Introduction to Power Management

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Learning Objectives for Today

Understanding of Power Management IC (PMIC) Basics:
Learn the key functions and importance of power management ICs.

Insight into Voltage Regulation:
Grasp the concepts of linear and switching regulators and their role in efficient power conversion.

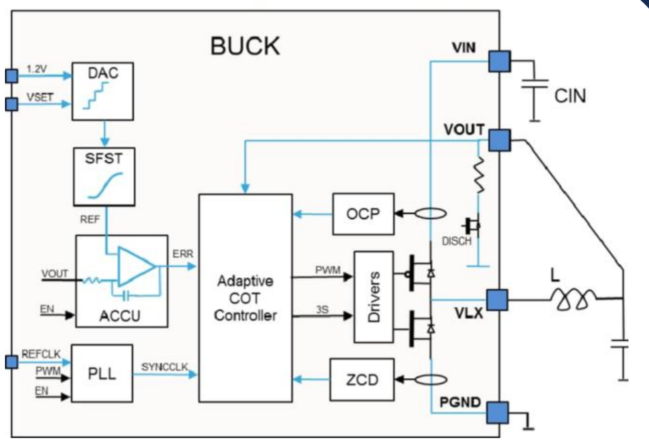
Knowledge of PMIC Applications:
Explore how PMICs are used in devices like smartphones, IoT, automotive, and more.

Design Considerations:
Understand critical factors like efficiency and switching frequency in PMIC design.

Awareness of Industry Trends:
Gain insight into the future of PMICs, including new technologies and trends shaping the industry.

What is a Power Management IC?

A ***Power Management IC (PMIC)*** is an integrated circuit that manages the power requirements and power distribution of a system.
PMIC regulates the power from an input source (such as a battery or external supply) and ensures that the correct voltages are provided to different parts of a device.



PMIC circuitry

Power management IC

https://gr.mouser.com/new/stmicroelectronics/stm-stpmic1-pmic/

What is its purpose?

The voltage of the battery powering a chip is rarely at the correct level for its internal circuitry:

•***Example***: A typical smartphone battery operates at 3.7V, but the chip's internal components require various voltages such as 1.8V for the processor, 1.2V for memory, and 3.3V for communication modules.

•*We need to* ***step up*** *or* ***step down*** *(convert) the battery voltage constantly, depending on what the internal circuitry needs at different points in the chip.*

Why are PMICs Important?

Energy Efficiency: Optimizes power usage, reduces power loss, and extends battery life in portable devices.

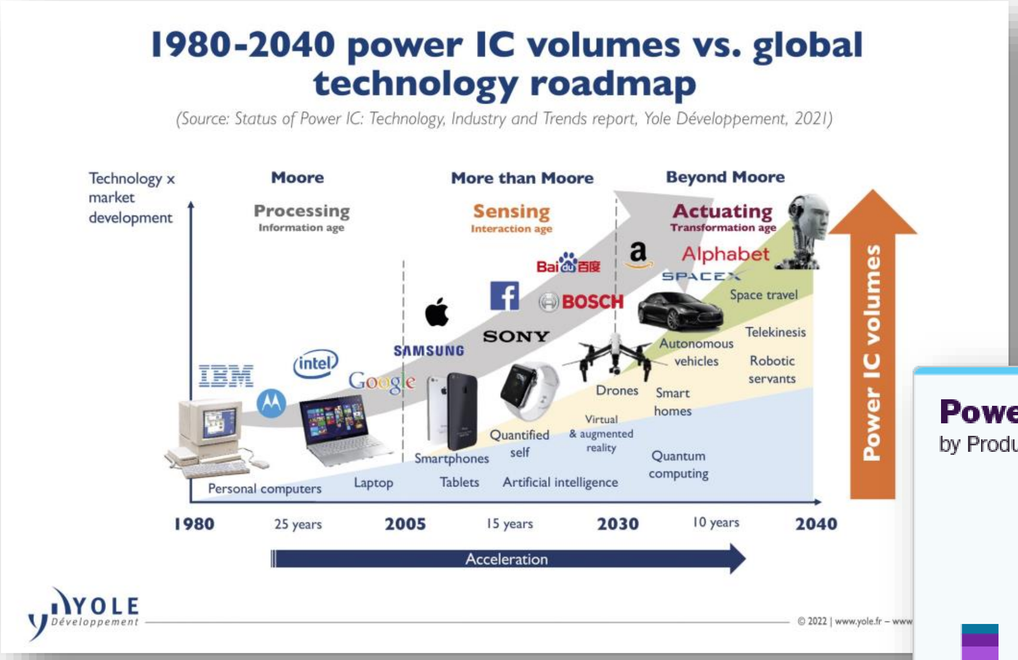
Space and Component Reduction: Integrates multiple functions into a single chip, reducing circuit size, complexity, and costs.

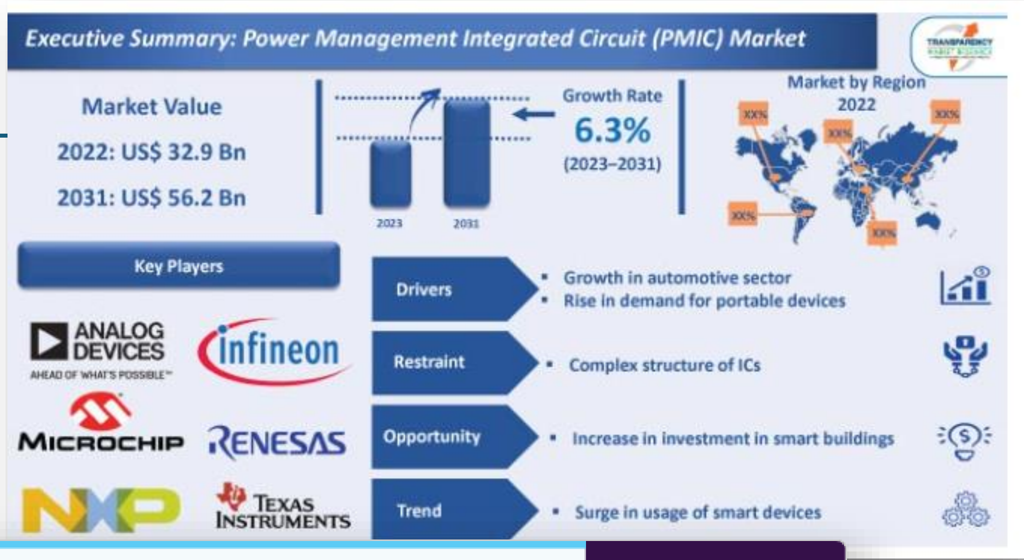
Power Stability: Ensures precise voltage regulation and proper power sequencing for stable operation.

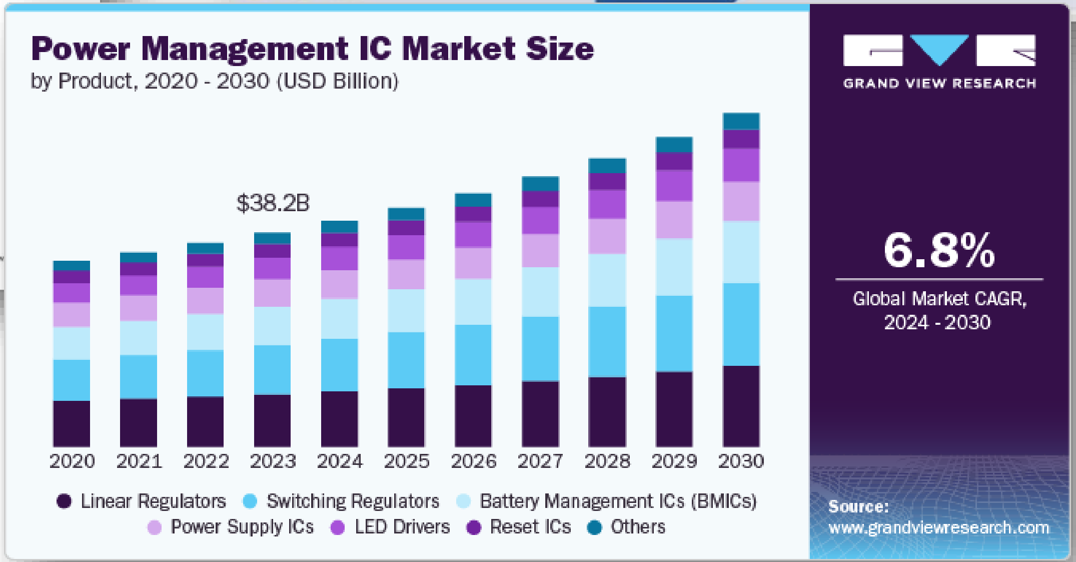
Advanced Features: Supports dynamic power management, ideal for IoT, wearables, and energy-harvesting applications.

Enabling Technology: Facilitates advancements in semiconductor technologies and critical applications like automotive and industrial systems.

PMIC Roadmap



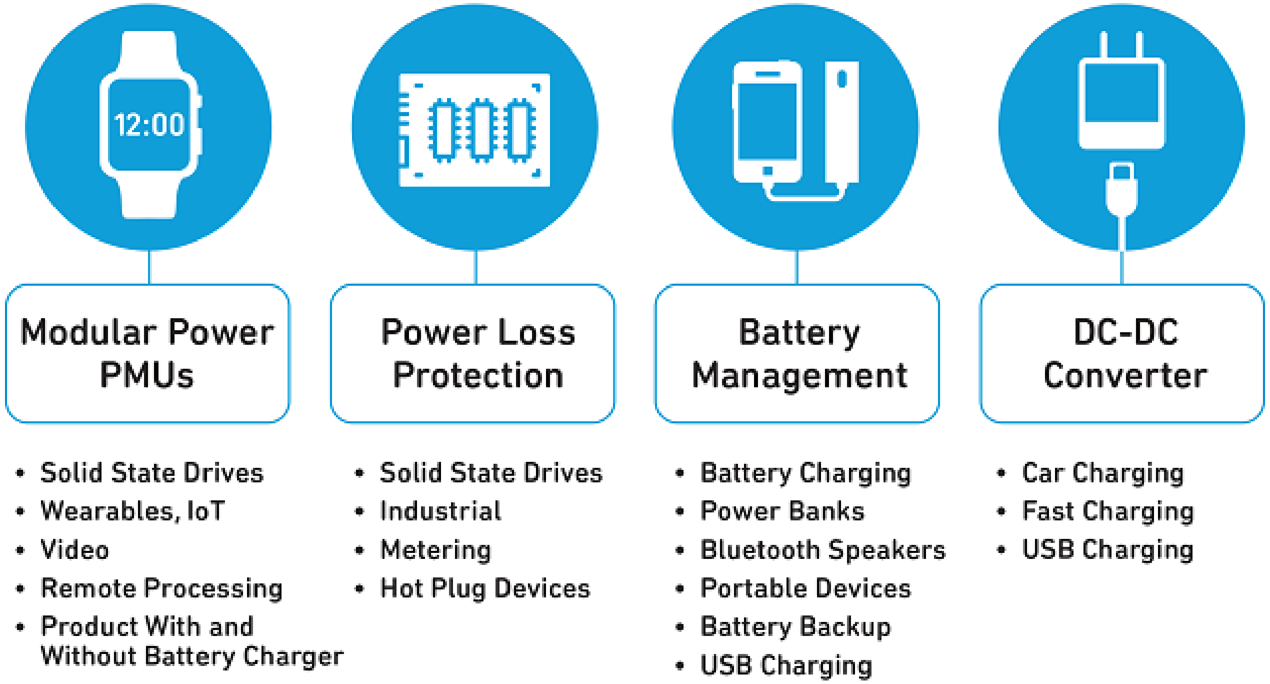




Key Features of PMICs

- ✓ **Voltage Regulation:** *Provides stable, precise output voltage to system components, ensuring reliable performance.*
- ✓ **Power Conversion:** *Efficiently converts input power using DC-DC converters (buck, boost, etc.) for optimized power delivery.*
- ✓ **Battery Management:** *Includes integrated charging circuits, monitoring, and protection for batteries in portable devices.*
- ✓ **Power Sequencing:** *Manages the order of powering up/down various components to prevent system damage.*
- ✓ **Low Power Modes:** *Supports sleep or standby modes to conserve energy when the system is idle.*
- ✓ **Monitoring and Diagnostics:** *Tracks power levels and system health for better performance and fault detection*

PMIC Applications



https://www.qorvo.com/design-hub/blog/how-customizable-pmics-simplify-power-management-system-design

PMICs in High Radiation Applications

ASICs

Home | Power Distribution | ASICs | Modules | Publications & Reports | R&D | Contacts

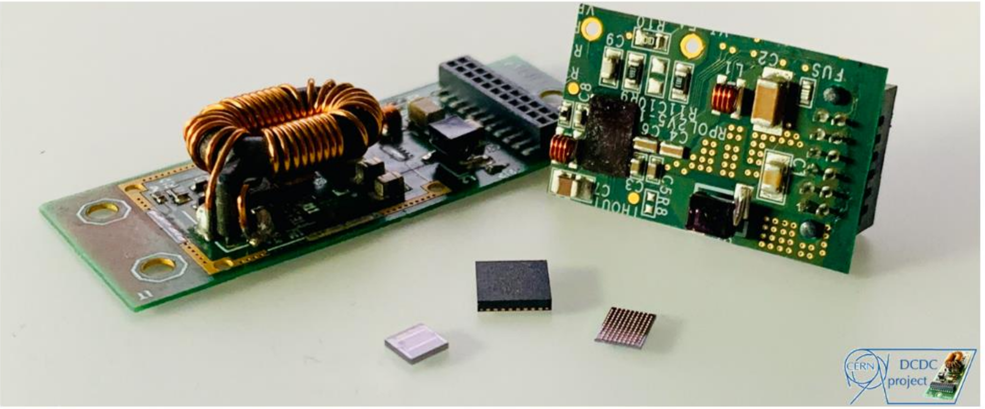
Conversion Stage	Name	Asic Version	Vin	Iout	Technology	Radiation specs	Availability
Stage 1	bPOL48V	V2	48V	10A	350nm CMOS with High Voltage extension at 80V	TID:50 Mrad SEE:46 MeV/(mg/cm²) DD:4e14 n/cm2 2.23e14 p/cm2(30MeV)	26k dies in 2022
Stage 2	bPOL12V	V6.1	12V	4 A	350nm CMOS with High Voltage extension at 25V	TID :150Mrad SEE :45 MeV/(mg/cm²) DD:4e15n/cm2 1.2e15p/cm2 (30MeV) 2.34e15p/cm2(200MeV)	6k dies in 2021 150k dies in 2022
	FEAST	V2.3	12V	4 A	350nm CMOS with High Voltage extension at 80V	TID :150Mrad DD:5e14n/cm2	Obsolete, production ended in 2020
Stage 3	bPOL2V5	V3.3	2.5V	3 A	130nmCMOS	TID:100Mrad SEE:40 MeV/(mg/cm²) DD:2e16n/cm2 6.6e15p/cm2 (25GeV)	22000 dies already available 75.000 dies in 2022
Linear regulator (limited current)	linPOL48V	V2	48V	200 mA	350nm CMOS with High Voltage extension at 80V	As for bPOL48V	Large quantities available upon demand in 2022
	linPOL12V	V1	12V	80 mA	350nm CMOS with High Voltage extension at 25V	Need to be confirmed, test ongoing from both ATLAS and CMS	4k dies available, larger quantities available upon demand

https://power-distribution.web.cern.ch/ASICS/

CERN Accelerating science

EP-ESE
ELECTRONIC SYSTEMS FOR EXPERIMENTS

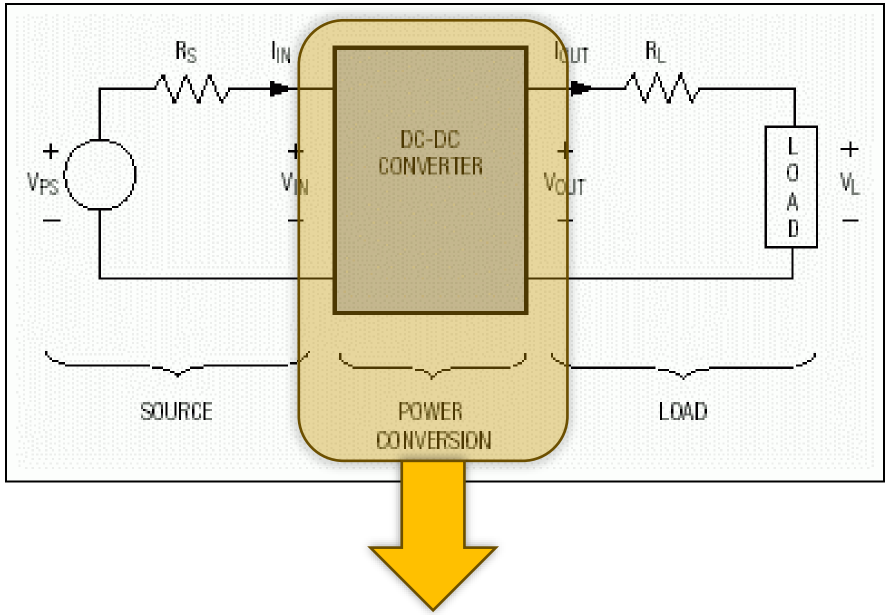
Radiation and magnetic tolerant DC-DC converters



The aim of this activity is to deliver DC-DC converters able to work in the hostile environment of the LHC experiments (very high radiation levels and tesla-scale magnetic fields). A DC-DC converter was produced for the phase-1 upgrade of the LHC experiments, namely the FEAST2 ASIC, which converted from 12V to a selectable output voltage and up to 4A as output current.

https://ep-ese.web.cern.ch/project/radiation-and-magnetic-tolerant-dc-dc-converters

PMIC core: The converter



DC-DC Conversion in the heart of every PMIC!

https://www.analog.com/en/resources/technical-articles/source-resistance-the-efficiency-killer-in-dcdc-converter-circuits.html

PMIC core: The converter

Converter categories:

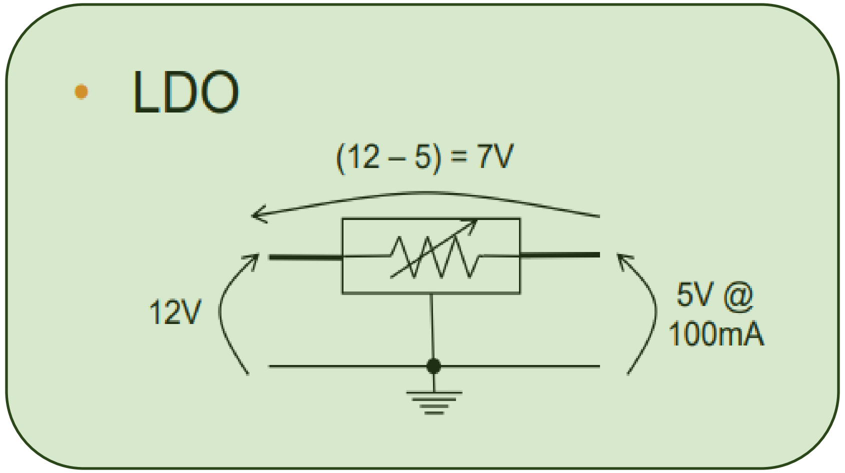
- ✓ **Linear Regulators** (also known as series pass regulator, series regulator or LDOs) and
- ✓ **Switching Regulators** (known as switch mode power supplies, or switching power supplies and power “converters”)

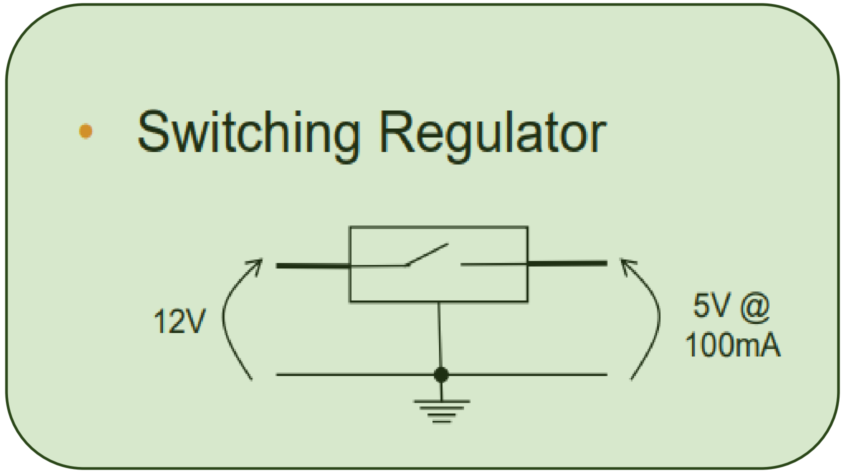
- ✓ the first job of the converter/regulator is to convert our input voltage to the output voltage level that our circuit requires
- ✓ The second job is to regulate – If there is an increase/decrease in the amount of current that we draw, the output voltage should not fall/rise

Selection of power converter based on:

- ✓ Different applications
- ✓ Desired efficiency and output ripple

PMIC core: The converter





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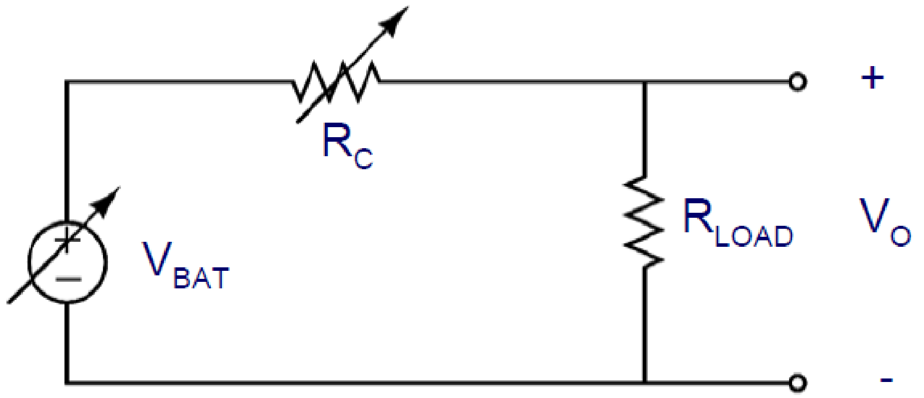
Linear Regulator

Taken from: Low Drop-Out (LDO) Linear Regulators: Design Considerations and Trends for High Power-Supply Rejection (PSR), E. Sánchez-Sinencio, TI J. Kilby Chair Professor Analog and Mixed-Signal Center, Texas A&M University, IEEE Santa Clara Valley (SCV) Solid State Circuits Society

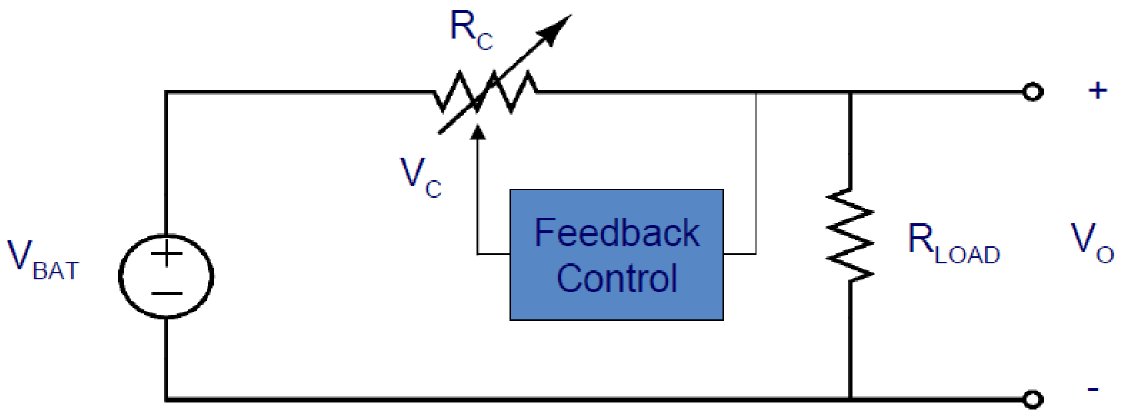
- **LDO** (Low Drop-Out), can operate at a low potential difference between input and output.
- It behaves as a variable resistor between the input and the output, lowering and controlling the voltage applied to the load.



Basic Concept

Basic Concept

Taken from: *Low Drop-Out (LDO) Linear Regulators: Design Considerations and Trends for High Power-Supply Rejection (PSR), E. Sánchez-Sinencio, TI J. Kilby Chair Professor Analog and Mixed-Signal Center, Texas A&M University, IEEE Santa Clara Valley (SCV) Solid State Circuits Society*



$$R_c << R_{LOAD}$$

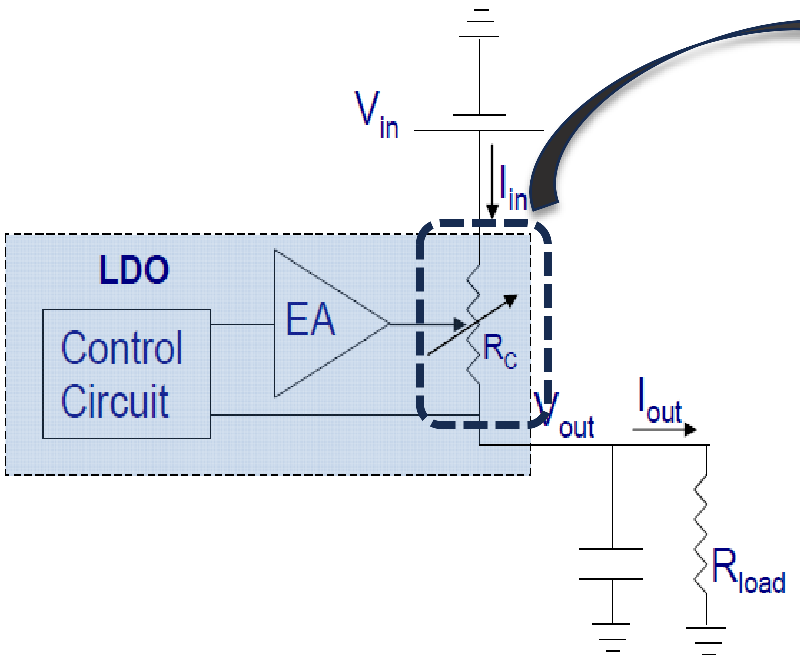
$$V_O = \frac{R_{LOAD}}{R_{LOAD} + R_C} V_{BAT}$$

- **Vo** stable
- **VBAT** decreases with time (battery discharge process)

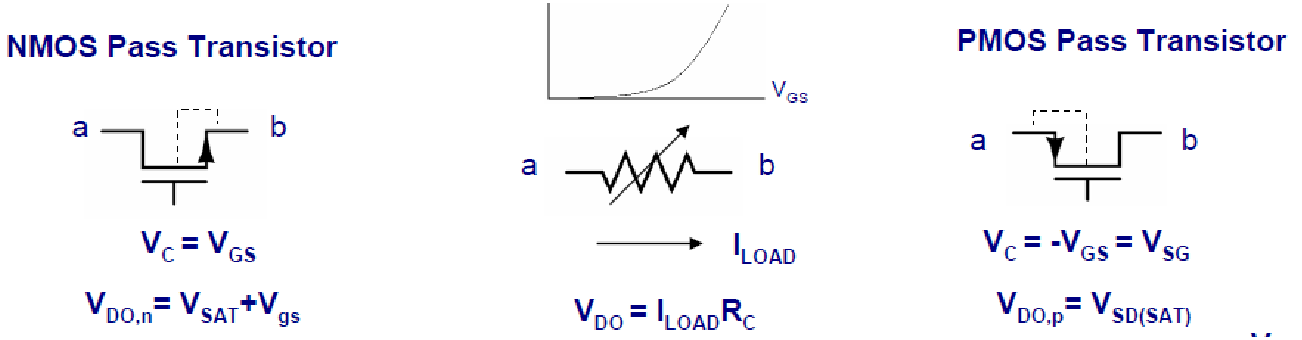
A feedback is used in order Rc to be adjusted always providing the desired Vout

Pass element

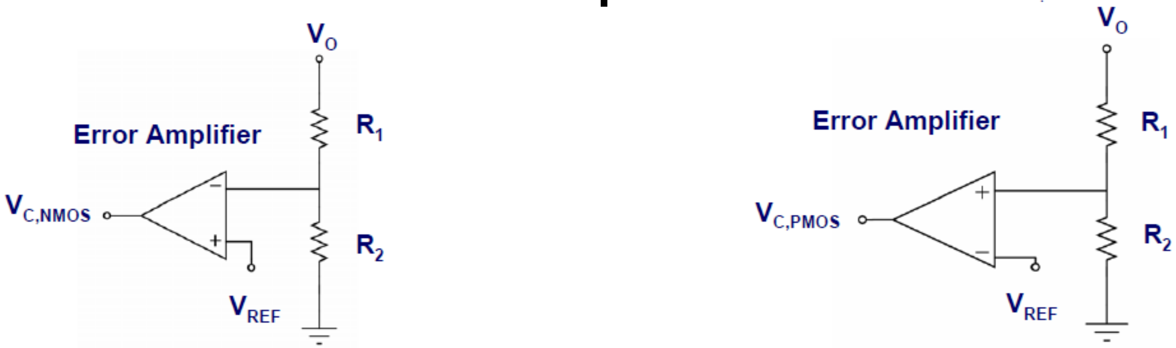
Taken from: *Low Drop-Out (LDO) Linear Regulators: Design Considerations and Trends for High Power-Supply Rejection (PSR), E. Sánchez-Sinencio, TI J. Kilby Chair Professor Analog and Mixed-Signal Center, Texas A&M University, IEEE Santa Clara Valley (SCV) Solid State Circuits Society*



Pass FET implementation

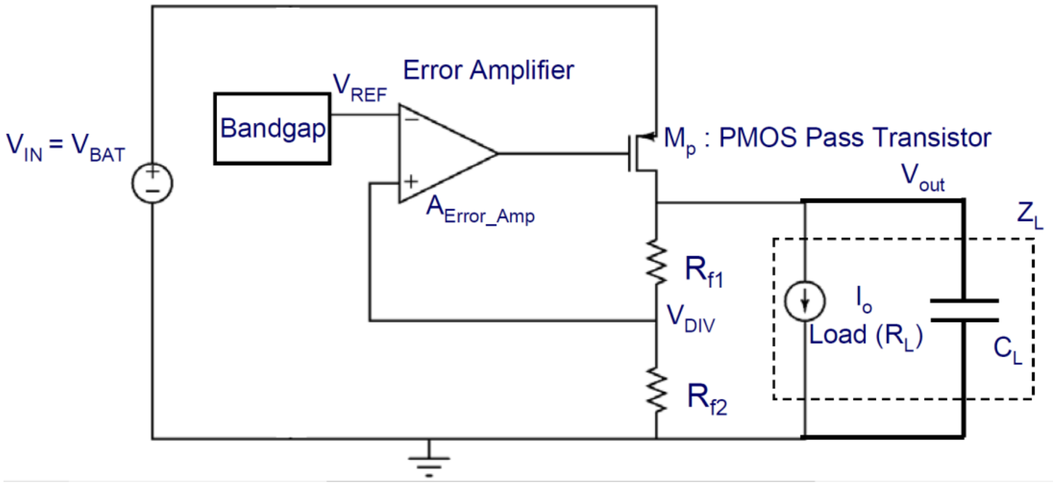


Feedback implementation



Design Considerations

Taken from: Low Drop-Out (LDO) Linear Regulators: Design Considerations and Trends for High Power-Supply Rejection (PSR), E. Sánchez-Sinencio, TI J. Kilby Chair Professor Analog and Mixed-Signal Center, Texas A&M University, IEEE Santa Clara Valley (SCV) Solid State Circuits Society



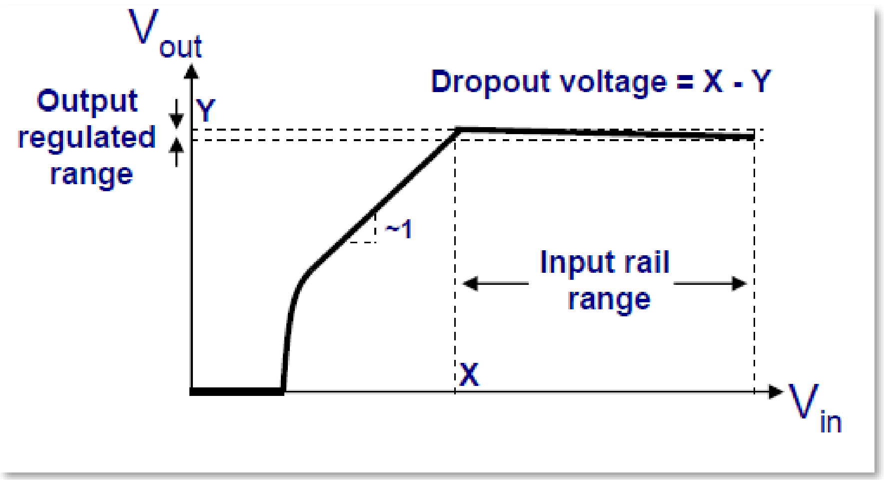
LDO block diagram

- **Pass transistor:**
  - ✓ implemented based on I_o
- **Stability and speed should be assured under all load conditions**
- **Capacitors and feedback resistors proper selection**

Characteristics

Taken from: *Understand Low-Dropout Regulator (LDO) Concepts to Achieve Optimal Designs, By Glenn Morita, https://www.analog.com/en/analog-dialogue/articles/understand-ldo-concepts.html*

- ***Dropout voltage :***
  - ✓ The difference at which the LDO is no longer able to regulate against further decrease in the input voltage.
- ***Input rail range:***
  - ✓ The input supply voltage range that can be regulated.
- ***Output regulated voltage range:***
  - ✓ The output voltage variation the regulator guarantees.



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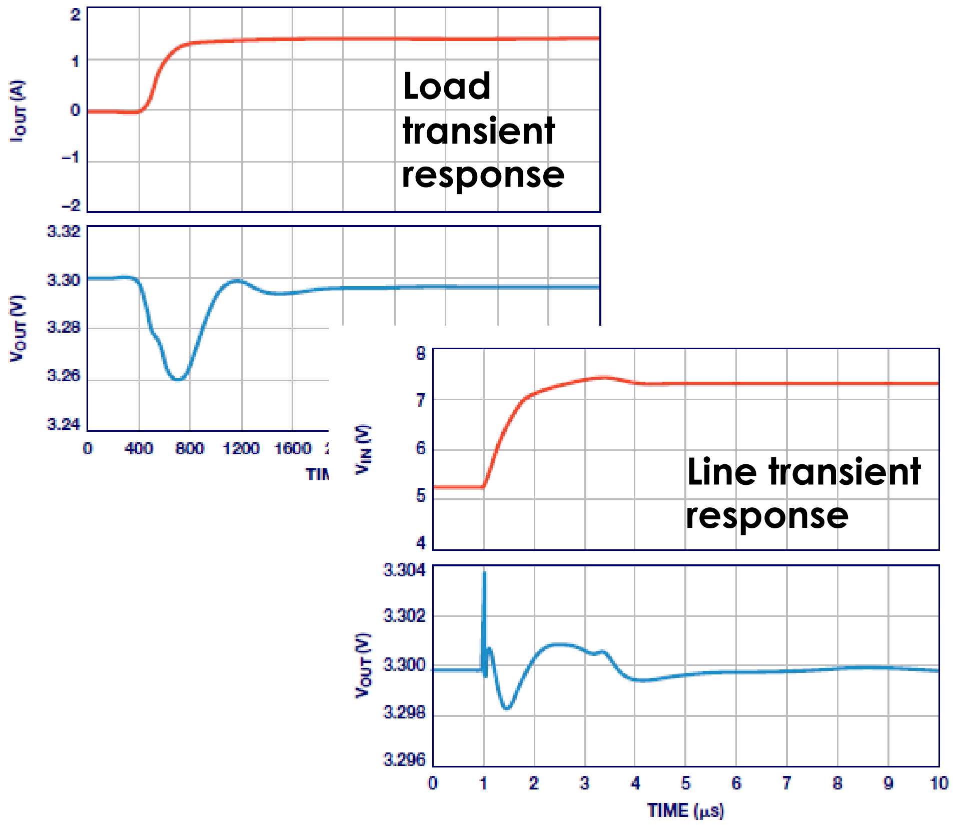
- ***Output current range***:
  - ✓ The output current handling capability of the regulated output voltage.
- ***Load regulation:***
  - ✓ The variation in output voltage from min. to max. output current
- ***Line regulation:***
  - ✓ This is the variation in output voltage from min. to max. input voltage
- ***Load/Line transient regulation***:
  - ✓ The response speed of the regulator when subjected to a fast load/supply change.



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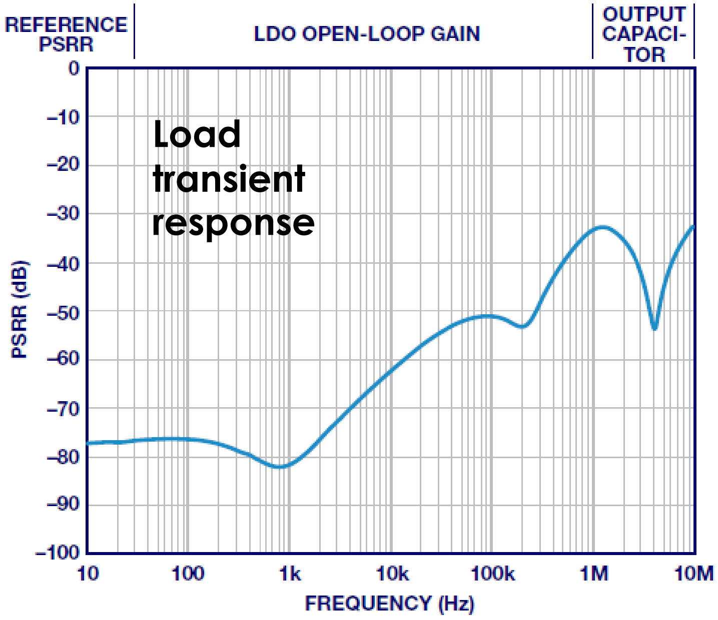
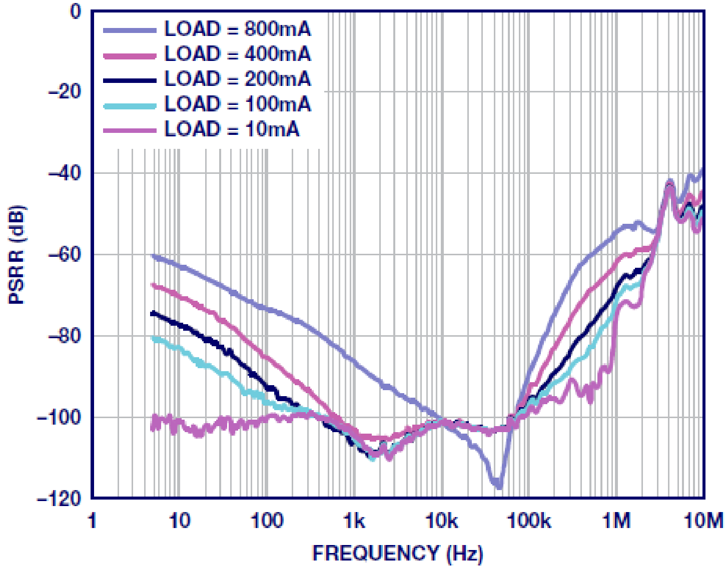
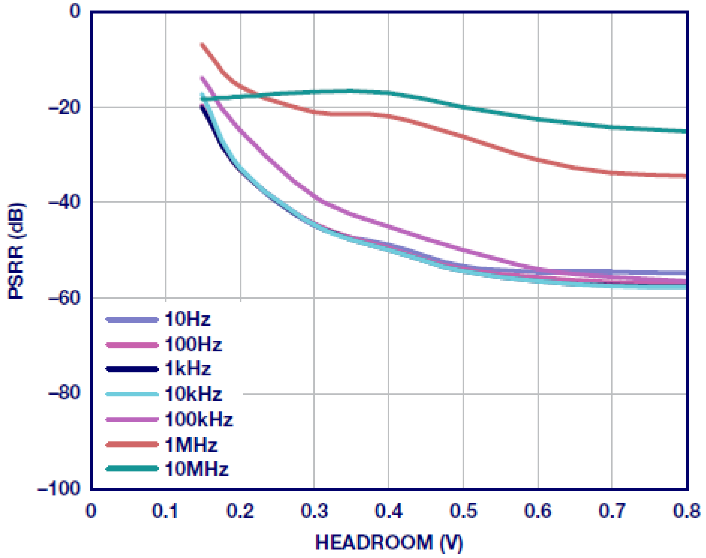
- ***PSRR:*** Power Supply Rejection Ratio (PSRR) is a measure of how well a circuit suppresses extraneous signals (noise and ripple) on the power supply input to keep them from corrupting the output.







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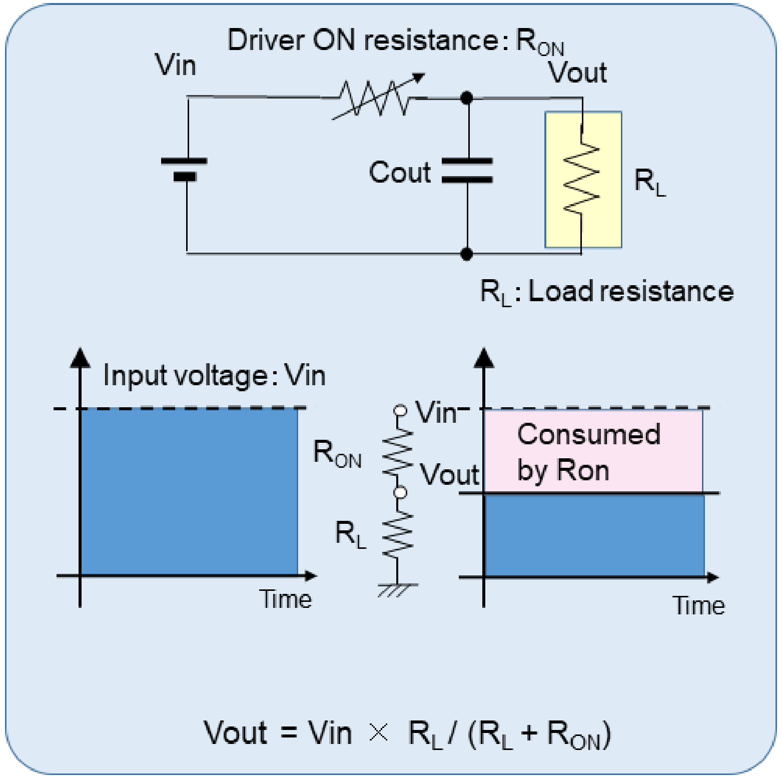
- ***Power Efficiency:***
  - ✓ The ratio of the output load power consumption to input supply power.
- ***Output capacitor range:***
  - ✓ The output capacitance selection in order to achieve stability for a given load current range.
- ***Short circuit current limit:***
  - ✓ The current drawn when the output voltage is short circuited to ground. The lower limit is determined by the maximum regulated load current.
- ***Overshoot:***
  - ✓ Elimination of high transient voltages at start-up and during load and line transients.

What Are the Drawbacks of LDOs?

Circuit Limitations:

- ✓ Low efficiency
- ✓ The voltage difference between input and output should not be too large
- ✓ Only step down operation
- ✓ The load should not be too large.

Switching Regulator Architectures can be much more efficient



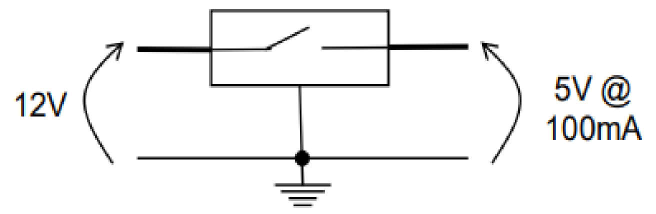
Taken from: https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/06-dc-dc-converter.html

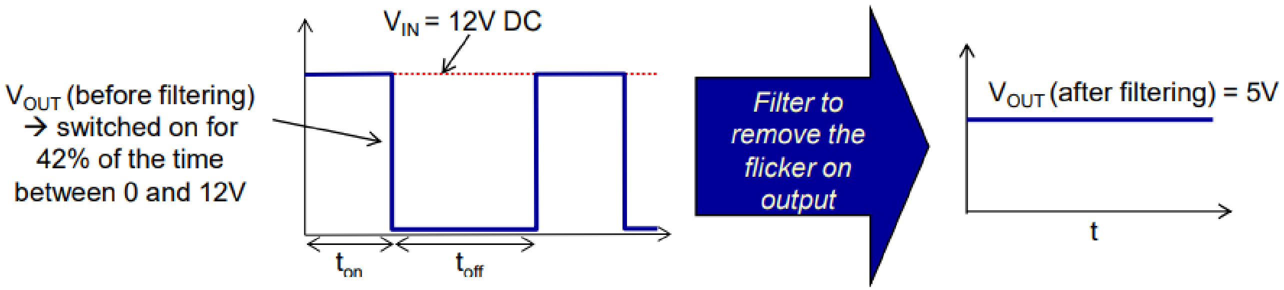
Switching Regulator (Power Converter)

Basic Principle of Switching Regulators

- **Linear Regulator Analogy**: Using a resistor to dim a light wastes energy, similar to how a linear regulator works.
- **Switching Regulator Concept**: By turning the switch on and off rapidly (e.g., 50% on, 50% off), we reduce power and dim the light without energy waste

- Switching Regulator



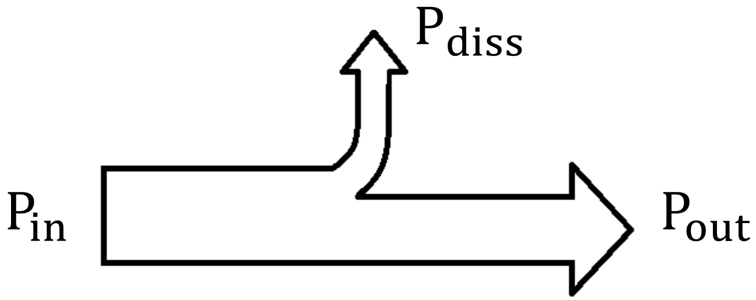


https://www.ti.com/lit/ml/snvp002a/snvp002a.pdf?ts=1726741128944&ref_url=https%253A%252F%252Fwww.google.com%252F

Switching Regulator (Power Converter)

- Converts a DC voltage V_{in} into a lower or higher DC voltage V_{out}.

- **Basic properties:**
  - Voltage conversion ratio $k = \frac{V_{out}}{V_{in}}$
  - Power conversion efficiency $\eta = \frac{P_{out}}{P_{in}}$



The Challenges

Designing Switch-Mode Power Supplies is Challenging!

- ✓ Requires a solid grasp of power electronics
- ✓ Strong knowledge of control theory is crucial
- ✓ Understanding parasitics (PCB or on-chip) is critical
- ✓ Component selection is tough, must handle worst-case scenarios
- ✓ Switching regulators generate significant EMI noise, making precise PCB/chip layout essential
- ✓ Many potential failures… often catastrophic!

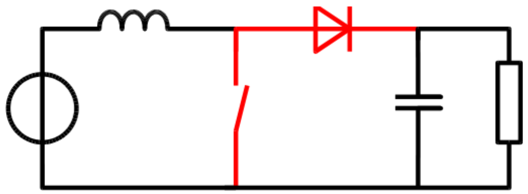
Radiation Effects

Effects of Radiation on DC-DC Converters:

- Efficiency Degradation
- Converter Output Voltage Variation
- Step Response Alteration
- Changes in Loop Gain Frequency Response
- Phase Margin Reduction
- Control Part Degradation

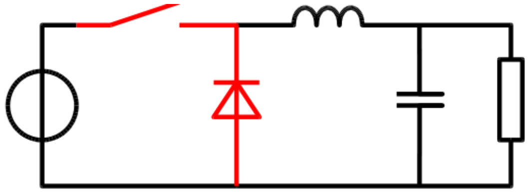
Basic Topologies

Boost Converter



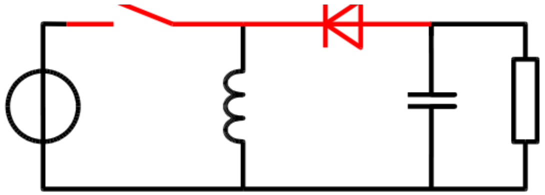
Boost Converter (Step-Up)
- ✓ Increases input voltage to a higher output voltage
- ✓ Efficient for powering devices from lower voltage sources
- ✓ Used in battery-powered systems and renewable energy applications

Buck Converter



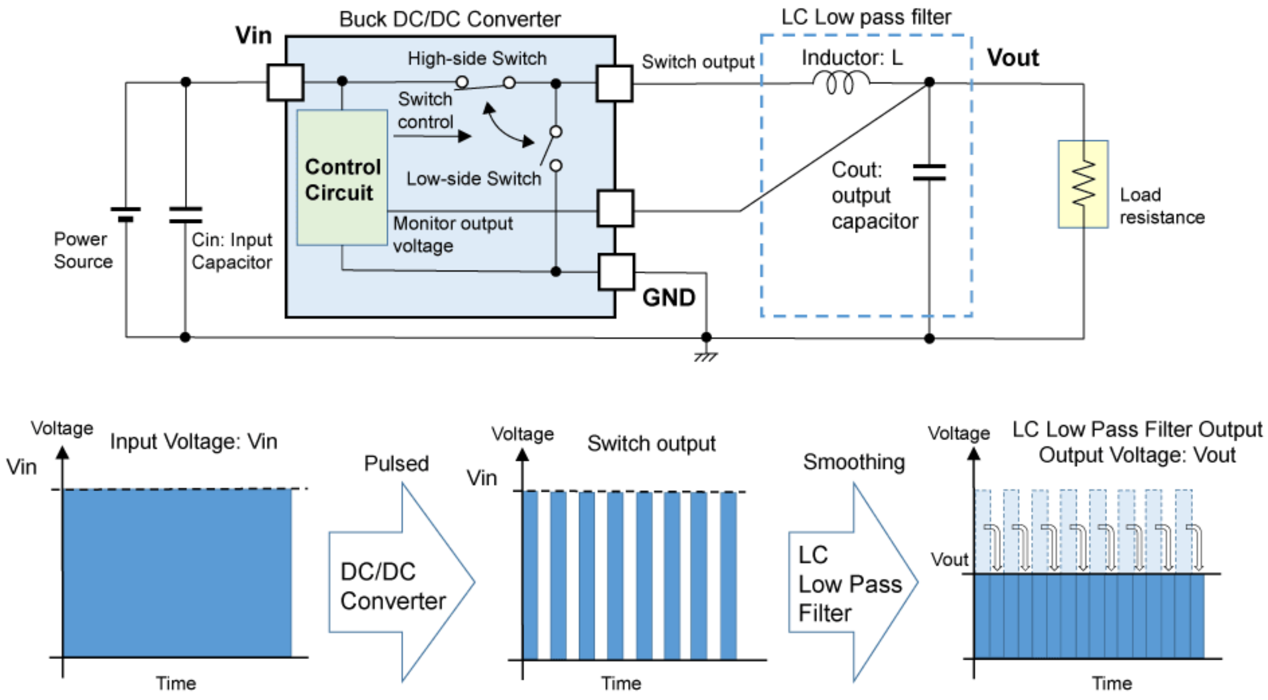
Buck Converter (Step-Down)
- ✓ Reduces input voltage to a lower output voltage
- ✓ High efficiency for voltage reduction
- ✓ Common in power supplies for low-voltage circuits

Buck-Boost Converter



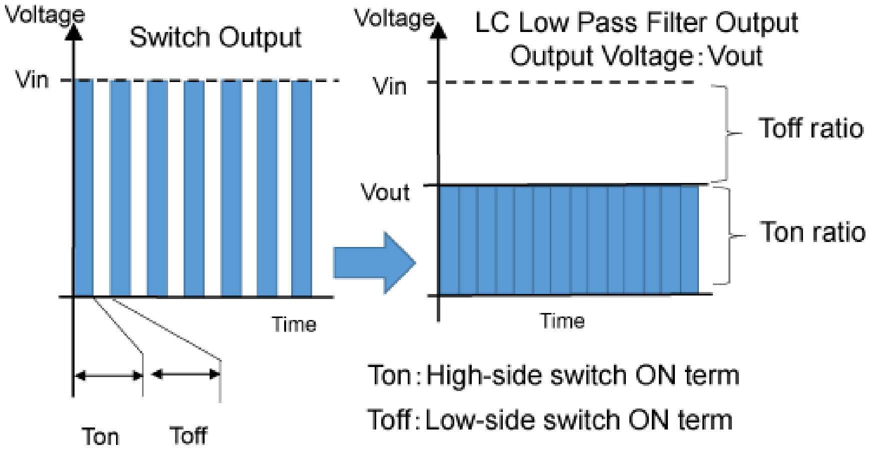
Buck-Boost Converter
- ✓ Can either step-up or step-down voltage depending on input/output
- ✓ Ideal for applications requiring variable voltage levels
- ✓ More complex but versatile for fluctuating input voltages

Basic Concept



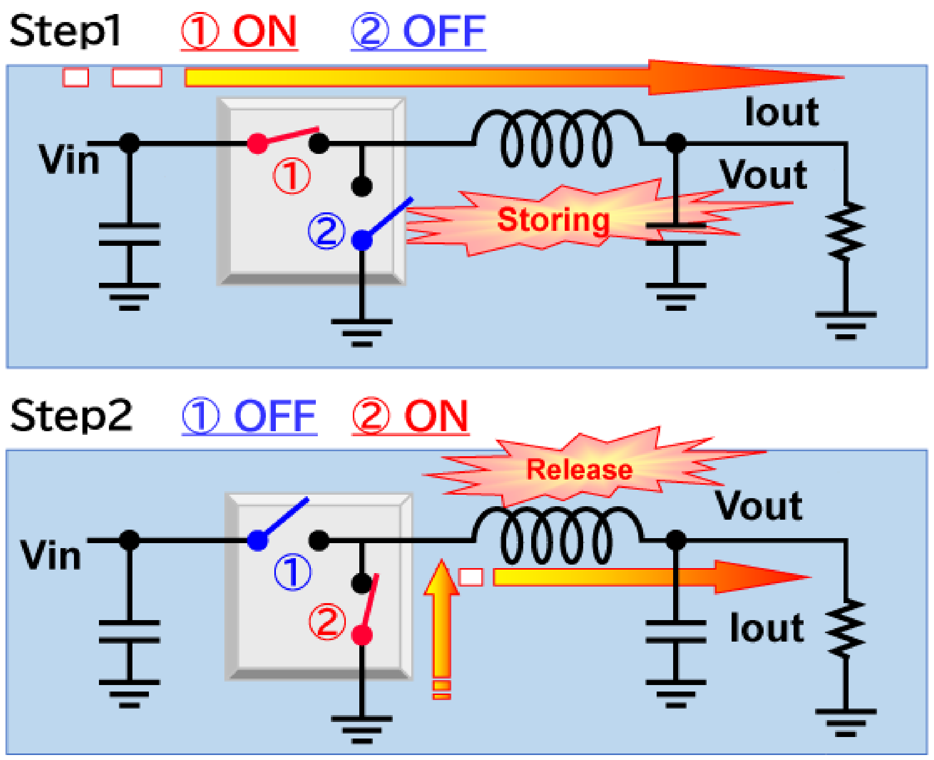
Vout = Vin × Ton / (Ton + Toff)

Example 1.
Vin = 5.0 V, Ton / (Ton + Toff) = 50%, Vout = 2.5 V



Taken from: https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/06-dc-dc-converter.html

Operation Principle



Phase 1

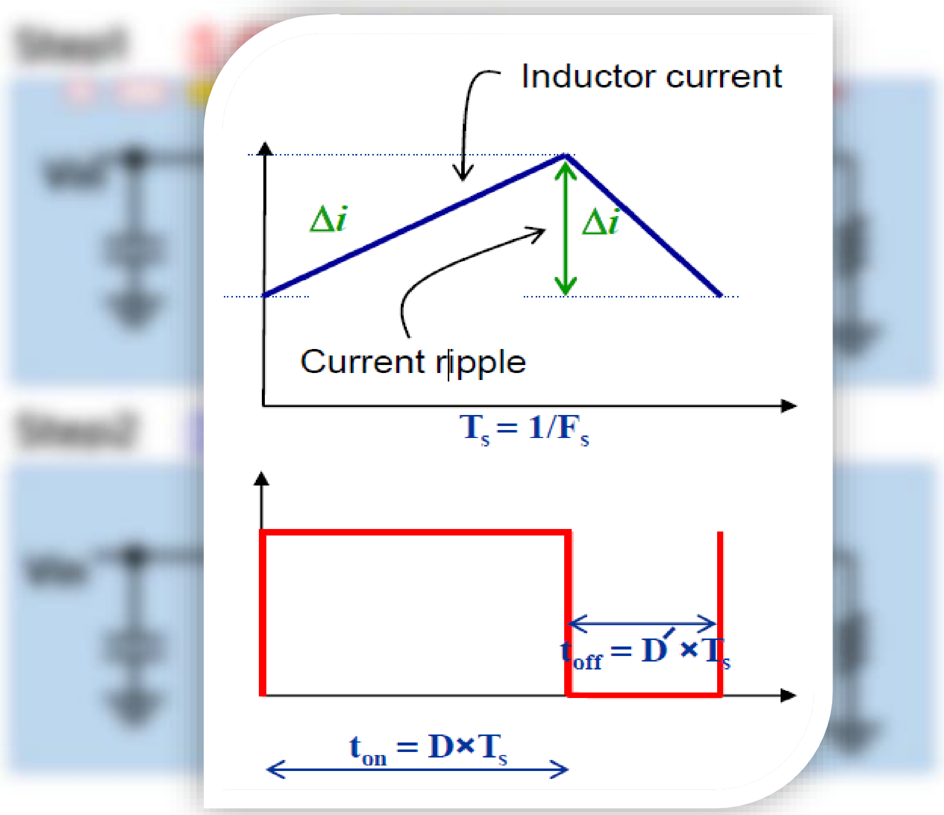
- Replace the switch (1) with a short circuit
- Replace the switch (2) with open circuit
- Inductor current will rise linearly

Phase 2

- Replace the switch (1) with open circuit
- Replace the switch (2) with short circuit
- Inductor current will fall linearly

Taken from: https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/06-dc-dc-converter.html

Operation Principle

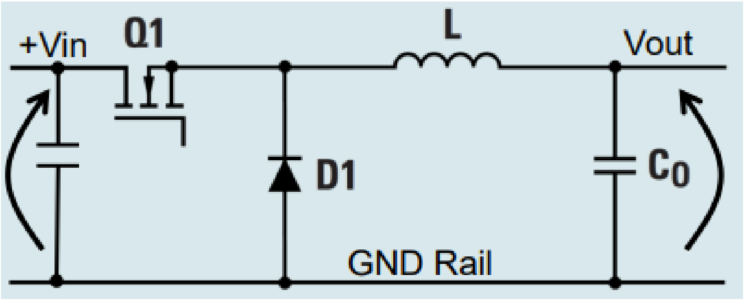


Observations:
- Inductor current increases linearly during turn-on
- Inductor current decreases linearly during turn-off
- Ripple in inductor current depends on the switch on/off duration

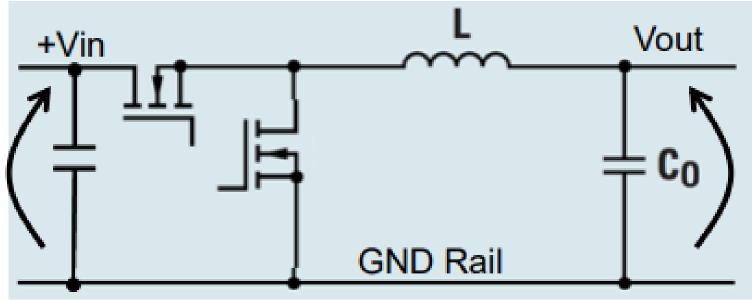
- **Longer switching periods** (slower frequency) result in larger current ripple
- **Inductor Ripple Current** is a key design parameter

https://www.ti.com/lit/ml/snvp002a/snvp002a.pdf?ts=1726741128944&ref_url=https%253A%252F%252Fwww.google.com%252F

Buck Converter Implementations



Normal buck



Synchronous buck

- ✓ **Simplicity and Cost-Effectiveness:** use a simple diode for the low-side switch, making the design less complex and more cost-effective compared to synchronous versions.
- ✓ **Easier Control and Design:** The absence of a second MOSFET simplifies control circuitry, suitable for low to moderate current applications.

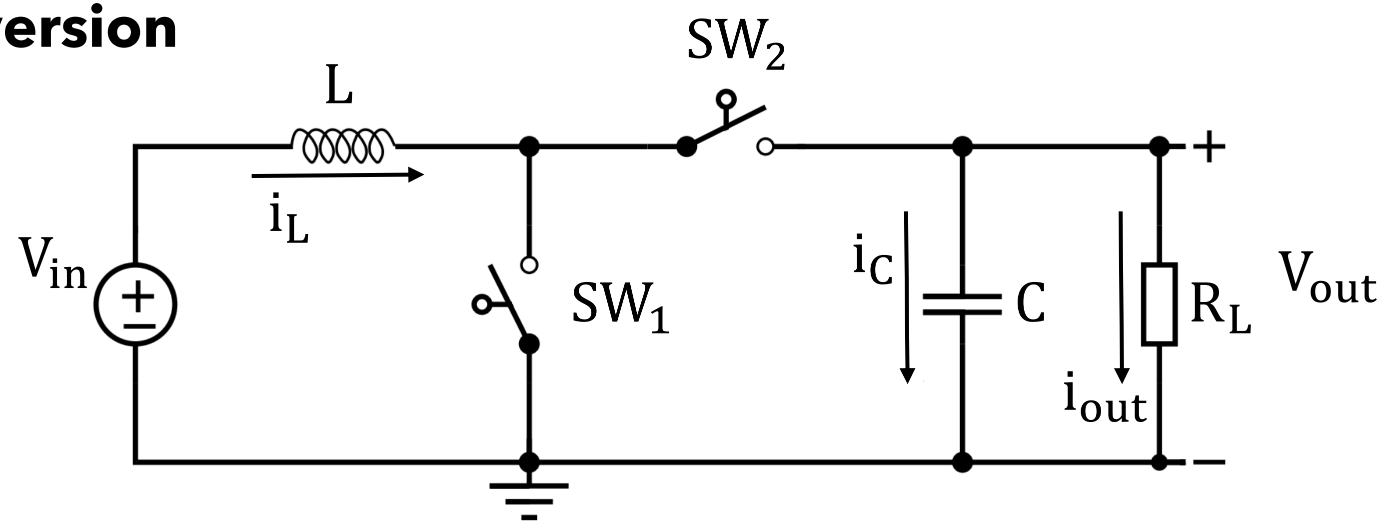
- ✓ **Higher Efficiency:** A synchronous converter uses a MOSFET instead of a diode for the low-side switch, reducing conduction losses and improving overall efficiency, especially at lower output voltages.
- ✓ **Better Performance at High Currents:** The lower losses in the MOSFET enable higher efficiency when dealing with high current loads.

https://www.ti.com/lit/ml/snvp002a/snvp002a.pdf?ts=1726741128944&ref_url=https%253A%252F%252Fwww.google.com%252F

Boost Converter

Taken form "Design and Implementation of Fully – Integrated Inductive DC – DC Converters in Standard CMOS", Mike Wens, Michiel Steyaert.

- **Step up Conversion**



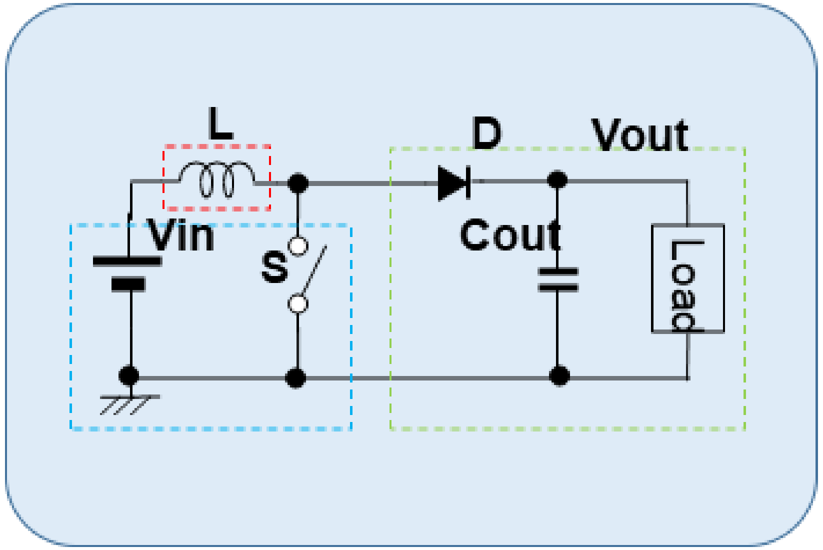
- Inductive DC - DC Step - Up Converters are used to convert the input voltage to a higher output voltage.

Taken form "Design and Implementation of Fully – Integrated Inductive DC – DC Converters in Standard CMOS", Mike Wens, Michiel Steyaert.

Boost Converter Implementations

Step-up converter

- ✓ Increases input voltage to a higher output voltage
- ✓ Switch is referenced to ground (low-side switch)– Enables the use of a simpler gate driver
- ✓ Best with current mode control in continuous conduction mode (CCM)

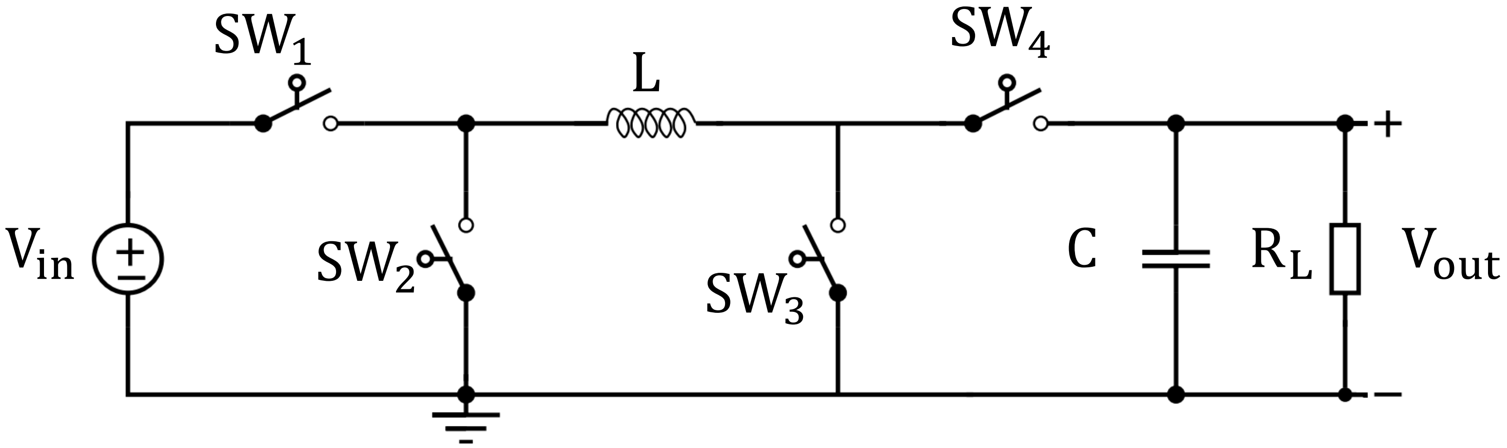


Drawback: No built-in current limiting – can't stop current by turning off the switch

Taken from: https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/06-dc-dc-converter.html

Buck/Boost Converter

Step up/Step down converter



- Inductive DC - DC Step Up/Down converters are used to convert the input voltage to a higher or lower output voltage.

Taken form "Design and Implementation of Fully – Integrated Inductive DC – DC Converters in Standard CMOS", Mike Wens, Michiel Steyaert.

Buck/Boost Converter Implementations

Buck-Boost Converter:

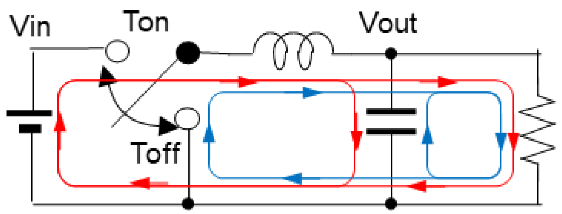
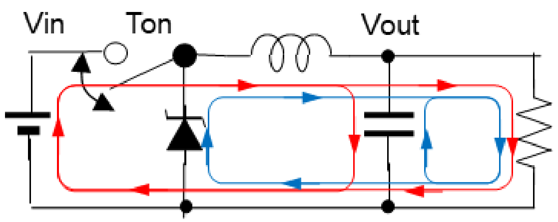
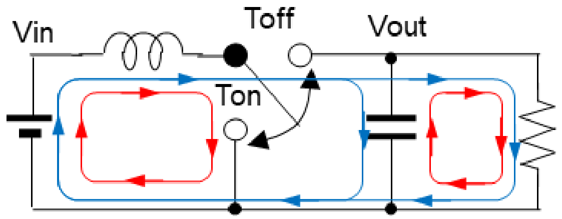
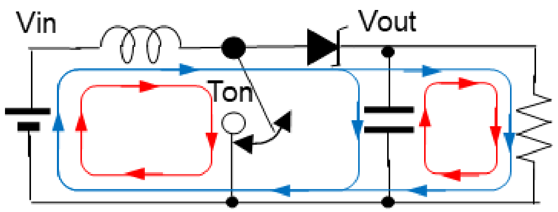
✓ **Steps both up and down**: Ideal for battery-powered devices where voltage needs vary

× Generates significant **EMI noise**

× Smoothly **transitioning between buck and boost modes** when the input voltage crosses the output voltage requires advanced control to prevent instability and oscillations.

DC/DC converters and output voltage calculation

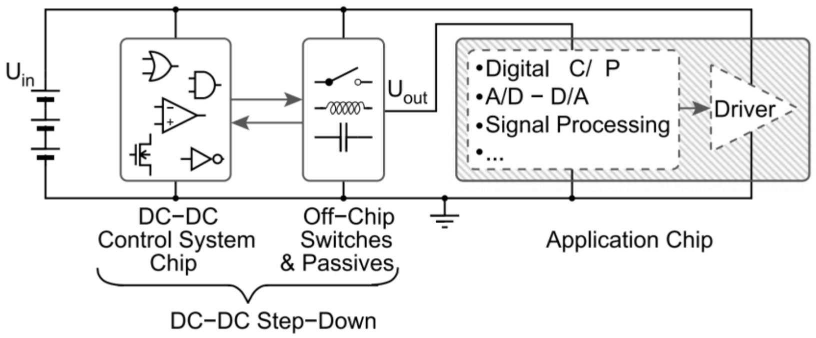
https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/09-dc-dc-converter.html

	Synchronous Rectification	Nonsynchronous (diode) Rectification	Calculation of Output Voltage (PWM method, and Continuous Conduction Mode)
Buck			**Vin × Ton / (Ton + Toff)**
Boost			**Vin × (Ton + Toff) / Toff**

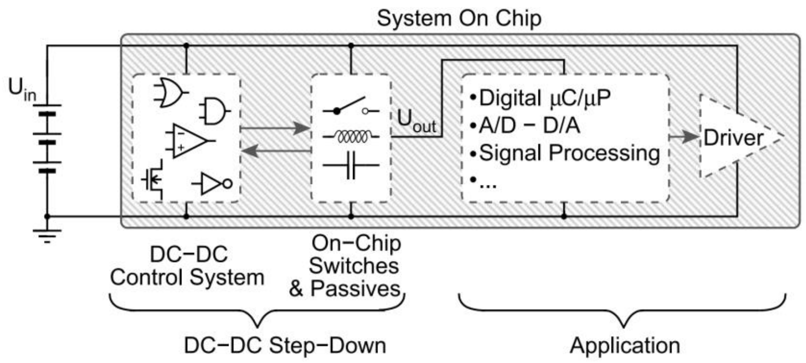
Monolithic DC – DC Converter

Taken form "Design and Implementation of Fully – Integrated Inductive DC – DC Converters in Standard CMOS", Mike Wens, Michiel Steyaert.

- Integrating all the necessary components of a DC - DC converter onto a single chip.
- Advantages:
  - ➢ Compact size
  - ➢ Weight reduction
  - ➢ Improved power conversion efficiency
  - ➢ Enhanced Reliability



→



Impact of Switching Frequency (Fs)

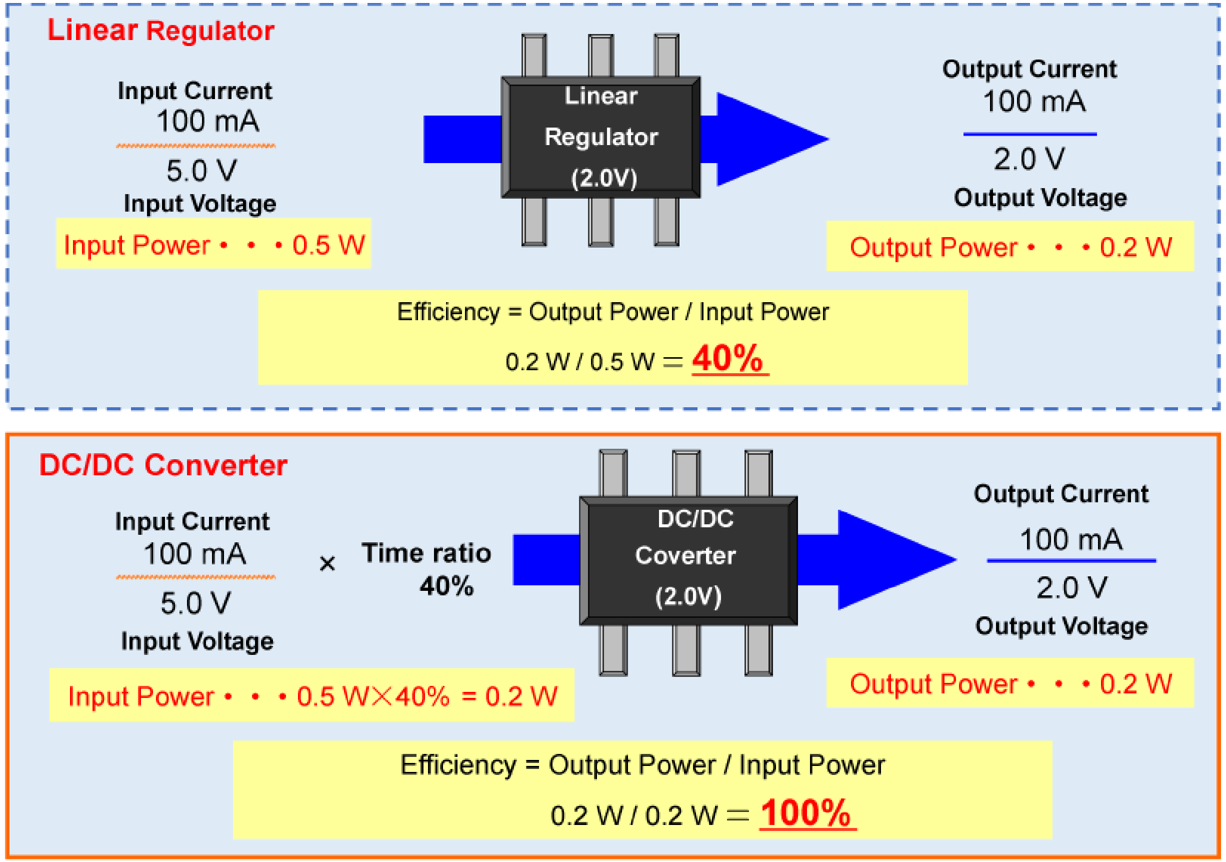
- **Directly affects power supply architecture**
  – Higher switching frequency = smaller inductor and output capacitor
  – Smaller components lead to more compact power supply designs
  – Critical for small handheld devices, where high Fs allows for miniaturization

- **Limits on inductor ripple**
  – Ripple must stay within safe limits to avoid inductor saturation
  – Tools can automatically size the inductor appropriately

- **Affects efficiency**
  – Higher Fs = increased **switching losses** (energy lost each time switch is turned on/off)
  – Lead to reduced efficiency and higher costs

LDO vs Power Converter

https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/09-dc-dc-converter.html



*) This efficiency is ideal value.
The real efficiency will be lower because of consumption current of IC itself and loss by external components.

LDO vs Power Converter

	Linear regulators	DC/DC converters	Remark
Efficiency	Bad	Good	• Efficiency of linear regulators is Vout/Vin. • Efficiency of DC/DC converters is up to 95%.
Output current	Small	Large	• Linear regulators are not suitable for large load current. • DC/DC converters are suitable for large current because of their high efficiency.
Noise	Small	Large	• DC/DC converters make switching noise. • The output noise of Linear regulators is extremely small due to their static operation.
Output topology	Step-down only	Step-up, Step-down, Step-up and down, and Inverting	• Changing connection order of switches and inductor, DC/DC converters can support step-down, step-up, step-up and down, and inverting topologies.
Circuit complexity	Small	Large	• Linear regulators consist of small number of circuit elements and are small in scale. • DC/DC converters have complex circuits and are large in scale.

Taken from: https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/06-dc-dc-converter.html

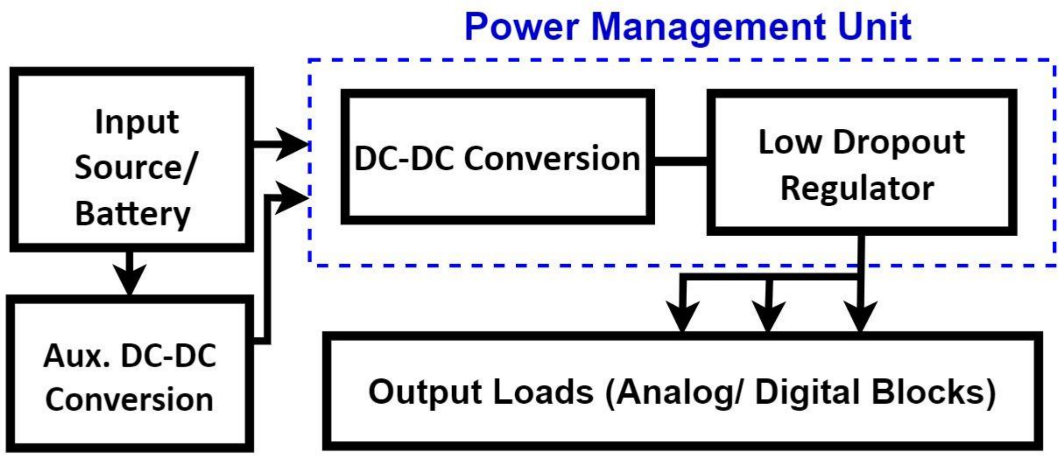
Power Converter & LDO Use

Why Use Both DC-DC Converter and LDO?

✓ **High Efficiency**:
DC-DC converters efficiently handle large voltage changes with minimal power loss.

✓ **Low Noise**:
LDOs smooth out noise and ripple from the DC-DC converter for cleaner output.

✓ **Precise Regulation**:
LDOs provide accurate, stable voltage for sensitive components.



Best of Both:
Combines efficiency of DC-DC with the low noise and precision of LDO!

Charge Pumps

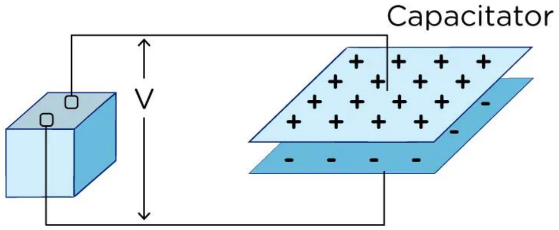
"Inductive DC/DC converters can generate stable voltage with high efficiency by controlling the time ratio of storing and releasing in the form of magnetic energy to the inductor. "

Inductors are not only devices which can store and release an energy!

Capacitors can also store and release energy in the form of charge and DC/DC converters can be realized without using inductors.

This is called a charge pump circuit!

Energy Stored on a Capacitator



$$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}QV = \frac{1}{2}CV^2$$

Where:

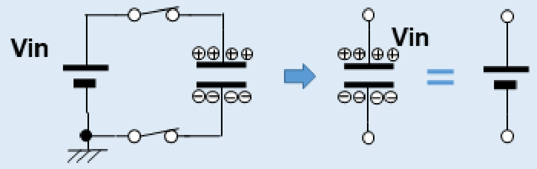
U = energy
Q = charge
V = voltage
C = capacitance

Charge Pumps

Capacitor-Based Voltage Conversion: Charge pump circuits use capacitors to store energy from the input power supply.

By controlling how capacitors are connected with switches, the circuit can:

- **Boost** voltage
- **Buck** (reduce) voltage
- Generate an **inverted** voltage (reverse polarity) compared to the input.



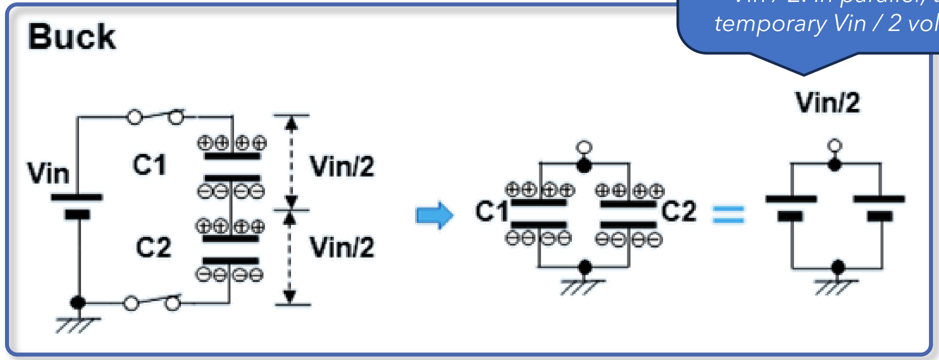
A capacitor charged with voltage of Vin is the same as a temporary battery with electromotive force of Vin.

Various voltages can be generated by changing connections of one or more capacitors.

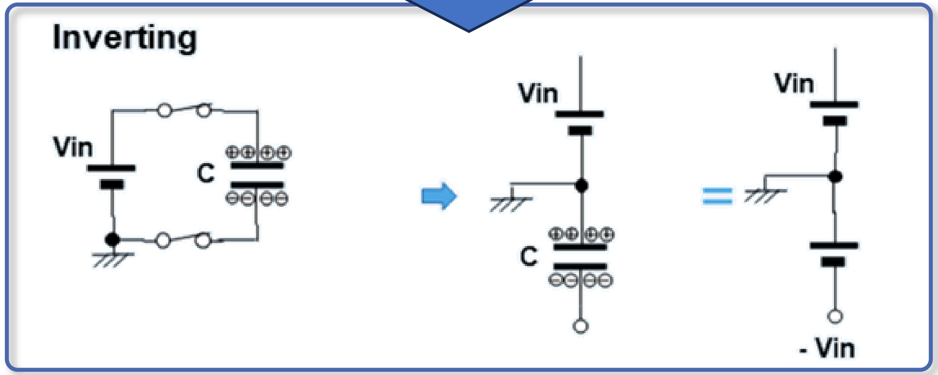
https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/09-dc-dc-converter.html

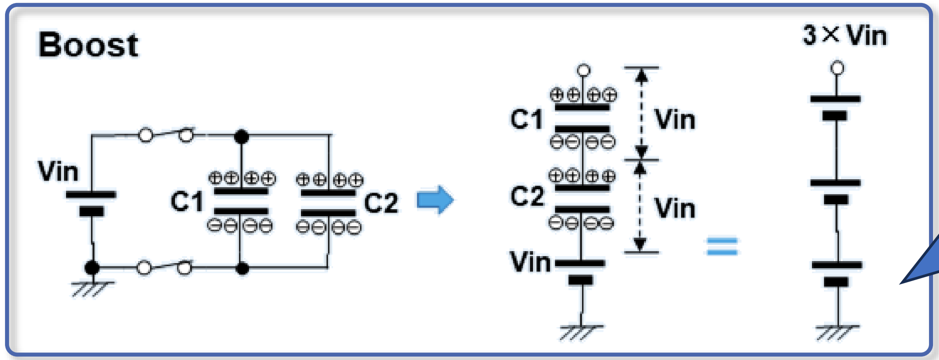
Charge Pumps

When capacitors C1 and C2 (same capacitance) are connected in series and charged, each holds Vin / 2. In parallel, they form a temporary Vin / 2 voltage source.



A capacitor charged with Vin has a polarity like that of a usual battery. Just as connecting the positive (+) side of a battery to GND produces a negative voltage of −Vin, connecting the positive (+) side of a capacitor charged with Vin to GND produces a negative power supply with the voltage of −Vin at negative (−) charged side.

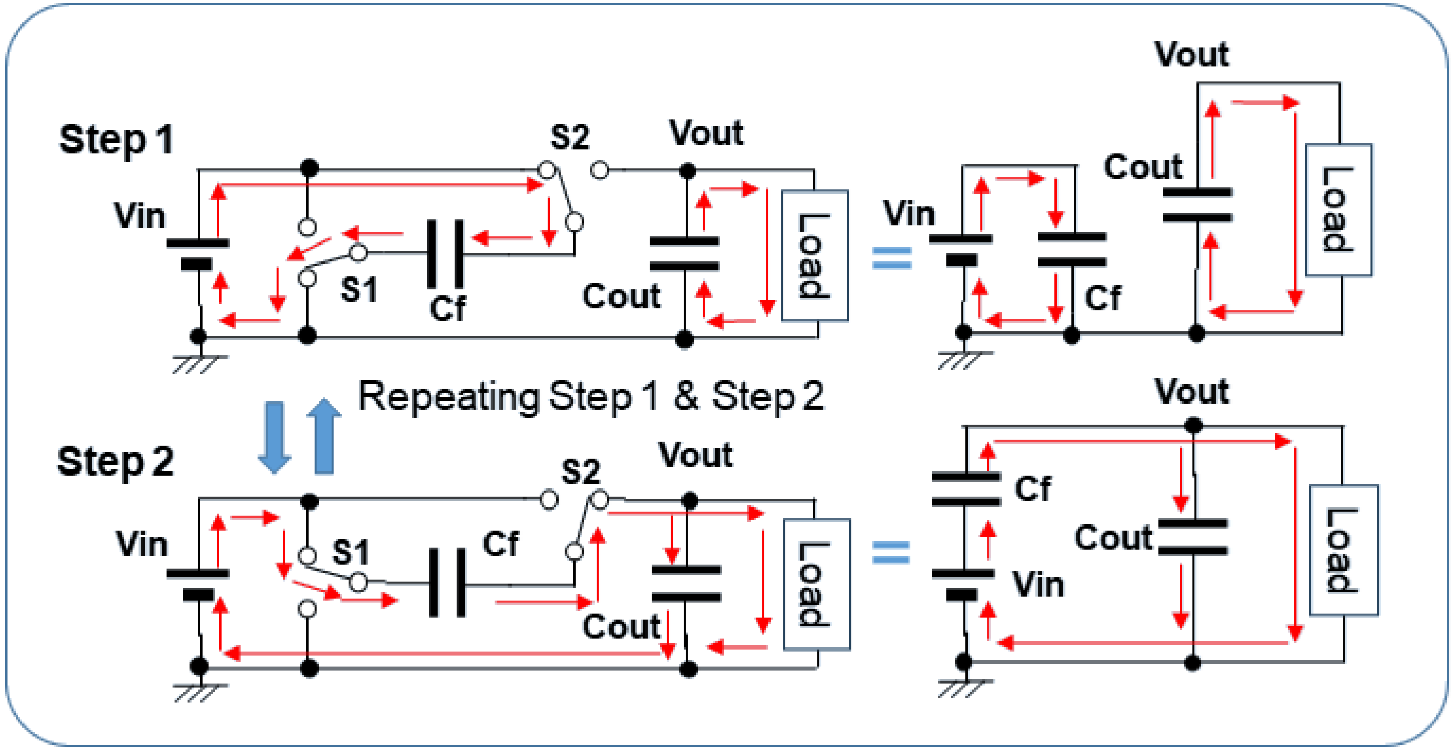




Capacitors C1 and C2 of the same capacitance are connected in parallel and charged with Vin. If the capacitors are connected in series and connecting the negative side to the positive (+) side of Vin, a temporary battery with voltage of 3 × Vin is realized.

https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/09-dc-dc-converter.html

Charge Pump Operation



https://www.nisshinbo-microdevices.co.jp/en/design-support/basic/09-dc-dc-converter.html

Charge Pump Considerations

Simple Design and Operation:

- ✓ No need for monitoring & feedback control like in linear regulators and DC/DC converters.
- ✓ Inductor-free architectures
- ✓ Can generate buck, boost, and inverting voltages with fully integrated components (Cout and flying capacitors, Cf).

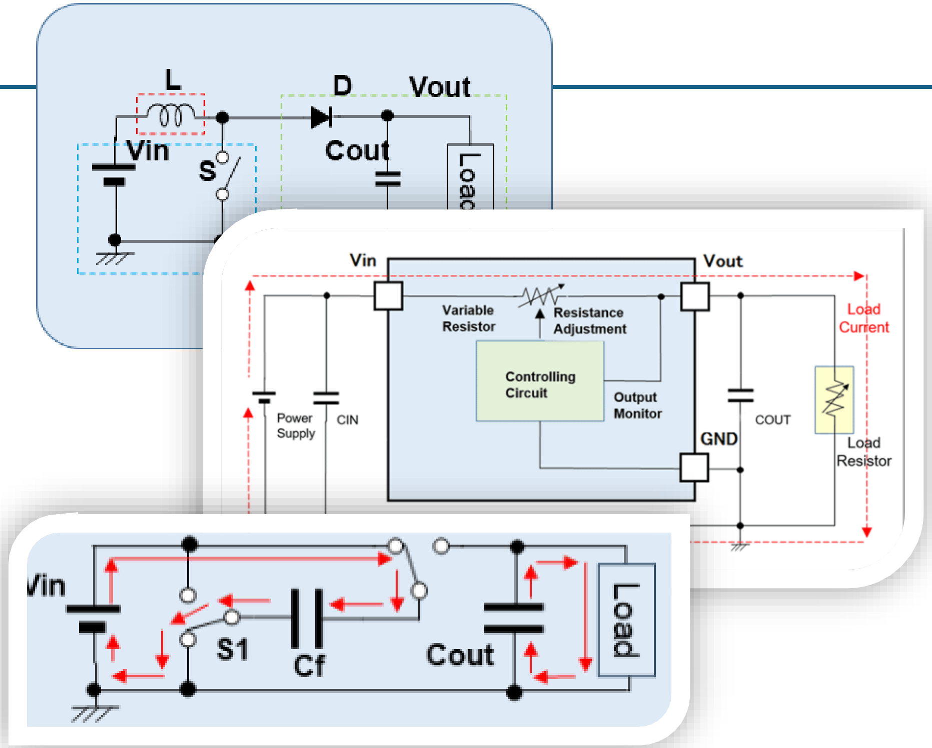
Voltage Steps and Accuracy:

- × Voltage of the flying capacitor is a fraction of Vin (e.g., 1/2, 1/3, 1/4).
- × Coarse voltage steps make fine adjustments difficult.
- × Output voltage fluctuates with input voltage, limiting use in high-precision applications.

Current Limitations:

- × Output current depends on the capacitance of the flying capacitor.
- × Larger ripple voltage when supplying high load currents.

Top Points to Remember

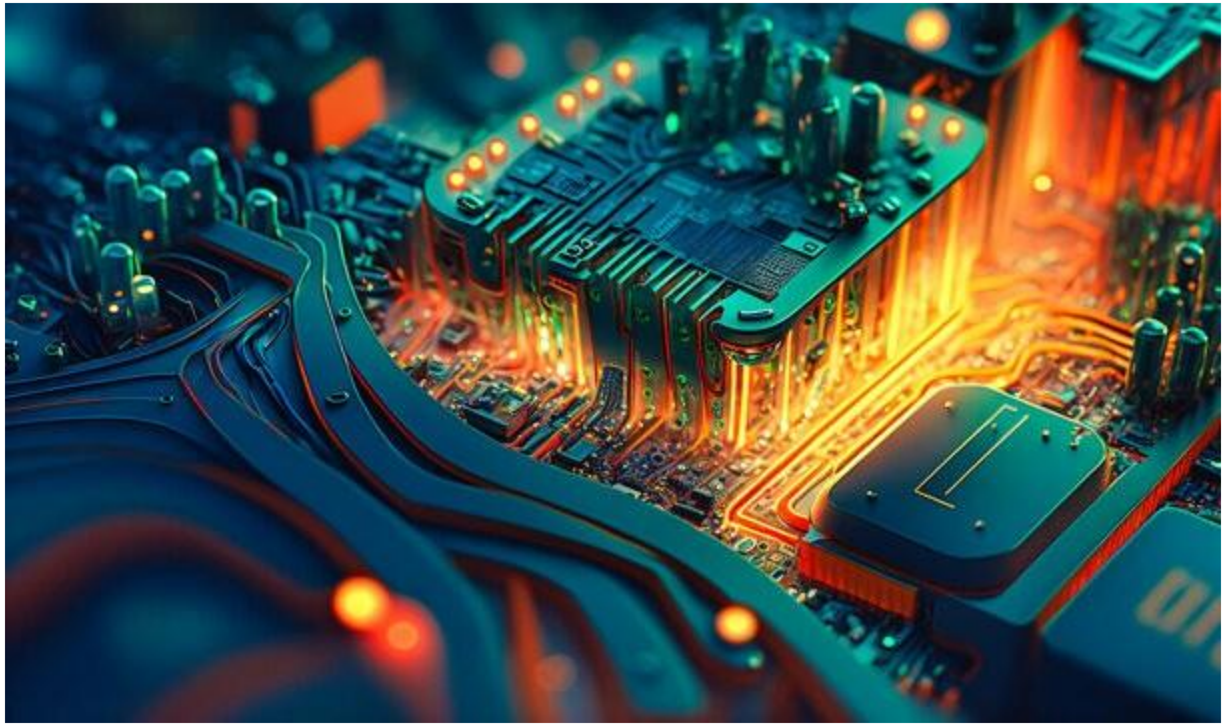


- **LDO Regulators:**
  - Offer low-noise, precise voltage regulation.
  - Best for low-noise, sensitive applications.
  - Simpler design but less efficient for large voltage drops.
- **DC-DC Converters:**
  - Highly efficient for large voltage changes.
  - Ideal for high-power applications.
  - Can provide buck, boost, and inverting voltages.
- **Charge Pumps:**
  - Inductor-free, compact solution for voltage conversion.
  - Suitable for low-power applications with moderate voltage adjustments.
  - Limited in precision and current handling capacity compared to DC-DC converters.

Power Electronics Market

Current & Future Trends

The power electronics market is set for substantial growth from 2024 to 2033, fueled by technological innovations, renewable energy adoption, and the rising demand for energy-efficient solutions.



https://www.linkedin.com/pulse/power-electronics-market-size-share-growth-analysis-trends-dhekale--tgz6f/

Key Discussion Points:

- ✓ Current Trends
- ✓ Key Drivers
- ✓ Emerging Opportunities
- ✓ Potential Challenges

Power Electronics Market

Current & Future Trends

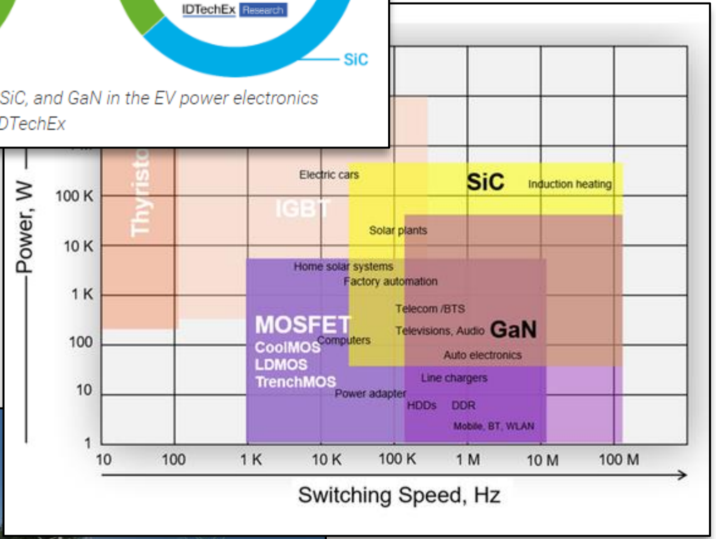
Key Market Drivers:

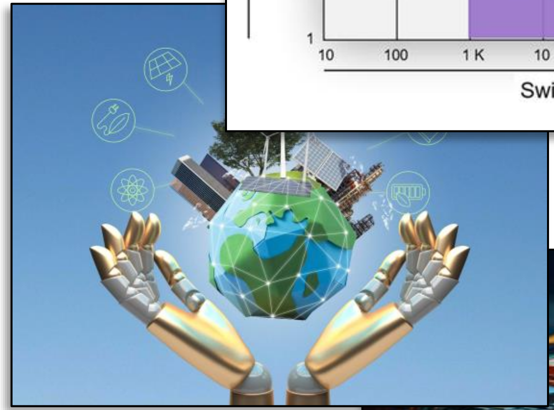
✓ **Technological Advancements:**
Innovation in **wide-bandgap semiconductors** like **SiC** and **GaN** enables higher efficiency, faster switching, and better thermal performance, ideal for high-power applications.

✓ **Renewable Energy Adoption:**
Global policies promoting **solar, wind,** and other **renewable energy sources** drive the demand for power electronics to efficiently manage energy conversion and storage.

✓ **Electric Vehicles (EVs):**
Growing EV adoption increases the need for **power management systems** for battery charging, motor control, and energy recovery, boosting demand for power electronics.

The change in GW demand for Si, SiC, and GaN in the EV power electronics market from 2023-2035. Source: IDTechEx





https://www.keysight.com/blogs/en/tech/sim-des/2024/2/26/what-s-next-for-power-electronics-beyond-silicon

Power Electronics Market

Current & Future Trends

Emerging Trends in Power Electronics:

- ✓ **AI and IoT Integration:**
  AI and IoT enable **real-time monitoring**, **predictive maintenance, and enhanced control**, improving the efficiency and performance of power systems.

- ✓ **Energy Storage Systems:**
  The rise of **advanced energy storage** technologies, such as lithium-ion and solid-state batteries, drives demand for power electronics to optimize charging cycles and extend battery life.

- ✓ **Smart Grids:**
  Power electronics are key to **smart grid** functionality, allowing dynamic control of power flow and seamless integration of **distributed energy resources** for improved grid reliability and efficiency.

https://www.voitatech.com/the-new-trends-in-the-evolution-of-dc-dc-converters/

Power Electronics Market

Current & Future Trends

Market Segmentation

By material

- Sapphire
- Silicon
- Gallium Nitride (GaN)
- Silicon Carbide (SiC)
- Others

By application

- Consumer Electronics
- Industrial
- Information and Communication Technology (ICT)
- Aerospace & Defense
- Automotive
- Others

By device

- Module
- Discrete
- Integrated Circuit (IC)

https://www.voitatech.com/the-new-trends-in-the-evolution-of-dc-dc-converters/

Power Electronics Market

Current & Future Trends

Challenges:

- × **High upfront costs** for advanced power electronics components can make it hard for smaller businesses to adopt them.
- × **Technical challenges** in integrating power electronics into existing systems require specialized skills.
- × **Meeting strict regulations** and standards can also be difficult, especially in regions with different rules.

Key Takeaways

DC-DC Converters: Powering Possibilities!

- ✓ **Efficiency is Everything!**
  DC-DC converters optimize energy use across various applications.

- ✓ **Versatile Power Solutions**
  From portable devices to industrial systems, they provide tailored voltage regulation.

- ✓ **Innovation at its Core**
  Advances in converter design are pushing boundaries for higher performance and smaller sizes.

- ✓ **The Future is Electric**
  As we move toward greener technologies, DC-DC converters will be vital in energy-efficient systems.

Thank You!

Any Questions?