The Handiman's Guide to the DJI V.2 ESC

Theory, Troubleshooting, and Repair

by Paul Harden

Introduction. *This guide is the result of repairing several DJI V.2 ESC (Electronic Speed Control) boards suffering premature failures and repaired at the component level. It is shared for those desiring to do the same. It contains some basic theory of operation, ESC board replacement, trouble-shooting steps, oscilloscope waveforms, the schematic diagram (reverse engineered), and PCB parts layout.*

Basic Theory of Operation.

The motors are 3-phase motors with 3 sets of coil windings DJI labels A, B and C. The electrical symbol is shown in **Fig. 1**. In reality, there are 12 coils and 14 fixed magnets as shown in **Fig. 2**. The "A" motor winding is actually four orthogonal windings, as are the "B" and "C" windings, offset by 30 degrees. It takes 168 steps (12 x 14) for one motor revolution.

These are "outrunner" motors, meaning the *outside* sleeve with the fixed magnets is what rotates (the rotor) and the coil windings are fixed (stator), wired direct to the ESC, for a *brushless* motor.

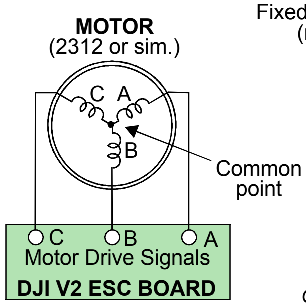


Fig. 1 – Electrical diagram of 3-phase motor and ESC

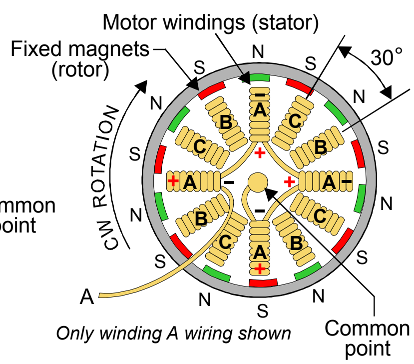


Fig. 2 – Mechanical arrangement of motor, coil windings and rotor

The idea is to energize a coil winding positive (POS=N pole) as it approaches a south (S) magnet, and negative (NEG=S pole) as it approaches a north (N) magnet pole to cause the windings and magnets to attract. This sequenced magnetic attraction is what makes the motor rotate. It is the job of the ESC to energize the windings, in the proper sequence and polarity, to produce the motor speed, direction, and power desired. This 6-step sequencing of the windings is called commutation and shown in **Fig. 3**.

Each ESC board receives *motor control signals* from the **Main Control Board/NAZA-M** controller. This signal is a *pulse width modulated* (PWM) 400 Hz square wave. As the pulse width gets wider, more power is provided to the motors.

Motor Winding	Commutation Sequence → 1	2	3	4	5	6
A	POS	POS	FLOAT	NEG	NEG	FLOAT
B	FLOAT	NEG	NEG	FLOAT	POS	POS
C	NEG	FLOAT	POS	POS	FLOAT	NEG
Windings						
ON →	AC	AB	CB	CA	BA	BC
OFF →	B	C	A	B	C	A

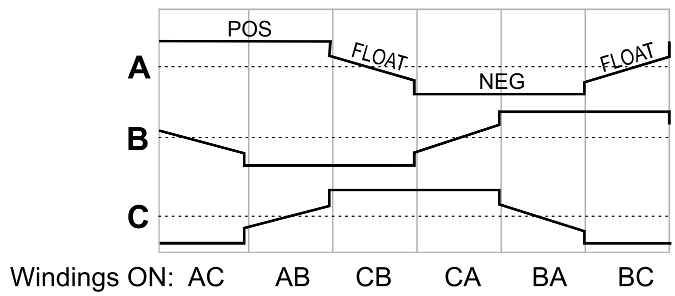


Fig. 3 – Commutation Sequence

The 8051 microprocessor unit (MPU) on the ESC board converts the PWM motor control signal into the six sets of sequential *motor drive signals*. **Fig. 3** shows that two windings are energized (ON) and one is OFF at any given instant.

The MOSFETs turn the selected windings ON and OFF. They convert the 3v MPU drive signals into the battery 11v high current drive for the motor windings. Two MOSFETs are turned ON at a time to route the current through two motor windings at a time. **Fig. 4** shows the case of windings A and B being energized (sequence #2) by Q13 sourcing and Q12 sinking the current to complete the circuit. Windings A and B are also energized in sequence #5 by Q11 as the source and Q12 the sink to reverse the magnetic polarities of the two windings.

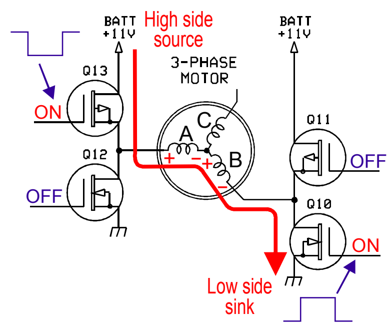


Fig. 4 – Current flow for sequence 2, windings A and B energized.

BEMF. Note that while windings A–B are ON, winding C is OFF or *floating* and generates a voltage pulse (called BEMF) that is used by the MPU to derive the *sensorless* position of the stator and rotor to make any adjustments in motor speed or power.

Oscilloscope waveforms on the following pages show this sequential commutation process in better detail or for troubleshooting purposes.

❶ Testing and ESC Replacement Preparation

1) Remove props; remove P2V+ top cover for ESC board access; keep GPS cable plugged in; remove gimbal clamp.
2) P2V+ normal turn on: RC remote on, then P2V+ quadcopter battery on; motors off. Range extender not needed.
3) Check +11v ESC input voltage and +3.3v microprocessor (MPU) voltage.

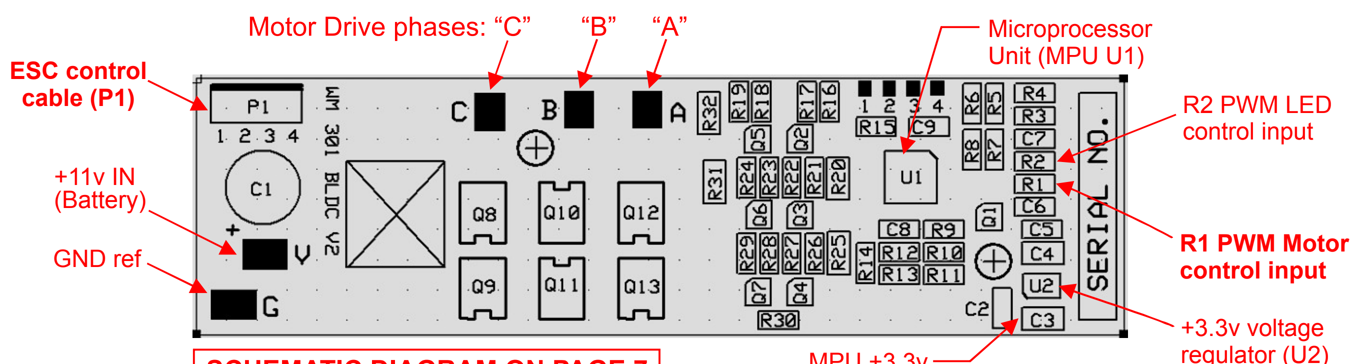
FAIL: No +11v: Check battery and +11v and GND wires soldered to ESC. **No 3.3v**: Check U2 voltage regulator.

❷ ESC Motor Control Inputs

*The **Main Control Board/NAZA-M** issues separate motor control signals to each ESC board and motor based on the throttle, yaw, and direction commands from the RC remote joy sticks. **ESC motor control signals** are 400Hz pulse width modulated (PWM) square waves. The microprocessor (MPU U1) internal clock "counts" how long the pulse is HI to control the speed of the motor from off (<1mS or <40% duty cycle) to full throttle (about 1.8mS or 75% duty cycle). PWM allows for precise motor speed control. PWM signal is on the 4-pin connector P1 and cable from the Main Control Board.*

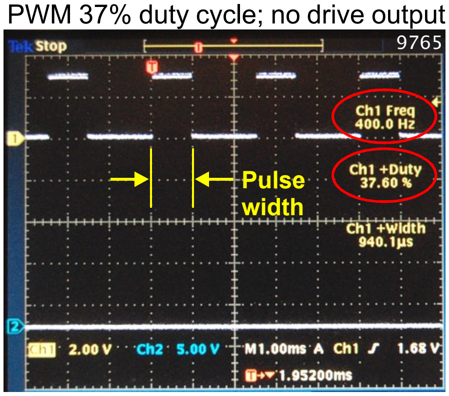
1) **Oscope** setup: Ch.1 2v/div; Ch.2 5v/div; sweep 1mS/div; trigger: Ch.1. PWM signal best seen at R2.
2) With motors off, PWM pulse width (PW) should be <1mS or about 37% duty cycle. (**Fig. 5**)
3) Turn on motors to idle. PW should be about 1.2mS or 47% duty cycle with motor drive signals active. (**Fig. 6**)
4) Increase motor speed. PW approaches about 1.8mS or 70-75% duty cycle at full throttle. (**Fig. 7**)
5) Turn off motors (leave P2V+ powered on). PWM returns to 37% duty cycle and motor drive A, B and C signals off.

FAIL: No PWM signal at R2 indicates a bad cable at P1 or a problem with the Main Control Board, not the ESC.



SCHEMATIC DIAGRAM ON PAGE 7

Fig. 5 – **P2V+ ON; motor OFF**
PWM 37% duty cycle; no drive output

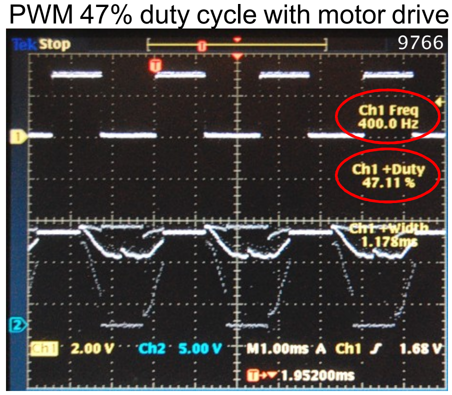


CH 1: PWM motor control input (at R1)
CH 2: Motor drive "A"

OK: 400Hz PWM signal at 37% duty cycle (about 1mS) indicates P2V+ is ready to fly (GPS, home point set, etc.)

Fail: If no 400Hz PWM, check GPS cable and for 6+ satellites, ESC control cable connected at P1, or possible failure of Main Control Board.

Fig. 6 – **P2V+ on; motor on idle**
PWM 47% duty cycle with motor drive

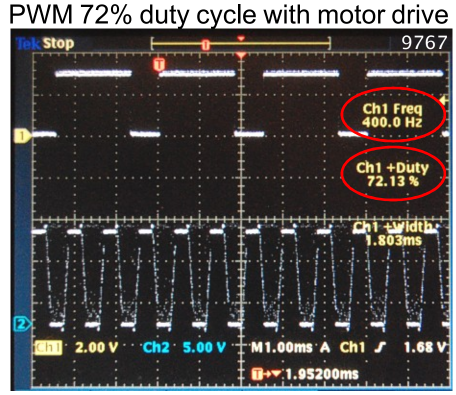


CH 1: PWM motor control input (at R1)
CH 2: Motor drive "A," "B" and "C"

OK: 400Hz PWM at 47% (about 1.2mS) indicates ESC and motors at proper idle speed.

Fail: If no motor drive output on phase "A," "B" and/or "C," problem is likely the MOSFETs for the failed phase(s).
Goto Step 3 - Motor drive signals

Fig. 7 – **P2V+ ON; motor full throttle**
PWM 72% duty cycle with motor drive



CH 1: PWM motor control input (at R1)
CH 2: Motor drive "A," "B" and "C"

OK: 400Hz PWM signal at >70% duty cycle (about 1.8mS) indicates P2V+ speed control is functioning normally.

Fail: If speed does not ramp up to full throttle, there may be a problem in the commutation or BEMF sense circuitry.
Goto Step 5 - BEMF sensing