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Low Output-Voltage CATV Flyback Converter

Analog circuit design covers plenty of ground, from narrow-band, frequency-domain RF to power converters. The following interaction is with an RF designer working on a CATV application. He is designing a 5-W converter using an LM5021 controller IC from National Semiconductor Corp. As an RF designer, he's feeling his way along on power-converter design.

Current Sensing Turn-On Spike

"Dear Dennis:

There is one thing you mention regarding MOSFET source current monitoring that I believe has been taken care of by the designers at National Semi, and that is keeping the turn-on transient, which can be rather sharp, from tripping the current-sense circuit. From Page 8 of the LM5021 data sheet, http://cache.national.com/ds/LM/LM5021.pdf "Current sense/Current Limit: The discharge switch remains on for an additional 90 ns leading edge blanking interval to attenuate the current sense transient that occurs when the external power FET is turned on." I believe this obviates the need for clever current-sense resistors and such. Please let me know if I am incorrect on this point."

Dennis Responds:

Actual turn-on current waveforms can ring for a while if the sense circuit is underdamped. If L is large enough and R small enough for L/R to be greater than about 25 ns, then 90 ns might not be enough blanking time. Minimizing sense-resistor inductance will minimize turn-on spiking and will tend to keep the spiking time within the IC blanking duration. The spike should also be kept short to allow for a small duty-ratio.

DCM vs CCM Flyback Design

"Dear Dennis:

Regarding CCM/DCM I believe that the LM5021-1, the part upon which my design is based after careful analysis of the full field of devices (including Power Integrations' off-line devices), is designed for DCM. I am not a switcher guru and do not understand the subtleties of CCM operation. I believe I will be able to filter the supply's conducted emissions well, and the radiated emissions are not a huge issue as we're not super tight for packaging real estate."

Dennis Responds:

If you are at all concerned about EMI (and for communications applications such as CATV you might well be), consider a *continuous-current mode* (CCM) flyback design that runs deep into CCM. The advantage is that the pk/avg value of the currents are much less. The disadvantage is that the control loop is harder to design. Otherwise a DCM flyback is simple, though noisy.

In CCM the current never goes to zero in all of the transductor (magnetic device) windings. Suppose that at the end of the switching cycle most of the current is still flowing in the secondary -- maybe only 10% below the peak. This is a converter running deep into CCM, a long way from zero current values and DCM. At turn-on it transfers back to the primary, and the turn-on current waveform starts at a value near the peak rather than at zero. These kinds of waveforms approach a square wave and have a much better (lower-value) *form factor* (pk/avg) than DCM, in which the current waveforms always include zero.

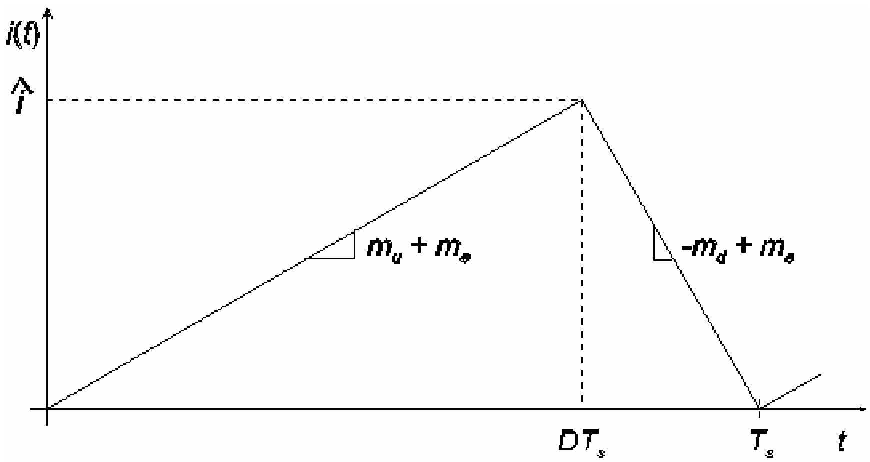
The CCM scheme does not have the added degree of freedom of the DCM. The zero-current interval of the DCM can vary without affecting pole-zero placement. In the CCM, there is an RHP zero, and those complicate compensation. But in practice, it is usually quite manageable.

While we're on the topic of instability, download my tech-note at www.analogzone.com/col_0321.pdf. The title doesn't look on-topic, but the negative-resistance oscillation possibilities of a line filter with the input of a constant-power-output converter are often overlooked.

"Dear Dennis:

I can see that you have read through the LM5021 sheet very thoroughly, and your discussion of the slope compensation indicates that you understand this aspect of the device far better than I did after one or two readings."

Dennis elaborates on some of the prior e-mail discussion: *Slope compensation* is a scheme for stablizing converter current waveforms. Derivation of slope compensation design equations can be worked out from the current waveform, as shown below.



Adding additional slope, m_e, to the current-waveform feedback keeps the waveform stable in time, so that the current values at beginning and end of each switching cycle are the same. The goal is to start with the time-domain waveform analysis and end up with *s*-domain expressions that you can use in incremental (small-signal) dynamic analysis of the feedback loop. The on-time waveform difference equation is:

$$i_{k-1} + (m_u + m_e) \cdot D \cdot T_s = \hat{i}$$

where, $k - 1$ is the current value at the beginning of cycle k.

For off-time:

$$i_k = \hat{i} + (-m_d + m_e) \cdot (1 - D) \cdot T_s$$
$$= \hat{i} - (m_d - m_e) \cdot T_s + (m_d - m_e) \cdot D \cdot T_s$$

where, $\hat{i}$ is the peak current, the controlling quantity that is input to the feedback loop.

When these equations are solved and transformed into the z domain, the peak-current input to current output transfer function, in the z domain, is:

$$\frac{i(z)}{\hat{i}(z)} = \left(\frac{m_u + m_d}{m_u + m_e}\right) \cdot \frac{z}{z + \left(\frac{m_d - m_e}{m_u + m_e}\right)}$$

From control theory, stability is achieved when the poles of *z* are within the unit circle, or whenever:

$$\left(\frac{m_d - m_e}{m_u + m_e}\right) < 1$$

Then, solving for the externally-introduced slope required for stability:

$$m_e > \frac{m_d - m_u}{2}$$

Whenever $m_u > m_d$ no external slope compensation is required. This is equivalent to a duty-ratio, $D < 0.5$.

We didn't quite get to an *s*-domain transfer function (which I will illustrate how to do in an upcoming technoteZONE tutorial on buck converters).This equation, however, allows calculation of the slope for basic design.

In the LM5021, m_e is added to the current waveform by adding an additional ramp, most conveniently generated by the oscillator. In some Unitrode/TI parts an inverted ramp is used instead, added to the PWM comparator input voltage. The effect and transfer function are the same for both implementations.

Power-Factor Correction?

"Dear Dennis:

Different systems use different waveforms for ac power. Some use a real sine-wave. Others use what they call a modified sine wave, which looks like a soft-limited sine-wave or trapezoid. This is the typical output from the ferroresonant supplies commonly used to minimize network voltage variations resulting from input-side (local power company) voltage variations. And more recently UPS units have become common, and some of these have a square-wave output. So a capacitively-coupled supply must accommodate a variety of input waveforms. Combined with the wide range of input voltages (both 60 V rms and 90 V rms systems are common) that we must tolerate, I figured that the cheap-and-dirty approach would only lead to trouble."

Dennis Responds:

For a 5-W supply, *power-factor correction* (PFC) is probably not worthwhile unless there will be many of these on the power line. Even then, with so many different waveshapes, a simple, low-cost PFC circuit would be an interesting challenge in itself. It will add an additional stage of conversion because a single stage does not have enough freedom to both regulate the output voltage and cause its input current waveshape to follow that of the input voltage.

Next month, the CATV flyback converter design considerations are continued.

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