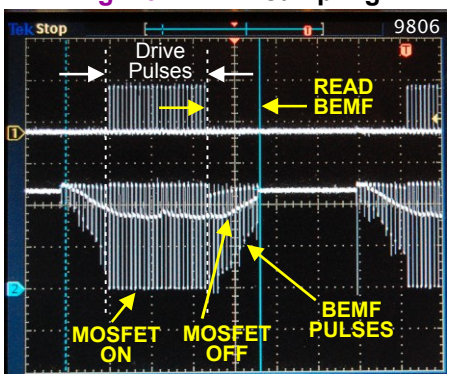
❺ BEMF Sensorless Rotor Sensing

Fig. 15 –BEMF sampling



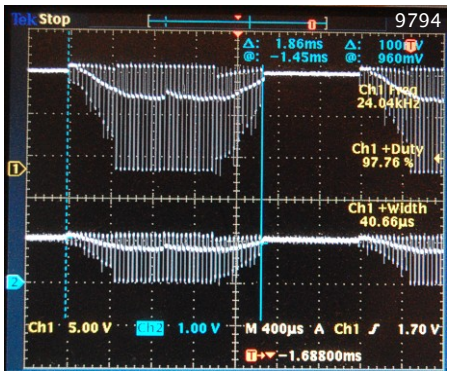
*The **motor drive signal** to a winding, when the low-side MOSFET is ON, is a burst of numerous pulses for precise speed control. When that MOSFET turns OFF, that drive line is floating. However, the rotor magnets are still moving, and moving past the floating winding, now acting as a generator (producing a voltage) and inducing the drive pulses from the two other active windings. This induced voltage is called the **back electromagnetic force** voltage, or BEMF. The MPU uses the BEMF voltage from the 3 motor drive lines to determine exactly where the rotor is in relation to the windings and adjusts the speed, up or down, as needed. This technique is called a **sensorless motor**, as no physical sensors are used to determine the position of the rotor. **Fig. 15** shows the winding drive pulses when the MOSFET is ON, and the induced BEMF pulses while the MOSFET is OFF, and the period of time BEMF pulses are "read" by the MPU.*

The 3 BEMF sensor voltages, about 11v, are applied to voltage dividers R7-R3 (A winding), R5-R4 (B), and R9-R11 (C) to form 1v BEMF pulses for the MPU (a 3.3v device). However, this voltage is not referenced to ground, but to the common node of the windings (the junction of the 3 windings - which has no electrical connection). The 3 BEMF voltages are summed together by R10, R6 and R8 and applied to the MPU for determining the common node voltage and the reference voltage (Vref) to a voltage comparator internal to the MPU. This comparator, and varying Vref, is a zero-crossing detector of the BEMF, effectively removing the BEMF "ramp" for accurate rotor position determination.

BEMF feedback is an important function of the ESC in properly controlling the speed and power control of the motor. With this scheme, speed and power adjustments are being applied to the motor constantly. If you've wondered how the Phantom can hover in place "solid as a rock," this is why. The motor speed is being checked and corrected constantly and several times within one motor revolution. BEMF is disabled during motor start up until idle speed is stable.

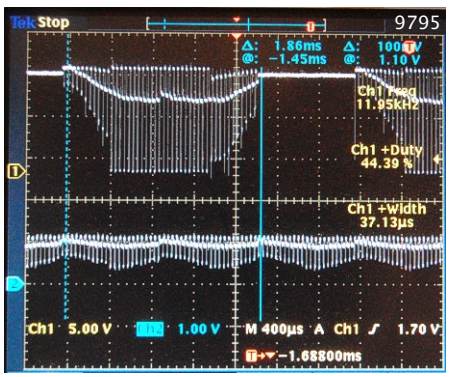
1) **O-scope setup**: Ch.1 5v/div; Ch.2 1v/div; sweep 400uS/div; trigger: Ch.1
   Ch. 1 to motor drive "A" signal
2) Turn on motors to idle. Place Ch. 2 probe on Motor Drive "A"
3) Ch. 1 probe to junction of R7–R8, drive "A" BEMF (**Fig. 16**)
4) Ch. 1 probe to junction R6–R8, BEMF common node sum (**Fig. 17**)
5) Repeat step 3 for drive and BEMF "B" (R5–R6) and "C" (R9–R10)

Fig. 16 –BEMF Voltage Divider



CH 1: Motor drive "A"
CH 2: BEMF, junction of R7-R8

Fig. 17 –BEMF Common Node Sense



CH 1: Motor drive "A"
CH 2: BEMF sum, junction R6-R8

OK: BEMF feedback sensing and the MPU are functioning normally

Fail: **If one of the BEMF signals is missing or incorrect (unlikely) with the motor running,** check the resistors in the associated voltage divider network. If BEMF OK at the MPU, it may be a failure in the MPU firmware. Lastly, turn off motor and move rotor by hand for smooth, consistent rotation. Any unusual resistence could indicate a bad bearing or debris (dirt, sand) in the motor.

❻ The LEDs

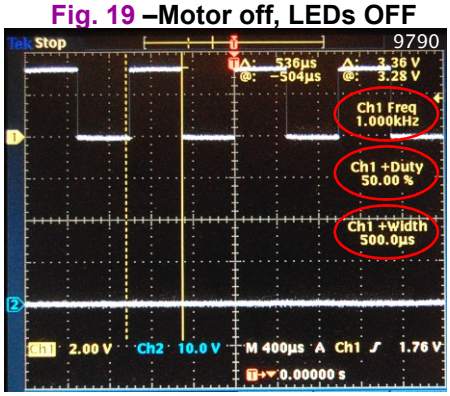
Fig. 18 –PWM LED Control Signal

Pulse width	Duty Cycle	LED color
500uS	50%	LEDs OFF
400uS	40%	Yellow
300uS	30%	Green
200uS	20%	Red

*The **Main Control Board/NAZA-M controller** issues separate LED control signals to each ESC board for illuminating the Phantom status LEDs on each arm. The LEDs are physically mounted on the underside of the ESC boards. **LED control signals** are 1000Hz pulse width modulated (PWM) square waves. The microprocessor (MPU U1) internal clock "counts" how long the pulse is HI to determine which color LED to illuminate. See **Fig. 18**. There are three green and three red LEDs on each ESC/arm. The MPU activates one output port line for the green LEDs, another port for RED, and both ports for YELLOW. These port signals are buffered by transistors Q1 (0v=LED on). The LED PWM signal is on the 4–pin connector P1 and cable from the Main Control Board. LED blinking and blinking rate is controlled by the Main Control Board, not the ESC.*

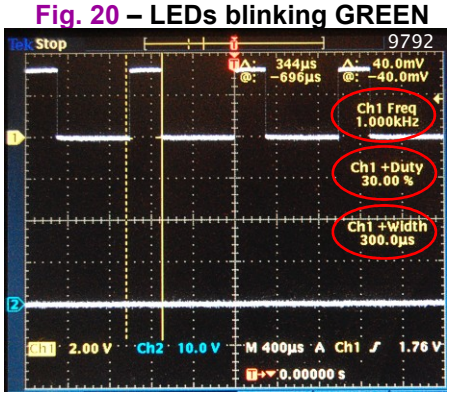
1) **Oscope setup**: Ch.1 2v/div; Ch.2 - not used; sweep 1mS/div; trigger: Ch.1. PWM LED signal best seen at R1.
2) Turn on PV2+. In NAZA-M mode, LEDs will flash yellow, green-red while searching GPS, and finally green with 6 satellites (ready to fly). This is ample time to observe the LED PWM changes for the three different colors.
3) Check Q1-3 and Q1-6 for collectors going LO (0v) to turn on respective LEDs.

Fig. 19 –Motor off, LEDs OFF



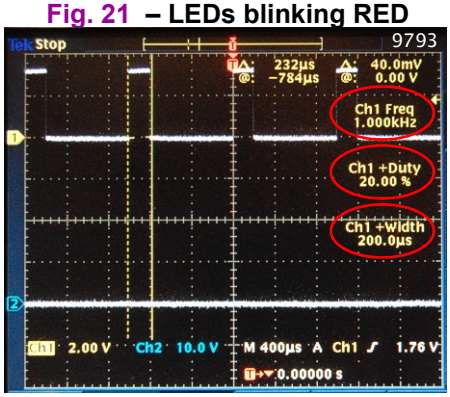
CH 1: LED CTL, R1
CH 2: None

Fig. 20 – LEDs blinking GREEN

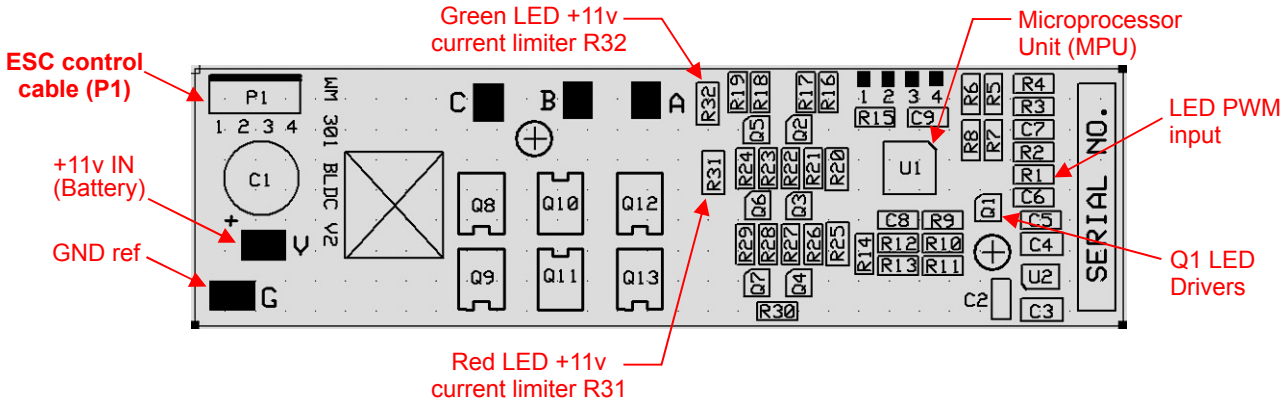


CH 1: LED CTL, R1
CH 2: None

Fig. 21 – LEDs blinking RED



CH 1: LED CTL, R1
CH 2: None



SCHEMATIC DIAGRAM ON PAGE 7