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ON Semiconductor®

GreenPoint™
From ON Semiconductor

220 W LCD TV Power Supply Documentation Package

1 Overview

This reference document describes a built-and-tested, GreenPoint™ solution for an LCD TV power supply.

The reference design circuit consists of one single-sided 130 mm x 200 mm printed circuit board designed to fit into an LCD TV. Height is 25 mm.

An overview of the entire circuit is provided by Figure 1. As shown in that figure, ON Semiconductor devices are available for every block of the LCD TV power supply; and by judicious choice of design tradeoffs, optimum performance is achieved at minimum cost.

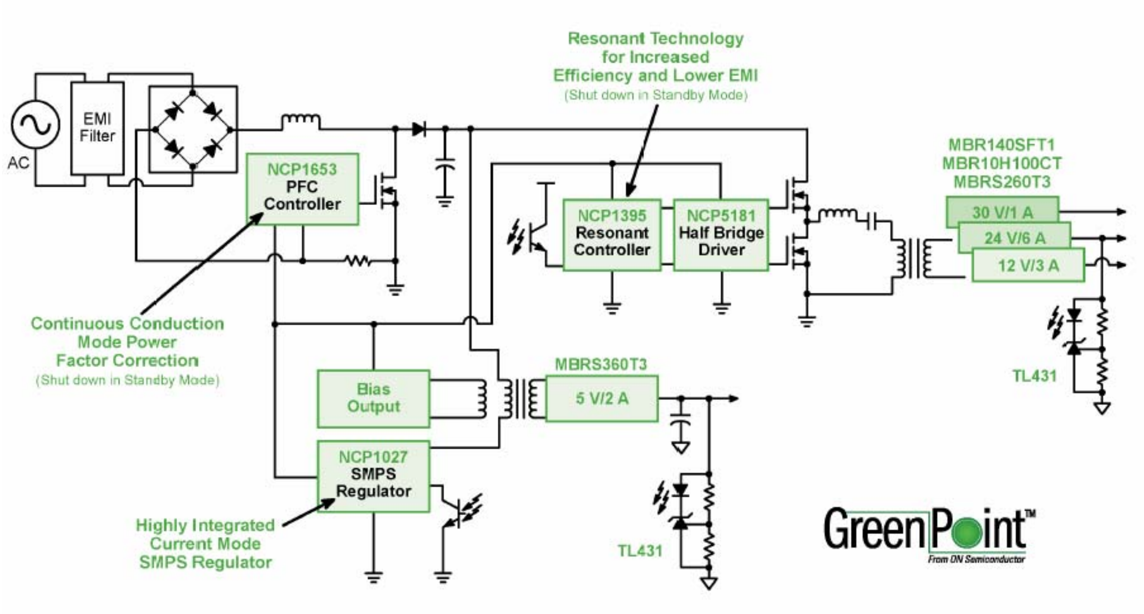


Figure 1

2 Introduction

From Tubes to Flat TVs

Since 1936 when the BBC begins the world's first public-television broadcast in London, the TV world made huge progress. A few examples:

- 1953: color broadcasting
- 1956: first VCR
- 1962: first television satellite (Telstar)
- 1981: NHK (Japan) demonstrates an HDTV system

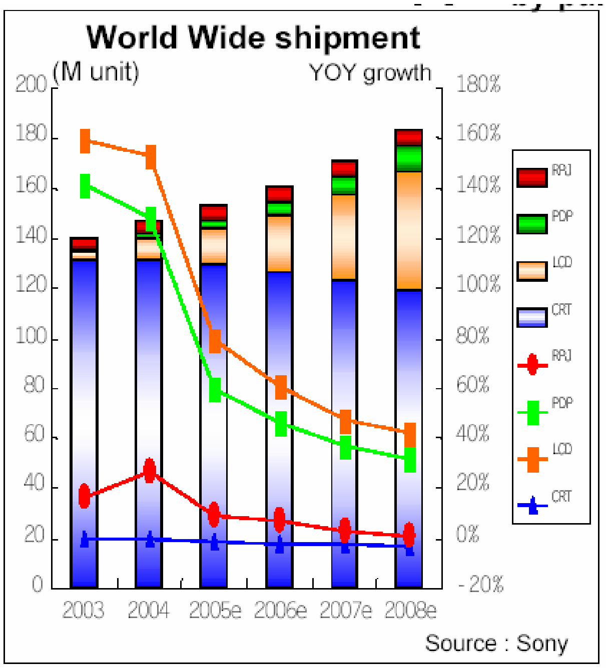
But "the idea of sitting in front of a box in your living room is becoming obsolete. For the TV industry, technology is creating vast opportunities". – Newsweek, June 2005.

Obviously Flat Panel Display (FPD) is one of the technologies that will drive these opportunities:

- High Definition TV (HDTV): Most of the flat TVs on the market are ready to cope with a higher resolution (more lines are needed and a classical CRT TV can not handle it). More and more events will use this new standard. As an example the 2006 Football World Cup will be broadcast in HDTV.
- Digital TV: The analog TV signal will be shut down soon in Europe, as it is replaced by Digital Terrestrial signal. Satellite and Cable Digital decoders are already very common. To get the best out of these digital signals, a high definition TV is definitively a plus. Digital TV will also allow CD-quality audio and six channels of surround sound.
- Bigger screen, smaller form factor: Now that we all have seen these fancy screens, who is willing to go back to the old big bulky box?

FPD includes both LCD (Crystal Liquid Display) and Plasma technologies.

Despite the fact that classical CRT TV will remain the main stream in TV worldwide shipment, FDP is expected to expand at a rapid growth. The CRT market is shrinking very rapidly in Europe, Japan and US.



RPJ: Rear ProJection
PDP: Plasma Display Panel
LCD: Liquid Crystal Display
CRT: Cathode Ray Tube

3 LCD TV Power Supply Requirements

In large FPD (> 27”), the power supply is generally internal as it requires from 100 W to 600 W. A few voltages are needed to supply the various blocks: backlighting, audio, video, demodulation, etc.

Because the input power is above 75 W, the application has to be compliant with the IEC1000-3-2 class D standard. Power Factor Correction is therefore needed. Since the main power supply has to be optimized for higher efficiency and slimmer form factor, an active PFC must be implemented to limit the variation of the input voltage in front of the main PSU.

Most of the LCD TV power supplies are designed to cope with universal mains: 90 Vac to 265 Vac, 47-63 Hz.

CCFL lamps (Cold Cathode Fluorescent) are mainly used for the backlighting. A 24 V rail is used to supply inverters that drive the lamps.

A 5 V auxiliary power supply is needed to supply the microcontroller that must remain alive in standby mode.

Some flat TVs may also already integrate a Digital Tuner that needs 30 V.

Having a low consumption in standby mode is also a key requirement. Recent studies and in situ measurement campaigns have indicated that in the average EU household, between 5% and 10% of its total yearly electricity consumption is due to the standby mode of consumer electronics equipment and other apparatus. TV sets are obviously one of the biggest contributors.

In 1997, the European Commission concluded a negotiated agreement with individual consumer electronics manufacturers and the EU trade association EACEM, to reduce the stand-by losses of TVs and VCRs. In the year 2003 a new agreement for TVs and DVDs was concluded.

Many initiatives have been taken around the word. Even if these requirements are not yet standards, most of the manufacturers have already applied these rules in their designs.

Hereinafter the list of the most important initiatives:

Region / Country	Program name	Requirements for Televisions	Demoboard compliance
China	CECP	3 W	Yes
Korea	Energy Saving	3 W	Yes
European Union	EU Eco-Label	1 W 9 W with a STB	Yes
European Union	EU Code of Conduct	3 W with a STB	Yes
Europe	GEEA	1 W	Yes
US	Energy Star	1 W to 15 W New revision on going	Yes
US	1 Watt Executive Order	1 W	Yes

4 Limitations of existing solutions

One of the key differentiating factors of a flat TV over a classical TV is the thickness of the cabinet - the thinner the better. But one must keep in mind:

- The amount of power to be delivered is relatively large: the number of watts per cm^3 is much larger compared to the one in a CRT TV.
- Because the TV will be used in the living room, audible noise can be a problem, and the use of fans is limited.
- Cost is key in the very competitive environment of the consumer electronics world.
- The panel, the power supply and the audio card are close to each other; therefore EMI and pollution could severely alter the picture and sound quality.

High efficiency and a low EMI signature at a reasonable cost are required, and classical topologies can hardly combine these needs:

- Flyback: transformer usage is far from being optimal
- Forward: the EMI signature is not reduced to its minimum

5 Overcoming limitations with NCP1653 / NCP1395 + NCP5181 / NCP1027

5.1 Architecture Overview

First, the use of active power factor correction in the front-end allows system optimization because the PFC output voltage is well regulated. The implementation of the active PFC front end is made simpler by using the NCP1653, an 8-pin Continuous Conduction Mode (CCM) PFC controller. By choosing the CCM approach for PFC, the peak and rms currents are kept low and better efficiency is achieved in the PFC stage. The output of the PFC stage is set at 385 V.

The SMPS stage uses a Half Bridge Resonant LLC topology. This topology offers a number of advantages as demonstrated in the schematics and the results. It improves efficiency, reduces EMI signature and provides better magnetic utilization. The NCP1395 controller and NCP5181 driver are used to implement the most effective control scheme of Half Bridge Resonant LLC converter.

For the standby output circuit, a higher integration level is made feasible by using the NCP1027, a PWM regulator that also incorporates an appropriate switch to provide all functionality in one package. The use of the true current mode control technique in NCP1027 allows better regulation of the standby power supply. During the standby mode both the PFC and the main PSU are shut off via the signal so called “SBE”. Thus, only the 5 V rail remains supplied and allows the compliance with the international recommendations.

In summary, the architecture selected for this reference design allows design optimization so that the desired performance is achieved without increasing the component costs and circuit complexity too much. The performance results section demonstrates the performance.

5.2 Main power supply: NCP1395 + NCP5181

5.2.1 Half Bridge Resonant LLC topology

The Half Bridge Resonant LLC topology, that is a member of the Series Resonant Converters (SRC), begins to be widely used in consumer applications such as LCD TVs or plasma display panels. In these particular applications, the output power level ranges from 100 W up to 600 W.

The Half Bridge Resonant LLC converter is an attractive alternative to the traditional Half Bridge (HB) topology for several reasons. Advantages include:

- **ZVS (Zero Voltage Switching) capability over the entire load range**: Switching takes place under conditions of zero drain voltage. Turn-on losses are thus nearly zero and EMI signature is improved compared to the HB, which operates under hard-switching conditions.
- **Low turnoff current:** Switches are turned off under low current conditions, and so the turn-off losses are also lowered compared to the HB topology.
- **Zero current turnoff of the secondary diodes:** When the converter operates under full load, the output rectifiers are turned off under zero-current conditions, reducing the EMI signature.
- **No increased component count:** The component count is virtually the same as the classical half bridge topology.

Figure 2 is the structure of this resonant converter. A 50 % duty-cycle half-bridge delivers high-voltage square waves swinging from 0 to the input voltage V_{IN} to a resonating circuit. By adjusting the frequency via a voltage-controlled oscillator (VCO), the feedback loop can adjust the output level depending on the power demand.

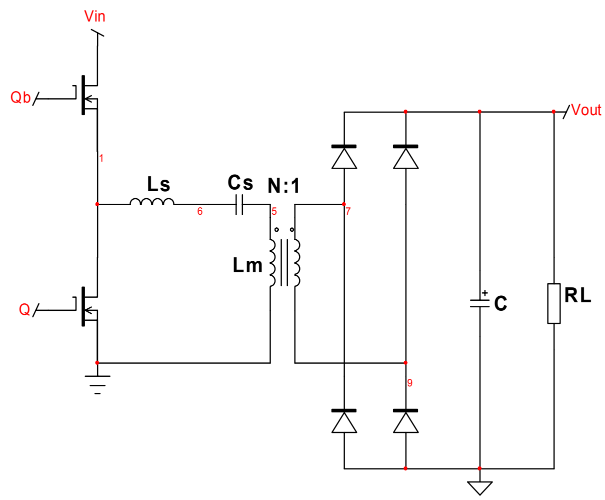


Figure 2

The resonating circuit is made of a capacitor, *Cs,* in series with two inductors, *Ls* and *Lm*. One of these inductors, *Lm*, represents the magnetizing inductor of the transformer and creates one resonating point together with *Ls* and *Cs*. The reflection of the load over this inductor will either make it disappear from the circuit (*Lm* is fully short-circuited by a reflected *RL* of low value at heavy load currents) or will make it stay in series with the series inductor *Ls* in light load conditions. As a result, depending on the loading conditions, the resonant frequency will move between a minimum and a maximum:

$$F_{max} = F_S = \frac{1}{2\pi\sqrt{L_S C_S}}$$

$$F_{min} = \frac{1}{2\pi\sqrt{(L_S + L_m)C_S}}$$

The frequency of operation depends on the power demand. For a low power demand, the operating frequency is rather high, away from the resonating point. To the contrary, at high power, the control loop reduces the switching frequency and approaches one of the resonant frequencies to deliver the necessary amount of current to the load.

This topology behaves like a frequency dependent divider.

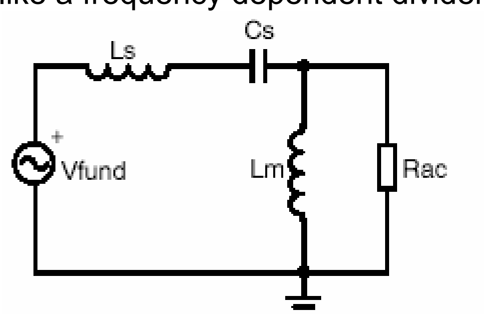


Figure 3: Substitutive schematic of the LLC resonant converter

$$R_{ac} = \frac{8 \cdot R_L}{\pi^2 \cdot n^2 \cdot \eta}$$

Where:
R_L is the real loading resistance
n is the transformer turns ratio
η is the expected efficiency

5.2.2 Protection

The NCP1395 differs from other resonant controllers thanks to its protection features. The device can react to various inputs like:

- **Fast events input:** Like an over-current condition, a need to shutdown (sleep mode) or a way to force a controlled burst mode (skip cycle at low output power).
- **Slow events input:** This input serves as a delayed shutdown, where an event like a transient overload does not immediately stop pulses but starts a timer. If the event duration lasts longer than what the timer imposes, then all pulses are disabled.

5.2.3 Half bridge driver: NCP5181

In a Half Bridge Resonant LLC the upper MOSFET is connected to the high voltage rail, therefore it can not be directly driven by the controller (NCP1395) that is referenced to the ground: a “level shifter” is needed.

The NCP5181 performs this function as it is a High Voltage Power MOSFET Driver that provides two outputs to drive two N-channel power MOSFETs. The NCP5181 uses the bootstrap technique to ensure a proper drive of the high-side power switch. The driver works with two independent inputs to accommodate any topology (including half-bridge, asymmetrical half-bridge).

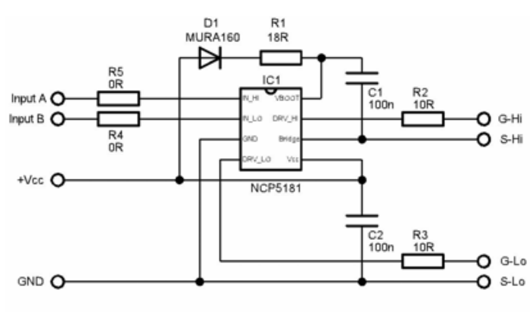


Figure 4: NCP5181

5.3 Standby Power Supply: NCP1027

A NCP1027 is used for the auxiliary flyback power supply. This power supply provides a stable Vcc to supply the NCP1653, the NCP1395 and the NCP5181 under all operating conditions, but it also supplies 5 V to the devices that must remain alive in standby mode.

NCP1027 characteristics:

- **Brown-out detection:** The controller will not allow operation in low mains conditions. You can adjust the level at which the circuit starts or stops operation.
- **Ramp compensation:** Designing in Continuous Conduction Mode helps to reduce conduction losses. However, at low input voltage (85 Vac), the duty-cycle might exceed 50% and the risk exists to enter a subharmonic mode. A simple resistor to ground injects the right compensation level.
- **Over power protection:** A resistive network to the bulk reduces the peak current capability and accordingly harnesses the maximum power at high line. As this is done independently from the auxiliary Vcc, the design gains in simplicity and execution speed.
- **Latch-off input:** Some PC manufacturers require a complete latch-off in the presence of an external event, e.g., over temperature. The controller offers this possibility via a dedicated input.
- **Frequency dithering:** The switching frequency (here 65 kHz) is modulated during operation. This naturally spreads the harmonic content and reduces the peak value when analyzing the signature.

5.4 Power Factor Correction: NCP1653

The NCP1653 is a controller for Continuous Conduction Mode (CCM) Power Factor Correction step-up pre-converters. It controls the power switch conduction time (PWM) in a fixed frequency mode and in dependence on the instantaneous coil current.

Housed in a DIP-8 or SO-8 package, the circuit minimizes the number of external components and drastically simplifies the PFC implementation. The NCP1653 is an ideal candidate in systems where cost-effectiveness, reliability and high power factor are the key parameters. It incorporates all the necessary features to build a compact and rugged PFC stage. More specifically, the following protections make the PFC stage extremely robust and reliable:

- **Maximum current limit:** The circuit immediately turns off the MOSFET if the coil current exceeds the maximum permissible level. The NCP1653 also prevents any turn on of the power switch as long as the coil current is not below this limit. This feature protects the PFC stage during the startup phase when large in-rush currents charge the output capacitor.
- **Undervoltage protection/shutdown:** The circuit stays in shutdown mode as long as the feedback current indicates that the output voltage is lower than 8% of its regulation level. In this case, the NCP1653 consumption is

very low (<50 µA). This feature protects the PFC stage from starting operation in case of too low AC line conditions or of a failure in the feedback network (e.g., bad connection).

- **Overvoltage protection:** Given the low bandwidth of the regulation block, PFC stages may exhibit dangerous output voltage overshoots because of abrupt load or input voltage variations (e.g., at startup). Overvoltage Protection (OVP) turns off the Power Switch as soon as Vout exceeds the OVP threshold (107% of the regulation level).

6 Specifications

Input Voltage: Universal input 90 Vac to 265 Vac, 47-63 Hz

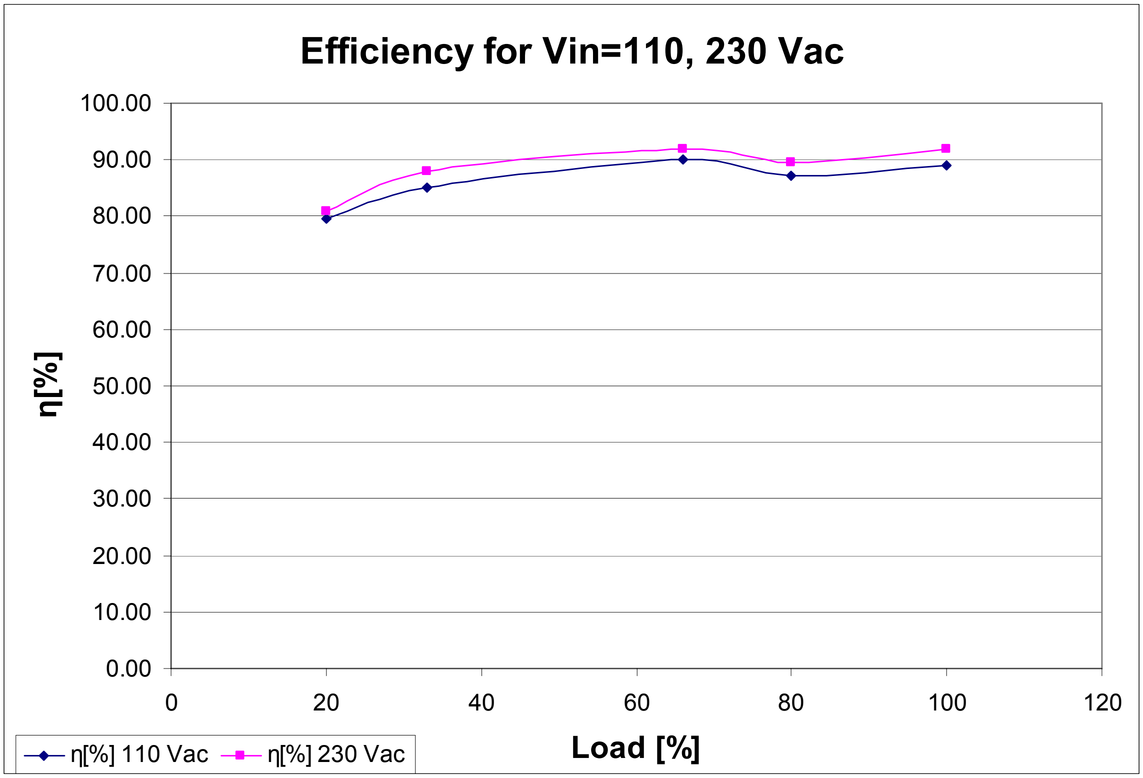
Main Power Supply Output voltages:
- 24 V/6A
- 12 V/3 A
- 30 V/1 A

Standby Power Supply:
- 5 V/2 A
- Pin < 1 W when the consumption on the 5 V is < 80 mA

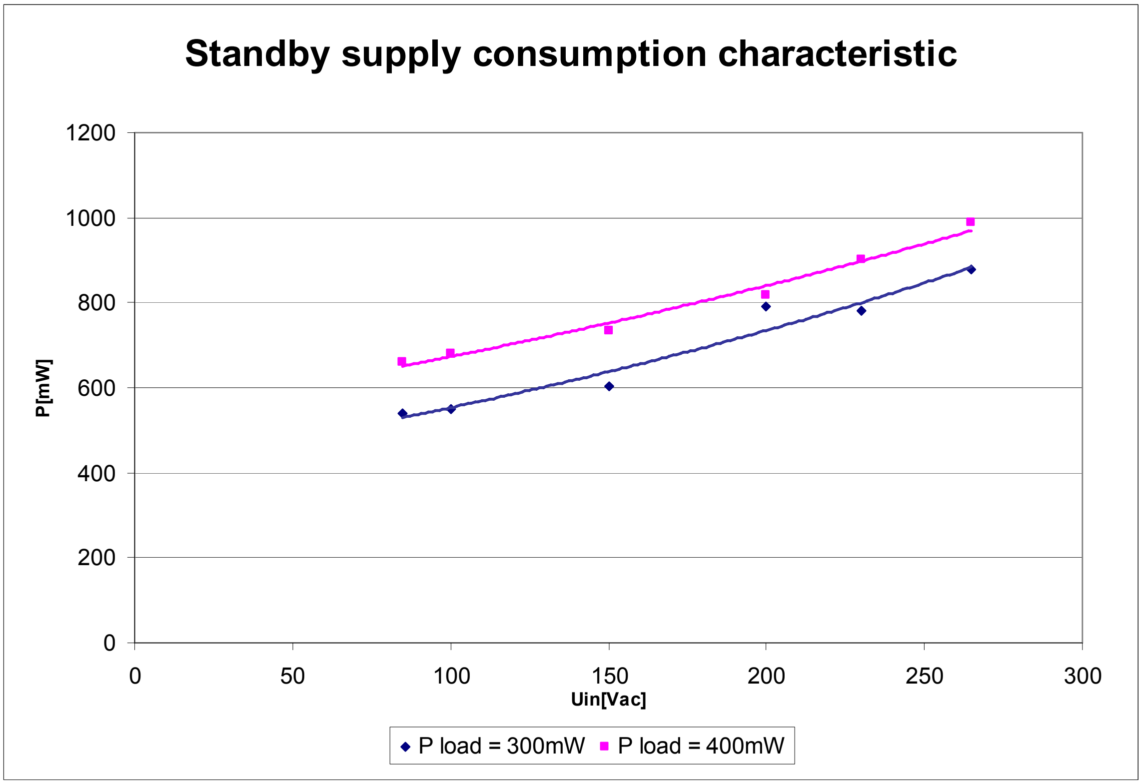
Power Factor Correction
- Compliant with IEC1000-3-2

7 Reference Design Performance Summary

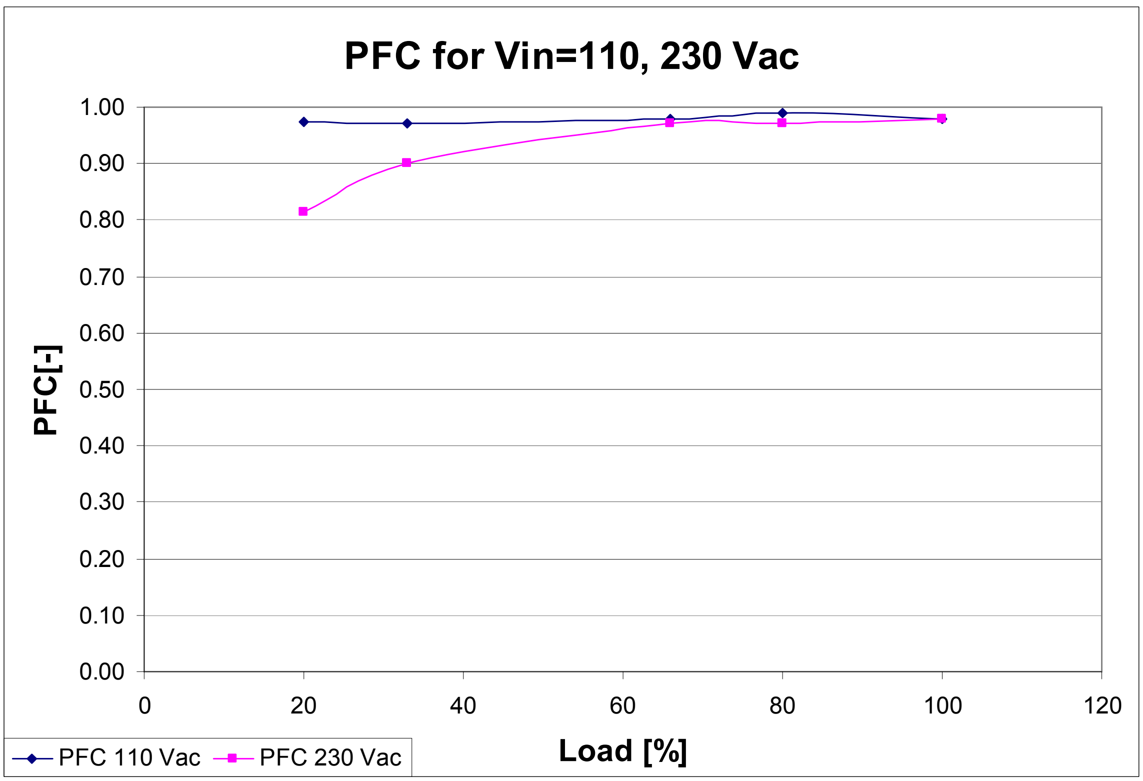
7.1 Efficiency



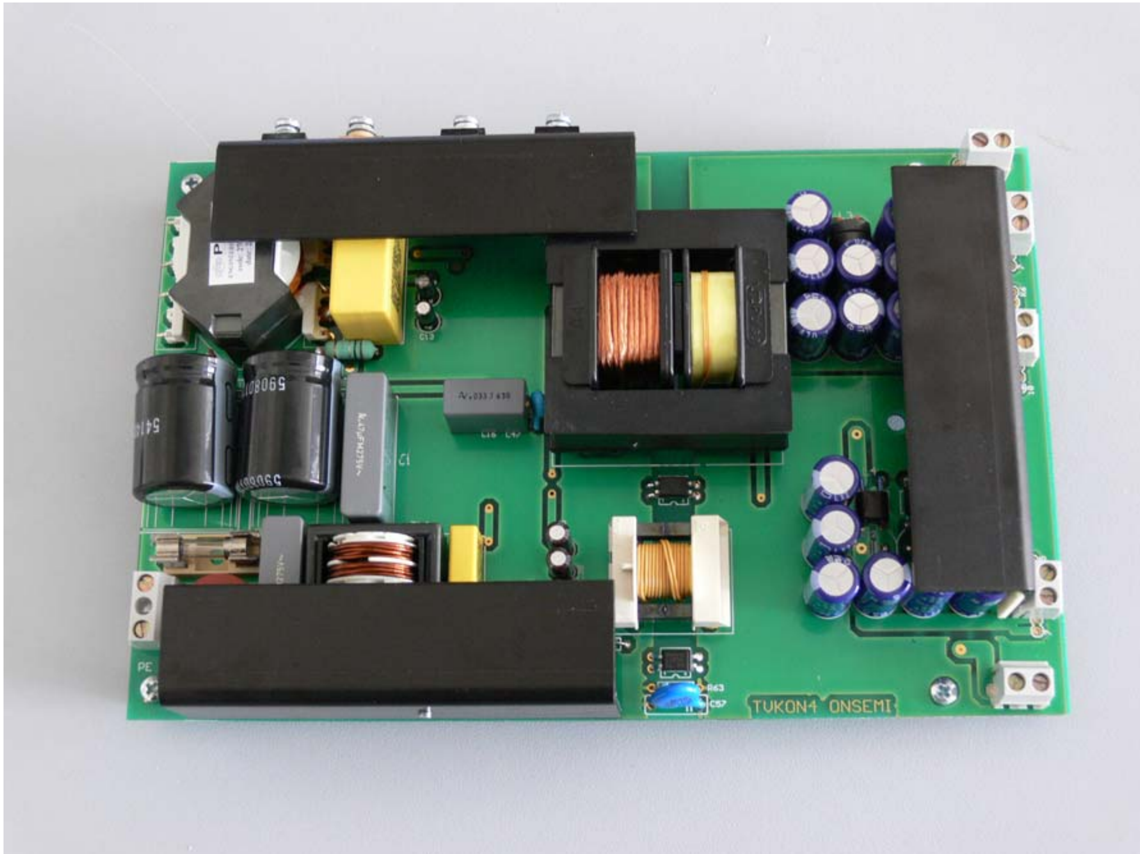
7.2 Standby Power (Output current: 60 & 80 mA)



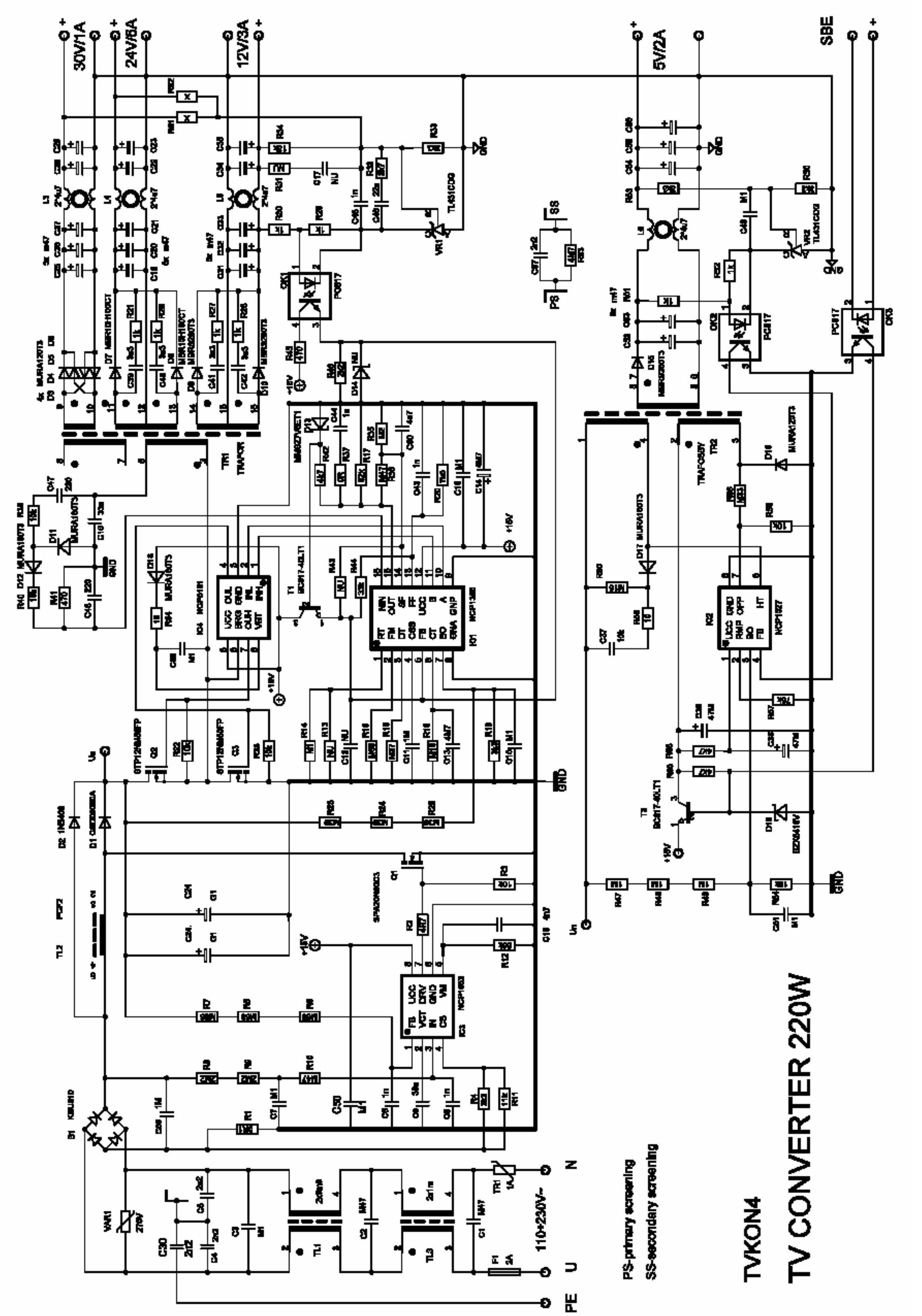
7.3 Power Factor Correction



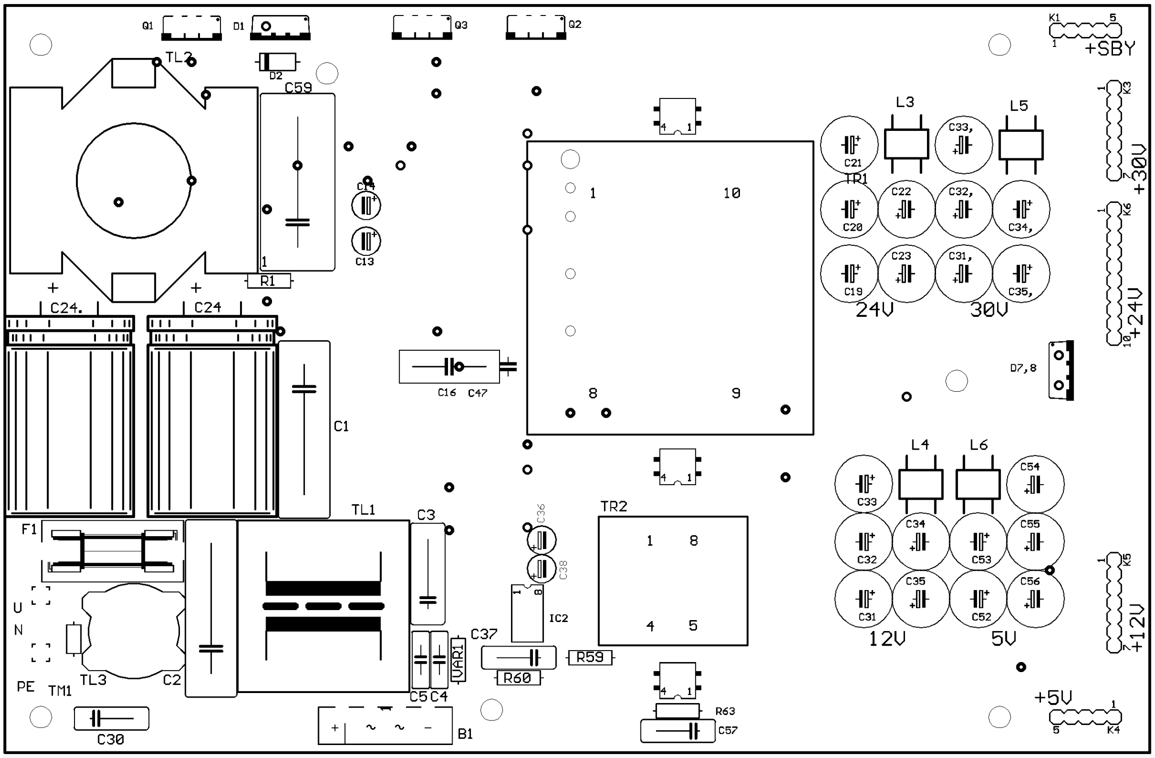
8 Board Picture

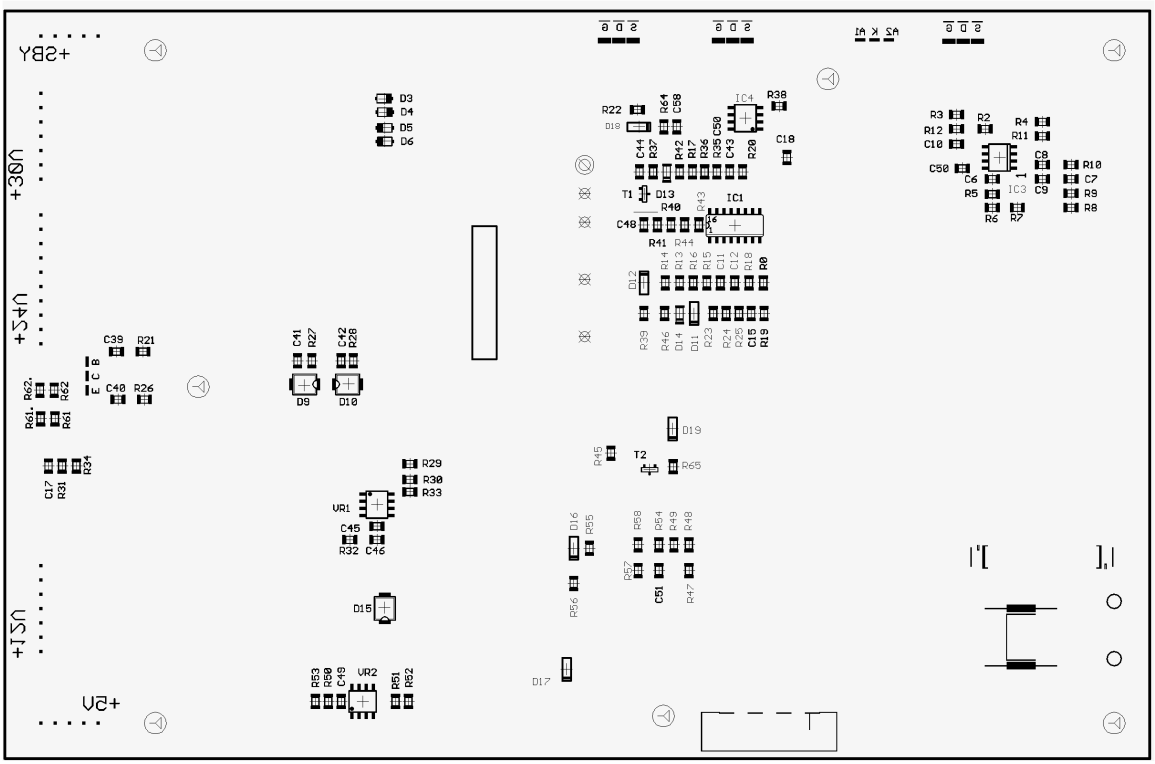


9 Schematic


30V/1A
24V/6A
12V/3A
5V/2A
SBE
110÷230V~
PS-primary screening
SS-secondary screening
TVKON4
TV CONVERTER 220W

10 Board Layout





11 BOM

Designator	Device	Supplier	Package	# Used
IC1	NCP1395	ON Semiconductor	SOIC-16	1
IC2	NCP1027P065G	ON Semiconductor	PDIP-8	1
IC3	NCP1653	ON Semiconductor	SOIC-8	1
IC4	NCP5181DR2G	ON Semiconductor	SOIC-8	1
B1	KBU810	Fuji	KBU	1
D1	CSD06060A	Cree	TO-220	1
D2	1N4007	ON Semiconductor	RM-10	1
D3-6	MURA120T3	ON Semiconductor	SMA	1
D7,8	MBR10H100CT	ON Semiconductor	TO-220	1
D9,10	MBRS260T3	ON Semiconductor	SMB	2
D11,12	MURA160T3	ON Semiconductor	SMA	2
D13	MMSZ7V5ET1	ON Semiconductor	SOD-123	1
D14	not used			
D15	MBRS260T3	ON Semiconductor	SMB	1
D16	MURA120T3	ON Semiconductor	SMA	1
D17,18	MURA160T3	ON Semiconductor	SMA	1
D19	MMSZ16ET1	ON Semiconductor	SOD-123	1
F1	3A/T		RM-22,5	1
L3-6	2*4u7	Amidon	RM-5*10	4
OK1-3	PC817A	Sharp	PDIP-4	3
Q1	SPA20N60C3	SGS	TO-220	1
Q2,3	STP12NM50FP	SGS	TO-220	2
T1,2	BC817-40LT1	ON Semiconductor	SOT-23	2
TL1	2*8m8	Pulse	6001,0063A	1
TL2	PFC2	Pulse	RM14-LP	1
TL3	2*1m	PMEC	101H	1
TM1	3,4A		RM-7,5	1
TR1	TRAFOR	Pulse	2652,0017A	1
TR2	TRAFOSBY	Pulse	E20-16-6	1
VAR1	275V		RM-10	1
VR1,2	TL431CDG	ON Semiconductor	SOIC-8	2
C1,2	M47/275V~X2	Tai Yao	RM27,5	2
C3	M1/275V~X2	Tai Yao	RM-15	1
C4,5	2n2/Y2	EASE	RM-10	2
C6,8	1n		1206	2
C7	M1		1206	1
C9	39n		1206	1
C10	4n7		1206	1
C11	1M		1206	1
C12	not used			
C13,14	4M7/35V=EXR		RM-2,5	1
C15	M1		1206	1
C16	33n/275V~X2		RM-15	1
C17	not used			
C18	M1		1206	1
C19-23	m47/35V=EXR	Hitano	RM-5/d10	5
C24,24	G1/400V=snap-in	Hitano	RM-10/d23*30	2
C25-29	m47/35V=EXR	Hitano	RM-5/d10	5
C30	2n2/Y1	Tai Yao	RM-10	1
C31-35	m47/35V=EXR	Hitano	RM-5/d10	5
C36,38	47M/35V=EXR	Hitano	RM-2,5	1
C37	10n/275V~X2	Tai Yao	RM-10	1
C39-42	3n3		1206	4
C43-45	1n		1206	3
C46	22n		1206	1
C47	220p/1kV=		RM-5	1
C48	220p		1206	1

Designator	Device	Supplier	Package	# Used
C49-51	M1		1206	1
C52-56	m47/35V=EXR	Hitano	RM-5/d10	5
C57	2n2/Y1		RM-10	1
C58	M1		1206	1
C59	1M/275V~	Tai Yao	RM-27,5	1
C60	4n7		1206	1
R1	0R1		RM-10	1
R2	4R7		1206	1
R3	10k		1206	1
R4	11k		1206	1
R5,6	M68		1206	2
R7	M56		1206	1
R8,9	2M2		1206	2
R10	M47		1206	1
R11	3k3		1206	1
R12	56k		1206	1
R13	not used			
R14	M1		1206	1
R15	M68		1206	1
R16	M27		1206	1
R17	82k		1206	1
R18	M15		1206	1
R19	3k3		1206	1
R20	5k6		1206	1
R21	1k		1206	1
R22	10k		1206	1
R23-25	M39		1206	3
R26-30	1k		1206	5
R31	not used			
R32	2k7		1206	1
R33	3k3		1206	1
R34	13k		1206	1
R35	M27		1206	1
R36	M47		1206	1
R37	0R0		1206	1
R38-40	10k		1206	3
R41	470R		1206	1
R42	4k7		1206	1
R43	not used			
R44	33k		1206	1
R45	470R		1206	1
R46	2k2		1206	1
R47-49	1M		1206	3
R50	3k3		1206	1
R51,52	1k		1206	1
R53	3k3		1206	1
R54	18k		1206	1
R55	10k		1206	1
R56	M33		1206	1
R57	75k		1206	1
R58	4k7		1206	1
R59	10R		RM-10	1
R60	M15		RM-10	1
R61,62	X		1206	4
R63	4M7/4kV		RM-10	1
R64	18R		1206	1
R65	4k7		1206	1

12 Appendix

12.1 NCP1395

- Datasheet
- AND8255: A Simple DC SPICE Model for the LLC Converter
- AND8257: Implementing a Medium Power AC-DC Converter with the NCP1395

12.2 NCP5181

- Datasheet
- AND8244: A 36 W Ballast Application with the NCP5181

12.3 NCP1653

- Datasheet
- AND8184: Four Key Steps to Design a Continuous Conduction Mode PFC Stage Using the NCP1653
- AND8185: 300 W, Wide Mains, PFC Stage Driven by the NCP1653
- NCP1653 PFC Boost Design Worksheet

12.4 NCP1027

- Datasheet
- AND8241: A 5 V/2 A Standby Power Supply for Intel Compliant ATX Applications
- NCP1027 Brownout Computing

12.5 References

Draft Commission Communication on Policy Instruments to Reduce Stand-by Losses of Consumer Electronic Equipment (19 February 1999)

- http://energyefficiency.jrc.cec.eu.int/pdf/consumer_electronics_communication.pdf

European Information & Communications Technology Industry Association

- http://www.eicta.org/
- http://standby.lbl.gov/ACEEE/StandbyPaper.pdf

CECP (China):

- http://www.cecp.org.cn/englishhtml/index.asp

Energy Saving (Korea)

- http://weng.kemco.or.kr/efficiency/english/main.html#

Top Runner (Japan):

- http://www.eccj.or.jp/top_runner/index.html

EU Eco-label (Europe):

- http://europa.eu.int/comm/environment/ecolabel/index_en.htm
- http://europa.eu.int/comm/environment/ecolabel/product/pg_television_en.htm

EU Code of Conduct (Europe):

- http://energyefficiency.jrc.cec.eu.int/html/standby_initiative.htm

GEEA (Europe):

- http://www.efficient-appliances.org/
- http://www.efficient-appliances.org/Criteria.htm

Energy Star:

- http://www.energystar.gov/
- http://www.energystar.gov/index.cfm?c=product_specs.pt_product_specs

1 Watt Executive Order:

- http://oahu.lbl.gov/
- http://oahu.lbl.gov/level_summary.html

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