Multi-Output Flyback Off-Line Power Supply
Basic Concept

• Add additional secondary windings, using the same turns/volt as the original secondary.

\[ V_{out 1} = \frac{nD}{D'} V_{in} \]
\[ V_{out 2} = \frac{mD}{D'} V_{in} \]

• Outputs can be positive or negative, depending on which side of the output (top or bottom) is grounded.
• Either output can be the “master” by connecting it to the feedback sensing circuit
• Formulas are not exact, due to the diode drops not being proportional to the number of turns!
Example of Adding a Negative Output

• There is no theoretical limit to the number of outputs.

Vout 1 = \( \frac{n_{D'}}{D'} \) Vin

Vout 2 = \( \frac{m_{D'}}{D'} \) Vin

Vout 3 = \( \frac{p_{D'}}{D'} \) Vin

• In this case, the negative output drawn like the positive ones, with the diode reversed and the polarity of the winding as shown.
Two Outputs with Feedback Regulation

- Typical regulated flyback converter
  - One output is the master (output 2 in this case)
  - Second output (output 1, in this case) is the “slave” (quasi-regulated).
  - For output voltages less than 2.5 V, a TLV431 (1.25 V) or other can be used.
  - Why do we need R3?
Improvement #1 – Stacked Windings

- Regulation of second output is improved, because only part of it is “alone.”
  - Only the “n” portion is unregulated. (Leakage inductance of n is less.)
- Again, one output is the master (output 2 in this case)
  - Second output (output 1, in this case) will vary with the load on the main output, due to its current flowing through the winding of output 2.
Improvement #2 Stacked Outputs

- Now, output 1 current flows through output #2's diode.
  - Output 1 is less dependent on output 2's load, because the bottom of its output doesn't move.
Improvement #3 No-Load Clamp

- When output 1 is unloaded, its stray output current flows down through the Zener and into the 5 V output.
- In this case, output 1 would be clamped at 14 V.
Improvement #4 – Combined Feedback

Now, both outputs are sensed, and the regulator controls the combination of outputs.

– Remember: There’s only one feedback point. Neither output will be as tightly regulated as the main one when it had the feedback to itself!
Weighting the Feedback

- If $W_1 = 0.9$ and $W_2 = 0.1$, then output 1 is nine times as important as output 2.
  - ($W_1$ has a weight of 90%, and $W_2$ has a weight of 10%)

\[
i_0 = i_1 + i_2 = W_1 \cdot i_0 + W_2 \cdot i_0 = i_0 (W_1 + W_2)
\]

Therefore, $W_1 + W_2 = 1$

$W_n$ is the “weight” of the feedback from output n.

- If $W1 = 0.9$ and $W2 = 0.1$, then output 1 is nine times as important as output 2.
  - ($W1$ has a weight of 90%, and $W2$ has a weight of 10%)
Designing the Feedback

\[ V_{out1} - V_{ref} = i_1 R_1 \]

\[ R_1 = \frac{V_{out1} - V_{ref}}{i_1} = \frac{V_{out1} - V_{ref}}{W_1 i_0} \]

\[ R_2 = \frac{V_{out2} - V_{ref}}{i_2} = \frac{V_{out2} - V_{ref}}{W_2 i_0} \]

\( i_1 + i_2 = i_0 \)
Example

Procedure:
- Given: $V_{out1} = 5$, $V_{out2} = 12$, $V_{ref} = 2.5$
- Choose $i_0 = 1$ mA
- Choose $W_1 = 0.7$ and $W_2 = 0.3$

Calculating the values:

$$R_0 = \frac{V_{ref}}{i_0} = \frac{2.5}{1 \text{ mA}} = 2.5 \text{ k}\Omega$$

$$R_1 = \frac{V_{out1} - V_{ref}}{W_1 i_0} = \frac{5 - 2.5}{0.7 \cdot 1 \text{ mA}} = 3.57 \text{ k}\Omega$$

$$R_2 = \frac{V_{out2} - V_{ref}}{W_2 i_0} = \frac{12 - 2.5}{0.3 \cdot 1 \text{ mA}} = 31.7 \text{ k}\Omega$$
More Outputs? No Problem

- Feedback can be from any number of outputs.
- Provided that: \( W_1 + W_2 + \ldots + W_n = 1 \)

\[
R_n = \frac{V_{out\ n} - V_{ref}}{W_n \cdot i_0}
\]
The “Magic” Capacitor

With cap: Clean pulse; improved regulation at low-current load

Vout 1 = \( \frac{nD}{D'} \) Vin

Low-current load (R1 = large)

Vout 2 = Vout 1 = \( \frac{nD}{D'} \) Vin

Load (R2)

With cap:

- Clean pulse
- Improved regulation at low-current load

\( n = \frac{m}{D} \)

\( D' = \frac{1}{D} \)

PWM Controller

Optocoupler

2.5 V ref. amplifier

R3, R4, R5

TL431

www.onsemi.com
Another Version of the “Magic” Capacitor

Here, since the bottom of upper secondary is tied to Vout 2 (which is dc), waveforms at each end of the capacitor are identical.

Overshoot & ringing at light load on Vout 1 is reduced by 5/7, since 5 of the 7 added turns are tightly coupled via the capacitor. (m = 5, n = 2, m+n = 7).
Adding an Output to a Buck Converter

- During the “off” time of the switch, the output voltage across the inductor is coupled to a new output via an added winding!
- No free lunch. There must be enough energy stored in the choke to feed the new output.
- Ampere-turns are preserved, so current drawn from the new output causes discontinuous current in the main output.
  - Ripple current in the main output capacitor increases.
Design Example, Built and Tested

65 Watt, 8 Output
Set Top Box
Power Supply

Frank Cathell,
Senior Applications Engineer
General Specifications

- **Input**: 90 to 135 Vac, 47 – 63 Hz
- **Inrush current**: 30 A cold start; 60 A warm start
- **Efficiency**: > 80% at nominal loading

- **Output Voltages/Regulation/Ripple**:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Vout</th>
<th>Output type</th>
<th>Regulation</th>
<th>Max Ripple</th>
<th>Current</th>
<th>Surge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.6 V</td>
<td>Buck reg.</td>
<td>+/-1%</td>
<td>40 mVP/p</td>
<td>3 A</td>
<td>4 A</td>
</tr>
<tr>
<td>2</td>
<td>3.3 V</td>
<td>Buck reg.</td>
<td>+/-1%</td>
<td>40 mVP/p</td>
<td>4 A</td>
<td>5 A</td>
</tr>
<tr>
<td>3</td>
<td>5 V</td>
<td>Main output</td>
<td>+/-2%</td>
<td>50 mVP/p</td>
<td>3 A</td>
<td>4 A</td>
</tr>
<tr>
<td>4</td>
<td>6.2 V</td>
<td>Quasi-reg.</td>
<td>+/-6%</td>
<td>50 mVP/p</td>
<td>1.5 A</td>
<td>2 A</td>
</tr>
<tr>
<td>5</td>
<td>9 V</td>
<td>3-T reg.</td>
<td>+/-1%</td>
<td>30 mVP/p</td>
<td>100 mA</td>
<td>200 mA</td>
</tr>
<tr>
<td>6</td>
<td>12 V</td>
<td>Main output</td>
<td>+/-2%</td>
<td>50 mVP/p</td>
<td>1 A</td>
<td>3 A</td>
</tr>
<tr>
<td>7</td>
<td>30 V</td>
<td>Quasi-reg.</td>
<td>+/-8%</td>
<td>100 mVP/p</td>
<td>20 mA</td>
<td>40 mA</td>
</tr>
<tr>
<td>8</td>
<td>-5 V</td>
<td>3-T reg.</td>
<td>+/-1%</td>
<td>30 mVP/p</td>
<td>30 mA</td>
<td>60 mA</td>
</tr>
</tbody>
</table>
- **Output overshoot**: 5% max; typically <1%
- **Overcurrent/short circuit protection**: Protected against accidental overloads via reduced duty cycle, burst mode operation
- **No load**: Output voltages are controlled and stable under no load conditions
- **Hold-up time/power fail detection**: Output will hold up for 20 ms following drop out at 100 V ac and nominal load; power fail warning following holdup period with 5 ms minimum delay to output voltage dropout.
- **Temperature**: Operation from 0 to 50°C (no over temp protection included)
Circuit Features

• Critical conduction mode flyback converter
  ➢ NCP1207
• 2.6 V and 3.3 V outputs derived from 12 V output
  ➢ NCP1580 synchronous buck controllers
• Low current outputs on -5 V and +9 V allowed use of conventional 3-T regulators
• Control loop closed via sum of 5 V & 12 V outputs; all other outputs quasi-regulated
• Transformer main secondary made from foil winding for low leakage inductance
• “Stacked” secondary windings utilized for improved cross-regulation
• Simple but effective power fail detection circuit utilizing TL431 and 2N2222
• Overcurrent protection implemented by initiating burst mode of NCP1207A
• 2-wire ac input with dual common mode EMI filter inductors
• Single-sided printed circuit board
Set-Top Box Test Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2.6V</th>
<th>3.3V</th>
<th>5V</th>
<th>Outputs</th>
<th>6V</th>
<th>9V</th>
<th>12V</th>
<th>30V</th>
<th>neg 5V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output type</td>
<td>Buck</td>
<td>Buck</td>
<td>Main</td>
<td>Quasi-reg</td>
<td>3-T reg</td>
<td>Main</td>
<td>Quasi-reg</td>
<td>3-T reg</td>
<td></td>
</tr>
<tr>
<td>Vout setpoint at typical loads</td>
<td>2.53V</td>
<td>3.4V</td>
<td>4.89V</td>
<td>6.27V</td>
<td>8.94V</td>
<td>12.54V</td>
<td>31.0V</td>
<td>4.96V</td>
<td></td>
</tr>
<tr>
<td>Vout setpoint at minimum loads</td>
<td>2.55V</td>
<td>3.42V</td>
<td>4.96V</td>
<td>6.38V</td>
<td>8.94V</td>
<td>12.33V</td>
<td>32.70V</td>
<td>4.98V</td>
<td></td>
</tr>
<tr>
<td>Vout setpoint at maximum loads</td>
<td>2.54V</td>
<td>3.34V</td>
<td>4.90V</td>
<td>6.29V</td>
<td>8.94V</td>
<td>12.53V</td>
<td>30.10V</td>
<td>4.95V</td>
<td></td>
</tr>
<tr>
<td>Vout setpoint at no output loading</td>
<td>2.56V</td>
<td>3.43V</td>
<td>5.02V</td>
<td>6.54V</td>
<td>8.93V</td>
<td>12.13V</td>
<td>29.60V</td>
<td>4.97V</td>
<td></td>
</tr>
</tbody>
</table>

Note: Vout setpoints measured at PC board
## More Test Results

### Efficiency Measurements (120VAC input)

<table>
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<tr>
<th>Parameter</th>
<th>2.6V</th>
<th>3.3V</th>
<th>5V</th>
<th>Outputs 6V</th>
<th>9V</th>
<th>12V</th>
<th>30V</th>
<th>neg 5V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>2.54</td>
<td>3.42</td>
<td>4.91</td>
<td>6.31</td>
<td>8.94</td>
<td>12.48</td>
<td>30.06</td>
<td>4.96</td>
</tr>
<tr>
<td>Output Current</td>
<td>3.8A</td>
<td>2.9A</td>
<td>1.56A</td>
<td>1.3A</td>
<td>91mA</td>
<td>1.0A</td>
<td>30mA</td>
<td>73mA</td>
</tr>
<tr>
<td>Output Power (W)</td>
<td>9.65</td>
<td>9.92</td>
<td>7.66</td>
<td>8.2</td>
<td>0.81</td>
<td>12.48</td>
<td>0.9</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Total Pout = 49.98W

Pin at 120VAC = 61.4W

Efficiency = 81.4%

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<th>30V</th>
<th>neg 5V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Ripple (@ max loads)</td>
<td>27mV</td>
<td>45mV</td>
<td>50mV</td>
<td>50mV</td>
<td>40mV</td>
<td>30mV</td>
<td>100mV</td>
<td>20mV</td>
</tr>
</tbody>
</table>

(10:1 scope probe)

Output Overshoot (turn-on) none none none none none none none none

Holdup Time (prior to PF warning) at 100 Vac in, maximum output loads: 25ms

Power Fail warning time (Vout decay to 90%): 15ms

Line Regulation: Minimal on all outputs; +/-20mV max
Conclusion

• Multiple output switched-mode power supplies save space, save cost, and can have high performance.
  – The “tricks” you’ve seen here can make them even better!

• Flybacks are popular, because there is only one magnetic component.

• They work best where the load ranges of the outputs are well-known.
  – This allows the designer to tailor the regulation characteristics to the load regulation requirements, favoring certain loads when necessary.

• For good cross-regulation, construction of the transformer is important.
  – Beware of changing vendors during production!
For More Information

• View the extensive portfolio of power management products from ON Semiconductor at www.onsemi.com

• View reference designs, design notes, and other material supporting the design of highly efficient power supplies at www.onsemi.com/powersupplies