# Group Number 26

Akash Chandra (akashc3)

Constantin Legras (clegras2)

Dhruv Kulgod (dkulgod2)

**Problem:**

We were inspired by project number 28 from the ECE power project ideas page and the work on UIUC's electric Formula SAE team, IEM.

Automobiles contain complicated wire harnesses. In place of this complexity, manufacturers are trying to move to a "one power one communication" arrangement in which all control and conversion is local.

However, all components on a car cannot run on the same voltage. For example, the IEM car contains components running at 3.3V, 5V, 12V, and 24V! While some of these voltage conversions are handled on PCBs themselves, there are still many different voltages that have to be run through the wire harness. This need is due to the various devices (notably sensors, actuators, cooling/heating devices) that are present on cars. Trends towards increased safety and self driving in the automotive industry mean that the number of such devices will only increase in the coming years.

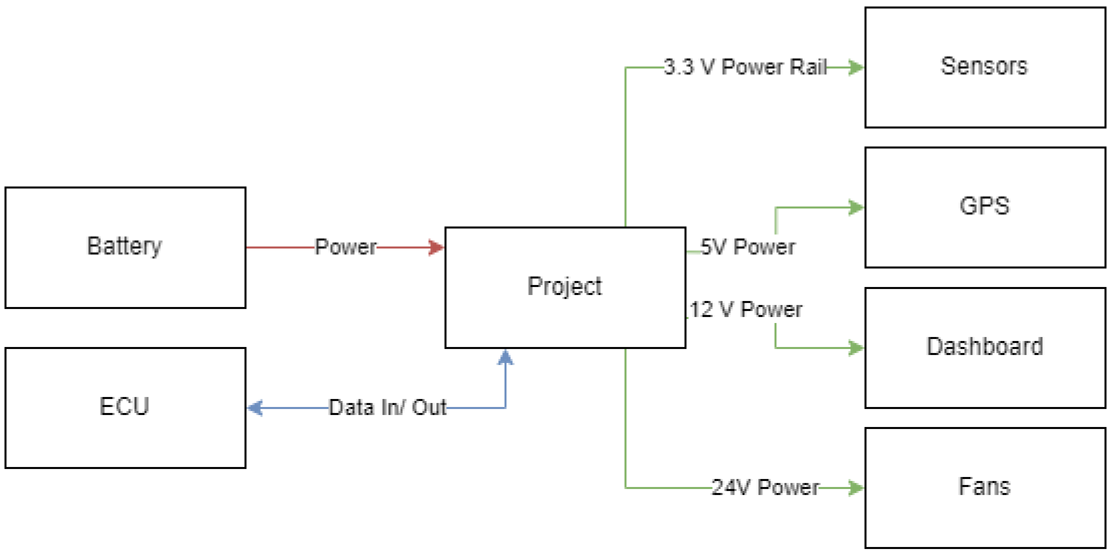
**Solution:**

This project involves the design of a multiple-output power supply that can handle an input range of about +11V to +15V, thereby serving a range of vehicular platforms running at various LV voltages. Our project will support four simultaneous power rails. Each rail can be configured to one of the following output levels: 3.3V, 5V, 12V and 24V. This creates a single versatile product that can be modified for the specific needs of each use case.

There will be a backplane that houses an MCU, and up to 4 power PCBs that will house the power electronics. The backplane will contain the power input, power output, and the CAN connection to the rest of the car.

There will be two variants of the power PCB: one serving the 3.3 - 5V range and another serving the 12 - 24V range. Each power PCB will contain the power electronics to buck or boost the voltage, talk to the MCU over a digital protocol, and share voltage and current usage to the MCU. The power PCBs will slot into the backplane. This will allow users to run multiple outputs simultaneously without worrying about heat generation affecting the other units. This design also allows us to quickly replace dead units without needing to redo the entire project. The two variants will have similar design, differing only in ICs and inductances.

**Visual Aid:**

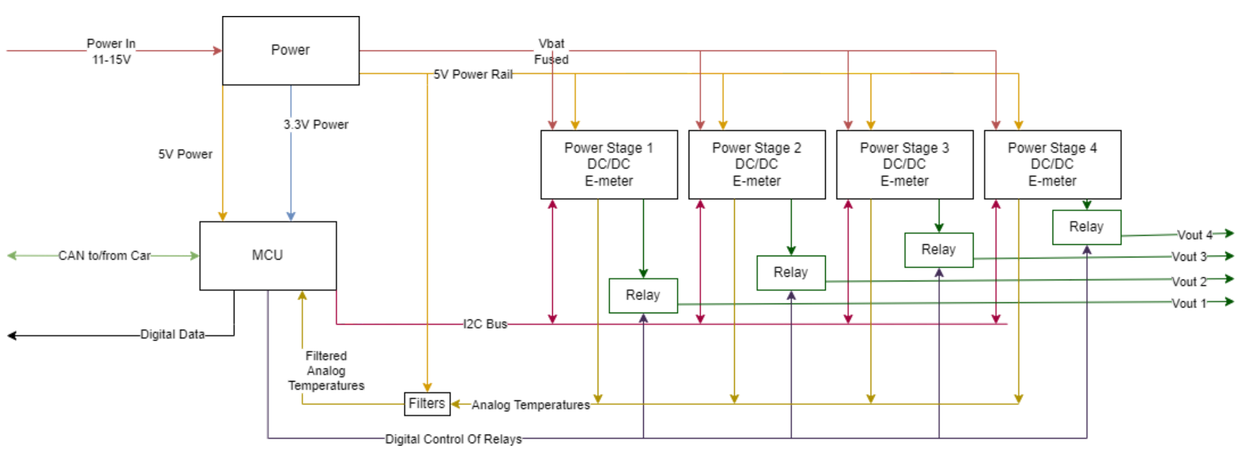



**High-level requirements list:** A list of three *quantitative* characteristics that this project must exhibit in order to solve the problem. Each high-level requirement must be stated in complete sentences and displayed as a bulleted list. Avoid mentioning "cost" as a high level requirement.

- The project could communicate power usage data and control the voltage output over CAN at 20 Hz in real time
- Provide 2A of power on each rail at the same time
- Stay under 60C while providing a 1A for over a hour with less than a 5% voltage ripple and a 5% current ripple

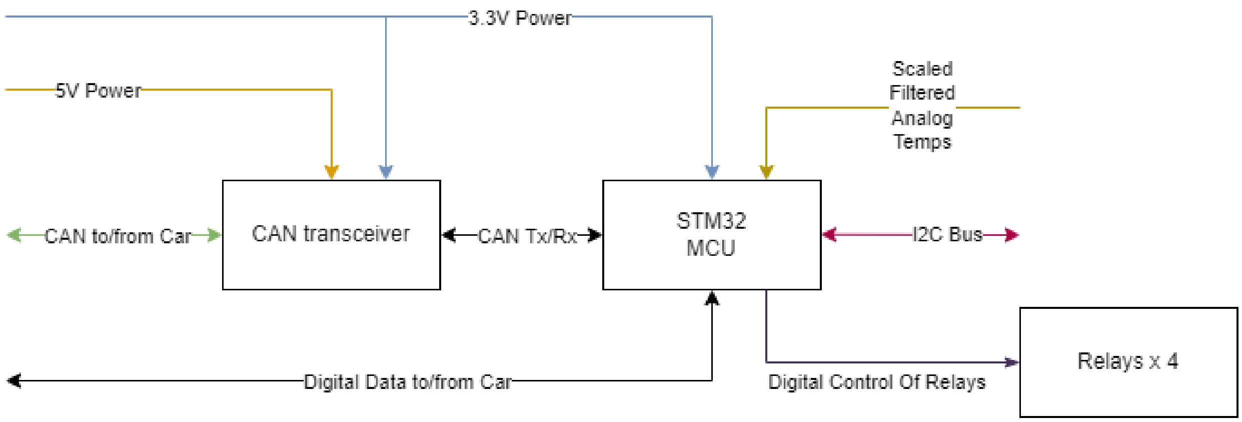
**Design**

**Block Diagram:** Break your design down into blocks and assign these blocks into subsystems. Label voltages and data connections

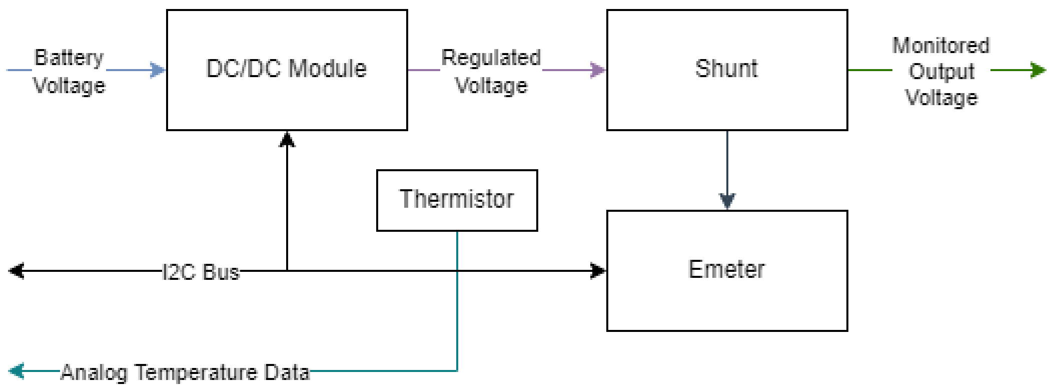


**Subsystem Overview:** A brief description of the function of each subsystem in the block diagram and explain how it connects with the other subsystems. Every subsystem in the block diagram should have its own paragraph.

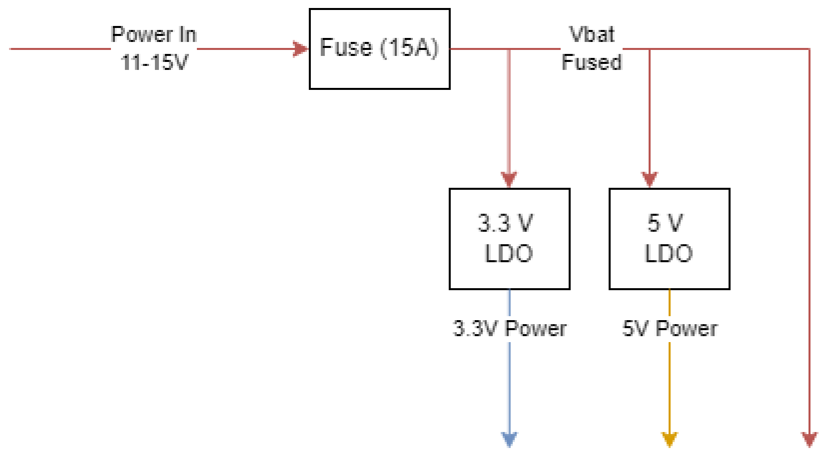
There will be two main subsystems in this project: the main PCB which will host the power input, the MCU, some communication chips, and will have slots for the secondary boards.



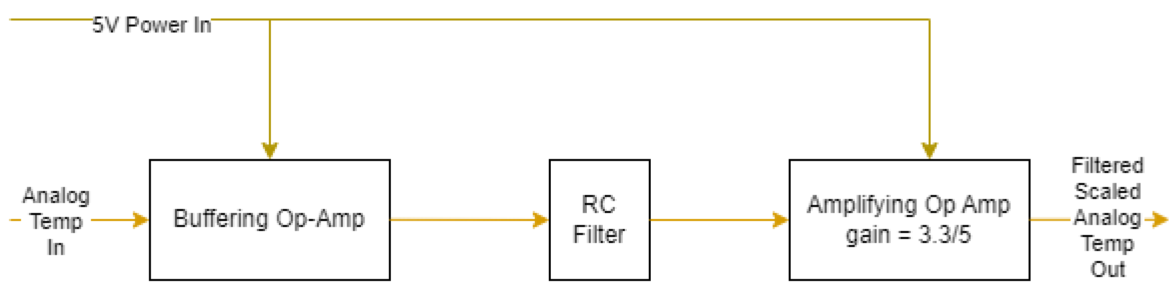

The secondary boards/ Power Stage will be the other major subsystem. They connect to the main board and, depending on which module is selected, will output different voltages. These boards are meant to be as simple as possible to ensure a small and cheap form factor for the final product.



The power system will simply provide power to the rest of the subsystems and contain a fuse.




The filters will be made using Op-Amps and RC LPF filters to help remove most of the switching noise, if any. The op amp will also bring the 5V down to 3.3V.




**Subsystem Requirements:** For each subsystem in your block diagram, you should include a highly detailed block description. Each description must include a statement indicating how the block contributes to the overall design dictated by the high-level requirements. Any interfaces with other blocks must be defined clearly and quantitatively. Include a list of requirements where if any of these requirements were removed, the subsystem would fail to function. Good example: Power Subsystem must be able to supply at least 500mA to the rest of the system continuously at 5V +/- 0.1V.

Power:

- Provide a stable 5V and 3.3V for the MCU and other external ICs such as the Op-Amps for 1.5x the operation current, 540 mA. Voltage for either rail should fall within a 5% tolerance.

MCU:

- The STM32 MCU must be able to communicate over a CAN bus to be controlled as well as transmit power information (such as temperature, voltage, and power usage) as well as any safety alerts (over voltage, over current, over temp, or unscheduled secondary board disconnection). It will also be responsible for communicating the DC/DC controllers on the secondary boards over the I2C protocol to configure them and get power information.

Powerstage:

- Supply the voltage requested over I2C
- Thermistor accurately reports temperature within 5%
- Provide 2A of power on each rail at the same time
- Stay under 60C while providing a 1A for over a hour with less than a 5% voltage ripple and a 5% current ripple

Filters:

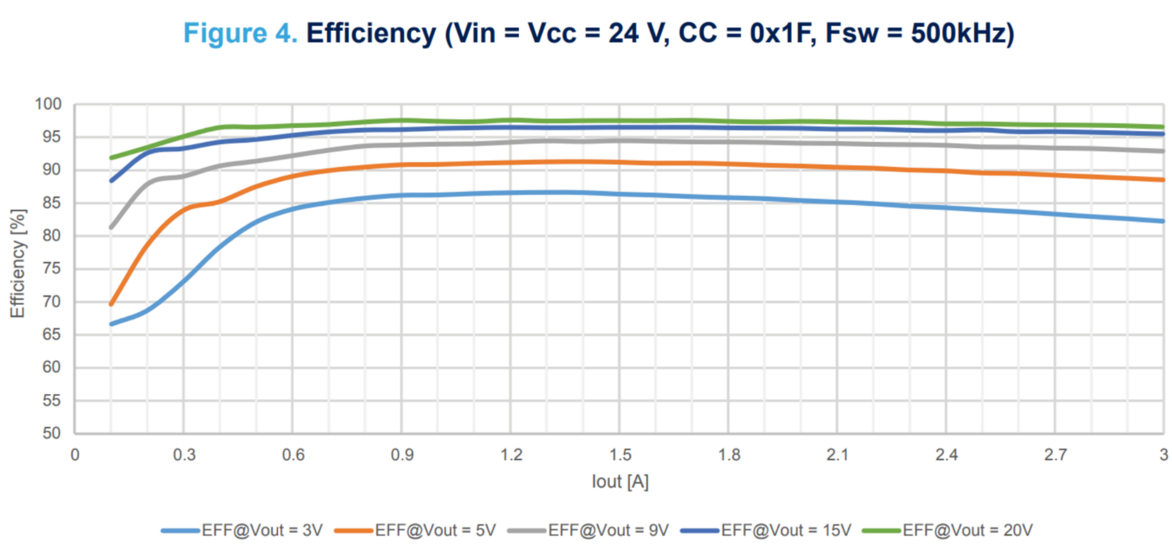
- Detect if the powerstage is not plugged in with a pull up resistor on the input
- Scale down the 5V signal to a 3.3V signal
- Reduce noise above 10 kHz by at least -3db

**Tolerance Analysis:** Identify an aspect of your design that poses a risk to successful completion of the project. Demonstrate the feasibility of this component through mathematical analysis or simulation.

Our project is to essentially design a power supply. As such, ensuring that our electronic components are operating within safe thermal limits is important to the success and safety of our project.

The two major components most vulnerable to overheating are the DC/DC module and the shunt resistor, both residing on the power stage PCB.

*Heat Output Calculations:*




*DC/DC Efficiency Curves*

Using the graph above, we can calculate the heat output using the following formula:

$$Power\ loss\ =\ Heat\ out$$

$$Heat\ out\ =\frac{Power\ delivered}{Efficiency}\ -\ Power\ delivered$$

$$Heat\ out\ =\ \frac{V_{out}I_{out}}{Efficiency}\ -V_{out}I_{out}$$

We can assume our worst-case $I_{out}$ to be 2A.

| Vout Level | Efficiency @2A | Heat Out |
|---|---|---|
| 20V | 0.97 | 1.24W |
| 15V | 0.96 | 1.25W |
| 9V | 0.94 | 1.15W |
| 5V | 0.9 | 1.11W |
| 3V | 0.85 | 1.06W |

Therefore, we can use 1.24W max output as our worst-case heat rejection requirement. Assuming a warm ambient temperature of 35°C, we can use this to calculate the required heatsink.

The calculations were done using a MATLAB script attached below.

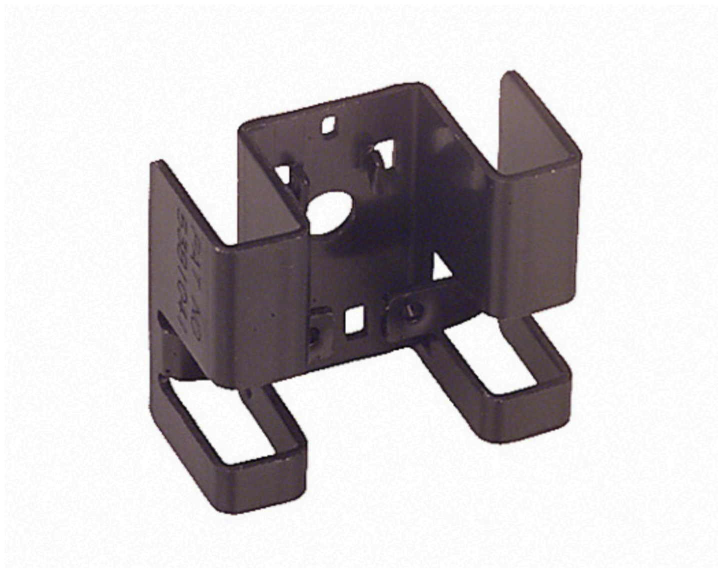
```
%2024 Senior Design Heatsink Calculations

% Establish constants
Max_T=60; %Celsius -Maximum desired temperature of chip
Ambient_Temperature=35; %Celsius
DCDC_Power=1.24; %W -Max heat power
hc=5.5; %W/(m^2*K) -natural air convection coefficient (Air, free)
Area1=12e-6; %m^2 -Surface area of convection surface (Accumulator)

%Given power, temp difference, we can calculate the
%theoretical max value of Max_Required_Thermal_Res that allows the resistor to stay below max
%temp.

%Formula: (T_resistor - T_air) / Precharge_Power = Thermal Resistance between chip and air

%Max thermal resistance of heatsink that prevents resistor from overheating
Max_Required_Thermal_Res = ((Max_T - Ambient_Temperature) / DCDC_Power)   %C/W


%Heatsink for precharge is Al Accumulator case
No_Heatsink_R = 1/(hc*Area1)      %C/W

%Calculate Maximum Precharge Resistor Temp with Chosen Heatsink
Chosen_Heatsink_R = 20; %C/W
syms T
Eqn1=(T-Ambient_Temperature)==DCDC_Power*(Chosen_Heatsink_R);
DCDC_Temp=vpasolve(Eqn1, T)     %C
```

Command Window

```
Max_Required_Thermal_Res =

   20.1613


No_Heatsink_R =

   1.5152e+04

>>
```

Since the thermal resistance of having no heatsink is much larger than the required resistance to dissipate the estimated amount of heat, we must therefore employ a cooling system to maintain our operating temperature.

The simplest solution here is a passive heatsink, which can be easily purchased from Digikey. An example of such a heatsink is:



*This heatsink has a thermal resistance of 20°C/W*

```
Command Window

DCDC_Temp =

59.8

fx >>
```

Thus, this heatsink will fulfill our requirements.

**Ethics and Safety**

Some important safety features to implement in this project are overcurrent, overvoltage, short circuit, and thermal protections. These are all necessary to ensure the safety of the users, and the protection of the components both on this board, and on any devices connected to it.

The modular board will solve a few common ethical issues that are becoming very common in the electronics industry. It will make it easily serviceable and repairable, meaning if a secondary or a primary board fails, the other boards connected to it can be reused, thereby greatly reducing waste and cost.