

Design Considerations for Powering Industrial Non-Isolated 24V Rail Applications

SIMPLE SWITCHER Team

Presented by Denislav Petkov

Applications Engineer

TI, Santa Clara, California

Agenda

- **Discrete Regulator Design**
 - Using WEBENCH for Part Selection
 - Design considerations
 - Selecting inductor, capacitors, and setting Vout
 - Layout example
- **Module Design**
 - Design considerations from module designer perspective
 - External component selection
 - Layout example
 - Hidden advantages of modules
- **TI's Wide V_{IN} DC/DC Step-Down Portfolio for Industry 4.0 Systems**

Discrete Regulator Design

Design Considerations for a Regulator

- Design Inputs
- Switching frequency
- Inductor selection
- Setting output voltage
- Input and output caps
- Layout guidelines

Regulator Design Inputs: 24V to 5V Intermediate Bus

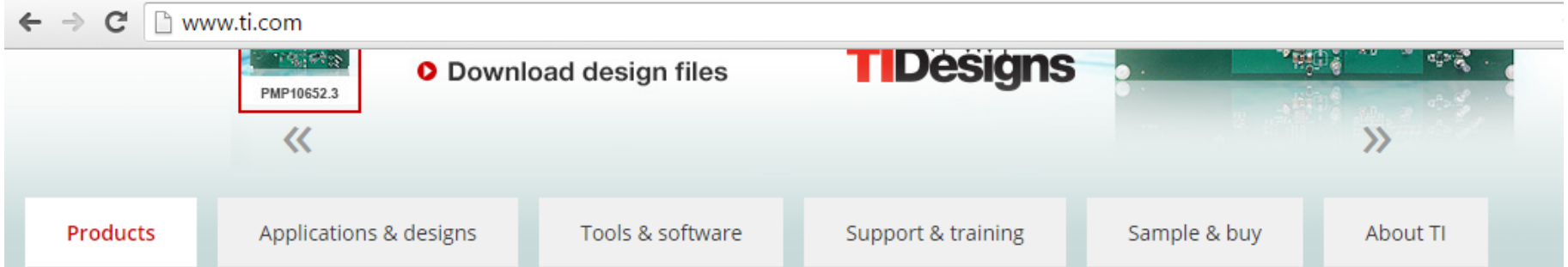
Input Specifications

- Nominal Input Voltage → **24V**
- Input Voltage Range → **18V to 42V**
- Output Voltage → **5V**
- Maximum Load Current → **2A**
- Synchronous Rectification → **Yes**

Desired Features

- Frequency Synchronization pin → **Yes**
- Low BOM count “Ease of Use” → **Yes**
- Small Solution Size → **Yes**

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Parametric selection tool

Find the right part fast!

WEBENCH® Designer *My Designs*

Filters	Sensors	Interface	Reference
Power	FPGA/μP	LED	Clocks

Enter your power supply requirements:

DC AC

Min Max

Vin V V

Vout Iout

Output V A

Ambient Temp °C

Multiple Loads Single Output

Power Architect **Start Design**

Enter Power Requirements

Select Power Supply Solution

The image shows a screenshot of the TI WEBENCH Optimizer interface. At the top, there are sections for 'WEBENCH Optimizer', 'Change Inputs' (with DC and AC radio buttons), and 'Advanced Filters' (with an 'Enable Pin' checkbox and an 'Efficiency' slider set to 79%). A large white box with a black border is overlaid on the center of the screen, containing the text 'Select your power supply solution' in red. Below this text are three columns representing different power supply solutions: 'Module', 'Integrated', and 'Controller'. Each column has an icon, a brief description, and a 'Choose Part' button. The 'Integrated' button is highlighted with a red box, and a red arrow points from a text box below to it. Below the three columns is an 'Or' label and a 'Compare All Part Types' button. At the bottom right of the white box is a 'Do not show this again' checkbox. The background of the screenshot shows various optimization metrics like 'Lowest BOM Cost', 'Smallest Footprint', and 'Most Efficient'.

Select your power supply solution

Module
Easiest to use
Low EMI
[Choose Part](#)

Integrated
Easy to use
Cost effective
[Choose Part](#)

Controller
Maximum flexibility
High performance
[Choose Part](#)

Or

[Compare All Part Types](#)

Do not show this again

For this example click here

Initial Device Selection Filter

WEBENCH® Optimizer

Lowest BOM Cost | Smallest Footprint | Highest Efficiency

Footprint: **302** | BOM Cost: **\$2.85** | Efficiency: **86%**

Recalculate

Change Inputs

DC AC

Vin Min: V Vin Max: V

Vout: V Iout: A

Amb. Temp: °C

Use Advanced Options >>

Recalculate

Advanced Filters

Enable Pin
 Power Good
 Automotive
 Soft Start
 Ext Sync
 Light Load
 Titan

Efficiency (>=):

Footprint (<=):

BOM Cost (<=):

Feature Filters ... Result Filters ... **Clear All**

Solutions																	
Part	Create	WEBENCH® Tools	Schematic	BOM Images	Design Considerations	BOM Footprint (mm2)	BOM Cost (1ku)	Eff (%)	BOM Count	Freq (kHz)	Vout p-p (mV)	Xover Freq (kHz)	Phase Margin (deg)	Topology	LDO	Temp (deg)	Iout Max (A)
LM46002	Open Design			288mm²	SIMPLE SWITCHER Buck Regulator	288	\$3.00	88%	13	500	2.92	36	69	Buck	N	77°C	2.00
LM25011	Open Design			281mm²	COT BUCK regulator with adjustable current limit	281	\$1.75	80%	13	1035	8.98	NA	NA	Buck	N	94°C	2.00
LM25005	Open Design			455mm²	Fast Transient Response	455	\$2.38	83%	14	572	2.56	NA	NA	Buck	N	57°C	2.50
LM25011-Q1	Open Design			281mm²	COT BUCK regulator with adjustable current limit	281	\$2.20	80%	13	1035	8.98	NA	NA	Buck	N	94°C	2.00
TPS54240	Open Design			361mm²	Step Down Converter with Eco-Mode	361	\$2.73	84%	16	384	2.50	29	61	Buck	N	84°C	2.50
TPS54560	Open Design			302mm²	Step Down Converter with Eco-Mode	302	\$3.20	86%	12	420	3.78	22	66	Buck	N	42°C	5.00

Filter results for parts with Ext Sync (frequency sync)

WEBENCH® Optimizer

Lowest BOM Cost
Smallest Footprint
Highest Efficiency

Footprint: **288**
BOM Cost: **\$3.00**
Efficiency: **88%**

Recalculate

Change Inputs

DC AC

Vin Min: 18 V Vin Max: 42 V
Vout: 5 V Iout: 2 A
Amb. Temp: 30 °C

Use Advanced Options >>

Recalculate

Advanced Filters

Enable Pin
 Power Good
 Automotive
 Soft Start
 Ext Sync
 Light Load
 Titan

Efficiency (>=):
 Footprint (<=):
 BOM Cost (<=): \$1 \$20

[Feature Filters ...](#) [Result Filters ...](#) [Clear All](#)

Add more feature filters

Solutions

Search: Solutions: (24 found) Show All Columns Export to: Excel Show Additional Devices

Part	Create	WEBENCH® Tools	Schematic	BOM Images	Design Considerations	BOM Footprint (mm2)	BOM Cost (1ku)	Eff (%)	BOM Count	Freq (kHz)	Vout p-p (mV)	Xover Freq (kHz)	Phase Margin (deg)	Topology	LDO	Temp (deg)	Iout Max (A)
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LM25005	Open Design			455mm ²	Fast Transient Response	455	\$2.38	83%	14	572	2.56	NA	NA	Buck	II	57°C	2.50
TPS54240	Open Design			361mm ²	Step Down Converter with Eco-Mode	361	\$2.73	84%	16	384	2.50	29	61	Buck	II	84°C	2.50
LM25576	Open Design			462mm ²	Fast Transient Response SIMPLE SWITCHER	462	\$2.98	85%	14	572	3.13	NA	NA	Buck	II	47°C	3.00
TPS54260	Open Design			361mm ²	Step Down Converter with Eco-Mode	361	\$3.10	84%	16	402	2.30	30	60	Buck	II	86°C	2.50
LM5005	Open Design			440mm ²	Fast Transient Response	440	\$3.03	84%	15	299	2.74	NA	NA	Buck	II	53°C	2.50

Filter results for parts with synchronous rectification

Synchronous rectification

WEBENCH® Optimizer

Lowest BOM Cost

Change Inputs

DC AC

Vin Min: 18 V Vin Max: 42 V

Output: 2 A

Temp: 30 °C

Use Advanced Options >>

Footprint: 288 BOM Cost: \$3.00 Efficiency: 88%

Recalculate

Feature Filters

IC Features

- Enable Pin
- Power Good
- Automotive
- Soft Start
- Ext Sync
- Light Load
- Sync Switch
- Adj. Curr Lim

Reg. Type

- Controller
- Integrated Switch
- LDO
- Module
- Simple Switcher®
- SWIFT™

Control Mode

- Constant On Time
- Emulated Current Mode
- Peak Current Mode
- Valley Current Mode
- Voltage Mode

WEBENCH® Tools

- Simulation
- WebTherm
- CAD Export
- TINA-TI Sim Export
- Altium Sim Export
- OrCAD Sim Export

Topology

- Buck

IC Package

All

Clear Less <<

>> Switch to Result Filters

Solutions

Search Solutions: (3 found) Show All Columns Export to: Excel Show Additional Devices

Part	Create	WEBENCH® Tools	Schematic	BOM Images	Design Considerations	BOM Footprint (mm2)	BOM Cost (1ku)	Eff (%)	BOM Count	Freq (kHz)	Vout p-p (mV)	Xover Freq (kHz)	Phase Margin (deg)	Topology	LDO	Temp (deg)	Iout Max (A)
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LM46002-Q1	Open Design			288mm ²	SIMPLE SWITCHER Buck Regulator	288	\$3.33	88%	13	500	2.92	36	69	Buck	N	77°C	2.00
LMZ36002	Open Design			196mm ²	SIMPLE SWITCHER Buck Module	196	\$8.87	81%	6	500	3.72	9	64	Buck	N	62°C	2.00

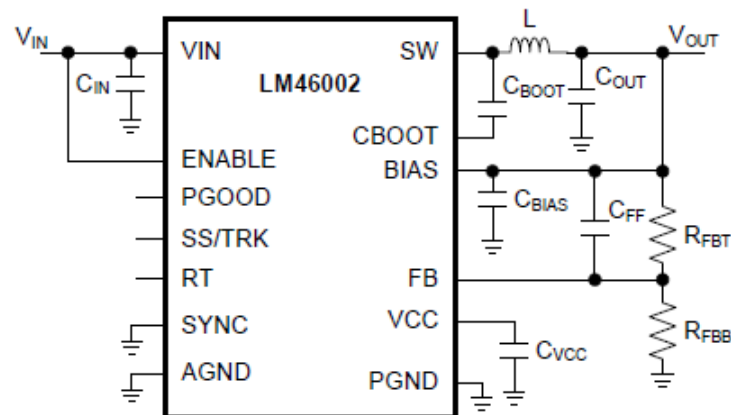
LM46002 SIMPLE SWITCHER® 3.5 V to 60 V 2 A Synchronous Step-Down Voltage Converter

1 Features

- 27 μ A Quiescent Current in Regulation
- High Efficiency at Light Load (DCM and PFM)
- Meets EN55022/CISPR 22 EMI standards
- Integrated Synchronous Rectification
- Adjustable Frequency Range: 200 kHz to 2.2 MHz (500 kHz default)
- Frequency Synchronization to External Clock
- Internal Compensation
- Stable with Almost Any Combination of Ceramic, Polymer, Tantalum, and Aluminum Capacitors
- Power-Good Flag
- Soft-Start into Pre-Biased Load
- Internal Soft-Start: 4.1 ms
- Extendable Soft-Start Time by External Capacitor
- Output Voltage Tracking Capability
- Precision Enable to Program System UVLO
- Output Short Circuit Protection with Hiccup Mode
- Over Temperature Thermal Shutdown Protection

2 Applications

- Industrial Power Supplies
- Telecommunications Systems
- Sub-AM Band Automotive
- Commercial Vehicle Power Supplies
- General Purpose Wide V_{IN} Regulation
- High Efficiency Point-Of-Load Regulation



Switching Frequency Selection

- **Size of Inductor**

- Higher frequency allows for a smaller inductor, both electrically and physically.

$$L \propto \frac{1}{F_S}$$

← Switching Frequency

$$L \propto N^2$$

← Number of Turns of Wire

- Higher frequency → Smaller L → Smaller N → Smaller package size

- **Efficiency**

- Higher switching frequency generates more power loss in regulator and the inductor; this reduces efficiency.

$$\text{Loss in regulator} \propto F_S \cdot T_t \cdot V_{IN} \cdot I_{LOAD}$$

← Switching Frequency

- Higher frequency → Increased Loss → Reduced Efficiency

Switching Frequency Selection

- **EMI**

- Some customers require that no harmonics of the DC/DC converter fall in the AM radio band.
 - Example: 530kHz to 1.7MHz
- Some systems require that the switching frequency be locked to a system clock.
 - Use a regulator with a synchronizing capability

LM46002 Switching Frequency Selection

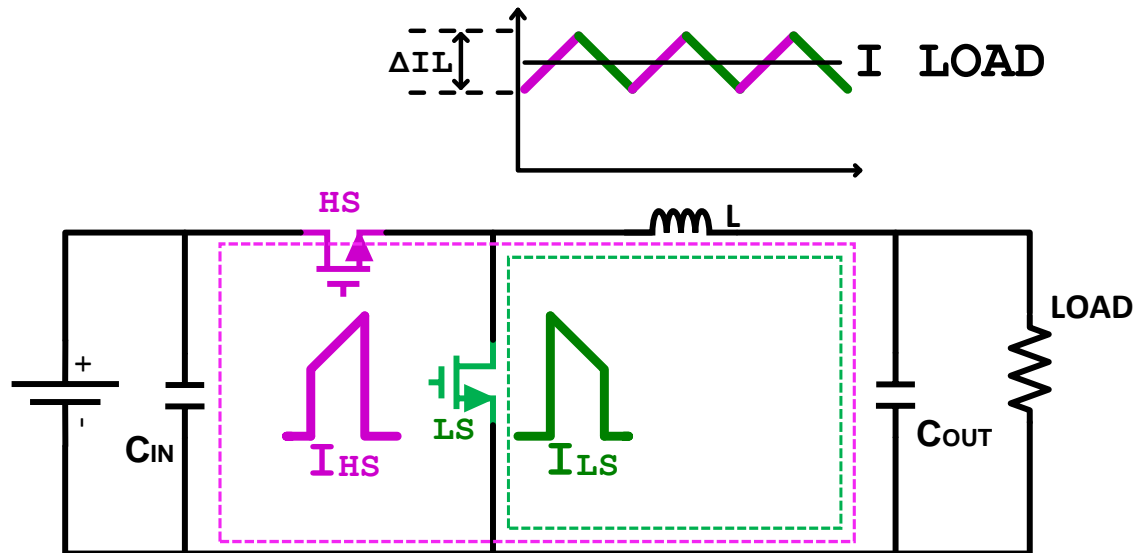
- **LM46002 is optimized for a switching frequency of 500kHz**
 - Can be adjusted with one resistor to tailor the regulator to the customer's requirements.
 - Can be synchronized to an external clock or to another DC/DC converter to reduce noise.
- **500 kHz will be used in this example**

Inductor Selection

- Inductor selection is one of the most important aspects of the DC-DC converter design.
 - Inductor characteristics
 - Inductance value
 - Affects size, ripple, transient response, peak current, efficiency
 - Winding resistance
 - Affects size, ripple, dropout, efficiency
 - Core material
 - Affects size, core power losses
 - Saturation current
 - Affects size, peak current, overload protection
 - Shielding
 - Affects EMI performance



Inductor Selection



• Electrical value of inductor

- Determines ripple current
 - Smaller inductor \rightarrow Large ripple current \rightarrow increased power loss
- Impacts maximum load current
 - Large ripple current \rightarrow large peak current \rightarrow need higher HS current limit to support load
- Impacts load transient response
 - Small inductance \rightarrow faster current response \rightarrow smaller output voltage transient

Inductor Selection

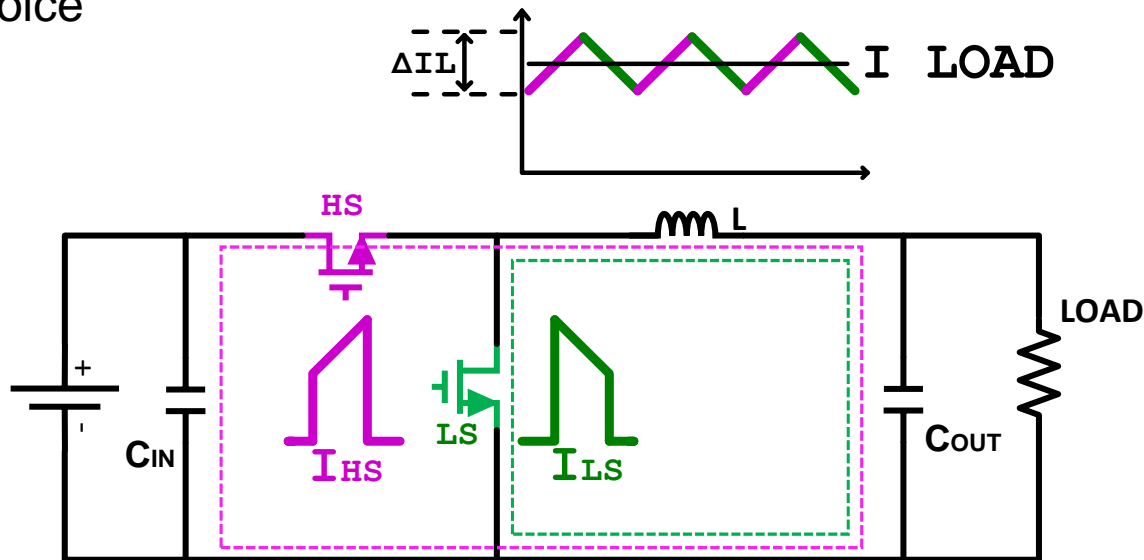
- **Electrical value of inductor (cont.)**

- Impacts physical size

- Larger inductance → more turns on winding → larger package → higher winding resistance

- **Select inductor ripple current**

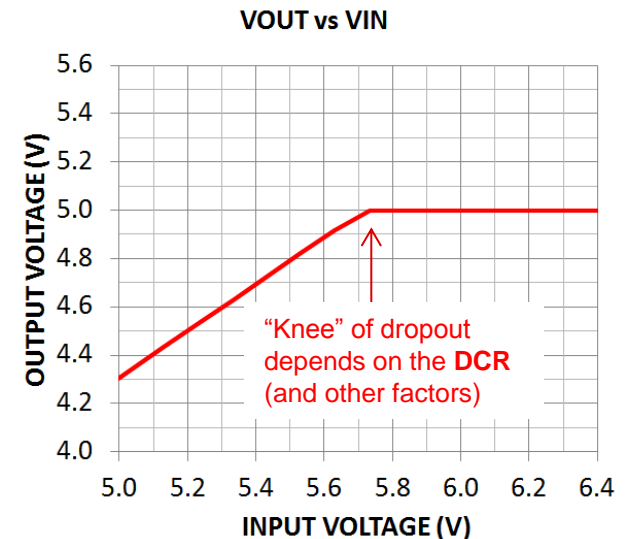
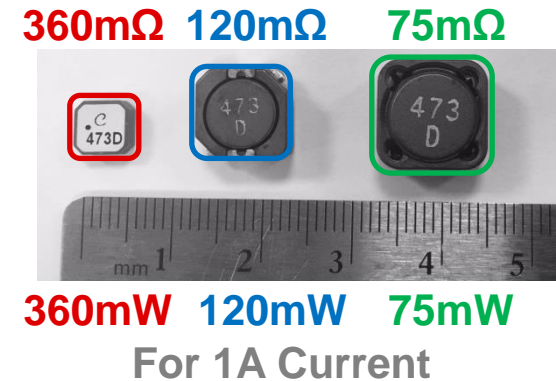
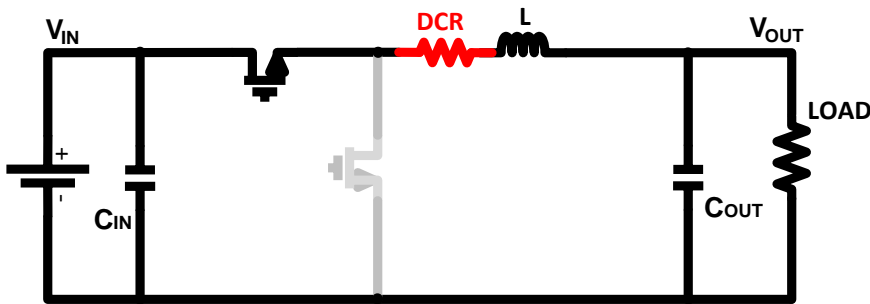
- ~30% of maximum load current is good compromise for the ripple current choice



Inductor Selection

- **Winding resistance**

- Resistance causes power loss ($I^2 \cdot R$)
 - Small resistance \rightarrow less loss \rightarrow larger wire \rightarrow larger package
- Impacts PCB temperature
 - Increased loss \rightarrow more heat to dissipate \rightarrow higher PCB temperature
- Affects regulator drop-out performance
 - Resistance causes voltage drops between input and output
 - Larger resistance \rightarrow more headroom between input and output needed for regulation.



Inductor Selection

- **Core Material**

- Ferrite core

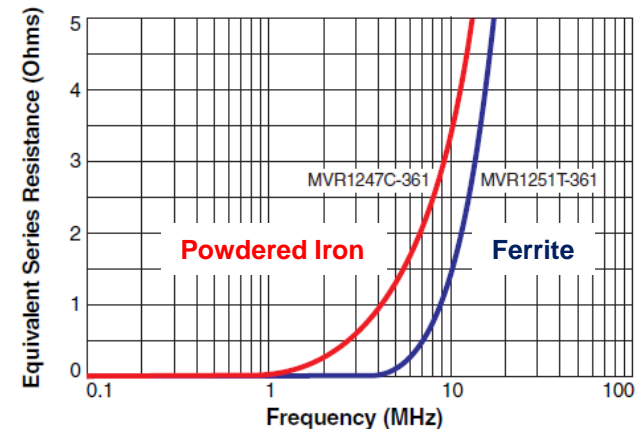
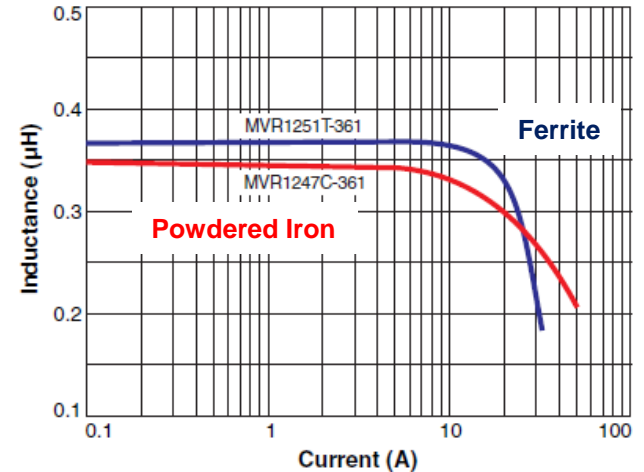
- Air gap causes “hard” saturation
 - Inductance falls very quickly with current, once the saturation value is reached

- Small A.C. core loss at >1MHz

- Powdered iron core

- Air gap is “distributed”; saturation is “soft”
 - Inductance falls slowly with current, once saturation value is reached
 - » More tolerant of overloads

- Large A.C. core loss at >1MHz



Inductor Selection

- **Saturation current**

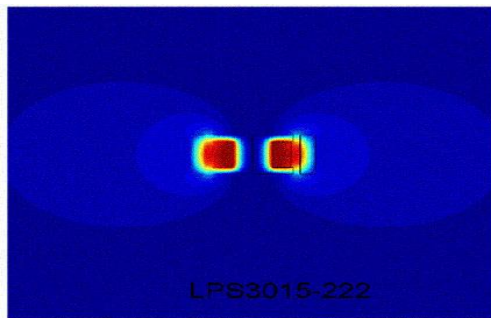
- Maximum current before inductance drops dramatically
 - Core saturation → air core inductor → very small inductance
- Very small inductance can damage regulator and other components
 - Small inductance means high current slew rate
 - Protection circuits may not respond fast enough to protect the system
- Select inductor saturation current based on regulator current limit
- For a “hard” saturating inductor
 - Select a saturation current \geq maximum regulator current limit
- For a “soft” saturating inductor
 - Select a saturation current \geq typical regulator current limit
- Impacts physical size
 - Higher current → larger wire in winding → larger package

- **Avoid inductor saturation**

Inductor Selection

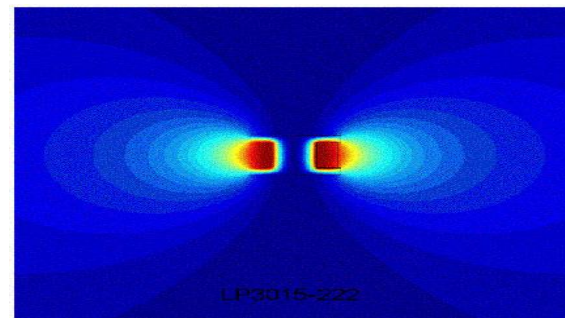
Shielded Inductor

- Helps to reduce EMI
 - Reduced external magnetic field
- More core material used for shield
 - More A.C. core loss
 - More expensive
 - Physically larger



Un-shielded Inductor

- Large external magnetic field
 - May be issue for some systems
- Minimum amount of core material needed
 - Less A.C. core loss
 - Less expensive
 - Physically smaller



Inductor Selection w/ LM46002

- Application Inputs

- $F_s = 500\text{kHz}$
- $V_{IN} = 42\text{V}$
- $V_{OUT} = 5\text{V}$
- $I_{LOAD} = 2\text{A}$
- Ripple current = $\Delta I = 0.3 \cdot 2\text{A} = 0.6\text{A}$

- Inductor value

$$L = \frac{(V_{IN} - V_{OUT})}{\Delta I \cdot F_s} \cdot \frac{V_{OUT}}{V_{IN}} = \frac{(42 - 5)}{0.6 \cdot 500e^3} \cdot \frac{5}{42} = 14.7\mu\text{H}$$

- Use the next closest standard value → **15 μH**

Inductor Selection w/ LM46002 (cont.)

- Check currents over full input voltage range at full load

Input Voltage	Ripple Current	Valley Current	Peak Current
18V	0.48A	1.76A	2.24A
24V	0.53A	1.74A	2.26A
42V	0.59A	1.71A	2.29A

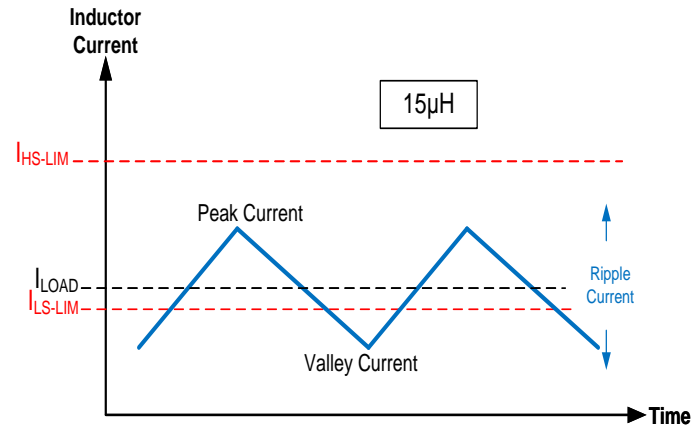
$$\Delta I = \frac{(V_{IN} - V_{OUT})}{L \cdot F_S} \cdot \frac{V_{OUT}}{V_{IN}}$$

$$I_{VALLEY} = I_{LOAD} - \frac{\Delta I}{2}$$

$$I_{PEAK} = I_{LOAD} + \frac{\Delta I}{2}$$

Inductor Selection w/ LM46002 (cont.)

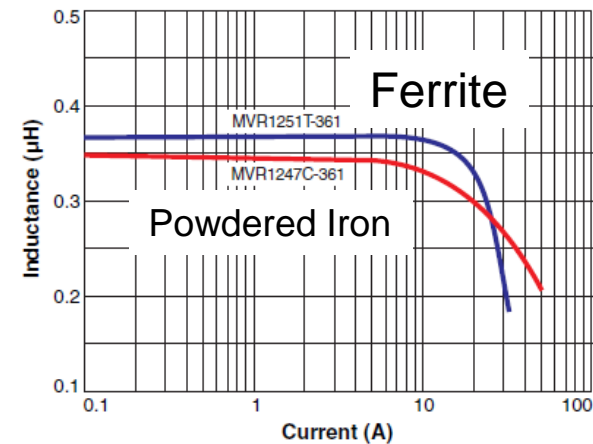
- The peak and valley current should be checked against the IC current limit specs. The LM46002 provides both peak and valley current limit protection



- The maximum peak inductor current must be less than the minimum specified high-side current limit of the LM46002
 - From data sheet → $I_{HS-LIMIT} = 3.6A$ (min)
 - Peak current in application → **2.29A** (max) ✓
- The maximum valley inductor current must be less than the minimum specified low-side current limit of the LM46002
 - From data sheet → $I_{LS-LIMIT} = 1.8A$ (min)
 - Valley current in application → **1.76A** (max) ✓

Inductor Selection w/ LM46002 (cont.)

- The inductor current rating selection depends on its saturation characteristics
 - A “hard” saturating ferrite inductor should be rated for the maximum peak current limit
 - A “soft” saturating powdered iron inductor can be rated for the typical peak current limit, or somewhat less.
- For a ferrite inductor select an conservative current rating
 - From LM46002 data sheet → $I_{HS-LIMIT} = 5A$ (max)
 - Use inductor with **5A** saturation current
- For a powdered iron inductor the current rating can be smaller
 - Inductance will not fall much when saturation current is reached
 - Use inductor with **3A** saturation current



Setting output voltage of LM46002

- From Webench Design Tool

- Feedback divider

- $R_{FBT} = 1M\Omega$
- $V_{FB} = 1.011V$

$$R_{FBB} = \frac{V_{FB}}{V_{OUT} - V_{FB}} \cdot R_{FBT} = \frac{1.011}{5 - 1.011} \cdot 1M\Omega = 253k \Rightarrow R_{FBB} = 255k$$

- Feed-forward Capacitor

- Can improve load transients and phase margin
- Easily tailored by customer
 - $C_{FF} = 27pF$

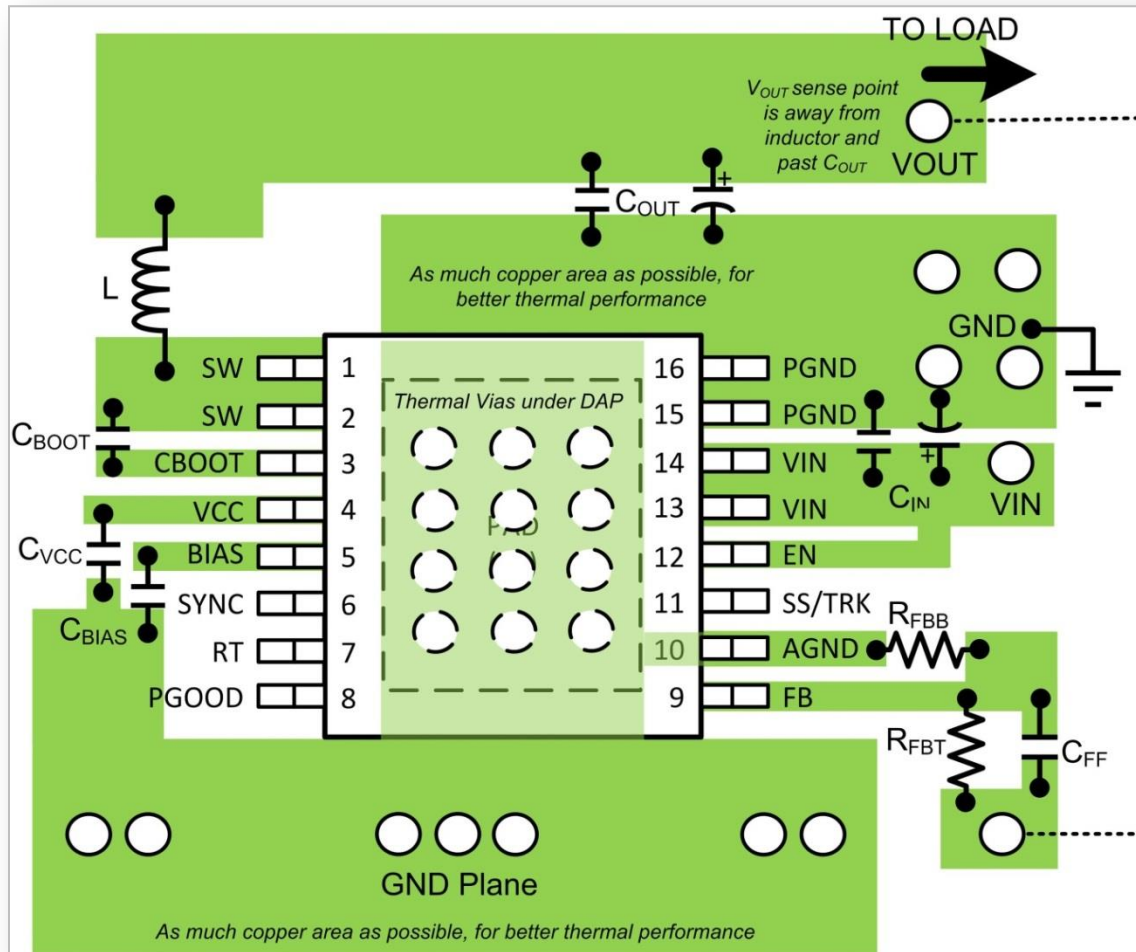
Input and Output Capacitors w/ LM46002

- From Webench Design Tool
 - Input Capacitor(s)
 - Supply pulse currents to regulator
 - Ensure low impedance input for control circuits
 - **$C_{IN} = 1 \times 1\mu F$ and $1 \times 4.7\mu F$, Ceramic**
 - Output Capacitor(s)
 - Value based on:
 - Output voltage ripple (depends on inductor current ripple)
 - Load transient response
 - **$C_{OUT} = 3 \times 22\mu F$, Ceramic**

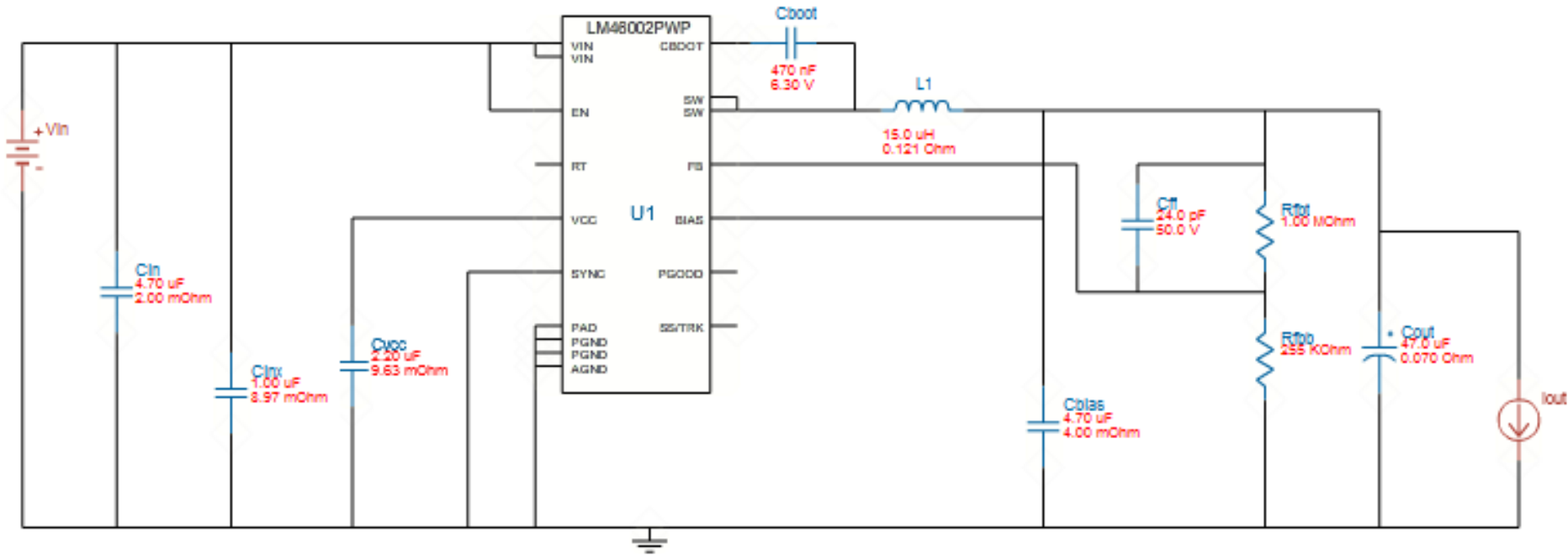
PCB Layout for example for LM46002 (regulator)

Minimum Best Practices for IC Layout

- ✓ Place C_{IN} very close to LM46002 input and ground pin. Grounding for both input/output caps should consist of localized top side planes that connect to the ground pins and PAD
- ✓ Make VIN and ground connections as wide as possible
- ✓ Both feedback resistors should be located close to the FB pin
- ✓ Use a ground plane in one of the middle layers as noise shielding and heat dissipation path. Have a single point ground connection to the plane.



Application Schematic in WEBENCH



The schematic (and layout!) can be exported to your favorite CAD tool!

Module Design

Supplier Considerations for Creating a Module

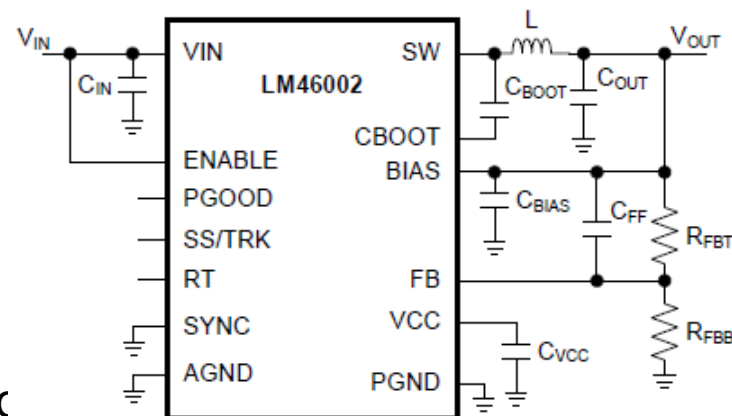
- Design inputs
- Silicon selection
- Package selection
- Internal component selection
 - Inductor
 - Stability components
 - Programming components
- Setting safe operating limits: electrical & thermal specifications
- External component considerations

Design Inputs

- Support wide input range: 4.5V to 60V
 - Nominal Input Voltage → 24V
 - Input Voltage Range → 18V to 42V
 - Output Voltage → 5V
- Support common output voltages: 2.5V, 3.3V, 5V
- Support output current up to 2A
- Small solution size
- Low EMI (Meet CISPR22 Class B Radiated EMI)
- Provide pin for synchronizing to external frequency
- Low BOM count
- Operate over industrial temperature range (-40C to 105C Ambient)

Silicon Selection

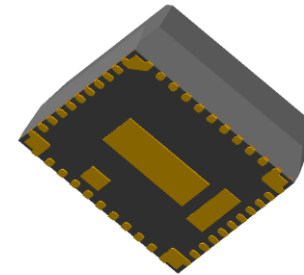
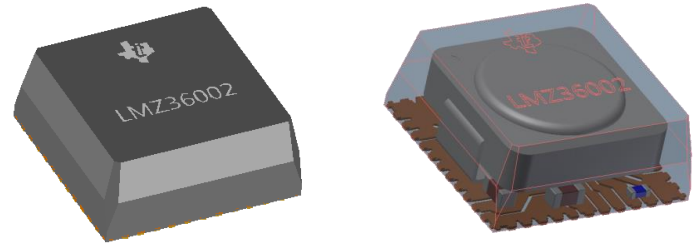
- Selected LM46002 to meet design inputs (surprise!)
 - V_{IN} range **3.5V-60V**
 - V_{OUT} Range **1.0V to 28V**
 - **Synchronous** Peak Current Mode architecture
 - Output current: **2A**
 - Precision Enable
 - Default frequency of 500kHz, Adjustable f_{s} Synchronize from **200kHz – 2.2MHz**
 - Power Good output
 - **Internal Compensation**
 - Operating Junction Temperature: **-40 to 125C**



Package Selection

Selected BQFN 3D Packaging

- **Better Thermal Efficiency in 40% Smaller Package**
 - 12-13°C/W (BQFN) vs 15.4-24.4°C/W (LGA)
 - Yields up to 50% longer life
- **Access to Signal Pins**
 - Pins on Outside
 - Easy to route Signals, Vias, Power
 - Easy to inspect solder joints
- **High Temp Reflow**
 - BQFN capability for 260°C
 - LGA / BGA <250°C otherwise internal solder can melt and spread thru delaminated areas



Module Internal Component Selection

- Inductor
 - Single value must cover
 - Input Voltage Range
 - Output Voltage Range
 - Entire Frequency Range
 - Current capability
 - Heating rating
 - Saturation current rating
- Compensation components
 - Stability
 - Transient response
- Integrated Programming Components
 - Bypass caps
 - Compensation
 - Features (soft-start, power good)

Internal Inductor Selection

$$V_{IN} = 60V, F_S = 500 \text{ kHz} \quad L = \frac{(V_{IN} - V_{OUT})}{\Delta I \cdot F_S} \cdot \frac{V_{OUT}}{V_{IN}} = \frac{(60-5)}{0.6 \cdot 500e^3} \cdot \frac{5}{60} = 15.3 \mu H$$

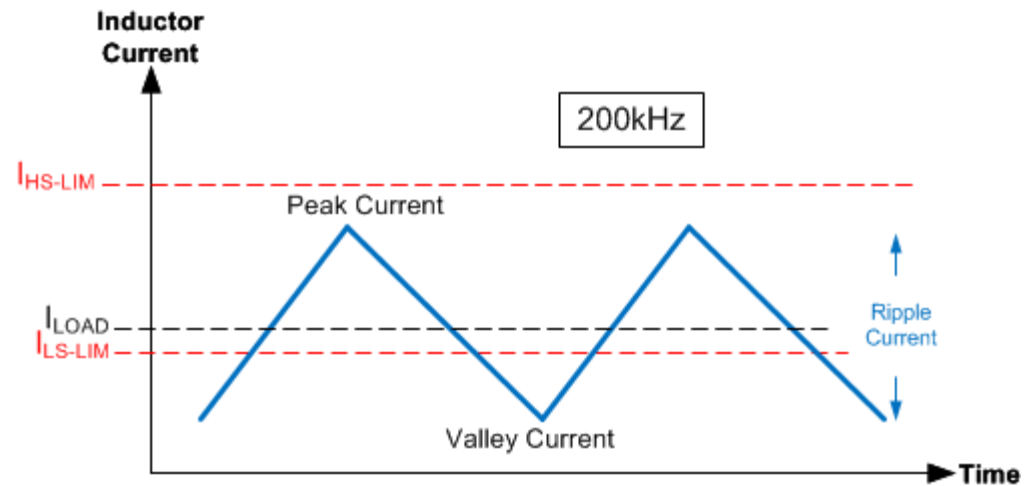
$$V_{IN} = 60V, F_S = 1 \text{ MHz} \quad L = \frac{(V_{IN} - V_{OUT})}{\Delta I \cdot F_S} \cdot \frac{V_{OUT}}{V_{IN}} = \frac{(60-5)}{0.6 \cdot 1000e^3} \cdot \frac{5}{60} = 7.6 \mu H$$

$$V_{IN} = 12V, F_S = 500 \text{ kHz} \quad L = \frac{(V_{IN} - V_{OUT})}{\Delta I \cdot F_S} \cdot \frac{V_{OUT}}{V_{IN}} = \frac{(12-5)}{0.6 \cdot 500e^3} \cdot \frac{5}{12} = 9.7 \mu H$$

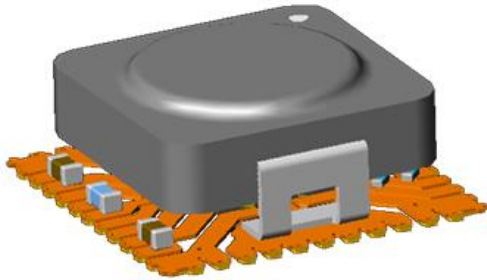
$$V_{IN} = 12V, F_S = 1 \text{ MHz} \quad L = \frac{(V_{IN} - V_{OUT})}{\Delta I \cdot F_S} \cdot \frac{V_{OUT}}{V_{IN}} = \frac{(12-5)}{0.6 \cdot 1000e^3} \cdot \frac{5}{12} = 4.9 \mu H$$

Inductance Selected: 10 μH

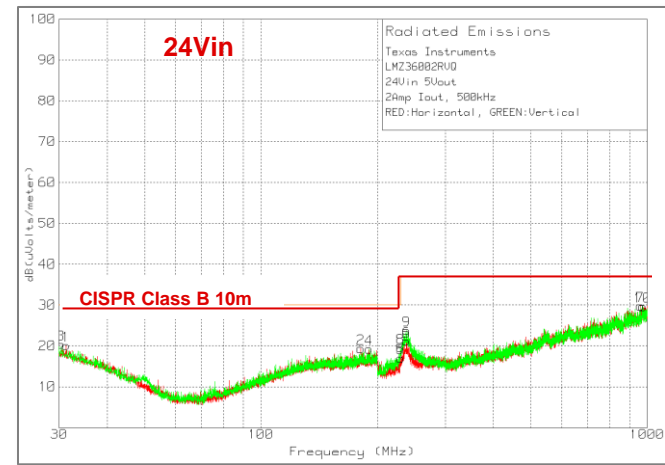
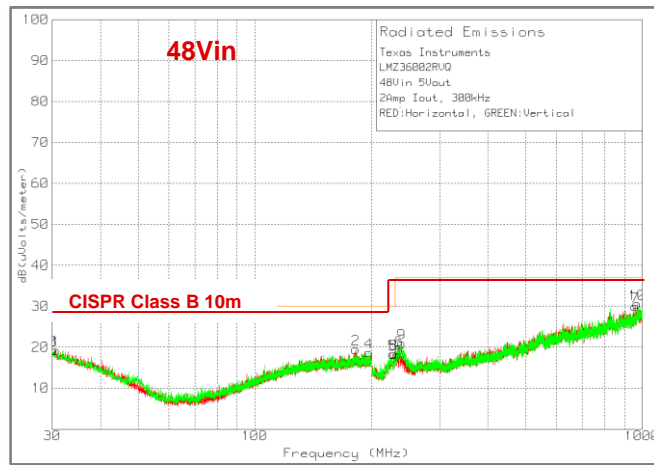
Fixed Inductance and Frequency Range



Integrated 10uH Shielded Inductor



- 10uH selected for best balance of performance over V_{IN} , V_{OUT} , and F_{SW} range
- Meets CISPR 22 Class B Radiated EMI
- Powdered iron for soft saturation



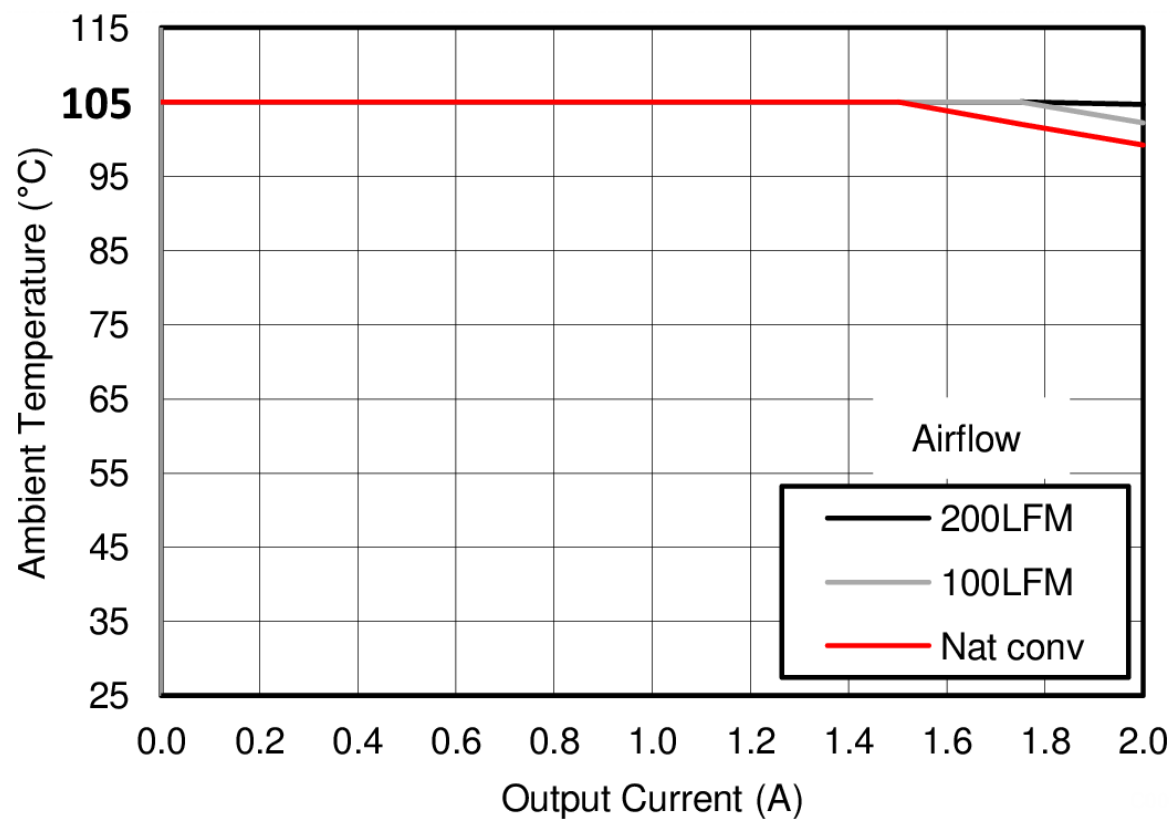
Setting Safe Design Limits

- V_{IN} , V_{OUT} , F_S Constraints
 - HS current limit
 - LS current limit
 - Slope compensation
 - Minimum T_{on}
 - Minimum T_{off}

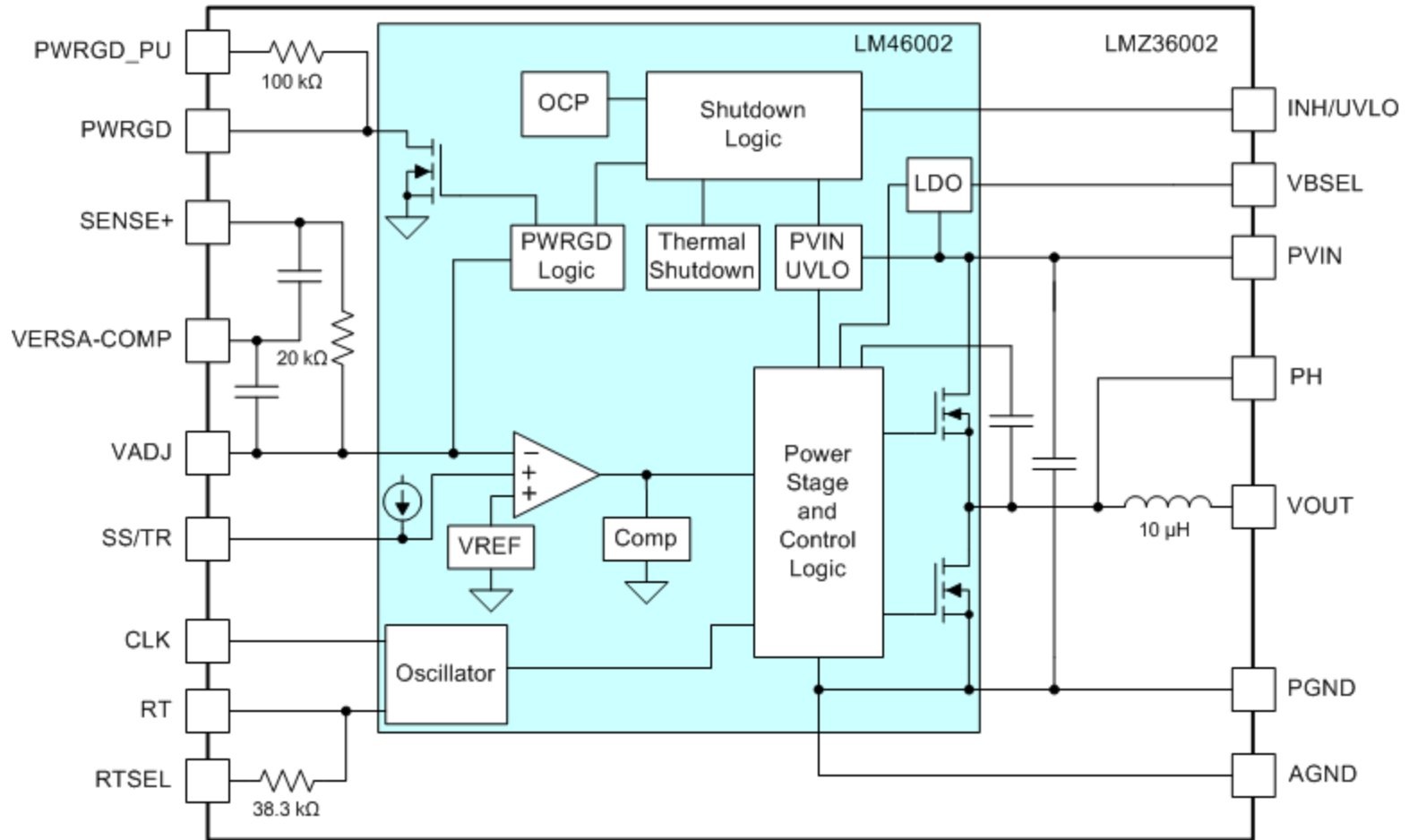
VOUT Range (V)	Switching Frequency Range (kHz)							
	PVIN = 12V		PVIN = 24V		PVIN = 36V		PVIN = 48V	
	Min	Max	Min	Max	Min	Max	Min	Max
2.5 - 3.5V	200	1000	200	600	200	400	200	300
>3.5V - 4.5V	200	1000	200	850	200	550	200	400
>4.5V - 5.5V	200	1000	200	1000	200	750	200	550
>5.5V - 6.5V	300	1000	200	1000	200	1000	200	630
>6.5V - 7.5V	300	900	300	1000	300	950	300	800

Thermal Safe Operating Area

- Thermal Performance
 - Based on V_{IN} , V_{OUT} , Airflow

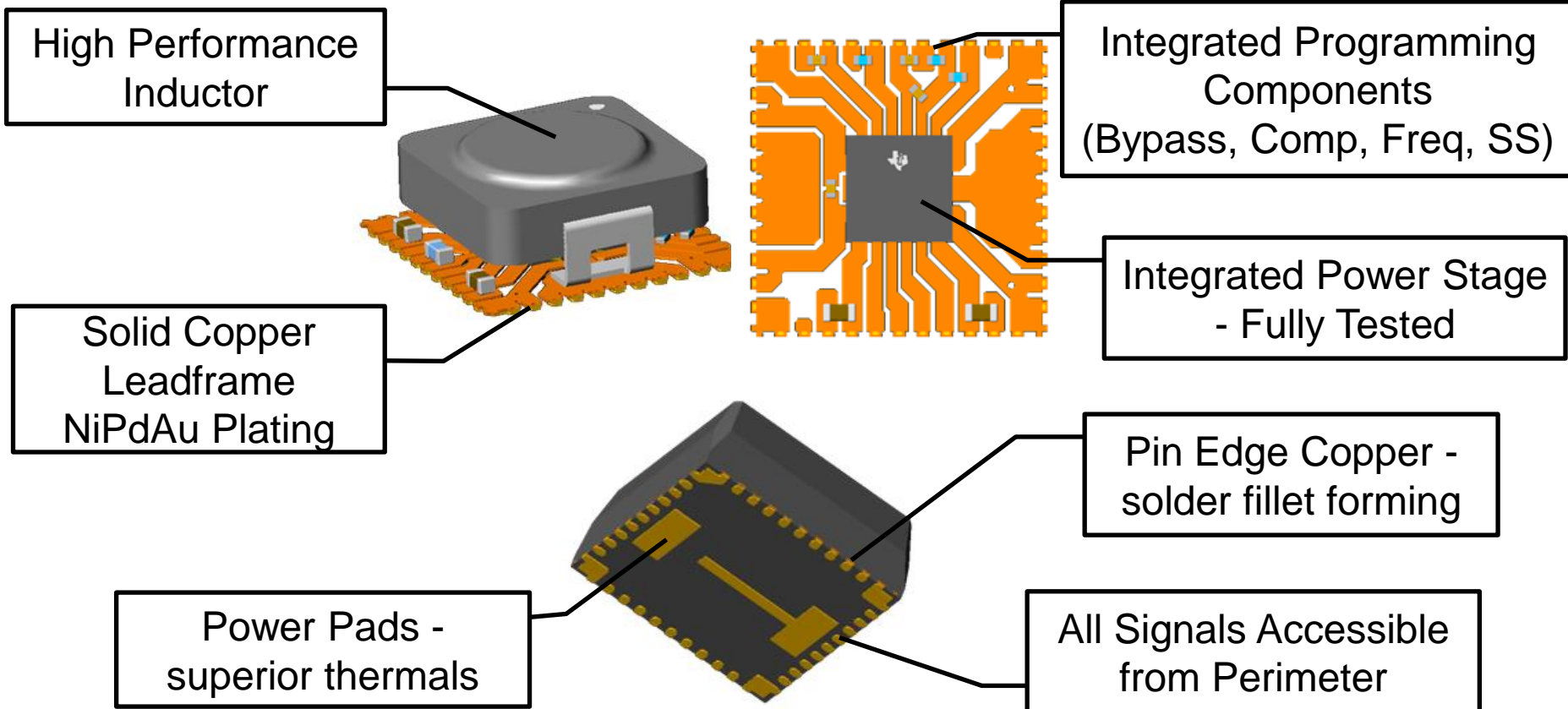


LMZ36002 Block Diagram



LMZ36002 Internal Tour

Thermally Enhanced Components on Copper Leadframe =
Low Temperature, Long Life Power Solution

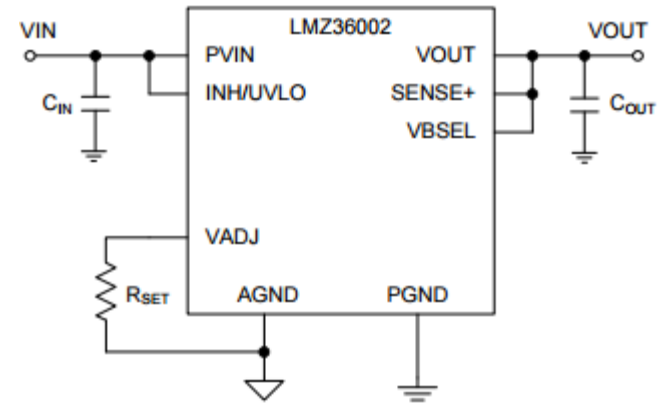


SIMPLE SWITCHER 4.5-V to 60-V Input, 2-A Power Module

1 Features

- ✓ Complete Integrated Power Solution Allows Small Footprint, Low-Profile Design
- 10 mm × 10 mm × 4.3 mm Package
- ✓ Wide-Output Voltage Adjust (2.5 V to 7.5 V)
- Adjustable Switching Frequency (200 kHz to 1 MHz)
- ✓ Synchronizes to an External Clock
- Automatic PFM Mode for Light Load Efficiency
- Adjustable Slow-start
- Output Voltage Sequencing / Tracking
- Power Good Output
- Programmable Undervoltage Lockout (UVLO)
- Over-Temperature Thermal Shutdown Protection
- Over-Current Protection (Hiccup Mode)
- Pre-Bias Output Start-Up
- Operating Temperature Range: -40°C to 105°C
- Enhanced Thermal Performance: 14°C/W
- Meets EN55022 Class B Emissions – Integrated Shielded Inductor

Simplified Schematic



External Component Considerations

- Inductor

Inductor Selection

- Inductor selection is one of the most important aspects of the DC-DC converter design.
- Inductor characteristics
 - Inductance value
 - Affects size, ripple, transient response, peak current, efficiency
 - Winding resistance
 - Affects size, ripple, dropout, efficiency
 - Core material
 - Affects size, core power losses
 - Saturation current
 - Affects size, peak current, overload protection
 - Shielding
 - Affects EMI performance



Inductor Selection

- Electrical value of inductor
 - Determines ripple current
 - Large ripple current → smaller inductor → increased power loss
 - Impacts load transient response
 - Small inductance → faster current response → smaller output voltage transient
 - Impacts maximum load current
 - Large ripple current → large peak current → need larger current limit to support load

Inductor Selection

- Electrical value of inductor (cont.)
 - Impacts physical size
 - more turns on winding → larger package
 - Larger inductance → more turns on winding → larger package
 - Select inductor ripple current
 - 30% of maximum load current is good compromise

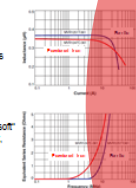
Inductor Selection

- Winding resistance
 - Resistance causes power loss (I²R)
 - Small resistance → less loss → larger wire → larger package
 - Impacts PCB temperature
 - Increased loss → more heat → decreases → higher PCB temperature
 - Affects regulator dropout performance
 - Resistance causes voltage drops between input and output
 - Large resistance → more reaction between input and output needed for regulation



Inductor Selection

- Core Material
 - Ferrite core
 - Air gap causes "hard" saturation
 - Inductance falls very quickly with current, once the saturation value is reached
 - Small A.C. core loss at >1MHz
- Powdered iron core
 - Air gap is "distributed", saturation is "soft"
 - Inductance falls slowly with current, once saturation value is reached
 - More tolerant of overloads
 - Large A.C. core loss at >1MHz



Inductor Selection

- saturation current
 - Inductors with ferrite cores have a limited ability to support direct current (DC)
 - In buck regulator inductor current consists of DC load current and ripple current
 - Core air used in some inductor cores to support D.C. load current
 - Inductor saturation current
 - Maximum current before inductance drops dramatically
 - Core saturation = air core inductor → very small inductance
 - Very small inductance can damage regulator and other components
 - Small inductance means high current slew rate
 - Protection circuitry may not respond fast enough to protect the system

Inductor Selection

- Saturation current (cont.)
 - Select inductor saturation current based on regulator current limit
 - For a "hard" saturating inductor
 - Select a saturation current > maximum regulator current limit
 - For a "soft" saturating inductor
 - Select a saturation current ≈ typical regulator current limit
 - Impacts physical size
 - Higher current → larger wire in winding → larger package
- Avoid inductor saturation

Inductor Selection

- Shielded Inductor
 - Helps to reduce EMI
 - Reduces external magnetic field
 - May be issue for some systems
 - More core material used for shield
 - More A.C. core loss
 - More expensive
 - Physically larger
- Un-shielded Inductor
 - Large external magnetic field
 - May be issue for some systems
 - Minimum amount of core material needed
 - Less A.C. core loss
 - Less expensive
 - Physically smaller

Inductor Selection w/ LM46002

- Application inputs
 - F_s = 500kHz
 - V_{IN} = 42V
 - V_{OUT} = 5V
 - I_{LOAD} = 2A
 - Ripple current = ΔI = 0.3-2A = 0.6A
- Inductor value
 - $$L = \frac{(V_{IN} - V_{OUT}) \cdot V_{OUT}}{\Delta I \cdot f_s} = \frac{(42 - 5) \cdot 5}{0.6 \cdot 500 \cdot 10^3} = 14.7 \mu\text{H}$$
 - Use the next closest standard value → 15μH

Inductor Selection w/ LM46002 (cont.)

- Check currents over full input voltage range at full load

Input Voltage	Ripple Current	Valley Current	Peak Current
18V	0.45A	1.76A	2.24A
24V	0.53A	1.74A	2.26A
42V	0.59A	1.71A	2.29A

 - $$\Delta I = \frac{(V_{IN} - V_{OUT}) \cdot V_{OUT}}{L \cdot f_s}$$
 - $$I_{VALLEY} = I_{LOAD} - \frac{\Delta I}{2}$$
 - $$I_{PEAK} = I_{LOAD} + \frac{\Delta I}{2}$$

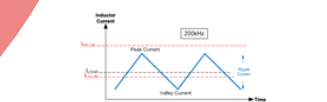
Inductor Selection w/ LM46002 (cont.)

- Peak and valley inductor current tracks with load current and ripple
 - Higher load current → higher peak and valley → risk tripping current limit
 - Output voltage falls out of regulation



Inductor Selection w/ LM46002 (cont.)

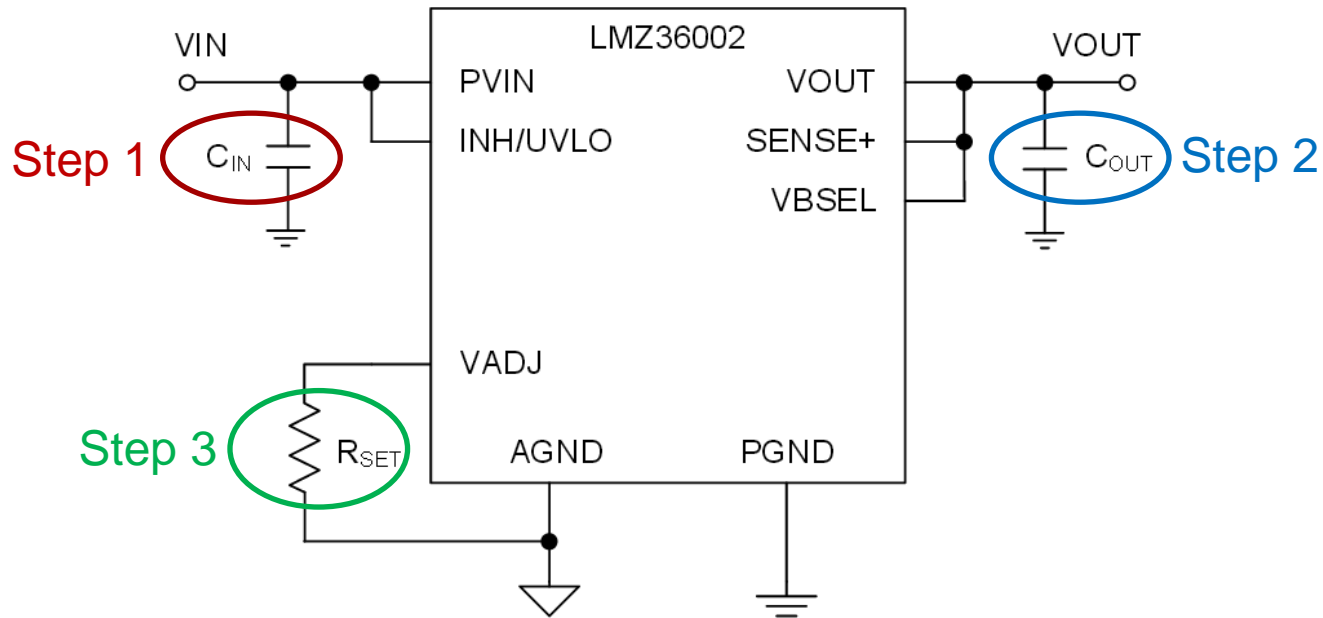
- Frequency (default or external synchronization) also affects the ripple
 - With the same L: Lower frequency → Higher peak → risk tripping current limit



External Component Considerations

CAPACITOR CHARACTERISTICS		
WORKING VOLTAGE (V)	CAPACITANCE ⁽²⁾ (μF)	ESR ⁽³⁾ (mΩ)
50	10	3
50	10	2
63	10	2

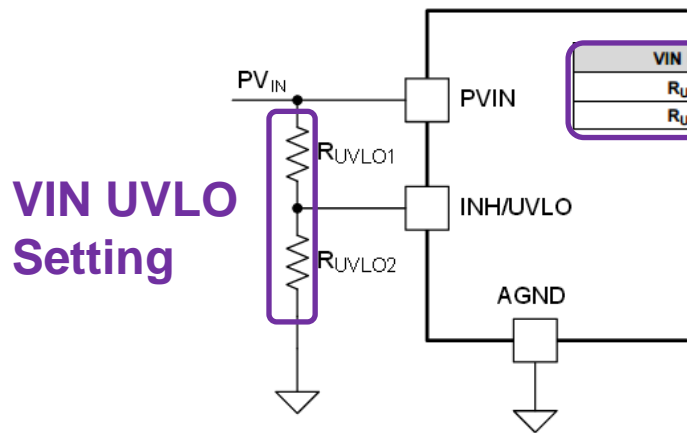
V _{out} (V)	MINIMUM REQUIRED C _{out} (μF) ⁽¹⁾ ⁽²⁾	MAXIMUM C _{out} (μF) ⁽²⁾	Versa-Comp Connection
2.5	64	350	Leave OPEN
3.3	64	350	Connect to VADJ
5.0	64	350	Connect to VADJ
6.0	64	200	Connect to VADJ
7.5	100	200	Connect to VADJ



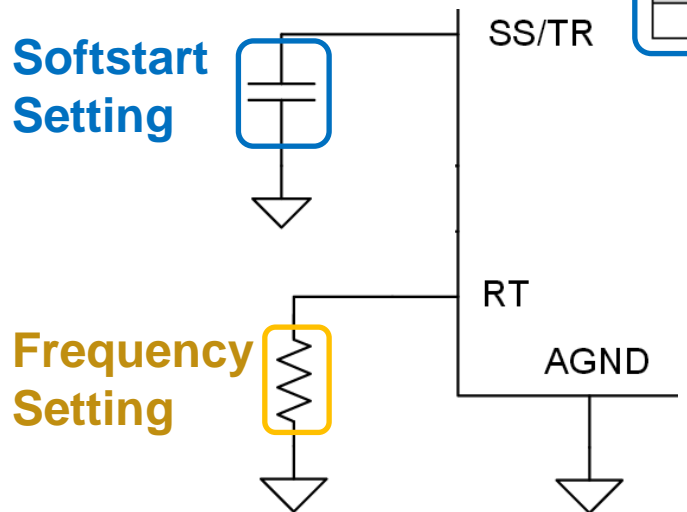
R _{SET} (kΩ)	OUTPUT VOLTAGE V _{OUT} (V)				
	2.5	3.3	5.0	6.0	7.5
	13.7	8.87	5.11	4.02	3.09

Other, Optional Components

(Leave Open or Tailor to Application Needs)



VIN UVLO (V)	4.5	10	15	20	25	30	35	40	45
R _{UVLO1} (kΩ)	100	100	100	100	100	100	100	100	100
R _{UVLO2} (kΩ)	46.4	21.0	14.0	10.5	8.45	6.98	6.04	5.23	4.64



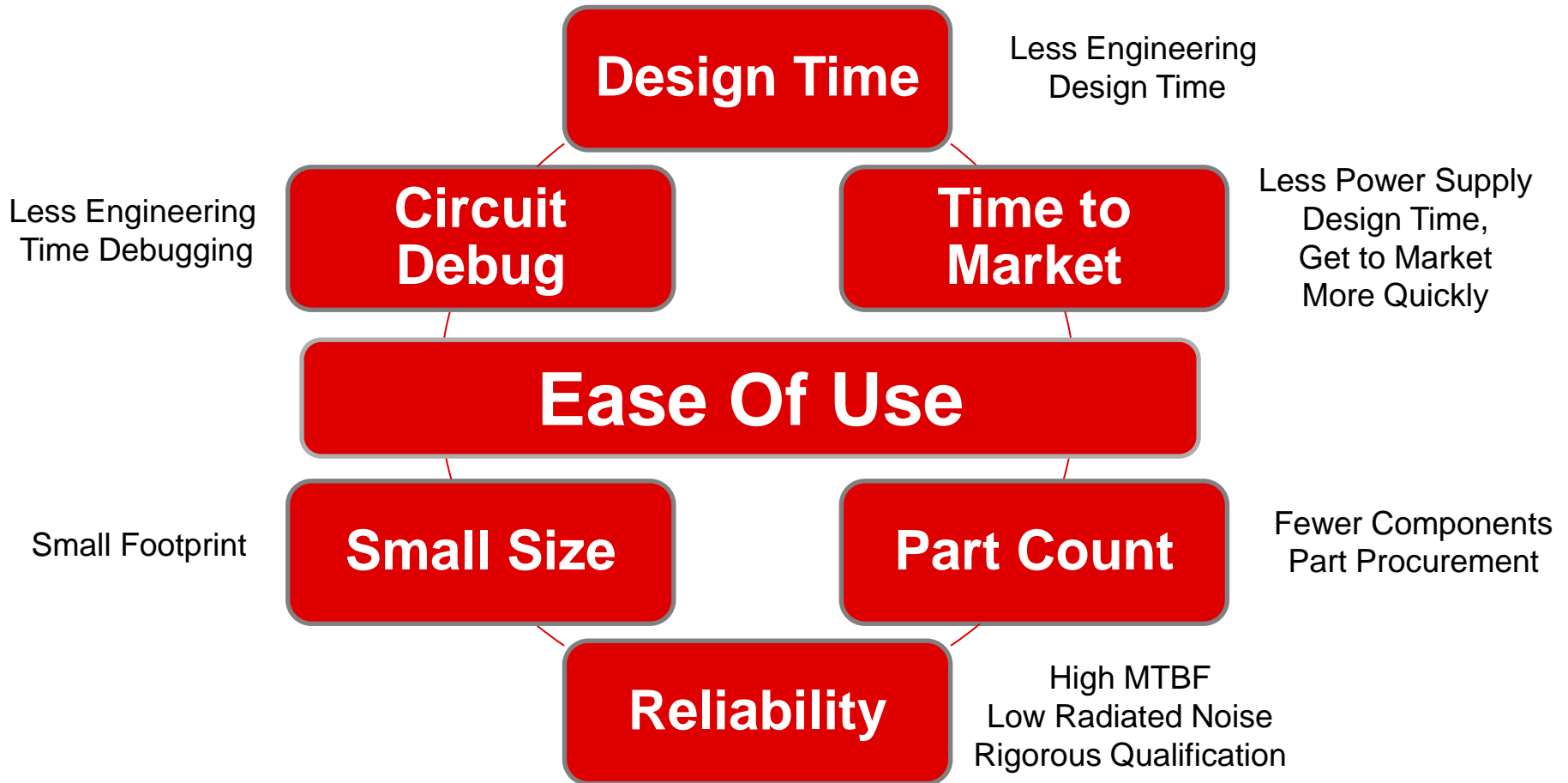
C _{SS} (nF)	open	15	22	33	47
SS Time (ms)	4.1	7	10	15	20

Switching Frequency	R _{RT} (kΩ)
250 kHz	158
500 kHz	78.7 or (RT pin OPEN, RTSEL pin OPEN)
750 kHz	53.6
1 MHz	38.3 or (RT pin OPEN, RTSEL pin to AGND)

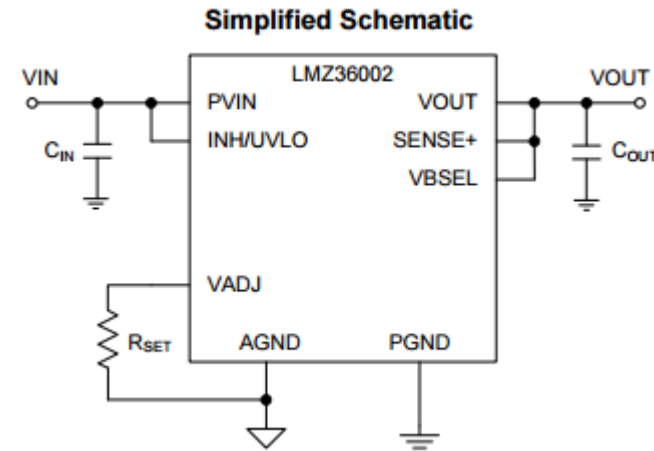
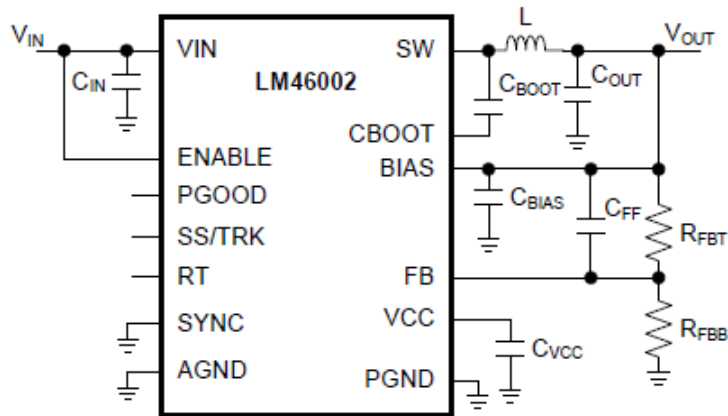
PCB Layout example for LMZ36002



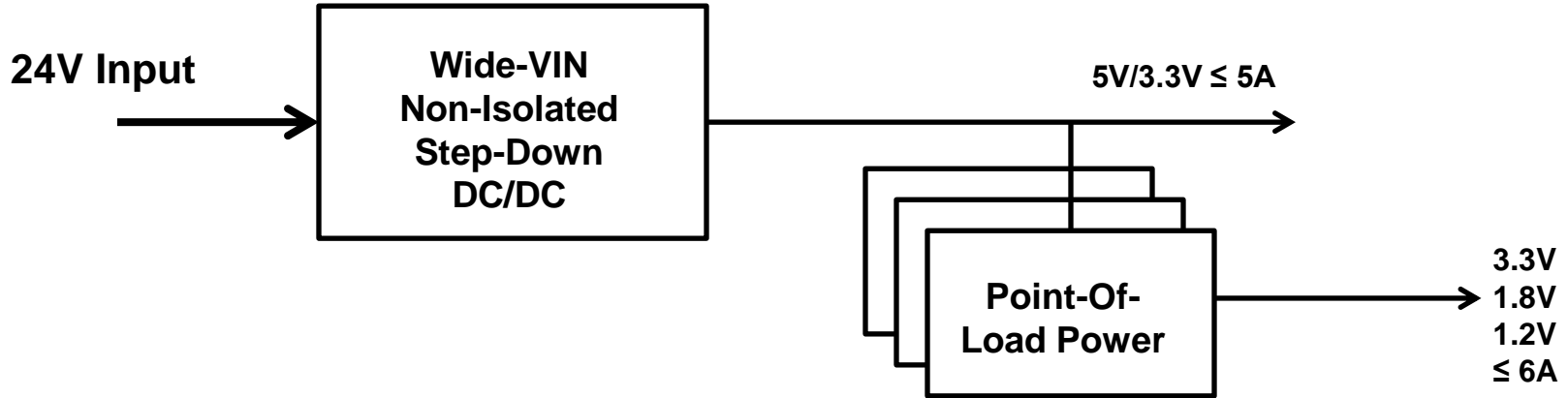
Hidden Advantages of Modules



LM46002 vs LMZ36002



Typical Line Powered Industrial System



TIDA00783

4.5V-40V → 3.3V, 1.8V, 1.2V, 6W total
38x38mm solution size



PMP9483

7V-36V → 5V, 2.5V, 1.8V, 15W total
20x30mm solution size

Design Challenges

- Small Solution Size
- High Efficiency
- Low BOM cost
- Fast Solution

Wide V_{IN} Power Quick Reference Guide

24V Non-Isolated DC/DC Converter (V_{IN} max 36-42V)

Key Power Requirement	1. Small footprint 2. BOM cost 3. High efficiency	1. BOM cost 2. Small footprint 3. High efficiency	1. High efficiency 2. Small footprint 3. BOM cost	1. Fast design 2. Small footprint 3. High efficiency
≤1A	LMR23610*	LMR14006 LMR14020	LM43600 LM43601	LMZ14201 LMZ35003
2A	LMR23625*	LMR14020	LM43602	LMZ14202 LMZ35003
3A	LMR23630*	LMR14030	LM43603	LMZ14203 LMZ23603
5A	LMR14050	LMR14050	LM73605*	LMZ23605

Non-Synchronous
Synchronous
Module

***Sampling now**

Wide V_{IN} Power Quick Reference Guide

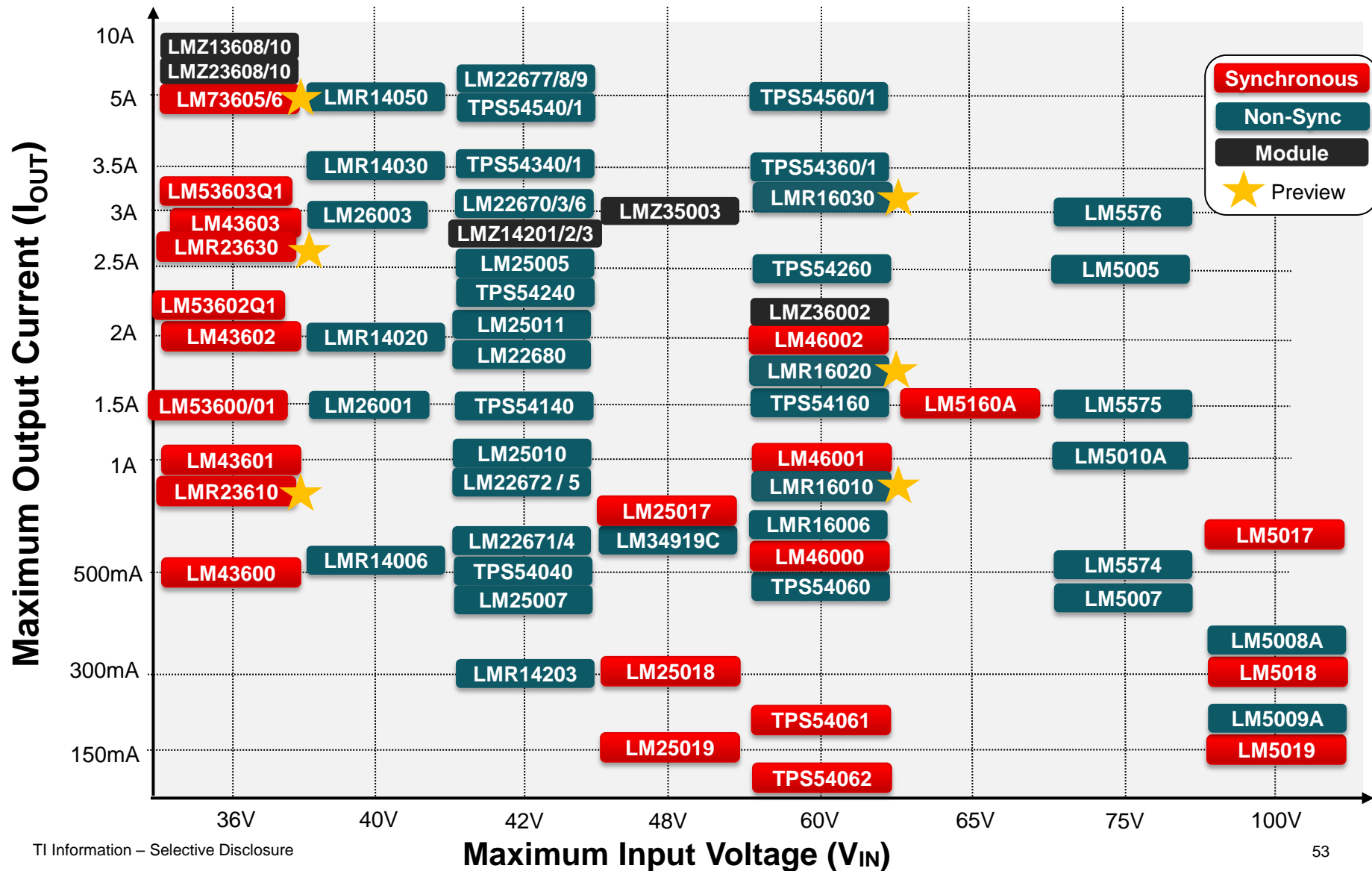
24V Non-Isolated DC/DC Converter (V_{IN} max >42V)

Key Power Requirement	1. Small footprint 2. BOM cost 3. High efficiency	1. BOM cost 2. Small footprint 3. High efficiency	1. High efficiency 2. Small footprint 3. BOM cost	1. Fast design 2. Small footprint 3. High efficiency
≤1A	TPS54062 TPS54061 LMR16010*	TPS54060 TPS54161	LM46000 LM46001	LMZ36002 LMZ35003
2A	TPS54260 LMR16020*	TPS54260	LM46002	LMZ36002 LMZ35003
3A	TPS54361 LMR16030*	TPS54361	TPS54561	
5A	TPS54561	TPS54561	TPS54560	

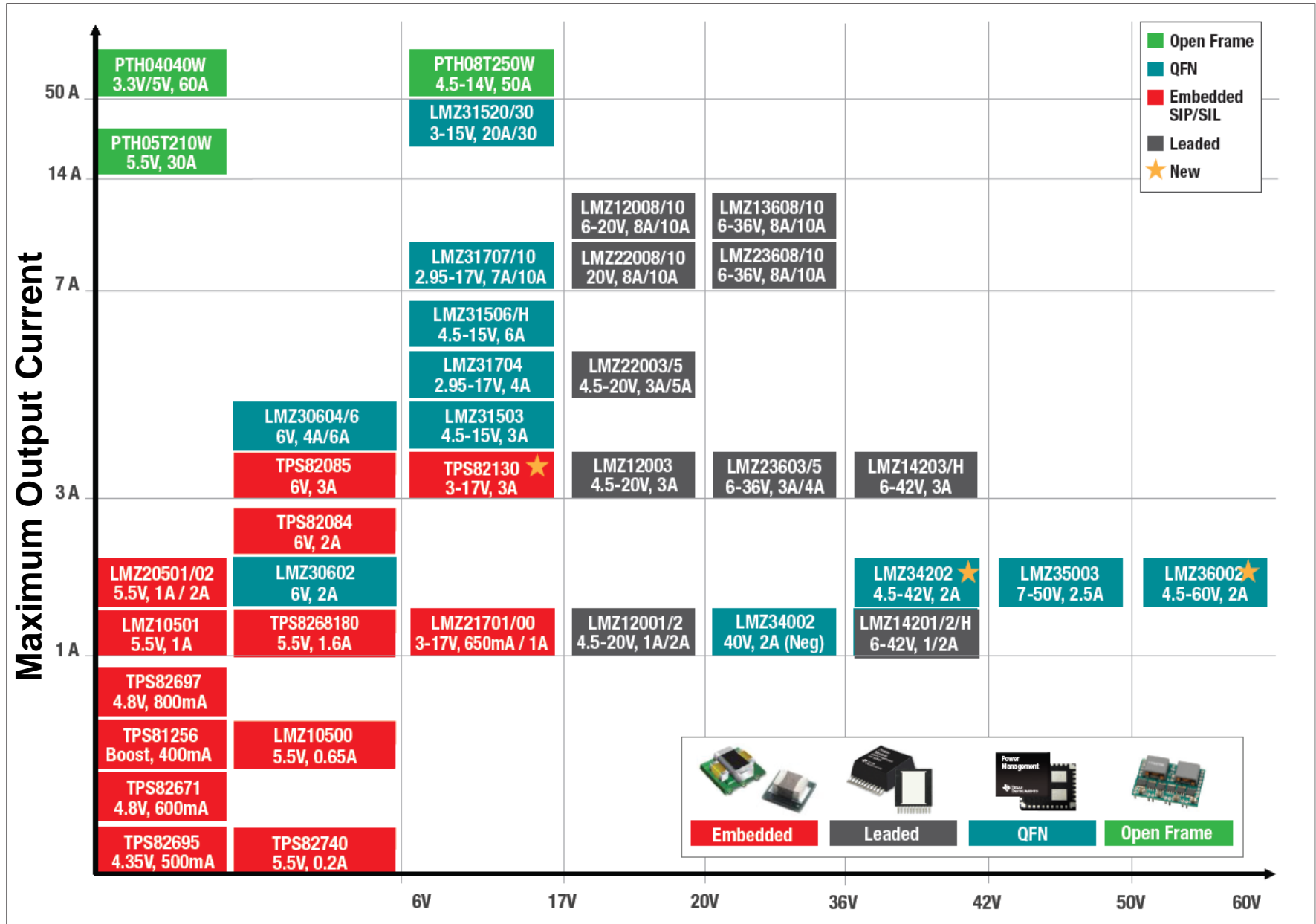
Non-Synchronous
Synchronous
Module

***Sampling now**

TI Wide V_{IN} DC/DC Step-Down Portfolio



TI's Power Module Portfolio



Maximum Input Voltage

Module or Discrete Regulator?

Module Solution

Pro

- Lower total cost of ownership
- Fewer components for procurement
- Less engineering time debugging
- IC, inductor, and passives in module qualified to TI's standard
- Small solution size

Con

- Narrower operating range
- Higher BOM cost



LMZ36002

Discrete Solution

Pro

- More design flexibility
- Optimize to your design conditions
- Lower total solution cost
- Spread heat over larger area
- Small size with optimized layout

Con

- Requires more design time
- Higher BOM count



LM46002

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Reliable Power for Demanding Applications

Robust, Flexible DC/DC solutions for systems requiring max Vin ≥30V

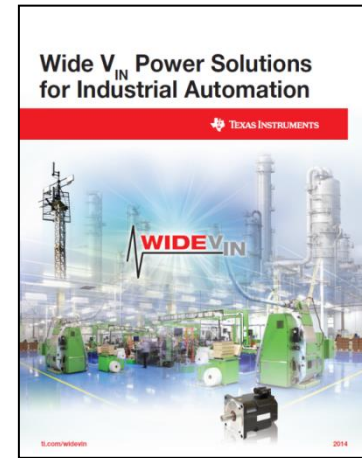
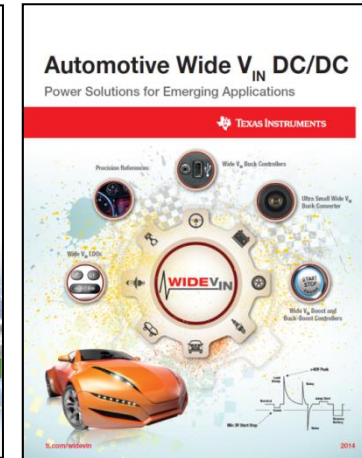
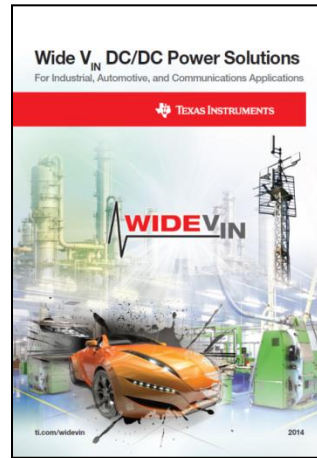
Texas Instruments provides the industry's most comprehensive wide input voltage range DC/DC regulator portfolio for today's most demanding systems. With operating voltages of up to 100V, TI's Wide Vin portfolio eliminates input protection components to reduce cost and solution size without sacrificing reliability. TI's easy-to-use, high-density, feature-rich Wide Vin converters, controllers, and power modules reduce BOM size and cost while improving scalability and reliability without comprising performance.

Wide Vin devices from TI offer:

- Increased robustness against input transients
- Scalable, easy-to-design solutions
- Low noise, low EMI, and feature-rich
- Browse products by function
- Find key products by application
- Download reference designs

Applications Requiring Wide Vin Power:

Automotive <ul style="list-style-type: none"> Infotainment Driver assist & safety Engine/body controls USB power Learn more >	Industrial <ul style="list-style-type: none"> Factory automation PLCs & sensors E-Meters Video surveillance Learn more >	Communications <ul style="list-style-type: none"> Wireless infrastructure Networking Cloud servers Merchant power Learn more >	Wide Vin DC/DC Power Solutions Find the ideal Wide Vin product for your next design Download Now! > Wide Vin Power White Paper
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Wide Vin Selection Guides

Wide Vin TI Designs
(Designs, searchable by application & end equipment)

Search TI Designs - Wide Vin

App Function End Equipment

View Designs	Products
CISPR 25 Class 3 RATED MULTI-OUTPUT POWER SUPPLY FOR AUTOMOTIVE CLUSTER III Infotainment System	SEPIC (Synchronous)
100W Automotive Amplifier with Start-Stop Support	Boost
Automotive Infotainment Display Power with CISPR 25 Class 5 Rating	SEPIC
Quad Output Isolated Bias Supply for Inverter Gate Drivers	Fly-Buck
Quad Output Isolated Bias Supply for Inverter Gate Drivers	Fly-Buck
Wide 7Vin Low Noise Triple Output Step Down Converter Reference Design	Buck (Synchronous)

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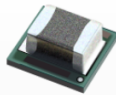
DC/DC Power Modules: Innovative solutions to fit design constraints

TI's broad portfolio of DC/DC modules integrate inductors, FETs, compensation, and other passive components into a single package to simplify prototyping, design, and manufacturing. Using a module reduces engineering time for design and verification to help speed development cycles for many applications, including personal electronics, industrial, and communications.

Browse by input voltage level

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Featured products for Power Modules



TPS82130

3-A 17V Step-down Converter Module with Integrated Inductor


[Online datasheet](#)



LMZ36002

SIMPLE SWITCHER® 4.5 V to 60 V, 2 A power module in QFN package

[Online datasheet](#)



LMZ34202

2A SIMPLE SWITCHER®, Step-Down Voltage Regulator

[Online datasheet](#)

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Support & training for Power Modules

LMZ36002 Features

- Enhanced thermal performance: 14°C/W
- CISPR 22 Class-B EMI standards
- Adjustable and synchronous switching frequency

Design support

Ask questions, share knowledge, explore ideas, and help solve problems with fellow engineers.

[Power module design support >](#)

Latest power modules blog posts

[Simplify Wide VIN Design with the SIMPLE SWITCHER LMZ36002, the Industry's Smallest 60V DC/DC Power Module IC.](#)
 Available in a 10mm x 10mm QFN package, the SIMPLE SWITCHER LMZ36002 is the industry's smallest 60V DC/DC power module IC. Watch as Tenille details how to use LMZ36002 and as few as three external components to design a robust DC/DC power supply.

[The Evolution of the MicroSIP™ DC/DC Power Module](#)
 Learn more about TI's highly-integrated MicroSIP™ power modules for low-power applications.

[SIMPLE SWITCHER® Nano Modules vs. LDOs](#)
 Stephen discusses the pros and cons of both solution types and explains why integrated-inductor DC/DC switching regulators may be a better choice over LDOs.


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LMZ36002 Power Module Evaluation Board

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3A Step-Down Converter with Integrated Inductor EVM

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WEBENCH® Designer

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Power	FPGA/µP	LED	Clocks

Enter your power supply requirements:

DC AC

Vin: Min 14.0 V Max 22.0 V
 Vout: 3.3 V Iout 2.0 A

Output Isolated Output

Ambient Temp: 30 °C
 Multiple Loads Single Output

[Power Architect](#) [Start Design](#)

Thank You!

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