

Fast Shutter Electronics Design Notes

Richard Abbott
07 March, 2014

1. Overview

What follows are a set of notes used to verify that the design of the fast shutter electronics meet the requirements, and in general adheres to good engineering practices. Refer to D1300780 for schematic details and T1300906 for requirements. Only the portions of the circuit involved in delivering energy to the in-vacuum shutter coil are discussed. The general housekeeping functions provided by the PSoC3 supervisory controller will be left for another note. The other miscellaneous circuitry is self-explanatory.

2. Excerpt From Requirements Document T1300906

Parameter	Value
Maximum time to block beam	≤ 1 mSec
Driver electronics peak output current	20 amperes peak
Driver electronics maximum output voltage	500 volts DC
Total time shutter must remain in blocked state	20 mSec to 40 mSec
Pulser duty factor	1 pulse per minute maximum
Fault detection	Must be able to detect disconnected interface cable from shutter controller or to shutter. Must be able to sense unpowered shutter controller.
Beam blocking modes	Fast blocking mode from rest condition plus a mode where the shutter can be held in the up position indefinitely

3. Main Drive FETs (M11 and M14) Bias operating point and details associated with the main P-channel FETs

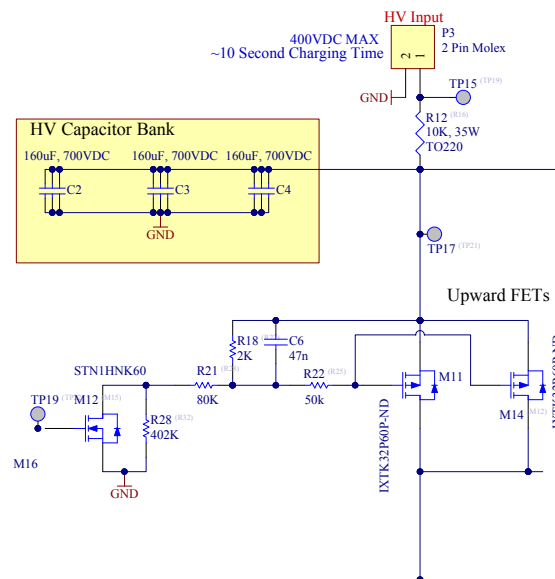


Figure 1

- a.** R18 is chosen such that the maximum gate-source voltage (20VDC Absolute Maximum) for M11 and M14 are not exceeded at the maximum supply voltage of ~500VDC. During the time when M12 is gated on, R28 is effectively bypassed and the majority of the applied voltage is dropped across R21. The power dissipation in R21 will be approximately 2.4 watts and the FETs see a 10V gate drive (The FET threshold voltage is 4V).
- b.** When no pulse is being applied, M12 is off. The gate drive voltage to M11 and M14 reduces to 2VDC, which is well below threshold. R28 will have ~1mA flowing through it when no pulse is commanded. This results in a power dissipation of ~0.4W, so R28 is sized as a 1 watt part. R28 must also be able to operate at 500V, so a suitable high voltage resistor was chosen.
- c.** R22 in conjunction with the gate capacity of the large P-channel FETs (M11 and M14) serves to soften the edges of the applied gate drive pulse such that the peak current and high frequency content of the pulse applied to the shutter coil are controlled. The ~50nC gate charge each for M11 and M14 and the chosen value of bias components cause the time delay associated with turning on M11 and M14 to be negligible in comparison to the timescale needed for this application.
- d.** Two FETs are used as a head nod in the direction of the Safe Operating Curve for these large FETs. Many thousands of cycles were completed with no failures on the prototype circuit, but the safety margin seemed slim. The decision was made to double up the number of FETs to halve the current carried by each.
- e.** The worst case heating due to power dissipation in M11 and M14 is small due to the short transient (10mSec) of the pulse (~15A peak for ~10mSec) applied to the shutter coil. In reality, it is not a rectangular current pulse that flows during the shutter trigger transient. The bobbin creates a back EMF that alters the current pulse shape. Assuming M11 and M14 are inadvertently both gated on, and the HV power supply was set to 500VDC across the 10k charging resistor (R12, not shown). This would cause 25mA of current to flow through each power FET. The steady state power dissipated in the 350 milliohm channel resistance would be negligible.
- f.** The 10k charging resistor has a worst case power dissipation (assuming the FETs fail on) of 500V across 10k ohms. This yields 25 watts. A 35 watt resistor was chosen. The 10k charging resistor also serves to limit the current to the shutter coil in the event of a failure. The 50mA current that would flow would dissipate about 60 milliwatts in the shutter coil.

- g. Another factor in the choice of the charging resistor is the time required to charge the energy storage capacitors (C2, C3, and C4).

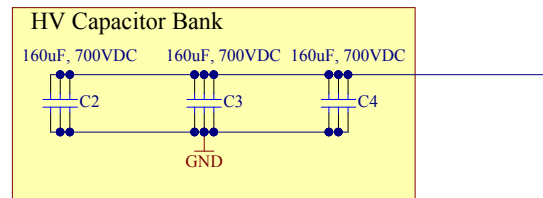


Figure 2, Capacitor Bank

Approximately 10 seconds are required to recharge the capacitors for the next pulse. This nicely limits the duty factor and simplifies the overall thermal design of the board and in-vacuum coil.

- h. The total energy stored in the capacitor bank is given by $1/2CV^2$ and with 500V and a capacitance of $3 \times 160\mu\text{F}$, the total stored energy is 60 joules. Assuming all this energy is dissipated in the 10g copper (0.386 J/g/K) coil, the maximum temperature rise would be 15.5 K per shot. The actual operating voltage is likely to be closer to 400V, so the temperature rise will rapidly decrease due to the quadratic dependence on voltage.
- i. Assuming a 20A pulse, the FET on the return leg of the coil (M18) only develops 7 volts peak, so considerations relating to SOA curves and thermal management do not apply.
- 4. Low Current Operating Modes** – There are times when the shutter must be maintained in the raised position (blocking the laser beam) for long periods of time. Several things must be thermally considered to ensure this is reasonable.
- a. **In-vacuum coil power dissipation** - The current required to reliably hold the shutter in the raised position has experimentally been determined to be approximately 200mA. With a coil resistance of 23 ohms, 1 watt of steady state heat load is deposited into the in-vacuum coil when it is in the raised position. All wiring in the system is quite capable of conducting this steady state current indefinitely. A test is being done to measure the equilibrium temperature of the coil under vacuum, but this is more to assess the potential for increased outgassing rather than for thermal damage to the shutter component.

- b. Current limiting resistors** – Resistors R32 (and R36, not shown) limit the current applied to the shutter coil to 200mA when the shutter is in the raised position (R32), or if the shutter is actively commanded down by a reverse polarity current (R36).

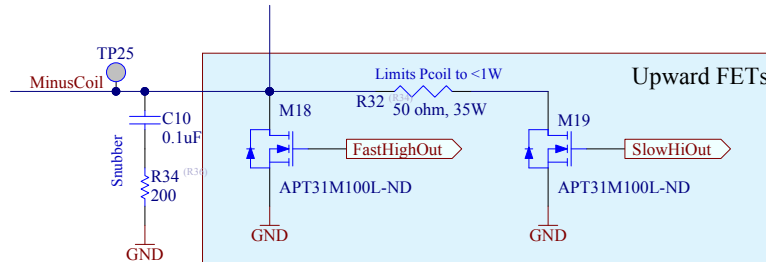


Figure 3

A voltage regulator supplies 15 VDC to the low current FETs. A total resistance of 75 ohms is required to limit the current to 200mA with 15 VDC supplies. As the coil resistance is 23 ohms, an additional 50 ohms is used. The power dissipation in these resistors is 2 watts. A 35 watt, TO220 style resistor was chosen as it was easier to heat-sink albeit overkill for the task. The 15VDC voltage regulator is thermally bonded to the chassis walls, and is capable of supplying 1A or more indefinitely.

5. Miscellaneous Design Details

- a. Snubber Network** – As seen in Figure 3, an RC snubber network composed of C10 and R34 is used to reduce ringing during the high current pulse mode.
- b. Reverse Current Diodes** – Diodes D4, D6, and D7 prevent a catastrophic reverse current flow seen during simulation of this circuit. It was easier to add them at the expense of ridicule than to be ridiculed when they were needed but absent. The high current is I believe due to body diode conduction, but that could be fiction.