Power factor correction

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References

Advertisement materials and application notes of „ON Semiconductor"

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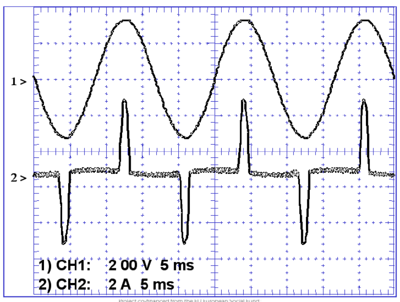
Input Characteristics of a Typical Switched-Mode Power Supply without PFC

Top: Input Voltage Bottom: Input Current



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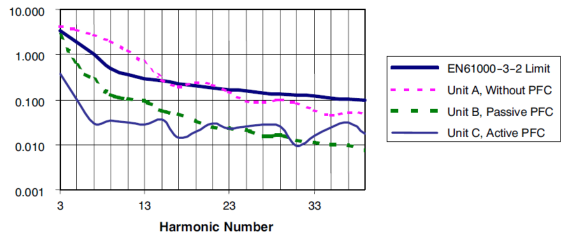
Input Harmonics of Three PC Power Supplies Relative to EN61000-3-2 Limits



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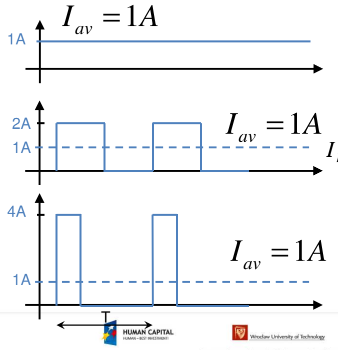
RMS vs. DC



$I_{av} = 1A$

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt} = 1A$$

$CF = 1; \quad FF = 1;$

$I_{av} = 1A$

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt} = \sqrt{2}A$$

$CF = \sqrt{2}; \quad FF = \sqrt{2};$

$I_{av} = 1A$

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt} = 2A$$

$CF = 2; \quad FF = 2;$

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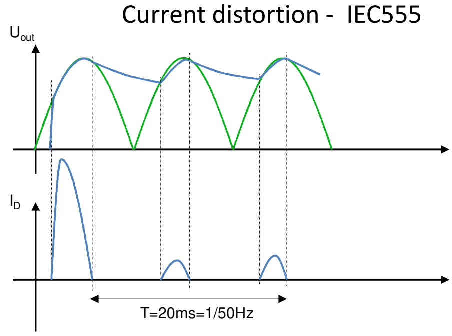
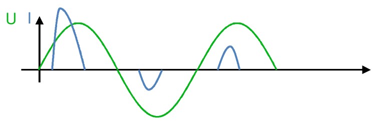
Current distortion - IEC555



Supply current distortion - IEC555 EN 61000-3-2



- harmonics (up to 40 harmonic)
- current fluctuations of load
- surge current ???

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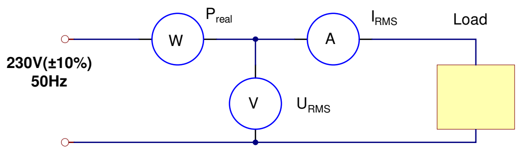
Power Factor



$$\eta = \frac{P_{real}}{U_{RMS} \bullet I_{RMS}} \leq 1 \quad \left[\frac{W}{VA}\right]$$

P – real power [w]
Q – reactive power [Var]
S – apparent power [VA]

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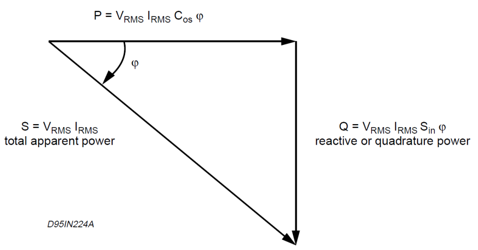
Power triangle (no current harmonics case)



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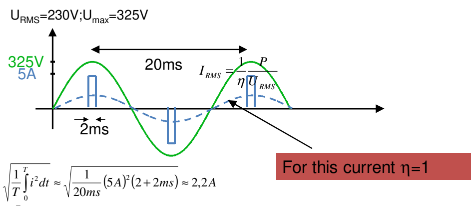
Power Factor η=cosθ



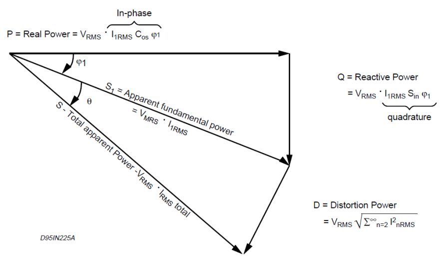
$$I_{RMS} = \frac{1}{\eta}\frac{P}{U_{RMS}}$$

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2 dt} \approx \sqrt{\frac{1}{20ms}(5A)^2(2+2ms)} \approx 2{,}2A$$

$$P_{real} = \frac{1}{T}\int_0^T u(t)i(t)dt \approx 320V \bullet 5A \bullet \frac{4ms}{20ms} = 320W$$

$$\eta = \frac{P_{real}}{U_{RMS} \bullet I_{RMS}} \approx \frac{320W}{230V \bullet 2{,}2A} \approx 0{,}63 \quad \left[\frac{W}{VA}\right]$$

Power triangle
(no current harmonics case)



Total P.F.= η = cos φ_1 cos θ

φ_1 is the "conventional" displacement angle (phase lag) between the in- phase fundamental I and V
θ is the distortion angle linked to the harmonic content of the current.

Both of reactive (Q) and distortion (D) powers produce extra RMS currents, giving extra losses so that then the mains supply network efficiency is decreased.

Improving P.F. means to improve both of factors i.e.:

φ_1 ->0 cos φ_1 -> 1 = reduce phase lag between I and
θ -> 0 cos θ -> 1 = reduce harmonic content of I

THD(i) vs. P.F. (cos φ_1 =1)

$$PF = \frac{1}{\sqrt{1+\left(\frac{THD(\%)}{100}\right)^2}}$$

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THD vs. P.F.

$$P.F. = \frac{\cos(\varphi_1)}{\sqrt{1+\left(\frac{THD(\%)}{100}\right)^2}} = \cos(\theta)\cdot\cos(\varphi_1)$$

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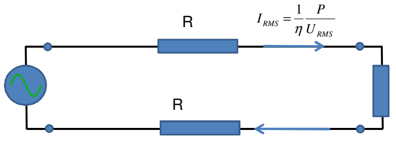
Why PF should be 1



$$I_{RMS} = \frac{1}{\eta}\frac{P}{U_{RMS}}$$

$$P = \frac{1}{T}\int_0^T u(t)i(t)dt = \eta U_{RMS} I_{RMS}$$

$$P_{LOST} = (I_{RMS})^2 R = \left(\frac{1}{\eta}\right)^2 \left(\frac{P}{U_{RMS}}\right)^2 R$$

$$\left(\frac{1}{\eta}\right)^2 = \left(\frac{1}{0,63}\right)^2 = 2,52$$

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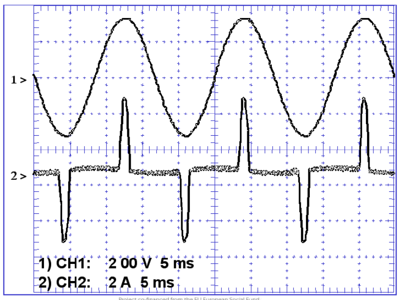

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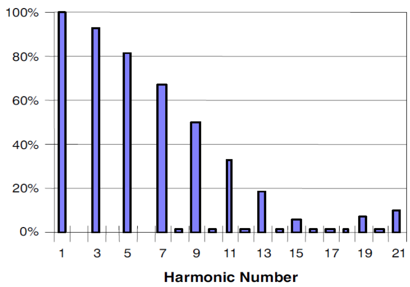
Harmonic Content of the Current Waveform



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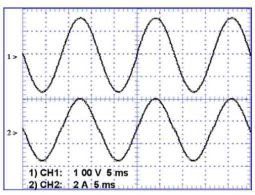
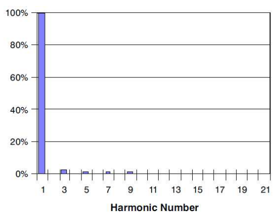
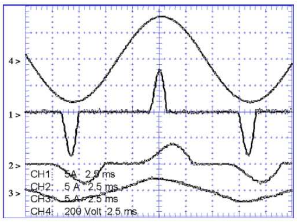
Input Characteristics of a Power Supply with Near-Perfect PFC





Input Characteristics of PC Power Supplies with Different PFC Types (None, Passive, and Active)

Waveforms:
1. Input current with no PFC
2. Input current with passive PFC
3. Input current with active PFC
4. Input voltage



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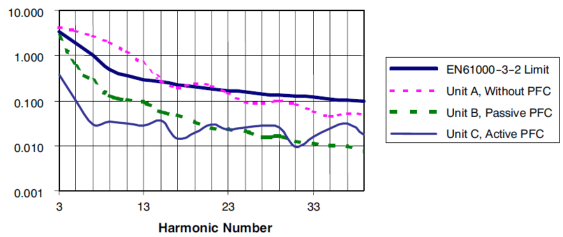
Input Harmonics of Three PC Power Supplies Relative to EN61000-3-2 Limits



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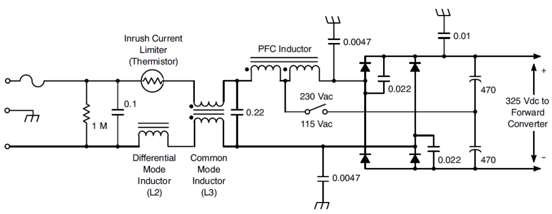
Passive PFC in a 250W PC Power Supply



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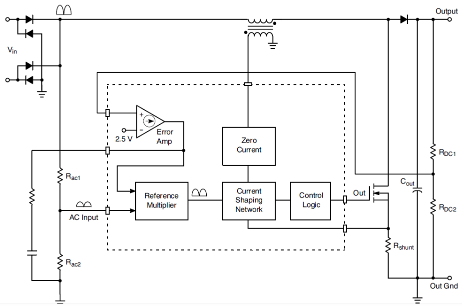
Basic Schematic for a Critical Conduction Mode Converter



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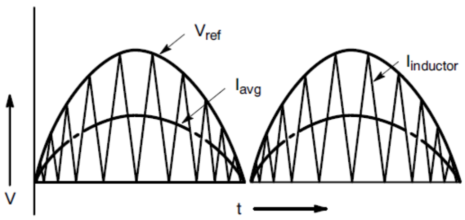
CRM Waveforms



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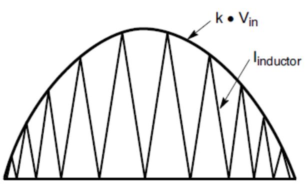
CRM Current Envelope

$$I_{pk} = k * V_{in}(t)$$

$$I_{pk} = \Delta I = \frac{V_{in}(t)}{L} * t_{on}$$



$$k * V_{in}(t) = \frac{V_{in}(t)}{L} * t_{on}$$

$$t_{on} = k * L$$

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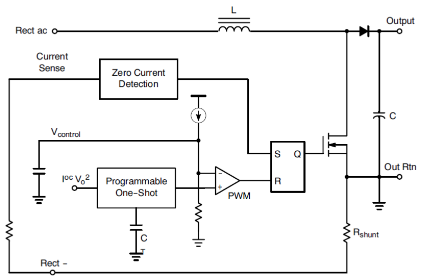
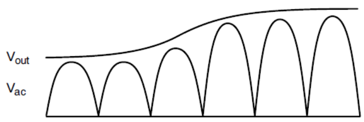
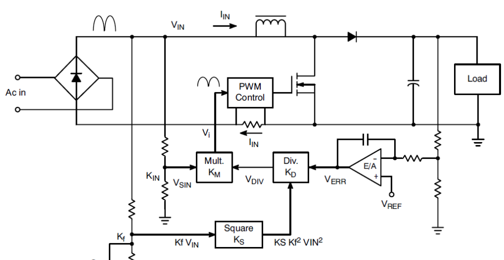
Simplifed Schematic of CRM Controller without Multiplier



Follower Boost

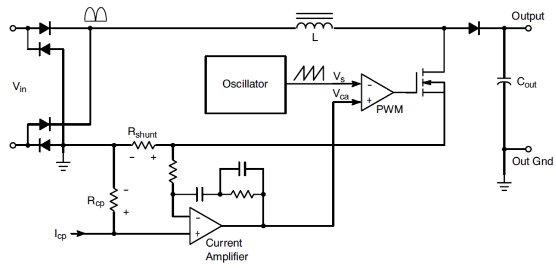


Block Diagram of the Classic PFC Circuit

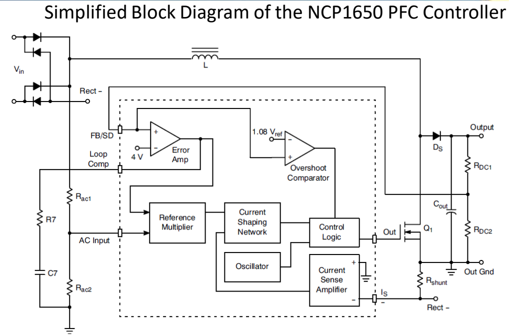


$$V_i = V_{DIV} \cdot K_M \cdot V_{SIN} = \frac{V_{ERR} \cdot K_M \cdot V_{SIN}}{K_D \cdot K_S \cdot K_f^2 \cdot V_{IN}^2}$$

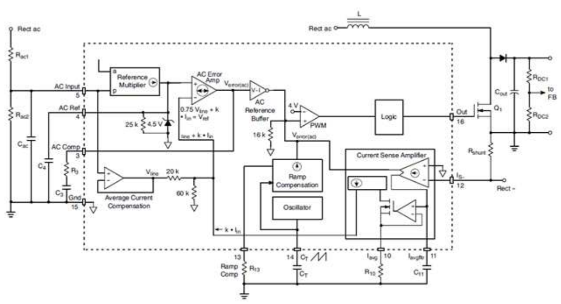
Diagram for Average Current Mode Control Circuit



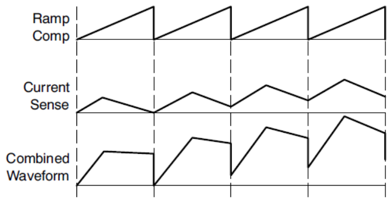
Simplified Block Diagram of the NCP1650 PFC Controller



Current Shaping Circuit of the NCP1650 PFC Controller



Summed Waveforms



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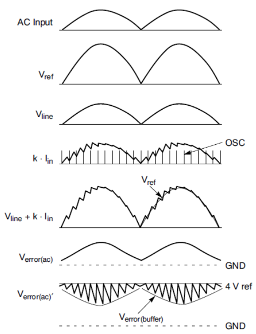
Waveshaping Circuit Waveforms



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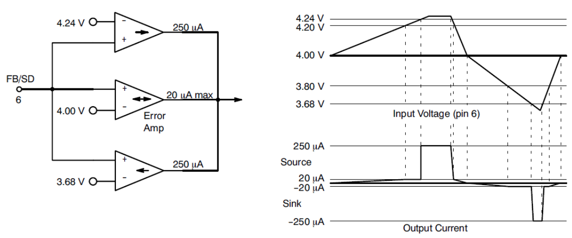
Representative Schematic of Voltage Loop Error Amplifier



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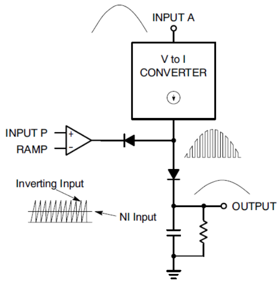
Switching Multiplier



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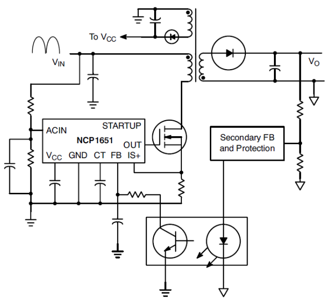
Single Stage PFC Using the NCP1651



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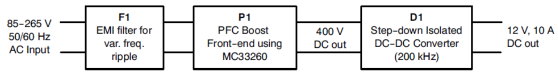
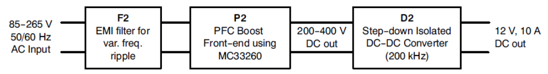
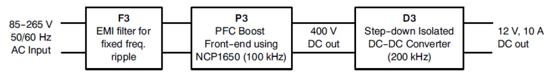
Critical Conduction Mode PFC with Fixed Output Voltage



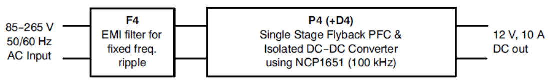
Critical Conduction Mode PFC with Variable Output Voltage



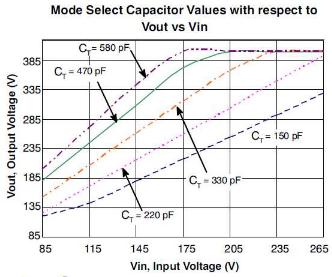
Continuos Conduction Mode PFC with Fixed Output Voltage



Continuos Conduction Mode Isolated Flyback PFC

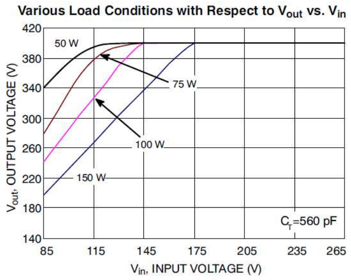


Mode Select Capacitor Values with Respect to Vout vs. Vin at Full Load



$$C_T \geq C_{int} + \frac{4 * K_{osc} * L_p * P_{in_{max}} * I_{reg_L}^{\ 2}}{V_{in_{min}}^{\ 2}}$$

Vout vs. Vin with Respect to Ct=560pF at Various Load Conditions



Inductor (Lp)

$$\mathrm{Iin}_{pk} = \frac{\sqrt{2} \cdot \mathrm{Pout}}{\eta \cdot \mathrm{Vin}_{min}}$$

$$\mathrm{Icoil\_pk} = 2 \cdot \mathrm{Iin}_{pk}$$

$$\mathrm{Lp} = \frac{2 \cdot \mathrm{T}_{total} \cdot \left(\frac{\mathrm{Vout}}{\sqrt{2}} - \mathrm{Vin}_{min}\right) \cdot \mathrm{Vin}_{min}}{\mathrm{Vout} \cdot \mathrm{I}_{coil\_pk}} = 607\ \mu\mathrm{H} \text{ for the traditional boost}$$

$$\mathrm{Lp} = \frac{2 \cdot \mathrm{T}_{total} \cdot \left(\frac{\mathrm{Vout}}{\sqrt{2}} - \mathrm{Vin}_{min}\right) \cdot \mathrm{Vin}_{min}}{\mathrm{Vout} \cdot \mathrm{I}_{coil\_pk}} = 200\ \mu\mathrm{H} \text{ for the follower boost}$$

Power Switch

$$IQ = \sqrt{\frac{1}{6} \cdot \frac{4\sqrt{2} \cdot Vin\,min}{9 \cdot \pi \cdot Vout}} \cdot Icoil\_pk$$

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Output Capacitor

Energy = Power x Time
where power = 150 W (output power)
and time = 20 ms (hold – up time)

$$\Delta U = U_1 - U_2 = \frac{1}{2} Cout (Vout^2 - Vout^2{}_{min})$$

$$Cout = \frac{2 \cdot \Delta U}{Vout^2 - Vout_{min}{}^2} = \frac{2 \cdot 3}{400^2 - 280^2}$$
$= 74\ \mu F$ for the Traditional Boost

$$Cout = \frac{2 \cdot \Delta U}{Vout^2 - Vout_{min}{}^2} = \frac{2 \cdot 3}{200^2 - 150^2}$$
$= 342\ \mu F$ for the Follower Boost

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Current Sense

Dissipation capability for RCS:

$$P_{CS} = \frac{1}{6} \cdot R_{CS} \cdot Icoil\_pk^2$$

Overcurrent protection resistor:

$$R_{OCP} = \frac{R_{CS} \cdot Icoil\_pk}{I_{OCP}}$$

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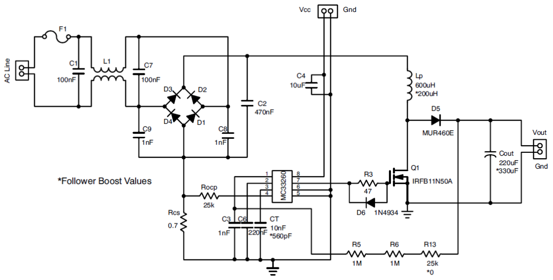
MC33260 Traditional and Follower Boost Schematic



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Design Table – Traditional and Follower Boost

Mode Select	Traditional Boost	Follower Boost
P_O (W)	150	150
L_p (μH)	607	200
C_O (μF)	220	330
R_{CS} (Ω)	0.7	0.7
R_{OCP} (kΩ)	20	20
C_T (pF)	10000	560

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Measurement Results for the Traditional Boost

150 W PFC Front End – MC33260 Traditional Boost				
Vin (Vac)	85	115	175	265
Efficiency (%)	87.8	91.6	94.3	96.2
THD (%)	8.87	11.04	14.8	17.6
PF (%)	99.49	99.32	98.83	97.61
Vout (V)	401.5	408.3	414.6	418

Measurement Results for the Follower Boost

150 W PFC Front End – MC33260 Follower Boost				
Vin (Vac)	85	115	175	265
Efficiency (%)	89.5	92.5	93.7	95.9
THD (%)	5.95	6.21	10.87	21
PF (%)	99.76	99.75	99.25	97.37
Vout (V)	203	276	391	400.7

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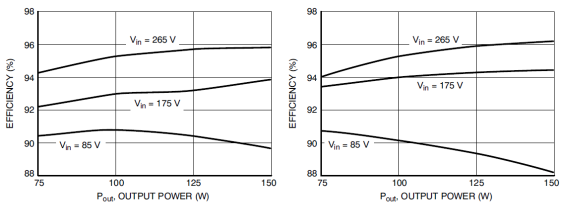
Measurement Results for the Follower Boost

150 W PFC Front End – MC33260 Follower Boost				
Vin (Vac)	85	115	175	265
Efficiency (%)	89.5	92.5	93.7	95.9
THD (%)	5.95	6.21	10.87	21
PF (%)	99.76	99.75	99.25	97.37
Vout (V)	203	276	391	400.7

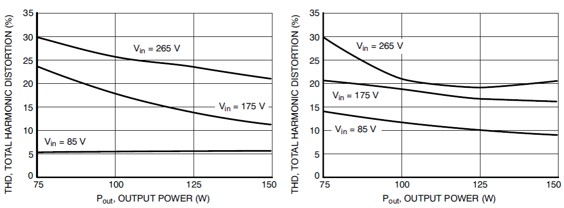
Efficiency vs. Output Power for Follower and Traditional Boost



FB: Efficiency vs. Output Power

TB: Efficiency vs. Output Power

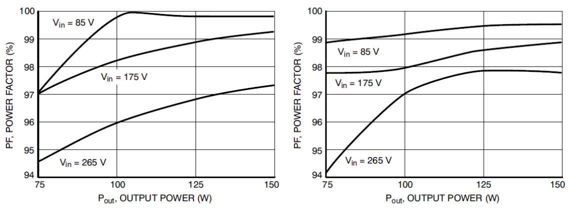
Total Harmonic Distortion vs. Output Power for Follower and Traditional Boost



FB: Total Harmonic Distortion vs. Output Power

TB: Total Harmonic Distortion vs. Output Power

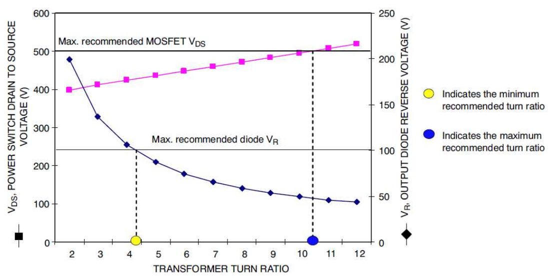
Power Factor vs. Output Power for Follower and Traditional Boost



FB: Power Factor vs. Output Power

TB: Power Factor vs. Output Power

Vds and Vr vs. Transormer Turns Ratio (12V Output)



Power Switch

$$V_{DS} = \sqrt{2}\cdot Vin_{max} + \frac{Np}{Ns}\cdot Vout + I_p\cdot\sqrt{\frac{L_p(leakage)}{C_p + C_{oss}}}$$

$$Ipk = \frac{\sqrt{2}\cdot Pin\cdot T}{Vin_{min}\cdot ton} + \frac{2\cdot\sqrt{2}\cdot Vin_{min}\cdot ton}{Lp}$$

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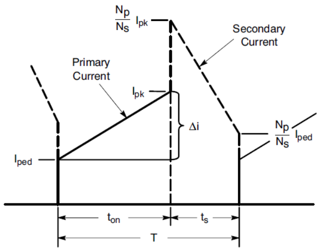
Primary and Secondary Currents of the Flyback Transformer



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Output Rectifier

$$V_R \geq Vout + \sqrt{2} \cdot Vin_{max} \cdot \frac{Ns}{Np}$$

$$Pd = V_F \cdot I_F \cdot (1-D) \text{ with } I_F = \frac{(Ipk + Iped)}{2} \cdot \frac{Np}{Ns}$$

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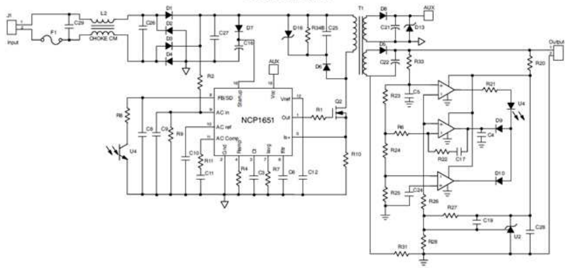
Simplified NCP1651 One Stage Flyback Power Factor Converter Schematic



NCP1651 PFC Circuit Results

Vin (Vac)	85	115	230	265
Pin (W)	153.8	146	140.1	140.3
Iline(rms)	1.80	1.27	0.63	0.56
Vout (V)	11.72	11.78	11.77	11.78
Iout (A)	10	10	10	10
Efficiency (%)	76.2	80.7	84.0	84.0
PF (%)	99.79	99.86	96.70	93.87
THD (%)	4.76	4.29	6.4	7.9

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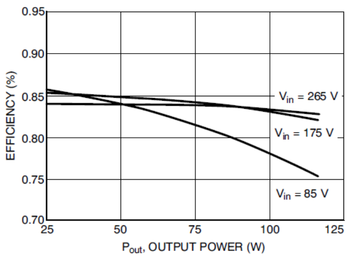
Efficiency vs. Output Power



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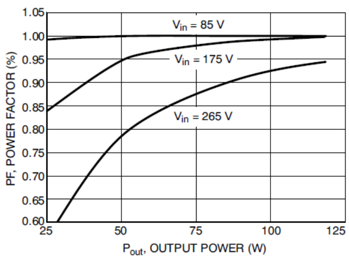
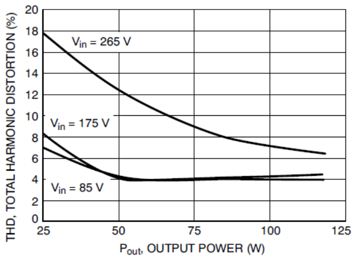
Power Factor vs. Output Power



THD vs. Output Power



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Summary

- PF definition
- PF vs. THD
- PFC methods

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