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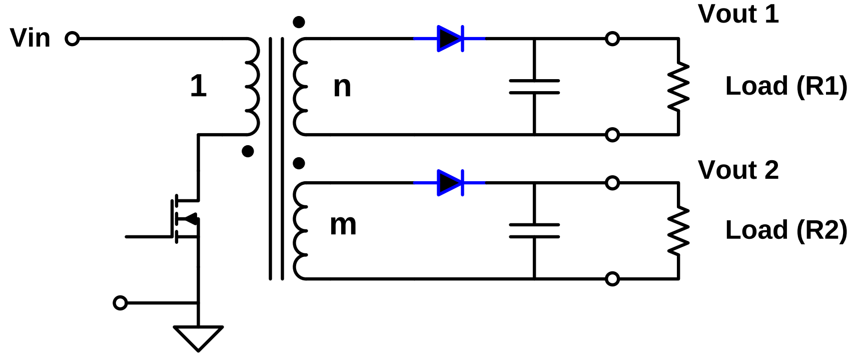
Multi-Output Flyback Off-Line Power Supply

Basic Concept

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



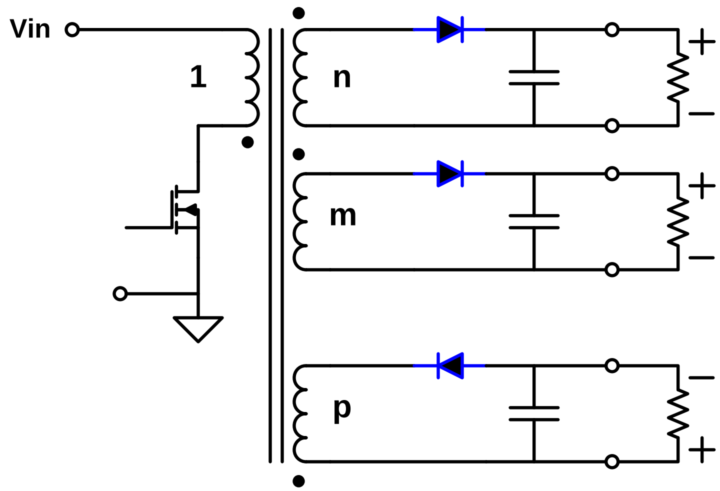
$$Vout\ 1 = \frac{nD}{D'} Vin$$

$$Vout\ 2 = \frac{mD}{D'} Vin$$

- 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.



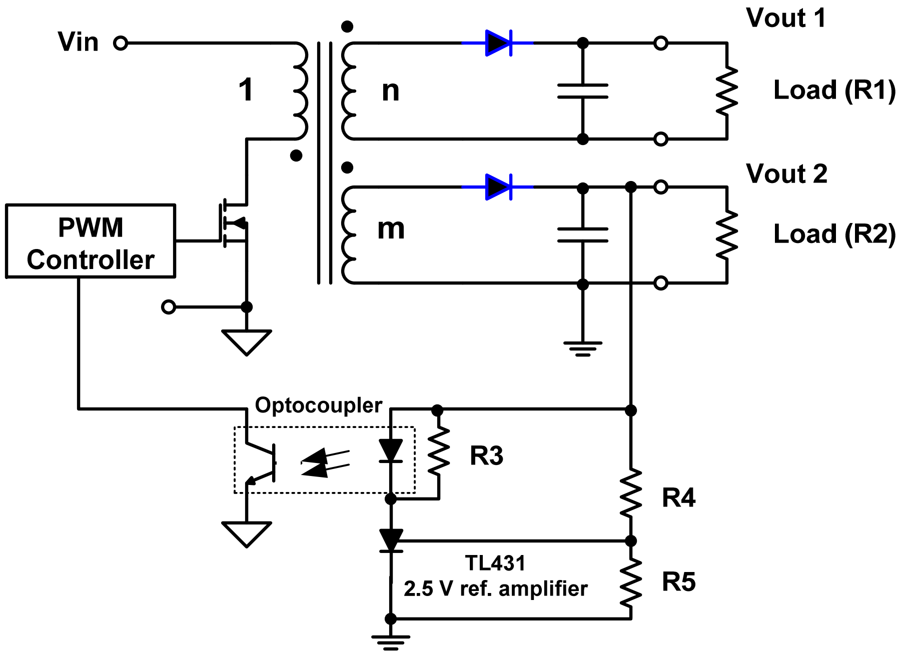
$$V_{out}1 = \frac{nD}{D'} V_{in}$$

$$V_{out}2 = \frac{mD}{D'} V_{in}$$

$$V_{out}3 = \frac{pD}{D'} V_{in}$$

- 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

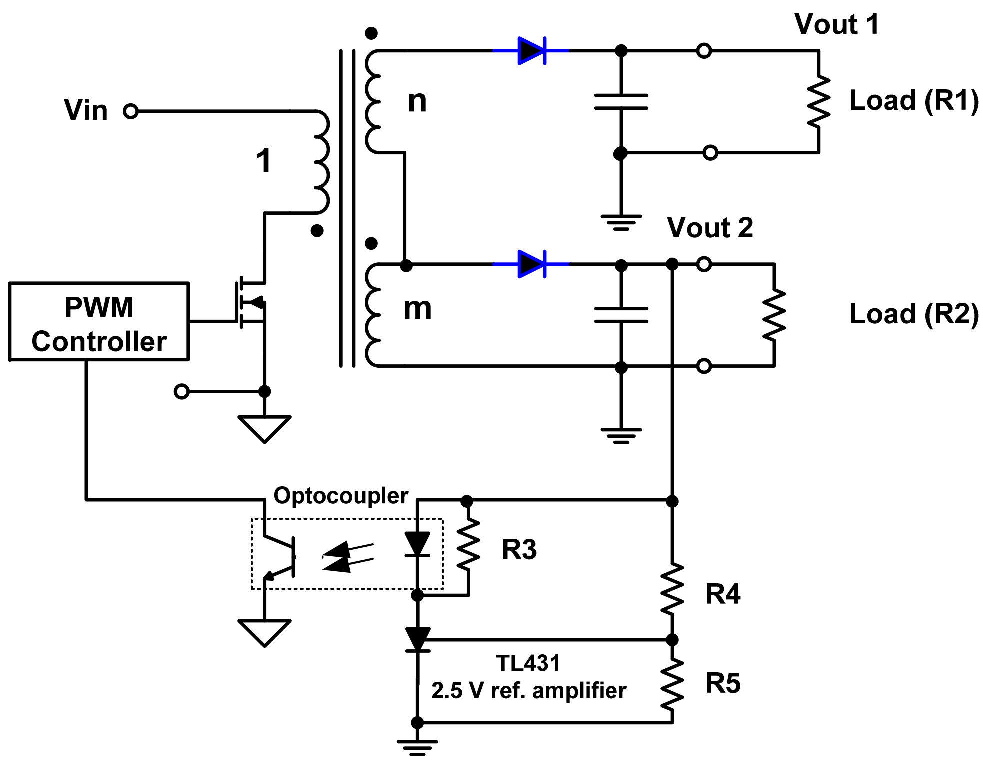


$$\text{Vout 1} = \frac{nD}{D'}\,\text{Vin}$$

$$\text{Vout 2} = \frac{mD}{D'}\,\text{Vin}$$

- 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

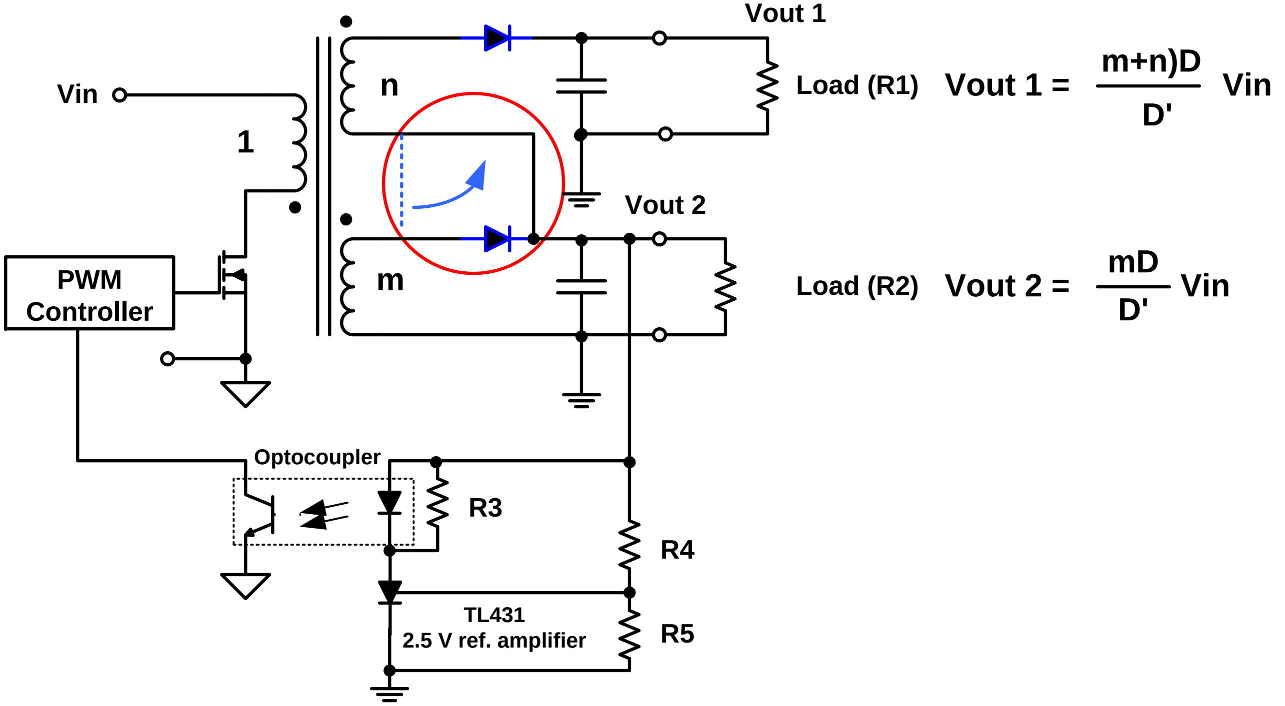


$$\text{Vout 1} = \frac{m+n)D}{D'}\,\text{Vin}$$

$$\text{Vout 2} = \frac{mD}{D'}\,\text{Vin}$$

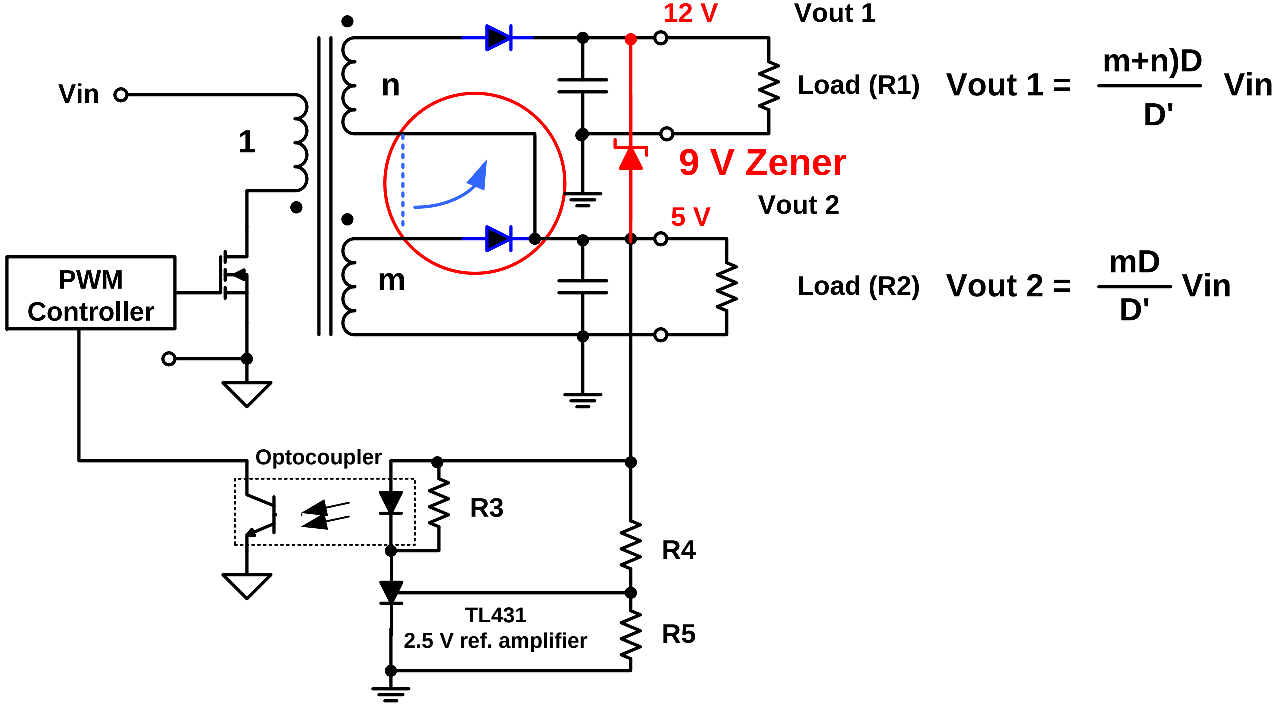
- Regulation of second output is improved, because only part of it is “alone.”
  - Only the “n” portion is unregulated. (Leakage inductance of n is less.)
- Again, one output is the master (output 2 in this case)
  - Second output (output 1, in this case) will vary with the load on the main output, due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

Improvement #2 Stacked Outputs



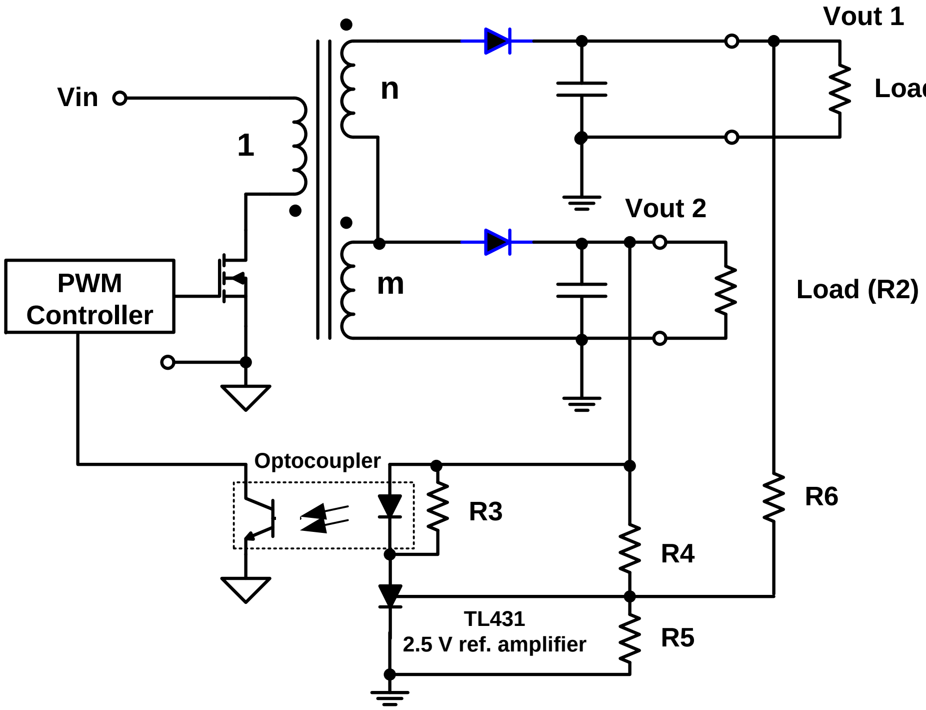
- Now, output 1 current flows through output #2's diode.
  - Output 1 is less dependent on output 2's load, because the bottom of its output doesn't move.

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

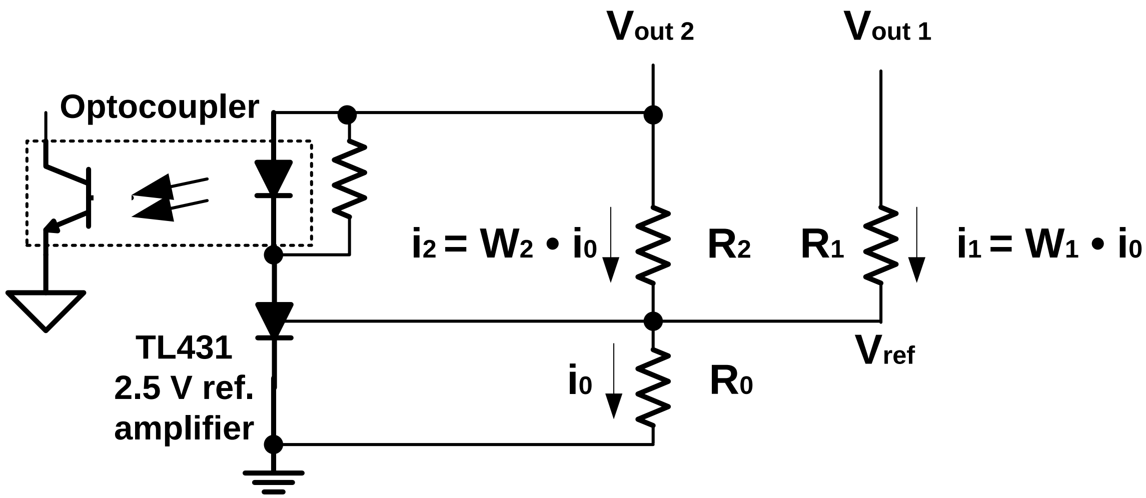


$$\text{Vout 1} = \frac{m+n)D}{D'}\,\text{Vin}$$

$$\text{Vout 2} = \frac{mD}{D'}\,\text{Vin}$$

- Now, both outputs are sensed, and the regulator controls the <u>combination</u> 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



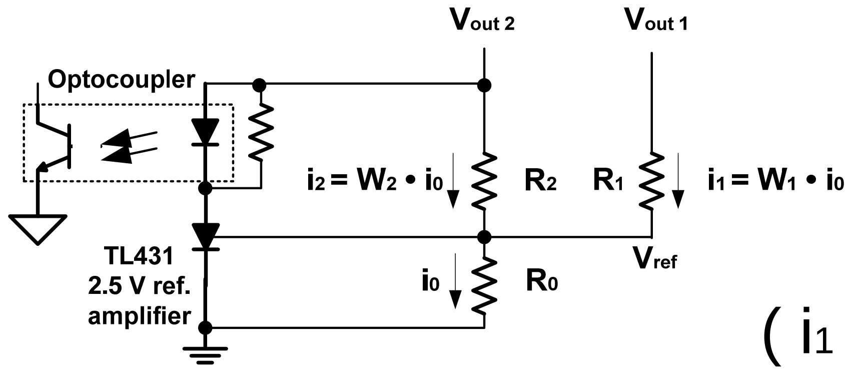
$$i_0 = i_1 + i_2 = W_1 \bullet i_0 + W_2 \bullet i_0 = i_0 (W_1 + W_2)$$

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



$(i_1 + i_2 = i_0)$

$$V_{out1} - V_{ref} = i_1 R_1$$

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

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

Example

Procedure:

- Given: **$V_{out\,1}$ = 5, $V_{out\,2}$ = 12, V_{ref} = 2.5**
- Choose **i_0** = 1 mA
- Choose **W_1 = 0.7** and **W_2 = 0.3**

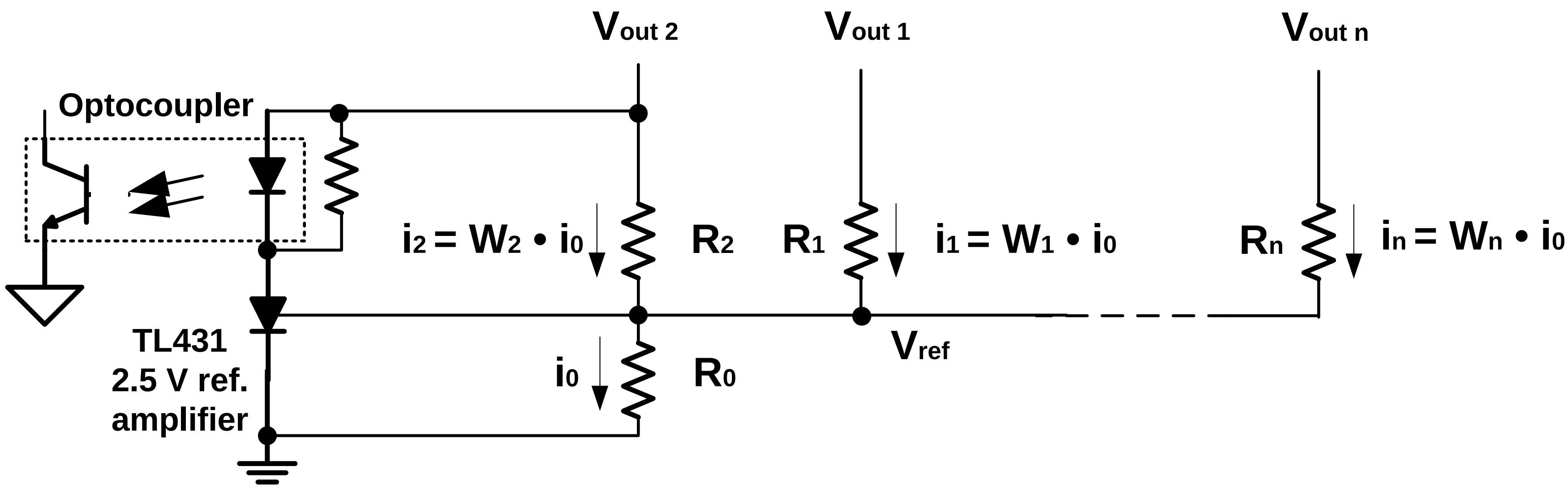
Calculating the values:

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

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

$$R_2 = \frac{V_{out2} - V_{ref}}{W_2 i_0} = \frac{12 - 2.5}{0.3 \cdot 1mA} = 31.7\,k\Omega$$

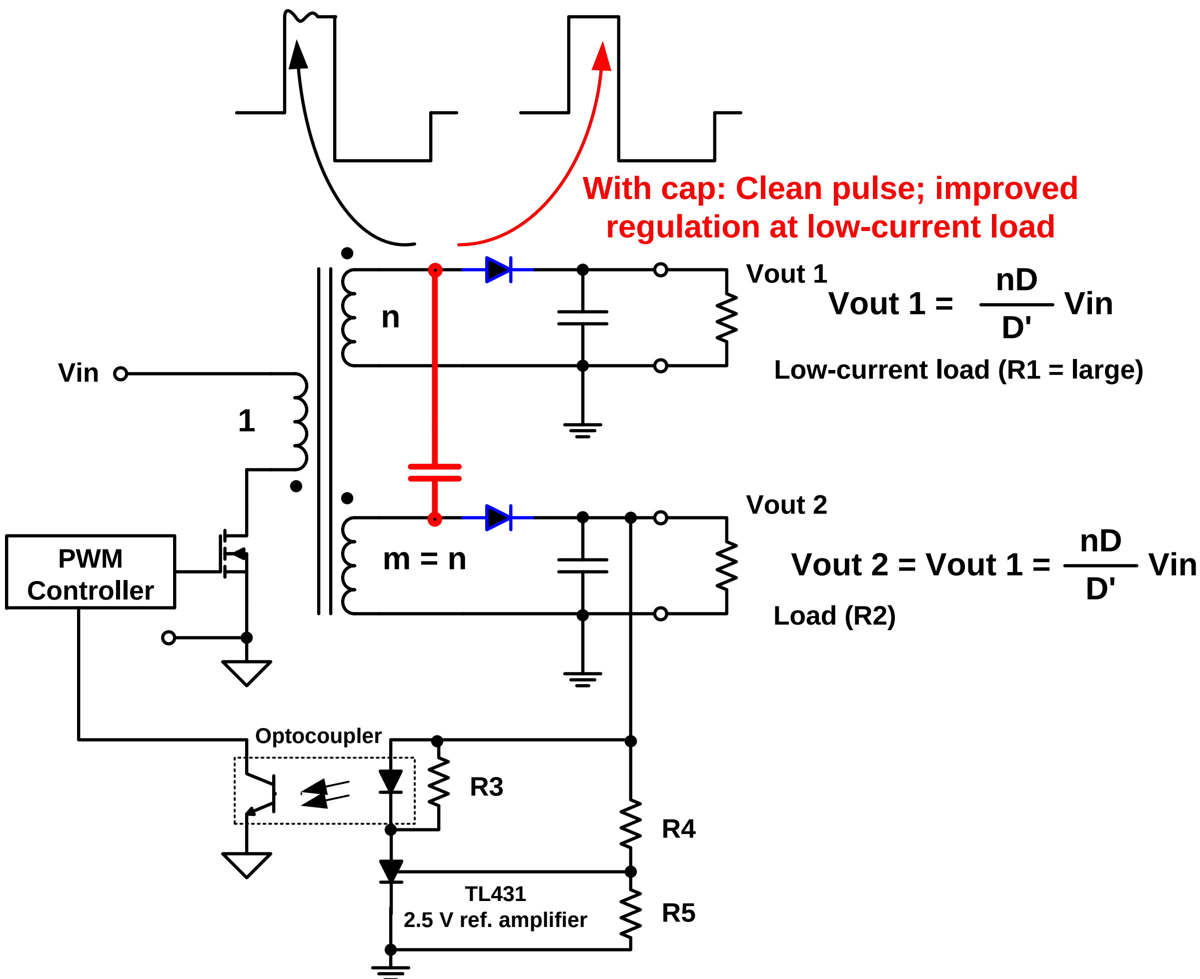
More Outputs? No Problem



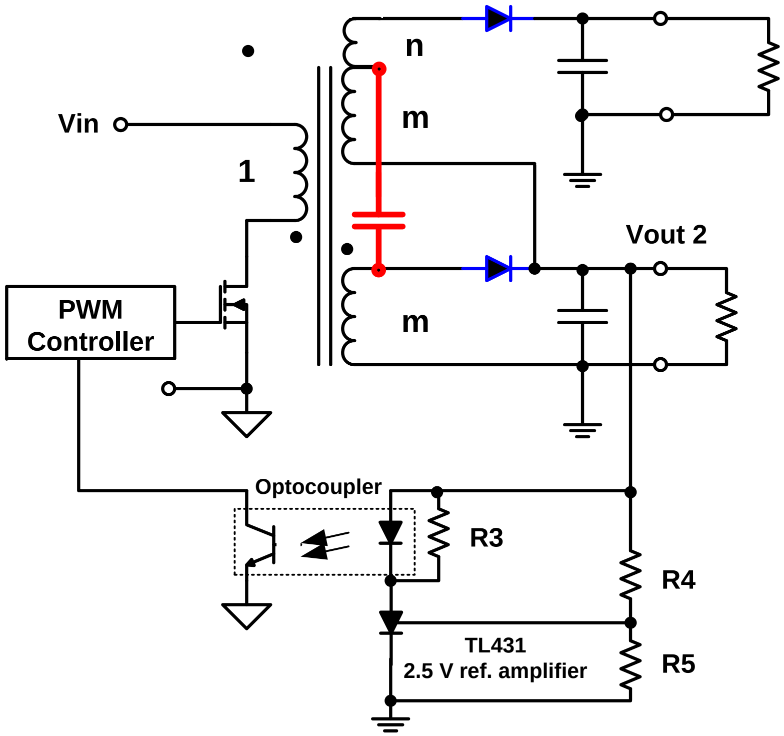
- Feedback can be from any number of outputs.
- **Provided that: W1 + W2 + ……..+Wn = 1**

$$R_n = \frac{V_{out\ n} - V_{ref}}{W_n \cdot i_0}$$

The “Magic” Capacitor



Another Version of the “Magic” Capacitor



$$\text{Vout 1} = \frac{2m+n)D}{D'}\,\text{Vin}$$

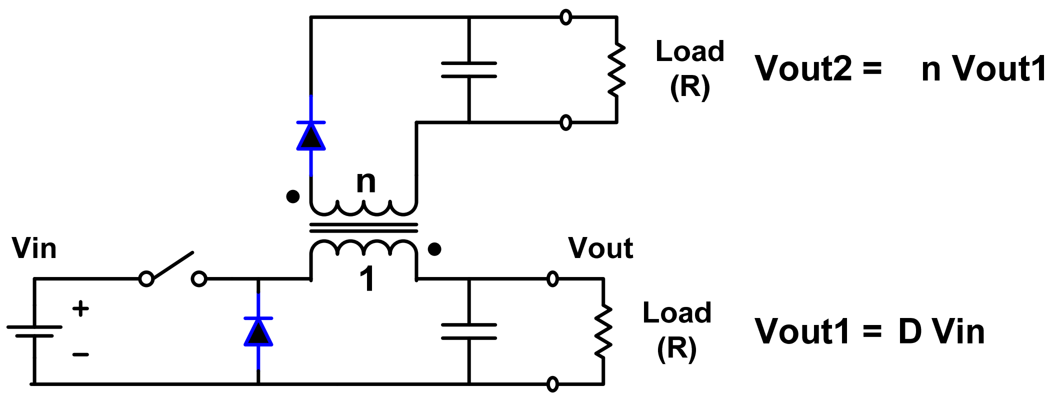
Example: 12 V

$$\text{Vout 2} = \frac{mD}{D'}\,\text{Vin}$$

Example: 5 V

- 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**:

Channel	Vout	Output type	Regulation	Max Ripple	Current	Surge
1	2.6 V	Buck reg.	+/-1%	40 mVp/p	3 A	4 A
2	3.3 V	Buck reg.	+/-1%	40 mVp/p	4 A	5 A
3	5 V	Main output	+/-2%	50 mVp/p	3 A	4 A
4	6.2 V	Quasi-reg.	+/-6%	50 mVp/p	1.5 A	2 A
5	9 V	3-T reg.	+/-1%	30 mVp/p	100 mA	200 mA
6	12 V	Main output	+/-2%	50 mVp/p	1 A	3 A
7	30 V	Quasi-reg.	+/-8%	100 mVp/p	20 mA	40 mA
8	-5 V	3-T reg.	+/-1%	30 mVp/p	30 mA	60 mA

- **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^{O} 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

Regulation Data (120VAC input)

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

Note: Vout setpoints measured at PC board

More Test Results

Efficiency Measurements (120VAC input)

Parameter	2.6V	3.3V	5V	6V	9V	12V	30V	neg 5V	
				Outputs					
Output Voltage	2.54	3.42	4.91	6.31	8.94	12.48	30.06	4.96	
Output Current	3.8A	2.9A	1.56A	1.3A	91mA	1.0A	30mA	73mA	
Output Power (W)	9.65	9.92	7.66	8.2	0.81	12.48	0.9	0.36	(49.98W total)

Total Pout = 49.98W

Pin at 120VAC = 61.4W

Efficiency = 81.4%

Parameter	2.6V	3.3V	5V	6V	9V	12V	30V	neg 5V	
				Outputs					
Output Ripple (@ max loads)	27mV	45mV	50mV	50mV	40mV	30mV	100mV	20mV	(10:1 scope probe)
Output Overshoot (turn-on)	none	none	none	none	none	none	none	none	

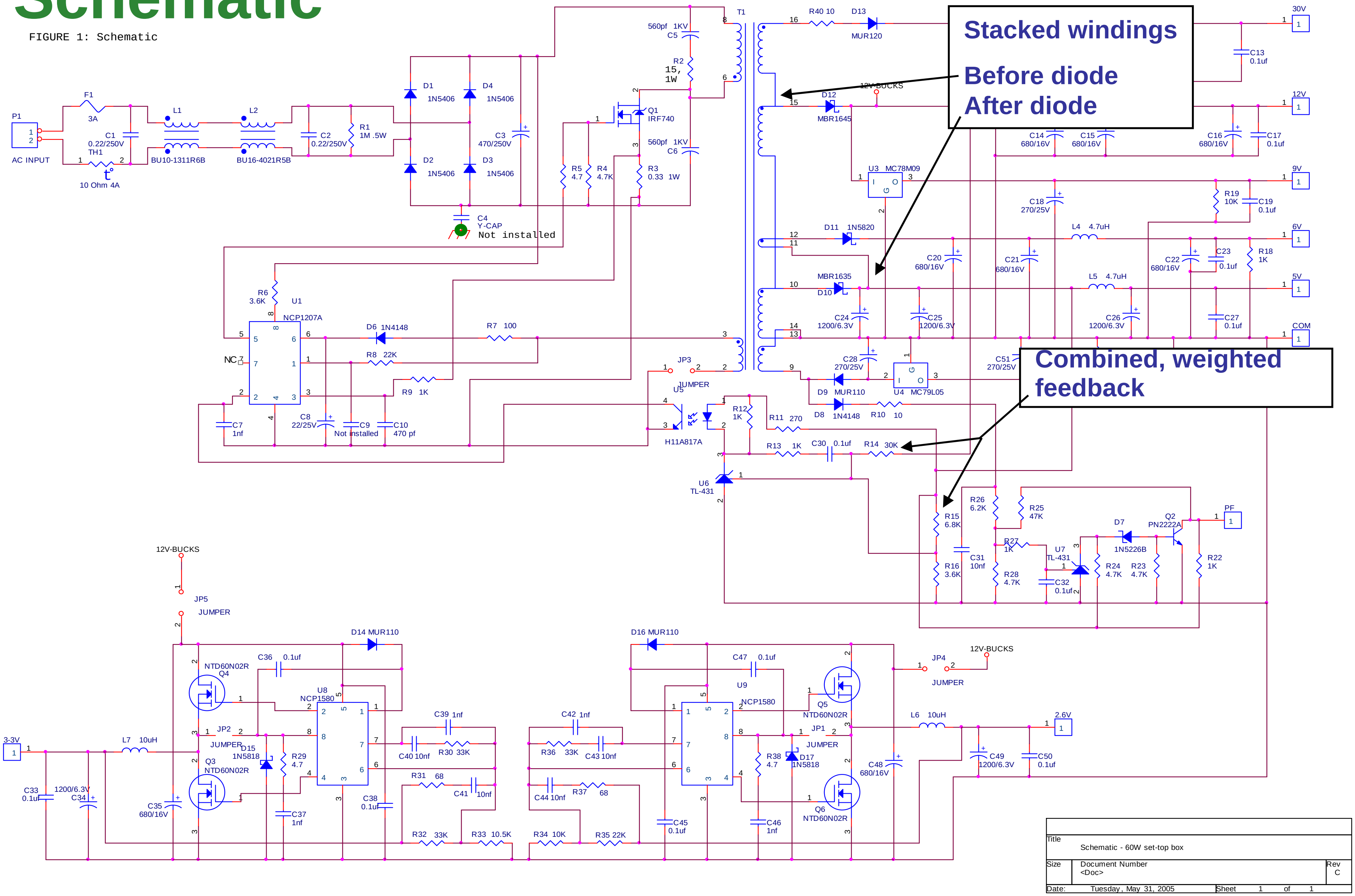
Holdup Time (prior to PF warning) at 100 Vac in, maximum output loads: 25ms

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

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

Schematic

FIGURE 1: Schematic



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