Génie Electrique et Electronique
Bachelor semestre 5

Cours « Conversion d'énergie »

Partie 3
Leçon d'introduction

Introduction à la conversion d'énergie électrique

Prof. Elison Matioli
POWERlab - EPFL

Systèmes de conversion pour la production d'énergie électrique

EPFL

Partie 1 – Disponibilité des ressources énergétiques
Partie 2 – Conversion electro-mécanique
Partie 3 – Conversion électrique

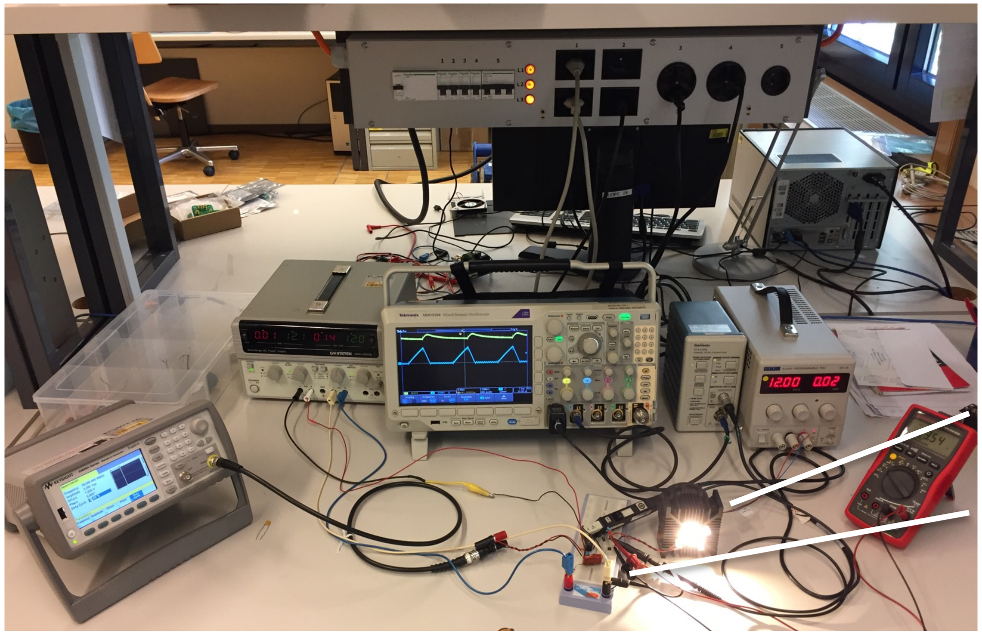
But de ce cours:

Conception des convertisseurs d'énergie électrique

Elements de théorie → Conception/Simulation → Demonstration

Objectif final du cours:

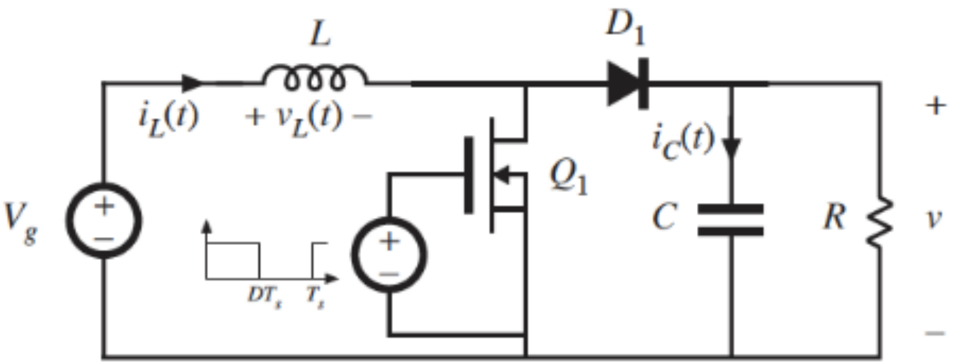
Conception et démonstration d'un convertisseur DC-DC: driver pour une lampe à LED

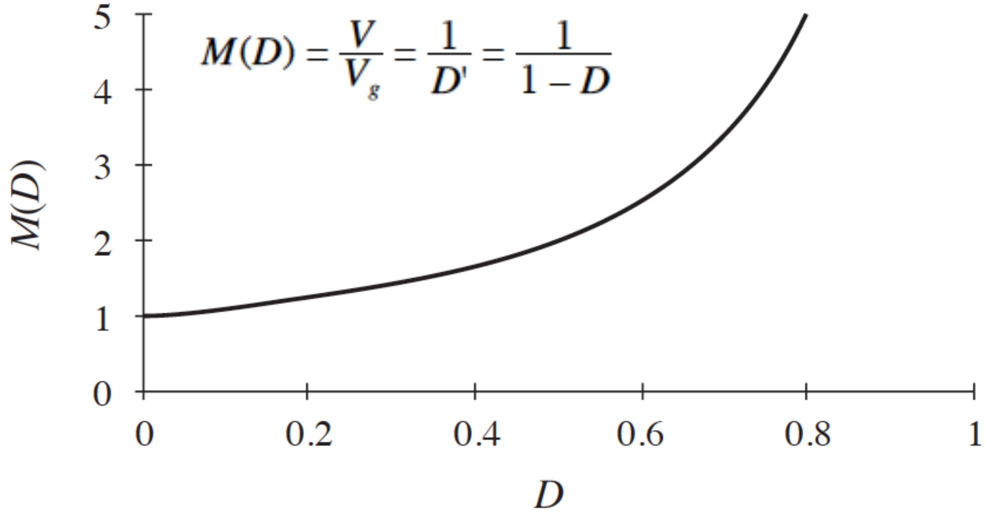


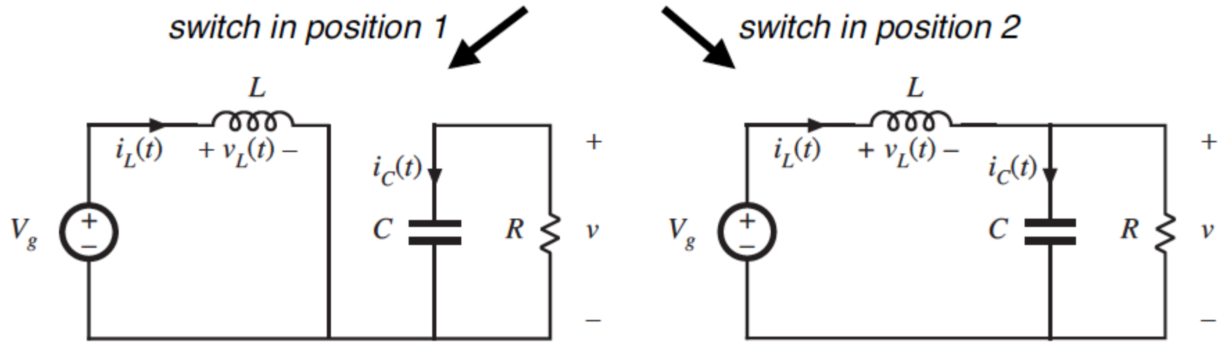
Conversion d’énergie électrique

Dans ce cours, nous allons apprendre:

1. La théorie de convertisseurs de puissance
2. Conception et simulation des convertisseurs
3. Mesure expérimentale des convertisseurs



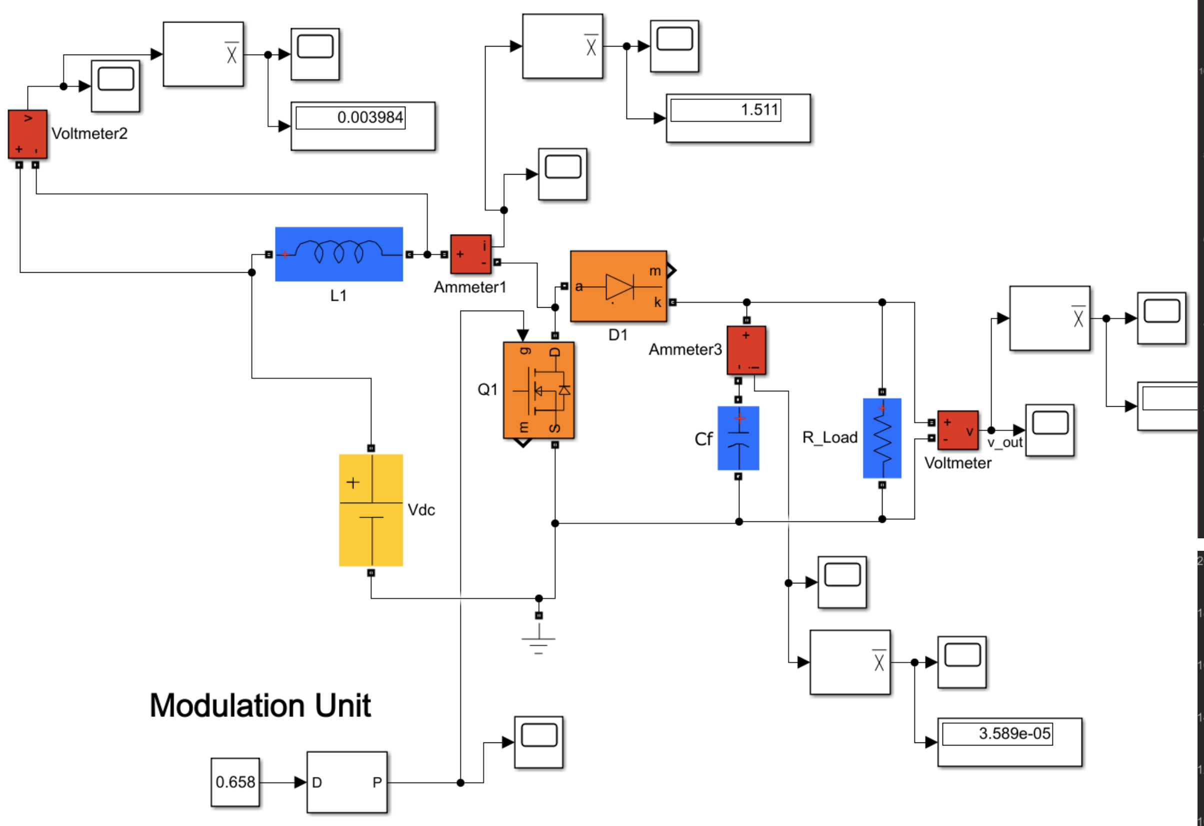


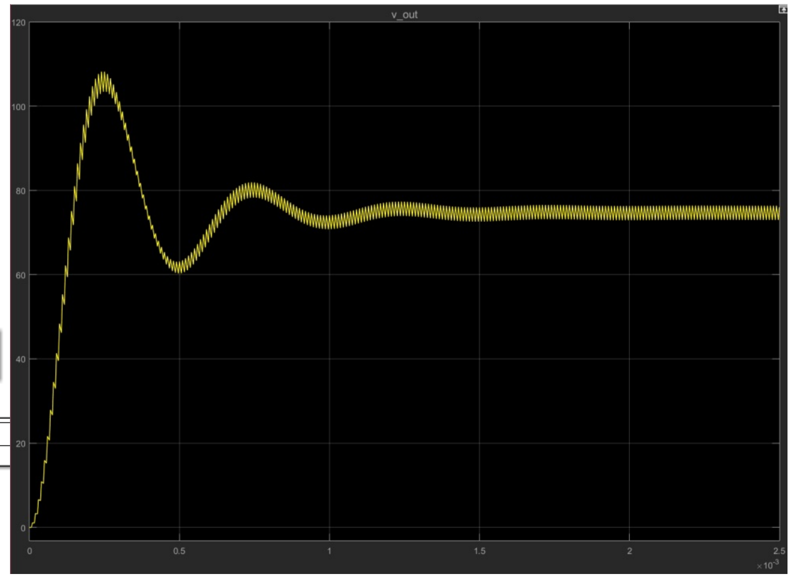


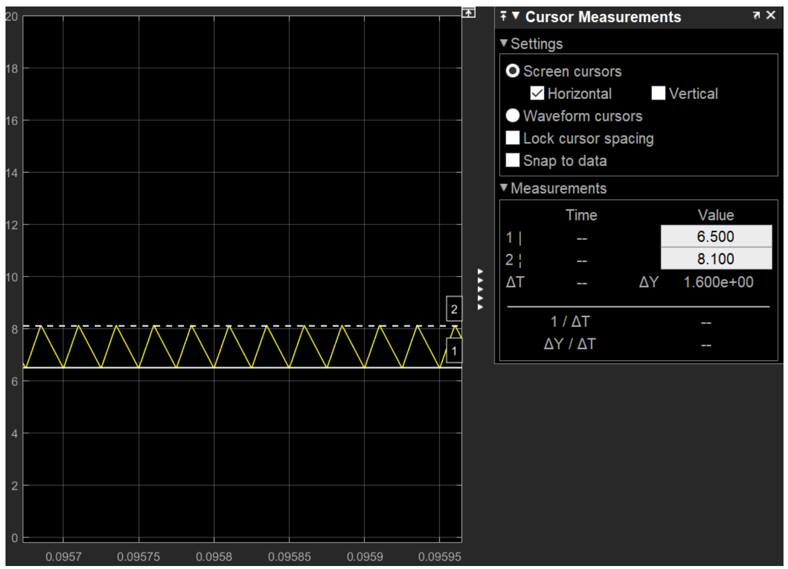
Conversion d’énergie électrique

Dans ce cours, nous allons apprendre:

1. La théorie de convertisseurs de puissance
2. Conception et simulation des convertisseurs
3. Mesure expérimentale des convertisseurs



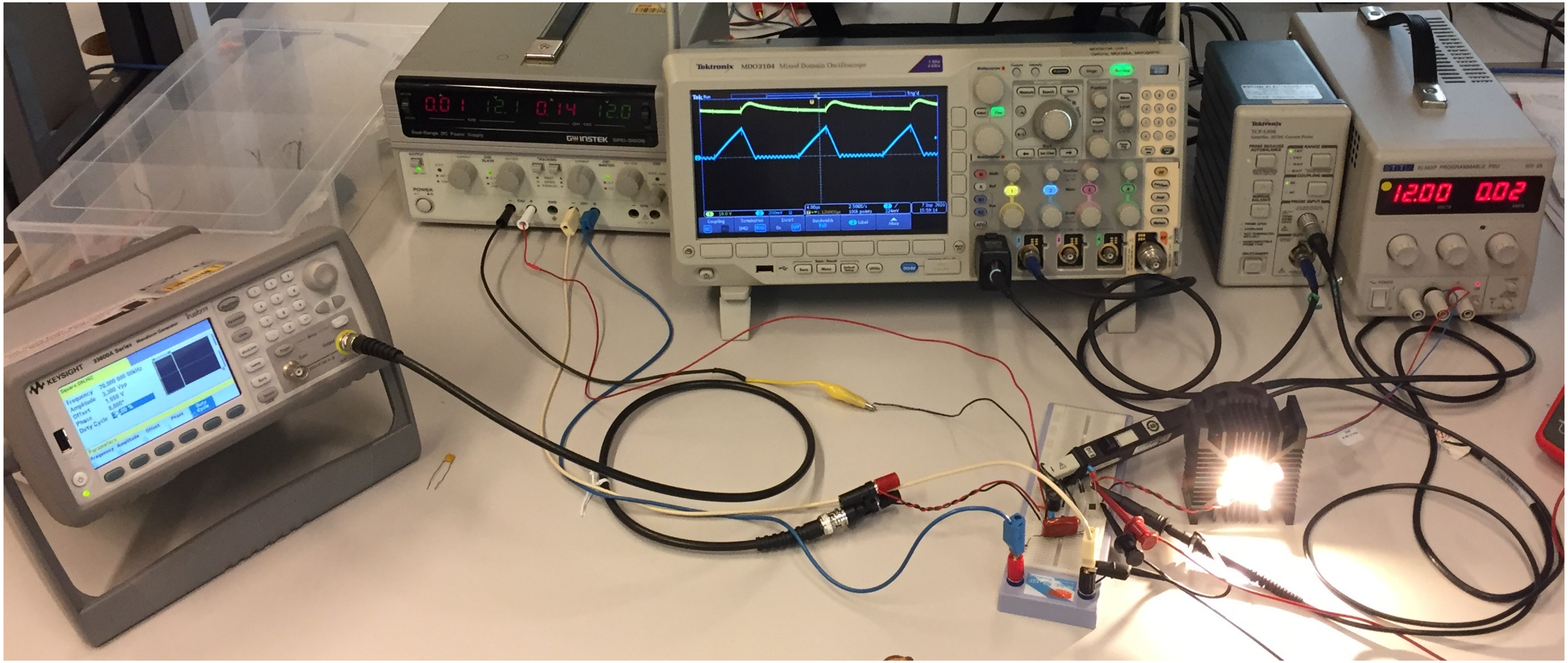




Conversion d’énergie électrique

Dans ce cours, nous allons apprendre:

1. La théorie de convertisseurs de puissance
2. Conception et simulation des convertisseurs
3. Mesure expérimentale des convertisseurs



Vous réaliserez le convertisseur que vous avez conçu en pratique

Le projet sera évalué sous forme de présentation en groupe a la fin du cours.

Contenu du cours

- Motivation: Pourquoi conversion d'énergie électrique
- Introduction à la conversion d'énergie électrique
  - Introduction a l'électronique de puissance
  - Convertisseurs
  - Composants semi-conducteurs de puissance
- Famille Convertisseurs:
  - Convertisseurs DC/DC (buck, boost)
  - Convertisseurs AC/DC (convertisseurs de courant)
  - Convertisseurs DC/AC (onduleurs de tension)
  - Convertisseurs AC/AC (cycloconvertisseurs)
- Conception et simulation des convertisseurs
- Caractérisation expérimentale
  - Mesure d'efficacité de conversion

Documentation du module

- Notes de cours – Prof. E. Matioli (http://moodle.epfl.ch)
- Fundamentals of Power Electronics – second edition – Robert W. Erickson and Dragan Maksimović, Kluwer Academic Publishers, 2004
- « Electronique de Puissance », P. Barrade, Presses Polytechniques et Universitaires Romandes, 2006

Systèmes de conversion pour la production d'énergie électrique

Partie 3 – Conversion électrique

Contenu spécifique du cours

	Syllabus	Location	EE360 - 3eme partie		hand out	turn in	
week 1	21.11.2025	BS260	Cours 1	**Introduction**	**Divide the groups in 4 each, 11 groups in total**		
				brief Introduction au projet - what we will learn in this class			
				Type de convertisseurs			
				buck and boost converters			
week 2	25.11.2025	ELD020	Cours 2	**Analise des convertisseurs**			
				Volts-second balance			
				Capacitor-charge balance			
				Exercises on volt-sec balance and C-charge balance			
	28.11.2025	BS260	Cours 3	**CCM and DCM**	**3 pdfs with project description, tutorial and exercises**		
				Discontinous conduction mode			
				PWM physical realization and Half bridges			
week 3	02.12.2025	ELD020	Cours 4	**Introduce the project- simulation and experimental: components, and the breadboard**	**Components and breadbord will be given here.**		
				tutorial - buck converter			
				Simulation of DC-DC converters (ideal)			
				Implementation of PWM	Homework during the weekend		
	05.12.2025	BS260	Cours 5	**Switch realization**		**Submit your PWM exercise for grades.**	
				Semiconductor power devices, Introduction to gate driver			
				calculate efficiency and share of losses			
week 4	09.12.2025	**ELD 040**	Cours 6	**Lab session: finish your circuit**		**Bring your circuit mounted. Points will be deducted if the circuit is not ready.**	
	12.12.2025	**ELD 040**	Cours 7	**Lab session**			
week 5	15.12.2025	ELD 040		**Additional lab session**			
	16.12.2025	**ELD 040**	Cours 8	**Projet experimental**			
				LED driver			
	19.12.2025			**Project presentation - submit your slides (presentation and slides will be graded)**	**Each student in the group will be tested separately. The entire group needs to be prepared.**		
			Group formation and rules	Groups of 4. Everyone in the group must do a part of the work, which includes: Theoretical Exercise; Simulation and Experiments. Everyone will have to present their parts and will be questioned at the final presentation			

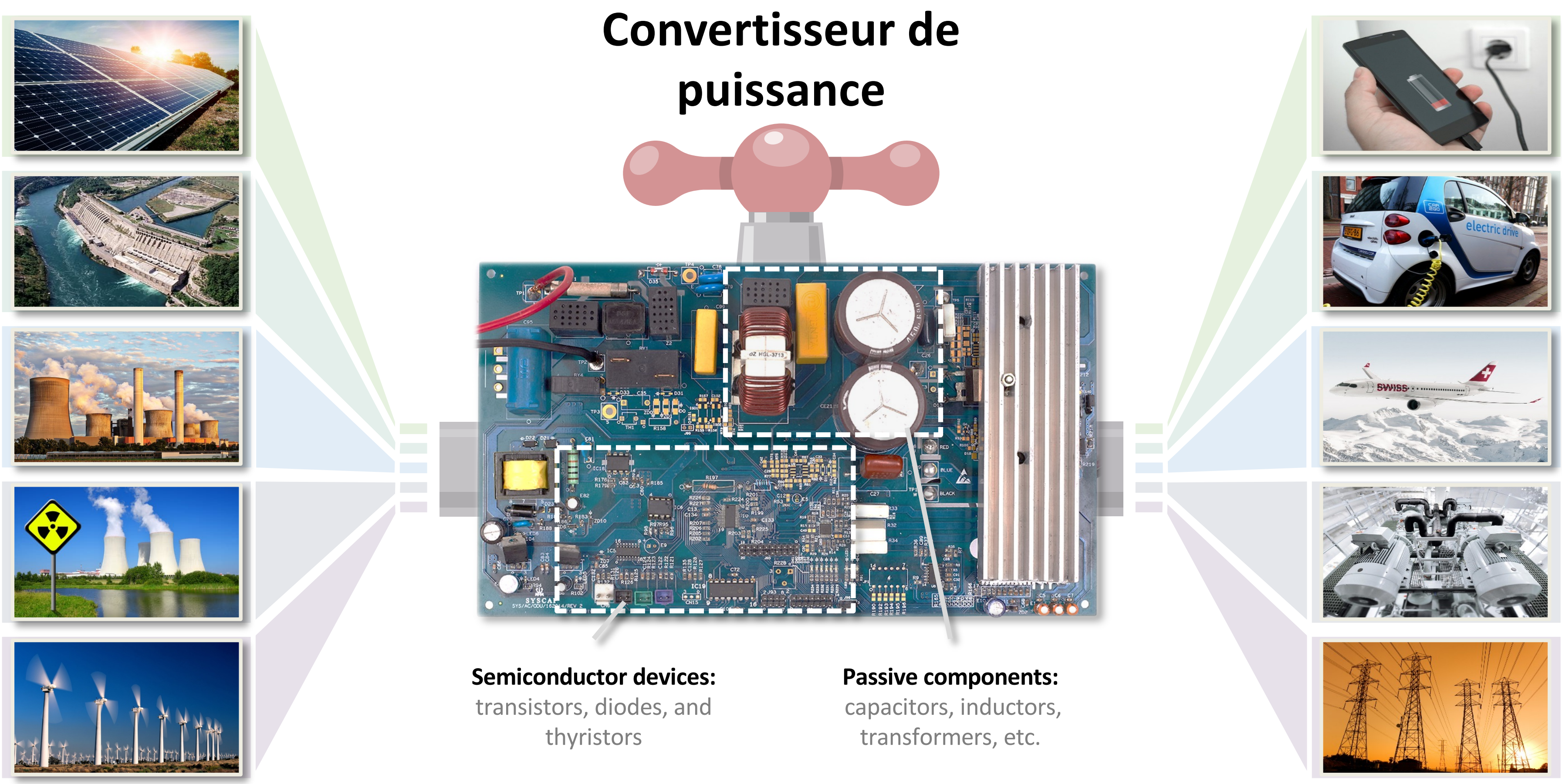
Formez vos groupes de 4 personnes. Chaque personne du groupe devra contribuer avec au moins un des aspects du projet (theorie, Simulation ou TP) et sera individuellement evaluée pendant la presentation a la fin du cours.

Résumé de ce cours

- Introduction
- Notion de commutation
- Convertisseurs

Motivation pour la conversion d'Energie:

- **Conversion d'énergie électrique**
- **Génération a partir d'énergie renouvelables**
- **Réduction en consommation**



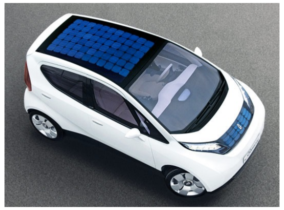
Motivation pour la conversion d'Energie:

- Conversion d'énergie électrique
- **Génération a partir d'énergie renouvelables**
- **Réduction en consommation**

Eolien

Solaire

Vehicules electriques

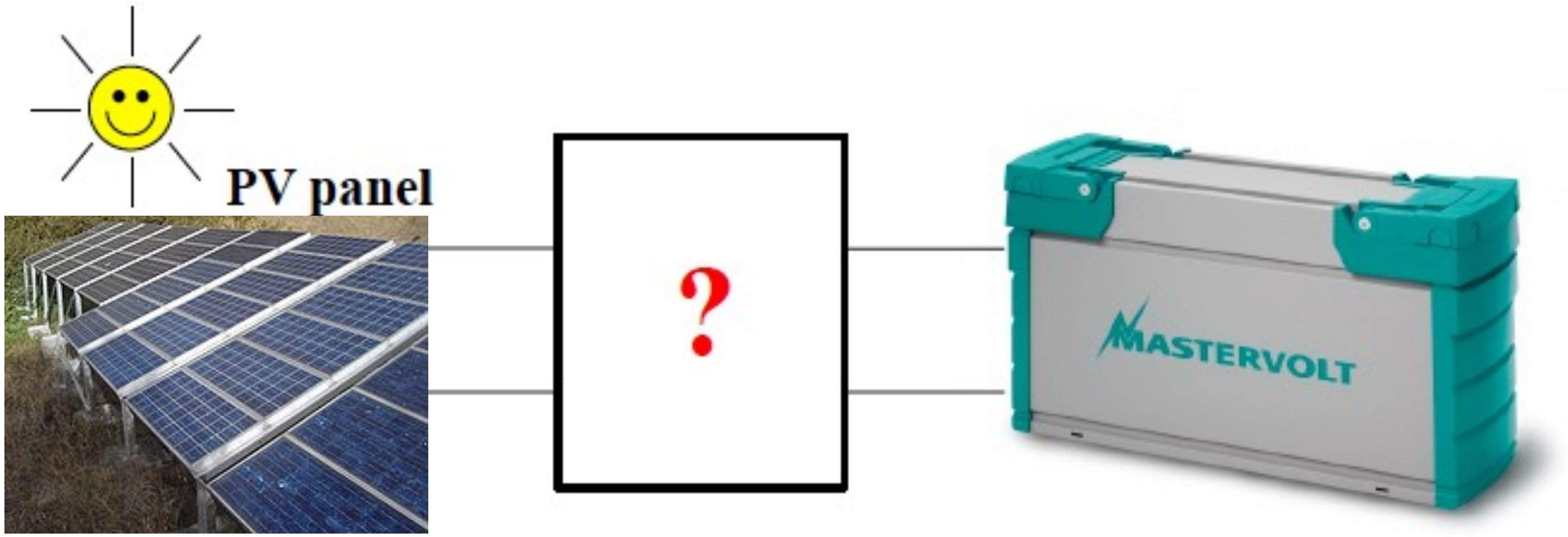


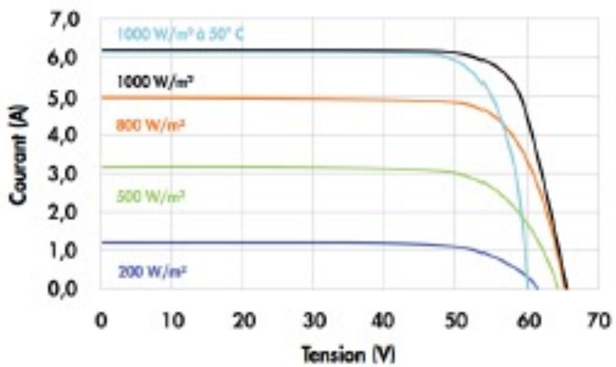
Data centers

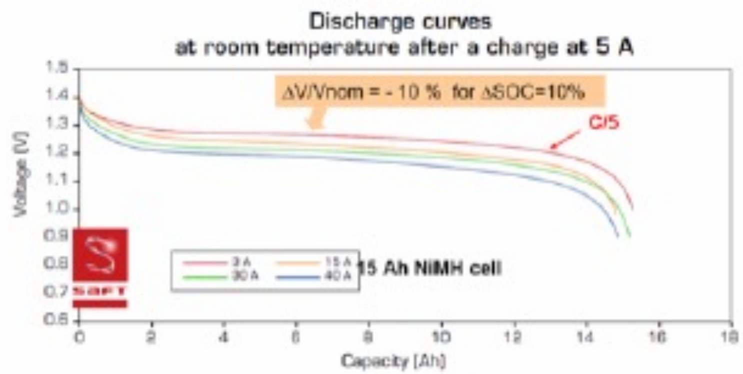
LEDs bulbs

Pourquoi l'énergie électrique?

Mise en forme de l’energie électrique:
Photovoltaïque, charge de batteries



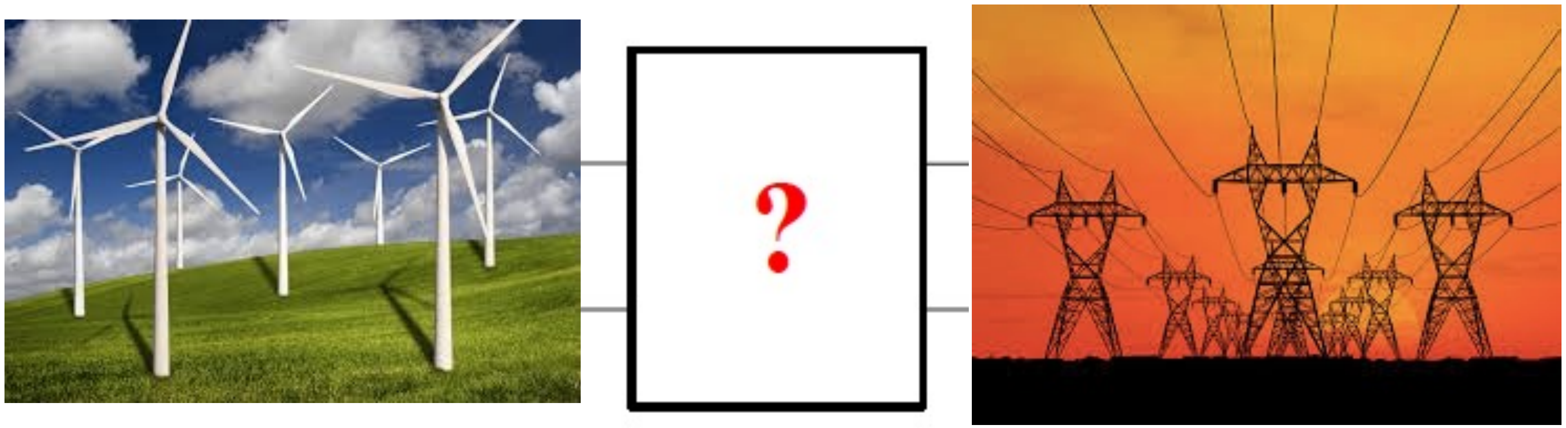




Mise en forme de l'energie electrique:

Éolienne

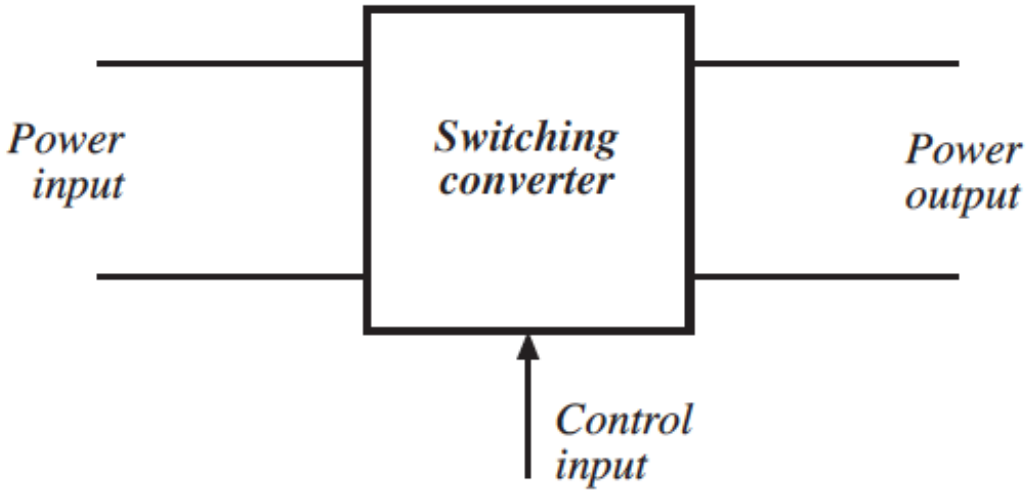
Comment réaliser cette interface?



Introduction

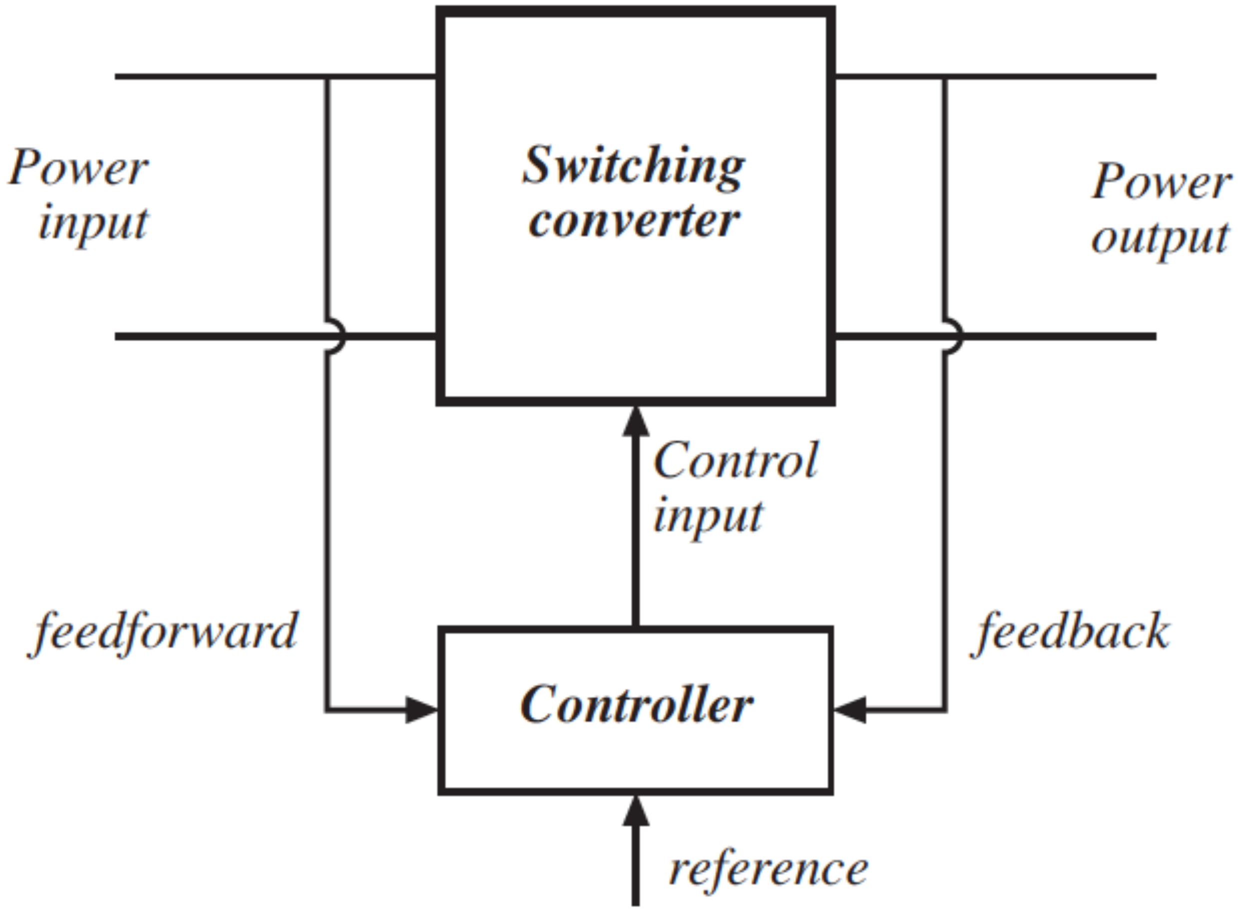
Convertisseur statique:

Système permettant d'adapter la source d'énergie électrique à un récepteur donné
Elément de base: commutateur (Switching-mode converter)



Dc-dc conversion: Change and control voltage magnitude
Ac-dc rectification: Possibly control dc voltage, ac current
Dc-ac inversion: Produce sinusoid of controllable magnitude and frequency
Ac-ac cycloconversion: Change and control voltage magnitude and frequency

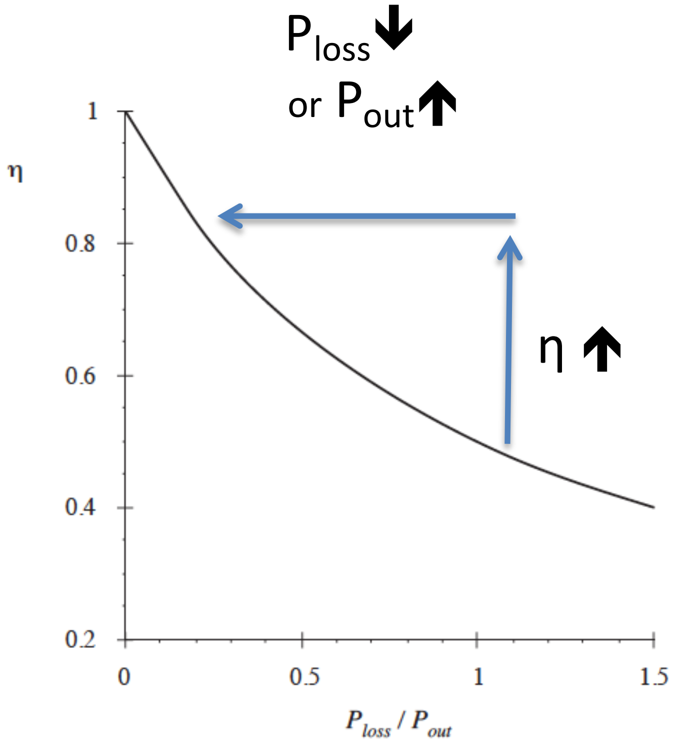
Contrôle est très important



Controller:

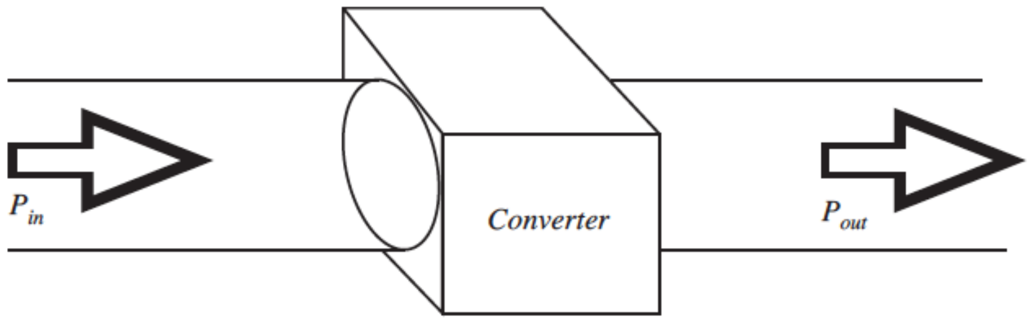
- Produce a regulated voltage, in the presence of variations in the input voltage and load current
- Analog feedback
- Sophisticated digital microcontrollers

Convertisseur à rendement élevé



$$\eta = \frac{P_{out}}{P_{in}}$$

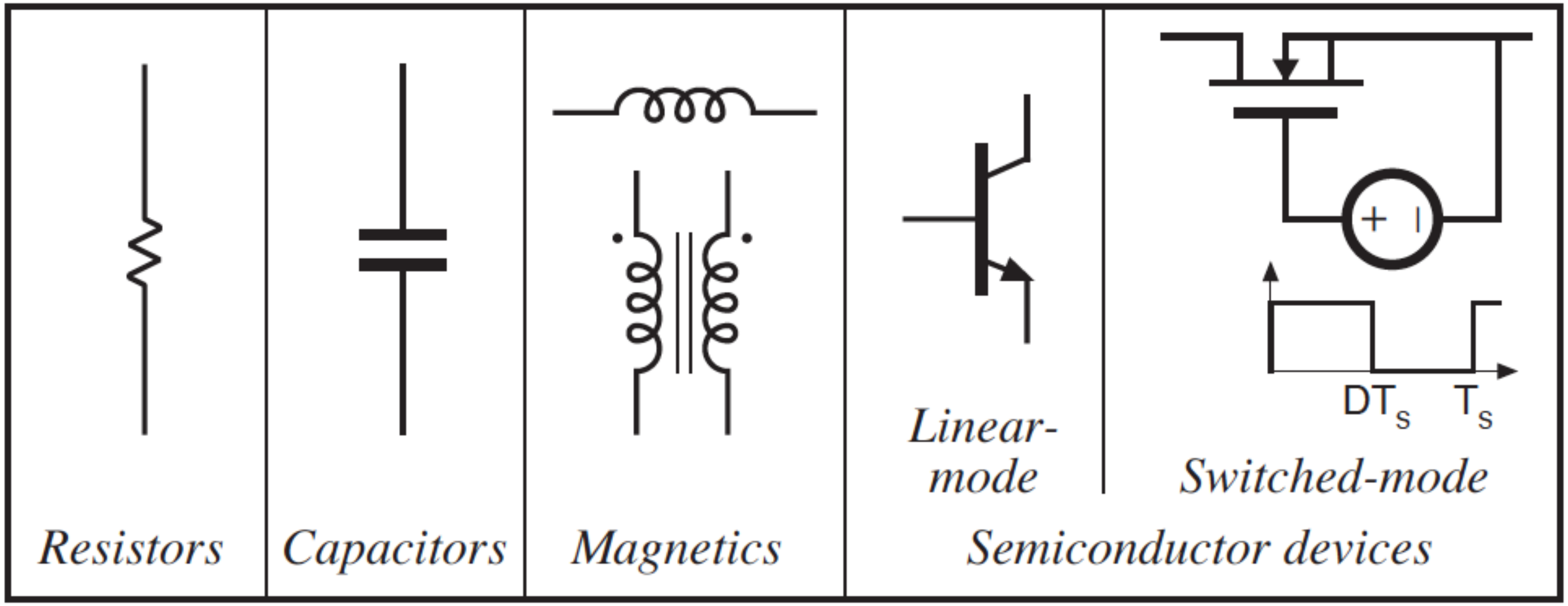
$$P_{loss} = P_{in} - P_{out} = P_{out}\left(\frac{1}{\eta} - 1\right)$$



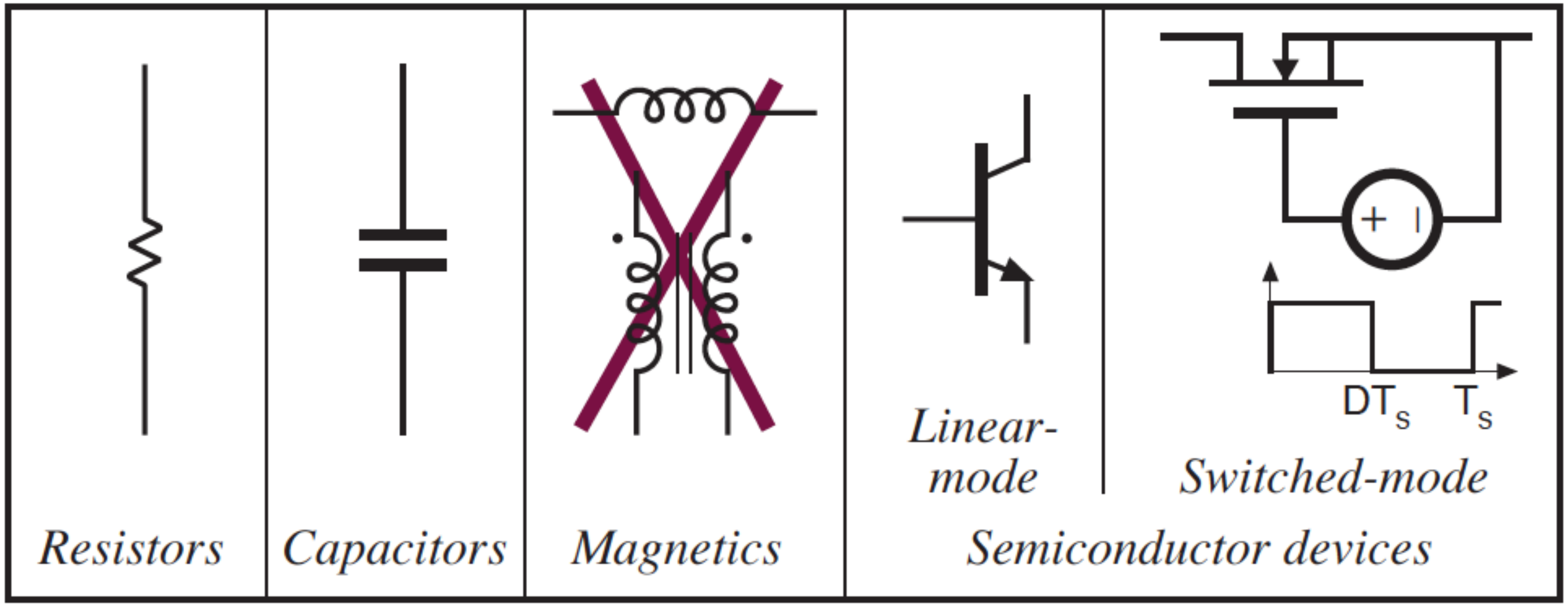
Rendement élevé: un des buts principaux dans la conception des convertisseurs

- Faible puissance dissipée: moins besoin de dissipateurs de chaleur
- Réduction de dimensions: couts plus faibles
- Avec la même taille: Plus forte puissance
- Amélioration de la de fiabilité

Composants disponibles

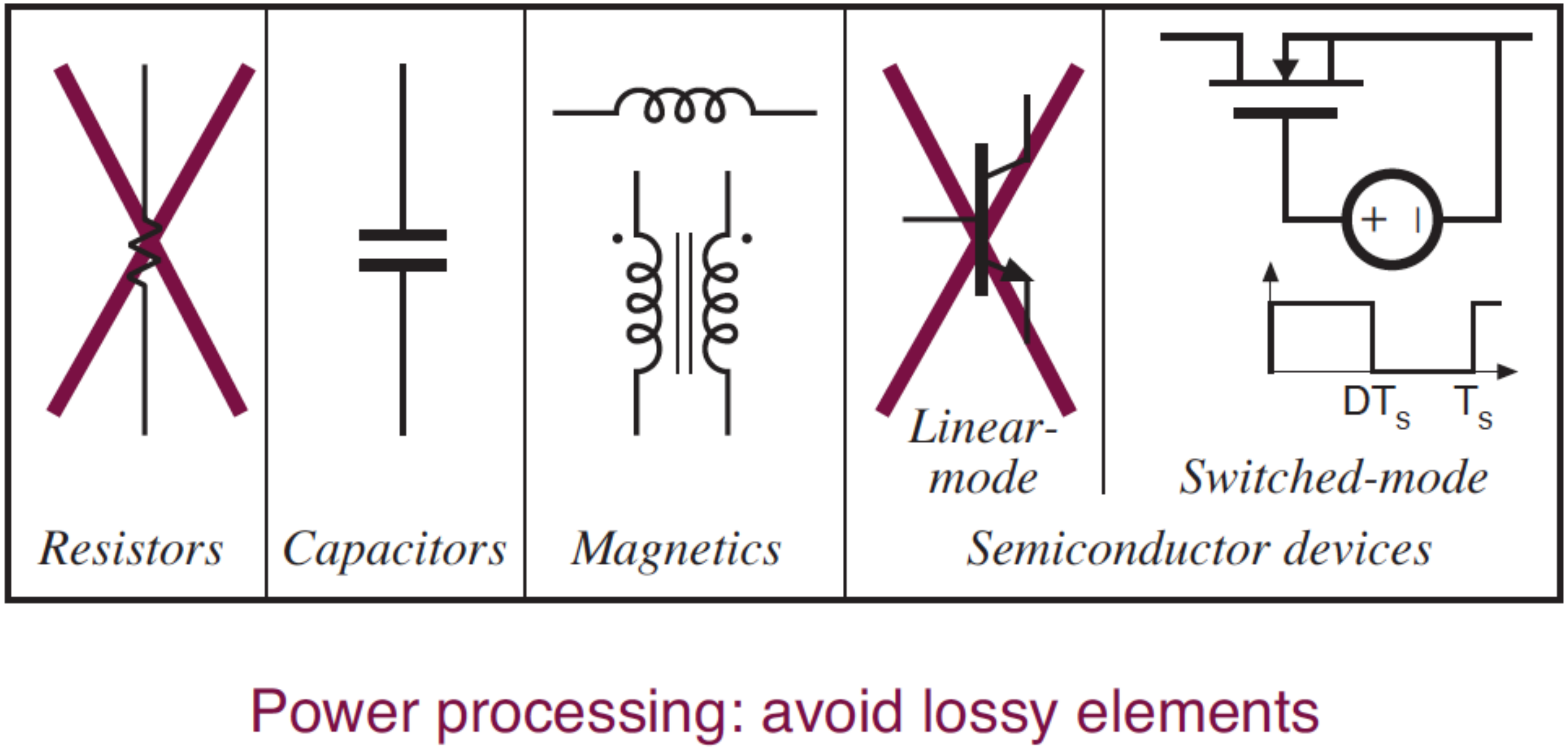


Composants disponibles



Signal processing: avoid magnetics

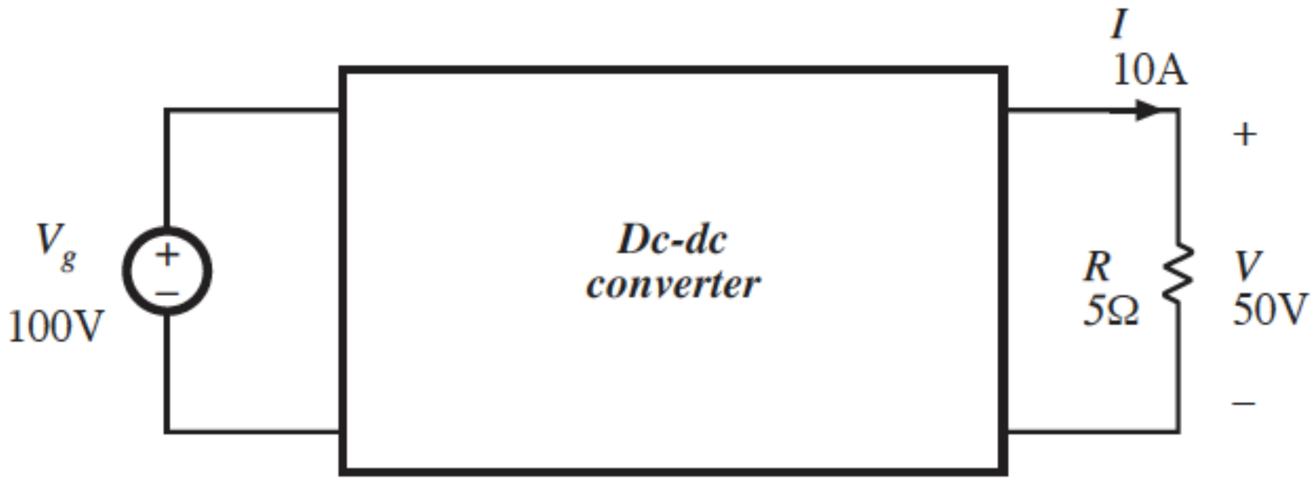
Composants disponibles



Condensateurs et inducteurs:

- Stockage d'énergie sans dissipation de puissance
- Energie stockée peut être réutilisée

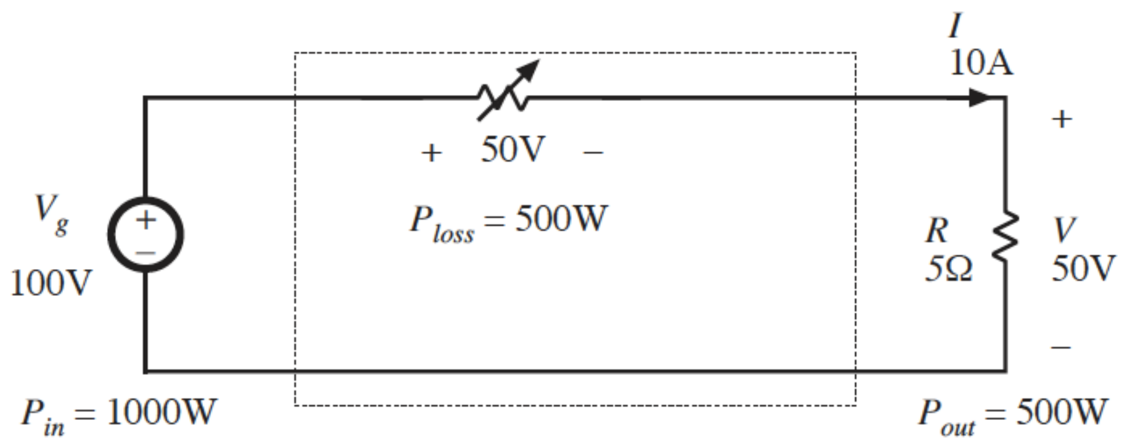
Convertisseur DC-DC



Un tel convertisseur, comment pourrait-il être réalisé?

Convertisseur DC-DC

Solution 1: pont diviseur résistif



Très inefficace: mauvaise solution!

Convertisseur DC-DC

Solution 2:

- Composant actif, type transistor
- Recherche de configurations qui maximisent le rendement

Transistor dans sa caractéristique linéaire

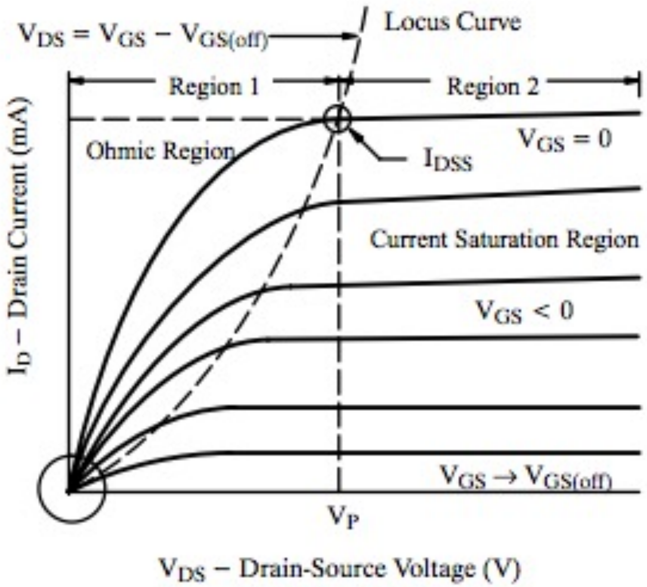
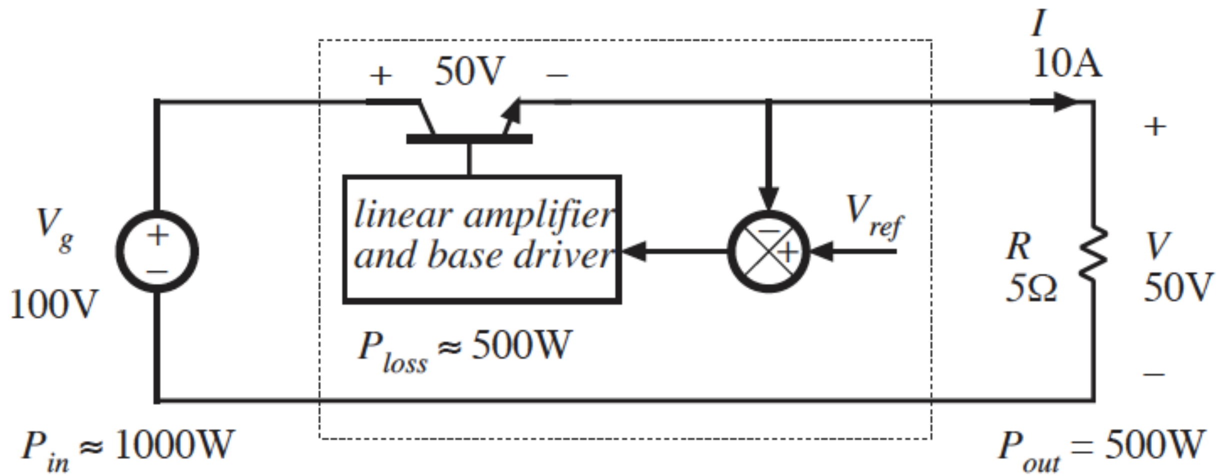


Figure 1. Typical N-Channel JFET Operating Characteristics

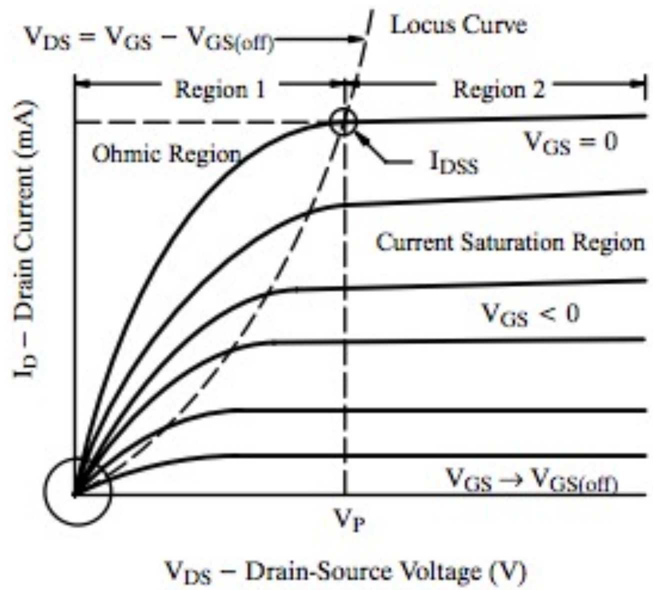
Résistance variable

Convertisseur DC-DC

Solution 2: linear amplifier

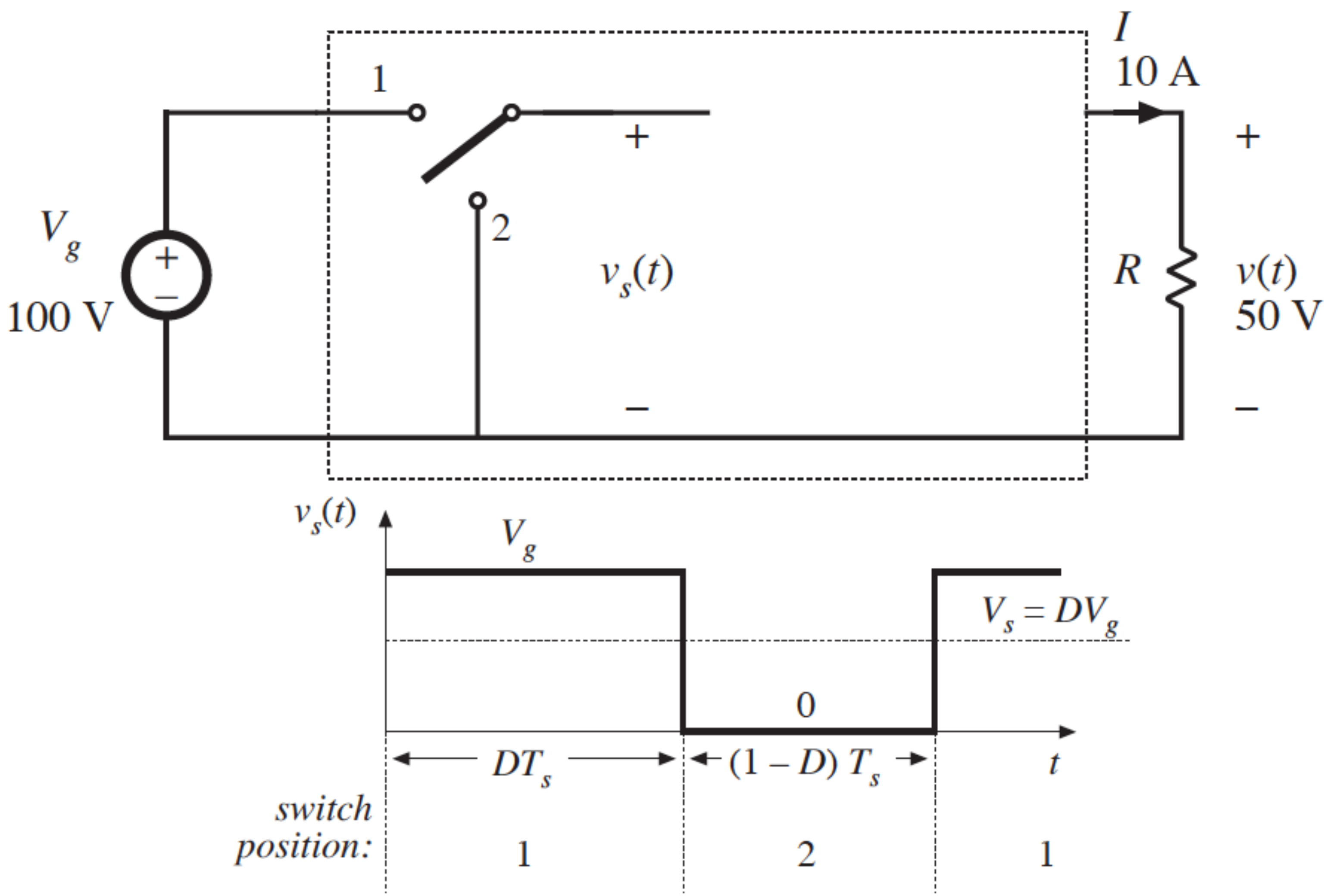


Résistance variable

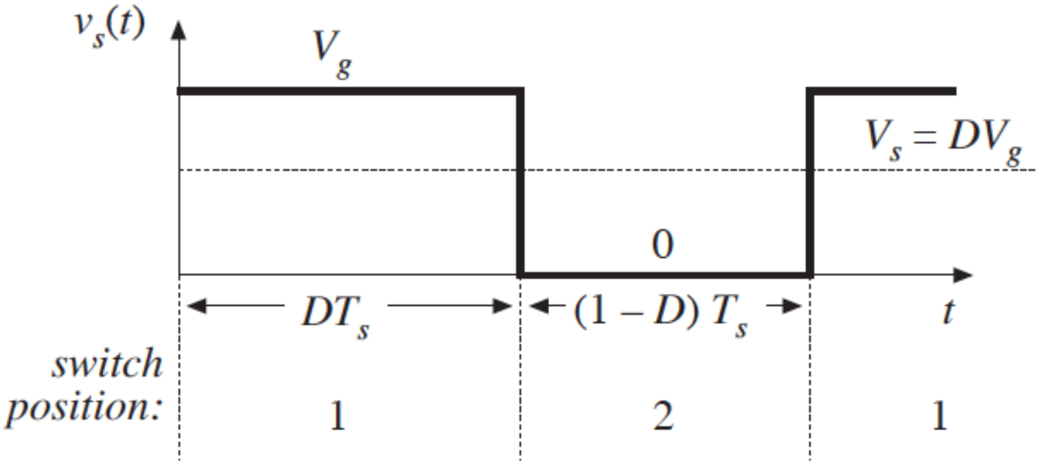


Très inefficace: mauvaise solution!

Notion de commutation



Contrôle du niveau DC de sortie



D = switch duty cycle
$0 \le D \le 1$

T_s = switching period

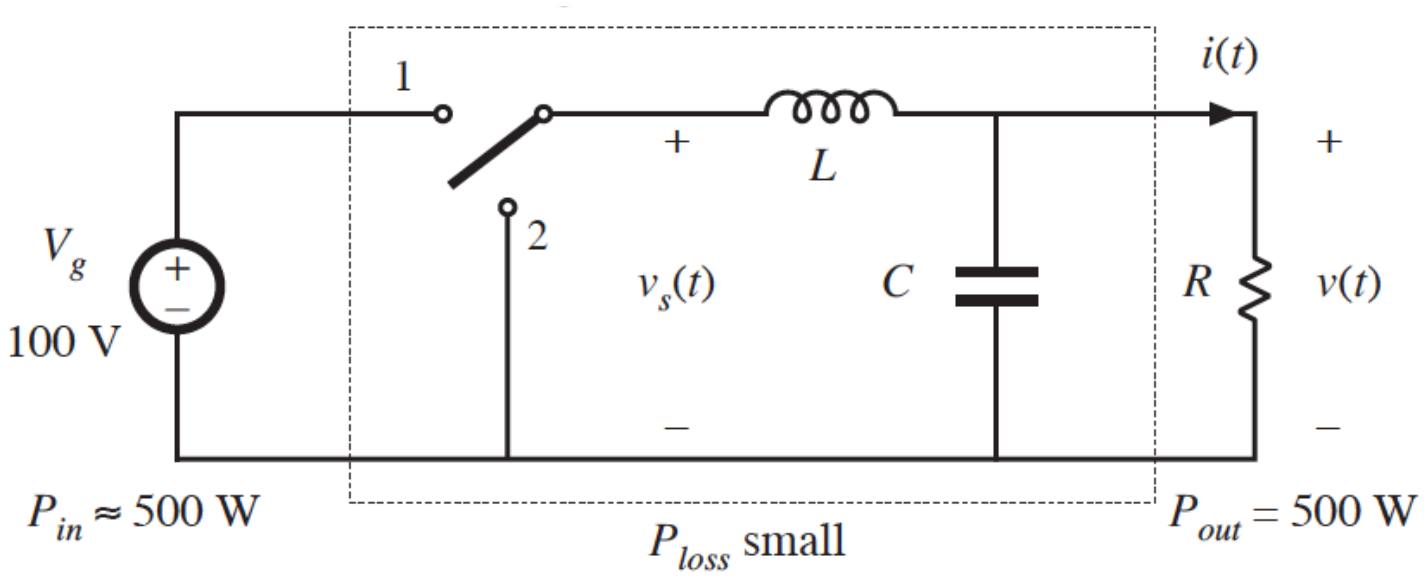
f_s = switching frequency
$= 1 / T_s$

DC component of $v_s(t)$ = average value:

$$V_s = \frac{1}{T_s}\int_0^{T_s} v_s(t)\,dt = DV_g$$

Plus filtre passe-bas

Addition d'un filtre passe-bas (LC) pour filtrer les harmoniques élevés



- Fréquence de coupure du filtre beaucoup plus faible que la fréquence de commutation: $\mathbf{f_0 << f_S}$
- Ce circuit est un **convertisseur Buck (tension de sortie est plus basse que celle à l'entrée)**

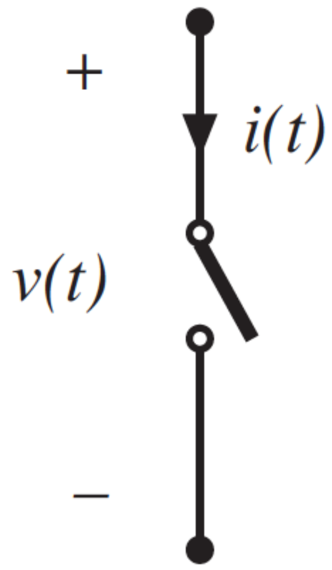
Interrupteur idéal - propriétés

Switch closed: $v(t) = 0$

Switch open: $i(t) = 0$

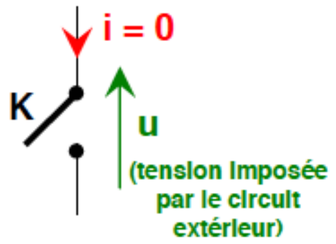
In either event: $p(t) = v(t)\ i(t) = 0$

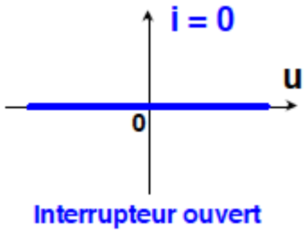
Ideal switch consumes zero power



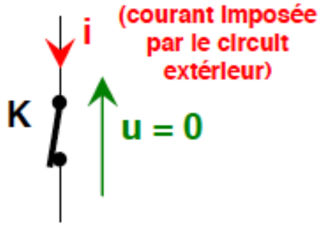
En plus, idéalement, ils doivent être très rapides

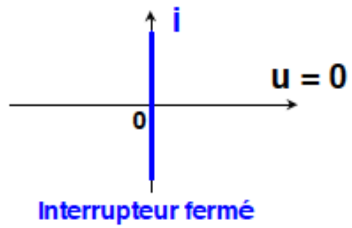
■ **Interrupteur ouvert** (position OFF : i = 0)



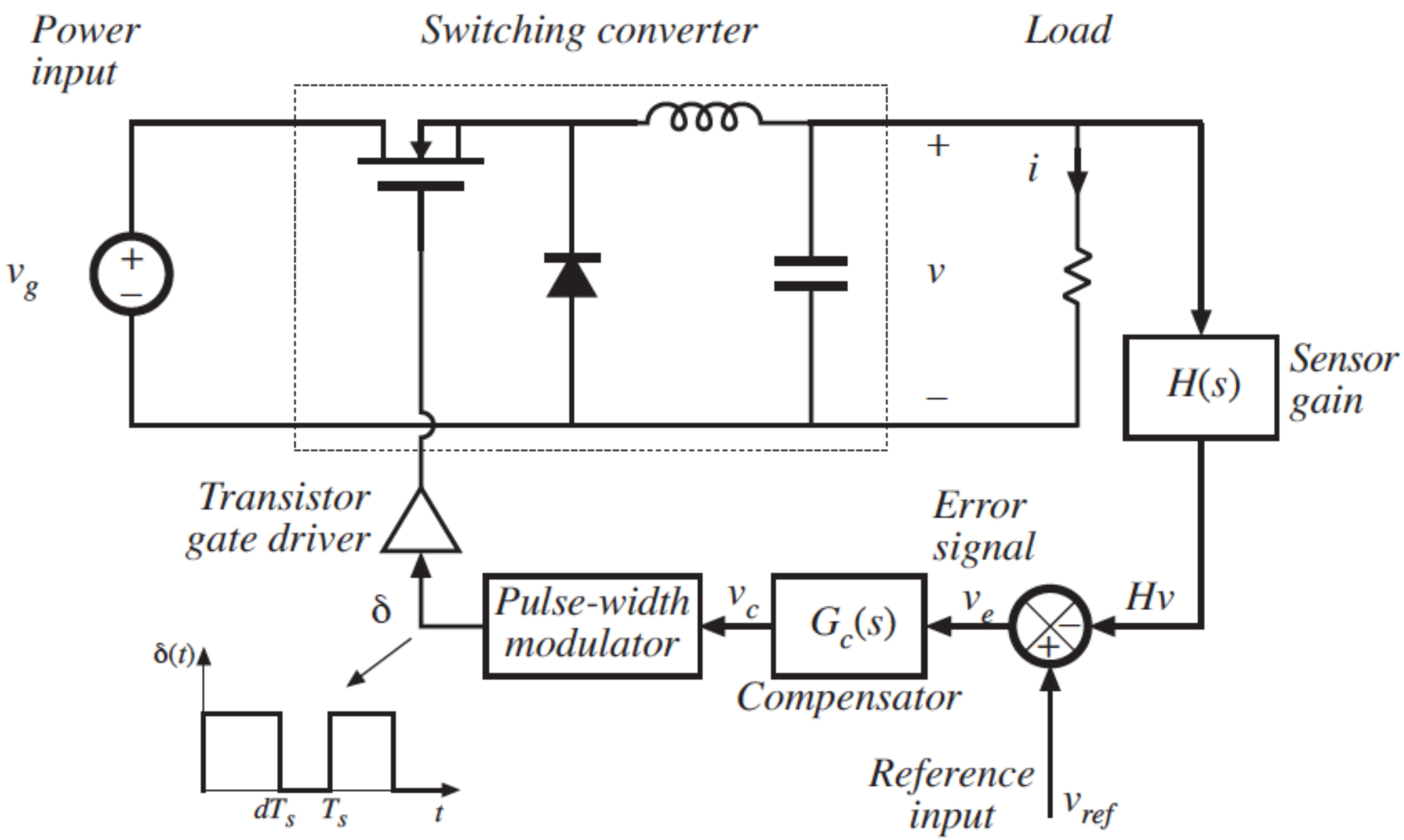


■ **Interrupteur fermé** (position ON : u = 0)

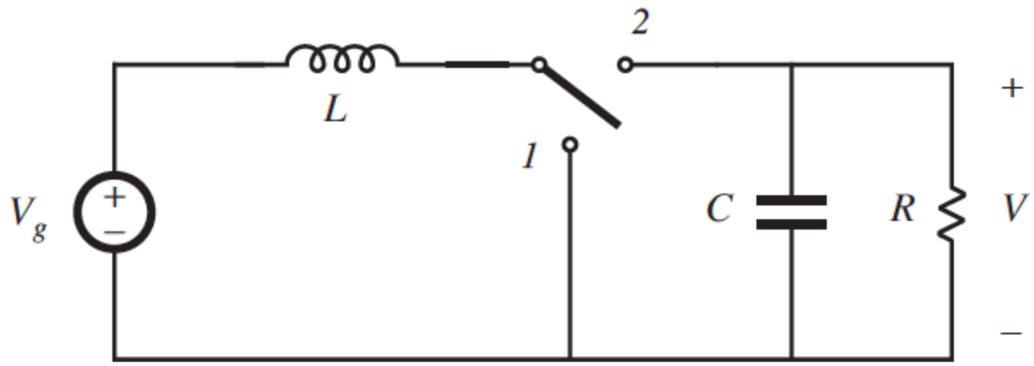


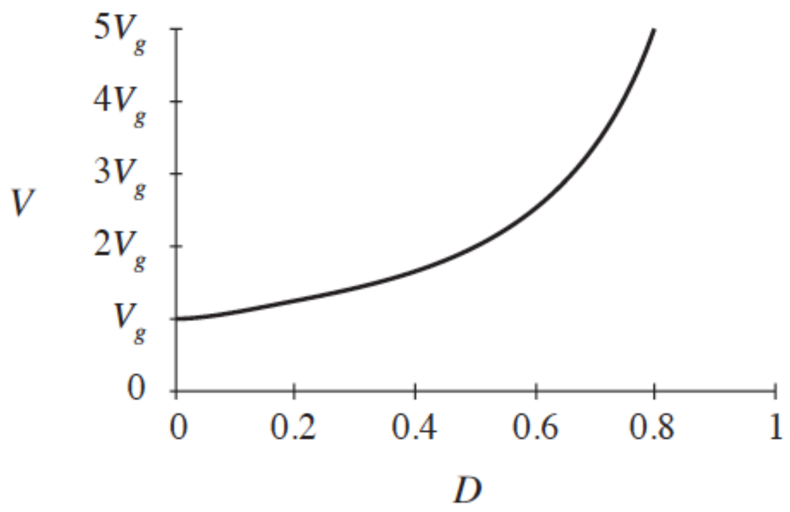


Réalisation:
Transistors + diodes + filtres + circuit de regulation



Convertisseur boost

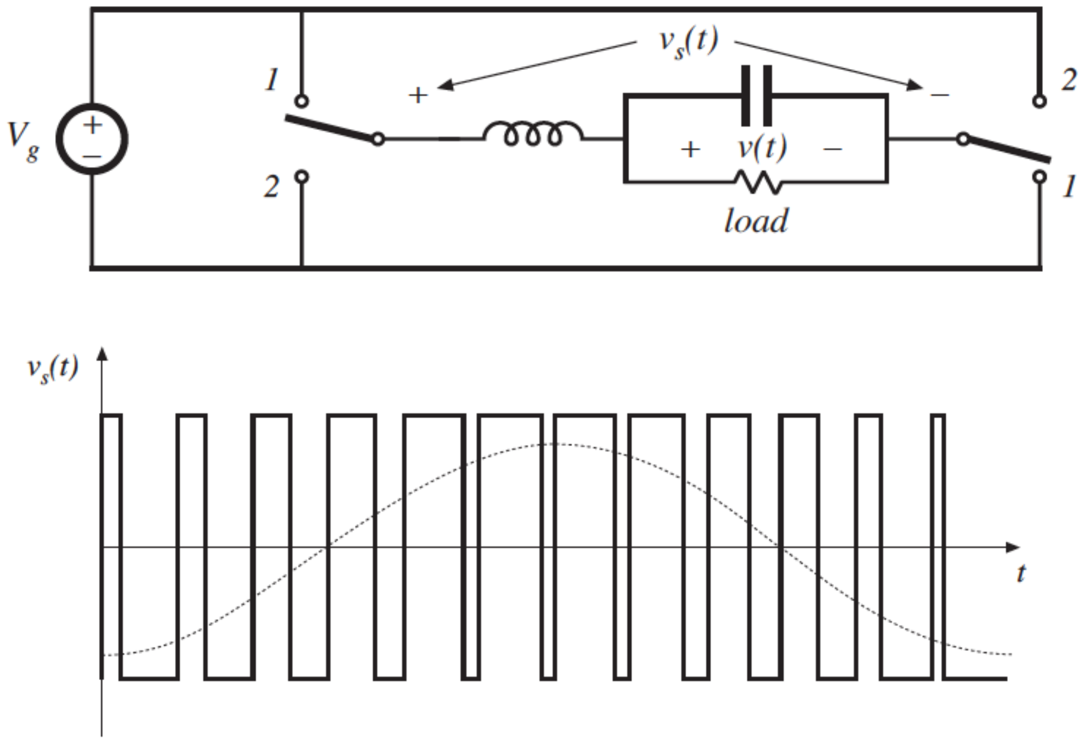




- Inductance: Placée avant le commutateur
  Résiste au changement brusque de courant

- Peut produire V plus élevé que Vg:
  convertisseur boost

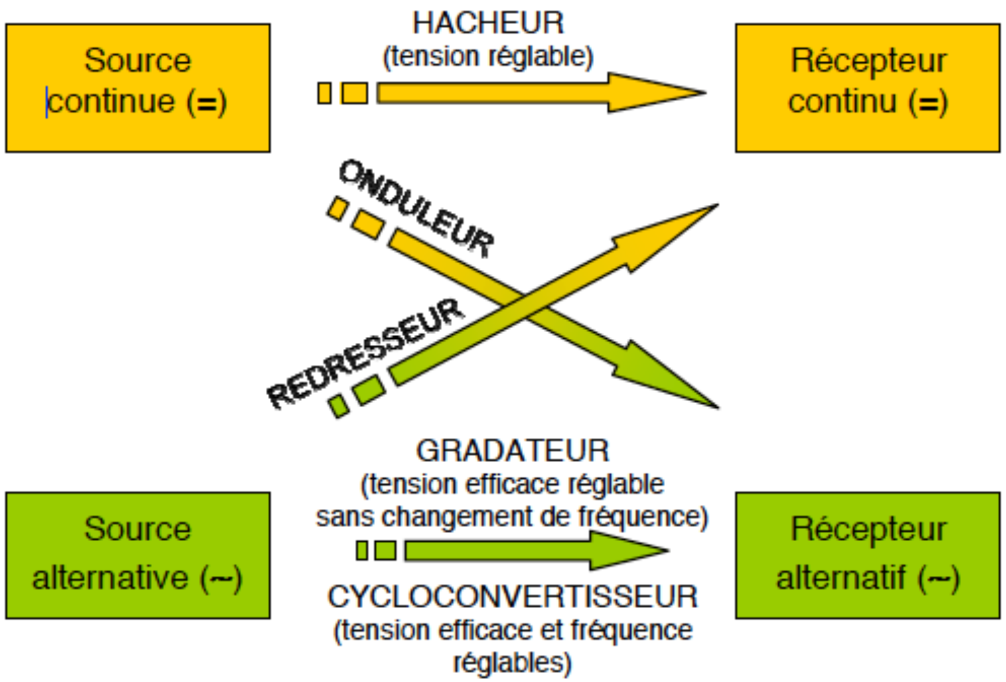
Onduleur monophasé



- Charge et commutateur connectés de façon différentielle
- Rapport cyclique D modulé sinusoïdalement
- Produit une onde sinusoïdal de basse fréquence à la sortie

Famille de convertisseurs statiques

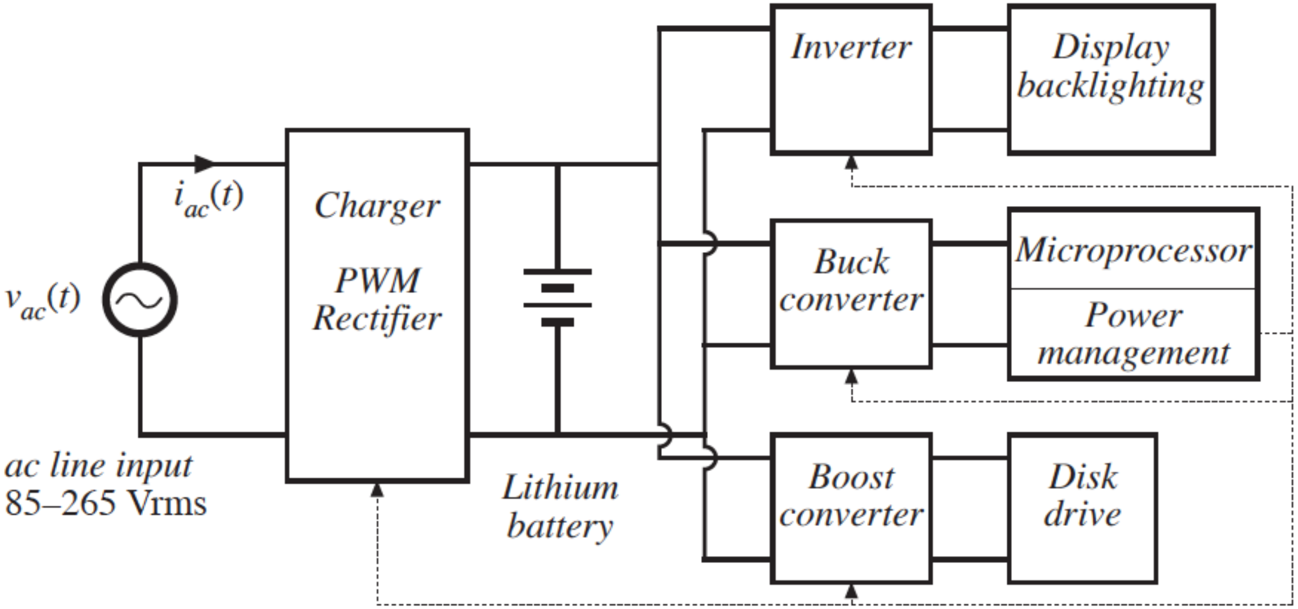
		I	
		dc	**ac**
U	**dc**	**Convertisseur DC/DC** Buck/boost/buck-boost Fly-back/forward	**Convertisseur DC/AC** Onduleur de tension
	ac	**Convertisseur AC/DC** Convertisseur de courant Commutateurs de courant	**Convertisseur AC/AC** Cycloconvertisseurs

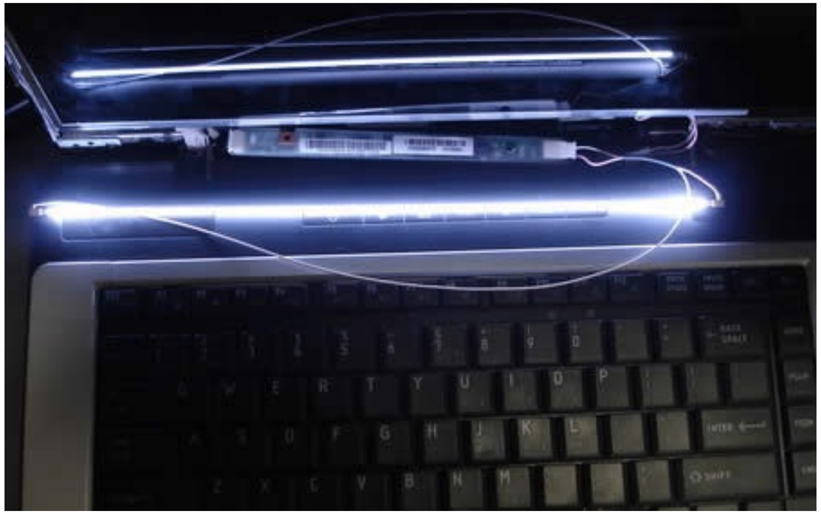


Niveau de puissance des convertisseurs à rendement élevé

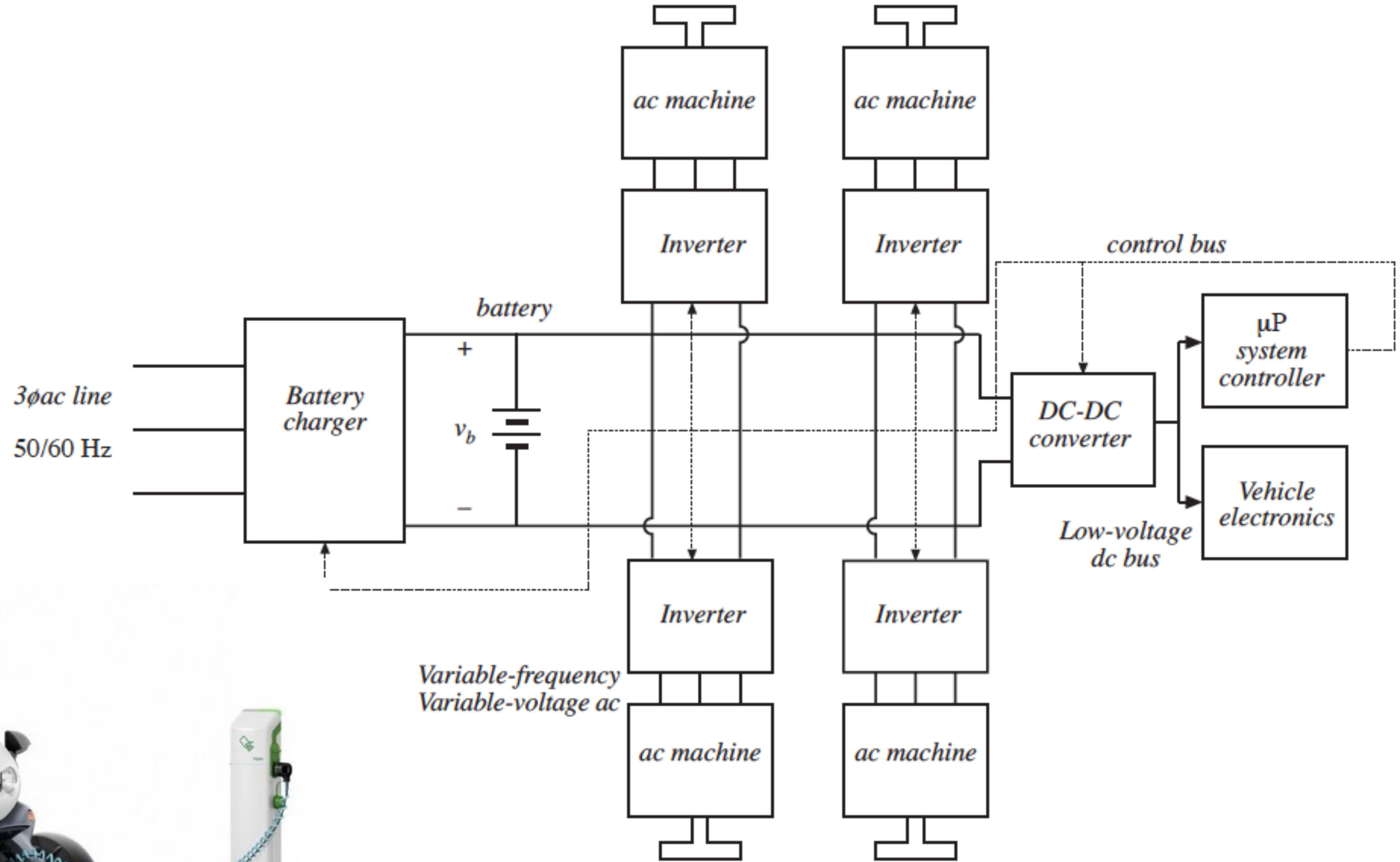
- **Moins que 1W** dans les équipements portables à batteries
  - Rendement > 90%, at 10 µA
  - Currents faibles (360 nA typical)
  - Tension de sortie change en pas de 100 mV
- **Dizaines, centaines ou milliers de Watts:** ordinateurs et équipements de bureau
- **kW et MW** moteurs à vitesse variable: climatisation, compresseurs, ventilation,
- **GW** redresseurs et onduleurs dans les lignes de transmission DC
  ABB HVDC: dizaines de Megawatts (MW) à 1,800 MW et ±500 kV

Exemples: Ordinateur portable





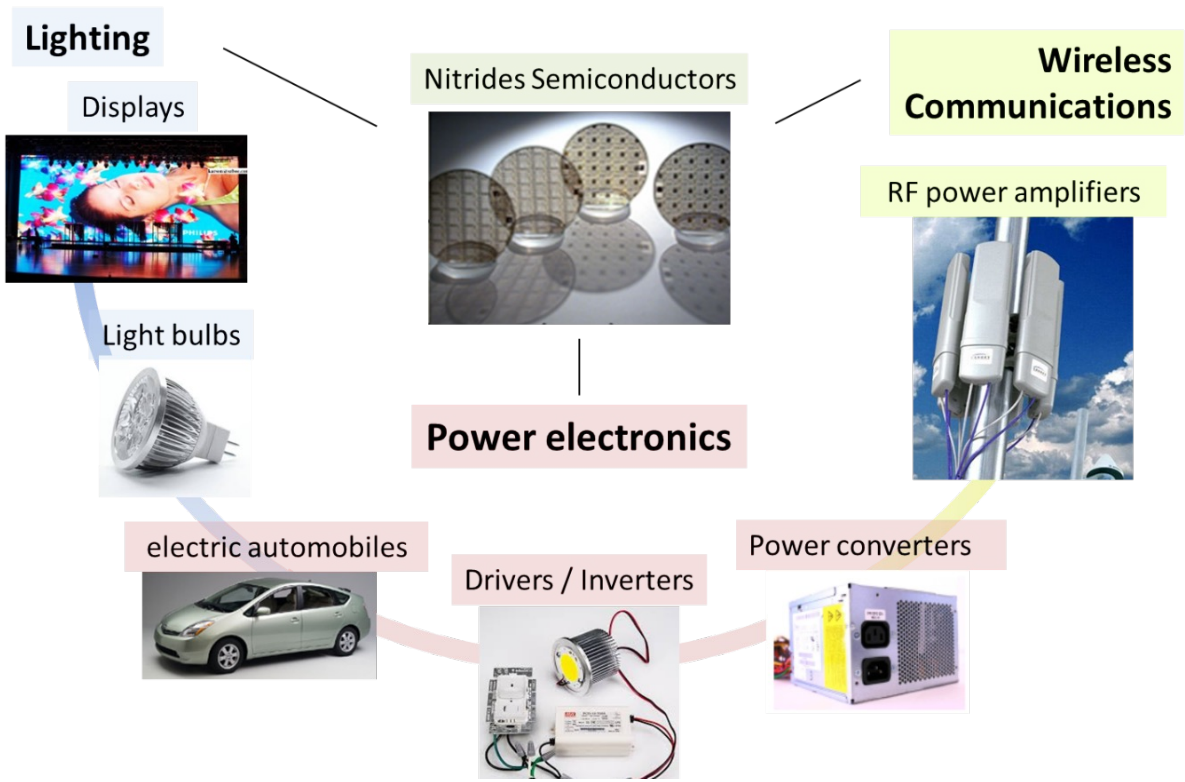
Exemples: Voiture électrique

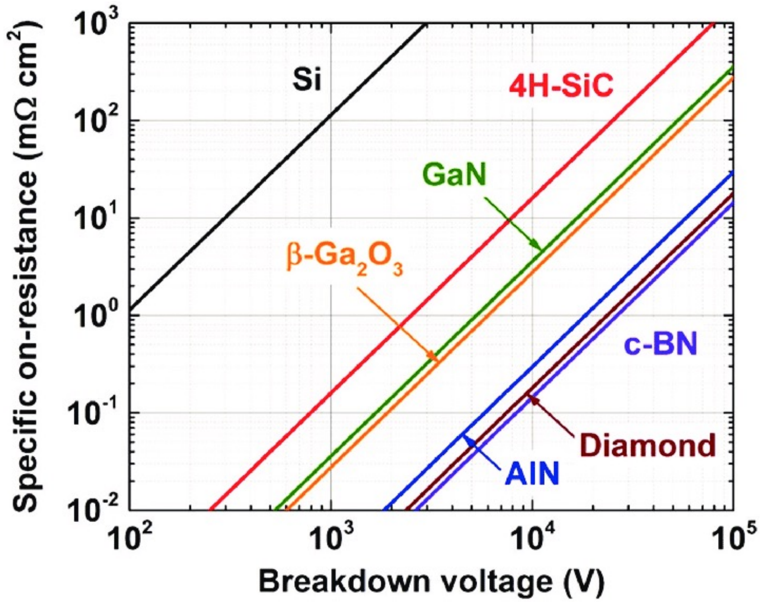


Résumé de ce cours

- Introduction
- Notion de commutation
- Convertisseurs
- POWERlab at EPFL

III-Nitrides are an exceptional material





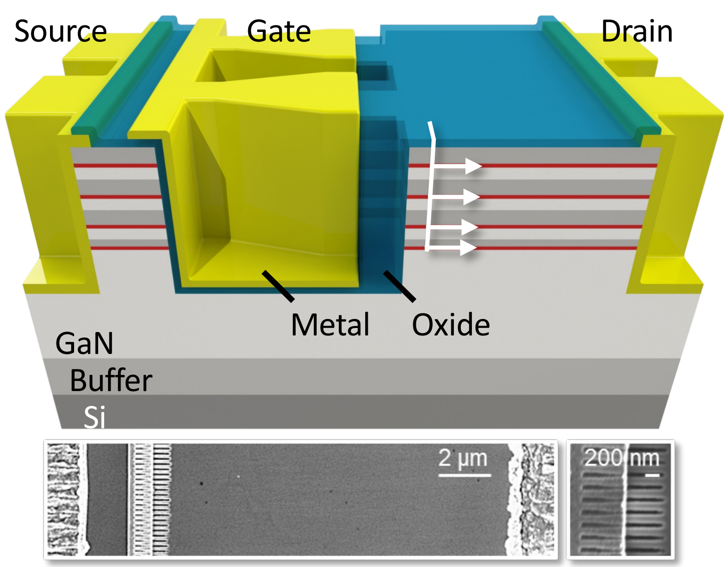
Optoelectronics:
- High internal quantum efficiency: LEDs
- Polarized light emission: displays
- Tunable direct band gap: solar cells

Electronics:
- High electron velocity (×3 than Si)
- High carrier density (×3 than Si)
- High breakdown voltage (>×10 than Si)

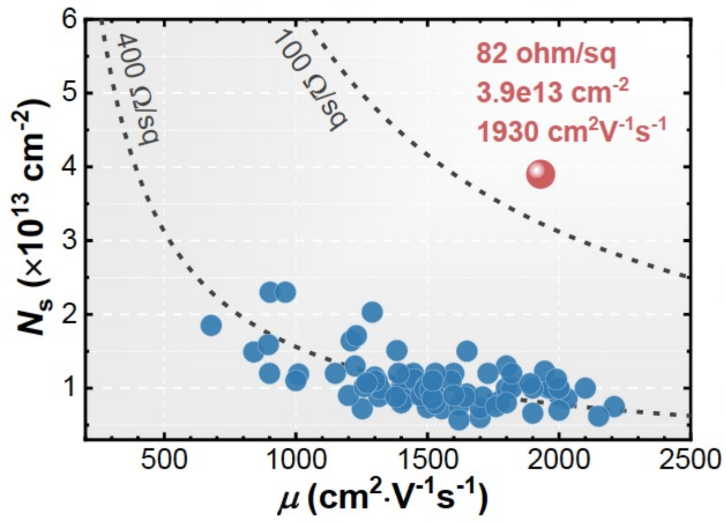
Snapshot of our laboratory:
I. Nanostructure for power electronic devices

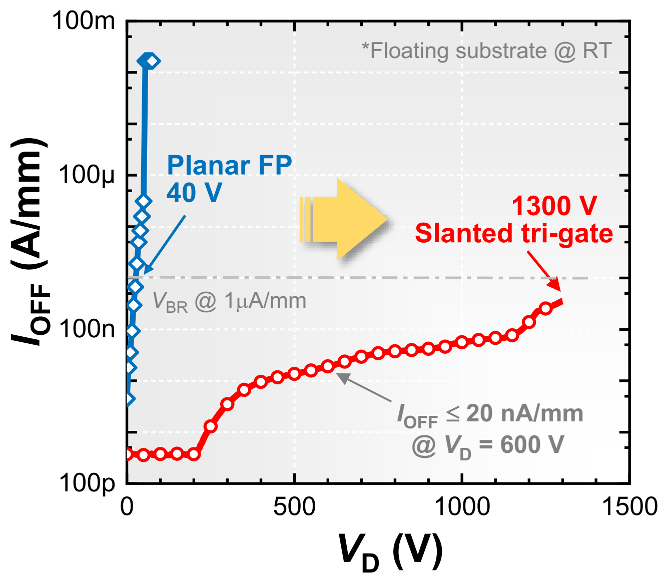
Multi-channel power devices for ultra-low resistance and high breakdown voltage

1. Multiple 2DEG channels



Much higher conductivity



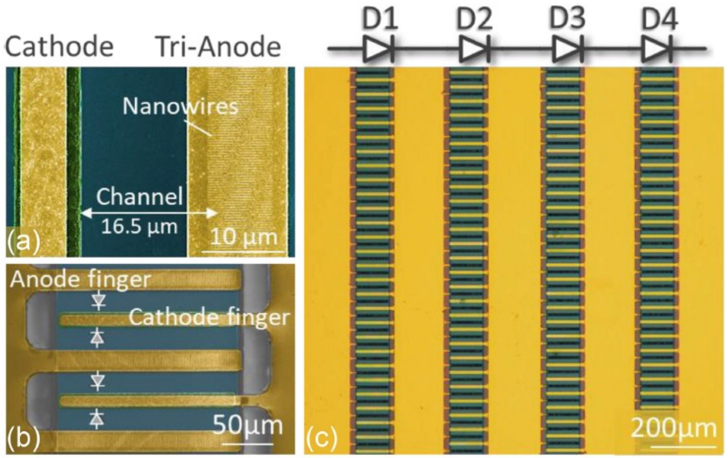


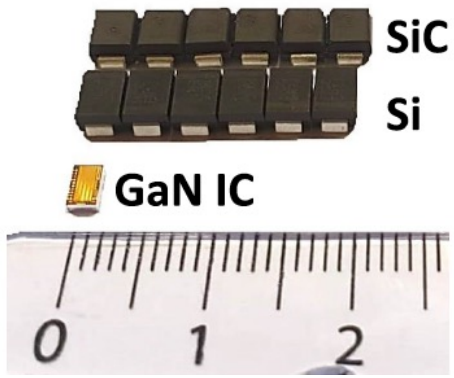
More than 5x-higher conductivity: significantly lower resistive losses!

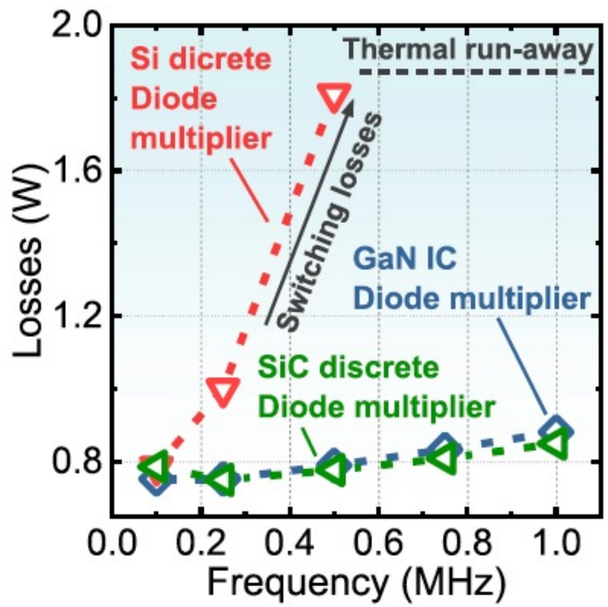
Snapshot of our laboratory: Integrated GaN-on-Si Schottky diodes

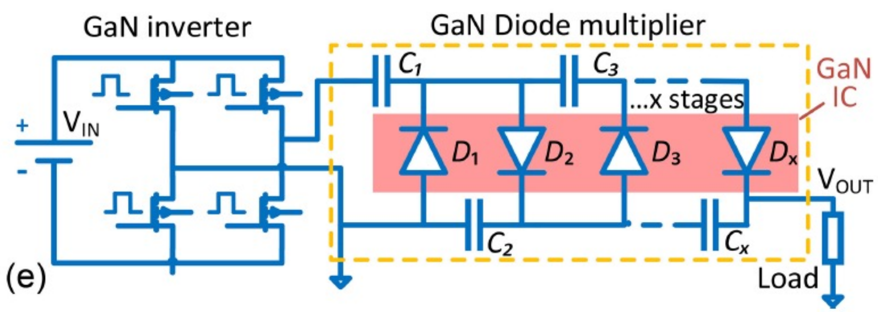
POWER lab

Diode voltage multiplier GaN IC





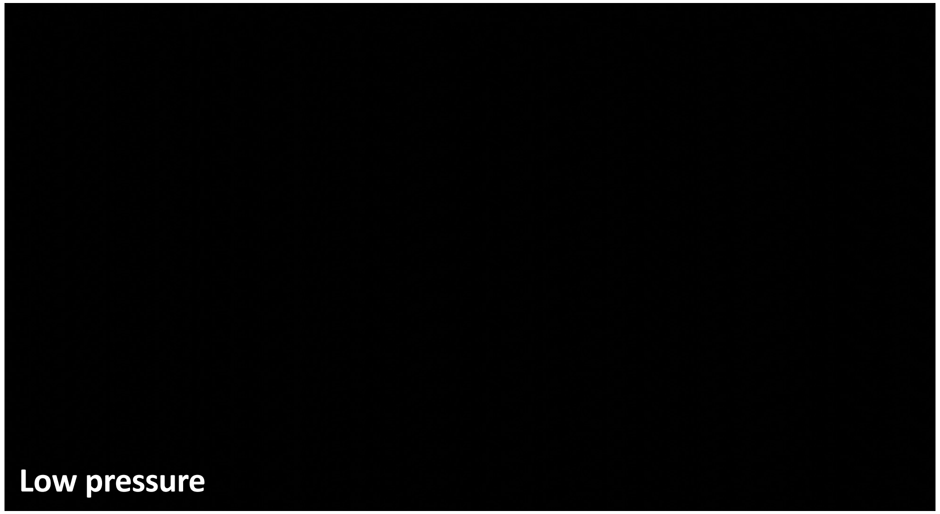




High frequency switching in GaN integrated devices: small devices and energy storage elements

L. Nela, R. Van Erp, G. Kampitsis, H. K. Yildirim, J. Ma and E. Matioli, "*Ultra-compact, High-Frequency Power Integrated Circuits Based on GaN-on-Si Schottky Barrier Diodes*" ***IEEE Transactions on Power Electronics,*** *vol. 36, no. 2, 2021*

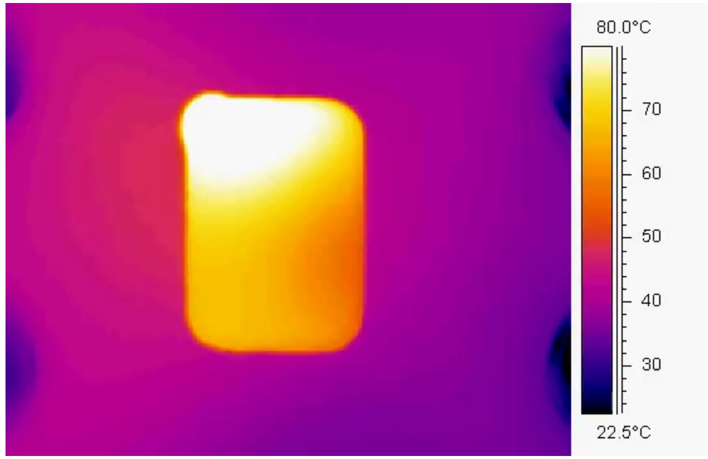
Snapshot of our laboratory: Near-junction microfluidic cooling



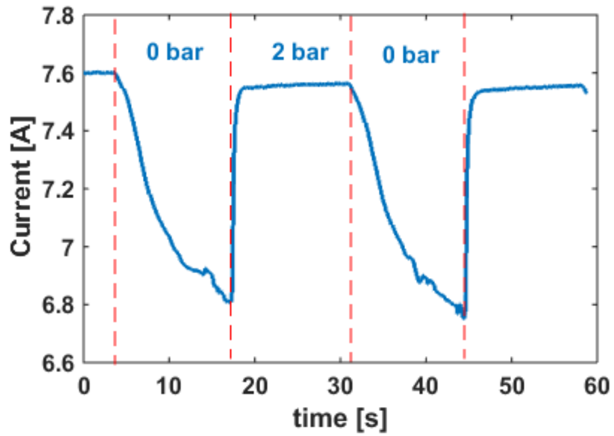
R. van Erp, G. Kampitsis, L. Nela, R. Soleimanzadeh and E. Matioli, ***Nature*, 2020**.

All devices were fabricated at the EPFL cleanroom facilities (CMI)

CMi EPFL Center of MicroNanoTechnology



Elison Matioli



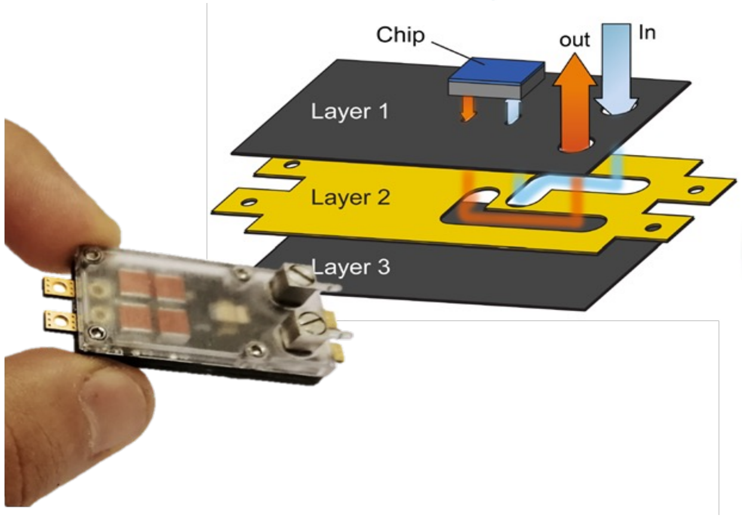
Snapshot of our laboratory:
Fully-integrated power IC with microfluidic cooling

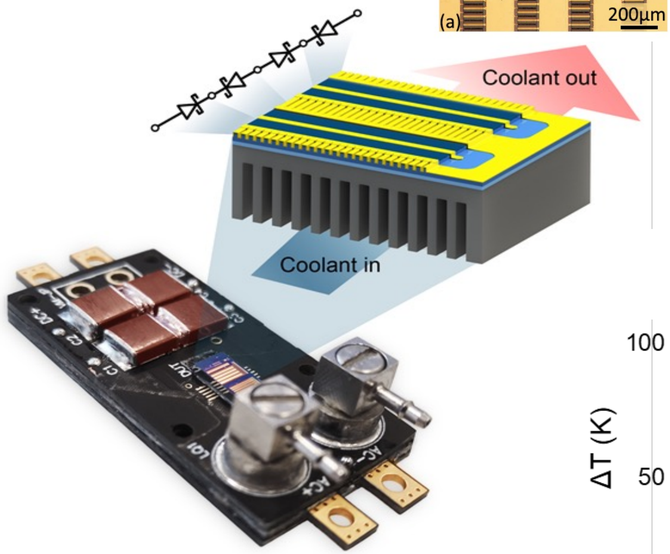
nature

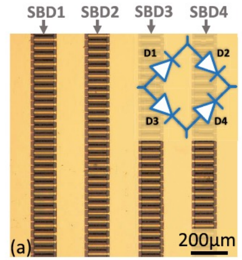
Article | Published: 09 September 2020

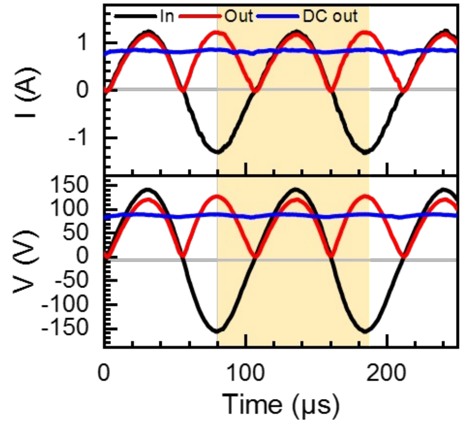
Co-designing electronics with microfluidics for more sustainable cooling

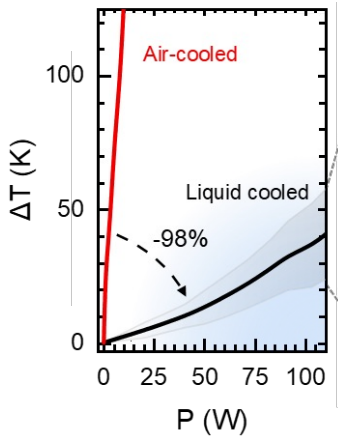
Remco van Erp, Reza Soleimanzadeh, Luca Nela, Georgios Kampitsis & Elison Matioli

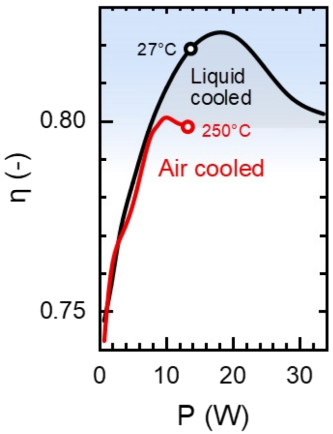












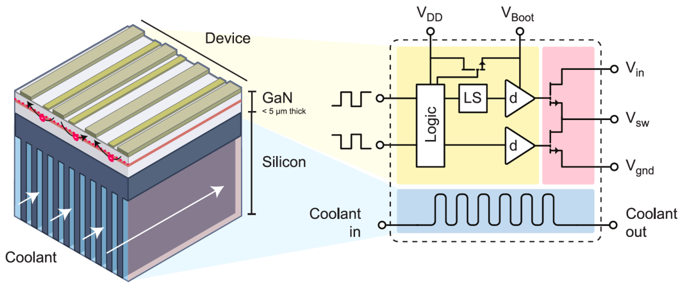
Efficient thermal management enables integration of power devices for high power density applications

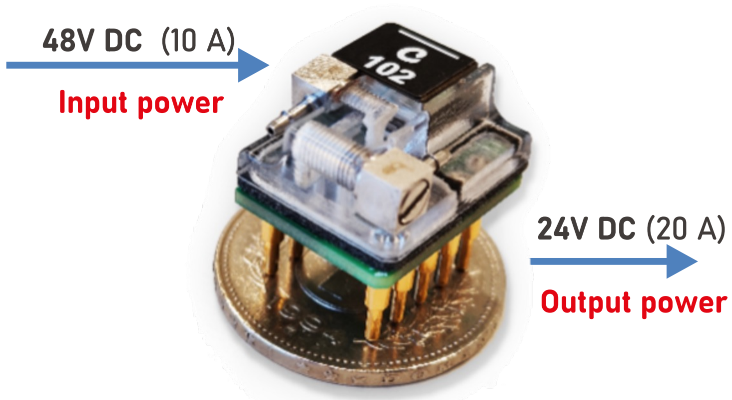
Elison Matioli

R. van Erp, R. Soleimanzadeh, L. Nela, G. Kampitsis and E. Matioli, ***Nature*** 585 (7824), 211-216 (2020).
L. Nela, R. Van Erp, G. Kampitsis, H. K. Yildirim, J. Ma and E. Matioli, ***IEEE Transactions on Power Electronics***, vol. 36, no. 2, pp. 1269-1273, Feb. 2021

Integrated buck converter with microfluidic cooling

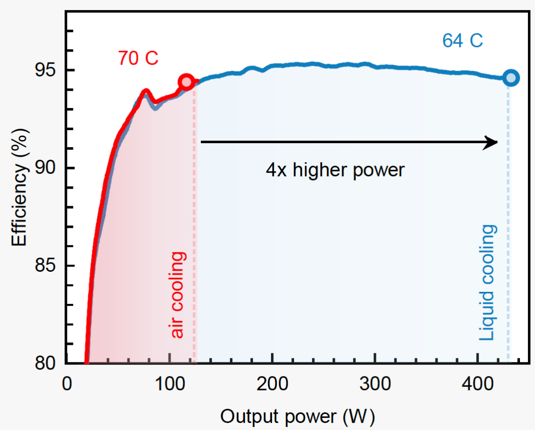
Cooling integrated on commercial integrated half-bridge with gate drivers and passives





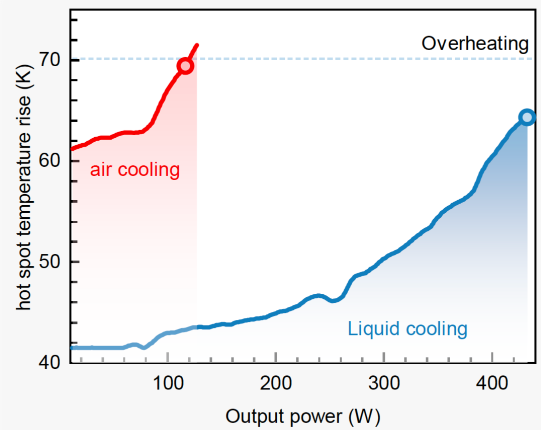
450 W output power
(78 kW / liter)

Higher power



- 4x-larger power compared to air cooling
- Peak efficiency above 95% at over 400W with lower peak temperature

Efficiency sweep



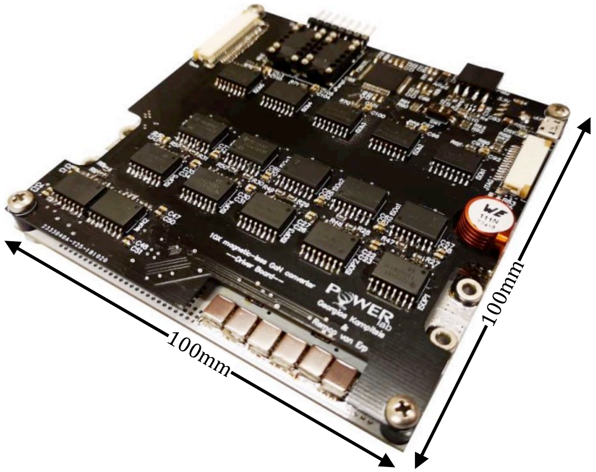
- At 450 W, maximum temperature rise was 65 °C

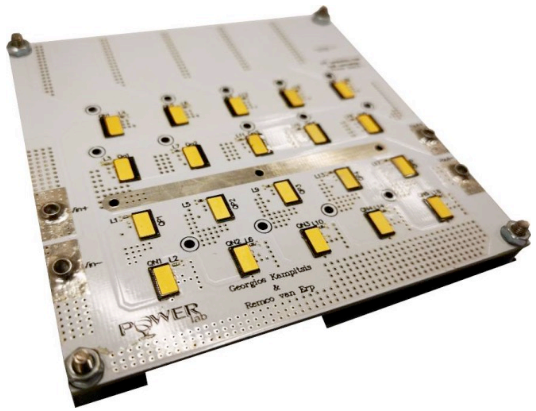
450 W DC-DC converter in a 1/32 brick form factor, with 78 KW/l and 95% peak efficiency

Powerlab at EPFL

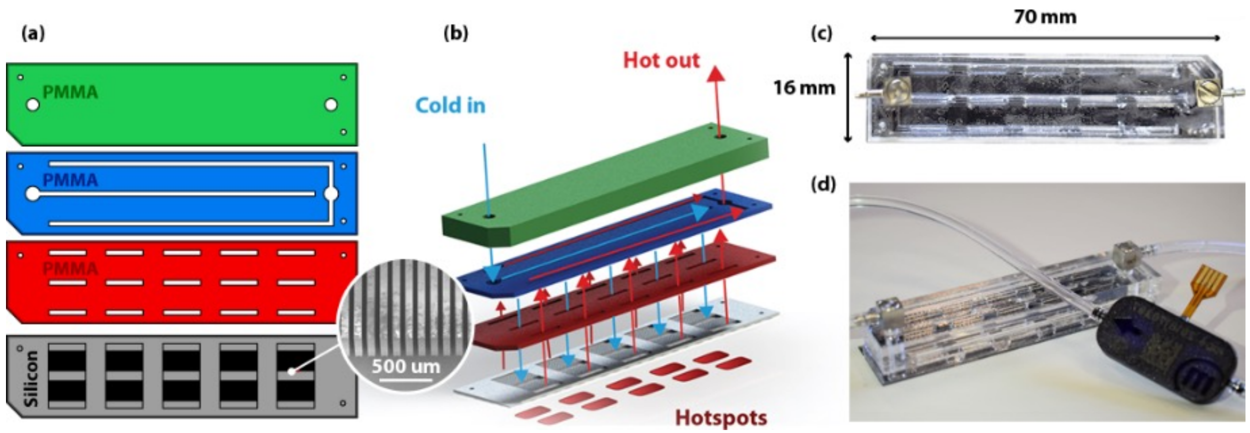
Ultra compact converters

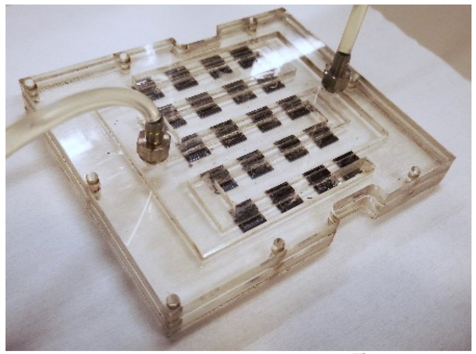
Developed PCBs of the high power magnetic-less 10X DC/DC converter.

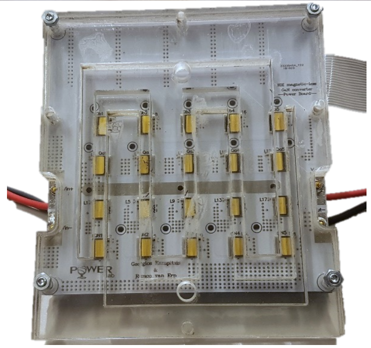




Microfluidic cooling

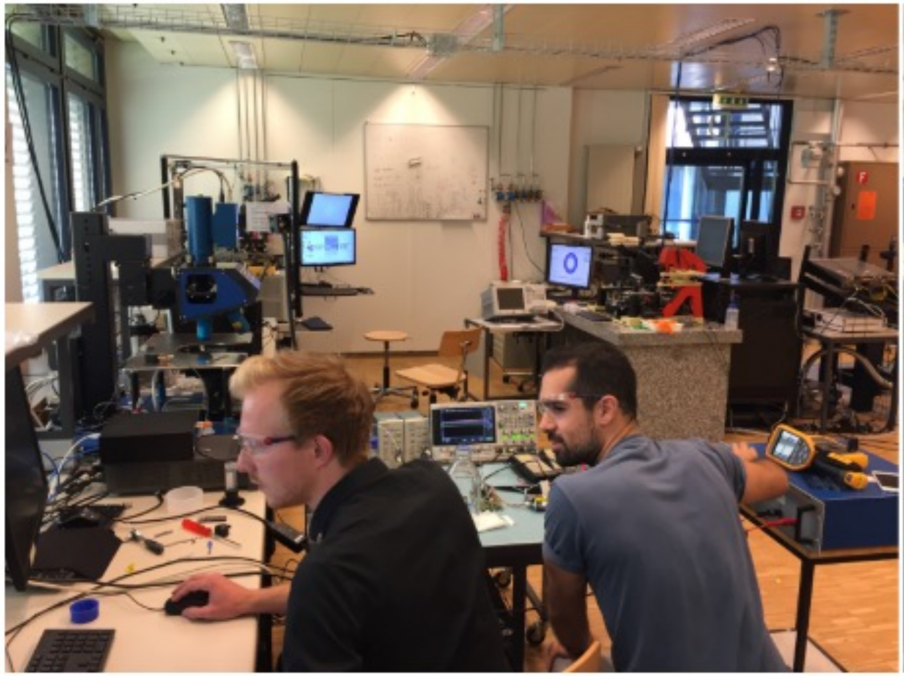


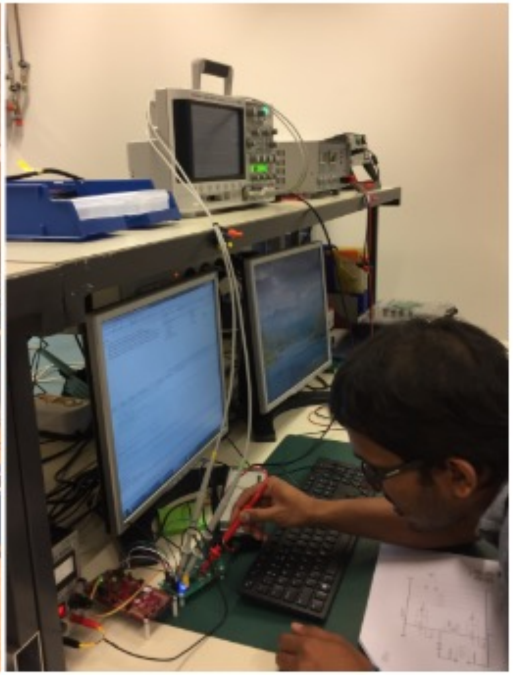




Projets de semestre disponibles

Bachelor and Masters Projects





The POWERlab offers several projects for EPFL students, at the bachelor and master levels, to work closely with our Ph.D. students and postdocs. Below is the list of available projects:

Bachelor and Master Semester Projects:

Master Thesis (30 ECTS credits)
There are several projects available for Master thesis for EPFL students. Please contact Prof. Matioli to discuss in more details.

If you are interested and would like to have more information please contact **elison.matioli@epfl.ch**