Power Conversion Design Guide
by Raoji Patel
Power Conversion Design Guide

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Component Review: Fred Blatt
Introduction

This guide presents an overview of power conversion technology and lists the major features of the most popular topologies. Basic guidance in selecting the proper topology and its associated components is provided, first through listing the advantages and disadvantages for each topology and secondly through component selection tables which are based on topology, output power and other significant factors.

Clarification of some of the basic questions related to power conversion technology are presented in Appendix I; furthermore, the task of designing of a power supply is made easier by providing some important design equations and related information in Appendix II.
Overview of Power Supply Technology

In recent years, there have been many significant technological changes in power supply design. These became possible with advances in power transistors, integrated circuits, capacitors, and design techniques. This has resulted in lower cost per watt with improved performance.

Techniques for conversion of unregulated DC voltage into the desired DC level continue to center around linear and switching regulators. Linears continue to be heavier, larger, and less efficient than switchers, but they are still less expensive, less complex, and offer better ripple, noise and EMI/RFI specs. Advances affecting linear regulators have been in capacitors with greater “CV” product in small sizes, three terminal regulators with better regulation specs, (like the UC7800A and UC7900A) and control integrated circuits like the UC3834 which offer the ability to build a high efficiency linear using PNP transistors.

Switching regulators continue to incorporate the most changes with many innovations and improvements in technology. Multiple output switchers (40 to 150 watts) are used in high volume for home computers and games. Their cost is setting new record lows, at 40 to 60 cents per watt. Large multiple output switchers (150 to 500 watts) are benefiting from lower cost bipolar switching transistors, such as Unitrode TO220 UMT13000 series transistors, Schottky rectifiers, like the USD TO220 series rectifiers, and broader selection of UC integrated circuits designed to replace large quantities of discrete parts needed to control pulse width modulation, current limit, over-voltage protection, and a variety of other control and monitor functions.

Conventional pulse width modulation (PWM) techniques are being challenged by two major innovations. One is the current mode control integrated circuit, like the UC3842 and UC3846, offering faster and more predictable response than conventional PWM techniques. Another is the voltage feed forward PWM technique which provides faster correction for input voltage changes. A third innovation allows an order of magnitude upward change in switching frequency. The latest technique, the series resonant power supply, operates from 100KHz to several megahertz. Using a sine wave instead of a square wave, this results in lower EMI, lower switching losses and practical reverse recovery requirements.

Unitrode’s power MOSFET’s are prime contributors to new designs, including the series resonant technique. MOSFET’s and high speed bipolar transistors like the UMT2003 are enabling power supply designers to raise PWM switching frequencies from 25KHz to 80KHz and up. This results in a reduction in size of the magnetic and capacitive components.

DC to DC converters continue to find applications in a variety of systems. New functional blocks, such as the PIC910, make the converter easier to build. This is a hybrid circuit with the switching transistors and related components conveniently matched and mounted in a single package including the control integrated circuit.

Designers are continuing to advance the state of the art in switching regulator technology by using new products which help to reduce the size and weight of power packages. Power MOSFET’s, Integrated Circuits, high speed platinum and Schottky rectifiers are such examples.

In an Uninterruptible Power Supply (UPS), some interesting advances are taking place. Small UPS products are emerging to serve the home and office computer market. Another new concept is Direct UPS (DUPS). Only a few small computers have incorporated this option, but its simplicity should attract widespread attention in the years to come. DUPS simply connects battery storage to the DC bus in the system power supply, instead of having to regenerate AC power. To make this a usable concept, designers will need to plan ahead for it in the early stages of system and power supply development.
How to use this “Guide”

The most common power sources and output voltages in a switching regulated power supply are shown in table I. The output voltage and its load current will depend upon the application. The power supply designs are tailored for each individual application.

There is no simple procedure in selecting the right topology for a given application; however, the factors which influence the selection of topology are identified in detail in the next section. One or more of the factors, listed in order of importance for a given application, will help to select the best topology.

1) Efficiency
2) Single vs. multiple output
3) Power output
4) Input voltage source
5) Maximum output current from each output
6) Performance
    • RFI
    • transient response
    • output ripple etc…
7) Size, weight & volume
8) Cost
9) Reliability

The chart shown in figure II provides an overview of most commonly used topologies, and lists the most important characteristics, in brief, for each topology. These characteristics are matched against applications needs for a proper choice of the topology. Further details for the selected topology should be evaluated for the final choice. Guidance for this evaluation is provided in section IV.

Most commonly used topologies in various applications are listed below:

A. Computer Main Frames
   • full-bridge switching regulator
   • current fed followed with a full-bridge
   • step-down or linears in secondary outputs

B. Personal computer, Word processor, Point of sale terminals
   • flyback switching regulator
   • half-bridge switching regulator
   • single transistor or two transistor forward converter
   • step-down or linears in secondary outputs

C. Home computer
   • linear regulator
   • low cost flyback regulator

D. Printer
   • linear regulator
   • step-down regulator
   • flyback regulator

E. PBX systems (switching station)
   • two transistor forward converter
   • half and full bridge regulator
   • step-down or linears in secondary outputs

F. CATV
   • step-down
   • linear regulator
   • flyback regulator

G. Video games
   • linear regulator
   • step-down regulator
   • flyback regulator
   • half-bridge regulator

H. Portable equipment (medical)
   • buck regulator
   • linear regulator
The component selection tables for the switching transistor are developed based on topology, input voltage and output power. The rectifier selection table uses the output voltage and output load current to determine the proper rectifier. The component selection table includes the effect of PWM regulation with 2:1 variation of input voltage.

The next section contains guidelines for selecting the appropriate PWM control circuit for a selected topology. It also describes features for various power supply supervisory circuits, support and monitoring circuits.

Appendices include answers to most often asked questions about power conversion technology and some design equations which will be helpful in the design of a switching regulated power supply.
### MOST COMMON POWER SOURCES FOR SWITCHING POWER SUPPLIES

<table>
<thead>
<tr>
<th>VOLTAGE</th>
<th>DC RANGE USED FOR WORST CASE DESIGN</th>
<th>WHERE USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. A.C. Lines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100V, 60Hz</td>
<td>90–165V</td>
<td>Japanese Power Lines</td>
</tr>
<tr>
<td>117V, 60Hz</td>
<td>100–190V</td>
<td>U.S. Power Lines</td>
</tr>
<tr>
<td>220/230V, 50Hz</td>
<td>200–380V</td>
<td>European Power Lines</td>
</tr>
<tr>
<td>B. Transformer Secondary</td>
<td>Output Voltage:</td>
<td>From AC lines in small equipment</td>
</tr>
<tr>
<td>25V AC</td>
<td>20–40V</td>
<td></td>
</tr>
<tr>
<td>C. DC Source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+12V</td>
<td>7–15V</td>
<td>Automotive batteries</td>
</tr>
<tr>
<td>+24V</td>
<td>14–30V</td>
<td>Truck, etc., batteries</td>
</tr>
<tr>
<td>+28V</td>
<td>18–36V</td>
<td>Aircraft</td>
</tr>
<tr>
<td>+48V</td>
<td>42–56V</td>
<td>Telecommunications</td>
</tr>
<tr>
<td>+400V</td>
<td>300–450V</td>
<td>Mines</td>
</tr>
</tbody>
</table>

### COMMON OUTPUT VOLTAGE FROM POWER SUPPLIES

<table>
<thead>
<tr>
<th>VOLTAGE</th>
<th>TYPICAL APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. −5V, 2.5V</td>
<td>ECL Logic</td>
</tr>
<tr>
<td>B. 3 to 18V, [Typical 12V]</td>
<td>CMOS</td>
</tr>
<tr>
<td>C. +5V</td>
<td>Bipolar Logic</td>
</tr>
<tr>
<td>D. −5 to −12V</td>
<td>PMOS</td>
</tr>
<tr>
<td>E. +5 to +12V</td>
<td>NMOS</td>
</tr>
<tr>
<td>F. ±12V, ±15V, +30V</td>
<td>Operational Amplifier, Commercial Aircraft</td>
</tr>
<tr>
<td>G. +28V</td>
<td>Aerospace, IC Regulators, DC Motors</td>
</tr>
<tr>
<td>H. +48V</td>
<td>Telephone</td>
</tr>
<tr>
<td>I. 1.5KV to 8KV</td>
<td>Focus Voltage CRT</td>
</tr>
<tr>
<td>J. 7KV to 30KV</td>
<td>Anode Voltage CRT</td>
</tr>
</tbody>
</table>

Table I. Possible input-output requirements of a switching regulated power supply.
Figure II. Overview of Power Supply Technology
Power Conversion Technology

This section considers advantages, disadvantages and component selection for various topologies which are commonly used for power conversion.
LINEAR REGULATOR
Output Power: Up To 25 Watts

IT'S USED FOR:
• Extremely low ripple and noise.
• Low input to output voltage difference.
• Tight regulation.
• Fast transient response.

ADVANTAGES
• Low output ripple and noise
• Fast transient response
• Low cost under 1.0 amp of output current
• No RFI or EMI
• No need for high speed switching transistor

DISADVANTAGES
• Efficiency
  Main Regulator ≈ 45%,
  Post Regulator ≈ 65%,
  (with ± 5% line).
• Large heat sink needed to remove the heat, bulky in size.
• In a 25 watt off line power supply, bulky 60Hz transformer is required
• Lower watt per cubic inch compared to switching regulator

TRANSISTOR SELECTION (Type 1)
BVCEO or BVDSS≥1.2 Vin(max)
IC(max) or ID (max)≥ Io(max)
IS/B≥Io(max) at Vin(max) at 125°C junction.
Linear Regulator

A. DEVICE SELECTION (Type 1)

IC control circuit (used for both positive and negative regulators)

- UC3834 High Efficiency Linear Regulator
- Low Input-Output Differential

**Output transistor:**

- Q1 Positive Regulator (>200mA)
  - 2N2907 and 2N4150, GE D44
- Negative Regulator (>200mA)
  - 2N4150

- Minimum \( V_{IN} - V_{OUT} \) less than 0.5V at 5A
- No additional pass device required for \( I_o < 200\text{mA} \)
- Adjustable Low Threshold Current Sense Amplifier
- Under- and Over-Voltage Fault Alert with Programmable Delay
- Over-Voltage Fault Latch with 100mA Crowbar Drive Output

B. DEVICE SELECTION (Type 2)

**Positive Linear Regulator**

<table>
<thead>
<tr>
<th>Output Current</th>
<th>Output Voltages*</th>
<th>adjustable +1.2 to 37V</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 5V</td>
<td>12V</td>
<td>15V</td>
</tr>
<tr>
<td>1.5A</td>
<td>UC7805CK</td>
<td>UC7805CT</td>
</tr>
<tr>
<td>1.5A</td>
<td>UC7805ACK</td>
<td>UC7805ACT</td>
</tr>
<tr>
<td>3.0A</td>
<td>UC7805K</td>
<td>UC7812K</td>
</tr>
</tbody>
</table>

*Max. Input Voltage = +40V

**Negative Linear Regulator**

<table>
<thead>
<tr>
<th>Output Current</th>
<th>Output Voltages*</th>
<th>adjustable −1.2 to −37V</th>
</tr>
</thead>
<tbody>
<tr>
<td>− 5V</td>
<td>− 12V</td>
<td>− 15V</td>
</tr>
<tr>
<td>1.0A</td>
<td>UC320-05K</td>
<td>UC320-05T</td>
</tr>
<tr>
<td>− 1.5A</td>
<td>UC7905CK</td>
<td>UC7905CT</td>
</tr>
<tr>
<td>− 1.5A</td>
<td>UC7905ACK</td>
<td>UC7905ACT</td>
</tr>
</tbody>
</table>

*Max. Input Voltage = −40V
SWITCHING REGULATOR

BUCK REGULATOR—(Step Down Regulator)

Output Power: 5 Watts And Up

IT’S USED FOR:
- High efficiency
- Ease of thermal management
- When only one or two outputs are required
- Large input to output voltage difference
- Spot regulation/point of load
- Battery operated portable equipment

ADVANTAGES
- Provides high efficiency
- Lower cost, size and weight
- Tolerant of line input variations

DISADVANTAGES
- No DC isolation between input and output (to protect output load: it requires a crowbar and fuse).
- Provides only one output per circuit
- Output ripple higher than Linear
- Slow transient response compared to Linear
- Power circuit has 2 pole roll-off characteristics

RECTIFIER SELECTION

Catch Diode
VR ≥ 1.2Vin(max)
IF ≥ IO(max); IF(avg) = IO(max) (1-Dmin)
Reverse recovery of diode should be at least 3 times faster than the current rise time of the transistor.

TRANSISTOR SELECTION

BVCEO or BVDSS ≥ 1.2 Vin (max)
Ic (max) or ID (max) ≥ 1.2 Io(max)
RDS (on) ≈ \frac{75}{ID} \Omega \text{ for } V_{in} \leq 100V
RDS (on) ≈ \frac{2}{ID} \Omega \text{ for } V_{in} \geq 100V
### Buck Regulator (Step Down Regulator)

**Semiconductor Component Selection**

<table>
<thead>
<tr>
<th>Max. Output Load Current</th>
<th>40V</th>
<th>60V</th>
<th>80V</th>
<th>100V</th>
<th>190V</th>
<th>380V</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid: PIC910 or PIC660</td>
<td>PIC601</td>
<td>PIC602</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transistor: UFN523</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>UMT13006</td>
<td>UMT13006</td>
<td>UMT13007</td>
</tr>
<tr>
<td>Rectifier: USD645* or UES1401 or UES1301 (axial)</td>
<td>UFN522</td>
<td>UFN522</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid: PIC910 or PIC660</td>
<td>PIC661</td>
<td>PIC662</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transistor: UFN531</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>UMT13008</td>
<td>UMT13008</td>
<td>UMT13009</td>
</tr>
<tr>
<td>Rectifier: USD645* UES1401</td>
<td>UFN530</td>
<td>UFN530</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid: PIC625</td>
<td>PIC626</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transistor: 2N5038 or UFN541</td>
<td>2N5038</td>
<td>2N5038</td>
<td>2N5038</td>
<td>2N5038</td>
<td>2N5038</td>
<td>2N5038</td>
</tr>
<tr>
<td>Rectifier: USD845* or UES1501</td>
<td>UES1502</td>
<td>UES1502</td>
<td>UES1502</td>
<td>UES1502</td>
<td>UES1502</td>
<td>UES1502</td>
</tr>
<tr>
<td>15A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid: PIC645</td>
<td>PIC646</td>
<td>PIC647</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transistor: 2N5671 or UFN151</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
</tr>
<tr>
<td>Rectifier: UES701</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
</tr>
<tr>
<td>20A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid: PIC670</td>
<td>PIC670</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transistor: 2N5671 or UFN151</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
<td>2N5671</td>
</tr>
<tr>
<td>Rectifier: UES701</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
<td>UES702</td>
</tr>
<tr>
<td>50A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectifier: USD545* or UES801</td>
<td>UES802</td>
<td>UES802</td>
<td>UES802</td>
<td>UES802</td>
<td>UES802</td>
<td>UES802</td>
</tr>
</tbody>
</table>

PIC600 and 800 series are power output stages for buck regulators which contain switching transistors and catch diodes.

PIC910 is a complete buck regulator except for the filter components (includes transistor, catch diode, and PWM control circuit).

*Input voltage 35 volts max.*

**RECOMMENDED PWM CONTROL CIRCUIT:** Refer to section "Selection of PWM control circuit"

Nomenclature: UFN: Power MOSFET; USD: Schottky Rectifier; UES: $t_r = 20-50$ ns Rectifier; SES: $t_r = 100$ ns Rectifier; PIC: Hybrid Circuit.
DISCONTINUOUS MODE FLYBACK REGULATOR

Power Output: Up To 200 Watts

IT'S USED FOR:
- Low cost
- Multiple outputs
- Wide variations in output load currents
- Providing input to output isolation
- Output current less than 7 Amps for any given output
- Good voltage tracking between outputs

ADVANTAGES
- All the output voltages track each other
- Output voltage can be sensed through power transformer
- Fast transient response
- Slow (trr) rectifier is acceptable in outputs
- Only one diode in secondary per output
- No filter inductor in secondary
- Easy to stabilize the closed loop.
  (single pole)

DISADVANTAGES
- Large peak current in the switching diodes and transistors.
- Output capacitor must be twice as large (to obtain lower ESR) when it is compared with continuous mode.
- Transformer is 3 times larger than continuous mode flyback regulator.
- In some cases VF matching is required to obtain proper output DC level for multiple outputs.

RECTIFIER SELECTION

\[
V_R \geq V_o + \frac{V_{\text{in(max)}}}{n} + \left\{ \begin{array}{l}
\text{leakage inductance spike} \\
\text{spike} = 2 \frac{P_o}{\eta V_{\text{in(min)}} D_{\text{max}}}
\end{array} \right.
\]

\[
I_{\text{Fpk}} \geq \frac{2 P_o}{(1-D_{\text{max}}) V_o}
\]

\[
I_{\text{F(avg)}} = 0.4I_{\text{Fpk}}
\]

Slow diode (100-400ns) is acceptable due to low di/dt during turn-off.
DISCONTINUOUS MODE FLYBACK REGULATOR

A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 117/220V AC line input</th>
<th>Input voltage 117V AC line input</th>
</tr>
</thead>
<tbody>
<tr>
<td>50W</td>
<td>UMT13005</td>
<td>UMT13006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN742</td>
</tr>
<tr>
<td>100W</td>
<td>UMT13007-9</td>
<td>UMT13008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN740</td>
</tr>
<tr>
<td>150W</td>
<td>UMT13009</td>
<td>UMT1011</td>
</tr>
<tr>
<td></td>
<td>2N6545</td>
<td>UFN740</td>
</tr>
<tr>
<td>200W</td>
<td>2N6546</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN350</td>
</tr>
</tbody>
</table>

B. RECTIFIER SELECTION

<table>
<thead>
<tr>
<th>Io = Output Current</th>
<th>Vo = Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ 5V</td>
</tr>
<tr>
<td>0.5A</td>
<td>USD1130</td>
</tr>
<tr>
<td>1.0A</td>
<td>USD1130</td>
</tr>
<tr>
<td>3.0A</td>
<td>USD635 IN5821</td>
</tr>
<tr>
<td></td>
<td>(axial)</td>
</tr>
<tr>
<td>5.0A</td>
<td>USD835</td>
</tr>
<tr>
<td>10A</td>
<td>USD935</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>15A</td>
<td>USD935</td>
</tr>
</tbody>
</table>

Snubber Diode — 1N3613, 1N3614
Clamp Diode — 1N3613
Baker Clamp Diode — 1N4946

C. CONTROL CIRCUIT SELECTION

Refer to section “Selection of PWM Control Circuits’
CONTINUOUS MODE FLYBACK REGULATOR

Power Output: Up To 250 Watts

VIN

O

VIN

O

IT'S USED FOR:
- Low cost
- Multiple outputs
- Wide variation in output load current
- Output current is less than 15A per output
- Providing input to output isolation

ADVANTAGES
- Output filter cap is half the size when it is compared with discontinuous mode flyback
- Peak diode and transistor current is approximately ½ times discontinuous mode

DISADVANTAGES
- Rectifier diodes should be 4 times faster than discontinuous mode flyback (trr ≈ 25-100 ns)
- Transformer T1 is larger than discontinuous mode flyback regulator
- Difficult to stabilize the loop because the power circuit has 2 poles and RHP zero

RECTIFIER SELECTION

VR>Vo + \frac{Vin(max)}{n}

IFpk≥\frac{1.2 P_O}{(1-D_{max})V_o}

IF(avg)=0.7IFpk

Rectifiers with fast reverse recovery are required.

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A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 220V AC line or 117V line with doubler</th>
<th>Input voltage 117V AC line</th>
</tr>
</thead>
<tbody>
<tr>
<td>50W</td>
<td>UMT13005</td>
<td>UMT13004 UFN732</td>
</tr>
<tr>
<td>100W</td>
<td>UMT13007</td>
<td>UMT13006 UFN742</td>
</tr>
<tr>
<td>150W</td>
<td>UMT13009 2N6545</td>
<td>UMT13008 UFN740 2N6675</td>
</tr>
<tr>
<td>250W</td>
<td>2N6547</td>
<td>UMT1011 UFN350</td>
</tr>
</tbody>
</table>

B. RECTIFIER SELECTION

<table>
<thead>
<tr>
<th>$I_o$ = Output Current</th>
<th>$V_o$ = Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$+5V$</td>
</tr>
<tr>
<td>0.5A</td>
<td>USD1130</td>
</tr>
<tr>
<td>1.0A</td>
<td>USD1130</td>
</tr>
<tr>
<td>3.0A</td>
<td>USD635 1N5821 (axial)</td>
</tr>
<tr>
<td></td>
<td>UES1301 (axial)</td>
</tr>
<tr>
<td>5.0A</td>
<td>USD835</td>
</tr>
<tr>
<td></td>
<td>UES1501</td>
</tr>
<tr>
<td>10A</td>
<td>USD935</td>
</tr>
<tr>
<td></td>
<td>UES701</td>
</tr>
<tr>
<td>15A</td>
<td>USD935</td>
</tr>
</tbody>
</table>

Snubber Diode — 1N3613, 1N3614
Clamp Diode — 1N3613
Baker Clamp Diode — 1N4946

C. CONTROL CIRCUIT SELECTION

Refer to section "Selection of PWM Control Circuits"
SINGLE ENDED FORWARD CONVERTER

Power Output: Up To 250 Watts

IT'S USED FOR:
- Low output noise and ripple voltage
- Avoiding flux symmetry problems

ADVANTAGES
- Drive circuit is simpler compared to other forward converters
- Only one switching transistor is required

DISADVANTAGES
- Higher cost than flyback design
- Inefficient use of power Transformer $T_1$ ($D_{max} \leq 50\%$) compared to bridge or push-pull topology
- Blocking voltage of transistor $Q_1$ is 2 times input voltage
- Regulation problem at light load for multiple output
- Power circuit has 2 pole small signal characteristic

TRANSISTOR SELECTION

- $V_{CEO} \geq 1.2 V_{in(max)}$
- $BVCER$ or $BVDSS \geq V_{in(max)} - \frac{1}{1-D_{max}}$
- $I_c(max)$ or $I_D(max) \geq \frac{1.2 P_o}{V_{in(min)} D_{max}}$
- $RDS(on) \approx \frac{2 \eta}{I_D(max)}$

RECTIFIER SELECTION

Output rectifier $D_1$

- $V_R \geq \frac{1.2 (V_o + V_F) V_{in(max)}}{V_{in(min)} D_{max}}$
- $I_{Fpk} \geq I_o(max)$
- $I_{F1(avg)} = D(max) I_o(max)$
- $I_{F2(avg)} \approx (1-D_{min}) I_o(max)$

- $D_1$ Reverse recovery $\approx 100-200$ ns
- $D_2$ Reverse recovery $\approx 25-100$ ns
SINGLE ENDED FORWARD CONVERTER

A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 220V AC line or 117V line with doubler</th>
<th>Input voltage 117V AC line</th>
</tr>
</thead>
<tbody>
<tr>
<td>75W</td>
<td>UMT13005</td>
<td>UMT13006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN732</td>
</tr>
<tr>
<td>150W</td>
<td>UMT13007-9</td>
<td>UMT13008</td>
</tr>
<tr>
<td></td>
<td>2N6545</td>
<td>UFN740</td>
</tr>
<tr>
<td>250W</td>
<td>2N6547</td>
<td>UMT1011</td>
</tr>
</tbody>
</table>

B. RECTIFIER SELECTION

<table>
<thead>
<tr>
<th>Io = Output Current</th>
<th>Vo = Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>±5V</td>
<td>±12, ±15V</td>
</tr>
<tr>
<td>1A, 2A</td>
<td>USD640C</td>
</tr>
<tr>
<td></td>
<td>1N5819 (axial)</td>
</tr>
<tr>
<td>5A</td>
<td>USD640C</td>
</tr>
<tr>
<td></td>
<td>1N5822 (axial)</td>
</tr>
<tr>
<td>10A</td>
<td>USD740C</td>
</tr>
<tr>
<td>20A</td>
<td>USD345C</td>
</tr>
<tr>
<td>40A</td>
<td>USM145C</td>
</tr>
<tr>
<td></td>
<td>USD545 (DO-5)</td>
</tr>
<tr>
<td>70A</td>
<td>USM145C</td>
</tr>
<tr>
<td></td>
<td>USD545 (DO-5)</td>
</tr>
</tbody>
</table>

Snubber Diode 1N3613, 1N3614
Clamp Diode 1N3614
Baker Clamp Diode 1N4946

C. IC SELECTION

Refer to section "Selection of PWM Control Circuits"
B. TWO TRANSISTOR FORWARD CONVERTER

Power Output: Up To 500 Watts

IT’S USED FOR:
- High input and transient voltage
- High efficiency and reliability
- Low output ripple and noise

ADVANTAGES
- Lower transistor voltage rating compared to single ended circuit
- High efficiency because of simple non-dissipative snubber and clamp
- Larger input transient capability

DISADVANTAGES
- Dual output drive circuits required
- Poor transformer utilization compared to push-pull and half bridge topology
- Other disadvantages are same as for single ended circuit
- Power circuit has 2 pole small signal characteristics

RECTIFIER SELECTION

Output rectifier

\[
\frac{1.2(V_o + V_F)Vin(max)}{Vin(min) D_{max}} \geq \{\text{leakage inductance spike}\}
\]

\[
IF_{pk} > I_o(max)
\]

\[
IF_1(\text{avg}) = D(max) I_o(max)
\]

\[
IF_2(\text{avg}) = (1-D_{min}) I_o(max)
\]

- \(D_1\), Reverse Recovery: 100–200 ns
- \(D_2\), Reverse Recovery: 25–100 ns
- Clamp diodes \(D_6-D_7\), reverse recovery: 200–400 ns

UNITRODE CORPORATION • 5 FORBES ROAD • LEXINGTON, MA 02173 • TEL. (617) 861-6540 • TWX (710) 326-6509 • TELEX 95-1064
A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 220V AC line or 117V line with doubler</th>
<th>Input voltage 117V AC line</th>
</tr>
</thead>
<tbody>
<tr>
<td>75W</td>
<td>UMT13005 UFN833</td>
<td>UMT13006 UFN731</td>
</tr>
<tr>
<td>150W</td>
<td>UMT13007-9 2N6673 2N6545 UFN843 UFN742 2N6768</td>
<td>UMT13008 UFN741</td>
</tr>
<tr>
<td>250W</td>
<td>2N6675 UFN841</td>
<td>2N6674 UFN351</td>
</tr>
<tr>
<td>500W</td>
<td>2N6678 UFN451</td>
<td>2N6676</td>
</tr>
</tbody>
</table>

B. OUTPUT RECTIFIER—DIODE D₁ and D₂ SELECTION

<table>
<thead>
<tr>
<th>( I₀ = ) Output Current</th>
<th>( V₀ = ) Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>±5V</td>
</tr>
<tr>
<td>1A, 2A</td>
<td>USD6410C U15819 (axial)</td>
</tr>
<tr>
<td>5A</td>
<td>USD640C U15822 (axial)</td>
</tr>
<tr>
<td>10A</td>
<td>USD740C U15841</td>
</tr>
<tr>
<td>20A</td>
<td>USD545C</td>
</tr>
<tr>
<td>40A</td>
<td>USM145C USD545 (DO-5)</td>
</tr>
<tr>
<td>70A</td>
<td>USM145C USD545 (DO-5)</td>
</tr>
</tbody>
</table>

Snubber Diode 1N3613 (2A-800V)

Clamp Diode \( D₆, D₇ \) 1N5420 1N4946

Baker Clamp Diode 1N4946

C. IC SELECTION

Refer to section "Selection of PWM Control Circuits"
HALF-BRIDGE CIRCUIT
Power Level: Up To 500 Watts

IT'S USED FOR:
- Providing high output power
- Optimizing transformer utilization by operating in 1st and 3rd quadrant
- To provide efficient design

ADVANTAGES
- Flux symmetry problems are corrected with capacitor C1
- Leakage inductance and magnetizing energy are pumped into input and output filter caps thus improving efficiency
- Transformer utilization is better than forward converter

DISADVANTAGES
- It requires two 60cps filter caps
- Transistor's storage time should have tight tolerances to avoid gross imbalance in operating flux level
- Power circuit has 2 pole small signal characteristics
- Can't use current-mode PWM control

RECTIFIER SELECTION
$$V_R \geq 2.2 \frac{[V_o + V_F] V_{in}(max)}{V_{in}(min)} + \begin{cases} \text{Voltage} \\ \text{spike due to leakage} \\ \text{inductance} \end{cases}$$

$$I_{Fpk} \geq I_{o(max)}; \quad I_{F(avg)} = 0.5 \quad I_{o(max)}$$

D1 and D2 should be fast (20-100ns)

TRANSISTOR SELECTION
$$BV_{CEO} \text{ or } BV_{DSS} \geq 1.1 \quad V_{in}(max)$$
$$I_{c(max)} \text{ or } I_{d(max)} \geq \frac{2 \cdot P_o}{\eta \cdot V_{in}(min)}$$
$$R_{DS(on)} \approx \frac{2 \cdot \Omega}{I_{D(max)}}$$
A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 220V AC line or 117V line with doubler</th>
<th>Input voltage 117V AC line</th>
</tr>
</thead>
<tbody>
<tr>
<td>50W</td>
<td>UMT13005, UFN821</td>
<td>UMT13006, UFN733</td>
</tr>
<tr>
<td>100W</td>
<td>UMT13007, 2N6543, UFN831</td>
<td>UMT13008, 2N6671, UFN743</td>
</tr>
<tr>
<td>150W</td>
<td>UMT13007, 2N6673, UFN843</td>
<td>UMT13008, 2N6671, UFN741</td>
</tr>
<tr>
<td>250W</td>
<td>UMT13009, 2N6673, UFN841</td>
<td>2N6674, UFN353</td>
</tr>
<tr>
<td>500W</td>
<td>2N6675, UFN451</td>
<td>UMT2003, UFN351</td>
</tr>
</tbody>
</table>

B. RECTIFIER SELECTION

<table>
<thead>
<tr>
<th>$I_o = \text{Output Current}$</th>
<th>$V_o = \text{Output Voltage}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\pm 5V$</td>
</tr>
<tr>
<td>1A, 2A</td>
<td>USD640C, 1N5819 (axial)</td>
</tr>
<tr>
<td>5A</td>
<td>USD640C, 1N5822 (axial)</td>
</tr>
<tr>
<td>10A</td>
<td>USD740C</td>
</tr>
<tr>
<td>20A</td>
<td>USD345C</td>
</tr>
<tr>
<td>40A</td>
<td>USM145C, USD545 (DO-5)</td>
</tr>
<tr>
<td>70A</td>
<td>USM145C, USD545 (DO-5)</td>
</tr>
<tr>
<td>100A</td>
<td>USM20045C, 2xUSD545</td>
</tr>
<tr>
<td>250A</td>
<td>3xUES801</td>
</tr>
</tbody>
</table>

Snubber Diode: 2N3613
Clamp Diode—$D_3, D_4$: 1N4946, 1N5420
Baker Clamp Diode: 1N4946

C. IC SELECTION

Refer to section "Selection of PWM Control Circuits"
FULL BRIDGE—SWITCHING REGULATOR

Power Level: 500–2000 Watts

IT'S USED FOR:

- Providing over 500 watts of output power. Sometimes transformers are paralleled to provide higher power output.

ADVANTAGES

- Provides same advantages as listed for half-bridge regulator
- Only one 60 cps filter cap is required except in doubler configurations
- Provides 2 times the output power of the half-bridge circuit with the same type switching transistor

DISADVANTAGES

- 4 switching transistors and clamp diodes are required
- Power circuit has 2 pole small signal characteristics

TRANSISTOR SELECTION

- \( BV_{CEO} \) or \( BV_{DSS} \geq 1.1 \, V_{\text{in(max)}} \)
- \( I_C(\text{max}) \) or \( I_D(\text{max}) \geq \frac{P_O}{\eta \, V_{\text{in(min)}}} \)
- \( R_{DS(\text{on})} \approx \frac{2}{I_D} \frac{Q}{Q} \)

RECTIFIER SELECTION

- \( V_{R(\text{min})} \geq 2.2 \frac{[V_O + V_F] \, V_{\text{in(max)}}}{V_{\text{in(min)}}} + \left( \text{Voltage spike due to leakage inductance} \right) \)
- \( I_{F(\text{max})} \geq I_{O(\text{max})} \)
- \( I_{F_{1,2}(\text{avg})} = 0.5 \, I_O \)
- \( D_1 \) and \( D_2 \) should be fast (20-100ns)
A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 220V AC line or 117 V line with doubler</th>
<th>Input voltage 117V AC line</th>
</tr>
</thead>
<tbody>
<tr>
<td>200W</td>
<td>UMT13007, 2N6543, UFN831</td>
<td>UMT13008, 2N6671, UFN743</td>
</tr>
<tr>
<td>300W</td>
<td>UMT13009, 2N6673, UFN843</td>
<td>UMT13008, 2N6671, UFN741</td>
</tr>
<tr>
<td>500W</td>
<td>UMT13009, 2N6673, UFN841</td>
<td>2N6674, UFN353</td>
</tr>
<tr>
<td>1000W</td>
<td>2N6675, UFN451</td>
<td>UMT2003, 2N6676, UFN351</td>
</tr>
<tr>
<td>2000W</td>
<td>UMT2003, 2N6678, UFN451(x2)</td>
<td></td>
</tr>
</tbody>
</table>

B. RECTIFIER SELECTION

<table>
<thead>
<tr>
<th>$I_o$ = Output Current</th>
<th>$V_o$ = Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>±5V</td>
</tr>
<tr>
<td>1A, 2A</td>
<td>USD640C, 1N5819 (axial)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>USD640C, 1N5822 (axial)</td>
</tr>
<tr>
<td>10A</td>
<td>USD740C</td>
</tr>
<tr>
<td>20A</td>
<td>USD345C</td>
</tr>
<tr>
<td>40A</td>
<td>USM145C, USD545 (DO-5)</td>
</tr>
<tr>
<td>70A</td>
<td>USM145C, USD545 (DO-5)</td>
</tr>
<tr>
<td>100A</td>
<td>USM20045C, 2xUSD545(DO-5)</td>
</tr>
<tr>
<td>250A</td>
<td>4xUSD545</td>
</tr>
</tbody>
</table>

Snubber Diode 1N3613, 1N3614
Clamp Diode—$D_6, D_7$ 1N4946, 1N5420
$D_8, D_9$
Baker Clamp Diode 1N4946

C. IC SELECTION

Refer to section “Selection of PWM Control Circuits"
CENTER TAPPED PUSH-PULL SWITCHING REGULATOR

Power Level: Up To 150 Watts

IT'S USED FOR:

- Small size and weight
- New control chip UC1846 solves flux symmetry problems associated with push-pull switching regulator.

ADVANTAGES

- Smaller size, weight and cost
- Efficient design
- Easier base drive (both referenced to ground)

DISADVANTAGES

- Inherent flux symmetry problems can be corrected with current-mode PWM control circuit
- Transformer must be slightly over-designed
- Transistor rating twice the input supply voltage
- Power circuit has 2 pole small signal characteristics
- Power circuit has 1 pole small signal characteristics with current-mode control

TRANSISTOR SELECTION

\[
BV_{CEO}(\text{min}) \geq 1.1 \times Vin(\text{max})
\]

\[
BV_{CER}(\text{min}) \text{ or } BV_{DSS} \geq 2 \times Vin(\text{max})
\]

\[
I_{C(\text{max})} \text{ or } I_{D(\text{max})} \geq \frac{P_o}{\eta \times Vin(\text{min})}
\]

\[
R_{DS(on)} \approx 0.75 \times \frac{ID(\text{max})}{ID(\text{max})}
\]

RECTIFIER SELECTION

\[
VR \geq 2.2 \times \frac{[V_o + VF]}{Vin(\text{max})} + \left\{\text{Voltage spike}\right\}
\]

\[
I_{Fpk} \geq I_o(\text{max})
\]

\[
I_{F1,2 \text{ (avg)}} = 0.5 \times I_o(\text{max})
\]

D₁ and D₂ should be fast reverse recovery rectifiers.
A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>12V DC Input</th>
<th>28V DC Input</th>
<th>117 VAC</th>
<th>220 VAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>20W</td>
<td>PIC610</td>
<td>PIC612</td>
<td>UMT13005</td>
<td>UMT13005</td>
</tr>
<tr>
<td></td>
<td>UFN531</td>
<td>UFN522</td>
<td>UFN821</td>
<td>UFN821</td>
</tr>
<tr>
<td>50W</td>
<td>PIC635</td>
<td>PIC637</td>
<td>UMT13005</td>
<td>UMT13005</td>
</tr>
<tr>
<td></td>
<td>UFN541</td>
<td>2N5038</td>
<td>UFN831</td>
<td>UFN831</td>
</tr>
<tr>
<td>100W</td>
<td></td>
<td>2N5038</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN542</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150W</td>
<td></td>
<td></td>
<td>UMT13007</td>
<td>2N6543</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>UFN841</td>
<td></td>
</tr>
</tbody>
</table>

B. RECTIFIER SELECTION

<table>
<thead>
<tr>
<th>$I_o$ = Output Current</th>
<th>$V_o$ = Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>±5V</td>
</tr>
<tr>
<td>1A-2A</td>
<td>USD640C</td>
</tr>
<tr>
<td></td>
<td>1N5819 (axial)</td>
</tr>
<tr>
<td>5A</td>
<td>USD640C</td>
</tr>
<tr>
<td></td>
<td>1N5822 (axial)</td>
</tr>
<tr>
<td>10A</td>
<td>USD740C</td>
</tr>
<tr>
<td>20A</td>
<td>USD345C</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>40A</td>
<td>USM145C</td>
</tr>
<tr>
<td></td>
<td>USD545 (DO-4)</td>
</tr>
</tbody>
</table>

Snubber Diode 1N3613

Clamp Diode—$D_3$, $D_4$ 1N3613

Baker Clamp Diode 1N4946 (600V) trr 250ns.
CURRENT-FED PUSH-PULL SWITCHING REGULATOR

Power Level: Under 150 Watts

IT'S USED FOR:
- Multiple outputs
- Low output ripple and noise
- Large input transient voltage
- Good voltage tracking between multiple outputs
- Providing good transient response to all multiple outputs.

ADVANTAGES
- Input filter inductor \( L_1 \) prevents flux symmetry and cross conduction problem
- Low output ripple due to continuous conduction of current in the output filter cap
- Provides isolation to large input transient voltages
- Reduces the minimum output load requirements

DISADVANTAGES
- Input filter inductor \( L_1 \) must have low leakage inductance to provide good current balance in \( T_1 \)
- Three output filter rectifiers are required
- Power circuit has 2 pole small signal characteristics

TRANSISTOR SELECTION

\[ \text{BVCER or BVdss} \geq V_{\text{in}} + n(V_{\text{o}} + V_F) + \{\text{Spikes}\} \]

\[ I_c(\text{max}) \text{ or } I_D(\text{max}) \approx 1.2 \frac{I_o}{n} \]

\[ R_D(\text{on}) = \frac{2}{I_D(\text{max})} \Omega \]

RECTIFIER SELECTION

Rectifier \( D_1 \) and \( D_2 \) could be a slow diode

\[ \text{voltage rating} \geq 2.2 (V_o + V_F) + \left\{ \begin{array}{l} \text{leakage inductance} \\ \text{spike} \end{array} \right\} \]

Diode \( D_3 \) must be fast (20-100 ns)

\[ \text{VR(min)} \geq V_o + \frac{(V_{\text{in(max)}} - nV_o)}{n} \]

Forward current \( I_{Fpk} \) is same as output current.

\[ I_F(\text{avg}) \approx 0.5 I_o(\text{max}) \]
## A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 220V AC line or 117V line with doubler</th>
<th>Input voltage 117V AC line</th>
</tr>
</thead>
<tbody>
<tr>
<td>75W</td>
<td>UMT13005</td>
<td>UMT13004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN720</td>
</tr>
<tr>
<td>150W</td>
<td>UMT13005</td>
<td>UMT13004</td>
</tr>
<tr>
<td></td>
<td>2N6545</td>
<td>2N6542</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN730</td>
</tr>
<tr>
<td>250W</td>
<td>UMT13007</td>
<td>UMT13006</td>
</tr>
<tr>
<td></td>
<td>2N6545</td>
<td>2N6544</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UFN740</td>
</tr>
</tbody>
</table>

## RECTIFIER SELECTION

### Diode D₁, D₂ Selection:

<table>
<thead>
<tr>
<th>Output Current I₀ (max)</th>
<th>±5V</th>
<th>±12V</th>
<th>±15V, ±28V</th>
<th>±48V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A, 2A</td>
<td>USD635C</td>
<td>SES5401C</td>
<td>SES5402C</td>
<td>SES5403C</td>
</tr>
<tr>
<td></td>
<td>USD1130</td>
<td>SES5101 (axial)</td>
<td>SES5002 (axial)</td>
<td>SES5503 (axial)</td>
</tr>
<tr>
<td>3A</td>
<td>USD635C</td>
<td>SES5401C</td>
<td>SES5402C</td>
<td>SES5403C</td>
</tr>
<tr>
<td></td>
<td>SES5301 (axial)</td>
<td></td>
<td>SES5302 (axial)</td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>USD635C</td>
<td>SES5401C</td>
<td>SES5402C</td>
<td>SES5403C</td>
</tr>
<tr>
<td>10A</td>
<td>USD635C</td>
<td>SES5401C</td>
<td>SES5402C</td>
<td>SES5403C</td>
</tr>
<tr>
<td>20A</td>
<td>USD835</td>
<td>SES5501</td>
<td>SES5502</td>
<td></td>
</tr>
<tr>
<td>40A</td>
<td>USM140C</td>
<td>UES701</td>
<td>UES702</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USD6035</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Diode D₃ Selection:

<table>
<thead>
<tr>
<th>±5V</th>
<th>±12V</th>
<th>±15V, ±28V</th>
<th>±48V</th>
</tr>
</thead>
<tbody>
<tr>
<td>USD1130</td>
<td>UES1001</td>
<td>UES1002</td>
<td>UES1003</td>
</tr>
<tr>
<td>1N5821</td>
<td>UES1301</td>
<td>UES1302</td>
<td>UES1303</td>
</tr>
<tr>
<td>USD635</td>
<td>UES1401</td>
<td>UES1402</td>
<td>UES1403</td>
</tr>
<tr>
<td>USD835</td>
<td>UES1401</td>
<td>UES1402</td>
<td>UES1403</td>
</tr>
<tr>
<td>USD935</td>
<td>UES1501</td>
<td>UES1502</td>
<td>UES1503</td>
</tr>
<tr>
<td>(x2)</td>
<td>UES701 (x2)</td>
<td>UES702 (x2)</td>
<td></td>
</tr>
</tbody>
</table>

### Snubber Diode
- 1N3613 (2A-800V)

### Clamp Diode
- 1N4946 (1A-600V)

### Baker Clamp Diode
- 1N4946

## D. IC SELECTION

Refer to section "Selection of PWM Control Circuits"
SERIES RESONANT SINE WAVE SWITCHING REGULATOR

Power Level: Less Than 150 Watts

IT'S USED FOR:
- Reduced size, weight and sometimes cost
- Low RFI and EMI
- Increased efficiency (85-90%)
- Higher frequency

ADVANTAGES
- Higher efficiency
- Smaller weight and volume
- Low switching losses allows high frequency operation. Thus reduced size of magnetics and heat sink.
- Reduced EMI—no trr related current spike, low di/dt current waveforms
- Increased reliability
  —LR acts as current limiter
  —zero current switching, no heat generated
- Problem with leakage inductance is minimized.

TRANSISTOR SELECTION
- $BVDSS \geq 1.1 \times \text{Vin(max)}$
- $I_D(\text{max}) \geq 3.5 \times \frac{2 \times P_O}{\text{Vin(min)}}$
- $I_D(\text{rms}) = 0.5 \times I_D(\text{max})$
- $RDS(\text{on}) \approx \frac{2V}{I_D(\text{rms})}$

DISADVANTAGES
- Requires additional resonant network, LR and CR
- Current rating of the switch is 3 to 4 times higher than conventional switching regulator
- Output filter cap carries high ripple current

RECTIFIER SELECTION
For $D_3$, $D_4$:
- $V_R \geq 2.2 \times V_O + \text{Voltage Spike}$
- $I_{Fpk} \geq \sqrt{2} \times I_O(\text{max})$
- $I_F(\text{avg}) = 0.35 \times I_{Fpk}$

For $D_1$ and $D_2$: $V_R = 1.2 \times \text{Vin(max)}$

For $D_3$ and $D_4$: slow reverse recovery diodes relative to frequency of operation can be used.
A. TRANSISTOR SELECTION

<table>
<thead>
<tr>
<th>Output Power</th>
<th>Input voltage 220V AC line or 117V line with doubler</th>
<th>Input voltage 117V AC line</th>
</tr>
</thead>
<tbody>
<tr>
<td>50W</td>
<td>UFN831</td>
<td>UFN743</td>
</tr>
<tr>
<td>100W</td>
<td>UFN841</td>
<td>UFN741</td>
</tr>
<tr>
<td>150W</td>
<td>UFN451</td>
<td>UFN351</td>
</tr>
</tbody>
</table>

B. OUTPUT RECTIFIER—DIODE D₃ or D₄ SELECTION

<table>
<thead>
<tr>
<th>Iₒ = Output Current</th>
<th>Vₒ = Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>±5V</td>
<td>±12V</td>
</tr>
<tr>
<td>1A, 2A</td>
<td>USD635C</td>
</tr>
<tr>
<td></td>
<td>USD1130 (axial)</td>
</tr>
<tr>
<td>3A</td>
<td>USD635C</td>
</tr>
<tr>
<td></td>
<td>SES5301 (axial)</td>
</tr>
<tr>
<td>5A</td>
<td>USD635C</td>
</tr>
<tr>
<td></td>
<td>SES5301 (axial)</td>
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<tr>
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<td>SES5301 (axial)</td>
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<tr>
<td>20A</td>
<td>USD835</td>
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<tr>
<td>40A</td>
<td>USM140C</td>
</tr>
<tr>
<td></td>
<td>USD6035</td>
</tr>
</tbody>
</table>

Snubber Diode 1N4944, 1N4946
Clamp Diodes D₁, D₂ 1N4944, 1N4946

C. IC SELECTION

Refer to section "Selection of PWM Control Circuits"
## SELECTION OF PWM CONTROL CIRCUITS

The important features of the PWM control circuit and their recommended applications are listed below. It should be used as a guideline for selecting the PWM control circuit.

<table>
<thead>
<tr>
<th>Conventional PWM Circuits</th>
<th>Features</th>
<th>Recommended Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>UC3524A</td>
<td>• pin to pin compatible with UC3524</td>
<td>• step-down regulator</td>
</tr>
<tr>
<td></td>
<td>• uncommitted push-pull with 200mA and 60V capability</td>
<td>• flyback-type</td>
</tr>
<tr>
<td></td>
<td>• under voltage lockout (8V)</td>
<td>• single ended forward</td>
</tr>
<tr>
<td></td>
<td>• ±1% reference</td>
<td>• two transistor forward</td>
</tr>
<tr>
<td></td>
<td>• fast pulse by pulse current limit with wide common mode input range</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• double pulse suppression circuit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• low stand-by current</td>
<td></td>
</tr>
<tr>
<td>UC3525A/3527A</td>
<td>• push-pull totem pole output with 500mA peak current capability</td>
<td>• power MOSFET single ended flyback and forward</td>
</tr>
<tr>
<td></td>
<td>• oscillator range up to 500KHz</td>
<td>• two transistor forward</td>
</tr>
<tr>
<td></td>
<td>• ±1% reference</td>
<td>• half bridge</td>
</tr>
<tr>
<td></td>
<td>• under voltage lock out (8V)</td>
<td>• push-pull/full bridge</td>
</tr>
<tr>
<td>UC3526</td>
<td>• push-pull totem pole output with 200mA peak current capability</td>
<td>• power MOSFET flyback regulator</td>
</tr>
<tr>
<td></td>
<td>• oscillator range up to 400KHz</td>
<td>• power MOSFET single ended forward</td>
</tr>
<tr>
<td></td>
<td>• ±1% reference</td>
<td>• two transistor forward</td>
</tr>
<tr>
<td></td>
<td>• under voltage lock out (8V)</td>
<td>• half bridge</td>
</tr>
<tr>
<td></td>
<td>• fast pulse by pulse current limit with wide common-mode input voltage</td>
<td>• push-pull/full bridge</td>
</tr>
<tr>
<td></td>
<td>• double pulse suppression circuit</td>
<td>• current-fed</td>
</tr>
<tr>
<td>UC493A series</td>
<td>• uncommitted push-pull output with a 200mA capability</td>
<td>• single ended forward</td>
</tr>
<tr>
<td></td>
<td>• under voltage lock out (6.5V)</td>
<td>• two transistor forward</td>
</tr>
<tr>
<td></td>
<td>• ±1% reference</td>
<td>• flyback-type</td>
</tr>
<tr>
<td></td>
<td>• two independent error amplifiers with a wide common-mode input voltage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• double pulse protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 80mV internal threshold included in one of the error amplifiers for UC493A and UC495B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• UC495A and B includes 39V zener for over 40V input supply</td>
<td></td>
</tr>
</tbody>
</table>
## SELECTION OF PWM CONTROL CIRCUITS (Cont’d)

### Feed-Forward PWM Control Circuit

<table>
<thead>
<tr>
<th>UC3840</th>
<th>Features</th>
<th>Recommended Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• single ended output with a 400mA output current capability  &lt;br&gt; • pulse by pulse and over current limiting amplifiers with a 3.0V common-mode input voltage range  &lt;br&gt; • ±1% reference  &lt;br&gt; • low stand-by current with a programmable start voltage  &lt;br&gt; • programmable under and over voltage protection circuit  &lt;br&gt; • intended for primary side control  &lt;br&gt; • UC3840 + UC3706 allows push-pull operation</td>
<td>• single ended forward  &lt;br&gt; • two transistor forward  &lt;br&gt; • flyback-type  &lt;br&gt; • current fed</td>
</tr>
</tbody>
</table>

### Current-mode PWM Control Circuits

<table>
<thead>
<tr>
<th>UC3842</th>
<th>Features</th>
<th>Recommended Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• low cost 8 pin IC circuit  &lt;br&gt; • single totem pole output circuit with a 200mA peak current capability  &lt;br&gt; • less than 1mA start-up current up to 16 volt  &lt;br&gt; • pre-set 16V start-up voltage and 10V under voltage lock-out  &lt;br&gt; • + 1 volt internally set threshold for pulse by pulse current limiting</td>
<td>• single ended forward  &lt;br&gt; • two transistor forward  &lt;br&gt; • flyback-type  &lt;br&gt; • current-fed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UC3846/47</th>
<th>Features</th>
<th>Recommended Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• push-pull totem pole output with 500mA peak current capability  &lt;br&gt; • ±1% reference  &lt;br&gt; • under voltage lock out (8V)  &lt;br&gt; • double pulse suppression  &lt;br&gt; • current sense amplifier with wide common-mode input voltages</td>
<td>• step-down regulators  &lt;br&gt; • push-pull/full bridge (not half bridge circuit)</td>
</tr>
</tbody>
</table>
## POWER SUPPLY SUPPORT FUNCTIONS

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Key Features</th>
</tr>
</thead>
</table>
| UC3543     | Power Supply Supervisory Circuit, Monitors and Controls Power Supply Output   | • Over/Under-Voltage, and Current Sensing Circuits  
• Programmable Time Delays  
• SCR “Crowbar” Drive of 300mA  
• Optional Over-Voltage Latch  
• Internal 1% Accurate Reference  
• Remote Activation Capability  
• Uncommitted Comparator  
• Inputs for Low Voltage Sensing (UC3544 series only) |
| UC3544     |                                                                            |                                                                                                                                             |
| UC3706     | Dual High Current MOSFET Compatible Output Driver                            | • Dual 1.5A Totem Pole Outputs  
• Parallel or Push-Pull Operations  
• Single-Ended to Push-Pull Conversion  
• Internal Overlap Protection  
• Analog, Latched Shutdown  
• High-Speed, Power MOSFET Compatible  
• Thermal Shutdown Protection  
• 5 to 40V Operation  
• Low Quiescent Current |
| UC3901     | Isolated Feedback Generator Stable and Reliable Alternative to an Optical Coupler | • An Amplitude-Modulation System for Transformer Coupling an Isolated Feedback Error Signal  
• Internal 1% Reference and Error Amplifier  
• Loop Status Monitor  
• Low-Cost Alternative to Optical Couplers  
• Internal Carrier Oscillator Usable to 5MHz  
• Modulator Synchronizable to an External Clock |
| UC3903     | Quad Supply and Line Monitor Precision System                               | • Monitor Four Power Supply Output Voltage Levels  
• Both Over- and Under-Voltage Indicators  
• Internal Inverter for Negative Level Sense  
• Adjustable Fault Window  
• Additional Input for Early Line Fault Sense  
• On Chip, High-Current General Purpose OP-AMP |
APPENDIX I

QUESTIONS MOST OFTEN ASKED

1. Define Topology.
The circuit configuration by which power is transferred from the input power source to the output. Topology refers to the type of power transfer circuit.

2. What is an error amplifier and error voltage?
The voltage difference between the fixed reference and the regulated output is amplified by the error amplifier of the control circuit. The output of this amplifier is called the error voltage. The error voltage is used to change the on-time of the power output switch.

3. What is the PWM technique?
PWM is the abbreviation for Pulse Width Modulation. This technique translates the voltage level of an analog signal into the appropriate pulse width by comparison with a voltage ramp circuit. At the beginning of the cycle, the ramp voltage starts at zero and the output of the comparator is set high. Ramp voltage increases linearly through the entire cycle. When the ramp voltage is equal to the analog signal, the comparator output is set low (the analog signal represents the output of an error amplifier). The peak amplitude of the ramp voltage is fixed in a conventional PWM technique.

4. Describe the input voltage feed-forward PWM technique & its advantages.
It is a variation of the pulse width modulation technique. The output pulse-width of the control circuit is not only controlled by the error voltage but also the input supply voltage. The level of the error voltage remains fairly constant for several cycles. (Note that the ramp voltage starts from zero at the beginning of the cycle, and continues to increase linearly for the entire cycle.) The ramp slope is proportional to the input line voltage. Thus any change in input line voltage is immediately translated into a change of pulse width in the same cycle.

The main advantages of the PWM technique are:
• Low input audio susceptibility
• Smaller transformer
• Less loop gain required

5. What are the basic differences between current-fed converter (topology) and current-mode control (control method) converters, and what are the main advantages of the current-mode PWM technique?
In a current-fed converter the power source used to power the post converter has constant current characteristics. Usually a filter inductor is used in the input line to achieve constant current source characteristics. With a current-mode control, the primary current is utilized to generate the ramp voltage, instead of the fixed ramp voltage which is used for the conventional PWM technique. This ramp voltage is needed to determine the output pulse width of the control chip. The major advantages of current-mode PWM techniques are:
• Stable circuit
• Fast transient response
• Pulse by pulse current limiting
6. **What is the main function of the compensation network?**
   It provides stabilization necessary to avoid oscillation, with the higher loop gain necessary for good line and load regulation.

7. **What is a right half plane (RHP) zero?**
   The RHP zero is a particular characteristic of the closed loop system. A right half plane zero in a control loop occurs only in a continuous-mode flyback topology rather than the control circuit. The continuous-mode flyback is an example. In a switching regulator, the on-time of the power switch increases when the output voltage drops below the desired level. This results in increased output power until output voltage reaches the desired level. However, in a continuous-mode flyback, this increase in on-time results in reduction of output power temporarily. (Note that power is delivered to output only during off-time.) This provides additional 90° phase lag in the control loop. This can result in unstable circuit operation at high frequency.

8. **What is pulse by pulse current limiting?**
   The pulse by pulse current limit circuit senses the switching current and if it exceeds the pre-set maximum current level, it terminates conduction of the output voltage control loop and switching transistor. The transistor turns on again at the beginning of the next cycle and if the switching current is over the current limit, the transistor immediately turns off.

9. **What is ripple?**
   The AC voltage across the output filter capacitor is referred to as the output ripple voltage. The peak to peak variation in current in an output filter inductor is also sometimes known as ripple current.

10. **Why is minimum reverse recovery time desirable?**
    To reduce current pulses which will result in:
    - Reduced radio frequency interference (RFI)
    - Reduced turn-on switching losses in transistor
    - Reduced turn-off losses in the rectifier

11. **What is the difference between a soft and an abrupt reverse recovery characteristic?**
    The rate at which reverse recovery current (di/dt) goes to zero determines the characteristic. Turn-off current waveforms for soft and abrupt reverse recoveries are shown below:

    ![Diagram of soft and abrupt reverse recovery characteristics]
12. **List advantages of a soft reverse recovery characteristic over an abrupt one.**

   Soft reverse recovery advantages are:
   - Lower RFI
   - Less voltage ringing

13. **Determine the reverse blocking voltage requirements for the output rectifiers in a +5V off-line PWM switching regulator.**

   The voltage waveforms to determine voltage requirements of the rectifier at low line are shown below:

   \[
   Yo = 2R \left( \frac{V_o}{(T - td)/T} + V_F \right) + \text{leakage inductance spike} \\
   \frac{(T - td)}{T} = 0.9 \text{ to } 0.95 \\
   = 4 \left[ \frac{5}{7} + 0.8 \right] + 7 = 32 \text{ volts}
   \]

   Note that the ratio (R) between the maximum input DC voltage across 60cps input filter capacitor (just before capacitor recharges—at minimum input voltage with full load) to the maximum DC voltage (at high line with no load) is approximately two.

14. **What are the functional differences between clamp, catch and rectifier diodes?**

   - **Clamp diode**—Limits the maximum voltage excursions across device.
   - **Catch diode**—Provides current path for the inductor load current or transformer magnetizing current.
   - **Rectifier diode**—Directly converts AC voltage into pulsating DC voltage.

15. **What is the main function of a crow-bar circuit?**

   The output voltage of the power supply provides power for many logic circuits. The voltage across these logic circuits must be limited to a safe value to prevent damage to these devices. The techniques used to limit excessive voltage are:
   - **A. Zener clamp**—
     It is used to limit voltage due to short duration transient pulses. Voltage is clamped with a power zener.
B. Crow-bar circuit—
When output voltage exceeds pre-determined value, the silicon controlled rectifier (SCR) across the output turns on, and clamps the voltage by the forward drop of the SCR. Crow-bar needs to be reset to resume normal operation.

16. What is a Synchronous rectifier?
A power MOSFET or bipolar transistor can be used in place of a rectifier to improve the efficiency. Operating these devices in on-state, the developed voltage drop is considerably less than the low forward drop of a schottky rectifier. The device operates from the AC input voltage and conducts when input voltage is slightly greater than output voltage.

17. What is the difference between a buck regulator and a step-down regulator?
They are the same circuit. This circuit converts a high input voltage to a lower output voltage.

18. What are the advantages and disadvantages of the single transistor forward converter compared to a buck regulator?
Advantages:
- Provides DC isolation between input supply voltage and the output voltage.
- Provides multiple outputs.
- Optimizes the switching transistor and rectifier utilization when there is a large difference between input and output voltage.

Disadvantages:
- Needs transformer in addition to filter inductor.
- Less efficient, it needs snubber network, switching losses are higher.
- More expensive.

19. Which is the lowest cost topology for multiple output power supply?
Discontinuous-mode flyback.

20. List the differences between a continuous-mode and a discontinuous-mode flyback.

<table>
<thead>
<tr>
<th>DISCONTINUOUS-MODE</th>
<th>CONTINUOUS MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• current in transformer drops to zero every cycle</td>
<td>• it has RHP zero and 2 poles</td>
</tr>
<tr>
<td>• smaller transformer</td>
<td>• needs fast output rectifier</td>
</tr>
<tr>
<td>• output filter caps 2 times larger</td>
<td>• approx. 2 times lower peak currents in transistor and rectifier</td>
</tr>
<tr>
<td>• single-pole</td>
<td></td>
</tr>
</tbody>
</table>

21. What is the main difference between an inverter and a converter?
Inverter has DC input and AC output;
converter has AC or DC input and DC output.

22. What is proportional base drive?
A base drive circuit where base current is always a certain fraction of the collector current. The ratio between these two currents is determined by the turns ratio of the current transformer used in the base drive circuit.
23. Define storage-time and why minimum storage-time is desirable.
The time elapsed between the on-set of the turn-off signal to the instant when collector voltage starts to increase. It is important to have low storage-time to:
- control minimum pulse width
- reduce saturation losses during storage time
- prevent core saturation due to transformer asymmetry

24. Give two main functions for the snubber network.
- to reduce peak power dissipation during switching
- to reduce radiated noise

25. What are the advantages of a power MOSFET over a bipolar device in a switching regulator application?
A. Higher Efficiency
B. Faster Switching Characteristics
C. Lower System Cost
   - drive circuit simpler
   - no snubber circuit required
   - smaller magnetics & filter capacitor
   - in a high current application, devices can be paralleled easily
D. Improved Performance
   - no cross conduction current in push-pull circuits (no storage time)
E. Allows the use of new topology—series resonant converter
F. Improved Reliability
   - no forward or clamped reverse bias second breakdown problems
   - uniform junction temperature
   - integral diode can reduce component count

26. Why is isolation necessary?
When an output is derived from a 117V or 220V AC line input voltage, the output should have 3750V isolation (VDE requirements) from the 117V or 220V AC line for safety reasons.

27. What is the function of a Baker Clamp?
The collector current of the power transistor in a switching regulator is proportional to variable output load current. Normally, with bipolar transistors the fixed base drive current is optimized for a maximum output load current. This can result in unacceptably large storage time at light load, because the transistor will be driven into deep saturation. The baker clamp prevents deep transistor saturation by providing a path for excessive base drive current. Many applications, such as flyback and forward converters, are utilizing this technique. The baker clamp diode must have a fast reverse recovery time.

28. Define power factor and why it is important to keep close to one.
In an off-line switching regulator, the pulsating DC input voltage is derived through an input bridge rectifier. This pulsating DC voltage is utilized to charge the (60cps) input filter capacitor. The capacitor charges during the peak portion of the input pulsating DC voltage. The input AC voltage is isolated from the capacitor during the rest of the cycle.
When the capacitor charges from the input line voltage, it draws large peak currents, rather than continuous currents during the entire cycle. This large current drawn from the line, during a short period of the cycle, causes additional $I^2R$ losses in the lines. The power factor can be defined by equation:

$$P.F. = \frac{\text{Output power}}{\text{Input AC voltage } \times \text{RMS input current}}$$

29. **Why does the input supply line see a negative input impedance when the output load is a switching regulator?**

With a fixed output load current, the peak current drawn from the input supply voltage remains the same even if input voltage is increased; however, the duty cycle is reduced to maintain output voltage regulation. Therefore average current drawn from the supply voltage is reduced while the input voltage increased to maintain constant power output. This negative change in current results in a line which sees a negative input impedance. Any inductance in the input line will cause oscillation if proper damping is not provided.

30. **Is efficiency affected by the absolute value of the output voltage?**

$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Output Power} + \text{Losses}}$$

Most of the power losses in a switching regulated power supply are due to the forward losses of the output rectifiers. For example, in a 5V supply, 20% of the output power will be lost in the rectifiers. This will limit the maximum efficiency to less than 80%. However, in a +12V supply only 8% of the output power will be lost in the rectifiers. This will result in maximum efficiency of approximately 92%.
APPENDIX II
ENGINEERING NOTE-BOOK "DESIGN EQUATIONS"

This section lists some of the important switching regulator design equations.

I. Input filter capacitor for 60 Hz rectification:

\[ C_{in} = \frac{P_O}{\eta f_L (V_{PK}^2 - V_{min}^2)} \]  

(EQ. 1)

where:
- \( V_{PK} \) — peak voltage at min. input line
- \( V_{min} : V_{PK} \) — ripple across the capacitor
- \( f_L \) — line frequency
- \( P_O \) — output power
- \( \eta \) — efficiency

with a line drop-out specification:

\[ C_{in} \approx \frac{P_O N}{f_L \eta (V_{PK}^2 - V_{min}^2)} \]  

(EQ. 2)

where:
- \( N \) — number of drop-out cycles

II. The output filter capacitor:

\[ C_o = \frac{\Delta I_L}{8 f_s \Delta V_o} \]  

(EQ. 3)

where:
- \( \Delta V_o = \) output ripple voltage

The selected capacitor must have \( \text{ESR} \leq \Delta V_o / \Delta I_L \)

III. Magnetic design

Energy stored in the core material

\[ W_c = \frac{1}{2} \frac{B \ Ae \ H \ le}{.4\pi} \cdot 10^{-8} \]  

(EQ. 4)

where:
- \( B \) — magnetic flux density in gauss
- \( H \) — magnetic field intensity in oersted
- \( Ae \) — effective magnetic cross section area in cm. sq.
- \( le \) — mean magnetic path length in cm.
The required circuit energy

\[ W_R = \frac{1}{2} L i_p^2 \]  

(EQ. 5)

Where: \( L \) — circuit inductance  
\( i_p \) — peak current in inductor

Magnetic potential, from Ampere's law:

\[ \frac{Hle}{4\pi} = N p i_p \]  

(EQ. 6)

\( l_g \) = gap in the magnetic path in cm  
\( l_e = l_g \)  
\( B = H \) for gapped inductor

The inductor value:

\[ L = A_L N p^2 \times 10^{-9} \text{ henries} \]  

(EQ. 7)

\( A_L \) inductance index  
\( L \) henries

From Faraday's law, the minimum number of primary turns for the push-pull converter

\[ N_{P_{\text{min}}} \geq \frac{V_{\text{in(max)}}}{4 f_s B_{\text{max}} A_e} 10^8 \]  

(EQ. 8)

Where: \( V_{\text{in(max)}} \) = max. input DC voltage  
\( f_s \) = switching frequency

For forward converter

\[ N_{P_{\text{min}}} \geq \frac{V_{\text{in(max)}}}{2 f_s B_{\text{max}} A_e} 10^8 \]  

(EQ. 9)

The output filter inductor in PWM switching regulator:

\[ L \approx \frac{V_o + V_F}{f_s \Delta I_L} \]  

(EQ. 10)

Where: \( V_o \) = output voltage  
\( V_F \) = forward voltage drop in the rectifier  
\( \Delta I_L \) = peak to peak inductor current  
\( \approx 2 I_o(max) \) or \( I_o(min) \)
The temperature rise of the core with natural convection cooling:

\[ \Delta t = \frac{850P_L}{A_s} \]  

**(EQ. 11)**

Where: \( P_L \) = power losses (copper and core losses)  
\( A_s \) = core surface area in cm²

IV. Equations for determining RMS current

\[ I_{\text{RMS}} = I_1 \frac{\sqrt{D}}{\sqrt{2}} \]

- **FULL WAVE SINUSOIDAL**  
  \( D = \frac{t}{T} \)

\[ I_{\text{RMS}} = I_1 \sqrt{\frac{D}{2}} \]

- **PULSED SINUSOIDAL**  
  \( D = \frac{t}{T} \)

\[ I_{\text{RMS}} = I_1 \sqrt{D} \]

- **RECTANGULAR**  
  \( D = \frac{t}{T} \)

\[ I_{\text{RMS}} = D \left[ \frac{I_1^2 + I_2^2 + I_3^2}{3} \right]^{\frac{1}{2}} \]

- **TRAPEZOID**  
  \( D = \frac{t}{T} \)

\[ I_{\text{RMS}} = I_1 \sqrt{\frac{D}{3}} \]

- **TRIANGLE**  
  \( D = \frac{t}{T} \)
V. EC CORE DATA

EC core data is from Ferroxcube databook.
There are many suppliers of this core series.
Pregapped cores are available. All dimensions are in centimeters:

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<th>CORE</th>
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Core Volume

| $b_W$ (E) | 2.45 | 2.78 | 3.18 | 5.55 |
| $h_W$ (H) | .66  | .77  | .98  | 1.22 |
| $A_W$    | 1.65 | 2.15 | 3.12 | 6.39 |

Bobbin Cross Section Area

| $A_S$ | 43.5 | 59  | 91  | 170 |
| $A_S A_W$ | 1.39 | 2.69 | 5.71 | 18.1 |

CORE LOSS vs. FLUX DENSITY

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### WINDING DATA

**WIRE TABLE — Copper Wire — Heavy Insulation:**

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<th>AWG</th>
<th>DIAMETER Copper cm</th>
<th>AREA Copper cm²</th>
<th>DIAMETER Insulated cm</th>
<th>AREA Ins. cm²</th>
<th>OHMS/CM 20 C</th>
<th>OHMS/CM 100 C</th>
<th>AMPS for 450A/cm²</th>
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