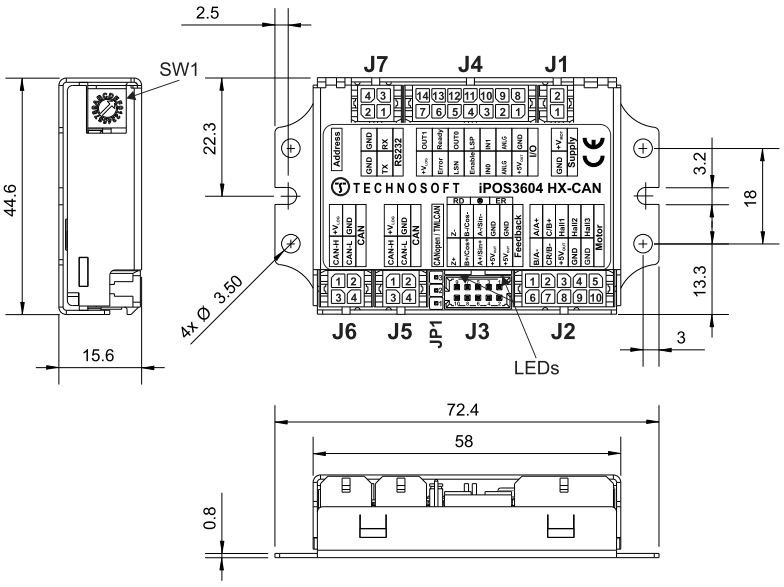



All dimensions are in mm.

| Motor – sensor configurations | | | | | |
|---|---|---|---|---|---|
| Sensor \ Motor | PMSM | BLDC | DC BRUSH | STEP (2-ph) | STEP (3-ph) |
| Incr. Encoder | ✓ | | ✓ | ✓ | |
| Incr. Encoder + Hall | ✓ | ✓ | | | |
| Analog Sin/Cos encoder | ✓ | | | | |
| Tacho | | | ✓ | | |
| Open-loop (no sensor) | | | | ✓ | ✓ |

**Mating Connector**

| Producer | Part No. | Connector | Description | Wire Gauge |
|---|---|---|---|---|
| MOLEX | 43025-0200 | J1 | MICROFIT RECEPTACLE HOUSING, 2x1 WAY | AWG 20..24 |
| MOLEX | 43025-0400 | J5,J6,J7 | MICROFIT RECEPTACLE HOUSING, 2x2 WAY | AWG 20..24 |
| MOLEX | 43025-1000 | J2 | MICROFIT RECEPTACLE HOUSING, 2x5 WAY | AWG 20..24 |
| MOLEX | 43025-1400 | J4 | MICROFIT RECEPTACLE HOUSING, 2x7 WAY | AWG 20..24 |
| MOLEX | 43030-0007 | J1,J2,J4,J5,J6,J7 | CRIMP PIN, MICROFIT, 5A | AWG 20..24 |
| MOLEX | 51110-1056 | J3 | MILLIGRID RECEPTACLE HOUSING, 2x5 WAY | AWG 24..30 |
| MOLEX | 50394-8400 | J3 | CRIMP PIN, MILLIGRID | AWG 24..30 |

## Features

- Motor supply: 9-36V. Optional logic supply: 9-36V
- Output current: 4A cont. (BLDC mode); $10A_{PEAK}$ , up to 100KHz PWM
- Digital Hall sensor interface (single-ended and open collector)
- Incremental encoder interface (single-ended, open collector and differential)
- Analogue sin/cos encoder interface (differential $1V_{pp}$)
- 5 digital inputs, 5-36V, PNP or NPN software selectable: Enable, 2 for limit switches, 2 general-purpose
- 4 digital outputs, 5-36V, 0.5A, NPN open-collector: Ready, Error, 2 general-purpose
- 1 analogue input: 12-bit, 0-5V: Reference or feedback or general purpose
- RS-232 serial & CAN-bus 2.0B interfaces with H/W selectable addresses
- TMLCAN and CANopen (CiA 301 v4.2 and CiA 402 v3.0) protocols selectable by jumper
- 2K × 16 SRAM for data acquisition
- 4K × 16 $E^2$ROM to store TML motion programs and data
- Operating ambient temperature: 0-40°C (over 40°C with derating)
- Hardware Protections: short-circuit between motor phases and from motor phases to GND, over-voltage, under-voltage and $I^2t$
- Firmware: F508M+ or F523E+

## Connector Description

| | Pin | Name | Type | Description |
|---|---|---|---|---|
| J1 | 1 | GND | - | Negative return (ground) of the power supply |
| | 2 | $+V_{MOT}$ | I | Positive terminal of the motor supply: 9 to $36V_{DC}$ / Positive terminal of the internal logic supply if J4 pin 7 not connected (I/Os work only when J4 pin 7 is connected) |

| | Pin | Name | Type | Description |
|---|---|---|---|---|
| J2 | 1 | A/A+ | O | **Phase A** for 3-ph motors, A+ for 2-ph steppers, Motor+ for DC brush motors |
| | 2 | C/B+ | O | **Phase C** for 3-ph motors, B+ for 2-ph steppers |
| | 3 | Hall 1 | I | Digital input Hall 1 sensor |
| | 4 | Hall 2 | I | Digital input Hall 2 sensor |
| | 5 | Hall 3 | I | Digital input Hall 3 sensor |
| | 6 | B/A- | O | **Phase B** for 3-ph motors, A- for 2-ph steppers, Motor- for DC brush motors |
| | 7 | CR/B- | O | **Chopping resistor / Phase B-** for step motors |
| | 8 | $+5V_{OUT}$ | O | 5V output supply - internally generated |
| | 9 | GND | - | Negative return (ground) of the motor supply |
| | 10 | GND | - | Negative return (ground) of the motor supply |

| | Pin | Name | Type | Description |
|---|---|---|---|---|
| J3 | 1 | GND | - | Return ground for sensors supply |
| | 2 | $+5V_{OUT}$ | O | 5V output supply for I/O usage |
| | 3 | GND | - | Return ground for sensors supply |
| | 4 | $+5V_{OUT}$ | O | 5V output supply for I/O usage |
| | 5 | A- /Sin- | I | Incr. encoder A- diff. input, or analogue encoder Sin- diff. input |
| | 6 | A+/Sin+ | I | Incr. encoder A+ diff. input, or analogue encoder Sin+ diff. input |
| | 7 | B-/Cos- | I | Incr. encoder B- diff. input, or analogue encoder Cos- diff. input |
| | 8 | B+/Cos+ | I | Incr. encoder B+ diff. input, or analogue encoder Cos+ diff. input |
| | 9 | Z- | I | Incr. encoder Z- diff. input, |
| | 10 | Z+ | I | Incr. encoder Z+ (index) diff. input |

| | Pin | Name | Type | Description |
|---|---|---|---|---|
| J4 | 1 | **+5V$_{OUT}$** | **O** | 5V output supply for I/O usage |
| | 2 | **ANLG** | **I** | Analogue input, 12-bit, 0-5V. Used to read an analog position, speed or torque reference, or an analogue position or speed feedback or as general purpose analogue input |
| | 3 | **IN0** | **I** | 5-36V general-purpose digital PNP/NPN input |
| | 4 | **IN4/Enable** | **I** | 5-36V digital PNP input. Drive enable input |
| | 5 | **IN3/LSN** | **I** | 5-36V digital PNP input. Negative limit switch input |
| | 6 | **OUT2/Error** | **O** | 5-36V 0.5A, drive Error output, active low, NPN open-collector/TTL pull-up. Also drives the red LED |
| | 7 | **+V$_{LOG}$**[1] | **I** | Positive terminal of the logic supply for inputs and outputs operation: 9 to 36V$_{DC}$ |
| | 8 | **GND** | - | Return ground for I/O pins |
| | 9 | **ANLG** | **I** | Analogue input, 12-bit, 0-5V. Used to read an analog position, speed or torque reference, or an analogue position or speed feedback or as general purpose analogue input |
| | 10 | **IN1** | **I** | 5-36V general-purpose digital PNP/NPN input |
| | 11 | **IN2/LSP** | **I** | 5-36V digital PNP/NPN input. Positive limit switch input |
| | 12 | **OUT0** | **O** | 5-36V 0.5A, general-purpose digital output, NPN open-collector/TTL pull-up |
| | 13 | **OUT3/Ready** | **O** | 5-36V 0.5A, drive Ready output, active low, NPN open-collector/TTL pull-up. Also drives the green LED. |
| | 14 | **OUT1** | **O** | 5-36V 0.5A, general-purpose digital output, NPN open-collector/TTL pull-up |

| | Pin | Name | Type | Description |
|---|---|---|---|---|
| J5, J6 | 1 | **+V$_{LOG}$** | **O** | Positive terminal of the logic supply: 9 to 36V$_{DC}$ |
| | 2 | **GND** | - | Return ground for CAN-Bus |
| | 3 | **Can-Hi** | **I/O** | CAN-Bus positive line (dominant high) |
| | 4 | **Can-Lo** | **I/O** | CAN-Bus negative line (dominant low) |

| | Pin | Name | Type | Description |
|---|---|---|---|---|
| J7 | 1 | **232TX** | O | RS-232 Data Transmission |
| | 2 | **GND** | - | Return ground for RS-232 pins |
| | 3 | **232RX** | I | RS-232 Data Reception |
| | 4 | **GND** | - | Return ground for RS-232 pins |

## Electrical characteristics

All parameters measured under the following conditions (unless otherwise specified):

- Tamb = 0…40ºC, VLOG = 24 VDC; VMOT = 36VDC
- Supplies start-up / shutdown sequence: -any-
- Load current (sinusoidal amplitude / continuous BLDC, DC, stepper) = 4A

| **Operating Conditions** | | **Min.** | **Typ.** | **Max.** | **Units** |
|---|---|---|---|---|---|
| Ambient temperature[2] | | 0 | | +40 | ºC |
| Ambient humidity | Non-condensing | 0 | | 90 | %Rh |
| Altitude / pressure[3] | Altitude (vs. sea level) | -0.1 | 0 ÷ 2.5 | [2] | Km |
| | Ambient Pressure | 0 [2] | 0.75 ÷ 1 | 10.0 | atm |
| **Storage Conditions** | | **Min.** | **Typ.** | **Max.** | **Units** |
| Ambient temperature | | -40 | | +85 | ºC |
| Ambient humidity | Non-condensing | 0 | | 100 | %Rh |
| Ambient Pressure | | 0 | | 10.0 | atm |
| **Mechanical Mounting** | | **Min.** | **Typ.** | **Max.** | **Units** |
| Airflow | | natural convection[4], closed box | | | |

| **Environmental Characteristics** | | **Min.** | **Typ.** | **Max.** | **Units** |
|---|---|---|---|---|---|
| Size ( Length x Width x Height ) | Without mating connectors | 72.4 x 44.6 x 15.6 | | | mm |
| | | ~2.85 x 1.76 x 0.61 | | | inch |
| Weight | Without mating connectors | 48 | | | g |
| Power dissipation | Idle (no load) | | 1 | | W |
| | Operating | | 3 | 5 | |
| Efficiency | | | 98 | | % |
| Cleaning agents | Dry cleaning is recommended | Only Water- or Alcohol- based | | | |
| Protection degree | According to IEC60529, UL508 | IP20 | | | - |

| **Logic Supply Input (+V$_{LOG}$)** | | | **Min.** | **Typ.** | **Max.** | **Units** |
|---|---|---|---|---|---|---|
| Supply voltage | Nominal values | | 9 | | 36 | V$_{DC}$ |
| | Absolute maximum values, drive operating but outside guaranteed parameters | | 5.9 | | 39 | V$_{DC}$ |
| | Absolute maximum values, continuous | | 0 | | 39 | V$_{DC}$ |
| | Absolute maximum values, surge (duration ≤ 10ms) † | | 0 | | +45 | V |
| Supply current | No Load on Digital Outputs | +V$_{LOG}$ = 9V | | 125 | 300 | mA |
| | | +V$_{LOG}$ = 12V | | 80 | 200 | |
| | | +V$_{LOG}$ = 24V | | 50 | 125 | |
| | | +V$_{LOG}$ = 39V | | 40 | 100 | |

| **Motor Supply Input (+V$_{MOT}$)** | | **Min.** | **Typ.** | **Max.** | **Units** |
|---|---|---|---|---|---|
| Supply voltage | Nominal values | 9 | | 36 | V$_{DC}$ |
| | Absolute maximum values, drive operating but outside guaranteed parameters | 8.5 | | 40 | V$_{DC}$ |
| | Absolute maximum values, continuous | 0 | | 42 | V$_{DC}$ |
| | Absolute maximum values, surge (duration ≤ 10ms) † | 0 | | +45 | V |
| Supply current | Idle | | 1 | 5 | mA |
| | Operating | -10 | ±4 | +10 | A |
| | Absolute maximum value, short-circuit condition (duration ≤ 10ms) † | | | 15 | A |

| **Motor Outputs (A/A+, B/A-, C/B+, CR/B-)** | | **Min.** | **Typ.** | **Max.** | **Units** |
|---|---|---|---|---|---|
| Nominal output current, continuous | for DC brushed, steppers and BLDC motors with Hall-based trapezoidal control | | | 4 | A |
| | for PMSM motors with FOC sinusoidal control (sinusoidal amplitude value) | | | 4 | |
| | for PMSM motors with FOC sinusoidal control (sinusoidal effective value) | | | 2.82 | |
| Motor output current, peak | maximum 2.5s | -10 | | +10 | A |
| Short-circuit protection threshold | measurement range | | ±13 | ±15 | A |
| Short-circuit protection delay | | 5 | 10 | | µs |
| On-state voltage drop | Nominal output current; including typical mating connector contact resistance | | ±0.3 | ±0.5 | V |
| Off-state leakage current | | | ±0.5 | ±1 | mA |

| Motor inductance (phase-to-phase) | | F$_{PWM}$ | | | | |
|---|---|---|---|---|---|---|
| | Recommended value, for current ripple max. ±5% of full range; +V$_{MOT}$ = 36 V | 20 kHz | 250 | | | µH |
| | | 40 kHz | 120 | | | |
| | | 60 kHz | 100 | | | |
| | | 80 kHz | 60 | | | |
| | | 100 kHz | 45 | | | |
| | Minimum value, limited by short-circuit protection; +V$_{MOT}$ = 36 V | 20 kHz | 75 | | | µH |
| | | 40 kHz | 25 | | | |
| | | 60 kHz | 20 | | | |
| | | 80 kHz | 10 | | | |
| | | 100 kHz | 5 | | | |

[1] If +V$_{LOG}$ (J4 pin7) is not connected, the digital outputs and inputs will not be operational.
[2] Operating temperature can be extended up to **+65ºC** with reduced current and power ratings.
[3] iPOS360x can be operated in vacuum (no altitude restriction), but at altitudes over 2,500m, current and power rating are reduced due to thermal dissipation efficiency.
[4] It is recommended to mount the iPOS3604 HX-CAN on a metallic support using the provided mounting holes, for better reliability and reduced de-rating due to heat dissipation

| | | | | | | |
|---|---|---|---|---|---|---|
| Motor electrical time-constant (L/R) | Recommended value for ±5% current measure-ment error | 20 kHz | 250 | | | µs |
| | | 40 kHz | 125 | | | |
| | | 60 kHz | 100 | | | |
| | | 80 kHz | 63 | | | |
| | | 100 kHz | 50 | | | |
| Current measurement | FS = Full Scale accuracy | | | ±4 | ±8 | %FS |
| **Digital Inputs (IN0, IN1, IN2/LSP, IN3/LSN, IN4/Enable)** | | | **Min.** | **Typ.** | **Max.** | **Units** |
| Mode compliance | | | PNP | | | |
| Default state | Input floating (wiring disconnected) | | Logic LOW | | | |
| Input voltage | Logic “LOW” | | | 0 | 1.6 | V |
| | Logic “HIGH” | | 1.8 | 24 | 39 | |
| | Floating voltage (not connected) | | | 0 | | |
| | Absolute maximum, continuous | | -10 | | +39 | |
| | Absolute maximum, surge (duration ≤ 1s) † | | -20 | | +40 | |
| Input current | Logic “LOW”; pulled to GND | | | 0 | 0 | mA |
| | Logic “HIGH” | | | 2.9 | 3.4 | |

| | | | | | |
|---|---|---|---|---|---|
| Mode compliance | | NPN/ TTL / CMOS / LVTTL (3.3V) / Open-collector | | | |
| Default state | Input floating (wiring disconnected) | Logic HIGH | | | |
| Input voltage | Logic “LOW” | 2 | 5÷24 | | V |
| | Logic “HIGH” | | 3 | | |
| | Floating voltage (not connected) | -10 | | +30 | |
| | Absolute maximum, continuous | -20 | | +40 | |
| | Absolute maximum, surge (duration ≤ 1s) † | 2 | 5÷24 | | |
| Input current | Logic “LOW”; Pulled to GND | | 0.6 | 1 | mA |
| | Logic “HIGH”; Internal 4.7KΩ pull-up to +3.3 | 0 | 0 | 0 | |
| | Logic “HIGH”; Pulled to +5V | | 0.15 | 0.2 | |
| | Logic “HIGH”; Pulled to +24V | | 2 | 2.5 | |

| | | | | | |
|---|---|---|---|---|---|
| Input frequency | | 0 | | 150 | kHz |
| Minimum pulse | | 3.3 | | | µs |
| ESD protection | Human body model | ±5 | | | kV |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Digital Outputs (OUT0, OUT1, OUT2/Error, OUT3/ Ready)** | | | **Min.** | **Typ.** | **Max.** | **Units** |
| Mode compliance | All outputs (OUT0, OUT1, OUT2/Error, OUT3/Ready) | | TTL / CMOS / Open-collector / NPN 24V | | | |
| Default state | Not supplied (+$V_{LOG}$ floating or to GND) | | High-Z (floating) | | | |
| | Immediately after power-up | OUT0, OUT1 | Logic “HIGH” | | | |
| | | OUT2/Error, OUT3/ Ready | Logic “LOW” | | | |
| | Normal operation | OUT0, OUT1, OUT2/Error | Logic “HIGH” | | | |
| | | OUT3/Ready | Logic “LOW” | | | |
| Output voltage | Logic “LOW”; output current = 0.5A | | | 0.2 | 0.8 | V |
| | Logic “HIGH”; output current = 0, no load | OUT2/Error, OUT3/ Ready | 2.9 | 3 | 3.3 | |
| | | OUT0, OUT1 | 4 | 4.5 | 5 | |
| | Logic “HIGH”, external load to +$V_{LOG}$ | | | $V_{LOG}$ | | |
| | Absolute maximum, continuous | | -0.5 | | $V_{LOG}$+0.5 | |
| | Absolute maximum, surge (duration ≤ 1s) † | | -1 | | $V_{LOG}$+1 | |

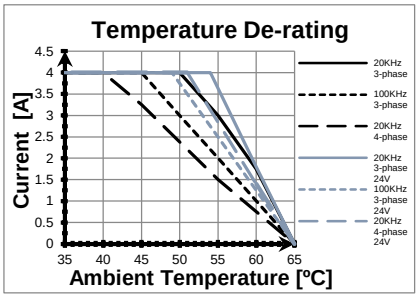
| | | | | | | |
|---|---|---|---|---|---|---|
| Output current | Logic “LOW”, sink current, continuous | | | | 0.5 | A |
| | Logic “LOW”, sink current, pulse ≤ 5 sec. | | | | 1 | A |
| | Logic “HIGH”, source current; external load to GND; $V_{OUT}$ >= 2.0V | OUT2/Error, OUT3/ Ready | | | 2 | mA |
| | | OUT0, OUT1 | | | 4 | mA |
| | Logic “HIGH”, leakage current; external load to +$V_{LOG}$; $V_{OUT}$ = $V_{LOG}$ max = 40V | | | 0.1 | 0.2 | mA |
| Minimum pulse width | | | 2 | | | µs |
| ESD protection | Human body model | | ±15 | | | kV |
| **Digital Hall Inputs (Hall1, Hall2, Hall3)** | | | **Min.** | **Typ.** | **Max.** | **Units** |
| Mode compliance | | | TTL / CMOS / Open-collector | | | |
| Default state | Input floating (wiring disconnected) | | Logic HIGH | | | |
| Input voltage | Logic “LOW” | | | 0 | 0.8 | V |
| | Logic “HIGH” | | 2 | 5 | | |
| | Floating voltage (not connected) | | | 4.4 | | |
| | Absolute maximum, surge (duration ≤ 1s) † | | -10 | | +15 | |
| Input current | Logic “LOW”; Pull to GND | | | | 1.2 | mA |
| | Logic “HIGH”; Internal 4.7KΩ pull-up to +5 | | 0 | 0 | 0 | |
| Minimum pulse width | | | 2 | | | µs |
| ESD protection | Human body model | | ±5 | | | kV |
| **Encoder Inputs (A/A+, A-, B/B+, B-, Z/Z+, Z)** | | | **Min.** | **Typ.** | **Max.** | **Units** |
| Differential mode compliance | For full RS422 compliance, see [1] | | TIA/EIA-422-A | | | |
| Input voltage, differential mode | Hysteresis | | ±0.06 | ±0.1 | ±0.2 | V |
| | Common-mode range (A+ to GND, etc.) | | -7 | | +7 | |
| Input impedance, differential | A+ to A-, B+ to B- | | 4.2 | 4.7 | | kΩ |
| | Z+ to Z- | | 6.1 | 7.2 | | |
| Input frequency | Single-ended mode, Open-collector / NPN | | 0 | | 500 | kHz |
| | Differential mode, or Single-ended driven by push-pull (TTL / CMOS) | | 0 | | 10 | MHz |
| Minimum pulse width | Single-ended mode, Open-collector / NPN | | 1 | | | µs |
| | Differential mode, or Single-ended driven by push-pull (TTL / CMOS) | | 50 | | | ns |
| Input voltage, any pin to GND | Absolute maximum values, continuous | | -7 | | +7 | V |
| Input voltage, any pin to GND | Absolute maximum, surge (duration ≤ 1s) † | | -11 | | +14 | V |
| ESD protection | Human body model | | ±1 | | | kV |
| **Sin-Cos Encoder Inputs (Sin+, Sin-, Cos+, Cos-)** | | | **Min.** | **Typ.** | **Max.** | **Units** |
| Input voltage, differential | Sin+ to Sin-, Cos+ to Cos- | | | 1 | 1.25 | $V_{PP}$ |
| Input voltage, any pin to GND | Operational range | | -1 | 2.5 | 4 | V |
| | Absolute maximum values, continuous | | -7 | | +7 | |
| | Absolute maximum, surge (duration ≤ 1s) † | | -11 | | +14 | |
| Input impedance | Differential, Sin+ to Sin-, Cos+ to Cos- [2] | | 4.2 | 4.7 | | kΩ |
| | Common-mode, to GND | | | 2.2 | | kΩ |
| Resolution with interpolation | Software selectable, for one sine/cosine period | | 2 | | 10 | bits |
| Frequency | Sin-Cos interpolation | | 0 | | 450 | kHz |
| | Quadrature, no interpolation | | 0 | | 10 | MHz |
| ESD protection | Human body model | | ±1 | | | kV |

[1] For full RS-422 compliance, 120Ω termination resistors must be connected across the differential pairs, as close as possible to the drive input pins.

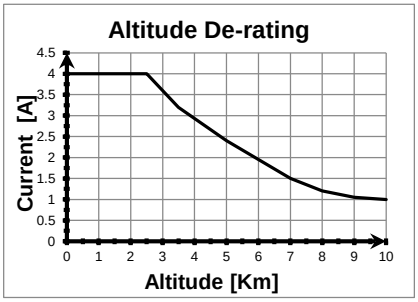
[2] For many applications, an 120Ω termination resistor should be connected across SIN+ to SIN-, and across COS+ to COS-. Please consult the feedback device datasheet for confirmation.

| Analog 0…5V Input (ANLG) | | Min. | Typ. | Max. | Units |
|---|---|---|---|---|---|
| Input voltage | Operational range | 0 | | 4.95 | V |
| | Absolute maximum values, continuous | -12 | | +18 | |
| | Absolute maximum, surge (duration ≤ 1s) † | | | ±36 | |
| Input impedance | To GND | | 30 | | kΩ |
| Resolution | | | 12 | | bits |
| Integral linearity | | | | ±2 | bits |
| Offset error | | | ±2 | ±10 | bits |
| Gain error | | | ±1% | ±3% | % FS[1] |
| Bandwidth (-3dB) | Software selectable | 0 | | 1 | kHz |
| ESD protection | Human body model | ±5 | | | kV |
| **RS-232** | | **Min.** | **Typ.** | **Max.** | **Units** |
| Compliance | | TIA/EIA-232-C | | | |
| Bit rate | Software selectable | 9600 | | 115200 | Baud |
| Short-circuit | 232TX short to GND | Guaranteed | | | |
| ESD protection | Human body model | ±2 | | | kV |
| **CAN-Bus** | | **Min.** | **Typ.** | **Max.** | **Units** |
| Compliance | | ISO11898, CiA-301v4.2 , 402v3.0 | | | |
| Bit rate | Software selectable | 125 | | 1000 | Kbps |
| Bus length | 1Mbps | | | 25 | m |
| | 500Kbps | | | 100 | |
| | ≤ 250Kbps | | | 250 | |
| Resistor | Between CAN-Hi, CAN-Lo | none on-board | | | |
| Node addressing | Hardware: by Hex switch | 1-15 & 255 | | | |
| | Software | 1 ÷ 127; 255 (CANopen); 1- 255 (TMLCAN) | | | |
| ESD protection | Human body model | ±15 | | | kV |
| **Supply Output (+5V)** | | **Min.** | **Typ.** | **Max.** | **Units** |
| Output voltage | Current sourced = 250mA | 4.8 | 5 | 5.2 | V |
| Output current | | 250 | 350 | | mA |
| Short-circuit | | NOT protected | | | |
| Over-voltage | | NOT protected | | | |
| ESD protection | Human body model | ±1 | | | kV |
| **Conformity** | | **Min.** | **Typ.** | **Max.** | **Units** |
| EU Declaration | | 2014/30/EU (EMC), 2014/35/EU (LVD), 2011/65/EU (RoHS), 1907/2006/EC (REACH), 93/68/EEC (CE Marking Directive), EC 428/2009 (non dual-use item, output frequency limited to 590Hz) | | | |

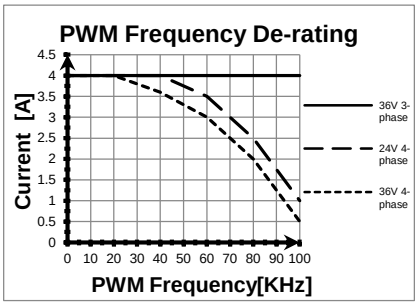
† Stresses beyond values listed under “absolute maximum ratings” may cause permanent damage to the device. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.



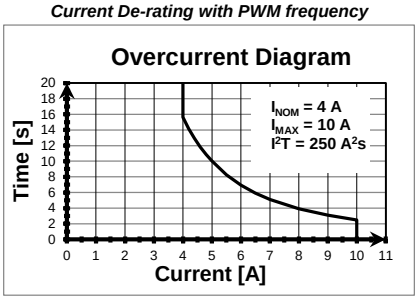

*De-rating with ambient temperature*



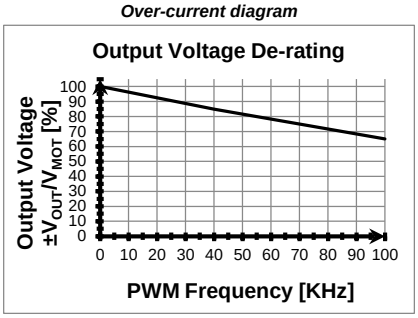

*De-rating with altitude*




*Current De-rating with PWM frequency*




*Over-current diagram*




*Output Voltage De-rating with PWM frequency[2]*

[1] “FS” stands for “Full Scale”
[2] $V_{OUT}$ – the output voltage, $V_{MOT}$ – the motor supply voltage