Operator's Manual

Hunter Electronic Speed Controller

Board Version V2
Software Version V7

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Overview

The Hunter Electronic Speed Controller (ESC) is a brushless DC motor drive designed to evaluate the Feed Forward Control motor control software for permanent magnet motors. The ESC is designed to drive a 3-phase brushless DC motor from a 12-24V DC supply. Suitable motors for the drive are three phase brushless DC motors up to 20A rated current.

There are two boards mounted back to back. One is the control board containing a microcontroller and gate drive IC's. The other is the power board containing six power MOSFETs and two current sensor ICs. These are illustrated in Figure 1.

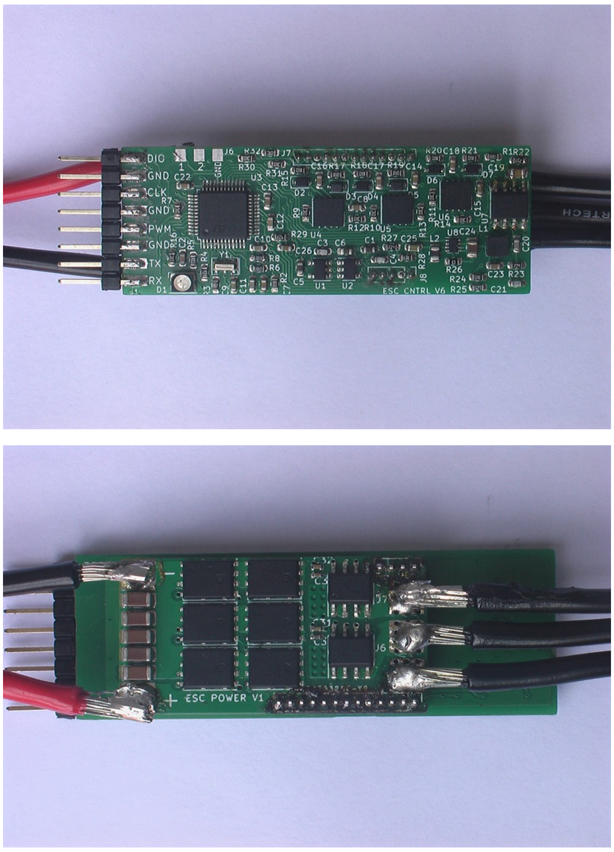


Figure 1. ESC front and back boards.

Special Note

The motor drive boards and the included software are experimental and under continuous development.

Some features have yet to be added.

Also, rigorous testing with different motors and loads has not been undertaken.

It would be appreciated if any shortcomings found by the user could be conveyed to the developer so they can be corrected in future versions.

Known Problems

The controller is sensitive to unbalanced motor phases due to, for instance, winding errors or excessive resistance in one phase. This will cause rough running at low speeds and in extreme cases cause unstable operation at standstill. Solution is to check motor connections and motor winding resistances.

The supplied USB to TTL RS232 cable and converter sometimes freezes probably due to noise. The solution is to unplug and replug J1, pin 1 (RX) connection.

Board Connections

The control board connections clockwise from the bottom left corner are as follows:

J1 TTL RS232, Pulse input and Software Debug

1: RX for TTL RS232
2: TX for TTL RS232
3: Ground
4: PWM/DShot input
5: Ground
6: Debug SWCLK
7: Ground
8: Debug SWDIO

J6 Test Port and Firmware Loader Boot

1: Test Pin 1
2: Test Pin 2 and Firmware Loader Boot (when grounded on power up)
3: Ground

The power board connections are as follows:

Left: DC Power Input

12-24VDC + and - inputs.

Right: Motor Connections

U, V and W 3-phase motor connections.

Control Board Indicator

There is one tri-colour LED indicator on the board indicating the operating mode as follows:

Red: Idle. SE command is set to zero.

Green: Run. SE command is not set to 0.

Blue: Program. Firmware loader is operating.

Green and Blue: MOSFET Over-temperature. Power is reduced.

RS232 Set Up

The drive is controlled via the TTL level RS232 connections on J1. The RS232 interface uses the following set-up:

Baud rate: 115200 baud

Data bits: 8

Stop bits: 1

Parity: none

Flow control: none

End of line terminator: LF only (preferred) or LF + CR

Local echo: off

For convenience, an USB to 3.3V logic level RS232 cable is supplied. The cable leads connections to J1 are as follows:

Green: pin 1 RX

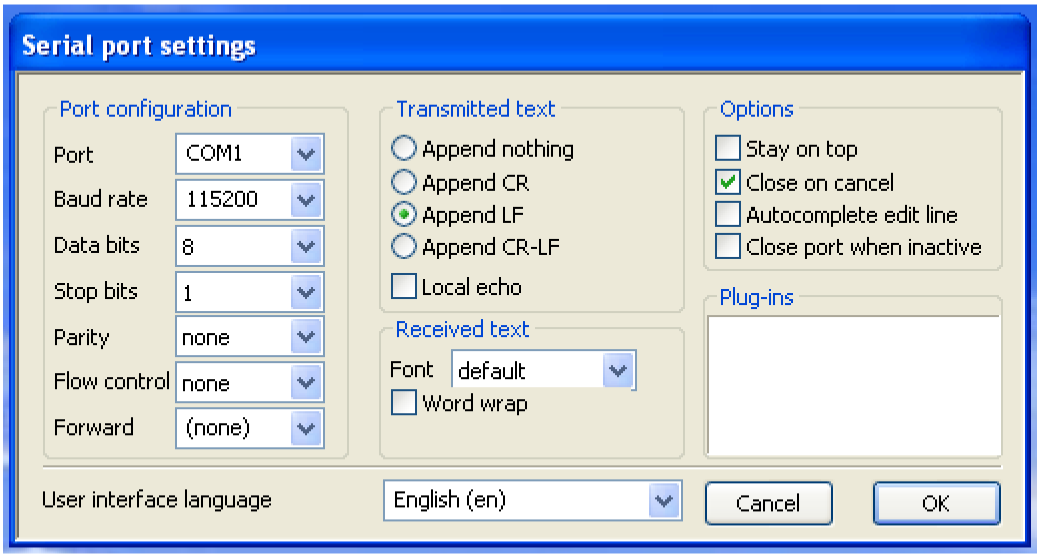
White: pin 2 TX

Black: pin 3 Ground

Red: not connected

With the USB cable plugged into a personal computer, the drive can be controlled via a terminal emulator program.

For the Windows operating system, the Termite.exe program by Compu Phase is recommended. The required settings for this program is shown in the set up window shown here:



The Port setting is allocated by the computer and can be found using the Windows Device Manager.

For a Linux operating system, the Cutecom program is recommended. Set up is similar to Termite for Windows.

For new firmware downloads in Windows, a terminal emulator that includes the Xmodem file transfer protocol is required. The Windows terminal emulator Tera Term should be used since Termite does not include the required Xmodem file transfer protocol. This can also be used as the main terminal emulator if desired. See the Firmware Loader section for details.

For new firmware downloads in Linux, Cutecom can be used.

Commands

Commands consist of two upper case letters or sometimes an upper case letter and a number followed by either a parameter and a line feed or just a line feed. The parameter may be floating or fixed point number depending on the command.

The drive always echoes any character sent to it providing an ongoing check on the connection.

For convenience, back-space is enabled allowing simple line editing before ending with a enter.

Available commands for controlling the drive are divided into three groups:

Parameter commands

Set point commands

Function commands

Parameter Commands

Parameter commands consist of two upper case letters, or sometimes an upper case letter and a number, followed by an optional floating point number and ending in a line feed. Spaces are ignored.

The floating point number, if included, is the new value of the parameter. Numbers can be entered as integer, decimal point, or scientific notation. For example:

543

10.67

0.00234

4.5213E-5

After the line feed is received the drive interface sends back the value of the parameter, updated to the new value if the optional floating point number is included in the command.

For example:

sent: `MT`↵

received: `0.25`

sent: `MT0.21`↵

received: `0.21`

New parameter values always take effect immediately. This allows easy tuning of the controller whilst the motor is running.

A list of the parameter commands and their values can be read out by using the `LP` function command.

Set Point Commands

Set point commands control the motion of the motor.

The input method is the same as that of a Parameter input using the RS232 interface, but differs in that the number format depends on the command. Some are floating point, some are integer only.

Floating point set point commands are entered using the same format as for parameters. Integer commands require an integer value in the range -2147483648 to 2147483647.

Integer values are used for position control and are in units of steps as set by the PR parameter.

Set point commands only take effect after the controller is enabled with a non-zero SE command and always default to SE = 0.

The motor control set points available are Speed, Position, Torque and Acceleration. Torque and Acceleration set points are very experimental and should not be regularly used.

The set point currently in operation is the last set point that was modified, so to change to a new set point type, just enter a value for that set point. When the controller is enabled with SE=1, the speed set point is in operation with speed set to zero.

Function Commands

Function commands have no argument. They are just a two letter command followed by a carriage return.

Definitions

Switch speed: Speed below which the holding current (d axis current) locking the rotor position is fully on and the gain of the feedback loop forcing the rotor in position via q axis current control is gradually reduced with speed.

Peak line to line current: Peak value of the current flowing from one phase to another when the third phase current is zero. Its value is the peak phase current times 0.866.

Initial Set Up

A suggested initial set up procedure is as follows:

1. Solder the motor leads to the U, V and W outputs.
2. Solder a 12-24V power supply to the + and - inputs.
3. Attach the USB to TTL RS232 cable to the board and plug the USB end to your PC.
4. Set up your terminal program (e.g. Termite.exe) on your PC and set RS232 settings to 115200 Baud, 8 bits, 1 stop bit, no parity, no flow control, echo off, line feed only at end of line.
5. Turn on the power supply. The LED mode indicator should show red. Also a message showing the current software version should be received on the RS232 terminal.
6. Enter the motor parameters if known.
7. Tune the drive to the motor.

Parameter Storage

Parameters are stored in flash memory and loaded automatically on power up. If memory is corrupted or the software is updated, default values are loaded. All parameter values can be read as a list using the LP command.

All storage commands can only operate when SE parameter is set to 0, i.e. the controller is off and the LED is red. Commands which affect storage are:

EB: Parameter backup

Backs up parameters to flash memory.

ER: Parameter restore

Restores parameters from flash memory.

ED: load defaults

Loads parameter defaults.

Motor Parameters

The motor parameters default to typical values for a 5 inch propeller quadcopter drone. For this application, the motor parameters can be just left at their default values although tuning will improve performance and is recommended.

For other setups, the motor parameters can be initially adjusted to best guess values. The controller will still run with large errors in the parameters. They can be adjusted to their correct values using the motor tuning procedures described in this manual.

The motor parameters should be set as follows

`MP`

Motor Pole Pairs (= motor pole number ÷ 2). Default value is 7.

This parameter must be set to the correct value before motor operation.

The position control parameters PR (position resolution) and PN (position range) should also be changed when MP is changed.

`MK`

Motor KV rating in rpm per Volt.

For a motor with a torque constant rating TC in Nm/A the following formula can be used to convert to KV:

$$KV=10/TC$$

Default value is 2500

`MR`

Motor average resistance in Ohms measured line to line. This also includes the inverter effective output resistance which is about 0.05 Ohms.

Default value is 0.1.

`ML`

Motor line to line inductance in millihenries. Default value is 0.005.

`MI`

Motor inertia in $g.cm^2$. This includes the load inertia. Default value is 50 which is typical of a quadcopter motor with a 5 inch propeller. Typical inertia without the propeller attached is 20.

`MD`

Motor direction. Changes motor direction for both speed and position without having to swap the motor connections.
0: normal direction, 1: reverse direction. Default value is 0.

`MF`

Motor differential resistance. If motor phase resistances differ by even a small amount, torque pulsations at low speed may occur. This parameter can be used to correct this problem. Rarely needed. See reference section for details.

Controller Parameters

Most controller parameters are automatically calculated from the motor parameters. The controller parameter that may need user adjustment is:

`CH`

Holding current at zero and low speed in Amps. Default is 5A.

The holding current needs to be enough to at least generate enough torque to overcome the cogging torque of the motor. Set speed to a low value such as 10 rpm and check that the motor turns. Increase the holding current if there is not enough torque to turn the motor.

Other controller parameters that are less often changed are:

`CJ` : Hold current reduction factor at zero speed.

`CI` : Torque limit in terms of peak line to line current in Amps.

`CQ` : Operating mode when in flux weakening.

`CW` : Extra *d* axis current at all speeds.

`CD` : Maximum flux weakening current before speed is reduced.

Useful controller read only commands are:

RV: DC bus volts

RD: D axis current

RQ: Q axis current

Controller Operation: Starting and Stopping

The command to stop and start the controller is:

SE: Setpoints enable

SE1: Turns controller on with speed set to 0, position set to 0. LED turns green.

SE0: Turns controller off. Output MOSFET's are turned off. LED turns red.

The SE command is disabled when under drone control.

The SE command has other modes of operation listed below which are used for tuning:

SE2: Turns controller on as in the SE1 command, but with stall detection disabled.

SE3: Measures inductance using a test pulse current through the windings.

SE9: Runs a continuous test current through V and W windings to calibrate the current sensors.

How these are used is described in the tuning section.

Speed Control and Parameters

The main speed control command is:

SS: Speed setting

SS followed by the required rpm sets the speed. Input format is floating point. Maximum value is set by the VM command which defaults to 30000 rpm. Resolution is 30000:1, so the speed can be set to as low as 1 rpm. Negative values can be used and the motor can be reversed at maximum deceleration/acceleration. If the speed setting is higher than what is possible with the available voltage, the speed will self limit to the maximum possible value. Note: this value can be increased by adjusting the KV and CD parameters.

The SS command is disabled when under pulse input speed control.

The main parameters related to speed control are:

VM: Maximum speed setting

Maximum speed in rpm. Note that resolution is always 30,000:1 so a lower maximum speed gives higher resolution.

VA, VD: Acceleration and deceleration rates

The VA parameter sets the acceleration rate and the VD parameter sets the deceleration rate in rpm per second. Normally, both are set to the same value. The default value for both is set to 6000 which is very low. To aid in setting this value, the expected current due to acceleration is calculated and reported with the read only RK command provided the flux, or KV constant, (MK parameter) and inertia (MI parameter) are set correctly.

For example, for an inertia of 20 $gm.cm^2$, and the motor flux parameter MK set to 2500, a VA value of 200E3 will give an expected acceleration current of 10A.

For the fastest motor dynamic response, VA and VD need to be set as high as possible. To do this, first tune the motor parameters inductance, resistance, KV constant and inertia to their correct values. Then adjust VA and VD so that the acceleration current is equal to the torque current limit (CI parameter). Note actual acceleration will be reduced due to the extra current required for the load (which is the thrust for a propeller load).

VB, VE: Proportional reduction in Acceleration and deceleration rates at start up

The VB and the VE commands proportionally reduce the acceleration and deceleration rates respectively at start up and up to the switch speed as read by the RS parameter, which is the speed which is high enough for the load torque to be reliably measured and compensated for. Values are set from 0 to 1 with a default value of 1.

These parameters have been added to allow reliable starting and stopping when the actual motor inertia differs greatly from the motor inertia setting (MI parameter). This is useful for variable inertia loads. They can also be used to get a less jerky start and stop. These parameters should be set by trial and error to obtain reliable starting and stopping.

These parameters could also be used to obtain a soft start or stop.

Useful read only commands for speed control are:

RM: Actual motor speed

This is useful to see if the speed has been limited by the available supply voltage or by torque limiting. Otherwise it will equal the set point speed setting SS.

Position Control and Parameters

When in position control mode, a request to move to a new position results in the rotor moving to that position using a trapezoidal speed profile.

The main position control command is:

SP: Position setting

Puts the controller in position mode and moves to the position set in the following value. The position is in units of position steps (set up with the PR and PN parameters) and must be a positive or negative integer.

The SP command is disabled when under pulse input speed control.

The parameters for position control are:

PT: Position zero point

This parameter provides a fine adjustment of the position zero point with respect to the electrical or internal position zero in units of pole pair pitch (not position steps so it does not change with PR setting). Floating point values are accepted allowing ultra-fine adjustment.

Related commands are:

PR: Position resolution.

Sets the position resolution in position steps per revolution. Default value is 60.

PN: Position range

Sets the maximum position range centred on zero in units of electrical cycles (pole pairs) before repeating for the controller's internal measurement of position. This allows the standstill propeller position to be set. This would normally be set to the number of pole pairs per motor revolution (default:7 giving a range of ±3.5 pole pairs about zero). To allow overhead for the position control loop to operate the range is actually reduced from its +/- limits by 11.25 electrical degrees.

If positioning to exactly half a rotation away from zero is required, it would be better to set PN to twice the number of pole pairs per revolution. The disadvantage of this is that the rotor may turn by more than one revolution to reach its final position.

The controller's internal measurement of position is continuously updated whenever the rotor moves either under position control or speed control. By setting the position range to the number of pole pairs per revolution the rotor can be set to an exact position in a revolution after running under speed control - useful for parking a propeller in the a known position by using the SP command after it stops spinning.

A PN value of zero is used to set the position range to its maximum value of 2^32 electrical cycles.

PA, PD: Profile acceleration and deceleration rates

In position control mode, the values of these parameters become the acceleration and

deceleration rates in rpm per second used for the trapezoidal speed profile used in a position movement. Default acceleration and deceleration rate is 6000 rpm/sec.
Note that the reduced acceleration at low speed settings VB and VE do not apply in position mode.

PS: Profile speed

Sets the maximum speed in rpm for the trapezoidal speed profile used for position movement. Default maximum speed is 8000 rpm.

Hardware and Tuning Commands

Setpoint commands:

SE: Tuning modes

3: Inductance test.

9: Current sensor calibrate.

Note: SE must be set to zero before these tuning modes are recognised.

Parameter commands:

HD: Inverter dead time

Inverter dead time in microseconds.

Default value is 0.2. This is a manufacturing parameter.

Too low a value will cause inverter shot-through. Higher values cause current waveform distortion and increased risk of low speed instability.

The inverter dead time only takes effect on power up. A parameter back up needs to be undertaken after this parameter is changed for it to take effect.

HG: Inverter dead time gain

Controls change in dead time verses current for low current values. Default value is 1.0. Should never need to be changed.

HT: Inverter dead time threshold

Threshold current ripple value as proportion of calculated value at which dead time compensation starts. Default value is 1.0. Should never need to be changed.

HL : Double output PWM carrier frequency.

0: 20KHz PWM carrier frequency. 1: 40KHz PWM carrier frequency. Default: 1

A change in carrier frequency only takes effect on power up. A parameter back up needs to be undertaken after this parameter is changed for it to take effect.

HS: V current sensor scaling

Scaling of the V phase sensor to match W phase sensor gain. Default value is 1.0.

AL: Inductance test current

Inductance test current setting in Amps.

Read only commands:

RA: V sensor current reading in Amps

RB: W phase sensor current reading in Amps.

RC: V phase scaling error when in SE 9 mode

RR: Resistance reading when stationary for adjusting MR (motor resistance) parameter

RL: Inductance reading after an inductance test

RH: Actual peak inductance test current

RX: Motor KV constant measurement

RK: Expected acceleration current from VA (acceleration rate) and MI (motor inertia) settings

RI: Measured inertia after test acceleration for adjusting MI (motor inertia) parameter

RT: Inverter MOSFET temperature in degrees C.

Current Sensor Calibration

For minimum torque ripple at low speed, the current sensors should be calibrated followed by individual winding resistance setting. This is rarely necessary except where very smooth low speed operation is required, which also requires the use of motors with very low cogging torque.

Calibration procedure is as follows:

1. Reset the current calibration by setting HS to 1.
2. Turn on controller in the current sensor calibrate mode with the SE 9 command. This disconnects the U phase and puts a test current through the V and W phases. The test current used is the holding current set with the CH command.
3. Read the scaling error of the V current sensor with respect to the W current sensor with the RC command. The RA command reads the V sensor current, the RB command reads the W sensor current and the RC command reads the scaling of the V sensor required for calibration.
4. If the readings are OK, transfer the RC reading to the scaling parameter HS. For example, if RC reads 0.98 during the test, set HS 0.98 then back up the parameters with the EB command after turning the controller off with the SE 0 command.
5. The RC reading should now be 1.0. If not, then for fine adjustment, adjust HS value to it’s present value times the RC reading.

Tuning

Tuning of the controller consists of setting the motor parameters to their correct values. If these are not adjusted, the motor will still run but performance will be poor and the motor could stall with heavy acceleration.

When operating under high acceleration values, the controller uses an internal motor model to instantaneously set the voltages and currents to their optimum values to make the motor do as commanded. When operating under steady state conditions, internal feedback loops take over adjustment of the voltages and currents ensuring the motor operates when motor parameters are in error.

To tune the motor, tests are provided to measure the main motor parameters: Inductance, Resistance, KV Constant (rpm per volt), and Inertia. The tests are described as follows:

Inductance

Inductance is measured by supplying a single voltage pulse to the motor and measuring the resulting current. The pulse ends when the measured current reaches the test current setting AL. The inductance is then calculated and read. Note that for a very small inductance, the actual peak test current will exceed the test current parameter AL due to measurement delays. The actual peak test current used can be found if desired with the RH command.

To measure inductance:

1. Set test current, AL parameter, or leave at default of 2A (recommended).
2. Make sure controller is off (SE set to 0).
3. Set SE to 3 which will run the test. SE automatically returns to 0 after test completion.
4. The resulting inductance measurement value in millihenries is immediately sent to the terminal as "L = *inductance*". The measured inductance value can also be read with the RL command. This can be used to update the inductance parameter ML.

Note: By moving and clamping the rotor position manually before measuring the inductance, the inductance variation with rotor position can be measured. If you use this procedure, it is best to set the motor inductance to the highest of the values found, which is the q axis inductance.

Resistance

The actual line to line motor resistance including the inverter resistance is continuously being estimated and reported in the RR Parameter whenever the motor is running. The best estimate is made when the motor is stationary. So to measure the resistance, start the motor in a stationary position and read the resistance with the RR parameter. If the value is acceptable, update the motor resistance Parameter MR.

To measure resistance:

1. Start the controller by setting SE to 2 (stall detection disabled) and leave at zero speed.
2. Read the measured resistance in Ohms with the RR command. This can be used to update the motor resistance parameter MR.
3. If desired, increase the holding current, CH parameter, e.g. from 5A to 10A and read the resistance again for better accuracy. Don't forget to reduce CH to its normal value afterwards.

Measuring resistance variation for motor checking:

The resistance is measured in the motor phases carrying the holding current, so to measure the resistance in different motor phases, use the SP position command or the PT position zero point command to move the motor to a different position. If the motor is moved by 90 electrical degrees, the change in resistance will show the variation in resistance in the motor windings.

KV Constant

The actual motor KV constant is continuously estimated whenever the motor is running and reported in the RX Parameter. The higher the motor speed the higher the accuracy, although very high accuracy is obtained at around typically 5000 rpm for a 5" quadcopter, so run the motor up to this speed and read the RX parameter to get the estimated KV constant. If this value is acceptable, update the motor KV constant MK parameter.

To measure the KV constant:

1. Run the motor up to a medium speed, e.g. 5000 rpm for small drone motors.
2. Read the measured KV in rpm/Volt with the RX command while running the motor. This can be used to update the motor MK parameter.

Inertia

The total inertia (motor plus load) is measured by accelerating the motor at a fixed rate and measuring the resulting q axis torque current due to inertia and load, then running the motor immediately after this measurement at a fixed speed and measuring the q axis torque current due to load only then calculating the actual inertia from these values and the acceleration rate. These calculations are automatically carried out by the controller whenever the motor accelerates and reported in the RI parameter for reading.

For the inertia test, the propeller needs to be attached to the motor as this is the main component of the inertia. Before starting the test, set the controller inertia value, MT parameter, to a rough estimate, typically 50 $gm.cm^2$ for a motor and 5 inch propeller. The test procedure is as follows:

1. Set the acceleration rate, VA parameter, to a value that gives an estimated acceleration current, calculated for you and given by the RK parameter, of about the same as the holding current, CH parameter, typically 5A. Typical value for the VA parameter would by 50000.
2. Reset the RI parameter with the RI 0 command, which provides the measured inertia after the test, to 0.
3. Start the motor by setting SE to 1.
4. Stay clear of the motor and propeller and set the SS speed command to a medium speed, say 5000 rpm, to accelerate the motor to that speed. Allow the motor and propeller to run at that speed for at least 2 seconds then set the SS command to 0 to stop the motor. Turn off the controller if you wish by setting SE to 0.
   If the motor stalls instead of accelerating, then the MI inertia parameter is too far off. Try reducing the acceleration rate or changing the MI parameter. Alternatively, you could reduce the initial starting acceleration rate by using the VB command.
5. Read the resulting measurement with the RI command. If the value looks OK, update the MI parameter to the new value.
6. Repeat the test with the updated MI parameter if you wish for a more accurate reading although this is not really necessary as the controller performance is not very sensitive to inertia errors.

Parameters to be Modified when Changing Motors

For reference, the parameters that may need to be modified when a different type of motor is connected to the controller are:

MP Motor pole pairs
MK Motor constant
MR Motor resistance
ML Motor inductance
MI Motor inertia
CH Holding current
HL PWM frequency, 20kHz or 40kHz
PN Position range in pole pairs
PA Position acceleration rate

PD Position deceleration rate
PS Position maximum speed
VM Maximum speed
VA Maximum acceleration
VD Maximum deceleration

Setting the Holding Current (Parameter CH)

The holding current is the current applied to the motor at zero and low speed to hold the motor in position. The value of the holding current sets the maximum holding torque which can be applied without the motor slipping. The minimum holding current required for a given load torque can be calculated from the motor torque constant (N.m/Amp), which can be calculated from the motor KV constant as 10/motor KV constant (MK parameter).

$$\text{Minimum Holding Current (Amps)} = \frac{\text{Load Torque (N.m)}}{\text{Torque Constant}}$$
$$= \frac{\text{Load Torque (N.m)} \,.\, \text{KV Constant (MK parameter)}}{10}$$

The value of CH should be set ideally at twice the holding current required for the expected starting torque. If this causes a problem, such as over heating, lower values down to the minimum holding current can be tried.

If required, the holding current can be reduced with the CJ parameter when the motor is stationary to reduce heating.

Note that if the motor inertia parameter is set to the actual inertia, the extra current required for acceleration is automatically added by the controller and does not have to be considered when choosing the CH value.

Setting the PWM Carrier Frequency

The PWM carrier frequency can be set to 40KHz (default) or 20KHz with the HL parameter. The choice is a trade off between higher motor losses due to higher PWM ripple current or higher inverter switching losses. As a guide, if motor inductance in uH/DC supply volts is greater than 0.5, changing to 20KHz should be considered.

Maximum Resistance Error plus PWM Error Parameter KE

The parameter KE determines the maximum resistance error plus the maximum inverter pulse width error that can be tolerated by the controller. Together with the motor parameters, it controls the switch speed. The chance of low speed instability, especially when operating near the switch speed, increases as the switch speed is reduced.

The parameter adjusts the switch speed (read by RS command) to a level where the inverter pulse width error does not affect drive operation. The default value is 1.0 which is suitable for most motors and loads.

Reduced values of the KE parameter lowers the speed at which torque changes can be detected and compensated for, but increases the risk of instability, usually detected by increased motor noise particularly around the switch speed.

Stall Detection

When a motor stall is detected, and the SE 1 mode is used, the controller turns of the motor and SE is reset to 0. The message “fault 017 Motor stall detected” is sent over the RS232 interface.

The motor stalls, i.e. the rotor stops, only under severe overload. Under mild overload, the motor torque limit operates, reducing the motor speed until the overload is removed.

When the SE 2 mode is used, the stall detection is disabled. The stall detection requires the motor parameter settings to be approximately correct to work properly so this mode of operation is included to allow tuning of a new motor.

Internally, a stall is detected by measuring the motor flux whilst the motor is spinning. If the actual motor flux drops below the flux setting by a proportional amount set by the FL parameter then a stall is registered and the motor is stopped.

The sensitivity of the stall detection is gradually reduced as the speed is reduced below a stall speed set to the switch speed (RS parameter) times the value of the FS parameter. This is needed to prevent false stall detection at low speeds. To reduce false stall detection at low speeds, this parameter should be increased.

If operating under Pulse Input speed control, the speed control must be re-armed after stall detection before the motor can start again.

Parameters:

FL: Stall detect sensitivity

> Flux error as a proportion of motor flux at which a stall is registered and the motor stopped. Default value is 0.2.

FS: Stall speed

> Speed as a proportion of the switch speed (RS parameter read only) below which stall detection sensitivity is gradually reduced. Default value is 4.0.

Over Temperature Protection

A temperature sensor is mounted close to the output MOSFETs. This us used to protect the MOSFETs from over heating. The temperature can be read with the RT command.

When the temperature reaches the value of the parameter KJ (default 100 °C) the maximum (line to line) output current starts reducing from the maximum ADC current (KM parameter, 62.5A), dropping to 0 at the temperature set by the parameter KK (default 125 °C).

When the maximum output current as determined by the temperature drops below the torque current limit set by the parameter CI, both blue and green LEDs turn on. This indicates that the maximum motor current is now controlled by temperature.

Parameters:

KJ: Temperature for maximum current.

KK: Temperature for zero current.

Pulse Input Speed Control

The Pulse input pin can be used for external speed control, typically from a drone flight controller. DShot, Bi-directional DShot and standard Pulse Width Modulation (PWM) protocols are recognised.

All protocols have an arm mode and a throttle control mode. In throttle control mode a throttle signal is send to the ESC which controls the speed. The throttle value can be set to control the speed directly or to control the square of the speed (IS parameter). This is particularly useful for a propeller load where the thrust is proportional to the square of the speed.

The arm mode is for safe start up. Any throttle value sent is ignored on starting until the input has been kept in arm mode for 0.3 seconds.

With pulse input control, when the motor is stopped by setting the throttle to its arm value, the motor parks itself at the zero position point. After parking, a holding current can be kept on if desired.

When operating under pulse input control, either PWM mode or Dshot mode, the blue LED comes on to indicate it is in this mode, on top of the usual red and green LED’s to indicate when the motor is disabled or enabled.

DShot Protocols

DShot and Bi-directional DShot are digital signal protocols where a throttle value is sent to the ESC using digital encoding. When the flight controller is first turned on and when the remote joystick throttle for that channel is set to 0, the flight controller sends a throttle value of zero to the ESC. This is the Arm mode. Throttle values from 1 to 47 are reserved as various control signals. These are currently treated as being 0, the Arm mode by the ESC. Throttle values of 48 to 1023 set the motor speed. Bi-directional DShot differs from DShot in that the actual motor speed value is returned to the flight controller on the Pulse input signal line after each DShot signal is sent. The motor speed is actually send as the electrical period. This results in a minimum motor speed value that can be sent, which depends on the motor pole number.

A detailed description of the DShot protocol can be found in the document “DSHOT - the missing Handbook” (brushlesswhoop.com).

PWM Protocol

The PWM protocol is the oldest and most common pulse input speed control protocol.

The input pulse width must be between 900 and 2200 us.

Setpoint commands:

SF: Disable pulse input

> SF1: Disable pulse input to allow manual speed and position control, mainly to allow tuning to be undertaken.
>
> SF0: Enable pulse position control. Allows pulse input control if a valid pulse input protocol is detected.

Parameter commands:

IS: Throttle to speed conversion

> Pulse input throttle input value to speed conversion curve. 0: Speed proportional to the square root of the throttle value, giving thrust proportional to throttle value for a propeller load. 1: Speed linearly proportional to the throttle value. Default value is 0.
>
> The maximum value is set by the VM parameter.

IH: Residual holding current

Residual holding current applied after the motor is parked at the stop position at zero speed. If this is zero, the motor controller is disabled after parking.

IA: Arm mode maximum pulse width

When in PWM mode, this is the pulse width in microseconds below which the throttle is in arm mode. Default value is 1050 us.

IB: Zero speed pulse width

When in PWM mode, this is the pulse width in microseconds for zero speed. Default value is 1100 us.

IC: Full speed pulse width

When in PWM mode, this is the pulse width in microseconds for maximum speed. Default value is 1950 us.

Read only commands:

RP: Pulse width input when in PWM mode

When in PWM mode, this reads the current pulse width on the input in microseconds. This is useful when setting the IA, IB and IC parameters.

Drone Control Procedure

When the ESC is used as part of a drone, speed is controlled from the flight controller via the Pulse input.

Connection:

Connect the signal output from the flight controller to the Pulse input of the ESC (pin 3, J1) and the signal ground to the ground input of the ESC (pin 4, J1).

Connect the DC power + and – inputs to the battery using 20A rated power cables.

Connect the the 3 phase motor outputs to the motor in any order.

Flight controller set up:

The flight controller Pulse signal must be set to PWM, DShot or Bi-directional DShot. Bi-directional DShot is preferred as this gives the flight controller the motor speed allowing it to add notch filters at this frequency on the signals from the gyro chip for improved noise immunity.

DShot signal speed can be set between 150 and 600 bits per second. A speed of 600 bits per second should be used unless other reasons prevent this.

If Bi-directional DShot is used, the number of pole pairs will also need to be set.

The flight controller will also require the minimum throttle setting for the ESC. This ESC can operate down to zero speed, so any value can be used including zero, if the flight controller allows this.

Thrust linearization for the PID operation should be turned off, instead use the ESC IS command.

ESC set up:

To set up the ESC, power up the ESC without the flight controller signal line connected or with the flight controller turned off. Alternatively, if it is inconvenient to disable the flight control signal, it can be disabled after the RS232 line is connected by setting the SF command to 1. Connect the RS232 line to the ESC as described in “RS232 Set Up”. Adjust the motor and controller parameters as described in this manual. Tune the ESC to the motor as described in the Tuning section.

Operation:

When the flight controller and ESC are first powered on the flight controller sends a throttle value of zero, also called an Arm signal, to the ESC. If the remote controller is on, the throttle values should be set to zero to ensure this. The ESC will detect the pulse signal immediately and switch to PWM, DShot or bi-directional DShot depending on the mode detected. It will then wait until a zero throttle value has been received for 0.3 seconds before allowing the flight controller to control the motor.

Once in PWM, DShot or bi-DShot mode, the controller will stay in that mode unless over-ridden by changing the SF setting to 1, which disables drone control.

If no valid signals are received from the flight controller for 0.1 seconds, the throttle value is set to zero to stop the motor. Recovery is immediate after a valid signal is received.

When the ESC is switched to drone mode and the RS232 line is connected, the Set commands SE, SS and SP for motor control cannot be used. Other RS232 commands can be used.

Adjusting parked holding torque

If a holding torque is required when parked, the IH parameter should be set to the required holding current instead of the default 0 value. This keeps the motor current flowing instead of turning off the motor output. A downside of this setting is that power will be drawn from the battery whilst parked.

Adjusting propeller parked position:

If the ESC is required to lock the propeller to a specific position when parked, move the propeller to that position before the throttle value is first increased. Check by running the motor from the remote to see if the propeller returns to the parked position. Remember to stand clear of the rotating propeller.

The position at which the propeller is parked can be finely adjusted by the PT parameter. Just turn on the idle current by setting it to a non zero value, say the holding current, to provide a zero position holding torque, then adjust the PT parameter to adjust the zero position.

Waveform Capture

A comprehensive but simple waveform capture system is available.

There are 4 channels of waveform capture with a fixed sample length of 8,192 samples. Pre and post sampling is available, i.e. you can capture the previous 8,192 samples or the following 8,192 sample from the point of triggering. Time between samples can be adjusted down to the internal microprocessor sample period of 20 microseconds.

The data collected are internal variables selected with the parameter commands TA, TB, TC and TD. All variables are in signed 15 bit format but are collected after transformation to decimal format with the range -32,768 to 32,767. The main variables and their scaling are shown in *Table I*. There are actually more than 100 other variables available which are mainly used for close scrutiny of controller operation.

Automatic triggering on a change in the speed setting is provided but only with post sampling.

The main commands are:

TL: Pre trigger sampling data collection

Samples and stores the 8,192 data points before the command is received.   No parameter.

TF: post trigger sampling data collection

Stores the 8,192 data point after the command is received. No parameter.

TM: Re-arm

Re-arms the waveform capture system after a previous capture. After a data capture, any further data captures are blocked until this command is sent. No parameter.

TX: Send data

Sends data over the serial port, one line of 4 channel values per sample. Each channel value is separated by a space with each line ending with a line feed. No parameters.

The data can be captured to a log file using your serial communications program. For the Termite program, the “Log file” filter plug-in will be needed with the log file turned on before sending the PX command and turned off after the data is received.

The resulting data file can be analysed with a data analysis program such as kst2 in Linux. The initial “TX” line and the trailing”OK” line in the data file will need to be deleted first using a text editor.

The relevant parameters are:

TU: Trigger on rising speed

Trigger speed in rpm which starts a data capture when the speed setting (SS parameter command) rises through this setting. A setting of zero turns off the trigger.

TV: Trigger on falling speed

Trigger speed in rpm which starts a data capture when the speed setting (SS parameter command) falls through this setting. A setting of zero turns off the trigger.

TN: Time between samples

Time between samples in units of internal 25 microsecond sample intervals as a power of 2. Thus TN4 results in a time between samples of $2^4 = 16$ times 25 microseconds or 400 microseconds. Maximum value is 10. Default value is 0.

TA, TB, TC, TD: Channel selection

These parameters select the variables connected to the 4 data capture channels A, B, C and D. The parameter values are selected from *Table I*.

Table I. Channel Selection Parameter Settings

Parameter	Output	Scaling
0	Zero	
1	V phase current	2^{13} = 62.5 A
2	W phase current	2^{13} = 62.5 A
3	α axis current	2^{13} = 62.5 A
4	β axis current	2^{13} = 62.5 A
5	D axis current	2^{13} = 62.5 A
6	Q axis current	2^{13} = 62.5 A
7	α axis modulation*	2^{13} = 1
8	β axis modulation*	2^{13} = 1
9	V phase modulation*	$2^{13}/\sqrt{3}$ = 1
10	W phase modulation*	$2^{13}/\sqrt{3}$ = 1
11	Rotational speed**	30,000 = max. speed (VM parameter)
12	Filtered rotational speed	30,000 = max. speed (VM parameter)
13	DC bus voltage	2^{12} = 69.3 V

* The modulation level is the output voltage as a proportion of the DC bus voltage.

** This includes feedback stability-correction noise. For a better measurement of the rotor speed use the filtered rotational speed.

Motor Damping

Unlike most drives, this drive provides extra damping to suppress load mechanical resonances. For maximum damping, the correct setting of MI is required. The damping can be even further increased by increasing the K0 parameter if required.

Firmware Loader

A firmware loader has been included in the on board flash memory. This allows new firmware to be downloaded and flashed to memory. The loader uses the Xmodem protocol for download.

There are two ways to start the firmware loader:

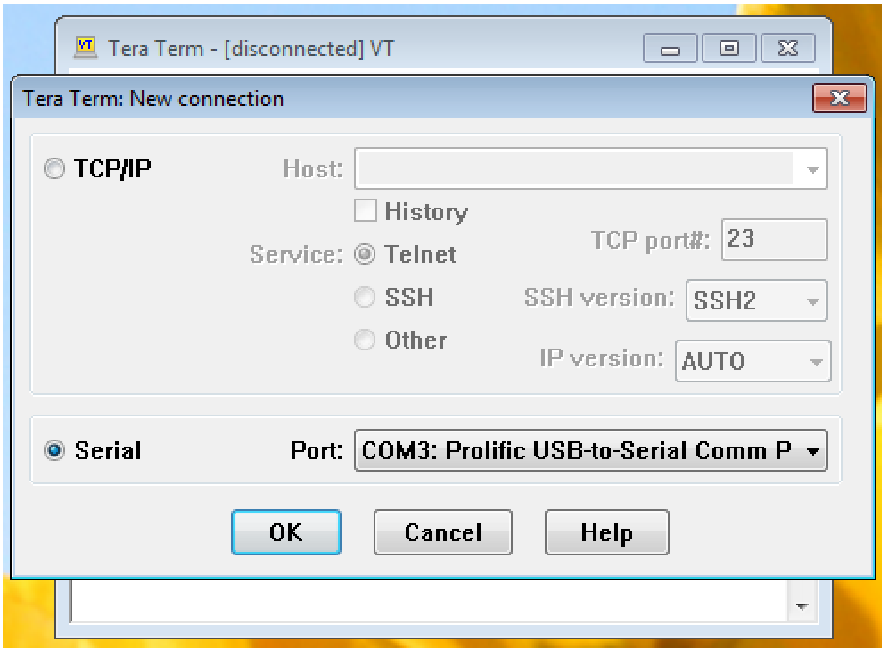
1. Enter the BT command. Make sure the drive is in the off state (SE 0).
2. Short pins 2 and 3 of J6 then turn on the power.

The LED turns blue to indicate that the loader is running.   Also the letter “C” is sent to the RS232 serial interface every 3 seconds while the loader is waiting for a download to start.

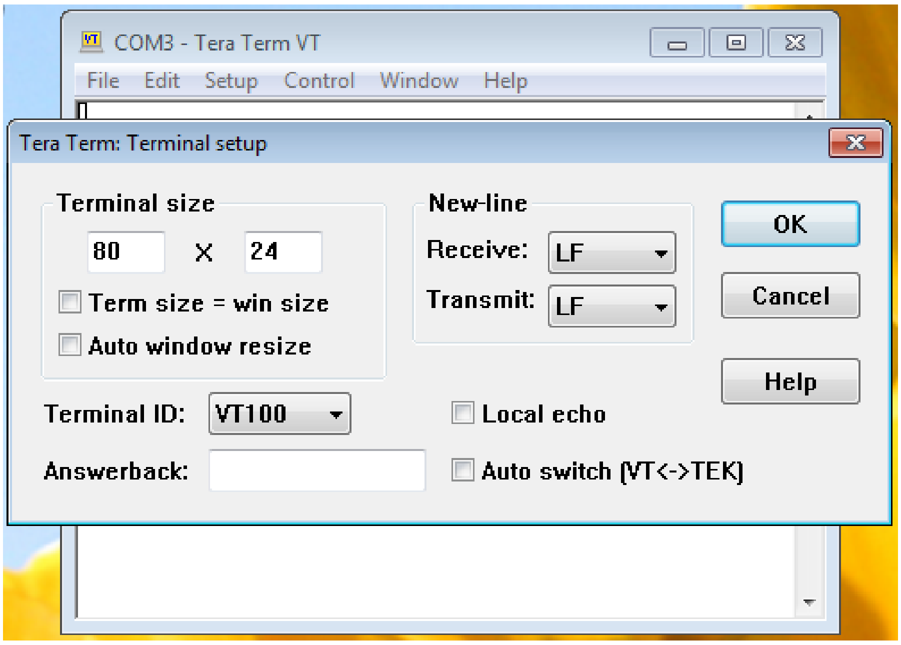
To download a new program file, an RS232 terminal program that can download files using the Xmodem protocol is needed. For Windows, the open source program TeraTerm is recommended.

The Termite program does not include Xmodem file transfers. Under Linux, the Cutecom program can be used.

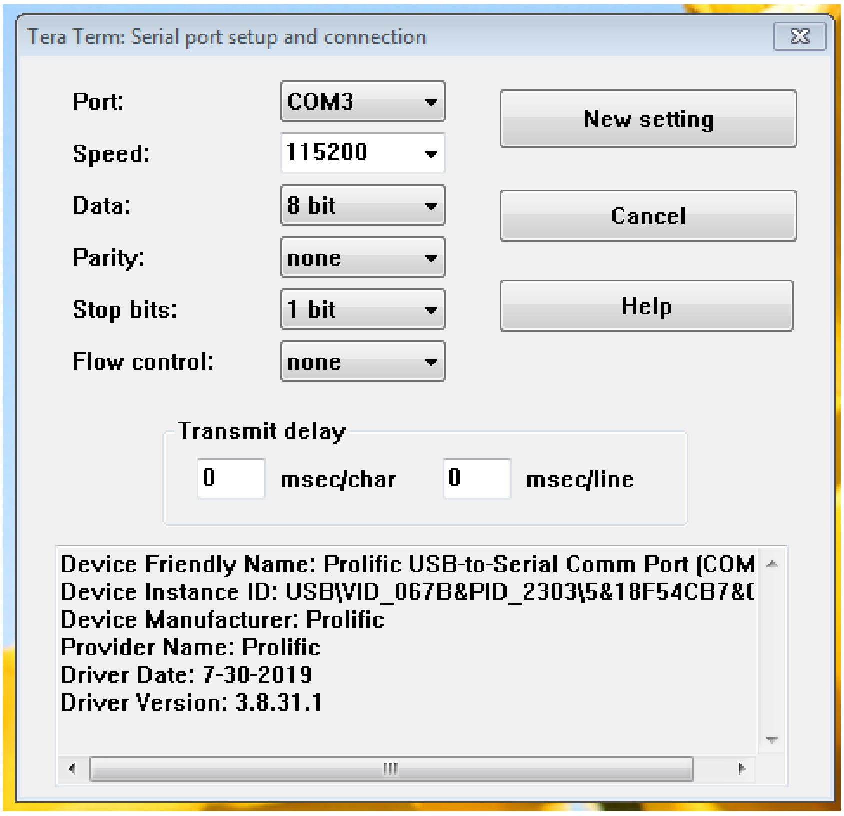
With the USB to serial lead plugged in and connected to the ESC, start Tera Term and under New Connection change to serial and adjust COM port:



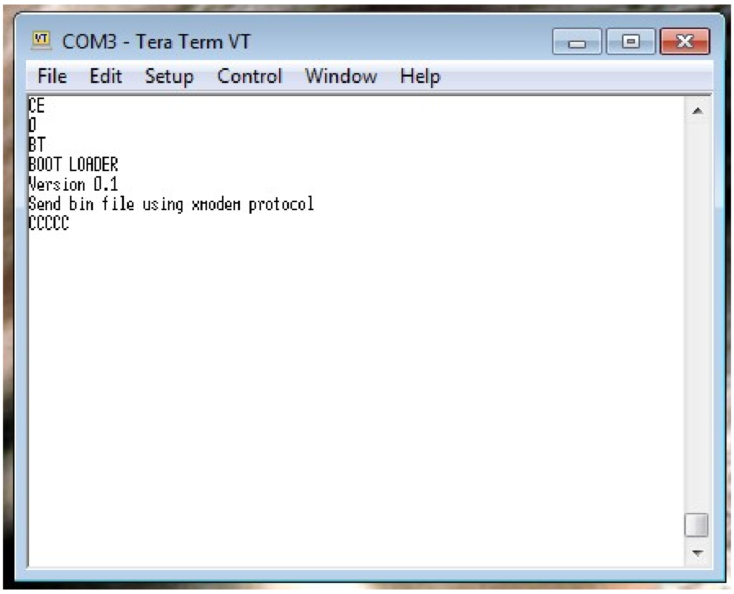
Under Setup->Terminal, change New Line Receive and Transmit to LF:



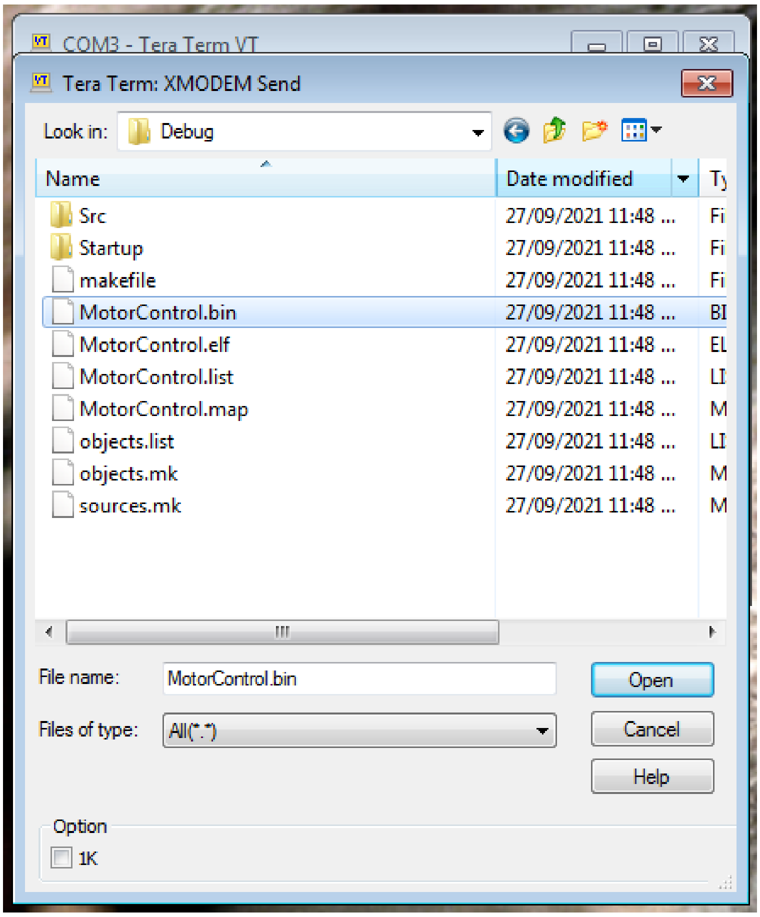
Under Setup->Serial port, change speed to 115200, then select New setting:



Check connection by sending, for example, a SE command, then send the BT command to switch to the firmware loader program:

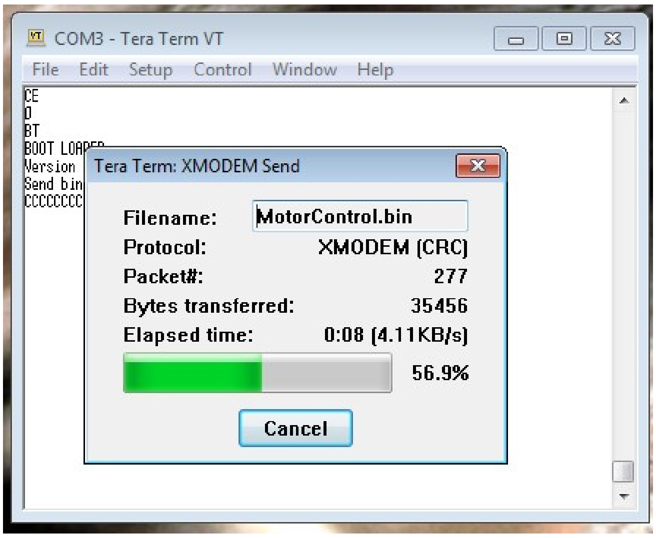


To download and install a new .bin program file, select File->Transfer->XMODEM->Send and select the .bin file then select Open to start the download:

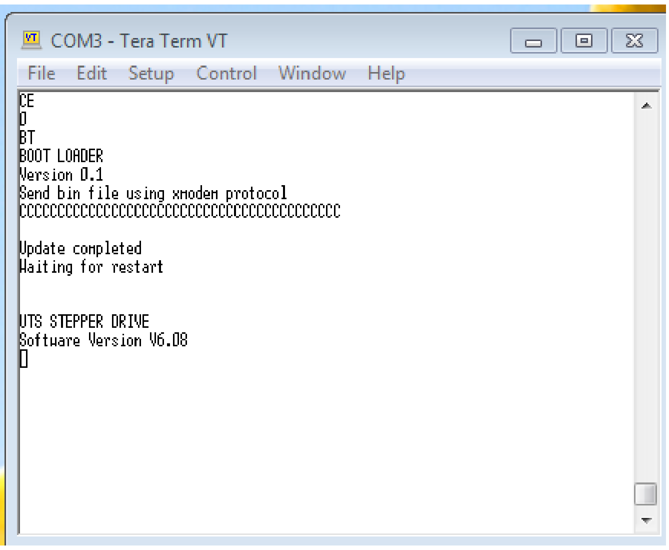


For a slightly faster download, the 1K option can be selected first (increasing the data packet size from 128 to 1k bytes).

Tera Term will show progress:



The new program will then be installed and started:



If the download fails, the boot loader will revert to the old program and restart it.

If an incorrect or corrupted .bin file is accidentally installed, the boot loader can be started manually by shorting pins 2 and 3 of J6 then powering up, allowing a valid .bin file to be downloaded.

Specifications

Operating Conditions

Parameter	Value	Notes
Nominal DC input voltage	20V	
DC operating voltage	12-24V	
Maximum transient DC voltage	30V	
Peak output current per phase	30A	Current sensors saturate at 50A.
rms output current per phase	20A	High air flow required
Short circuit protection current limit	38A	Adjustable with KH command. All phases disconnected on short.

Overload Characteristics

The overload characteristics depend on the motor speed relative to the Switch Speed, read with the RS parameter. For speeds below the Switch Speed, the motor tends to stall on overload, recovering when the load torque is reduced to approximately half the holding torque as set with the CH parameter. For speeds above the Switch Speed, the motor goes into torque limit as set with the CT parameter, reducing the speed to the point where the load torque matches the torque limit at which the speed will stabilise, or to the point where the speed falls below the Switch Speed. The characteristics are listed in the following table:

Speed	Overload Characteristic
Zero	Stalls for load torques greater than the Holding Torque Current (CH parameter).
0 to 1 x Switch Speed	Stalls for torques greater than a rising proportion the Torque Current Limit (CI parameter) plus a falling proportion of the Holding Torque Current (CH parameter) as speed rises.
Greater than 1 x Switch Speed	Goes into torque limit set by lower of the Torque Current Limit (CI parameter) or the maximum available current at that speed limited by the inductive impedance and the supply voltage. Holding current in *d*-axis gradually reduces to zero at 2 X Switch Speed.

Note that there is no sudden change in overload characteristics as speed changes. There is only a gradual change across the boundaries indicated in the table.

Reference

Parameter Commands

Motor Setup Parameters

`MP`

Motor Pole Pairs (= motor pole number ÷ 2). Default value is 7.

This parameter must be set to the correct value before motor operation or auto tune procedure.

`MK`

Motor KV Constant, rpm per Volt when supplied with 6 step current waveform, in rpm/V.

For a brushless DC motor with a torque constant rating TC which is peak torque over line to line current (current through two phases with third phase current zero) in Nm/A, the motor KV constant is approximately given by:

$$KV = \frac{1}{0.95}\frac{60}{2\pi}\frac{1}{TC} = 10/TC$$

the modulation level is the output voltage as a proportion of the DC bus voltage.

This is assuming the KV rating is defined as (speed in rpm) over (peak line-line no load voltage X 0.95) which is the definition most commonly used by motor manufacturers.

`MR`

Motor average resistance in Ohms measured line to line.

This also includes the inverter effective output resistance which is about 0.03 Ohms.

Default value is 0.1.

`ML`

Motor line to line inductance in millihenries. Default value is 0.005.

An incorrect value will result in the rotor phase estimate to be in error and maximum torque available at higher speeds will be reduced.

A very large error in this value may result in instability.

`MI`

Motor inertia in $g.cm^2$. This includes the load inertia. Default value is 50 which is typical of a mid-sized quad-copter motor such as the EMAX RS2205 with a 5 inch 2-blade propeller.

Dynamic performance depends on this parameter being correct, although an error as high as 50% has only a slight effect. Very large errors (up to x5 or more) can be tolerated but the motor may stall or over-shoot under high acceleration. For a load coupled by a very compliant shaft, setting MI to lower than actual values may work better to reduce load oscillations.

`MD`

Motor direction. Changes motor direction for both speed and position. This has the same effect as swapping two motor phases to change the motor direction. Internally, it just changes the sign of the speed and position set points.
0: normal direction, 1: reverse direction. Default value is 0.

`MF`

Motor differential resistance.

Difference between the V-W resistance and the average of the U-V and U-W resistances in Ohms.

Default value is 0.

This parameter is included to allow compensation for unequal motor resistance which may otherwise cause low speed torque pulsations. This parameter rarely needs adjustment from its zero default value.

Controller Operation Parameters

`CH`

Holding Current at zero and low speeds in Amps. This is the peak line to line current at standstill. Default value is 5. Usually set to a value higher than that required for the expected low speed load torque. For a quad-copter motor the only low speed load torque is the motor cogging torque.

With default settings of K6 and K7 parameters, the motor keeps the full holding current applied up to 1.0 times the Switch Speed (RS parameter) then ramps it down to zero at 2.0 times the Switch Speed.

`CJ`

Hold current reduction factor at zero speed. Range 0.1-1.0. Default value is 1.0. Only works in speed control mode and when parking a propeller in pulse input mode for a drone.

The reduction can be applied to reduce motor heating while the motor is stationary. Can also be used when holding a propeller stationary in pulse input mode.

Note there is no delay in increasing the holding current when speed goes above zero.

`CI`

Maximum torque in terms of peak line to line current in Amps. Range 0-30. Default value is 20. This sets the maximum torque when operating above the Switch Speed. When the q axis current exceeds this value, the drive will go into torque limit mode, reducing speed to maintain this torque. Above the Switch Speed, the motor will tend to go into torque limit on overload. Below the switch speed, the motor will tend to slip poles under a torque overload greater than the holding torque limit set by the holding current (CH parameter).

The transition between the two torque limit modes is gradual and is set by the K6, K7, K8 and K9 parameters.

This torque limit tends to operate slowly, so for transient torques, fast acting limits are imposed on the q axis current error as determined by the KA, KI and KL parameters.

`CQ`

Operating mode when in flux weakening. Set to 1 for high dynamic operation. Set to 2 to make available extra torque at high speeds at the expense of ability to handle very fast transients or very high acceleration without slipping poles. Default value is 2. This parameter is only relevant for high inductance motors. It has no effect for low inductance motors such as quad-copter motors.

`CW`

Extra *d* axis current at all speeds. Used for advanced tuning, normally set to 0. The *d* axis current is normally set to the holding current at low speed (determined by the CH parameter) reducing to 0 at high speeds. The CW parameter allows for extra *d* axis current to be applied, Its value can be positive or negative.

`CD`

Controller maximum flux weakening current in Amps. To use flux weakening, the impedance of the motor inductance at top speed when flux weakening would begin must be greater than the resistance. This is not the case for most quad-copter motors so this value should be kept at the default value of 0.

Stall Detection Parameters

`FL`

Stall detect sensitivity. Flux error as a proportion of motor flux at which a stall is registered and the motor stopped. Default value is 0.2.

`FS`

Stall speed. Speed as a proportion of the Switch Speed (RS parameter read only) below which stall detection sensitivity is gradually reduced. Default value is 4.0.

Input Interface Parameters

`IS`

Pulse input throttle input value to speed conversion curve. 0: Speed proportional to the square root of the throttle value, giving thrust proportional to throttle value for a propeller load. 1: Speed linearly proportional to the throttle value. Default value is 0.

The maximum value is set by the VM parameter.

`IH`

Residual holding current applied after the motor is parked at the stop position at zero speed. If this is zero, the motor controller is disabled after parking.

`IA`

Arm mode maximum pulse width. When in PWM mode, this is the pulse width in microseconds below which the throttle is in arm mode. Default value is 1050 us.

`IB`

Zero speed pulse width. When in PWM mode, this is the pulse width in microseconds for zero speed. Default value is 1100 us.

`IC`

Full speed pulse width. When in PWM mode, this is the pulse width in microseconds for maximum speed. Default value is 1950 us.

Hardware Parameters

`HD`

Inverter PWM Dead Time in microseconds. Default value is 0.2. This is a manufacturing parameter.

HL

Double PWM carrier frequency. Set to 0 for carrier frequency of 20kHz. Set to 1 for carrier frequency of 40kHz. The higher frequency gives lower current ripple and thus lower motor

HT

Threshold current ripple value as proportion of calculated value at which dead time compensation starts. Default value is 1.0.

HG

Controls change in dead time verses current for low current values. Default value is 1.0.

HT and HG parameters can be adjusted by running a motor below the switch speed and monitoring the current waveforms using the waveform capture system. These parameters can be adjusted for best current waveforms. Refer to the Drive Description document for details.

HS

V current sensor scaling adjustment factor. This is used to adjust the V sensor scaling to match the W current sensor. Default value is 1.0.

Tuning Parameters

AL

Test current in Amps for the pulse inductance measurement. Default value 2 A.

Read Only Parameters

RA

Filtered V phase sensor current. Used for current sensor calibration.

RB

Filtered W phase sensor current. Used for current sensor calibration.

RT

Power MOSFETs temperature in degrees Celsius.

RV

Inverter DC bus voltage in Volts. 1% accuracy.

RN

Motor natural resonance converted to rpm.

This parameter is included for user convenience.

RM

Controller Actual Speed in rpm. Reads actual speed of rotation. This will be the same as the set point speed except when operating in torque limit or when accelerating or decelerating. This reading is included mainly for checking actual speed when operating in a constant torque limit for instance during a continuous overload.

RD

D axis current in Amps. Filtered amplitude of the magnetising or d axis current scaled to the peak phase current times √3/2. Filter time constant is 0.5 seconds.

RQ

Q axis current in Amps. Filtered amplitude of the torque or q axis current scaled to the peak phase current times √3/2. Filter time constant is 0.5 seconds.

Note the phase rms current can be calculated by:

$$I_{rms} = \sqrt{\frac{\mathrm{RD}^2 + \mathrm{RQ}^2}{1.5}}$$

RF

Motor natural resonant frequency in Hz.

This parameter is included for user convenience.

RZ

Motor resonant impedance in Ohms. Note that for brushless DC and servo motors this is the phase impedance. Line to line value is double this.

This parameter is included for user convenience.

RS

Switch Speed in rpm. Speed above which the holding current starts to decrease to transition to full back emf control of the rotor position.

RR

Resistance reading when stationary for adjusting MR (motor resistance) parameter.

RP

Pulse width input when in pulse width control mode.

RI

Measured value of inertia in $\mathrm{gm.cm}^2$ calculated after a positive stepped change in speed. Must wait 2 seconds after the step speed change before this parameter is updated. Used for motor inertia tuning.

RJ

Acceleration current in amps just before acceleration stopped due to a stepped change in speed. Used for motor inertia tuning.

RK

Expected q axis acceleration current required for the acceleration rate set by the PA parameter. Provided to assist in setting the PA acceleration rate parameter.

RH

Estimated peak current during L pulse measurement test.

RL

Inductance in milliHenries measured by L pulse measurement test.

Position Mode Profile Setting Parameters

PT

Position Zero Point. This parameter provides a fine adjustment of the position zero point with respect to the electrical or internal position zero in units of cycles (1 cycle = 2 pole pitches). Floating point values are accepted allowing ultra-fine adjustment. Default value is 0.

PR

Position Resolution in steps per revolution. This is the unit of measurement used for the position set points. Default value is 60.

PN

Position range in electrical cycles. When the position value exceeds half the PN value, it folds back to -half the PN value. When set to one motor revolution, the motor rotor can be moved to a given position in position control mode after stopping under speed control. When set to zero, range is set to its maximum value (2^32). Default value is 7 giving a range of ±3.5 pole pairs about zero. To allow overhead for the position control loop to operate the range is actually reduced from its +/- limits by 11.25 electrical degrees.

If positioning to exactly half a rotation away from zero is required, it would be better to set PN to twice the number of pole pairs per revolution. The disadvantage of this is that the rotor may turn by more than one revolution to reach its final position.

The controller's internal measurement of position is continuously updated whenever the rotor moves either under position control or speed control. By setting the position range to the number of pole pairs per revolution the rotor can be set to an exact position in a revolution after running under speed control - useful for parking a propeller in the a known position after it stops spinning.

PA

Profile Acceleration in rpm/sec. This is the acceleration limit when operating in position control mode. If set too low (usually much less than 1) speed steps will be noticeable due to internal digital resolution limit. If set too high the torque limit will dictate the acceleration rate. Default value is 6000.

PD

Profile Deceleration in rpm/sec. Same limits as for PA. Also, the motor will regenerate when decelerating, so if it is set too high dangerous DC bus voltages could result unless controlled by the KC and KD parameters. Default value is 6000.

PS

Profile Speed in rpm. Sets the maximum speed in position control mode. Together with PA and PD, defines the trapezoidal speed profile taken for a change in position. Default value is 8000.

Speed Mode Profile Setting Parameters

VM

Maximum speed setting in rpm. Default is 30000. Note that the speed is adjustable in steps of CM ÷ 30,000 making this step size the speed resolution and the lowest possible speed setting.

The maximum recommended value of this setting is the value that gives an eRPM value, which is the rpm value times the motor pole pair number (set with the MP parameter), of 300,000.

VA

Maximum Acceleration in speed control mode in rpm/sec. If set too low (usually much less than 1) speed steps will be noticeable due to internal digital resolution limit. If set too high (usually greater than 300000 for an unloaded stepper motor), the torque and output voltage limits will dictate the acceleration rate. Default value is 6000.

VD

Maximum Deceleration in speed control mode in rpm/sec. Same limits as for VA. Also, the motor will regenerate when decelerating, so if it is set too high dangerous DC bus voltages could result unless controlled by the KC and KD parameters. Default value is 6000.

VB

Proportional reduction in the Maximum Acceleration (VA parameter) at start up from zero speed up to the switch speed as read by the RS parameter, which is the speed which is high enough for the load torque to be reliably measured and compensated for. Values are set from 0 to 1 with a default value of 1.

This parameter has been added to allow reliable starting when the actual motor inertia differs greatly from the motor inertia setting (MI parameter). This is useful for variable inertia loads. This parameter should be set by trial and error to obtain reliable starting.

VE

Proportional reduction in the Maximum Deceleration (VD parameter) during stopping from the switch speed as read by the RS parameter down to zero speed. Values are set from 0 to 1 with a default value of 1.

This parameter has been added to allow reliable stopping when the actual motor inertia differs greatly from the motor inertia setting (MI parameter). This is useful for variable inertia loads. This parameter should be set by trial and error to obtain reliable stopping.

Normally Unchanged Constants Parameters

K0

Torque disturbance damping constant. Default value 1.0. Range 0.1 to 2.0. The value of 1.0 should be optimum for all applications. This may have to be increased to overcome load resonances. For stepper motors, it may have to be reduced to stop unstable operation due to heavy motor saturation at high holding current settings.

K1

Torque disturbance normalised integral gain constant. Default value is 0.25. Range 0.1 to 0.8. The default value should be optimum for all applications. Raising to 0.5 will halve the torque change response time but may cause rougher running due to higher current measurement noise sensitivity.

K2

Torque disturbance normalised second integral gain constant. Default value 0.125. Range 0.1 to 0.8. Should be set to half the K1 value.

K3

Zero speed feedback gain constant of the torque disturbance second integral controlling DC gain. DC gain is 1/K3. Affects settling time after stopping. Default value 1.0. Range 0.1 to 1.0. The value of 1.0 should be optimum for all applications. Value of 0.25 may improve stepper motor performance under step loads at low speed.

K4

Position controller frequency response roll-off constant as proportion of natural frequency $\omega_n = \lambda_r / \sqrt{LJ}$. Also part of speed controller frequency response (=K4.K5. ω_n). Default value is 0.5. No range limit but normally set between 0.01 to 0.5. The default value is usually optimum. This gives fastest frequency response without overshoot. It may be reduced of a slower frequency response is desired.

K5

Position controller damping constant. Also part of speed controller frequency response (=K4.K5. ω_n). Default value is 1.0. Range 0.5 to 2.0. The default value should be optimum for all applications.

K6

Speed at which the *d* axis holding current (set with CH command) begins to drops to zero as multiple of the switch speed (S_S). Default value is 1.0. Range 0.1 to 2.0. Can be increased for difficult starting conditions or when an inertia mismatch is possible. The default value is usually optimum.

K7

Adjusts the speed at which the *d* axis holding current (set with CH command) finally drops to zero as multiple of the switch speed relative to K6. Thus actual speed at which the *d* axis current drops to zero is (K6 + K7)S_S. Default value is 1.0. Must be greater than 0. Range 0.1 to 2.0. Can be increased for difficult starting conditions or when an inertia mismatch is possible. The default value is usually optimum.

Parameters K6, K7, K8 and K9 have default values set to maximise the chance of recovery from a large step load change at low speeds. If such a load change is not expected, their values can be reduced to start the reduction in holding current at lower speeds to reduce motor heating.

K8

Speed at which the feedback gain controlling second integral DC gain (see K3 parameter) begins to drops to zero as multiple of the switch speed (see K6 parameter). Default value is 1.0. Range 0.1 to 2.0. Can be increased for difficult starting conditions or when an inertia mismatch is possible. The default value is usually optimum. K8 is usually set to the value of K6.

K9

Speed at which the feedback gain controlling second integral DC gain finally drops to zero as multiple of the switch speed (see K6 parameter) relative to K8. Thus actual speed at which the feedback gain drops to zero is (K8 + K9)S_S. Default value is the same as for K7. Must be greater than 0. Range 0.1 to 2.0. Can be increased for difficult starting conditions or when an inertia mismatch is possible. The default value is usually optimum. K9 is usually set to the value of K7.

KA

Read Only parameter. Shows the actual clipping limit imposed on the q axis current error

determined by the lower of the two settings by the KI and KL parameters.
The q axis current error is exceeded when the motor is suddenly stalled. When this occurs the q axis current error to speed correction gains are greatly increased to ensure the controller motor position tracks the actual motor position in such a situation. This also results in the peak current error being effectively clipped to this value.

KF

Proportion of natural resonant speed for reference speed above which the output speed is prevented from reversing due to undershoot when operating in torque limit. This feature is added to aid recovery from a sudden braking load. The default value should be optimum for all applications. Default value is 0.5. Range is from 0 to 1.

KI

Maximum value in Amps of *q* axis current error before clipping begins unless under-ridden by KL setting resulting current error. Default value is 0.3 for stepper motors, 10 for brushless DC and servo motors which effectively disables it.

KR

Effective drive output resistance including motor resistance compensation as a proportion of the natural resistance $R_n = \lambda_r \sqrt{L/J}$ at zero speed to control zero speed damping. Default value is 1.0. Range is 0.5 to 2.0. The default value should be optimum for all applications. Has no effect if motor resistance is greater than this value.

KL

Maximum value of the sine of the torque angle before current feedback gain boost occurs to limit any further increase unless under-ridden by KI setting. Default value is 0.4 for stepper motors, 0.1 for brushless DC and servo motors. This prevents pole slipping under sudden and large load torque changes.

KG

Gain boost applied to the q axis current feedback when torque angle exceeds KL setting or q axis current error exceeds KI setting. Default value is 8.0 for stepper motors, 10.0 for brushless DC and servo motors.

KP

Maximum Q axis voltage as a proportion of the maximum output voltage if parameter CQ is set to 1. Default value is 0.7. Range is 0.5 to 0.95.

KQ

Maximum Q axis voltage as a proportion of the maximum output voltage if parameter CQ is set to 2. Default value is 0.9. Range is 0.5 to 0.95. Reducing this value may improve stability under high load and high acceleration at the expense of maximum available torque at higher speeds.

KV

Maximum output voltage as a proportion of the available DC bus voltage. Default value is 1.1 which is 10% over-modulation. If the output waveform must always stay sinusoidal (no over-modulation) then set KV to 1.0. Range is 0.5 to 1.5 allowing 50% over-modulation. Not recommended to go above 1.1.

KT

Ramp up time in milliseconds per Amp for holding current at start up. Used to avoid sudden jerks of the motor when rotor snaps into alignment at start up. Default value is 10.

KB

Speed limiting feedback loop frequency response as a proportion of the natural resonant frequency. Default value is 1.0.

KE

Error in change of estimated resistance from heating as a proportion that will result in a error from the rotor angle error calculator of 15° at the switch speed. This is used internally to calculate the switch speed (which can be consequently read using the RS parameter). Default value is 0.25. Note that motor resistance estimated value is automatically corrected whenever the motor speed drops to below KX times switch speed so the KE parameter only needs to consider the expected maximum change in resistance between times when the rotor speed drops to below this speed.

KX

Speed as a proportion of switch speed below which automatic correction of the estimated resistance is undertaken. Default value is 0.1.

KS

Proportion of the natural resonant speed to which the switch speed is set if this is higher than the switch speed setting obtained from the resistance error and the KE setting. Default value is 0.5 for stepper motors, 1.0 for brushless DC and servo motors.

KC

DC bus voltage at which the negative torque current limit starts ramping down to prevent over voltage from regeneration. Default value is 12.0. Currently turned off.

KD

DC bus voltage at which the negative torque current limit ramps down to zero to prevent over voltage from regeneration. Default value is 24.0. Currently turned off.

Note the gradual ramp down of the regeneration limit allows co-ordination with other controllers on the same DC bus.

KH

Absolute current limit in Amps. Current above which all output transistors are turned off and the controller is put into the off mode with SE=0. Default value is 38.

KJ

Measured MOSFET temperature in °C at which the over temperature current limit starts ramping down from the maximum ADC current (KM parameter, 50A default for this hardware). Default is 100.

KK

Measured MOSFET temperature in °C at which the over temperature current limit ramps down to zero. Default is 125. When setting this, keep in mind the temperature sensor is specified to 125°C maximum.

Set Point Commands

Set point commands control the motion of the motor.

The input method is the same as that of a Parameter input using the RS232 interface, but differs in that the number format depends on the command. Some are floating point, some are integer only.

Floating point set point commands are entered using the same format as for parameters. Integer commands require an integer value in the range -2147483648 to 2147483647.

Integer values are in units of steps as set by the `PR` parameter.

Set point commands only take effect after the controller is enabled with SE=1 and always default to zero.

The set point currently in operation is the last set point that was modified, so to change to a new set point type, just enter a value for that set point. When the controller is enabled with SE=1, the speed set point is in operation with speed set to zero.

The set point commands are listed below:

`SE`

Controller enable mode:

0: Controller disabled

1: Controller enabled normal running mode

2: Controller enabled with stall detect disabled. Used for tuning

3: Inductance measurement. Reverts to SE0 mode when finished

An output pulse applied between V+ and U,W- and finished when V current measures 2A as set by AL parameter.
The current is measured twice by the V A/D current sensor at 7us and 21 us after the end of the pulse.
These measurements are used to estimate the peak current at the end of the pulse.
The peak current, the pulse width and the DC Volts are then used to calculate the inductance.
The measured inductance can be read with the RL parameter.
Note that at low inductances, the peak current will be much greater than AL setting due to the 2us measurement delay inherent in the current sensor.

9: Current sensor calibrate

The controller is put into current sensor calibrate mode. The U phase is disconnected and a fixed current set to the holding current (CH parameter) is passed between the V and W phases which have the two A and B current sensors. Each current sensor reading can be measured using the RA and RB parameters and used to adjust the gain of the A sensor as stored in the HS parameter to calibrate.

`ST`

Set Torque in equivalent peak phase current in Amps. Floating point format. Range -3.0 to 3.0. This is experimental in the current software version so may not work correctly.

`SA`

Set Acceleration in equivalent inertial torque current in Amps. Floating point format. Range -3.0 to 3.0. This is experimental in the current software version so may not work correctly.

SS

Set Speed in rpm. Floating point format. Maximum speed is set by the VM command.

SP

Set Absolute Position in steps, step size set by the CR command. Integer format. Range set by CN command. Absolute zero is the motor position when the controller was last enabled with the SE command or the motor position when the SZ command was last executed.

SR

Set Position Relative to the last position in steps, step size set by the CR command. Integer format. Range -2147483648 to 2147483647.

SF

Set pulse input control off.

1: Disable pulse input to allow manual speed and position control, mainly to allow tuning to be undertaken.

0: Enable pulse position control.

Function Commands

Function commands have no argument. They are just a two letter command followed by a carriage return.

the modulation level is the output voltage as a proportion of the DC bus voltage.the modulation level is the output voltage as a proportion of the DC bus voltage.Function commands are listed below:

SZ

Set Absolute Zero Position to the current position. Used with the SP set point command. This command is not implemented in the current software version. Use the SE command instead to set absolute position.

EB

Eeprom Backup. Saves the current parameters to non-volatile memory. These values are automatically loaded when the controller is powered up. This command is blocked unless SE command is set to 0.

ER

Eeprom Restore. Restores last saved parameters from non-volatile memory. This command is blocked unless SE command is set to 0.

ED

Restore Defaults. Restores parameter default values. Does not affect values previously backed up in non-volatile memory. This command is blocked unless SE command is set to 0.

TL

Stop data collection for plotting pre trigger. 8k X 4 channel data up to time of TL is stored.

TF

Start data collection for plotting post trigger. 8k X 4 channel data from time of TF is stored.

`TX`

Send plot data over serial port.

`TM`

Plot arm. Re-arm triggers for new data collection.

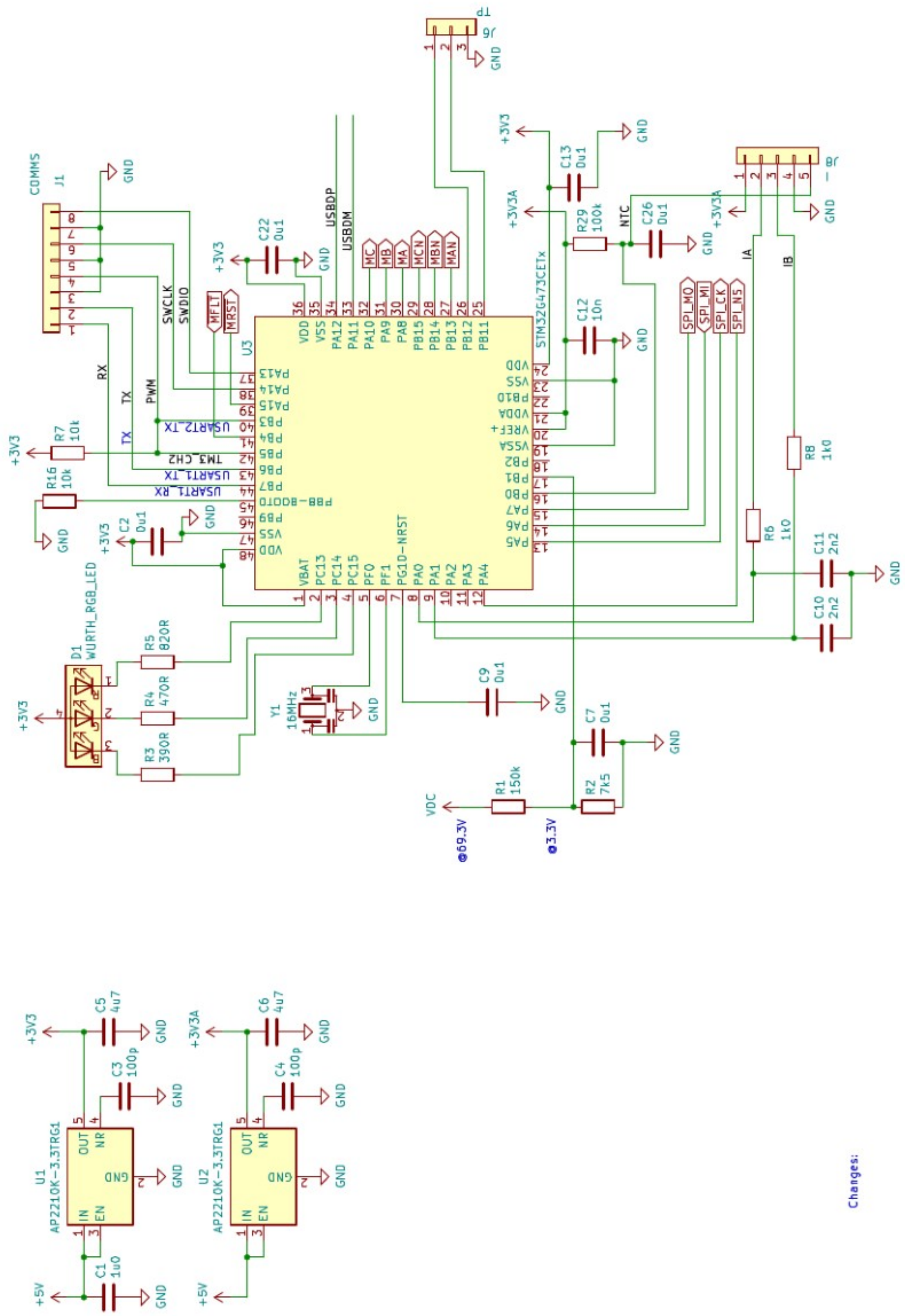
`ZE`

Resets phase error between the internal position and an external incremental encoder to zero for DAC phase error output. Operates only when SE=1.

`LP`

List all parameters and their values. Note parameters used for software debugging may also be listed in beta versions of the software.

Schematics



COMMS
J1
GND
+3V3
R7
10k
R16
10k
C2
0u1
C22
0u1
USBDP
USBDM
SWCLK
SWDIO
RX
TX
PWM
MFLT
MRST
U3
STM32G473CETx
USART2_TX
TM3_CH2
USART1_TX
USART1_RX
PB8-BOOT0
VBAT
PG10-NRST
MC
MB
MA
MCN
MBN
MAN
J6
TP
+3V3A
C13
0u1
R29
100k
NTC
C26
0u1
C12
10n
J8
IA
IB
SPI_MO
SPI_MI
SPI_CK
SPI_NS
R8
1k0
R6
1k0
C11
2n2
C10
2n2
D1
WURTH_RGB_LED
R5
820R
R4
470R
R3
390R
Y1
16MHz
C9
0u1
C7
0u1
VDC
R1
150k
R2
7k5
@69.3V
@3.3V
U1
AP2210K-3.3TRG1
U2
AP2210K-3.3TRG1
+5V
C1
1u0
C3
100p
C4
100p
C5
4u7
C6
4u7
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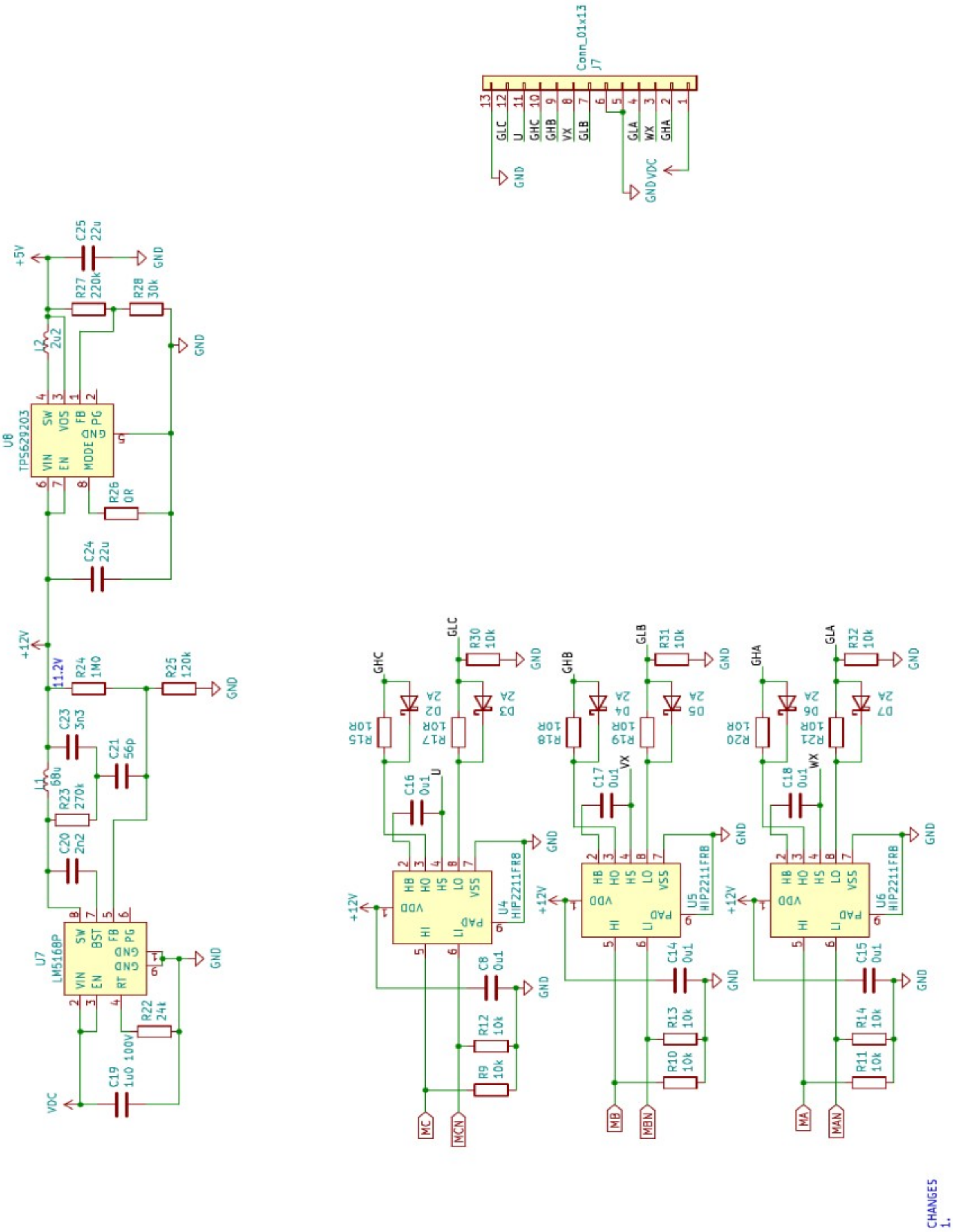
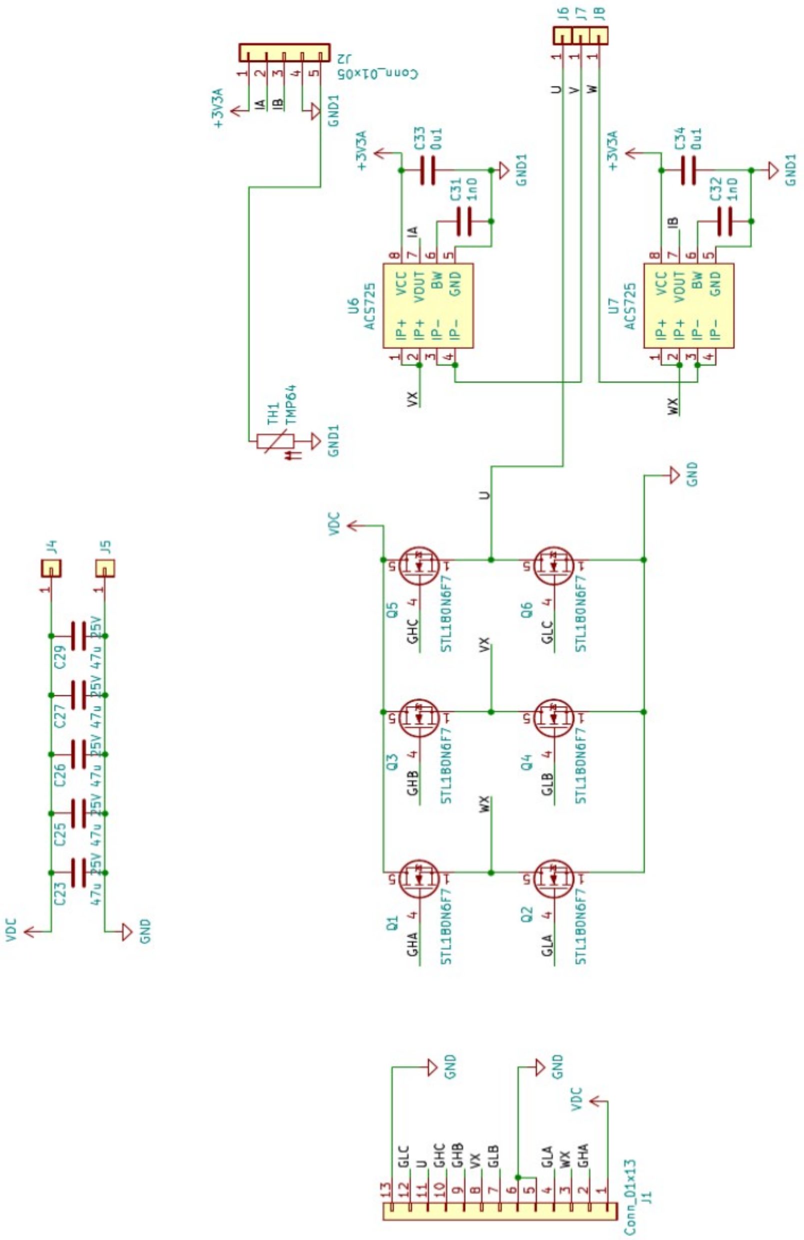


Conn_01x13
J7
GLC
U
GHC
GHB
VX
GLB
GLA
WX
GHA
GND
VDC
U8
TPS629203
SW
VOS
FB
PG
VIN
EN
MODE
+5V
C25
22u
R27
220k
R28
30k
L2
2u2
R26
0R
C24
22u
+12V
11.2V
R24
1M0
R25
120k
C23
3n3
C21
56p
L1
68u
R23
270k
C20
2n2
U7
LM5168P
BST
RT
R22
24k
C19
1u0 100V
U4
HIP2211FR8
U5
HIP2211FR8
U6
HIP2211FR8
HB
HO
HS
LO
VSS
VDD
HI
LI
PAD
R15
10R
R17
10R
R18
10R
R19
10R
R20
10R
R21
10R
D2
D3
D4
D5
D6
D7
2A
R30
10k
R31
10k
R32
10k
C16
C17
C18
0u1
C8
C14
C15
R9
R10
R11
R12
R13
R14
10k
MC
MCN
MB
MBN
MA
MAN
CHANGES
1.


J2
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+3V3A
IA
IB
GND1
J6
J7
J8
U
V
W
C33
0u1
C34
0u1
C31
1n0
C32
1n0
U6
ACS725
U7
ACS725
VCC
VOUT
BW
GND
IP+
IP-
VX
WX
TH1
TMP64
VDC
GND
Q1
Q2
Q3
Q4
Q5
Q6
STL180N6F7
GHA
GLA
GHB
GLB
GHC
GLC
J4
J5
C23
C25
C26
C27
C29
47u 25V
J1
Conn_01x13