Design a Forward CONVERTER

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AGENDA

• Forward converter v.s Buck converter vs. Flyback converter
• Features of Forward converter
• Operation of Forward Converter
  - Operation
  - Current waveforms
  - Magnetics of forward converter
  - Reset schemes
  - Synchronous forward converter

• Design Procedures
  - Design a transformer
  - Measure the magnetic inductance & leakage inductance of transformer
  - Mosfet
  - Secondary rectifier
  - Output inductor
AGENDA --- cont.

• Design Procedures --- cont.
  Output Capacitor
  Loop compensation

Active Clamp Forward converter --- LM5025
  ZVS --- zero voltage switching
  Operation
  Decide the Cr

• Other Topologies
  Double end Forward
  Half bridge
  Full bridge
  Phase-shift Full bridge
  Current double forward
Buck vs. Forward vs. Flyback

**Buck Converter**
\[
\frac{V_o}{V_{in}} = D
\]
12Vin → 3.3V, duty=27.5%

**Forward Converter**
\[
\frac{V_o}{V_{in}} = n
\]
48Vin → 3.3V, duty=6.87%

**Flyback Converter**
\[
\frac{V_o}{V_{in}} = \frac{D}{N(1-D)}
\]
The features of Forward Converter

A. For larger Vin to Vo step ex. Vin=48, Vo=3.3V
B. Isolation
C. Lower ripple & noise --- compare to Flyback converter
D. Smaller transformer --- compare to Flyback converter
Operation

Mode 1: Q1 on, D1 (Forward diode) on, D2 (free wheel diode) off

Mode 2: Q1 off, D1 off, D2 on --- Free wheel

Note: Work like buck converter, L maintain the output current continuous. T1, transformer, step down the input voltage by Np/Ns turn ratio.
Operation of Forward converter

(1)
Operation of Forward converter

\[(2)\]

- \(V_{in}\)
- \(N_p\)
- \(N_s\)
- \(V_s\)
- \(V_g\)
- \(I_{D1}\)
- \(I_{D2}\)
- \(I_L\)
Operation of Forward converter

(3)

\[ V_{g} \]
\[ D_{1} \]
\[ D_{2} \]
\[ V_{s} \]
\[ I_{D_{1}} \]
\[ I_{L} \]
\[ I_{D_{2}} \]

\[ V_{g} \]  
\[ V_{s} \]  
\[ I_{D_{1}} \]  
\[ I_{D_{2}} \]  
\[ I_{L} \]  

Vin \[ N_{s} \]

\[ \frac{N_{s}}{N_{p}} \]

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Operation of Forward converter

\[(4)\]

- \(V_{g}\)
- \(V_{s}\)
- \(I_{D1}\)
- \(I_{D2}\)
- \(I_L\)
- \(V_{in} \cdot \frac{N_s}{N_p}\)
Operation of Forward converter

\[(5)\]

\[V_g\]

\[V_s\]

\[I_{D1}\]

\[I_{D2}\]

\[I_L\]

\[I_o\]

\[Vin\cdot\frac{N_s}{N_p}\]
Model of Forward Transformer

Overhead of forward transformer

Lm

Np : Ns

Q1

D2
Current waveforms

Magnetizing current

: ripple current

Io

ΔI

Q1

D2

Lm

IΔ

IΔ

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Magnetics of Forward converter

Overhead of forward transformer

Flux Density $B = \int_{0}^{T} \frac{V}{N \cdot A_e} dt$

Magnetic Force $H = \frac{N \cdot I_m}{l}$
Magnetics of Forward converter
Flux need be reset in every cycle

\[ B = \int_0^T \frac{V}{N \cdot A_e} dt \]

Flux Density \( B \) (Gauss)

\[ H = \frac{N \cdot I_m}{l} \]

Magnetic Force \( H \) (A/m)

Overhead of forward transformer

\[ N \frac{d\Phi}{dt} = V \]
\[ N \frac{dB \cdot A_e}{dt} = V \]
\[ B = \int \frac{V}{N \cdot A_e} dt \]
Need a negative voltage in the rest of time to reset the flux

Flux Density $B = \int_{0}^{T} \frac{V}{N \cdot A_e} dt$

Overhead of forward transformer

$\frac{d\Phi}{dt} = V$
$N \frac{dB \cdot A_e}{dt} = V$
$B = \int \frac{V}{N \cdot A_e} dt$

$H = \frac{N \cdot I_m}{l}$

Magnetic Force (A/m)

VT balance

$V_1 \cdot t_1 = V_2 \cdot t_2$
Then the transformer can work again

\[ N_p : N_s \]

Overhead of forward transformer

Flux Density
\[ B = \int_{0}^{T} \frac{V}{N \cdot A_e} dt \]

Magnetic Force
\[ H = \frac{N \cdot I_m}{l} \]

V1 \cdot t1 = V2 \cdot t2

VT balance

\[ N \frac{d\Phi}{dt} = V \]
\[ N \frac{dB \cdot A_e}{dt} = V \]
\[ B = \int \frac{V}{N \cdot A_e} dt \]
Unfortunately, Forward converter inherent no rest path

Mode 1: Q 1 on, D1 (Forward diode) on, D2 (free wheel diode) off

Mode 2: Q 1 off, D1 off, D2 on --- Free wheel

In this case, there is no negative current path

In order to make the magnetic current continuous, transformer will induce a very high voltage thus destroy the Mosfet, Q1
Flyback has inherent rest path
Reset schemes

Reset winding

RCD clamp

Active Clamp
Cost effective solution for magnetic reset
Disadvantage --- higher Vds, but may be lower switching loss while Mosfet turned on

\[ f = \frac{1}{2\pi \sqrt{L_mC_s}} \]

Larger Cs

smaller Cs

higher switching loss

Lower switching loss
Synchronous Forward Converter

Q1 on, Q2, On, Q3 off
Q1 off, Q2, Off, Q3 on
DESIGN Procedure

Vi: Input voltage
Ii: Input current
Vo: Output voltage
Ro: Output load resistance
Vr: Output voltage ripple
D: Duty cycle
Fs: Switching frequency
A. Design a transformer
   a. Select a magnetic core

![Diagram of performance vs frequency for different magnetic cores](image)

- **EFD20**
  - 21.0 MAX
  - 20.1 x 0.3
  - 1.0 x 0.4

- **EFD20**
  - 22.0 MAX
  - 1.0x0.4
  - 3.76
b. Pick $A_e$ --- effective core area & $A_t$

\[
A_t : \text{inductance per turns}^2 \text{nH} / T \quad +/ - 25\%
\]

\[
L = N^2 \cdot A_t
\]
c. Calculate $N_p$ --- Primary tunns

$$N_p = \frac{V_i \cdot D_{\text{max}}}{\Delta B \cdot A_e \cdot F_s} \cdot 10^{10}$$

$V_i$: Maximum input voltage

$D_{\text{max}}$: Maximum duty cycle

$A_e$: Effect core area

$\Delta B$: Delta flux density  Note: $\approx 2000$ gauss

$F_s$: Switching Frequency

$$L_m = N_p^2 \cdot A_L$$  Lm : the larger is the better
d. Calculate Turn ratio:

\[ n = \frac{N_p}{N_s} \leq \frac{V_{i(min)} \cdot D_{max}}{V_o + V_d} \]

You must decide maximum duty cycle(<50%)

e. Calculate wire diameter:

**Criterion : cross area/current**

\[ I = 4D^2 \Rightarrow \phi = 0.50mm \text{ for } 1A \Rightarrow \approx 400 \text{ circul mil / A} \]
\[ I = 6D^2 \Rightarrow \phi = 0.41mm \text{ for } 1A \Rightarrow \approx 256 \text{ circul mil / A} \]
\[ I = 8D^2 \Rightarrow \phi = 0.35mm \text{ for } 1A \Rightarrow \approx 190 \text{ circul mil / A} \]
Create a specification for the transformer

**Schematic**

\[
\begin{align*}
\psi &= 2 \times 0.6\text{mm}, 12\text{Ts} \\
\psi &= 0.16\text{mm}, 8\text{Ts} \\
\psi &= 2 \times 0.6\text{mm}, 12\text{Ts} \\
\psi &= 0.6\text{mm} \times 4, 2\text{Ts} \\
\psi &= 0.6\text{mm} \times 4, 2\text{Ts} \\
\end{align*}
\]

**Electrical Specification**

Converter Type: Forward  
Vin,min: 32V, Vin,max: 60V  
Duty,max: 0.45  
Frequency: 250KHz  
Vo: 3.3V  
Io: 10A

1. Magnetic Core: EFD30
2. Leakage Inductance: Pin 1 \( \phi = 0.6\text{mm} \times 2\% \)  
Ns: Pin9,10~6,7 \( \phi = 0.6\text{mm} \times 8 \)  
Nb: Pin4~5 \( \phi = 0.16\text{mm} \)
3. Wire diameter
   I. Np 6 Turns, 加TAPE  
   II. Ns 2 Turns, 加TAPE  
   III. Nb 8 Turns, 加TAPE  
   IV. Np 6 Turns, 加TAPE
4. Winding sequence
   I. Np 6 Turns, 加TAPE  
   II. Ns 2 Turns, 加TAPE  
   III. Nb 8 Turns, 加TAPE  
   IV. Np 6 Turns, 加TAPE
5. High pot
   1500V 1,4 6,7  
   1500V 1,4,6,7 CORE

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Planar transformer
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Core Losses

Core loss = hysteresis loss + eddy current loss

\[ = K(\Delta B)^m f^n \]

\[ m = 2-2.5 \]
\[ n = 1.1-1.5 \]

Ferrite: <2MHz
Powder core: <1MHz
Alloy: <200KHz
Amorphous: <300KHz
How to measure Lm & leakage inductance?

a. Measure Lm

![Diagram showing measurement of Lm with an LCR meter in a circuit with secondary open.]

b. Measure Leakage inductance $L_l$

![Diagram showing measurement of leakage inductance with an LCR meter in a circuit with secondary shorted.]

$L_m >> L_l$
Power Stage

1. Components

A. Power Mosfet

Vds : >2*Vin, max, it is dependent on the reset capacitor Cs (refer to page)

Ids :

Rds(on)

Ciss

Coss

Tfall (fall time)

International

IR Rectifier

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated
- Ease of Paralleling
- Simple Drive Requirements

Description

Fifth Generation HEXFET® Power MOSFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.

The D²PAK is a surface mount power package capable of accommodating die sizes up to HEX-4. It provides the highest power capability and the lowest possible on-resistance in any existing surface mount package. The D²PAK is suitable for high current applications because of its low internal connection resistance and can dissipate up to
B. Output Diode

- **Vr**: reverse voltage
- **If(average)**: Forward current
- **If(peak)**: $I_o + \frac{1}{2} \Delta I$
- **Vd**:
- **Cj**:

\[ V_r > \left( \frac{V_{in\text{max}}}{N_p} \right) \cdot N_S , \quad V_o + V_{reset} \cdot \frac{N_S}{N_p} \]

---

**Major Ratings and Characteristics**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{F(\text{AV})}$ Rectangular waveform</td>
<td>30</td>
<td>A</td>
</tr>
<tr>
<td>$V_{RHM}$</td>
<td>25 - 30</td>
<td>V</td>
</tr>
<tr>
<td>$I_{FDM}$ @ $t_b = 5$ μs sine</td>
<td>900</td>
<td>A</td>
</tr>
<tr>
<td>$V_F$ @ 15 Apk, $T_J = 125°C$</td>
<td>0.40</td>
<td>V</td>
</tr>
<tr>
<td>$T_J$ range</td>
<td>-55 to 150</td>
<td>°C</td>
</tr>
</tbody>
</table>

**Description/Features**

The 32CTQ... Schottky rectifier series has been optimized for low reverse leakage at high temperature. The proprietary barrier technology allows for reliable operation up to 150°C junction temperature. Typical applications are in switching power supplies, converters, free-wheeling diodes, and reverse battery protection.

- 160°C $T_J$ operation
- High purity, high-temperature epoxy encapsulation for enhanced mechanical strength and moisture resistance
- Low forward voltage drop
- High frequency operation
- Guard ring for enhanced ruggedness and long term reliability

**Case Styles**

- **32CTQ...**
- **32CTQ... S**
- **32CTQ... -1**
Output inductor

\[ L \frac{di}{dt} = V \]
\[ dt = (1 - D_{\text{vin@max}}) \cdot Ts \]
\[ D_{\text{vin@max}} = n \cdot \frac{V_d + V_o}{V_{\text{in,max}}} \]
\[ n = \frac{N_p}{N_s} \]

\[ L = \frac{dt}{di} (V_o + V_d) \]
\[ di = 0.2 \cdot I_{\text{lo,max}}(A) \]

\[ Ts = \frac{1}{F_s} \]

Maximum ripple happen when Vin@max
Output capacitance

1. Consider transient response

\[ \frac{1}{2} (\Delta I)^2 L = \frac{1}{2} (\Delta V)^2 C \]

\( \Delta I \): transient load \hspace{1cm} \Delta V \): accepted overshoot

2. Consider ripple voltage

\[ ESR \leq \frac{V_r}{\Delta I_L} \]

\( \Delta I_L \): inductor ripple current

\( V_r \): Ripple voltage
Comparison with high value capacitors – variety of capacitors

Multilayer ceramic capacitor
Ni based electrodes (TAIYO)

OS-CON (SANYO)

Al electrolytic capacitor

SP Cap (Panasonic)

Ta electrolytic capacitor

POS CAP (SANYO)
<table>
<thead>
<tr>
<th>Problem</th>
<th>Polarity</th>
<th>Derating</th>
<th>Ripple Current Limit</th>
<th>Solder Heat Resistance</th>
<th>Anti-solvent</th>
<th>Loading Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLCC</td>
<td>No</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Ta cap</td>
<td>Yes</td>
<td>×</td>
<td>△</td>
<td>×</td>
<td>△</td>
<td>×</td>
</tr>
<tr>
<td>AE cap</td>
<td>Yes</td>
<td>×</td>
<td>×</td>
<td>△</td>
<td>×</td>
<td>△</td>
</tr>
</tbody>
</table>

- ◎ is Excellent
- △ is Limited
- × is Bad
Comparison of Capacitor’s Self Heat Generation

Temperature Rise characteristics due to ripple current

- **Al electrolytic capacitor 47uF**
- **Ta electrolytic capacitor 10uF**
- **Multilayer capacitor 4.7uF**

![Graph showing temperature rise characteristics for different capacitor types.](image-url)
Impedance vs. Frequency

Impedance VS Frequency characteristics

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MLCC vs. OS-CON

Impedance and ESR versus Frequency characteristics

22uF MLCC
22uF OS-CON

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The ripple current of 47uF MLCC is about 2.5A
NPO vs. X7R vs. Y5V

-55~125

-55~125

10~85

+/-30 ppm

+/-15%

+22%~56%
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Sense resistor

\[ I_o + \frac{1}{2} \Delta I_L \]

\[ n = \frac{I_o + \frac{1}{2} \Delta I_L}{n} \]

\[ R_s = \frac{V_{CS}}{I_o + \frac{1}{2} \Delta I_L} \]

\[ V_{CS} = 0.5 \sim 0.8V \]

\[ Loss = \frac{V_{CS}^2}{R_s} \]

\[ 6.4W = \frac{0.8^2}{0.1\Omega} \]

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## Current transformer

\[ Loss = I^2 \cdot DCR \]

\[
loss = \frac{V^2}{R} = 0.1W
\]

<table>
<thead>
<tr>
<th>Part number</th>
<th>Turns ratio</th>
<th>Inductance (mH)</th>
<th>DCR max (Ohms)</th>
<th>Sensed current (A)</th>
<th>Terminating resistance (Ohms)</th>
<th>Volt-time product (V-μsec)</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>CST1-020L_</td>
<td>1 : 20</td>
<td>91.0</td>
<td>0.006</td>
<td>0.400</td>
<td>10</td>
<td>2.0</td>
<td>Red</td>
</tr>
<tr>
<td>CST1-030L_</td>
<td>1 : 30</td>
<td>180.0</td>
<td>0.006</td>
<td>0.870</td>
<td>10</td>
<td>3.0</td>
<td>Orange</td>
</tr>
<tr>
<td>CST1-040L_</td>
<td>1 : 40</td>
<td>320.0</td>
<td>0.006</td>
<td>1.140</td>
<td>10</td>
<td>4.0</td>
<td>Yellow</td>
</tr>
<tr>
<td>CST1-050L_</td>
<td>1 : 50</td>
<td>500.0</td>
<td>0.006</td>
<td>1.500</td>
<td>10</td>
<td>5.0</td>
<td>Green</td>
</tr>
<tr>
<td>CST1-060L_</td>
<td>1 : 60</td>
<td>730.0</td>
<td>0.006</td>
<td>1.980</td>
<td>10</td>
<td>6.0</td>
<td>Blue</td>
</tr>
<tr>
<td>CST1-070L_</td>
<td>1 : 70</td>
<td>980.0</td>
<td>0.006</td>
<td>4.750</td>
<td>10</td>
<td>7.0</td>
<td>Violet</td>
</tr>
<tr>
<td>CST1-100L_</td>
<td>1 : 100</td>
<td>2000.0</td>
<td>0.006</td>
<td>5.500</td>
<td>10</td>
<td>10.0</td>
<td>Gray</td>
</tr>
<tr>
<td>CST1-125L_</td>
<td>1 : 125</td>
<td>3000.0</td>
<td>0.006</td>
<td>6.500</td>
<td>10</td>
<td>12.5</td>
<td>Black</td>
</tr>
</tbody>
</table>
Reset capacitor --- Cs

\[ f = \frac{1}{2\pi \sqrt{L_m \cdot C_s}} \]

\[ \frac{1}{2} \cdot \frac{1}{f} \leq \frac{1 - D_{\text{max}}}{F_s} \]

\[ \frac{1}{2\pi \sqrt{L_m \cdot C_s}} \geq \frac{F_s}{2 \cdot (1 - D_{\text{max}})} \]

\[ C_s \leq \frac{(1 - D_{\text{max}})^2}{\pi \cdot F_s} \]

\[ C_s \approx 100 \text{pF} \sim 1000 \text{pF} \]

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Output diode snubber

\[ f_r = \frac{1}{2\pi \sqrt{L_i \cdot C_j}} \]

\[ R = \frac{1}{\sqrt{\frac{L_i}{C_j}}} = \frac{1}{2\pi f_r \cdot C_j} \]

\[ C \cong 2\sim5 \text{ times of } C_j \]

\( L_i \): leakage inductance

\( C_j \): diode junction capacitance
Control Loop

Current Mode Controller

Open loop

Vin → L → C → Vin

Vo ↑ FB ↑ Id ↑ Ic ↑ Ve(comp) ↓ Ip ↓ Vo ↓

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Photo Coupler --- For isolation

Photo Coupler provide signal transfer, the idea is a DC gain

\[ V_{\text{comp}} = V_{\text{cc}} - R5 \cdot I_c = V_{\text{cc}} - R5 \cdot \left( \frac{V_o - V_e}{R4} \cdot CTR \left( \frac{I_c}{I_d} \right) \right) \]

\[ \Delta V_{\text{comp}} = \Delta V_e \cdot \frac{R5}{R4} \cdot CTR \]

1. CTR : Current Transfer Ratio
   80% ---- 150%

2. Bandwidth --- must > cross over frequency of flyback converter (1/10 of switching frequency)

3. Popular solution: PC817 --- Sharp
   TLP521 --- Toshiba
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Gain

0db

9.9Hz 142Hz 33KHz f

Close over frequency

Close loop Gain( )

With Photo Coupler

\[ \frac{V_o}{V_e} = \frac{R_1}{R_2} \left( 1 + \frac{s}{w_z} \right) \left( 1 + \frac{s}{w_p} \right) \]

\[ \frac{10K}{0.91K} = 10.9 \]

\[ w_z \approx 338\text{Hz} \]

\[ w_p \approx 79\text{KHz} \]
With Photo Coupler

Gain

0db

9.9Hz 142Hz 33KHz

Close over frequency

Close loop Gain( )
TL431 --- Shunt regulator

$$I_{KA} = \frac{\text{Vin} - \text{Vo}}{R_L} \quad I_{o,max} = I_{KA}$$

**Cathode Current**

**TL431**
Band gap reference of 431

\[ I_1 = 10I_2 \]

\[ V_{BE(Q1)} \neq V_{BE(Q2)} \therefore I_1 = 10I_2 \]

\[ I_2 = \frac{V_{BE(Q1)} - V_{BE(Q2)}}{R3} \]

\[ V_{REF} = V_{BE(Q3)} + (V_{BE(Q1)} - V_{BE(Q2)}) \frac{R2}{R3} \]

\[ V_{BE(Q1)} - V_{BE(Q2)} = \frac{KT}{q} \ln \frac{I_1}{I_2} \]

\[ V_{BE(Q3)} = V_{go}(1 - \frac{T}{To}) + V_{BEO}(\frac{T}{To}) \]

\[ V_{go} = \text{band-gap} \]

\[ \frac{dV_{REF}}{dt} = -\frac{V_{go}}{To} V_{BEO} + \frac{V_{BEO}}{To} + \frac{R2}{R3 q} \ln \frac{I_1}{I_2} \]

If,

\[ R2 \ln \frac{I_1}{I_2} = (V_{go} - V_{BEO(Q3)}) \frac{q}{KTo} \]

\[ \frac{dV_{REF}}{dt} = 0 \quad V_{go} = 1.22V \]
Control Loop

a. Open loop --- Similar to current mode Buck converter

A. DC gain : \( n \cdot \frac{R_o}{R_s} \)  
   Note: \( R_o \) : load resistance 
   \( n \) : main transformer turn ratio, \( N_s/N_p \)

B. Low frequency Pole : \( \frac{1}{2\pi \cdot C \cdot R_L} \)

C. ESR zero : \( \frac{1}{2\pi \cdot C \cdot R_{esr}} \)

D. Double Pole : \( \frac{F_s}{2} \)

Note:

\[
DCgain = \frac{I_o \cdot R_o}{V_e} = \frac{I_o \cdot R_o}{I_{in} \cdot R_s} = \frac{N_p \cdot R_o}{N_s \cdot F_i}
\]
1. Lower $f_z$ more phase margin, stable but slow response
2. Lower $f_p$ less phase margin, but noise immunity
3. DC gain & crossover frequency is limited by 431 & photo couple

$$f_z = \frac{1}{2\pi R3C1} \quad f_p = \frac{1}{2\pi R3C2}$$

$$R3 \frac{R}{R1\|R2}$$

Gain

$F_s$$\frac{F_s}{2}$

Crossover frequency

Vo

Gain

0db

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Vcc Bias

High power dissipation $\frac{Vin}{R_{\text{large}}}$
Long start up time
Simple

High power dissipation $\frac{Vin}{R_{\text{large}}}$
short start up time
Complex

Lower power dissipation $\frac{Vin}{R_{\text{large}}}$
short start up time
Simple
Design Example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vin,min</td>
<td>36</td>
</tr>
<tr>
<td>Vin,max</td>
<td>78</td>
</tr>
<tr>
<td>Duty, max</td>
<td>0.55</td>
</tr>
<tr>
<td>Vo</td>
<td>3.3</td>
</tr>
<tr>
<td>Vs</td>
<td>3.4</td>
</tr>
<tr>
<td>Io</td>
<td>30</td>
</tr>
<tr>
<td>eff</td>
<td>0.85</td>
</tr>
<tr>
<td>In</td>
<td>Vo<em>Io/Vin</em>eff</td>
</tr>
<tr>
<td>Fs</td>
<td>240000</td>
</tr>
<tr>
<td>Vbias</td>
<td>12</td>
</tr>
<tr>
<td>n(Np/Ns)</td>
<td>5.824</td>
</tr>
<tr>
<td>n(Np/Ns)</td>
<td>$n = \frac{V_{n,x} \times D_{n}}{V_{O} + V_{D}}$</td>
</tr>
</tbody>
</table>

**Transformer section**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic Core</td>
<td>EFD 30</td>
</tr>
<tr>
<td>Delta B</td>
<td>2000</td>
</tr>
<tr>
<td>Ae</td>
<td>(mm²)</td>
</tr>
<tr>
<td>Al</td>
<td>nH</td>
</tr>
<tr>
<td>Np</td>
<td>13.0</td>
</tr>
<tr>
<td>Lm</td>
<td>3.61E-04</td>
</tr>
<tr>
<td>Ns</td>
<td>2.2</td>
</tr>
<tr>
<td>Nb</td>
<td>7.9</td>
</tr>
<tr>
<td>Skin depth (mm)</td>
<td>0.15</td>
</tr>
<tr>
<td>Maximum Diameter of wire</td>
<td>0.29</td>
</tr>
<tr>
<td>Dim, pri, total</td>
<td>0.65</td>
</tr>
<tr>
<td>wire # (primary)</td>
<td>4</td>
</tr>
<tr>
<td>Dim, pri, per wire</td>
<td>0.32</td>
</tr>
<tr>
<td>Dim, sec</td>
<td>1.94</td>
</tr>
<tr>
<td>wire # (secondary)</td>
<td>8</td>
</tr>
<tr>
<td>Dim, sec, per wire</td>
<td>0.68</td>
</tr>
<tr>
<td><strong>Secondary section</strong></td>
<td><strong>Output Inductor</strong></td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>DeltaL</strong></td>
<td>0.2* Io, max</td>
</tr>
<tr>
<td><strong>D@vin,max</strong></td>
<td>(Vo+Vd)*n/Vin,max</td>
</tr>
<tr>
<td><strong>L</strong></td>
<td>( L = \frac{(Vo+V_d) \cdot (1 - D_{@vin,max})}{F_s \cdot \Delta I} )</td>
</tr>
<tr>
<td><strong>( \Delta I_o )</strong></td>
<td>1.8E-06</td>
</tr>
<tr>
<td><strong>I_o</strong></td>
<td>( I_0 + \frac{1}{2} \Delta I_L )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Output capacitor</strong></th>
<th><strong>Output capacitor</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vripple</strong></td>
<td>accepted ripple voltage</td>
</tr>
<tr>
<td><strong>I_{transient}</strong></td>
<td>transient current</td>
</tr>
<tr>
<td><strong>V_{overshot}</strong></td>
<td>accepted overshoot in transient response</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>( C = \frac{L \cdot I^2}{V^2} )</td>
</tr>
<tr>
<td><strong>ESR</strong></td>
<td>( \frac{V_{ripple}}{\Delta I_L} )</td>
</tr>
<tr>
<td><strong>Sense resistor</strong></td>
<td><strong>Sense resistor</strong></td>
</tr>
<tr>
<td><strong>V_{s,max}</strong></td>
<td>Maximum current sensing voltage</td>
</tr>
<tr>
<td><strong>R_s</strong></td>
<td>( r_s = \frac{V_s}{\Delta I_L} )</td>
</tr>
<tr>
<td><strong>Reset capacitor</strong></td>
<td><strong>Reset capacitor</strong></td>
</tr>
<tr>
<td><strong>L_m</strong></td>
<td></td>
</tr>
<tr>
<td><strong>C_s</strong></td>
<td>( C_s \leq \frac{(1-D_{max})^2 \cdot F_s}{\pi \cdot F_s} )</td>
</tr>
<tr>
<td></td>
<td>( C_s \leq \frac{1-D_{max}}{L_m} )</td>
</tr>
<tr>
<td>Loop compensation</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>---</td>
</tr>
<tr>
<td>RL</td>
<td>Vo/lo</td>
</tr>
<tr>
<td>C</td>
<td>0.0009</td>
</tr>
<tr>
<td>ESR</td>
<td>0.0040</td>
</tr>
<tr>
<td>DC gain</td>
<td>$N \cdot \frac{R_o}{R_s}$</td>
</tr>
<tr>
<td>Cross over frequency</td>
<td>10000</td>
</tr>
<tr>
<td>First pole</td>
<td>$\frac{1}{2\pi \cdot C \cdot R_z}$</td>
</tr>
<tr>
<td>ESR zero</td>
<td>$\frac{1}{2\pi \cdot C \cdot R_{esr}}$</td>
</tr>
<tr>
<td>open loop Gain at cross over</td>
<td>DC gain - loss</td>
</tr>
<tr>
<td>R3/R*</td>
<td>0.16</td>
</tr>
<tr>
<td>R*</td>
<td>2000</td>
</tr>
<tr>
<td>R3</td>
<td>319</td>
</tr>
<tr>
<td>C1</td>
<td>$C_1 = \frac{1}{2\pi R_3 \cdot f_z}$</td>
</tr>
<tr>
<td>C2</td>
<td>$C_2 = \frac{1}{2 \pi R_3 \cdot f_z}$</td>
</tr>
</tbody>
</table>
Thanks

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Technical Marketing

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Cellular phone : 0935041907