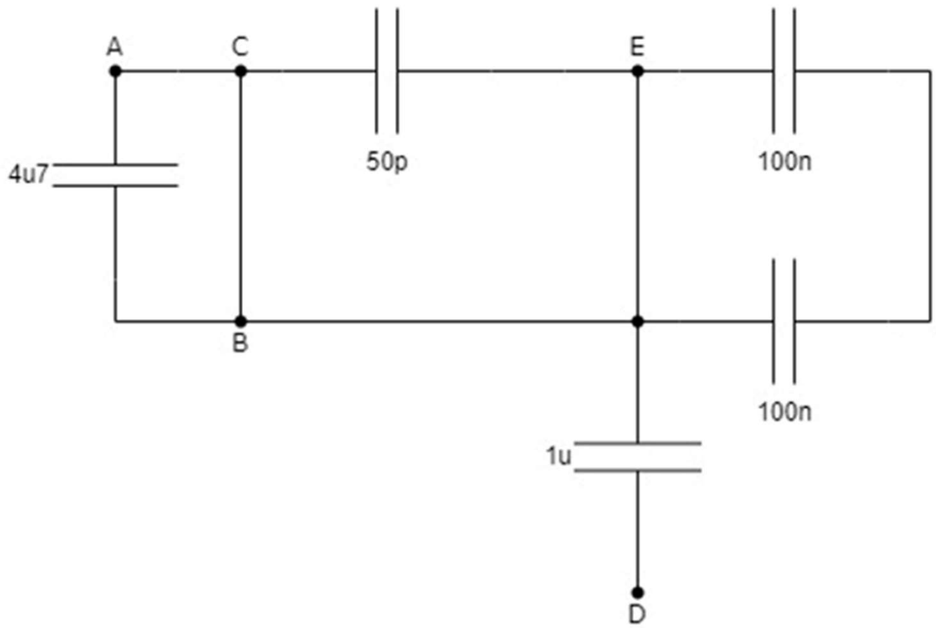
CV, EV

Q: What is the capacitance between points A and D?



a) 1.2 µF
b) 1000 nF
c) 5.7 µF
d) 200 nF

A: b

CV, EV

Q: Which of the following statements is true for LV batteries which are not hybrid system energy storages?

a) They must have short circuit protection no more the 4 inches away from ungrounded terminals.
b) LV batteries must have a hermetically sealed housing.
c) $LiFePO_4$ cells must be installed in a fire retardant casing.
d) If wires are used to measure voltage of LiPo cells, it must be possible to disconnect a voltage measurement wire during technical inspection.

A: d

CV, EV

Q: How much load will be transferred on the elastic elements on the front suspension of a car, which has a mass of 186 kg, 54% mass distribution on the front, 10% of the mass is unsprung, 1.2 m front track, 25 cm CoG height and 60 mm front roll centre height, while steady state cornering with 1 G and a 71 kg driver sitting in CoG? Mark the nearest value from the options below.

a) 3600 N
b) 2600 N
c) 2000 N
d) 1800 N

A: c

Solution:

$$total\ mass = 186\ kg \rightarrow 1860\ N$$

$$front\ mass\ force = \ 0.54 \cdot 1860\ N = 1004.4\ N$$

$$front\ sprung\ mass\ force = 0.9 \cdot 1004.4\ N = 903.96\ N$$

Driver is in CoG, so 54% of his/her mass lays on the front

$$driver\ front\ mass\ force = 710\ N \cdot 0.54 = 383.4\ N$$

$$total\ sprung\ mass\ force\ on\ front\ axle = 903.96\ N + 383.4\ N = 1287.36\ N$$

elastic load transfer = sprung mass * lateral acceleration * (CoG height – roll centre height) / track width

$$dF\ elastic = 1287.36 \cdot (1 \cdot 9.81) \cdot \frac{(0.25 - 0.06)}{1.2} = 1999.59\ N \rightarrow 2000\ N$$

CV, EV

Q: Which option does not influence the roll stiffness of the suspension?

a) tire
b) coil spring
c) track width
d) anti-roll bar

A: a

CV, EV

Q: Your team wants to make a part lighter by changing its original aluminium material to CFRP composite. The part has complex load cases, so the team optimizes for a quasi-isotropic and symmetrical layup. You want to optimize for the minimum number of layers used to be competitive while meeting the requirements.
The original part has a thickness of 3 mm, width of 1 m and has a modulus of 70 GPa.
The CFRP fabric has the following parameters:

E_1	55000	MPa
E_2	55000	MPa
G_{12}	4100	MPa
v_{12}	0,3	-
t	0,2	mm

How many layers does it take to match the stiffness parameters (both axial and bending stiffness) of the original plate?
Mark the nearest answer using engineering approximation, use constant composite membrane stiffness throughout the calculations.

a) 20
b) 24
c) 26
d) 28

A: d

Equivalent plate						targets				
E	70000	MPa	A	0.003	m2	EA	2.100E+08	Pa*m2		
t	3	mm	I	2.25E-09	m4	EI	157.5000	Pa*m4		
b	1	m								
					calculated by	https://abdcomposites.com/				
E1	55000	MPa		Ex	38222.5	MPa	(use membrane stiffness)			
E2	55000	MPa								
G_12	4100	MPa		layer must be QI		-->	total layer number must be multiplication of 2			
v_12	0.3	-		layer must be symmetri		-->	total layer number must be multiplication of 4			
t	0.2	mm								
				layer no.	t	A	I		EA	EI
				4	0.8	0.0008	4.26667E-11		3.06E+07	1.6308
				8	1.6	0.0016	3.41333E-10		6.12E+07	13.0466
				12	2.4	0.0024	1.152E-09		9.17E+07	44.0323
				16	3.2	0.0032	2.73067E-09		1.22E+08	104.3729
				20	4	0.004	5.33333E-09		1.53E+08	203.8533
				24	4.8	0.0048	9.216E-09		1.83E+08	352.2586
				28	5.6	0.0056	1.46347E-08		2.14E+08	559.3735
				32	6.4	0.0064	2.18453E-08		2.45E+08	834.9833
				36	7.2	0.0072	3.1104E-08		2.75E+08	1188.8726

CV, EV

Q: What is the earliest date you can finish a project with the following constraints:

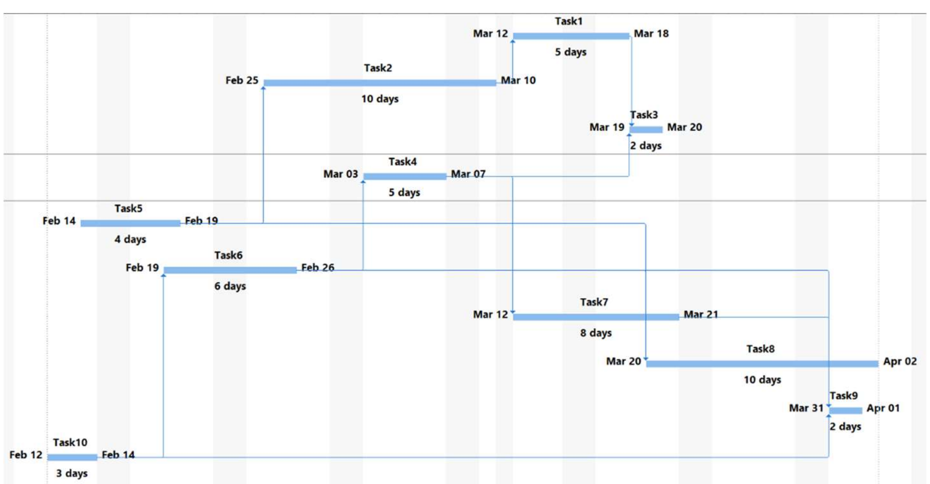
- **The team only works on weekdays, (Monday-Friday), except on national holidays.**
- **The duration is not changed if the amount of the associated resource change.**
- **Following days are national holidays:**
  - **22/February/2025**
  - **11/March/2025**
  - **7/April/2025**
- **The project starts on 12/February/2025.**

Dependencies and start of tasks:

Task Name	Duration	Predecessors	Task start date is not earlier than
Task1	5 days	2	12/February/2025
Task2	10 days	5	25/February/2025
Task3	2 days	4;1	12/February/2025
Task4	5 days	6	1/March/2025
Task5	4 days		14/February/2025
Task6	6 days	10	19/February/2025
Task7	8 days	4	12/March/2025
Task8	10 days	5;6	20/March/2025
Task9	2 days	6;10;7	31/March/2025
Task10	3 days		12/February/2025

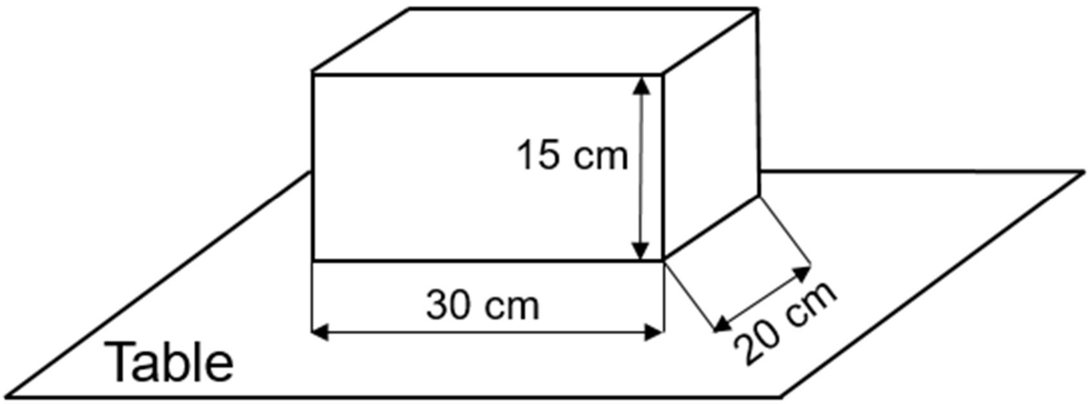
a) 17/March/2025
b) 25/March/2025
c) 01/April/2025
d) 02/April/2025
e) 04/April/2025

A: d



CV, EV

Q: A 20 kg, 30 cm x 20 cm x 15 cm block of unknown material is heated to 100 °C. How long will it take for it to cool down to 25 °C if the ambient temperature is 20 °C?
The only known properties are the following: The material's specific heat capacity is 350 J/kgK, the heat transfer coefficient between the block and its surroundings is 75 W/m²K (constant). The block is sitting on a table made of a perfect thermal insulator.



a) 1232,3 s
b) 333,3 s
c) 61,6 s
d) 958,4 s

A: a

Solution:

$$Newton's\ Law\ of\ cooling: T = T_{amb} + (T_0 - T_{amb}) \cdot e^{-kt}$$

$$A = 0{,}2 \cdot 0{,}3 + 2 \cdot 0{,}3 \cdot 0{,}15 + 2 \cdot 0{,}2 \cdot 0{,}15 = 0{,}21 m^2$$

$$C = c \cdot m = 350 \cdot 20 = 7000\ J/K$$

$$k = \frac{h \cdot A}{C} = \frac{75 \cdot 0{,}21}{7000} = 0{,}00225\ 1/s$$

$$25 = 20 + (100 - 20) \cdot e^{-0{,}00}$$

```
In[1]:= Solve[20 + 80 * e^(-0.00225 * t) == 25, t]

        Solve: Inverse functions are being used by Solve,

Out[1]= {{t -> 1232.26 / Log[e]}}
```

+ Can be double checked here https://www.omnicalculator.com/physics/newtons-law-of-cooling

CV, EV

Q: Your car recuperates 100 kW for 0.5 s under braking at your motor(s). Then accelerates with 75 kW for 2 s, measured again at your motor(s). What is the total energy recuperated into the battery as a result of the braking and what is the amount of energy drawn from the battery for the subsequent acceleration? Your powertrain efficiency from motor(s) to battery is 95% in charge & discharge directions equally, while your battery charge efficiency is 96% and your battery discharge efficiency is 98%.

The answers are in the following format: E_into_battery; E_drawn_from_battery

a) 50 kJ; 150 kJ
b) 45.6 kJ; 139.7 kJ
c) 54.8 kJ; 161.1 kJ
d) 45.6 kJ; 161.1 kJ

A: d

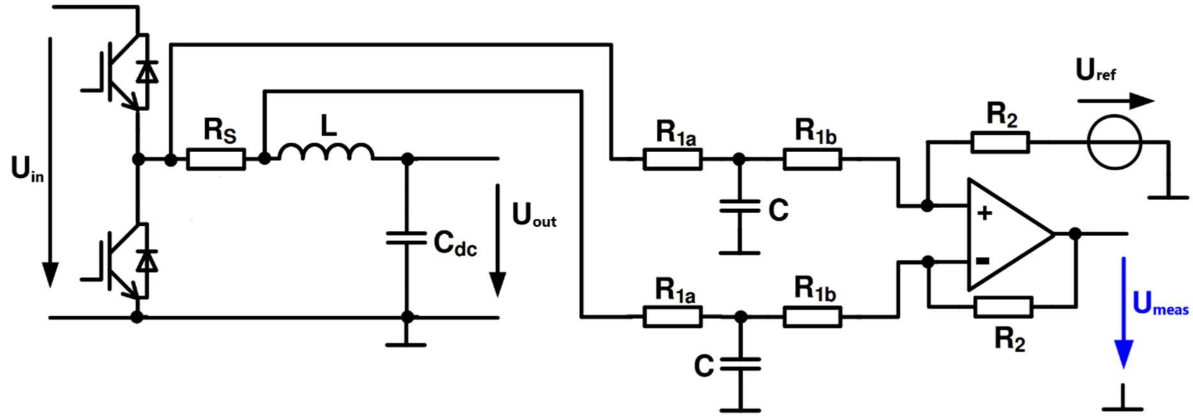
Solution:

$$E_{charg} = P_{brake} \cdot t_{brake} \cdot \eta_{PT} \cdot \eta_{batt_{ch}} = 100 \cdot 0.5 * 0.95 * 0.96 = 45.6\ kJ\ (= kWs)$$

$$E_{discharge} = \frac{P_{accel} \cdot t_{accel}}{\eta_{PT} \cdot \eta_{batt_{dch}}} = \frac{75 \cdot 2}{0.95 \cdot 0.98} = 161.1\ kJ\ (= kWs)$$

CV, EV

Q: A Syncron buck converter has 100 V on its input. The desired output voltage is 24 V. The coils inductance is 470 µH. The output capacitance is 200 µF. The switching frequency is 20 kHz. We want to measure the coil current with the circuit below if the converters maximum output current is ±20 A (current in both directions). Our processor's ADC input can handle 0 to 3.29V and the maximum shunt power is 1 W (peak), it's inductance is 100 nH. Choose the highest resistance shunt from the E96 series and calculate the optimal value of R2 resistor if R1a = R1b = 1 kΩ, rounding to three significant digits. The value of C is chosen so the anti-aliasing filter (formed by R1a and C) doesn't effect the amplitude of the signal connected to the amplifier.



a) 126 kΩ
b) 63 kΩ
c) 69.4 kΩ
d) 138 kΩ

A: c

Solution:

$$Duty\ cycle\ of\ the\ converter: d = \frac{Uout}{Uin} = \frac{24V}{100V} = 0.24$$

$$On\ time\ of\ the\ high\ side\ switch: ton = d * T = \frac{d}{fsw} = \frac{0.24}{20kHz} = 12\mu s$$

$$Current\ ripple\ of\ the\ inductor: dIL = \frac{Uin - Uout}{L} * ton = \frac{100V - 24V}{470\mu H} * 12\mu s = 1.9404A$$

$$Maximu\ output\ current: Imax = Iav + \frac{dIL}{2} = 20A + \frac{1.9404A}{2} = 20.9702A$$

$$Maximum\ shunt\ size: Rs = \frac{P}{Imax^2} = \frac{1W}{(20.9702A)^2} = 2.274m\Omega$$

$$The\ next\ step\ is\ the\ search\ for\ the\ 1\ step\ smaller\ E96\ resistor, this\ can\ be\ done\ by\ anybody,$$
$$the\ result\ is\ 2.26m\Omega$$

link: https://en.wikipedia.org/wiki/E_series_of_preferred_numbers

$$Maximum\ voltage\ of\ the\ shunt: Umax = I * R = 2.26m\Omega * 20.9702A = 47.3927mV$$

$$The\ required\ voltage\ gain: A = \frac{\frac{Uadc}{2}}{Umax} = \frac{\frac{3.29V}{2}}{47.3927} = 34.710$$

$$Since\ A = \frac{R2}{R1}: \quad R2 = A * (r1a + r1b) = 34.710 * 2k\Omega = 69\ 420\Omega$$

CV, EV

Q: Given a 100 uF capacitor with a maximum voltage of 100 V. The impedance of the capacitor measured at 10 kHz is 0.18 Ω, ESL and leakage resistance are negligible. What will be the voltage on 2 capacitors in series if they are supplied by a symmetrical square wave current with the following parameters?

- **Frequency: 10 kHz**
- **Amplitude: 1 A**
- **Duty cycle: 50%**

(round to 4 decimal places)

a) ±0.5000 V
b) ±0.5840 V
c) ±1.0000 V
d) ±1.0840 V
e) ±1.1680 V

A: e

Solution:

$$|X_C| = \frac{1}{\omega_C} = \frac{1}{2\pi f C} = \frac{1}{2\pi * 10kHz * 100\mu F} = 0.1592\Omega$$

$$ESR = \sqrt{Z^2 - X_C^2} = \sqrt{0.18^2 - 0.1592^2} = 0.0840\Omega$$

$$\text{2 capacitors in series:}$$

$$C_E = \frac{C}{2} = 50\mu F, ESR_E = 2 * ESR = 0.1680\Omega$$

$$U_{ESR} = ESR_E * I = 0.1680\Omega * \pm 1A = \pm 0.1680V$$

$$\Delta U_C = \frac{I}{2 * f_I * C_E} = \frac{\pm 1A}{2 * 10kHz * 50\mu F} = \pm 1V$$

$$\Delta U = \Delta U_C + U_{ESR} = \pm(1V + 0.1680V) = \pm 1.1680V$$

CV, EV

Q: You are using an NTC in a voltage divider to measure temperature. The nominal resistance of the NTC is 10 000 Ω at 25 °C and 680 Ω at 100 °C. Supply voltage for the divider and the ADC is 5 V.

The temperature tolerance of the NTC is ± 0.2 K.
You use ERJ-PB3B1002V (temperature coefficient of Resistance is neglected) as R1, and your ADC resolution is 12 bits.

What is the highest and lowest ADC value at 100 °C?

a) 254; 268
b) 260; 262
c) 256; 266
d) 265; 256

A: b

Solution:

$$\beta = \frac{ln\frac{R_{T1}}{R_{T2}}}{\frac{1}{T_1} - \frac{1}{T_2}} = \frac{ln\frac{10\,000}{680}}{\frac{1}{25 + 273.15} - \frac{1}{100 + 273.15}} \cong 3988$$

$$\alpha = -\frac{\beta}{T^2} = -\frac{3988}{(273.15 + 100)^2} = -2.9\ \%$$

$$R_{tol100} = \alpha \cdot \Delta T = -2.9 \cdot 0.2 = \pm 0.58\ \%$$

$$R_{min} = R_{T2} - \left(\frac{R_{tol100}}{100} \cdot R_{T2}\right) = 680 - \left(\frac{0.58}{100} \cdot 680\right) = 676.06\ \Omega$$

$$R_{max} = R_{T2} + \left(\frac{R_{tol100}}{100} \cdot R_{T2}\right) = 680 + \left(\frac{0.58}{100} \cdot 680\right) = 683.94\ \Omega$$

$$R_{1min} = 9\,990\ \Omega$$

$$R_{1max} = 10\,010\ \Omega$$

$$U_{min} = U_0 \cdot \frac{R_{min}}{R_{min} + R_{1max}} = 5 \cdot \frac{676.06}{676.06 + 10\,010} = 0.317\ V$$

$$U_{max} = U_0 \cdot \frac{R_{max}}{R_{max} + R_{1min}} = 5 \cdot \frac{683.94}{683.94 + 9\,990} = 0.32\ V$$

$$ADC_{min} = \frac{U_{min}}{ADC_{Ures}} = \frac{0.317}{\frac{5}{4095}} = 260$$

$$ADC_{max} = \frac{U_{min}}{ADC_{Ures}} = \frac{0.32}{\frac{5}{4095}} = 262$$

CV, EV

Q: To validate your aerodynamic package you perform straight runs with constant velocity on horizontal surface (no inclination) and log the measured values of your linear potentiometers mounted on your suspension in parallel with the springs and dampers. Both the sensors and the springs have linear characteristics in the measurement domain (F [N] spring force ~ Δs [m] spring ~ U [V] measured voltage).

First, you measure the mass of the car without the driver. On the front axle you measure the total mass of 81.8 [kg] (sum of left and right sides) and on the rear axle 88.3 [kg] (left and right side together). Meanwhile the average of the measured voltages of the two linear potentiometers on the front axle is 2.36 [V] and on the rear axle is 2.45 [V].

Then you also measure the mass of the car with the driver inside. The results are the following: 120.7 [kg] and 3.33 [V] on the front axle and 121.2 [kg] and 3.25 [V] on the rear axle.

Then your driver performs the constant velocity runs with the car. Based on the logs with the appropriate data filtering you calculate that the velocity was 60.48 [km/h] and on the front axle the average measured voltage was 4.26 [V], while on the rear it was 4.23 [V].

During the test you also operated a mobile mini weather station. From this you know that the ambient pressure was 103 [kPa] and the air temperature was 26.3 [°C]. The humidity was low; thus you can use 0.02896 [kg/mol] as the molecular mass of the air. Wind speed was 0.

The frontal surface of your vehicle is A = 1.14 [m^2]. Use g = 9.81 [m/s^2] as the constant for gravity.

Calculate your vehicle's lift (downforce) coefficient from the results of the testing! Calculate the position of the CoG and the CoP (relative to the wheelbase) at the velocity measured during the run! Where is the CoP relative to the CoG?

From the options below select one cl [-] value and one CoG-CoP relationship option!

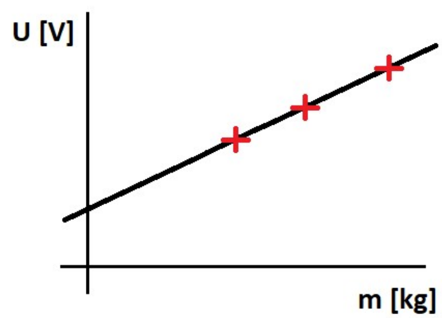
a) cl = -3.949 [-]
b) cl = -3.575 [-]
c) cl = -3.438 [-]
d) cl = -3.232 [-]
e) CoP is 1.8% behind CoG
f) CoP is 1.9% in front of CoG
g) CoP is aligned with CoG

A: a) and e)

Solution: See next page

	Front axle		Rear axle				
	U_F [V]	m_F [kg]	U_R [V]	m_R [kg]	m_{total} [kg]		
1) Jacked up	0.3203	0	0.3029	0			
2) Without driver	2.36	81.8	2.45	88.3	170.1		
3) With driver	3.33	120.7	3.25	121.2	241.9	Driver mass [kg]	71.8
4) At speed	4.26	157.996	4.23	161.503	319.498	"Downforce weight" [kg]	77.598
k [V/kg] coeff.	0.02494		0.02432				

From the measurements with and without the driver we can calculate the coefficient between the voltage and the mass values.



$$k_F = \frac{U_{F3} - U_{F2}}{m_{F3} - m_{F2}} = \frac{3.33[V] - 2.36[V]}{120.7[kg] - 81.8[kg]} = 0.2493573 \left[\frac{V}{kg}\right]$$

$$k_R = \frac{U_{R3} - U_{R2}}{m_{R3} - m_{R2}} = \frac{3.25[V] - 2.45[V]}{121.2[kg] - 88.3[kg]} = 0.2431611 \left[\frac{V}{kg}\right]$$

Note that at 0 [kg] mass the voltage is not 0 [V]: the sensors are in their measurement domain even when the car is jacked up and the tires are unloaded!

Based on the coefficients for the front and the rear we can calculate the load on the tires when the car is performing the run. They are 158 [kg] on the front and 161.5 [kg] in the rear.

$$m_{F4} = m_{F3} + \frac{U_{F4} - U_{F3}}{k_F} = 120.7[kg] + \frac{4.26[V] - 3.33[V]}{0.2493573[V/kg]} = 157.996[kg]$$

$$m_{R4} = m_{R3} + \frac{U_{R4} - U_{R3}}{k_R} = 121.2[kg] + \frac{4.23[V] - 3.25[V]}{0.2431611[V/kg]} = 161.503[kg]$$

This load is the mass of the car with the driver + the downforce. Thus at the given velocity we have 77.6 [kg] “downforce weight” from this 37.3 [kg] is on the front axle and 40.3 [kg] is on the rear axle. With g = 9.81 [m/s^2] we can convert these “weights” into forces: 761.3 [N] total downforce, from this 365.9 [N] on the front and 395.4 [N] on the rear axle.

$$F_{lF} = m_{lF} * g = (m_{F4} - m_{F3}) * g = (158[kg] - 120.7[kg]) * 9.81 \left[\frac{m}{s^2}\right] = 365.9[N]$$

$$F_{lR} = m_{lR} * g = (m_{R4} - m_{R3}) * g = (161.5[kg] - 121.2[kg]) * 9.81\left[\frac{m}{s^2}\right] = 395.4[N]$$

$$F_l = F_{lF} + F_{lR} = 365.9[N] + 395.4[N] = 761.3[N]$$

The CoG (center of gravity) can be calculated from the weight measurement with the driver (it is only relevant to calculate it in driving conditions, with the driver inside). The CoP (center of pressure) can be calculated from the downforce values above. The results are in the table below:

	F	R	checksum
CoG	49.9%	50.1%	100.0%
CoP	48.1%	51.9%	100.0%
		-1.8%	

We can see that the CoP is **1.8% behind** the CoG!

To calculate the lift/downforce coefficient we need to know the density of the air. We can calculate this from the pressure and temperature data taking the molecular mass of the air and the universal gas constant into account:

$$T_{air} = 26.3[°C] = 299.45[K]$$

$$p_{air} = 103[kPa] = 103000[Pa]$$

$$\rho_{air} = \frac{p_{air} * M_{air}}{R * T_{air}} = \frac{103000\left[\frac{N}{m^2}\right] * 0.02896\left[\frac{kg}{mol}\right]}{8.314\left[\frac{N * m}{K * mol}\right] * 299.45[K]} = 1.198123\left[\frac{kg}{m^3}\right]$$

The equation to calculate the downforce: $F_l = \frac{1}{2}\rho_{air} * c_l * A * v^2$

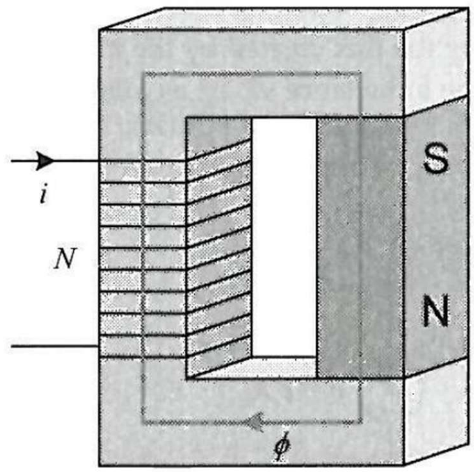
The velocity of the vehicle: $v = 60.48\left[\frac{km}{h}\right] = 16.8\left[\frac{m}{s}\right]$

From this:

$$c_l = \frac{F_l}{\frac{1}{2}\rho_{air} * A * v^2} = \frac{761.3\,[N]}{\frac{1}{2} * 1.198123\left[\frac{kg}{m^3}\right] * 1.14[m^2] * \left(16.8\left[\frac{m}{s}\right]\right)^2} = 3.949[-]$$

EV

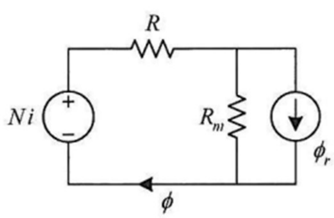
Q: What is the flux linkage in the following magnetic circuit, where N=200 turns on the winding, i=30 mA current is flowing through the winding, the magnet has a remanence of Br=1.3 T, cross section of A=500 cm^2 the magnet leakage permeance is Pm= 10 mH, and the core reluctance is R=50 [1/H].



a) 0.04 Wb
b) 16.67 Vs
c) 8 Wb
d) 0.083 Vs

A: b

Solution:



Partial flux values:

$$\Phi_1 = \frac{N*i}{R+R_m}$$

$$\Phi_m = \frac{R_m*\Phi_r}{R+R_m}$$

Flux linking the coil:

$$\Phi = \Phi_1 + \Phi_m$$

The flux linkage of the windings:

$$\lambda = \Phi * N$$

remanence flux ϕ_r = Br*A,

Reluctance: Rm=1/Pm

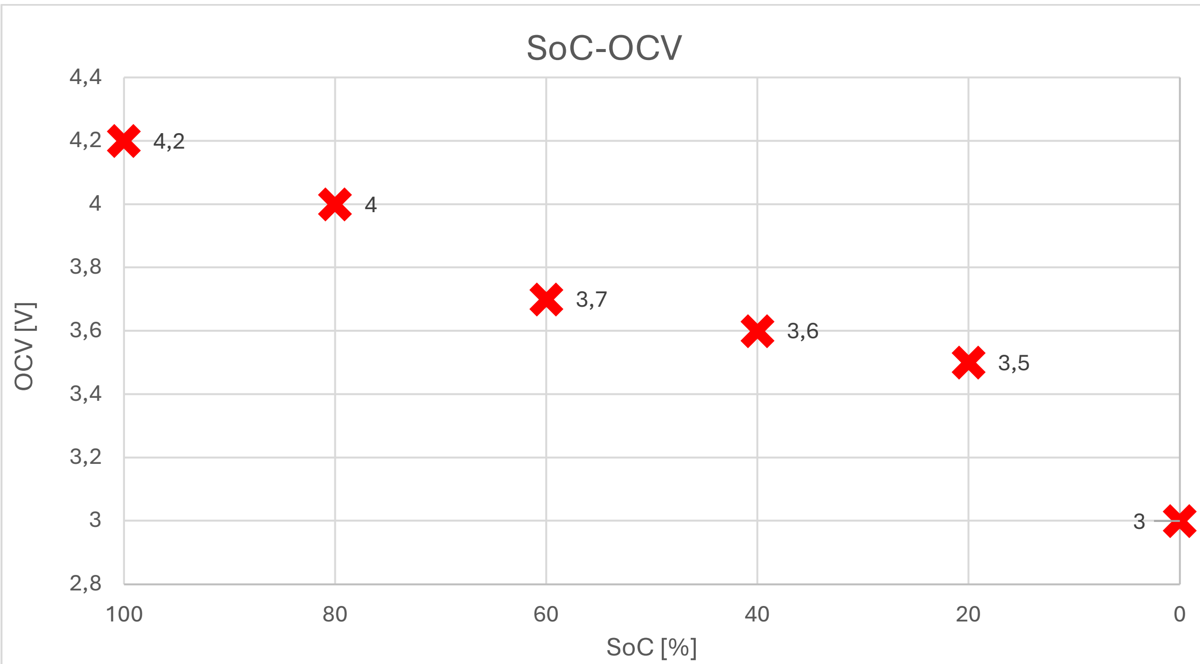
$$\lambda = \frac{N^2 i + N R_m \phi_r}{R + R_m} = \frac{200^2 30mA + 200\frac{1}{10mH}1.3T500cm^2}{50A/Wb + \frac{1}{10mH}} = 16.67Vs$$

Wb=Vs, just a little trick to throw off teams

EV

Q: Your team uses a 6 [Ah] cell with the following SoC-OCV (Open Circuit Voltage) curve in 120s2p configuration. The SoH (State of Health) of your cells is 90%. Calculate the number of full endurance laps left in your TS Accu if the average energy consumption is 303 [Wh] per lap and the current OCV of your most discharged cell pair is 3.88 [V]. The following simplifications can be used:

- **SoC-OCV curve is linear between the known points.**
- **There is no recuperation.**
- **The energy stored in one cell at 100% SoC and 100% SoH is calculated according to EV 5.1.2.**
- **The actual discharge current has no impact on the remaining energy.**



a) 11
b) 12
c) 13
d) 14

A: b

Solution:

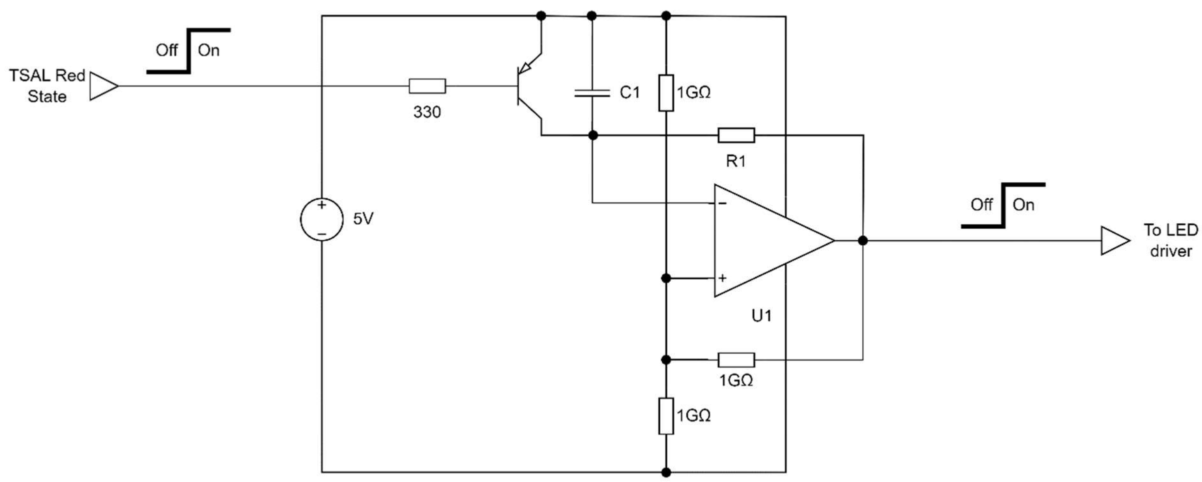
$$SoC_{3.88} = 20\% \cdot \frac{(3.88 - 3.7)}{4 - 3.7} + 60\% = 72\%$$

$$E_{remaining} = E_{cell} \cdot N_{cell} \cdot SoC \cdot SoH = (6 \cdot 4.2) \cdot (120 \cdot 2) \cdot 0.72 \cdot 0.9 = 3919.1\ [Wh]$$

$$Lap_{remaining} = \frac{E_{remaining}}{E_{lap_{avg}}} = \frac{3919}{303} = 12.93 \rightarrow 12$$

EV

Q: You plan to use this circuit to generate the blinking pattern for the Red LEDs of your TSAL. Assume that U1 is a perfect operational amplifier. Which combination of R1 and C1 leads to a rules-compliant TSAL?



a) R1 = 22 MΩ, C1 = 10 nF
b) R1 = 47 MΩ, C1 = 10 nF
c) R1 = 10 MΩ, C1 = 10 nF
d) R1 = 33 MΩ, C1 = 2.2 nF

A: a

Solution:

When U1 outputs high, the voltage at the non-inverting input is $U_1 = 3.33V$, when it outputs low, the voltage at the non-inverting input is $U_2 = 1.67V$.

In the high state of the output, C1 is charged from U_2 to U_1, and in the low state the other way around.

The oscillation frequency can be then calculated as

$$f_0 = -\frac{1}{2R_1C_1 \ln\frac{5V - U_1}{5V - U_2}}.$$

The allowed frequencies are in the range 2Hz to 5Hz (EV 4.10.2). Only answer 1 leads to a frequency in this range.

Simulation with Spice will not always lead to correct answers for this task, as the resistances are very large. The Opamp model in Spice needs to be adjusted first.