 25mA total average, which should be sufficient for the overall application.*

2.2 External supply application

In this instance the internal DCDC controller and voltage regulators are turned off and bypassed, the sensor then needs to be supplied with a single regulated 1.8V.

Table 3. Power supply and power consumption

	Run			IDLE1(1)	IDLE2(2)	SLEEP(3)
	4,000fps	2,000fps	1,000fps			
Conditions	speed>14ips	7ips < speed < 14ips	7ips >speed	wake up latency 10ms	wake up latency 100ms	wake up latency 500ms
Total @Vtop/Vbat/Dvdd/ Avdd (1.8V) Chip + LED/laser	5.3mA	3mA	1.9mA	0.22mA	0.08mA	0.06mA

1. No motion for 50 ms
2. No motion for 8 seconds
3. No motion for 10 minutes

3 Electrical characteristics

3.1 Supply voltages (using DC/DC controller)

Table 4. Supply voltages using DC/DC controller

Symbol	Parameter	Min.	Typ.	Max.	Unit
VTOP	Boosted supply(1)	2.0	2.2	3.2	V
VBAT	Supply from single AA cell	1.0	1.25	2.0	V
AVDD	Analog supply(2)	1.7	1.8	2.0	V
DVDD	Digital core supply(2)	1.7	1.8	2.0	V

1. Value defined by resistors ratio
2. Internally generated

3.2 Supply voltages (direct drive, bypassing DC/DC controller)

Table 5. Supply voltage values (direct drive, bypassing DC/DC controller)

Symbol	Parameter	Min.	Typ.	Max.	Unit
VTOP	Boosted supply	1.7	1.8	2.0	V
VBAT	Supply from single AA cell	1.0	1.8	2.0	V
AVDD	Analog supply	1.7	1.8	2.0	V
DVDD	Digital core supply	1.7	1.8	2.0	V

3.3 Logic IO

Table 6. Digital IO electrical characteristics

Symbol	Parameter	Min.	Typ.	Max.	Unit
CMOS digital inputs					
V_{IL}	Low level input voltage	0V		0.3VDD	V
V_{IH}	High level input voltage	0.7VDD		5.5V	V
I_{IL}	Low level input current			-1	µA
I_{IH}	High level input current			1	µA
CMOS digital outputs					
V_{OL}	Low level output voltage (4mA load)			0.3VDD	V
V_{OH}	High level output voltage (4mA load)	0.7VDD			V

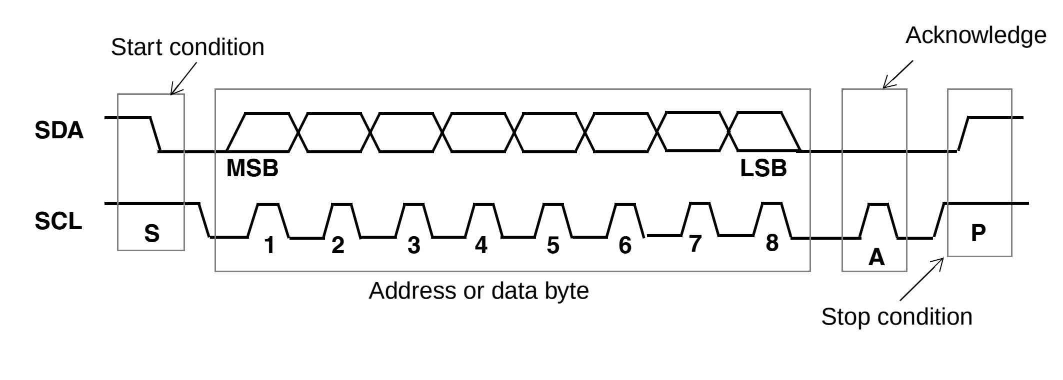
Note: All digital inputs/outputs are 1.8V capable, 5V tolerant.

4 Interface

The interface is 400 kHz I2C, with very fast polling rate for high CPI applications (down to 1 ms period).

4.1 Protocol

Figure 3. Serial interface data transfer protocol



4.2 Data format

Information is packed in 8-bit packets (bytes) always followed by an acknowledge bit. The internal data is produced by sampling *sda* at a rising edge of *scl*. The external data must be stable during the high period of *scl*. The exceptions to this are *start* (S) or *stop* (P) conditions when *sda* falls or rises respectively, while *scl* is high.

The first byte contains the device address byte which includes the data direction *read,* (r), *~write*, (~w), bit.

Figure 4. VT5376 serial interface address

0	0	1	0	0	0	0	R/W

The byte following the address byte contains the address of the first data byte (also referred to as the *index*).

4.3 Message interpretation

All serial interface communications with the sensor must begin with a *start* condition. If the *start* condition is followed by a valid address byte then further communications can take place. The sensor will acknowledge the receipt of a valid address by driving the *sda* wire low. The state of the *read/~write* bit (lsb of the address byte) is stored and the next byte of data, sampled from *sda,* can be interpreted.

During a write sequence the second byte received is an address index and is used to point to one of the internal registers. The serial interface will automatically increment the index address by one location after each slave acknowledge. The master can therefore send data bytes continuously to the slave until the slave fails to provide an acknowledge or the master terminates the write communication with a *stop* condition or sends a *repeated start*, *(Sr)*.

As data is received by the slave it is written bit by bit to a serial/parallel register. After each data byte has been received by the slave, an acknowledge is generated, the data is then stored in the internal register addressed by the current index.

During a read message, the content of the addressed register is then parallel loaded into the serial/parallel register and clocked out of the device by *scl.*

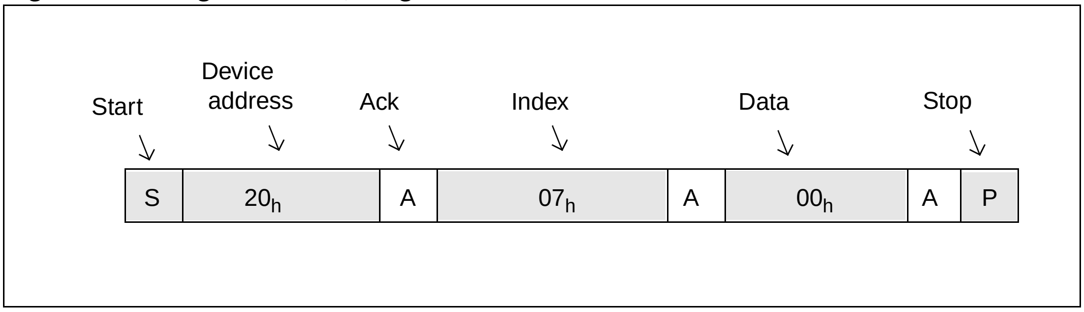
At the end of each byte, in both read and write message sequences, an acknowledge is issued by the receiving device. A message can only be terminated by the bus master, either by issuing a stop condition, a repeated start condition or by a negative acknowledge (NAck) after reading a complete byte during a read operation.

4.4 Type of messages

Single location, single data write

When a random value is written to the sensor, the message will look like this:

Figure 5. Single location, single write

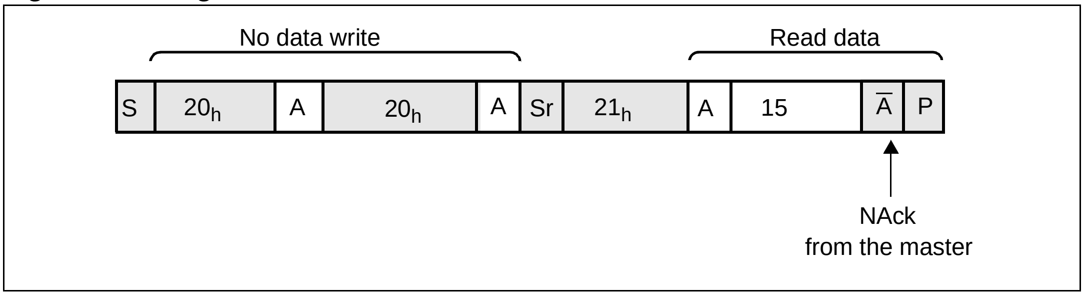


The r/w bit is set to zero for writing. The write message is terminated with a stop condition from the master.

Single location read

When a location is to be read, but the value of the stored index is not known, a write message with no data byte must be written first, specifying the index. The read message then completes the message sequence. To avoid relinquishing the serial to bus to another master a repeated start condition is asserted between the write and read messages.

Figure 6. Single read



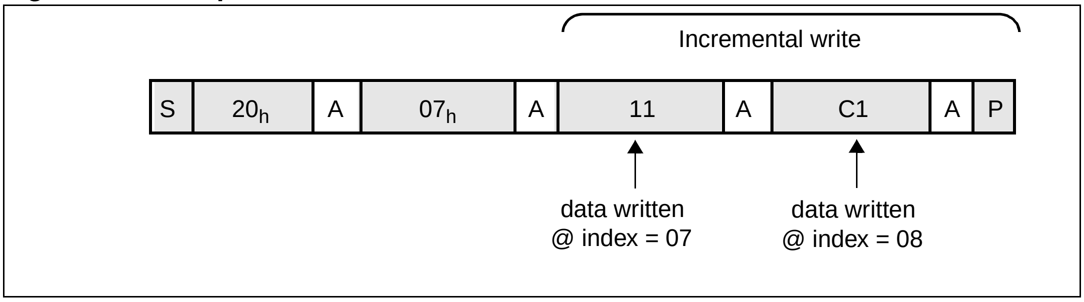
As mentioned in the previous example, the read message is terminated with a negative acknowledge ($\overline{A}$) from the master.

Multiple location write

It is possible to write data bytes to consecutive adjacent internal registers without having to send explicit indexes prior to sending each data byte.

Note: An auto-increment write is assumed if no stop condition occurs.

Figure 7. Multiple location write

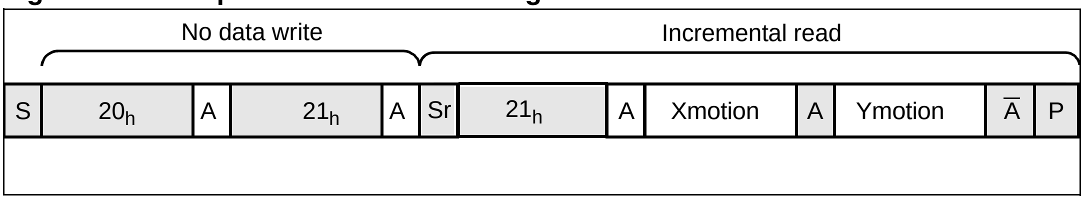


Multiple location read: reading motion value example

Multiple locations can be read within a single read message. An auto-increment write is assumed.

Note: Registers are read until the master Nacks the data.

Figure 8. Multiple location read: reading motion



5 I2C control register map

Table 7. I2C control register map

Address	Bits	Name	R/W	Default	Description
0x00	[7:0]	Device Hardware revision	RO	00h	HW revision: set by the mask set revision
0x01	[7:0]	Device Soft revision	RW	00h	FW revision: is updated every time internal firmware of minor revision is done.
0x05	[0]	Automatic Power management	RW	0h	When set, the device controls its own power mode state machine in no motion condition. If not set, POWERDOWN controls the state of the device (stdby/run)
	[1]	Laser Selected		0h	When set, the device sets all internal variables to optimize system for laser illumination. Also if set, LASER_OUT is active to direct drive a VCSEL, and LASER_NEN controls its power supply switch. If not set, LASER_NEN becomes the LED_ON signal, toggling at frame rate.
	[2]	Use External Supply		0h	1: The device switches its internal 1.8 V regulator off, and assumes 1.8 V will be supplied at all time onto Vtop, DVDD and AVDD. 0: Device uses internal regulators (Vtop must be set > 2.2 V)
	[3]	Host Config Done		0h	This bit must be set to 1 to indicate to the chip that the boot configuration of the sensor (mainly this register) is complete, and it can start motioning.
	[4]	Laser Fault Detect		0h	If set to 1, and if laser is selected (bit1), the device will undergo its own fault detection after host_config_done is asserted. If no fault detected, the device will start normally. Otherwise, the LASER_NEN signal will remain high, and the LASER_OUT will be inactive. In this case a power-up sequence is required to come out of this stdby mode.
	[5]	Led dac driven		0h	If set to 1, and the mice is set in LED mode, then the LED is direct driven by the internal DAC.

Table 7. I2C control register map (continued)

Address	Bits	Name	R/W	Default	Description
0x0A	[7]	Force LaserOUT ON	RW	0h	If set to 1, this sets the LASER_OUT DAC always ON (instead of toggling normally). This mode is provided in case the DAC current needs calibrating. To confirm this mode, register 0x0D will also need to be written to (complement data).
	[6:0]	DAC current setting		7Fh	Sets DAC current setting. To validate the setting, register 0x0D will also need to be written to (complement data). 0x7F: 3.4 mA 0x00: 10 mA
0x0D	[7]	Force LaserOUT ON (Compl)	RW	1h	If set to 0, this sets the LASER_OUT DAC always ON (instead of toggling normally). This mode is provided in case the DAC current needs calibrating. To confirm this mode, register 0x0A will also need to be written to (complement data).
	[6:0]	DAC current setting (Compl)		00h	Sets DAC current setting. To validate the setting, register 0x0A will also need to be written to (complement data). 0x00: 3.4mA 0x7F: 10mA
0x21	[7:0]	X_motion	RO		This register holds the overall X movement data since last polling was done. Value is 8 bit 2's complement.(1)
0x22	[7:0]	Y_motion	RO		This register holds the overall Y movement data since last polling was done. Value is 8 bit 2's complement.(1)
0x29	[7:0]	Min_features[13:6]	RW	0000_0100	This register represents the feature threshold below which motion is no longer valid (in this case, the device reports "0" motion). This is linked to the value reported in registers 0x31/0x32
0x2A	[7:0]	Scaling for X motion vectors	RW	0001_0000	Sets resolution as CPI: 8: 400 CPI 16: 800 CPI Assuming lens magnification of x0.5

Table 7. I2C control register map (continued)

Address	Bits	Name	R/W	Default	Description
0x2B	[7:0]	Scaling for Y motion vectors	RW	0001_0000	Sets resolution as CPI: 0x08: 400 CPI 0x10: 800 CPI Assuming lens magnification of x 0.5
0x31	[15:8]	Features count	RO		Feature count report: the higher the value, the more distinctive features the surface possess, for the motion detection machine to operate reliably.
0x32	[7:0]				
0x47	[7:0]	Vbat converted data	RO		This register holds the current converted data from the Vbat input voltage. The data range is as follows: 0000_0000: Vbat = 0.6 V 1111_1111: Vbat = 1.6 V The response is linear for each value in between, and ADC step are 1V/256 = 3.9mV
0x4F	[7:0]	Exp max value	RO		This registers holds the maximum pixel value (before CDS) for the current frame. It shows if some pixels are saturated or not.
0x61	[7:0]	IMAGE[7:0]	RO		This register contains the pixel value when image dump feature has been activated (with reg 0x62, bit 0). To read the 400 pixels from the captured frame, the register must be read 400 consecutive times,
0x62	[0]	Enable image dump mode	RW	0	If set to 1, the device will capture a single frame. When the frame is captured and ready to be downloaded via reg 0x60, bit 4 (image ready) is set.
	[2]	Image ready for download	RO	0	This bit is asserted when the captured image is ready to be downloaded via reg 0x60 read. When image download is complete, bit 3 and bit 4 are reset
	[3]	Image upload complete		o	This flag is set when all 400 pixels have been read by I2C host.

1. Internal ACCUMULATOR is reduced from this value every time it is read.

6 Laser

6.1 Direct laser drive and calibration

The sensor includes a 7-bit DAC and an output current source.

The DAC value must be set via two I2C commands after power-up (default is MIN = 3.4 mA, with Rbin = 12 K).

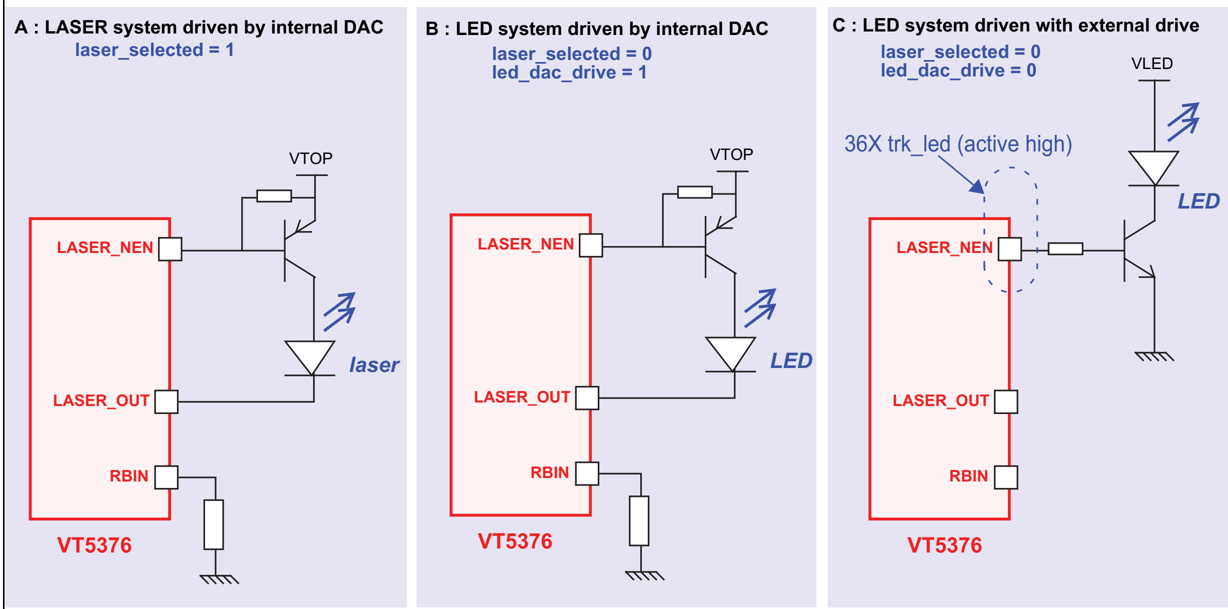
To allow VCSEL output power measurements to be done, the user can set the laser out (normally strobed during operation) to continuously on via an I2C command. This feature is optional and is designed to offer maximum flexibility.

Alternatively, the user may be satisfied with adjusting the external Rbin resistor to control the DAC current away from the nominal max value of 10mA (max 13mA). Rbin must be set to 12K nominally. Idac max is set by the formula:

Idac (max) = 120/Rbin (result in mA, Rbin in kohms)

No external driver is required, just a FET power switch controlled by LASER_NEN signal.

Figure 9. Application schematics using Laser or LED (driven with internal DAC or external current source)



6.2 Laser fault detection and safety feature

The sensor includes a set of self-diagnostics features at power-up. At power-up, it will successively perform the following tests:

- Measure Rbin, and check it's not shorted to GND (>0.4 V)
- Set LASER_OUT on (10 mA), and check LASER_OUT is not shorted to VDD (<1.2 V)
- Set LASER_OUT to VDD via internal resistor, and check LASER_OUT is not shorted to GND (>0.4V)

If any of the above conditions is not respected, the sensor will switch the LASER_OUT pad off, and assert LASER_NEN pin high, disconnecting the VCSEL from its supply.

7 General features

7.1 Device clocking

The device integrates its own oscillator. It does not require an external Xtal or resonator, instead it requires only an external capacitor of 33 pF. The accuracy of this cap will determine the accuracy of the internal clock. Ignoring the capacitor accuracy, the frequency will be accurate within10 % range.

7.2 Battery level monitoring

The device includes an 8-bit ADC that translates the VBAT voltage into an 8-bit value that can be read via I2C. The external MCU can upload this value and take any action required.

7.3 Resolution setting (counts/inch)

Due to accurate an on-chip interpolation process, the device operates below the pixel resolution. This enables the user to easily select any desired resolution via a simple register write.

Note: Different resolutions can be applied to X and Y, this could be useful in case of optical non-symmetry or distortion.

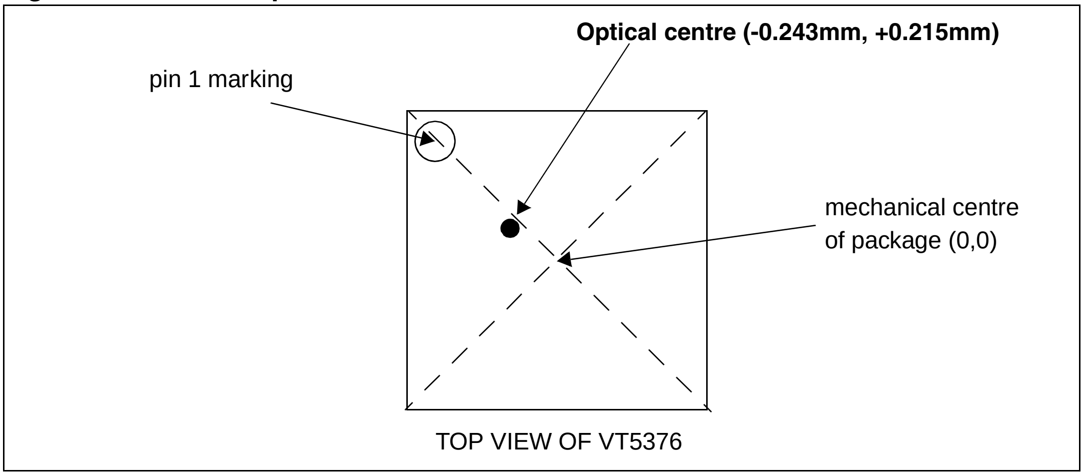
7.4 Image monitoring

It is possible to capture an image and download it via simple I2C write/read sequence. This is useful to calibrate optics during development or to perform basic tests.

7.5 Optical centre

The optical centre of the VT5376 is NOT in the centre of the package, it is offset by -0.243 mm in the X-axis and 0.215 mm in the Y axis with respect to the centre of the package as shown in *Figure 10*. The PCB designer must take this into account when laying out the PCB.

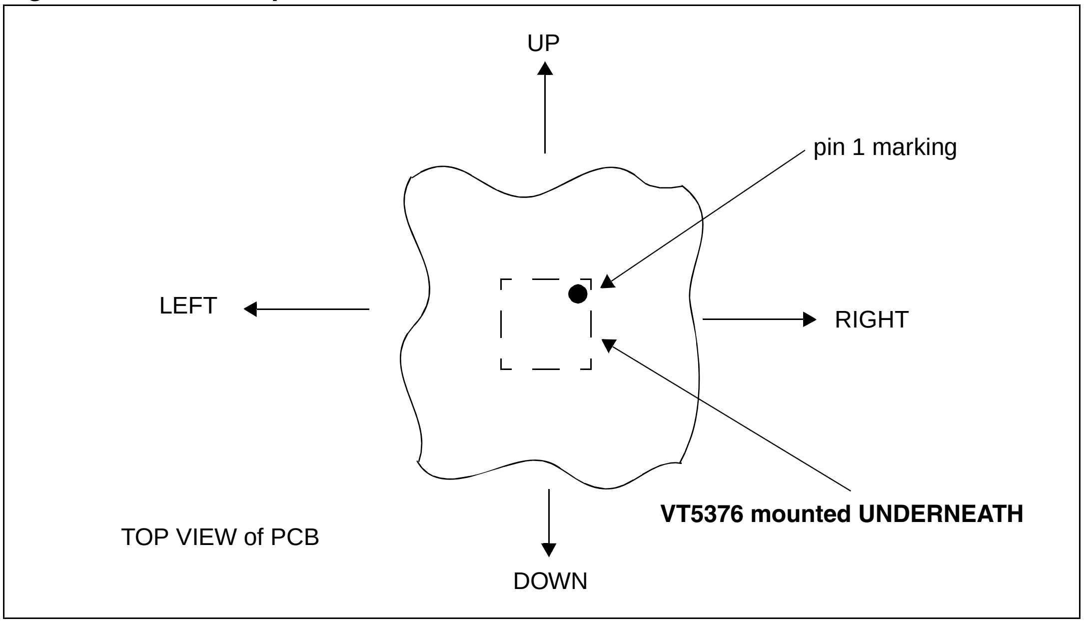
Figure 10. VT5376 optical centre



7.6 Sensor orientation on PCB

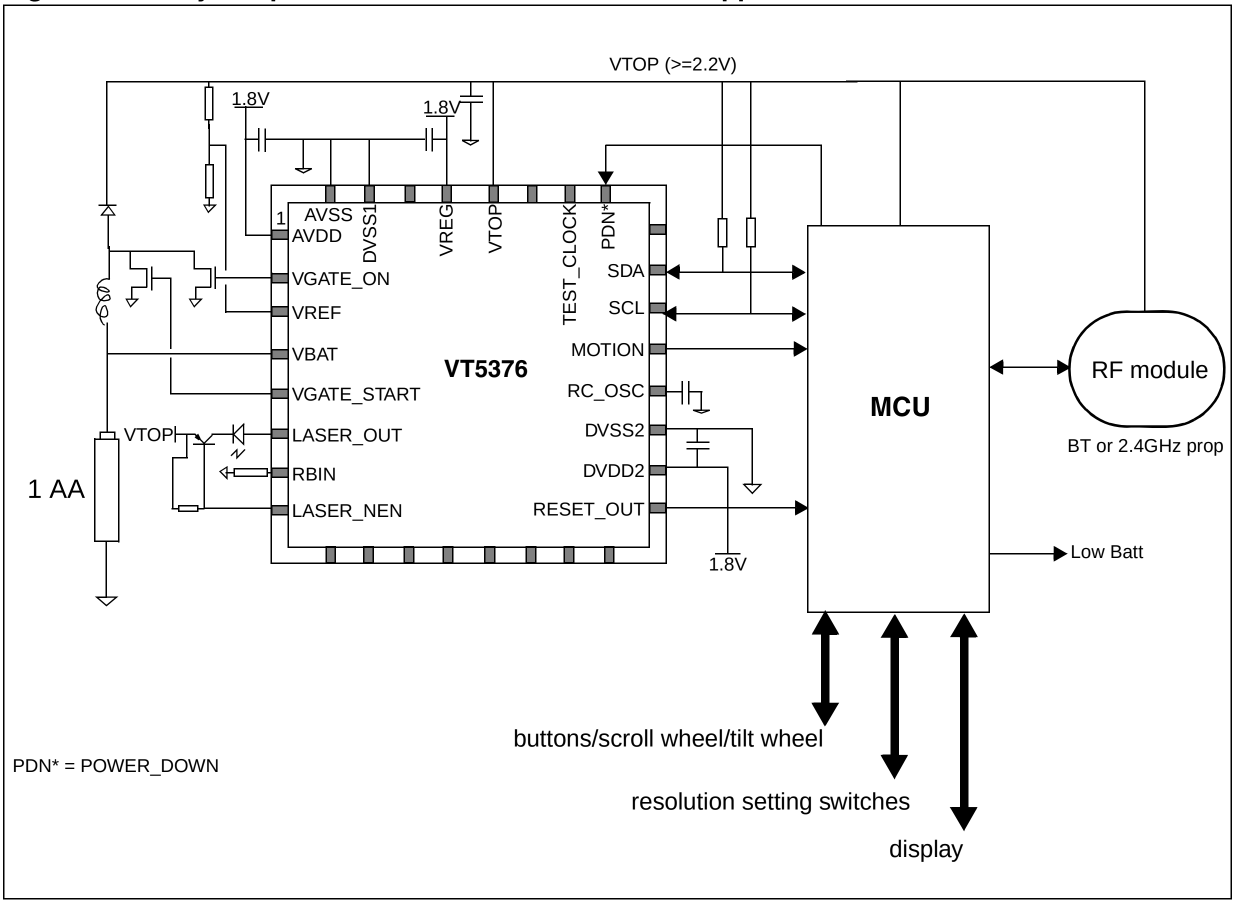
The VT5376 must be orientated correctly on the PCB in order to move the cursor in the correct directions when the mouse is moved. This is shown in *Figure 11*.

Figure 11. VT5376 optical centre



8 Typical application

Figure 12. Very low power and low cost wireless laser application



8.1 Overall 2.4GHz mouse power consumption example

Assumptions

- VCSEL, MCU and 2.4 GHz Tx operate from 2.2 V
- MCU consumes 1 mA in running mode and 50 uA in standby mode. In no motion period, it remains in standby until it receives an interrupt from the VT5376, indicating that MOTION has been detected.
- 2.4 GHz Tx consumes 10 mA, but data is sent by bursts of 500 µs every 5 ms (that is Nordic nRF2402).
- Maximum current is delivered to VCSEL (10 mA strobed).
- DCDC efficiency is 70%
- Ambient temperature

Table 8. Power supply and power consumption

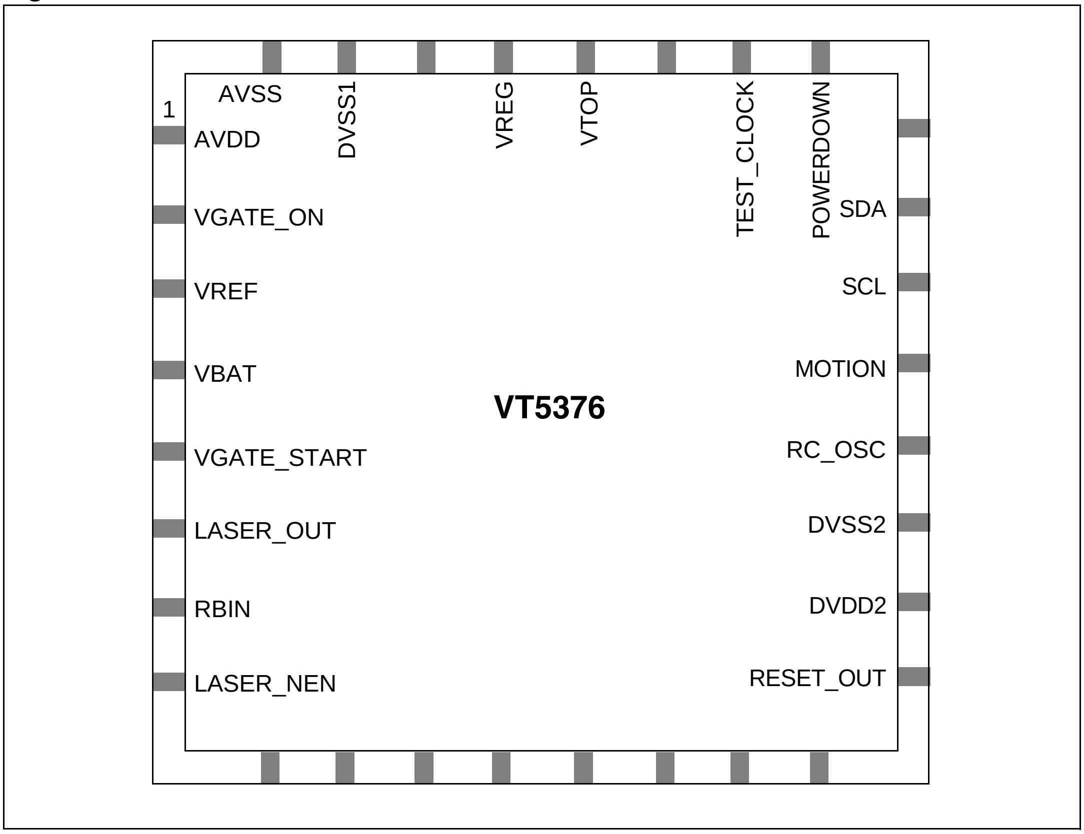
	Run			IDLE1(1)	IDLE2(2)	SLEEP(3)
	4,000 fps	2,000 fps	1,000 fps			
Total @Vbat (1.25 V)	18 mA	12 mA	9.3 mA	0.59 mA	0.29 mA	0.24 mA

1. No motion for 50 ms
2. No motion for 8 seconds
3. No motion for 10 minutes

Using STMicroelectronics battery life model, these values would enable the mouse to operate for 54 weeks from 2 AA batteries in parallel.

9 Pinout

Figure 13. Pinout



9.1 Pin description

Table 9. VT5376 pin description

Pin No.	Pin Name	Type	Description
1	AVDD	PWR	1.8 V regulated and analog supply
2	VGATE_ON	I/O	Digital IO (supplied by VTOP)
3	VREF	ANA	Analog ref input
4	VBAT	PWR	Single battery supply (0.9 Vto 2 V)
5	VGATE_START	ANA	Output (supplied by Vbat)
6	LASER_OUT	ANA	Laser drive set by internal DAC
7	RBIN	ANA	Set maximum laser/led current
8	LASER_NEN	I/O	Laser enable
17	RESET_OUT	I/O	Digital IO
18	DVDD2	PWR	1.8 V regulated and digital supply
19	DVSS2	PWR	Digital Ground
20	RC_OSC	ANA	6MHz Oscillator
21	MOTION	I/O	Digital IO
22	SCL	I/O	Digital IO
23	SDA	I/O	Digital IO
25	POWERDOWN	I/O	Digital IO
26	TEST_CLOCK	I/O	Digital IO
28	VTOP	PWR	Power supply for internal regulators
29	VREG	PWR	1.8 V regulated supply
31	DVSS1	PWR	Digital ground
32	AVSS	PWR	Analog ground

Note: All other pins are NOT CONNECTED

10 Ordering information

Table 10. Order code

Part number	Package	Packing
VT5376V032	TQFP 32 OPTO 7 mm x 7 mm x 1.4 mm	Tray

11 Revision history

Table 11. Document revision history

Date	Revision	Changes
27-Sep-2007	1	Initial release.