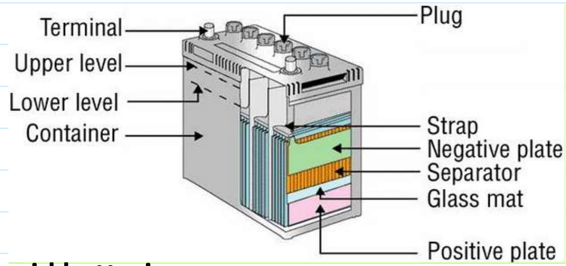
Lab3: Design a PWM charger circuit for a 12V, 7 Ah lead acid battery.

Valve Regulated Lead Acid (VRLA) battery

$$PbO_2 + Pb + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2PbSO_4 + 2H_2O$$



These are general voltage ranges for *six-cell* (12V) lead-acid batteries:

- Open-circuit (quiescent) at full charge: 12.6 V to 12.8 V (2.10-2.13V per cell)
- Open-circuit at full discharge: 11.8 V to 12.0 V
- Loaded at full discharge: 10.5 V.
- Continuous-preservation (float) charging: 13.4 V for gelled electrolyte;
  (13.5 V for AGM (absorbed glass mat) and 13.8 V for flooded cells)

Battery for this lab:

(Some batteries in the lab are from B.B.)

TYSONIC®

NON-SPILLABLE SEALED RECHARGEABLE BATTERY

TY-12-7.5

☆ SPECIFICATION		☆ CHARACTERISTICS	
● NOMINAL VOLTAGE	: 12 V	● CAPACITY 25 ℃ / 77 ℉	
● NOMINAL CAPACITY(20 hrs)	: 7.5 Ah	20 hr @ 0.375 A	: 7.5 Ah
● DIMENSIONS		10 hr @ 0.675 A	: 6.75 Ah
TOTAL HEIGHT	: 100 mm (3.94 inches)	5 hr @ 1.2 A	: 6 Ah
CONTAINER HEIGHT	: 94 mm (3.70 inches)	1 hr @ 4.5 A	: 4.5 Ah
LENGTH	: 151 mm (5.95 inches)	1 C @ 7.5 A	: 3.75 Ah
WIDTH	: 65 mm (2.56 inches)	● INTERNAL RESISTANCE(25℃ , 77 ℉) : 25 mΩ	
WEIGHT	: APPROX 2.56 kg (5.64 lbs)	● CHARGING VOLTAGE (25℃ , 77 ℉)	
● MAX DISCHARGE CURRENT : 75 A (5 sec)		STANDBY USE	: 2.275±0.025 V/CELL
● MAX SHORT- DURATION DISCHARGE CURRENT : 225 A(0.1 sec)			: (-3.3mV / ℃ / CELL)
● STANDARD TERMINALS	: FO-02/FO-03	CYCLE USE	: 2.45±0.05 V/CELL
● CONTAINER MATERIAL	: GENERAL GRADE ABS		: (-5 mV / ℃ / CELL)
		● MAX CHARGING CURRENT	: 2.25 A

Faster discharge
less output energy
(losses, heat)

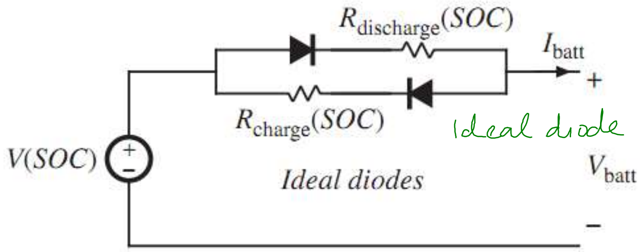
2.5V/cell ×6 = 15V

$V_{in} \approx 15V$

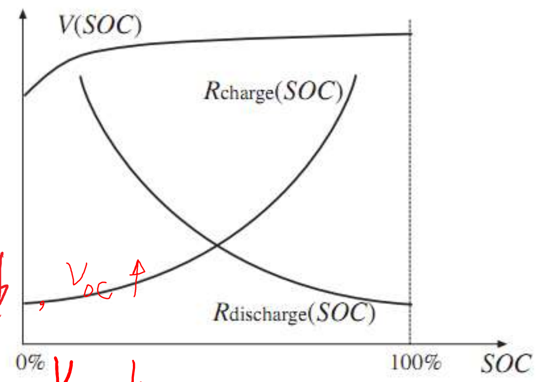
Lead acid battery model

Basic model

Dependence of model parameters on battery state of charge (SOC)



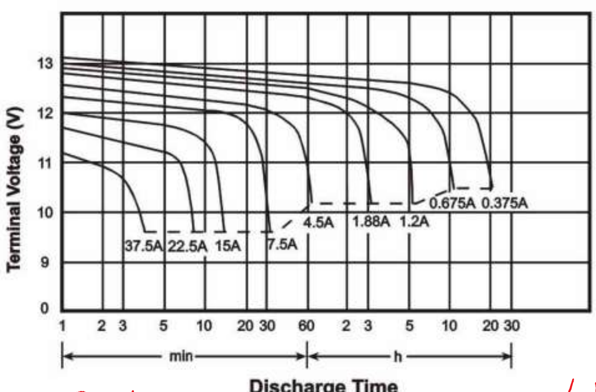
Ideal diode



SOC ↑, R charge ↑, R discharge ↓, V_{oc} ↑

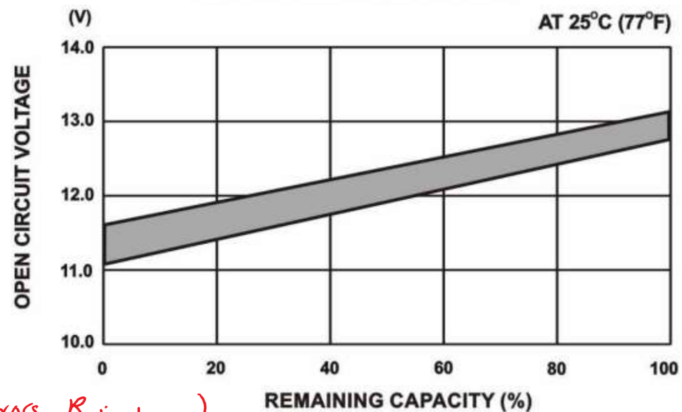
SOC ↓, R_{charge} ↓, $R_{discharge}$ ↑, V_{oc} ↓

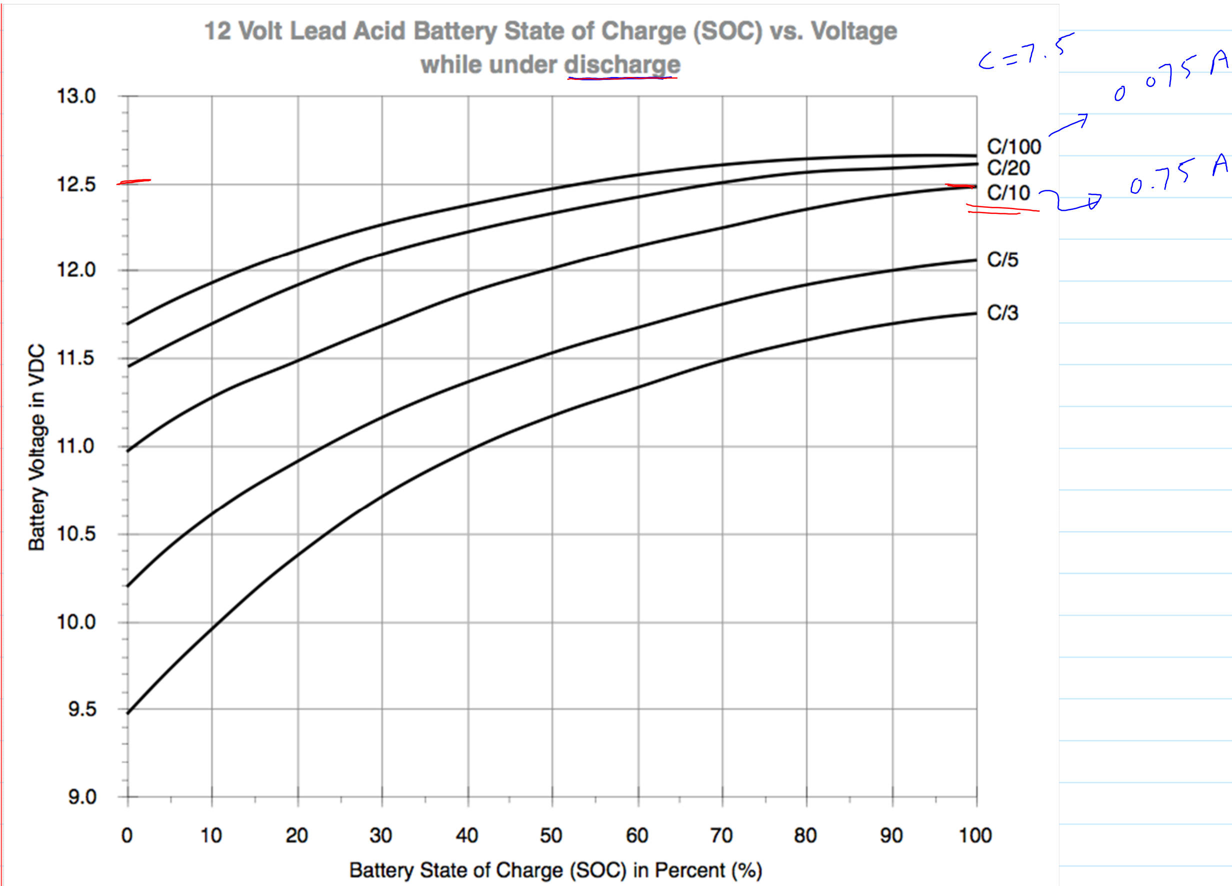
Discharge Characteristics 25 °C (77 °F)



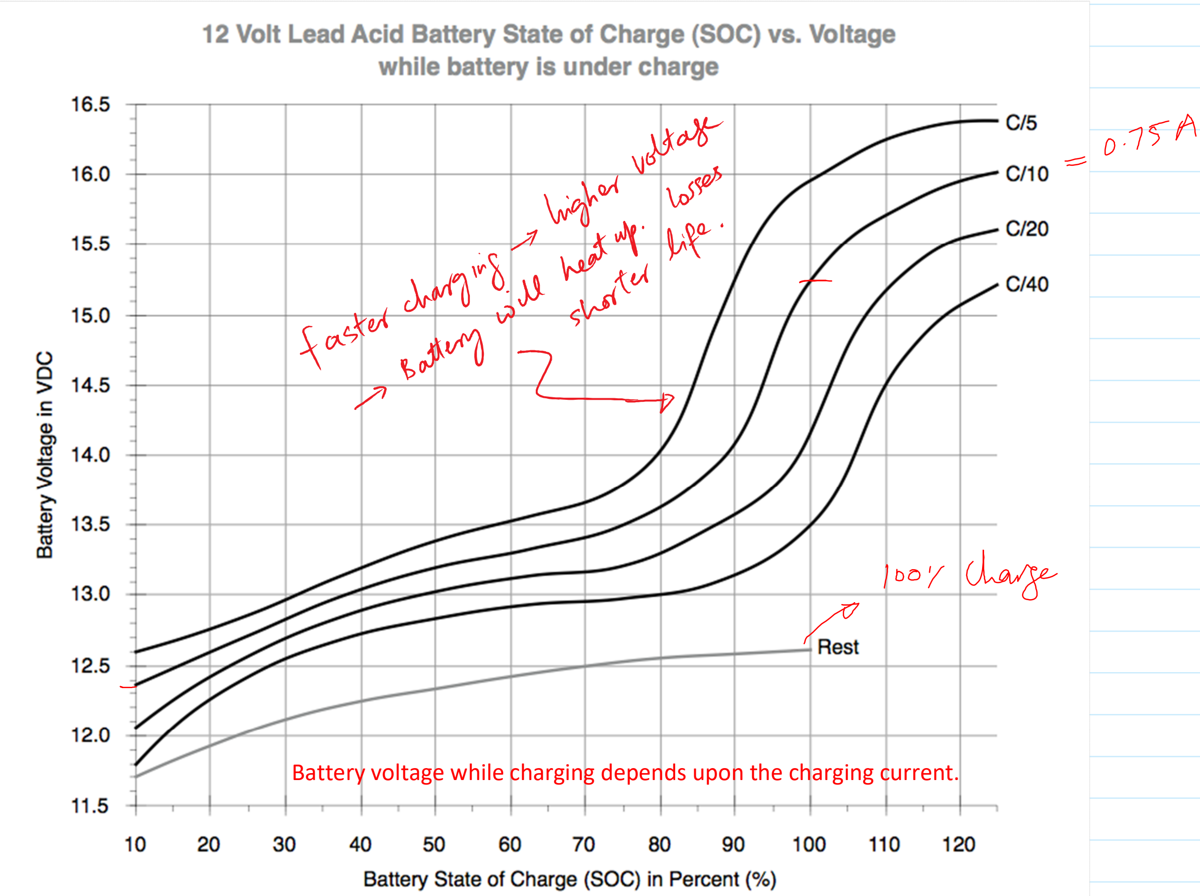
Faster discharge less voltage (drop across $R_{discharge}$)

OPEN CIRCUIT VOLTAGE VS REMAINING CAPACITY

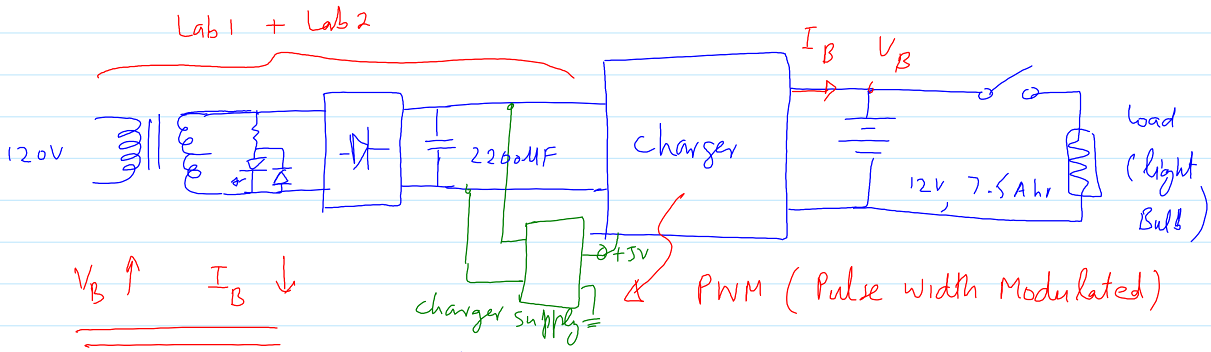




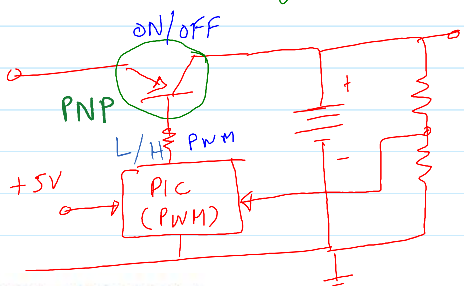
cycle use $V_{charge} = 2.5V/cell \Rightarrow 2.5 \times 6 = 15V$ (Maximum)

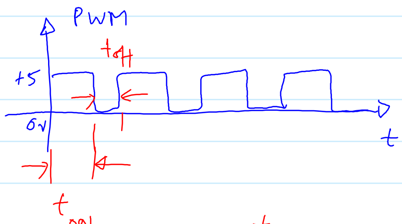


charger Block diagram



circuit idea





$DC = \text{Duty cycle} = \dfrac{t_{on}}{t_{on} + t_{off}}$

DC Controls I_B

TIP125/TIP126/TIP127

PNP Epitaxial Darlington Transistor

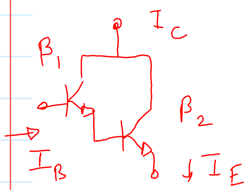
- Medium Power Linear Switching Applications
- Complementary to TIP120/121/122

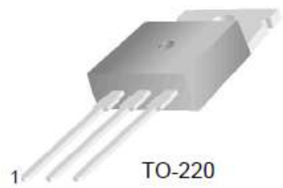
Darlington, High β

Equivalent Circuit

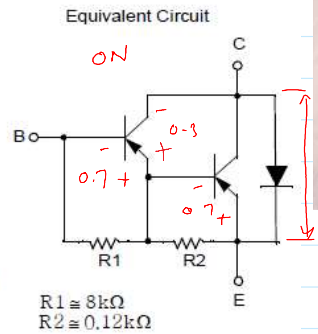
• Complementary to TIP 120/121/122

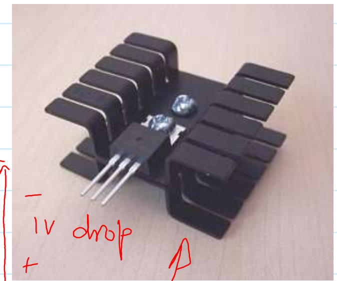
Darlington, High β





1.Base 2.Collector 3.Emitter





Mount TIP 125 on a heat sink

$$\beta = \frac{I_C}{I_B} \approx \beta_1 \beta_2$$

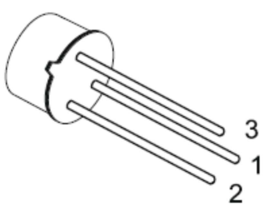
$$I_C = I_{C_2} + I_{C_1} \Rightarrow \beta = \frac{I_{C_2} + I_{C_1}}{I_{B_1}} = \frac{\beta_2 (I_{E_1}) + \beta_1 I_{B_1}}{I_{B_1}} = \frac{\beta_2 \beta_1 I_{B_1} + \beta_2 I_{B_1} + \beta_1 I_{B_1}}{I_{B_1}}$$

$$\beta = \beta_2 \beta_1 + \beta_2 + \beta_1$$

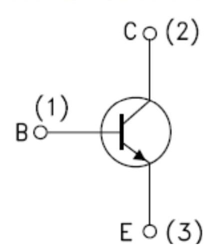
Electrical Characteristics* T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
V_{CEO}(sus)	Collector-Emitter Sustaining Voltage : TIP125 : TIP126 : TIP127	I_C = -100mA, I_B = 0	 -60 -80 -120			 V V V
I_{CEO}	Collector Cut-off Current : TIP125 : TIP126 : TIP127	 V_{CE} = -30V, I_B = 0 V_{CE} = -40V, I_B = 0 V_{CE} = -50V, I_B = 0			 -2 -2 -2	 mA mA mA
I_{CBO}	Collector Cut-off Current : TIP125 : TIP126 : TIP127	 V_{CB} = -60V, I_E = 0 V_{CB} = -80V, I_E = 0 V_{CB} = -100V, I_E = 0			 -1 -1 -1	 mA mA mA
I_{EBO}	Emitter Cut-off Current	V_{BE} = -5V, I_C = 0			-2	mA
h_{FE}	* DC Current Gain	V_{CE} = -3V, I_C = 0.5A V_{CE} = -3V, I_C = -3A	1000 1000			
V_{CE}(sat)	* Collector-Emitter Saturation Voltage	I_C = -3A, I_B = -12mA I_C=-5A, I_B=-20mA			-2 -4	V V
V_{BE}(on)	* Base-Emitter On Voltage	V_{CE} = -3V, I_C = -3A			-2.5	V
C_{ob}	Output Capacitance	V_{CB} = -10V, I_E = 0, f = 0.1MHz			300	pF

2N2222A



INTERNAL SCHEMATIC DIAGRAM



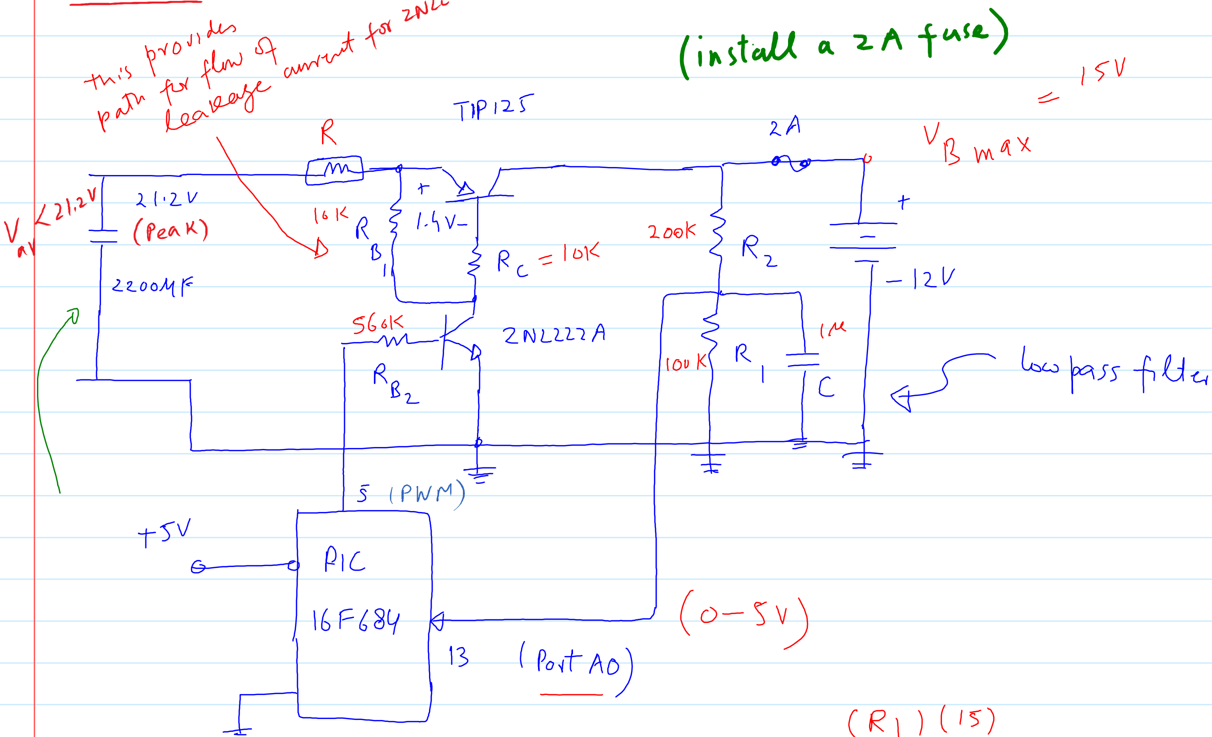
I_c < 600ma

NPN

$V_{(BR)CBO}$	Collector-Base Breakdown Voltage (I_E = 0)	I_C = 10 µA	75			V
$V_{(BR)CEO}$*	Collector-Emitter Breakdown Voltage (I_B = 0)	I_C = 10 mA	40			V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage (I_C = 0)	I_E = 10 µA	6			V
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 150 mA I_B = 15 mA I_C = 500 mA I_B = 50 mA			0.3 1	V V
$V_{BE(sat)}$*	Base-Emitter Saturation Voltage	I_C = 150 mA I_B = 15 mA I_C = 500 mA I_B = 50 mA	0.6		1.2 2	V V
h_{FE}*	DC Current Gain	I_C = 0.1 mA V_{CE} = 10 V I_C = 1 mA V_{CE} = 10 V I_C = 10 mA V_{CE} = 10 V I_C = 150 mA V_{CE} = 10 V I_C = 500 mA V_{CE} = 10 V I_C = 150 mA V_{CE} = 1 V I_C = 10 mA V_{CE} = 10 V	35 50 75 100 40 50		 300	

$V_{(BR)CBO}$	Collector-Base Breakdown Voltage (I_E = 0)	I_C = 10 μA	75			V
$V_{(BR)CEO}$*	Collector-Emitter Breakdown Voltage (I_B = 0)	I_C = 10 mA	40			V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage (I_C = 0)	I_E = 10 μA	6			V
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 150 mA I_B = 15 mA I_C = 500 mA I_B = 50 mA			0.3 1	V V
$V_{BE(sat)}$*	Base-Emitter Saturation Voltage	I_C = 150 mA I_B = 15 mA I_C = 500 mA I_B = 50 mA	0.6		1.2 2	V V
h_{FE}*	DC Current Gain	I_C = 0.1 mA V_{CE} = 10 V I_C = 1 mA V_{CE} = 10 V I_C = 10 mA V_{CE} = 10 V I_C = 150 mA V_{CE} = 10 V I_C = 500 mA V_{CE} = 10 V I_C = 150 mA V_{CE} = 1 V I_C = 10 mA V_{CE} = 10 V T_{amb} = -55 °C	35 50 75 100 40 50 35		300	

circuit

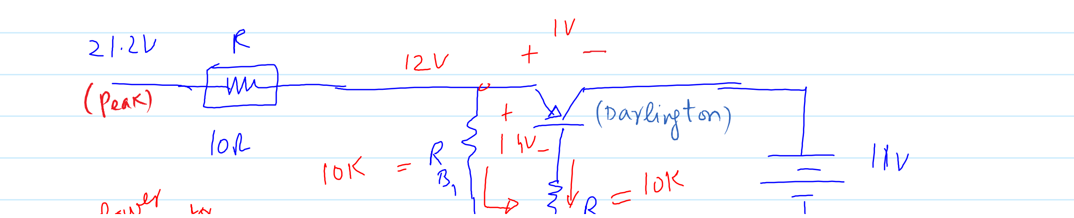


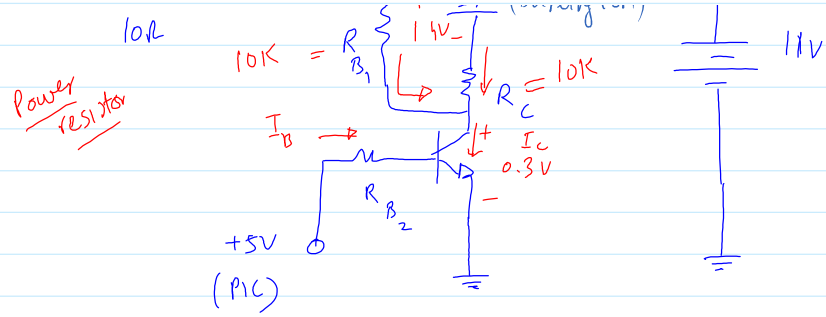
$$5V = \frac{(R_1)(15)}{R_1 + R_2}$$

Take $R_1 = 100K \rightarrow R_2 = 200K$

Say $\tau = R_1 C = 0.1\,sec \Rightarrow R_1 = 100K \Rightarrow C = 1\,\mu F$

Say Battery is discharged → $V_B = 11V$ → connected to the charger





$$I_C = \frac{12V - 1.4 - 0.3V}{R_C} + \frac{12V - 0.3}{R_{B_1}} = \frac{10.3}{10K} + \frac{11.7}{10K}$$

$$I_C = 1.03\,mA + 1.17\,mA = 2.2\,mA$$

I_B darlington $= 1.03\,mA$, $\beta = 1000$, $I_C = 1.03\,A$ (max) (Actual I_C may be smaller)

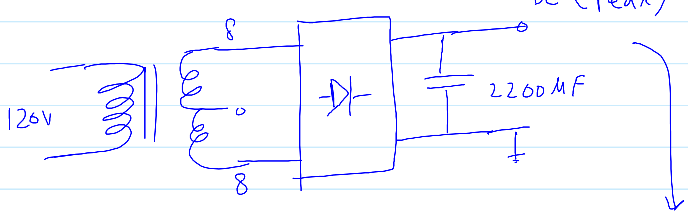
$$I_B = \frac{I_c}{\beta} = \frac{2.2\,mA}{200} = 11\,\mu A$$

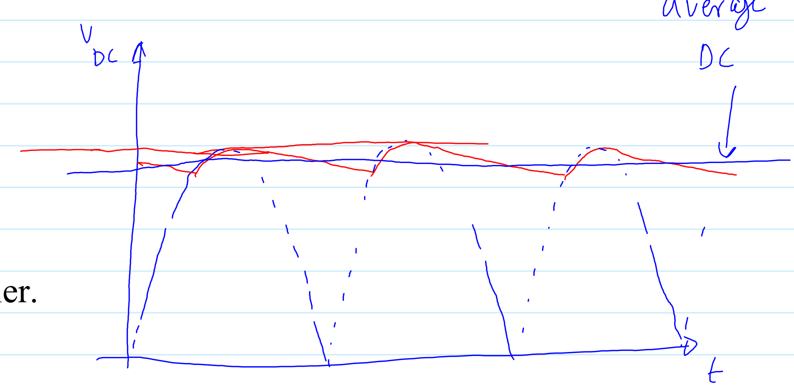
10VA transformer

$V = 12\,V$ $\quad I = \frac{10}{12} = 0.83A$

$$R_{B_2} = \frac{5 - 0.7}{11\,\mu A} = 390\,K\Omega$$

$$V_{DC}(\text{Peak}) = \sqrt{2}(16) - 1.4 = 21.2\,V$$





Average voltage will be smaller.

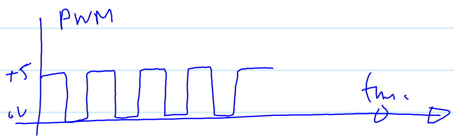
12V battery, 10VA transformer $\longrightarrow$ $I_{DC} = \frac{10}{12} = 0.833A$

Say $I_{DC\,(max)} \approx 1A$

... R = 21.2 V − 12 V = 9.2 V (Actual drop

$Dc\,(max') =$

Maximum drop across the resistor $R = 21.2V - 12V = 9.2V$ (Actual drop will be smaller)



$R = \frac{9.2V}{1A} = \underline{\underline{9.2\Omega}} \Rightarrow 10\Omega$ $\underline{\underline{7W}}$?

A PWM output Example for PIC16F684
(It will not work as such)

```
program PWM_rc2_an0
dim dc1 as byte
main:
TRISA=$01
cmcon0=0  'comparators off
ANSEL=$01
ADCON0=$80 'right justified
ADCON1=$70 'set clock frequency
TRISC = 0
PORTC=$FF     'initial value
PWM1_Init(1000)    ' initializes PWM module, freq = 1kHz.
PWM1_Start    ' starts PWM
While true
dc1= word(ADC_read(0) >> 2)   'read adc and kick two LSBs out
Delay_ms(100)   'change duty every 100ms
PWM1_Set_Duty(dc1) ' changes duty ratio
wend
end.
```

$(255 - K * dc1)$??

$V_{DC(av)} = 0.9\,V_{ac} - 1.4V$

$V_{DC_{av}} = 0.9 \times 16 - 1.4 = 13V$

Drop across the resistor $= 1V$

$R = {}^{1V}/_{0.833A} = 1.2\,\Omega$

(Resistor could be removed or reduced)

Program PIC16F684 using PICkit1

$V_B \uparrow$, PWM duty ratio $\downarrow$

$11V < V_B < 15V$, $100\%\,(255) <$ PWM Duty $< 0\%\,(0)$, voltage divider is $1/3$

$V_B = 11V \longrightarrow V_{ADC} = \frac{11}{3} = 3.66V$, $V_B = 15V \longrightarrow V_{ADC} = \frac{15}{3} = 5V$

Requirement: $3.66V \longrightarrow dc1 = 255$ and $5V \longrightarrow dc1 = 0$ (Proportional Controller)

$$\frac{dc1 - 255}{0 - 255} = \frac{V_{ADC} - 3.66}{5 - 3.66} \Rightarrow dc1 = 255 - \frac{255}{1.34}(V_{ADC} - 3.66)$$

$$\boxed{dc1 = 951.5 - 190.3\,V_{ADC}} \Rightarrow V_{ADC} = \frac{5\,(\text{data1})}{1023} \text{ where}$$

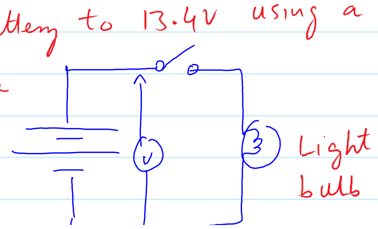
$\Rightarrow$ Write your own code in Mikrobasic. Use float variables.

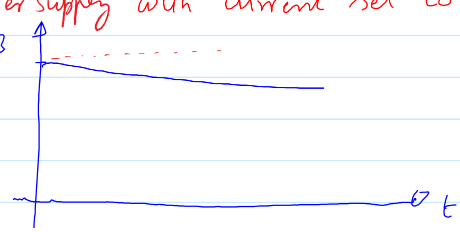
Testing:

#1 <u>Plot Battery discharge curve</u>

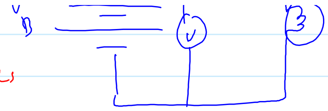
charge battery to 13.4V using a power supply with current set to less than 1A.

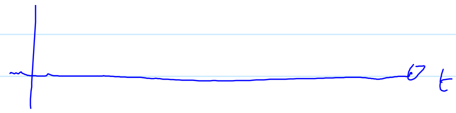
then discharge and log V_B voltage values





and log voltage values

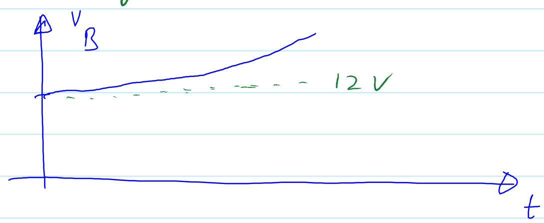




Record V_B when battery is being discharged.

#2 Plot battery charging curve

Connect your charger circuit to the battery and record V_B as the battery is being charged



#3 Record waveforms in your circuit while battery is charging.

→ rectifier output, PIC out, V_B, Darlington V_B

#4 Find PWM charger η

$$\eta = \frac{V_o I_o \quad \text{dc}}{V_{in} I_{in} \quad \text{ac}}$$

(it may be a low number)

#5 Find charger η without resistor R.

Submit report on the course website in pdf format