4-SWITCH BUCK-BOOST CONVERTER VERIFICATION IN BATTERY APPLICATIONS

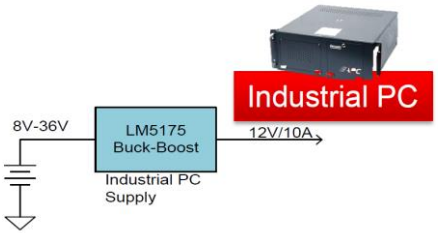
ROHDE&SCHWARZ

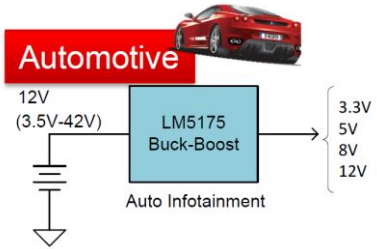
Make ideas real

TABLE OF CONTENT

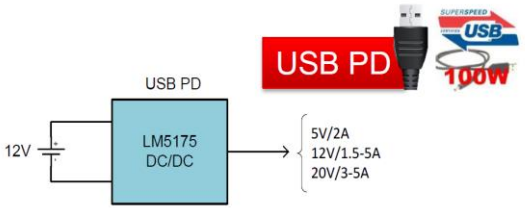
APPLICATIONS

- Automotive Battery Stabilization (Voltage Dips Due To Heavy Loads)
- Industrial Computers





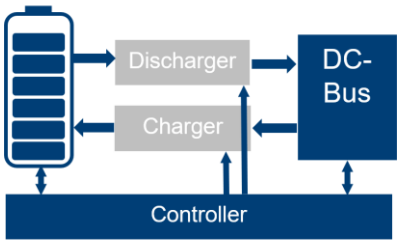
- USB Power Delivery



- Variable Supplies For Amplifier
- Local Energy Storage Systems (Bidirectional) E.g. USB Power Bank

KEY CHARACTERISTICS OF POWER CONVERTER IN BATTERY POWERED APPLICATIONS

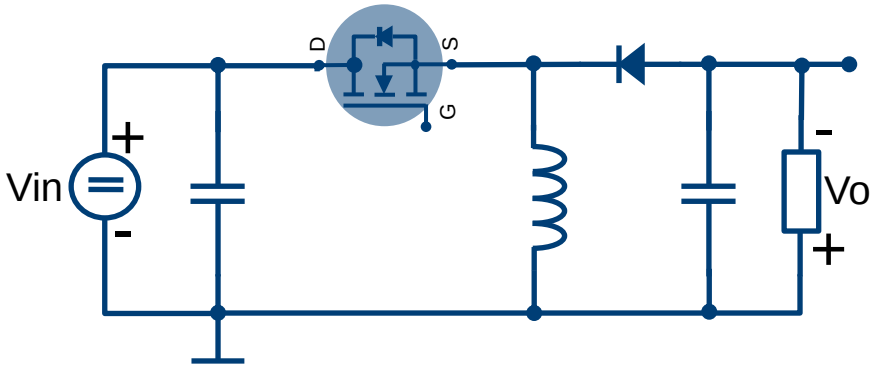
- Input Voltage Variation In All Battery Supplied Application Exists
  - Step-Up/Step-Down Function Is Required (A Simple Buck or Boost Is Not Suitable)
  - In Some Applications, The Output Voltage Need To Be Programmable
- In Most Applications, Output Should Provide A Positive Voltage With Respect To Ground
- Some Applications Require Power Conversion Bidirectionally
- High Efficiency >95% And Power Levels Up To 250W
- Non-Isolated System
- Digital Control



SINGLE SWITCH BUCK-BOOST CONVERTER

- The Magnitude of Output is Higher when Duty Cycle > 0.5
- The Magnitude of Output is Lower when Duty Cycle < 0.5
- Single Switch Topology Provides Negative Output Voltage

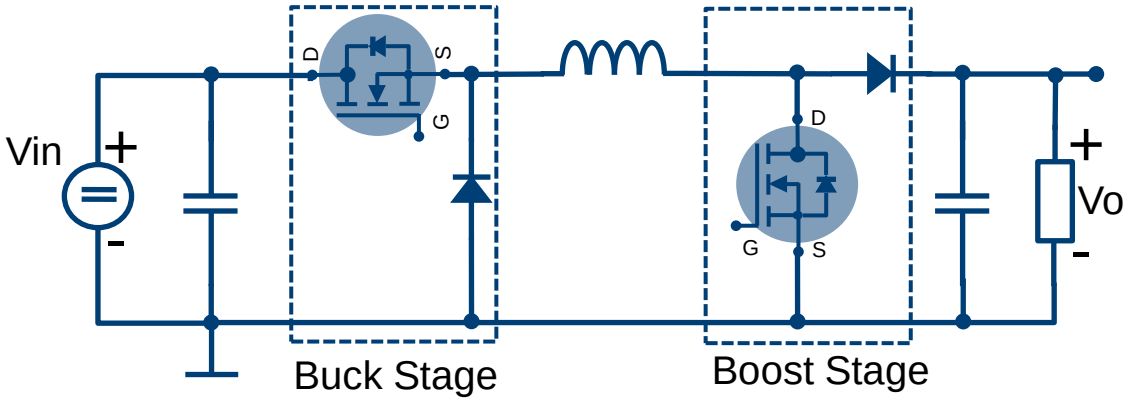
$$M = -\frac{D}{1-D}$$



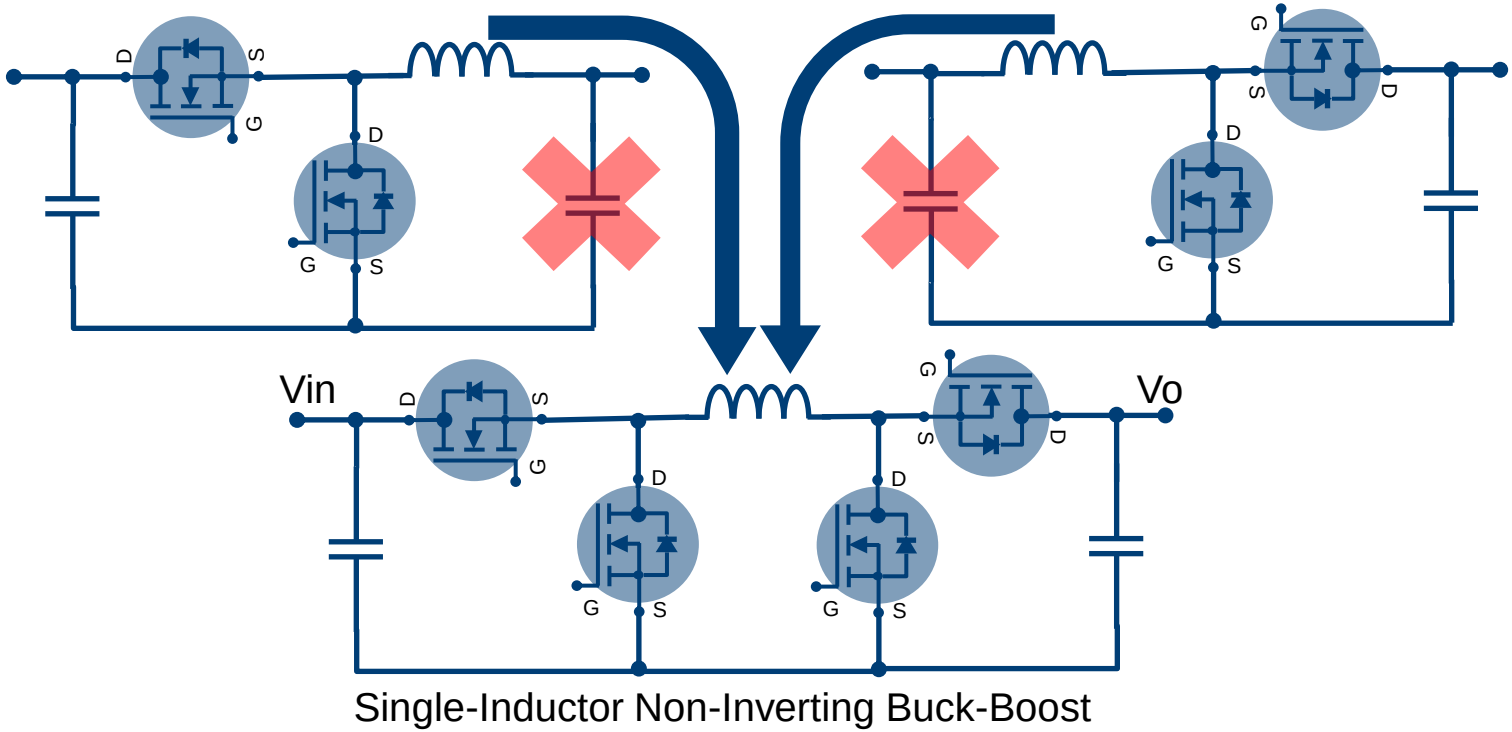
2-SWITCH BUCK-BOOST CONVERTER

- The Magnitude of Output is Higher when D > 0.5
- The Magnitude of Output is Lower when D < 0.5
- Non-Inverting Buck-Boost Solution
- Bidirectional Power Flow Is Not Possible

$$M = \frac{D}{1-D}$$



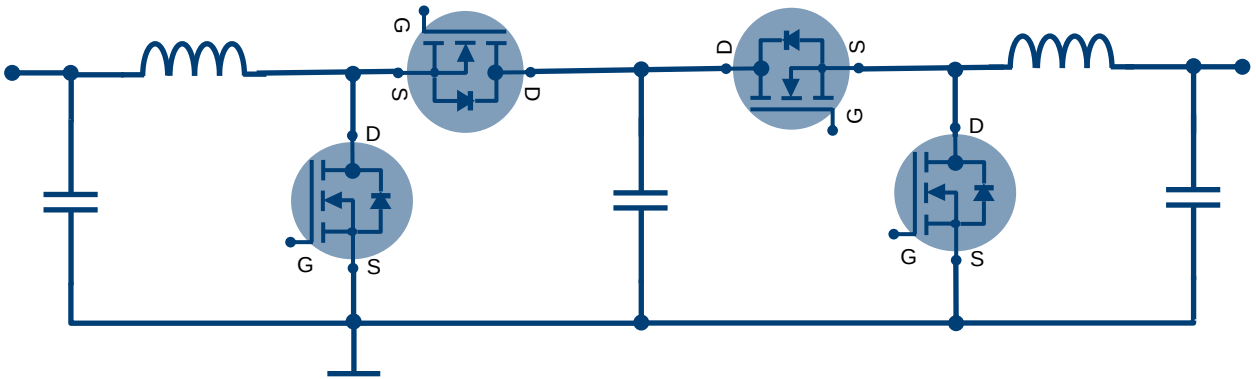
4-SWITCH BUCK-BOOST DERIVATION



Single-Inductor Non-Inverting Buck-Boost

CASCADED BOOST AND BUCK CONVERTER

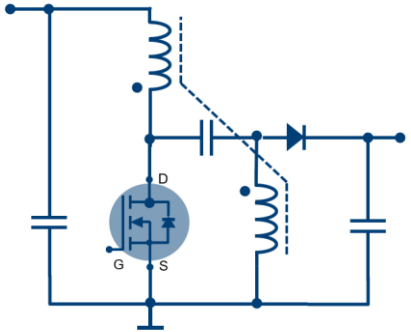
- Two Independent Controllers
- Two Inductors
- Bad Efficiency



SEPIC AND FLYBACK CONVERTER

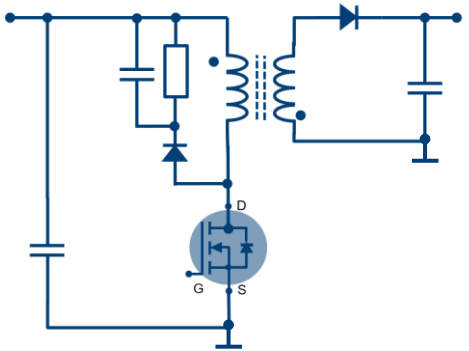
SEPIC (Single Ended Primary Inductance Converter)

- 2 Inductors
- Coupling AC-Capacitor



Flyback

- Coupled Inductors
- High Break Down Voltage

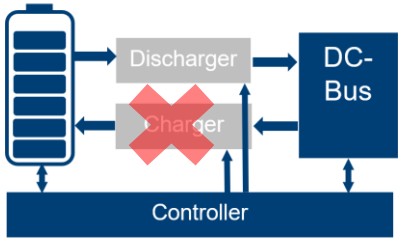


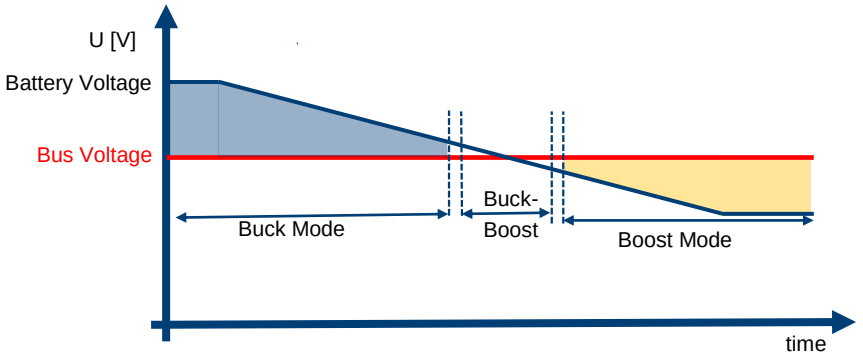
STEP-UP/DOWN TOPOLOGY COMPARISON

Topology	Strengths	Weaknesses	Power Level	Efficiency
Cascaded Boost-Buck	Low Input & Output Noise	Two Inductors Two Controllers	< 40W	85%
Sepic	Single Low Side Switch	Two Inductors High Switch Voltage	< 75W	90%
Flyback	Single Low Side Switch	Coupled Inductors High Switch Voltage	< 75W	88%
2-Switch Buck-Boost	Single Inductor	Diode Rectifier High Switch Current	< 25W	90%
4-Switch Buck-Boost	Single Inductor Synch Rectifier	Limited Controllers Compensation	25 - 250W	96%

4-SWITCH BUCK-BOOST OPERATION

- A Varying Input Voltage Drives The Converter Into 3 different Operating Modes (Unidirectional)
  - Buck Mode (U_{in} >> U_{out})
  - Boost Mode (U_{in} << U_{out})
  - Buck-Boost/Transition Mode (U_{in} <= U_{out} & U_{in} >= U_{out})



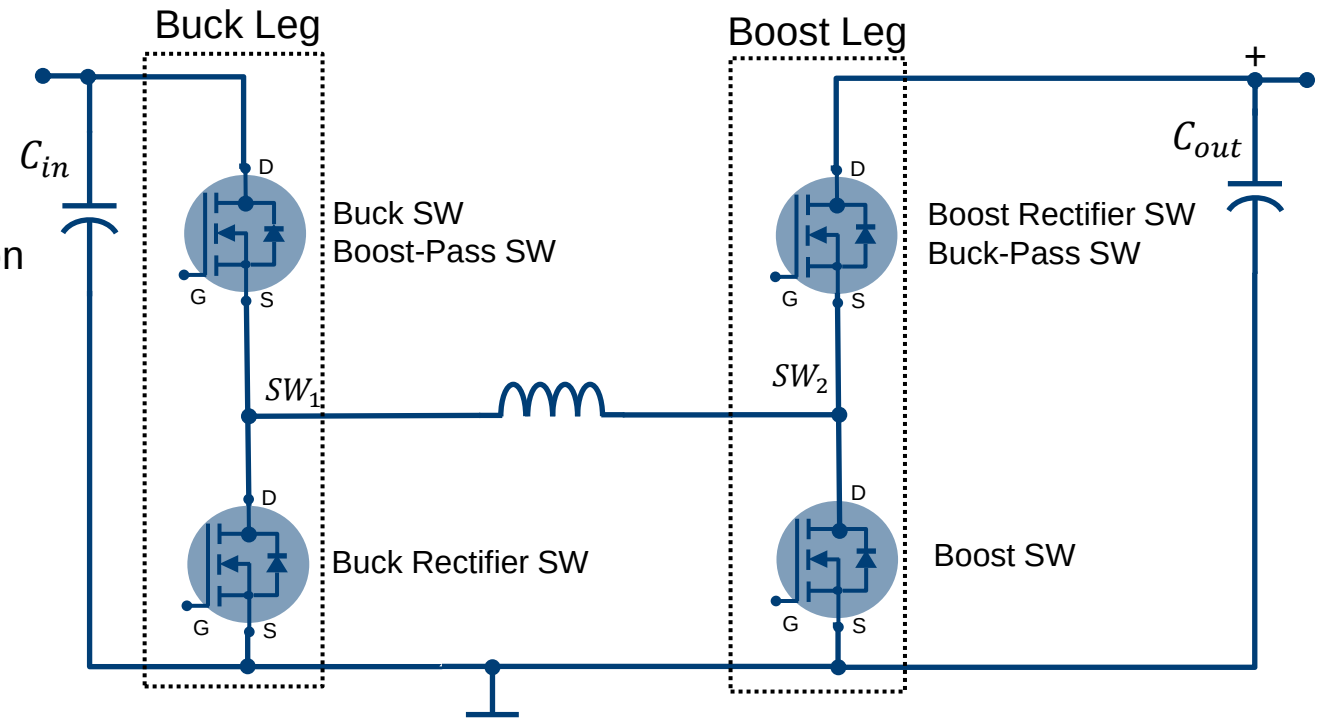


- Battery Simulation Product Is Very Helpful To Simplify Your Validation

4-SWITCH BUCK-BOOST TOPOLOGY

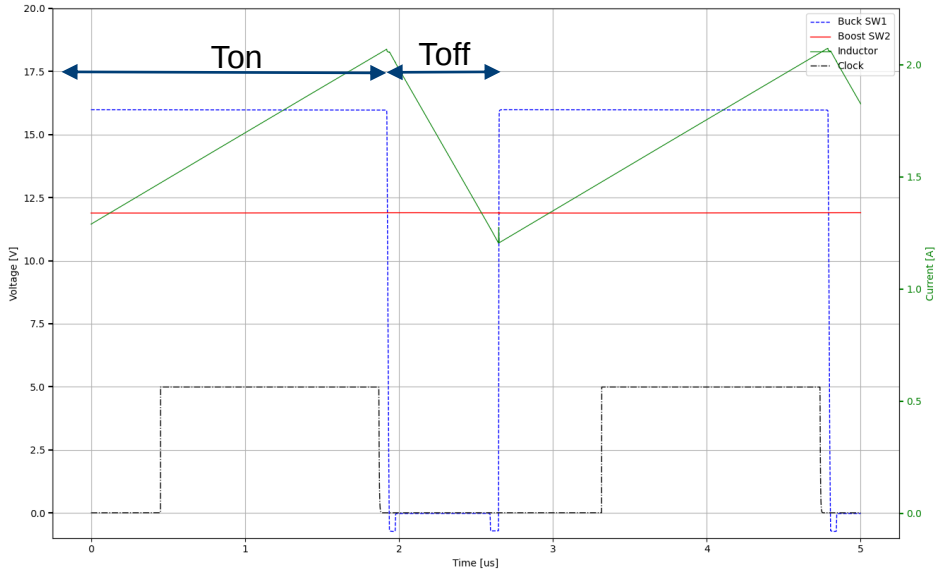
► High-Side Switches
Provide Two Functions

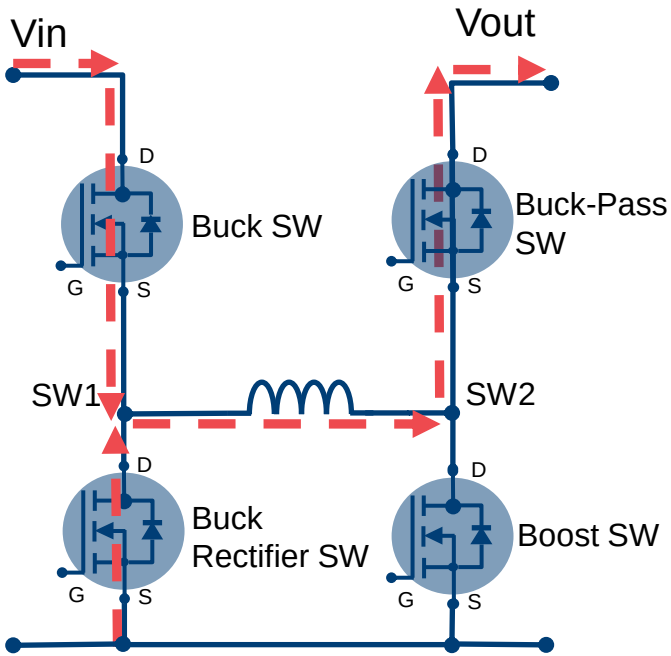
► Low-Side Switches
Provide Only One Function



BUCK-MODE

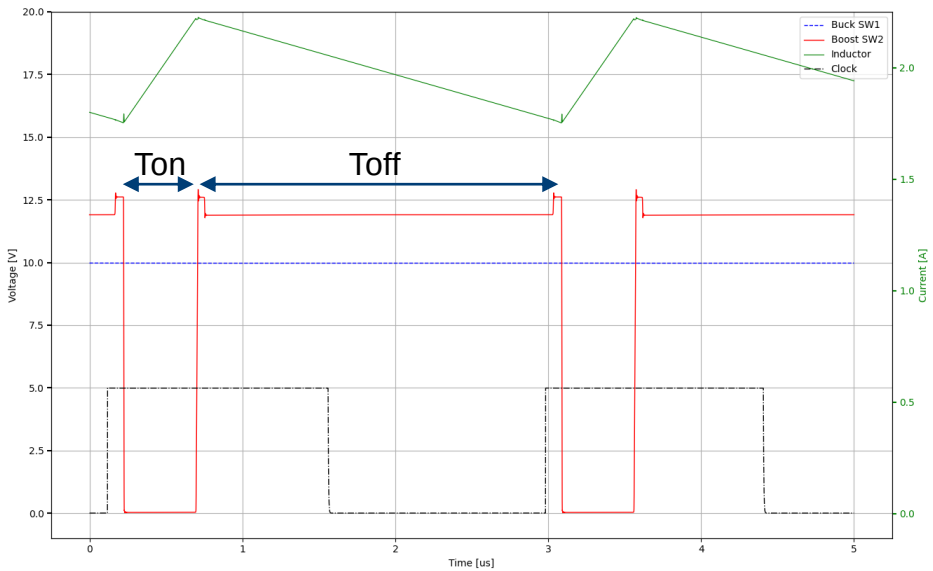
- Condition Vin >> Vout
- Switching Pattern Like Simple Buck

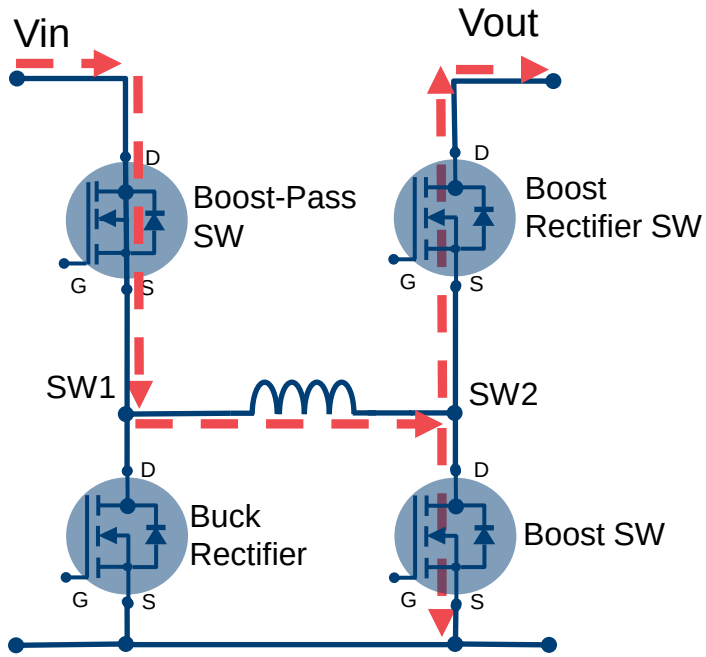




BOOST-MODE

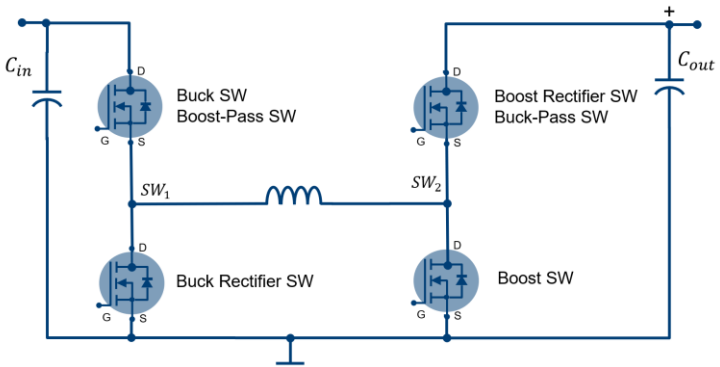
- Condition Vin << Vout
- Switching Pattern like Simple Boost

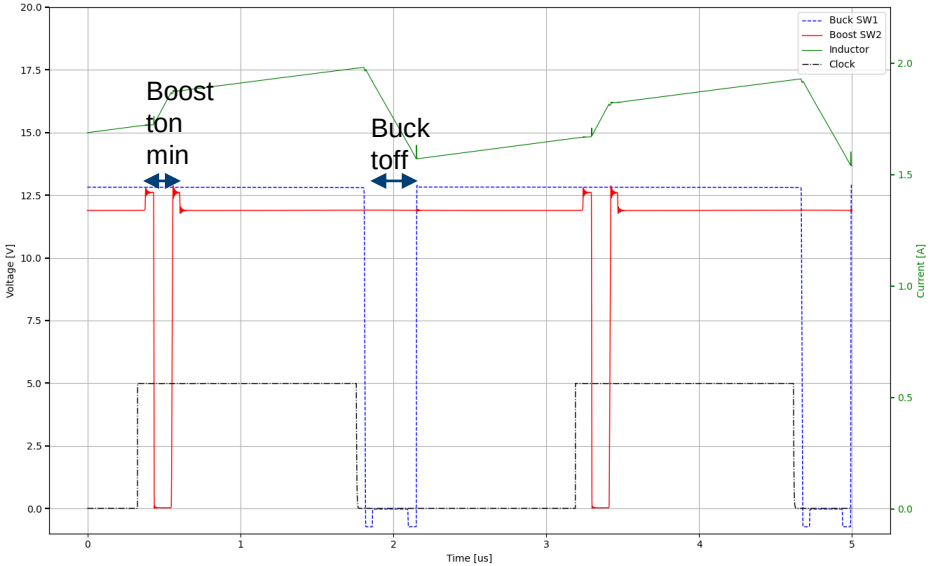




BUCK-BOOST (TRANSITION MODE BUCK)

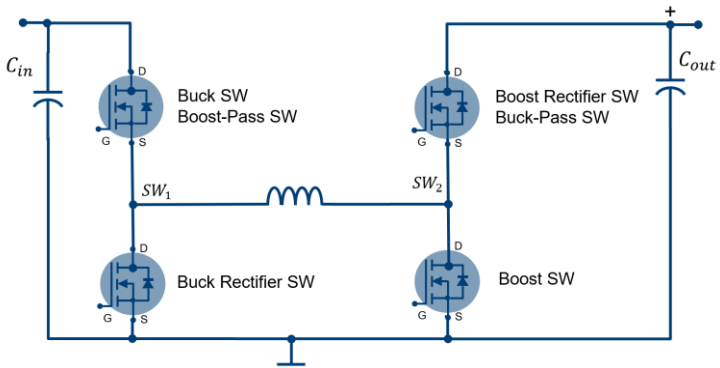
- Transition Mode (Uin >= Uout)
- Alternating Interleaved Buck and Boost Cycles
- Boost On Time Is Fixed At Minimum
- Buck Function Is Active

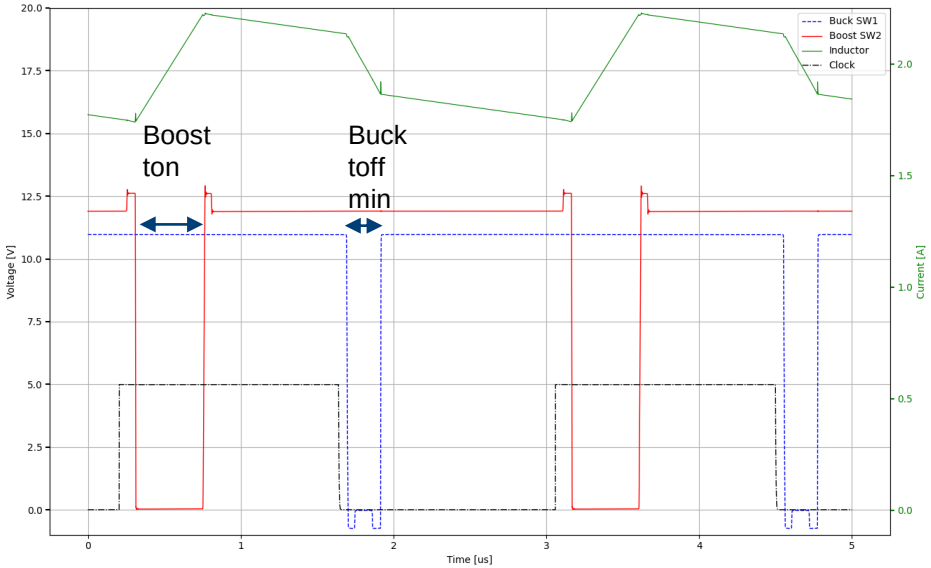




BUCK-BOOST (TRANSITION MODE BOOST)

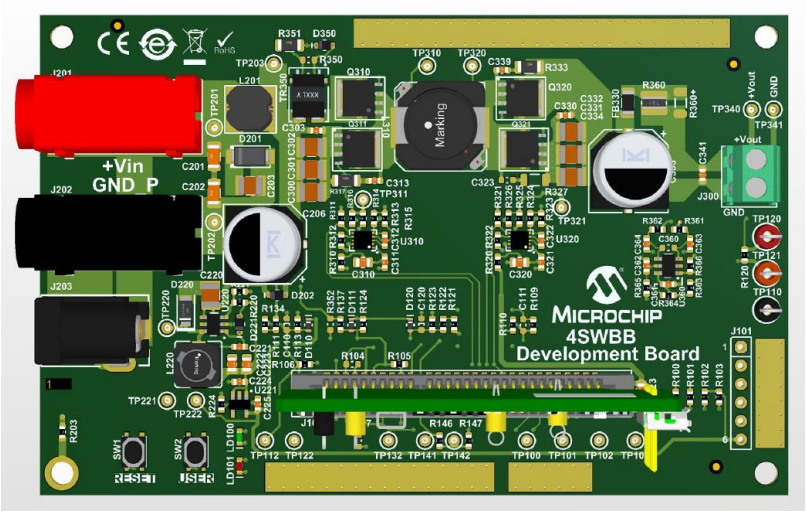
- Transition Mode (Uin <= Uout)
- Alternating Interleaved Buck and Boost Cycles
- Buck Off Time Is Fixed At Minimum
- Boost Function Is Active





4-SWITCH BUCK-BOOST DEVELOPMENT BOARD

- Nominal Operating Input Voltage: 8V<Vin<18V
- Output Power Max: 20W
- Output Current Max: 2A
- Output Voltage Max: 20V
- Typical Output Voltage: 12V
- Efficiency: 90% (Auxiliary Supply, EMI Filter)
- Protection Mechanism:
  - Over Voltage Detection
  - Under Voltage Detection
  - Over Current Detection
  - Etc.

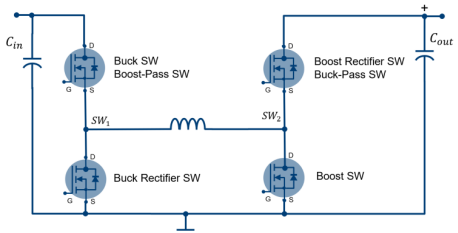


www.microchip.com/en-us/development-tool/ev44m28a

Only Buck-Boost Mode Implemented In Firmware!!!

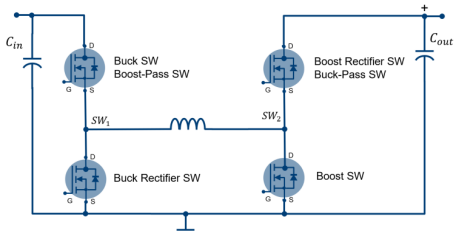
SWITCHING PATTERN VERIFICATION

- Uin ≈ Uout
- Uin > Uout
- Uin < Uout



SWITCHING PATTERN ANOMALY

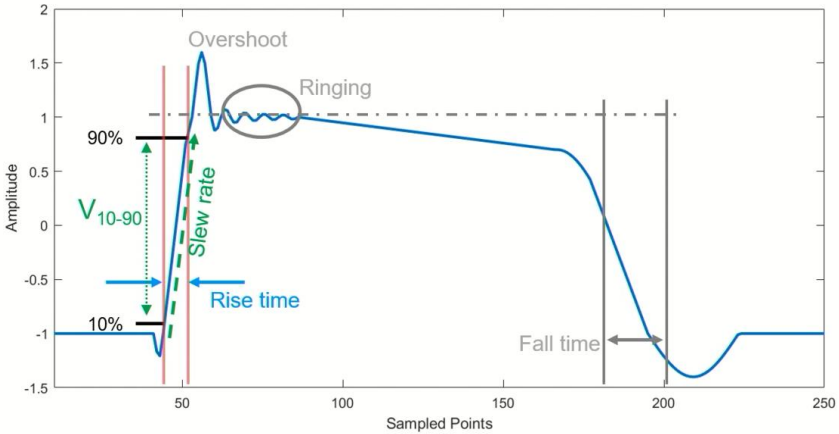
- Uin ≈ Uout
- Boost Rectifier Switch Does Not Switch
- It Happens At Smaller Output Current



PRE-RECORDED VIDEO OF SWITCHING PATTERN

SWITCH NODE ANALYSIS

- 2 x Switch Node (SW1 & SW2)
  - Overshoot
  - Ringing
  - Rise and Fall Time
- 4 x Gate Source Measurements
  - Ringing
  - Gate Level
  - Dead Time

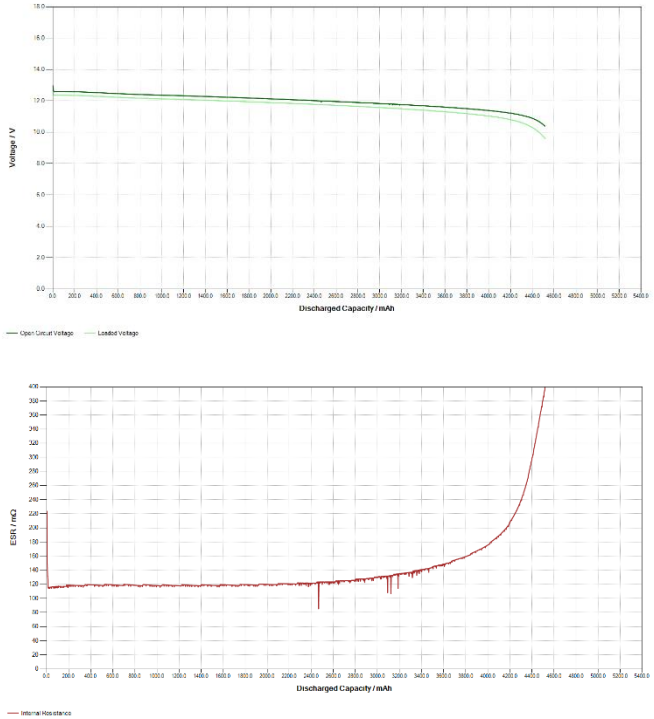


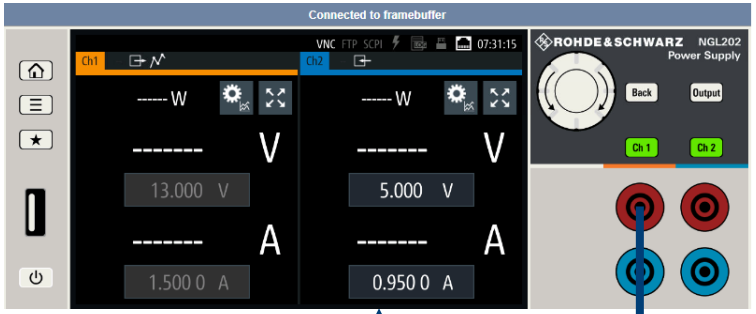
- Correlation to Frequency Domain Can Be Useful

SWITCH NODE MEASUREMENTS

- Over and Undershoot At Switch Nodes
- Rise Time and Fall Time At Switch Nodes
- Switch Node Ringing Measured By Curser
- Dead Time Between Buck & Boost Leg (Gates)

BATTERY MODEL CREATION

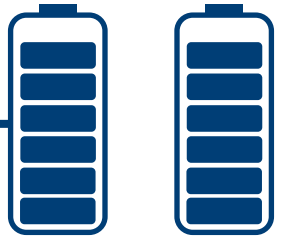




R&S Battery Cycle Tool

LiFe 12V/5Ah

Lead Acid 12V/5Ah



www.rohde-schwarz.com/appnote/1GP130

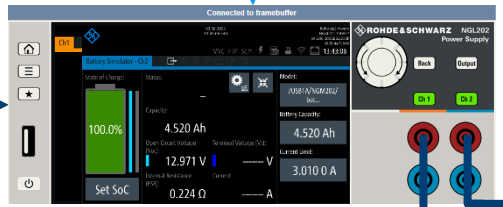
SYSTEM SETUP EXAMPLE

Verification That Output Voltage Is Stable Over The Complete Discharge Cycle

Window Trigger
(11,5V - 12,5V)

Trigger In
(Digital IO)

R&S
Battery
Model



Vin
8V-14V

DUT
(Buck-Boost
Converter)

Vout
12V/1,7A

CONCLUSION

- 4-Switch Buck-Boost Is A Suitable Topology For Battery Applications, Where The Input Voltage Varies And A Bidirectional Flow Is Required

- An Oscilloscope Like the MXO58 Is A Great Tool To Verify The Converter Design Regarding Switching Pattern And Switching Analysis Efficiently

- An Instrument Like the NGM202 Can Create Battey Models And Simulate Batteries Avoiding Any Real Battery → Very Efficient And Reproducible Verification

- The NGM202 Can Be Use As Electronic Load To Program Any Load For The Converter
  - Including The Trigger In/Out Capability, This Enables The User To Verify The System Fully Automatically

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