The +500V high voltage busbar needs to be stepped down based on the PID controller's output for coil control. This is achieved via a synchronous buck converter, which employs a second switching element for higher efficiency—up to 90%—compared to a standard buck converter using a diode, thanks to the lower conduction losses of the MOSFET.

7.4 Levitation Synchronous Buck Converter

The NUCLEO-L432KC development board controls the coil output. The goal is to apply the +500V high-voltage bus to the coil and drive a current of 5–7A through it, thereby generating controllable magnetic force. This is achieved using two half-bridge drivers to control NMOS transistors. Compared with a standard buck converter using diodes, this approach results in lower conduction losses due to the MOSFETs. Additionally, the NUCLEO-L432KC is connected to other sensors to enable precise control of the coil current.

7.4.1 Circuit Design

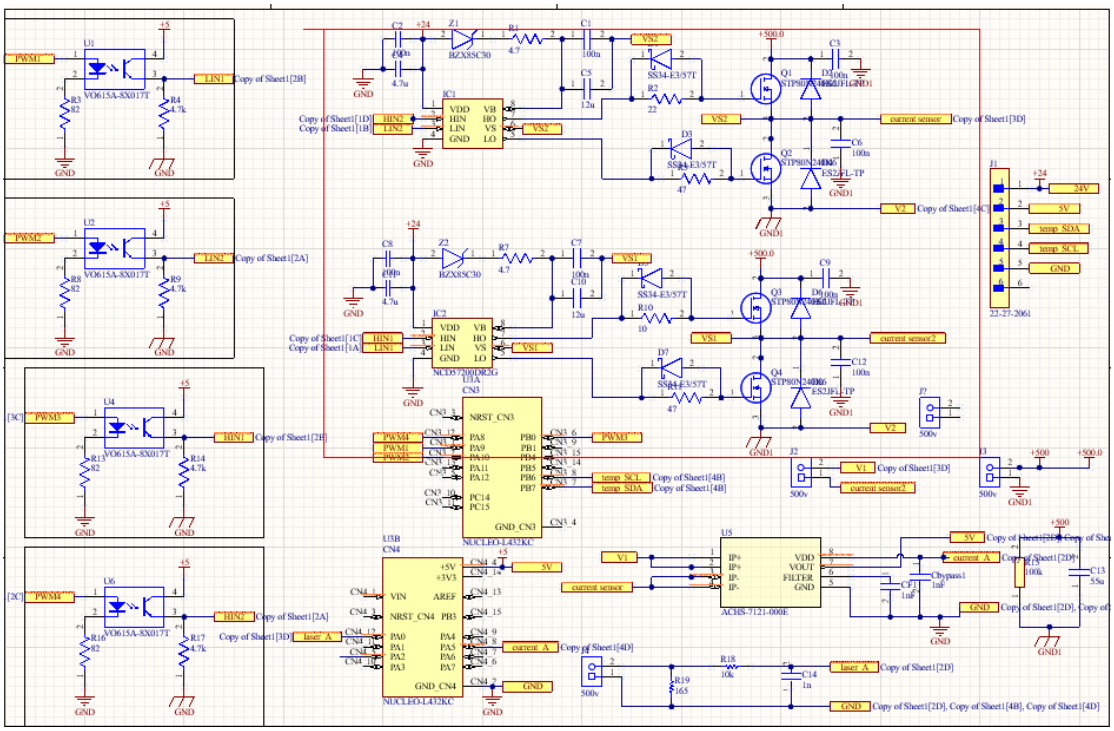

Figure 7.4.1: Buck converter schematic.

- **Main Controller Board: NUCLEO-L432KC**

  Based on the STM32L432KCU6 microcontroller, the NUCLEO-L432KC provides rich timer and communication interfaces. It is responsible for PWM signal output and sensor data acquisition, and controls the high-voltage driver circuit via optocouplers for electrical isolation. The board is connected to a laser sensor (RF602), a temperature sensor (STTS22HTR), and a current sensor (ACHS-7121-000E), enabling closed-loop control.

- **Optocoupler: VO615A-8X017T**

The VO615A optocoupler is used to electrically isolate the PWM signal output from the NUCLEO-L432KC before it drives the gate driver. With an isolation voltage of up to 5000 Vrms and a high current transfer ratio (CTR), it is suitable for signal transmission in high-voltage environments, enhancing system safety and noise immunity.

- **Gate Driver: NCD57200DR2G**

  The NCD57200 is a high-speed low-side MOSFET driver that supports output currents up to ±6A. Its input is TTL-compatible and can be directly driven by the optocoupler. It is used to drive the high-voltage MOSFETs, enabling fast switching control, reduced switching losses, and improved system efficiency.

- **Power MOSFET: STP80N240K6**

  The STP80N240K6 is a high-voltage, high-current N-channel MOSFET with a voltage rating of 800V and current capacity of 80A. Its low on-resistance reduces power loss. In a half-bridge configuration, it enables efficient control of the +500V busbar, delivering 5–7A of current to the coil for magnetic force output.

7.4.2 PCB Design

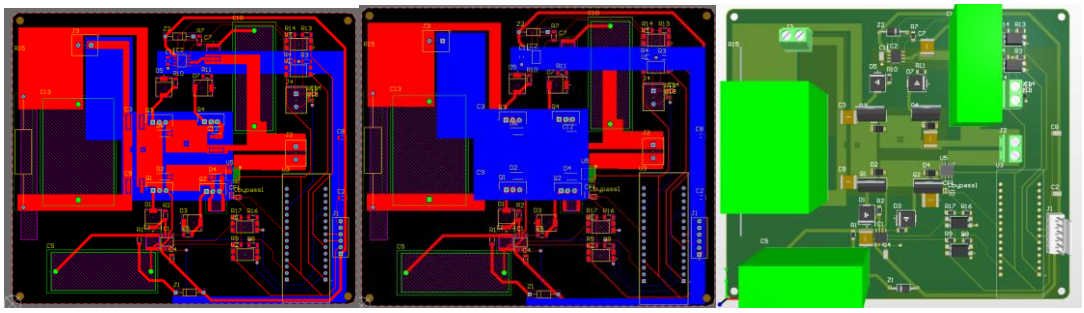

Figure 7.4.2: PCB top layer Figure 7.4.3: PCB Bottom layer Figure 7.4.4: 3D image of PCB

To ensure the PCB is properly rated for a 500V supply voltage and a peak current of 8A, considerations must include creepage and clearance distances, board materials, and the thickness/weight of copper layers. To handle high currents, a **polygon-based approach** is used instead of traditional traces. Furthermore, due to thermal concerns, adequate space is reserved for headers and other high-power components.

7.4.3 Manufacture

To ensure the converter board meets the high-voltage and high-current operational requirements, the PCB is fabricated externally, while all components are soldered and tested in-house by the team. The assembly process includes soldering all components, securing the PCB inside a custom enclosure, and connecting high-voltage, low-voltage, power, and communication ports to the EMS/HEMS coil interfaces. Cable terminals are crimped using proper tools to enhance electrical contact reliability and safety.

7.4.4 BoM

Component number	Number (Total)	Manufacturer	Description
NUCLEO-L432KC	8	STMicroelectronics	Control
ACHS-7121-000E	8	Broadcom	Current sensor
STTS22HTR	8	STMicroelectronics	Temperature sensor
RF602	6	Althen sensor	Laser sensor
NCD57200DR2G	16	ON Semiconductor	Half bridge driver
1729128	18	Phoenix Contact	Terminal Block Header
ES2JFL-TP	32	ON Semiconductor	600V rectifier diode
C0603CB	32	KEMET	630V surface-mount capacitor
B32776E8206J000	8	TDK	800V Film capacitors
ROX5SJ100K	8	TE Connectivity	100kΩ Metal Oxide Resistor
EZP-V60126LTB	16	Panasonic	600V Film Capacitor

7.4.5 Testing

Testing of the DC-DC converter begins with basic open-loop switching verification under low voltage to ensure that each submodule on the PCB functions independently. The voltage is then gradually increased, while current and temperature responses are monitored to validate the accuracy of current sensors and thermal stability of onboard components, ensuring safe operation under rated current.

After initial validation, the converter is integrated into the levitation module in a lab environment. The system's response and magnetic force output are monitored and compared with control expectations. All key parameters are logged. Ultimately, the system will undergo full testing prior to integration with the complete pod, ensuring stability and safety in full operation.

7.4.6 FMEA (Failure Mode and Effects Analysis)

Failure Mode	**Effect**	**Sev.**	**Cause**	**Occ.**	**RPN**	**Mitigation**
HV bus short to chassis	Risk of electric shock or electrocution to maintenance personnel	5	Conductive object bridges the HV bus and chassis	2	10	Isolation Monitoring Device (IMD) disconnects HV relays immediately upon fault detection.
HV+ to HV– short circuit	Cable overheating and melting, potential fire risk	4	Conductive object causes a short between HV+ and HV–	2	8	Same IMD response: disconnects HV relays to prevent escalation.
Human contact with HV	Severe burns or fatal injury	5	Personnel creates a current path through the body	3	15	All HV components are enclosed in insulated housings; no exposed conductors; protected connectors used.
Poor	Increased	3	Inadequate	2	6	All terminals are

electrical contact	resistance causes heating and insulation melting		crimping or loose bolts in connectors			checked for proper torque after assembly.
Secondary electric shock	Pain or minor burns from brief HV contact	3	Accidental ground path contact during operation	4	12	Structural shielding and insulated connectors minimize exposure risk.
MOSFET overheating	Device failure, localized PCB overheating	2	Load current exceeds MOSFET's rated value	4	8	Appropriately rated MOSFETs with thermal margin and heatsinking/copper plane enhancement.