If Your Standby Power Is Too High, Your Power Converter Will Not Sell

David Chen, Energy Management Industry Session, APEC 2020

ac-dc converters led drivers gate drivers motor drivers

What is Standby Power?

- **Standby power is the power used by electronics and appliances when not performing their main function**
  - Can be a significant portion of the overall energy use of a device
- **Energy efficiency standards set standby power limits**
  - All new federal efficiency standards are required to include standby power
  - Horizontal standby regulation in EU is under revision and targeting stricter limits
- **As a power supply designer, what can one do?**
  - Aim is to optimize efficiency to maximize available power within the prescribed limits
  - Example: 15 W dual-output power supply design to meet emerging EU standby regulation

European Commission Has Different Levels of Requirements

- **Ecodesign Directive**
  - Regulatory framework in the EU to reduce the environmental impact of products throughout their entire lifecycles

- **Energy Labelling**
  - Policy instrument used to influence consumer behavior toward conservation
- **Code of Conduct**
  - Sets out the basic principles to be followed by all parties involved in power supplies operating in Europe with respect to energy efficient equipment
  - Voluntary

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Ecodesign and Labelling Under Revision

Product	ENER Lot	Status in the EuP process
PCs and servers	3	Regulation in force 2013. Revision ongoing.
Televisions and electronic displays	5	Revision ongoing.
Standby and off-mode losses	6	Revision ongoing. Consultation Forum 20 Dec 2017
Battery chargers and external power supplies	7	Regulation in force 2009. Revision ongoing.
Linear, CFL, and HID lamps and ballasts	8-9	Regulation in force 2009. Revision ongoing.
Ventilation fans	11	Revision ongoing.
Electric pumps	11	Revision ongoing. Consultation Forum 8 Dec 2017
Domestic refrigerators and freezers	13	Revision ongoing. Consultation Forum 6 Dec 2017
Domestic washing machines	14	Revision ongoing. Consultation Forum 18 Dec 2017
Domestic dishwashers	14	Revision ongoing. Consultation Forum 19 Dec 2017
Household tumble driers	16	Regulation in force 2012. Revision ongoing.
Vacuum cleaners	17	Regulation in force 2013. Revision ongoing.
Directional lighting	19	Revision ongoing. Consultation Forum 7 Dec 2017
Domestic lighting (general lighting equipment)	19	Revision ongoing. Consultation Forum 7 Dec 2017
Networked standby losses	26	Revision ongoing. Consultation Forum 20 Dec 2017
https://www.eceee.org/ecodesign/		

Ecodesign Regulations for Standby/Off-Mode

- **Impact assessment finalized**
  - Review study on standby published in April 2017; consultation forum held in December 2017
  - Status of adoption pending

- **Regulation (EC) No 1275/2008 is under revision**
  - Horizontal requirement → applies across all energy-using product categories

- **Proposed changes**
  - Standby/off-mode requirement reduced to 0.3 W from 0.5 W
  - Network standby requirement reduced to 2 W from 3 W
    - WiFi load is always on (~1 W) plus other functions (screen, camera, etc.)
    - Example: Smart Speaker OEMs targeting <2 W input power with 1.5 W system load in standby

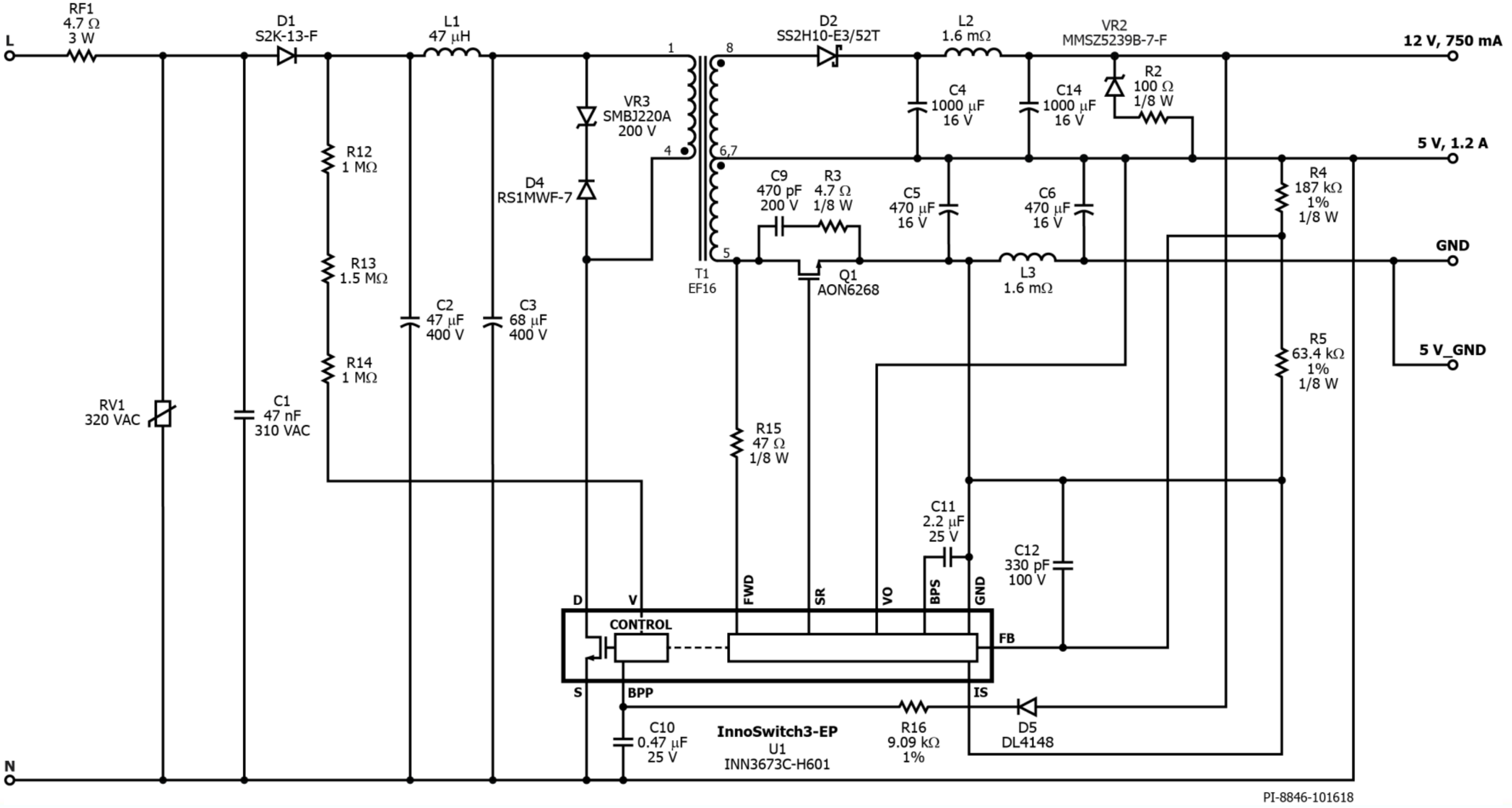
- **Timeline**
  - Entry into force likely delayed to end of 2020

15 W Dual-output Power Supply Design Example

Specification

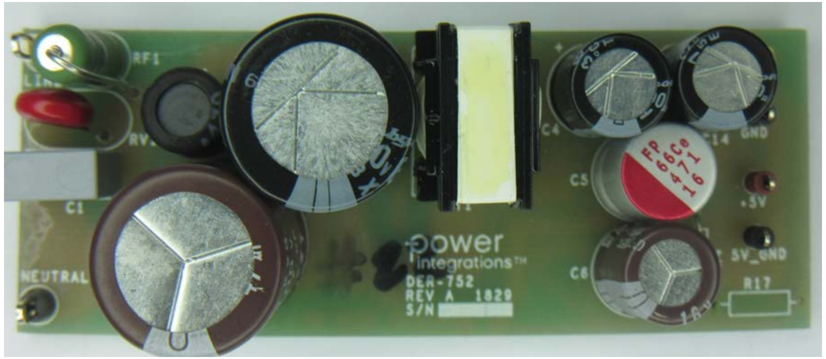
Description	Symbol	Min	Typ.	Max	Units	Comment
Input						
Voltage	V_{IN}	85	115/230	277	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
No-load Input Power				45	mW	230 VAC Input.
Output						
Output Voltage 1	V_{OUT1}		5		V	±5% PCB Connector Side.
Output Current 1	I_{OUT1}		1.2		A	
Output Ripple Voltage 1	$V_{RIPPLE1}$			150	mVpp	Measured at the PCB Connector.
Output Voltage 2	V_{OUT2}		12		V	±10% PCB Connector Side.
Output Current 2	I_{OUT2}	0.02	0.75		A	
Output Ripple Voltage 2	$V_{RIPPLE2}$			200	mVpp	Measured at the PCB Connector.
Continuous Output Power	P_{OUT}			15	W	
Efficiency						
Average 25%, 50%, 75%, and 100%	$\eta_{AVE[BRD]}$	80			%	115 and 230 VAC Input
Environmental						
Conducted EMI	CISPR22B / EN55022B Load floating					Resistive Load, 6 dB Margin.
Safety	IEC950 / UL1950 Class II					Designed to Meet.
Differential Line Surge		1			kV	230 VAC Input
Ambient Temperature	T_{AMB}	0		40	ºC	Free Convection, Sea Level in Sealed Enclosure.

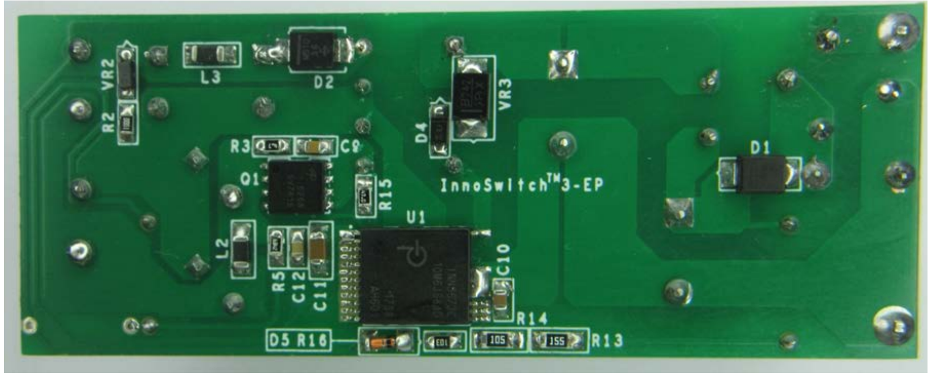
Schematic

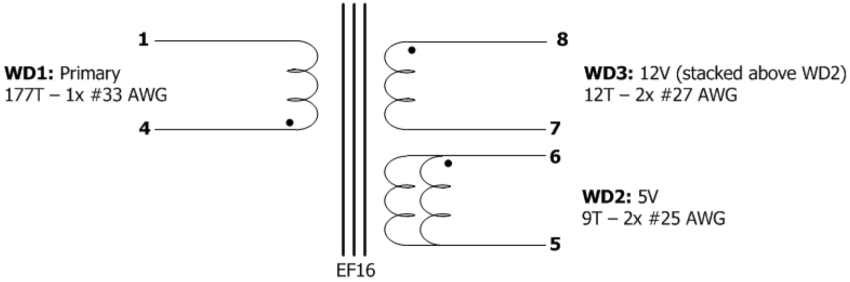


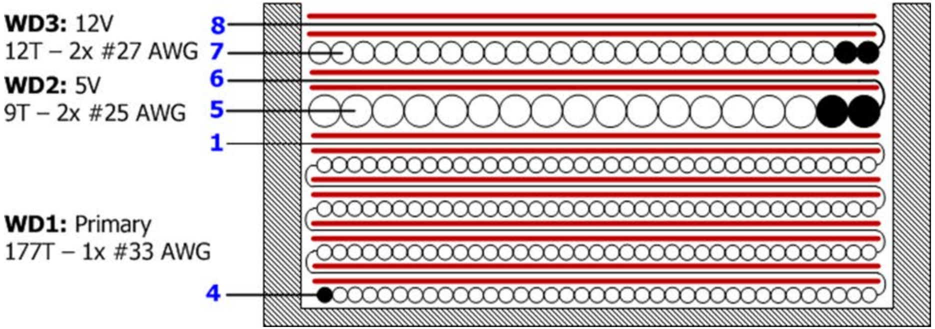
L
RF1
4.7 Ω
3 W
D1
S2K-13-F
L1
47 µH
VR3
SMBJ220A
200 V
D4
RS1MWF-7
R12
1 MΩ
R13
1.5 MΩ
R14
1 MΩ
C2
47 µF
400 V
C3
68 µF
400 V
RV1
320 VAC
C1
47 nF
310 VAC
N
T1
EF16
D2
SS2H10-E3/52T
L2
1.6 mΩ
VR2
MMSZ5239B-7-F
12 V, 750 mA
C4
1000 µF
16 V
C14
1000 µF
16 V
R2
100 Ω
1/8 W
5 V, 1.2 A
C9
470 pF
200 V
R3
4.7 Ω
1/8 W
C5
470 µF
16 V
C6
470 µF
16 V
R4
187 kΩ
1%
1/8 W
GND
Q1
AON6268
L3
1.6 mΩ
R5
63.4 kΩ
1%
1/8 W
5 V_GND
R15
47 Ω
1/8 W
C11
2.2 µF
25 V
C12
330 pF
100 V
D
V
CONTROL
FWD
SR
VO
BPS
GND
FB
S
BPP
IS
C10
0.47 µF
25 V
InnoSwitch3-EP
U1
INN3673C-H601
R16
9.09 kΩ
1%
D5
DL4148
PI-8846-101618

Open Frame Design









Standby Efficiency Optimization

1. **Primary clamp**
   - RCD clamp vs. Zener clamp
2. **Transformer**
   - VOR, winding technique, core material
3. **5 V output**
   - Output capacitors, RC snubber
4. **BP bias circuit**
5. **Input section**
6. **5 V output rectifier**

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Primary Clamp Design

- **To minimize losses, tune the primary clamp such that $V_{DS(max)}$ of the primary MOSFET is 85-90% of rated breakdown voltage (BV_{DSS})**
  - Measure at the highest AC input voltage

- **Choosing between a Zener clamp and an RCD clamp**
  - Both implementations can be used given that the above criterion is met
  - With Zener clamp, the voltage rating of the Zener (TVS) diodes have big voltage steps (e.g. 180 V, 200 V, 220 V, 250 V, 300 V, 350 V)
  - With RCD clamp, the components can be more easily tuned to meet derating target

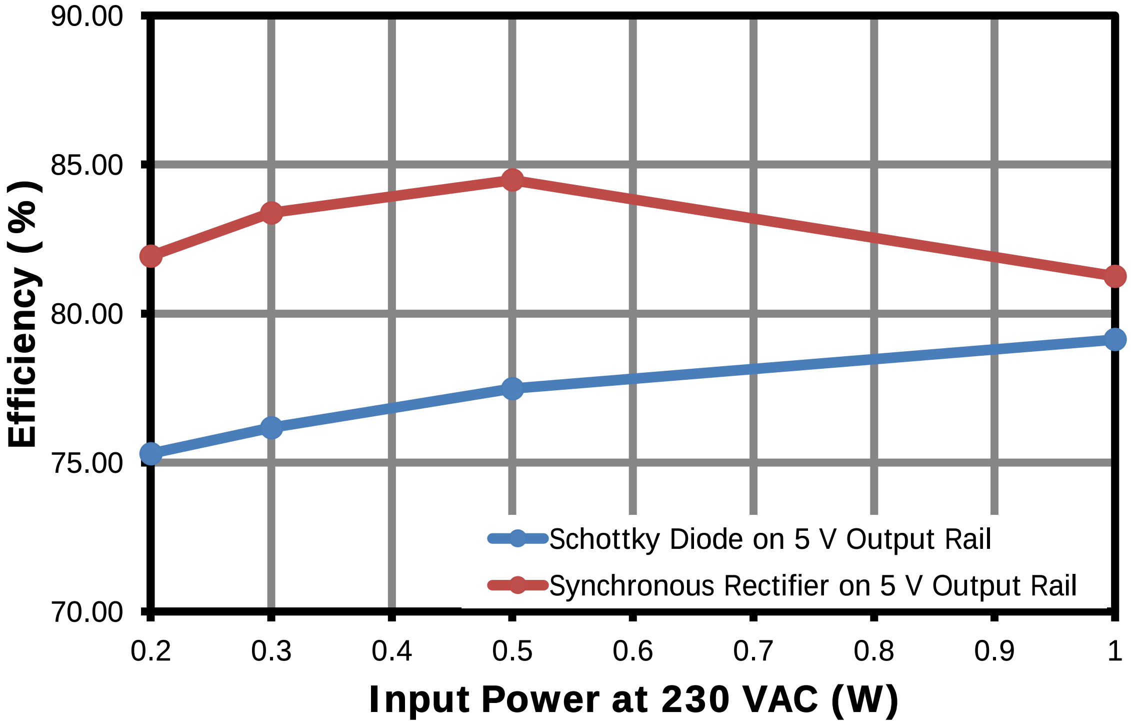
Transformer – VOR Optimization

- **Adjusting the reflected voltage (VOR) of the transformer has a direct effect on efficiency**
- **Decreasing VOR increases efficiency**
  - Lower VOR yields lower secondary-peak, RMS and average currents
    - Reduces conduction loss in the output diodes
  - Lower VOR increases the peak inverse voltage (PIV) – limited by diode de-rating

Section	Iteration	Reflected Voltage	Improvement per step	300 mW Standby Efficiency	5 V Output Diode PIV (rated 60 V)
Transformer	0	VOR = 90 V		75.98%	46.29
	1	VOR = 85 V	↑ 0.40%	76.38%	46.40
	2	VOR = 80 V	↑ 0.35%	76.73%	50.08
	3	VOR = 75 V	↑ 0.06%	76.79%	58.14

Design approach: start with conservative VOR and iterate design reducing VOR until diode voltage margin is minimized

Increasing Standby Efficiency with Synchronous Rectification on 5 V Output



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Standby Power Improvement

					60.30%
Primary Clamp	Primary Snubber	RCD Clamp R1=200 kΩ, C8=470 pF D4=S1ML (trr=1.8 us), R11=20 Ω	Zener Clamp VR1=SMBJ200A D4=RS1MWF (trr=500 ns)	⇧ 9.26%	**69.56%**
Transformer	VOR	VOR = 110 V	VOR = 100 V	⇧ 4.12%	**73.67%**
	Core Material	N27 (A_L = 950 nH, μ_e = 1410)	N87 (A_L = 1000 nH, μ_e = 1490)	⇧ 0.19%	**73.87%**
5 V Output	5 V Output Capacitor	C5 = 470 µF 16 V E-cap Low ESR = 53 mΩ	C5 = 470 µF 16 V Polymer Cap Low ESR = 10 mΩ	⇧ 0.47%	**74.33%**
	5 V Output Rectifier RC Snubber	C9 = 1500 pF R13 = 10 Ω	C9 = 470 pF R13 = 4.7 Ω	⇧ 0.30%	**74.63%**
BP Pin	BP Bias Resistor	R16 = 18 kΩ (IBP = 195 µA)	R16 = 9.09 kΩ (IBP = 230 µA)	⇧ 0.82%	**75.45%**
Input Section	Input Choke Filter	L1 = 1000 µH 0.28 A DCR = 2.37 Ω	L1 = 47 µH 1.6 A DCR = 0.14 Ω	⇧ 0.72%	**76.17%**
5 V Output	5 V Output Rectifier	D3 = STPS5L60S 60 V 5 A SMC	Q1 = AON6268 60 V 44A 6.3 mΩ	⇧ 7.21%	**83.38%**

Standby Power Optimization Design Challenges

Section	Item	Challenge
Primary clamp	Zener Clamp	Verify the primary MOSFET voltage derating and EMI margin
Transformer	Lower VOR	Verify the maximum peak reverse voltage across output diode in worst case
	Core material	Higher transformer cost
5 V output capacitor	Low ESR capacitor	Lower ripple but higher cost
5 V output diode rectification	RC Snubber	Verify the output diode voltage derating and radiated EMI
BP pin	Proper supply current (230 µA to 250 µA)	Insufficient external supply current may cause IC self-supply
Feedback circuit	High value feedback divider resistor	Verify noise immunity and regulation/ripple
Input choke	Lower DC resistance differential choke	Verify the surge performance and ensure safe voltage margins across the input bulk cap, primary MOSFET and output rectifier; validate conducted EMI
5 V SR rectification	SR FET used for 5 V output	Higher cost

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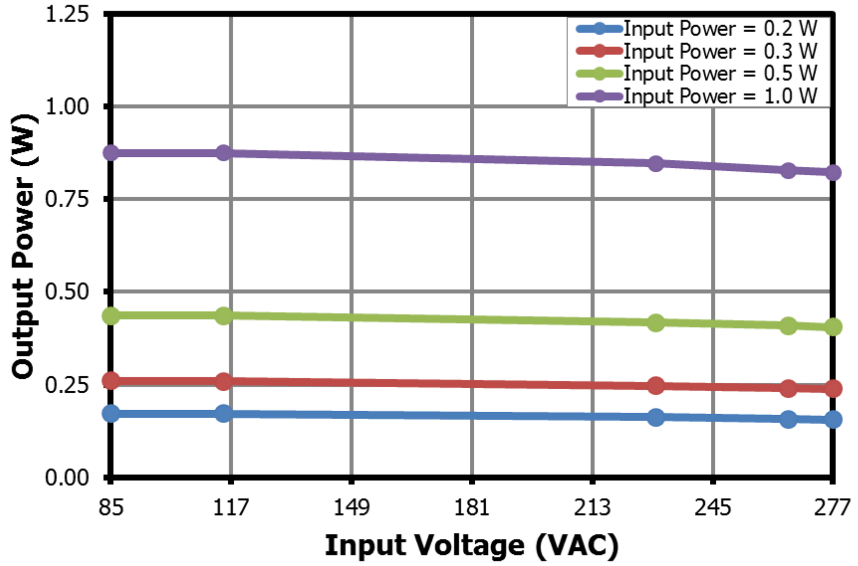
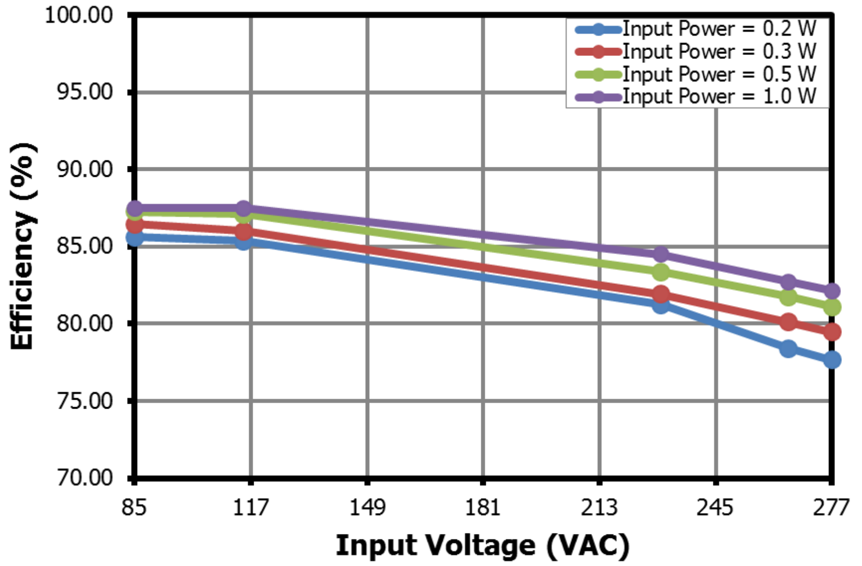
PSMA

Available Power and Efficiency in Standby Mode

- **Test Condition: Soak at full load for 5 minutes and decrease load to standby mode for 5 minutes for each line step**





Summary

- **Standby power matters!**
  - Global impact of standby power consumption – ~1% of global CO_2 emissions *
  - Typically 5-10% of residential electricity use in developed countries *
  - Standby power growing as more appliances incorporate standby functions, especially connectivity

- **Power supply design optimization enables compliance to standby regulations worldwide**

* https://standby.lbl.gov/faq/

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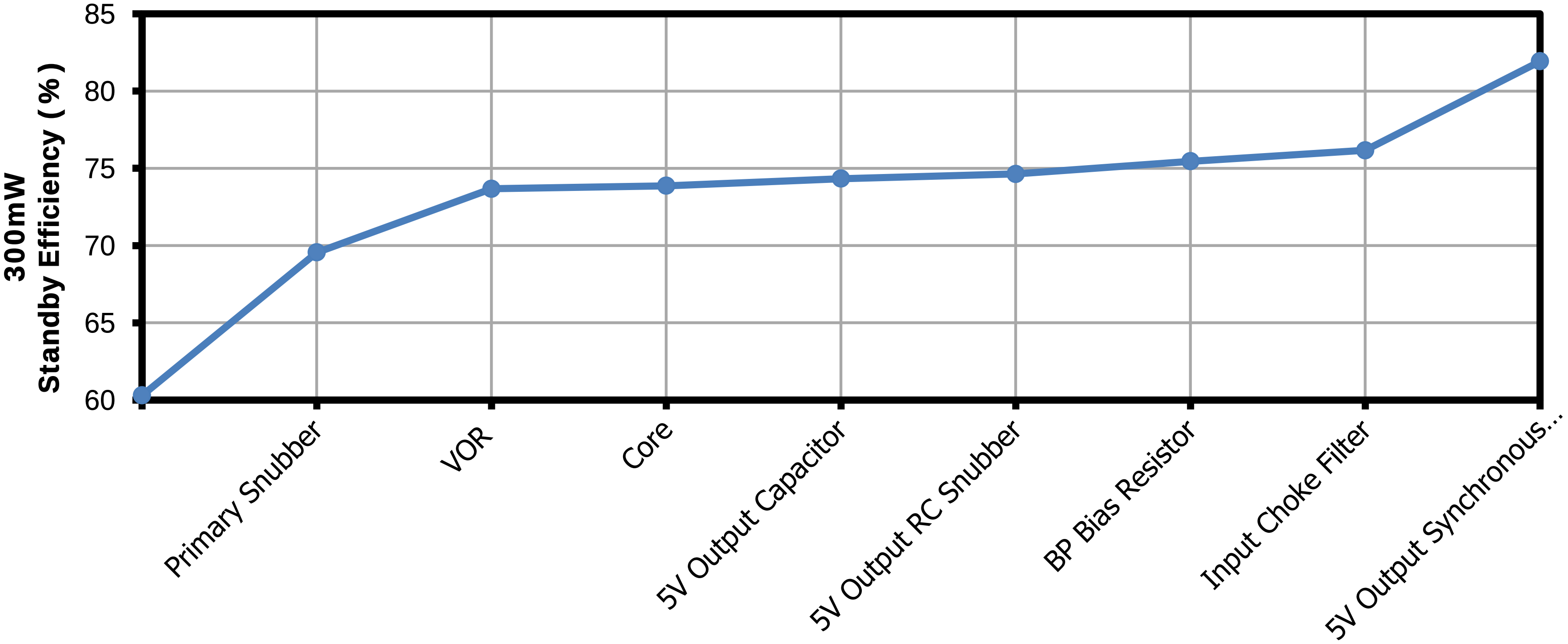
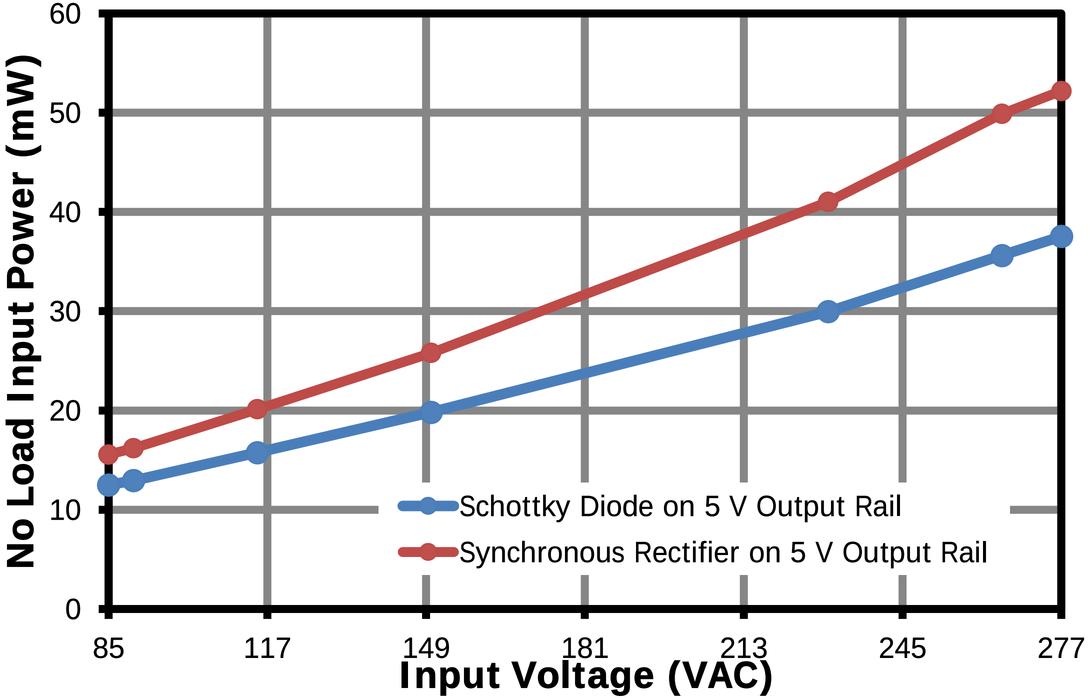
Improving Standby Efficiency



Lower No-load Input Power Can Be Achieved By Using Diode Rectifier on 5 V Output

- **Soak for 15 minutes and 3 minutes integration time for each line/step**



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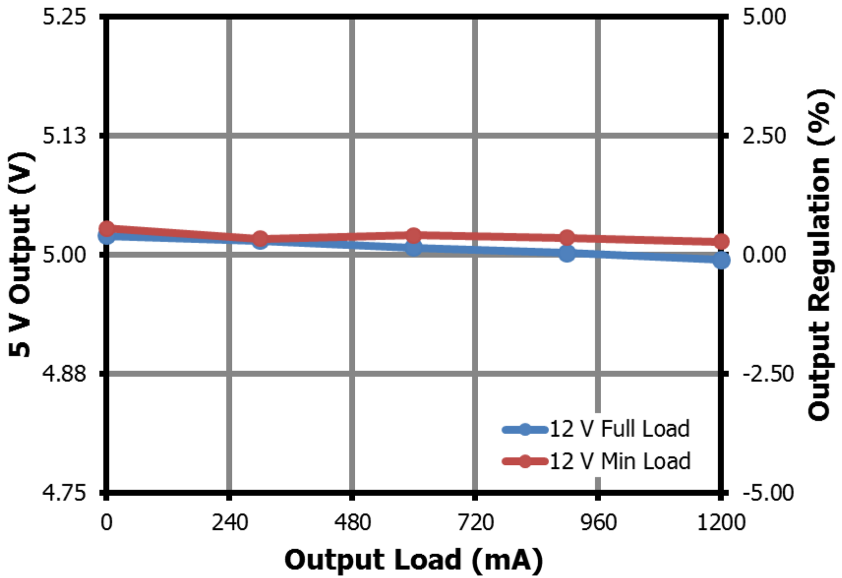
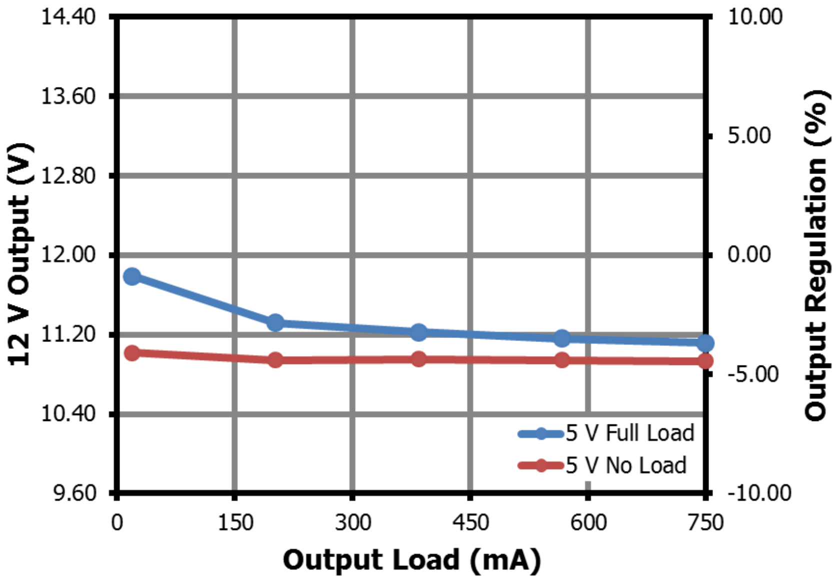
Load Regulation

- 5 V output at 230 VAC input



- 12 V output at 230 VAC input

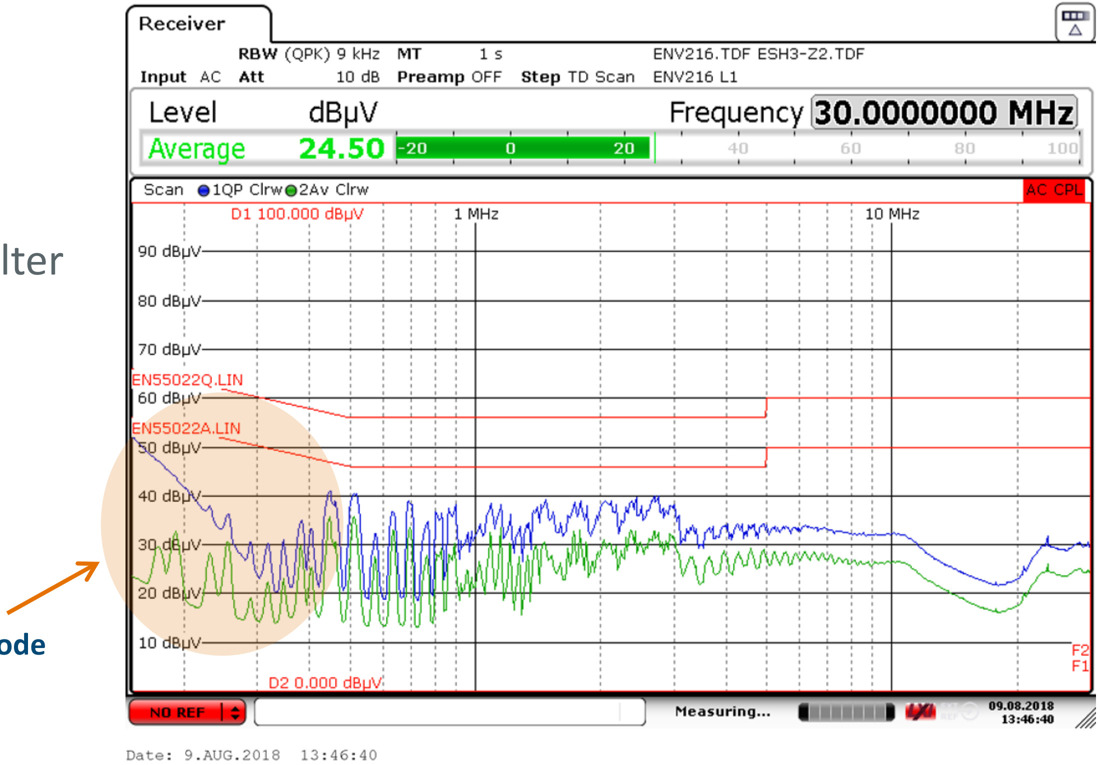


Stress Analysis

Input Voltage	Operation	Output Load	Primary FET VDS		5 V Output Diode PIV		12 V Output Diode PIV	
			725 (V)	Derating	60 (V)	Derating	100 (V)	Derating
277 VAC	Normal Running	5 V/1.2 A 12 V/0.75 A	658	90.8%	36.8	61.4%	47.5	47.5%
		5 V/NL, 12 V/NL	627	86.5%	33.0	54.9%	48.4	48.4%
	Startup	5 V/1.2 A 12 V/0.75 A	656	90.5%	41.6	69.3%	74.0	74.0%
		5 V/NL, 12 V/NL	656	90.5%	38.6	64.3%	57.0	57.0%

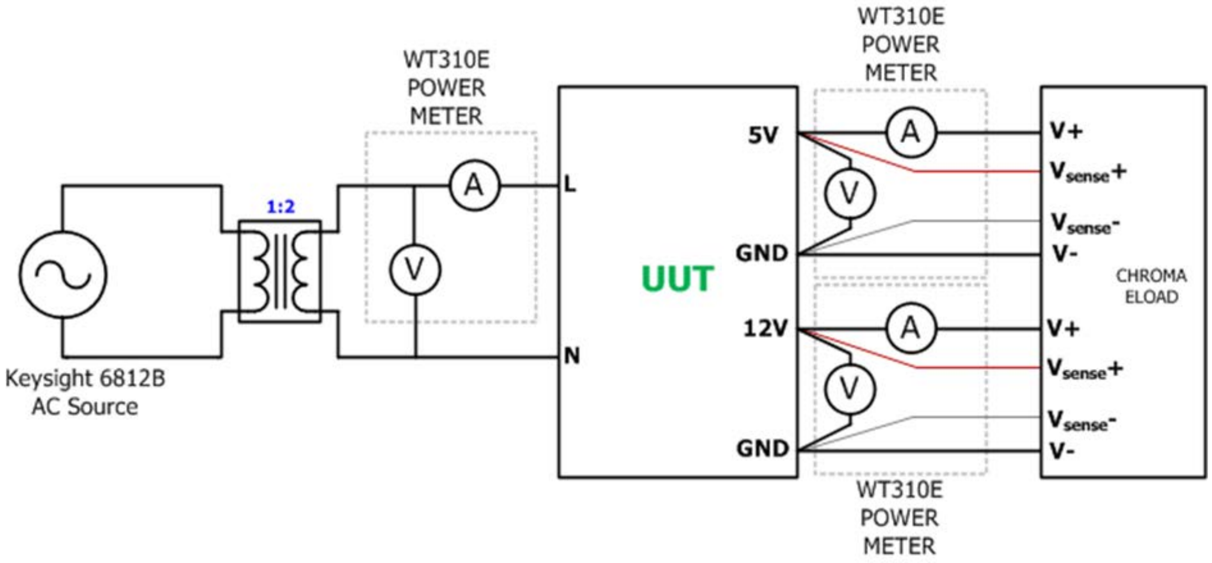
Conducted EMI Verification

- **Can be effected by:-**
  - Transformer construction
  - Input bulk capacitor ESR
  - Differential inductor in π filter
  - RC snubber
  - PCB layout



Measurement Setup

- **Applicable for standby efficiency and average efficiency measurement**
- **Input and output power meter settings**
  - Line filter: OFF
  - Frequency filter: OFF
  - Sync: Volt
  - Averaging: ON
    - Linear, 32 points
  - Range
    - Voltage: AUTO
    - Current: AUTO



PSMA

Measurement Setup

- **Standby power measurement**
  - Set desired input AC voltage and apply full load across the 5 V and 12 V output
    - Soak time at full load: 240 seconds (4 minutes)
  - Reduce load to meet desired standby input power (300 mW, 250 mW, 500 mW)
    - Soak time at standby load: 240 seconds (4 minutes)
  - Record input/output voltage, current, and power measurements
- **Average efficiency measurement**
  - Soak time: 120 seconds
  - Delay per line: 120 seconds
  - Delay per load step: 120 seconds
  - Reduction of load: 100%, 75%, 50% , 25%, 10%

Input/output Conditions For Standby Efficiency Optimization

- **Input voltage: 230 VAC**
- **Input power: 300 mW**
- **Output load**
  - Increase 5 V load until target input power is reached
  - Assumes no-load on 12 V output

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